The Effects of Environmental Change on Fish Availability in the Inuvialuit Settlement Region

by

Alexander Kaleb Einar Chila

A Thesis Submitted in Partial Fulfillment

of the Requirements for the Degree of

MASTER OF SCIENCE

in the School of Environmental Studies

University of Victoria

Supervisory Committee

The Effects of Environmental Change on Fish Availability in the Inuvialuit Settlement Region

by

Alexander Chila

B.Sc., University of British Columbia, 2017

Supervisory Committee

Dr. Trevor C. Lantz, School of Environmental Studies

Supervisor

Dr. Karen Dunmall, School of Environmental Studies, Fisheries and Oceans Canada

Departmental Member

Abstract

Supervisory Committee

Dr. Trevor C. Lantz, School of Environmental Studies

Supervisor

Dr. Karen Dunmall, School of Environmental Studies

Departmental Member

Rapid climate change is altering Arctic ecosystems and affecting the lifeways of Arctic Indigenous peoples. For the six Inuvialuit communities in the Canadian Arctic, access to fish is an important source of food and cultural connection. In my MSc research, I analyzed two distinct but interconnected effects of environmental change on fish availability throughout the Inuvialuit Settlement Region (ISR) in the Northwest Territories, Canada. In the first part of my thesis, I investigated changes in Pacific salmon harvest. I conducted 54 interviews with Inuvialuit fishers about this harvest and concurrent changes to local environments and fish species. I found that historic, incidental salmon harvest in the ISR ranged from infrequent to common among Delta communities but was rare or unprecedented among Outer communities. Salmon are now frequently caught in each community, a change that is concerning to many Inuvialuit fishers. Participants attributed the increase in salmon harvest to environmental change, but explained that there are many other effects of environmental change on fishing. Notably, interview participants described how worsening summer weather is negatively affecting peoples' access to fishing. In the second part of my thesis, I explored this further and quantified the effects of weather on access to fishing from 1979 to 2019. To do so, I paired questionnaires completed by fishers in each community and ERA-5 climate reanalysis data to create the Index of Fishing Opportunity (IFO). This index showed high inter-annual and seasonal variation in access to fishing. Windspeed and direction had the highest impact on fishing conditions, followed by sea-ice, temperature, then rain. Long-term trends varied among locations, but were not representative of the experiences of Inuvialuit fishers. This suggests the index is suitable for comparing relative access to fishing between seasons, years, and communities, but lacks the precision required to represent long-term trends. By partially quantifying the influence of weather conditions on access to fishing, the IFO provides a novel way for the effects of climate change on access to inform fisheries management. Together, my two investigations show that Inuvialuit fisheries are changing rapidly and highlight the need for ongoing research to inform adaptive climate strategies.

Table of Contents

Supervisory Committee .... *ii*
Abstract .... *iii*
Table of Contents .... *v*
List of Tables .... *vii*
List of Figures .... *viii*
Acknowledgements .... *x*
Dedication .... *xii*
Chapter 1 – Introduction *1*
Study Rationale 1
Personal Location 3
Indigenous and Western Knowledges 4
Inuvialuit 5
Inuvialuit Fishing Practices 6
Fisheries, Health, and Well-being in the Arctic 8
Climate Impacts on Fisheries 9
Pacific Salmon in the Arctic 10
Connections: Research Objectives 11
References 12
Chapter 2 – Inuvialuit Knowledge of Pacific Salmon Range Expansion in the Western Canadian Arctic *25*
Introduction 25
Study Background 26
Author Positionality 28
Methods 28
Results 32
Delta Communities 35
Outer Communities 35
The Nature of the Salmon Harvest 36
Causes of Range Expansions 38
Impacts of Increased Salmon 38
Sociocultural Changes 40
Discussion 41
References 47
Appendix A 56
Environmental Conditions Questions 56
Salmon Interview Questions 57
Native Fish Questions 59
Appendix B 60
Chapter 3 – Quantifying the Effects of Weather on Access to Fishing in Inuvialuit Communities *61*
Introduction 61
Study Area 63
Methods 65
Interviews 65
Questionnaires 66
Corrected Weather Reanalysis Data and the Index of Fishing Opportunity 66
Groundtruth 71
Contributions and Positionality 72
Results 72
Questionnaire Results 75

Groundtruth 77
Discussion 78
References 84
Appendix A 96
Chapter 4 - Conclusion *97*
Summary 97
Insights from combining the two studies and the research process 99
Limitations and Future Research 99
Chapter 2: 99
Chapter 3: 101
Conclusion 102
References 104

List of Tables

Table 2.1 Summary data showing whether participants' elders had caught salmon, and if the participants themselves had caught salmon. In this context we define elders as parents, grandparents, or other community figures who passed important knowledge of fisheries to the interview participants. 32
Table 2.2. Details of the salmon harvests described by Inuvialuit fishers in the six communities in the ISR. Individual interview participants were counted more than once if they caught salmon across multiple categories. 37
Table 2.3. Potential causes of changing Pacific salmon harvest levels as described by Inuvialuit fishers. Indented causes were discussed as sub-categories of broad-scale climate change. The number of participants indicate how many people referred to each cause as a specific driver of change. 38
Table 2.4. Changes to local fish harvests described in the interviews. We included effects and causes for a given community if consensus within that community was either high or moderate. High => 2/3 of participants, Moderate => 1/3 of participants, Low <= 1/3 of participants. * Asterisks denote changes that may be directly influenced by salmon according to our interviews. 39
Table 2.5 Codes used for thematic interview analysis. Thematic categories are bolded and indentation reflects the structure of codes and subcodes. 60
Table 3.1 Results of the correlation and regressions analyses of ERA-5 climate reanalysis by Environment and Climate Change Canada climate data. All of the locations where we calculated IFO had ECC climate data except for East Whitefish. We used data from the Tuktoyaktuk weather station (25 km to the E) to correct for observations at East Whitefish as it is the nearest station. We used the least squares regression formulae to convert the thresholds identified by fishers to values comparable to the reanalysis data. 68
Table 3.2 Participant defined thresholds for wind, temperature, and rainfall that make conditions unfavourable for fishing in each community. Thresholds were adjusted using the regression formulas in Table 3.1, adjusted values are provided in parentheses. 87
Table 3.3 Other environmental conditions that limit the availability of fish. Approximate distances between community and fishing location are shown in brackets for sites that are not directly adjacent to the community.. 88
Table 3.4 Comparisons of IFO scores to weather suitability reports from the Arctic char monitors setting nets at the mouth of the Hornaday River near Paulatuk, NT. The agreement column shows instances where the IFO correctly classified conditions, the underestimated column indicates cases where the IFO predicted unfavourable fishing conditions, but fishers reported favourable ones, and the overestimated column shows instances where the IFO predicted favourable conditions but fishers reported unfavourable ones. 89

List of Figures

Figure 2.1. The left panel shows a map of the current and limited distribution of Pacific salmon (Oncorhynchus spp.). Distribution data adapted from Augerot and Foley 2005. The red box in the left panel is expanded on the right to show the locations of the six communities in the Inuvialuit Settlement Region. 27

Figure 2.2. Number of participants across all six communities who recalled catching salmon in a given decade compared to the number of participants interviewed (n=53) that were fishing in that decade. The red triangles and red line show the number of salmon returned to the Arctic Salmon Project in the last two decades and are plotted on a second, log-scaled y axis. 33

Figure 2.3. Number of participants who recalled catching salmon in a given decade compared to the number of participants interviewed that were fishing in that decade. Each panel represents the participants from one Inuvialuit community. The red triangles and red line show the number of salmon returned to the Arctic Salmon Project in the last two decades and are plotted on the on the second y axis. 34

Figure 2.4 Photos of salmon in the ISR. A) A chum salmon drying next to broad whitefish in Tuktoyaktuk (Photo: Zander Chila); B) A sockeye salmon harvested in the same net as Arctic char and broad whitefish from the Hornaday River in November (Photo: Steve Illasiak); C) A fisher preparing salmon for drying at Shingle Point (Photo: Collin Gallagher); D) A chum salmon compared to a lake trout caught near Paulatuk in December (Photo: John Sam Green). 41

Figure 3.1 Map of the six communities (circles) and two important marine fishing locations (triangles) in the Inuvialuit Settlement Region. The white box in the inset map (upper left) shows the location on main map within Canada. 64

Figure 3.2 Flow chart showing the process used to assign daily scores for access to fishing based on daily rainfall and hourly temperature and wind conditions based on the ERA-5 Climate Reanalysis Dataset. Any day with a sea-ice-concentration of zero from January 1979-December 2019 was scored. Thresholds for weather conditions were locally specific and determined by fishers with many years of fishing experience in that location (Table 1). We considered days to be good if rainfall did not exceed the threshold, and if less than half of its hours had conditions for temperature or windspeed which exceeded the thresholds identified by fishers. Shaded sections indicate the three steps in assigning scores: blue for initialization, green for the modification based on consecutive fishing days, and purple for normalization across each season. 71

Figure 3.3 The Index of Fishing Opportunity at six coastal fishing locations in the Inuvialuit Settlement Region (columns). The IFO is shown for each of three “seasons” identified by fishers (rows). Spring refers to May-June, summer to July-Aug, and fall to Sep-Oct. IFO was calculated between 1979-2019 inclusive using ERA-5 climate reanalysis data (Hersbach et al. 2020) corrected with observations from Environment and Climate Change Canada (ECCC 2021). Red asterisks in the top left corner of each plot denote time series with slopes that are significantly different from 0 (p<0.05). All significant slopes were positive. 73

Figure 3.4 Percent of days in the time series (1979-2019) when fishing conditions were unfavourable. Red dashed lines indicate the percent of days with sea-ice concentrations that were above zero. The bars indicate the percent of ice-free days which were unfavourable because of rain (R), high temperature (HT), low temperature (LT), unfavourable wind direction (WD), and high wind speed (WS). Days were counted twice when conditions were unfavourable for multiple reasons. We considered a day to be unfavourable when rain exceeded the daily threshold, when more than half of the hours in that day had wind, or when temperature conditions were outside of the thresholds described in Table 1. 74

Acknowledgements

First and foremost, I am grateful to have spent time in Inuvialuit territory. Quyanainni to the communities of Aklavik, Inuvik, Paulatuk, Sachs Harbour, Tuktoyaktuk, and Ulukhaktok for your warm welcomes in the cold weather. My most humble thanks to all of the interview and questionnaire participants who shared their knowledge: Agnes Kuptana, Allen Kogiak, Bertha Joe, Brian Wade, Cheryl Arey, Christopher Felix, Dean Arey, Doug Esagok, Eileen Jacobson, George Krengektak, Hank Angasuk, Isaac Inuktalik, Jack Akhiatak, Jeff Kuptana, Jerry Angasuk, Jody Illasiak, Joe Kudlak, John Keogak, John Sam Green, Johnnie Storr, Joseph Carpenter, Kate Inuktalik, Lawrence Kaglik, Lawrence Ruben, Lena Wolki, Liz Kuptana, Mabel Noksana, Margaret Kanayok, Melissa D. Rogers, Michael Green, Michelle Gruben, Miles Robert Dillon Sr., Nellie Arey, Noel Green, Patrick Akhiatak, Phillip Ross, Randy Gruben, Rebecca Kaglik, Renie Arey, Richard Carpenter, Robert Kuptana, Roland Notaina, Steve Illasiak, Tony Alanak, Tony Green, Trevor Lucas, Wayne Thrasher, William Storr, and those who chose to remain anonymous. Thank you all for encouraging me laugh at myself, and for teaching me that sometimes the most important research methodology is coffee and Dad's Oatmeal Cookies.

Thank you to the staff and board members at the Hunters and Trappers and Fisheries Joint Management Committees, and to everyone who helped me conduct interviews and surveys. This thesis was only possible with your help. A special thanks to Tracey Proverbs for holding my hand through my first interviews.

Thanks to the organizations who funded this research: Fisheries and Oceans Canada, the Social Sciences and Humanities Research Council, the Weston Family Foundation, the University of Victoria, and the Arctic Institute of North America. Chapters 2 and 3 are written as co-authored manuscripts. Chapter 2 is co-authored with Tracey Proverbs, Karen Dunmall, Trevor Lantz, the Aklavik Hunters and Trappers Committee, the Inuvik Hunters and Trappers Committee, the Olohkahtomiut Hunters and Trappers Committee, the Paulatuk Hunters and Trappers Committee, and the Sachs Harbour Hunters and Trappers Committee. Thank you to the Tuktoyaktuk Hunters and Trappers Committee who chose not to be listed as an author. Chapter 3 is co-authored with

Colin Gallagher, Karen Dunmall, and Trevor Lantz. I feel honoured to have worked with each of you. To my supervisors Karen and Trevor, thank you for trusting me and for seeing me through.

I am grateful and humbled to have lived and worked on Lək̓ʷəŋən, W̱SÁNEĆ, and Kʷikʷəƛ̓əm territories during this research. A land acknowledgement will never suffice, but I hope I've managed to tread lightly during my time here. To both of my University of Victoria cohorts, thank you for sustaining me physically and emotionally. My warmest thanks and biggest hugs to Hana Travers-Smith, Jordan Seider, Kiyo Campbell, Angel Chen, Nicola Shipman, Kalina Hunter, Tanya Tran, Jennie Long, Kevin Gully, and Darcy McNicholl. I feel so lucky to have inspiring, supportive, and generous friends. Finally, endless thanks to family for your support.

I hope you all know how much I love you.

Dedication

to my families.

original,

& found

Chapter 1 – Introduction

Study Rationale

There is growing concern over the future of subsistence fisheries around the globe as climate change and over-exploitation become increasingly impactful on eco-cultural systems (FAO 2018; Ford *et al.* 2013; ICC 2020; IPCC 2019; Marques *et al.* 2010). Many Indigenous communities are facing these effects earlier and more acutely than settler communities while working to maintain their reciprocal relationships with fisheries (ICC 2020; IPCC 2019; Proverbs *et al.* 2019; Usher 2002; Whyte 2017). For example, Inuit and other Arctic peoples are experiencing temperature increases at a rate more than twice the global average, and dramatic environmental changes that are influencing marine and freshwater fish (ACIA 2005; IPCC 2019; Niemi *et al.* 2019). Given the nature and speed of environmental changes in their territory, the relationships between Arctic Indigenous peoples and fish are threatened (Ford *et al.* 2013; Galappaththi *et al.* 2019; Tai *et al.* 2019). Research investigating environmental and social changes in Arctic fisheries is therefore paramount.

Many northern communities are particularly concerned about the impacts of climate on the availability of important species and the cultural traditions of harvesting (ICC 2020; Todd 2016). For example, fish distributions have already begun to shift poleward (Cheung *et al.* 2019; Dunmall *et al.* 2018; Sunday *et al.* 2015). Simultaneously, environmental changes are impacting peoples' access to fish by limiting their ability to engage in harvest activities as they would in the past (Ford *et al.* 2013; Hansen *et al.* 2013). For instance, erosion related to the thawing permafrost is increasing sediment and debris in some rivers, limiting peoples' ability to set nets in those rivers (Proverbs *et al.* 2020). These processes are facilitating a decrease in the availability of culturally important food fish, with impacts on community and individual well-being (Lambden *et al.* 2007; Parlee and Furgal 2012; Petrasek MacDonald *et al.* 2017; Pecl *et al.* 2017; Proverbs *et al.* 2020).

Research on the impacts of climate change in the Arctic must be informed by local worldviews and oriented towards local self-governance, yet hold to account the global colonial societies responsible for dramatic environmental change in the Arctic (Cameron 2012; ICC 2020; Reid 2018; Whyte 2017; Wong *et al.* 2020). Previous climate-impact studies in the Arctic have focused on the vulnerability and adaptive capacity of Arctic peoples (Ford 2009; Ford and Smit 2004; Laidler *et al.* 2009); these are certainly concerning issues to Arctic peoples. However, as Cameron (2012) explains, any failure to consider the ways that colonialism shapes vulnerability in Indigenous communities contributes to a modern colonial project (see also Reid 2018). This compounds the extractive and appropriative legacy of research on/with Indigenous peoples (Cameron 2012; Simpson 2004; Smith 1999). As the call for research and policy to respectfully include Indigenous experiences amplifies, we must respond, yet be sure to reckon with our past and hold ourselves to account (Cameron *et al.* 2012; Ford *et al.* 2016; ICC 2020; Reid *et al.* 2020; Simpson 2004; Wong *et al.* 2020).

My MSc research builds upon previous work examining changes to Arctic fish communities and the impacts of climate change on northern Indigenous livelihoods (Dunmall *et al.* 2018; ICC 2020; IJS 2003; Proverbs *et al.* 2020; Todd 2016; Wesche and Chan 2010). The overarching goal of my research was to characterize some of the environmental changes influencing fish availability in the Inuvialuit Settlement Region (ISR). My thesis is composed of two complementary research projects written as unique stand-alone manuscripts. My work is a product of partnerships with Inuvialuit organizations and Fisheries and Oceans Canada (DFO). Through these partnerships I hope to inform adaptive measures and co-management processes.

For chapter two of this thesis, I worked with Inuvialuit fishers to understand changes in fish harvests occurring throughout their territory. Increasing harvests of Pacific salmon in the ISR are indicative of potential northward shifts in the distribution of these five species, but previous research on this topic does not provide historical information about the Inuvialuit salmon harvest (Dunmall *et al.* 2018; Stephenson 2006). Knowing that Inuvialuit harvesters hold important insights, the Fisheries Joint Management Committee, an Inuvialuit-DFO co-management body, requested an Inuvialuit knowledge project be done to fill this gap. The results of this study are presented in chapter two of my thesis, where I explore the following research question: how have Pacific salmon harvests changed over the last generation in the ISR? To answer this question I partnered with DFO and local Hunters and Trappers Committees to conduct a series of semi-structured interviews in each Inuvialuit community. I synthesized the knowledge of Inuvialuit harvesters to construct a timeline of salmon harvest in the ISR. I also summarize Inuvialuit knowledge of the potential drivers of shifting range margins and the impacts of these changes. The historical dynamics of the salmon harvest, how it has changed in recent years, and what changes salmon might be responding to will provide critical information to managers and fishers invested in the future of Arctic fisheries.

In chapter three of this thesis I explore the impact of recent changes in climate on fishing opportunity across the ISR. I ask, can we use weather reanalysis data to describe changes in access to fish? This study emerged from observations shared during the interviews conducted for chapter 2. During these interviews several participants noted that climate change is causing new weather conditions that are impacting Inuvialuit ability to fish. With the help of the Hunters and Trappers Committees, I designed questionnaires to understand the nature of weather that is considered "good" or "bad" for fishing. I used this feedback to create an index to represent the quality of marine fishing conditions in the summer. Subsequently, I used weather re-analysis data from 1979-2019 to investigate if this index could be used to track changes in fishing opportunity over time.

In the final chapter of my thesis I synthesize the findings of chapters two and three and discuss further applications of my work, and how it relates to the future of Inuvialuit fisheries. The remainder of this chapter provides critical context that is not included in chapters two or three. Topics covered include: my personal location; the use of Indigenous and western knowledges; Inuvialuit territory and history; Inuvialuit fishing practices; the relationships between fisheries, health, and well-being; the impacts of climate change on fisheries; and Pacific salmon in the Arctic.

Personal Location

I am a queer, white settler born on the territories of Qayqayt and Kʷikʷəƛ̓əm First Nations in what is now known as British Columbia. My families landed here from Iceland, the United Kingdom, and Italy by way of the territories of Očhéthi Šakówiŋ (Sioux), Néhiyaw (Cree), and Siksikaitsitapi (Blackfoot), throughout Manitoba, Saskatchewan, and Alberta. Coast Salishan territories provided me the first lessons about environmental studies and the relationships between people and place. For the majority of my masters research I lived and worked on the territories of the Lək̓ʷəŋən and SENĆOŦEN speaking peoples. Throughout my life I have benefitted immeasurably from the historical and ongoing land stewardship of First Nations in BC. My unlearning of settler colonialism is ongoing. Each day I strive to adopt anti-colonial practices of walking these lands upon which I remain an uninvited guest.

For this research I had the privilege of learning from Inuvialuit and their territory. Both of the substantive research chapters in my thesis rely, to varying degrees, on Inuvialuit knowledge. I engaged in Community Based Participatory Research practices with the goal of sharing the benefits of this research with Inuvialuit youth and fishers. Through conversations, self-reflection, and constant re/unlearning I have strived to temper the influences of my settler positionality on this research project. My goal has been to tread lightly. It is my sincerest hope that my work can contribute to Inuvialuit self-governance and an anti-colonial future.

Indigenous and Western Knowledges

Recent decades have seen a rise in publications focused on Indigenous Knowledge (IK) across many academic disciplines and in public facing media outlets (Grenier 1998; Inglis 1993; Johannes 1989; Linden 1991; Wenzel 1999). Ecologists, botanists, anthropologists, and philosophers of western and Indigenous backgrounds have engaged in a conversation to introduce and define IK, examine its structure, and discuss its relationships to other forms of knowledge (Houde 2007; Johannes 1989; Nadasdy 2003; Simpson 2004; Turner *et al.* 2000). The breadth and popularity of this work has led to the uptake of IK into various levels of governance, from local-scale wildlife management, to federal policy (Usher 2000; Houde 2007; Berkes 2012). In many regions it has become a requirement to incorporate local IK into decision making processes (Usher 2000; Houde 2007). The manifestations of this requirement are extremely variable but range from meaningful consideration to tokenism (Ellis 2005; Berkes *et al.* 2001; Manseau *et al.* 2005).

As publications including IK have risen, so too has the discourse surrounding ethical research relationships involving Indigenous peoples (Battiste and Youngblood Henderson 2000; Castellano 2004; Castleden *et al.* 2012; Glass and Kaufert 2007; Nadasdy 2003; Smith 1999). The history of this research conducted by academia is inseparable from the history of colonialism, and extractive research practices and inequitable distributions of resources and opportunities persist (Battiste and Youngblood-Henderson 2000; ITK 2019b; Smith 1999; Wong *et al.* 2020). Shifts towards knowledge co-production, the relocation of research activities within communities, and more equitable distribution of research benefits are small ways in which the academy has begun to reconcile our colonial history (Castleden *et al.* 2012; ICC 2020; ITK 2019b; Wong *et al.* 2020).

Inuvialuit

I had the incalculable privilege of doing my Masters research with Inuvialuit fishers in their homelands. These lands span the sub-Arctic boreal forest through the high Arctic tundra, with annual average temperatures ranging from -8.2°C in Aklavik to -12.8°C in Sachs Harbour (Environment Canada 2018a and 2018b). The southwestern portion of the Inuvialuit Settlement Region (ISR) has a warmer climate, which supports more productive woodland and tundra ecosystems (ECG 2009 and 2012). In the northern and eastern portions of the ISR, the climate is cooler, and tundra ecosystems are less productive and more sparsely vegetated (ECG 2013). The ISR includes a number of lake-rich areas such as the Mackenzie River Delta and the Tuktoyaktuk Coastlands, as well as near- and off-shore marine ecosystems of the Beaufort Sea.

Inuvialuit have gone through many cultural shifts over the last 1000 years, beginning with the migration of their Thule ancestors from Alaska to the northern Yukon the western Arctic (Betts 2009). Early after this migration, they identified as Siglit and lived in eight distinct settlements stretching from Herschel Island to Cape Parry (Betts 2009). These populations considered themselves apart from their Inuit and Gwich'in neighbours, but had frequent and amicable interactions with Iñupiat in what is now Alaska (Naggy 1994; Stefansson 1919). Each settlement had unique subsistence economies oriented toward the ecological productivity of their immediate environment (Betts 2009).

Resources in Inuvialuit territory are temporally and spatially heterogeneous (Betts 2005). Many wildlife populations are highly migratory and only seasonally available. Additionally, the extreme seasons limit when resources are available for harvest. Winter village sites were built in areas with significant harvest opportunity, but large parts of the year were spent travelling to harvest elsewhere (Alunik *et al.* 2003; Betts 2009; Lyons 2009). A significant part of Inuvialuit identity is drawn from relationships with these animals (Alunik *et al.* 2003; Lyons 2009). Particularly significant animals include *qilalukkat* (beluga, *Delphinapterus leucas*), *tuktuvialuit* (caribou, *Rangifer tarandus granti*), *omingmak* (muskox, *Ovibos moschatus*) and a wide range of fish and bird species (Alunik *et al.* 2003; Freeman *et al.* 1992; Lyons 2009).

As elsewhere around the globe, colonial agents came to meet Inuvialuit. Early interactions, such as the journeys of Mackenzie and Franklin, had minimal effects on the lifeways of the Indigenous peoples of the western Arctic, but set the stage for the colonial project that would follow (Lyons 2009). Soon after those early "explorers" came the whaling ships that brought the brief but intensive baleen industry (Alunik *et al.* 2003; Freeman *et al.* 1992; Lyons 2009). When whaling collapsed, agents of the Hudson's Bay Company and various churches ushered in the longer fur-trade era, defined by continued colonial expansion into Inuvialuit homelands and lucrative trading opportunities for some Inuvialuit trappers (Alunik *et al.* 2003; Betts 2009; Lyons 2009). Exploration for oil and gas followed, and the effects of climate change began to take root (Alunik *et al.* 2003; IRC 2018; Usher 1971).

In 1970, Inuvialuit organizers formed the Committee for Original People's Entitlement (COPE) as a voice to represent themselves to outsiders (IRC n.d.). COPE spearheaded negotiations with the Canadian Government which would culminate in the signing of the Inuvialuit Final Agreement (IFA) in 1984 (Canada 1984). Throughout this time the term Inuvialuit, meaning the real people, became widely used as a way to unify the people in the region. Modern Inuvialuit speak three dialects of Inuvialuktun: Sallirmiutun, Uummarmiutun, and Kangiryuarmiutun. These languages hold the histories of Inuvialuit experience, and reflect the diverse people now known as Inuvialuit.

The IFA formally recognized the 435,000 km^2 Inuvialuit Settlement Region (ISR). It also established the legal methods by which Inuvialuit govern their lands and laid out the responsibilities of the parties to be involved (Canada 1984). In the context of this thesis, the most significant process implemented by the IFA is co-management. The IFA established 5 co-management boards and community Hunters and Trappers Committees with the mandate of governing the use of resources in the ISR (Canada 1984). My MSc research has been done under the guidance of some of these organizations: including the Fisheries Joint Management Committee, Hunters and Trappers Committees, and the Inuvialuit Game Council.

Inuvialuit Fishing Practices

While Inuvialuit fishing methods have changed in the last 200 years, the importance of fishing activities has not. Historically fishing took place under the ice in late fall and early spring, and throughout the open water period (Alunik *et al.* 2003; Morrison 2000; Usher 2002). Fishing efforts are often concentrated during the runs of anadromous fish and feature the use of nets and hooks (Alunik *et al.* 2003; Morrison 2000; Usher 2002). While everyone has their own favourite fish to eat, popular ones are *iqalukpik* (arctic char, *Salvelinus alpinus*), *anaakłiq* (broad whitefish, *Coregonus nasus*), and *singayuriaq* (lake trout, *Salvelinus namaycush*). In the past, travel to and from spring and winter fishing locations was done by dog-teams whose diets were composed primarily of fish. Fishing effort before the introduction of snowmobiles was therefore much higher to feed the numerous dogs kept by each family (Alunik *et al.* 2003; Usher 2002). Travel to and from summer fishing locations frequently occurs by boat, historically in large umiaqs or smaller kayaks, then by schooners, and now by smaller aluminum boats (Alunik *et al.* 2003).

Inuvialuit relationships with fish may change, or be forced to change, under new environmental conditions (Ford and Pearce 2010; ICC 2020). Changing sea-ice, unpredictable weather, permafrost thaw, and erosion are only some of the changes mediating peoples' ability to fish (Communities of Aklavik, Inuvik, Holman Island, Paulatuk and Tuktoyaktuk *et al.* 2005; Ford *et al.* 2013; IRC 2018; Pearce *et al.* 2015). Meanwhile, ongoing colonial processes have mediated the loss of Inuvialuit knowledge and language, and a disconnection between generations and from the land, further compounding the effects of environmental change (Cameron 2012; Communities of Aklavik, Inuvik, Holman Island, Paulatuk and Tuktoyaktuk *et al.* 2005).

Inuvialuit are responding to these pressures culturally and politically. Individuals are adapting the timing and methods of their fishing, and traveling via new modes and routes to and from fishing locations (Ford and Pearce 2010). Community efforts to increase resilience include food-sharing, community freezers, practicing Inuvialuit culture on the land, and elder-youth mentoring programs (Berkes and Jolly 2002; Ford and Pearce 2010; IRC 2018; Lyons 2009). Finally, in coordination with other Inuit, Inuvialuit organizations are advocating for environmental protection and monitoring in their homeland that is informed by their own worldviews (ICC 2020; ITK 2019 a & b). They are doing so while calling for climate-accountability and environmental justice at regional, national, and international scales (ICC 2020; ITK 2019 a & b, Watt-Cloutier 2005).

Fisheries, Health, and Well-being in the Arctic

Fish provide a critical source of nutritious food to Inuvialuit, and to Indigenous peoples throughout the Arctic (ICC 2020; ITK 2019a; Kenny *et al.* 2018; Kuhnlein and Receveur 2007). Broadly, Inuit throughout Inuit Nunangat experience food insecurity at eight times the rate of the general Canadian population (Kenny *et al.* 2018). Inuvialuit fishing is important for reducing this food insecurity, and provides essential nutrients (Kuhnlein and Receveur 2007; Wesche and Chan 2010). Reduced access to country foods such as fish, results in reductions in protein, vitamin D, iron, zinc, and omega-3 fatty acids (Wesche and Chan 2010). Market foods are often low quality and may cost twice as much as food in southern Canada (Kenny *et al.* 2018; Kuhnlein and Receveur 2007).

Fishing is also essential to well-being more broadly (Cunsolo Willox *et al.* 2011; Petrasek MacDonald *et al.* 2015; Proverbs *et al.* 2020). Drawing on Indigenous conceptions of wellness in the Arctic (RCAP 1996), we employ Parlee and Furgal's (2012:7) definition of individual well-being as "balance between the emotional, mental, spiritual, and physical dimensions of the person in connection to family, community, and environment". For Inuit throughout the Canadian Arctic, being in good reciprocal relationship with their lands leads to feelings of happiness, and stronger senses of community and individual identity (Cunsolo Willox *et al.* 2011; ICC 2020; Searles 2009). Fishing and hunting are important ways that Inuit have always maintained their relationships with their homelands (ICC 2020; Searles 2009). The absence of these cultural activities and traditions has also been linked to unhappiness and disconnection (Kral *et al.* 2011).

By impacting the future of Inuit fisheries, rapid environmental change stands to affect not only food security, but holistic measures of Inuit health (Cunsolo Willox *et al.* 2011; ITK 2014; Kral *et al.* 2011; Petrasek MacDonald *et al.* 2015). Inuit Tapirit Kanatami (ITK) has outlined eleven social determinants of health in Inuit communities in Canada (2014). Four of these link directly to fishing practices: culture and language; livelihoods; food security; and the environment (ITK 2014). Dramatic environmental changes have been linked to feelings of anxiety, depression, fear, and sadness in youth across Inuit Nunangat (Cunsolo Willox *et al.* 2011). Through its connection to culture and community, fishing can help to protect Inuit well-being (Petrasek MacDonald *et al.* 2015).

Climate Impacts on Fisheries

Global climate change is predicted to impact the availability of fish to Inuvialuit harvesters (FAO 2018; Ford and Pearce 2010; ICC 2020; Niemi *et al.* 2019). Changes to abiotic conditions driven by a changing climate are likely to impact the physiology and productivity of Arctic fish populations (Brander 2007; Cheung *et al.* 2009; Fossheim *et al.* 2015; Niemi *et al.* 2019; Pankhurst and Munday 2011; Sheridan and Bickford 2011). Shifts in temperature, pH, and weather patterns will drive physiological responses in fish and influence population dynamics (Brander 2007; Niemi *et al.* 2019; Heuer and Grosell 2014; Rijnsdorp *et al.* 2009). While climate change is exerting these effects on individual species, they cannot be considered in isolation. Changes in interactions among species, including competition and predation, are likely to have complex effects on ecological communities and are challenging to predict (Carozza *et al.* 2019; Cheung *et al.* 2019; Niemi *et al.* 2019; Tai *et al.* 2019). For example, increased primary productivity ascending through trophic levels may offset negative physiological effects of climate change on fish (Carozza *et al.* 2019). Predictions about the future of Arctic fish communities are uncertain, but some studies suggest that fish productivity in the Arctic may increase with climate change, facilitating larger marine fisheries (Lam *et al.* 2014; Reist *et al.* 2006; Tai *et al.* 2019).

Many fish species are responding to increasing temperatures by shifting their ranges poleward (Cheung *et al.* 2019; Free *et al.* 2019; Sunday *et al.* 2015). These shifts are expected to result in high species turnover in Arctic regions (Cheung *et al.* 2009). This phenomenon is expected in all habitats, but is hypothesized to occur rapidly in the oceans, where connectivity does not limit movement in the same way that it does on land (Sunday *et al.* 2015). The redistribution of biodiversity is likely to decrease Inuvialuit access to culturally important fish species, and facilitate new biotic interactions, with the potential to decrease Arctic fish populations (Cheung et al. 2009; Fossheim *et al.* 2015; Pecl *et al.* 2017).

These temperature changes, and other anthropogenic impacts, may also impact fish health, and thus their suitability for human consumption (Chiaramonte *et al.* 2016; Coleman *et al.* 2019;

Marques *et al.* 2010). A warming climate and a longer ice free season in the Arctic will affect the survival and health of fish species at all life-history stages (e.g., delayed spawning events, reduced body size) (Carton *et al.* 2015; Pankhurst and Munday 2011; Sheridan and Bickford 2011). Environmental changes could also alter the prevalence of parasites in fish (Lõhmus and Björklund 2015). Contaminants such as mercury or microplastics have also been observed in some Arctic fishes, and may have negative effects on human health (Carrie *et al.* 2010; Mozaffarian and Rimm 2006). Finally, with declines in Arctic sea ice, new economic opportunities such as increased ship traffic and new resource extraction projects are being proposed. These are also likely to contribute to rapid environmental change and influence future fisheries (Collins and Kumral 2020; Hauser *et al.* 2018; Lemly 1994).

Pacific Salmon in the Arctic

The five species of Pacific salmon (*Onchorynchus spp.*) in North America have highly diverse life-history traits and strategies (Groot 1991 & 2010; Qin and Kaeriyama 2016). This is likely a product of their successful diversification in response to dramatic changes in topography, glaciations, and climate of the west coast of North America over the last five million years (Montgomery 2000; Waples *et al.* 2008). Each species has different habitat use, physiological tolerances, and timing of life-history strategies (Groot 1991 & 2010; Qin and Kaeriyama 2016). For example, pink salmon (*O. gorbuscha*) migrate to the ocean soon after hatching and return to spawn within 18 months, thus completing a two year lifecycle (Groot 1991). Chinook salmon (*O. tshawytscha*) migrate later and may spend as long as eight years in the ocean (Groot 2010). During their ocean stages, salmon feed on a variety of species as determined by salmon morphology, physiology, and environment (Auburn and Ignell 2000; Kaeriyama *et al.* 2004; Tadokoro *et al.* 1996; Qin and Kaeriyama 2016). These generalist traits have likely contributed to their expansions into the warming Arctic (Carothers *et al.* 2019; Dunmall *et al.* 2013 & 2018; Nielsen *et al.* 2013).

Across the ISR the harvest of Pacific salmon has increased considerably in the last 30 years (Dunmall *et al.* 2013 & 2018). In order from most to least common, fishers are catching chum, pink, sockeye, chinook, and coho; all five of the species found on the west coast of North America (Dunmall *et al.* 2018). With the exception of a small population of chum in the Liard River

(Dunmall 2018; Irvine *et al.* 2009), established populations of salmon are unknown in Canadian Arctic drainages. Establishment is the greatest barrier to salmon colonization of the Arctic, and is mediated by the lower thermal limit during critical early life-stages (Dunmall *et al.* 2016). Salmon range expansion at the end of the last glacial maximum (20,000 years ago) suggests that recent climate change is also likely to facilitate northern expansion, but additional research and monitoring are required (Dunmall *et al.* 2016; Farley *et al.* 2020; Nielsen *et al.* 2013 & 2020; Yoon *et al.* 2015).

Connections: Research Objectives

My thesis knits these topics through two case-studies. First, I analyze Inuvialuit knowledge of changing fish distributions, specifically the recent dramatic increase in the harvest of Pacific salmon. I synthesize observations of salmon harvest, and the potential impacts of shifts in abundance that were shared by fishers across the ISR. Following the guidance of these fishers, I frame salmon harvests as an indicator of ecosystem-level shifts. Given the holistic nature of Inuvialuit knowledge, many non-salmon themes arose from this knowledge sharing as affecting fishing practices. One notable observation mentioned by numerous participants was that new weather conditions are reducing access to fish. In chapter three, I explore this observation in more detail using questionnaires and climate re-analysis data to assess how changes in weather have influenced access to fishing. Together, these two chapters contribute to our knowledge of how climate change may shape the future of Inuvialuit fisheries. In my thesis, I have sought to provide insight into the rapid environmental changes occurring in the ISR, and their related influences on future of Inuvialuit fisheries.

References

ACIA. (2005). *Arctic Climate Impact Assessment. ACIA. Overview Report.* Cambridge University Press. https://www.amap.no/documents/doc/arctic-arctic-climate-impact-assessment/796

Alunik, I., Morrison, D. A., & Kolausok, E. D. (2003). *Across time and tundra: The Inuvialuit of the western Arctic*. Raincoast Books. Vancouver, BC.

Appadurai, A. (Ed.). (1986). *The Social Life of Things: Commodities in Cultural Perspective*. Cambridge University Press. doi.org/10.1017/CBO9780511819582

Auburn, M. E., & Ignell, S. E. (2000). Food Habits of Juvenile Salmon in the Gulf of Alaska July-August 1996. North Pacific Anadromous Fish Commission. *2*, 89-97.

Battiste, M., & Youngblood-Henderson, J. (2000). Protecting Indigenous Knowledge and Heritage: A Global Challenge. UBC Press.

Berkes, F., & Jolly, D. (2002). Adapting to Climate Change: Social-Ecological Resilience in a Canadian Western Arctic Community. *Conservation Ecology*, *5*(2). https://www.jstor.org/stable/26271828

Berkes, F., Mathias, J., Kislalioglu, M., & Fast, H. (2001). The Canadian Arctic and the Oceans Act: The development of participatory environmental research and management. *Ocean & Coastal Management*, *44*(7), 451–469. doi.org/10.1016/S0964-5691(01)00060-6

Betts, M. (2009). Chronicling Siglit identities: Economy, practice, and ethnicity in the western Canadian Arctic. *Alaska Journal of Anthropology*, *7*, 1–28.

Betts, M. W. (2005). Seven Focal Economies for Six Focal Places: The Development of Economic Diversity in the Western Canadian Arctic. *Arctic Anthropology*, *42*(1), 47–87.

Bintanja, R., & Andry, O. (2017). Towards a rain-dominated Arctic. *Nature Climate Change*, *7*(4), 263–267. doi.org/10.1038/nclimate3240

Brander, K. M. (2007). Global fish production and climate change. *Proceedings of the National Academy of Sciences*, *104*(50), 19709–19714. doi.org/10.1073/pnas.0702059104

Cameron, E. S. (2012). Securing Indigenous politics: A critique of the vulnerability and adaptation approach to the human dimensions of climate change in the Canadian Arctic. *Global Environmental Change*, *22*(1), 103–114. doi.org/10.1016/j.gloenvcha.2011.11.004

Canada. (1984). The western Arctic Claim: A guide to the Inuvialuit Final Agreement.

Carothers, C., Sformo, T. L., Cotton, S., George, J. C., & Westley, P. A. H. (2019). Pacific Salmon in the Rapidly Changing Arctic: Exploring Local Knowledge and Emerging Fisheries in Utqiaġvik and Nuiqsut, Alaska. *Arctic*, *72*(3), 273–288. doi.org/10.14430/arctic68876

Carozza, D. A., Bianchi, D., & Galbraith, E. D. (2019). Metabolic impacts of climate change on marine ecosystems: Implications for fish communities and fisheries. *Global Ecology and Biogeography*, *28*(2), 158–169. doi.org/10.1111/geb.12832

Carrie, J., Wang, F., Sanei, H., Macdonald, R. W., Outridge, P. M., & Stern, G. A. (2010). Increasing Contaminant Burdens in an Arctic Fish, Burbot (Lota lota), in a Warming Climate. *Environmental Science & Technology*, *44*(1), 316–322. doi.org/10.1021/es902582y

Carton, J. A., Ding, Y., & Arrigo, K. R. (2015). The seasonal cycle of the Arctic Ocean under climate change. *Geophysical Research Letters*, *42*(18), 7681–7686. doi.org/10.1002/2015GL064514

Castellano, M. B. (2004). Ethics of Aboriginal Research. *International Journal of Indigenous Health*, *1*(1), 98–114. doi.org/10.3138/ijih.v1i1.28935

Castleden, H., Morgan, V. S., & Lamb, C. (2012). “I spent the first year drinking tea”: Exploring Canadian university researchers’ perspectives on community-based participatory research involving Indigenous peoples. *The Canadian Geographer*, *56*(2), 160–179. doi.org/10.1111/j.1541-0064.2012.00432.x

Cheung, W. W. L., Lam, V. W. Y., Sarmiento, J. L., Kearney, K., Watson, R., & Pauly, D. (2009). Projecting global marine biodiversity impacts under climate change scenarios. *Fish and Fisheries*, *10*(3), 235–251. doi.org/10.1111/j.1467-2979.2008.00315.x

Chiaramonte, L., Munson, D., & Trushenski, J. (2016). Climate Change and Considerations for Fish Health and Fish Health Professionals. *Fisheries*, *41*(7), 396–399. doi.org/10.1080/03632415.2016.1182508

Coad, B. W., Reist, J. D., Moller, P. R., Renaud, C. B., Alfonso, N. R., Dunmall, K., Power, M., Sawatzky, C. D., Berkes, F., Dempson, J. B., Harris, L. N., & Swanson, H. K. (2018).

Marine Fishes of Arctic Canada. University of Toronto Press. www.jstor.org/stable/10.3138/j.ctt1x76h0b

Coleman, M. A., Butcherine, P., Kelaher, B. P., Broadhurst, M. K., March, D. T., Provost, E. J., David, J., & Benkendorff, K. (2019). Climate change does not affect the seafood quality of a commonly targeted fish. *Global Change Biology*, *25*(2), 699–707. doi.org/10.1111/gcb.14513

Collins, B., & Kumral, M. (2020). Environmental sustainability, decision-making, and management for mineral development in the Canadian Arctic. *International Journal of Sustainable Development & World Ecology*, *27*(4), 297–309. doi.org/10.1080/13504509.2019.1684397

Communities of Aklavik, Inuvik, Holman Island, Paulatuk and Tuktoyaktuk, Nickels, S., Buell, M., Furgal, C., & Moquin, H. (2005). *Unikkaaqatigiit—Putting the Human Face on Climate Change: Perspectives from the Inuvialuit Settlement Region*. Joint publication of Inuit Tapiriit Kanatami, Nasivvik Centre for Inuit Health and Changing Environments at Université Laval and the Ajunnginiq Centre at the National Aboriginal Health Organization.

Cunsolo Willox, A., Harper, S. L., Edge, V. L., Landman, K., Houle, K., & Ford, J. D. (2011). The land enriches the soul: On climatic and environmental change, affect, and emotional health and well-being in Rigolet, Nunatsiavut, Canada. *Emotion, Space and Society*, *6*, 14–24. doi.org/10.1016/j.emospa.2011.08.005

Dunmall, K. (2018). *Pacific salmon in the Canadian Arctic: Indicators of change* [PhD, University of Manitoba]. https://mspace.lib.umanitoba.ca/bitstream/handle/1993/32856/Dunmall_Karen.pdf?sequence=3&isAllowed=y

Dunmall, K. M., Mochnacz, N. J., Zimmerman, C. E., Lean, C., & Reist, J. D. (2016). Using thermal limits to assess establishment of fish dispersing to high-latitude and high-elevation watersheds. *Canadian Journal of Fisheries and Aquatic Sciences*, *73*(12), 1750–1758. doi.org/10.1139/cjfas-2016-0051

Dunmall, K. M., Reist, J. D., Carmack, E. C., Babaluk, J. A., Heide-Jorgensen, M. P., & Docker, M. F. (2013). Pacific Salmon in the Arctic: Harbingers of Change. In F. J. Mueter, D. M.

S. Dickson, H. P. Huntington, & J. R. Irvine (Eds.), *Responses of Arctic Marine Ecosystems to Climate Change*. Alaska Sea Grant, University of Alaska Fairbanks. doi.org/10.4027/ramecc.2013.07

Dunmall, K., McNicholl, D., & Reist, J. (2018). Community-based Monitoring Demonstrates Increasing Occurrences and Abundances of Pacific Salmon in the Canadian Arctic from 2000 to 2017. North Pacific Anadromous Fish Commission. 11, 87–90. doi.org/10.23849/npafctr11/87.90

Ecosystem Classification Group. (2009). *Ecological regions of the Northwest Territories, Taiga Plains*. Dept. of Environment and Natural Resources, Govt. of the Northwest Territories.

Ecosystem Classification Group. (2012). *Ecological regions of the Northwest Territories, southern Arctic*. Dept. of Environment and Natural Resources, Govt. of the Northwest Territories.

Ecosystem Classification Group. (2013). *Ecological regions of the Northwest Territories, northern Arctic*. Dept. of Environment and Natural Resources, Govt. of the Northwest Territories.

Ellis, S. C. (2005). Meaningful Consideration? A Review of Traditional Knowledge in Environmental Decision Making. *Arctic*, *58*(1), 66–77. doi.org/10.14430/arctic390

Environment Canada. (2018a). *Canadian Climate Normals 1981-2010 Station Data: Inuvik*. https://climate.weather.gc.ca/climate_normals/results_1981_2010_e.html?searchType=stnName&txtStationName=inuvik&searchMethod=contains&txtCentralLatMin=0&txtCentralLatSec=0&txtCentralLongMin=0&txtCentralLongSec=0&stnID=1669&dispBack=1

Environment Canada. (2018b). *Canadian Climate Normals 1981-2010 Station Data: Sachs Harbour*. https://climate.weather.gc.ca/climate_normals/results_1981_2010_e.html?searchType=stnName&txtStationName=sachs+harbour&searchMethod=contains&txtCentralLatMin=0&txtCentralLatSec=0&txtCentralLongMin=0&txtCentralLongSec=0&stnID=1794&dispBack=1

FAO (2002). *The state of world fisheries and aquaculture, 2002*. Food and Agriculture Organization of the United Nations.

FAO (2018). *The state of the world's fisheries and aquaculture*. Food and Agriculture Organization of the United Nations.

Farley, E. V., Murphy, J. M., Cieciel, K., Yasumiishi, E. M., Dunmall, K., Sformo, T., & Rand, P. (2020). Response of Pink salmon to climate warming in the northern Bering Sea. *Deep Sea Research Part II: Topical Studies in Oceanography*, *177*, 104830. doi.org/10.1016/j.dsr2.2020.104830

Ford, J., Cameron, L., Rubis, J., Maillet, M., Nakashima, D., Cunsolo, A., & Pearce, T. (2016). Including indigenous knowledge and experience in IPCC assessment reports. *Nature Climate Change*, *6*, 349–353. doi.org/10.1038/nclimate2954

Ford, J. D. (2009). Vulnerability of Inuit food systems to food insecurity as a consequence of climate change: A case study from Igloolik, Nunavut. *Regional Environmental Change*, *9*(2), 83–100. doi.org/10.1007/s10113-008-0060-x

Ford, J. D., McDowell, G., Shirley, J., Pitre, M., Siewierski, R., Gough, W., Duerden, F., Pearce, T., Adams, P., & Statham, S. (2013). The Dynamic Multiscale Nature of Climate Change Vulnerability: An Inuit Harvesting Example. *Annals of the Association of American Geographers*, *103*(5), 1193–1211. doi.org/10.1080/00045608.2013.776880

Ford, J. D., & Pearce, T. (2010). What we know, do not know, and need to know about climate change vulnerability in the western Canadian Arctic: A systematic literature review. *Environmental Research Letters*, *5*(1), 014008. doi.org/10.1088/1748-9326/5/1/014008

Ford, J. D., & Smit, B. (2004). A Framework for Assessing the Vulnerability of Communities in the Canadian Arctic to Risks Associated with Climate Change. *Arctic*, *57*(4), 389–400. doi.org/10.14430/arctic516

Fossheim, M., Primicerio, R., Johannesen, E., Ingvaldsen, R. B., Aschan, M. M., & Dolgov, A. V. (2015). Recent warming leads to a rapid borealization of fish communities in the Arctic. *Nature Climate Change*, *5*(7), 673–677. doi.org/10.1038/nclimate2647

Free, C. M., Thorson, J. T., Pinsky, M. L., Oken, K. L., Wiedenmann, J., & Jensen, O. P. (2019). Impacts of historical warming on marine fisheries production. *Science*, *363*(6430), 979–983. doi.org/10.1126/science.aau1758

Freeman, M. M. R., Wein, E. E., & Keith, D. E. (1992). *Recovering Rights: Bowhead Whales and Inuvialuit Subsistence in the Western Canadian Arctic*. The University of Alberta Press.

Galappaththi, E. K., Ford, J. D., Bennett, E. M., & Berkes, F. (2019). Climate change and community fisheries in the arctic: A case study from Pangnirtung, Canada. *Journal of Environmental Management*, *250*, 109534. doi.org/10.1016/j.jenvman.2019.109534

Glass, K., & Kaufert, J. (2007). Research Ethics Review and Aboriginal Community Values: Can the Two Be Reconciled? *Journal of Empirical Research on Human Research Ethics*, *2*, 25–40. doi.org/10.1525/jer.2007.2.2.25

Grenier, L. (1998). *Working with Indigenous Knowledge: A Guide for Researchers*. International Development Research Centre, Ottawa.

Groot, C. (2010). *Physiological Ecology of Pacific Salmon.* UBC Press.

Groot, G. (1991). *Pacific Salmon Life Histories*. UBC Press.

Hansen, W. D., Brinkman, T. J., Leonawicz, M., Chapin, F. S., & Kofinas, G. S. (2013). Changing Daily Wind Speeds on Alaska's North Slope: Implications for Rural Hunting Opportunities. *Arctic*, *66*(4), 448–458.

Hasbrouck, T. R., Brinkman, T. J., Stout, G., Trochim, E., & Kielland, K. (2020). Quantifying effects of environmental factors on moose harvest in Interior Alaska. *Wildlife Biology*, *2020*(2). doi.org/10.2981/wlb.00631

Hauser, D. D. W., Laidre, K. L., & Stern, H. L. (2018). Vulnerability of Arctic marine mammals to vessel traffic in the increasingly ice-free Northwest Passage and Northern Sea Route. *Proceedings of the National Academy of Sciences*, *115*(29), 7617–7622. doi.org/10.1073/pnas.1803543115

Heuer, R. M., & Grosell, M. (2014). Physiological impacts of elevated carbon dioxide and ocean acidification on fish. *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology*, *307*(9), R1061–R1084. doi.org/10.1152/ajpregu.00064.2014

Houde, N. (2007). The Six Faces of Traditional Ecological Knowledge: Challenges and Opportunities for Canadian Co-Management Arrangements. *Ecology and Society*, *12*(2), 34. doi.org/10.5751/ES-02270-120234

ICC (Inuit Circumpolar Council Alaska). (2020). *Food Sovereignty and Self-Governance: Inuit role in managing Arctic marine resources*. https://iccalaska.org/wp-icc/wp-content/uploads/2020/09/FSSG-Report_-LR.pdf

IJS (Inuvialuit Joint Secretariat). (2003). *Inuvialuit Harvest Study: Data and Methods Report.* https://jointsecretariat.ca/wp-content/uploads/2015/11/IHS10yrDataMethodsReport.pdf

Inglis, J. (1993). *Traditional Ecological Knowledge: Concepts and Cases*. International Development Research Centre, Ottawa.

IPCC (Intergovernmental Panel on Climate Change). (2019). *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate.* IPCC, Geneva.

IRC (Inuvialuit Regional Corporation). (2018). *Inuvialuit on the Front Line of Climate Change*.

IRC (Inuvialuit Regional Corporation). (n.d.). *Committee for Original People's Entitlement (COPE)*. https://irc.inuvialuit.com/about-irc/inuvialuit-final-agreement/committee-original-peoples-entitlement-cope

Irvine, J., Linn, E., Gillespie, K., Mcleod, C., & Reist, J. (2009). Pacific Salmon in Canada's Arctic draining rivers with emphasis on those in British Columbia and the Yukon. *Pacific Fisheries Resource Conservation Council*.

ITK (Inuit Tapirit Kanatami). (2014). *Social Determinants of Inuit Health in Canada*. https://www.itk.ca/wp-content/uploads/2016/07/ITK_Social_Determinants_Report.pdf

ITK (Inuit Tapirit Kanatami). (2019a). *National Inuit Climate Change Strategy*. http://www.deslibris.ca/ID/10102688

ITK (Inuit Tapirit Kanatami). (2019b). *National Inuit Strategy on Research Roundtable*. https://www.itk.ca/wp-content/uploads/2019/11/ITK_NISR_Roundtable_11.pdf

Johannes, R. E. (1989). *Traditional ecological knowledge: A collection of essays*. IUCN. https://www.iucn.org/content/traditional-ecological-knowledge-a-collection-essays

Kaeriyama, M., Nakamura, M., Edpalina, R., Bower, J., Yamaguchi, H., Walker, R., & Myers, K. (2004). Change in feeding ecology and trophic dynamics of Pacific salmon (Oncorhynchus spp.) in the central Gulf of Alaska in relation to climate events. *Fisheries Oceanography*, *13*, 197–207. doi.org/10.1111/j.1365-2419.2004.00286.x

Kenny, T.-A., Fillion, M., MacLean, J., Wesche, S. D., & Chan, H. M. (2018). Calories are cheap, nutrients are expensive – The challenge of healthy living in Arctic communities. *Food Policy*, *80*, 39–54. doi.org/10.1016/j.foodpol.2018.08.006

Kral, M. J., Idlout, L., Minore, J. B., Dyck, R. J., & Kirmayer, L. J. (2011). Unikkaartuit: Meanings of well-being, unhappiness, health, and community change among Inuit in Nunavut, Canada. *American Journal of Community Psychology*, *48*(3–4), 426–438. doi.org/10.1007/s10464-011-9431-4

Krupnik, I., Aporta, C., Gearheard, S., Laidler, G. J., & Holm, L. K. (Eds.). (2010). *SIKU: Knowing Our Ice: Documenting Inuit Sea Ice Knowledge and Use*. Springer Netherlands. doi.org/10.1007/978-90-481-8587-0

Kuhnlein, H., & Receveur, O. (2007). Local Cultural Animal Food Contributes High Levels of Nutrients for Arctic Canadian Indigenous Adults and Children. *The Journal of Nutrition*, *137*, 1110–1114. doi.org/10.1093/jn/137.4.1110

Laidler, G. J., Ford, J. D., Gough, W. A., Ikummaq, T., Gagnon, A. S., Kowal, S., Qrunnut, K., & Irngaut, C. (2009). Travelling and hunting in a changing Arctic: Assessing Inuit vulnerability to sea ice change in Igloolik, Nunavut. *Climatic Change*, *94*(3), 363–397. doi.org/10.1007/s10584-008-9512-z

Lam, V. W. Y., Cheung, W. W. L., & Sumaila, U. R. (2016). Marine capture fisheries in the Arctic: Winners or losers under climate change and ocean acidification? *Fish and Fisheries*, *17*(2), 335–357. doi.org/10.1111/faf.12106

Lambden, J., Receveur, O., & Kuhnlein, H. (2007). Traditional food attributes must be included in studies of food security in the Canadian Arctic. *International Journal of Circumpolar Health*, *66*, 308–319. doi.org/10.3402/ijch.v66i4.18272

Lemly, A. D. (1994). Mining in northern Canada: Expanding the industry while protecting arctic fishes—A review. *Ecotoxicology and Environmental Safety*, *29*(2), 229–242. doi.org/10.1016/0147-6513(94)90022-1

Linden, E. (1991). Lost Tribes, Lost Knowledge. *Time*, 46–54.

Lõhmus, M., & Björklund, M. (2015). Climate change: What will it do to fish—parasite interactions? *Biological Journal of the Linnean Society*, *116*(2), 397–411. doi.org/10.1111/bij.12584

Lyons, N. (2009). Inuvialuit rising: The evolution of Inuvialuit identity in the modern era. *Alaska Journal of Antropology*, *7*(2), 18.

Manseau, M., Parlee, B., & Ayles, B. (2005). A Place for Traditional Ecological Knowledge in Resource Management. In F. Berkes, R. Huebert, H. Fast, M. Manseau, & A. Diduck (Eds.), *Breaking Ice: Renewable Resource and Ocean Management in the Canadian North*. University of Calgary Press. doi.org/10.2307/j.ctv6gqvp5

Marques, A., Nunes, M. L., Moore, S. K., & Strom, M. S. (2010). Climate change and seafood safety: Human health implications. *Food Research International*, *43*(7), 1766–1779. doi.org/10.1016/j.foodres.2010.02.010

Montgomery, D. (2000). Coevolution of the Pacific salmon and Pacific Rim topology. *Geology*, *28*, 1107–1110. doi.org/10.1130/0091-7613(2000)28<1107:COTPSA>2.0.CO;2

Morrison, D. (2000). Inuvialuit Fishing and the Gutchiak Site. *Arctic Anthropology*, *37*(1), 1–42. JSTOR.

Mozaffarian, D., & Rimm, E. B. (2006). Fish Intake, Contaminants, and Human HealthEvaluating the Risks and the Benefits. *JAMA*, *296*(15), 1885–1899. doi.org/10.1001/jama.296.15.1885

Nadasdy, P. (2003). *Hunters and Bureaucrats: Power, Knowledge, and Aboriginal-State Relations in the Southwest Yukon*. UBC Press. http://site.ebrary.com/lib/alltitles/docDetail.action?docID=10130588

Nagy, M. I. (1994). Yukon North Slope Inuvialuit Oral History: Occasional Papers in Yukon History No. 1 (First Edition). Government of Yukon, Queen's Printer.

Nielsen, J. L., Ruggerone, G. T., & Zimmerman, C. E. (2013). Adaptive strategies and life history characteristics in a warming climate: Salmon in the Arctic? *Environmental Biology of Fishes*, *96*(10), 1187–1226. doi.org/10.1007/s10641-012-0082-6

Nielsen, J., Rosing-Asvid, A., Meire, L., & Nygaard, R. (2020). Widespread occurrence of pink salmon (*Oncorhynchus gorbuscha*) throughout Greenland coastal waters. *Journal of Fish Biology*, *96*(6), 1505–1507. doi.org/10.1111/jfb.14318

Niemi, A., Ferguson, S., Hedges, K., H Melling, Michel, C., Ayles, B., Azetsu-Scott, K., Coupel, P., Deslauriers, D., Devred, E., Doniol-Valcroze, T., Dunmall, K., Eert, J., Galbraith, P., Geoffroy, M., Gilchrist, G., Hennin, H., Howland, K., Kendall, M., … Zimmerman, S.

(2019). *State of Canada's Arctic Seas*. Canadian Technical Report of Fisheries and Aquatic Sciences. http://publications.gc.ca/collections/collection_2019/mpo-dfo/Fs97-6-3344-eng.pdf

Pankhurst, N. W., & Munday, P. L. (2011). Effects of climate change on fish reproduction and early life history stages. *Marine and Freshwater Research*, *62*(9), 1015–1026. doi.org/10.1071/MF10269

Parlee, B., & Furgal, C. (2012). Well-being and environmental change in the arctic: A synthesis of selected research from Canada's International Polar Year program. *Climatic Change*, *115*(1), 13–34. doi.org/10.1007/s10584-012-0588-0

Pearce, T., Ford, J., Willox, A. C., & Smit, B. (2015). Inuit Traditional Ecological Knowledge (TEK), Subsistence Hunting and Adaptation to Climate Change in the Canadian Arctic. *Arctic*, *68*(2), 233–245.

Pecl, G. T., Araújo, M. B., Bell, J. D., Blanchard, J., Bonebrake, T. C., Chen, I.-C., Clark, T. D., Colwell, R. K., Danielsen, F., Evengård, B., Falconi, L., Ferrier, S., Frusher, S., Garcia, R. A., Griffis, R. B., Hobday, A. J., Janion-Scheepers, C., Jarzyna, M. A., Jennings, S., … Williams, S. E. (2017). Biodiversity redistribution under climate change: Impacts on ecosystems and human well-being. *Science*, *355*(6332). doi.org/10.1126/science.aai9214

Petrasek MacDonald, J., Cunsolo Willox, A., Ford, J. D., Shiwak, I., & Wood, M. (2015). Protective factors for mental health and well-being in a changing climate: Perspectives from Inuit youth in Nunatsiavut, Labrador. *Social Science & Medicine*, *141*, 133–141. doi.org/10.1016/j.socscimed.2015.07.017

Proverbs, T., Lantz, T. C., Lord, S. I., Amos, A., Gwich'in Tribal Council Department of Cultural Heritage, & Ban, N. C. (2020). Social-Ecological Determinants of Access to Fish and Well-Being in Four Gwich'in Communities in Canada's Northwest Territories. *Human Ecology*, *48*, 155–171. doi.org/10.1007/s10745-020-00131-x

Qin, Y., & Kaeriyama, M. (2016). Feeding Habits and Trophic Levels of Pacific Salmon (Oncorhynchus spp.) in the North Pacific Ocean. *North Pacific Anadromous Fish Commission Bulletin*, *6*, 469–481. doi.org/10.23849/npafcb6/469.481

RCAP (Royal Commission on Aboriginal Peoples). (1996). *Gathering Strength (volume iii)*. Ministry of Supply and Services.

Reid, A. J., Eckert, L. E., Lane, J.-F., Young, N., Hinch, S. G., Darimont, C. T., Cooke, S. J., Ban, N. C., & Marshall, A. (2020). “Two-Eyed Seeing”: An Indigenous framework to transform fisheries research and management. *Fish and Fisheries, 22*(2), 243-261. doi.org/10.1111/faf.12516

Reid, J. (2018). The cliche of resilience: Governing indigeneity in the arctic. *Arena Journal*. https://search.informit.org/doi/abs/10.3316/INFORMIT.103400062328338

Reist, J. D., Wrona, F. J., Prowse, T. D., Power, M., Dempson, J. B., Beamish, R. J., King, J. R., Carmichael, T. J., & Sawatzky, C. D. (2006). General Effects of Climate Change on Arctic Fishes and Fish Populations. *AMBIO: A Journal of the Human Environment*, *35*(7), 370–380. doi.org/10.1579/0044-7447

Rijnsdorp, A., Peck, M., Engelhard, G., Moellmann, C., & Pinnegar, J. (2008). Resolving climate impacts on fish stocks. *ICES Journal of Marine Science*, *66*: 1570–1583

Searles, E. (2009). Food and the Making of Modern Inuit Identities. *Food and Foodways*, *10*(1–2), 55–78. hdoi.org/10.1080/07409710212485

Sheridan, J. A., & Bickford, D. (2011). Shrinking body size as an ecological response to climate change. *Nature Climate Change*, *1*(8), 401–406. doi.org/10.1038/nclimate1259

Simpson, L. R. (2004). Anticolonial Strategies for the Recovery and Maintenance of Indigenous Knowledge. *American Indian Quarterly*, *28*(3/4), 373–384.

Smith, L. T. (1999). Decolonizing Methodologies: Research and Indigenous Peoples. Zed Books.

Stefansson, V. (1914). *The Stefánsson-Anderson Arctic Expedition of the American Museum: Preliminary ethnological report.* Anthropological papers of the AMNH. digitallibrary.amnh.org/handle/2246/242

Stephenson, S. A. (2006). A Review of the Occurrence of Pacific Salmon (*Oncorhynchus spp.*) in the Canadian Western Arctic. *Arctic*, *59*(1), 37–46.

Sunday, J. M., Pecl, G. T., Frusher, S., Hobday, A. J., Hill, N., Holbrook, N. J., Edgar, G. J., Stuart-Smith, R., Barrett, N., Wernberg, T., Watson, R. A., Smale, D. A., Fulton, E. A., Slawinski, D., Feng, M., Radford, B. T., Thompson, P. A., & Bates, A. E. (2015). Species traits and climate velocity explain geographic range shifts in an ocean-warming hotspot. *Ecology Letters*, *18*(9), 944–953. doi.org/10.1111/ele.12474

Tadokoro, K., Ishida, Y., Davis, N. D., Ueyanagi, S., & Sugimoto, T. (1996). Change in chum salmon (Oncorhynchus keta) stomach contents associated with fluctuation of pink salmon (O. gorbuscha) abundance in the central subarctic Pacific and Bering Sea. *Fisheries Oceanography*, *5*(2), 89–99. doi.org/10.1111/j.1365-2419.1996.tb00108.x

Tai, T. C., Steiner, N. S., Hoover, C., Cheung, W. W. L., & Sumaila, U. R. (2019). Evaluating present and future potential of arctic fisheries in Canada. *Marine Policy*, *108*. doi.org/10.1016/j.marpol.2019.103637

Todd, Z. (2016). "You never go hungry": Fish pluralities, human-fish relationships, indigenous legal orders and colonialism in Paulatuuq, Canada. [PhD, University of Aberdeen]. https://eu03.alma.exlibrisgroup.com/view/delivery/44ABE_INST/12152958330005941

TRCC (Truth and Reconciliation Commission of Canada). (2015). *Canada's residential schools: The final report of the Truth and Reconciliation Commission of Canada*. http://publications.gc.ca/site/eng/9.807830/publication.html

Turner, N. J., Ignace, M. B., & Ignace, R. (2000). Traditional Ecological Knowledge and Wisdom of Aboriginal Peoples in British Columbia. *Ecological Applications*, *10*(5), 1275–1287. doi.org/10.2307/2641283

Usher, P. (1971). The Canadian Western Arctic: A Century of Change. *Anthropologica*, *13*(1/2), 169–183. doi.org/10.2307/25604848

Usher, P. J. (2000). Traditional ecological knowledge in environmental assessment and management. *Arctic*, 183–193.

Usher, P. J. (2002). Inuvialuit Use of the Beaufort Sea and its Resources, 1960-2000. *Arctic*, *55*(5), 18–28. doi.org/10.14430/arctic732

Walsh, J. E., Overland, J. E., Groisman, P. Y., & Rudolf, B. (2011). Ongoing Climate Change in the Arctic. *AMBIO*, *40*(1), 6–16. doi.org/10.1007/s13280-011-0211-z

Waples, R. S., Pess, G. R., & Beechie, T. (2008). Evolutionary history of Pacific salmon in dynamic environments. *Evolutionary Applications*, *1*(2), 189–206. doi.org/10.1111/j.1752-4571.2008.00023.x

Watt-Cloutier, S. (2005). Petition to the Inter American Commission on Human Rights Seeking Relief from Violations Resulting from Global Warming Caused by Acts and Omissions of the United States.

Wenzel, G. W. (1999). Traditional Ecological Knowledge and Inuit: Reflections on TEK Research and Ethics. *Arctic*, *52*(2), 113–124.

Wesche, S. D., & Chan, H. M. (2010). Adapting to the Impacts of Climate Change on Food Security among Inuit in the Western Canadian Arctic. *EcoHealth*, *7*(3), 361–373. doi.org/10.1007/s10393-010-0344-8

Whyte, K. (2017). Indigenous Climate Change Studies: Indigenizing Futures, Decolonizing the Anthropocene. *English Language Notes*, *55*(1), 153–162.

Wong, C., Ballegooyen, K., Ignace, L., Jane, M., Johnson, G., & Swanson, H. (2020). Towards reconciliation: 10 Calls to Action to natural scientists working in Canada. *Facets*, *5*. doi.org/10.1139/facets-2020-0005

Yoon, S., Watanabe, E., Ueno, H., & Kishi, M. J. (2015). Potential habitat for chum salmon (Oncorhynchus keta) in the Western Arctic based on a bioenergetics model coupled with a three-dimensional lower trophic ecosystem model. *Progress in Oceanography*, *131*, 146–158. doi.org/10.1016/j.pocean.2014.12.009

Chapter 2 – Inuvialuit Knowledge of Pacific Salmon Range Expansion in the Western Canadian Arctic[1]

Introduction

Accelerated rates of warming in Arctic regions have put circumpolar communities on the front lines of the climate crisis (Ford *et al.* 2014; Krupnik *et al.* 2010; NOAA 2017; Pearce *et al.* 2015). In the western Arctic in what is now called Canada, the cultural traditions and livelihoods of Inuvialuit are strongly linked to their terrestrial and marine ecosystems (Alunik *et al.* 2003). Over the last 150 years, Inuvialuit lifeways have faced repeated change with the arrival of whalers, traders, and missionaries, disease epidemics, and the institution of colonial policies and economies (Alunik *et al.* 2003; Usher 2002).

Like many Arctic peoples, Inuvialuit communities now face rapid environmental shifts that are altering aquatic and terrestrial ecosystems and the distributions of species with cultural and subsistence importance (Ford *et al.* 2014; Krupnik *et al.* 2010; Pearce *et al.* 2015). The primary drivers of these changes include anthropogenic climate warming (IPCC 2019), sea ice loss (Krupnik *et al.* 2010), permafrost thaw (Lantz and Kokelj 2008), vegetation change (Chen *et al.* 2021), and altered weather conditions (Bintanja and Andry 2017; Walsh *et al.* 2011). These environmental changes are also facilitating the range expansion of southern species into Arctic environments (NOAA 2017; Tape *et al.* 2016; Tape *et al.* 2018). These combined effects will have significant impacts on Inuvialuit lifeways (Alunik *et al.* 2003; IRC 2018).

The northward expansion of Pacific salmon (*Oncorhynchus spp.*) into the Inuvialuit Settlement Region (ISR) (Figure 1) is an example of a change that is likely to affect subsistence fishing (Carothers *et al.* 2019; Dunmall *et al.* 2013; Dunmall *et al.* 2018). Inuvialuit harvesters are particularly concerned about the potential for salmon to prey on or outcompete subsistence fish, such as *iqalukpik* (Arctic char, *Salvelinus alpinus*) and *anaakłiq* (broad whitefish, *Coregonus nasus*) (Alunik *et al.* 2003; Krupnik *et al.* 2010; Pearce *et al.* 2015). The importance of these

[1] The research presented in this chapter was a collaboration with multiple parties including my supervisory committee, Tracey Proverbs, and the Hunters and Trappers Committees in Aklavik, Inuvik, Paulatuk, Sachs Harbour, Tuktoyaktuk, and Ulukhaktok.

"country" foods goes far beyond subsistence. They are critical to individual and community health, well-being, and cultural identity (Alunik *et al.* 2003; Kuhnlein and Receveur 1996; Proverbs *et al.* 2020). As such, the northward expansion of salmon is also likely to influence sociocultural and socioeconomic processes. To evaluate the risks and opportunities salmon pose to Arctic fish populations, and Inuvialuit communities, additional research on salmon abundance, spatial distribution, and habitat use is urgently needed. Detailed knowledge held by Inuvialuit fishers provides an important source of insight into these questions. In this research project we documented: 1) changes in the magnitude of salmon harvest over the last four decades, 2) co-occurring changes in local fish populations attributed to increasing salmon, and 3) environmental factors influencing salmon range expansions. This work is part of the larger Arctic Salmon Project (ASP, Dunmall *et al.* 2018) the goal of which is to understand the changing harvest of salmon in Arctic Canada. This paper synthesizes Inuvialuit knowledge to provide historical context on the diversity and distribution of Pacific salmon in the nearshore and freshwater environments of the ISR. This in turn may inform management, mitigation, and policy that addresses species range shifts which may affect Inuvialuit cultural activities.

Study Background

This research project is based in the Inuvialuit Settlement Region (Figure 1). Historically, Inuvialuit moved throughout their territory to harvest *qilalukkat* (beluga), *tuktuvialuit* (caribou), *omingmak* (muskox), and diverse fishes, and gathered in large numbers for hunts and celebrations (Alunik *et al.* 2003). Ancestors of the Inuvialuit have lived in this area for over a thousand years (Alunik et al. 2003) and access to cultural practices is an integral component of Inuvialuit identity and well-being (Alunik et al. 2003). There are three dialects of Inuvialuktun in the ISR: Sallirmiutun, Uummarmiutun, and Kangiryuarmiutun, and Inuvialuit share many cultural and relational ties to Inuit throughout the Arctic.

As elsewhere throughout the Americas, Euro-American settlers brought colonial worldviews and practices to the ISR in the early 1800s. Exploitative trading operations were common, beginning with the harvest of bowhead whales in the late 1800s, then transitioning into the longer fur trade era. These settler industries led to rapid socioeconomic change supported by anti-Indigenous racist policy (Cameron 2012).

In 1984, the history and importance of Inuvialuit ties to the land were recognized by the Canadian government with the signing of the Inuvialuit Final Agreement (IFA) (Canada 1984). Among other things, the IFA established the legal methods by which Inuvialuit govern the Inuvialuit Settlement Region (ISR) under colonial law, and the organizations responsible for that governance. Some of these organizations include the Inuvialuit Game Council, the Fisheries Joint Management Committee (FJMC), and the Hunters and Trappers Committees (HTCs) in each community. These organizations work together, and with federal and territorial governments, to advise the relevant Ministers regarding marine and terrestrial management in the ISR, and to ensure that resource management mobilizes and relies on Inuvialuit worldviews and knowledge (Binder and Hanbridge 1993).

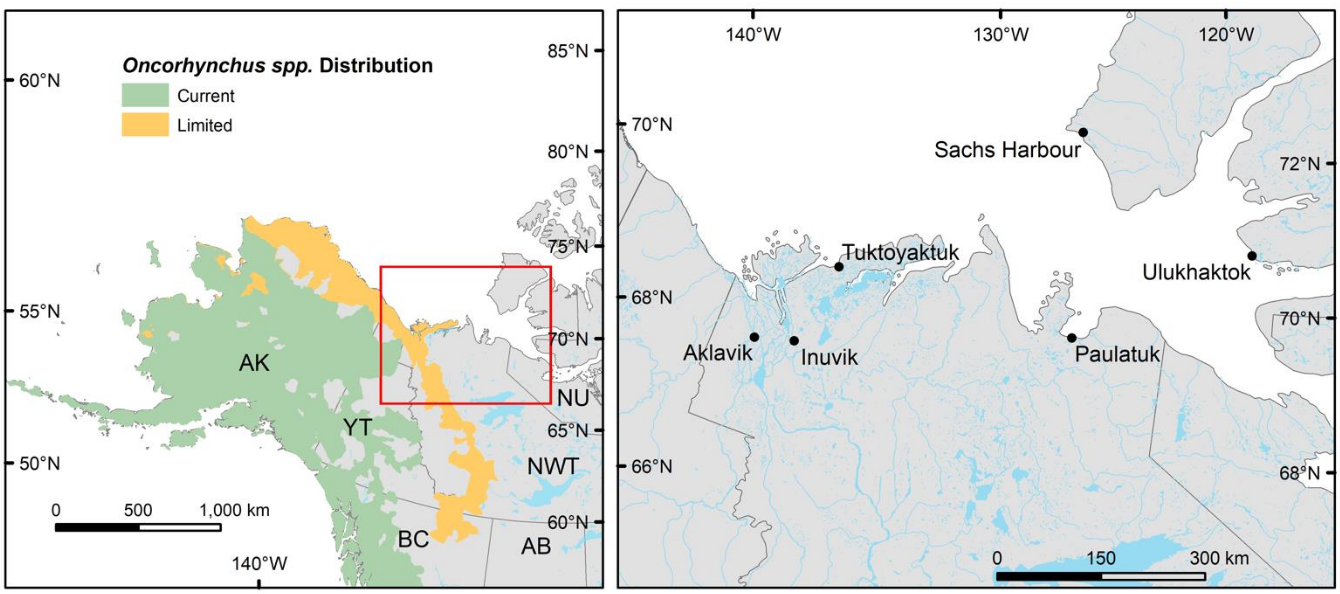

Figure 2.1. The left panel shows a map of the current and limited distribution of Pacific salmon (*Oncorhynchus* spp.). Distribution data adapted from Augerot and Foley 2005. The red box in the left panel is expanded on the right to show the locations of the six communities in the Inuvialuit Settlement Region.

The ISR has six permanent communities: Aklavik, Inuvik, Paulatuk, Sachs Harbour, Tuktoyaktuk, and Ulukhaktok. Locally, Aklavik, Inuvik, and Tuktoyaktuk are known as the Delta communities as they are located in or near the fresh or brackish water ecosystems of Mackenzie River delta and estuary. All three of these communities are located near the treeline ecotone where a warmer climate supports more productive woodland and tundra ecosystems (ECG 2009, 2012). Paulatuk, Sachs Harbour, and Ulukhaktok are known as the Outer communities. They are in the eastern ISR and experience a colder climate, are surrounded by less productive tundra ecosystems, and have reduced access to freshwater ecosystems (ECG 2013). The ecological differences between Delta and Outer regions of the ISR are reflected in the subsistence opportunities and preferences of each community. Detailed information on each community's fishing activities, fish preferences, and unique management priorities can be found in their Community Conservation Plans (AHTC *et al.* 2016; IHTC *et al.* 2016; OHTC *et al.* 2016; PHTC *et al.* 2016; SHHTC *et al.* 2016; THTC *et al.* 2016).

Author Positionality

The authorship team is composed of both settler and Indigenous experts. Z.C., K.D., and T.L. are white, settler scholars and T.P. is a scholar of Kaska-Dena, European, and Bajan descent, all of whom live outside of the ISR. The community HTCs are composed of Inuvialuit harvesters elected by the community whose mandate includes engaging in "conservation, research, and management" in their regions of the ISR (Canada 1984, 30). Z.C., K.D., T.P., and T.L. have worked to temper their positionalities through self-reflection, ongoing development of relationships, continual reporting of results to communities, and earnestly seeking community feedback on their contributions.

Methods

This project was developed at the request of the Fisheries Joint Management Committee (FJMC) and Inuvialuit Game Council (IGC), and was completed through a partnership among the six Hunters and Trappers Committees (HTCs), University of Victoria researchers, and Fisheries and Oceans Canada. We followed a community-based participatory research methodology (CBPR, Castleden *et al.* 2012) which increases the knowledge of all parties by equitably involving community members and organizations at all stages of the research process. Iterative stages of input from communities and the primary research team shape the methods, analysis, and interpretation of the research (Castleden *et al.* 2012). Our research demonstrated the tenets of CBPR by directly answering community questions, collaborating with community and regional management organizations, engaging community members at local dinners, reporting throughout the process, and community validation of results.

Our interview questions explored temporal and spatial variation in the harvest of Pacific salmon, historical harvests of Arctic fish species, and the changes in the coastal and freshwater conditions that influence fish populations (Appendix 1). Questions that focused on changes in coastal and freshwater conditions varied among communities because of their different environments. Asking slightly different questions among communities positioned us to more accurately understand the changes being experienced by Inuvialuit fishers in different locations. The semi-structured nature of the interviews provided participants the opportunity to direct the conversation, and participants each had the opportunity to review their transcript for inaccuracies.

From September 2018 to September 2019, Z.C., T.P., and local interview technicians conducted eight to nine interviews in each Inuvialuit community (total of 53). Local interviewers were hired by the HTC and chose not to be identified in this publication. Interview participants were selected by the HTC based on their knowledge of local fisheries, environmental change, and the history of salmon harvest in the area. Participants were all Inuvialuit, and included men and women who ranged in age from approximately 30 to approximately 85. Each provided informed consent prior to participating in their interview following a protocol approved by the University of Victoria Human Ethics Research Board (application 19-0101). Participants indicated whether they wanted accreditation by name in this report. Many had lived their whole lives in the community in which we interviewed them, and some had moved between communities and spoke to historical harvests in multiple locations in different years. With one exception, all interviews were conducted in English. One elder chose to do their interview in Kangiryuarmiutun, so we hired a local translator to facilitate the interview and our interactions. While visiting communities we also hosted open houses where community members could come to learn about this project and provide their input over a shared meal. These were advertised variously on community posting boards, local radio, and HTC Facebook pages. They ranged in attendance from approximately 15-30 fishers. While no formal data collection occurred in these settings, they provided visiting members of the research team with context of community perceptions of salmon and their implications. They also facilitated deeper relationships between visiting researchers and local fishers.

Z.C. coded and analyzed interview transcripts with a combination of inductive and deductive approaches using NVivo software (Version 10). In the first round of deductive coding Z.C. reviewed the text of each interview to highlight themes that were identified as important by the IGC and FJMC, such as: 1) salmon, 2) local fish species, 3) environmental change, and 4) fishing experience. In further rounds of coding Z.C. refined these categories into codes designed to answer questions posed by the research team and partner organizations (stated in the introduction). Further rounds of coding followed an inductive, grounded theory approach. Three additional themes arose from the inductive approach: 1) Inuvialuit culture, 2) access to fishing, and 3) changes in local mammal populations. A total of 145 codes were nested within seven thematic categories (Appendix 2). The most common thematic category "salmon" focused on several dimensions of the salmon harvest such as: 1) the estimated catch over a fisher's lifetime, 2) the timing and location of catch, and 3) methods of salmon harvests. Other thematic categories included changes to local fish populations and changes to the local aquatic environments that may influence or be influenced by salmon presence.

The identification of Pacific salmon to the level of species is a new skill for many Inuvialuit fishers. Even in locations where salmon have been caught for generations, identification skills are limited because historically harvests only included one species (chum salmon (*Oncorhynchus keta*)). To facilitate conversations about species identification we brought a species identification guide with images and descriptions of each species in both silver and spawning phases, and asked individuals to identify the salmon species they had caught. Despite the guide, many fishers remained unsure about species identification, especially if the fish they were trying to identify had been caught years or decades prior. While identification of salmon species proved challenging, fishers were unsurprisingly adept at distinguishing between salmon and local fish species. Throughout this paper, references to salmon (*Oncorhynchus*. spp) will therefore include all five species of Pacific salmon in North America with an understanding that chum (*O. keta*) and pink (*O. gorbuscha*) are the most common in the ISR, followed by sockeye (*O. nerka*), then chinook (*O. tshawytscha*), and finally coho (*O. kisutch*) (Dunmall *et al.* 2018; Stephenson 2006).

In this paper, we present the information from the interviews alongside harvest data from the Arctic Salmon Project (ASP). In the 1990s, Fisheries and Oceans Canada began tracking novel salmon occurrences throughout the Arctic when concerned fishers submitted these unknown fish for identification (Babaluk *et al.* 2000). Around the year 2000, the numbers of salmon being returned began to increase, which prompted a more concerted effort to collect salmon that would become the ASP. The ASP continues to rely on fishers who submit the entire body or the head of a salmon that they caught to their local management office. Fishers are compensated for their contribution with a gift-card for the local grocery store, and the salmon are sent to the ASP research team at Fisheries and Oceans Canada. Over the last two decades the ASP has received thousands of observations, monitoring relative salmon abundance across the Canadian Arctic. It is important to note that the voluntary nature of the fish collection means that the number of fish returned to the ASP does not precisely represent salmon abundance. However, in this study we combine information from interviews with fishers and the ASP data to better interpret real changes in salmon harvest. While common in other disciplines, methods such as ours are still emergent in fisheries science (Cooke *et al.* 2021).

The following summarizes the contributions of each member of the authorship team to the research process. The FJMC conceived the idea. Z.C., K.D., and T.L. created the project plan which was then approved by the FJMC, Inuvialuit Game Council, and each HTC. The HTCs selected interview participants and hired a local interviewer. Z.C., T.P. and the local interviewers conducted the interviews. Z.C. analyzed the interview transcripts and drafted the results. HTCs validated the results, provided additional clarity and nuance to our interpretation, and indicated which findings were appropriate and important to include in this manuscript. Z.C. prepared the manuscript with input from K.D., T.P., and T.L. FJMC and HTCs reviewed the manuscript. K.D. and T.L. provided funding and supervised the project. Fishers and elders in each community contributed their knowledge, feedback, and direction at open-house community presentations and dinners. HTCs chose whether or not to be listed as co-authors.

Results

The interviews we conducted indicate that prior to the 1990s, salmon catches were rare or unheard of in the Outer communities of Paulatuk, Sachs Harbour and Ulukhaktok, but had occurred infrequently in the Delta communities of Aklavik, Inuvik, and Tuktoyaktuk for at least the last two generations (Table 1). Our interviews also show that salmon harvest has increased in all communities within the last three decades. Of the 53 Inuvialuit fishers that we interviewed across the ISR, over 80% had personally caught salmon (Table 1). Among this group, more than 70% were confident that their parents or grandparents had never caught salmon. All of the fishers who confidently remember their elders catching salmon (approximately 25%) were from Delta communities.

Table 2.1 Summary data showing whether participants' elders had caught salmon, and if the participants themselves had caught salmon. In this context we define elders as parents, grandparents, or other community figures who passed important knowledge of fisheries to the interview participants.

	Elders Caught Salmon			Participants Caught Salmon	
	Yes	Maybe	No	Yes	No
Aklavik (n=10)	5	3	2	9	1
Inuvik (n=9)	2	1	6	6	3
Tuktoyaktuk (n=8)	2	1	5	8	0
Sachs Harbour (n=8)	0	0	8	5	3
Ulukhaktok (n=9)	0	1	8	9	0
Paulatuk (n=9)	0	0	9	6	3
Total (n=53)	9	6	38	43	10

Of the 53 participants we spoke with, 25 said that in recent years the salmon harvest has been increasing, three said it was stable, and one said it was decreasing, while the other 24 expressed uncertainty about the trend. Participants explained that they were hesitant to describe the trends in salmon harvest in certain terms because of high inter-annual variability in salmon harvest, and their limited knowledge of salmon life history. Fishers told us that they wanted to learn more about salmon and indicated that they did not possess the knowledge of salmon habitat, diet, or life history that they did for other fishes. It is noteworthy that fishers felt more confident discussing the population dynamics of important food species such as whitefish, Arctic and or Dolly Varden Char, and lake trout.

The reports of salmon catches in our interviews showed that the salmon harvest has increased across the ISR, particularly over the last 30 years. This information supports interpreting the increase in returned salmon as an increase in harvested salmon (Figure 2). While there are differences among communities in timing and magnitude, an increase in salmon harvest was described in all six communities (Figures 2 and 3). Note that we distinguish between salmon harvest and salmon abundance, as the number of salmon that people harvest does not accurately reflect the abundance of salmon in the ISR. The relationship between salmon harvest and abundance is outside the scope of this research.

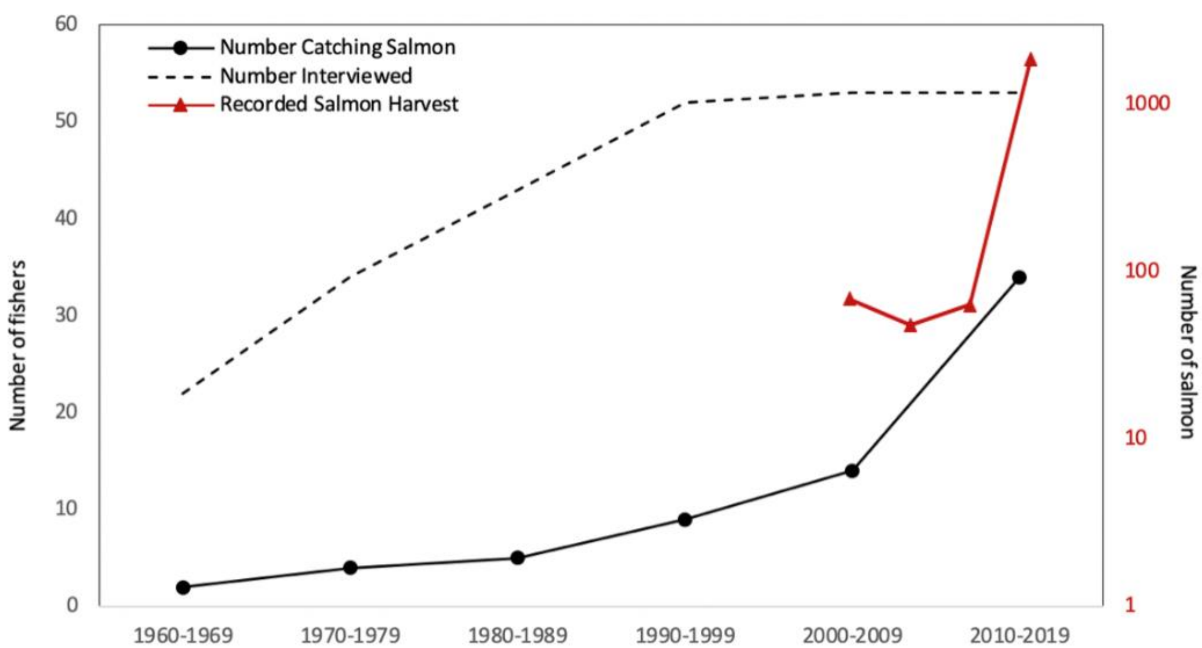

Figure 2.2. Number of participants across all six communities who recalled catching salmon in a given decade compared to the number of participants interviewed (n=53) that were fishing in that decade. The red triangles and red line show the number of salmon returned to the Arctic Salmon Project in the last two decades and are plotted on a second, log-scaled y axis.

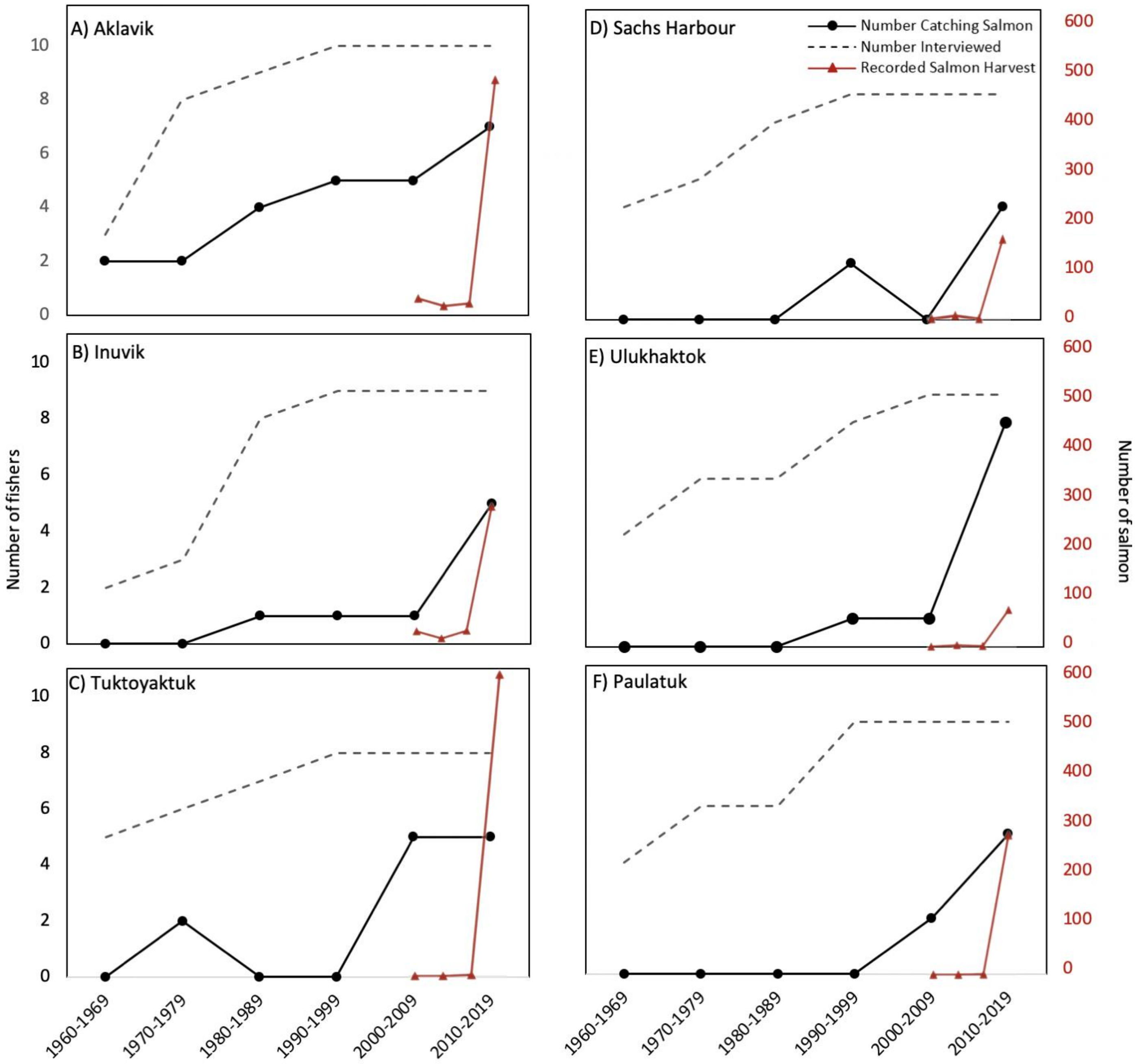

Figure 2.3. Number of participants who recalled catching salmon in a given decade compared to the number of participants interviewed that were fishing in that decade. Each panel represents the participants from one Inuvialuit community. The red triangles and red line show the number of salmon returned to the Arctic Salmon Project in the last two decades and are plotted on the on the second y axis.

Delta Communities

Interviews showed that fishers in the Delta communities (Aklavik, Tuktoyaktuk, and Inuvik) have been catching salmon longer than those in the Outer communities (Sachs Harbour, Ulukhaktok, and Paulatuk). Participants from Aklavik made it clear that people in this community have been catching salmon for generations. Many older participants spoke of their parents or grandparents catching salmon regularly in the Mackenzie Delta. William Storr noted that "*people used to catch a lot of salmon actually*". He suggested that salmon catches were larger in the past, had decreased in the interim, and were now increasing again. Descriptions of cyclical wildlife population abundances were common throughout the interviews, but this was the only mention of salmon abundance following a similar, multi-decadal cycle.

All but one participant in Aklavik reported catching salmon themselves, and many indicated that they have been catching salmon since before they can remember. In some cases, fishers also made reference to specifically targeting salmon in their fishing activities. Explaining why she hadn't caught salmon that year, Nellie Arey said it was because "*we never fish[ed] where we used to fish for salmon*". Outside of Aklavik, none of the fishers we interviewed reported targeting salmon, and no one had experienced catching any for as long as they could remember.

In Inuvik and Tuktoyaktuk only three participants in each community recalled their elders speaking of catching salmon. These participants remember their elders only ever catching a few, and these accounts do not date back as far as those from Aklavik. The earliest accounts of interviewees catching salmon in Tuktoyaktuk and Inuvik are from the late 1970s and early 1980s respectively. The participants who reported these catches both had elders who had caught salmon before them. In the last decade (2010-2019) all three communities in the Delta region have seen an increase in the number of harvesters catching salmon, and the number of fish returned to the Arctic Salmon Project (Figure 3A, 3B, 3C).

Outer Communities

In the Outer communities of Sachs Harbour, Ulukhaktok, and Paulatuk, no participants confidently remembered their elders ever catching salmon. In Sachs Harbour, Lena Wolki told us "*We never* *used to have salmon here.*" Across all three communities the consensus was that semi-regular salmon harvest began between the late 1990s and early 2000s. Fishers in Ulukhaktok noted the possibility that sporadic salmon harvests may have begun as early as the 1970s, but did not identify a specific instance of salmon harvest occurring before the 1990s. In Sachs Harbour and Paulatuk, none of the participants knew of any salmon harvests by their elders or others in the community predating those described in our interviews.

In Sachs Harbour, the earliest account we heard of salmon being caught was in the 1990s in the harbour in front of town. Another interview participant shared a second account of salmon harvest around this time, but after this event there were no accounts of salmon harvest until the mid 2000s. When asked if there were ever salmon before the 1990s, Joe Kudlak said "*I don't think so. Just the ones in a can!*" In Ulukhaktok, the earliest primary record of salmon harvest occurred in the 1990s and was reported by a participant who was out fishing with his father, who had also never seen a salmon before. Since then, the number of people catching salmon, and the magnitude of the annual harvest have increased steadily (Figure 3E). In response to this change Isaac Inuktalik noted "*you can't stop the salmon from invading our island.*" In Paulatuk, the earliest account of salmon harvest occurred in the early 2000s. Prior to this, none of the fishers we interviewed had primary or secondary knowledge of salmon harvest. When we asked Noel Green about the changes in salmon harvest he told us that salmon are "*hanging around, or making their way up here slowly*". As with all of the other communities, the number of people catching salmon in Paulatuk and the number of salmon being harvested have increased since the 2000s (Figure 3F).

The Nature of the Salmon Harvest

The interview participants were clear that salmon harvest across the ISR is incidental and occurs during the harvest of primary subsistence fish including: Arctic char, Dolly Varden, whitefish, trout, and ciscoes. With the exception of two participants in Aklavik, we didn't speak to anyone who intentionally targeted salmon. Fishers are catching salmon wherever they fish, but harvesters who fished with a gill-net during the period from August-October generally caught the most salmon.

Across the entire ISR reports of salmon harvest occurred most frequently in nearshore marine waters, followed by rivers, then lakes (Table 2). Variation from this pattern in individual communities was likely because salmon were most often harvested in the most popular fishing locations of each community. Participants in all six communities also reported that incidental salmon harvest is expanding geographically within their region, as people are regularly catching salmon in new locations.

Table 2.2. Details of the salmon harvests described by Inuvialuit fishers in the six communities in the ISR. Individual interview participants were counted more than once if they caught salmon across multiple categories.

**	Location			Method		Colour		Conditions		Timing		Use		
	Lake	River	Ocean	Hook	Net	Red	Silver	Healthy	Sick	Open	Ice	Consumption	Distribution	ASP
Aklavik (9)	0	8	1	0	9	4	7	8	1	8	2	5	3	2
Inuvik (6)	1	5	3	0	6	3	5	4	2	6	0	3	0	3
Tuktoyaktuk (8)	0	0	8	0	8	2	7	8	0	8	0	3	2	4
Sachs Harbour (5)	2	1	5	0	5	3	3	5	1	5	0	5	2	2
Ulukhaktok (9)	9	1	5	1	9	2	7	8	0	7	7	6	0	3
Paulatuk (6)	1	4	2	1	6	2	4	5	2	4	2	1	0	5
ISR (43)	13	19	24	2	43	16	33	38	6	38	11	23	19	7

Participants reported catching the most salmon during the open water period, between July and October. After freeze up, people continue to catch salmon, but less frequently, in fewer numbers, and exclusively in rivers and lakes. Some participants also noted that the dates of first and last catch every year were extending earlier and later respectively. Elders in Aklavik who had been catching salmon their whole life remember catching salmon in the narrow window of immediately before freeze-up, but not after. Interview participants made it clear that salmon harvest in the last two decades, has begun well before freeze-up, as early as July, and extends far into the winter months, typically as late as December.

Across the ISR, interview participants reported catching salmon in their silver phase more frequently than in their spawning phase (Table 2). This was true in every community except for Sachs Harbour, where participants reported catching an even distribution of silver and spawning phases. When we asked about salmon health, most fishers indicated that fish generally seemed to be in good condition (Table 2), but frequently noted that they were not familiar with indicators of salmon health, like they were for culturally important food fish. As a fisher in Paulatuk noted, "*I wouldn't know what healthy is for them*".

Causes of Range Expansions

Our interviews revealed a range of factors that may be driving shifts in salmon catches, but the majority of fishers pointed to changing climatic conditions as the root cause (Table 3). A Paulatuk harvester said "*I think it's global warming. That's the big issue today and we're not blind to it up here, we're seeing it first hand.*" Table 3 summarizes the effects of climate change that participants noted were affecting salmon ranges. Some participants also discussed additional, possibly compounding, factors influencing salmon harvests such as disturbances in salmon native ranges related to oil exploration in Alaska, earthquakes, or native stream destruction.

Table 2.3. Potential causes of changing Pacific salmon harvest levels as described by Inuvialuit fishers. Indented causes were discussed as sub-categories of broad-scale climate change. The number of participants indicate how many people referred to each cause as a specific driver of change.

Cause	Number of participants (n = 53)
Climate Change	45
Increased air temperature	13
Changing water levels (rivers)	9
Changing ice thickness, extent, and timing	6
Increased water temperature	5
Changing weather patterns	5
Permafrost thaw	4
Changing water quality	3
Increased development	4
A change in the earth's axis	3

Impacts of Increased Salmon

All participants expressed concern about potential interactions between salmon and other fish species, but most of the fishers we spoke with told us that they did not know enough to describe the effects that salmon have on local fishes with certainty. Of the 53 people we interviewed, only five confidently described interactions between local fish species and salmon. All of these interactions were described as negative. Despite this uncertainty, or perhaps because of it, most

Inuvialuit fishers consider salmon an unwelcome addition to their waters. *"I think they scare our char"*, said Margaret Kanayok from Ulukhaktok. Many participants described the potential for negative competitive and predatory interactions between salmon and culturally important food fish such as Arctic char and broad whitefish. Several specific effects on local fish were noted and cautiously attributed to salmon. All communities except Sachs Harbour reported catching more local fish (non-salmon) with scars or open wounds. These wounds were thought to be inflicted by salmon, other fish, or mammals. All communities reported catching more fish with parasites and more fish with soft flesh. Both of these health concerns were linked to warming waters, and some participants hypothesized that salmon may be transporting parasites into Arctic waters. Even fishers in Aklavik, who have a long history of harvesting salmon, expressed concerns about the negative impacts of increasing salmon populations on other fish. Underlying this view was a concern that even if salmon do not have direct negative impacts on local fish populations, salmon are responding to broad-scale changes (Table 3), which will have negative impacts on local fish populations.

Table 2.4. Changes to local fish harvests described in the interviews. We included effects and causes for a given community if consensus within that community was either high or moderate. High => 2/3 of participants, Moderate => 1/3 of participants, Low <= 1/3 of participants. * Asterisks denote changes that may be directly influenced by salmon according to our interviews.

Community Affected	Change	Potential Causes cited in interviews	Consensus
All	Increased variability of fish harvest composition and yield, and a decreasing trend in harvest yield	Changes in local fish populations and increase in adverse weather conditions	High
All	Increase in the variability of population demographics (e.g., size), and migration timing	Climate change	High
All	* Increase in the number of fish with parasites	Warming waters, and salmon may be acting as vectors for parasites	Moderate
All	Increase in fish with soft flesh	Warmer waters	High
All	* Increase in fish with wounds	Predation by marine mammals or other fish, including salmon	Moderate
Tuktoyaktuk and Aklavik	Decrease in the herring harvest. Arctic cisco (*Coregonus autumnalis*) and Pacific herring (*Clupea Pallasii*) are both called herring in these communities	Climate change	High
Paulatuk	* Change in Arctic char flesh colour, from bright orange to pale or white	Increase in salmon, and/or climate change	High

Sachs Harbour	* Lasting declines in Arctic char harvest	Increase in salmon and decrease in Arctic char population	High
Sachs Harbour and Ulukhaktok	The presence of a new species, Saffron cod (*Eleginus gracilis*), in low numbers	Climate change	Moderate

Sociocultural Changes

Many participants expressed concerns about the impact of salmon and climate change on the cultural practice of fishing. In Inuvik we spoke with Doug Esagok about the inter-generational knowledge of fishing practices and he told us that what some fishers "*learned growing up we can't even apply it today because it's so different. It's just like we don't live in the same place anymore.*" This concern was also linked with the importance of fish for health and well-being. In Tuktoyaktuk a harvester told us "*it's very concerning because most everybody in Tuk likes to fish. They depend on the whitefish."* Similar concerns were widespread, but many fishers also described their responses to ongoing changes. John Sam Green in Paulatuk noted that "*You learn to adapt; you learn to find new ways.*" This resilience manifested in conversations about both individual and community adaptations to change and highlighted that local and traditional knowledges are not static. People are now fishing in different areas, at different times, and with different techniques in order to practice Inuvialuit culture and to supply families and communities with appropriate food.

People are also adapting to the presence of salmon. While salmon are ubiquitously considered a threat, many people will still eat them. Of the 43 participants who had personally caught salmon, 23 ate these fish, 19 returned them to the Arctic Salmon Project (ASP), and seven distributed the salmon throughout the community for others to eat (Table 2). Paulatuk was unique in their use of salmon as we only heard one account of someone eating the fish; everyone else returned their salmon to the ASP. The high rates of salmon return to the ASP reflect a heightened concern in Paulatuk regarding salmon. As one participant explained, everyone is returning their salmon to the ASP "*not because of the benefits monetarily but trying to understand why they [salmon] are coming into our area.*"

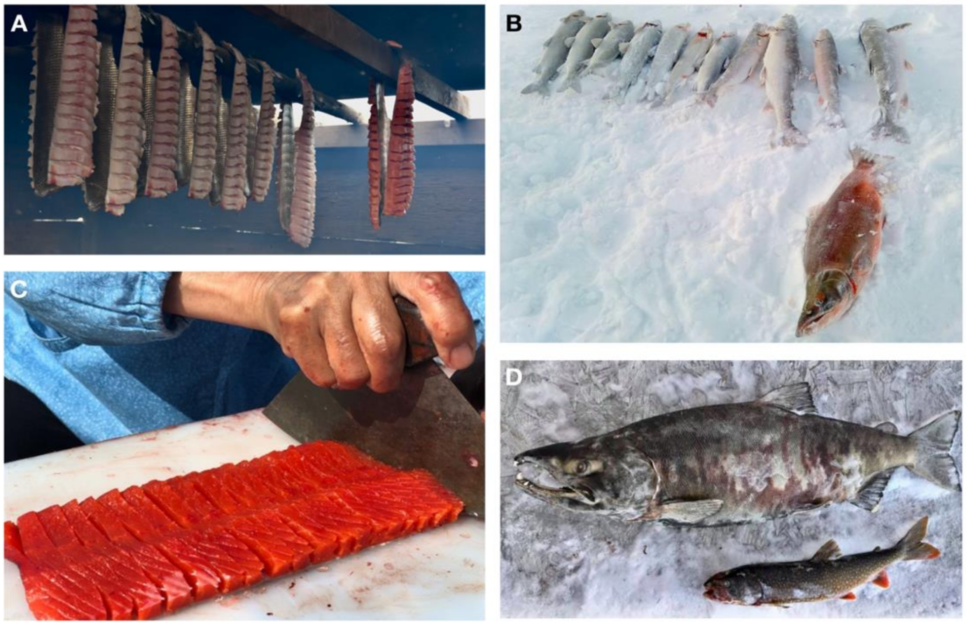

Figure 2.4 Photos of salmon in the ISR. A) A chum salmon drying next to broad whitefish in Tuktoyaktuk (Photo: Zander Chila); B) A sockeye salmon harvested in the same net as Arctic char and broad whitefish from the Hornaday River in November (Photo: Steve Illasiak); C) A fisher preparing salmon for drying at Shingle Point (Photo: Collin Gallagher); D) A chum salmon compared to a lake trout caught near Paulatuk in December (Photo: John Sam Green).

Discussion

Widespread reports of increasing salmon harvest in areas of the western Arctic where there is no precedent of these species provide additional evidence that regional changes in climate are associated with the northward range expansion of Pacific salmon (Babaluk *et al.* 2000; Carothers *et al.* 2019; Dunmall *et al.* 2018; Farley *et al.* 2020; Nielsen *et al.* 2020; Yoon *et al.* 2015). In our interviews, 85% of participants cited the effects of climate change as the main drivers of the increase in Pacific salmon harvest. Increasing sea surface temperatures, decreasing sea ice duration, extent, and thickness, and increased marine productivity (Gibson *et al.* 2020; IPCC 2019; Niemi *et al.* 2020) may be contributing to increased salmon abundance by ameliorating the environmental conditions in the Arctic Ocean for salmon survival. Oceanographic changes could also be affecting salmon abundance through an altered seasonal cycle (Carton *et al.* 2015) and changing ocean currents (Niemi *et al.* 2020). Additionally, these oceanographic factors could be contributing to changes in salmon harvest such as fishers catching salmon later in the fall and winter. The observations from our interviews are also consistent with projections of a northward range shift based on bioenergetic and life history models for chum and pink salmon (Farley *et al.* 2020; Yoon *et al.* 2015).

Our interviews, combined with historical records of harvest and unpublished Arctic Salmon Project data, indicate that the range margin of Pacific salmon now extends further north than widely recognized in the literature (Figure 1) (Abdul-Aziz *et al.* 2011). Fishers in Aklavik have been catching salmon for generations; in 1979 the community recorded a harvest of 11,547 chum salmon (Stephenson 2006). There is at least one genetic population of chum salmon natal to the Mackenzie River drainage (Coad *et al.* 2018; Dunmall 2018; Irvine *et al.* 2009), and it is likely that Aklavik's historic harvests of chum salmon originated from this population (Stephenson 2006). It is possible that semi-regular salmon harvests in the Outer communities began earlier than the reports from our interviews, but we consider this unlikely. Participants from these communities noted that their elders had never caught salmon, nor did they mention their elders regularly catching other novel fish. While fishers may not have known what salmon were if they caught them, they would certainly have known that they were unusual. Given the nature of our interviews and expertise of the participants, we can assume that a semi-regular harvest of unusual fish would have been reported.

The voluntary nature of the Arctic Salmon Project data collection limits the interpretation of its data, however our interviews indicate that the increase in salmon being returned to the Arctic Salmon Program represent real increases in salmon harvest in the ISR. We asked fishers who had caught salmon about the changes they have experiences to their salmon harvests, and how they use the salmon that they catch. Many may not return these fish to the Arctic Salmon Program, but they indicated that the reports of increasing returns to the ASP reflect a real increase in salmon harvest. No fishers told us that those returns were a false representation of the number of salmon being harvested at any time. In fact, fishers often told us that the number of salmon being reported was an underestimation of the salmon being harvested in each community.

According to Aklavik fishers and the published literature, the salmon harvest has always been subject to high inter-annual variation (Stephenson 2006). This variation is also evident in the salmon harvests that have emerged in Sachs Harbour, Ulukhaktok, and Paulatuk in recent decades (Dunmall *et al.* 2018). Fishers mentioned that the inter-annual variation in salmon harvest is driven by both fishing conditions and salmon abundance. In other words, a large annual salmon harvest can only occur if the fishing conditions are suitable and the salmon are present. The differences in salmon harvest across communities are also driven by diverging local fishing practices. This suggests that historical harvest and knowledge of salmon is related to historical fishing conditions, salmon abundance, and local fishing practices. A complete investigation into how these factors have influenced local knowledges of salmon throughout the ISR is beyond the scope of our regional study but could be an interesting avenue for future research as it would better contextualize our understanding of historical salmon occurrences in the Arctic.

While early increases in salmon harvest in the ISR mirror increases throughout the North Pacific, more recent changes indicate that these systems may be diverging. The increasing harvest of salmon across the ISR in the mid-90s corresponds to a period of high abundance of salmon in the North Pacific and an above average salmon harvest in Iñupiat communities on the North Slope of Alaska (Carothers *et al.* 2019; Ruggerone and Irvine 2018). Within the last decade, however, the abundance of salmon in the North Pacific has declined (Mueter *et al.* 2002; Ruggerone and Irvine 2018; Welch *et al.* 1998), but catches on Alaska's North Slope and in Arctic Canada have remained high, or increased (Carothers *et al.* 2019). Iñupiat communities on the Alaska North Slope (Carothers *et al.* 2019), communities along the Mackenzie River (Dunmall *et al.* 2018), and Inuit communities throughout Nunavut (Bilous and Dunmall 2020; ASP unpublished data) are experiencing increasing salmon harvest levels and are concerned about the impacts of these changes. Research on barriers and opportunities for salmon colonizing the Arctic has not been extensive (Dunmall *et al.* 2016; Nielsen *et al.* 2013; Salonius 1973; Yoon *et al.* 2015), but the consensus is that salmon abundance in the Arctic will likely increase (Connors et al. 2020; Farley et al. 2020; Yoon *et al.* 2015).

Inuvialuit fishers do not welcome increasing salmon harvests because of their potentially negative impacts on culturally important fisheries. These concerns, and a lack of data on interactions among species, highlight the urgent need for more research. At present the ecological relationships between Pacific salmon and each of Arctic char (*Salvelinus alpinus*), Dolly Varden (*Salvelinus malma*), and broad whitefish (*Coregonus nasus*) remain understudied. Interview participants made it clear that these species are occupying the same physical spaces, but little is known about the diet of salmon in the Arctic, or its overlap with the diet of Arctic fishes. Salmon diet likely varies across functional morphology, physiology, and environment (Auburn and Ignell 2000; Kaeriyama *et al.* 2004; Qin and Kaeriyama 2016; Tadokoro *et al.* 1996) therefore data from other regions cannot be used to infer competitive potential. The plasticity of Arctic char diets has facilitated their coexistence with some competitive species (Eloranta *et al.* 2011; Morrissey-McCaffrey *et al.* 2018), but studies in other regions suggest that new competitive interactions mediated by climate change will reduce habitat for Arctic char (Hein *et al.* 2012). The change in colour of Arctic char flesh described in Paulatuk, and lasting declines of Arctic char in Sachs Harbour may indicate that changes to local fish populations have already begun (Table 4).

Comparable research on the responses of Dolly Varden and broad whitefish to climate change is more limited and also highlights the need for further study. In some regions, salmon-derived nutrients have been shown to increase the fitness of stream-resident fishes (Bilby *et al.* 1995; Denton *et al.* 2009; Jaecks and Quinn 2014; Wipfli *et al.* 2003), providing up to 80% of the nutrients for some populations of Dolly Varden (Jaecks and Quinn 2014). Both Dolly Varden and Arctic char have been shown to benefit from salmon-derived nutrients, but it is unclear if broad whitefish may also benefit in this way. Additionally, the benefits of salmon to other fishes are mediated by genetics and environment (Denton *et al.* 2010), and it is unclear if these interactions would be similar in the ISR. Stable isotope analyses investigating the use of salmon nutrient subsidies and potential dietary competition between salmon and Arctic fishes will be critical to advance our understanding climate change impacts on species assemblages in the ISR (Bilby *et al.* 1995; Denton *et al.* 2009; Jaecks and Quinn 2014; Wipfli *et al.* 2003). Given the importance of local fisheries, this research will be critical for developing a management strategy for salmon in the Arctic that accounts for the potential impacts of salmon on Inuvialuit fishing practices and culture.

Our interviews did not directly address the socio-cultural changes related to pacific salmon, but they indicated the complexity of the changes in fish communities and that those changes will impact social-ecological systems. Future research in this area is critical. Some fishers were not sure if salmon have direct effects on important fish species but noted that salmon are an indicator of other changes (Tables 3 and 4) with potential negative impacts on local fish. Every participant with whom we spoke highlighted the threat these changes pose to important fish species. John Keogak from Sachs Harbour said there is "*nothing better to do than fish.*" Remarks such as this were common throughout the interviews and reflect the significance of fishing as an activity. The effects of environmental change on Inuvialuit food systems also have the potential to influence sociocultural practices, health, and well-being (Alunik *et al.* 2003; Cunsolo Willox *et al.* 2014; ICC 2020; Proverbs *et. al.* 2020). Access to country foods, such as fish, provides numerous benefits and their "*intangible cultural relevance is incalculable*" (ICC 2020 p.22). People are more food secure, are happier, and have stronger senses of identity and community when they eat culturally appropriate foods and participate in the practices of harvesting those foods (Cunsolo Willox *et al.* 2014; ICC 2020; Searles 2009). In five of the six communities we spoke with fishers who really enjoy eating salmon, but could not separate their enjoyment of the fish from their concerns about its potential ecological impacts. Speaking to this, a participant in Sachs Harbour noted that "*it was really something to catch a salmon, really everybody's happy to get a couple of salmon…but now get this damn thing out of here!*" By affecting Arctic fish populations, salmon have the potential to interfere with important cultural relationships.

Despite the impacts of climate change and salmon on Arctic fish, many harvesters we spoke with expressed optimism about the future of Inuvialuit fisheries. The ways that salmon will shape the future of Inuvialuit fishing practices remain unclear, but participants stressed their ability to adapt. Joseph Carpenter in Sachs Harbour said "*We can't really do anything here about it, so the trick is to adapt to it. And people are doing that*." Harvesters told us that they will continue to eat the salmon so long as it's healthy, but often noted that they did not know how best to prepare salmon and were curious to learn new ways. In response, the Arctic Salmon Project created an Arctic Salmon cookbook (DFO 2020) with the hopes that this might contribute to adaptive efforts. Future research should prioritize engaging Inuvialuit fishers to develop strategies for mitigating and adapting to these changes.

We relied on the interconnectedness of social-ecological systems to design this research, use interviews with fishers to validate the interpretation of Arctic Salmon data, and expand our knowledge of salmon in Arctic regions. This practice is common in the field of ethnoecology, but its application is still emerging in fisheries contexts (Cooke *et al.* 2021). Other recent studies point to local and/or Indigenous knowledge being used to develop and validate species distribution models (Lima *et al.* 2017; Lopez *et al.* 2018), and to perform broad ecosystem assessments (Rosellon-Druker *et al.* 2019). The methods we present here could be adapted for research on other species or regions and contribute to a better understanding of ecological systems and their social dimensions. Given the uncertainty regarding the effects of climate change and salmon, efforts to understand the social dimensions of change and support adaptive fishing practices are crucial. Given the potential impacts to Inuvialuit livelihoods, these efforts must be informed by, and center on, Inuvialuit perspectives and values.

References

Abdul-Aziz, O., Mantua, N., & Myers, K. (2011). Potential climate change impacts on thermal habitats of Pacific salmon (Oncorhynchus spp.) in the North Pacific Ocean and adjacent seas. *Canadian Journal of Fisheries and Aquatic Sciences*, *68*, 1660–1680. doi.org/10.1139/f2011-079

AHTC (Aklavik Hunters and Trappers Committee), Aklavik Community Corporation, The Wildlife Management Advisory Council (NWT), The Fisheries Joint Management Committee, & the Joint Secretariat. (2016). *Aklavik Community Conservation Plan Akaqvikmiut Angalatchivingit Niryutinik*. https://static1.squarespace.com/static/5e2093a7fd6f455447254aff/t/5e2f2af9871a582cf4b55785/1580149532235/2016-Aklavik-Community-Conservation-Plan-R.pdf

Alunik, I., Morrison, D. A., & Kolausok, E. D. (2003). *Across time and tundra: The Inuvialuit of the western Arctic*. Raincoast Books, Vancouver BC.

Auburn, M. E., & Ignell, S. E. (2000). *Food Habits of Juvenile Salmon in the Gulf of Alaska July-August 1996.*

Augerot, X., & Foley, D. (2005). Atlas of Pacific Salmon. University of California Press. https://www.ucpress.edu/book/9780520245044/atlas-of-pacific-salmon

Babaluk, J. A., Reist, J. D., Johnson, J. D., & Johnson, L. (2000). First Records of Sockeye (Oncorhynchus nerka) and Pink Salmon (O. gorbuscha) from Banks Island and Other Records of Pacific Salmon in Northwest Territories, Canada. *Arctic, 53*(2), 161–164.

Bilby, R., Fransen, B., & Bisson, P. (2011). Incorporation of Nitrogen and Carbon From Spawning Coho Salmon Into the Trophic System of Small Streams: Evidence From Stable Isotopes. *Canadian Journal of Fisheries and Aquatic Sciences, 53*, 164–173. doi.org/10.1139/cjfas-53-1-164

Bilous, M., & Dunmall, K. (2020). Atlantic salmon in the Canadian Arctic: Potential dispersal, establishment, and interaction with Arctic char. *Reviews in Fish Biology and Fisheries, 30*(3), 463–483. doi.org/10.1007/s11160-020-09610-2

Binder, L., & Hanbidge, B. (1993). The Inuvialuit of the Western Arctic and Resource: Co-management Under a Land Claims Settlement. In J. Inglis (Ed.), *Traditional Ecological Knowledge: Concepts and Cases*. Canadian Museum of Nature.

Bintanja, R., & Andry, O. (2017). Towards a rain-dominated Arctic. *Nature Climate Change, 7*(4), 263–267. doi.org/10.1038/nclimate3240

Cameron, E. S. (2012). Securing Indigenous politics: A critique of the vulnerability and adaptation approach to the human dimensions of climate change in the Canadian Arctic. *Global Environmental Change, 22*(1), 103–114. doi.org/10.1016/j.gloenvcha.2011.11.004

Canada (1984). Western Arctic Claim—The Inuvialuit Final Agreement.

Carothers, C., Sformo, T. L., Cotton, S., George, J. C., & Westley, P. A. H. (2019). Pacific Salmon in the Rapidly Changing Arctic: Exploring Local Knowledge and Emerging Fisheries in Utqiaġvik and Nuiqsut, Alaska. *Arctic, 72*(3), 273–288. doi.org/10.14430/arctic68876

Carton, J. A., Ding, Y., & Arrigo, K. R. (2015). The seasonal cycle of the Arctic Ocean under climate change. *Geophysical Research Letters, 42*(18), 7681–7686. doi.org/10.1002/2015GL064514

Castleden, H., Morgan, V. S., & Lamb, C. (2012). "I spent the first year drinking tea": Exploring Canadian university researchers' perspectives on community-based participatory research involving Indigenous peoples. *The Canadian Geographer, 56*(2), 160–179. doi.org/10.1111/j.1541-0064.2012.00432.x

Chen, A., Lantz, T. C., Hermosilla, T., & Wulder, M. A. (2021). Biophysical controls of increased tundra productivity in the western Canadian Arctic. *Remote Sensing of Environment, 258*, 112358. doi.org/10.1016/j.rse.2021.112358

Christie, L., Dunmall, K., Bilous, M., McNicholl, D., & Reist, J. (2020). *A Salmon Cookbook for the Arctic.*

Coad, B. W., Reist, J. D., Moller, P. R., Renaud, C. B., Alfonso, N. R., Dunmall, K., Power, M., Sawatzky, C. D., Berkes, F., Dempson, J. B., Harris, L. N., & Swanson, H. K. (2018). *Marine Fishes of Arctic Canada.* University of Toronto Press. https://www.jstor.org/stable/10.3138/j.ctt1x76h0b

Connors, B., Malick, M. J., Ruggerone, G. T., Rand, P., Adkison, M., Irvine, J. R., Campbell, R., & Gorman, K. (2020). Climate and competition influence sockeye salmon population dynamics across the Northeast Pacific Ocean. *Canadian Journal of Fisheries and Aquatic Sciences.* doi.org/10.1139/cjfas-2019-0422

Cooke, S.J., Nguyen, V.M., Chapman, J.M., Reid, A.J., Landsman, S.J., Young, N., Hinch, S.G., Schott, S., Mandrak, N.E., Semeniuk, C.A.D., 2021. Knowledge co-production: A pathway to effective fisheries management, conservation, and governance. Fisheries 46, 89–97. https://doi.org/10.1002/fsh.10512

Cunsolo Willox, A., Stephenson, E., Allen, J., Bourque, F., Drossos, A., Elgarøy, S., Kral, M. J., Mauro, I., Moses, J., Pearce, T., MacDonald, J. P., & Wexler, L. (2015). Examining relationships between climate change and mental health in the Circumpolar North. *Regional Environmental Change, 15*(1), 169–182. doi.org/10.1007/s10113-014-0630-z

Denton, K. P., Jr, H. B. R., & Quinn, T. P. (2009). Diet, Movement, and Growth of Dolly Varden in Response to Sockeye Salmon Subsidies. *Transactions of the American Fisheries Society, 138*(6), 1207–1219. doi.org/10.1577/T09-006.1

Denton, K. P., Rich, H. B., Moore, J. W., & Quinn, T. P. (2010). The utilization of a Pacific salmon Oncorhynchus nerka subsidy by three populations of charr Salvelinus spp. *Journal of Fish Biology, 77*(4), 1006–1023. doi.org/10.1111/j.1095-8649.2010.02746.x

Dunmall, K. (2018). *Pacific salmon in the Canadian Arctic: Indicators of change* [PhD, University of Manitoba]. https://mspace.lib.umanitoba.ca/bitstream/handle/1993/32856/Dunmall_Karen.pdf?sequence=3&isAllowed=y

Dunmall, K. M., Mochnacz, N. J., Zimmerman, C. E., Lean, C., & Reist, J. D. (2016). Using thermal limits to assess establishment of fish dispersing to high-latitude and high-elevation watersheds. *Canadian Journal of Fisheries and Aquatic Sciences, 73*(12), 1750–1758. doi.org/10.1139/cjfas-2016-0051

Dunmall, K. M., Reist, J. D., Carmack, E. C., Babaluk, J. A., Heide-Jorgensen, M. P., & Docker, M. F. (2013). Pacific Salmon in the Arctic: Harbingers of Change. In F. J. Mueter, D. M. S. Dickson, H. P. Huntington, & J. R. Irvine (Eds.), *Responses of Arctic Marine Ecosystems to Climate Change.* Alaska Sea Grant, University of Alaska Fairbanks. doi.org/10.4027/ramecc.2013.07

Dunmall, K., McNicholl, D., & Reist, J. (2018). Community-based monitoring demonstrates increasing occurrences and abundances of Pacific salmon in the Canadian Arctic from 2000 to 2017. *North Pacific Anadromous Fish Commission Tech Report.* (No. 11; pp. 87–90). doi:10.23849/npafctr11/87.90

Ecosystem Classification Group. (2009). *Ecological regions of the Northwest Territories, Taiga Plains.* Dept. of Environment and Natural Resources, Govt. of the Northwest Territories.

Ecosystem Classification Group. (2012). *Ecological regions of the Northwest Territories, southern Arctic.* Dept. of Environment and Natural Resources, Govt. of the Northwest Territories.

Ecosystem Classification Group. (2013). *Ecological regions of the Northwest Territories, northern Arctic.* Dept. of Environment and Natural Resources, Govt. of the Northwest Territories.

Eloranta, A. P., Siwertsson, A., Knudsen, R., & Amundsen, P.-A. (2011). Dietary plasticity of Arctic charr (Salvelinus alpinus) facilitates coexistence with competitively superior European whitefish (Coregonus lavaretus). *Ecology of Freshwater Fish, 20*(4), 558–568. doi.org/10.1111/j.1600-0633.2011.00504.x

Farley, E. V., Murphy, J. M., Cieciel, K., Yasumiishi, E. M., Dunmall, K., Sformo, T., & Rand, P. (2020). Response of Pink salmon to climate warming in the northern Bering Sea. *Deep Sea Research Part II: Topical Studies in Oceanography, 177*, 104830. doi.org/10.1016/j.dsr2.2020.104830

Ford, J. D., Willox, A. C., Chatwood, S., Furgal, C., Harper, S., Mauro, I., & Pearce, T. (2014). Adapting to the Effects of Climate Change on Inuit Health. *American Journal of Public Health, 104*(Suppl 3), e9–e17. doi.org/10.2105/AJPH.2013.301724

Gibson, G., Weijer, W., Jeffery, N., & Wang, S. (2020). Relative Impact of Sea Ice and Temperature Changes on Arctic Marine Production. *Journal of Geophysical Research: Biogeosciences, 125*(7), e2019JG005343. doi.org/10.1029/2019JG005343

Hein, C. L., Öhlund, G., & Englund, G. (2012). Future Distribution of Arctic Char Salvelinus alpinus in Sweden under Climate Change: Effects of Temperature, Lake Size and Species Interactions. *AMBIO, 41*(3), 303–312. doi.org/10.1007/s13280-012-0308-z

ICC (Inuit Circumpolar Council Alaska). (2020). *Food Sovereignty and Self-Governance: Inuit role in managing Arctic marine resources*. https://iccalaska.org/wp-icc/wp-content/uploads/2020/09/FSSG-Report_-LR.pdf

IHTC (Inuvik Hunters and Trappers Committee), Inuvik Community Corporation, The Wildlife Management Advisory Council (NWT), The Fisheries Joint Management Committee, & the Joint Secretariat. (2016). *Inuvik Community Conservation Plan Inuuvium Angalatchivingit Niryutinik*. https://static1.squarespace.com/static/5e2093a7fd6f455447254aff/t/5e262b04166a41157ca93855/1579559719275/2016-Inuvik-Community-Conservation-Plan-R.pdf

IPCC (Intergovernmental Panel on Climate Change). (2019). *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate*. IPCC, Geneva.

IRC (Inuvialuit Regional Corporation). (2018). *Inuvialuit on the Front Line of Climate Change*.

ITK (Inuit Tapirit Kanatami). (2019). *National Inuit Climate Change Strategy*. http://www.deslibris.ca/ID/10102688

Irvine, J., Linn, E., Gillespie, K., Mcleod, C., & Reist, J. (2009). Pacific Salmon in Canada's Arctic draining rivers with emphasis on those in British Columbia and the Yukon. *Pacific Fisheries Resource Conservation Council.*

Jaecks, T., & Quinn, T. P. (2014). Ontogenetic shift to dependence on salmon-derived nutrients in Dolly Varden char from the Iliamna River, Alaska. *Environmental Biology of Fishes, 97*(12), 1323–1333. doi.org/10.1007/s10641-014-0221-3

Kaeriyama, M., Nakamura, M., Edpalina, R., Bower, J., Yamaguchi, H., Walker, R., & Myers, K. (2004). Change in feeding ecology and trophic dynamics of Pacific salmon (Oncorhynchus spp.) in the central Gulf of Alaska in relation to climate events. *Fisheries Oceanography, 13*, 197–207. doi.org/10.1111/j.1365-2419.2004.00286.x

Kelsey, E. (2016). Propagating Collective Hope in the Midst of Environmental Doom and Gloom. *Canadian Journal of Environmental Education, 21*(0), 23–40.

Krupnik, I., Aporta, C., Gearheard, S., Laidler, G. J., & Holm, L. K. (Eds.). (2010). *SIKU: Knowing Our Ice: Documenting Inuit Sea Ice Knowledge and Use.* Springer Netherlands. doi.org/10.1007/978-90-481-8587-0

Kuhnlein, H. V., & Receveur, O. (1996). Dietary change and traditional food systems of indigenous peoples. *Annual Review of Nutrition, 16*, 417–442. doi.org/10.1146/annurev.nu.16.070196.002221

Lantz, T. C., & Kokelj, S. V. (2008). Increasing rates of retrogressive thaw slump activity in the Mackenzie Delta region, N.W.T., Canada. *Geophysical Research Letters, 35*(6). doi.org/10.1029/2007GL032433

Lima, M., Lins Oliveira, J., Nobrega, M., Lopes, P., 2017. The use of Local Ecological Knowledge as a complementary approach to understand the temporal and spatial patterns of fishery resources distribution. Journal of Ethnobiology and Ethnomedicine 13. https://doi.org/10.1186/s13002-017-0156-9

Lopes, P., Verba, J., Begossi, A., Pennino, M., 2018. Predicting species distribution from fishers' local ecological knowledge: an alternative for data-poor management. Canadian Journal of Fisheries and Aquatic Sciences 76. https://doi.org/10.1139/cjfas-2018-0148

Morrissey-McCaffrey, E., Shephard, S., Kelly, F. L., & Kelly-Quinn, M. (2018). Non-native species and lake warming negatively affect Arctic char Salvelinus alpinus abundance; deep thermal refugia facilitate co-existence. *Journal of Fish Biology, 94*(1), 5–16. doi.org/10.1111/jfb.13837

Mueter, F., Peterman, R., & Pyper, B. (2002). Opposite Effects of Ocean Temperature on Survival Rates of 120 Stocks of Pacific Salmon (Oncorhynchus spp.) in Northern and Southern Areas. *Canadian Journal of Fisheries and Aquatic Sciences, 59*, 456–463. doi.org/10.1139/F02-020

Nielsen, J. L., Ruggerone, G. T., & Zimmerman, C. E. (2013). Adaptive strategies and life history characteristics in a warming climate: Salmon in the Arctic? *Environmental Biology of Fishes, 96*(10), 1187–1226. doi.org/10.1007/s10641-012-0082-6

Nielsen, J., Rosing-Asvid, A., Meire, L., & Nygaard, R. (2020). Widespread occurrence of pink salmon (Oncorhynchus gorbuscha) throughout Greenland coastal waters. *Journal of Fish Biology, 96*(6), 1505–1507. doi.org/10.1111/jfb.14318

Niemi, A., Ferguson, S., Hedges, K., H Melling, Michel, C., Ayles, B., Azetsu-Scott, K., Coupel, P., Deslauriers, D., Devred, E., Doniol-Valcroze, T., Dunmall, K., Eert, J., Galbraith, P., Geoffroy, M., Gilchrist, G., Hennin, H., Howland, K., Kendall, M., … Zimmerman, S.

(2019). *State of Canada's Arctic Seas.* Canadian Technical Report of Fisheries and Aquatic Sciences. http://publications.gc.ca/collections/collection_2019/mpo-dfo/Fs97-6-3344-eng.pdf

NOAA (National Oceanic and Atmospheric Administration). (2017). *Arctic Report Card 2017*. http://www.arctic.noaa.gov/Report-Card

OHTC (Olokhaktomiut Hunters and Trappers Committee), Ulukhaktok Community Corporation, The Wildlife Management Advisory Council (NWT), The Fisheries Joint Management Committee, & the Joint Secretariat. (2016). *Olokhaktomiut Community Conservation Plan Ulukhaqtuum Angalatchivingit Niryutinik.* https://static1.squarespace.com/static/5e2093a7fd6f455447254aff/t/5e262b83e3c0a94c0a904bf2/1579559867490/2016-Uluhaktok-Community-Conservation-Plan-R.pdf

Pearce, T., Ford, J., Willox, A. C., & Smit, B. (2015). Inuit Traditional Ecological Knowledge (TEK), Subsistence Hunting and Adaptation to Climate Change in the Canadian Arctic. *Arctic*, *68*(2), 233–245.

PHTC (Paulatuk Hunters and Trappers Committee), Paulatuk Community Corporation, The Wildlife Management Advisory Council (NWT), The Fisheries Joint Management Committee, & the Joint Secretariat. (2016). *Paulatuk Community Conservation Plan Paulatuum Angalatchivingit Niryutinik*. https://static1.squarespace.com/static/5e2093a7fd6f455447254aff/t/5e274528c179bf7b311b59be/1579632184779/2016-Paulatuk-Community-Conservation-Plan-R.pdf

Proverbs, T., Lantz, T. C., Lord, S. I., Amos, A., Gwich'in Tribal Council Department of Cultural Heritage, & Ban, N. C. (2020). Social-Ecological Determinants of Access to Fish and Well-Being in Four Gwich'in Communities in Canada's Northwest Territories. *Human Ecology, 48*, 155–171. doi.org/10.1007/s10745-020-00131-x

Qin, Y., & Kaeriyama, M. (2016). Feeding Habits and Trophic Levels of Pacific Salmon (Oncorhynchus spp.) in the North Pacific Ocean. *North Pacific Anadromous Fish Commission Bulletin, 6,* 469–481. doi.org/10.23849/npafcb6/469.481

Rosellon-Druker, J., Szymkowiak, M., Cunningham, C., Kasperski, S., Kruse, G., Moss, J., Yasumiishi, E., 2019. Development of social-ecological conceptual models as the basis for an integrated ecosystem assessment framework in Southeast Alaska. Ecology and Society 24. https://doi.org/10.5751/ES-11074-240330

Ruggerone, G. T., & Irvine, J. R. (2018). Numbers and Biomass of Natural- and Hatchery-Origin Pink Salmon, Chum Salmon, and Sockeye Salmon in the North Pacific Ocean, 1925–2015. *Marine and Coastal Fisheries, 10*(2), 152–168. doi.org/10.1002/mcf2.10023

Salonius, P. O. (1973). Barriers to Range Extension of Atlantic and Pacific Salmon in Arctic North America. *Arctic, 26*(2), 112–122.

Searles, E. (2009). Food and the Making of Modern Inuit Identities. *Food and Foodways, 10*(1–2), 55–78. doi.org/10.1080/07409710212485

SHHTC (Sachs Harbour Hunters and Trappers Committee), Sachs Harbour Community Corporation, The Wildlife Management Advisory Council (NWT), The Fisheries Joint Management Committee, & the Joint Secretariat. (2016). *Sachs Harbour Community Conservation Plan Sachs Harbour Angalatchivingit Niryutinik*. https://static1.squarespace.com/static/5e2093a7fd6f455447254aff/t/5e2f2b5058c98526e5a69f9c/1580149613890/2016-Sachs-Harbour-Community-Conservation-Plan-R.pdf

Stephenson, S. A. (2006). A Review of the Occurrence of Pacific Salmon (Oncorhynchus spp.) in the Canadian Western Arctic. *Arctic, 59*(1), 37–46.

Tadokoro, K., Ishida, Y., Davis, N. D., Ueyanagi, S., & Sugimoto, T. (1996). Change in chum salmon (Oncorhynchus keta) stomach contents associated with fluctuation of pink salmon (O. gorbuscha) abundance in the central subarctic Pacific and Bering Sea. *Fisheries Oceanography, 5*(2), 89–99. doi.org/10.1111/j.1365-2419.1996.tb00108.x

Tape, K. D., Gustine, D. D., Reuss, R. W., Adams, L. G., & Clark, J. A. (2016). Range expansion of moose in arctic Alaska linked to warming and increased shrub habitat. *PLoS ONE 11*(4), 12. doi.org/10.1371/journal.pone.0152636

Tape, K., Jones, B., Arp, C., Nitze, I., & Grosse, G. (2018). Tundra be dammed: Beaver colonization of the Arctic. *Global Change Biology, 24*. doi.org/10.1111/gcb.14332

THTC (Tuktoyaktuk Hunters and Trappers Committee), Tuktoyaktuk Community Corporation, The Wildlife Management Advisory Council (NWT), The Fisheries Joint Management Committee, & the Joint Secretariat. (2016). *Tuktoyaktuk Community Conservation Plan Tuktuuyaqtuum Angalatchivingit Niryutinik*.

https://static1.squarespace.com/static/5e2093a7fd6f455447254aff/t/5e262a8ae3c0a94c0a8ffa4a/1579559611016/2016-Tuktoyaktuk-Community-Conservation-Plan-R.pdf

Usher, P. J. (2002). Inuvialuit Use of the Beaufort Sea and its Resources, 1960-2000. *Arctic*, *55*(5), 18–28. doi.org/10.14430/arctic732

Walsh, J. E., Overland, J. E., Groisman, P. Y., & Rudolf, B. (2011). Ongoing Climate Change in the Arctic. *AMBIO*, *40*(1), 6–16. doi.org/10.1007/s13280-011-0211-z

Welch, D., Ishida, Y., & Nagasawa, K. (1998). Thermal limits and ocean migrations of sockeye salmon (Oncorhynchus nerka). *Canadian Journal of Fisheries and Aquatic Sciences*, *55*, 937–948. doi.org/10.1139/cjfas-55-4-937

Wipfli, M. S., Hudson, J. P., Caouette, J. P., & Chaloner, D. T. (2003). Marine Subsidies in Freshwater Ecosystems: Salmon Carcasses Increase the Growth Rates of Stream-Resident Salmonids. *Transactions of the American Fisheries Society*, *132*(2), 371–381.

Yoon, S., Watanabe, E., Ueno, H., & Kishi, M. J. (2015). Potential habitat for chum salmon (Oncorhynchus keta) in the Western Arctic based on a bioenergetics model coupled with a three-dimensional lower trophic ecosystem model. *Progress in Oceanography*, *131*, 146–158. doi.org/10.1016/j.pocean.2014.12.009

Appendix A

Interview questions investigating changes in environmental conditions, Pacific salmon harvest, and local fish species.

Environmental Conditions Questions

- What is your name, age, and where do you live?
- Do you travel on the water regularly?
    - If so, how many days a week/month?
    - Do you travel on rivers or on the ocean or both?
    - Where do you usually travel? Can you show me on a map? (or google earth)
- Are the rivers or the coastal environment where you usually travel the same or different than 10/20/30/40 years ago?
    - If different, what has changed?
    - If different, when did you notice these changes? (years/time of year/season).
        - Sometimes it can help to use other points of reference here (age of kids /grandkids at the time / boat + outboard operated at that time.
    - Can you show me on a map any locations that have changed?
- Are there any environmental changes you have noticed that you think are affecting rivers, lakes, or the ocean near the coast?
    - If so, what changes have you observed?
    - If so, when did you notice these changes? (years/time of year/seasons).
    - Can you show me on a map where you have noticed these changes?
- Are there any changes to the rivers/lakes/coast where you travel that have affected where/how you can travel?
    - If so, what changes have you observed?
    - If so, are there any areas that you can't travel anymore that you used to be able to?
    - If so, when did you notice these changes? (years/time of year/seasons).
    - Can you show me on a map these locations?
- Have you noticed any changes in the water levels of the rivers and lakes you travel on?
    - If so, what changes have you observed?
    - If so, when did you notice these changes? (years/time of year/seasons).
    - Can you show me on a map where you have noticed these changes?
- Have you noticed any changes to rivers, lakes, or coastal areas like sand bars, erosion, changes to cut banks, water quality, vegetation, water flow?
    - If so, what have you noticed?
    - If so, when did you notice these changes? (years/time of year/seasons).
    - Can you show me on a map where you have seen these changes?

- Throughout your life, would rivers, lakes, or coastal areas (water levels, colour, sand bars) often or sometimes change?
    - Or, are any changes you have noticed unlike conditions you have seen before (i.e. unprecedented)?
- If you have noticed any changes in the rivers, lakes, or coastal areas, how do you feel about these changes? (concerned/surprised/unconcerned/welcoming/etc.).
- If you have noticed changes in rivers, lakes, or coastal areas, are the changes affecting your access to fish camps and other fishing locations?
    - If so, can you show me these locations on a map?
- If you have noticed changes in rivers, lakes, or coastal areas are these changes affecting any fish you harvest?
    - If so, which species?
    - Can you show us on a map locations where you've caught species that are impacted?
- If you have noticed any changes in rivers, lakes, or coastal areas why do you think these changes may be happening?
- How do you think that rivers, lakes, and coastal areas in the ISR should be cared for in the future?
- Over the time that you've been fishing, have environmental conditions changed?
    - Have you noticed changes to the water, ice, or bottom habitats?
        - Timing of Ice on, ice off
        - Amount and timing of snow
        - Overflow, winter stream flow – location and timing?
        - Water temperature
        - Turbidity (timing, duration, location)
        - Ocean conditions (e.g., waves)
    - Have you noticed changes to the weather?
        - Types and/or frequency of weather events (e.g., high winds, storms)
        - Wind (timing of shifts in wind direction?)
        - Air temperature
- Have you observed connections between changes in the environment and the types of fish and prey that you see?
    - E.g., do the fish or prey communities change depending on prevailing winds or ice conditions?
    - Any examples of strange weather and fish/prey/predator catches or behaviour occurring at the same time? Anything you remember hearing from your parents/grandparents?

Salmon Interview Questions

- Do you fish in the ISR?
    - If so, how many times per week/month?

    - Do you fish in the rivers or in the coastal environment?
    - Can you show us on a map where you fish? (**You do not have to**).
- Did you grow up fishing? How old were you when you learned how?
- When you go fishing, do you catch salmon?
    - If so, do you know what kinds of salmon you catch? Has this changed through your lifetime? When did this change occur?
        - Sometimes it can help to use other points of reference here (age of kids /grandkids at the time / boat + outboard operated at that time).
    - If so, when have you caught salmon before? (year/season)
    - If so, would you use them in the past? How?
    - Would you use them if you catch them now/in the future? How?
    - If not, do you know what you could use them for?
    - Can you show us on a map where you have caught them?
    - What is the body condition of the salmon you caught?
        - Are they silver or colourful?
        - Were the salmon ready to spawn?
        - Are the eggs ripe – if you run your fingers along their belies do egg come out
    - Did your parents or grand-parents talk about catching salmon? How often and when?
- Have you noticed a change in the amount of salmon you catch when you fish?
    - If so, when did you notice this change? (what boat were you using, what year)
    - If so, how many salmon did you catch in a week/month of fishing before you noticed this change? How many salmon per week/month would you catch after you noticed this change?
- What time of year/season do you start catching salmon in your net?
    - How long after break up?
    - Has this gotten later, earlier, or unchanged?
    - Can you show me on a map where you were fishing when you first observed salmon or caught them in your net?
- Have your fishing practices changed through time? i.e. harvest locations, mesh size, using gillnets or jiggling or other methods
    - If so, what year did these changes occur? Or how old were you? [See previous reference points]
- When you catch salmon, do you catch any other fish in the net?
    - If so, what kinds of fish do you catch with salmon?
        - Consult salmon booklets so participants can visualize the different types
    - If so, how many salmon do you catch in a net and how many other species of fish do you catch in the net? i.e. for every salmon, how many other fish are there in the net?
- When you catch salmon, do you see signs that they are eating or not? I.e. full stomachs, do they look like they're eating, are they in places where other fish are eating?

- Do you catch salmon when fishing on rivers, lakes, or the ocean?
    - Can you show us these locations on a map? (**it is ok if they don't want to disclose**).
- What equipment do you catch salmon with? i.e. gill net, hook, line, etc.
- Do you catch salmon on windy or calm days or both? Do you know what direction the wind usually is when you catch salmon?
- Does the amount of rain change the chances of catching salmon?
- Do you catch salmon when you fish under the ice? In rivers, lakes or on the ocean? Nearshore or away from shore?

Native Fish Questions

- What kinds of fish do you normally catch in your subsistence fishing activities?
- Have you noticed changes in the amount of fish that you catch or see?
    - If so, are some kinds of fish increasing, while others are decreasing in abundance?
    - When did these changes happen?
- Have you noticed changes in the types of species that you catch or see?
    - How has the fish community changed?
    - When did these changes happen?
    - Do you see the same species each year, or do the types of species you see vary by year?
- Have you noticed changes in the types of prey that fish are eating?
    - How has the prey community changed?
    - When did these changes happen?
    - Do you see the same prey each year, or does the types of prey you see vary by year?
- Have you noticed changes in the types of prey that marine mammals are eating?
    - What kinds of marine mammals are showing these changes in diet? (e.g, seal, whale)
    - How has the diet changed for these marine mammals?
    - When did these changes happen?
    - Do you see the same prey each year, or does the types of prey you see vary by year?
- Is there anything else you think we should know or that you'd like to tell us, or other important locations we should note on the map?

Appendix B

Table 2.5 Codes used for thematic interview analysis. Thematic categories are bolded and indentation reflects the structure of codes and subcodes.

Salmon	**Environmental Change**	**Experience**
Catch Location	Affecting Travel	How Long Have They Been Fishing
Lake	Air Temperatures	How Often They Fish
Ocean	Causes of Change	Target Fish
River	Climate Change	Typical Fishing Methods
Catch Method	Development	Gill Net
Jiggling	Earth's Axis	Jiggling
Netting	Effects on Fish or Fishing	Rod and Reel
Rod and Reel	Aklavik Effects on Fish(ing)	When They Fish
Change	Inuvik Effects on Fish(ing)	Open Water
Decrease	Paulatuk Effects on Fish(ing)	Under Ice
Increase	Sachs Effects on Fish(ing)	Where they fish
Neutral	Tuktoyaktuk Effects on Fish(ing)	Darnley Bay East
Changing salmon harvest time	Ulu Effects on Fish(ing)	Darnley Bay West
Conditions influencing salmon	Erosion	Eileen Jacobson Bush Camp
Cultural Use	Feelings	Hornaday River
Consumption	Historical Changes	Husky Lakes
Discarded	Ice Cover	Inuvik - Lakes
Distribution	Ocean Conditions	Mackenzie Delta East
Dogs	Permafrost Associated Changes	Mackenzie Delta West
Salmon program	Sand Bars	OuterDelta - Ocean
Estimated catch over lifetime	Snow	Paulatuk Harbour
First Catch	Strange Phenomena	Paulatuk Lakes
Fish Condition	Timing of Environmental Events	Sachs Harbour
Eggs or Milt	Vegetation	Sachs Lakes
Healthy	Water Levels	Sachs River
Sick	Lakes	Shingle
Parasites	Ocean	Tuktoyaktuk Harbour
Skinny	Rivers	Ulukhaktok - Lakes
Soft	Water Quality	Ulukhaktok - Ocean
Silver	Water Temperatures	**Fishing Opportunity**
Spawning	Weather	**Cultural**
Interactions with other fish	What To Do	Cultural Change
Never Caught a Salmon	**Local Fish**	Fish Culture
Parents/Elders caught salmon?	Diet	Resilience
Maybe	Fish Health	Stories
No	General Changes	**Mammals**
Yes	Predation	Beavers
Species ID	Species	Caribou
Chinook	Cod	Muskox
Chum	Coney	Muskrats
Coho	Dolly Varden	Otters
Pink	Herring	Seals
Sockeye	Jackfish	Whales
Target Fishes	Land-locked Char	
Time of Catch	Loche	
Approximate Year	Ocean Char	
00s	Sandlance	
10s	Trout	
2019	Whitefish	
60s	Weather Effects	
70s		
80s		
90s		
Open Water		
Under Ice		
Weather of catch		

Chapter 3 – Quantifying the Effects of Weather on Access to Fishing in Inuvialuit Communities[2]

Introduction

Across Inuit Nunangat, productive fisheries are integral to food sovereignty, culture, and well-being (Alunik *et al.* 2003; ICC 2020; ITK 2014). Fishing supports a suite of cultural traditions; increasing peoples' time spent on the land, sustaining relationships among generations of fishers, and maintaining important relationships between people and their homeland (ICC 2020; ITK 2014; Heredia Vazquez 2019; Todd 2016). Inuit report being happier and having a stronger sense of identity and community when in good relationship with their lands and fishing practices (Cunsolo Willox *et al.* 2015; ICC 2020; Searles 2009). Fishing also supports food security, providing essential nutrition in communities where food prices are more than twice those in major Canadian cities (Alunik *et al.* 2003, Kenny *et al.* 2018; Kuhnlein and Receveur 2007; Wesche and Chan 2010). Maintaining the complex social-ecological relationships between Inuit and their lands, including fisheries, is also a central goal of local, national, and international Inuit organizations (ICC 2020; IJS n.d.; ITK 2019a).

Despite significant adaptive capacity in northern communities, global climate change threatens local fisheries in several ways (FAO 2018; Ford & Pearce 2010; ICC 2020; IPCC 2019). Warming temperatures, ocean acidification, altered fish distributions, and new biotic interactions are affecting the physiology, phenology, and productivity of fish populations (Brander 2007; Cheung *et al.* 2009; FAO 2018; Fossheim *et al.* 2015; Lynch *et al.* 2016; Pankhurst and Munday 2011; Sheridan and Bickford 2011). These effects may influence the abundance of culturally important fish (Campana *et al.* 2020; Cheung *et al.* 2009; Fossheim *et al.* 2015) and facilitate new biotic interactions that could be detrimental to culturally important fish populations (Cheung *et al.* 2009; Fossheim *et al.* 2015; Pecl *et al.* 2017). As new communities of fish assemble, their suitability for human consumption will likely be influenced by environmental changes such as altered prevalence of toxic plankton blooms, parasites, or contaminants (Chiaramonte *et al.*

[2] The research presented in this chapter was a collaboration with multiple parties including my supervisory committee, Colin Gallagher, and the Hunters and Trappers Committees in Aklavik, Inuvik, Paulatuk, Sachs Harbour, Tuktoyaktuk, and Ulukhaktok.

2016; Coleman *et al.* 2018; Marques *et al.* 2010). Arctic fisheries are of special concern because the circumpolar rate of climate warming is more than twice the global average (Ford *et al.* 2013; Ford & Pearce 2010; ICC 2020; IPCC 2019; Niemi *et al.* 2019). The Arctic also faces unique climate impacts such as decreases in sea ice, and related increases in shipping, opportunity for commercial fishing, and resource development (Ford & Pearce 2010; Hansen *et al.* 2013; ICC 2020; Niemi *et al.* 2019). Together, these cumulative changes stand to affect the distribution and abundance of Arctic fishes and their availability to Inuit communities (Ford & Pearce 2010; IPCC 2019; Niemi *et al.* 2019).

Climate change is also affecting harvester access to fish, and thus reducing annual harvests (Brinkman *et al.* 2016; Hansen *et al.* 2013; Johnson *et al.* 2016; Proverbs *et al.* 2020). In their work with four communities in Alaska, Brinkman *et al.* (2016) found that concerns regarding access to resources were more common than concerns about resource abundance or distribution. Physical access to fish in the Arctic is being altered by changes such as decreased sea-ice extent and thickness, altered weather patterns, and thawing permafrost (Bintanja & Andry 2017; Krupnik *et al.* 2010; Lantz and Kokelj 2008; Walsh *et al.* 2011). Ribot and Peluso (2003, 153) define access as “the ability to derive benefits from things”. Access can be mediated through social processes or relationships such as identity, authority, labour, or markets (Appadurai 1986; Berry 1989; Blaikie 1985; Moore 1986; Ribot & Peluso 2003). Access can also be gained through capital, knowledge, or technology (Ribot & Peluso 2003; Ribot 1998; Brinkman 2016; Proverbs *et al.* 2020). An individual’s access to fish is thus enabled or constrained by these “means, relations, and processes” (Ribot & Peluso 2003, 153) as well as their physical access to fishing activities.

In this study we investigate physical access to subsistence fishing in the Inuvialuit Settlement Region (ISR). This project was developed in response to observations made by Inuvialuit fishers that colder, wetter, and windier weather is reducing the number of good fishing days in the summer and affecting people’s access to fish (described in detail in Chapter 2). Margaret Kanayok from Ulukhaktok, NT put it succinctly by stating that: “If the weather don’t cooperate […] we can’t do any fishing”. Our objective was to assess weather impacts on access to nearshore, coastal fishing during the ice-free season through the creation and use of a fishing index. We then sought to use this index to assess change in access to fishing over the last 40 years. Total harvest and catch-effort are inextricably linked to the ability to set nets to catch fish.

These are important metrics used in assessment and co-management of fisheries and are influenced by environmental factors such as weather. Using a combination of Inuvialuit knowledge and archived weather data to investigate the role of the environment on access to fishing is a novel approach for the western Canadian Arctic and will inform co-management and improve dialogue among stakeholders. It will also help predict how climate change may affect the frequency of days with favourable weather conditions required for Arctic coastal fisheries by Inuvialuit.

Study Area

The Inuvialuit homeland lies along the lower reaches of the Mackenzie Delta and coastlines of the Beaufort Sea and Amundsen Gulf (Alunik *et al.* 2003). Inuvialuit culture, language, and livelihoods are linked to these lands and waters through relationships with *qilalukkat* (beluga, *Delphinapterus leucas*), *tuktuvialuit* (caribou, *Rangifer tarandus granti*), and *omingmak* (muskox, *Ovibos moschatus*) (Alunik *et al.* 2003; Freeman *et al.* 2003; Lyons 2009). Examples of important fish species include *iqalukpik* (Arctic char, *Salvelinus alpinus*), *anaakłiq* (broad whitefish, *Coregonus nasus*), and *singayuriaq* (lake trout, *Salvelinus namaycush*) (IJS 2003). Seasonal movement allowed Inuvialuit family groups to follow the migrations of key species, and in the winter, families would gather in larger community groups for hunts and celebrations (Alunik *et al.* 2003). Modern Inuvialuit maintain vital relationships with these culturally important species by harvesting in all seasons and working with a range of organizations to guide the co-management of their territory for future generations (Alunik *et al.* 2003; Ford & Pearce 2010).

Climate change is only the latest disturbance to Inuvialuit livelihoods and cultural traditions, in a history of disruption stretching over more than a century (Alunik *et al.* 2003; Lyons 2009; Whyte 2017). Beginning in the late-1800s, Euro-Americans and their alien worldviews initiated the rapid growth of exploitative economies, first focused on whaling, transitioning to the fur-trade era, then to recent oil and gas exploration (Alunik *et al.* 2003; Freeman *et al.* 2003; Lyons 2009; Usher 1971). The early industries caused environmental degradation (Alunik *et al.* 2003; Freeman *et al.* 2003; Usher 1971) and introduced diseases including measles, influenza, and syphilis, causing mortality rates of up to 90% (McGee and Laverie 1974). The inter-generational trauma of colonialism, notably the residential school system, and racist anti-Indigenous policies still in effect, continue to influence life in communities (Indian Act 1985; Kral 2016; TRCC 2015). These policies have contributed to poverty, inter-generational separation, and knowledge degradation in communities throughout the Arctic, which in turn has eroded social processes through which people may gain access to fish (Cameron 2012). While our analysis is focused on the climate-drivers of access to fish, it is also important that our research is informed by the broader range of processes influencing access.

In 1984, Inuvialuit signed the Inuvialuit Final Agreement (IFA) (Canada 1984), delineating the 435,000 km^2 of the Inuvialuit Settlement Region, and establishing mechanisms for Inuvialuit co-management of land and resources. The IFA was the first modern land claim in northern Canada and provides a framework for furthering Inuvialuit self-governance and independent participation in Canada's economy (Alunik *et al.* 2003; Lyons 2009). There are six communities in the ISR: Aklavik, Inuvik, Paulatuk, Sachs Harbour, Tuktoyaktuk, and Ulukhaktok (Figure 1). Paulatuk, Sachs Harbour, Tuktoyaktuk, and Ulukhaktok are located on the coast of the Arctic Ocean, while Aklavik and Inuvik are located in the Mackenzie River Delta. All coastal communities fish in the harbours directly in front of town, and many families have nearby camps where they spend extended periods fishing during the summer. Fishers from Aklavik and Inuvik utilize lakes and the Mackenzie River and to travel to locations such as Shingle Point and East Whitefish (Figure 3.1) to engage in marine fishing. Coastal and freshwater fisheries are an

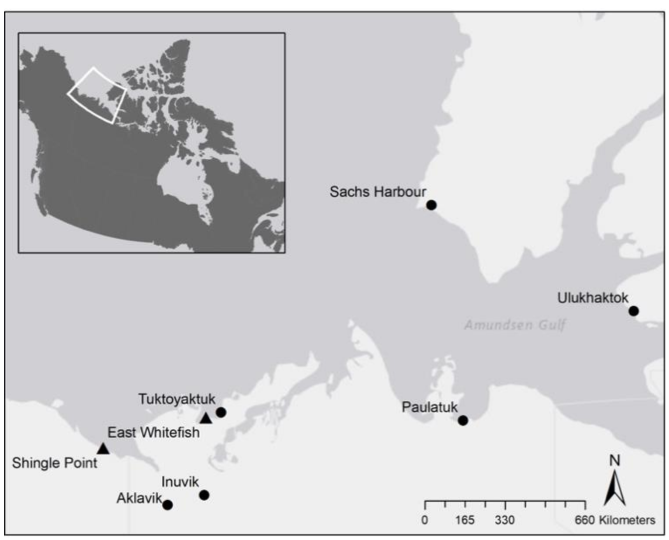

Figure 3.1 Map of the six communities (circles) and two important marine fishing locations (triangles) in the Inuvialuit Settlement Region. The white box in the inset map (upper left) shows the location on main map within Canada.

important component of the mixed-economy in each community (Usher 2000), but in this analysis we focus on coastal fisheries.

Methods

In this study we combined semi-structured interviews and structured questionnaires to guide the development of an index that characterizes the influence of weather on access to fishing. We then calculated the values of this index using reanalysis and observational weather data. Climate reanalysis is a form of synthetic climate data that interpolates available historical data from weather stations to estimate historical climate conditions where data from weather stations is unavailable. It interpolates this data through space, and is available as a gridded dataset. Reanalysis is the most suitable data for this analysis because historical climate data in the Beaufort Delta Region has many missing values (Lawrence *et al.* 2019). There are many reanalysis products available, we chose to use the ERA-5 climate reanalysis product as it is the most accurate reanalysis product representing observed weather conditions (Graham *et al.* 2019; Jakobson *et al.* 2012; Lindsay *et al.* 2014). Given its synthetic nature, reanalysis is prone to bias so we investigated the relationship between ERA-5 climate reanalysis data and Environment and Climate Change Canada (ECCC) data to account for and minimize the influence of these biases (Staffell & Pfenninger 2016; Terink *et al.* 2010). Finally, to assess the accuracy of the IFO, we compared its predictions to the daily fishing conditions reported by community-based monitors in an Arctic char fishery monitoring program (2014-2020) located near Paulatuk, NT (Gallagher *et al.* 2017).

Interviews

Throughout 2019, we visited each Inuvialuit community to conduct semi-structured interviews on changing fish distributions and associated environmental changes. The detailed methods and findings of these interviews can be found in Chapter 2 of this thesis and followed an ethics protocol approved by HTCs and the University of Victoria Human Ethics Research Board (project number 19-0101). In these interviews we asked fishers to describe recent environmental changes that were related to their fishing practices. One of the major changes noted by participants was shifts in access to fishing caused by less favourable weather conditions. Across all six communities, wind speed, wind direction, temperature, rain, and sea-ice were the most common factors identified as limiting fishing access in the ice-free months.

Questionnaires

In response to these observations, we met with the Hunters and Trappers Committee (HTC) in each community and proposed to investigate the effects of weather conditions on fishing access. We chose to focus on fishing during the ice-free season in coastal marine locations because this is an important fishing period for many people. We developed questionnaires (Appendix A) to identify thresholds for the upper limits of wind speed and rain, and upper and lower limits of temperature, above or below which people would no longer consider going fishing (Table 3.1). We also asked participants to distingish between wind directions favourable and unfavourable for fishing. We also assumed that when sea-ice was present within the coastal water there was no access to fishing. When the HTC had approved the proposal and questionnaire, each board selected up to three individuals in their community to provide responses that represented how the broader community fished. The HTC also selected a member of their community to ensure that each participant provided their informed consent, and to distribute questionnaires and answer questions which arose. With help from HTCs, we completed 13 questionnaires across six communities in February 2021, complying with the same ethics protocol as above.

Corrected Weather Reanalysis Data and the Index of Fishing Opportunity

Subsequently, we created an index of fishing opportunity (IFO) based on the results of the questionnaires. The IFO calculates seasonal fishing access scores based on the suitability of weather conditions for fishing. We combined historical data from ECCC weather stations and weather reanalysis data and adjusted the thresholds identified by fishers to account for the bias in reanalysis data. We adjusted the thresholds for each fishing location individually, using ECCC data from the nearest weather station (https://climate.weather.gc.ca/historical_data/search_historic_data_e.html). Subsequently, we used these adjusted thresholds to calculate the IFO in all years from 1979-2019 among spring (May 1st-June 30th), summer (July 1st-August 31st), and fall (September 1st-October 31st) seasons. We then used the IFO time-series to investigate changes in fishing access caused by weather conditions. We completed this analysis for each location using the thresholds specific to each community and local reanalysis data. For our purposes we define fishing opportunity as a measure of the suitability of weather conditions for fishing activities within a given fishing season.

We used ERA-5 climate reanalysis data (https://cds.climate.copernicus.eu/#!/search?text=ERA 5&type=dataset, Hersbach *et al.* 2020) and R (version 4.0.2) to calculate IFO scores for the six marine fishing locations (Table 3.1). Reanalysis products, such as ERA-5, are comprehensive but may provide inaccurate estimates of historical conditions (Graham *et al.* 2019; Jakobson *et al.* 2012; Lindsay *et al.* 2014). We chose to account for any biases by comparing ERA-5 estimates to data from nearby ECCC weather stations (details included in Table 3.1, ECCC 2021a, b, c, d, e) using correlation and regression analyses. We then scaled the threshold values identified by fishers in the questionnaires to be comparable with the reanalysis data, using the linear formulas identified using regression analysis (Table 3.1). Similar methods have been shown to increase the accuracy of reanalysis data in estimating precipitation, windspeed, and temperature (Staffell & Pfenninger 2016; Terink *et al.* 2010).

In the first step of the correction, we performed a Spearman rank correlation to compare wind, precipitation, and temperature data from the ECCC and ERA-5 data sets. We found significant correlations between temperature and wind speed, but the Spearman's r values for precipitation were all below 0.5; therefore, we chose not to adjust the thresholds for precipitation. Despite not adjusting the precipitation threshold, we decided to keep the data in the index as it was mentioned by fishers as an important weather driver. We also do not know if ERA-5 precipitation estimates are in fact misrepresentative of actual rainfall.

For temperature and wind speed, we ran least-squares regressions to identify the linear relationship between ECCC and ERA-5 data sets. Next, we used these regression equations to scale fishers' thresholds and account for the systematic under- or over-estimation in reanalysis data for different weather variables. The evaluation of conditions as suitable or unsuitable for fishing (described in detail below) relied on comparing the data to the thresholds. As long as the data and thresholds are scaled to each other, their comparison is not affected by which one is adjusted using their linear relationship. Table 3.1 provides more detail on the relationship between reanalysis and observed data, including specific statistics and equations.

Table 3.1 Results of the correlation and regressions analyses of ERA-5 climate reanalysis by Environment and Climate Change Canada climate data. All of the locations where we calculated IFO had ECC climate data except for East Whitefish. We used data from the Tuktoyaktuk weather station (25 km to the E) to correct for observations at East Whitefish as it is the nearest station. We used the least squares regression formulae to convert the thresholds identified by fishers to values comparable to the reanalysis data.

ECCC Observed Variable (B)	ERA-5 Reanalysis Variable (R)	Fishing Location	Number of comparisons	Spearman r value	Linear model p value	Linear model r2	Least Squares Regression formula
Daily Maximum Temperature	Daily Maximum 2m Temperature	Shingle Point	3400	0.669	< 0.001	0.469	R = 0.50*B + 5.50
Daily Maximum Temperature	Daily Maximum 2m Temperature	East Whitefish	4021	0.678	< 0.001	0.479	R = 0.67*B + 5.85
Daily Maximum Temperature	Daily Maximum 2m Temperature	Tuktoyaktuk	4021	0.678	< 0.001	0.479	R = 0.67*B + 5.85
Daily Maximum Temperature	Daily Maximum 2m Temperature	Paulatuk	4065	0.712	< 0.001	0.508	R = 0.67*B + 4.80
Daily Maximum Temperature	Daily Maximum 2m Temperature	Sachs Harbour	3717	0.779	< 0.001	0.618	R = 0.54*B + 3.45
Daily Maximum Temperature	Daily Maximum 2m Temperature	Ulukhaktok	4338	0.827	< 0.001	0.673	R = 0.61*B + 3.07
Daily Minimum Temperature	Daily Minimum 2m Temperature	Shingle Point	3431	0.706	< 0.001	0.520	R = 0.67*B - 1.71
Daily Minimum Temperature	Daily Minimum 2m Temperature	East Whitefish	4028	0.736	< 0.001	0.532	R = 0.75*B - 2.12
Daily Minimum Temperature	Daily Minimum 2m Temperature	Tuktoyaktuk	4028	0.736	< 0.001	0.532	R = 0.75*B - 2.12
Daily Minimum Temperature	Daily Minimum 2m Temperature	Paulatuk	4049	0.761	< 0.001	0.583	R = 0.81*B - 2.66
Daily Minimum Temperature	Daily Minimum 2m Temperature	Sachs Harbour	6393	0.771	< 0.001	0.574	R = 0.67*B - 1.26
Daily Minimum Temperature	Daily Minimum 2m Temperature	Ulukhaktok	4259	0.817	< 0.001	0.655	R = 0.77*B - 1.52
Daily Maximum Gust Speed	Daily 10 m Gust Speed	Shingle Point	1011	0.650	< 0.001	0.515	R = 0.17*B + 2.11
Daily Maximum Gust Speed	Daily 10 m Gust Speed	East Whitefish	363	0.636	< 0.001	0.498	R = 0.18*B + 3.17
Daily Maximum Gust Speed	Daily 10 m Gust Speed	Tuktoyaktuk	363	0.636	< 0.001	0.498	R = 0.18*B + 3.17
Daily Maximum Gust Speed	Daily 10 m Gust Speed	Paulatuk	525	0.595	< 0.001	0.404	R = 0.17*B + 2.48
Daily Maximum Gust Speed	Daily 10 m Gust Speed	Sachs Harbour	950	0.753	< 0.001	0.620	R = 0.22*B + 1.50
Daily Maximum Gust Speed	Daily 10 m Gust Speed	Ulukhaktok	977	0.730	< 0.001	0.581	R = 0.19*B + 3.12

Daily Precipitation	Daily Convective Precipitation	Shingle Point	1137	0.476	< 0.001	0.123	N/A
Daily Precipitation	Daily Convective Precipitation	East Whitefish	1386	0.348	< 0.001	0.076	N/A
Daily Precipitation	Daily Convective Precipitation	Tuktoyaktuk	1386	0.348	< 0.001	0.076	N/A
Daily Precipitation	Daily Convective Precipitation	Paulatuk	2562	0.391	< 0.001	0.076	N/A
Daily Precipitation	Daily Convective Precipitation	Sachs Harbour	2677	0.380	< 0.001	0.058	N/A
Daily Precipitation	Daily Convective Precipitation	Ulukhaktok	3831	0.322	< 0.001	0.047	N/A

Using this combination of modified (windspeed, temperature) and unmodified (rain) thresholds, we calculated values of the IFO for each year between 1979 and 2019 at each fishing location. We chose to narrow our analysis to the period between sea-ice break-up and freeze-up. Since people do not fish in the dark, we also excluded any times when the sun was fully below the horizon. We then assigned access scores based on rain, wind, and temperature conditions, for every day when the ERA-5 reanalysis reported a sea-ice concentration of zero (Figure 3.2). We averaged the ERA-5 estimates over the four 0.25 degree square grid cells nearest each fishing location to avoid possible error associated with using a single grid cell.

We calculated daily scores for rain and temperature by using the fishers' thresholds. Days when no rain fell received a daily-rain-score of one ($R_D = 1$), while those where rainfall exceeded the threshold received a daily-rain-score of zero ($R_D = 0$). Days where rainfall was between zero and the threshold received a score between zero and one corresponding to the amount of rain that fell ($R_D = 1 - (\text{rainfall}*\text{threshold}^{-1})$). This ensured that days where the total rainfall nearly exceeded the daily threshold would receive a lower score than days where very little rain fell. Temperature scores were calculated differently, by using hourly, rather than daily, ERA-5 data. When the hourly temperature was between the low and high thresholds we assigned a temperature-score of one ($T_H = 1$). When the temperature exceeded either threshold we assigned a score of zero ($T_H = 0$). The daily-temperature-score was the sum of hourly temperature-scores ($T_D = \text{sum}(T_H)$).

We calculated wind-scores in a similar manner to the temperature scores. When the wind gust speed was below or above the threshold we assigned a respective hourly-wind-score of one ($W_H = 1$) or zero ($W_H = 0$). Subsequently, we used wind direction to modify the hourly scores. If the wind was below the threshold, the direction of the wind was used to modify the hourly wind score to reflect the impact of wind direction on fishing. When the wind direction was unfavorable for an otherwise favourable hour, we reduced the hourly wind-score by half ($W_H = W_H * 0.5$) (Figure 3.2). If the wind speed was above the locally determined threshold, its direction did not matter and the wind-score was zero. The daily wind-score was the sum of hourly wind-scores ($W_D = sum(W_H)$).

Consecutive good fishing days provide greater access to fishing than good days interspersed with poor days because they allow for fishers to plan their activities and travel to preferred fishing locations which may be further from town or camp. We modified each weather score to account for the additional benefit that stems from consecutive good fishing days. To do this, we first classified each day as good or bad for each variable. Days were considered bad if: 1) there was ice in the water, 2) the rain threshold was exceeded, 3) more than half of the hours in the day had unfavourable temperatures, or 4) windspeeds exceeded the threshold. Then, for each variable, if a good day was followed by another good day, its score was modified by adding 0.1 for each good day that preceded it. This approach ensured that a long stretch of good fishing conditions resulted in a higher total score than the same number of days interspersed with unfavourable days. Once each day in a fishing season had been scored for temperature, wind, and rain, we normalized daily scores by dividing each score by its seasonal maximum so that no factor had a disproportionate impact on the overall access score (Figure 3.2).

The process of calculating daily scores was divided into three steps: 1) scoring reanalysis data using thresholds from questionnaires, 2) analyzing for consecutiveness, and 3) normalizing across each season (Figure 3.2). Within a given fishing season, each day had three scores (R_D, T_D, and W_D) that ranged from zero to one. We used the sum of these scores as the estimate for overall daily fishing access ($A_D = R_D+T_D+W_D$), and the sum of daily scores across each season as our index of fishing opportunity for that season ($IFO = sum(A_D)$). We assessed for trends in the IFO using a Theilsen regression as it is insensitive to outliers.

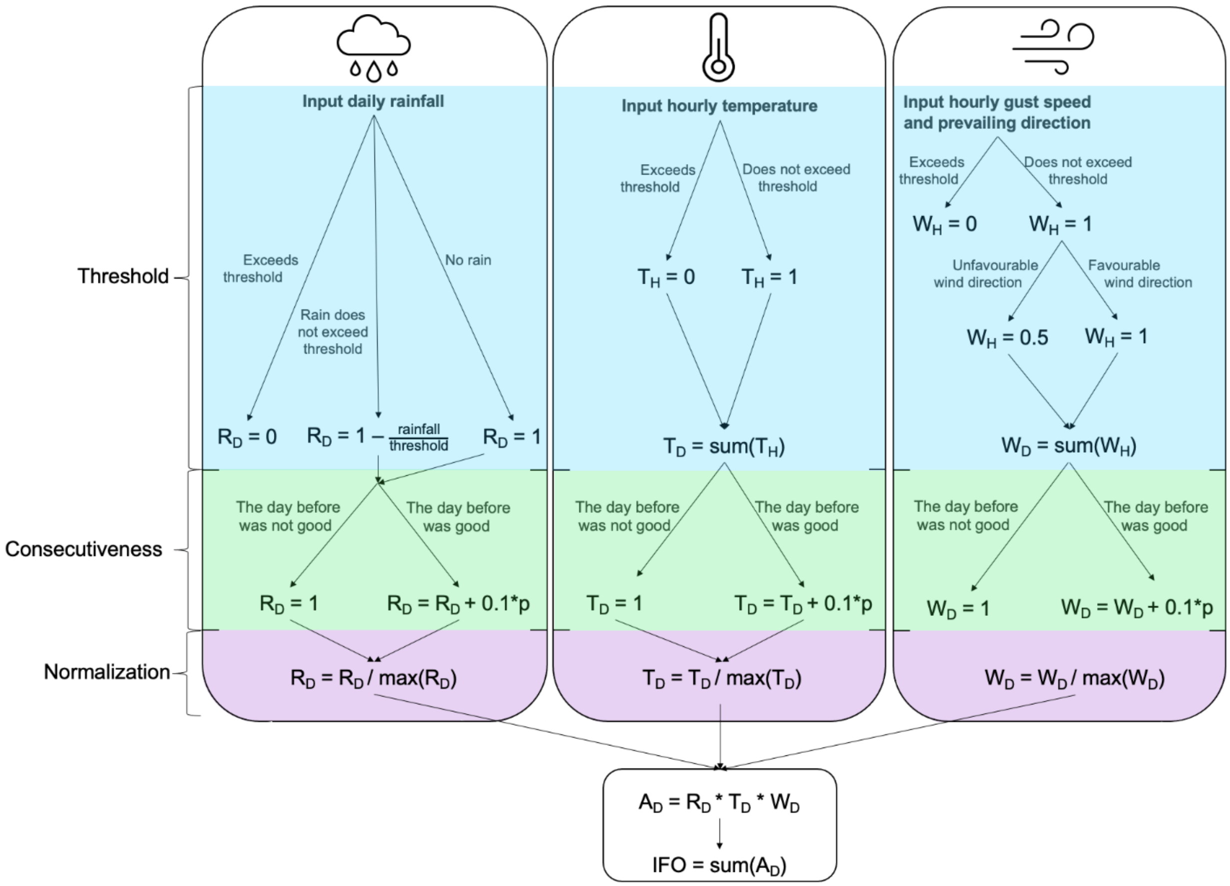

Figure 3.2 Flow chart showing the process used to assign daily scores for access to fishing based on daily rainfall and hourly temperature and wind conditions based on the ERA-5 Climate Reanalysis Dataset. Any day with a sea-ice-concentration of zero from January 1979-December 2019 was scored. Thresholds for weather conditions were locally specific and determined by fishers with many years of fishing experience in that location (Table 1). We considered days to be good if rainfall did not exceed the threshold, and if less than half of its hours had conditions for temperature or windspeed which exceeded the thresholds identified by fishers. Shaded sections indicate the three steps in assigning scores: blue for initialization, green for the modification based on consecutive fishing days, and purple for normalization across each season.

Groundtruth

In order to assess the accuracy of the IFO, we compared the values of this index to data from a fisheries monitoring project near Paulatuk (Gallagher *et al.* 2017). In this project, Inuvialuit fishers collect catch-per-unit-effort data for Arctic char using a standardized method in the nearshore environments at the mouth of the Hornaday River over a three-to-four-week period in the summer. Fishers record when they set their nets, for how long, and the resulting number of char that they harvest (Gallagher *et al.* 2017). In 2014, fishers also began describing the daily environmental conditions influencing their fishing including: wind speed and direction, sea-ice, wave height, precipitation, temperature, and turbidity. In addition, they also provided a yes or no answer to indicate whether the daily combination of these environmental conditions was “too rough to set a net?” We compared the yes or no answers to the IFO predictions of good or bad days (described above) for all dates where there was overlapping data. We grouped the results of this comparison into three categories: 1) agreement, instances where the IFO correctly predicted if the conditions were favourable or unfavourable for fishing, 2) overestimation, cases where the IFO predicted the conditions were favourable, but the monitors reported that conditions were unfavourable, and 3) underestimation, days where the IFO predicted that the conditions were unfavourable, but the monitors reported that conditions were favourable.

Contributions and Positionality

The work of this research was divided amongst authors. The contributions of each author to the interviews are detailed in Chapter 2. Z.C., K.D., and T.L. conceptualized this study and proposed it to each HTC who provided their input and approval. Z.C. wrote the questionnaires which were approved by the HTCs. Each HTC chose the representative fishers to answer the questionnaire and hired a technician to facilitate local research activities. Z.C., K.D., and T.L. developed the IFO and analyzed the results which the HTCs then verified. C.G. contributed data from the Arctic Char monitoring project. The manuscript was drafted by Z.C. with contributions from C.G., K.D, and T.L..

While this study was developed in response to Inuvialuit observations of changing weather conditions, and in partnership with Inuvialuit HTCs, it is important to note that C.G., K.D., T.L., and Z.C. are white settlers. By following community direction, critically considering our own positions, and working for open and honest communications about these positions with Inuvialuit collaborators, we worked to mitigate the colonial history of research activities and to un-learn our biases. This work is ongoing and relational, and we thank our research collaborators for their guidance.

Results

The IFO revealed that fishing conditions were highly variable, within and among years (Figure 3.3). Within years, the IFO in summer was typically higher than in the fall, which was generally higher than in the spring. The IFO also varied considerably among years, indicating that good seasons can be followed by poor ones (Figure 3.3). Interannual variation was generally highest in the summer, when IFO ranged from 0-13.9 (Figure 3.3). Variation in IFO among years was typically lower in the fishing locations near the Mackenzie Delta (Shingle Point, East Whitefish, and Tuktoyaktuk), than in the Outer communities (Paulatuk, Sachs Harbour, and Ulukhaktok).

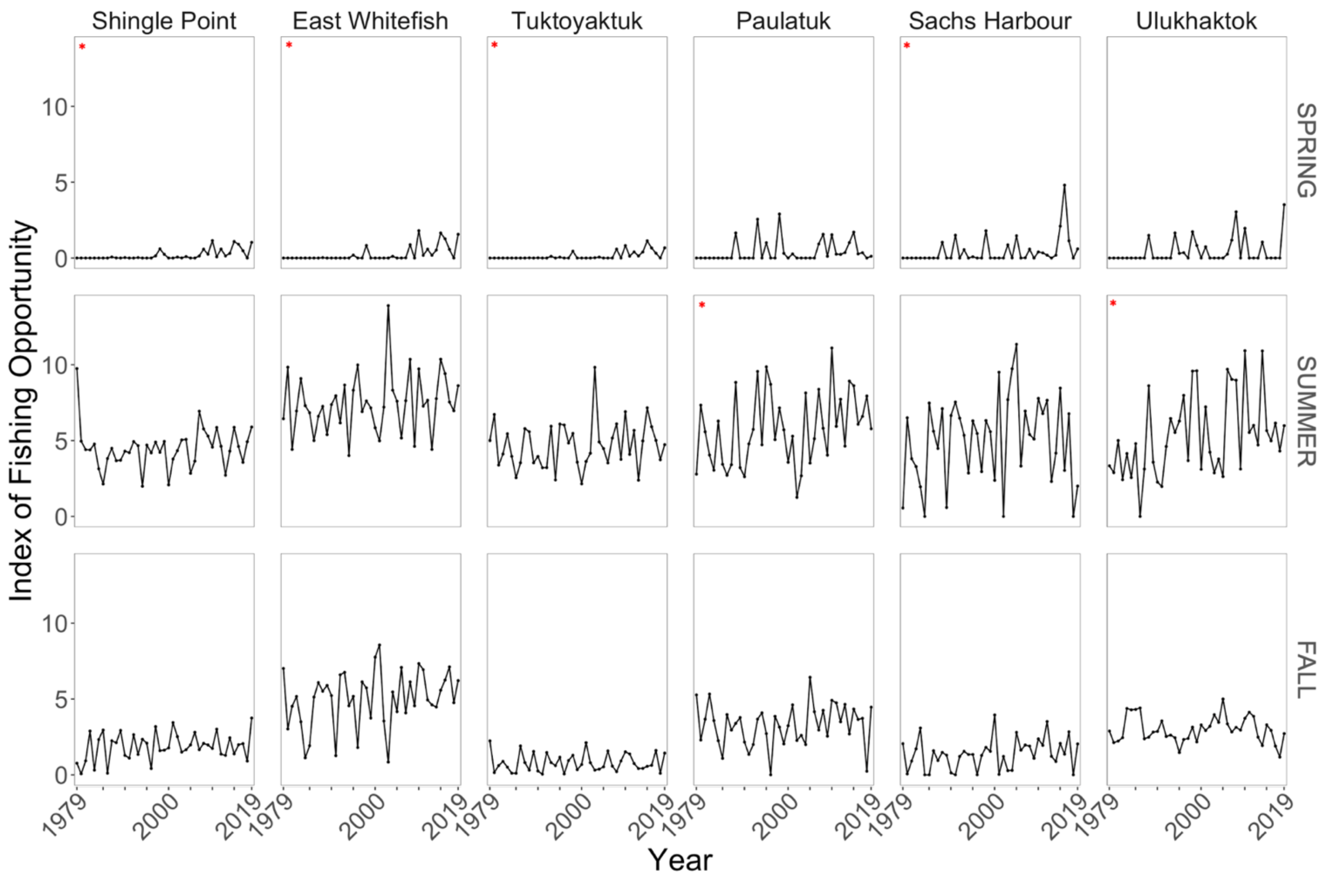

Figure 3.3 The Index of Fishing Opportunity at six coastal fishing locations in the Inuvialuit Settlement Region (columns). The IFO is shown for each of three “seasons” identified by fishers (rows). Spring refers to May-June, summer to July-Aug, and fall to Sep-Oct. IFO was calculated between 1979-2019 inclusive using ERA-5 climate reanalysis data (Hersbach et al. 2020) corrected with observations from Environment and Climate Change Canada (ECCC 2021). Red asterisks in the top left corner of each plot denote time series with slopes that are significantly different from 0 ($p<0.05$). All significant slopes were positive.

Twelve out of eighteen locations and seasons the IFO did not show a trend indicating change over the last 41 years. However, increasing trends in several time series suggests that fishing access has improved in some locations and seasons (Figure 3.3). IFO in the spring was zero for most years before the late 1980s, after which, this season began to have sporadic years where IFO was above zero (Figure 3.3). At Shingle Point, East Whitefish, Tuktoyaktuk, and Sachs Harbour, IFO showed a significantly increasing slope in the spring season. In summer, Paulatuk and Ulukhaktok both had a significantly increasing IFO slope. The IFO in the fall season did not show significant trends at any of the fishing locations.

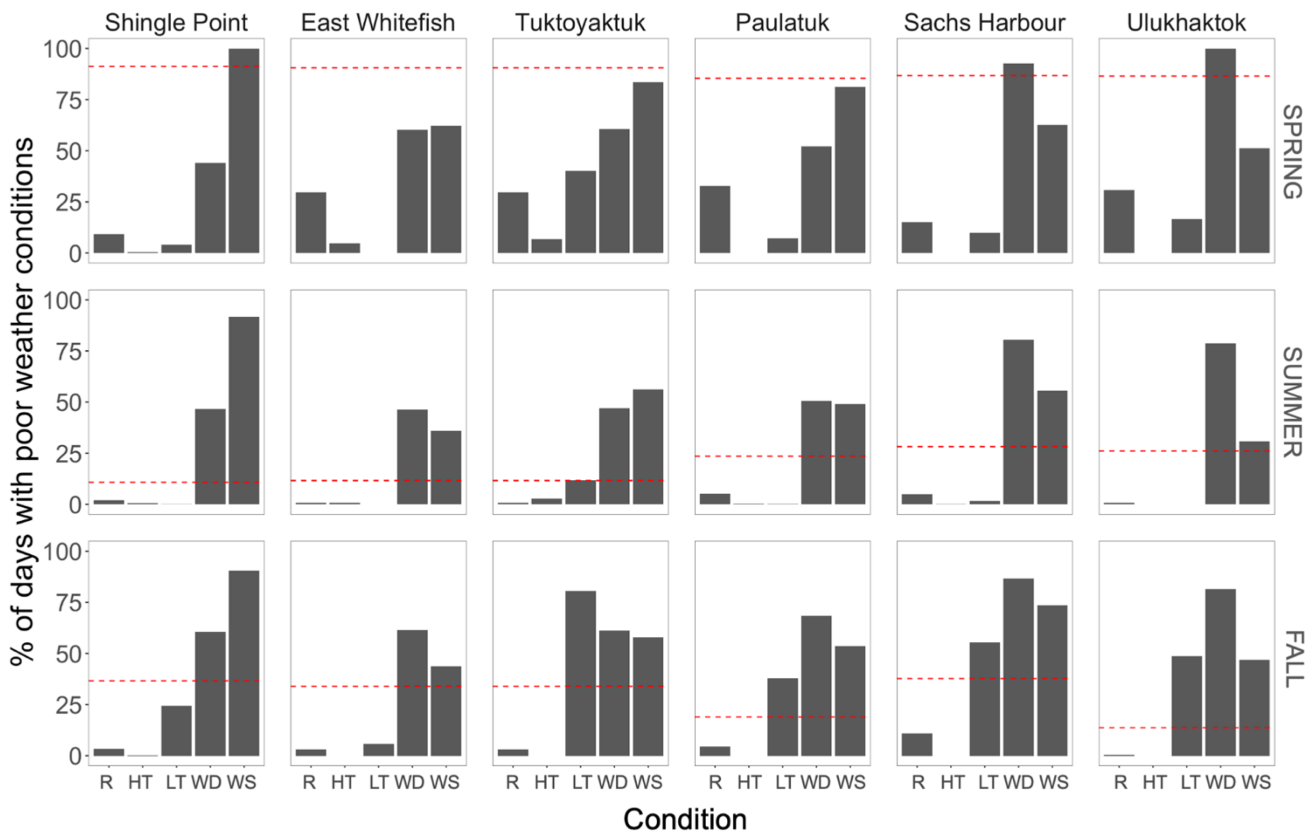

Figure 3.4 Percent of days in the time series (1979-2019) when fishing conditions were unfavourable. Red dashed lines indicate the percent of days with sea-ice concentrations that were above zero. The bars indicate the percent of ice-free days which were unfavourable because of rain (R), high temperature (HT), low temperature (LT), unfavourable wind direction (WD), and high wind speed (WS). Days were counted twice when conditions were unfavourable for multiple reasons. We considered a day to be unfavourable when rain exceeded the daily threshold, when more than half of the hours in that day had wind, or when temperature conditions were outside of the thresholds described in Table 1.

Figure 3.4 shows how different weather parameters influenced the IFO. It displays the percent of days when conditions were poor for each of the parameters in the index. The red dashed line shows the number of days when sea-ice concentration was greater than 0. Each bar represents the percent of ice-free days that were unfavourable due to one of rain, low or high temperatures, or wind direction or speed in each location and fishing season. In the spring, 85-91% of days had sea-ice concentrations that made fishing unfavourable. Of the unfavourable days that were ice-free, most were caused by wind speed and direction, but rain was also important. In the summer, 10-28% of days had unfavourable ice conditions. For the unfavourable days that were ice-free in the summer, wind speed and direction were the most important influences, followed by rain. In the fall, 13-38% of days had unfavourable ice-conditions. In the fall, wind speed and direction, and cold temperatures were all important determinants of unfavourable fishing days.

Questionnaire Results

Table 3.2 Participant defined thresholds for wind, temperature, and rainfall that make conditions unfavourable for fishing in each community. Thresholds were adjusted using the regression formulas in Table 3.1, adjusted values are provided in parentheses.

Community	Fishing Location	Coldest Temperature (°C)	Hottest Temperature (°C)	Maximum Daily Rainfall (mm)	Maximum Wind Speed (km/hr)	Unfavourable Wind directions
Aklavik	Shingle Point	0 (-1.71)	25 (18)	6	10 (3.81)	W, N
Inuvik	East Whitefish	-10 (-9.62)	20 (19.5)	20	25 (7.67)	W, N
Tuktoyaktuk	Tuktoyaktuk	8 (3.88)	20 (19.5)	1	20 (6.77)	N, W
Paulatuk	Paulatuk	0 (-2.66)	25 (21.55)	20	20 (5.88)	N
Sachs Harbour	Sachs Harbour	0 (-1.26)	25 (16.95)	15	30 (8.1)	E, S, W
Ulukhaktok	Ulukhaktok	0 (-1.52)	N/A	5	30 (8.82)	E, S, W

The weather thresholds identified by fishers were generally similar among communities, but notable differences include the maximum rainfall threshold in Tuktoyaktuk, and the coldest temperature thresholds in Tuktoyaktuk and East Whitefish. The impacts of these thresholds are evident for Tuktoyaktuk where more unfavourable days were caused by temperature than elsewhere (Figure 3.4). Conversely, in East Whitefish, the number of unfavourable days caused by temperature was much lower.

To investigate the reasons for these differences we asked fishers from Tuktoyaktuk and Inuvik about why they prefer to fish in these conditions. Fishers in Tuktoyaktuk explained that they prefer to fish when conditions are optimal for preparing and drying their fish, which they do immediately after harvesting them. Since they do not have to travel long distances to reach their preferred fishing locations, they explained that they can be more flexible when deciding whether or not to set or pull their nets, and fish only when conditions are optimal. The temperature and rain thresholds they identified are essential for their method of preparing and drying fish. Colder temperatures make it more difficult to dry the fish, while warmer ones lead to increased rates of spoiling. Any amount of rainfall makes for poor drying conditions. Fishers who harvest at East Whitefish reported that better quality fish are harvested in colder conditions. They associated warmer air and water temperatures with soft-fleshed fish, which is less desirable. As such, fishers in this location harvest while the temperatures were cooler and the fish were of better quality. The IFO for this location reflects this preference with higher index values at East Whitefish in the fall than elsewhere.

In addition to wind, rain, temperature, and sea-ice, fishers in communities across the ISR mentioned many environmental factors influencing fish availability at more localized scales. We chose not to include these factors in the IFO as they were locally specific and we lacked comparable data. We present them in Table 3.3 as they provide important context to a larger discussion of access to fish in the ISR.

Table 3.3 Other environmental conditions that limit the availability of fish. Approximate distances between community and fishing location are shown in brackets for sites that are not directly adjacent to the community.

Community	Fishing Location		Other Environmental Determinants of Fish Availability
Aklavik	Shingle Point (130 km)	-	Erosion along the coast and in the river, increasing the difficulty for travel and for setting nets
		-	Decreasing fish abundances
Inuvik	East Whitefish (140 km)	-	Rising water levels
		-	Increasing turbidity and debris making it harder to set nets
		-	Erosion along the route from Inuvik to East Whitefish increasing the difficulty of travel
Tuktoyaktuk	Tuktoyaktuk	-	Increasing beaver populations, preventing anadromous fish from reaching their spawning areas

		- Decreasing predictability of fish runs
Paulatuk	Paulatuk	- Increasing water temperatures negatively affect harvest size and fish quality
		- Changing aquatic communities reduce target fish abundances
		- Decreasing predictability of fish runs
Sachs Harbour	Sachs Harbour	- Debris in the water, associated with erosion and permafrost thaw
		- Decreasing target fish abundance, and more variation in fish size between years
		- Increasing water temperatures negatively affects harvest size and fish quality
Ulukhaktok	Ulukhaktok	- Increasing number of "foggy" days
		- Increasing water and air temperatures having negative effects on harvest size and fish quality

Groundtruth

Comparisons of the IFO values and reports from Paulatuk fishers showed 98 instances (62%) of predictions which matched harvester reports, and 53 instances (33%) of underestimation, where IFO predicted poor fishing conditions, but harvesters reported favourable ones. There were only 8 instances (1%) where the IFO overestimated fishing opportunity (i.e., the IFO predicted favourable fishing conditions but the harvester reports showed unfavourable conditions).

Table 3.4 Comparisons of IFO scores to weather suitability reports from the Arctic char monitors setting nets at the mouth of the Hornaday River near Paulatuk, NT. The agreement column shows instances where the IFO correctly classified conditions, the underestimated column indicates cases where the IFO predicted unfavourable fishing conditions, but fishers reported favourable ones, and the overestimated column shows instances where the IFO predicted favourable conditions but fishers reported unfavourable ones.

Year	**Agreement**	**Underestimated**	**Overestimated**
2014	13	10	0
2015	16	3	3
2016	14	10	0
2017	17	13	0
2018	23	7	0
2019	15	10	5
Total	98 (62%)	53 (33%)	8 (1%)

Discussion

The Index of Fishing Opportunity (IFO) demonstrates that access to coastal fishing varies in response to environmental conditions. It quantifies the impacts of wind, rain, temperature, and sea-ice, highlighting how each of these conditions influences access. Wind had the strongest impact on access to fishing, a finding which is consistent with the results from interviews, as poor fishing conditions were most often attributed to wind. Wind acted throughout all seasons, which may explain why many fishers considered it to be the most limiting factor. Wind affects people's fishing activities by changing fish behaviour and distribution in the nearshore environment (Hinz 1989; Stoner 2004). Based on our interviews, wind also influences fishing by driving wave-height, and causing net foul. In contrast to wind, the negative effects of high and low temperatures were primarily limited to the spring and fall seasons. We anticipated this result given our intuitive understanding that temperatures tend to be less favourable in the spring and fall. The IFO does suggest that, other than in Tuktoyaktuk, higher temperatures driven by global climate change are not decreasing access to fishing. This is supported by interview participants who stated that climate change has made summers more variable, but not excessively hot. Generally, rain was most influential in the spring, and was stable in the summer and fall. We interpret the results of rain with caution given that they are based on the comparison of reanalysis data to un-adjusted thresholds. While the influence of rain relative to other variables may be mis-represented in our results, its influence relative to other seasons is likely more accurate because re-analysis bias is more consistent in each location (Staffell & Pfenninger 2016; Terink *et al.* 2010). The poor relationship between observed and reanalyzed precipitation data, described in Table 3.1, could be caused by widely recognized errors in the measurement of precipitation (Metcalfe *et al.* 1997).

Like wind, temperature, and rain, sea-ice had a larger impact on fishing access in the spring and fall than in the summer. According to interviews with experienced fishers, the way in which ice affects fishing is different in each season. In developing the IFO, we simplified the effects of sea-ice for the purposes of our analysis by assuming that sea-ice concentration greater than zero created poor fishing conditions. In the IFO, summer influence of ice on access to fishing is limited to ice drifting into and out of fishing areas. Sea ice impacts on fishing in the spring and fall are related to drifting ice, but more importantly are tied to break-up and freeze-up events, respectively. Break-up and freeze-up events limit fishing activities by changing fish distributions, limiting the setting of nets from shore, and preventing boat access. The disproportionate scale of these events drives the higher influence of ice in the spring and fall compared to summer. Recent changes in the timing of these events is shown in the IFO. The IFO in spring shows an increase in access to fishing associated with more ice-free days in May and June, beginning in the 1980s. Fall IFO, however, does not show an increasing trend. Since the IFO does not estimate access to fishing activities under the ice, earlier break-up and later freeze-up (Comiso *et al.* 2008; IPCC 2019; Sanderson *et al.* 2017; Stroeve *et al.* 2014) should contribute to increased access to fishing. The fact that the IFO does not show an increase in the fall suggests that fall weather conditions are becoming less favourable and counteracting the increase in IFO predicted by decreased sea-ice.

By quantifying the impacts of weather and sea ice on fishing activities, the IFO provides a tool to explain some of the variation in the number of fish harvested each year. The total fish harvest varies between years in each location, according to a range of factors such as fish abundance, fish distribution, access to fishing, and corresponding fishing effort. The IFO provides a way to quantify access to fishing and therefore explain some of the inter-annual variation in fish harvest. Our analysis does this on a local scale by considering how the effects of environmental conditions on access to fishing vary with local fishing practices. For example, in East Whitefish, local temperature thresholds reflect a preference for harvesting fish in cooler conditions. This contributed to East Whitefish having the highest access to fishing in the fall season. In Tuktoyaktuk, rain and temperature thresholds reflected the impact of these conditions on the process of drying fish. Low thresholds for rain and cold temperatures contributed to Tuktoyaktuk having lower access to fishing, especially in the spring and fall. The direct incorporation of local fishing practices and access thresholds into the calculations for the IFO shows that these differences strongly impact access and is one of the IFOs strengths.

Another key strength of the IFO is its simplicity and flexibility, which could facilitate its use to evaluate access to fishing in other locations or across different timeframes. This flexibility could facilitate the IFO being adapted to evaluate access to ice-fishing. This is of interest because it would necessitate an improved representation of break-up and freeze-up. While it is very common to fish in the ocean during the ice-free season, fishing in lakes and rivers, and under the ice is also an important source of food and cultural connection (AHTC *et al.* 2016; IHTC *et al.* 2016; OHTC *et al.* 2016; PHTC *et al.* 2016; SHHTC *et al.* 2016; THTC *et al.* 2016). For example, many people from Inuvik and Aklavik do their primary fishing at camps throughout the Mackenzie Delta (AHTC *et al.* 2016; IHTC *et al.* 2016). In Ulukhaktok, people set nets under the ice at Fish Lake as soon it is thick enough in the fall (OHTC *et al.* 2016). Access to these fishing activities is determined by different weather factors, but the IFO could easily be adapted for use across different seasons and in different locations. The IFO could also be expanded to investigate how other environmental parameters influence access to fishing, including parameters specific to individual locations (e.g., turbidity, fog, water levels). The IFO could also be modified to explore the impact of weather on access to other harvesting activities, such as hunting for *tingmiaq* (geese) or *omingmak* (muskox). This would contribute to a greater understanding of the determinants of access to country foods, and to the important nutritional and cultural processes which they support (ICC 2020; ITK 2019; Cunsolo-Willox *et al.* 2015).

Although Inuvialuit fishers reported that colder, wetter, and windier conditions during the summer months are decreasing access to fishing, the change was not apparent in the IFO data. In the summer months, most locations showed no trend in IFO apart from Paulatuk and Ulukhaktok, which demonstrated a significant increase over time. The IFO provides an index of relative access, but it may not be suited to track long-term change as multiple factors contribute to high uncertainty. The IFO relies on reanalysis data that are known to have a high degree of spatial and temporal error. Reanalysis data present the most plausible conditions for weather variables based on nearby observations (when available) and model forecasts from previous time-steps. The availability of observational data varies through time and the network of weather stations contributing observational data to reanalysis models has expanded dramatically since 1979 (Hersbach *et al.* 2020). As a result, reanalysis data from early in the time-series are likely less accurate than those from recent years. Additionally, the model calculations used to predict conditions from previous time-steps are prone to error (Graham *et al.* 2019; Jakobson *et al.* 2012; Lindsay *et al.* 2014). The high degree of uncertainty in the reanalysis products affects the predictions made by the IFO, however the agreement between IFO predictions and reports from Arctic Char monitors suggest that the uncertainty of reanalysis does not prohibit its use for our purposes. Future work to decrease uncertainty in the IFO should explore the use of different reanalysis data sets such as Met1km (Zhang *et al.* 2020) or GlobSIM (Cao *et al.* 2019). This uncertainty could also be decreased with higher quality observational data in the Arctic, calls for which are repeated throughout the literature (Bromwich *et al.* 2010; ITK 2014 and 2019b;

Johnson *et al.* 2015; WMO 2021). Better observation networks would also increase our collective ability to monitor and understand changes occurring in Arctic environments, and contribute to the adaptive capacity Arctic peoples (ITK 2014 and 2019b).

The fact that the IFO does not account for how changes in fish abundance throughout the fishing season influence fishing activity may also partly explain the mismatch between the long-term trends shown in the IFO and fisher observations of long-term change. In this analysis we divided the ice-free season into spring, summer, and fall to broadly illustrate how access to fishing changes throughout the year. Although the IFO shows increasing fishing opportunity in the spring, these increases may not represent true increases in opportunity because the composition and relative abundance of fish changes within each season (AHTC *et al.* 2016; IHTC *et al.* 2016; IJS 2003; OHTC *et al.* 2016; PHTC *et al.* 2016; SHHTC *et al.* 2016; THTC *et al.* 2016) and fish may not be available at this time. Within the summer season, a fisher may need a smaller number of good fishing days at times when a high proportion of migratory fish are passing by than they would at other times. The weather conditions during these critical times would therefore contribute disproportionately to overall access to fishing. By dividing the fishing season into spring, summer, and fall we did not account for the ways that important times within each season disproportionately influence overall access to fishing. To use the IFO to assess long-term trends in access to fishing, additional work with fishers in each location to identify key fishing times is required. This information could then be used to assign varying weights to times within each season. A more thorough investigation of this topic seems particularly important given that Inuvialuit fishers told us the dates of critical fishing times are changing.

Another potential limitation of our approach is that the thresholds we used may not reflect the fishing practices of all fishers in a community. Comparisons with fishing-suitability reports from Arctic char monitors indicate that some fishers set nets in conditions outside of the thresholds identified by the questionnaire participants. In the future the IFO could be refined to include upper and lower bounds around fishing conditions, which would provide a range of values that characterize community fishing practices. Similar methods are becoming more common in research to understand environmental change in collaboration with fishers (Cooke *et al.* 2021; Mantyka-Pringle *et al.* 2017).

In this study we focused on how weather influences access to fishing, but a holistic understanding of all social determinants of access to fish is critical to future fish management efforts in Arctic regions (Brinkman *et al.* 2016; Wesche and Chan 2010; Proverbs *et al.* 2020). Previous research shows that there are many other processes involved in determining access to fish (Brinkman *et al.* 2016; Proverbs *et al.* 2020; Ribot and Peluso 2003). The availability of equipment such as boats and nets, and the price of gas required for travelling to and from fishing locations are simple examples of other factors that influence access (Proverbs *et al.* 2020; Ribot and Peluso 2003). Access to fishing also requires time. Many Inuvialuit fishers are now engaged in the wage economy, which facilitates buying the necessary equipment, but limits fishing activities to evenings and weekends (Proverbs *et al.* 2020; Usher 1971 & 2002). Access to fish can also be mediated through social mechanisms such as relationships between harvesters and non-harvesters or food-sharing programs that redistribute catches to elders or single parent families (Berkes and Jolly 2001; Ford *et al.* 2013; Proverbs *et al.* 2020). Knowledge of how, where, and when to fish is also critical to access (Brinkman *et al.* 2016; Proverbs *et al.* 2020; Ribot and Peluso 2003) and is facilitated and strengthened by inter-generational relationships and teaching in the community (ITK 2019a; Ford *et al.* 2014; Proverbs *et al.* 2020). Many of these factors are not easily quantified, therefore could not be incorporated into IFO calculations. Nevertheless, future research within Inuvialuit communities to understand the social drivers of access could identify concerns and adaptive opportunities to strengthen access as social and environmental changes continue throughout the region.

The IFO has the potential to inform fisheries management by providing an indicator of access, which can then be used in decision-making processes. Inuvialuit fishers have a detailed understanding regarding the impact that weather has on access to fishing; however, there is currently no direct mechanism to have this knowledge inform key fisheries management decisions. Current quantitative fisheries management is primarily influenced by knowledge of the abundance and distributions of fish species (DFO 2020). Comparatively, access to fisheries is less often considered and less well understood (Brinkman *et al.* 2013 & 2016). An index like the IFO has the potential to be applied directly to information on abundance and distribution to answer the questions about fish availability that remain outside the scope of current management practices. For example, the IFO could be compared to post-season harvest data to explain inter-annual variation in harvest totals based on varying weather conditions. Such analyses could ultimately contribute to a more holistic model of fisheries management by explicitly considering the factors influencing access to fish, and thus fish availability (Brinkman *et al.* 2016; Hansen *et al.* 2013; Sangha *et al.* 2015; Tobias and Richmond 2014).

Increasing environmental stressors acting on northern fisheries have prompted calls for holistic management approaches that account for changes to access (Parlee *et al.* 2005; Proverbs *et al.* 2020; Sangha *et al.* 2015; Tobias and Richmond 2014). In this research we describe a method to measure physical access to fisheries that can inform decision-making regarding fish availability. By including access in management frameworks, decision makers can further prioritize local food sovereignty (Cusolo-Willox *et al.* 2015; ICC 2019; Searles 2002). Decision-making that considers access will also support strong land-based relationships, and their associated benefits to community and individual health and well-being (Cusolo-Willox *et al.* 2015; ICC 2020; ITK 2014; Kral 2016).

References

AHTC (Aklavik Hunters and Trappers Committee), Aklavik Community Corporation, The Wildlife Management Advisory Council (NWT), The Fisheries Joint Management Committee, and the Joint Secretariat (2016). *Aklavik Community Conservation Plan Akaqvikmiut Angalatchivingit Niryutinik.* Aklavik, NT. https://static1.squarespace.com/static/5e2093a7fd6f455447254aff/t/5e2f2af9871a582cf4b55785/1580149532235/2016-Aklavik-Community-Conservation-Plan-R.pdf.

Alunik, I., Morrison, D.A., and Kolausok, E.D. (2003). *Across time and tundra: the Inuvialuit of the western Arctic*. Raincoast Books, Vancouver.

Appadurai, A. (ed.) (1986). *The Social Life of Things: Commodities in Cultural Perspective*. Cambridge University Press, Cambridge. doi:10.1017/CBO9780511819582.

Berkes, F., and Jolly, D. (2001). Adapting to Climate Change: Social-Ecological Resilience in a Canadian Western Arctic Community. *Conservation Ecology, 5*. [Online] Available: https://www.jstor.org/stable/26271828 [2021 Apr. 7].

Berry, S. (1989). Social Institutions and Access to Resources. *Africa: Journal of the International African Institute, 59*: 41–55. [Cambridge University Press, International African Institute]. doi:10.2307/1160762.

Bintanja, R., and Andry, O. (2017). Towards a rain-dominated Arctic. *Nature Climate Change, 7*: 263–267. Nature Publishing Group. doi:10.1038/nclimate3240.

Blaikie, P. (2016). *The Political Economy of Soil Erosion in Developing Countries*. Routledge.

Brander, K.M. (2007). Global fish production and climate change. *PNAS, 104*: 19709–19714. National Academy of Sciences. doi:10.1073/pnas.0702059104.

Brinkman, T.J., Hansen, W.D., Chapin, F.S., Kofinas, G., BurnSilver, S., and Rupp, T.S. (2016). Arctic communities perceive climate impacts on access as a critical challenge to availability of subsistence resources. *Climatic Change, 139*: 413–427. doi:10.1007/s10584-016-1819-6.

Brinkman, T.J., Kofinas, G., Hansen, W.D., Chapin, F.S., and Rupp, S. (2013). A New Framework to Manage Hunting. *The Wildlife Professional, 7*: 38–43.

Bromwich, D., Kuo, Y.-H., Serreze, M., Walsh, J., Bai, L.-S., Barlage, M., Hines, K., and Slater, A. (2010). Arctic System Reanalysis: Call for Community Involvement. *Eos, Transactions American Geophysical Union, 91*: 13–14. doi:10.1029/2010EO020001.

Cameron, E.S. (2012). Securing Indigenous politics: A critique of the vulnerability and adaptation approach to the human dimensions of climate change in the Canadian Arctic. *Global Environmental Change, 22*: 103–114. doi:10.1016/j.gloenvcha.2011.11.004.

Campana, S.E., Stefánsdóttir, R.B., Jakobsdóttir, K., and Sólmundsson, J. (2020). Shifting fish distributions in warming sub-Arctic oceans. *Scientific Reports, 10*: 16448. doi:10.1038/s41598-020-73444-y.

Canada (1984). Western Arctic Claim - the Inuvialuit Final Agreement.

Cao, B., Quan, X., Brown, N., Stewart-Jones, E., and Gruber, S. (2019). GlobSim (v1.0): deriving meteorological time series for point locations from multiple global reanalyses. *Geoscientific Model Development, 12*: 4661–4679. Copernicus GmbH. doi:10.5194/gmd-12-4661-2019.

Cheung, W.W.L., Lam, V.W.Y., Sarmiento, J.L., Kearney, K., Watson, R., and Pauly, D. (2009). Projecting global marine biodiversity impacts under climate change scenarios. *Fish and Fisheries, 10*: 235–251. doi:10.1111/j.1467-2979.2008.00315.x.

Chiaramonte, L., Munson, D., and Trushenski, J. (2016). Climate Change and Considerations for Fish Health and Fish Health Professionals. *Fisheries, 41*: 396–399. doi:10.1080/03632415.2016.1182508.

Coleman, M.A., Butcherine, P., Kelaher, B.P., Broadhurst, M.K., March, D.T., Provost, E.J., David, J., and Benkendorff, K. (2018). Climate change does not affect the seafood quality of a commonly targeted fish. *Global Change Biology, 25*: 699–707. doi:10.1111/gcb.14513.

Comiso, J.C., Parkinson, C.L., Gersten, R., and Stock, L. (2008). Accelerated decline in the Arctic sea ice cover. *Geophysical Research Letters, 35*. doi:10.1029/2007GL031972.

Cooke, S.J., Nguyen, V.M., Chapman, J.M., Reid, A.J., Landsman, S.J., Young, N., Hinch, S.G., Schott, S., Mandrak, N.E., and Semeniuk, C.A.D. (2021). Knowledge co-production: A pathway to effective fisheries management, conservation, and governance. *Fisheries, 46*: 89–97. doi:10.1002/fsh.10512.

Cunsolo Willox, A., Stephenson, E., Allen, J., Bourque, F., Drossos, A., Elgarøy, S., Kral, M.J., Mauro, I., Moses, J., Pearce, T., MacDonald, J.P., and Wexler, L. (2015). Examining relationships between climate change and mental health in the Circumpolar North. *Regional Environmental Change, 15*: 169–182. doi:10.1007/s10113-014-0630-z.

DFO (Fisheries and Oceans Canada) (2020). Sustainable Fisheries Framework [online]. Fisheries and Oceans Canada. Available: https://www.dfo-mpo.gc.ca/reports-rapports/regs/sff-cpd/overview-cadre-eng.htm [2021 Apr. 7].

ECCC (Environment and Climate Change Canada) (2021a). *Canadian Historical Climate Reports 1948-2021 Station Data: Tuktoyaktuk*. [Online] Available: https://climate.weather.gc.ca/historical_data/search_historic_data_stations_e.html?searchType=stnName&timeframe=1&txtStationName=tuktoyaktuk&searchMethod=contains&optLimit=yearRange&StartYear=1840&EndYear=2021&Year=2021&Month=4&Day=22&selRowPerPage=25.

ECCC (Environment and Climate Change Canada) (2021b). *Canadian Historical Climate Reports 1955-2021 Station Data: Sachs Harbour.* [Online] Available: https://climate.weather.gc.ca/historical_data/search_historic_data_stations_e.html?searchType=stnName&timeframe=1&txtStationName=sachs+harbour&searchMethod=contains&optLimit=yearRange&StartYear=1840&EndYear=2021&Year=2021&Month=4&Day=22&selRowPerPage=25.

ECCC (Environment and Climate Change Canada) (2021c). *Canadian Historical Climate Reports 1963-2021 Station Data: Holman*. [Online] Available: https://climate.weather.gc.ca/historical_data/search_historic_data_stations_e.html?searchType=stnName&timeframe=1&txtStationName=holman&searchMethod=contains&optLimit=yearRange&StartYear=1840&EndYear=2021&Year=2021&Month=4&Day=22&selRowPerPage=25.

ECCC (Environment and Climate Change Canada) (2021d). *Canadian Historical Climate Reports 1973-2021 Station Data: Shingle Point.* [Online] Available:

https://climate.weather.gc.ca/historical_data/search_historic_data_stations_e.html?searchType=stnName&timeframe=1&txtStationName=shingle+&searchMethod=contains&optLimit=yearRange&StartYear=1840&EndYear=2021&Year=2021&Month=4&Day=22&selRowPerPage=25.

ECCC (Environment and Climate Change Canada) (2021e). *Canadian Historical Climate Reports 1987-2021 Station Data: Paulatuk.* [Online] Available: https://climate.weather.gc.ca/historical_data/search_historic_data_stations_e.html?searchType=stnName&timeframe=1&txtStationName=paulatuk&searchMethod=contains&optLimit=yearRange&StartYear=1840&EndYear=2021&Year=2021&Month=4&Day=22&selRowPerPage=25.

FAO (ed.) (2018). *The state of the world's fisheries and aquaculture.* Food and Agriculture Organization of the United Nations, Rome.

Ford, J.D., McDowell, G., Shirley, J., Pitre, M., Siewierski, R., Gough, W., Duerden, F., Pearce, T., Adams, P., and Statham, S. (2013). The Dynamic Multiscale Nature of Climate Change Vulnerability: An Inuit Harvesting Example. *Annals of the Association of American Geographers, 103*: 1193–1211. doi:10.1080/00045608.2013.776880.

Ford, J.D., and Pearce, T. (2010). What we know, do not know, and need to know about climate change vulnerability in the western Canadian Arctic: a systematic literature review. *Environmental Research Letters, 5*: 014008. IOP Publishing. doi:10.1088/1748-9326/5/1/014008.

Ford, J.D., Willox, A.C., Chatwood, S., Furgal, C., Harper, S., Mauro, I., and Pearce, T. (2014). Adapting to the Effects of Climate Change on Inuit Health. *American Journal of Public Health, 104*: e9–e17. doi:10.2105/AJPH.2013.301724.

Fossheim, M., Primicerio, R., Johannesen, E., Ingvaldsen, R.B., Aschan, M.M., and Dolgov, A.V. (2015). Recent warming leads to a rapid borealization of fish communities in the Arctic. *Nature Climate Change, 5:* 673–677. doi:10.1038/nclimate2647.

Freeman, M.M.R., Wein, E.E., and Keith, D.E. (2003). *Recovering Rights: Bowhead Whales and Inuvialuit Subsistence in the Western Canadian Arctic.* The University of Alberta Press, Edmonton, Alberta.

Gallagher, C., Howland, K., and Harwood, L. (2017). *Harvest, catch-effort, and biological information of Arctic Char (Salvelinus alpinus) collected from subsistence harvest monitoring programs at Hornaday River, Lasard Creek, and Tippitiuyak, Darnley Bay, Northwest Territories.* Fisheries and Oceans Canada.

Graham, R.M., Hudson, S.R., and Maturilli, M. (2019). Improved Performance of ERA5 in Arctic Gateway Relative to Four Global Atmospheric Reanalyses. *Geophysical Research Letters, 46*: 6138–6147. doi:10.1029/2019GL082781.

Hansen, W.D., Brinkman, T.J., Leonawicz, M., Chapin, F.S., and Kofinas, G.S. (2013). Changing Daily Wind Speeds on Alaska's North Slope: Implications for Rural Hunting Opportunities. *Arctic, 66*: 448–458.

Hasbrouck, T.R., Brinkman, T.J., Stout, G., Trochim, E., and Kielland, K. (2020). Quantifying effects of environmental factors on moose harvest in Interior Alaska. *Wildlife Biology, 2020*: 2. Nordic Board for Wildlife Research. doi:10.2981/wlb.00631.

Heredia Vazquez, I. (2019). *Implications of Socio-Ecological Changes for Inuvialuit Fishing Livelihoods and the.* MA Thesis, University of Ottawa, Ottawa, Canada.

Hersbach, H., Bell, B., Berrisford, P., Hirahara, S., Horányi, A., Muñoz-Sabater, J., Nicolas, J., Peubey, C., Radu, R., Schepers, D., Simmons, A., Soci, C., Abdalla, S., Abellan, X., Balsamo, G., Bechtold, P., Biavati, G., Bidlot, J., Bonavita, M., Chiara, G.D., Dahlgren, P., Dee, D., Diamantakis, M., Dragani, R., Flemming, J., Forbes, R., Fuentes, M., Geer, A., Haimberger, L., Healy, S., Hogan, R.J., Hólm, E., Janisková, M., Keeley, S., Laloyaux, P., Lopez, P., Lupu, C., Radnoti, G., Rosnay, P. de, Rozum, I., Vamborg, F., Villaume, S., and Thépaut, J.-N. (2020). The ERA5 global reanalysis. *Quarterly Journal of the Royal Meteorological Society, 146*: 1999–2049. doi:10.1002/qj.3803.

Hinz, V. (1989). Monitoring the fish fauna in the Wadden Sea with special reference to different fishing methods and effects of wind and light on catches. *Helgolander Meeresunters, 43*: 447–459. doi:10.1007/BF02365903.

ICC (Inuit Circumpolar Council Alaska) (2020). Food Sovereignty and Self-Governance: Inuit role in managing Arctic marine resources. [Online] Available: https://iccalaska.org/wp-icc/wp-content/uploads/2020/09/FSSG-Report_-LR.pdf.

IHTC (Inuvik Hunters and Trappers Committee), Inuvik Community Corporation, The Wildlife Management Advisory Council (NWT), The Fisheries Joint Management Committee, and the Joint Secretariat (2016). *Inuvik Community Conservation Plan Inuuvium Angalatchivingit Niryutinik.* Inuvik. [Online] Available: https://static1.squarespace.com/static/5e2093a7fd6f455447254aff/t/5e262b04166a41157ca93855/1579559719275/2016-Inuvik-Community-Conservation-Plan-R.pdf.

IJS (Inuvialuit Joint Secretariat) (2003). *Inuvialuit Harvest Study: Data and Methods Report.* [Online] Available: https://jointsecretariat.ca/wp-content/uploads/2015/11/IHS10yrDataMethodsReport.pdf.

IJS (Inuvialuit Joint Secretariat) (n.d.) *What we Do.* [Online] Available: https://www.jointsecretariat.ca/what-we-do [2021 Mar. 1].

Indian Act (1985). R.S., c. I-6, s. 1.

IPCC (Intergovernmental Panel on Climate Change) (2019). *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate*. IPCC, Geneva.

ITK (Inuit Tapirit Kanatami) (2014). *Social Determinants of Inuit Health in Canada.* Ottawa. [Online] Available: https://www.itk.ca/wp-content/uploads/2016/07/ITK_Social_Determinants_Report.pdf.

ITK (Inuit Tapirit Kanatami) (2019a). *National Inuit Climate Change Strategy.* Ottawa. [Online] Available: http://www.deslibris.ca/ID/10102688 [2021 Feb. 4].

ITK (Inuit Tapirit Kanatami) (2019b). *National Inuit Strategy on Research Roundtable.* Ottawa. [Online] Available: https://www.itk.ca/wp-content/uploads/2019/11/ITK_NISR_Roundtable_11.pdf.

Jakobson, E., Vihma, T., Palo, T., Jakobson, L., Keernik, H., and Jaagus, J. (2012). Validation of atmospheric reanalyses over the central Arctic Ocean. *Geophysical Research Letters, 39*. doi:10.1029/2012GL051591.

Johnson, I., Brinkman, T., Britton, K., Kelly, J., Hundertmark, K., Lake, B., and Verbyla, D. (2016). Quantifying Rural Hunter Access in Alaska. *Human Dimensions of Wildlife, 21*: 240–253. Routledge. doi:10.1080/10871209.2016.1137109.

Johnson, N., Alessa, L., Behe, C., Danielsen, F., Gearheard, S., Gofman-Wallingford, V., Kliskey, A., Krümmel, E.-M., Lynch, A., Mustonen, T., Pulsifer, P., and Svoboda, M. (2015). The Contributions of Community-Based Monitoring and Traditional Knowledge to Arctic Observing Networks: Reflections on the State of the Field. *Arctic, 68*: 28–40. Arctic Institute of North America.

Kenny, T.-A., Fillion, M., MacLean, J., Wesche, S.D., and Chan, H.M. (2018). Calories are cheap, nutrients are expensive – The challenge of healthy living in Arctic communities. *Food Policy, 80*: 39–54. doi:10.1016/j.foodpol.2018.08.006.

Kral, M.J. (2016). Suicide and Suicide Prevention among Inuit in Canada. *Canadian Journal of Psychiatry, 61*: 688–695. doi:10.1177/0706743716661329.

Krupnik, I., Aporta, C., Gearheard, S., Laidler, G.J., and Holm, L.K. (eds.) (2010). *SIKU: Knowing Our Ice: Documenting Inuit Sea Ice Knowledge and Use.* Springer Netherlands. doi:10.1007/978-90-481-8587-0.

Kuhnlein, H., and Receveur, O. (2007). Local Cultural Animal Food Contributes High Levels of Nutrients for Arctic Canadian Indigenous Adults and Children. *The Journal of Nutrition, 137*: 1110–4. doi:10.1093/jn/137.4.1110.

Laidler, G.J., and Elee, P. (2008). Human geographies of sea ice: freeze/thaw processes around Cape Dorset, Nunavut, Canada. *Polar Record, 44*: 51–76. Cambridge University Press. doi:10.1017/S0032247407007061.

Lantz, T.C., and Kokelj, S.V. (2008). Increasing rates of retrogressive thaw slump activity in the Mackenzie Delta region, N.W.T., Canada. *Geophysical Research Letters, 35*. doi:10.1029/2007GL032433.

Lawrence, H., Bormann, N., Sandu, I., Day, J., Farnan, J., and Bauer, P. (2019). Use and impact of Arctic observations in the ECMWF Numerical Weather Prediction system. Quarterly *Journal of the Royal Meteorological Society, 145*: 3432–3454. doi:10.1002/qj.3628.

Lindsay, R., Wensnahan, M., Schweiger, A., and Zhang, J. (2014). Evaluation of Seven Different Atmospheric Reanalysis Products in the Arctic. *Journal of Climate, 27*: 2588–2606. American Meteorological Society. doi:10.1175/JCLI-D-13-00014.1.

Lyons, N. (2009). Inuvialuit rising: the evolution of Inuvialuit identity in the modern era. *Alaska Journal of Antropology, 7*: 18.

Mantyka-Pringle, C., Jardine, T., Bradford, L., Bharadwaj, L., Kythreotis, A., Fresque-Baxter, J., Kelly, E., Somers, G., Doig, L., Jones, P., and Lindenschmidt, K.-E. (2017). Bridging science and traditional knowledge to assess cumulative impacts of stressors on ecosystem health. *Environment International, 102*. doi:10.1016/j.envint.2017.02.008.

Marques, A., Nunes, M.L., Moore, S.K., and Strom, M.S. (2010). Climate change and seafood safety: Human health implications. *Food Research International, 43*: 1766–1779. doi:10.1016/j.foodres.2010.02.010.

Martell, A.M., Dickinson, D.M., and Casselman, L.M. (1984). *Wildlife of the Mackenzie Delta Region.* CCI Press.

McGhee, R., and Laverie, D.W. (1974). *Beluga Hunters: An Archaeological Reconstruction of the History and Culture of the Mackenzie Delta Kittegaryumiut.* University of Ottawa Press. doi:10.2307/j.ctv16qrd.

Metcalfe, J. R., Routledge, B., and Devine K. (1997). Rainfall Measurement in Canada: Changing observational methods and archive adjustment prodecures. *Journal of Climate, 10*: 92-101.

Moore, S.F. (1986). *Social Facts and Fabrications: "Customary" Law on Kilimanjaro, 1880–1980.* Cambridge University Press.

Morrison, D. (2000). Inuvialuit Fishing and the Gutchiak Site. *Arctic Anthropology, 37*: 1–42. University of Wisconsin Press.

Niemi, A., Ferguson, S., Hedges, K., H Melling, Michel, C., Ayles, B., Azetsu-Scott, K., Coupel, P., Deslauriers, D., Devred, E., Doniol-Valcroze, T., Dunmall, K., Eert, J., Galbraith, P., Geoffroy, M., Gilchrist, G., Hennin, H., Howland, K., Kendall, M., Kohlbach, D., Lea, E., Loseto, L., Majewski, A., Marcoux, M., Matthews, C., McNicholl, D., Mosnier, A., Mundy, C., Ogloff, W., Perrie, W., Richards, C., Richardson, E., Reist, J., Roy, V., Sawatzky, C., Scharffenberg, K., Tallman, R., Tremblay, J., Tufts, T., Watt, C., Williams, W., Worden, E., Yurkowski, D., and Zimmerman, S. (2019). *State of Canada's Arctic Seas.* Canadian Technical Report of Fisheries and Aquatic Sciences. [Online] Available:

http://publications.gc.ca/collections/collection_2019/mpo-dfo/Fs97-6-3344-eng.pdf [2020 May 20].

OHTC (Olokhaktomiut Hunters and Trappers Committee), Ulukhaktok Community Corporation, The Wildlife Management Advisory Council (NWT), The Fisheries Joint Management Committee, and the Joint Secretariat. (2016). *Olokhaktomiut Community Conservation Plan Ulukhaqtuum Angalatchivingit Niryutinik*. [Online] Available: https://static1.squarespace.com/static/5e2093a7fd6f455447254aff/t/5e262b83e3c0a94c0a904bf2/1579559867490/2016-Uluhaktok-Community-Conservation-Plan-R.pdf.

Pankhurst, N.W., and Munday, P.L. (2011). Effects of climate change on fish reproduction and early life history stages. *Marine and Freshwater Research, 62*: 1015–1026. doi:10.1071/MF10269.

Parlee, B., Berkes, F., and Gwich'in, T. (2005). Health of the Land, Health of the People: A Case Study on Gwich'in Berry Harvesting in Northern Canada. *EcoHealth, 2*: 127–137. doi:10.1007/s10393-005-3870-z.

Pecl, G.T., Araújo, M.B., Bell, J.D., Blanchard, J., Bonebrake, T.C., Chen, I.-C., Clark, T.D., Colwell, R.K., Danielsen, F., Evengård, B., Falconi, L., Ferrier, S., Frusher, S., Garcia, R.A., Griffis, R.B., Hobday, A.J., Janion-Scheepers, C., Jarzyna, M.A., Jennings, S., Lenoir, J., Linnetved, H.I., Martin, V.Y., McCormack, P.C., McDonald, J., Mitchell, N.J., Mustonen, T., Pandolfi, J.M., Pettorelli, N., Popova, E., Robinson, S.A., Scheffers, B.R., Shaw, J.D., Sorte, C.J.B., Strugnell, J.M., Sunday, J.M., Tuanmu, M.-N., Vergés, A., Villanueva, C., Wernberg, T., Wapstra, E., and Williams, S.E. (2017). Biodiversity redistribution under climate change: Impacts on ecosystems and human well-being. *Science, 355*. American Association for the Advancement of Science. doi:10.1126/science.aai9214.

PHTC (Paulatuk Hunters and Trappers Committee), Paulatuk Community Corporation, The Wildlife Management Advisory Council (NWT), The Fisheries Joint Management Committee, and the Joint Secretariat. 2016. *Paulatuk Community Conservation Plan Paulatuum Angalatchivingit Niryutinik.*[Online] Available: https://static1.squarespace.com/static/5e2093a7fd6f455447254aff/t/5e274528c179bf7b311b59be/1579632184779/2016-Paulatuk-Community-Conservation-Plan-R.pdf.

Post, E. (2017). Implications of earlier sea ice melt for phenological cascades in arctic marine food webs. *Food Webs, 13*: 60–66. doi:10.1016/j.fooweb.2016.11.002.

Proverbs, T., Lantz, T.C., Lord, S.I., Amos, A., Gwich'in Tribal Council Department of Cultural Heritage, and Ban, N.C. (2020). Social-Ecological Determinants of Access to Fish and Well-Being in Four Gwich'in Communities in Canada's Northwest Territories. *Human Ecology, 48*: 155–171. doi:10.1007/s10745-020-00131-x.

Ribot, J.C. (1998). Theorizing Access: Forest Profits along Senegal's Charcoal Commodity Chain. *Development and Change, 29*: 307–341. doi:10.1111/1467-7660.00080.

Ribot, J.C., and Peluso, N.L. (2003). A Theory of Access*. *Rural Sociology, 68*: 153–181. doi:10.1111/j.1549-0831.2003.tb00133.x.

Sanderson, B.M., Xu, Y., Tebaldi, C., Wehner, M., O'Neill, B., Jahn, A., Pendergrass, A.G., Lehner, F., Strand, W.G., Lin, L., Knutti, R., and Lamarque, J.F. (2017). Community climate simulations to assess avoided impacts in 1.5 and 2 °C futures. *Earth System Dynamics, 8*: 827–847. Copernicus GmbH. doi:10.5194/esd-8-827-2017.

Sangha, K., Brocque, A.L., Costanza, R., and Cadet-James, Y.L. (2015). Ecosystems and indigenous well-being: An integrated framework. *Global Ecology and Conservation, 4*: 197–206. Elsevier. doi:10.1016/j.gecco.2015.06.008.

Searles, E. (2009). Food and the Making of Modern Inuit Identities. *Food and Foodways, 10*: 55–78. Routledge. doi:10.1080/07409710212485.

Sheridan, J.A., and Bickford, D. (2011). Shrinking body size as an ecological response to climate change. *Nature Climate Change, 1*: 401–406. Nature Publishing Group. doi:10.1038/nclimate1259.

SHHTC (Sachs Harbour Hunters and Trappers Committee), Sachs Harbour Community Corporation, The Wildlife Management Advisory Council (NWT), The Fisheries Joint Management Committee, and the Joint Secretariat. (2016). *Sachs Harbour Community Conservation Plan Sachs Harbour Angalatchivingit Niryutinik.*[Online] Available: https://static1.squarespace.com/static/5e2093a7fd6f455447254aff/t/5e2f2b5058c98526e5a69f9c/1580149613890/2016-Sachs-Harbour-Community-Conservation-Plan-R.pdf.

Staffell, I., and Pfenninger, S. (2016). Using bias-corrected reanalysis to simulate current and future wind power output. *Energy, 114*: 1224–1239. doi:10.1016/j.energy.2016.08.068.

Stoner, A.W. (2004). Effects of environmental variables on fish feeding ecology: implications for the performance of baited fishing gear and stock assessment. *Journal of Fish Biology, 65*: 1445–1471. doi:10.1111/j.0022-1112.2004.00593.x.

Stroeve, J.C., Markus, T., Boisvert, L., Miller, J., and Barrett, A. (2014). Changes in Arctic melt season and implications for sea ice loss. *Geophysical Research Letters, 41*: 1216–1225. doi:10.1002/2013GL058951.

Terink, W., Hurkmans, R.T.W.L., Torfs, P.J.J.F., and Uijlenhoet, R. (2010). Evaluation of a bias correction method applied to downscaled precipitation and temperature reanalysis data for the Rhine basin. *Hydrology and Earth System Sciences, 14*: 687–703. Copernicus GmbH. doi:10.5194/hess-14-687-2010.

THTC (Tuktoyaktuk Hunters and Trappers Committee), Tuktoyaktuk Community Corporation, The Wildlife Management Advisory Council (NWT), The Fisheries Joint Management Committee, and the Joint Secretariat. (2016). *Tuktoyaktuk Community Conservation Plan Tuktuuyaqtuum Angalatchivingit Niryutinik.* [Online] Available: https://static1.squarespace.com/static/5e2093a7fd6f455447254aff/t/5e262a8ae3c0a94c0a8ffa4a/1579559611016/2016-Tuktoyaktuk-Community-Conservation-Plan-R.pdf.

Tobias, J., and Richmond, C. (2014). "That land means everything to us as Anishinaabe .... ": Environmental dispossession and resilience on the North Shore of Lake Superior. *Health and Place, 29*: 26–33. doi:10.1016/j.healthplace.2014.05.008.

Todd, Z. (2016). “You never go hungry”: fish pluralities, human-fish relationships, indigenous legal orders and colonialism in Paulatuuq, Canada. PhD, University of Aberdeen, Aberdeen, Scotland. [Online] Available: https://eu03.alma.exlibrisgroup.com/view/delivery/44ABE_INST/12152958330005941 [2021 Jan. 4].

TRCC (Truth and Reconciliation Commission of Canada) (2015). C*anada’s residential schools : the final report of the Truth and Reconciliation Commission of Canada.* [Online] Available: http://publications.gc.ca/site/eng/9.807830/publication.html [2021 Jan. 27].

Usher, P. (1971). The Canadian Western Arctic: A Century of Change. *Anthropologica*, *13*: 169–183. Canadian Anthropology Society. doi:10.2307/25604848.

Usher, P.J. (2002). Inuvialuit Use of the Beaufort Sea and its Resources, 1960-2000. *Arctic, 55*: 18–28. doi:10.14430/arctic732.

Walsh, J.E., Overland, J.E., Groisman, P.Y., and Rudolf, B. (2011). Ongoing Climate Change in the Arctic. *AMBIO, 40*: 6–16. doi:10.1007/s13280-011-0211-z.

Wesche, S.D., and Chan, H.M. (2010). Adapting to the Impacts of Climate Change on Food Security among Inuit in the Western Canadian Arctic. *EcoHealth*, *7*: 361–373. doi:10.1007/s10393-010-0344-8.

Whyte, K. (2017). Indigenous Climate Change Studies : Indigenizing Futures, Decolonizing the Anthropocene. *English Language Notes*, *55*: 153–162. Duke University Press.

WMO (World Meteorological Organization) (2021). *Arctic Climate Change Update 2021: Key Trends and Impacts.* [Online] Available: https://public.wmo.int/en/media/news/arctic-assessment-report-shows-faster-rate-of-warming [2021 Jun. 21].

Zhang, Y., Qian, B., and Hong, G. (2020). A long-term, 1-km resolution daily meteorological dataset for modeling and mapping permafrost in Canada. *Atmosphere*, *11*. doi:10.3390/atmos11121363.

Appendix A

Weather Questionnaire

- What top three weather conditions do you think about when deciding if you want to go fishing on the ocean? These might be things that you check the forecast for in the morning.
- If you're looking at the forecast, how much **rain** (in millimetres) has to fall in one day to make it a bad day for fishing?
- How much rain has to fall to make fishing unpleasant?
- In the ice-free season, what is the **coldest** and **hottest** temperature that you would say are good for fishing?
- How cold and hot would it have to be to make fishing to be unpleasant?
- What is highest **wind speed** that is safe for fishing on the ocean?
- What wind speed would make fishing unpleasant?
- Are there **wind directions** that make fishing on the ocean better or worse? If so, please list them:
  - Good Directions:
  - Bad Directions:
- If you had to guess, how many good fishing days does it take for you to get enough fish for the year?
- (Circle one) In your life, has this number **increased**, **decreased**, or **stayed the same**?
- Please list other factors that might affect the number of fish you catch. These could be anything from the environment, to your equipment, to policies about fish.

Chapter 4 - Conclusion

Summary

Rapid environmental change is affecting social-ecological systems around the globe (IPCC 2019) and is occurring at an unparalleled rate in the Arctic (IPCC 2019; ICC 2020; ITK 2019; Niemi *et al.* 2019). Shifts in northern Indigenous cultural landscapes are not novel (Lyons 2009; Whyte 2018), but the current rate and nature of ongoing changes is cause for concern (Alunik *et al* 2003; Ford and Pearce 2010; Niemi *et al.* 2019). Arctic Indigenous peoples remain deeply connected to their homelands and are being forced to adapt travel routes, and hunting, fishing and trapping practices to widespread ecological changes (ICC 2020; ITK 2019). In the Inuvialuit Settlement Region (ISR), people rely on fishing as a source of food and important cultural practices (Alunik *et al.* 2003; ICC 2020). As availability of fish is integral to current and future Inuvialuit well-being, there is a need to better understand the factors that influence the availability of fish and fishing (Alunik *et al.* 2003; ICC 2020; ITK 2014).

The overall goal of my MSc research has been to increase our understanding of the factors influencing the availability of fish and fishing to Inuvialuit. I investigated changes affecting two aspects of fish availability, distribution and access, by combining multiple methods in two separate but complementary studies. In Chapter 1, I introduced the conceptual frameworks and key concepts on which I based these studies. In Chapter 2, I presented the results from 54 semi-structured interviews with Inuvialuit knowledge holders about environmental change and changes to fish distributions in the ISR. While not their original intent, these interviews highlighted the need for further research to consider the impact of weather on access to fishing. Using questionnaires and quantitative modelling, in Chapter 3 I examined the effects of weather on Inuvialuit access to fishing. Now in my final chapter, I summarize the findings of chapters 2 and 3, highlight insights from combining these two studies, discuss the limitations of my research, and explore opportunities for future study.

The research presented in Chapter 2 investigated the question: how has the harvest of Pacific salmon by Inuvialuit fishers changed over the last 100 years? Inuvialuit fishers are concerned about increasing harvest of Pacific salmon where catches had previously been rare or unprecedented. In

2018, decision-makers and scientists at the Fisheries Joint Management Committee (FJMC) and Fisheries and Oceans Canada (DFO) identified a need to fill gaps in our knowledge of Pacific salmon in the ISR by interviewing Inuvialuit fishers. To this end, I partnered with Hunters and Trappers Committees (HTCs) to conduct 8-10 interviews in each community focused on: 1) changes in the magnitude of salmon harvest over the last four decades, 2) co-occurring changes in local fish populations attributed to increasing salmon, and 3) environmental factors influencing salmon range expansions. I found that regional changes in climate were associated with increased salmon harvest, and that fishers were deeply concerned about the unknown effects of salmon in Arctic ecosystems. Interview participants also made it clear that salmon are only one of many changes that are affecting the availability of Arctic fish for Inuvialuit. One of the other main changes that participants described was a climate-mediated decrease in access to fishing. In response to this observation, I designed a mixed-methods approach to investigate this change.

In Chapter 3 I presented my research exploring the influence of weather on access to fishing in the ISR. This work involved designing questionnaires to characterize weather as good or bad for fishing during ice-free seasons in marine fishing locations used by each community. Using information from these questionnaires, and building on the results of the interviews from Chapter 2, I designed a qualitative index of access to fishing that I termed the Index of Fishing Opportunity (IFO). Next, I calculated the IFO over time (1979-2019) using ERA-5 climate reanalysis data corrected with historical observational data from Environment and Climate Change Canada (ECCC 2021a-2021e; Hersbach *et al.* 2020). This allowed me to investigate how IFO varied between 1979 and 2019 in key community fishing locations. I also compared the daily classifications from the IFO regarding suitable or unsuitable fishing conditions to those reported by Inuvialuit harvesters in a standardized harvest study (Gallagher *et al.* unpublished data). I then presented all of these results to HTCs for validation. My analysis in Chapter 3 showed that the IFO has potential to characterize the influence of weather conditions on fishing access, but that high uncertainty limits its analysis of long-term trends. The IFO is impacted by several restrictions that require additional research, which I describe below.

Insights from combining the two studies and the research process

My thesis demonstrates the value of using multiple methods to understand change in social-ecological systems. In Chapter 2 I created a timeline of Pacific salmon harvest in each community in the ISR by conducting semi-structured interviews in partnership with Inuvialuit organizations and fishers. In these interviews, fishers described an increase in Pacific salmon and highlighted their concerns about this and other impacts of climate change on their fisheries. Harvesters related changes in salmon to changes in temperature, ice conditions, water levels, and weather conditions. Fishers explained that these environmental changes are also impacting their ability to monitor salmon. People track changes in salmon through their regular fishing activities, and access to these fishing activities is being affected by environmental change. Therefore, access to fishing influences how many salmon are caught and reported each year. Fishers explained that in some years, weather may be especially limiting to their fishing practices, leading to underestimation of salmon abundance in the ISR. So a low salmon harvest may not mean that few salmon were present, but may be the result of low fishing activity. Additionally, if access to fishing is decreasing, salmon abundance may be increasing faster than salmon being returned to the ASP. This inspired the development of an index of access to fishing based on fishing weather that I developed in Chapter 3.

My data analysis in Chapter 3 showed high inter-annual variability in access to fishing in all six communities and reinforced the findings of the interviews in Chapter 2. In some years the IFO had very low values. For example, the IFO from Sachs Harbour in 2018 suggests that harvesters had no access to fishing during the times when salmon are typically caught. In our interviews, fishers described the 2018 fishing season as having extremely poor fishing conditions. This year of low fishing access also coincides with a very low harvest of Pacific salmon (Dunmall *et al.* unpublished data). This suggests that low access to fishing may be contributing to low reported salmon harvests and illustrates how the IFO might inform future harvest studies in the ISR. It also demonstrates the power of combining multiple methods to create a more complete understanding of change.

Limitations and Future Research

Chapter 2:

One of the limitations in Chapter 2 was that the interview questions did not explore Inuvialuit perspectives on adaptive measures and the future of regional salmon management. To address this gap, future research should investigate Inuvialuit perspectives on adaptive management practices and document strategies to increase resilience to changing fish distributions in the ISR. Many fishers told us that the number of salmon that they harvest will likely continue to increase. Others expressed uncertainty about the trends in salmon abundance but wanted to learn more about salmon life-history, and the potential for salmon to colonize Arctic drainages. The novelty of salmon in Arctic regions, and high inter-annual variability in salmon reports, made Inuvialuit fishers uncertain about the future of salmon in the region. Despite their uncertainty about the future, fishers are concerned about recent increases in salmon harvest. Developing management practices which account for the changes in salmon, co-occurring changes in local fish species, and the accelerated rate of environmental change could increase regional resilience to the broader impacts and opportunities of climate change on fishing.

Future research on salmon in the Arctic should also prioritize the perspectives of fishers between the ages of 13-20. Given the historical focus of our study, we[3] interviewed primarily older, more experienced fishers whose fishing knowledge dates back over the past 10-40 years. As a result, chapter 2 does not consider how younger generations of Inuvialuit fishers feel about salmon, or their perspectives on good management strategies for protecting Inuvialuit fisheries. In Alaska, a similar study about cultural perceptions of salmon in Iñupiat communities found that younger generations generally perceived salmon more positively than older generations (Carothers *et al.* 2019). Scholars have also made it clear that the perspectives of youth are essential to proper land management practices (Karsgaard and Davidson 2021; McKay *et al.* 2020; Ritchie 2021; Whyte 2018). Future work to engage younger generations in research on the future of salmon and the importance of Inuvialuit fishing would provide important perspectives on management practices. Indeed, the goal of management is to ensure that these generations can continue to be in good relationship with fish, so their voices and perspectives must be included in the decision-making process (Simpson 2004).

The fishers who we[3] interviewed in each community were local experts, and this level of knowledge regarding fisheries may have influenced our results. It would also be interesting for future research to interview Inuvialuit land-users who fish at different intensities and may have different levels of experience. Perhaps people who fish less, or for different reasons might feel differently about salmon. Broadening the scope of people involved in future interviews would also contribute to an improved understanding of how salmon are perceived throughout Inuvialuit communities.

Chapter 2 also had a limited geographical scope. Understanding the historical harvest of salmon in the ISR is critical to our interpretation of the regional changes in salmon harvest, but salmon harvests are increasing across the entire Canadian Arctic (Dunmall *et al.* 2018; 2013). The effects and perceptions of these changes are likely unique in each community. Understanding these effects and perceptions will be critical to developing management strategies which are locally effective and appropriate. Future research should investigate recent changes in salmon harvest, and the social-ecological effects of those changes, in partnership with communities throughout the Arctic.

Chapter 3:

One weakness of the research I presented in Chapter 3 is our limited understanding of how well the Index of Fishing Opportunity (IFO) described access to fishing for a broad community of fishers. I parameterized the Index of Fishing Opportunity (IFO) for each community with questionnaire responses from two to three fishers, where participants were asked to describe weather conditions that were unsuitable for fishing. This was an essential step in the process of linking historical weather data to the experiences of Inuvialuit fishers; however, it proved challenging for multiple reasons.

Fishing practices likely vary among individuals and characterizing the range of suitable conditions requires a larger sample size. It is likely that I was unable to describe a full range of people's fishing experiences by working with only two to three individuals from each community. The decision to fish or not fish is complex, and the factors influencing it are likely to vary from

[3] I use the plural pronoun to indicate the contributions of Tracey Proverbs and local Inuvialuit interviewers

individual to individual. For example, preferred fishing gear, or a fisher's experience level might influence their individual weather thresholds. The time of year, and associated abundance of target fish species, also contribute to the decision to go fishing. Additional surveys to more fully characterize variability in fishing practices throughout a community, and within the fishing season, would provide a more complete understanding of how weather influences community access to fishing. Additionally, the IFO only reflects access to fishing based on present conditions and fishing practices. As climate and environmental changes intensify, the conditions in which people fish, and the factors limiting access to fishing, may also change. Fishers may adjust their fishing habits to suit new environments, and access to fishing may be mediated by different environmental variables. Therefore, the thresholds for weather parameters in the IFO should be kept up to date through regular reporting. The flexible approach I used in developing the IFO would also allow for new parameters to be added if they become relevant. Work to identify the changing pressures on Inuvialuit access to fish must continue, and be incorporated into any future versions of the IFO.

Future research should also focus on developing a more holistic understanding of access. Fishing requires time, equipment, capital, and knowledge (Ribot and Peluso 2003). Access to fish can also be supported through social initiatives such as food sharing programs or family relationships. Research into the social drivers of access may also illuminate ways in which resilience to change may be reinforced throughout the ISR. A better understanding of the processes enhancing Inuvialuit access to fishing could facilitate the development of adaptive management strategies designed to counteract the impacts of ongoing environmental change. Strengthening social axes of access could be a goal of holistic management programs to ensure a future where food security and good land-based relationships thrive.

Conclusion

The overall goal of my thesis research was to contribute to our understanding of the influences of environmental change on fish availability in the Inuvialuit Settlement Region. Interviews with fishers in all six Inuvialuit communities show that the harvest of Pacific salmon, while not novel in some communities, has been increasing in recent decades in association with accelerated environmental change. Some Inuvialuit fishers are very concerned about the changes related to salmon. Interview participants also highlighted that changing weather conditions are altering access to fishing. In Chapter 3 I investigated this observation in more detail by creating a quantitative index of access to fishing based on sea-ice cover, rainfall, wind, and temperature conditions. I used this index to model the influence of weather conditions over time on access to fishing. Further work is required to refine this index, but it shows promise as a method of incorporating concerns about access into modern fish management practices.

As the climate crisis in the Arctic intensifies (IPCC 2019), work that investigates its social and ecological implications is critical to informing the future of Inuvialuit fisheries. These fisheries provide essential cultural and nutritional value to Inuvialuit and ensuring the future availability of fish is crucial. The research described in both data chapters of my thesis demonstrates the importance of engaging with Indigenous knowledge systems to generate a more complete understanding of the effects of global climate change on fisheries. In part, collaborative research like what I have presented in my thesis can address our urgent, collective need to identify, mitigate, and adapt to social-ecological change.

References

Alunik, I., Morrison, D.A., and Kolausok, E.D. (2003). *Across time and tundra: the Inuvialuit of the western Arctic.* Raincoast Books, Vancouver.

Carothers, C., Sformo, T.L., Cotton, S., George, J.C., and Westley, P.A.H. (2019). Pacific Salmon in the Rapidly Changing Arctic: Exploring Local Knowledge and Emerging Fisheries in Utqiaġvik and Nuiqsut, Alaska. *Arctic*, *72*: 273–288. doi:10.14430/arctic68876.

ECCC (Environment and Climate Change Canada) (2021a). *Canadian Historical Climate Reports 1948-2021 Station Data: Tuktoyaktuk.* [Online] Available: https://climate.weather.gc.ca/historical_data/search_historic_data_stations_e.html?searchType=stnName&timeframe=1&txtStationName=tuktoyaktuk&searchMethod=contains&optLimit=yearRange&StartYear=1840&EndYear=2021&Year=2021&Month=4&Day=22&selRowPerPage=25.

ECCC (Environment and Climate Change Canada) (2021b). *Canadian Historical Climate Reports 1955-2021 Station Data: Sachs Harbour.* [Online] Available: https://climate.weather.gc.ca/historical_data/search_historic_data_stations_e.html?searchType=stnName&timeframe=1&txtStationName=sachs+harbour&searchMethod=contains&optLimit=yearRange&StartYear=1840&EndYear=2021&Year=2021&Month=4&Day=22&selRowPerPage=25.

ECCC (Environment and Climate Change Canada) (2021c). *Canadian Historical Climate Reports 1963-2021 Station Data: Holman.* [Online] Available: https://climate.weather.gc.ca/historical_data/search_historic_data_stations_e.html?searchType=stnName&timeframe=1&txtStationName=holman&searchMethod=contains&optLimit=yearRange&StartYear=1840&EndYear=2021&Year=2021&Month=4&Day=22&selRowPerPage=25.

ECCC (Environment and Climate Change Canada) (2021d). *Canadian Historical Climate Reports 1973-2021 Station Data: Shingle Point.* [Online] Available: https://climate.weather.gc.ca/historical_data/search_historic_data_stations_e.html?searchType=stnName&timeframe=1&txtStationName=shingle+&searchMethod=contains&opt

Limit=yearRange&StartYear=1840&EndYear=2021&Year=2021&Month=4&Day=22&selRowPerPage=25.

ECCC (Environment and Climate Change Canada) (2021e). *Canadian Historical Climate Reports 1987-2021 Station Data: Paulatuk.* [Online] Available: https://climate.weather.gc.ca/historical_data/search_historic_data_stations_e.html?searchType=stnName&timeframe=1&txtStationName=paulatuk&searchMethod=contains&optLimit=yearRange&StartYear=1840&EndYear=2021&Year=2021&Month=4&Day=22&selRowPerPage=25.

Ford, J.D., and Pearce, T. (2010). What we know, do not know, and need to know about climate change vulnerability in the western Canadian Arctic: a systematic literature review. *Environmental Research Letters, 5*: 014008. doi:10.1088/1748-9326/5/1/014008.

Hersbach, H., Bell, B., Berrisford, P., Hirahara, S., Horányi, A., Muñoz-Sabater, J., Nicolas, J., Peubey, C., Radu, R., Schepers, D., Simmons, A., Soci, C., Abdalla, S., Abellan, X., Balsamo, G., Bechtold, P., Biavati, G., Bidlot, J., Bonavita, M., Chiara, G.D., Dahlgren, P., Dee, D., Diamantakis, M., Dragani, R., Flemming, J., Forbes, R., Fuentes, M., Geer, A., Haimberger, L., Healy, S., Hogan, R.J., Hólm, E., Janisková, M., Keeley, S., Laloyaux, P., Lopez, P., Lupu, C., Radnoti, G., Rosnay, P. de, Rozum, I., Vamborg, F., Villaume, S., and Thépaut, J.-N. (2020). The ERA5 global reanalysis. *Quarterly Journal of the Royal Meteorological Society*, *146*: 1999–2049. doi:10.1002/qj.3803.

ICC (Inuit Circumpolar Council Alaska) (2020). *Food Sovereignty and Self-Governance: Inuit role in managing Arctic marine resources.* [Online] Available: https://iccalaska.org/wp-icc/wp-content/uploads/2020/09/FSSG-Report_-LR.pdf.

IPCC (Intergovernmental Panel on Climate Change) (2019). *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate.* IPCC, Geneva.

ITK (Inuit Tapirit Kanatami) (2014). *Social Determinants of Inuit Health in Canada.* Ottawa. [Online] Available: https://www.itk.ca/wp-content/uploads/2016/07/ITK_Social_Determinants_Report.pdf.

ITK (Inuit Tapirit Kanatami) (2019a). *National Inuit Climate Change Strategy.* Ottawa. [Online] Available: http://www.deslibris.ca/ID/10102688 [2021 Feb. 4].

Karsgaard, C., and Davidson, D. (2021). Must we wait for youth to speak out before we listen? International youth perspectives and climate change education. *Educational Review, 0*: 1–19. Routledge. doi:10.1080/00131911.2021.1905611.

Lyons, N. (2009). Inuvialuit rising: the evolution of Inuvialuit identity in the modern era. *Alaska Journal of Antropology, 7*: 18.

MacKay, M., Parlee, B., and Karsgaard, C. (2020). Youth Engagement in Climate Change Action: Case Study on Indigenous Youth at COP24. *Sustainability, 12*: 6299. Multidisciplinary Digital Publishing Institute. doi:10.3390/su12166299.

Niemi, A., Ferguson, S., Hedges, K., H Melling, Michel, C., Ayles, B., Azetsu-Scott, K., Coupel, P., Deslauriers, D., Devred, E., Doniol-Valcroze, T., Dunmall, K., Eert, J., Galbraith, P., Geoffroy, M., Gilchrist, G., Hennin, H., Howland, K., Kendall, M., Kohlbach, D., Lea, E., Loseto, L., Majewski, A., Marcoux, M., Matthews, C., McNicholl, D., Mosnier, A., Mundy, C., Ogloff, W., Perrie, W., Richards, C., Richardson, E., Reist, J., Roy, V., Sawatzky, C., Scharffenberg, K., Tallman, R., Tremblay, J., Tufts, T., Watt, C., Williams, W., Worden, E., Yurkowski, D., and Zimmerman, S. (2019). *State of Canada's Arctic Seas.* Canadian Technical Report of Fisheries and Aquatic Sciences. [Online] Available: http://publications.gc.ca/collections/collection_2019/mpo-dfo/Fs97-6-3344-eng.pdf [2020 May 20].

Ribot, J.C., and Peluso, N.L. (2003). A Theory of Access*. *Rural Sociology, 68*: 153–181. doi:10.1111/j.1549-0831.2003.tb00133.x.

Ritchie, J. (2021). Movement from the margins to global recognition: climate change activism by young people and in particular indigenous youth. *International Studies in Sociology of Education, 30*: 53–72. Routledge. doi:10.1080/09620214.2020.1854830.

Simpson, L.R. (2004). Anticolonial Strategies for the Recovery and Maintenance of Indigenous Knowledge. *American Indian Quarterly, 28*: 373–384. University of Nebraska Press.

Whyte, K. (2018). Critical Investigations of Resilience: A Brief Introduction to Indigenous Environmental Studies & Sciences. *Daedalus, 147*: 136–147. doi:10.1162/DAED_a_00497.