AN INTERDISCIPLINARY ASSESSMENT OF COMMUNICATING SOCIAL AND NATURAL IMPACTS OF CLIMATE CHANGE IN THE CANADIAN ARCTIC

by

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Dedication

I would like to dedicate this thesis in loving memory of my grandmother Ursula Hahn (my namesake), who passed away while I was completing my studies at Dalhousie University, and whom I miss dearly. I also dedicate it to my remaining family and friends back home and in Halifax, as without their invaluable support, I would not have been able to accomplish this.

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ABSTRACT

Accelerated climate warming has cascading effects on Arctic ecosystems and northern communities, resulting in an urgent need for adaptation and communication strategies across circumpolar regions. As such, Arctic amplification has sparked a large volume of research projects from various disciplines. The purpose of this research was to investigate the social and natural impacts of climate change in the Canadian Arctic, by employing an interdisciplinary approach. A systematic comparison between Inuit responses in interviews about climate change across Alaska, Canada, and Greenland, suggested that while impacts of climate change are largely perceived as negative in the way they affect Inuit well-being, climate impacts are prioritized differently in urban versus remote communities. This difference in conceptualizing the issue of climate change has implications for communicating climate change and developing adaptive strategies, both within the social and natural sciences. To complement the analysis of social climate impacts, a limnological assessment of lakes within a transitional Arctic ecotone in the Western Canadian Arctic highlights the importance of discussing habitat and lake morphology differences when studying environmental change over large latitudinal gradients. Semi-structured interviews with practitioners of Arctic organizations were conducted to gain insight into current strategies and recommendations for early career researchers to communicate their climate change-related research across the Canadian Arctic in a way that is both meaningful and productive for Arctic communities. In a shifting Arctic research paradigm, interdisciplinary approaches offer a versatile strategy for gaining an enhanced understanding of complex phenomena such as climate change in the Arctic; yet this integration, meaningful community engagement, and knowledge mobilization of climate change-related research remain challenging. More guidelines and training opportunities for researchers, both at the start and continuously throughout their research careers, are needed to support them in a rapidly evolving Arctic.

LIST OF ABBREVIATIONS USED

°C	temperature (degrees Celsius)
%DO	percent dissolved oxygen
δD	delta deuterium
$\delta^{18}O$	oxygen-18 isotopes
µS/cm	microsiemens per centimeter
ARI	Aurora Research Institute
CCA	Constrained Cluster Analysis
CO_2	carbon dioxide
COND	conductivity
CH_4	methane
DOC	dissolved organic carbon
DOM	dissolved organic matter
ECRs	early career researchers
EPA	Environmental Protection Agency
GPS	global positioning system
HC g^{-1} DW	head capsules per gram of dry weight
iCAP™ ICP-MS	Inductively Coupled Plasma Mass Spectrometry
iCAP™-RQ ICPMS	Single Quadrupole Inductively Coupled Plasma Mass Spectrometry
ICARP	International Conference on Arctic Research Planning
IndVal	Indicator Species Analysis
IQ	*Inuit Qaujimajatuqangit*
IPY	International Polar Year
IRC	Inuvialuit Regional Corporation
ISR	Inuvialuit Settlement Region
ITH	Inuvik-Tuktoyaktuk Highway
KOH	potassium hydroxide
Lat.	latitude
Long.	longitude
ha	area (in hectares)
m	distance/depth (in meters)
MΩ•cm	resistivity
MRT	Multiple Regression Tree Analysis
mVORP	oxidation-reduction potential
N_2	nitrogen
NRI	Nunavut Research Institute
NT	Northwest Territories
NU	Nunavut

OCAP	Ownership, Control, Access, and Possession
p	statistical p-value
P_4	phosphorus
pH	acidity/alkalinity
ppm TDS	total dissolved solids
psi	water pressure
PSU	salinity
QBIC	Quantitative Bio-element Imaging Centre
REB	Research Ethics Board
RDA	Redundancy Analysis
SSHRC	Social Science and Humanities Research Council of Canada
TC-EA	Temperature Conversion Elemental Analysis
TEK	Traditional Ecological Knowledge
TN	total nitrogen
TNM-1	Total Nitrogen Measurement Unit
TOC	total organic carbon
TOC-V	Total Organic Carbon Analyzer
TP	total phosphorus
VIF	variance inflation factor
WESS	Laboratory for Water and Environmental Sustainability Science

STATEMENT

Taking positionality in research is becoming increasingly important in today's academic society, as it allows scientists to reflect on their own experiences and assumptions that they bring to the project, and how that will influence the research they conduct. Positionality typically describes a person's view of the world, their assumptions on knowledge, and how they interact with their environment (Holmes 2020). Having a background in both Psychology and Biology stirs my interest in trying to understand the nature of cross-cultural perceptions and communication of complex phenomena such as climate change. Being an early career researcher in the process of completing graduate school, with little previous research experience, makes creating an enhanced understanding and developing guidelines for meaningful Arctic research and knowledge mobilization, a quest that is motivated by personal experiences. Further, being a European citizen, as well as not a Native English speaker, has widened my insight into the conversational challenges that come with communicating in a language that is not your own, and its implications on discussing abstract concepts and feelings. Given that I grew up and lived in central Europe for most of my life, I see the increased necessity to enhance my understanding and cultural sensitivity for conducting research in the Canadian Arctic. With all this in mind, I am grateful to the guiding hands of experienced practitioners in the Canadian Arctic, who helped me shape this study, and explore possible solutions to some of the challenges that come along with interdisciplinary Arctic research. Together, we aim to contribute to a meaningful interdisciplinary approach to Arctic research, with the common goal of finding adaptation strategies to protect this unique ecosystem.

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This project would not have been possible without the support of so many lovely people.

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CHAPTER 1 INTRODUCTION

1.1 Introduction

The average temperature in some regions across the circumpolar Arctic has risen between 2-3°C over the last 50 years, suggesting that the global North is warming at a rate twice as fast as anywhere else on this planet, and pointing to the urgency of finding effective means to communicate this trajectory (Casagrande et al. 2021; Moser 2016). As a response to this phenomenon, often referred to as Arctic amplification, natural ecosystems have been changing rapidly (Serrezze and Barry 2011). Reduced ice coverage, glacial and permafrost degradation, changes in tundra vegetation, as well as progressive northward densification of shrubs, are evident (Kivilä et al. 2022). Over the past decades, paleolimnological and limnological research has shown that aquatic freshwater systems are among the most vulnerable ecosystems in the Arctic, due to their interaction with the terrestrial environment (Smol and Douglas 2007; Korosi et al. 2022). Drastic terrain- and landscape disturbances as a result of accelerated warming can change the aquatic-terrestrial interface and cause rapid alterations in the biological and chemical composition of lakes, rivers, and streams (Kokelj et al. 2009; Yang et al. 2010).

Indigenous Peoples, who have been living in the circumpolar Arctic for millennia, have been observing these changes in the environment that are affecting fundamental aspects of their way of life (Ford and Pearce 2010; The Royal Canadian Geographical Society 2018). Inuit have reported increasing unpredictability of local weather as early as the 1990s, followed by observations of receding sea ice, declines in wildlife populations, and changes in animal migration patterns (Laidler et al. 2009). Their perceptions of climate change are therefore a useful source of information as Inuit have lived in the

Arctic for many generations and hold rich knowledge about the land (Sansoulet et al. 2020). In the past, many scientists overlooked the value of including Indigenous communities and their rich knowledge about the Arctic regions, when trying to understand how climate change is impacting the Arctic. Yet, in recent years, researchers become increasingly aware of this gap and have started adopting more community-based approaches to co-producing knowledge (Callaghan and Johansson 2021). Yua et al. (2022) define co-producing knowledge as “a process that brings together Indigenous Peoples’ knowledge systems and science to generate new knowledge and understandings of the world that would likely not be achieved through the application of only one knowledge system”. As such, the emphasis is put on equity in research relationships, to allow for the collaborative generation of a deeper and more meaningful body of knowledge (Yua et al. 2022).

Combining Western science with Indigenous observations can ultimately provide a more holistic picture of how climate change is affecting the Arctic, across various interconnected levels. However, it remains a complicated endeavor in practice, due to - but not limited to - the inherent differences in quantitative and qualitative approaches to research (Williams et al. 2018). Differences in the conceptualization of climate change between science and Traditional Knowledge systems make communication about climate change, especially climate change adaptation solutions, challenging (Gagnon and Derteaux 2009). Community-based research takes time, and there are certain obstacles that scientists continue to face when trying to conduct meaningful research in the Arctic, especially for early career researchers (ECRs). Some of these obstacles include budgetary or time constraints, as well as limited experience with Arctic research, which creates challenges that need to be addressed to promote research that is more respectful and inclusive of Indigenous knowledge and values (Tondu et al. 2014).

Here, I seek to understand how knowledge mobilization of influences of climate change on the environment can be conducted in a way that is respectful and meaningful to local communities. I approached the issue of knowledge mobilization in an interdisciplinary way, to not only examine a primary ecological component of my understanding of environmental change but also attempt to enhance trust within Arctic communities by reflecting on how to communicate that knowledge in a meaningful, respectful, and collaborative way. To be able to understand the context of how climate change is perceived in the Arctic, a systematic literature review on climate change perceptions of Inuit was conducted and compared to an interview case study from Iqaluit, Nunavut (NU) in Chapter 2, to explore whether there are substantial differences in how climate change is conceptualized and prioritized in urban communities compared to remote communities. Then the effective use of biological indicators in an ecological assessment was explored in Chapter 3. Here, the importance of habitat and lake morphology on the abundance and diversity of chironomids (Diptera: *Chironomidae*), which are commonly used by paleolimnologists and limnologists to detect environmental change, were examined (Medeiros et al. 2012, Niemeyer et al. 2022). In Chapter 4, a reflection on semi-structured interviews with practitioners from Arctic organizations was provided to gain informed insight into current practices and recommendations for communicating climate change research to local communities in a respectful and meaningful way. Finally, Chapter 5 provides a synthesis of these approaches to Arctic research to outline the strengths of interdisciplinary research designs when trying to get a more complete understanding of the multifaceted and interconnected ramifications that climate change in the Arctic has, both on the natural ecosystems as well as on the Peoples who call this place their home. Ultimately, this thesis attempts to provide an example - within the bounds of a Master's degree program - of how to collaborate with Indigenous communities in the Arctic to better understand how to work together to progress our mutual understanding of the effects of climate change on the Arctic.

1.1.1 Overview of the problem to be addressed

Climate change impacts on the Arctic are very complex and often highly interconnected. Many causal links between climate change and what drives it are yet to be completely understood, and future climate scenarios especially in an Arctic context remain hard to predict (Phoenix and Lee 2004). Therefore, the combination of multifaceted research approaches is needed to be able to develop a more holistic picture of the impact that climate change is having on Arctic regions (Petrov et al. 2016). In recent years, the Arctic research paradigm has increasingly shifted towards knowledge co-production. However, to this day, the extent of community engagement in research still varies depending on the discipline, research team, funding agency, and institution (Gearheard and Shirley 2007; Brunet et al. 2014; Mallory et al. 2018); and the quality of such collaborations between scientists and community is difficult to evaluate due to the large amount of research being conducted in the Arctic (Gearheard and Shirley 2007). The combination of inherently different approaches within the social and natural sciences remains a challenging task, and many researchers continue to struggle with applying interdisciplinary approaches in practice (Gearheard and Shirley 2007). To address this issue, more research is needed on how researchers can effectively and meaningfully communicate across various disciplines, as well as outside of the academic sphere (Flynn and Ford 2020). This thesis seeks to apply an interdisciplinary approach, combining both social and natural science research, to get a better understanding of how climate change impacts the Canadian Arctic and how such knowledge should be communicated in a respectful and meaningful way.

1.1.2 Purpose statement and research objectives

With research suggesting that climate change impacts are highly interconnected and compound each other across the various scientific disciplines, the most recent International Conference on Arctic Research Planning (ICARP) conducted in 2015 calls for more interdisciplinary approaches to reveal the full extent of the ramifications of environmental change in the Arctic (Petrov et al. 2016). For this reason, the application of an interdisciplinary approach is central to this thesis.

By combining the use of well-established methodologies in both the natural and social sciences (Strøm 1929; Knott et al. 2022), three primary research objectives are being addressed: 1) Exploring Inuit observation of climate change between urban and remote Arctic communities to see whether there are fundamental differences in how climate change is being experienced, 2) investigating the importance of habitat and lake morphology when using biological indicators to understand the extent of environmental change in Arctic freshwater systems, and 3) establishing guidelines for ECRs in how scientific research should be communicated in a way that is respectful and meaningful to Arctic communities. Ultimately, the goal is to combine the knowledge obtained through systematically reviewing existing literature, conducting interviews with Inuit and practitioners in Arctic organizations, and applying limnological methods, to get a more complete picture of how climate change is impacting the Canadian Arctic (Figure 1.1).

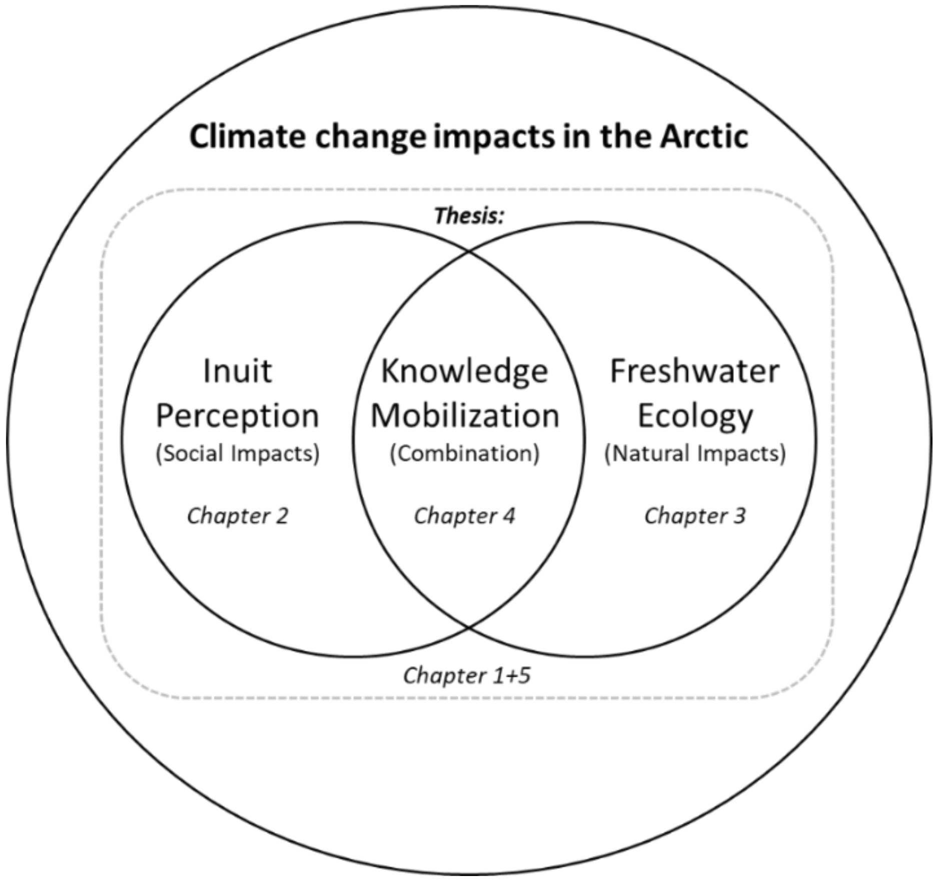

Figure 1.1 Venn diagram illustrating the interdisciplinary research approach. The big circle represents the scope of climate change impacts in the Arctic, the smaller circles represent select social and natural impacts respectively as discussed in this thesis. The overlap represents where both disciplines intersect, here referred to as the combination through - but not limited to - knowledge mobilization. The dashed line represents the limited scope of the thesis, acknowledging the complexity of climate change impacts in the Arctic.

1.2 Background

1.2.1 Observations of change

Over millennia, Inuit have adapted to life under harsh conditions, by having a close connection with the natural environment in which they live. This has resulted in rich Traditional Knowledge, which has been passed on over generations (Archer et al. 2017). Many Inuit report changes in weather predictability and sea ice retreat, as well as changes in migration patterns of wildlife, which has drastic implications for local diets, based on compromised hunting opportunities (Laidler et al. 2009). Not all associate those observed changes with climate change, often grounded in the knowledge that things have always been changing and in the conviction that "things will get back to normal next year" (Ford et al. 2009). Still, many Inuit in the Arctic Nations agree that climate change constitutes a continuous threat to their culture and livelihood in Arctic communities, but are often confronted with other social equity, economic, and health problems that are perceived as more pressing (Prno et al. 2011).

Vivid memories of colonial history and ongoing Westernized influences continue to diminish the transmission of local knowledge and practices, which are a major concern to Indigenous communities (Datta 2018). Manifested also within research practice, Indigenous Peoples often suffer from the exploitation of their lands and knowledge for the furthering of science. Fortunately, this reality is increasingly recognized and attempts are being made to address inequities within Canadian society and the scientific community (Nadeau et al. 2022). Some milestones towards reconciliation in Canada include - but are not limited to - the Calder Case (1973) resulting in the first negotiations of land claim agreements across Canada (Bone 2016); the Scientists Act (1988) which makes Indigenous consultation mandatory within the research licensing process in Nunavut (Gearheard and Shirley 2012); the development of The First Nations Ownership, Control, Access, and Possession (OCAP) principles in 1998 which recognize and protect Indigenous rights to control data collection processes and ownership; and The Truth and Reconciliation Commission of Canada (TRC) created in 2008 to raise awareness and recognition for the traumatic experiences of Indigenous Peoples in Canadian residential schools (Williams et al. 2020). On April 1st, 1999, the formation of Nunavut (Inuktitut for "our land") partially reinstated the sovereignty of Inuit on their land and towards self-governance, and as such making Inuit voices heard (Bone 2016). This history, along with cultural customs and traditions, is important to take into account when trying to understand how Inuit are dealing with and adapting to a rapidly changing environment (Petrov et al. 2016). Many Indigenous Peoples acknowledge that maintaining their ancestral ties to the land they live on is what gives them the strength to heal, and roots within the cultural value of protecting their environment (Tagalik 2011; Durkalec et al. 2015).

The long history of Inuit living in Arctic regions makes their observations and perceptions a valuable source of information complementary and essential to scientific research. A lot of research has been conducted on how Inuit perceive climate change across Alaska, Canada, and Greenland, often in context or relation to scientific data (Honda 2018). These studies have shown that there is a consensus between scientific data and Traditional Knowledge passed on by Inuit (Riedlinger and Berkes 2001). Hence, looking at both scientific data and Traditional Knowledge can increase confidence in the accuracy of observations, regarding ongoing changes in the Arctic regions (Sansoulet et al. 2020). As such, meaningful knowledge mobilization is an important aspect of the combination of Traditional Knowledge and scientific knowledge (Pearce et al. 2009). Flynn and Ford (2020) define knowledge mobilization as a bidirectional and beneficial flow of information between two or more parties within and outside of the academic context. They suggest that there is no 'one success formula' for knowledge mobilization, but rather a general guideline that needs to be adapted to specific cultural contexts within the North American Arctic. As such, they put forth three key principles for effective knowledge mobilization: Respect, mutual understanding, and researcher responsibility (Flynn and Ford 2020). The principle of respect involves entering a working relationship based on trust, which is especially important when the two parties come from very different geographical and/or cultural backgrounds. The principle of mutual understanding implies understanding the value of combining different yet equally important knowledge systems. Finally, the principle of research responsibility is about implementing knowledge co-production by including Indigenous communities in all steps of the scientific process (Flynn and Ford 2020). In practice, however, this implementation remains challenging, especially within the natural sciences, where researchers receive very little training on community-based research (Gearheard and Shirley 2007). Technical jargon and persisting language barriers also continue to get in the way of meaningful and mutual understanding (McBean and Hengeveld 2000; Gearheard and Shirley 2007). Climate change by itself is complex enough to be described coherently and holistically, given the interplay of various factors involved, which limits scientists' ability to accurately predict future outcomes (Ballantyne 2016). As such, careful consideration is needed when communicating climate change, in a way that it is productive and leads towards the creation of effective and feasible adaptation strategies in the northern range of the Arctic Nations (Moser 2016).

1.2.2 Environmental impacts of climate change

Climate change in Arctic regions occurs at a rate twice as fast as in any other geographical zone (Casagrande et al. 2022). As such, an increased frequency of drastic weather events (e.g., storm surge), continuous ice and permafrost retreat, and warmer air and ground temperatures have been observed in the Western Canadian Arctic (Vermaire et al. 2013). These climatic developments induce changes to the Arctic terrain, vegetation, and biodiversity (Lantz et al. 2022). For many centuries, low temperatures around the Poles have kept the ground consistently frozen; permafrost, the matrix of water, soil, and organic contents that is completely frozen for at least two consecutive years, is covered by a thin layer that continuously thaws in the summer and refreezes in the winter, also referred to as the active layer (Dobinski 2011). As global temperatures increase, permafrost starts to decay (Kokelj et al. 2017). Depending on the state of decay and the region, permafrost can be either continuous, discontinuous, or sporadic (Dobinski 2011). Degrading permafrost increases the occurrence of retrogressive thaw slumps, which are land erosions that happen when permafrost at northern latitudes melts and the ground collapses (Kokelj et al. 2017; Lewkowicz and Way 2019).

With increasing ground temperatures and the growing thickness of the active layer, the spatial range of vegetation in the Arctic continues to change (Wilcox et al. 2019). Arctic spruce woodlands are slowly progressing northwards, and shrubbery across the Arctic tundra is increasing in height, size, and distributional range (Wilcox et al. 2019). Permafrost is more resilient to global warming when covered by sedge meadows rather than shrubbery, which has been shown to accelerate the thawing of the ground by keeping parts of the active layer snow-free and exposing them to the sun much earlier in the spring months (Wilcox et al. 2019). Thus, regions in which permafrost becomes increasingly unstable, are generally more sensitive to climate change (Lantz et al. 2022). Regions where permafrost remains mostly still intact are covered to a large extent by freshwater lakes, as the ice prevents water drainage into the ground (MacDonald et al. 2015; Jones et al. 2022). Here, precipitation and snowmelt travel mostly vertically and collect in low-lying basins (Jones et al. 2022). As a result, these lakes provide habitats for rich ecosystems that are highly sensitive to climate change (Medeiros et al. 2014). Plug et al. (2008) showed that the total lake area in the Arctic fluctuates depending on the evaporation pressures posed by annual air temperature and precipitation rate. While lake formation and drainage are part of a natural cycle, it appears that climate change disturbs this process (Skeeter et al. 2020). Lake mixing naturally occurs more frequently in shallow lakes than in deeper lakes, which are seasonally stratified (MacIntyre et al. 2010). However, a rise in water temperature can permanently distort these mixing patterns, which directly determines the availability of oxygen and nutrients at different lake strata, and thereby changes the vertical distribution of biological organisms in the lake. As air temperature increases, so does the evaporative pressure of aquatic systems, whose lake level depends on the dynamic interplay of evaporation and precipitation, as well as groundwater sources. Rising air temperature further decreases the thickness and duration of lake ice cover, whereby lakes are subjected to further warming for prolonged periods throughout the year (Prowse et al. 2011; Adrian et al. 2014).

Accelerated warming also increases hydrology and aquatic connectivity along northern latitudes. Permafrost runoff can cause alterations in water clarity, and nutrient availability, which directly affects the range of species that can survive in the evolving habitat (Kokelj et al. 2009; Skeeter et al. 2020; Vucic et al. 2020; Yang et al. 2010). Permafrost holds a rich storage of organic matter, and research suggests that permafrost thawing may have a direct impact on how much dissolved organic matter (DOM) is present in aquatic systems (Coleman et al. 2015). DOM can be defined as the amount of organic matter that is small enough to pass through a 0.45 μm filter (Perdue & Ritchie, 2003); and its concentration is directly linked to freshwater ecology, as it can affect light penetration due to alterations in water clarity. Light penetration on the other hand has important implications for which species can survive in the aquatic system (Lidberg 2012). Permafrost runoff can also induce eutrophic processes (Koch et al. 2018). Eutrophication, which is the result of excessive nutrient influx, increases lake productivity, leading to algal blooms. Some blue-green algae contain nerve toxins, which can affect drinking water (Chislock et al. 2013). They also consume a lot of the dissolved oxygen available, which in case of an overproduction of algae, can lead to oxygen depletion in the system. Anoxic conditions result in the death of fish stock and other aquatic species; and dead fish release phosphorus (P_4) stored in the sediment into the lake water, which amplifies the vicious cycle (Lidberg 2012). This in turn has implications for the water and food security of Arctic communities who heavily rely on those lakes for drinking water and fish both for subsistence and cultural recreation (Alessa et al. 2010).

Decaying permafrost also initiates the emergency of thermokarst lakes, which form when permafrost meltwater collects in low-lying basins (in ’t Zandt et al. 2020). Those lakes are naturally high in DOC, phosphorus, and nitrogen (N_2), which until that point had been stored in the permafrost and are now gradually being released into the aquatic system (Arsenault et al. 2022). Permafrost also acts as an important sink of potent global greenhouse gasses, such as carbon dioxide (CO_2) and methane (CH_4), which are gradually released back into the atmosphere as permafrost decays (Standen and Baltzer, 2021). As such, the degradation of the Arctic environment is a significant contributor and driver of global warming (Corell 2006).

1.2.3 Monitoring and inferring climate change

While long-term monitoring of climate change in these high-latitude environments is logistically challenging, Traditional Knowledge and aquatic systems offer two promising solutions to reconstruct current and past environmental changes (Griffiths et al. 2017; Sansoulet et al. 2020). These approaches offer different yet complementary insights into socio-environmental issues that if considered together can harness the benefits of both, thereby providing a more enhanced and complete picture of climate change impacts on Arctic ecosystems and the Peoples who depend on it (Sansoulet et al. 2020).

On the one hand, interviews are a common approach in Traditional Knowledge studies with Indigenous Peoples. Depending on the nature of the interview and the type of questions asked, they can either be very rich and qualitatively informing on the individual responses if questions are open-ended, or largely representative of a region if administered in the form of a large-scale closed-answer survey (Libakova and Sertakova

2015). Either way, interviews are a versatile means to capture a wide range of Traditional Knowledge, a lot of which is traditionally passed on through conversation and story-telling rather than writing (Wilson 2020). However, interview studies are not without criticism. While harnessing the oral nature of knowledge sharing often practiced in Indigenous cultures, interviews create a rather ‘artificial’ setting that is different from traditional ways of knowledge sharing such as through yarning and talking circles, thereby possibly compromising the authenticity of the shared knowledge (Edwards and Holland 2020). Hence, it is important to keep in mind that any knowledge shared in an interview is construed within the context of the interaction itself, and is therefore subject to psychological biases (Adams-Quackenbush 2019; Edwards and Holland 2020). Furthermore, participants’ unfamiliarity with the interview process can create confidentiality issues, especially if topics discussed are highly sensitive and include reflections on trauma and grief (McGrath et al. 2013).

On the other hand, within the aquatic sciences, paleolimnological and limnological methods allow for reconstructions of long-term variability in the climate because lake sediment acts as an archive of regional temperature shifts, extreme weather events, and soil erosion (Walker 2001; Cincio et al. 2012). The choice of proxy depends on the research focus; and chironomids (non-biting midges) are widely accepted biological indicators for climate change research (Figure 1.2), as these macroinvertebrates are largely distributed across all geographical zones and are very sensitive to subtle temperature variations and changes in water chemistry (Walker 2001). Chironomid head capsules are preserved in lake sediment. Hence to extract and identify these chironomid remains, researchers must first collect lake sediment. Many researchers rely on different identification keys. Some frequently used examples are guides by Wiederholm (1993) and Brooks et al. (2007). The Wiederholm (1993) identification methods rely heavily on characteristics of chironomids, that may be absent on fossilized head capsules. Brooks et al. (2007) addressed this limitation and designed a key that relies on characteristics that are most often still intact. Still, there are persisting knowledge gaps in the field of chironomid paleolimnology and limnology. Many identification keys are incomplete, making a holistic understanding of environmental changes in various areas in the Arctic difficult. Cooperation between scientists and sharing of knowledge is therefore highly important for progress in Arctic climate change research. Biskaborn et al. (2013) point out that many published studies focus on larger aquatic systems and often overlook the utility of studying small and shallow lakes. However, these lakes are particularly vulnerable and sensitive to environmental disturbances and therefore an important source of information on climate change (MacDonald et al. 2015). More research exploring changes in small aquatic systems is needed to fill this gap and contribute to a more enriched understanding of climate change in Arctic environments.

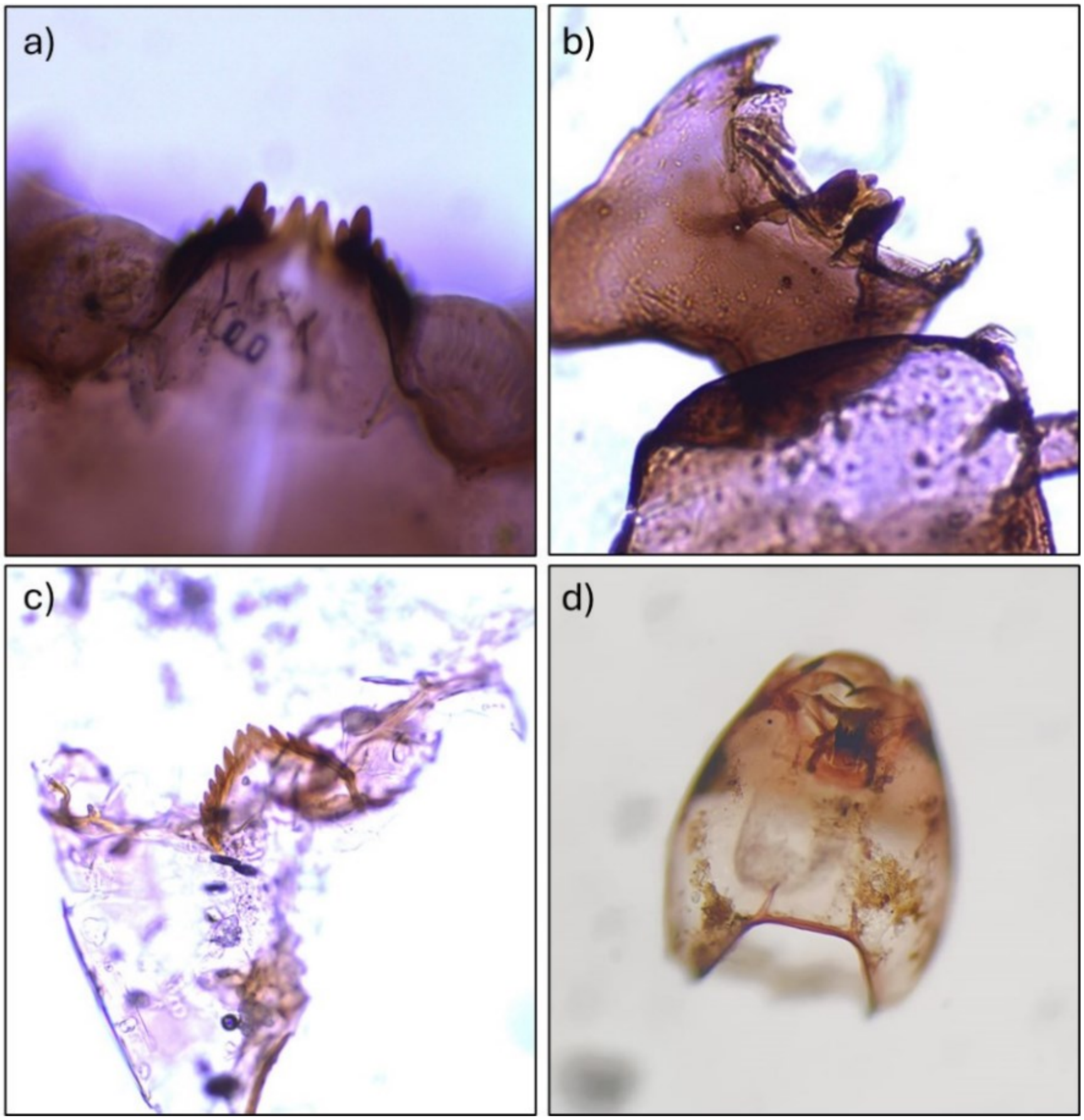

Figure 1.2 Microscopic photographs of four chironomid taxa prevalent in the Western Canadian Arctic: a) *Microtendipes pedellus-type* (Chironomini), b) *Corynocera ambigua* (Tanytarsini), c) *Psectrocladius sordidellus-type* (Orthocladiinae), d) *Procladius* (Tanypodinae). Photos by Annabe U. Marquardt.

1.3 Research approach

By combining scientific research with Indigenous knowledge, one can create an even stronger line of evidence than by using each approach on its own (Reid et al. 2021). As such, Petrov et al. (2016) summarize indications for a recent and ongoing research paradigm shift in Arctic research across the disciplines. Many research designs are increasingly making use of mixed-methods approaches, gradually moving towards more interdisciplinary work; and co-production and community-informed research designs are increasingly seen as more successful in addressing local issues accordingly (Houde et al. 2022). Still, more meaningful collaborations and engagement with local communities and organizations to advance the understanding of complex Arctic phenomena are needed, especially in research designed to address urgent problems. It is important to note that co-production in practice still occurs along a spectrum, ranging from Indigenous Peoples being solely informants to being co-researchers (Bandola-Gill et al. 2023).

Recommendations for future research brought forward by the most recent ICARP suggest that new Arctic research needs to be more historically-minded, to further decolonize research approaches (Petrov et al. 2016); and that putting more emphasis on multidisciplinary, interdisciplinary, and transdisciplinary designs to be able to better explain the complex interplay of social and environmental factors and impacts of climate change, is a necessity. More research is needed to understand dynamics in urban and remote contexts, and how they compare and differ, as this has implications for communication and research priorities which are integral to successful action-based research (Morris 2016; Petrov et al. 2016). Overall, new research should synthesize and add to already existing work, and critically assess the relationship between social and natural variables in previous research studies (Petrov et al. 2016).

As such, there exists a push in the Arctic research paradigm for combining different methodological approaches, disciplines, and knowledge systems through means of increased collaboration and co-production (Petrov et al. 2016). Therefore, it is important to point out the subtle yet important differences between advocated approaches such as multidisciplinary, interdisciplinary, and transdisciplinary research (Stock and Burton 2011; Fawcett 2013). Multidisciplinary research refers to the use of multiple independent disciplines (i.e. social and natural science), each within their bounds to get both perspectives on a shared topic. Interdisciplinary research, on the other hand, combines disciplines in such a way that draws reciprocal links between them to inform one another, thereby blurring the boundaries between the disciplines. Transdisciplinary research eliminates the boundaries between disciplines and blends them to create a combined approach (Fawcett 2013). In practice, these three approaches are often viewed as a continuous spectrum rather than distinct categories, which often leads to improper use of the terms as one may be viewed as more 'fashionable' and attracts more funding compared to others (Choi and Pak 2006; Stock and Burton 2011). However, clear distinctions are important when trying to be more transparent about research processes (Stock and Burton 2011). As such, this thesis employs an interdisciplinary approach, with more overarching conceptual linkages between the different research approaches: While the objectives of each approach used in Chapters 2-4 are separate from one another and thereby can be viewed as stand-alone pieces, there are noteworthy cross-linkages as to how this project design has unfolded. Chapter 2 introduces the context and the difference in how climate change is perceived by Inuit from a social science perspective, while Chapter 3 is a natural science study that examines the impact of climate change on regional freshwater systems in response to community concerns communicated to the research group between 2012 and 2014. Chapter 4 takes the lessons learned from Chapters 2 and 3 to be able to communicate this knowledge in a meaningful and productive way. Finally, Chapter 5 reflects on the implications of this thesis and research approach for future interdisciplinary work.

1.4 Research site

1.4.1 Mackenzie Uplands Region

The Mackenzie Uplands Region (Figure 1.3) lies in the Northwest of the Northwest Territories (NT) and comprises an Arctic transitional ecotone, from boreal forest near Inuvik in the South to Arctic tundra closer to the coast of the Arctic Ocean near Tuktoyaktuk in the North (Kokelj et al. 2017; Lantz et al. 2022). The area is characterized by its large abundance of freshwater lakes, and its permafrost gradient (Kokelj et al. 2017). Permafrost is largely sporadic in this region, varying between <100 m depth in the South to 700-800 m depth in the North (Brown et al. 1998; Dobinski 2011).

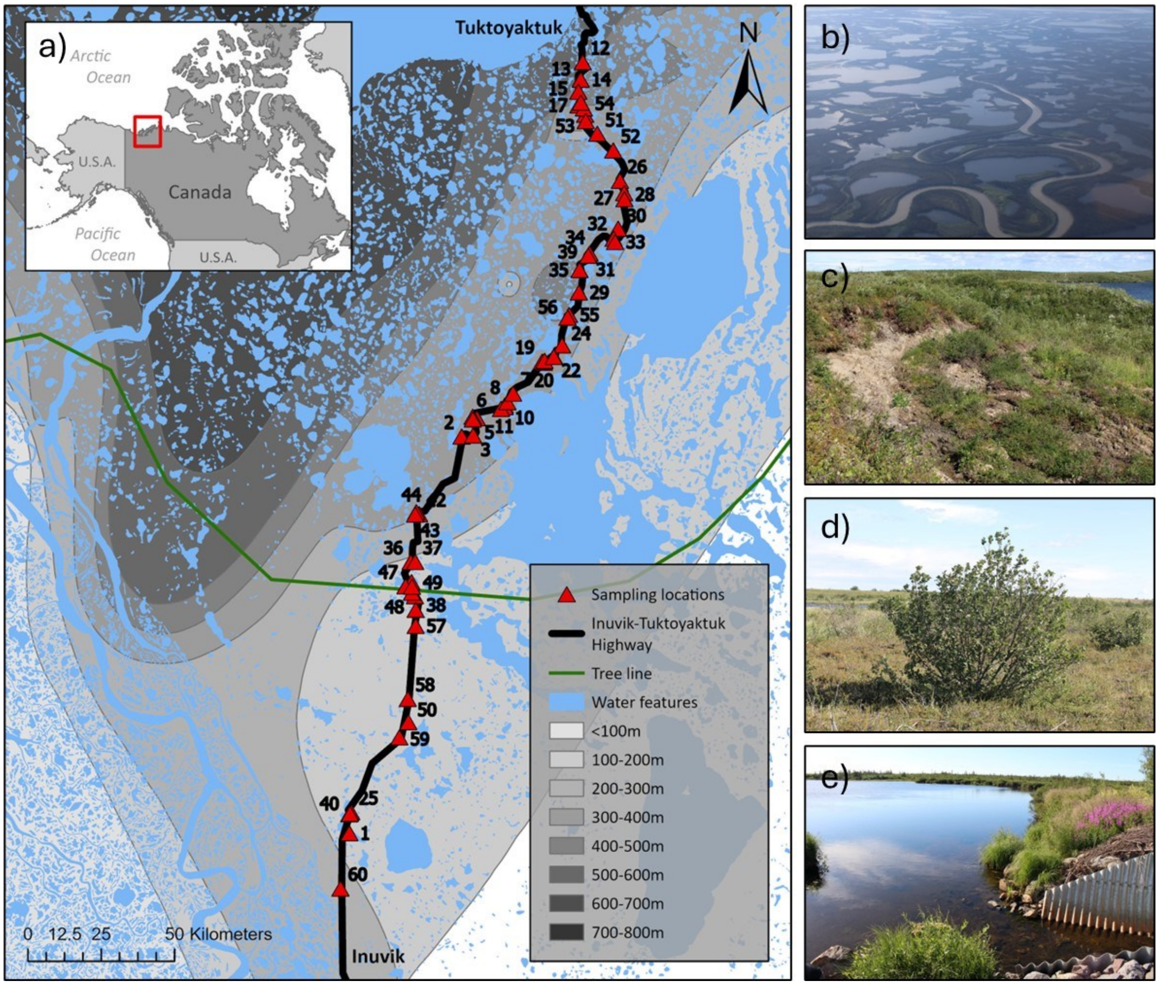

Figure 1.3 Visualization of common landscape characteristics along sampling locations in the Mackenzie Uplands Region, NT: a) Map of sampling locations, b) Aerial image of the Mackenzie Uplands Region and the Mackenzie River, c) Slump scar in the catchment of Lake 45, d) Large birch (*Betula*) in the Arctic tundra, e) Culvert and vegetated road embankment in the catchment of Lake 40. Photos by Annabe U. Marquardt, Bailey Nash, Jack De Swart, and Mia Tuccillo.

1.4.1.1 Inuvik

The town of Inuvik (68° 19′ N, 133° 37′) is a small urban center with a population of 3,243 (Statistics Canada 2021). It was founded in 1954 to relocate the community of Aklavik, which had suffered severe damage from flooding. The city grew considerably in the 1970s and 1980s due to oil extraction in the Beaufort Sea (NWT Bureau of Statistics 2024). It is located below the tree line, surrounded by mostly white spruce (*Picea glauca*) forest (Kokelj et al. 2017). Inuvik is home to one of the research stations of the Aurora Research Institute (ARI), which hosts and provides logistical assistance for many external researchers from all around the world each year (ARI 2024).

1.4.1.2 Tuktoyaktuk

Tuktoyaktuk (69° 26′ N, 133° 2′ W) is a traditional Inuvialuit settlement within the Inuvialuit Settlement Region (ISR) with a population of 898, located on the coastline of the Arctic Ocean (Statistics Canada 2021a). It is the first Indigenous community in Canada's history to revert to its Indigenous name (Hamlet Tuktoyaktuk 2024). Recently, it has been progressively affected by storm surges, which have increased erosion of the coastline along which the settlement lies (Johnson et al. 2003). Some residents are concerned about these developments and in need of new infrastructural solutions as climate change progresses (Andrachuk and Smith 2012).

1.4.1.3 Inuvik-Tuktoyaktuk Highway

The Inuvik-Tuktoyaktuk Highway (ITH), is an all-season gravel highway, between the communities of Inuvik and Tuktoyaktuk, and effectively connects the Arctic Ocean with the Canadian South, through connections with the Dempster Highway further south. It was opened to the public in 2017, and has since allowed more mobility between the communities, that previously were only connected by boat, air, or ice road in the winter (Bennett 2018; Grozic et al. 2018). As such, the ITH has contributed to reducing the 'remoteness' of Tuktoyaktuk and created shifts in the socio-economic structure, by increasing the average employment income by CAD 4,500 (Fellows et al. 2022). While average household income and high school completion rates in the community have increased, so have food prices due to reduced governmental food subsidies and the availability of addictive substances (Fellows et al. 2022; Povoroznyuk et al. 2022). Research on the Dempster Highway and Dalton Highway in Alaska has further shown that gravel roads affect Arctic ecosystems, through the far-reaching distribution of road dust (Walker and Everett 1987; Zhu et al. 2019). Depending on wind conditions, the dust can travel as far as 100 m into the tundra and has been shown to change the pH of the soil, thereby altering local vegetation (Auerbach et al. 1997). Settled road dust also reduces the albedo effect within that range, leading to ground warming (Walker and Everett 1987). Higher ionic compositions have been found in lakes within a 1 km radius of the road (Zhu et al. 2019). Similar effects from the ITH are presumed to be limited at this point, given the timeframe in which the ITH has been operative; however, the increased sighting of Arctic fireweed (*Epilobium latifolium*) in road embankments does suggest an onset of landscape disturbance in the area (Griggs 1934; Barrett et al. 2012). Inuvik-based Indigenous-led initiatives are meanwhile researching the impact of the ITH on the fish stock and migration routes of nearby freshwater lakes and streams (FJMC 2024).

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CHAPTER 2 INUIT PERSPECTIVES ON CLIMATE CHANGE AND WELL-BEING: A COMPARISON BETWEEN URBAN AND REMOTE COMMUNITIES IN THE ARCTIC

Chapter context: This chapter continues work initiated in 2014 for the project entitled "Water Security for Northern Peoples" by Andrew S. Medeiros and Sonia Wesche. Interviews completed in 2014 and 2019 were framed on water security issues in Iqaluit, Nunavut (see supplementary material), yet interviewees often deviated from the initial questions asked towards hour-long discussions about other social priorities. This raised the question of why such deviations to seemingly 'unrelated' topics were occurring among all of the 16 people interviewed, despite the concurrent water crisis that made water security discussions in Iqaluit more acute and relevant than ever. To investigate this question further, this chapter was designed to explore Inuit conceptualizations of climate impacts, such as water security and others, and potential differences between urban centers like Iqaluit and remote communities, which comprise the majority of Arctic settlements.

2.1 Statement of Student Contributions

Study design by Annabe U. Marquardt, Clarissa Jewel, and Andrew S. Medeiros. Systematic literature review and qualitative analysis conducted by Annabe U. Marquardt, interviews and qualitative analysis conducted by Clarissa Jewel, chapter writing by Annabe U. Marquardt and Clarissa Jewel with editorial contributions from Andrew S. Medeiros and Sonia Wesche.

2.2 Abstract

The generational knowledge of weather and climate is a foundational component of subsistence for Inuit in the Arctic. This knowledge is now challenged by the reality of anthropogenic climate change at a pace that, for Inuit, is impeding fundamental aspects of life in a single generation. To better understand how climate change moderates relationships between Inuit communities and the ecosystem services they rely on, the literature on how climate change is perceived in the circumpolar Arctic was systematically reviewed. The perspectives of Inuit as described in 75 studies were contrasted with those queried from a series of semi-structured interviews with 16 residents of Iqaluit, Nunavut. Within the literature, the themes most frequently mentioned in remote communities were concerns arising about the environment, community, and health. However, the inverse was true for studies that focused on urban communities. Participants from the semi-structured interviews described how colonialism still shapes knowledge translation, which has lasting effects on Arctic climate literacy for Inuit and non-Inuit. As such, an academic knowledge gap in the colonial context in which climate change operates was identified, which requires a way forward that can lead to improvements in the social context for Inuit.

2.3 Introduction

For Inuit, knowledge of the environment is fundamental for a successful subsistence-based economy, but an increasingly variable climate has had an impact on society, culture, education, health, and well-being. In the Arctic, temperature has increased at twice the global rate, a process known as Arctic amplification (Larsen et al. 2014). Indigenous Peoples in Arctic Canada, which are predominantly comprised of Inuit, are among the most directly affected by environmental change due to their integral relationship with the environment (Harper et al. 2021; Sawatzy et al. 2021). As climate variability can cascade across all aspects of life and culture (Ford et al. 2010), Inuit observations of climate and perspectives of how change impacts Arctic communities are imperative for understanding environmental change at various scales.

The observations collected by Inuit over millennia of successive activities on the land, including hunting, recreation, and travel, can contribute to knowledge that science would otherwise rely on local climate data to provide. Inuit knowledge can form the baseline of observations that can be used alongside metrological data to expand the shared understanding of climate change (Alexander et al. 2011). Environmental observations are enshrined in the core knowledge system of *Inuit Qaujimajatuqangit* (*IQ*), defined as: "all aspects of traditional Inuit culture including values, worldview, language, social organization, knowledge, life skills, perceptions and expectations" (Tester and Irniq 2008). *IQ* is recognized as a body of knowledge gained through centuries of rigorous observation of the environment (Watt-Cloutier 2015). The core of *IQ* also represents the structure of governance, which includes laws, beliefs, and values that educate each generation that are shared by Inuit across the circumpolar world

(Karetak and Tester 2017). Integral to IQ, as with many Indigenous worldviews, is the importance of caring for the environment; "The land is so important for us to survive and live on; that's why we treat it as part of ourselves" (Mariano Aupilaarjuk as quoted in Evaloardjuk et al. 2004).

Inuit Knowledge can help augment gaps in data collection on climate change, while also contributing a missing and important human dimension to the scientific understanding of this phenomenon (Riedlinger and Berkes 2001). However, the scientific imposition of defining Indigenous Knowledge is common and also applied across all Indigenous Peoples as if it were some uniform concept (McGregor 2004). Leduc (2007) notes that *IQ* is cultivated in the mind and manifested as actions in the world. This highlights the belief that *IQ* "cannot be incorporated or integrated into science because societal values are broader than traditional knowledge, which is anyway, by nature, unlike scientific knowledge" (NTI 2005). Instead, *IQ* should be acknowledged as complementary, but not interchangeable or substitutable with science. It is also important to acknowledge that Indigenous knowledge systems are not homogenous frameworks to be contrasted in a binary with science; Indigenous Knowledge is diverse and complex, incorporating relationships, motivations, assumptions, accountability, and self-reflection of the researcher (Johnston et al. 2018). Likewise, there can be potential negative implications from the oversimplification of Indigenous ways of knowing by non-Indigenous researchers, including further harm from extractive research practices.

Colonialism has had and continues to have, a lasting negative effect on Inuit well-being, and this history is important to understand in the context of climate change. The continuing effects of colonialism in the context of climate change are not always reflected in academic literature and colonial attitudes are still prevalent in non-Indigenous academic research spaces, especially where the direction and objectives of the research, action, and decision-making are made without meaningful engagement or input of Indigenous Peoples (Johnson et al. 2022). Reibold et al. (2023) note that the capacity and capabilities of Indigenous Peoples concerning self-determination and subsequent climate change adaptation response are often ignored or undermined.

Inuit have experienced rapid and often damaging sociocultural change as they shifted from subsistence hunting and gathering to economic activities associated with trapping and trading with the arrival of the settlers and later the establishment of the Hudson Bay Company (Tester 2017). Following World War II, Inuit were increasingly encouraged, coerced, or forced into moving to permanent settlements and giving up their seasonal nomadic way of life (McGregor 2010). Inuit faced several other challenges, including - but not limited to - the removal of children from their families into residential schools, Project Surname[1] and the interference with Inuit naming and identity, collapse of the Arctic fox pelt trade economy, caribou population declines, outbreaks of tuberculosis and other infectious diseases, inhumane treatment of sled dogs, and abuse from Canadian settlers in positions of power (Alia 1994; Mancini Billson and Mancini 2007; McGregor 2010; Watt-Cloutier 2015; Tester 2017). These and other challenges are important to understand because Inuit, like many Indigenous Peoples today, still experience many of the negative and lingering consequences of colonialism including "poverty, loss of

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[1] Project Surname was a governmental project launched in 1969, where Inuit were asked to pick a surname as the basis of their identity. It was launched in response to the growing opposition to the numbering system introduced in the 1930s, where Inuit were given identification numbers, starting with 'E" for 'Eastern Artic' and 'W" for 'Western Arctic' (Alia 1994).

traditional culture, loss of language, loss of control over resource development, suicide, addictions, and physical and mental health disparities" (Cameron 2012). From a health perspective, the influence of colonialism can compound the effects of climate change, which both manifest as an allostatic load in response to stress and trauma (Berger et al. 2015).

Colonialism is compounded by the effects of capitalism and neoliberalism: Capitalism drives climate change and environmental destruction through the relentless pursuit of profit over sustainability (Hickel 2016), while neoliberalism pushes for a radically free market that manifests indifference toward poverty, cultural decimation, resource depletion, and environmental destruction (Brown 2009). Thus, there is likely a difference between the context of how climate affects Inuit communities depending on the geography of colonialism; those in urban centers with a higher degree of capitalism versus more remote communities that still substantially practice a subsistence sharing-based economy. This context is critical for the understanding of Inuit well-being today as well as how climate will affect Inuit communities in the future. As such, peer-reviewed literature was systematically reviewed, to analyze the extent to which articles address how climate change influences Inuit society with a differentiation between urban and remote contexts. Core themes identified in the literature were compared to a participatory case study in Iqaluit, to contrast urban perspectives on climate adaptation and society. The purpose was to understand how climate change affects the well-being of Inuit, which includes social, cultural, political, and environmental effects; many of which are systemic (Ford et al. 2010). As such, well-being was defined here based on the findings of a study by Kral et al. 2011, who interviewed 50 Inuit in Nunavut on what well-being and the absence thereof means to them. Inuit participants identified well-being as the presence of family, communication, and the presence of traditional values and practices (Kral et al. 2011). By comparing interviews with residents and governmental workers in Iqaluit to themes identified through the systematic review, the aim was to; 1) discuss how perceptions of climate adaptation and climate literacy for Inuit may differ between larger urban centers and smaller remote communities, 2) show how the effects of climate change are moderating relationships of Inuit to water and land, and 3) understand how these relationships are linked to Inuit well-being. As such, an improved understanding of the way that climate adaptation can be perceived with interconnected social, economic, and cultural realities, is discussed.

2.4 Positionality

Many Indigenous methodologies speak to the importance of positionality, a practice through which the researcher describes themselves in relation to their research: who they are; their personal relationships and connections to the work; their background and personal history; their assumptions, biases, motivations; and the accumulated knowledge they bring to their endeavours (Russell-Mundine 2012). The authors each come with a different background and perspective on how environmental change is influencing the future; Annabe U. Marquardt is a European Citizen completing her graduate education at Dalhousie University, Clarissa Jewell is a settler of Euro-Canadian descent and ECR, and Andrew S. Medeiros is of mixed heritage and settler on the ancestral and unceded territory of the Mi'kmaq. None of the authors identify as Indigenous and approach this study with knowledge of Arctic communities without a connection to culture or identity.

As such they present their findings and interpretations supported by the participants in this research study, who have contributed significantly to the information and perspectives presented, and of which many wish to remain anonymous within the research process. Together, the authors and participants aim to create a space in which they can bring together both Western and Inuit ways of knowing for the betterment of all.

2.5 Methods

2.5.1 Research approach

The goal was to understand the extent and depth of published academic peer-reviewed literature on how Inuit perceive climate adaptation and contrast those perspectives with research methodologies that incorporate pre- and post-interviews through a decolonizing lens. The decolonizing lens here was defined as an interpretative perspective that seeks to dismantle colonial authority and challenge the notion that the Western way of life, language, culture, science, and understanding of the world is superior to that of Indigenous Peoples themselves (Keane et al. 2017). Tuck and Yang (2012) caution against the conflation of the term decolonization with social justice and anti-colonial movements, arguing that decolonization is not a metaphor and can only be used to refer to the repatriation of land, power, and privilege to Indigenous Peoples; however, here it is still believed that there is work that needs to be done within academia to create space for Indigenous voices and epistemologies (Battiste 2000; Smith 1999 in Datta 2018).

2.5.2 *Systematic review processs*

The extent and depth of academic literature were reviewed in a systematic approach (Haddaway et al. 2015) to synthesize themes attributed to Inuit with respect to observations of climate change. Data, as presented and embedded in publically assessible peer-reviewed articles on interview studies conducted in urban and remote communities, was compared. The systematic process used a Boolean keyword search (Table 2.1), which included three peer-reviewed indexes: Web of Science, Scopus, and PubMed.

Table 2.1 Boolean search criteria for peer-reviewed articles relating to the perceptions of climate change influence society. The search was initially conducted on November 5, 2022, and updated on September 23rd, 2023.

	Index databases		
Boolean search criteria	*PubMed*	*Web of Science*	*Scopus*
Inuit AND climate change AND educat*	7	34	15
Inuit AND climate change AND (wellbeing OR "well-being")	11	59	29
Inuit AND climate change AND ("traditional knowledge" OR "Indigenous knowledge" OR "Inuit Qaujimajatuqangit")	12	111	73
Inuit AND climate change AND resilienc*	6	56	25
Inuit AND climate change AND adapt* AND vulnerab*	13	112	56

Search terms were generated to capture a breadth of climate change impacts on societal well-being. Duplicate articles between the three indexes were removed. Articles represented all primary peer-reviewed research articles published between 1980 and 2023 by the three indexes as of February 1st, 2023, and reviewed on March 10th, 2023 by all authors. The systematic analysis was repeated on September 23rd, 2023, to update for new articles published and to ensure consistency of decisions. A total of 631 articles were identified by all three databases, of which 316 were duplicates among the five search strings. Articles were screened using the ROSES protocol (see supplementary material), and 132 articles were selected as relevant based on title and abstract screening. Six articles were excluded due to inaccessibility. Further narrowing of results was based on the following inclusion criteria: 1) the research is situated in Alaska, Canada, or Greenland, 2) the participants are Inuit, 3) the research reports primary data, 4) the researchers employed interviews, questionnaires, surveys, focus groups, or is an Inuit perspectives piece, 5) the research addresses perceptions of climate change, 6) the researchers conducted community-based research, and 7) the research was conducted in either urban or remote communities, not both. By deploying these inclusion criteria, 51 papers were excluded for a final total of 75 articles that were included in the systematic analysis. The initial search and data extraction was completed by AUM, with consistency of decisions made by ASM.

2.5.3 Data analysis

The 75 articles included in the systematic analysis were classified as having participants based in either remote or urban contexts. There are currently no universal definitions of ‘urban’, especially in an Arctic context, but typical classifications use accessibility, population size, and population density. Arctic communities were classified as ‘urban’ based on a population of >3,000 and a population density of >50 people/km^2 based on a modified remoteness index from Statistics Canada, adjusted for Arctic Canada (Subedi et al. 2020). Using this definition only Inuvik and Iqaluit are considered ‘urban’ in this study, as these are the only two locations that included Inuit respondents in an urban context (see supplementary material). Applying this definition resulted in 70 articles identified as primarily based on interviews with participants in remote communities (3466+ participants) and five articles based on urban communities (1259 participants) (Figure 2.1).

All articles were systematically analyzed using the NVivo 12 software. Thematic analysis was conducted using an inductive/deductive hybrid approach (Proudfoot 2023), which resulted in the deductive identification of three main themes using *IQ* as a framework (Tagalik 2011), and multiple inductive sub-themes identified from the interview responses embedded in the publically accessible peer-reviewed papers. The number of articles in which one or more interviewees discussed each theme and sub-theme was quantified. Word clouds were created using Nvivo 12 software based on the word frequency of the top 100 words, for remote and urban contexts (see supplementary material).

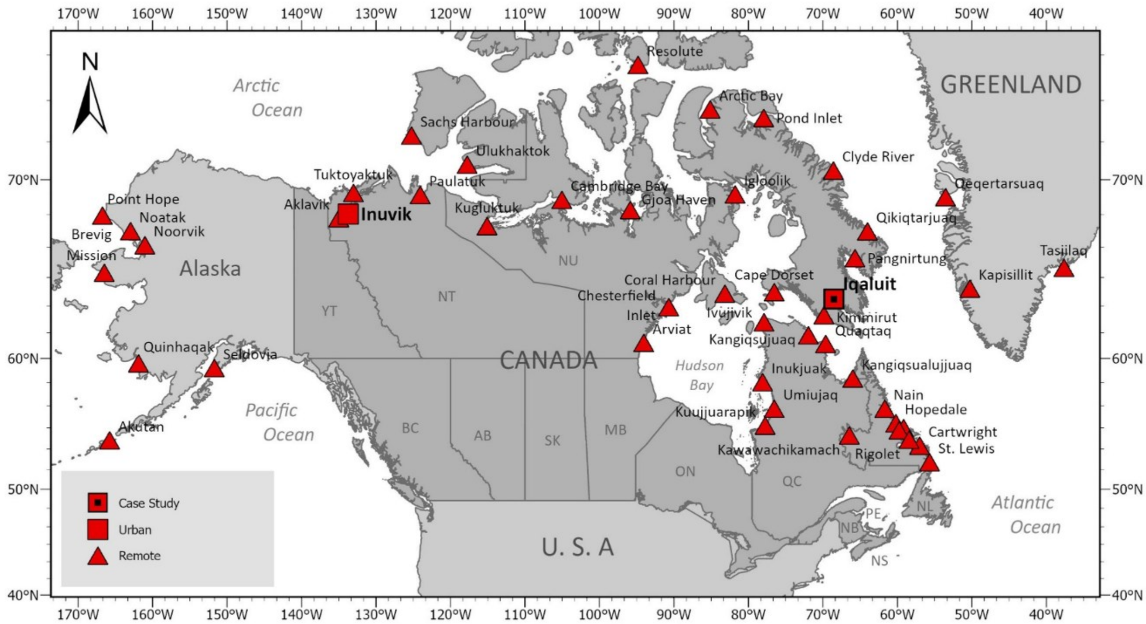

Figure 2.1 Map of the Arctic displaying the location of interview studies included in the systematic literature review and case study, classified as urban or remote respectively.

2.5.4 Pre- and post-interview process

All 16 participant interviews were conducted in English by CJ during in-person visits to Iqaluit (63.7467° N, 68.5170° W), the capital of Nunavut, Canada. As of the 2021 census, the population was 7,429 residents, of which 3,830 identify as Inuit (Statistics Canada 2023). All research activities were approved by the York University Office of Research Ethics (ORE file number 4098 and Certificate # 2019-215). Interviews were conducted with a Social Science research license (02 005 20R-M) issued by the Nunavut Research Institute (NRI). Pre- and post-interview data was collected through two sets of interviews conducted in Iqaluit in 2014 and 2019. During the summer of 2014, a series of semi-structured questionnaires were completed with seven residents to identify concerns related to how environmental change influenced the urban environment. Building on these findings, in-depth interviews with five additional residents were conducted in 2019. One resident who was employed by the local municipal government and three residents employed by the territorial government were also interviewed. In total, nine participants identified as male, and seven participants identified as female (Table 2.2).

The semi-structured questionnaire deployed in 2014 included a series of questions on environmental issues, with prompts about water security, water harvesting, and local knowledge about water resources; it focused on open questions to prompt respondents to discuss relevant issues that mattered to them (see supplementary material). Most participants identified as Inuit and had resided in Iqaluit for five years or longer. Participants for the questionnaire were identified using snowball sampling (Biernacki and Waldorf 1981) initiated through initial contacts identified by the NRI. In 2019, five semi-structured and four unstructured interviews were conducted, to explore broader topics informed by responses given during the 2014 interviews. These participants were also identified using snowball sampling with the initial contact identified from the 2014 contacts. Unstructured interviews were conducted with government employees at both municipal and territorial levels and discussed perspectives on climate change, water security, and the current challenges facing Inuit in local governance. The 2019 semi-structured interviews were conducted with five Inuit participants and followed a series of eight questions from which participants were encouraged to talk about issues that mattered most to them. Themes included how participants accessed freshwater in their communities, how they experienced climate change, their views of how Inuit are portrayed in popular culture, and views of how climate change is often discussed as it pertains to the Arctic (see supplementary material). All interviews were conducted face-to-face at a place of the participant's choosing.

2.5.5 Thematic analysis

Notes were taken during the 2014 questionnaires. Verbatim transcripts from the 2019 interviews were transcribed using speech-to-text software, Otter.ai, which were then verified for accuracy; transcription errors were corrected manually. A thematic analysis using an iterative coding process employing a mixture of deductive and inductive coding (Creswell 2013) was conducted: Key themes were identified deductively based on the framework of *IQ* (Tagalik 2011), and sub-themes were identified inductively from the interview notes and transcripts. This was done iteratively by multiple, close readings of the interview data and then the creation of memos and codes, which were then distilled and categorized into the final set of themes and sub-themes. A word cloud was created using MAXQDA based on the word frequency of the top 100 words used at least 5 times using the transcripts of the 2019 interviews, excluding interviewer questions and comments (see supplementary material).

Table 2.2 Research participant characteristics, including participant code, affiliation, year interviewed, and type of interview conducted.

Participant code	Affiliation	Year of interview	Interview structure
IR14-1	Iqaluit resident	2014	structured questionnaire
IR14-2	Iqaluit resident	2014	structured questionnaire
IR14-3	Iqaluit resident	2014	structured questionnaire
IR14-4	Iqaluit resident	2014	structured questionnaire
IR14-5	Iqaluit resident	2014	structured questionnaire
IR14-6	Iqaluit resident	2014	structured questionnaire
IR14-7	Iqaluit resident	2014	structured questionnaire
IR19-1	Iqaluit resident	2019	semi-structured interview
IR19-2	Iqaluit resident	2019	semi-structured interview
IR19-3	Iqaluit resident	2019	semi-structured interview
IR19-4	Iqaluit resident	2019	semi-structured interview
IR19-5	Iqaluit resident	2019	semi-structured interview
CI1	City of Iqaluit/ Iqaluit resident	2019	unstructured interview
GN1	Government of Nunavut/ Iqaluit resident	2019	unstructured interview
GN2	Government of Nunavut/ Iqaluit resident	2019	unstructured interview
GN3	Government of Nunavut/ Iqaluit resident	2019	unstructured interview

2.6 Results

2.6.1 Systematic literature review

Three primary themes within the 75 articles included in the systematic review were deductively derived, representing key topics adapted from *IQ* (Tagalik 2011): the *Environment*, *Health*, and *Community*. Thematic analysis of articles then identified sub-themes that were categorized into three broad themes through hierarchical coding (Proudfoot 2023). Inductive sub-themes relating to *adaptation*, *advancement*, *feeling unheard*, *finances*, *sharing*, and *tradition* were grouped under the theme *Community*; sub-themes relating to *catastrophes*, *wildlife*, *climate change*, *development*, *ice, snow, water*, *weather*, and *travel* were grouped under the theme *Environment*; and sub-themes *drinking water*, *food and subsistence*, *mental health*, and *physical health* were grouped under the theme *Health*.

When comparing articles that focused on participants in remote communities, it was found that respondents mentioned the environment more frequently, followed by topics about their community, and lastly health. On the contrary, articles that focused on urban communities mentioned topics related to health and well-being more frequently than community or environmental topics (Figure 2.2).

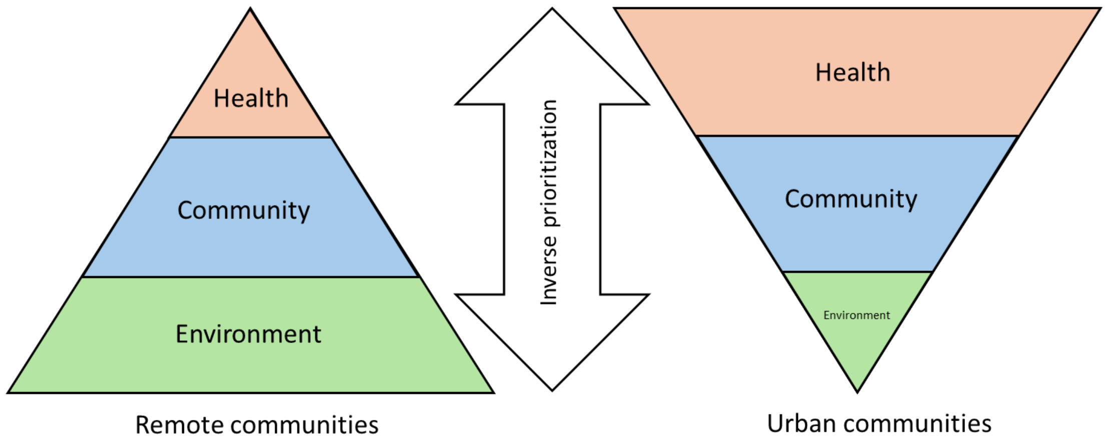

Figure 2.2 Visualization of the three major themes as mentioned by participants in the context of climate change perceptions, ranked by importance, illustrating the inverse prioritization of climate change within urban and remote communities. Importance was defined as the number of studies in which each theme was addressed by one or several participants.

2.6.2 Iqaluit case study

The notes and transcripts of interviews from the 2014 and 2019 interviews were combined, categorized into three broad themes deducted from *IQ* (Tagalik 2011), and organized into sub-themes through hierarchical coding (Proudfoot 2018). Even though participants were largely asked questions about the environment and climate (see supplementary material), they often spent more time discussing other issues, such as Inuit well-being and education. Sub-themes relating to *relationships to freshwater*, *changes on the land*, and *understanding climate change through IQ* were grouped under the theme *Environment*; sub-themes relating to *pollution and sustainability*, *social issues*, and *Inuit sovereignty* were grouped under the theme *Health well-being*; and sub-themes of *southern perceptions of Inuit and the North*, *challenges in teaching IQ*, and *climate literacy in the North* were grouped under the theme *Knowledge and colonialism* (Figure 2.3).

Representations of Inuit in mainstream North American media, if they happen at all, were mentioned to be shallow or affect tokenism (IR19-3, IR19-4), and misrepresentation was identified as common (IR19-4);

> *"We love the shows, we love the movies, we love the storyline. But if you don't include us, that's kind of saying we don't matter, but you'll use our culture"* (IR19-5).

Respondents also identified a need to adapt science and education in Arctic communities to be more inclusive of *IQ* and Inuit values, which goes hand in hand with the *IQ* guiding principles of *Pilimmaksarniq* (knowledge acquisition), *Pilirqatigiingniq* (common purpose) and *Aajiiqatigiinniq* (consensus). An important reflection of how science education is approached was noted:

> *"We are scientific thinkers, we had to be to survive here. But going to school here, I was being told (...) we have to dumb down the curriculum for Inuit students. You know, Inuit aren't good at math, Inuit aren't good at science, like focus on the arts, because that's how Inuit make their living. I am glad that art is a huge program and a huge part of life because that's also an important educational tool. And it's also extremely important in our culture. But at the same time, we need to have more of a focus on science, but it needs to be Inuk science"* (IR19-3).

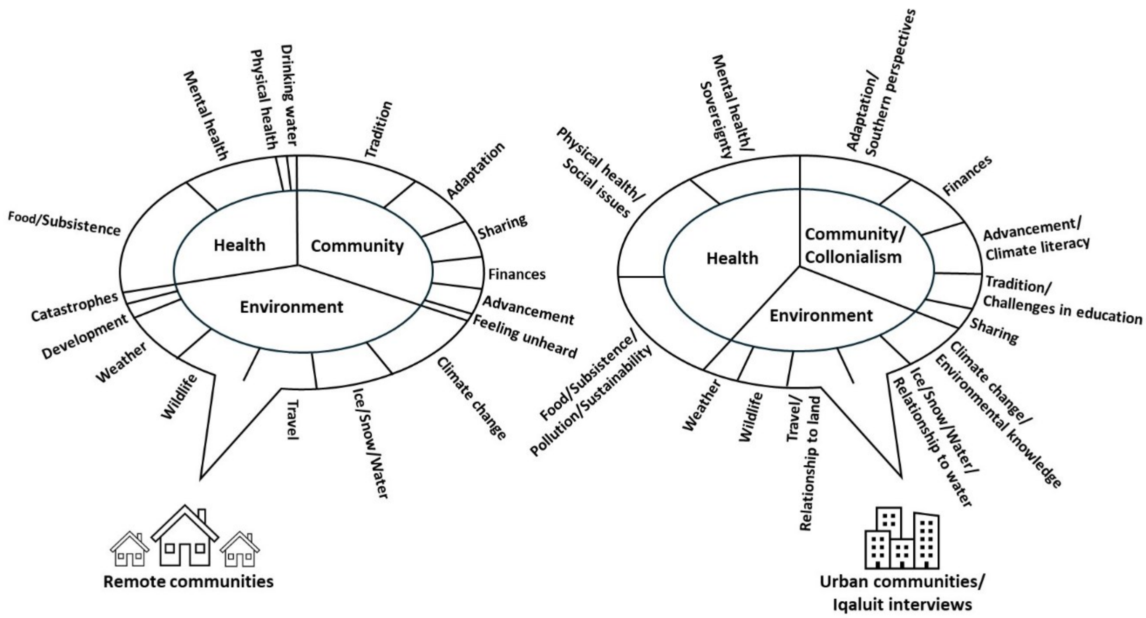

Figure 2.3 Visualization of Inuit perceptions of climate change, based on their frequency in urban versus remote communities as discussed in the academic literature, and the transcripts of the interviews with participants in Iqaluit, NU. Themes are listed inside the sunburst diagram, and sub-themes are identified outside.

Fortunately, it was also noted that there are increasing efforts in communities to help youth acquire knowledge and skills and prevent increasing loss of Inuit values:

> *"There's a lot of programs that are working towards bringing back our cultural practices and values, and all these things that I grew up with, and stuff I didn't learn"* (IR19-5)

Likewise, the recognition that these traditional practices allow for a better means of adaptation to improve the well-being of Inuit living in a changing Arctic was mentioned:

> *"I honestly think that if we have a healthy population, we will have a healthy environment. And I've already talked about the access to knowledge and access to*

> *programs in terms of climate change. Right now, when you're living in third-world conditions, that's not a priority"* (IR19-3).

The recognition that sometimes adaptation was already a component of *IQ* was also made:

> *"It always have been different timing. The time of the thawing out, the time the ice flows away, what time the ice melt[s], the time of snow melt, the time of the ice freeze up. It was never the same, and it's still never the same"* (IR19-1).

However, discussions about climate change were also identified as coming from "a very Ethnocentric viewpoint" (IR19-2). Respondents noted that science places emphasis on statistics and written knowledge, which puts Indigenous Knowledge at a disadvantage due to its oral nature: "[B]ecause it's not written, nobody believed it. It's our oral history" (IR19-1). One participant described a recent example of Western scientists not working with Inuit:

> *"[E]ven a few years ago, there were the celebrations for the [150th anniversary of Canada]. There was this ship coming up with researchers that were studying codfish for the last 20 years, and they've never talked to Inuit about cod […], And you know, they are considered experts in their field and there was not just one person, there was a whole ship of people who are basically saying oh, I've never been to the Arctic even though this is my subject for the last 15 or 20 years. So that's caused a lot of issues"* (IR19-2)

2.7 Discussion

While the basis for culture, governance, and well-being fundamentally links the relationship between the environment and society, climate change challenges the practice of core values and principles of Inuit knowledge systems in Arctic communities. Through a combined systematic review of the literature and interviews with residents from Iqaluit, it was shown how perceptions of climate adaptation and climate literacy for Inuit may differ between larger urban centers and smaller remote communities. It was further outlined how participants describe the moderating effects of climate change on the relationships of Inuit to water and land and how these relationships are fundamentally linked to well-being.

For Inuit, differences in prioritization need to be examined from a culturally sensitive and knowledge-inclusive standpoint (Vogel and Bullock 2021). In the social sciences, it has long been understood that cognitive processes, including attention, perception, and memory, are influenced and shaped by culture (Han and Ma 2014; Ji and Yap 2016). Therefore, some of the commonly used Western frameworks and approaches to understanding cognition may not apply cross-culturally in all the same ways (Christopher et al. 2014). For this reason, a framework based on the four *maligait* (laws) and six guiding principles of *IQ* (Tagalik 2011) was used, to conceptualize and discuss Inuit perspectives on climate change, Inuit well-being, and knowledge translation (Figure 2.4).

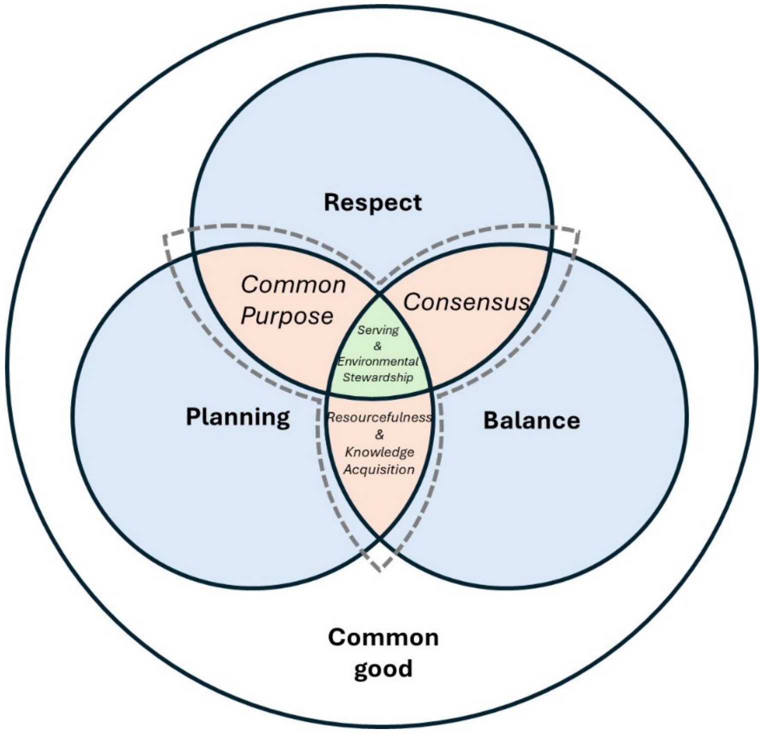

Figure 2.4 Framework based on the four *maligait* (laws) and six guiding principles of *IQ* to conceptualize Inuit perspectives of Climate Change, Inuit Well-being, and Knowledge Translation. This diagram is based on *IQ* (Tagalik 2011) and developed for illustrative purposes only. The four *maligait* are outlined in bold and represented by the three intersecting circles, and the circle that encompasses all other circles. The six guiding principles are outlined in italics and placed where the four *maligait* overlap.

2.7.1 Differences between urban and remote contexts

When comparing the results from the studies included in the systematic literature review to the respondents that were directly surveyed from Iqaluit, it was found that the topics discussed were largely consistent but prioritized differently. Topics discussed in the literature were summarized under the three main themes of *Health*, the *Environment*, and

Community. In the transcribed interviews from Iqaluit, respondents focused on topics that were categorized as *Health*, the *Environment*, *Knowledge translation and colonialism*. It was found that the participants in the Iqaluit case study had much more specific mention of knowledge translation and colonialism as compared to the studies included in the systematic literature review. Several participants from Iqaluit described challenges with securing representation at higher levels in the territorial government, with Inuit often at a disadvantage in the competitive process because they do not have the required education or credentials for these positions (IR19-2, M. GN1).

The effects of colonialism were only explicitly discussed to a small extent in four of the 75 studies from the systematic review of the literature. For example, Durkalec et al. (2015) note that participants referred to being out on the land as a necessity to escape colonial influence, as this is where they felt most closely connected to their ancestors and traditional way of life. Likewise, Giles et al. (2013) note that some participants reject certain Western safety standards, such as lifejackets, when going out to hunt on their boats because they feel a "little bit weird" (young woman, as quoted in Giles et al. 2013). Others mentioned a general lack of representation and regard for Inuit and *IQ* in science and policy-making in the Arctic, which fosters distrust within the community towards outsiders (Gyapay et al. 2022, Young 2021);

> *"I urge scientists not to come to our communities and ask how our knowledge can be integrated into science…help us find ways to integrate your knowledge into the Inuit way of seeing the world. Help us turn the question around. This way, science can indeed be relevant to us"* (Terry Audla, 2014, as quoted in Young 2021).

The vast majority of the studies in the systematic literature review address the socioeconomic concerns of their participants that were not explicitly linked to the effects of colonialism. Guo et al. (2015) note that food insecurity in Arctic communities was three times as high as the Canadian average. However, there is an imbalance within and between communities, with Inuit families more prone to suffer from food insecurities as compared to non-Inuit households. During the interviews in Iqaluit, one participant explained that "there are people whose families are going hungry because [country food] was their means of getting food for their family" (IR19-3). Ford et al. (2013) also highlight this imbalance:

> *"Do we really have choices? We can't get [traditional] foods at the store, so we have to get the meat from the south. The [traditional] food at the community freezer is too expensive, so we can't access it. The food from the food bank is useful, but it's always the same thing. Sometimes we get to choose between canned vegetables and canned beans […]"* (Participant, as quoted in Ford et al. 2013).

Reduced consumption of country food is a commonly mentioned concern about health: "[A]nything from the land and the sea, the body needs those elements to be healthy" (Mitiarjuk Manguik, Ivujivik, May 24, 2014, as quoted in Rapinski et al. 2018). Participants across studies in the literature review, as well as during the interviews in Iqaluit, expressed concerns about the social, economic, and housing situation within their communities (Andrachuk and Smith 2012; Beaumier et al. 2015; Archer et al. 2017). As a consequence, young people leave their communities to find employment and more affordable living elsewhere (Flint et al. 2011).

When examining the differences between literature from urban and remote contexts, as well as the responses from participant interviews in Iqaluit, it becomes apparent that most Inuit perspectives of climate change, well-being, and knowledge translation are largely linked to topics and discussions that have a negative outcome for well-being, with a few positive references (see supplementary material). Earlier snowmelt and changes in sea ice conditions pose serious safety concerns when travelling on land and by traditional travel routes (Archer et al. 2017; Fawcett et al. 2018; Lede et al. 2021). Many participants report having to travel farther distances to find country foods, which is often associated with increased financial costs;

> *"Ice formation every year, it's different. Some years it might be smooth to go across, some years it will be really rough. So it will take a lot longer to get to the mainland. And we have to find routes on the ocean, where we can get through the really rough ice"* (Participant from Cambridge Bay, as quoted in Panikkar et al. 2018).

Some participants mentioned concerns about how recent changes in the environment compromise their access to clean drinking water. It was noted that "ponds have completely dried up", which raises concerns about water security in some communities (Harper et al. 2015). This was a concern also for interviewees from Iqaluit, who mentioned a preference for natural water sources, due to regional tap water often being "darker, sometimes with a shiny layer on top" (IR19-1), and "tast[ing] a little bit like chlorine" (IR19-2). Declines in the health of native species were mentioned, and often it seems unclear what is causing them: "Arctic char meat is white now. It's not red anymore, not sure why … most of them are smaller than back then…" (as quoted in

Galappaththi et al. 2019). The warming climate is also leading to changes in plant growth, along with new flora and fauna appearing where they had never been seen historically: dandelions, different insects, and salmon (IR19-2; IR19-3). However, it is important to note that not all responses were negative: Generally, the systematic literature review revealed that there seems to be a sense of resilience among many participants across studies:

> *"The way you cope with things really makes you who you are. There's always going to be change, the world ain't going to stay the same forever. There are just some things where you have no control over; […] like you have to make the best of it and adapt"* (16-year-old male, as quoted in MacDonald et al. 2015).

2.7.2 Relationships with the environment

Living in harmony with the land and protecting it is an important part of the traditional Inuit lifestyle, which is reflected in *Avatittinnik Kamatsiarniq*, the *IQ* guiding principle of environmental stewardship (Government of Nunavut 2023). The largest portion of the results from both the systematic literature review and interview data from Iqaluit can be considered under *Avatittinnik Kamatsiarniq*. The systematic literature review suggests that topics discussed in this context were largely consistent between studies conducted in urban and remote communities. The main differences were that catastrophes and development were not mentioned in urban communities. One possible explanation could be the lack of the necessary infrastructural solutions to deal with catastrophes, such as erosion and flooding, in remote communities as compared to urban communities (Jensen et al. 2018). Recent climatic developments suggest that Arctic communities will be faced with an increase in catastrophic weather events, including increases in (coastal) erosion, due to permafrost decay and increased impacts from flooding and harsh storms. The literature suggests that many remote communities will need to make substantial adjustments to their already existing infrastructure and find new solutions to mitigate future risks (Warren et al. 2005). For example, Tuktoyaktuk, a small community in the Northwest Territories in Canada situated at the shore of the Arctic Ocean, has experienced severe coastal erosion from increased storm surges since the 1930s (Johnson et al. 2003). Residents are concerned and fear the possibility of having to relocate: "Erosion of the shoreline has been happening for a while now. We are noticing it more and more as it gets warmer and warmer" (Maureen Gruben, Tuktoyaktuk resident, as quoted in Andrachuk and Smith 2012). With the help of ongoing scientific monitoring of shoreline erosion, the community has since been working on developing suitable strategies to adapt their local infrastructure to mitigate further impacts on the settlement (Johnston et al. 2003).

Living in the Arctic requires certain levels of creativity and innovation to survive with limited access to resources (Government of Nunavut 2023). There was a strong consensus between urban and remote communities about *Qanuqtuurunnarniq*, the *IQ* guiding principle of resourcefulness. Climate change is having diverse and cumulative effects on the way that Inuit spend time on the land, affecting the timing for hunting, fishing, and harvesting, and making it more dangerous to travel on the land (Weatherhead et al. 2010): "Right now, when you travel, even if you are a good hunter, it is dangerous. [The ice] looks like it is all the same, but underneath it is not" (E. Ishulutaq, 2013, as quoted in Rathwell 2020). These safety concerns were also addressed by the interviewees from Iqaluit. As a result, Inuit "have to be extra careful or [do not] go [out on the land] at all" (IR19-5). Adaptation strategies to these dangers are similar in both types of communities. For example, the use of modern technology, such as the Smart Ice application (Bell et al. 2014; Reed et al. 2024) and weather forecasts to help with navigating challenges and emergency response out on the land, are common. Beaulieu et al. (2023) showcase how Inuit researchers and non-Inuit partners can mentor youth and empower communities to use their own language, experience, and knowledge, to improve safety and the monitoring of the environment. Elders often reflect on how education and technology can help mobilize Traditional Knowledge across generations: "Now we need young people to teach us" (Elder as quoted in Galappaththi et al. 2019).

Our systematic review of the literature identified numerous studies that focused on climate change, with mention of the earlier snowmelt, changes in sea ice, vegetation, and warmer weather (Laidre et al. 2018; Lede et al. 2021); however, not all participants within these studies identified that the recent changes in the environment are associated with climate change. Some participants expressed the belief that "things will get back to normal next year" (Ford et al. 2009). Indeed, during the interviews with participants in Iqaluit, several expressed that climate change was an imposed Western concept, noting that climate has always been in flux (IR19-1).

2.7.3 Health and well-being

There was a difference in prioritization between topics in the literature, where urban interviewees predominantly mentioned topics about health and well-being, while remote interviewees focused mostly on concerns about the state of the environment. Similarly, when prompted to discuss issues related to water and land, participants interviewed in Iqaluit often diverted the discussion toward economic and social issues related to past and ongoing effects of colonialism. This suggests that for Inuit living in an urban community, health and social concerns were more prominent than concerns regarding the environment and climate change. Participants from Iqaluit identified social issues as the biggest obstacle for Inuit in their day-to-day lives, affecting physical and mental health and disrupting relationships with the land. The rapid shift from a subsistence lifestyle to the wage economy, especially seen through the lens of colonialism, has been dislocating physically, emotionally, and spiritually: “Honestly, in a place that has so many other social issues, and issues within systemic issues and things like that, a lot of people just can't afford to pay attention to [climate change] right now” (IR19-3). This was a sentiment that was also reflected in the literature; while many participants stressed the urgency of addressing climate change, one participant in a study by Prno et al. (2011) mentioned that while climate change is a concern, their “‘community has [social] issues [that they] need to deal with first’’. As such, it becomes apparent that climate change cannot be viewed in isolation from socioeconomic impacts, as there are intersecting issues that combined manifest as an allostatic load that can affect well-being, including pollution, sustainability, social issues, and sovereignty (Berger et al. 2015).

Concerns about the loss of traditional practices and *IQ* in relation to climate change were commonly mentioned in both the systematic literature review as well as by participants from the case study in Iqaluit. The loss of a connection to traditional lifestyle was referred to as having a strong implication for Inuit mental health and well-being (Flint et al. 2011, Durkalec et al. 2015, Bishop et al. 2022). Knowledge is traditionally passed on from generation to generation; however, recently there are fewer opportunities for youth to engage in traditional practices and learn from their Elders;

> *"Back then, more young people were trained to be hunters and providers. But not anymore. That knowledge isn't passed on. Because there's less incentive. [Young people] can eat store bought food, they also have school. They are preoccupied"* (Anonymous, 2015, as quoted in Archer et al. 2017).

There are some differences between urban and remote communities, as to which sub-themes were addressed. In remote communities, challenges in education and climate literacy were not mentioned. One possible explanation for this difference could be the decreasing practice of intergenerational education between Elders and youth in urban communities, as compared to remote communities where the Traditional Knowledge transfer is still somewhat intact (Herrmann 2016). Simonee (2021), who is an Inuit researcher, notes that Inuit "often feel stuck in the middle between Traditional Knowledge and modern services, trying to determine what information is most reliable […]". As weather and wind patterns continue to change, Indigenous Knowledge will get less reliable for navigating on the land (Archer et al. 2017).

A vital component of Inuit culture is the inherent care for others and maintaining strong relationships between members of a community (Government of Nunavut 2023). *Pijitsirniq*, the *IQ* guiding principle of serving, was largely consistent in how it was addressed in responses from both remote and urban communities. Increasing structural change and shifts towards a wage economy have replaced the sharing culture for the most part (Goldhar and Ford 2010; Gilbert et al. 2021): "I don't like selling [the traditional foods] for money, but how else can I afford to hunt?" (Male hunter, middle-aged, as quoted in Ford and Beaumier 2011). Many participants expressed their frustration and sense of helplessness: “There’s nothing you can do” (Youth, as quoted in MacDonald et al. 2013). A subsistence-sharing culture is only one of the many traditional practices that are gradually being lost or replaced by adopting a more Western way of life (Archer et al. 2017).

2.8 Conclusions

An increasingly variable climate challenges the subsistence-based sharing economy of Inuit, which can negatively affect their well-being. To get a better understanding of how climate change affects the Inuit relationship with the land, their well-being, and whether these experiences differ between urban and remote communities, published literature on interview studies with Inuit across the North American Arctic was examined and compared with an interview study with residents conducted in Iqaluit. This approach, which considers *IQ* values within the analysis, reveals that there are some positive outcomes for Inuit well-being in the context of climate change, such as building resilience, developing adaptation strategies, and revival of traditional practices for a more well-balanced lifestyle. However, climate change is predominantly affecting Inuit relationships to water and land in a negative way, and this is exacerbated by differences between Inuit and Western understandings of climate and environment. Results have been largely consistent across urban and remote communities, with differences in the prioritization of certain topics in the context of climate change. A greater need to listen to and understand Inuit perspectives to respect the knowledge that they hold, to include observations of how climate change is affecting the Arctic, and to implement their knowledge in decision-making and funding acquisition in Arctic research, was identified. Inuit well-being should be of primary concern not only for Inuit, but also for the non-Inuit who live, work, and conduct research in the Arctic. More effort needs to be put into developing a complementary knowledge system for science and IQ, with care to not value either above the other.

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CHAPTER 3 IMPORTANCE OF HABITAT AND LAKE MORPHOLOGY IN UNDERSTANDING WITHIN-REGION VARIABILITY OF CHIRONOMID ASSEMBLAGES IN AN ARCTIC TRANSITIONAL ECOTONE

Chapter context: This research was first initiated through community concerns about the limited scientific knowledge of the climate impacts on freshwater systems in the Mackenzie Uplands Region communicated to Andrew S. Medeiros' research team between 2012 and 2014. The initial conception of this study occurred in 2014, before the construction of the all-season road, with initial research outputs documented in Niemeyer et al. (2022). Several lakes presented in this study were identified as important to the communities, both as a source of drinking water and serving as important migration routes and spawning areas for locally sourced fish. This chapter furthers this work by making use of the increased accessibility provided by the opening of the Inuvik-Tuktoyaktuk Highway in 2017, to provide an enhanced understanding of the impacts of small-scale differences in habitat and lake morphology on freshwater systems, by studying the distribution of macroinvertebrates, which are at the lower end of the aquatic food chain and an essential part of healthy freshwater ecology.

3.1 Statement of Student Contributions

Study design by Annabe U. Marquardt and Andrew S. Medeiros. Limnological data was collected by Annabe U. Marquardt, Jennifer Eamer, Connor Nishikawa, Mia Tuccillo, Bailey Nash, and Jack De Swart. Data analysis by Annabe U. Marquardt under the guidance of Kathleen Hipwell, Connor Nishikawa and Andrew S. Medeiros, chapter writing by Annabe U. Marquardt with editorial contributions by Andrew S. Medeiros.

3.2 Abstract

While temperature is an important driver of the distribution of freshwater biota in the Arctic, within-region variability may pose challenges for the interpretation of temperature-environment relationships. The abundance and diversity of chironomids (Diptera: *Chironomidae*) are often used in paleoecological and ecological research to infer climatic changes within the circumpolar Arctic, due to their sensitivity to changes in regional temperature. However, temperature is often collinear with other limnological variables, such as water chemistry, productivity, and depth. While temperature is known to be a primary driver of chironomid distributions across large latitudinal ranges, within-region variability may pose challenges to the interpretation of their abundance and diversity. Here, surficial sediments and water samples from 60 lakes within a transitional Arctic ecotone in the Mackenzie Uplands Region, Northwest Territories, were examined, to discuss the relevance of accounting for within-region variability by exploring the importance of habitat and lake morphology in driving chironomid distribution. It was found that chironomid assemblages differed significantly due to variability in conductivity, total phosphorus, dissolved organic carbon, and total lake area between the sampled lakes. As such, these findings validate previous research suggesting that within-regional variability is important for the diversity of chironomids in Arctic lakes, and future research should assess within-region variability of other environmental gradients when sampling lakes with the aim of inferring temperature models derived from chironomid indicators.

3.3 Introduction

Freshwater lakes are among the most vulnerable ecosystems to anthropogenic climate change in the circumpolar Arctic (Brodersen and Anderson 2002). Accelerated warming, also known as Arctic amplification, has been shown to enhance lake stratification, reduce lake ice cover, and alter hydrological processes (Lau et al. 2019; Niemeyer et al. 2022). A warming Arctic is also altering catchment vegetation, which influences biogeochemical cycling in lake catchments (Lau et al. 2019). Changes in catchment-mediated inputs due to increased terrestrial productivity are also affecting aquatic habitat characteristics, by altering the carbon and nutrient transport (Lau et al. 2019). Increased riparian vegetation, otherwise known as shrubification of the Arctic, directly affects the availability of organic matter in the aquatic food chain, while the increasing thickness of the active layer adds additional nutrients. Both processes increase lake productivity and are moderated by ongoing permafrost decay at northern latitudes (Wrona et al. 2016).

Permafrost degradation enhances thermokarst processes, thaw-driven slope erosions, and increased lake drainage (Lantz et al. 2022; Niemeyer et al. 2022). These landscape disturbances through permafrost decay can cause an increased sediment and nutrient influx into aquatic systems, which increases their productivity and hydrological connectivity (Niemeyer et al. 2022). Changes at this scale can lead to drastic shifts in the aquatic biota that are increasingly subjected to adapt to new habitat characteristics (Lau et al. 2019).

Freshwater macroinvertebrates, which are an essential part of the aquatic food chain, are particularly sensitive to such changes in limnological variables, like temperature, dissolved oxygen, nutrient availability, and dissolved organic carbon (DOC)

(Moquin et al. 2014). As such, they are a commonly used biological proxy to understand and reconstruct ongoing changes in aquatic systems (Belle and Goedkoop 2021). Chironomids are the most common and diverse family of macroinvertebrates at northern latitudes and are very sensitive to fluctuations in temperature and catchment characteristics induced by climatic changes, which drastically affect their aquatic habitat (Loskutova 2020). Chironomids undergo four different life cycles, namely egg, larva, pupa, and adult, of which their aquatic forms are the longest, and therefore most descriptive of their habitat preferences (Medeiros and Quinlan 2011). Current ecological conditions ultimately determine the length of the aquatic life cycle, which can persist for years, until the conditions allow for pupation, the transition into the short-span terrestrial adult life of these insects. When transitioning through those different stages, chironomids shed their chitinized head capsule. These remains are then preserved in the sediment and can be extracted to identify the characteristic chironomid assemblage in any given aquatic freshwater system, thereby allowing scientists to make inferences based on the habitat characteristics or regional environmental change (Medeiros and Quinlan 2011).

Due to their sensitivity to temperature, chironomids are seen as one of the most useful biological indicators for climate change (Batterbee 2000). Walker et al. (1991) showed that certain species are more prevalent in temperate habitats, compared to others that are predominantly found along northern latitudes, which has led to the conclusion that there is a significant temperature relationship associated with the range of distribution of chironomid species. Since then, there has been an extensive research effort using chironomids to understand temperature developments in various regions of the circumpolar Arctic, as well as research looking into the other possible relationships of chironomids with limnological variables, such as trophic conditions and lake depth (Brodersen and Anderson 2002; Self et al. 2011; Eggermont and Heiri 2012; Lento et al. 2022; Medeiros et al. 2022). While Medeiros and Quinlan (2011) note that temperature is the primary driver of chironomid distribution along large latitudinal gradients, Medeiros et al. (2015) found that several secondary gradients are also important, especially for lakes in transitional ecotones. Brodersen and Anderson (2002) acknowledge the difficulty of decoupling temperature from catchment- or trophic-related variables when looking at large-scale ranges of chironomids; and, these relationships remain difficult to describe to the full, given the limited number of studies that examine lakes along smaller latitudinal gradients (Brodersen and Andersen 2002; Medeiros and Quinlan 2011).

Given the unexpectedly high number of warm-adapted species in northern latitudinal gradients, it is likely that the distribution is not only determined by temperature, but also by morphological characteristics, such as depth, UV light penetration, and nutrient availability (Medeiros and Quinlan 2011; Niemeyer et al. 2022). When taking into account within-regional variability, it becomes apparent that considering lake morphology differences, and different catchment characteristics within the same region, is crucial when selecting sampling locations, especially along a large latitudinal transect (Medeiros and Quinlan 2011). Niemeyer et al. 2022 have shown that deeper and larger lakes are more resistant to temperature change and landscape disturbance, and can mask drastic changes in the region, whereas smaller and shallower lakes are more sensitive which makes their biota more vulnerable to environmental change. Nyman and Brooks (2005) found that while temperature did play a significant role in chironomid distribution, other habitat-related factors, such as sediment organic content, total organic carbon (TOC), pH, and lake-specific temperature, explained the largest variance across an Arctic transitional ecotone in northern Finland.

Here, an exploratory gradient analysis in an Arctic transitional ecotone was conducted, across a relatively small latitudinal gradient in the Mackenzie Uplands Region. Sixty lakes were sampled that spanned a permafrost gradient which determines the aquatic-terrestrial connectivity in the region (Kokelj et al. 2017) to 1) examine which gradients are primary drivers of differences in chironomid assemblages across this region, 2) investigate the optima and tolerance of specific chironomid indicators that respond to catchment-mediated gradients, and 3) discuss the importance of within-regional variability when trying to understand the extent of climate change impact on Arctic aquatic ecosystems. This research aims to contribute to the understanding of which environmental factors mediate chironomid distribution within the same region to argue the importance of taking into account within-region variability in large-scale environmental assessments.

3.4 Methods

3.4.1 Study area

Sixty lakes and ponds were sampled along an approximately 130 km latitudinal gradient between Inuvik (68° 19′ N, 133° 37′) and Tuktoyaktuk (69° 26′ N, 133° 2′ W) (Figure 3.1). The selected lakes varied in size (0.4 ha – 83.87 ha), depth (0.4 m – 7.5 m), and catchment characteristics. The terrain is largely characterized by its abundance of lakes within an Arctic transitional ecotone (Kokelj et al. 2017; Lantz et al. 2022). Near Inuvik, the vegetation is dominated by black spruce forest (*Picea mariana*) and upright shrubbery, such as green alder (*Alnus viridis*), willows (*Salix*), and dwarf birch (*Betula nana*). Closer to Tuktoyaktuk, the tundra is mostly characterized by grasses and dwarf shrubbery (*Betula nana*) (Lantz et al. 2022). A rise in regional temperatures and increased ground fertility provided by drained lake basins have increased the size, density, and distributional range of large shrubbery in the tundra in recent decades (Kokelj et al. 2017; Wilcox et al. 2019; Lantz et al. 2022). The weather is on average warmer and wetter in the South, compared to drier and colder conditions closer to the coastline in the North, with a mean annual temperature of 3-7 °C (Kokelj et al. 2017). Large shrubs expose the active layer to earlier warming in the spring, which further contributes to regional ground temperature variability (Kokelj et al. 2017; Wilcox et al. 2019). Commonly observed vegetation in the catchment of the lakes in the dataset, depending on their location in the transect, were birch (*Betula*), willow (*Salix*), cloudberry (*Rubus chamaemorus*), blueberries (*Vaccinium corymbosum*), crowberries (*Empetrum nigrum*), reindeer lichen (*Cladonia rangiferina*), peat moss (*Sphagnum*), liverwort (*Marchantiophyta*), labrador tea (*Rhododendron groenlandicum*), Arctic cotton (*Eriophorum callitrix*), fireweed (*Chamaenerion angustifolium*), black spruce (*Picea mariana*), and emergent grasses. The permafrost depth in the sampling area varied with latitude, with <100 m depth in the southern part, and up to 600 m depth in the northern region (Brown et al. 1998). Some lakes within the transect had prominent permafrost decay features, such as thaw polygons, retrogressive thaw slump scars, small streams, and anthropogenic landscape disturbances, such as road embankments and culverts, within their catchment. Increasingly variable ground conditions in the region have implications for local infrastructure, such as roads and pipelines, and are further amplified by such anthropogenic landscape changes (Kokelj et al. 2017).

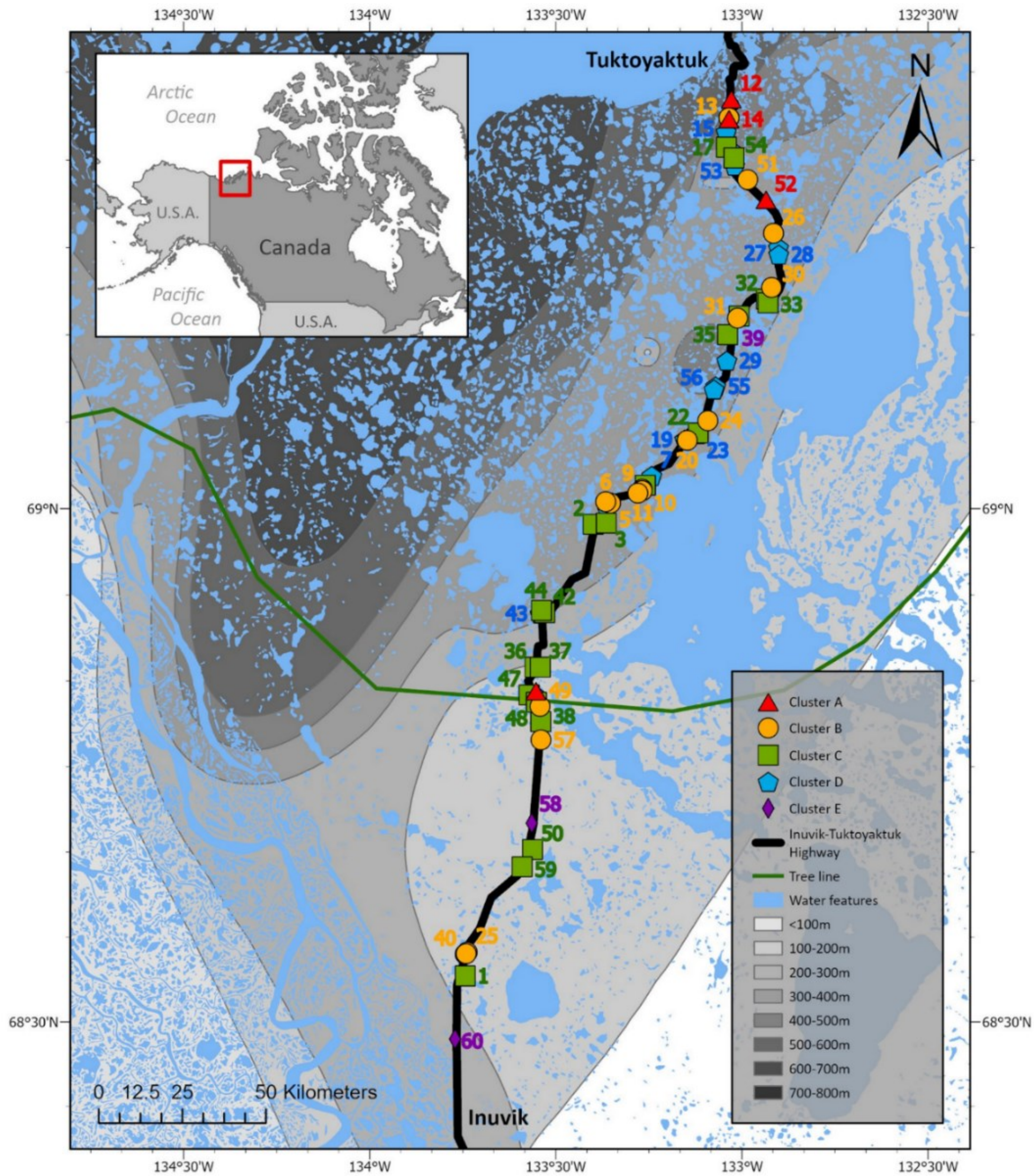

Figure 3.1 Map depicting the five clusters (A-E) of sampling locations in the Mackenzie Uplands Region, NT, displayed in relation to permafrost depth (<100-800m) and tree line.

3.4.2 Field sampling

Throughout two field seasons in July 2022 and July 2023, 60 lakes located within 200 meters of the ITH were sampled. Lakes were accessed using a six-foot zodiac to collect surface sediment and water samples. Surface sediment (top 1 cm) was collected using a combination of Uwitec gravity corer (8.4 cm tube diameter) and Ekman grab, stored in Whirl-Pal® bags, and transported in coolers back to the laboratory where they were stored at 4°C for further processing. Water quality measurements including acidity/alkalinity (pH), oxidation-reduction potential (mVORP), percent dissolved oxygen (%DO), conductivity (µS/cm), resistivity (MΩ•cm), total dissolved solids (ppm TDS), salinity (PSU), temperature (°C) and water pressure (psi) were taken at each lake using a Hanna 98494 Waterproof Portable Meter. The water transparency and total depth were measured using a Secchi disk. 200 ml water samples were collected in small plastic bottles and analyzed for oxygen-18 isotopes ($\delta^{18}O$) and delta deuterium (δD). Additional water samples were collected for analysis of organic carbon and nutrients, including DOC, TOC, total phosphorus (TP), and total nitrogen (TN). Each sample's global positioning system (GPS) location was saved using a Garmin GPS device. Hand-written notes on the catchment characteristics, as well as digital photographs, were taken at each sampling location.

3.4.3 Laboratory analysis

Surface sediment samples were processed according to standard protocols (Walker 2001) to extract subfossil chironomids in the Dalhousie University's Laboratory for Water and Environmental Sustainability Science (WESS). Surface sediment from each lake was deflocculated using 10% potassium hydroxide (KOH) on a hot plate at 75°C for 30 minutes. Afterwards, the sediment was sorted using stacked 212 and 106 µm sieves and washed into a scintillation vial with 95% ethanol. Samples were then sorted using a Borogov counting tray, where a minimum of 50 head capsules per lake were picked out under a microscope at 20-40x magnification using fine tweezers (Quinlan and Smol 2001). To ensure a >95% capture rate, the vessel was sifted at least three times. The subfossil chironomid head capsules were permanently mounted on a microscopic slide using Entellen® and identified under a microscope using 10-40x magnification with the aid of Oliver and Roussel (1983), Brooks et al. (2007), and Andersen et al. (2013). Head capsules per gram of dry weight (HC g^{-1} DW) were calculated for each lake.

Water samples were analyzed for phosphorus contents using a Thermo Scientific™ iCAP™-RQ ICPMS (Single Quadrupole Inductively Coupled Plasma Mass Spectrometry) following EPA (Environmental Protection Agency) Method 200.8 and Standard Methods 3125, and TOC/DOC/TN contents using a Shimadzu TOC-V (Total Organic Carbon Analyzer) with a TNM-1 (Total Nitrogen Measuring) unit, following Standard Method 5310B in the Clean Water Laboratory at Dalhousie University. Isotopic analyses were performed externally using Temperature Conversion Elemental Analysis (TC-EA) in the Quaternary Sediment Laboratory at Northwestern University, while major ions analyses were performed by Northwestern University's Quantitative Bio-element

Imaging Centre (QBIC) using a Thermo Scientific^{TM} iCAP^{TM} ICP-MS (Inductively Couple Plasma Mass Spectrometry).

3.4.4 Numerical analysis

To examine the relationships between environmental data and chironomid assemblies, a series of ordinations were performed in R version 4.3.1 using the *vegan* package, unless otherwise specified. Relative species abundance was calculated, the 2%-in-2-lakes criterion was applied to down-weigh rare taxa (Fortin et al. 2015) and data was transformed using the Hellinger standardization method (Legendre and Gallagher 2001). A Redundancy Analysis (RDA) (Legendre and Legendre 2012) was applied using a forward selection process (*packfor*) to identify only variables found to be statistically significant ($p < 0.05$) when performing constrained ordinations (Miller and Farr 1971). Adjusted R-squared was calculated for each forward selection process to find goodness of fit. To minimize the collinearity of statistically significant variables ($p < 0.05$), variables with a variance inflation factor (VIF > 10) were subsequently removed from the analysis. A Constrained Cluster Analysis (CCA; *rioja*) was performed on the distance matrix computation to establish statistically significant ($p < 0.05$) differences in the sites based on the chironomid assemblages. A broken stick model (*rioja*), Ward D2 method (*stats*), and Mantel-optimal number test were subsequently used to determine the optimal number of clusters in this dataset (Legendre and Legendre 2012). Using Multiple Regression Tree Analysis (MRT) (*mvpart*) and Indicator Species Analysis (IndVal; *labdsv*), the habitat preferences of chironomids between the clusters were visualized (Dufrene and Legendre 1997).

3.5 Results

3.5.1 Chironomid assemblages

More than 3700 chironomid subfossil head capsules were identified from the surface sediment samples from the 60 sampled lakes, with an average of 63 head capsules per lake (median = 58; range 40[2]-116). Forty-nine different taxa were identified. Using CCA and IndVal, five distinct clusters (A-E) were identified based on Mantel-optimal number, with their respective indicator species (Figure 3.2). The given indicator species for each cluster were *Corynoneura edwardsi-type* (p = 0.04), *Cricotopus intersectus-type* (p = 0.008), and *Cricotopus tremulus* (p = 0.445[3]) for Cluster A (12, 14, 45, 52); *Microtendipes pedellus-type* (p = 0.001) for Cluster B (5, 6, 9, 10, 11, 13, 20, 24, 25, 26, 30, 31, 40, 41, 49, 41, and 57); *Corynocera ambigua* (p = 0.002) for Cluster C (1, 2, 3, 8, 17, 22, 32, 33, 34, 35, 36, 37, 38, 42, 44, 48, 50, 54, and 59); *Tanytarsus lugens-type* (p = 0.342), and *Limnophyes-Paralimnophyes* (p = 0.502) for Cluster D (4, 7, 15, 18, 19, 21, 23, 27, 28, 29, 43, 46, 53, and 55); *Paratanytarsus penicillatus-type* (p = 0.246), and *Psectrocladius sordidellus-type* (p = 0.072) for Cluster E (16, 39, 58, and 60).

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[2] Due to a sampling complication, the sample taken from Lake 16 did not contain enough head capsules to satisfy the minimum criteria of 50 head capsules per lake.

[3] While statistically insignificant, *Cricotopus tremulus* was still deemed an important indicator based on the high abundances within Cluster A. The same applies to *Tanytarsus lugens-type* and *Limnophyes-Paralimnophyes* for Cluster D, and *Paratanytarsus penicillatus-type* for Cluster E.

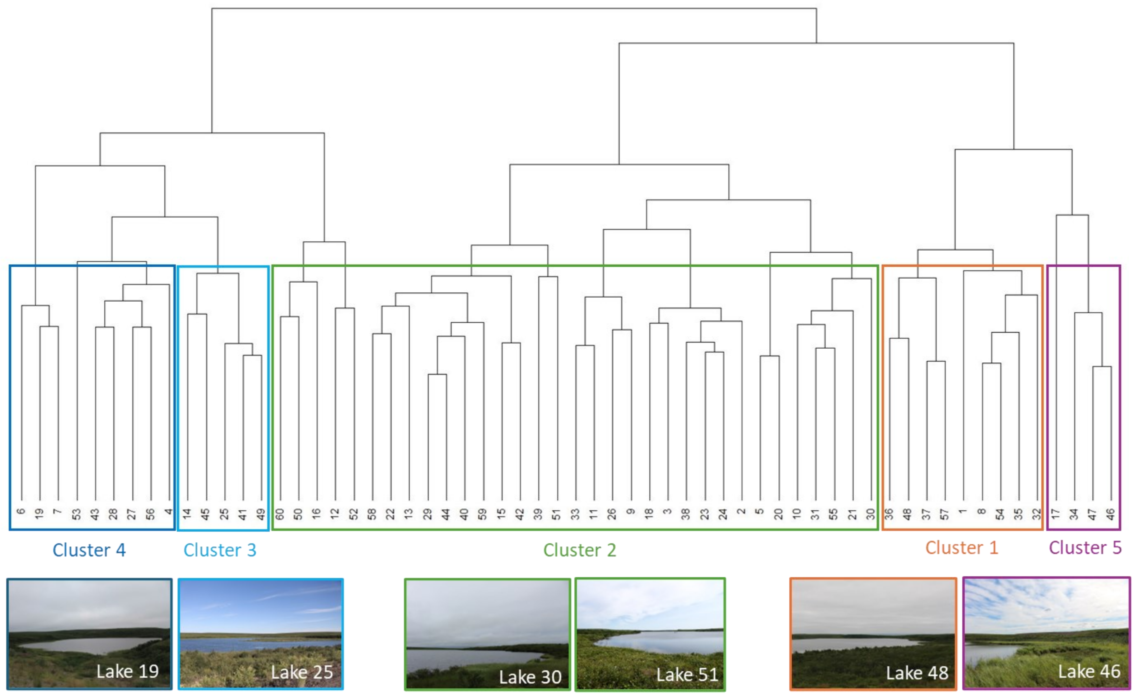

Figure 3.2 Output of Constrained Cluster Analysis using Mantel optimal number of clusters. Representative pictures of each cluster depicting common characteristics are shown below each cluster. Photos by Annabe U. Marquardt, Bailey Nash, Jack De Swart, and Mia Tuccillo.

3.5.2 Ordination analyses

Using the forward step-wise selection criteria to perform constrained ordinations on each environmental variable from this dataset individually, the RDA (Figure 3.3) identified conductivity (COND), TP, DOC, and area (ha) as statistically significant ($p < 0.05$) predictors of the variation in chironomid assemblages across the 60 sampled lakes, eliminating the remaining variables from further analysis. The total species variance

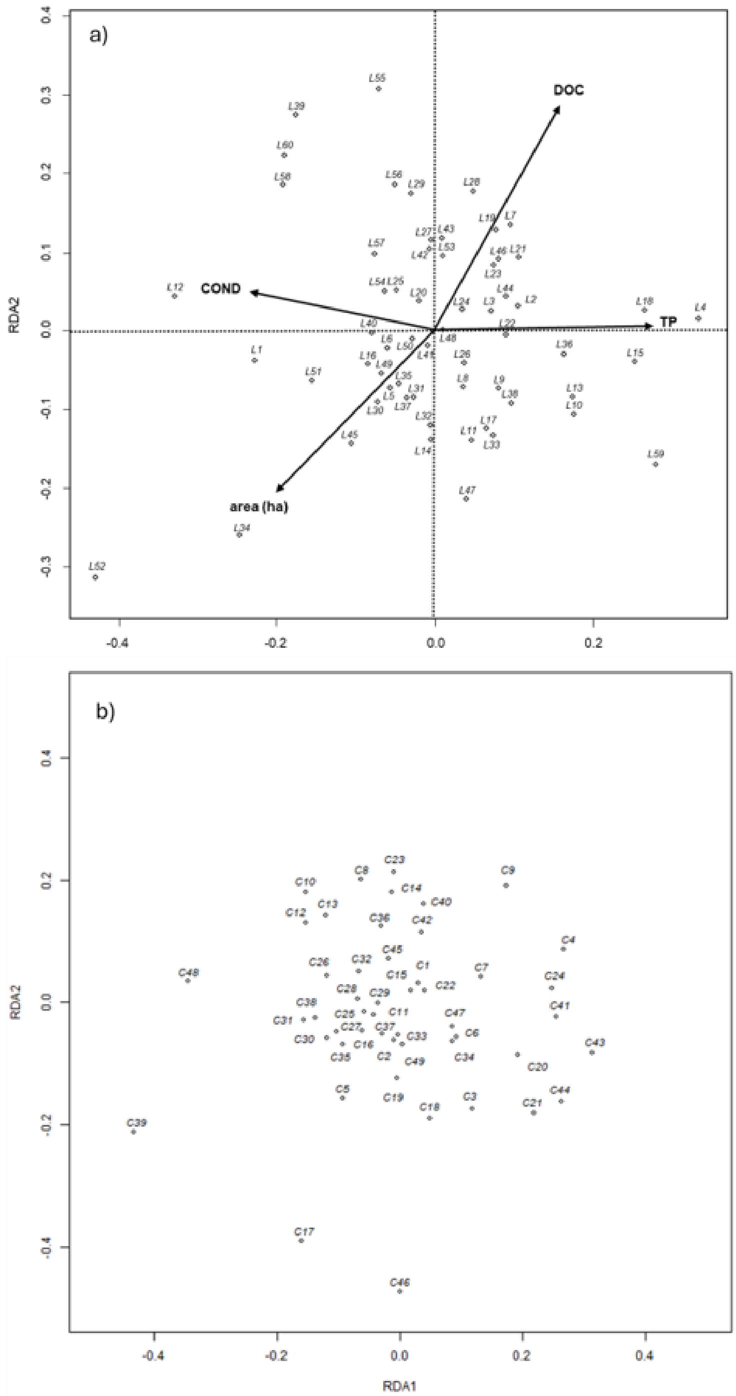

Figure 3.3 Output of Redundancy Analysis: a) significant environmental gradients in sampling lakes (L1-L60), b) significant environmental gradients in chironomid species (C1-C49). See Table S.3 for species identification.

explained with all significant indicators combined in this statistical model was 43.18%. TP and DOC were significantly correlated to RDA axis 1 while conductivity and area were significantly correlated with RDA axis 2, each expressing a significant ($p < 0.001$) amount of species variation in the dataset.

3.5.3 Environmental gradients

The MRT indicated four significant distinctions between lakes based on environmental data (Table 3.1). The first significant distinction was between very clear lakes (DOC < 7.6), as opposed to lakes with a darker tea-like colour. The second significant division differentiated lakes with higher levels of TDS (>= 120.5), and lower levels of TDS. The third significant division again differentiated lakes with higher levels of DOC (> 15.61) and lower levels of DOC. The fourth significant distinction between lakes was based on higher conductivity (>=139.5) as opposed to lower conductivity. Mapping the results from the IndVal onto the Regression Tree Analysis suggests that clear lakes were preferred habitats of *Corynocera edwardsi-type*, *Cricotopus intersectus-type* and *Cricotopus tremulus*; *Paratanytarsus penicillatus-type* and *Psectrocladius sordidellus-type* were predominantly present in lakes with higher levels of TDS; *Tanytarsus lugens-type* and *Limnophyes-Paralimnophyes* were more frequently counted in lakes very dark complexion; and *Corynocera ambigua* was more prevalently found in lakes with higher salinity, while *Microtendipes pedellus-type* was more frequently counted in lakes where salinity was lower (Figure 3.4).

Table 3.1 Biogeochemical data and lake morphology characteristics for the 60 sampling lakes, organized by Cluster (A-E) and listed alphabetically.

Cluster	**Lake**	**Lat. (°N)**	**Long. (°W)**	**Area (ha)**	**Depth (m)**	**Temp. (°C)**	**pH**	**COND**	**TP**	**DOC**
	12	69.39195	-133.029	8.50	1.83	19.95	8.64	548	12.241	7.131
A	14	69.37317	-133.035	26.47	1.10	19.93	8.21	181	27.748	7.576
	45	68.82465	-133.554	60.28	1.83	20.50	8.47	120	5.496	6.214
	52	69.29672	-132.935	1211.51	1.95	18.93	8.64	146	8.411	5.067
	5	69.00510	-133.353	22.15	3.40	18.42	8.30	153	14.629	8.597
	6	69.00663	-133.366	4.15	7.45	18.38	8.19	159	11.141	9.141
	9	69.01881	-133.268	4.10	6.00	22.65	9.07	222	57.430	10.740
	10	69.01715	-133.268	4.86	3.00	21.01	8.60	211	90.287	11.930
	11	69.01524	-133.279	8.76	3.00	21.50	8.74	188	35.257	7.783
	13	69.37317	-133.035	4.87	2.00	20.25	7.81	163	75.756	12.640
	20	69.06561	-133.148	20.05	4.00	20.77	8.18	141	27.414	13.730
	24	69.08479	-133.092	8.09	2.00	21.28	8.00	155	37.911	13.890
B	25	68.56865	-133.738	10.02	0.40	25.82	9.06	151	19.219	12.850
	26	69.26378	-132.915	3.19	1.25	18.31	8.41	226	46.131	10.900
	30	69.21190	-132.920	29.18	2.05	20.67	8.39	146	11.248	7.774
	31	69.18295	-133.012	10.68	1.50	21.38	8.41	164	17.445	8.104

Cluster	Lake	Lat. (°N)	Long. (°W)	Area (ha)	Depth (m)	Temp. (°C)	pH	COND	TP	DOC
	40	68.56645	-133.744	57.33	1.00	25.63	9.45	179	28.181	12.140
	41	68.56700	-133.742	9.12	0.76	24.86	9.29	148	23.179	10.990
	49	68.80894	-133.543	11.10	2.50	19.44	8.76	152	10.177	8.316
	51	69.31485	-132.984	83.87	6.97	18.65	8.42	148	8.512	8.566
	57	68.7760	-133.540	1.33	2.04	22.08	8.56	185	17.209	13.3200
	1	68.54517	-133.744	184.32	6.70	19.21	7.96	138	6.908	9.8240
	2	68.98489	-133.400	3.66	2.39	18.61	7.65	65	27.926	15.1100
	3	68.98603	-133.365	7.28	4.00	19.84	7.64	66	21.918	14.1800
	8	69.02254	-133.260	2.39	7.50	20.66	8.74	124	18.750	9.0880
	17	69.34545	-133.042	3.92	5.00	20.43	9.25	130	24.194	8.0130
	22	69.07277	-133.117	7.25	2.00	23.52	8.84	113	39.076	13.6300
	32	69.20097	-132.934	32.72	1.85	20.17	8.01	95	13.092	8.0790
	33	69.19741	-132.930	2.68	4.80	20.13	7.85	96	16.287	7.6200
	34	69.18478	-133.008	816.82	1.50	23.92	8.97	116	24.556	7.8220
	35	69.16696	-133.039	46.71	1.00	22.36	8.24	116	15.289	9.6400
C	36	68.84676	-133.556	14.69	1.67	19.74	8.11	57	42.234	14.7300
	37	68.84676	-133.542	59.86	2.60	20.09	7.79	83	12.857	9.5690
	38	68.79385	-133.541	3.75	1.64	22.26	7.33	81	21.305	9.6660
	42	68.89948	-133.530	3.36	1.54	19.87	7.86	125	22.681	15.5800

Cluster	Lake	Lat. (°N)	Long. (°W)	Area (ha)	Depth (m)	Temp. (°C)	pH	COND	TP	DOC
	44	68.90175	-133.539	4.30	1.60	19.78	7.17	58	22.967	15.1400
	47	68.81988	-133.572	168.19	1.65	19.95	8.77	53	25.585	8.5510
	48	68.81279	-133.552	14.57	4.50	19.62	8.05	126	25.547	12.4000
	50	68.66908	-133.563	0.85	1.65	22.52	7.62	123	9.094	9.5650
	54	69.33534	-133.021	3.75	2.68	19.37	7.89	112	7.518	11.6000
	59	68.65224	-133.591	13.61	1.28	20.47	7.24	50	63.619	11.7600
	4	69.00377	-133.365	0.63	2.54	16.31	7.89	0	35.251	19.4100
	7	69.03204	-133.242	7.53	4.00	18.83	8.02	108	53.670	20.8600
	15	69.36014	-133.042	7.70	1.00	20.23	7.44	81	81.642	16.6500
	18	69.34203	-133.025	2.32	2.50	18.62	7.52	95	96.531	19.8100
	19	69.06706	-133.153	1.69	4.80	18.46	7.93	89	34.097	18.7700
	21	69.06786	-133.146	0.52	3.00	21.00	7.72	95	39.663	17.6600
	23	69.07209	-133.118	1.99	2.50	21.53	7.60	96	32.465	16.5600
D	27	69.25040	-132.902	0.67	4.00	21.38	7.60	122	20.492	15.6300
	28	69.24390	-132.901	1.57	2.99	21.19	7.47	123	40.916	20.7400
	29	69.14244	-133.041	1.87	1.00	18.98	7.91	131	21.767	18.1400
	43	68.89913	-133.542	5.86	1.12	19.63	7.50	88	19.075	16.6500
	46	68.81935	-133.552	3.10	2.22	20.59	7.64	73	28.486	17.16297
	53	69.32838	-133.020	5.99	1.98	19.43	7.74	93	19.979	15.7500

Cluster	Lake	Lat. (°N)	Long. (°W)	Area (ha)	Depth (m)	Temp. (°C)	pH	COND	TP	DOC
	55	69.11799	-133.071	1.11	1.50	21.64	8.18	154	26.812	24.1000
	56	69.11499	-133.075	1.26	3.28	21.70	7.60	147	21.185	17.9500
	16	69.34846	-133.035	4.06	5.00	20.56	9.34	347	33.908	8.4580
E	39	69.18243	-133.012	0.40	1.50	21.03	8.47	255	17.425	18.8500
	58	68.69497	-133.565	0.53	1.90	20.11	7.29	273	11.855	14.1500
	60	68.48315	-133.771	1.79	4.91	22.74	8.05	306	20.426	16.4700

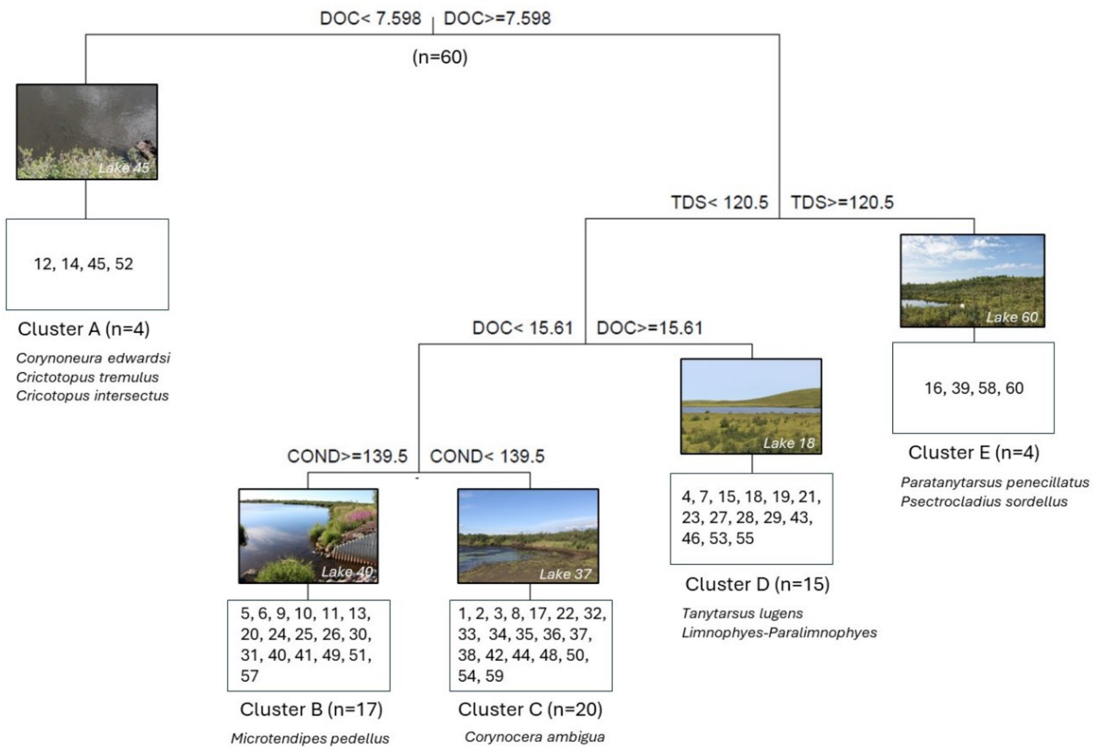

Figure 3.4 Output of Multiple Regression Tree Analysis depicting five clusters (A-E) of 60 sampling locations. Representative pictures of each cluster depicting common characteristics are shown below each cluster Sampling sites in each cluster are listed in the boxes below. Indicator species for each cluster, as identified through IndVal, are listed underneath each box. Photos by Annabe U. Marquardt, Bailey Nash, Jack De Swart, and Mia Tuccillo.

3.6 Discussion

By comparing chironomid assemblages and water chemistry data from 60 lakes within a transitional Arctic ecotone in the Mackenzie Uplands Region, the relative importance of habitat, lake morphology, and within-regional variability in paleoecological and ecological assessments of chironomid-environment relationships becomes evident.

3.6.1 Environmental gradients

Chironomids are responsive to many limnological variables, including different environmental conditions, based on lake morphology (Medeiros and Quinlan 2011; Niemeyer et al. 2022). With a relatively short terrestrial lifespan, chironomids spend most of their life in larval form in aquatic environments, which are therefore most descriptive of their habitat preferences (Medeiros and Quinlan 2011).

Given the marginal temperature variability with latitude in the sampling area, and the lakes clusters scattered all across the sampling gradient, differences between the chironomid assemblages in this dataset, cannot be attributed to temperature. Instead, it was found that lake morphology was the main driver of biota differences. *Corynoneura edwardsi-type*, *Cricotopus intersectus-type*, and *Cricotopus tremulus*, associated with Cluster A, were primarily found in very clear and shallow lakes (<2 m). Few lakes in this cluster, show signs of potential thaw slump scars in their catchment, which could be one possible explanation for the water clarity, given that thaw slumping has been shown to decrease DOC within aquatic systems (Kokelj et al. 2009). Interestingly, while *Cricotopus* is generally considered to be more cold-adapted (Medeiros and Quinlan 2011), *Corynocera edwardsi-type* is associated with more temperate systems (Brooks et al. 2007). The low depth and levels of DOC within these lakes render this cluster of lakes especially vulnerable to increasing permafrost decay in the near future (MacDonald et al. 2015; Fowler et al. 2020).

Like many regions of the Canadian Arctic, the Mackenzie Uplands Region is extremely lake-rich, due to a combination of sedimentation, permafrost aggregation, and thermokarst processes (Marsh and de Jong 2015). Thermokarst lakes within the sampling area were prime habitats for *Tanytarsus lugens-type* and semi-terrestrial *Limnophyes-Paralimnophyes* (Brooks and Birks 2004). Those lakes, associated with Cluster D, were the highest in DOC, TN and TP within this dataset, which is to be expected given that thermokarst lakes form as water accumulates in mineral-rich depressions of thawed permafrost or yedomas (Arsenault et al. 2022). *Tanytarsus lugens-type* is commonly found in deep lakes with high DOC concentrations and TOC (Luoto 2011; Medeiros and Quinlan 2011), while the presence of *Limnophyes-Paralimnophyes* and peat moss are correlated and an indication of increasingly wetter conditions (Porinchu et al. 2019).

3.6.2 Importance of habitat

Although paleolimnological and limnological research commonly focuses on the large temperature gradients in chironomid distribution, the influence of habitat and lake morphology has shown to be an equally important driver of chironomid assemblages, especially with regard to within-region variability (Brodersen and Anderson 2002; Medeiros and Quinlan 2011). In rapidly changing regions, such as the circumpolar Arctic, changes in the terrestrial-aquatic interface can have far-reaching consequences for selection pressures on aquatic biota (Niemeyer et al. 2022); and it is often not possible to attribute change to a single variable, such as temperature, given change in complex systems is highly multivariate. It is recommended to reconstruct both temperature and lake habitat when assessing environmental change in any region of the Arctic (Brodersen and Anderson 2002).

Within the dataset, *Microtendipes pedellus-type* was commonly found in lakes with high mineralization, associated with Cluster B. The high supply of minerals and ions in those lakes could be attributed to a multitude of reasons. For one, situated in a region where permafrost decays, soluble ions which aggregate in near-surface ground ice can get washed into those aquatic systems (Dugan et al. 2012). In cases of thaw slumping, this can lead to large increases in TDS within these systems (Kokelj et al. 2009). The impacts of elevated TDS on aquatic biota remain poorly understood and more research is needed to fully explain the extent of these sometimes-rapid ecological changes (Dugan et al. 2012). In theory, high mineral contents in these lakes could also be partly attributed to the proximity to the ITH, and the presence of culverts and road embankments in the lake catchments (Zhu et al. 2019). To date, most studies on calcareous-rich road dust impact have focused on changes in the terrestrial environment and vegetation, and impacts on aquatic systems remain largely understudied. Yet, Zhu et al. (2019) show that lakes within 1 km reach of the Dempster Highway near Fort McPhearson, exhibit elevated levels of calcium and dissolved salts, compared to lakes outside of road impact reach, while diatomic assemblages in their sediment core data remain largely unaffected. *Microtendipes* is often associated with forest proximity, yet it can also be found in large, relatively warm and productive systems far north of tree line, favouring coarse sediment with low inorganic content (Brodensen and Lindegraad 1999; Medeiros and Quinland 2011). Therefore, a large abundance of *Mictrotendipes* in those systems could suggest that the impact of the ITH remains limited to date.

3.6.3 Indictors of change

Accelerated warming of air and ground temperatures in the Arctic regions have and continue to distort natural processes in aquatic ecosystems, including stratification, mixing patterns, evaporation, drainage, and hydrology (Adrian et al. 2009; Medeiros and Quinlan 2011; Skeeter et al. 2020). Arctic lakes and their catchments are influenced by a multitude of interconnected biogeochemical processes, whose effects are sometimes hard to disentangle (Brodersen and Anderson 2002). Bordersen and Anderson (2002) describe a theoretical scenario in which a lake could simultaneously undergo warming and oligotrophication, and both processes would go unnoticed if researchers were to only look for a change in chironomid assemblages within those systems because the response to both processes would cancel each other out. This implies that the more scientists know about the biology of these indicator species, the more accurately will they be able to explain environmental change, both in the past and present (Medeiros and Quinlan 2011).

Within the dataset, *Corynocera ambigua* was most prevalent in the lakes with marshy and densely vegetated shorelines. Those lakes, associated with Cluster C, had comparatively low levels of ions, likely sequestered by the high prevalence of macrophytes observed in these lakes (Mesquita et al. 2010). While little is known about the biology of *Corynocera ambigua*, it has been suggested that it is commonly found in highly productive or eutrophic aquatic systems and prefers a pH level of 7-8 (Brodersen and Lindegraard 1999a; Luoto 2011; Medeiros and Quinlan 2011), which is in accordance with the observations in this study. Cluster E contained the lakes with the highest presence of macrophytes and emergent vegetation in the dataset, the primary habitat of *Psectrocladius sordidellus-type* and *Paratanytarsus penicillatus-type*, two species known to prefer habitat with abundant aquatic vegetation (Luoto 2011). As such, macrophytes are both an important part of the aquatic food chain and provide habitat heterogeneity (Mesquita et al. 2010). *Psectrocladius* is a eurytropic species, and without other context not very descriptive of specific habitat conditions (Paasivirta et al.1988).

While temperature-induced changes in the future are expected, such that cold-adapted species disappear and warm-adapted species move north, the extent of this effect will depend on lake morphology; for example, deep lakes can protect from this effect somewhat as compared to shallow lakes which will warm faster (Nyman and Brooks 2005). Ultimately, researchers should not look at temperature gradients in isolation of habitat and lake morphology, as there may be important differences within the same area that need to be put into the context (Brodersen and Anderson 2002). Future researchers need to pay close attention to documenting various habitat characteristics of the lakes they sample, including information on general location (e.g., latitude, elevation), lake morphology (e.g., mean and max depth, relative littoral area), and water chemistry (e.g., Secchi depth, pH, conductivity, DOC), as well as catchment characteristics (e.g. vegetation, thaw slump scars). Given chironomids' placement in the aquatic food chain, food-web studies can further provide interesting insights into the cascading effects of ecological changes in Arctic lakes (Balasubramanian et al. 2017; Lau et al. 2019).

3.7 Conclusions

Temperature is an important determinant for chironomid assemblages over large latitudinal gradients, yet research suggests that within regional variability matters as chironomids are sensitive to many limnological variables, that may conflate the temperature signal if unaccounted for. The Mackenzie Uplands Region is an interesting region to study within-regional variability in chironomid assemblages, because of its variable permafrost gradient, within an Arctic transitional ecotone. By comparing 60 lakes along a 130km gradient between Inuvik and Tuktoyaktuk, it was found that chironomid assemblages in the sampling gradient varied significantly, due to differences in conductivity, TP, DOC, and total lake area between the sampling sites. The results validate previous studies that suggest that chironomid assemblages are not only driven by temperature but also by other limnological variables, that may vary based on lake morphology. This study provides evidence and further grounds for considering habitat and lake morphology when assessing environmental change across large latitudinal gradients. More research on the biology and habitat preferences and tolerances of chironomids is needed, so that researchers can more accurately reconstruct past and ongoing environmental change. By expanding the scientific knowledge of these versatile indicators, chironomids will continue to be a useful biological proxy for understanding ongoing climatic developments in a rapidly changing Arctic.

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CHAPTER 4 THE CHALLENGE OF MEANINGFUL KNOWLEDGE MOBILIZATION OF CLIMATE CHANGE RESEARCH IN THE CANADIAN ARCTIC FOR EARLY CAREER RESEARCHERS

Chapter context: While Chapter 2 introduced the differences in how climate change is perceived between urban and rural communities, and Chapter 3 examined biological indicators of climate change to be able to make inferences about environmental change, a mechanism to be able to communicate these results back to the communities was still needed. The initial engagement with Inuvik and Tuktoyaktuk occurred between 2012 and 2014, with field sampling that occurred over multiple summers from 2014-2023 (not consecutively). Annabe U. Marquardt initiated extended conversations and collaboration with local Indigenous organizations, including the Inuvialuit Regional Corporation, to understand local preferences for knowledge mobilization, which resulted in the creation of an additional interview project to get a more informed insight into current approaches and guidelines for researchers. This allowed for a more informed reflection on how to meaningfully mobilize knowledge generated from Chapters 2 and 3 in line with concurrent community needs, which in this case resulted in the issuing of two research summaries to the ISCC's Inuvialuit Research Newsletter, and the sharing of recommendations provided by experts, as described in this chapter, with the Aurora Research Institute to make them more widely accessible to all researchers.

4.1 Statement of Student Contributions

Study design by Annabe U. Marquardt and Andrew S. Medeiros under the guidance of Sarah Rosolen and Shanay Williams. Interviews and qualitative analysis conducted by Annabe U. Marquardt, chapter writing by Annabe U. Marquardt with editorial contributions from Andrew S. Medeiros.

4.2 Abstract

Communication of climate-change-related research in a way that is meaningful and respectful to Indigenous Peoples is challenging. Knowledge mobilization of research in the Canadian Arctic faces many barriers, such as insufficient funding, extensive regulatory processes, and time-frames that exceed a normal graduate-level experience; yet, engagement with Indigenous Peoples is now increasingly incorporated into the basic research process in academia. To better understand the challenges that early career researchers are faced with, and subsequently provide some guidance on how these barriers can be mitigated, six interviews with practitioners of knowledge mobilization in the Canadian Arctic were conducted. These informed accounts show that early career researchers face many logistical and cultural barriers. While communicating knowledge purposefully depends largely on the research context and communities involved, researchers are encouraged to be well-informed, resourceful, and flexible in their research approaches. By applying advice outlined by experienced practitioners, and reviewing academic literature, researchers can communicate knowledge in a more culturally sensitive manner. However, more community-based research is needed to continue to enhance the understanding of how to mobilize knowledge on climate change in a meaningful way, to create informed guidelines and support systems, and to make them widely accessible to researchers at all stages of their careers.

4.3 Introduction

Knowledge of the environment has been the foundation of the culture, heritage, and governance of Inuit for generations; yet, anthropogenic climate change has challenged multiple scales of the interconnectedness between the environment and society (Durkalec et al. 2015). Maintaining harmony and continually planning and preparing for the future are core cultural beliefs of Inuit (Tagalik 2011); however, an increasingly variable climate has directly challenged these concepts in a single lifetime. The need for more research on how climate change influences the Arctic is clear, but effective communication of the knowledge generated from these studies to Inuit is equally as important (Barber et a. 2008; Moser 2016).

Over the past 50 years, the average temperature of the Arctic has risen by 2-3 °C, which has drastic impacts on ecosystems, as well as on Indigenous Peoples living in the Arctic (Ford and Pearce 2010; Griffiths et al. 2017; Casagrande et al. 2021). This phenomenon, also known as Arctic amplification, and its impact on the environment and communities, has led to an increasing interest by researchers from various scientific disciplines and sparked a large number of research projects in both the natural and social sciences situated in the northern parts of the United States of America, Canada, Greenland, Scandinavia, and Russia (Aknes and Hessen 2009; Serreze and Barry 2011). For example, the last International Polar Year (IPY), a large international and interdisciplinary initiative, led to extensive global efforts to understand climate change impacts on terrestrial, lacustrine, and marine ecosystems, as well as on the relationships between climate change and Indigenous well-being, sense of place, and adaptive capacities (Barber et al. 2008; ISC 2008; Ford and Furgal 2009; Walsh et al. 2011; Henry et al. 2012; Durkalec et al. 2015). In recent years, it has been increasingly recognized within the scientific communities, that the combination of both natural and social science approaches to understand climate impacts is crucial for a more holistic way forward to establish effective adaptation strategies in the circumpolar Arctic (Barber et al. 2008).

To better understand climate change in the Arctic, it is equally important to widen the perspective on how this knowledge should subsequently be communicated, as these insights could have far-reaching implications on national and international policymaking (Flynn and Ford 2020). There are many different conceptualizations and synonyms for research communication in the literature, which differ slightly based on discipline. Burns et al. (2003) define science communication as "the use of appropriate skills, media, activities, and dialogue". This definition is inherently grounded in producing awareness, effective responses, interest, opinions, and understanding of the information communicated. Burns et al. (2003) therefore focus on the intention for intervention and application as a principal mechanism of communication. Similarly, the Social Science and Humanities Research Council of Canada (SSHRC) defines knowledge mobilization as "the reciprocal and complementary flow and uptake of research knowledge between researchers, knowledge brokers, and knowledge users - both within and beyond academia". In practice, this implies that a two-way transfer of knowledge, the demonstration of reciprocal and complementary flow, should inform research priorities, theories, and methodologies within academia. Outside of academia, the ability to engage and communicate reciprocally should inform public debates and policymaking, as well as lead to informed decision-making by businesses, governments, the global media, and civilians (SSHRC 2021).

In a diverse society, effective communication and informed decision-making requires the representation of all parties involved. The concept of *Etuaptmumk* (Two-eyed seeing) was initially introduced by Mi'kmaw Elders Albert and Murdena Marshall of the Eskasoni First Nation to make scientific approaches more knowledge-inclusive (Bartlett et al. 2015). It emphasizes that a combination of Western scientific knowledge paradigms and Indigenous knowledge systems, and collaboration between scientists and Indigenous Peoples in research, is key to a more holistic and complete understanding and provides the path to clear and meaningful communication (Wright et al. 2009). Here, the definition outlined by the SSHRC was used, while also emphasizing the inclusion of Indigenous values and knowledge concerning the reciprocity and complementation of information flow.

While reciprocal communication and engagement with Indigenous Peoples are now recognized as a principal basis for decision-making in Canada, researchers often do not have a sense of how to initiate these conversations before, during, and after their projects (Bowie 2013; Henri et al. 2020). When the community's and researcher's needs and interests converge, it can lead to a highly productive collaborative partnership, through which knowledge can be co-produced in a way that benefits all parties involved. Wolfe et al. (2011) reflect on such a scenario, where an IPY project in Old Crow in the Yukon, was developed in close partnership over several years to further the understanding of the impact of climate change on the environment and society. However, researchers often continue to struggle with meaningful community involvement and communication, even if they have the right ideas at the start. Discussions about research agency, research impact, and appropriate methodologies continue to get in the way of a two-way transfer of knowledge and collaboration between researchers and Indigenous communities (Gearheard and Shirley 2007).

The communication of climate change remains an inherently difficult task, due to the scope and complexity of climate change itself. The uncertain trajectory of climate change and its impacts on this planet have continuously introduced controversy and skepticism among some elements of society (Ballantyne 2016). Many causal links between the changes seen and experienced, are yet to be understood, which is even more apparent when discussing Arctic systems. Even if changes are immediately visible, the trajectory of change may not be apparent due to a lack of context, as the effects of climate change in the Arctic are often constrained to a single lifetime (Myers-Smith et al. 2020). As such, the contextualization and communication of climate change research often require a definition of what the message will be to effectively communicate it. Technical language is difficult to absorb and appreciate, and researchers often have a difficult time summarizing results in a way that is non-technical yet at the same time preserving the core findings (McBean and Hengeveld 2000). Likewise, the collective ecological knowledge of generations forms the baseline for Inuit society, and observed changes to the environment should be put into that perspective (Pearce et al. 2009; Flynn and Ford 2020). Intrinsically, communication about climate change requires careful thought into the purpose of the message, how it should be framed, who should frame it, and which mode or channel of communication is most appropriate (Moser 2016).

Community-based approaches to research take time, which for ECRs can be difficult to achieve in the allotted time associated with their undergraduate or graduate programs. While budgetary obstacles are always an issue, the lack of time to gain the amount of experience necessary to conduct meaningful engagement with Indigenous Peoples is a primary challenge. Likewise, meaningful knowledge mobilization requires an enhanced understanding of local contexts, followed by clear guidelines on how engagement should occur and how communication can be improved on the individual research scale. There is currently limited guidance on how to overcome some of these obstacles outlined above, specifically directed at ECRs (Tondu et al. 2014; Flynn and Ford 2020). As such, the purpose here was to establish how Arctic organizations recommend ECRs to approach communication of climate change-related research in the Canadian Arctic. By drawing on the perspectives of experienced practitioners in the Canadian Arctic, the aim was to: 1) outline common challenges and barriers for ECRs to conduct and communicate their research in a way that is meaningful to the target audience, 2) provide informed guidelines as starting points for ECRs to engage in more meaningful science communication despite common challenges, and 3) highlight knowledge gaps for future work to advance the current understanding and guidelines on how climate change research should be communicated in practice. Through these reflections on challenges and advice outlined, the goal was to contribute to the ongoing discussion around meaningful and community-focused science communication and to encourage researchers to start thinking about their role in the purposeful mobilization of knowledge early on in their research process, so they can take the necessary steps when starting or continuing their careers in the Arctic.

4.4 Methods

4.4.1 Preparation and ethics approval

It is often difficult to know how to disseminate knowledge to communities in a meaningful and effective way and requires engagement in the current best practices of knowledge mobilization. Initial conversations with the ARI and the Inuvialuit Regional Corporation (IRC) helped frame the scope and focus of this project (Figure 4.1). Following these discussions, common objectives for this study were identified, and a Knowledge Co-Production Agreement was drafted between the researchers and the IRC. Feedback on the research approach and design was sought from Indigenous organizations in July 2023. Based on these initial conversations, many of which were conducted in person, two Research Ethics Board (REB) applications were submitted in parallel to Dalhousie University (REB # 2023-6747) and the ARI. A pre-existing Natural Science research license (Northwest Territories Scientific Research Licence No. 17199) was amended by the ARI to incorporate the social-scientific aspects of this research project. A provisional approval from the REB at Dalhousie University was subsequently submitted to the ARI for their approval, which was then accepted by the Dalhousie REB.

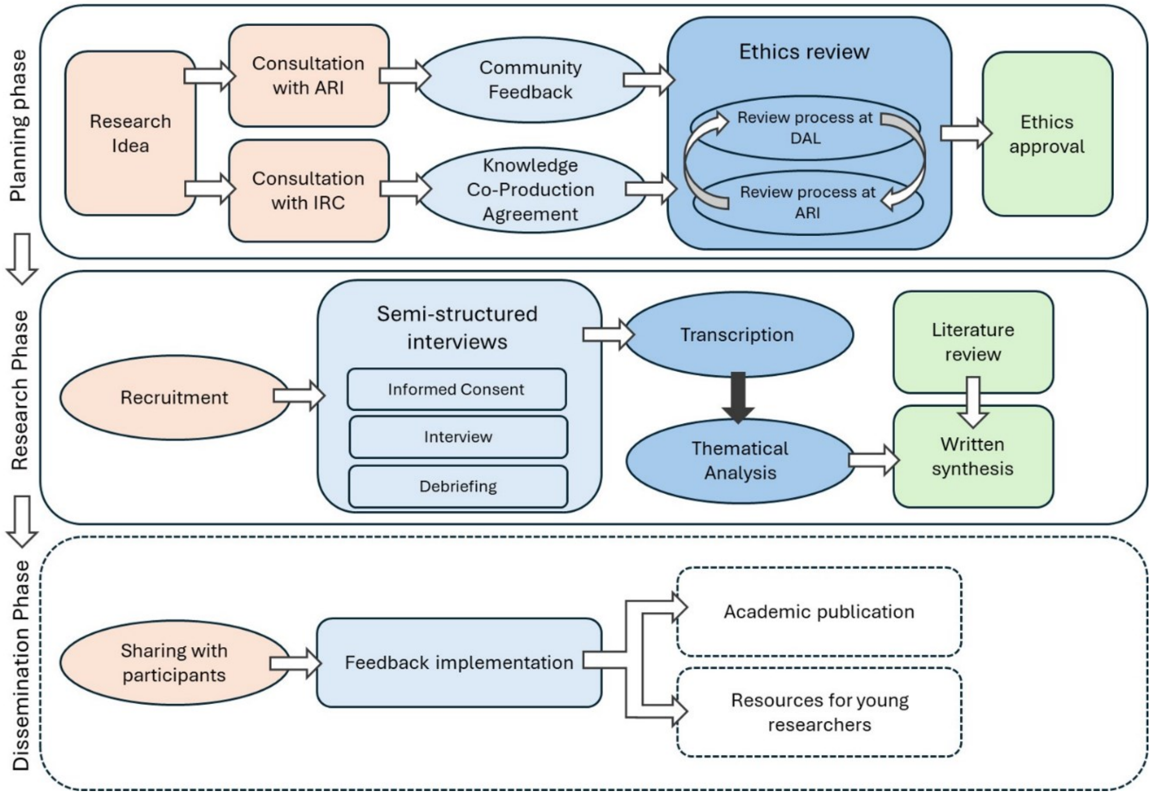

Figure 4.1 Visualization of the methodological workflow of the research development, implementation, and dissemination phase.

4.4.2 Semi-structured interview process

Practitioners from four Arctic organizations, which were identified as experts in climate change-related research with respect to Indigenous Peoples in the Arctic, were invited, either via phone or email, to participate in a 30-60-minute interview on how academic researchers in Canada should approach knowledge mobilization. Participation was voluntary and each participant was provided an opportunity to have informed consent; the ability to review the study objectives and agree to interview questions on their own time before the scheduled interview date. All meetings were conducted virtually via Microsoft

Teams. At the start of each interview, the participant was verbally briefed on the information outlined on the consent form, including the purpose of the research, the right to withdraw, data management procedures, and measures of confidentiality, and asked for permission for audio recording. All semi-structured interviews were conducted in English. The researcher followed an interview guide with a list of qualitative questions and conversational prompts (see supplementary material). After each interview, participants were asked to review their choices made on the consent form and apply any changes if wished. Participants were informed that they would be recontacted for any direct use of their knowledge, such as quotes, for approval.

4.4.3 Thematic analysis

Interviews were transcribed promptly after the completion of each interview. The transcript from each participant was shared for review and correction if necessary. Recordings were subsequently deleted. Interview transcripts were thematically analyzed in NVivo using iterative categorization, a mixture of deductive and inductive coding (Neale 2016), to identify key themes and sub-themes based on commonalities among the participants' responses. For this process, responses were deductively split into *Challenges* and *Advice*, based on the focus of the interview questions. Interview transcripts were read closely, and responses from each participant were manually coded in the form of inductive nodes in the software. These nodes were then merged into apparent sub-themes and clustered by themes. Quotations from transcripts to reinforce topics were chosen and shared with participants for permission for use.

4.5 Results

A total of six practitioners from the Northwest Territories and Nunavut were interviewed (Table 4.1). Half of the participants indicated that they grew up in the Canadian Arctic, while the other half indicated that they moved to the Arctic for work at a later stage in life. Five of the participants interviewed, identified that they were currently in a profession that is directly involved with knowledge mobilization of climate change research, while one indicated to have worked in this capacity in a previous role.

All participants mentioned that they, or their organization, are frequently consulted by external researchers on how to communicate their research back to the communities in a meaningful way - and all six participants agreed that there is a need for better and more purposeful communication of knowledge in climate change research. Participants mentioned different means by which they work together with communities to obtain feedback and guidance on how to conduct knowledge mobilization in a more dedicated way, including community visits, consultations with community leaders, workshops, presentations, youth outreach projects, teleconferences, and surveys (P2; P3; P4; P5). When asked about the challenges they see for ECRs, participants voiced many challenges from a logistical standpoint, as well as from a community engagement perspective (Figure 4.2). To overcome some of those challenges, participants offered some advice on how to conduct research in a way that allows for a more meaningful knowledge exchange (Figure 4.3).

Table 4.1 Research participant characteristics, including participant code, affiliation, and involvement within knowledge mobilization of climate change-related research.

Participant Code	Affiliation	Involvement
P1	Territorial Organization	Conservation projects Community outreach International conferences
P2	Territorial Organization	Research promotion Community outreach Press releases
P3	Regional Organization	Community-based programs Community research priorities
P4	Territorial Organization	Research training Community outreach National conferences
P5	Territorial Organization	Research licensing Research logistical support Community outreach
P6	National Organization	Research strategy Policy advice Community outreach (Inter)national conferences

4.5.1 Challenges

During the interviews, participants identified many challenges that ECRs are faced with on their path to conducting and communicating their research in a meaningful way. The challenges discussed here can be largely classified into logistical and cultural obstacles.

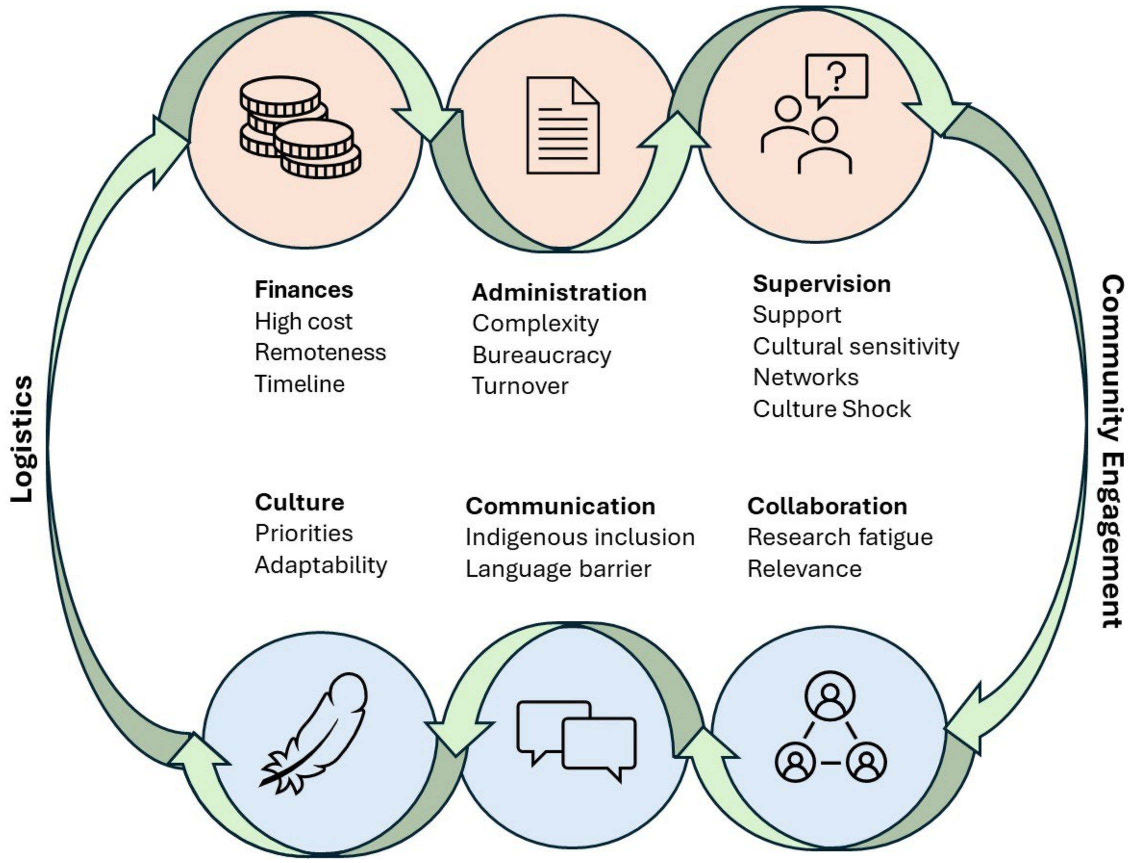

Figure 4.2 Visualisation of challenges for ECRs concerning meaningful knowledge mobilization, as summarized by thematic analysis of expert interviews. Challenges can be categorized into logistical challenges, and community engagement challenges, which create obstacles for ECRs.

All participants acknowledged the discrepancy between the high cost of research in the Arctic and the funding made available. Hosting in-person workshops or events to seek feedback from the community before the research project, as well as communicating research results back to the community, is therefore not always feasible. Many Arctic communities are very remote, and infrastructure is sparse, which makes community visits even more difficult (P1; P4). However, upfront in-person visits are fundamental in establishing close relationships with local partners and learning more about local research priorities, which is essential to shaping research designs and methodologies before the start of each project (P3; P5; P6). Participants highlighted the fact that community work takes a lot of time and local presence to build connections and trust, a process that often extends way beyond the timeline that a Master's or Ph.D. project would allow for (P3; P4; P5). While diligent research takes time, life in the community continues, priorities shift, and results and outputs can fall behind (P5). Besides creating obstacles to knowledge mobilization, a lack of funding and limited time can also create other problems, such as a heightened willingness to take risks during bad weather conditions that can put both researchers and local research assistants at risk (P4);

> "*Occasionally we hear about researchers being a bit pushy, (…) they have their narrow time windows where they scheduled to be in the north, and they get there and maybe the weather is too dangerous to be going out to the site because that happens*" (P4).

While licensing processes, ethics reviews, and community engagement are broadly known to be important, they also take time (P1). Between the high workload of staff and the fast turnover of employees in the Arctic, messages can get lost and non-responses can be high. This adds a layer of complexity where it is hard to keep track of the professionals to contact with questions concerning communication of knowledge (P2; P5; P6). Therefore, having well-connected networks is very important, but often ECRs do not have the time to establish these relationships upfront, which limits the availability of local support (P2; P3). Participants note that most academic researchers come from a

Western context and would benefit from more guidance on how to conduct their research in a more culturally sensitive manner (P2). Cultural sensitivity is particularly important when it comes to communicating controversial research results to communities and the public, and it requires a lot of informed reading and immersion in the culture and history of the communities to avoid causing harm (P4; P6);

> "*I've seen that a lot with researchers where they're like, 'Oh my God, I got this data on this new parasite that's coming to affecting the health of beluga whales. It can totally affect human health. I better tell somebody about that'. And they do it in very irresponsible manner, without any other contextualizing of the information - and so huge fear comes in, people stop eating. We have people in the Kivalliq region who do not eat beluga whale to this day because of a message that was given 40-50 years ago about mercury levels in beluga whale*" (P6).

With the large volume of research projects, due to the increased interest in climate change impacts, participants said it is also crucial to make sure that the new research is relevant to the communities, to avoid generating research fatigue (P4; P5). If communities are overwhelmed with the sheer amount of research being conducted, research fatigue can constitute a barrier to community engagement in research and knowledge communication, as one participant highlighted (P5).

> "*I've heard this, that Inuit are one of the most studied people on Earth, and there is quite a lot of research fatigue that occurs. So, it's not really that we want more researchers, is that we want more quality researchers*" (P4).

The history of research fatigue means that much more diligence is required to review baseline research on the topic before engagement with communities, such that feelings of repetition do not occur for subsequent projects on the same topic (P5). At the same time, ECRs should remain humble, recognize and accept when proposed projects are decided to not be moved forward (P4). Communication and engagement are also impeded by differences in language. Seldom are ECRs well-versed in the local dialects, or have the funds to hire a local translator, which further limits the scope of their outreach (P1; P5; P6).

Meaningful involvement of Indigenous Knowledge and skillsets within the principal research itself, let alone communication of results, is often challenging according to participants. Several participants noted that even with the creation of best practices to decolonize the research process, there remains a challenge to establish how effectively these policies are implemented on a small scale (P2; P5). For example, P5 noted that it is commonplace for research teams to contact a local outfitter for assistance in bear monitoring, but questions the applicability of this in terms of meaningful engagement:

> "*There's a lot of ways that researchers can claim that they are incorporating local knowledge or involving community members that are really perfunctory or not meaningful, but it's again so hard to really do a qualitative audit on all of these hundreds of projects to determine 'OK, which are legitimately meaningfully incorporating new knowledge and building capacity and using that knowledge to inform our research approach?'. It's difficult*" (P5).

4.5.2 Advice

Participants were asked how they would advise ECRs to communicate the knowledge produced by the work that they do. The recommendations that were given by the participants of this study can be summarized broadly as approaching research in a well-informed, resourceful, and flexible manner.

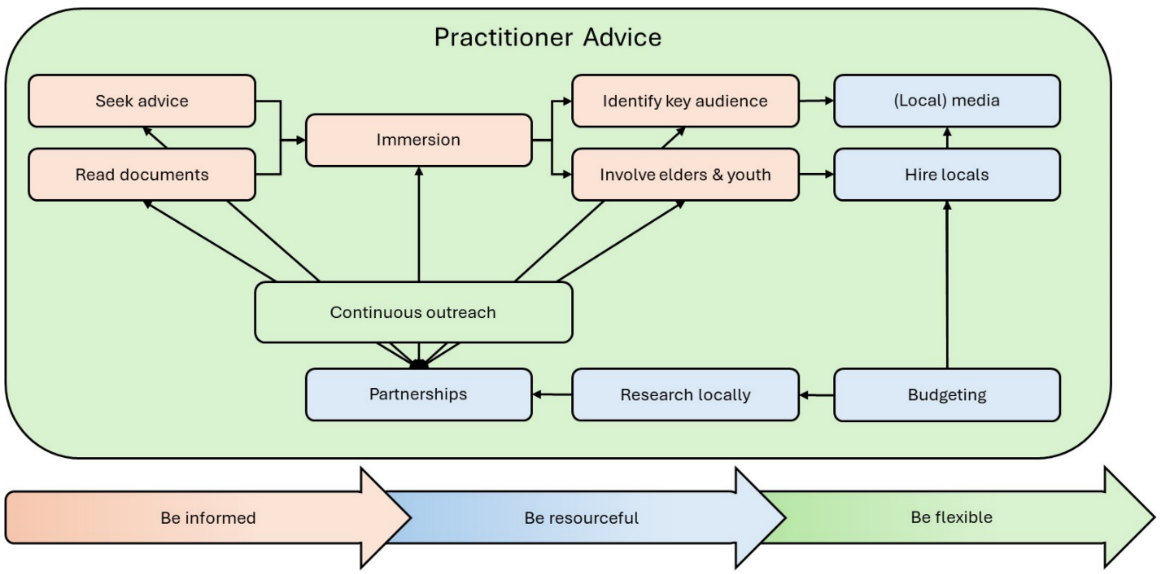

Figure 4.3 Visualisation of the advice for ECRs concerning meaningful knowledge mobilization, as summarized by thematic analysis of expert interviews. Advice can be categorized into three generally applicable mandates: 1) Be informed, 2) Be resourceful, and 3) Be flexible. (Bi)directional arrows show which processes inform each other qualitatively.

Participants broadly suggested that researchers seek advice from communities at an early stage, ideally before the research project has started (P1; P2; P3; P5; P6). The highlighted benefit is to establish a grounded support network from an early point, which can be helpful both in shaping the research project to make it community-relevant, and making a feasible project-tailored dissemination plan of how the research will be communicated to the community (P3; P5; P6). The best way of doing this well is through direct partnerships (P3; P4; P5; P6). Here, it can be helpful to have a supervisor who is well-connected with the communities of interest, to help establish these partnerships and make those connections on behalf of the student, to save time and resources (P3). Local partnerships are mutually beneficial in that they can provide important contacts, help you to identify your target audience, or help find effective modes of communication, such as connecting you with local schools or local media sources; but they can also make sure that your research is in line with local research priorities (P1; P2). Participants mentioned popular means of knowledge mobilizing in their communities, or communities they work with, are the use of local radio, hanging posters in the regional post office, organizing open houses, posting events and connecting on Facebook (P1; P2; P3; P5; P6). Proceeding, as well as alongside seeking advice, the ECRs should be doing a lot of background research, both on what has already been done on that specific research topic, as well as on the history and culture of the target community, as this will be a necessary step towards more culturally sensitive conduct, both concerning the research process itself and knowledge mobilization (P4; P5; P6);

> "*There are a number of stories, and I guess historical context, that researchers should be aware of coming working with Inuit, and I would advise that you become familiar with Inuit history, Inuit political history, and that sort of thing before coming up. That would help you recognize the sensitivities around certain*

subjects and that would go a long way toward not souring any relationships that you're trying to develop" (P4*).*

As P1 summarized, ultimately, the best approach is to "come up North and find out". While spending time in Arctic communities is costly, setting a few extra days aside to attend community events has been noted to have an enormous value in building trust, as well as getting a sense of the community (P4). Participants pointed out that when thinking about knowledge communication, researchers must ask themselves what they are trying to achieve with the information that they are communicating, for example, whether the communication is directed at awareness or action (P5; P6). Likewise, research that focuses on passing information from Elders to youth is especially appreciated;

"*We often like to involve youth in activities because that develops their skill set and it (…) makes for us to have a strong future workforce - not really the way I want to describe it - a strong future generation of adults. If they're able to have these opportunities for children, so any sort of research that incorporates that type of skill development in youth usually is a lot more favourable within a community*" (P4).

With limited funding availabilities, ECRs often must be creative (P4; P6). For example, having a strong connection with local partners can be helpful to communicate research locally and avoid costly travel (P4). Being based in a "community hub city" (P4), where travel to the Arctic is more accessible due to the established infrastructure, can also further reduce some of the costs associated with communicating knowledge. However, most participants agreed that it is important for knowledge mobilization to be treated as a continuous process and occur throughout the project, and not be left until the end (P1; P3; P6).

4.6 Discussion

Early and continuous communication among researchers and communities is key to establishing mutual ground by which both parties can benefit from the research being proposed and conducted. To bridge some of these barriers, ECRs are encouraged to follow more community-based approaches (Hill et al. 2023). However, ECRs are often faced with logistical and cultural challenges with respect to working and communicating with Indigenous Peoples given the funding and deadlines associated with their projects. The six participants who were interviewed allowed the identification of some of the most prevalent and apparent barriers and informed strategies on how to mitigate those obstacles, provided here as guidelines for ECRs in the hope of making their research process less challenging. Here, it is important to take a step back and note that while interview questions and participants' advice were intentionally phrased for ECRs, both are more broadly applicable to all researchers, at any stage in their careers.

4.6.1 Logistical challenges

Research in Arctic regions will inherently involve many logistical challenges, including financial, administrative, and supervisory barriers. Mallory et al. (2018) suggest that research in the Arctic is on average eight times as costly as comparable projects conducted elsewhere in southern parts of four of the Arctic Nations (Canada, the United States of America, Greenland, and Norway). This is a significant discrepancy that needs to be addressed by policymakers and funding agencies (Gearheard and Shirley 2007). Thanks to the global IPY initiative, there has been an increase in funding allocated towards Arctic research, which supported some short-term projects; however, more substantial long-lasting funding is needed to carry on this legacy (Mallory et al. 2009; Wolfe et al. 2011). A large part of the funding for Arctic research projects is allocated to logistical expenses, such as travel and shipments of equipment (Mallory et al. 2009), and knowledge mobilization can fall short in budgetary considerations;

> "*It's much more challenging and time-consuming to organize these [knowledge mobilization] activities than the researcher would have anticipated, and so plans change. Funds allocated for this work are quietly reallocated to lab analysis and the training program, or the knowledge component of a study is very quietly shelved, or deferred, or delayed*" (P5).

Transportation in the Canadian Arctic is limited, and many communities are serviced primarily by costly air transportation (Koch 2021). This complicates travel for researchers, limiting their time spent in the communities. Researchers are also often pressured by time constraints when conducting their fieldwork, the expectation of results after one to two years limits the amount of community engagement opportunities, both before the commencement of fieldwork activities, but especially after their projects have concluded (Pearce et al. 2009; Flynn and Ford 2020).

The limited capacity of Arctic organizations can also limit the amount of assistance available to researchers. While there are numerous potential partners across the circumpolar Arctic, the capacity of facility and staff is limited. Participants in this study noted a high turnover rate of their staff can constitute a major hindrance to assisting researchers. The lack of capacity of Arctic organizations is also evident when it comes to meaningful and long-lasting communication of research results (Pearce et al. 2009; Flynn and Ford 2020);

> "*The thing that's really important for people to realize is that the turnover rate at the community level is so great that even though you may have done a really good communication component the year before, it may be a whole new people in that organization that now need to know it again; and so the challenges is to find ways to communicate, in a long term element rather than a kind of a one-shot dea*l" (P6).

Consequently, many researchers continue to struggle with communicating their research back to communities, especially in the context of climate change, which is "massive in scope" (P6) and affects the environment and community across many different levels (Pearce et al. 2009; Walsh et al. 2011). Even though researchers are now obligated to communicate and consult with local communities as part of their funding and research licensing process, there remains a lack of clarity as to how this should be done, and local research organizations cannot constantly monitor all ongoing research activities or the dissemination of their results. With limited support available, researchers struggle with meaningful engagement, especially those in the natural sciences given that they tend to be less trained in theoretical and practical applications of community-based research compared to social scientists (Gearheard and Shirley 2007).

4.6.2 Community engagement

The current research paradigm in the Arctic is increasingly leaning towards knowledge co-production, which entails extensive community engagement, before, during, and after each research project (Armitage et al. 2011). This requires community involvement in developing the research design as well as administering it in practice (Pearce et al. 2009; Flynn and Ford, 2020). Hiring locals to part-take in the research, can help mitigate linguistical and cultural barriers, as well as mobilize research skills. Involving communities in the dissemination process can also help determine how knowledge will be translated into action, for example, through local policymaking (Pearce et al. 2009). Flynn and Ford (2020) established that knowledge mobilization depends on trust, mutual understanding, and researcher responsibility, using academic literature and key informant interviews. This means that researchers must form close relationships and partnerships with communities, combine different knowledge systems, and communicate beyond their academic sphere (Flynn and Ford 2020);

> "*You need both the buy-in from the researcher, and you need the buy-in from the regional organization, and you need the buy-in from the community to do [research] successfully - without that, without any of those things going, it's not going to work*" (P6).

The need for a presence in a community, outside of the research activities, is a crucial step for proper engagement, networking, and ultimately a meaningful and respectful two-way transfer of knowledge in a culturally sensitive manner (Gearheard and Shirley 2007; Pearce et al. 2009). However, research fatigue has been noted by participants to be common in small communities, where population numbers are low, but can also arise if projects have insufficient community involvement (Chambers et al. 2021). Technical jargon complicates the ability to align research objectives to community priorities (McBean and Hengeveld 2000; Prno et al. 2011);

> "*I think when a researcher does research, that is an inherently interesting topic to them, so anything that they're finding (...) or wherever they're doing this research is interesting because that's the nature of doing research. However, when you try to tell this to community members or something, it might not necessarily be interesting to them"* (P3).

While climate change in the Arctic is often perceived as a threat to their cultural existence, many Indigenous Peoples stress the fact that they have other more pressing issues to attend to first (Prno et al. 2011; Sloan 2019). Economic and health-related issues can supersede environmental concerns (Lede et al. 2021). Housing is sparse, and costs, unemployment rates, and substance abuse are high (Kruse et al. 2008; Mead et al. 2010; Perreault et al. 2020). Climate change impacts compound with some of these pressing challenges, and therefore these impacts cannot be studied or communicated in isolation from one another (Lede et al. 2021).

Ultimately, applications of community engagement in research will vary across the disciplines of Arctic research. Every community is a little bit different, including differences in language and dialect, and therefore engagement and communication need to also vary accordingly (Wolfe et al. 2007). Since audits of what constitutes meaningful community engagement on project-level are logistically infeasible (Gearheard and Shirley), the responsibility lies within the realm of the researcher to have open and honest lines of communication that incorporate feedback in a research approach;

"*You already know what the project is, what the goals of the project are, and at that point in time if you're asking community members, your thoughts – it's not true collaboration, it is more extractive than anything else*" (P3).

4.6.3 Advice and future work

There is a pressing need for well-informed guidelines on how to communicate research meaningfully in the Arctic regions (Tondu et al. 2014). To date, there is a large consensus within academic literature that researchers must be well informed, both on their research topic, and their target community's culture, history, and research priorities (Pearce et al. 2009; Tondu et al. 2014; Flynn and Ford 2020). These studies emphasize the importance of understanding and reflecting on the local history through immersion in, and interaction with communities, to be able to conduct research in a culturally sensitive manner. It is also largely recognized that working in close partnership with Indigenous Peoples is a great means of being resourceful when conducting research (Pearce et al. 2009; Brunet et al. 2014; Tondu et al. 2014; Flynn and Ford 2020). One of the many benefits of close partnerships is a clearer emphasis on the combination of knowledge systems with the common goal of advancing the understanding of complex phenomena, such as climate change impacts in the Arctic (Brunet et al. 2014). This is a process that requires a great deal of flexibility and adaptability on the side of the researcher, both in working with Indigenous Peoples, adapting current academic modes of communicating research, and overall assimilating with a more interdisciplinary approach towards Arctic research (Pearce et al. 2009; Tondu et al. 2014; Flynn and Ford 2020).

Discussions about the need for meaningful and effective knowledge mobilization are ongoing across all of the Arctic organizations that were contacted for this study. The acknowledgment of vague protocols and guidelines was made during the conversations with participants. Participants noted that sometimes reaching out to the community can be 'as easy as' putting up a poster at the regional post office or making an announcement through the local radio or Facebook (P1; P2; P6). There will likely never be a 'one-fits-all' answer for how to conduct effective communication and engagement, and it is highly dependent on the nature of the research, the community involved, and the partnerships and trust built between the researcher and the community (Wolfe et al. 2007; Pearce et al. 2009; Flynn and Ford 2020; P3). However, researchers, communities, and organizations will need to continue this conversation together, to expand mutual understanding, when it comes to communicating research;

> "*There's no silver bullet to communication and it's all about understanding the needs of that community at that time, at that place and those people, and also regionally, and nationally, and internationally as well. So, to be open and to be kind of adaptable to the changes of communication are just as important as being adaptable and open to your research that you're doing as well*" (P6).

4.7 Conclusions

Climate change is a complex phenomenon, which makes knowledge mobilization of climate change-related research in the Canadian Arctic even more challenging, especially for ECRs, who have limited resources and experience with research in the Arctic. Informed guidelines and resources on how to conduct effective and meaningful knowledge mobilization are sparse. Six experienced practitioners in the Canadian Arctic were interviewed to provide their informed perspectives. Based on these interviews, it became apparent that researchers face many logistical and cultural barriers; and to mitigate these challenges, researchers should be well-informed, resourceful, and flexible in their approach. Ultimately, the question of knowledge mobilization is context-dependent, and the best approach may vary depending on the research project and the communities involved. However, learning from the recommendations provided by practitioners and academic literature, from an early stage of the research process, can support researchers to mobilize knowledge in a more culturally sensitive way. More community-based research is needed to advance and inform the understanding of how knowledge of climate change impacts in the Arctic can be communicated in a meaningful way.

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CHAPTER 5 CONCLUSION AND FUTURE DIRECTIONS

5.1 Introduction

The influence of climate change has far-reaching implications for natural ecosystems and Indigenous communities who rely on those systems to survive (Griffiths et al. 2017). This is why we need to communicate them outside of both disciplinary and cultural bounds, by combining well-established methodologies in both the social and natural sciences (Strøm 1929; Ford and Pearce 2010; Lau et al. 2019; Knott et al. 2022). This final chapter provides a concise reflection on the key insights laid out in the previous chapters. As such, it concludes that an interdisciplinary approach to Arctic research is more fruitful for developing a more complete understanding of the multifaceted and interconnected impacts of climate change in the Arctic, than any one scientific discipline alone. While this thesis provides three chapters that have standalone approaches, when considered together, they highlight how future research could further this knowledge in a more interdisciplinary way.

5.2 Key insights

A strong connection with the environment lies at the core of Inuit identity, yet increasingly variable climatic conditions have far-reaching consequences for Inuit culture and society, which should guide research practice and knowledge mobilization strategies (Thériault 2013; Pearce et al. 2009; Flynn and Ford 2020). Chapter 2 seeks to gain an informed insight into how climate change is affecting Inuit well-being and their adaptive capacity to change. As such, a systematic literature review of interview studies available through three academic databases was blended with an interview case study with residents in Iqaluit. It became apparent that climate change is perceived mostly negatively, in the way that it impacts Inuit relationship to water and land.

This sentiment was also reflected in initial conversations started in 2012 when the communities of Inuvik and Tuktoyaktuk voiced concerns about the limited scientific understanding of how climate change impacts the lakes within the Mackenzie Uplands Region. Many of those lakes are of cultural importance serving both as sources of drinking water and habitats for locally harvested fish (FJMC 2024). Therefore, Chapter 3 investigates climate change impacts on local freshwater ecology by exploring the distribution of chironomids, which are an integral part of the aquatic ecosystem and food chain, while being sensitive to climate change-induced fluctuation in habitat conditions (Moquin et al. 2014; Lau et al. 2019). A limnological assessment of lakes along a small transect between Inuvik and Tuktoyaktuk revealed that chironomid assemblages in this region vary significantly due to lake morphology differences, in conductivity, TP, DOC, and total lake area, highlighting the important role that within-regional variability plays in chironomid distribution (Brodersen and Anderson 2002). To avoid overlooking this within-regional variability in large-scale latitudinal research, scientists should emphasize the documentation of habitat characteristics (Brodensen and Anderson 2002; Lau et al. 2019). Continuous monitoring of lakes within the Mackenzie Uplands Region could provide further insights into how these changes will progress and in turn how the cultural use of those lakes will be impacted.

Another important insight gained through Chapter 2 was that there appears to be a difference in how negative climate impacts are prioritized in urban and remote communities. While Inuit in remote communities more frequently voiced concerns about impacts on the environment, followed by changes in community and lastly impacts on physical and mental health, the inverse was found for Inuit in more urbanized contexts. This difference in conceptualizing the issue of climate change has important implications for communicating research and developing adaptation strategies and is therefore important to consider (O'brien et al. 2007). To reflect on current challenges and guidelines of knowledge mobilization approaches of Arctic research, six interviews with practitioners of Arctic organizations were conducted and subsequently discussed in Chapter 4. As such, there is a large consensus between the practitioner interviews and the academic literature, that recognizes that the importance of immersion in local history and culture at the early stage, before the start of any project, is equally important as building strong local partnerships that guide research practices (Pearce et al. 2009; Brunet et al. 2014; Tondu et al. 2014; Flynn and Ford 2020). To overcome both logistical and community-engagement challenges, researchers are advised to be well-informed, resourceful, and adaptable as they are learning how to communicate their research to communities in a way that is in line with concurrent community needs and priorities (Pearce et al. 2009; Tondu et al. 2014; Flynn and Ford 2020).

Ultimately, this synthesis aims to contribute to the ongoing discussion on meaningful and community-focused interdisciplinary research and knowledge mobilization to encourage researchers to think more intently about their role in research, regardless of the stage of their careers. Furthering collaborations between disciplines and impactful knowledge mobilization holds the key to raising and increasing awareness of important climatic development in vulnerable parts of this planet.

5.3 Reflections

An interdisciplinary lens on meaningful communication of both social and natural impacts of climate change lies at the core of this thesis and has informed the design process of this project throughout. However, it is important to be cognizant of the scope and as such the boundaries and limitations of this thesis as well. After all the project faced significant time constraints that cannot and should not be discounted (Figure 5.1).

A considerable amount was spent on relationship building, research licensing, and ethical applications, both within these two years as well as before this project started as early as 2012. This is a crucial step in research as thoroughly discussed in Chapter 4.

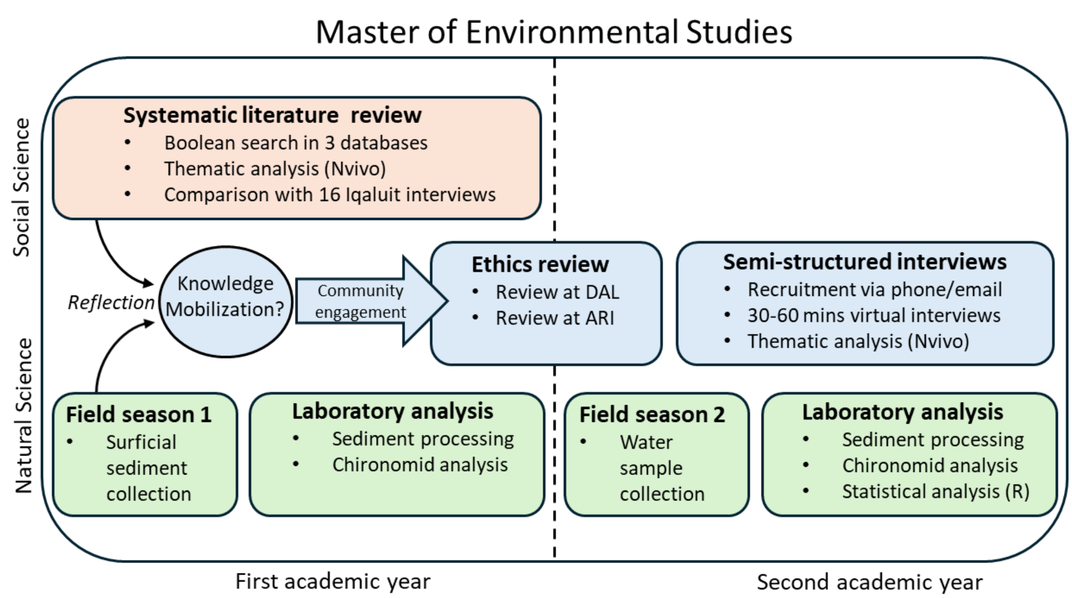

Figure 5.1 Visualization of the thesis process, spanning over the allotted two years of a Master's degree program, illustrating the interactions between and the amount spent on each component.

However, within a two-year time window allotted to a Master's degree, this process inevitably reduced the overall time and resources available to reach out to organizations and schedule interviews for the project outlined in Chapter 4. As a result, recruitment and interviews were limited to only one month, before the expiry of the research permit. This has considerably limited the scope of my outreach, and therefore the overall sample size, which certainly has implications for the generalizability of the results (Tipton et al. 2017). Fortunately, I was able to connect with four of the five well-established Arctic organizations, that I have contacted, thereby providing a broad range of perspectives on the local, regional, and national levels.

Another notable limitation related to both time and budget constraints refers to the knowledge mobilization outputs of this thesis. While in hindsight, it might have been insightful to have conducted an in-person workshop or announcement on the local radio, it is also crucial to keep in mind that 'doing more isn't necessarily doing better'. At the end of the day, what can be considered meaningful mobilization of knowledge should be determined by the communities involved and as such informed through concurrent community needs. I spent months, since the early stages of this project, communicating with the IRC and ARI, via phone calls, emails, and in person, to inquire about the community's preferred forms of knowledge mobilization. Through these interactions, I was invited to contribute two research summaries to the ISCC's Inuvialuit Research Newsletter over the course of two years and was approached by the ARI to collaborate on creating a resource webpage to make the recommendations, discussed in Chapter 4, more accessible to all researchers working within the ISR.

In the end, I learned a lot throughout this project about both the benefits and challenges of interdisciplinary research. Outweighing the pros and cons, I am convinced that successful interdisciplinary research is the way forward in a changing Arctic research paradigm. By fostering meaningful collaborations between researchers and communities, as well as between researchers from various disciplines, can we truly advance the collective understanding of the complex and rapid progression of climate change impacts on the Arctic. Each researcher, regardless of the stage of their career, has the responsibility to strive towards being well-rounded within their own disciplines, while also being open to other approaches and ways of gathering knowledge. This paradigm shift needs to be encouraged not only from the bottom up but also from the top down, by increasing governmental and institutional support, through funding initiatives and the incentivization of collaborative and interdisciplinary approaches in Arctic research. At the end of the day, these insights are nothing new. Brown et al. (2015) conclude that successful interdisciplinary work depends on five key principles: A shared mission, t-shaped researchers (researchers that are both well-established in and beyond their discipline), constructive dialogue, institutional support, and the bridging of research, policy, and practice. In other words, the foundation for productive change already exists, so now it is up to us, the research community, to make it happen.

5.4 Future directions

This thesis suggests that there is a difference in how climate change impacts are prioritized between urban and remote communities, consequently enforcing the suggestion that climate change cannot be studied in isolation from confounding socioeconomic impacts. Future projects could investigate more specifically how this difference in prioritization is manifested, both culturally and psychologically. One interesting hypothesis to test in future research would be the premise that climate change acts as an 'umbrella term' for many loosely connected associations that an individual makes based on their own experiences. As such, the topic 'climate change' could trigger a chain of associations that could lead to an apparent 'deviation' from the focus of the conversation to other seemingly 'unrelated' topics, as was evident in the Iqaluit interviews from 2014 and 2019 (Figure 5.2). If confirmed, this theory would further enforce the suggestion that climate change cannot be studied in isolation from confounding socioeconomic impacts.

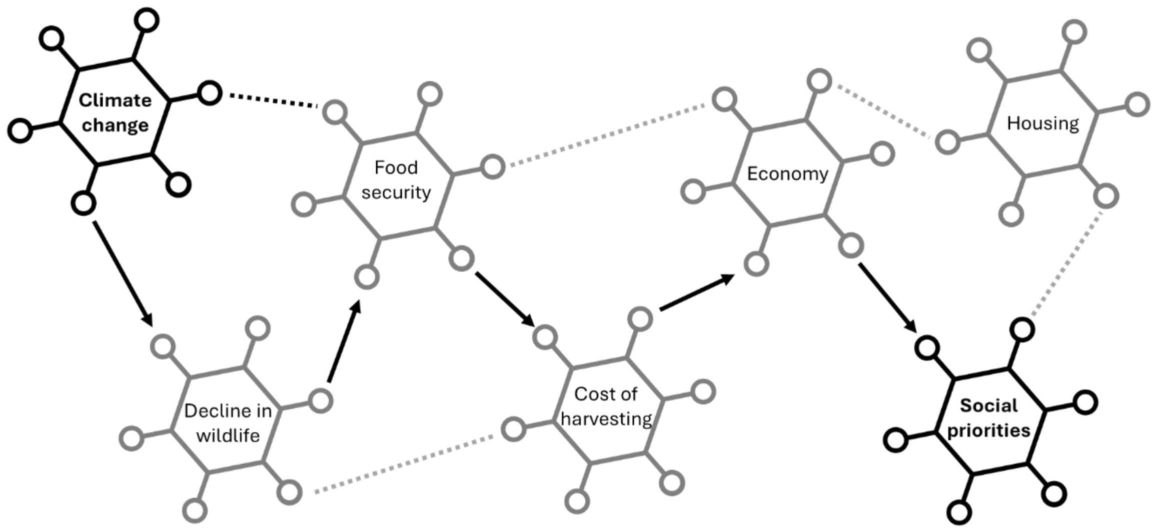

Figure 5.2 Visualization of one possible explanation of how individual associations with climate change could be connected, to explain deviations to seemingly 'unrelated' topics (e.g. social priorities) within the flow of a conversation on climate change. Nodes represent individual associations with climate change. Dashed arrows represent connections between these associations. Arrows represent the mechanism by which associations are linked within a conversational flow.

Further, this thesis also suggests that continuous terrain change in the Mackenzie Uplands Region will not only have implications for freshwater ecology but also for the cultural use of those lakes by local communities. Through conversations with residents from Inuvik and Tuktoyaktuk, many of the lakes studied in this thesis have been identified as common sources of drinking water and important habitats for locally sourced fish (FJMC 2024). As such, future researchers should make informed decisions when choosing which lakes to monitor, to make sure that their scientific assessments remain relevant to communities' acute needs. By doing so, research can not only be more meaningful to communities but also be more informative on the extent to which climate change is impacting not only the environment alone but also the Peoples who depend on it.

Unfortunately, combined assessments that weigh natural and socioeconomic factors equally within their study design will remain challenging in practice due to - but not limited to - the inherent differences in qualitative and quantitative data and methodologies (Williams et al. 2018). A combined approach to Arctic research is still in its infancy, and a lot of work still needs to be done on establishing standard protocols and training programs on how to combine methodologies and data (Wolfe et al. 2011). Especially researchers within the natural sciences would greatly benefit from well-established research training programs on community engagement and community-based research approaches (Gearheard and Shirley 2007). To date, such support systems remain limited, and a lot of the discussion on establishing such guidelines is still ongoing (Flynn and Ford 2020). Meanwhile, ECRs continue to struggle with conducting and communicating their research in a respectful and encompassing manner, due to a lack of professional experience with research in the Arctic (Tondu et al. 2014). Future social science research should add to the knowledge and help establish regional-specific guidelines for meaningful knowledge mobilization, fitted to the needs and research interests of the local communities. Ultimately, to provide long-lasting support for researchers at all stages of their careers, communities, organizations, and scientists need to continue the conversation on how research can be done and communicated in a way that is both respectful and productive in raising awareness of local research needs; thus, advancing the scientific understanding of complex Arctic phenomena, and establishing effective and long-lasting adaptive strategies within a rapidly evolving environment.

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APPENDIX: SUPPLEMENTARY MATERIALS FOR UNDERSTANDING CLIMATE CHANGE IMPACTS IN THE CANADIAN ARCTIC

Statement of Student Contributions

Study design by Annabe U. Marquardt and Andrew S. Medeiros, tables, figures and supplementary produced by Annabe U. Marquardt, except for Figure S.3, Supplementary S1 and Supplementary S2 by Clarissa Jewel and Andrew S. Medeiros, supplemental material writing by Annabe U. Marquardt with editorial contributions from Andrew S. Medeiros.

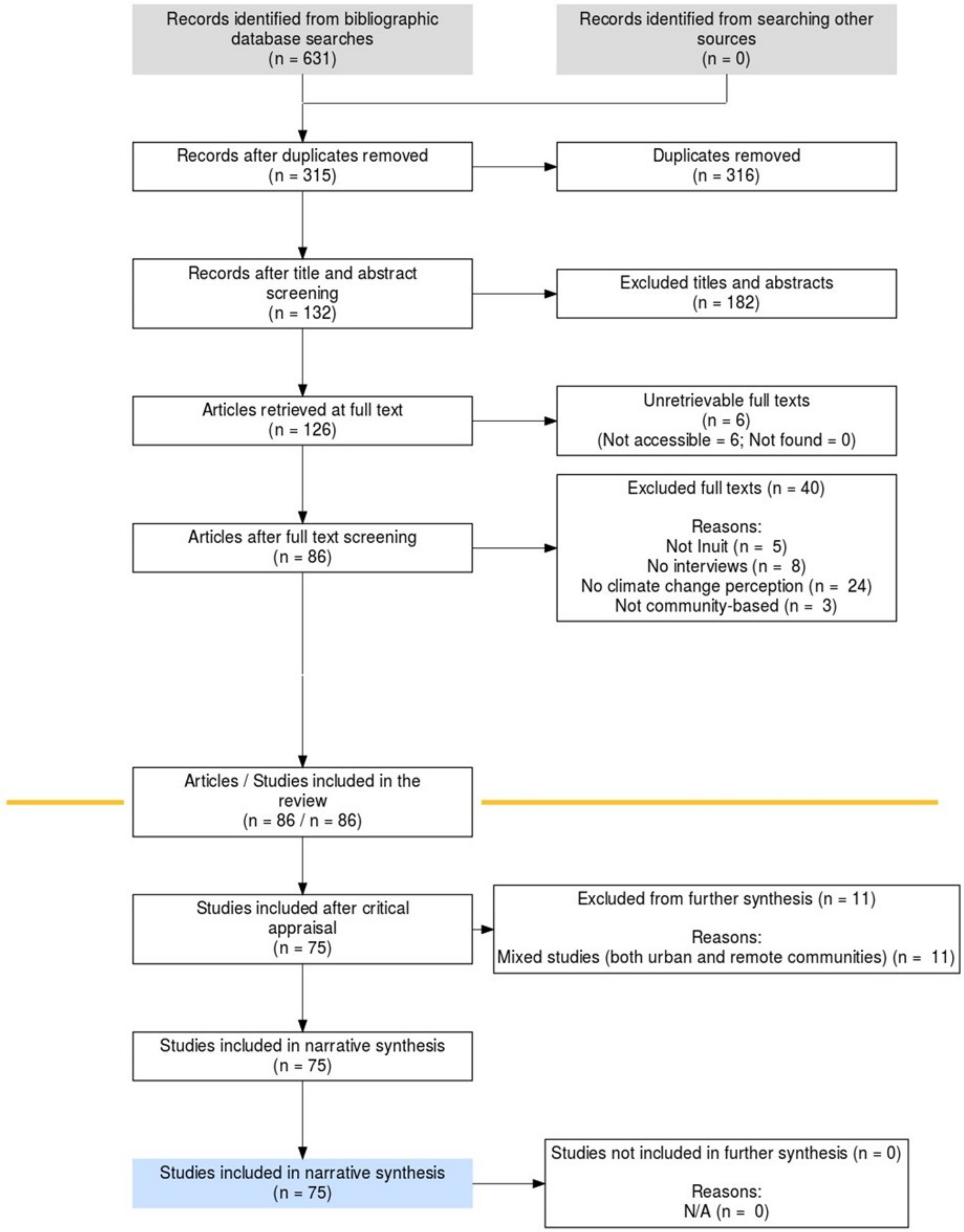

Figure S.1 ROSES flow chart of the screening process.

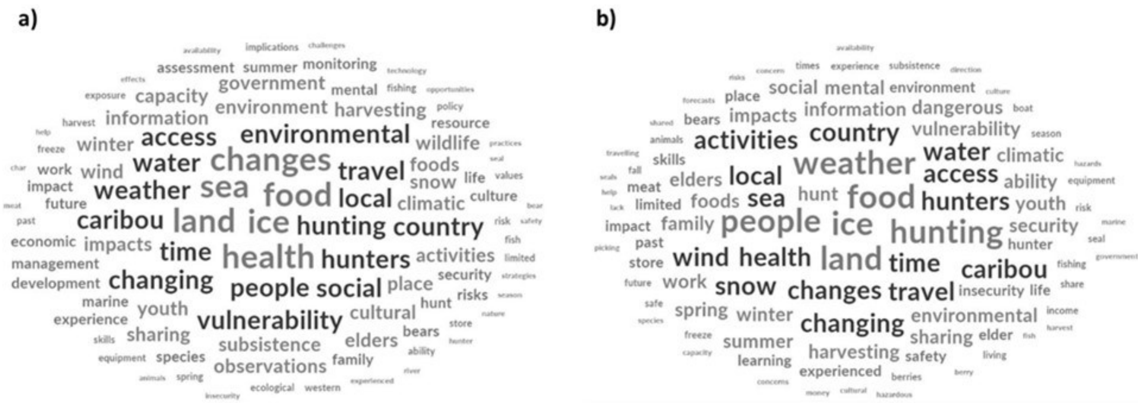

Figure S.2 Word cloud based on word frequency from interview studies conducted in a) remote communities, and b) urban communities.

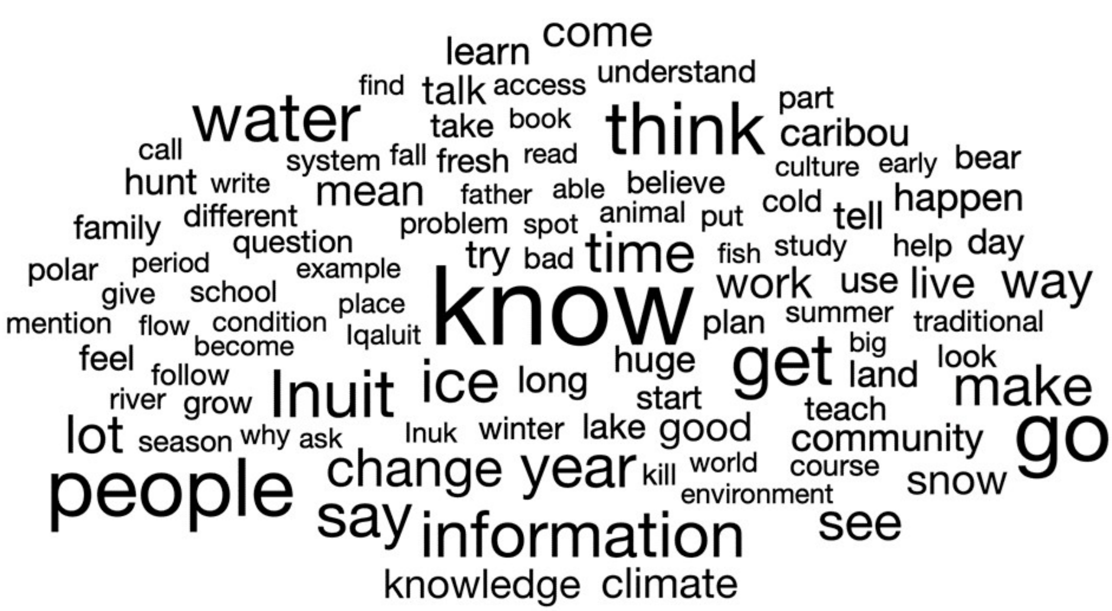

Figure S.3 Word cloud based on word frequency from the five transcribed 2019 semi-structured interviews, excluding questions and interviewer comments.

Table S.1 Overview of all communities included in the systematic literature review. Communities are in alphabetic order. Displayed are the total number of studies conducted in each community, the total number of participants (n) from all studies combined for each community, population size/density, and classification (urban/remote). Population estimates are based on census data from Statistics Canada 2016/2021, United States of America census data, and Statistics Greenland. Given the small population size of communities, it is likely that the same participants took part in multiple studies and are thereby overrepresented. *Estimates of n based on available information are provided for studies which did not specify the exact number of participants from each surveyed community.

Community	# studies	Total n	Population size	Population density (per km^2)	Classification (urban/ remote)
Aklavik	1	32	536	43.6	remote
Akutan	1	30	1,589	24.8	remote
Arctic Bay	2	115	994	4.1	remote
Arviat	2	>90*	2,864	22.7	remote
Brevig Mission	1	12	428	-	remote
Cambridge Bay	6	95	1,760	9.0	remote
Cape Dorset	3	>14*	1,396	141.2	remote
Cartwright	1	18	439	74.8	remote
Chesterfield Inlet	1	27	397	2.8	remote
Clyde River	2	50-52*	1,181	11.4	remote
Coral Harbour		10	1,035	8.2	remote

Community	# studies	Total n	Population size	Population density (per km^2)	Classification (urban/ remote)
Gjoa Haven	1	*	1,349	47.3	remote
Hopedale	4	>10*	596	273.7	remote
Igloolik	8	344	2,049	19.5	remote
Inukjuak	2	18	1,821	33.2	remote
Inuvik	1	61	3,137	50.0	urban
Iqaluit	4	1,198	7,429	144.0	urban
Ittoqqortoormiit	1	9	354	-	remote
Ivujivik	2	14	412	11.7	remote
Kangiqsualujjuaq	2	16	956	27.9	remote
Kangiqsujuaq	3	129	837	67.5	remote
Kapisillit	1	1	43	-	remote
Kawawachikamach	1	26	641	19.7	remote
Kimmirut	1	10	426	184.6	remote
Kugluktuk	5	87	1,382	2.6	remote
Kuujjuarapik	1	7	792	106.3	remote
Makkovik	4	>4*	365	123.5	remote
Nain	6	>59*	847	9.1	remote
Noatak	1	12	570	-	remote
Noorvik	1	11	694	-	remote
Pangnirtung	3	137	1,504	188.5	remote
Paulatuk	1	28	298	4.7	remote
Point Hope	2	89	830	-	remote

Community	# studies	Total n	Population size	Population density (per km^2)	Classification (urban/ remote)
Pond Inlet	3	32-34*	1,555	9.1	remote
Postville	3	>4*	188	78.7	remote
Qeqertarsuaq	2	217	852	-	remote
Qikiqtarjuaq	1	15-17*	593	4.5	remote
Quaqtaq	1	12	442 (2016)	15.5	remote
Quinhaqak	1	34	776	-	remote
Resolute	1	*	183	1.6	remote
Rigolet	14	>724*	327	62.0	remote
Sachs Harbour	2	>16	104	0.4	remote
Seldovia	1	91	235	-	remote
St. Lewis	1	24	181	18.0	remote
Tasiilaq	1	16	2,725	-	remote
Tikiranajuk	1	*	-	-	remote
Tuktoyaktuk	2	57	937	74.0	remote
Ulukhaktok	3	164	408	3.4	remote
Umiujaq	1	17	541	19.1	remote

Table S.2 Overview of emergent themes and sub-themes from combined results through the lens of an IQ-based framework.

Guiding principles	**Themes (combined)**	**Sub-themes (combined)**	**Potential outcome for Inuit well-being**		**Mentioned in communities**	
			Positive	*Negative*	*Remote*	*Urban*
Serving	Community	Sharing	Traditional practice	Decreased sharing	X	X
Consensus/ Common purpose	Community	Feeling unheard		Colonialism	X	
	Know. Trans. & Col.	Southern Perceptions		Misrepresentation		X
	Rel. to env.	Inuit Sovereignty		Workload		X
Knowledge Acquisition	Community	Tradition	Return to traditions	Loss of traditions/TEK	X	X
	Know. Trans. & Col.	Chall. in Education		Loss of traditions/TEK		X
	Know. Trans. & Col.	Under. cc. through IQ	Being on the land	Western dominance		X
	Rel. to env.	Climate Literacy		Western dominance	X	X
Environmental Stewardship	Environment	Catastrophes		Erosion, floods, fires	X	
	Environment	Ch. in local spec.		Changes in wildlife	X	X
	Environment	Climate change		(Urgent) concern	X	X
	Environment	Development		(Noise) pollution	X	
	Environment	Ice, snow, water		Less snow and ice	X	X
	Environment	Travel	Healing	Safety concerns	X	X
	Environment	Weather		Unpredictability	X	X
	Health/Rel. to env.	Drink. water/Rel. to w.		Water insecurity	X	X
	Inuit Well-being	Rel. to the land		Land is changing	X	X
	Inuit Well-being	Pollution and Sust.		Pollution & energy	X	X
Resourcefulness	Community	Adaptation	Resilience		X	X
	Community	Advancement	New technologies	Loss of traditions	X	X
	Community	Finances		High living expenses	X	X

Guiding principles	Themes (combined)	Sub-themes (combined)	Potential outcome for Inuit well-being		Mentioned in communities	
	Community	Food and subsistence		Food insecurity	X	X
	Health	Mental health	Eating country food	Less time on the land	X	X
	Health	Physical health		Accidents, diseases	X	X
	Inuit Well-being	Social Issues		Dominant concern	X	X

Note. Ch. to local spec. = Changes to local species; Chall. in Education = Challenges in Education; Know. Trans. & Col. = Knowledge Translation and Colonialism; Pollution and Sust. = Pollution and Sustainability; Rel. to env. = Relationship to environment; Rel. to the land = Relationship to the land; Drink. water/Rel. to w. = Relationship to water; TEK = Traditional Ecological Knowledge; Under. cc. through *IQ* = Understanding Climate change through *IQ*.

Supplemental S1: 2014 Semi-structured interview guide.

Questions to be asked verbally. Answers noted by researcher.

1. Where do you get your water from?
2. Has your household ever run out of water?
3. Do any members of your family drink water from any of the local streams in the area?
    a. If so: Which streams?
        i. Is it important for you to be able to drink from the local streams? Why?
    b. If so/not: Do you know of anyone else who drinks water from any of the local streams?
        i. If so: Why do they drink from the local streams?
4. Are you concerned about water shortages?
5. Do you know of any issues about water pollution in the water you use or drink?
6. Are there any water sources locally you would not drink from?
    a. If so: Why?
    b. Are there animals or fish there?
    c. If so: Have you seen changes in these water sources or the animals that are there?
7. Were you taught to get water from a specific stream or lake in the area?
8. Do you use water for anything other than drinking and cleaning?
    a. Does water have a symbolic meaning to you?
9. Where are you from?
    a. If from elsewhere, how long have you lived in current area?

Supplemental S2: 2019 Unstructured interview guide.

Questions to be asked verbally. Answers recorded by researcher.

1. What are your experiences with accessing freshwater in your community?
2. What sources of water do you most often access?
3. How have you been impacted by climate change?
4. What do you think are some ways that Inuit have successfully adapted to climate change?
5. What activities and initiatives do you think would help Inuit to succeed and thrive in the future? How do you think climate change is talked about in the South?
6. What do you think about how Inuit are represented in global media? In movies? On TV? In fictional books? Do you play video games? Are you aware of games like Never Alone?
7. Do you think that positive representation on Inuit and Inuit adaptability to climate change would have a positive impact on global climate change adaptation efforts?

Supplemental S3: 2023 Semi-structured interview guide.

Questions to be asked verbally. Answers were recorded by the researcher.

1. Could you tell me a little bit about yourself (and your work with Knowledge mobilization of climate change research)?
    a. How long have you lived in/worked with your community?
    b. What is your work? Main duties?
    c. How are you involved with Knowledge mobilization of climate change research?
2. How is knowledge mobilization of climate change research currently being addressed in your community/organization?
    a. Can you tell me more about current/past/future projects?
3. Do you know how these projects are perceived by the community?
    a. How do you obtain feedback/assess effectiveness?
4. To what extent do external researchers get involved with knowledge mobilization projects organized by/within your community?
    a. Do you frequently get asked for advice on knowledge mobilization by external researchers?
    b. Do you collaborate with external researchers on some of your knowledge mobilization projects?
5. Do you think there is a need for better knowledge mobilization approaches and community involvement from researchers coming to your community?
    a. What is lacking/missing?
    b. What advice do you have for external researchers?
6. Do you think that external researchers adequately incorporate local knowledge into their approaches to research and results dissemination?
    a. If not, how could that be improved?
7. What are the main challenges you see for effective and meaningful knowledge mobilization of climate change research?
8. Do you have any recommendations for how community involvement in scientific research can be improved?
    a. Do you have future projects/innovative ideas in mind?

9. Do you have any recommendations for how knowledge mobilization can be improved?
    a. Do you have future projects/innovative ideas in mind?
10. Would you like to add anything, before I stop the recording?

Table S.3 Species identification and RDA scores as labelled in Figure 3.3.

Label	RDA1	RDA2	Species identification
C1	0,013447	0,014134	Chironomini larvula
C2	-0,00476	-0,02628	Chironomus anthracinus-type
C3	0,054077	-0,07522	Chironomus plumosus-type
C4	0,122955	0,037806	Chironomus undiff.
C5	-0,04237	-0,06808	Cladopelma lateralis-type
C6	0,042022	-0,0243	Cladotanytarsus mancus-type
C7	0,060631	0,0181	Constempellina-Thienemanniola
C8	-0,02876	0,086928	Corynocera ambigua
C9	0,080032	0,082643	Corynocera oliveri-type
C10	-0,07007	0,078008	Corynoneura edwardsi-type
C11	-0,01972	-0,00854	Cricotopus cylindraceus-type
C12	-0,0706	0,056369	Cricotopus intersectus-type
C13	-0,0549	0,06142	Cricotopus-Orthocladius
C14	-0,00591	0,07824	Cricotopus tremulus
C15	0,008389	0,008474	Cryptochironomus
C16	-0,02788	-0,02024	Derotanypus
C17	-0,07316	-0,1685	Dictrotendipes
C18	0,022521	-0,08223	Endochironomus impar-type
C19	-0,00203	-0,05351	Glyptotendipes pallens-type
C20	0,088184	-0,03734	Limnophyes
C21	0,10064	-0,07828	Limnophyes-Paralimnophyes
C22	0,018595	0,008626	Macropellapini
C23	-0,00427	0,092679	Micropsectra insignilobus-type
C24	0,113755	0,009792	Microtendipes pedellus-type
C25	-0,02686	-0,0063	Nanocladius
C26	-0,05471	0,019161	Neozavrelia
C27	-0,04734	-0,02059	Orthocladius species 2
C28	-0,03156	0,002231	Orthocladius trigonolabis-type

Label	RDA1	RDA2	Species identification
C29	-0,01618	-0,00019	Orthocladius type I
C30	-0,05482	-0,02548	Parakiefferiella nigra-type
C31	-0,07161	-0,01243	Parakiefferiella type B
C32	-0,03028	0,022164	Paratanytarsus penicillatus-type
C33	-0,00107	-0,02255	Paratanytarsus undiff.
C34	0,038937	-0,02746	Phaenospectra
C35	-0,04234	-0,02998	Polypedilum nubifer-type
C36	-0,01366	0,05379	Procladius
C37	-0,01326	-0,02237	Psectrocladius barbatipes-type
C38	-0,06326	-0,01088	Psectrocladius septentrionalis-type
C39	-0,19879	-0,09204	Psectrocladius sordidellus-type
C40	0,017561	0,06977	Sergentia
C41	0,117156	-0,01006	Stempellinella-Zavrelia
C42	0,016123	0,050022	Stictochironomus rosenschoeldi-type
C43	0,143976	-0,03577	Tanytarsus lugens-type
C44	0,120832	-0,06992	Tanytarsus mendax-type
C45	-0,00848	0,031307	Tanytarsus nemorosus-type
C46	0.013726	-0,20494	Tanytarsus pallidicornis-type
C47	0,038966	-0,01711	Tribelos
C48	-0,15888	0,015459	Zalutschia lingulata pauca
C49	0,002277	-0,02987	Zalutschia zalutschicola

Note. undiff. = undifferentiated