

The Challenges and Opportunities Associated with Climate Change for First Nations Living in
the Canadian Subarctic

by

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Examining Committee Membership

The following served on the Examining Committee for this thesis. The decision of the Examining Committee is by majority vote.

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Author's Declaration

I hereby declare that this thesis consists of material all of which I authored or co-authored, please refer to the Statement of Contributions included in the thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

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Statement of Contributions

The research included within this thesis consists of some material that is a result of joint research effort. I am first author on all contributing papers and therefore was responsible for the development, data collection, data analysis and preparation of each of the manuscripts found in this dissertation. All contributions from co-author's are as follows:

Chapter 3: *Study I*

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Dr. Don Cowan and Dr. Leonard JS Tsuji provided ongoing guidance and supervision from the initial research design of the geomatics system for use in monitoring bush travel conditions to the design of the project, data collection and analysis. All co-authors reviewed the final manuscript and provided editorial advice and guidance.

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Abstract

Background: The impacts of climate change are more pronounced in high latitude regions of the world, which includes the Canadian arctic and subarctic. Warming events are triggering widespread ecological and social impacts – resulting in increased challenges to those who call these regions home. It is predicted that Canadian Aboriginal Peoples (First Nations, Inuit, and Metis) living in remote and isolated arctic and subarctic communities are likely to be those most impacted by climate change. With a history of social and environmental marginalization, this region has experienced a loss in adaptive capacity. The increased occurrence of extreme weather events and unpredictable travel conditions are creating hazardous travel conditions, severely impacting the ability for people to partake in traditional subsistence pursuits, as well as everyday activities. Despite these challenges, warming surface air temperatures in the subarctic have introduced the potential for local sustainable food production, under ambient conditions. High rates of food insecurity in subarctic First Nations communities have been well documented within the academic literature. The easing of harsh winter weather and the warming of summer temperatures presents the opportunity to address food security concerns through the production of local foods.

Objectives: The overall objective of this dissertation was to develop a better understanding of the challenges and opportunities associated with climate change in relation to First Nations in the Canadian subarctic, while fostering increased adaptive capacity in these northern communities. The objective of *Study I* was to work with the community of Fort Albany First Nations to develop a real-time, decision-support tool to help reduce the degree of exposure of James Bay Cree to hazardous bush travel conditions. The objective of *Study II* was to seize the opportunity

to grow vegetables under ambient conditions in subarctic Ontario in a more sustainable manner. *Study III* builds upon *Study II* and examined soil chemistry, biomass, and yield in the context of intercrops grown in treed and non-treed sites; import substitution and evaluating more sustainable agricultural practices were the end goals.

Methods: *Study I:* The University of Waterloo's Computer Systems Group has developed a novel decision-support tool termed the collaborative-geomatics informatics tool. This web-based tool allows for the community to monitor, in real-time, the safety of travel routes. Using handheld GPS tracking systems, the utility of the informatics tool to present real-time travel conditions, was carried out in a subarctic Ontario, Canada. *Study II:* The feasibility of more sustainably growing potatoes (*Solanum tuberosum* L.) utilizing agroforestry practices to enhance food security in remote subarctic communities was explored through a field study in Fort Albany First Nation in northern Ontario, Canada. Potato and green bush beans (*Phaseolus vulgaris* L.) were grown over a two-year period under ambient conditions in treed and non-treed sites. *Study III:* Biomass and yield production of bush bean and potato intercrops grown over a two-year period in two sites (treed, windbreak-lined with native willow, *Salix*. spp.; and non-treed, or open) in the subarctic were collected and analyzed. Soil samples from each site were also collected and analyzed for a suite of elements.

Results and Discussion: The results from *Study I* showed that the collaborative-geomatics informatics tool offers the potential to monitor and store information on the safety of travel routes in subarctic Ontario. The results from *Study II* revealed that sole-cropped potatoes and bush beans could be grown successfully in the subarctic without the use of greenhouses, with yields comparable to more conventional high-input agricultural methods. *Study III* revealed that

intercrops grown in the windbreak lined-site produced significantly greater ($p < 0.05$) yields and biomass compared to the non-treed site. Soil chemistry (pH, P, K, Mg, NO_3 , NH_4 and total N) showed that nutrient amendments would be required for continued agricultural use. Thus, food import-substitution strategies in subarctic Ontario have the potential to enhance community resilience in light of present and future environmental change.

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Dedication

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Chapter 1: Introduction

1.1 Problem Context and Research Rationale

Arctic and subarctic regions are facing an increasing number of social and environmental challenges. It is now certain that human induced climate change is having widespread and often devastating impacts on our social and ecological systems on a global scale. Atmospheric concentrations of greenhouse gases are at the highest level in the last 800,000 years resulting in less sea ice, changing global sea level, and an increase in extreme weather events (IPCC, 2014a). It is likely that by the end of the 21st century there will be an increase in global, surface air temperature that will exceed 2°C (IPCC, 2013). However, these temperature changes will not be uniform, with some regions experiencing disproportionate temperature changes. The polar region has been warming since 1980 at a rate of approximately 1°C per decade (IPCC, 2014b). Sea ice in the Arctic Ocean is being lost at an average rate of 13% per decade; the Intergovernmental Panel of Climate Change (IPCC) estimates that it is likely that the Arctic Ocean will be ice-free within this century (IPCC, 2014b). These changes are predicted to have immense impacts on the ecological and social fabric of this region. The magnitude of impact, whether negative or positive, will vary not only by region but also by the adaptation and mitigation measures adopted (Lemon and Parrod, 2012).

Approximately half of Canada's Aboriginal populations live in remote northern (subarctic and arctic) regions. The ability to travel on land, ice, snow and by water is an integral part of many Aboriginal peoples' lifestyles. Traditional ways of life for many Aboriginal communities involve the consumption of seasonal foods, such as, waterfowl, caribou (*Rangifer tarandus*), seal (*Phoca vitulina*), fish, muskox (*Ovibos moschatus*) and whale (*Cetacea* spp.) (McDonald et al., 1997). In subarctic Ontario, Canada, the spring season is an important time for

subsistence harvesting. Hunters usually begin the spring hunt in late March or early April (Ho et al., 2005; McDonald et al., 1997) and continue the hunt until break-up in late April or early May. Often hunters remain on the land anywhere from 10 to over 100 days (Berkes et al. 1995). Environmental change in the subarctic is creating challenges for First Nation communities. Often traveling by boat or snowmobile, changes to ice depths, snow type, river depths and ice free areas can significantly hinder the ability to get to these camps along with the length of time that can be spent there (Berkes and Jolly, 2001). To date, addressing these challenges have been reactive in nature and have been carried out on an individual level. However, as the impacts of climate change become more intense and more unpredictable, there is a need to develop a community-driven system to help monitor bush travel conditions in real-time to help foster community resilience and adaptive capacity. A warming subarctic climate presents challenges, but also offers the opportunity for local agricultural production that can increase food security and promote a more sustainable food system.

Aboriginal people in Canada experience disproportionately high rates of diet-related illnesses, such as obesity and diabetes. Food insecurity has been identified as a contributing factor to these illnesses along with a loss of a traditional lifestyle (Council of Canadian Academies, 2014). Current food systems within northern subarctic and arctic regions of Canada rely heavily on imported foods that are expensive (when available), and are environmentally unsustainable. With climate change, northern regions are predicted to experience longer and more favorable growing conditions with the potential to grow crops that would have previously been too fragile for such harsh growing conditions. This potential for increased local food production will not only promote greater food security, but has the potential to support community empowerment and resilience towards other social and environmental

challenges (Barbeau et al. 2015). Historically, early European missionaries introduced local farming to help support residential schools in northern communities (Barbeau et al. 2015; Scott, 2014). Harsh winter climates and short, cool growing seasons limited the variety of crops that could be produced even with greenhouses (Spiegelhaar & Tsuji, 2013). As residential schools closed, much of the agriculture in the North was stopped and the reliance on imported foods increased. With a warming climate, it is predicted that the harsh environmental constraints on northern agriculture will ease, resulting in the potential for more sustainable food production in the Canadian arctic and subarctic. More sustainable agricultural activities using agroforestry practices have been shown to be both environmentally and socially sustainable in temperate and tropical regions; however, there is very little research regarding their use in subarctic regions and specifically for increased food security in First Nations communities (Gordon & Newman, 1997; Brandle et al. 2004). The use of agroforestry practices – trees as windbreak barriers along with multi-crop cropping systems – has the potential to generate environmental and socially positive benefits to promote adaptive capacity in First Nations communities in the subarctic.

1.2 Research Objectives

The research objective of this dissertation was to explore the challenges and opportunities associated with climate change in First Nations communities in the Canadian subarctic – with the goal of helping to develop community-driven adaptive strategies focused on promoting resilience and increased capacity – to the shocks and stresses resulting from continual environmental change.

1.2.1 Study I:

Increasing the Adaptive Capacity of Indigenous People to Environmental Change: The Potential Use of an Innovative, Web-Based, Collaborative-Geomatics Informatics Tool to Reduce the Degree of Exposure of First Nations Cree to Hazardous Travel Routes.

The objectives of this study were to work with the community of Fort Albany First Nations to develop a real-time, decision-support tool (termed collaborative geomatics) to help reduce the degree of exposure of James Bay Cree to hazardous bush travel conditions, and to increase the ability for communities in the subarctic to cope with the challenges created by climate change. The secondary objective of this study was to field-test the geomatics tool to develop a better understanding of its utility to reduce the degree of exposure to unsafe travel routes for James Bay Cree.

1.2.2 Study II:

*Sustainable Agriculture and Climate Change: Producing Potatoes (*Solanum tuberosum* L.) and Bush Beans (*Phaseolus vulgaris* L.) for Improved Food Security and Resilience in a Canadian Subarctic First Nations Community.*

The objectives of this second study were to develop a better understanding of the opportunities associated with a warming climate in the western James Bay region and the potential for more sustainable local food production (treed versus non-treed sites). The research

goals of this project were to compare the potential potato production in the subarctic using more sustainable agricultural practices to global potato yields (i.e. more conventional agricultural methods) and to gain insight into the ecological and social sustainability constraints that northern agriculture might face.

1.2.3 Study III:

Sustainable Local Food Production in a Subarctic Indigenous Community: The Use of Willow (Salix spp.) Windbreaks to Increase the Yield of Intercropped Potatoes (Solanum tuberosum) and Bush Beans (Phaseolus vulgaris).

The research objective of the final study was to explore intercropping in the context of treed and non-treed sites, soil chemistry, and biomass and yield.

1.3 Dissertation Structure

This dissertation has been structured in a manuscript format featuring three manuscripts. Chapter 1 begins with an overall introduction by giving a broad synthesis of my dissertation and the research papers that are presented in the following chapters. Chapter 1 also contains the objectives of my dissertation, followed with more specific objectives for each of the research projects featured in Chapters 3-5. The second chapter of this dissertation aims to help the reader develop a better understanding of the relevant literature and background knowledge that is required to situate this research into a broader context and to help define the need for the projects discussed in Chapters 3-5.

The body of this dissertation is three manuscripts that address the opportunities and challenges associated with climate change in a First Nations community in the Canadian subarctic. Chapter 3 (*Study I*) addresses the challenges associated with a warming subarctic. This study was published as a peer-reviewed book chapter in the book, *Geospatial Technology*, in

2016. Chapter 4 (*Study II*) features a research paper that was published in the peer-reviewed journal *Sustainability* in 2015. The final paper, in Chapter 5 (*Study III*), has been accepted with minor revisions for publication in the peer-reviewed journal *International Journal of Sustainable Agriculture*. The formatting of these papers has been modified to adhere to the requirements set out by this dissertation. There have been no changes made to the content of the papers. Chapter 6 is the concluding chapter of this dissertation and summaries the main outcomes from each project, and the overall outcomes and key contributions from this dissertation. A compiled reference list is given after these concluding thoughts.

Chapter 2: Literature Review

2.1 Introduction

This chapter has been designed to give relevant background information in order to situate this dissertation in the greater context of the literature, and to help better define the rationale behind this research. The first section of this chapter focuses on climate change. It begins with a general discussion on global climate change and then focuses on climate change in the subarctic region of western James Bay, Ontario. The second section of this introductory chapter addresses the history of marginalization of Canadian Aboriginal people and the need for increased adaptive capacity. The third and final section will introduce and discuss the challenges and opportunities created by climate change for First Nations living in the Canadian subarctic.

2.2 Observed Changes and Global Climate Predictions

2.2.1 Surface Temperatures

Since 1850, each decade has been successively warmer than the previous decade. The Northern hemisphere likely has seen the warmest 30-year period over the past 1400 years (IPCC, 2014a). All climate models under doubled CO₂ concentrations used by the Intergovernmental Panel on Climate Change (IPCC) show a change in climate on a sub-continental scale (Flato et al. 2013). It is now virtually certain that Earth's troposphere has warmed since the mid-20th century. Globally since 1880, there has been an overall, combined land and ocean-surface temperature increase of 0.85°C (IPCC, 2014a). There is agreement among climate models on a global scale; however, questions surrounding the reliability of predications at a regional scale remain.

Regardless of this uncertainty, it is largely confirmed that climate change will be greater in the 21st century than the 20th century (Flato et al. 2013).

Without any mitigation measures to our current greenhouse gas production, all climate models show that there will be a global increase in mean surface air temperatures through the 21st century; this increase will range from 0.3°C to 0.7°C (IPCC, 2014a; Flato et al. 2013). Earth's lower atmosphere will continue to warm, while the stratosphere cools. Greatest warming will be seen in higher latitudes in winter, with warming slowest in the tropics. The “best-estimate” for global temperature increase is between 2.0°C – 4.5°C with the models tending to agree on a temperature increase of around 3.0°C (Flato et al. 2013). It is also expected that there will be more frequent extreme temperature events over most major land masses; these extreme temperatures will range on a daily and seasonal timescale (IPCC, 2014a).

2.2.2 Precipitation

Warming surface temperatures will increase evaporation leading to a predicated increase in intense precipitation events (Flato et al. 2013; Neelin, 2010). Furthermore, it is predicated that there will be an increase in heavy and very heavy rain events. Precipitation rates in the form of rainfall are predicated to increase by 3-15% in high latitudes (Flato et al. 2013; Neelin, 2010). Changing precipitation patterns are also predicted to impact the quantity and quality of water resources (IPCC, 2013).

2.2.3 Oceans

There is high confidence that the ocean's near surface (upper 75 m) has increased in temperature by 0.11°C since 1971. Furthermore, it is likely that the entire ocean has warmed since 1992 (IPCC, 2014a). Over the past 131 years there has been an increased sea level rise of approximately 20 cm (Richardson et al. 2011; Flato et al. 2013).

2.2.4 Sea Ice

Thinning arctic sea-ice has been documented since 1978. Satellite imagery of Arctic sea ice has shown a disturbing pattern in the rate of decline in ice. Winter months show a rate of decline in ice occurring at 2.7% per decade; while, summer shows a rate of decline of 7.4% per decade (IPCC, 2007). Current models are predicting a continued decline in sea ice in the Arctic. It appears that as sea ice continues to decline there will be a threshold change resulting in a new state of greater ice-free periods due to the relationships of positive feedback loops (Lenton et al. 2008; Lindsay and Zhang, 2005). An increased area of open water increases the amount of solar energy absorbed into the ocean. This increased amount of solar absorption results in a decreased albedo and convective warming on the water. As the water warms, first-year ice formation, such as that which forms in James Bay, becomes thinner, feeding into longer periods of open water (Lenton et al. 2008; Lindsay and Zhang, 2005). It is argued within the literature that due to this positive ice-albedo feedback, we might have already reached a tipping point, as seen by the already significant rate of ice decline (Kerr, 2007). It is likely that by 2050, there will be a nearly ice-free summer in the Arctic (IPCC, 2014a; Larsen et al. 2014)

2.2.5 Biological

The biological response to climate change is difficult to predict due to the substantial role that current human non-climatic impacts are playing. Non-climatic influences create ‘noise’ in data analysis, making it difficult to differentiate between correlations and causations (Parmesan and Yohe, 2003). This is especially difficult at the species level. Therefore, a systematic analysis between diverse species at an ecosystem level can reveal climatic relationships (Parmesan and Yohe, 2003). Changes to species abundance and distribution have already been seen. Studies involving the distribution of 99 species of bird, butterfly and alpine herbs have already shown a

range shift of on average 6.1 km northward per decade (Parmesan and Yohe, 2003).

Phenological changes are also taking place as a result of climate change. Herbs, shrubs, trees, butterflies, birds and amphibians are showing on average earlier spring events such as budding and breeding at a rate of 2.3 days per decade (Parmesan and Yohe, 2003). Research into mammal population response to climate change has shown northwards shift in their distribution along with changes to elevation gradients (Guralnick, 2006). Species such as *Peromyscus leucopus* (white-footed mouse) have expanded their ranges northward by 225 km as a result of climatic warming (Guralnick, 2006). Overall, the general global prediction of the biological response to climate change is a loss of species (through extinctions) and decline in global biodiversity (Sala et al. 2000).

2.3 Climate Change in Canada and Polar Amplification

As previously stated, typically the reliability of current climate predictions is greater at the global scale and become less dependable at regional scales. However, there is a high level of confidence that certain impacts are predicted to occur regionally across Canada. Surface temperatures are expected to increase across Canada with coastal Labrador predicted to see cooler temperatures for a few years due to iceberg melting (IPCC, 2007; White, 2010). Much of this warming will occur during the winter months with an increase in drought and extreme heat days during the summer in the Prairies and central British Columbia (IPCC, 2007; White, 2010). Mudslides are expected to increase in mountainous areas within the Rockies due to increased heavy rainfall and intense weather events. Sea-level rise as a result of melting sea ice and glaciers will impact Canadian coastal regions such as the Arctic, Prince Edward Island and Vancouver (White, 2010). It is very likely that Canada will receive increased amounts of annual

precipitation especially in the winter with the northern most parts of Canada seeing increased snowfall (Christensen et al. 2007)

2.3.1 Polar Amplification

Northern latitudes, are predicted to experience climate change earlier and to a greater extent than the rest of the world (Berkes and Jolly, 2001; IPCC, 2007). Global surface temperatures have increased $0.74^{\circ}\text{C} \pm 0.18^{\circ}\text{C}$ over the last 100 years (IPCC, 2007). Even more ominous is the fact that the rate of temperature increase for arctic regions is nearly double that of the global average with temperatures expected to increase $5\text{-}7^{\circ}\text{C}$ (Christensen et al. 2007; IPCC, 2007; Ford and Smit, 2004). Precipitation trends are also indicating that there will be a significant increase in rainfall in arctic regions, unlike the tropics which are predicted to see increased drought (Christensen et al. 2007; IPCC, 2007; Stirling and Parkinson, 2006; Gough et al. 2004a). There are two main types of terrestrial impacts that will be seen in northern latitudes, namely changes in vegetation composition and structure resulting in biodiversity changes and changes in belowground structure and processes (IPCC, 2007; Anisimov et al. 2007). Nutrient poor, but environmentally important, bog systems found in the arctic and subarctic regions are predicted to be the most impacted terrestrial ecosystem (Alm et al. 1999). Currently, due to their low rate of decomposition and anoxic conditions, bog systems act as carbon sinks, a natural reservoir for carbon dioxide gas. However, changes to albedo due to decreased snowfall and decreased water availability in summer months may turn these ecosystems from carbon sinks to carbon sources (IPCC, 2007; Alm et al. 1999). Such extreme ecological changes are certain to have significant impacts on ecosystem function in the arctic and subarctic.

Climatic models are also predicting that there will be a northward movement of tundra vegetation followed by the northward movement of boreal tree species (IPCC, 2007; Anisimov et

al. 2007). Such vegetative reshuffling will have significant impacts on the distribution of plant and animal species in these regions. In some cases, species will follow the advancement of vegetation; however, it is more likely that regional species will be left behind, resulting in population and potentially species wide declines. Such dramatic environmental changes are likely to result in an increase in biological invasions (Rahel and Olden, 2008). New invasive species of microbes, fungi, plants and animals have already been observed in polar regions, indicating that climate change impacts are already at work (Frenot et al. 2005). Increased prevalence of biting insects successfully overwintering due to milder temperatures, and the introduction of novel insects that have migrated northward with climate warming can act as vectors for human diseases, such as, tick-borne encephalitis and H5N1 Bird flu (Larsen et al. 2014; Tokarevich et al. 2011; Ogden et al. 2010). Along with the introduction of insect disease vectors, increases in biting insect populations can significantly impact native species. *Rangifer tarandus* (woodland caribou) and *Alces alces* (moose) have been shown to lose body condition when overwhelmed by an increased number of biting insects (Newton et al. 2015). Poor condition and greater rates of mortality for caribou and moose would not only impact the arctic ecosystem but the cultural importance of the species in traditional uses by many Indigenous communities.

2.4 Climate Change in the Hudson's Bay Lowlands

The Hudson's Bay Lowlands, which extend from Herchmer, Manitoba, in the north, below James Bay in the south and across to the Eastmain River in Quebec, are an environmentally significant region. The Lowlands contain 292,500 km² of peatland (the largest in North America), which is estimated to hold 12% of all organic carbon stored in Canadian soils

(Humphreys et al. 2014; McLaughlin & Webster, 2014). Increased soil temperatures and disturbance from resource extraction is predicted to result in a release of these carbon stores back into the atmosphere in the form of CO₂ and methane, resulting in a new climatic tipping point (McLaughlin & Webster, 2014).

Historically, the Hudson's Bay Lowlands have remained cooler than the surrounding arctic and subarctic due to the moderating role that the sea ice in Hudson's Bay has had on the region. Beginning in the 1990s, this buffered effect was no longer enough and the Hudson's Bay Lowlands began to show the effects of climate warming in the region (Ruhland et al. 2013).

A study by Tam et al. (2013) looked into the ecological changes occurring in the western James Bay region of the Hudson's Bay Lowlands. Community members of Fort Albany First Nations, located along the Albany River, have seen noticeable changes in the seasons and weather patterns. Spring mean air temperatures in the region have increased significantly from 1962, when the mean spring air temperature was -12.4°C to -9.8°C in 2002 (Tam et al. 2013; Ferguson et al. 2005). Winters have been shorter and milder, with more rain, humidity and lightening storms (Tam et al. 2013; Hori et al. 2012). River freeze-up along the Albany River is occurring at a later date, impacting the ability to travel on the land (Ho et al. 2005; Tam et al. 2011). Precipitation is predicted to increase ranging from 3.2 to 7.1 mm per month by 2050 and from 5.2 to 11.3 mm per month by 2080 relative to 1961–1990 amounts (Gagnon & Gough, 2005).

Non-traditional ice break-ups along the Albany River are becoming more regular in the spring (Ho et al. 2005). Biological changes have already been noted by First Nations community members. Changes to local flora and fauna as a result of climate change are impacting traditional diets and lifestyles (Tam et al. 2013). Interviews with Fort Albany community members

revealed that species, such as, caribou, and *Alopex lagopus* (white fox) have already declined in numbers (Tam et al. 2013). Furthermore, the ability to forage has been impacted with the noted decline in *Vaccinium uliginosum* (blueberry), *Vaccinium oxycoccos* (cranberry) and *Rubus idaeus* (raspberry) (Tam et al. 2013). Novel species such as *Ursus maritimus* (polar bears), *Pelecanus spp.* (pelicans) and *Columbidae spp.* (pigeons) have also been seen in the area and there is concern that these invasive species might negatively impact native species (Tam et al. 2013).

2.5 Canadian and International Indigenous History

Globally, there are approximately 400 million Indigenous people (Gracey and King, 2009). The definition of Indigenous is at times controversial; however, according to Gracey and King there are some common criteria that have been used to help better define Indigenous (2009:66);

- *Self-identification as Indigenous peoples by individuals and acceptance as such by their community*
- *Historical continuity and land occupation before invasion and colonization, strong links to territories (land and water) and related natural resources*
- *Distinct social, economic, or political systems*
- *Distinct language, culture, religion, ceremonies, and beliefs*
- *Tendency to form non-dominant groups of society*
- *Resolution to maintain and reproduce ancestral environments and systems as distinct peoples and communities*
- *Tendency to manage their own affairs separate from centralized state authorities*

According to the United Nations, the term Indigenous refers “to people with long traditional occupation of a territory, but who are now under pressure as minorities or

disenfranchised populations within an industrialized or industrializing nation-state” (Kesler, 2009:4). Within Canada, and according to the Canadian Constitution, Canadian Indigenous people are referred to as Aboriginal. This term is used to reflect all Indigenous groups (Inuit, First Nations and Métis) throughout Canada.

Compared to non-Indigenous groups, globally Indigenous people are the most poor and disadvantaged groups (Gracey & King, 2009; Salick & Byg, 2007). Prior to European contact, generations of Indigenous people lived as stewards of the land, relying on it for subsistence livelihoods supported by hunting, fishing, foraging and cultural practices (Gracey & King, 2009). This traditional way of living on the land resulted in a sustainable lifestyle that not only protected the environment, but also the rich environmental knowledge that was developed from centuries of tradition. Colonization not only directly impacted Indigenous people through the introduction of certain infectious diseases, such as, *variola* virus (small pox), but it also limited the ability for communities to practice traditional harvesting practices, allowing for the ultimate reliance on non-traditional diets (Gracey & King, 2009). Such fundamental changes “resulted in serious long-term effects on health and caused severe social, psychological, and emotional damage” (Gracey & King, 2009:66). Since colonial times, there have been continued and ongoing marginalization, inequities and abuses toward Indigenous people globally, which have subtly shaped the lives and futures of not only individuals but entire communities (Elias et al. 2012:1560). One such example is that of the residential school systems in Canada.

The residential school system within Canada resulted in “cumulative emotional and psychological wounding over generations” (Braveheart, 1999; as cited by Elias et al. 2012:1560). Starting in the early 1890s, Roman Catholic and Anglican churches began removing Indigenous children from their homes and families to assimilate and introduce Christianity (Elias et al.

2012). During the early 1900s the Canadian Government began to further initiate policies to assimilate Aboriginal culture into what was considered to be “mainstream” culture. Residential schools, relocations, and the outright outlawing of Aboriginal practices and the implementation of laws containing “interventionist” measures such as the Indian Act were promoted (Royal Commission of Aboriginal People, 1996:42). With the closure of the last government run residential school in 1996, the 100 year period of assimilation at the hand of the Canadian Government ended having “exposed tens of thousands of Indigenous children to a system fraught with structural and systemic problems, impacting their wellbeing and that of their families, communities and future generations” (Elias et al. 2012:1561). It is believed that there were approximately 373,350 survivors of the Canadian residential school systems, with at least 80,000 still alive (Stout & Peters, 2011).

Children who experienced residential schools were exposed to not only isolation from their families and communities, but also their language and culture often along with extreme abuse and neglect. The resulting trauma associated with the emotional and physical abuse experienced at these schools led to a loss of traditional knowledge, skills and the ability for self-respect and the respect of others (Elias et al. 2012). Parents, families and communities who lost their children were unable to develop not only parenting skills, but also the ability to pass traditional knowledge to the next generation (Morrissette, 1994; Elias. et al. 2012). A clear indication of this disconnect as given by one survivor:

“We were incarcerated for no other reason than being Indian. We were deprived of the care, love, and guidance of our parents during our most critical years of childhood. The time we could have learned the critical parenting skills and values was lost to the generations that attended residential schools, the effects of which still haunt us and will continue to have impacts upon our people and communities. In many instances, our models were the same priests and nuns who were our sexual predators and

perpetrators” (Aboriginal Healing Foundation, 2008:24).

Within the literature there has been an attempt to discuss the individual effects of residential schools such as a loss of traditional language, experiences of racism and substance abuse (Stout & Peters, 2011). However, these individual effects cannot be considered solely in isolation, they should be combined together to develop a broader understanding of effects of residential schools. Stout & Peters (2011) groups the individual impacts of residential schools as falling under the loss of inter-generational transmission. The profound loss of over four generations of knowledge transmission left individuals, families and communities without the ability to heal. The current state of Canadian Aboriginal communities is that of one that is broken. With the increasing threat of climate change there is an even more pressing need to promote adaptation strategies that not only increase adaptive capacity, but support traditional knowledge generation.

2.6 Social Vulnerability to Climate Change

It is becoming apparent that social systems are vulnerable to climate change, especially to extreme environmental events (Wilbanks et al. 2007). Vulnerability can be defined as “the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes” (IPCC, 2007:6). The degree to which people are vulnerable to the impacts of climate change is strongly related to not only physical location, but other social factors, such as, income, health and cultural practices (Cutter et al. 2000). Three components determine social and individual vulnerability; *exposure*, the likelihood that a person(s) will be in a location and experience the stressors or hazards of climate change (IPCC, 2012), *sensitivity*, the underlying attributes that determine the severity of the climate change

impact and *adaptive capacity*, the ability for a system to adjust to meet the challenges of observed or expected changes or to take advantage of new opportunities (Edwards and Wiseman, 2011; Adger et al. 2005).

It is expected that the world's Indigenous populations living in arctic and subarctic regions are the most vulnerable to climate change and will experience the greatest impacts (Buhrich, 2010; Parry et al 2007). In order to understand and develop adaptive action to climate change, it is important to first understand the nature of the vulnerability that Aboriginal people in Canada's arctic and subarctic are facing (Ford and Pearce, 2010). This includes developing a better understanding of who and what are vulnerable and in what way (Ford and Pearce, 2010).

2.6.1 Vulnerability of Canadian Aboriginal Communities to Climate Change

Within Canada, 1.4 million people identify as Aboriginal (Métis, Inuit and First Nations), approximately 4.3% of the total Canadian population (Statistics Canada, 2011). Aboriginal groups within Canada experience a shorter life expectancy than non-Aboriginal Canadians (Statistics Canada, 2001). Some of the main factors influencing Aboriginal life expectancy are increased rates of poverty, addiction, suicide, overcrowding and environmental contamination (Barbeau et al. 2015; Statistics Canada, 2011; Ford et al. 2010b; Macdonald et al. 2010; Macmillian et al. 1996). Aboriginal Canadians also experience disproportionately higher rates of obesity compared to non-Aboriginals (Gates et al. 2011; Skinner et al. 2006). Such high obesity rates have resulted in high levels of cardiovascular disease and type II diabetes (Shields, 2005; Anand et al. 2001). These diet-related diseases have been attributed to the high rates of food insecurity in Aboriginal Canadian communities, especially remote northern communities. In the

western James Bay region, ~70% of households were found to be food insecure (Skinner et al. 2006).

Approximately half of Canada's Aboriginal population referred to as "remote aboriginal populations" live in the northern territories, on reserves, or in rural and remote communities (Ford et al. 2010b). The Canadian North represents more than 60% of Canada's land mass and is home to close to 100 communities, many of which are Aboriginal (Furgal & Prowse, 2008). Remote Aboriginal populations usually share close relationships with the land and its resources and practice traditional land-based lifestyles (Ford et al. 2010b; Richmond & Ross, 2009; Furgal & Seguin, 2006). Furthermore, resource development in Canada's North has increased the sensitivity of Aboriginal groups to climate change impacts (Tookenay, 1996; MacMillan et al. 1996).

2.6.2 Food Insecurity in Northern Aboriginal Communities

Food insecurity is amplified in northern remote communities due to restricted access to adequate and nutritious foods. Food insecurity refers to the "inadequate or uncertain access to an acceptable amount and quality of healthy food" (Council of Canadian Academies, 2014:xiv). Historically, traditional foods such as fish, berries and wild game allowed for a holistic diet, one that was socially, physically and environmentally rich. Environmental contamination, climate change and a loss of traditional knowledge has resulted in high rates of food insecurity.

Residential schools resulted in the loss of a generation of traditional knowledge relating to many social and environmental aspects of traditional food acquisition (Spiegelaar and Tsuji, 2013). This loss of knowledge along with environmental changes has led to communities becoming more reliant on an import-based food system, which is input intensive, of poor quality and expensive. In a recent government survey, over half of northern Canadians were concerned

with the cost of food available within their communities (Environics Research Group, 2010). In remote communities, not only is food up to 4 times more expensive than urban areas, produce (when available) is often spoiled. The 2011 Canadian Community Health Survey showed that 27% of off-reserve Aboriginal households experienced some form of food insecurity; nearly double that of non-Aboriginal households (Council of Canadian Academies, 2014). The 2007-2008, Nunavut Inuit Child Health Survey found that 31% of Inuit children experienced food insecurity. The survey also revealed that 58% of Inuit children between the ages of 3 to 5 were living in food insecure homes, unlike the rest of Canada where only 5.2% of families with children were considered to be food insecure (Willow et al. 2012; Egeland, 2010).

The Canadian government has attempted to address food insecurity in the North through their introduction of a food subsidy program called *Nutrition North*. This program replaced the previous food mail program and was implemented to provide subsidies toward the shipping costs of staple food items and fresh produce. This program received much criticism about its effectiveness in actually supplying less expensive food to those communities most in need (Skinner et al. 2013; Papatsie, 2011). In 2014, the Canadian Auditor General addressed this criticism with a report. The Auditor General found many shortcomings with the 60 million dollar per year government program. Two of the main criticisms noted were the lack of transparency in the program and the eligibility of communities in the program. Community subsidies were based on permanent road access and previous participation in the food mail program, not on the current need of the community. This strict eligibility requirement resulted in some communities receiving full support, while neighboring communities only received partial support (Auditor General of Canada, 2014). Another key shortcoming was that retailers were not required to report their profit margins and there was no crosschecking of retail prices to determine if the

subsidy was being passed onto community members. The Auditor General concluded that the *Nutrition North* had not managed to meet its goals of making nutritious foods more accessible in northern communities. The final recommendation was that the program be re-evaluated in the following year. To date the response to food insecurity in remote arctic and subarctic Aboriginal communities has been limited. There is a serious need to establish food security in the Canadian North. Community-based research concerning local and sustainable community food systems has been identified as an essential step towards improved food security in the Canadian North (Council of Canadian Academies, 2014).

2.6.3 Loss of Traditional Environmental Knowledge

Aboriginal groups living in Canada's arctic and subarctic regions are particularly vulnerable to climate change due to their interconnectedness with the land (Herrmann et al. 2012; Ford et al. 2010). Traditional ways of living include hunting and harvesting practices that are guided by seasonal cycles. Historically, using environmental indicators, Aboriginal groups have been able to accurately predict seasonable changes and weather patterns (Laidler and Gough, 2003; Laidler et al. 2009). This knowledge about the land "often accumulates incrementally, tested by trial-and-error and transmitted to future generations orally or by shared practical experiences" (Ohmagari and Berkes, 1997 as cited in: Berkes et al. 2000:1252). Therefore, this knowledge played an important role in the adaption to environmental conditions on a seasonal and yearly basis (Laidler et al. 2009). However, social inequalities such as the introduction of residential schools resulted in a loss of traditional environmental knowledge (TEK) between generations (Ball, 2004; Macmillan et al. 1996). This loss of TEK, coupled with pre-existing marginalization and the increase in unpredictable environmental changes (e.g., increased flooding, sea ice, river changes and animal distribution changes) as a result of climate

change, has led to the increased vulnerability of northern Canadian Aboriginal communities.

As environmental change continues in the arctic and sub arctic regions, the resulting direct and indirect impacts will affect traditional lifestyles. It is likely that communities that are flood-prone, remote, isolated and subsistence-based will be the most impacted by climate change (Edwards and Wiseman, 2011). Many Aboriginal groups are already experiencing increased challenges and vulnerabilities as a result of environmental changes.

2.7 Challenges Associated with Climate Change

Climate-induced changes are expected to create challenges for Aboriginal people living in Canada's North. These challenges both current and predicted can be grouped into four interrelated categories; *access to resources*, *health and safety*, *predictability* and *species availability* (Berkes and Jolly, 2001). Grouping these challenges will allow for a more thorough understanding of the potential for adaptive capacity and resilience within these northern Aboriginal communities.

2.7.1 Access to Traditional Resources

The ability to travel on land, ice, snow and by water to acquire resources is an integral part of many Aboriginal peoples' lifestyles. Traditional ways of life for many Aboriginal communities involve the consumption of seasonal foods such as waterfowl, caribou, seal, fish, *Ovibos moschatus* (muskox) and *Cetacea* (whale) (McDonald, 1997). In James Bay, the spring harvest is an important time for subsistence harvesting. Hunters usually begin the spring hunt in late March or early April (Ho, 2005; McDonald, 1997) and continue the hunt until break-up in late April or early May. Often hunters remain on the land anywhere from 10 to over 100 days (Berkes et al. 1995). Changes to the timing of ice break-up and river depths can affect access to

family spring camps. Often traveling by boat or snowmobile, changes to ice depths, snow type, river depths and ice free areas can significantly hinder the ability to get to these camps along with the length of time that can be spent there (Berkes and Jolly, 2001). Furthermore, changes to bush travel can lead to a reduction in the amount of other traditional food collected, such as, berries and tea.

2.7.2 Health and Safety

2.6.2.1 Mental Health

Cultural impacts as a result of climate-induced changes are affecting the psychological status of many Aboriginal people (Ford et al. 2010b). Traditional harvesting allows for the development of relationships and important cultural activity while out on the land. Relationships are also strengthened with community and family members during the processing and consumption of traditional foods (Ford et al. 2010b). The American Psychological Association Task Force on the Interface between Psychology and Global Climate Change has called for research to focus on mental health and the impacts of climate change on Aboriginal groups (MacDonald et al. 2015). It is suggested that remote and isolated Aboriginal populations in arctic and subarctic regions, who already have high rates of preexisting mental health illnesses, will experience increased rates of mental illness with continued climate change (MacDonald et al. 2015).

2.7.2.2 Physical Health and Safety

Temperature increases have the potential to increase the prevalence of foodborne, zoonotic, and vector-borne diseases, due to warming temperatures (Ford et al. 2014). Warming

temperatures are predicted to allow for an increase in biting insects and therefore insect-borne diseases (Frugal & Seguin, 2006).

Species distribution changes also present a health and safety risk to Aboriginal people living in northern communities. For example, First Nation communities along the western James Bay coast have documented periodic sightings of polar bears out of their normal range, some of which may be related to earlier sea ice break-up in James Bay (Barbeau et al. 2013). These encounters pose a significant threat to the safety of First Nation Cree and to the polar bears themselves that are often shot out of self-defense. First Nations in this region do not have a history with polar bears, whose ranges do not naturally extend that far south. However, with changing sea ice conditions, polar bears are moving further inland in search of food coming into contact with First Nation hunters during spring waterfowl harvesting (Barbeau et al. 2013).

Related to this ability to access traditional resources and the importance behind such resources, the safety of Aboriginal people while out on the land is an important challenge when facing the impacts of climate change. Younger generations especially are viewing the land with more fear and uncertainty and believe that it is less accessible (Wesche & Chan, 2010:4). Many safety issues are arising in relation to sea ice and early spring thaws. In many arctic communities, sea ice is important for winter hunting activities, such as, polar bear and seal hunting (Berkes & Jolly, 2001). However, with ice conditions becoming less reliable, sudden changes in ice conditions are more common, resulting in safety issues for those who are out on the land and water. Changes in ice-thickness, ice condition, ice movement and the extent of open water can become a safety issue, while out on the ice hunting. Also, early thawing of ice and ground along bush trails is resulting in stranded snowmobiles and increased risk of drowning and hypothermia (Frugal & Prowse, 2008). Sudden changes to wind conditions often occur rapidly, resulting in

dangerous and potentially life-threatening conditions for those already out on the land and water, making navigation difficult. Research has shown that the incident rate of accidents in northern coastal Aboriginal communities has increased as result of changes in weather (Furgal & Prowse, 2008; Ford et al. 2006).

2.7.2 Predictability

Safety, while out on the land, relates to the predictability of environmental conditions such as ice extent and extant, river depths, snow and ice types and weather (Berkes & Jolly, 2001). Traditionally, Aboriginal people have been able to predict environmental conditions through their intimate knowledge of the land and their TEK. This traditional knowledge showed a great level of flexibility and consisted of harvesting at different times and for different species, with many backup plans to ensure a successful harvest (Berkes & Jolly, 2001; Sydneysmith et al. 2010). It has become more difficult to use traditional knowledge to predict events such ice-break up and weather patterns because they are occurring “at the wrong time” (Berkes & Jolly, 2001:7). For example, an increase in extreme weather events, such as summer storms, develop too quickly to predict prior to heading out onto the land (Ford et al. 2006). There is concern that as adaptive and flexible as TEK is, the rate and magnitude of climate-induced change might be too unpredictable for TEK to adapt to (Berkes & Jolly, 2001; Sydneysmith et al. 2010; Hovelsrud et al. 2008).

2.7.3 Species Availability

As previously mentioned, it is highly likely there will be a northward movement of species (Anisimov et al. 2007). Warming temperatures are impacting the health and availability of subarctic and arctic species. Early spring rain has already been attributed to the melting and resulting collapse of birthing dens for ringed seals (*Pusa hispida*) exposing newborn pups to

hypothermia and predation (Pearce et al. 2010; Post et al 2009). Changes to winter freeze-thaw cycles and snow type are predicted to have negative impacts on muskox and caribou. Increased winter precipitation is predicted to fall as freezing rain, causing snow-crusting, cutting the legs of caribou and muskox and requiring energy expensive digging for food (Pearce et al. 2010). A crust thick enough to carry the weight of a caribou can raise the energy cost of walking by 570% (Gunn, 1995). These changes are resulting in unhealthy animals and a high rate of over-winter mortality (Ford et al. 2010b; Gunn, 1995). As previously mentioned, warmer summer temperatures promote an increase in biting insects, specifically *Culicidae* (mosquitoes). These insects can have detrimental impacts on the health and condition of certain terrestrial species, such as, the woodland caribou which must consistently move to avoid being bitten resulting in changes to the condition of their fur and meat (Ford et al. 2010b). Warming waterways and longer ice-free periods will likely impact numerous aquatic organisms, such as, fish, algae and plankton (Adger et al. 2007). It is expected that new fish species will appear in arctic and subarctic oceans and rivers, while local species will experience altered migrations. Changes to the distribution and health of some fish species have already been noted in some northern Aboriginal communities (Ford et al. 2006). Similarly, invasive species found on the land have also been reported by local harvesters. For example the appearance of the *Vulpes vulpes* (red fox) has resulted in a decline of the *Alopex lagopus* (arctic fox) (Post et al. 2009). All of these biological changes will pose challenges to Aboriginal harvesting and traditional livelihoods that are built on the harvesting, sharing and consumption of many traditional species (Lemelin et al. 2010)

2.8 Adaptation and Resilience to Climate Change Challenges

The story of human history in the arctic has been described as “a series of adaptations, or

a process of sequentially accumulating cultural mechanisms, designed to deal with the characteristics of the environment” (Berkes & Jolly, 2001:9). Aboriginal people in the arctic and subarctic have successfully managed a high level of environmental variability throughout their history. Historically, traditional knowledge and strong social networks have allowed Aboriginal people to sustain their traditional lifestyles and adapt to seasonal and yearly changes to weather and animal patterns. According to historical records of human adaptation in the North there are common characteristics of adaptive behaviors that have been successful in the past; mobility, flexibility, local knowledge generation and a strong community network (Berkes et al. 2001). However, it was not until recently that climate change research has begun to consider if any of these adaptive mechanisms are still viable and if they are currently being used towards modern day climate change (Berkes & Jolly, 2001).

Adaptability is the characteristic of a community high in adaptive capacity, a critical component of resilience and one way in which vulnerability can be reduced (Smit & Wandel, 2006; Walker & Salt, 2006). Here adaptive capacity is defined as a critical component of vulnerability reduction “that reflects learning and an ability to experiment and foster innovative solutions in complex social and ecological circumstances” (Armitage, 2005:703-704).

Adaptation focuses on promoting and building resilience now, learning from previous mistakes and working together to increase adaptive capacity for the future (Tschakert & Dietrich, 2010). Resilience can be defined as “the capacity to recover after disturbance, absorb stress, internalize it, and transcend it. Resilience is thought to conserve options and opportunity for renewal and novelty” (Berkes et al. 2000: 1252). It is important to approach the idea of adaptation and adaptive capacity through the lens of resilience thinking since “a resilience perspective on adaptation emphasizes learning, self-organization, and flexibility as crucial ingredients for

navigating complex feedbacks, thresholds, and system changes” (Tschakert & Dietrich, 2010:4).

Two types of strategies can be employed to address the climate related challenges that Aboriginal people in Canada’s arctic and subarctic are facing. Coping mechanisms are short-term, small-scale responses usually at the individual or family level to climate change impacts effecting livelihoods and according to Berkes & Jolly (2001) take the form of emergency response. For example, switching the types of species harvested to a non-traditional one, due to migration changes, would be considered a coping mechanism. On the other hand, adaptive strategies describe long-term, large scale changes usually at the community level in cultural and ecological adaptations (Berkes & Jolly, 2001). The combination of these two strategies and the interaction between them promote resilience (Berkes & Jolly, 2001).

2.8.1 Adaptation as a Process

It is important to understand adaptation as a process and “the wider implications of such a process for resilience” (Tschakert & Dietrich, 2010:1). This process includes understanding the risks, learning about the potential response options and developing the conditions conducive for a successful adaptive response (Tschakert & Dietrich, 2010). To date, the emphasis within the literature has been “project focused” which according to Tschakert and Dietrich “appears as a linear, largely self-limiting trajectory that favors readily identifiable and discrete adaptation actions, both anticipatory and reactive (before and after a shock), often presented in lists or inventories. Problematically, this view obscures the very processes that shape adaptation and resilient livelihoods” (2010:2). It should also be stressed that it is important that this adaptation process is dynamic, one that is informed by two-way communication and public value, that can adjust and react to new information and evolve to improve (Tschakert & Dietrich, 2010). Successful adaption must also include the ability to realize and embrace opportunities not just

challenges (Anisimov et al. 2007). The goal of a successful adaptation process is as T. Downing suggested “not to be well adapted but to adapt well” (as cited by Tschakert & Dietrich, 2010:2).

2.8.2 Development of Adaptive Learning

Within the current adaption arena there is an apparent lack of appropriate methodological tools to help develop, promote and sustain adaptive learning (Tschakert and Dietrich, 2010). According to Tschakert and Dietrich (2010) there is a lack of tools that support the process of adaptation and help to understand how and when “people learn to manage change, absorb shocks, take advantage of new opportunities, adjust, or completely alter their lives and livelihoods” (Tschakert and Dietrich, 2010:4). Understanding the embedded concept of learning within the adaptation process is an important step in developing resilience (Armitage et al. 2011). There appears to be two forms of learning with respect to resilience development; the first is small-scale innovation that occurs rapidly and can induce changes at the larger slower scale. The second type of learning is where slow changes at the larger scale impacts small scales through accumulated knowledge and reorganization. It is important to remember that there are key characteristics that make up “successful learning”. These include innovation, flexibility, memory and the willingness to move beyond unfavorable changes and states. Another key aspect of successful learning and adaptation is to employ forward or foresight thinking or what the literature terms anticipatory action learning (AAL). Key characteristics of AAL is the “ iterative cycles of acting, reflecting, and determining “windows” for solving emergent questions (allowing) researchers and participants alike to develop and test theories through action and facilitate learning about complex situations (Tschakert & Dietrich, 2010:6). Two other key elements make up AAL, reflection on learning and the learning process and anticipation of future learning avenues (Tschakert & Dietrich, 2010)

2.9 Adaptive Responses to Challenges Associated with Climate Change

Despite the current and predicted vulnerability of the socio-ecological systems in the arctic and subarctic, Aboriginal people in this region are “far from powerless” and are actively adapting at the individual and community level to challenges imposed by climate change (Ford et al. 2010b). It appears that Aboriginal people in the North are very flexible and innovative in their response to climatic change. In fact, flexibility to changing conditions and the use of different types of knowledge and technology is important in addressing uncertainty and promoting adaptation and resilience (Sydney-Smith et al. 2010). Traditional ecological knowledge has played a large role in successful adaptation to previous challenges that faced Aboriginal groups and it will continue to play a significant role (Sydney-Smith et al. 2010). There appears to be two schools of thought surrounding whether or not western knowledge and southern lifestyles will erode away TEK and thus Aboriginal peoples’ adaptive capacity. Some feel that western influences will alter and gradually displace TEK (Sydney-Smith et al. 2010). However, there is another point of view that has risen in popularity, that TEK actively pulls upon and experiments with outside sources of knowledge and that this integration is a source of adaptive capacity. According to Sydney-Smith et al. TEK “is thus an evolving understanding of change, defined in terms of how it incorporates and not how it excludes external or nontraditional sources of knowledge” (2010:149).

There is evidence throughout communities in the North that people are adapting to climate change through behavioral and technological adaptive strategies. Many of these responses have been reactive in nature to every-day climate related challenges, although there is emerging evidence of proactive planning, particularly in regard to harvesting practices (Ford & Pearce, 2010; Ford, 2009). Many of these responses have been coping strategies, often in

response to emergencies on the land. However, it is the accumulated knowledge from these coping strategies and experiences that is helping communities to increase their resilience and to promote decision-making and resource management (Ford et al. 2010b). This knowledge generation will help to further decrease future vulnerability to climate related changes.

2.9.1 Technology and Adaptive Capacity

There is extensive evidence of TEK evolving with the inclusion of western knowledge in promoting adaptation and growth of TEK. Technological advances are one area where western knowledge has been incorporated into TEK to allow for increased adaptive capacity in many Aboriginal communities across Canada's North. The 1960s saw the settlement of many semi-nomadic Aboriginal communities across Canada. This led to an increase in the use and dependence on technology such as powerboats, snowmobiles and all-terrain vehicles to be able to travel far enough onto the land for harvesting (Ford et al. 2006). Changes in ice conditions, resulting in more ice-free days, are being addressed through the choice of vehicle used for harvesting. Boats are allowing for access to new harvesting areas that otherwise would not be safely accessed on snowmobile (Ford et al. 2010b). Furthermore, the use of guns, satellite phones, CB radios, personal location beacons and geographic information systems (GIS) are examples of western technologies that have also been readily incorporated into Aboriginal lifestyles by allowing for a greater opportunity to maintain traditional lifestyles (Sydney-Smith et al. 2010; Ford et al. 2006).

Traditionally TEK has allowed for risk avoidance strategies. Many of the technological advances that are currently being used today by Aboriginal people are for risk avoidance (Ford et al. 2006). For example, global positioning systems (GPS) use has become more common in communities across Canada's North, helping people to navigate on dangerous and unpredictable

land and mark important locations (e.g. location of a kill or cultural sites) (Ford et al. 2010b).

Sudden changes to ice conditions, visibility and weather patterns can be monitored through GPS as well as helping hunters out on the land to navigate hazards (Sydney Smith et al. 2010). Larger and faster boats are making travel safer as well. Hunters can quickly get away from dangerous areas while being more protected from the elements. Also, larger boats are able to carry more supplies, such as, exposure gear, food and water so hunters can be more prepared to stay longer on the land if conditions require.

Mapping is also playing an important role in developing adaptation to climate change. Since the 1990s Aboriginal communities in Canada have been using GIS mapping (Eades & Sieber, 2011). GIS mapping has been recognized as a powerful tool for Aboriginal communities to map valuable information, such as, traditional land-use such as hunting, fishing and harvesting (Eades & Sieber, 2011). The use of GIS mapping plays an important role in informing TEK and storing TEK. Unlike traditional paper maps, GIS maps have the ability to be easily developed and modified to represent and archive current environmental conditions and/or traditions (Eades & Sieber, 2011). An advance on traditional GIS mapping, participatory GIS (PGIS) aims to promote greater community involvement and more collaborative planning (Sieber, 2006). Participatory GIS can be used by community members to build a database of value-based, traditionally intangible information (Sieber, 2006). This collection of information can lead to increased adaptive capacity through empowerment and knowledge generation and transmission between community and family members. Community mapping also has the ability to have direct health and safety benefits for community members. Bush travel has become increasingly dangerous due to unpredictable trail conditions. Bush trail mapping on a real-time basis can help harvesters to be informed on the safety of trail conditions prior to heading out onto the land.

2.9.2 Behavioral Changes

Behavioral changes are occurring alongside technological changes within Aboriginal communities across Canada's North. Changes to animal populations and behaviors, such as altered migration patterns, have always been a part of Aboriginal lifestyles. Flexibility has allowed for the maintenance of traditional harvesting despite variability in resources (Ford et al. 2010b). Species distributional changes have resulted in new species and changes to the migrations of native species. Access to traditional food is important for food security and for the health and wellbeing of many Aboriginal people in the arctic and subarctic (Wesche & Chan, 2010). The substitution of one species for another has been a common practice throughout history for Aboriginal communities and plays an important role in adaption today (Wesche & Chan, 2010). While climate change is expected to cause a decline in certain species, such as polar bears, it has been noted that in many regions, such as in some Inuvialuit communities, species such as muskox, *Alces alces* (moose) and *Castor Canadensis* (beaver) are becoming more abundant (Wesche & Chan, 2010). Such population changes offer suitable substitutes for harvest. Despite species substitutions it is likely that there will be times when other climatic challenges will make harvesting difficult. Food sharing offers an adaptive measure to address food insecurity within communities during difficult times (Ford et al. 2006). Some communities are turning to "super-hunters", people who harvest enough to be shared with community members through food sharing networks (Sydney Smith et al. 2010).

Despite the overwhelming body of evidence regarding the challenges that Canadian Aboriginals living in the arctic and subarctic are facing and will continue to face in the future, there are some opportunities that are predicted to occur with a warming North.

2.10 Opportunities Associated with Climate Change

It is clear that climate change is resulting in many challenges for Aboriginal people in Canada's North. Often these challenges are the main focus in the literature on climate change research and Aboriginal people. However, there are opportunities that climate change brings to these communities. Many of these opportunities are a result of warmer summer temperatures and declines in sea ice and freshwater ice.

The reduction in sea ice cover will likely create numerous opportunities for people in the Canadian Arctic. The opening of the Northwest Passage (White, 2010) will allow for a longer shipping period in the North and will likely reduce ice damage to many ships (Hengeveld et al. 2005; Furgal and Prowse, 2008). Longer ice-free period could also promote the development of seaports along the arctic coast opening the North to greater trade and increased accessibility to northern communities. Less ice in freshwater lakes and rivers will also help in barge transportation, allowing for greater accessibility to supplies in remote and isolated communities (Furgal and Prowse, 2008). Increased accessibility to the North is also expected to lead to an increase in resource exploration, extraction, production and transportation. Oil and mineral deposits will be more accessible resulting in potential economic benefits in the North.

Warmer water is expected to impact some fish species positively through the increase in food availability and decline in over-winter mortality. Populations of culturally important species such as the threatened Lake Sturgeon (*Acipenser fulvescens*) will likely increase with warmer waters. New species of fish will also migrate North with warming waters (Hengeveld et al. 2005). These changes will have impacts on commercial, recreational, and subsistence fishing. Open sea ice and new species of fish will allow for new opportunities for commercial and recreation

fisheries, both of which present economic opportunities for northern communities, but there will also be impacts on subsistence harvesters, and not always positive (Hori et al. 2012)

Terrestrial changes such as warmer summers, warmer soil temperatures, changes to precipitation rates, and changes in soil quality will impact the distributions of vegetation in the North. Overall, the net impact of these climate-induced changes will be a more productive Canadian forest ecosystem, potentially supporting a forest industry in new areas (Hengeveld et al. 2005). Warmer winter temperatures will also allow for a decrease in heating costs for many communities across the North (Anisimov et al. 2007).

Despite an agricultural industry that is worth billions, agriculture in Canada is limited by a short growing season. Southern Canadian regions experience a growing season of approximately 200 days while northern arctic and subarctic regions can see growing periods as little as a few weeks (Hengeveld et al. 2005). Severe winter temperatures and early frost damages crops. Harsh winds make it hard for communities in northern regions to grow crops for food and to generate economic income from local markets. With warming temperatures, predictions for 2050 will see growing seasons in arctic areas, such as Yellowknife and Whitehorse similar to that of Edmonton today (Hengeveld et al. 2005). Such agricultural opportunities can promote increased food security within remote and isolated communities. Fresh locally-grown foods would not only have positive health benefits, but would have beneficial economic impacts by decreasing the reliance on highly priced and imported foods. The opportunity for high-latitude sustainable agriculture shows promise to enhance resilience within arctic and subarctic communities (Anisimov et al. 2007).

2.10.1 Tree-Based Intercrops for Sustainable Food Production

Conventional agricultural practices are characterized by large-scale monocropping, a high

use of agrochemicals, reliance of irrigation in semi-arid regions, increased soil degradation and pollution of surrounding undisturbed ecosystems and an overall loss in organic carbon stores (Lithourgidis et al. 2011). With the realization of the unsustainable nature of conventional agricultural practices, the use of sustainable agroecosystem management systems such as agroforestry practices, which includes the implementation of windbreaks or shelterbelts, offers an alternative to these highly consumptive systems.

Windbreaks or shelterbelts are barriers made of perennial or annual crops, grasses, trees, shrubs, wooden fences or similar materials arranged alongside agricultural crops and/or animals on the same land management unit (Brandle et al. 2004; Schroth & Sinclair, 2003:2). Numerous ecological benefits from the use of windbreaks have been found, such as erosion control, water and nutrient retention, wind protection, increased biodiversity, carbon sequestration, protection, microclimate regulation, food production and increased wildlife biodiversity (Brandle et al. 2004; Schroth & Sinclair, 2003; Izac, 2003). To date, the majority of research concerning tree-based crops has been conducted in warmer climates such as the tropics, subtropics and temperate regions (Brandle et al. 2004; Gordon & Newman, 1997). This research has shown that tree-based systems can play an important role in enhancing economic, ecological and social benefits to many impoverished communities (Kohli et al. 2008). Furthermore, the reduction of wind speed in many agricultural systems has proven to be successful on a global scale (Brandle et al. 2004). Windbreaks have been shown to help reduce soil erosion from blowing wind and snow, to provide changes to microclimates in the sheltered zone, to increase radiant flux density, provide changes in soil temperatures, and result in less soil evaporation and increased replenishment of organic matter (Brandle et al. 2004; Kort, 1988). In general, the impact of windbreaks on crops planted within tree lines is positive and produces a greater yield (Brandle *et al.* 2004; Kort, 1988).

Globally, many countries have acknowledged the benefits of windbreaks to sustainable agricultural production (Brandle *et al.* 2004). The Canadian government has developed recommendations on the establishment of windbreaks. Despite this, only 37% of Canadian farms have either natural or manmade windbreaks (Statistics Canada, 2007). Under climate change scenarios, windbreaks are predicted to compensate for the increased environmental stresses that crops will experience. In a study conducted by Easterling *et al.* (1997), using climate and crop modeling scenarios of increased temperatures and precipitation levels (70% - 103%) of normal levels, and wind speed changes of $\pm 30\%$, sheltered crops were able to maintain yields over that of non-sheltered crops (Brandle *et al.* 2004; Easterling *et al.* 1997). Within windbreaks, the planting of more than one variety of crop species has the potential to promote more sustainable and resilient food production in the North.

Salix. spp (willow) makes for an ideal windbreak due to it being suited to wet, cool growing conditions, its fast growth rate and ease of propagation (Kuzovkina & Quigley, 2005). Multiple stemmed trunks also increase the trees density as a windbreak, especially in winter when the lack of foliage can decrease the wind protection of a site (Isebrands & Richardson, 2014). The willow is also an important plant for snowshoe hares (*Lepus americanus*), moose, beaver and caribou that graze upon the leaves, shoots and branches (Uchytil, 1992). Historically, willow has also played an important role in traditional medicine, being used as a natural pain reliever by First Nations. Willows exhibit many key physiological traits that make them suitable for future agricultural use in the arctic and subarctic. Willows are native to most of the subarctic. It has become well established in the literature that there will be a northward migration of shrubs and trees into the Arctic (Parry *et al.* 2007; Sturm *et al.* 2001). Research by Sturm *et al.* (2001) showed that over the past 50 years there has been an increase of more than 320 km² of

willow, dwarf birch (*Betula nana*) and green alder (*Alnus crispa*) into the Arctic. This northward ecological shift towards a greener Arctic holds the potential for future agroforestry initiatives using willow. With an increasing number of naturally occurring willows in many Northern regions and the potential for more favorable growing conditions in the future, there is great potential for almost immediate use of willows as windbreaks for agricultural crops.

Planting of two or more crop varieties known as intercropping has been heralded as the key to global food production (Li et al. 2009; Thrupp, 2000). Crop biomass production has been shown to increase with greater biodiversity (Li et al. 2009). Furthermore, intercrops provide greater pest resistance and a decreased use of fertilizers (Horwith, 1985). Interaction between plants can be both positive and negative. Positive interactions lead to positive yields of both plants; however, negative interactions, such as, over shading and competition for nutrients can lead to a decrease in yield (Horwith, 1985). Globally, intercropping is one of the main forms of agricultural practice. Connolly et al. (2001) found that 80% of published research on intercropping has been conducted in either Africa or Asia (Hauggaard-Nielsen et al. 2001). To date there has been very little research into successful intercrops in arctic and subarctic regions.

2.10.2 Potato and Green Bush Bean Intercrops

The intercropping of beans and potatoes has shown to be a positive interaction (Manrique, 1996). There are historical accounts of potatoes playing an important role in many First Nation communities (Barbeau et al. 2015; Wenstob, 2011). Although not considered a traditional food, potatoes are now considered a staple in many northern diets. Due to their size and weight, potatoes, when available, are very expensive due to importation costs. Not only are potatoes nutritious, being high in vitamin C and antioxidants, they are also ideally adapted to being sustainably grown in arctic and subarctic conditions with a short, cold-tolerant growing season

and long term storage ability (Kolasa, 1993).

Literature has shown that despite current commercial growing methods of potatoes, such as, high input large-scale sole crops, there is potential for greater potato yields through the use of windbreaks and intercropping, especially in northern climates (Manrique, 1996). Planting potatoes in windbreaks has not only been shown to increase plant growth but it has also been shown to increase potato yields by up to 7.7% in plants grown close to tree lines (Sun and Dickinson, 1994). As previously mentioned, to date the majority of potato production has focused on sole-cropped potato production; however, a wealth of evidence supports the use of intercropped systems to increase potato yield and decrease crop disease, while increasing food production (Manrique, 1996). The majority of potato-based intercrops currently used are located in tropical locations where potatoes are often grown alongside *Zea mays* (maize) and *Sccharum officinar* (sugar cane) (Manrique, 1996). Throughout regions such as Peru, India, Columbia and Africa, potatoes have been planted successfully alongside beans (Manrique, 1996). The literature has shown that in general, the inclusion of legumes increases crop productivity of non-legume crops grown in close proximity (Peoples et al. 2009). However, there is little evidence within the literature that potatoes have been successfully grown with bush beans in northern climates, despite the fact that bush bean and potato intercrops have been touted as a successful mix in climates with warmer soil temperatures (Manrique, 1996). Furthermore, beans offer the potential to provide an added nutritional food product.

Chapter 3

Increasing the Adaptive Capacity of Indigenous People to Environmental Change: the Potential Use of an Innovative, Web-Based, Collaborative-Geomatics Informatics Tool to Reduce the Degree of Exposure of First Nations Cree to Hazardous Travel Routes

3.1. Introduction

3.1.1 Global and Arctic Climate Change

With the release of the Fifth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC), it is now unequivocally certain that global warming is due to anthropogenic emissions, resulting in widespread social and ecological impacts (IPCC, 2014a; IPCC, 2014b). Globally the atmosphere and oceans have warmed, and there have been more frequent heavy precipitation events and heat waves (Wilbanks et al. 2007). It is becoming apparent that social systems, like ecological ones, are vulnerable to climate change, especially to extreme environmental events (Wilbanks et al. 2007). The spatial convergence of climate change impacts will likely compound risks to already vulnerable populations, globally (Noble et al. 2014). Regions such as the arctic are predicted to experience disproportionately greater ecological and social impacts from global warming (Anisimov et al. 2007). Indeed, the duration of the sea-ice free season has decreased in the arctic-subarctic region of Canada, and sea levels have changed and will continue to change (Tsuji et al. 2016; Tsuji et al. 2009; Gough, Cornwell & Tsuji, 2004).

The Canadian arctic and subarctic regions have already experienced a general warming of up to 5 °C, the most rapid rates of increasing average surface temperatures in the world (Gagnon & Gough, 2002; Anisimov et al. 2007; Hori et al. 2012). Thinning arctic sea ice has been

documented since 1979 (IPCC, 2013). Satellite imagery of arctic sea ice has shown a disturbing pattern in the rate of decline in ice extent. Winter months show a rate of decline in ice occurring at 3.5 to 4.1% per decade, while summer shows a rate of decline of 9.4 to 13.6% per decade (IPCC, 2013). Current models are predicting a continued and unprecedented decline in sea ice in the arctic. Sea ice retreat in the arctic will significantly impact arctic precipitation, the resulting increase in surface evaporation will lead to an amplified arctic hydrological cycle (Bintanja & Selten, 2014).

Climate models and precipitation trends are indicating that there will be a significant increase in rainfall in arctic regions (Gough, Gagnon & Lau, 2004; Stirling & Parkinson, 2006; IPCC, 2007; Christensen et al. 2007). By the end of the 21st century, it is predicted that precipitation rates in arctic regions will increase by 50% and will peak during the autumn and winter months, resulting in a likely increase in river discharge (Britanja & Selten, 2014). It is very likely that continued warming will result in changes to spring snow and river melt timing, pushing the spring peak flows earlier (IPCC, 2012).

Increased atmospheric warming has also impacted permafrost in the arctic. Since the early 1980s, permafrost temperatures have warmed by approximately 3°C, resulting in an overall thinning and loss in the extent of permafrost. The southern boundary of continuous permafrost in the arctic-subarctic region has already advanced northward by approximately 50km (IPCC, 2013). Warming global temperatures are producing climate extremes. Arctic regions have already recorded increased wind speeds in all seasons (IPPC, 2012). Changes to sea level pressure around mid-latitudes, has resulted in longer and more frequent winter storms over the lower Canadian arctic (IPCC, 2012). Continuing global warming is predicted to not only have devastating and irreversible ecological impacts on the arctic-subarctic environment, it is now

becoming apparent that there will be equally significant social impacts on the individuals and communities who call this region home.

3.1.2 The Risk and Challenges Associated With Climate-Related Impacts

Globally, Indigenous groups represent some of the most vulnerable populations but are rarely considered in climate change discourse (Salick & Byg, 2007). It is expected that the world's Indigenous populations, living in arctic and subarctic regions, are some of the most vulnerable and will experience the greatest impacts of climate change (Buhrich, 2010; Parry et al. 2007). Within Canada, Indigenous communities are defined as including First Nations, Inuit and Métis people. The 2011 Canadian National Household Survey determined that just over four percent of Canada's population is Indigenous, approximately 1.4 million people (Statistics Canada, 2011). Canadian Indigenous people experience many inequalities compared to Canadian non-Indigenous people, such as shorter life expectancy, higher rates of diabetes and infectious disease (e.g., tuberculosis), and higher rates of suicide and substance abuse (Ford et al. 2010; Richmond & Ross, 2009). Approximately half of Canada's Indigenous population — referred to as Aboriginal Peoples in the Canadian Constitution — live in northern Canada, on reserves or in rural and remote communities (Ford et al. 2010). Remote Indigenous populations usually share close relationships with the land and practice traditional land-based lifestyles (Durkalec et al. 2015; Richmond & Ross, 2009). Thus, Indigenous groups living in Canada's arctic and subarctic regions are particularly vulnerable to climate change due to their interconnectedness with the land (Herrmann, Royer & Cuciurean, 2012; Ford et al. 2010).

Traditional ways of living include hunting and harvesting practices that are guided by seasonal cycles. Using environmental indicators such as seasonal cycles, Indigenous groups have been able to predict seasonable changes and weather patterns (McDonald, Arragutainaq &

Novalinga, 1997). This Indigenous knowledge about the land, termed Traditional Ecological Knowledge (TEK) can be defined as being “a body of knowledge and beliefs transmitted through oral tradition and first-hand observation. It includes...a set of empirical observations about the local environment... With its roots firmly in the past, TEK is both cumulative and dynamic, building upon the experience of earlier generations and adapting to the new technological and socioeconomic changes of the present” (Stevenson, 1996). Therefore, this knowledge played an important role in the adaptation to environmental conditions on a seasonal and yearly basis (Laidler et al. 2009). However, social inequalities such as the introduction of residential schools in Canada in the 1930s have resulted in a loss of language, culture and knowledge and the disruption of transmission of TEK between generations (Ball, 2004; MacMillian et al. 1996). This loss of TEK, coupled with pre-existing marginalization and the increase in unpredictable environmental changes (e.g., increase in the number and severity of storms, increased flooding, sea ice and river changes) as a result of climate change, reveal the vulnerability of northern Canadian Indigenous communities. Climate-induced changes are expected to create challenges for Indigenous people living in Canada’s north, some of which are already being seen. These challenges both observed and predicted can be related to access to resources, and health and safety (Berkes & Jolly, 2001).

The ability to travel on land, ice, snow and by water to acquire resources is an integral part of many Indigenous peoples’ lifestyles. Traditional ways of life for many Indigenous communities involve the consumption of seasonal foods, such as, waterfowl, game mammals and fish (McDonald, Arragutainaq & Novalinga, 1997). Changes to the timing of ice break-up and river depths can affect access to family hunting camps. Often traveling by boat or snowmobile, changes to ice depths, snow type, river depths and ice-free areas can significantly hinder the

ability to get to these camps along with the length of time that can be spent there (Ball, 2004). A recent study showed that one of the most significant impacts of changing winter conditions is the inability to travel onto the land and participate in traditional harvesting activities, resulting in emotional feelings of being trapped and imprisoned (Wolf, Allice & Bell, 2012). Furthermore, participants reported changes to their eating habits, consuming more costly and less nutritious store bought foods.

Related to this ability to access traditional resources and the importance behind such resources, the safety of Indigenous people while out on the land is an important challenge when facing the impacts of climate change. Younger generations especially, are viewing the land with more fear and uncertainty and believe that it is less accessible (Ford, McDowell & Pearce, 2015; Wesche & Chan, 2010). Many safety issues are arising in relation to sea ice and early spring thaws. In many Indigenous communities, sea ice is important for winter hunting activities such as hunting sea mammals (Berkes & Jolly, 2001). However, ice conditions are less reliable, sudden changes in ice conditions are becoming more common, resulting in safety issues for those who are out on the land and water. Changes in ice-thickness, ice condition, ice movement and the extent of open water can become a safety issue while out on the ice hunting. Also, early thawing of ice and ground along bush trails is resulting in stranded snowmobiles and increased risk of drowning and hypothermia (Furgal & Prowse, 2008). Sudden changes to wind conditions often occur rapidly, resulting in dangerous and potentially life-threatening conditions for those already out on the land and water, making navigation difficult. Research has shown that the incident rate of accidents in northern coastal Indigenous communities has increased as result of changes in weather (Furgal & Prowse, 2008). Furthermore, an increase in extreme weather events, such as, an increase in unpredictable, and intense summer storms present a risk to boaters

out on the water (Furgal & Prowse, 2008; Ford, Smit & Wandel, 2006).

Cultural impacts as a result of these climate-induced changes are affecting the psychological status of many Indigenous people (Ford et al. 2010a). Since, traditional harvesting activities allow for the development of social relationships, and the processing and consumption of traditional foods any disruption to these activities negatively impacts Indigenous culture (Ford et al. 2010a).

Safety while out on the land relates to the predictability of environmental conditions (e.g. weather) (Berkes & Jolly, 2001). Historically, Indigenous people have been able to predict environmental conditions through their intimate knowledge of the land; however, it has become more difficult to use traditional knowledge to predict environmental events (e.g. ice-break up and weather patterns), as these things are occurring “at the wrong time” (Berkes & Jolly, 2001). There is concern that as adaptive and flexible as TEK is, the rate and magnitude of climate-induced change might be too unpredictable for TEK to adapt (Sydney Smith et al. 2010; Berkes & Jolly, 2001). Therefore, there is a need for decision-support tools that are culturally appropriate and community informed that can display real-time information on the safety of travel routes in arctic and subarctic Indigenous communities (Pearce et al. 2015; Pearce et al. 2012; Barbeau et al. 2011).

3.1.3 Using Geomatics to Make Travel Safer

Since the 1990s, Indigenous communities throughout Canada have been using Geographic Information Systems (GIS) for mapping (Eades & Sieber, 2011). Defined as “an organized collection of specific computer hardware, software, geographic data and personnel designed to efficiently capture, store, update, manipulate, analyze and display all forms of

geographically referenced information (e.g. raster/vector) that can be drawn from different sources” (McCarthy et al. 20011; European Commission, 2000). Within Indigenous communities, GIS have been used to map information, such as, traditional land-use (e.g. hunting, fishing and harvesting) (Eades & Sieber, 2011; Tsuji et al. 2007). The ability to map traditional land-use activities and assets has played an important role in the collection and storage of TEK. Unlike traditional paper maps, GIS maps have the ability to be easily developed and modified to represent and archive current environmental conditions and/or traditions (Eades & Sieber, 2011). However, there has been concern, within the academic arena, that GIS can be a marginalizing technology (Stewart, Jacobson & Draper, 2013). Concern over how people, space and the environment were represented by GIS systems has resulted in the shift from GIS technology to Public Participation GIS (PPGIS).

PPGIS draws upon conventional GIS techniques and builds upon them, allowing for what has been described as “a wider, more distributed use and development of geographic data, information and knowledge (McCarthy et al. 2013). Although hard to define, PPGIS has been described as “the use of geographic information systems (GIS) to broaden public involvement in policy making as well as to the value of GIS to promote the goals of nongovernmental organizations, grassroots groups and community-based organizations” (Sieber, 2006; McCarthy et al. 2013). PPGIS supports a range of interactive approaches and web-based applications that focus on ease of use and accessibility to support youth, elders, women, First Nations and other vulnerable segments of society, that have often been marginalized and excluded from decision making processes (Stewart, Jacobson & Draper, 2013). Within arctic and subarctic Indigenous communities, PPGIS offers the opportunity for communities to work together and build a database of value-based information (Sieber, 2006). This collection of information can lead to

increased adaptation with respect to the impacts of climate change, through empowerment and knowledge sharing, between community and family members. Travel route (e.g. bush trails, ice roads) mapping on a real-time basis can help community members to be proactive and make informed decisions, on the safety of trail and ice-road conditions prior to heading out onto the land. It is with this knowledge, and First Nations community involvement, that the Computer Systems Group at the University of Waterloo developed a PPGIS termed Collaborative Geomatics.

Geomatics is a method used to link geospatial data (e.g., cities, regions, countries) and attribute data (e.g., social, economic, ecological and cultural data) (Cusimano et al. 2007). Collaborative geomatics is a PPGIS mapping tool based on geo-web technology where participants can collaborate, discuss and communicate about community-based cultural asset maps and databases (McCarthy et al. 2013; Cowan, Fenton & Mulholland, 2006). The use of the collaborative-geomatics informatics tool by First Nation groups has been shown to build capacity in the communities through the complementary archiving of western science and TEK (Gardner-Youden et al. 2011) while having the potential to use the collaborative real-time function to plan and deal with the complex and dynamic nature of environmental change within subarctic environments. In this context, we worked with a subarctic First Nation community to develop and implement a collaborative-geomatics informatics tool, that can use real-time geospatially referenced environmental change information, to reduce the degree of exposure to unsafe travel routes and support the growth of community-wide adaptive capacity. In this chapter, we will present results from the initial step in our iterative process, related to the development of a decision-support tool (i.e. the collaborative-geomatics informatics tool) to reduce the degree of exposure of First Nations Cree people to hazardous bush travel routes.

3.2 Methods

3.2.1 Study Location

The western James Bay region of Ontario, Canada is populated by ~10,000 Cree who inhabit four coastal First Nations communities, and one town (i.e. Moosonee; Figure 3.1)(Tsuji & Nieboer, 1999). Our focal community, Fort Albany, is located on the Albany River (52°15'N, 81°35'W) being a remote fly-in community with a population of approximately 900 people. Year-round access to the village is by aircraft only, with ice-road access in the winter. The James Bay winter road is 312 km long and connects the First Nations community of Attawapiskat in the north to Moose Cree First Nation (i.e. the community of Moose Factory) in the south, running by the First Nations communities of Kashechewan, and Fort Albany (Figure 3.1). The winter road is a vital connection for First Nations communities along the western James Bay coast. These roads provide access to hunting camps, fishing sites, firewood collection areas, and other important subsistence-activity sites. The winter road is also lifeline that connects families that are spread out between the communities along the coast. With access to Moose Factory and Moosonee in the winter — Moosonee is the northern terminus of the rail line — northern First Nations have the ability to purchase less expensive food and household supplies. Fibre-optics and/or satellite Internet connections are available in all the western James Bay communities, with cellphone service only available in Moose Factory and Moosonee.

Fort Albany lies within the Mushkegowuk Territory (i.e. the western James Bay region), which is comprised of ecologically important muskeg and wetlands. This region provides resources that many First Nations rely upon for subsistence, such as, traditional game species (e.g., large ungulates, small mammals, game birds, fish) which are also, socially and culturally important (Tam, Tsuji & Gough, 2011; Tsuji et al. 2001). Seasonal harvest of traditional foods is

still an important part of life for First Nation Cree along the James Bay coast (Tsuji & Nieboer, 1999; McDonald, Arragutainaq & Novalinga, 1997). The spring harvest, which begins the middle of March, with the setting up of spring camps, is an important time of year for the harvesting of traditional food that will be stored for consumption throughout the year. This time spent out on the land is also an important time where families come together to re-affirm their culture (Barbeau et al. 2012). The spring hunt continues until river break-up, late April or early May (Ho, Tsuji & Gough, 2005; McDonald, Arragutainaq & Novalinga, 1997)

With respect to climate change, this region has already experienced significantly earlier sea-ice break-up events (0.8 days/ year) and significantly longer sea-ice-free seasons (0.32 to 0.55 days/year) (Tam, Gough & Tsuji, 2011; Gagnon & Gough, 2005; Gough, Cornwell & Tsuji, 2004). The Albany River and Attawapiskat River have also seen earlier break-up dates impacting the communities along their banks (Tam, Gough & Tsuji, 2011; Ho, Tsuji & Gough, 2005). Sudden warming events in the late spring combined with increased rainfall events have been attributed to extreme flooding events in the First Nations communities along the Albany River (Adbelnour, 2008). It is predicted that by the year 2100 in the western James Bay region, summer temperatures will increase by 4.1°C and winter temperatures by 7.5°C, along with an increase in extreme weather events (IPCC, 2013).

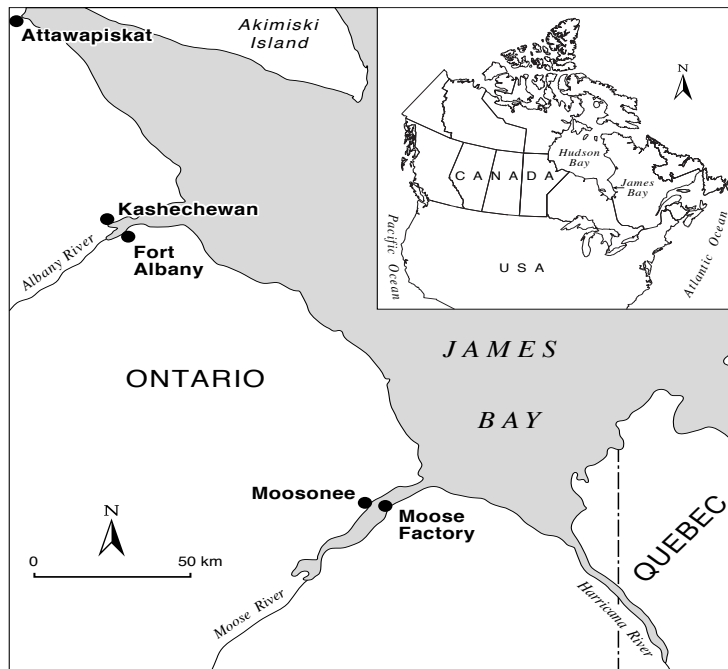


Figure 3.1 Map of the Mushkegowuk Cree territory First Nations, Western James Bay, Ontario, Canada

3.2.2 The Collaborative-Geomatics Informatics Tool

The term collaborative geomatics is defined as “a participatory approach to both the development and use of online, distributed-authority, geomatics applications ” (McCarthy et al. 2012). Similar to neogeography, collaborative geomatics builds upon the concept of PPGIS and Collaborative GIS, where public participation is paramount (McCarthy et al. 2012).

Collaborative geomatics is a system that is “centered on the designs, processes, and methods that integrate people, spatial data, exploratory tools, and structured discussions for planning, problem solving, and decision-making” (Balram & Dragicevic, 2006).

What makes our geomatics decision-support tool unique is that it is based on the declarative application engine termed WIDE (Web Informatics Development Environment). The

WIDE software toolkit was developed by the University of Waterloo, to construct, design, deploy and maintain relatively inexpensive complex web-based systems (Charania, Cowan & Tsuji, 2013). The WIDE toolkit allows for a forms/wizards-based approach to system construction that supports the rapid development and modification of the tool. The WIDE toolkit is provided as a software service over the Internet and is supported by standard web browsers (McCarthy et al. 2012).

The collaborative-geomatics informatics tool supports a common high-resolution imagery reference map, similar to how Google Earth® presents data (McCarthy et al. 2013) (Figure 3.2). Some of the basic features of the tool includes the entry of real-time geospatial information (oral, written and visual [photographic, video]) that is securely housed within the system through accessibility safeguards (usernames and passwords). The ability to develop groups within the system and send both public and private messages, similar to Facebook® Messenger® supports the development of social networks (Figure 3.3). Furthermore, a forums section within the system allows for members to discuss a variety of topics with other users in their community network (Figure 3.4).

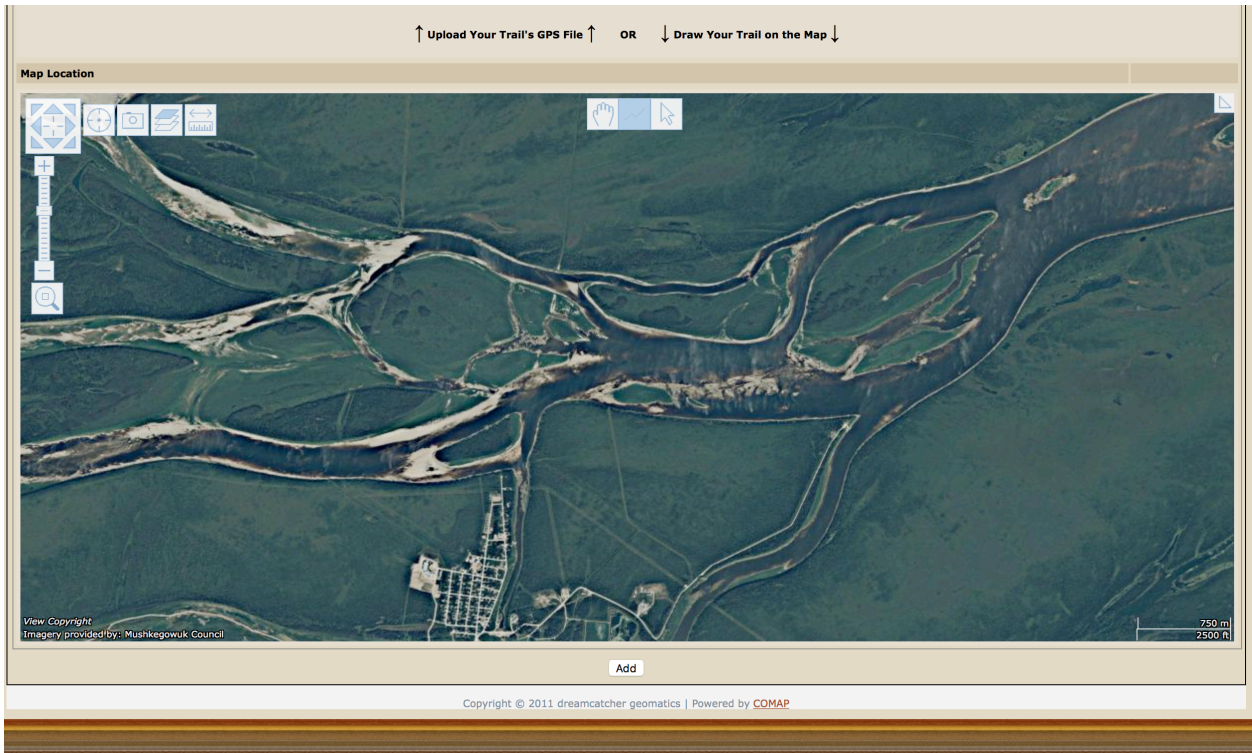


Figure 3.2 Satellite imagery on the collaborative-geomatics informatics tool of Fort Albany First Nation

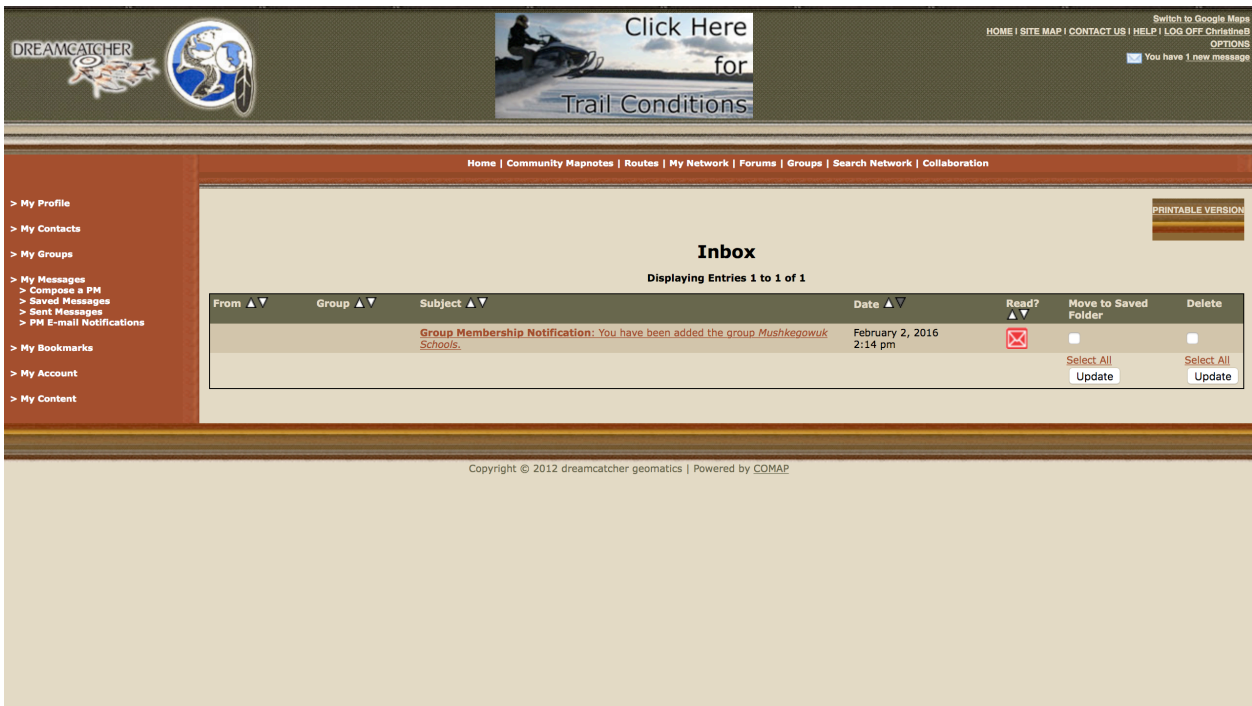


Figure 3.3 Group development application on the collaborative-geomatics informatics tool



Figure 3.4 Forum development application on the collaborative-geomatics informatics tool.

The WIDE toolkit and collaborative geomatics system is a proven technology that has been successfully used in governmental, resource management and cultural heritage applications (McCarthy et al. 2013; McCarthy et al. 2012). One question that had been raised in the initial development of the geomatics tool with Chiefs and Councils of Fort Albany First Nations, and community members, was that of the security/confidentiality of TEK such as locations of hunting camps and community bush trails that will be collected and stored in the informatics tool. As TEK is intellectual property, the security of TEK is of utmost importance. It was explained that all data (including TEK) would be stored only on secure servers within the communities (and/or secured data vaults off-site). Added to the physical security aspect of the tool, TEK would also be operationally secure with access to TEK on the tool being password protected through profiles vetted by the chosen representatives of the individual communities. In some cases, differential access would be controlled by Chiefs & Councils, while in other cases

by family gatekeepers (McCarthy et al. 2013). Granting of differential access was dependent on the type of TEK and the proposed use of TEK (McCarthy et al. 2013; McCarthy et al. 2012). It should be emphasized that other iterations of the informatics tool have provided storage for sensitive data for government ministries using the exact same safeguards as described above (McCarthy et al. 2012). Even the researchers do not have access to TEK on the tool unless granted by a gatekeeper. Our approach is guided by the Indigenous principles of OCAP (First Nations Centre, 2007): community Ownership, Control, Access, and Possession of their data. With data housed within the communities and with the applications accessible through any Internet connection, the short-term accessibility is not in question. Over the medium to long-term, there were concerns about the sustainability of a system that requires upgrades and development from a third-party organization. Given this issue, a stand-alone version of WIDE toolkit is currently being developed to allow communities to create their own unique applications for their informatics tool (McCarthy et al. 2013). With some basic training, community members could develop and evolve their system to meet the future geospatial knowledge needs; this is one of the unique features of the WIDE toolkit's wizards-based approach.

3.2.3 Field Testing of the Informatics Tool

In 2016, using handheld GPS units (Garmin® Oregon® 550) alongside a mobile Apple iPhone® GPS tracking app (Track Kit®), the western James Bay winter road was tracked by vehicle and the associated .GPX files were uploaded onto the collaborative-geomatics informatics tool. The Garmin GPS units have been shown by previous research in the same subarctic community to be easy to transport and were easy to use when tracking and georeferencing important locations (Isogai et al. 2015). The Apple iPhone® GPS tracking app (Track Kit®) was chosen to act as a back-up, and to support the tracking of travel routes, due to the low

cost associated with this program and the fact that many community members in Fort Albany own and use Apple products, such as, the Iphone®, Ipad® and Ipod®, all of which are supported by the Track Kit® app. Prior to using the app, the associated background map of the western James Bay coast was loaded from an internet connect.

While mapping the winter road, important river crossings and areas known to flood were marked as waypoints and photographed. These waypoints and photographs were then uploaded onto the informatics tool. Community bush trails as identified by community members were also tracked using the same GPS devices. With the help of a community elder these trails were driven by snowmachine and the use and cultural importance of these travel routes were discussed. These tracks were saved as .GPX files and uploaded onto the informatics tool as a bush-trail layer. Important landmarks were also marked using waypoints and photographed using both the GPS cameras and Apple Iphone® camera. The collaborative-geomatics informatics tool supports photographs uploaded in either .JPG, .PNG or .GIF file format. The initial evaluation of the potential use of the collaborative-geomatics informatics tool was qualitative, using a combination of field notes and participant observations (Isogai et al. 2015; Churchill et al. 2010; Bryman, 2001).

3.3 Results and Discussion

3.3.1 Ease of Use (Hands-on Testing)

With the use of handheld GPS tracking systems, the tracking of community bush trails and the winter ice road were successfully tracked and uploaded as .GPX files onto the collaborative-geomatics informatics tool. Pictures and important locations were also noted and marked as waypoints and uploaded (as .JPG files) onto the informatics tool (Figure 3.5). The ability to add geospatial information in the form of photographs/videos in real-time has the ability to provide even more detailed information on travel conditions.

Travel conditions were colour coded according to road and trail conditions (white = clear conditions, yellow = use caution some areas may become dangerous, red = avoid use, dangerous conditions). Five of the most frequently used community bush trails were mapped along with the 312 km James Bay winter road both north (Figure 3.6) and south of Fort Albany. Overall, the ability to track and map community travel routes and upload them as a layer onto the informatics tool was simple and accurate; we could visualize the winter road on our base layer, satellite imagery, to check the accuracy of the waypoints uploaded. While the Garmin® GPS units were easy to use, the ease of use and ability to take detailed pictures and notes on the mobile App, made the Track Kit® app the most useful GPS unit in mapping travel routes. Furthermore, the pre-loaded high-resolution imagery on the App allowed for navigation while travelling along the bush trails and winter road.

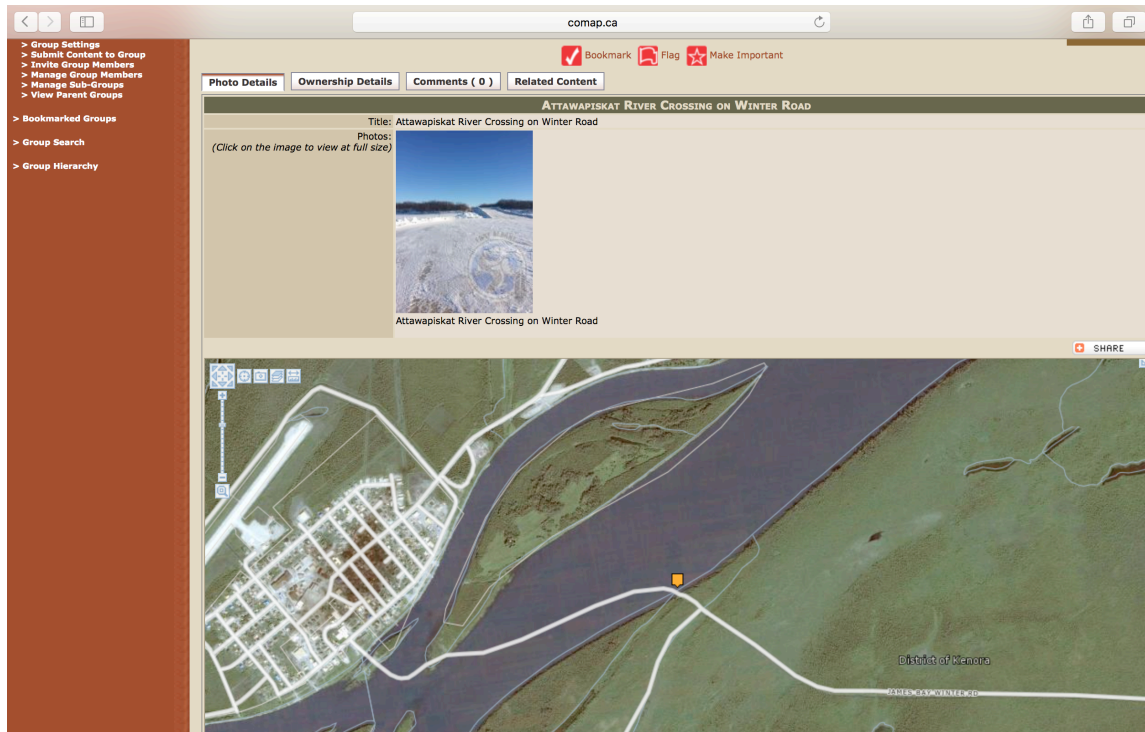


Figure 3.5 Geospatially referenced photograph of a river-crossing located on the James Bay winter road.

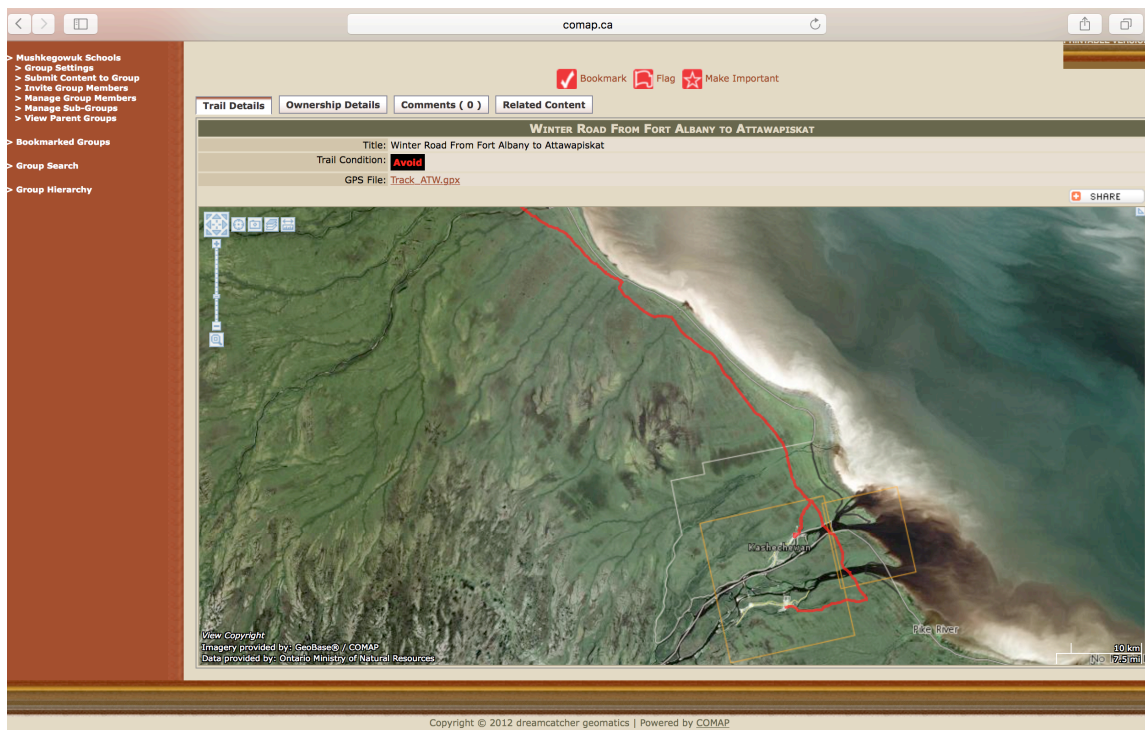


Figure 3.6 James Bay winter road, north of Fort Albany First Nations to Attawapiskat First Nation, tracked via handheld GPS units and uploaded as a layer onto the collaborative-geomatics tool.

3.3.2 The Potential Use of the Collaborative-Geomatics Informatics Tool to Build Adaptive Capacity

The meaning of names and relationships with the land are often propagated in narratives from elders to children. This oral history helps First Nation children to develop a sense of place within their environment from a very young age. This sense of place with the land and the memories and connections to a place are responsible for guiding future societal activities, land uses, oral history and cultural transmissions of traditional knowledge. It is widely recognized that First Nations have developed an extensive understanding of the environment (CEAA, 2010). In the past, this knowledge of the environment was transmitted within and between generations, solely through oral traditions. This knowledge allowed First Nations people to sustain their subsistence lifestyles and adapt to environmental change. Historically, northern Indigenous communities addressed changes in the environment through TEK and skillsets acquired over generations on the land (Ford et al. 2006; Berkes & Jolly, 2001). Due to rapid changes in the environment as a result of a warming climate, knowledge once used to respond and adapt is becoming increasingly difficult to apply, thus decreasing First Nations' adaptive capacity (Ford et al. 2006; Berkes & Jolly, 2001). As environmental change continues in the arctic and subarctic regions, the resulting direct and indirect impacts have affected and will affect traditional lifestyles (Hori et al. 2012; Tam et al. 2011). At present, there is a great disconnect between what is currently being done on a global climate scale in terms of adaptation measures to climate change, and what is needed locally (Berkes & Jolly, 2001, Wilbanks & Kates, 1999). Increasing a community's adaptive capacity is one way in which vulnerability can be reduced (Smit & Wandel, 2006; Walker & Salt, 2006). The collaborative-geomatics informatics tool is a

decision-support tool that has the potential to increase the adaptive capacity of northern Canadian Indigenous people to climate change impacts.

The following factors have resulted in less predictable and more dangerous travel routes: changes in the extent and extant of ice on lakes and rivers; later ice formation; earlier and more rapid spring melting; changes in the quality and amount of snow; increased precipitation especially in the form of freezing rain; increased wind events; unpredictable wind directions; and an increased number of storms (Pearce et al. 2012; Ford, 2012; Prno et al. 2011; Berkes & Jolly, 2002). The biophysical impacts of climate change on the safety of travel routes in the Canadian arctic and subarctic are having negative physical, social, cultural and economic impacts on the Indigenous communities in the region (Durkalec et al. 2015; Pearce et al. 2012; Pennesi, Arokium & McBean, 2012; Prno et al. 2011; Wesche & Chan, 2010). The collaborative-geomatics informatics tool has the potential to act as a decision-support tool to make bush travel safer, by promoting informed decisions prior to bush travel. The real-time capabilities of the tool can help determine the safest and most appropriate travel time and route prior to heading onto the land. This knowledge can directly protect the health and safety of individuals, but also can help relieve the anxiety associated with the unpredictability of travel routes; thus allowing for greater ability to practice traditional land-use.

The collaborative-geomatics informatics tool would allow for the support of social networks where real-time travel information in the form of mapped trails/commentary/picture /videos can be posted online, allowing for further networking and discussion. The sharing of information via social networks can further help to rapidly mobilize community response in times of crisis (Ford, Smit & Wandel, 2005). Indeed, Pennesi et al. (2012) noted that one of the main barriers towards climate change adaptation in the arctic was the lack of social networks to

support the informed decision on the safety of land-based activities. Historically, community and family units played an important role in supporting adaptive capacity in northern Indigenous communities (Ford, Smit & Wandel, 2005). However, with changes to the social and cultural structures, many Indigenous communities have seen radical changes in lifestyles, resulting in the erosion of the social networks that have historically supported adaptation to environmental challenges (Ford, Smit & Wandel, 2005). The building and support of social networks in arctic Indigenous communities to build relationships of support and trust have been identified as key components in contributing to adaptability (Ford, Smit & Wandel, 2005). The collaborative-geomatics informatics tool has the potential to support the use of multiple social networks, where users can invite others to join a group and share specific information with those members. Thus, the collaborative-geomatics informatics tool has the potential to increase the adaptive capacity of arctic-subarctic Indigenous communities by supporting the transfer of TEK (Table 3.1). The transfer of information can be horizontal across age groups and/or vertical between age groups (Isogai et al. 2015; Barbeau et al. 2012). Adaptive capacity has been described as “a set of resources that represent an asset base from which adaptations can be made” (Pearce et al. 2015). TEK plays a pivotal role in the manifestation of adaptive capacity and is considered to be a vital component in the effectiveness of adaptive strategies (Pearce et al. 2015; IPCC 2014c; Barbeau et al. 2012; Pennesi, Arokium & McBean, 2012)

Table 3.1 Key features of the collaborative-geomatics informatics tool important for the monitoring of unsafe travel routes

<i>Features of the Informatics Tool</i>	<i>Importance</i>
Geospatial Information (Oral, Written, Visual [Picture/Video])	<p>Ability to store geospatial information on culturally important locations, such as, bush trails (Isogai et al. 2014; Barbeau et al. 2011)</p> <p>Linking youth and elders through technology and traditional knowledge in the form of oral history (Barbeau et al. 2011)</p>
Social Networking (Groups and Forum Development)	<p>Allows for social networking to help decrease the risks associated with heading out onto the land</p> <p>Formation of groups and forums within the geomatics tool to share information and discuss experiences (Barbeau et al. 2011)</p> <p>Communication can foster the collaboration and exchange of information between individuals and communities along the coast that share resources and travel routes (Ford et al. 2006)</p>
Real-time Capabilities	<p>Real-time travel information will allow families and communities members to determine the safest time to travel and empower youth to travel onto the land</p> <p>Greater safety can allow for more travel between communities and the resulting transfer of knowledge</p> <p>Real-time capabilities can help with the selection of the safest travel route going out on the land</p>

Access to TEK is important in the formation of appropriate adaptive responses that together support the building of adaptive capacity. The effectiveness and strength of an adaptive measure is directly related to the quality of information available (Pearce et al 2012). Individuals and communities that readily have access to TEK will possess the depth of knowledge required to develop strong adaptive responses towards hazardous and unpredictable travel routes. Three areas of adaptive responses; *flexibility*, *hazard avoidance* and *emergency preparedness*, have been identified as being important in building adaptive capacity in the arctic (Noble et al. 2014; Pearce et al 2012). The collaborative-geomatics informatics tool has the ability to support each of these adaptive responses.

The diversity and flexibility in travel routes and resources are vital in the adaptability towards unpredictable climate events and dangerous travel conditions (Ford, Smit & Wandel, 2006). The collaborative-geomatics informatics tool imbues flexibility, by allowing for modification and adjustments to travel routes prior to heading out onto the land. Based on real-time trail and road conditions, decisions can be made with respect to changes in modes of transportation, harvesting equipment, and location of harvesting activities (Sydney Smith et al. 2010; Pearce et al. 2010). Flexibility and diversity in behavior leads to the development of new skills and knowledge, that can further support the ability to make flexible and diverse decisions, resulting in increased adaptive capacity. There are some constraints to behavioral flexibility that can be addressed through features of the collaborative-geomatics informatics tool. Income constraints have been shown to restrict the flexibility and diversity of behaviors (Pearce et al. 2010). Changes in the mode of transportation and type of harvesting equipment are resource dependent and can act as barriers to adaptation. Social networking, such as, discussion forums and group settings, supported by the informatics tool, can link community members together to

share resources, exchange ideas and develop groups that could pool their resources and travel together.

Hazard avoidance of dangerous and unsafe travel routes is another adaptive response important to the development of increased adaptive capacity. Technology has been shown to play an important role in the avoidance of hazards (Pearce et al. 2012). Geospatial information provided in the informatics tool acts as a knowledge base from which individuals and groups can accurately identify real-time hazardous locations and determine the safest way to travel or whether to travel at all. Photographs and videos uploaded onto the tool can also provide valuable in-depth detail and real-time travel information of hazards to be consulted prior to heading out onto the land. The real-time capabilities of the informatics tool can also support more efficient maintenance and repair of hazardous locations on travel routes. Geospatial information uploaded onto the tool can inform ice-road maintenance crews of the exact locations of hazardous conditions allowing for quicker and more efficient resource use.

When facing unpredictable environmental conditions, emergency preparedness is an important adaptive response. Anticipating adverse travel conditions prior to travelling can help to avoid dangerous and potentially deadly situations. The collaborative-geomatics informatics tool can serve as a decision-support tool that allows individuals and groups to make informed decisions on travel conditions before heading out. Some of these decisions are regarding the equipment and supplies required to travel safely. The modification of equipment used while on the land, such as, more powerful boat engines and snowmobiles can reduce the degree of exposure to dangerous situations (Ford, Smit & Wandel, 2006). The packing of extra and/or emergency supplies (e.g. extra gas, food, water and warm clothing) is a proactive adaptive response to hazardous (or potentially hazardous) situations while travelling on the land. The

informatics tool can help in emergency preparedness through proactive route planning.

Individuals or groups heading out onto the land can geospatially mark locations on the tool prior to heading out to identify where they could be located if any issues were to arise. Furthermore, the social networking abilities of the tool can help to bring individuals together to form travelling groups reducing the likelihood of emergencies and sharing of supplies to reduce the costs associated with bush travel. In this way, communities can build their adaptive capacity to deal with an unpredictability environment.

A dimension of adaptive capacity is the ability for a community to be innovative (McCarthy et al. 2012; Westley, 2009). Innovation can be defined as an “initiative, product, process or program that profoundly changes the basic routines, resources and authority flows or beliefs of any social system” (McCarthy et al. 2012; Westley, 2009). The collaborative-geomatics informatics tool can not only help reduce the degree of exposure to unsafe travel routes, but it can also allow communities to monitor, store and analyze various forms of information to help monitor cumulative impacts of environmental change in the area. The ability of the informatics tool to nurture diversity and flexibility of different forms of knowledge is a key attribute to the development of innovation (McCarthy et al. 2012). Increased innovation would allow for subarctic First Nations communities to not only adapt to climate related impacts, but to actively engage in community-based land use planning, increasing the community’s ability to respond to change associated with the ever increasing developmental pressures, in the region (McCarthy et al. 2012).

3.3.3 Future Development of the Informatics Tool

The next step in the development and implementation of this real-time informatics tool will be to work towards developing it as a mobile App supported by Apple Iphone®, Ipad®, Ipod®

and Andriod® phones. This would allow for the tracking and mapping of not only community travel routes, but also personal and family trails. With the development of a collaborative-geomatics informatics tool mobile App, the tracking of travel routes and the storage of TEK could be accomplished without the expense of having to purchase GPS tracking devices. Furthermore, due to privacy concerns around third party Apps, a mobile geomatics app would allow individuals to have control over their own information. Having a handheld informatics tool that could seamlessly track travel routes and automatically upload trails without the use of cables and computers, would allow for greater accessibility by community members who might not have access to computers and the skills to use traditional GPS devices. Another added benefit of developing a handheld mobile version of the informatics tool would be using the tool for navigation. High-resolution base maps used in the current geomatics system, when loaded onto the tool prior to heading out onto the land, could act as a navigation tool to help guide individuals or groups around hazardous areas or during emergencies.

Although the monitoring and mapping of real-time safe-travel routes is a specific application, this collaborative-geomatics informatics tool could also be used for other purposes (Isogai et al. 2015). Once the collaborative-geomatics informatics tool has been fully community-tested and modified to meet the community's needs, the informatics tool will be given to the community, as a stand-alone, secure system, at no cost to the community. It should be emphasized that this type of innovative approach and technology has the potential to help other Indigenous communities in the Canadian arctic and subarctic, as well as Indigenous communities located outside of Canada.

3.4 Conclusion

It is clear from numerous scientific studies that global air temperatures are rising at a rate never experienced before. This elevation in temperatures is having impacts on Earth's ecosystems, resulting in changes in snowfall, rainfall, sea levels and species distributions. Such environmental changes have been well documented, but there has been relatively little research into the impacts of climate change on social systems. As the global population continues to rise and the divide between the rich and poor widens, it is expected that climate change effects will disproportionately impact already marginalized populations. Furthermore, experts predict that northern latitudes will experience the greatest impacts of environmental change due to global warming. First Nation communities in Canada have a history of marginalization and social inequalities especially in communities located in northern regions of the country. Despite these differences, there has been relatively little done to mitigate the impacts of environmental change on Indigenous people. The ability to travel on land, ice, snow and by water to acquire resources is an integral part of many Indigenous peoples' lifestyles. However, changes to the extent and expanse of ice on lakes and rivers, changes in the quality and quantity of snow, increased precipitation especially in the form of freezing rain and unpredictable storms — have resulted in less predictable and more dangerous travel conditions — impacting not only the health and safety of individuals, but the traditional lifestyle that are vital to the cultural wellbeing of these Indigenous communities.

This study set out to examine the potential of a novel decision-support tool to reduce the degree of exposure to unsafe travel routes for James Bay Cree. It is clear from this research that the collaborative-geomatics informatics tool developed by the University of Waterloo's Computer Systems Groups has the potential to allow for the community to monitor, in real-time,

the safety of travel routes. The ability to monitor and store information, on the safety of travel routes, has the potential to promote adaptive capacity and aid in knowledge transfer within arctic and subarctic First Nations Cree communities. The use of TEK and western science as complementary knowledge system should be encouraged (Tsuji & Ho, 2002). Increased adaptive capacity can lead to social and ecological resilience, allowing for Indigenous communities' to better withstand the shocks and stresses that further environmental change and future resource development will bring (Walker & Salt, 2006; Armitage, 2005; Gunderson & Holling, 2002).

Chapter 4

Sustainable Agriculture and Climate Change: Producing Potatoes (*Solanum tuberosum* L.) and Bush Beans (*Phaseolus vulgaris* L.) for Improved Food Security and Resilience in a Canadian Subarctic First Nations Community

4.1 Introduction

4.1.1 Canadian Aboriginal Health

Aboriginal groups (Metis, Inuit and First Nations) face a shorter life expectancy from birth compared to non-Aboriginal Canadians (Statistics Canada, 2001). This difference in life expectancy has been attributed to numerous environmental factors, such as overcrowding, poverty, environmental contamination, geospatial remoteness, and food insecurity (Macdonald, Rigillo & Brassard; 2010; Ford et al. 2010; MacMillan et al. 1996). Restricted access to nutritional foods has resulted in disproportionately higher rates of obesity in Aboriginal communities. Over the last 25 years, obesity rates in Aboriginal communities rose more than 50% compared to the rest of Canada (Gates et al. 2012). At present, obesity rates in Aboriginal children and adolescents are increasing which will ultimately lead to increased incidences of diet-related illnesses, such as type 2 diabetes and cardiovascular disease (Gates et al. 2011; Skinner, Hanning & Tsuji, 2006; Shields, 2005; Anand et al. 2001).

Food insecurity in Aboriginal populations in Canada is an urgent issue that must be addressed (Skinner et al. 2013). Food insecurity can be defined as individuals within a household not having adequate physical, social or economic access to sufficient, safe and nutritious food (Food and Agriculture Organization of the United Nations, 2003). Indeed, results from the 2008 First Nations Regional Health Survey found that among Canadian Aboriginals over 50% of households were considered to be food insecure. The high rate of food insecurity in Aboriginal Canadian communities was attributed to multiple factors including environmental contamination,

climate change, and the movement away from a traditional subsistence diet to a modern diet (Skinner, Hanning & Tsuji, 2006). Further, there appears to be a strong relationship between food security and community location (Skinner, Hanning & Tsuji, 2006). It was suggested that the more northerly and remote a community's location, the higher the incidence of food insecurity (Skinner et al. 2013; Skinner, Hanning & Tsuji, 2006). Prevalence rates were reported as high as 70% for remote Aboriginal communities (Skinner et al. 2013; Skinner, Hanning & Tsuji, 2006). For the purpose of this article, northern Aboriginal communities are defined as communities in arctic and subarctic regions, north of the 51° latitude.

4.1.2 Current Food Systems in Northern Canadian Aboriginal Communities

Historically, traditional diets included wild game, berries and plants that promoted physical and mental health (Spiegelaar & Tsuji, 2013). However, with time, the consumption of traditional foods declined in many Aboriginal communities. The loss of hunting and fishing for traditional meats was attributed to numerous barriers including a rise in gasoline prices, unpredictable and dangerous environmental conditions, and lack of time (Barbeau et al. 2013). Furthermore, a loss of Indigenous knowledge due to the Government of Canada's attempt to assimilate Aboriginal Canadians into "mainstream" Canadian society resulted in a loss of knowledge on hunting, gathering and traditional food preparation techniques (Spiegelaar & Tsuji, 2013). Today, many northern diets contain little traditional food with wild meat, fish and berries replaced with modern import-based processed foods (Spiegelaar & Tsuji, 2013; Willows, 2006).

A major barrier to eating nutritious market foods in many arctic and subarctic communities is the high cost of poor-quality food items and, when fresh produce is available, it is often spoiled (INAC, 2009; Skinner, Hanning & Tsuji, 2006; Willow, 2005; INAC, 2004).

Due to geospatial constraints and climate, the majority of food available in northern Aboriginal communities is imported by air year-round, by sea during the ice-free summer months, and by winter ice-road after freeze-up and before break-up. Not only does remoteness result in food prices 2–4 times greater than those in southern communities, it also perpetuates an unsustainable petroleum-based economy, contributing to greenhouse gas emissions and climate change.

Efforts were made by the Canadian Government through the *Nutrition North* program to improve the affordability and availability of fresh and nutritious foods in remote communities. These efforts were associated with mixed success. Critics noted that this program was tailored to what is considered a healthy lifestyle by “outsiders” and there is little control over produce quality (Skinner et al. 2013; Papatsie, 2011). Despite attempts from the Canadian Government to improve food security in northern communities, recent research in one remote First Nation community revealed that most respondents interviewed worried about having enough food and if they could afford to eat balanced meals (Skinner, Hanning & Tsuji, 2013).

4.1.3 Current Global Agricultural Practices

The current northern-Canadian import-based food system is unsustainable, with the majority of imported food produced in southern regions through conventional high-input agricultural practices. Current intensive agriculture “has come to draw the inputs which it uses from more distant sources, both spatially and sectorally, to derive an increasing proportion of its energy supplies from non-renewable sources, to depend upon a more narrow genetic base and to have an increasing impact on the environment. This is particularly reflected in its heavy reliance on chemical fertilizers and pesticides, its dependence upon subsidies and price support and its external costs such as threats to other species, environmental pollution, habitat destruction and risks to human health and welfare” (Hodge, 1993:3). Therefore, there is a need for sustainable,

healthy and local-subsistence food systems to meet not only the nutritional needs of Aboriginal Canadians living in northern regions, but also, to promote social and ecological health. Historically, agriculture in northern Canada was severely limited by temperature; however, a warming climate presents an opportunity to better understand the potential for more sustainable agricultural practices in the north (Hengeveld, Whitewood & Fergusson, 2005).

4.1.4 More Sustainable Agriculture in Canada's North

Despite an agricultural industry that is worth billions, agriculture in Canada is limited by a short growing season and harsh temperatures (Hengeveld, Whitewood & Fergusson, 2005). Southern Canadian regions experience a growing season of approximately 200 days while northern arctic and subarctic regions can see growing periods as little as a few weeks (Hengeveld, Whitewood & Fergusson, 2005). Severe winter temperatures and early frost harm crops; harsh winds make it hard for northern communities to grow crops naturally for food and to generate economic income from local markets. However, the predicted rate of temperature increase for northern regions is nearly double that of the global average, with temperatures expected to increase 5 °C–7 °C (IPCC, 2007; Christensen et al. 2007; Ford & Smit, 2004). With warming temperatures, the growing season in arctic areas such as Yellowknife, Northwest Territories, Canada and Whitehorse, Yukon Territory, Canada will be similar to that of Edmonton, Alberta, Canada today by the year 2050 (Hengeveld, Whitewood & Fergusson, 2005). Such a change in climate can provide agricultural opportunities to promote increased food security within rural, remote and isolated communities using agroforestry stewardship practices. Agroforestry utilizes woody perennials and crops in patterns that optimize biological interactions.

Fresh produce, grown more sustainably and locally has a positive effect on health and decreases the reliance on costly imported foods. Promotion of local, more sustainable agriculture

in Aboriginal communities in the Canadian arctic and subarctic has the potential to enhance food security in a socially and environmentally sustainable way. Warming temperatures in the Canadian arctic and subarctic present an opportunity to investigate the potential for local, more sustainable food production in Aboriginal communities. The aim of this study was to examine the potential to sustainably grow potatoes (*Solanum tuberosum* L.) in a subarctic First Nations community with the goal of helping to enhance food security.

4.2 Methods

4.2.1 Research Community

The First Nations community of Fort Albany was chosen as the location for this pilot study. Fort Albany is located in the Canadian subarctic on the western James Bay coast, northern Ontario, Canada. Located along the south shore of the Albany River (52°15' N, 81°35' W), Fort Albany is a remote fly-in community with a population of approximately 850 people. Within the community there is one grocery store and two small convenience stores where groceries can be purchased. However, availability of produce is highly variable and staple food items, such as, potatoes are unavailable for weeks. Traditional foods, such as moose (*Alces alces*), caribou (*Rangifer tarandus*), waterfowl, and fish, are an important part of many community members' diets; however, accessibility issues such as travel costs, unpredictable travel conditions, and changes in bird migration patterns have made the procurement and consumption of traditional foods a challenge (Barbeau et al. 2013).

The western James Bay region is characterized by short, cool summers (mean annual temperature of -1.1 °C) with a high annual precipitation (728 mm) and annual growing degree-days (a measure of accumulated heat energy) of 830 (>5 °C) (Riley, 2011). Fort Albany, like many other communities in arctic and subarctic regions of the world, has already experienced

climatic warming (Hori et al. 2012). Climate change modeling for this region predicts a future increase in surface-air temperatures and summer rainfall events resulting in potentially favorable agricultural conditions (Barbeau et al. 2013; Hori et al. 2012; Riley, 2011; IPCC, 2007; Christensen et al. 2007; Stirling & Parkinson, 2006; Gough, Gagnon & Lau, 2004).

Fort Albany has a history of conventional and unsustainable agricultural practices (Spiegelhaar & Tsuji, 2013). In 1930, Roman Catholic Missionaries cleared some areas close to the community, and planted and maintained relatively large areas of potato, turnip (*Brassica rapa*) and hay (Spiegelhaar & Tsuji, 2013). Smaller gardens were planted with beet (*Beta vulgaris*), radish (*Raphanus sativus*), cabbage (*Brassica oleracea* var. *capitata*), lettuce (*Lactuca sativa*), strawberry (*Fragaria ananassa*), onion (*Allium* spp.), tomato (*Solanum lycopersicon*) and carrot (*Daucus carota*) (Spiegelhaar & Tsuji, 2013). Agricultural production was maintained using machinery and pesticides; crops were watered during dry periods from a nearby lake and cow manure was used as fertilizer. Greenhouses were also utilized to extend the growing season of the crops. Community members were required to work in the fields to help plant, maintain and harvest the crops, thereby taking people away from spending time practicing traditional skills (Spiegelhaar & Tsuji, 2013). By the 1970s, Missionary support of conventional agriculture stopped, although some community members continued to plant small patches of potatoes, for several years. Previous research showed that community members view gardens as “a means to acquire produce at a cheaper price, especially potatoes, which are favored but very expensive” (Spiegelhaar & Tsuji, 2013:8).

4.2.2 More Sustainable Potato Production

The potato is an ideal crop as a starting point in helping to foster and promote sustainable local-food production in northern Aboriginal communities. There are historical accounts dating

back to 1858 of potatoes playing an important role in cultural traditions in some Canadian First Nations communities (Wenstob, 2011). Further, the potato has become a staple of the modern diet in northern communities. However, the purchase of potatoes in the north is expensive due to their high bulk and weight, increasing air transportation costs. Thus, producing potatoes locally would make potatoes relatively inexpensive. Further, the potato is a cool climate crop that has a requirement of 1000–1100 ($>5^{\circ}\text{C}$) growing degree-days to reach optimum harvest (International Arctic Science Committee, 2014). In addition, the potato is extraordinarily adaptive, easy to cultivate, has a long storage life and is nutritious.

A 150 g potato contains 110 calories per serving, has a high amount of antioxidants and nearly half of the recommended daily intake of vitamin C. With more potassium than a banana and 10% of the daily value of dietary fiber and iron, potatoes help support a nutritious diet (Spiegelaar, Tsuji & Oelbermann, 2013). For the purposes of the presented research, the Shepody Potato variety cultivar was selected, after a pilot study of three potato types in 2011. The Shepody is a white fleshed, russet potato that is well adapted to a short growing season. It is an ideal baking and cooking potato that requires 10%–20% less nitrogen to produce the same yield as other varieties (Potato Research Centre, 2012).

In order to promote more sustainable potato production, Good Agricultural Practices (GAPs) from the Food and Agriculture Organization of the United Nations were used as a guideline in the implementation of this research (Spiegelaar, Tsuji & Oelbermann, 2013). By definition, GAPs are “principles and codes of practice that are applied to on-farm production and post-production processes and aim at ensuring safe and healthy food and non-food agricultural products while taking into account economical, social and environmental sustainability” (Lutaladio et al. 2009:19). Soil and water conservation are two leading GAP principles. Thus,

our methods included minimal tillage, hand-weeding, and leaving crop residue in the field to conserve the natural resource base. Potatoes were grown in rotation to help prevent disease and pests. Potatoes were also planted the second year in areas that had been previously planted with legumes (Lutaladio et al. 2009). In this study, bush beans (*Phaseolus vulgaris* L.) were picked as the legume to be used in rotation with potatoes because it is a nutritious crop. The Provider Bush Bean cultivar was chosen because this variety is known for tolerating a cool soil temperature, a short growing season, with high yields, and a sweet taste.

4.2.3 Site Description

A two-year field study was conducted in the First Nations community of Fort Albany. Two sites were suggested by community members to plant potato crops. The sites were located within a few hundred meters of the community, far enough away to avoid any disturbances but close enough to the community for logistical reasons. Detailed soil and vegetation analyses were carried out by Spiegelhaar *et al.* who noted that the sites had soil conditions amenable for agricultural use (Spiegelhaar, Tsuji & Oelbermann, 2013). The treed sites (Site A and B in Spiegelhaar et al. (2013) were located within mature, parallel rows of willow (*Salix* spp.) growing on the banks of old drainage ditches. The open site (Site C in Spiegelhaar et al. 2013) was located ~200 m from the treed sites, in an open field without any trees. Soil samples from all sites were collected to carry out toxicological analyses—a suite of persistent organic pollutants and a suite of toxic metals—since there is a history of environmental contamination in many First Nations reserves across Canada. Soil toxicological results showed that one treed site and the open site had acceptable levels for agricultural use. However, the other treed site had toxicological results that exceeded acceptable agricultural levels and was excluded from use (Reyes, Liberda & Tsuji, 2014). The usable treed site had three plots of potato and three plots of bean measuring 10.0 m ×

3.3 m, while the open site had three potato and three bean plots measuring 9.0 m × 3.3 m. The size of each plot was determined by the stands of willow and natural contours of the land. The locations of each plot within each site were randomly assigned for the first field season, and used again in the second field season.

4.2.4 Field Season 2012

Commencing in late May 2012, each site was prepared for planting. In order to maintain appropriate water content, old drainage trenches were re-dug or new ones dug between each plot. The trenches were dug as deep as possible, to control soil moisture within the crops as recommended by Spiegelhaar *et al.* (2013). All sites were mechanically tilled with two vertical and two horizontal passes to ensure a tilled depth of approximately 20 cm. Any biomass on the soil surface was tilled into the soil to help enhance levels of soil organic matter, as recommended by Spiegelhaar *et al.* (2013).

4.2.5 Planting

Planting of potatoes and beans took place on 7 June 2012, Shepody seed potatoes were acquired from a commercial supplier located 404 km south of the community. They were stored in a cool, dark basement for one week prior to planting. The seed potatoes were examined prior to cutting for any signs of disease, and any potentially diseased tuber was discarded. Each seed was cut with a clean knife ensuring they had at least two eyes. Potatoes were planted by hand to a shovel depth of ~20 cm and soil was then mounded over each potato after being placed by shovel into the soil. Potatoes were planted in rows 82 cm (± 0.2 cm) apart, with 28 cm (± 0.2 cm) between plants. Bush bean seed was purchased from a commercial retailer. The bush beans were planted to depth of 4 cm (± 0.2 cm), in rows 50 cm (± 0.2 cm) apart, with 11 cm (± 0.2 cm) between each plant.

After plant emergence, hand-weeding around the plants began and continued throughout the growing season. In early August 2012, hoes were used to mound soil onto the potatoes. Rainfall throughout the summer was adequate for the growing crops; that is, no supplemental water was required.

4.2.6 Potato and Bean Harvest

Beginning mid-August 2012, bush beans were ready to be harvested. Beans were picked from a sub-sample plot of 2.5 m × 5.0 m located in the middle of each plot. These samples were weighed and the weights of the pods were recorded. The yield (tonnes/hectare) of bush bean was calculated for each site. Those bush beans harvested from the sites were given to the community.

The potato plots were harvested on 25 September 2012. A sub-sample plot measuring 1.5 m × 1.0 m was taken in the center of each potato plot. The number of potato plants and potatoes were noted within each sub-sample plot. The potatoes were exposed to the air to cure for four hours, placed in labeled mesh bags and weighed (± 0.1 g) for yield determination. These sub-sample potatoes from the treed and open sites were then given to community members. Once this sampling was completed for all sites there was a community harvest day.

4.2.7 Community Potato Harvest

Potatoes left in both sites were then harvested through a community harvest day that was advertised on social media. Community members came out and were shown how potatoes were grown and harvested. They were also taught proper storage methods for their harvest. Numerous families including children and Elders came out. Each family took home one or two 9 kg bags of potatoes.

4.2.8 Field Season 2013

Beginning 7 June 2013, crop residue from the previous year was worked into the soil using a small push tiller working the soil with one pass vertically and horizontally. Planting took place on 9 June 2013. Location of the potato plots was reversed from the previous field season; locating this year's crop in plots where beans were grown in the previous season in order to prevent disease. Unlike the previous season, beans were over-seeded and then thinned upon emergence to ensure an optimal plant spacing of 11 cm (± 0.2 cm), since it was noted that the seed planted the previous season had a sub-optimal germination rate.

The first two weeks after planting were drier than the previous year and the plots required watering by hand. Water was obtained from surrounding irrigation trenches. The 2013 season saw more community engagement in the way of weeding, mounding of potatoes and general care. Following the 2012 methodology, beans were harvested beginning 28 August 2013.

The potato harvest took place on 6 October 2013, following the 2012 methods. A community potato harvest day took place on 9 October 2013. Again, families took home approximately 9 kg of potatoes each. To better understand what community members thought of the project and of the future of potato production in the community several community members were interviewed. These interviews followed a semi-structured style and were audio-recorded with permission by the interviewee. The interviews were then transcribed verbatim into electronic format. The transcriptions were analyzed following a template organizing approach (Bryman, 2001; Crabtree & Miller, 1999).

4.2.9 Data Analysis of Mean Yield

Differences in the mean values of potato and bush bean yields between sites and between years were examined using two-way analysis of variance (ANOVA). Results were considered to be significant when $p < 0.05$. Data analyses were carried out using the program SPSS version 22 (SPSS Inc., Chicago, IL, USA). Analysis of the variance of means for the bush bean yields revealed that the mean yields showed equal variance and therefore, supported the homogeneity of variance assumption of ANOVA. Analysis of the variance of means revealed that the variances of the mean yields for the potatoes were not equal; however, this has been shown to have little effect on the level of significance in ANOVA (Glass, Peckham & Sanders, 1972).

4.3 Results

4.3.1 Potato Yields

The treed site produced the greatest yield of potatoes over both field seasons, and produced double the yield of the open site in 2013 (Figure 4.1). There was a significant ($p = 0.02$) difference in the potato yields between the treed and open sites. In addition, in 2012, the mean weight of a potato for the treed site was 115.39 g and 89.68 g for the open site. The mean potato weight for the 2013 field season was 136.67 g for the treed site and 83.33 g for the open site. Not only did the treed site produce a larger yield than the open site, but the potatoes were also larger. There was no significant interaction between year and site ($p = 0.27$) and there was no statistically significant difference between years in potato production ($p = 0.95$).

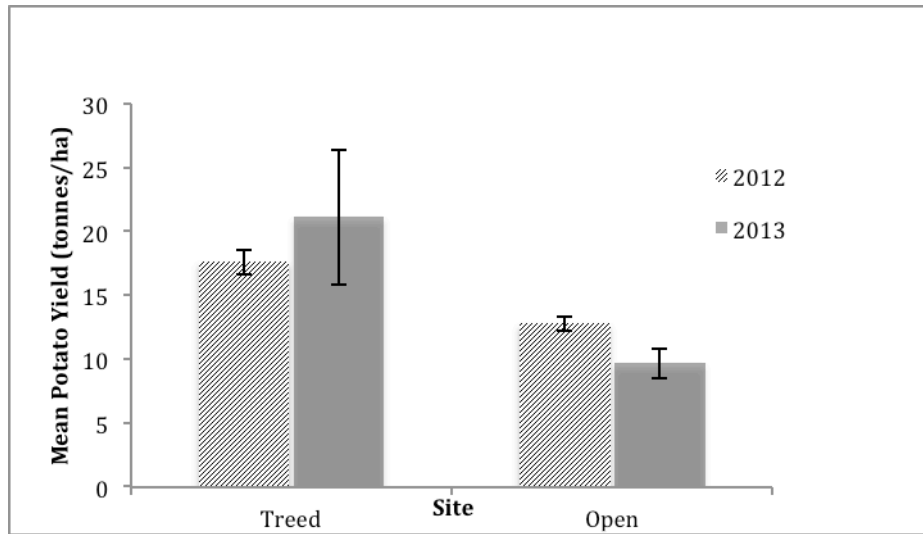


Figure 4.1. Mean potato yield (tonnes/hectare) in the treed and open sites over the two field seasons in Fort Albany, Ontario, Canada. Error bars report standard error for the mean potato yield per plot.

When the mean potato yields for both sites from 2012 were compared to the most recent mean yield information available for provincial (Ontario), national (Canadian) and global potato production, it became apparent that potato production in the subarctic, although less than the Canadian mean, was comparable to the global mean (Figure 4.2). If the mean yield for the treed site for the 2012 season is used in comparison to the provincial, national and global means, then not only is the yield greater than the global mean but it is close to the provincial and Canadian means.

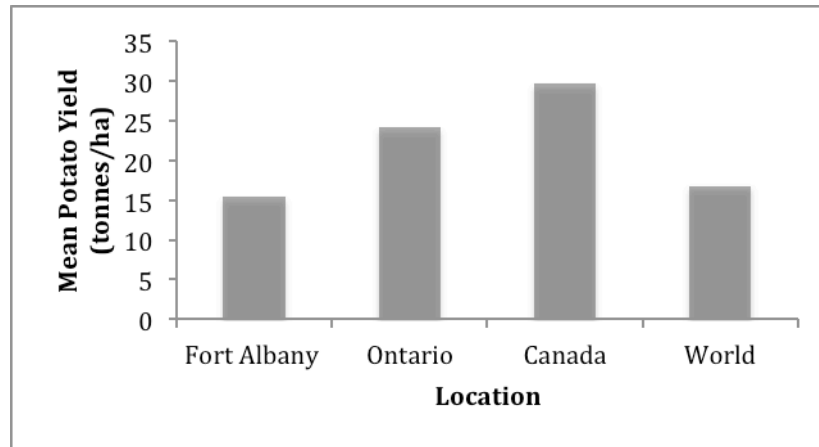


Figure 4.2 Comparing the mean potato yield from Fort Albany to reported provincial, national and global means of potato yields (tonnes/hectare) (Statistics Canada, 2013; Food and Agriculture Organizations of the United Nations, 2008).

4.3.2 Bean Harvest

Although not the focus of this research, the bush beans were planted to support future potato production and help maintain soil fertility due to their ability to assimilate atmospheric nitrogen, the beans proved to be an important crop that was given to the community. One community member stated that:

“Introducing the beans was really (an) eye opener for others that I gave [them] and for myself too. When I was collecting, when I took a bite of it, it was really sweet”

(Interviewee FA1, 2013).

The treed site produced significantly ($p = 0.01$) more bush beans regardless of year (Figure 4.3). Similar to the potato yield, it was found that there was no significant interaction ($p = 0.76$) between year and site. Furthermore, beans picked throughout the study were given away to community members via a local store. Beans were placed in small bags and left in a basket for people to take home (Figure 4.4). Many people noted that they picked up the beans as they went through the checkout. Since bush beans were relatively new to many community members there was a pre-conceived belief that they had to be boiled before eating. However, after a team

member explained that they could be eaten raw, many people ate freshly picked beans without further processing.

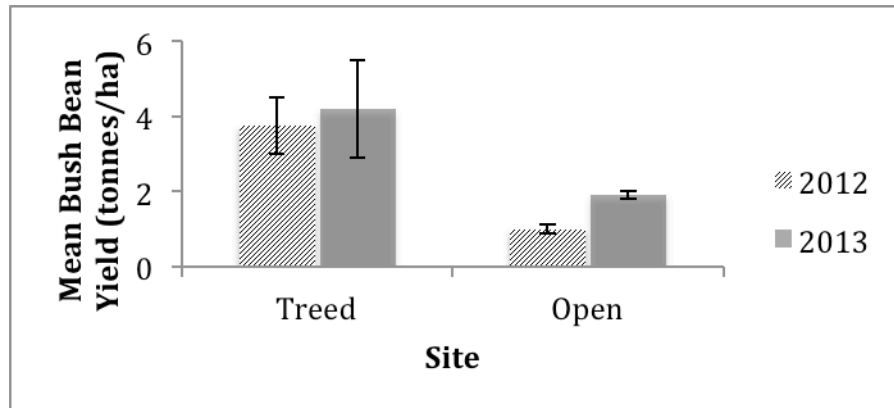


Figure 4.3 The mean yield of bush bean in tonnes/hectare produced in the treed and open sites over the two field seasons in Fort Albany, Ontario, Canada. Error bars report standard error for the mean bush bean yield per plot.



Figure 4.4 Basket of bush beans left at a local store for community members to bring home.

4.3.3 Community Involvement and Food Security

The community of Fort Albany was accepting and excited about the potential to grow potatoes in their community. One community member stated that:

“When we were harvesting the potatoes you hear a lot of interest, a lot of interest. They want to see it in their own backyard” (Interviewee FA1, 2013).

When asked if people felt that this type of gardening would help the community their response was:

“I think this is a good idea, yeah for the community” (Interviewee FA2, 2013).

“It helps me so I am sure it will help everybody” (Interviewee FA3, 2013).

Community members noted many benefits of local potato production. One of the main benefits was that there was a sense of community ownership, it was *“the community’s thing”* and that it brought people together to plant the crops and talk about gardening, and how they might start their own backyard potato patches. Some community members that attended the 2013 potato harvest already showed interest in planting potatoes on their property the following year. Furthermore, during the community harvest, it was noted how expensive the potatoes would have been if they had been purchased at the local store. One community member mentioned that a large majority of the produce available at the local store was imported and that community members were concerned about potential contamination, because they did not know under what environmental conditions the produce was grown. Community members felt that growing their own food in the community would help ensure that they would know what they were eating. Local potato production was seen by many people as a great opportunity to grow their own food and that it offered an opportunity to do things on their own and to look after themselves. When asked about the potential impacts of climate change and if warming temperatures might allow for more food production one community member stated that:

“When it comes to agriculture, you know planting, and it’s really something that we should start getting into. And taking advantage of (the) warmer temperatures and

trying to adapt with it. Because I mean if we are not going to adapt with it, I think that just at the end you are probably (going) to hurt yourself if we are not going to adapt to climate change” (Interviewee FA1, 2013).

When asked if there was a future for local potato production in the community, many people thought there was. Numerous community members felt that many people “*would pick it up*” (Interviewee FA3, 2013) and that the more people who saw the gardens and were involved, then the more likely it would be for the community to work together towards local food production. It was apparent that the key to the future of food production in the community is engagement including hands-on experience.

4.4 Discussion

4.4.1 Ecological Sustainability of Potato Production in Northern Aboriginal Communities

Sustainable agricultural practices are developed over time. Sustainability is a process, and not merely a method or a set of rules or principles (Rigby & Cáceres, 2001). By thinking of sustainability as a process, people can set aside pre-conceived notions of what is sustainable agriculture and move towards making informed decisions based on retrospective analysis of system-specific information. According to Rigby and Cáceres, in order to evaluate how sustainable a system is, a question must be asked: “given local conditions, and the agricultural and ecological history of an area, are the agricultural systems operating there becoming more sustainable, are they coming closer to achieving a goal that is constantly being refined and redefined as knowledge and attitudes change?” (Rigby & Cáceres, 2001:33). The GAPs of sustainable potato production helped to guide our initial field trials. The goal was to understand if sustainable potato production was possible in northern First Nations communities. Based on yield information alone, potatoes can be successfully grown at levels close to the Canadian mean. This is an important finding because the yields reported for Ontario, Canada and the World

(Figure 1) are from conventional high-input potato production systems, while this study used a low-input process and received similar yields. This is a promising result indicating that local, low-input potato production can be successful and provide high yields to the community. Despite this success, there are common constraints related to long-term potato production that need to be addressed for continued sustainability (Table 4.1).

Table 4.1 Recommendations to overcome future constraints to sustainable potato production in northern First Nations communities

Sustainability Constraints	Recommendations
High Fertilizer Requirements	<ul style="list-style-type: none"> • Addition of organic compost through the development of community-wide composting systems. • Use of community fish waste as organic fertilizers. • Crop rotation with legumes (Lutaladio et al. 2009).
Lack of Efficient Seed Systems	<ul style="list-style-type: none"> • Training of community members to harvest and store quality seed potatoes (Lutaladio et al. 2009).
Prevalence of Diseases and Insect Pests	<ul style="list-style-type: none"> • Use of three year crop rotation schedule. • Use of good quality seed and different varieties. • Focus on soil health. • Use of integrated pest management practices. • Community monitoring for the beginning of disease and pest problems (Lutaladio et al. 2009).
Conservation of Natural Resource Base	<ul style="list-style-type: none"> • Maintain soil organic matter by leaving as much crop residue as possible especially from beans or other native legumes. Minimum tillage (e.g., autumn chisel plow or spring disk) to maintain water-use efficiency and nutrients (Sharratt, Zhang & Sparrow, 2006). • Use of windbreak/shelter belts to improve soil quality and maintain soil moisture. • Use of mulch or cover-crop towards the end of the growing season to help avoid erosion over winter and to enhance levels of soil organic matter (Lutaladio et al. 2009).

One of the greatest challenges with northern potato production is the accessibility and availability of seed potatoes. Seed potatoes for this study were shipped into the community from the closest supplier that was 404 km south of Fort Albany. Having to import seed by air is very expensive both financially and environmentally. Farmer seed systems (where farmers use potatoes stored from the previous season's crop as seed potato) offer the opportunity to address

these challenges. Historically, there have been constraints surrounding farmer seed systems. This method can result in poor seed quality due to the increased chance of disease in seed potatoes due to improper storage and handling. However, formal training on proper care and storage of seed would help to overcome such challenges (Lutaladio et al. 2009). Recent research into sustainable potato production has developed no-till methods of production. During no-till methods potatoes are placed on the surface of the soil and then are covered by mulch, ideally straw. Potatoes then develop under the thick mulch and are easily harvested without digging. This method protects the soil from erosion, regulates soil temperature and moisture, builds soil organic matter and ensures the long-term availability of soil nutrients that help achieve high potato yields (Lutaladio et al. 2009). Future potato production in northern communities might be able to employ similar production methods using local plant material such as native legumes and grass clippings instead of straw.

The use of windbreaks also shows promise to increase potato yield while conserving the natural resource base. The treed site was located between rows of willow and produced greater yields compared to the open site for both crops and both seasons. Some of the main benefits of windbreaks include water and nutrient retention, wind protection, increased biodiversity, carbon sequestration, protection from soil erosion and microclimate regulation (Schroth & Sinclair, 2003; Izac, 2003).

4.4.2 Social Sustainability of Potato Production in Northern Communities

Local food production offers communities the opportunity to take control of their food, their health and their futures. Health and health promotion is a requirement of social sustainability, but also requires community action through community development (WHO, 1986). Community development focuses on using community resources, such as local food

production to empower communities to take control of their endeavors and future (WHO, 1986). Recent research on the barriers driving food insecurity in Fort Albany identified empowerment as a key issue requiring attention (Food and Agriculture Organization of the United Nations, 2003). Empowerment according to Wallerstein is “a social action process that promotes participation of people, organizations, and communities towards the goals of increased individual and community control, political efficiency, improved quality of community life and social justice” (Stroink & Nelson, 2009:198). Spiegelaar et al. (2013) found that community members felt disempowered due to their reliance on grocery stores and their lack of control over the quantity and quality of foods that were brought into their community. Local sustainable food production, whether from potatoes or other crops, has the potential to break the feeling of being tied to the grocery store and enhance social equity and democracy (Spiegelaar, Tsuji & Oelbermann, 2013). Community action and its resulting empowerment can enhance community resilience towards environmental change.

Community resilience is an important component of social sustainability (Magis, 2010). Community resilience is defined as “the existence, development, and engagement of community resources by community members to thrive in an environment characterized by change, uncertainty, unpredictability, and surprise” (Magis, 2010:401). In a region with documented environmental change, community resilience offers the opportunity for a community to respond to environmental change through adaptation (Barbeau et al. 2013). Local food production has the potential to support mental wellbeing through individual and community empowerment. Recent research into local food production in Aboriginal communities found that producing local foods promoted feelings of health, wellness, life satisfaction and social capital (Vandenburg, 2014; Stroink & Nelson, 2009). The act of gardening also promoted family time through the

involvement of children in the food growing process (Vandenburg, 2014). Not only does this improve relationships between family members and among families, but it can support knowledge transfer between generations.

4.4.3 The Future of Sustainable Food Production in Northern Communities

When asked if there was a future for sustainable potato production in the community of Fort Albany, community members unanimously said there was. What is unknown is whether it would be in the form of larger plots of potato production as in this study and/or in the form of backyard home gardens, which we have also initiated (Vandenburg, 2014). Backyard home gardens would address the concern that the larger potato plots are not as centrally located and accessible to the community, as a backyard garden. Although not as visible and accessible, large community plots located away from the community have the benefits of avoiding vandalism and community dogs, which have been seen as a problem with backyard home gardens (Vandenburg, 2014).

Financial constraints to local food production were noted as potential barriers to future crop production, especially in northern regions where seed and equipment, including rakes and shovels, must be imported. Vandenberg et al. found that despite financial requirements, many community members felt so positively towards local food production that they were willing to fund their own gardens (Vandenburg, 2014). Larger community plots could be supported through the work of volunteers, fundraisers, and the Band Office (*i.e.*, locally elected government made of Chief and Band Council). The ultimate goal of local food production would be self-sufficiency with complete community control over the funding, production and harvesting of the crops. Current research is investigating ways to support this goal. Collecting and saving seeds from previous season's crops would help reduce the financial costs of planting. In addition, using

local seeds, transplanting and cultivating traditional plants would also help to promote financial sustainability. Costly soil amendments such as fertilizers can be locally sourced in the form of community composting initiatives.

Lack of knowledge and education on local food production was also viewed as a barrier to future success. Previous research into backyard gardens reported that many community members reported feeling they lacked important skills such as trouble identifying vegetables (due to a lack of familiarity) and weeds, and understanding proper planting and harvesting techniques (Vandenburg, 2014). One example observed during this study was the lack of familiarity with bush beans. Hands-on workshops on sustainable growing practices and vegetable use have recently been given by our research group to help provide information, and empower community members with the knowledge required to successfully grow their own food whether in their backyards or in community plots. Photo books documenting planting, weeding and harvesting methods and skills would help to educate when hands-on workshops are not available. Indeed, our research team has even held youth camps where a large component of hands-on activities included visits to the community plots, to begin engaging the next generation (Isogai et al. 2014)

4.4.4 Traditional Food Production

The local production of bush beans and potatoes has the potential to complement traditional diets. Harvesting of traditional foods has become a challenge due to increased travel costs and rapid climate change (Barbeau et al. 2013). Local food production shows a culturally appropriate response to not only the dependence on an import-based food system but also to global warming. The successful production of potato and bean crops shows that there is community support for local food production and that food crops can in fact be sustainably grown. With the implementation of long-term food production our hope is to help the community

to grow more traditional crops, such as, berries and medicinal plants along side potatoes and beans to promote community empowerment, resilience and independence.

4.5 Conclusions

A warming climate in the arctic and subarctic offers opportunities for northern Canadian Aboriginal communities—and other subarctic and potentially arctic communities world-wide—to sustainably grow local foods to promote food security. Through the use of more sustainable agricultural practices, potatoes were successfully produced alongside bush beans in subarctic Ontario, Canada. Community members acknowledged the benefits of local food production and believed that there was a future for more sustainable food production in their community. Introducing local food production systems in northern Aboriginal communities worldwide may foster empowerment and enhance community resilience toward future challenges such as climate change.

Chapter 5

Sustainable Local Food Production in a Subarctic Indigenous Community: The Use of Willow (*Salix* spp.) Windbreaks to Increase the Yield of Intercropped Potatoes (*Solanum tuberosum*) and Bush Beans (*Phaseolus vulgaris*)

5.1 Introduction

The demand for food has increased with the rise of global population and the desire for a more diverse and resource intensive diet (Garnett et al. 2013). This has led to agricultural intensification characterized by the use of high-yield monoculture crop varieties and dependence on chemical pesticides and fertilizers (Matson et al. 1997). The ecological implications of this intensification have been significant – including both local ecological impacts such as increased soil erosion, decreased soil fertility, and reduced biodiversity and global impacts such as increased atmospheric greenhouse gases (Matson et al. 1997). Critics of the principles behind agricultural intensification have shifted their focus towards sustainable intensification of agricultural and agroecology. Sustainable intensive agriculture focuses on applying technological advances to increase agricultural productivity while enhancing ecological and social benefits (Kershen, 2013). Agroecology seeks to apply ecological science to the development and management of sustainable agricultural systems (Kershen, 2013). Both fields focus on the development of sustainable agriculture. Sustainable agriculture, defined as meeting the current needs of production without compromising the future in terms of resource degradation or depletion, takes into account the challenges of increased productivity and the need to support the local social and biophysical specific contexts of food production (Garnett et al. 2013; Matson et al. 1997: 509). The goal of sustainable agriculture needs to be diverse and focus on achieving sustainable food security (Tilman, 1999). Sustainable agriculture methods, drawing from

principles of both sustainable intensification of agriculture and agroecology fields, are required to address current issues surrounding local food security, ecological composition, loss of diversity and increased disturbance (Tilman, 1999; Matson et al. 1997).

Anthropogenic climate change is impacting social and ecological systems globally. It is likely that by the end of the 21st Century there will be an increase in global surface air temperature that will exceed 2°C (IPCC, 2013). However, these temperature changes disproportionately impact subarctic and arctic regions worldwide (IPCC, 2014a; IPCC, 2014b). Thus, subarctic and arctic regions are predicted to experience longer and more favorable growing conditions for crops, allowing for sustainable agricultural activities that would not have been previously possible. This opportunity for increased local food production has the potential to not only promote greater food security and community empowerment but also support global sustainable agricultural initiatives (Barbeau, Oelbermann, Karagatzides, & Tsuji, 2015). Unlike the rest of Canada, northern regions (the arctic and subarctic) experience high rates of food insecurity often due to being remote and isolated – relying on air transportation to bring food into the communities (Council of Canadian Academics, 2014). Health disparities, such as increased prevalence of obesity and diet related diseases, such as type II diabetes, and heart disease resulting from high rates of food insecurity, are common in northern Indigenous (First Nations, Inuit, and Métis) communities (Gates *et al.* 2011; Skinner *et al.* 2006; Shields, 2005; Anand *et al.* 2001).

Historical accounts of food insecurity and the barriers to food accessibility in the subarctic First Nations community of Fort Albany have been well documented (Skinner et al. 2013; Gates et al., 2012). European missionaries in northern Canada introduced conventional farming practices (e.g. clear cutting, the use of agrochemicals, and the use of greenhouses) in the

1930s to help support residential schools. However, when residential schools closed, much of the conventional agricultural activity in northern Canada discontinued and reliance on imported foods increased (Barbeau et al., 2015; Rapati, 2015; Garnett et al. 2013; Spiegelhaar & Tsuji, 2013). Nutritional surveys of school-age children in Fort Albany revealed that there was significant need to increase the availability of fruits and vegetables within the community (Gates et al. 2011). More conventional food security interventions in the form of school-snack and breakfast programs and greenhouses have been introduced into the community with varied success and a few noted shortcomings. A review of these programs has shown a need for a more sustainable and harmonized import-substitution based food system.

Historically, conventional agricultural activities were not sustainable in northern Canada, but this does not preclude the viability of other agricultural activities including agroforestry practices, especially under a changing climate. A feature of current agricultural systems has been an increased focus on crop specialization, leading to monoculture cropping systems planted in isolation from surrounding ecosystems and resulting in declines in ecosystem biodiversity (Matson et al. 1997). Planned diversity in cropping systems and relying on surrounding regional diversity can offer significant ecological services to support sustainable local food production.

Windbreaks, one of five recognized agroforestry practices, are barriers (e.g. perennial or annual crops, trees, shrubs) arranged alongside agricultural crops on the same land management unit (Schroth & Sinclair, 2003; Brandle, Hodges, & Zhou, 2004). Ecological benefits of windbreaks include erosion control, water and nutrient retention, wind protection, increased biodiversity, carbon sequestration, microclimate regulation and food production (Brandle et al., 2004; Schroth & Sinclair, 2003; Izac, 2003; Peri & Bloomberg, 2002). Intercropping, where crop intensification occurs in both time and space, is defined as the simultaneous growth of more than

one species in the same field (Vandermeer, 1992). In temperate regions, where crops are commonly produced in single stands (sole crops), intercropping is of particular interest because soil resources are used more efficiently (Hauggaard-Nielsen, Ambus, & Jensen, 2001). The mixing of two resource types also benefits agroecosystem functioning through interactive biotic and abiotic effects that create a synchrony between nitrogen (N) supply and crop demand (Gentile, Vanlauwe, & Chivenge, 2011; Cong, Hoffland, Li, Janssen, & van der Werf, 2015; Redin et al., 2014). Spatial and temporal complementarity in intercrops also causes interspecific interactions that enhance N acquisition by the cereal crop and through N₂-fixation by the legume (Bedoussac et al., 2015). For example, Manrique (1996) found that intercropping *Phaseolus vulgaris* L (bush beans) and potatoes (*Solanum tuberosum*) facilitated positive interaction between both crops that enhanced the productivity of the potato crop.

To date, research on intercrops grown between windbreaks have been conducted in tropical and temperate regions (Gordon and Newman, 1997; Brandle et al. 2004), and showed that these systems enhance economic, ecological, and social benefits to many impoverished communities (Dixon, Winjum, Andrasko, Lee, & Schroeder, 1994). However, there is a lack of knowledge on the productivity of intercrops established between windbreaks in subarctic climates. The goal of this study was to determine the feasibility of using sustainable agroforestry practices as a means to support sustainable local food production in a subarctic First Nations community in Ontario, Canada. The objective of this study was to evaluate the productivity of intercropped beans and potatoes established between native willow (*Salix* spp.) windbreaks compared to an open site, and to determine differences in soil chemistry between the two sites. Results obtained from this study will guide future implementation and design of sustainable crop

production in communities across the subarctic to enhance food security in this vulnerable region.

5.2 Materials and Methods

5.2.1 Study site

The study site was located at Fort Albany First Nations (52°15'N; 81°35'W), a small subarctic community with a population of approximately 850 Omushkego Cree (Barbeau et al. 2015). The community is located on the banks of the Albany River, along the Western James Bay coast in subarctic Ontario, Canada. The mean annual temperature is -1.1°C, with an average annual rainfall of 728 mm and annual growing degree-days of 830 (>5°C) (Riley, 2011). This region has already been affected by climate change, with earlier sea ice break-up events, sudden spring warming events and increased rainfall (Prowse et al. 2006). Climate models have predicted that summer temperatures will increase by 4.1°C and winter temperatures by 7.5°C by the year 2100 in the western James Bay region (Hori et al. 2012).

This study was carried out during the May to September growing season in 2012 and 2013, and was conducted in two fallow sites located within 200 m of the community. The soil, with a silt-loam texture, was previously cultivated during missionary times, beginning in the 1930s. The site has been abandoned since the early 1970s and has been under natural fallow (Spiegelhaar & Tsuji, 2013; Spiegelhaar, Tsuji, & Oelbermann, 2013). In this study, the site referred to as treed, is located within mature parallel rows of mixed *Salix* (willow) species (*Salix bebbiana* and *Salix discolor*) growing in old drainage ditches (Lafleur & Rouse, 1998). The site referred to as open, is a non-treed site located 189 m from the treed site. The distance to the nearest trees in the open site is 58 m. Prior to planting crops, the sites were tilled using a rototiller to manage weeds and ditches were dug to control soil drainage (Barbeau et al. 2015).

Initial soil analysis and vegetation surveys for each of the sites were reported by Spiegelaar et al. (2013). *Shepody* potatoes were used, as this variety is cold tolerant and easily stored (Barbeau et al. 2015). The green *Provider* bush bean was chosen due to its cold tolerance and fast growth rate.

5.2.2 Experimental design and site management

The windbreak lined site measured 33 m × 12 m and was divided into three replicate plots each measuring 10 m × 12 m. Each of these three replicate plots contained three (10 m × 3.3 m) subplots of each treatment (bean sole crop, potato sole crop, 1:1 intercrop with one row of beans and one row of potatoes). The open site was 30 m × 12 m with three replicate plots. These three replicate plots each measuring 9 m × 12 m contained three subplots (9 m × 3.3 m) of each cropping treatment. The location of each plot and the subplots was determined randomly in the treed and open sites. In the second field season (2013), sole crops were rotated to minimize soil borne pathogens and to maximize the N₂-fixation potential of the beans (Pretty, 2008).

Therefore, potatoes were grown on plots that were planted to beans in 2012 and *vice versa*.

Beans were planted to a depth of 4 cm and potatoes were planted to a depth of 20 cm and covered with mounded soil. Potatoes were planted in rows 82 cm apart, with 28 cm between plants. Beans were planted in rows 50 cm apart with 11 cm between each plant. Intercrops remained in the same plot for both years. Intercrops were planted at the same row spacing as the sole potato crop with every other row being planted as a bean row (Barbeau et al., 2015). After plant emergence, beans were thinned by hand to a distance of 11 cm between each plant. Weeds were pulled by hand and crops were irrigated using water from the drainage ditches to ensure adequate conditions for germination. After the first month of growing, soil was mounded over the potatoes to encourage potato production.

5.2.3 Soil chemistry

Soil samples were extracted in October 2013, following harvest. Three soil samples were randomly extracted within each treatment plot in the treed and open sites to a 20 cm depth using a soil corer with a 4.5 cm inner diameter. The three soil samples per treatment replicate were combined into one sample (Spiegelhaar & Tsuji, 2013). The labeled and frozen samples were prepared for transport and analysis at the Guelph Soil and Nutrient Lab. Soil samples were analyzed for pH, total nitrogen (N), ammonium (NH₄), nitrate (NO₃), phosphorus (P), potassium (K) and magnesium (Mg).

5.2.4 Crop yield and biomass

Bean yield was determined in mid-August by collecting plants from a 5 m x 2.5 m area in the centre of each treatment replicate. Fresh weights of the pods were recorded and the beans were distributed to community members for consumption. Once the potatoes showed evidence of senescence (late September), the tubers were collected from the centre of each treatment replicate using an area of 1.5 m x 1.0 m. The number of potato tubers was recorded.

To determine the amount of crop residues produced in each site, the above- and below-ground biomass for both the beans and potatoes were collected from an area of 1.5 x 1 m in the sole cropped plots. Within the intercropped plots, this sub-sample plot was taken twice, side-by-side for a total sub-sample area of 3 m² to ensure that the same number of rows of each crop was sampled. Aboveground biomass was cut 1 cm above the soil's surface to avoid soil contamination, and roots (belowground biomass) were removed using a spade. Root samples were washed the same day using cold water over a 2 mm sieve. Fresh weights for above- and below-ground biomass and yields were recorded. Subsamples, from each of the biomass

samples, were dried at 72°C until a constant weight was obtained. Any remaining beans and potatoes were distributed among community members for consumption.

5.2.5 Statistical analysis

All datasets were tested for homogeneity of variance using Levene's Test of Equality of Variances. Using analysis of variance (ANOVAs) we analyzed sole and intercropped plantings of both bean and potato in 2012 for the main effect of cropping treatment, site and any possible interactions. Intercropped subplots were analyzed for the main effect of site and year (plus any interaction) on yield and biomass production. Our Levene's test revealed, that after a Log_{10} transformation, the variance of the mean bean pod yields of intercropped beans in the treed site in 2012 and 2013 were not equal. However, ANOVAs have been shown to be robust to towards unequal variance (Glass, Peckham, & Sanders, 1972). Soil chemistry was analyzed using a two-sample t-test to determine the main effect of site on soil pH and concentrations of soil N, P, K, Mg, NH_4 , NO_3 . Soil pH was found to have unequal variance and therefore, the two-sample t-test assuming unequal variance was used. The threshold of probability for determining significant differences was set at $p < 0.05$. All statistical analyses were carried out using SPSS version 22 (SPSS, Inc., Chicago, IL, USA)

5.3 Results

5.3.1 Crop yield and biomass

In 2012, the treed site produced significantly more bean pods compared to that of the open site ($p = 0.02$). Similarly, aboveground ($p = 3.20 \times 10^{-5}$) and belowground ($p = 0.02$) bean biomass in the treed site was significantly greater compared to the open site. However, there was no significant difference between sole crops or intercrops on bean pod yield ($p = 0.33$; Table 1; Figure 5.1). There was a significant interaction between the site and crop treatment (e.g. intercrop versus sole crop) on the below-ground bean biomass produced in 2012 ($p = 0.01$). The treed site maintained similar below-ground biomass production in both planting treatments. This trend was not seen in the open site where the intercropped beans produced half of the below-ground biomass that the sole crop did.

Similar to the beans, in 2012 the treed site produced significantly more potato tubers ($p = 2.78 \times 10^{-4}$) and above-ground biomass ($p = 0.01$) (Table 5.1). Planting treatment significantly impacted potato tuber ($p = 0.01$) and above-ground biomass ($p = 0.03$) production with the sole cropping producing greater yields.

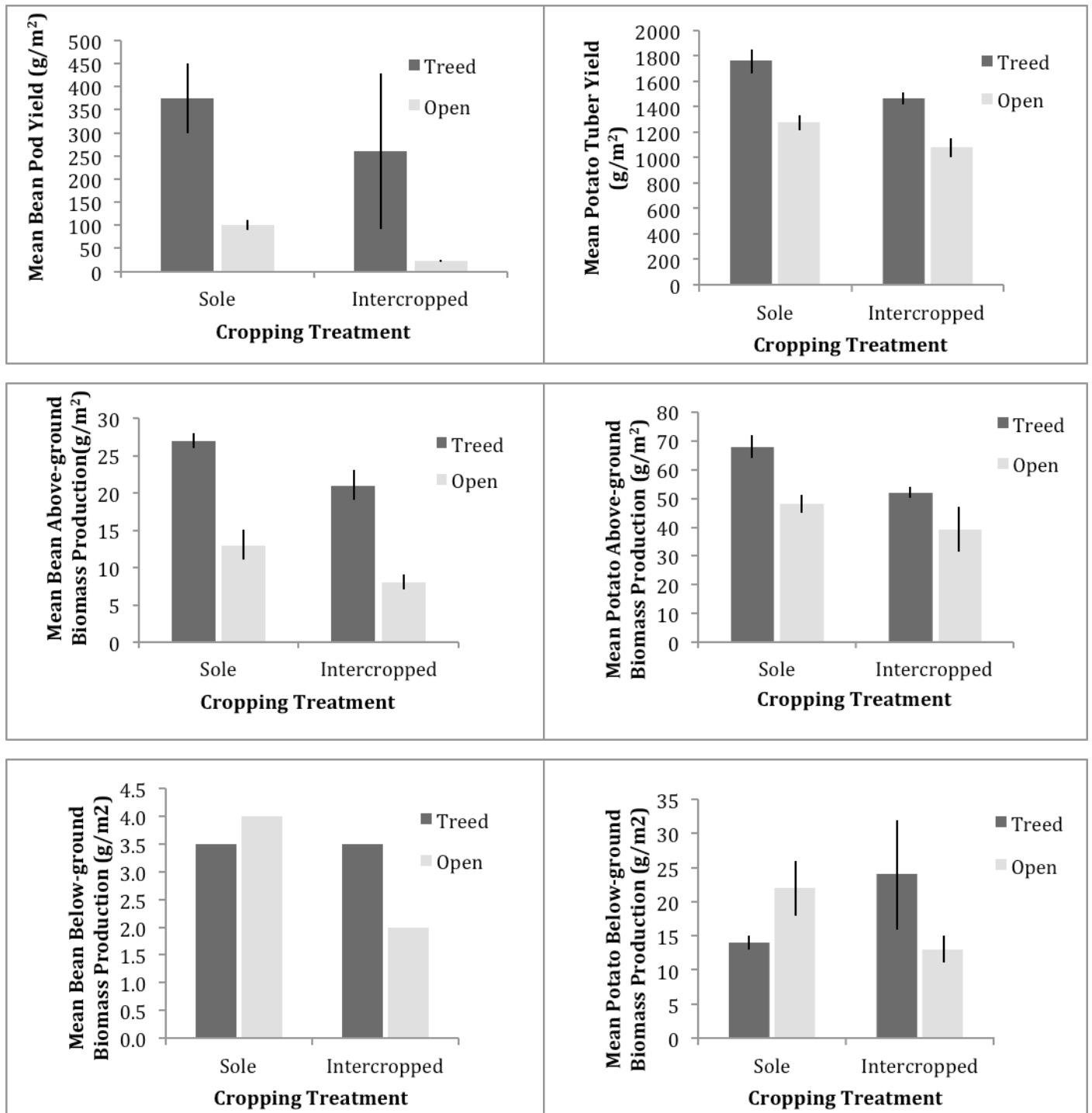


Figure 5.1 Mean (\pm SE; n=3) yield (fresh weight) and biomass production (dry weight) from the 2012 growing year for sole and intercropped beans and potatoes grown in a treed (windbreak lined) and open (no windbreak) site, in the James Bay lowlands, Fort Albany First Nations, Ontario, Canada.

Table 5.1: ANOVA summary table for the effect of treatment (intercropped vs. sole) and growing site (tree vs. open) on yield and biomass production in the 2012 growing season.

Bean Pod Yield	F	P
Site	7.68	0.02
Treatment	1.06	0.33
Site * Treatment	0.04	0.85
Bean Above Ground Biomass	F	P
Site	69.64	3.20×10^{-5}
Treatment	12.66	0.01
Site * Treatment	0.08	0.78
Bean Below Ground Biomass	F	P
Site	8.274	0.02
Treatment	10.142	0.01
Site * Treatment	10.142	0.01
Potato Tuber Yield	F	P
Site	37.66	2.78×10^{-4}
Treatment	12.15	0.01
Site * Treatment	0.47	0.51
Potato Above Ground Biomass	F	P
Site	12.20	0.01
Treatment	7.04	0.03
Site * Treatment	0.39	0.55
Potato Below Ground Biomass	F	P
Site	0.08	0.79
Treatment	0.03	0.86
Site * Treatment	4.00	0.08

*n = 3, df = 1 for all cases

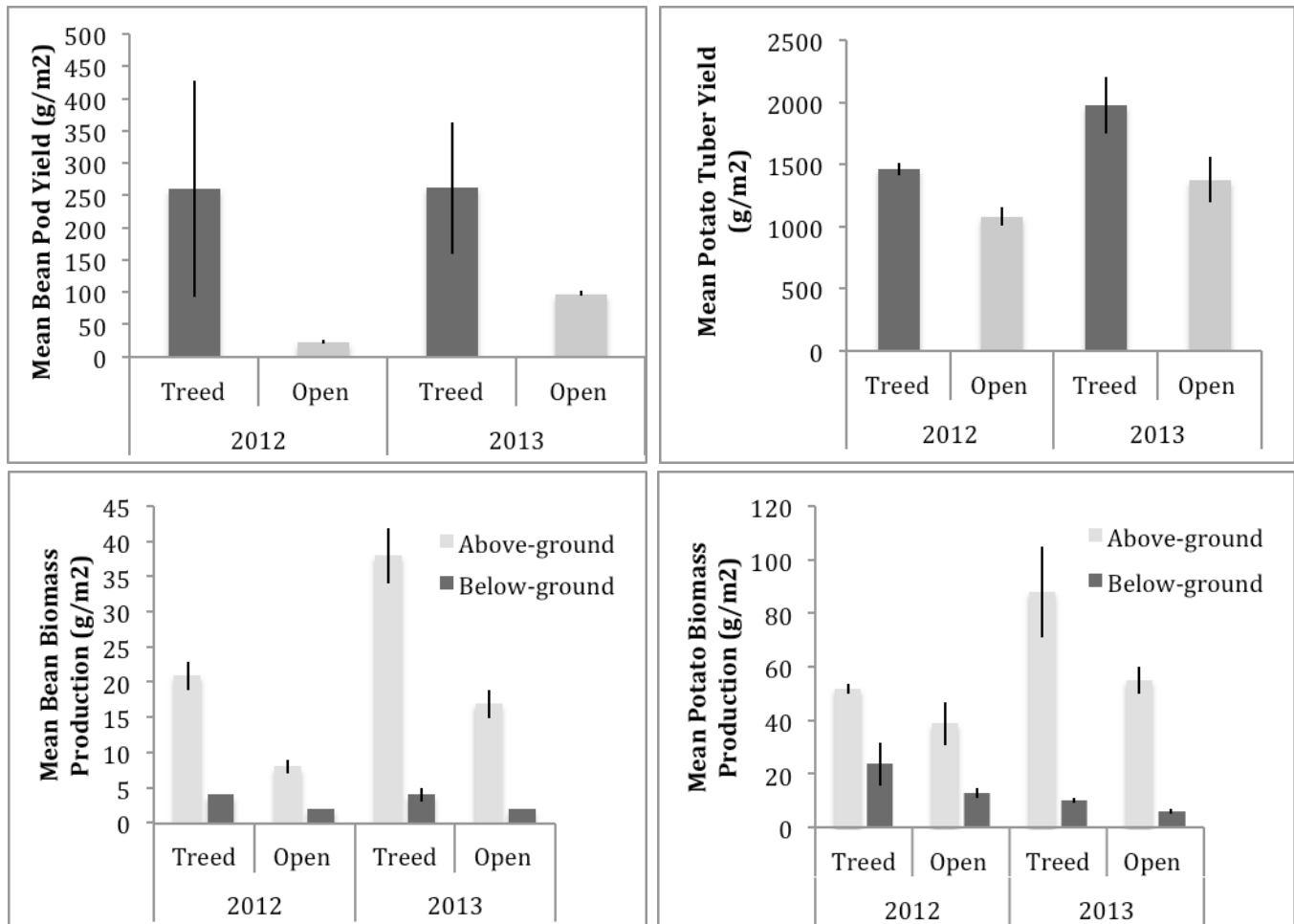


Figure 5.2 Mean (\pm SE; $n=3$) yield (fresh weight) and biomass production (dry weight) from intercropped beans and potatoes in treed (windbreak lined) and open (no windbreak) sites in the James Bay lowlands, Fort Albany First Nations, Ontario, Canada.

The treed site produced significantly more bean aboveground ($p = 1.9 \times 10^{-4}$) and belowground biomass ($p = 3.0 \times 10^{-3}$) in beans intercropped with potato in both 2012 and 2013 (Table 5.2, Figure 5.2). The 2013 growing year produced significantly more aboveground bean biomass from intercropped beans compared to the previous year ($p = 1.0 \times 10^{-3}$). There was no significant difference between the pod yields of intercropped beans grown in the treed and open site ($p = 0.08$) or between the two growing years ($p = 0.71$). Intercropped potatoes grown in the treed site produced significantly more potato tubers ($p = 0.01$) than the open site (Table 2, Figure 2). In the second year (2013), intercropped potatoes produced significantly more potato tubers ($p =$

0.03) and aboveground ($p = 0.03$) and belowground biomass ($p = 0.04$) compared to 2012 (Figure 2).

Table 5.2 ANOVA summary table for intercropped beans and potatoes over two growing years (2012, 2013) and two growing sites (tree vs. open) and the effect on mean yield and biomass production

Bean Pod Yield	F	P
Year	0.14	0.71
Site	4.17	0.08
Year * Site	0.14	0.72
Bean Above Ground Biomass	F	P
Year	23.03	1.0×10^{-3}
Site	42.42	1.9×10^{-4}
Year * Site	2.45	0.16
Bean Below Ground Biomass	F	P
Year	1.15	0.31
Site	17.66	3.0×10^{-3}
Year * Site	0.34	0.58
Potato Tuber Yield	F	P
Year	7.15	0.03
Site	10.59	0.01
Year * Site	0.50	0.51
Potato Above Ground Biomass	F	P
Year	7.03	0.03
Site	5.49	0.05
Year * Site	0.98	0.35
Potato Below Ground Biomass	F	P
Year	5.97	0.04
Site	3.21	0.11
Year * Site	0.58	0.47

*n = 3, df = 1 for all cases

5.3.2 Soil chemistry

There were significant differences in soil chemical characteristics between the treed and open sites (Figures 5.3a – 5.3f). The treed site had a significantly higher P ($p = 0.001$; Figure 5.3b), K ($p = 0.03$; Figure 5.3c) and NH_4 concentrations ($p = 1.27 \times 10^{-4}$; Figure 5.3e) compared to the open site. In contrast, the open site had significantly higher concentrations Mg ($p = 8.20 \times 10^{-5}$; Figure 5.3d) and NO_3 ($p = 9.0 \times 10^{-6}$; Figure 5.3e). There was no significant difference in soil pH ($p = 0.06$; Figure 5.3a) and total N ($p = 0.93$; Figure 5.3f) between the treed and open sites.

Figure 5.3 Soil Chemistry Results

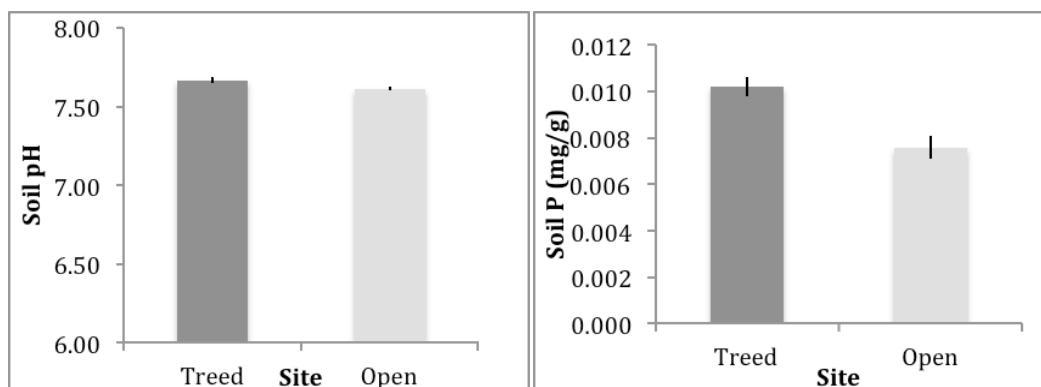


Figure 5.3a. Mean (\pm SE; $n=9$, t -value = 2.05, $p = 0.06$) soil pH for October 2013 (after harvest) for treed vs. non-treed open sites located in the James Bay lowlands, Fort Albany First Nations, Ontario, Canada

Figure 5.3b. Mean (\pm SE; $n=9$, t -value = 4.02, $p = 0.001$) soil P concentrations for October 2013 (after harvest) for treed vs. non-treed open sites located in the James Bay lowlands, Fort Albany First Nations, Ontario, Canada

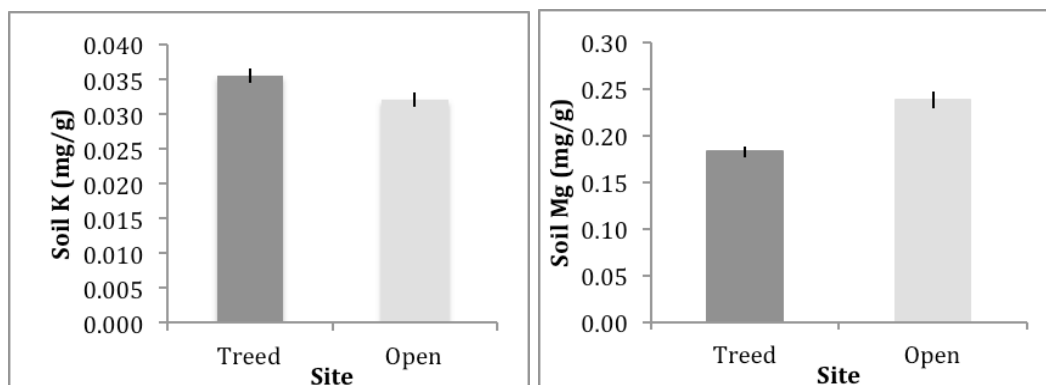


Figure 5.3c. Mean (\pm SE; $n=9$, t -value = 2.36, $p = 0.03$) soil K concentrations for October 2013 (after harvest) for treed vs. non-treed open sites located in the James Bay lowlands, Fort Albany First Nations, Ontario, Canada

Figure 5.3d. Mean (\pm SE; $n=9$, t -value = -5.24, $p = 8.20 \times 10^{-5}$) soil Mg concentrations for October 2013 (after harvest) for treed vs. non-treed open sites located in the James Bay lowlands, Fort Albany First Nations, Ontario, Canada

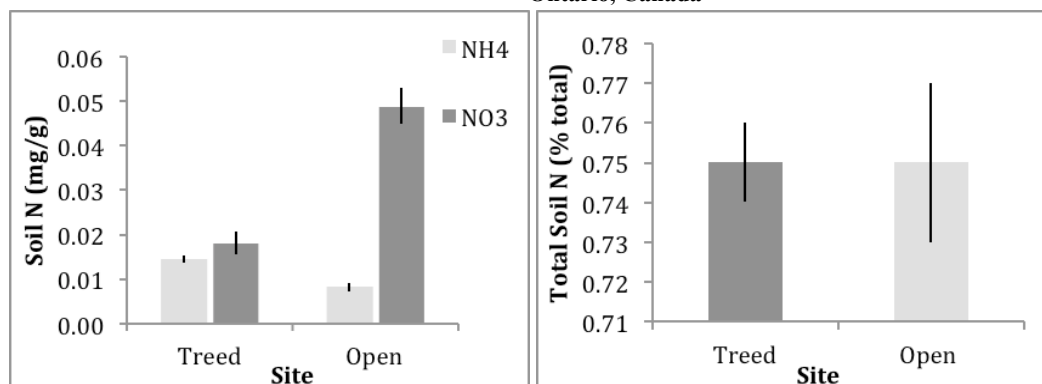


Figure 5.3e. Mean (\pm SE; $n=9$) soil NH₄ (t -value = 5.02, $p = 1.26 \times 10^{-4}$) and soil NO₃ (t -value = -6.40, $p = 9.0 \times 10^{-6}$) soil concentrations for October 2013 (after harvest) for treed vs. non-treed open sites located in the James Bay lowlands, Fort Albany First Nations, Ontario, Canada

Figure 5.3f. Mean (\pm SE; $n=9$, t -value = -0.09, $p = 0.93$) total soil N concentrations for October 2013 (after harvest) for treed vs. non-treed open sites located in the James Bay lowlands, Fort Albany First Nations, Ontario, Canada

5.4 Discussion

The significantly greater crop and above- and belowground biomass in intercropped and sole crop systems in the treed site suggests that there is an overall positive windbreak effect on bean and potato productivity. Similar to our results, studies in temperate and tropical regions also showed an increase in crop yield in the presence of a windbreak (Campi, Palumbo, & Mastrorilli, 2009; Brandle et al., 2004; Brandle, Hodges, & Wight, 2000; Sun & Dickinson, 1994; Puri, Singh, & Khara, 1992; Kort, 1988; Ogbuehi & Brandle, 1981).

Willows are native to most regions of the subarctic (Parry, Canziani, Palutikof, van der Linden, & Hansen, 2007; Sturm, Racine, & Tape, 2001) and grow quickly under wet and cool conditions (Kuzovkina & Quigley, 2005). Multi-stemmed willow also increase the windbreak density (Isebrands & Richardson, 2014). For example, willows windbreaks in agricultural landscapes reduce the amount of soil lost due to erosion by 85% (Peri & Bloomberg, 2002). However, knowledge on windbreak design with respect to stand density, type of tree species, and orientation for optimal crop productivity in subarctic regions is lacking (Peri & Bloomberg, 2002).

There are numerous benefits related to maintaining intercropped cropping systems within willow windbreaks in subarctic Indigenous communities. This study showed that beans and potatoes can be successfully intercropped with no significant impact on the yield of either potatoes or beans when grown within a windbreak-lined site. The continued use of intercropping is both ecologically (e.g. maintaining or increasing species biodiversity; Thevathasan et al., 2014; Sage, Cunningham, & Boatman, 2006) and socially beneficial to Indigenous subarctic communities.

The introduction of intercrops grown between willow windbreaks as a community-level initiative promotes numerous social benefits. High rates of food insecurity in Canada's northern Indigenous communities are often related to the lack of availability, expense and the quality of food (Gates et al., 2012; Skinner, Hanning, & Tsuji, 2012). Therefore, community-level local food production can increase the availability, affordability and accessibility to fresh, nutritious and sustainable food. Intercrop systems that mix crops with different harvesting times and storage ability enhances food security throughout the year in these communities. In our study, intercropping beans with potatoes allowed for the continuous production of bean pods throughout the summer and therefore provided an ongoing source of nutrition. Additionally, due to their later harvest time, potatoes provided food that can be utilized after bean productivity ceased but also can be stored for later consumption. Based on our results, intercrop plantings of peas (*Pisum sativum*) and root crops such as turnip (*Brassica rapa*) and red beets (*Beta vulgaris*) can achieve similar benefits as the bean-potato intercrop (Vandenberg, 2014).

In addition to the nutritional health benefit of local food production, windbreak intercrops can support Indigenous wellbeing (Barbeau et al., 2015; Vandenberg, 2014; Speigelaar & Tsuji, 2013). This includes, and is not limited to, the involvement of youth in planting, harvesting and maintenance activities, community ownership and a sense of community pride (Barbeau et al., 2015; Vandenberg, 2014). There is a strong connection between Indigenous people and their land that builds strong spiritual, emotional and physical connections not only between individuals, but also within communities (Stroink & Nelson, 2010; Wilson, 2003).

Soil chemistry results indicate that the soil is capable of supporting future sustainable agricultural use. However, there is a need to maintain and in some cases enhance soil quality. The treed site showed significantly higher concentrations of P, K, and NH_4^+ but Mg and NO_3^-

concentrations were significantly lower at this site. Variations in soil nutrients, found in sites in close proximity to each other, is related to the vegetation and organic matter quality present (Schmidt, Jonasson, & Michelsen, 1999). For example, willows likely had a greater uptake of NO_3^- , but this nutrient is returned to the site through autumnal litterfall where it becomes available to the growing crop (Oelbermann & Gordon, 2000).

Soil K and Mg concentrations, although lower than previously found when the treed site was fallow, are still above optimal levels as recommended for mixed cropping systems (Agricultural Analytical Services Lab, 2016; Spiegelhaar & Tsuji, 2013). Soil pH in the treed site was slightly more alkaline than what is considered to be optimal for mixed cropping systems, likely, as a result of the underlying limestone and dolomite marine and glacial sediments found in this region (Glaser, Hansen, Siegel, Reeve, & Morin, 2004; Bostock, 1970). Despite this, it is predicted that the soils in both sites have an adequate pH for future agricultural use (Agricultural Analytical Services Lab, 2016). Locally-sourced soil enhancement will also help to maintain these levels of soil nutrients and prevent further declines with continued agricultural use.

Northern soils are nutrient limited especially in soil N and P (Chapin et al., 2002; Ruess, Michelsen, Schmidt, & Jonasson, 1999). Soil N levels are time dependent and soil concentrations of NH_4^+ and NO_3^- vary dramatically throughout the growing season (Spargo, 2013, Chapin et al., 2002). Thus, there is no standard recommendation for optimum soil nitrogen levels for mixed garden planting. Despite this, it is recommended that during the growing season, soil levels of NO_3^- above 30 ppm is sufficient for mixed cropped systems (Spargo, 2013). The treed and open sites had soil NO_3^- concentrations well below 30 ppm. Differences in soil organic matter due to litter input from the trees, and the uptake of NO_3^- by the willows could result in lower NO_3^- concentrations at certain times during the growing season in the windbreak site. Willow are

significant users of nitrogen and take up greater amounts of N compared to other nutrients such as P, K, Ca, and Mg (Adegbidi et al., 2001). It was shown that the annual removal of N by willow ranges from 18-103 kg/ha (Adegbidi et al., 2001). However, the continued use of legumes within intercropping cropping systems will enhance the soil inputs of fixed N, especially in soils that are typically low in available N (Peoples et al., 2009).

The mean soil P concentration for the treed site was 10.19 ppm. The optimal soil P concentration for mixed-home gardens is between 35 – 70 ppm (Agricultural Analytical Services Lab, 2016). Despite this sub-optimal soil P concentration, the treed site in 2013 had a higher soil P concentration compared to 8.17 ppm when the site was under fallow (Spiegelaar & Tsuji, 2013). This indicates that the current cropping method within the treed site has the potential to maintain and enhance soil P concentrations. However, supplementation of soil P and N through the utilization of local sources is recommended.

Local amendments could be developed from community based organic waste (Barbeau et al., 2015; Mikkelsen & Hartz, 2008). By-products of subsistence activities, such as offal and bones could be sourced locally (Mikkelsen & Hartz, 2008). Community composts using organic food waste have already been successful in producing nutrient rich topsoil in arctic communities such as Iqaluit, Nunavut, Canada (Council of Canadian Academies, 2014). Continued use of crop residues such as above- and belowground biomass, minimum tillage and hand weeding would further support soil structure and maintain soil nutrients (Sharratt, Zhang, & Sparrow, 2006).

Multi-crop cropping systems supported by native windbreaks in the arctic and subarctic can address some of the current ecological and social challenges that global agricultural intensification is having (Matson et al. 1997). Addressing local food insecurity in arctic and subarctic communities, such as Fort Albany First Nations, with an ecologically and socially

sustainable food production system has the opportunity to not only strengthen local communities but to invest in the social, financial, natural and physical capital required for a globally sustainable agricultural system (Garnett et al. 2013).

5.5 Conclusions

Climate change will continue to disproportionately impact northern Canada. However, a warmer climate in the subarctic (and arctic) could offer the opportunity for local sustainable agricultural production. The use of bean and potato intercrops, using native willow as windbreaks, can increase sustainable food production in remote, subarctic, Indigenous communities. This will enhance food security, and provide other social and ecological benefits. Future research should focus on developing a better understanding of the optimal willow windbreak stand density and orientation, using different crop combinations, along with further community engagement and education. These steps will be vital in realizing the social and ecological benefits that willow windbreak intercrops could provide for subarctic Indigenous communities and a globally sustainable agricultural system.

Chapter 6

6.1 Conclusion

This chapter summarizes the main research findings from each of the three studies and the contributions to the literature that have been made from this dissertation. Since this dissertation was guided by the principles of community-based research, the contributions to the involved community are highlighted along with my personal reflections of conducting this research in collaboration with a First Nation community. This chapter will conclude with recommendations for future research.

6.2 Major Research Findings

The overall objective of this dissertation was to explore the challenges and opportunities created by climate change in First Nations communities in the Canadian subarctic and to develop a better understanding of potential culturally-appropriate and sustainable adaptation measures that can be adopted within these communities. Using the First Nations community of Fort Albany as a pilot community, it was found that local food production along with the use of the collaborative-geomatics informatics tool could promote adaptive capacity through the generation and transmission of knowledge. Both projects showed that the community is rich in social capital, and has the potential to become more resilient to not only the challenges associated with climate change, but also the social inequalities that the community is facing.

Chapter 3 (*Study I*) presented an initial assessment of the utility of a decision-support tool to help reduce the risk and degree of exposure of First Nations people to dangerous bush travel conditions. The results of this study showed that the collaborative-geomatics informatics tool has

the potential to help reduce the risk associated with dangerous and unpredictable bush travel routes through its real-time monitoring of travel conditions. Further, the ability for the system to acquire, store and transmit traditional knowledge could be used to promote increased adaptive capacity towards climate related challenges. This initial hands-on pilot study has demonstrated that the system is viable.

Chapter 4 (*Study II*), the objectives of this second study were to develop a better understanding of the opportunities associated with a warming climate in the western James Bay region and the potential for sustainable local food production. The results of this study showed that potatoes could be more sustainably grown (i.e. no pesticides and no chemical fertilizers) with yields similar to global potato yields. Semi-directed interviews along with community harvests revealed that local-food production was being accepted and adopted by the community of Fort Albany First Nation. Our research findings indicate that communities with food security concerns similar to that of Fort Albany could use intercrops lined with windbreaks to address the challenges associated with replacing an import-based food system.

Chapter 5 (*Study III*), this final study aimed to develop a more in-depth understanding of some specific agricultural sustainability principles of local-food production. Drawing upon soil chemistry information and cropping dynamics, I was able to develop a more robust understanding on the future of sustainable food production in the subarctic. Soil chemistry results showed that the soils in the region were capable, with some sustainable amendments, to support future agricultural production. Intercropping was shown to be a viable cropping treatment due to the numerous social and environmental benefits that it could introduce to the community and environment. Similar to *Study II*, the treed, windbreak-lined site outperformed the open site

suggesting that there is a positive benefit of the willow windbreak on yield and biomass production as well as soil chemistry.

Despite the social and environmental challenges that the community of Fort Albany is facing, the results from these three studies suggest that the community is resilient and there is great capacity for culturally appropriate and sustainable opportunities to help to mitigate the impacts of climate change.

6.3 Key Research Contributions

In addition to making significant and original contributions to the literature, this research aimed to make contributions at the community-level to help address a number of social and environmental challenges. Each of the included projects were based on the principles of community-based research, where each project specifically addressed a community concern that was initiated by the community themselves at the grass roots level (National Institute of Environmental Health Services, 2009; Whyte, 1991). Specific concerns as defined by the community of Fort Albany First Nation were addressed, with respect to capacity building, in response to environmental change. The priority of this research was to make community-level impacts to the community of Fort Albany. Contributions to more traditional academic avenues were developed as a secondary research goal.

6.3.1 Community Contributions

Each of the projects presented in this dissertation were based on addressing a need/problem as determined by the community of Fort Albany. Each project was designed to promote co-learning, facilitate collaboration and to promote the strengths and resources within the community (Burke et al. 2013). One of the primary goals of this research was to develop

capacity for long-term adaptation through the implementation of projects that were sustainable. Projects that support collaborative, multilevel, culturally appropriate and sustainably driven community-level impacts have the greatest potential to be drivers of change in Aboriginal communities (Trickett et al. 2011). The development of projects that maintained this requirement of community-level sustainability was the primary goal of this dissertation.

The projects within this dissertation, as a whole, address the four categories of climate-induced challenges for Aboriginal people living in Canada's North: *access to resources, health and safety, predictability* and *species availability* (Berkes and Jolly, 2001). The collaborative geomatics tool in *Study I* supports increased access to traditional resources along with increased predictability of travel conditions. Real-time geospatially-linked information allows accurate identification of real-time hazards supporting the flexibility and diversity in travel routes and the identification of the safest route. Decisions can be made on the best mode of transportation, type of harvesting equipment and location of harvesting area, allowing for greater access to traditional resources.

All three studies address the challenge of wellbeing by building capacity, allowing for adaptation to climate change effects. Practicing traditional land-use through resource harvesting (*Study I*) or spending time working the land for gardening purposes (*Study II* and *III*) develops meaningful connections to the land and helps to promote wellbeing. *Study I* supports physical health by allowing community members to pack the appropriate equipment and supplies required to travel safely and the ability to geospatially mark locations of harvesting activities, so any rescue efforts are efficient. Further, the social networking capabilities can help for the formation of hunting groups that can travel together to help increase bush safety.

The ability of the geomatics system (*Study I*) to store traditional knowledge on the availability of species of plants and animals will help First Nations communities to monitor the impacts of environmental change on species abundance, migration patterns and habitat use, especially those species that are of cultural significance to the community. As previously mentioned, willows when used as windbreaks will help to support the increased availability of animals that feed on the leaves and branches, allowing for increased opportunity for traditional uses.

Local food production in the form of bean and potato intercrops grown between willow windbreaks (*Studies II & III*) provided food for the community over the two-year growing period described within this dissertation. The results of this initial project have guided the establishment of locally-based food security in Fort Albany. Since 2013, additional crops consisting of *Brassica oleracea* (kale) and carrots have been successfully grown in the treed willow site, along with the introduction of a cover crop comprised of *Vicia villosa* (hairy vetch), *Fagopyrum esculentum* (buckwheat), tillage radish, *Lolium multiflorum* (annual ryegrass) and *Trifolium incarnatum* (crimson clover). Based on the soil chemistry analysis from *Study III*, the cover crop was added to the treed site to help reduce soil loss, maintain soil fertility and reduce the presence of weeds.

Perennial species of edible *Fragaria L.* (strawberries) and *Rubus leucodermis* (raspberries), *Ribes* spp. (gooseberries) and *Vaccinium* spp. (cranberries) have also been established within the treed willow site. Environmental change has resulted in many traditional berries becoming rare in-and-around the community; therefore, harvesters must travel further on land to collect berries. Bush travel as noted in *Study I* is becoming increasingly more dangerous. Having berries grown in agricultural sites within the community would increase the accessibility of berries for traditional and nontraditional uses.

With the ultimate goal of community control of local food production, there has been greater focus on community involvement and education since the completion of *Study III*. Grade school class trips to the treed site, to help harvest and learn about soil and plant health, along with climate change impacts have taken place. There has been the development and introduction of a Facebook community group dedicated to sharing ideas and pictures of community food production. In fact, the layout of the treed site for the 2016 growing season was designed and implemented based on community input and introduced additional crops. The goal of the project is for the community to begin taking control of the treed site in 2017, in a phased-in process, while also scaling up the initiative. In this way, the community will further develop the knowledge and skills necessary to successfully and sustainably produce local foods. The collaborative-geomatics informatics tool (*Study I*) has similar potential to supporting long-term adaptive capacity within the community of Fort Albany.

Field-testing and community workshops on using the collaborative-geomatics informatics tool will continue to be carried out within the community of Fort Albany. Further, the development of an application to be used on handheld electronic devices will allow for the collaborative-geomatics informatics tool to be more widely used, while out in the bush. Having the system available on hand-held devices will contribute to the ability to more easily monitor, store and map environmental and traditional knowledge, while travelling on the land. Once the tool has been fully tested and modified accordingly to meet the community's needs, it will be given to the community, as a stand-alone, secure system at no cost. Due to the unique platform on which the informatics tool is built, the WIDE-toolkit, once control of the tool has been given to the community it will allow for the further development of the tool to meet the unique and evolving needs of the community, all without outside input, access or control. Control and

development of the tool by the community will help to create opportunities for innovation to address future challenges, such as, climate change and resource development, that the community will face (McCarthy et al. 2012).

6.3.2 Key Contributions to the Literature

The following is a description of the contributions to the literature that *Studies I, II & III* have made.

1. Development of Sustainable Northern Agriculture

It is predicted that the rate of climate warming will be rapid in arctic and subarctic regions and research concerning northern agriculture must begin immediately (Peltonen-Sainio, 2012). To date the majority of climate change research has focused on the challenges that a warming climate will bring to the ecological and social systems in the arctic and subarctic (Ford et al. 2012a; Ford et al. 2012b). Despite a robust literature base on the biophysical impacts of climate change and the resulting changes to arctic and subarctic ecosystem dynamics, there has been little research on the opportunities that such changes might bring to Aboriginal communities in these regions (Ford et al. 2012a; Ford et al. 2012b). All areas of food security including the access, availability and affordability of food, are likely to be impacted by climate change (IPCC, 2014a). According to a recent literature review, there is a need for case study research to focus on “identifying and characterizing sustainable and feasible adaptation interventions” (Ford et al. 2012a:808). Critical adaptive measures for the improvement in the resilience of cropping systems, such as, diversification of crops, inclusion of nitrogen-fixing legumes and more sustainable methods, to address water and pest concerns are required to successfully promote northern food production (Peltonen-Sainio, 2012; Peltonen-Sainio & Niemi, 2012). Local sustainable food production in northern regions, such as, the western James

Bay region of Ontario, presents an opportunity for remote First Nations communities to address key concerns surrounding food security.

Studies II & III, are to my knowledge, the first to look into the potential use of intercropped beans and potatoes grown between native willow windbreaks to promote sustainable food production in a northern subarctic First Nations community, under ambient conditions. *Studies II & III* presented novel evidence that intercropped beans and potatoes could be sustainably grown between native willow windbreaks. The intercrop design introduced in *Study III* addresses the need for improved resilience of cropping systems, diversification of crops and inclusion of nitrogen fixing legumes. Windbreaks allow for sustainable methods to address water and pest concerns. Importantly, the soil chemistry analysis presented in *Study III*, has shown that soils in this region can support continued agricultural production with some augmentation. The long-term monitoring of soil chemistry, using the results from *Study III* as baseline data, can guide future agriculture practices as well as the monitoring of terrestrial climate change impacts. Taking advantage of warmer temperatures, local food production has the potential to address some critical food security issues facing many Aboriginal communities across the Canadian subarctic.

2. Regional knowledge contributions

As previously stated, it has been recognized that First Nations communities in the arctic and subarctic regions face unique social and environmental challenges. Within the literature there is a high level of confidence that the impacts of climate change both social and biophysical will exhibit strong heterogeneity due to strong regional ecological and social diversity (Larsen et al. 2014). Community-level, case study assessments play a critical role in developing a better

understanding on how the stress of climate-related challenges will impact the vulnerability and adaptive strategies of communities (McDowell et al. 2016; Ford et al. 2012; Evengard & McMichael, 2011; Furgal & Seguin, 2006; Laidler & Gough, 2003). The International Panel on Climate Change has called for more comprehensive studies in polar communities with research focused on the long-term monitoring of the health, well-being and the impacts on traditional livelihoods at local and regional levels due to climate related impacts (Larsen et al. 2014:1596; Ford et al. 2012). Further, there has been a call for increased examination of knowledge, specifically sustainability knowledge across different spatial and temporal scales (Petrov et al. 2016). *Study I* expands the scope and supplements our understanding of climate change at a regional scale through the ability of the collaborative-geomatics informatics tool to acquire, store and transmit real-time environmental data, to make better-informed decisions. The use of the informatics tool has the potential to empower the community and increase adaptive capacity through a bottom-up approach. Community members of Fort Albany can use the informatics tool to gather, store and analyze their own year-to-year (and decade-to-decade) environmental change in the western James Bay region, especially the Albany River basin.

3. Decision Support for Subsistence Activities

Community members in northern First Nations communities have expressed that access to traditional foods is critical to the health and well-being of their communities (Socha et al. 2012). The ability to access resources and maintain traditional harvesting practices is vital to food security and sustaining the cultural and economic well-being of northern Aboriginal communities (Brinkman et al. 2016). Interviews with harvesters in communities in Alaska identified 47 important relationships between climate change impacts and availability of subsistence resources, of which 60% were directly related to the accessibility of these resources

(Brinkman et al. 2016). Climate models have forecast an overall reduction in the accessibility of subsistence resources over the next 30 years (Larson et al. 2014). Research focused on quantifying and describing the characteristics and mechanisms surrounding the access to traditional harvesting is required in order to address what has been called a “critical knowledge gap” (Brinkman et al. 2016). With the ability to store and share knowledge on real-time travel conditions of bush trails, waterways and winter roads, alongside information on waterways, snow, ice and temperature changes, the collaborative-geomatics informatics tool (*Study I*) can contribute to knowledge generation and exchange on the challenges and accessibility of subsistence activities in the western James Bay region. Specifically, having information on the safety of routes on a hourly/daily/weekly basis would be of great importance to communities who travel on snow, ice and water to harvest subsistence resources. As mentioned previously, Elders and bushmen are particularly concerned for the bush safety of inexperienced community members. The tool has the potential to provide remote communities with the ability to monitor and share knowledge between youth and elders (both science and TEK), which can foster adaptive capacity and mutual learning through proactive planning rather than reactionary responses.

4. Traditional knowledge generation and transfer

Internationally, there is an increasing awareness of the need to incorporate Indigenous knowledge to help inform adaptive planning with respect to climate change. “Indigenous, local and traditional knowledge are a major resource for adaptation but these have not been used consistently in existing adaptation efforts. Integrating such forms of knowledge into existing practices increases the effectiveness of adaptation” (IPCC, 2014a:14). It has also been recognized by the Canadian government that Aboriginal groups have a unique understanding of

the environment being both cumulative and dynamic (CEAA, 2010; Tsuji & Ho, 2002). Social, environmental and economic challenges have resulted in a reduction in the ability to carry out traditional land-based activities that are vital to the development, transference, and reinforcement of TEK.

Climate change weakens the land-based skills of younger generations by decreasing the amount of time spent practicing these land-based skill, and limiting the time youth and elders spend together, both of which are vital to the development of adaptive capacity (Laidler et al. 2009). To build capacity in this region, there is a need to use both scientific and TEK as complementary constructs. The collaborative-geomatics informatics tool, presented in *Study I*, enables First Nations to collect, display, and share information, as well as collaborate with other communities and/or groups. This allows for the storage, creation and transmission of traditional knowledge between communities and between community members (Barbeau et al. 2011). During the initial development of the informatics tool, it was shown that the tool could be used to facilitate knowledge transmission between youth and elders.

6.4 Reflections on Working with First Nations: Lessons Learned

Without the long standing relationship with the community of Fort Albany, resulting from ~30 years of collaborative research headed by our research group with the community, the research undertaken for this dissertation would not have been possible. With a history of extensive environmental and social inequalities resulting from outside “western” influence, there is a great deal of distrust within many Canadian Aboriginal communities. I have found through working with Fort Albany that the most important principle of community research concerning First Nations is that of fostering trust. A relationship of trust with the community takes years to develop. I have seen it grow over the years of conducting my research during both my Masters

and PhD. The most important time spent conducting research was just being in the community, being seen and recognized and having the opportunity to help out wherever possible. Being part of such a dynamic research team has meant being part of many diverse projects. These projects have ranged from school based nutrition studies (Isogai et al. 2015; Gates et al. 2012; Skinner et al. 2006) to cultural asset mapping, land-use planning (Gardner –Youden et al. 2011) and health programs (Charania et al. 2013). Our research team has forged a strong, collaborative relationship with the formal leadership (Chiefs and Councils), education and health services units of Fort Albany, along with many youth and Elders. The knowledge on how to work towards building trust and partnerships within a First Nations community is the greatest contribution that I have received from the development of this dissertation.

6.5 Recommendations for Future Research

Future research within the community of Fort Albany and other Aboriginal communities needs to continue with a focus on environmental change and sustainability. In relation to *Studies II & III* future research needs to focus on working with Aboriginal communities to develop a better understanding of sustainable site designs and locations. Proximity to the community is a vital component of successful local-food programs. A site that is too close to the community risks vandalism and destruction by community dogs; however, too far and there is less involvement and recognition by community members (Vandenburg, 2014). Local sustainable soil amendments will be required to support continued success of the agricultural sites. Sources of sustainable soil P need to be sourced locally to support further soil enrichment.

Focusing on continued community involvement in the development and implementation of a handheld collaborative-geomatics informatics tool will help to ensure that the new system is tailored to the unique requirements of bush travel in a unpredictable subarctic environment.

Interactive workshops comprised of both youth and Elders need to be continued to further showcase the unique abilities of the WIDE toolkit. These hands-on workshops, focused on skill building, are required to begin the transition towards community ownership and control of the tool.

6.6 Concluding Remarks

Aboriginals living in the Canadian North are already experiencing the impacts of climate change, and climate change will continue into the future. Melting ice conditions, flooding, coastal erosion and changes to snow and rainfall are presenting challenges to people living in arctic and subarctic communities. Planning using the collaborative-geomatics informatics tool can help to reduce the risk associated with travelling on the land in a time of climate unpredictability. Despite these challenges, there are also opportunities that can be seized. Agricultural crops grown in windbreak-lined sites controlled by First Nations communities offer a more sustainable alternative than fruits and vegetables grown using conventional agriculture and then imported to the Canadian North.

It is important to remember that First Nations communities are far from powerless and that they have resources and knowledge that can grow their own social capacity. It is vital that future research supports the continued empowerment of First Nations communities to identify their own needs and to maintain ownership and control of their knowledge and resources. Working together, First Nations and academics can generate a rich resource base of knowledge that will continue to support communities in a time of environmental change.

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