Understanding the Relationships Between Land Disturbance, Mercury and Fishing Practices in the Moose Cree Territory:

A Foundation for Risk Assessment

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ABSTRACT

Understanding the Relationships Between Land Disturbance, Mercury and Fishing Practices in the Moose Cree Territory:

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The ᐃᓕᓕᐧᐊᐢᑭᕀ | Ililiwaskiy (Moose Cree First Nation Territory) in Ontario's James Bay region has long faced industrial impacts on its ecosystems. Community concerns about mercury in culturally important fish prompted an interdisciplinary study bringing together chemical analysis and community knowledge. Researchers partnered with Moose Cree members through workshops, training, and interviews, while sampling over 180 fish across six sites. Walleye showed the highest mercury levels, often exceeding Health Canada's 0.5 ppm guideline for large fish and the 0.2 ppm guideline for subsistence consumers, women, and children. Community input highlighted fish as both a cultural cornerstone and food source, while noting how land-based changes have impacted fishing practices. Findings reveal elevated mercury in traditional foods and broader impacts on land-based practices and food security. The project underscores the importance of rethinking risk assessments, mitigating risks from resource extraction, water management, and supporting Moose Cree leadership in stewardship.

Key Words: Mercury; Fish; Consumption; Indigenous knowledge; Cumulative effects; Risk

POSITIONALITY STATEMENT

I am a first-generation settler on Turtle Island on my maternal side and a second-generation settler on my paternal side. I grew up on land belonging to the Huron-Wendat and Haudenosaunee Peoples, and the Anishnabek of the Williams Treaties, who have and continue to take care of the land. I am grateful for their resilience and courage in the face of colonialism and capitalism. I recognize my responsibility as a settler to understand the true history of the land, its peoples and how I can live in a way that honours the relationships between the First Peoples, Turtle Island and the beings who call it home.

I recognize the immense harm that the education system I grew up in has had on Indigenous peoples across Turtle Island. I hope that through my own re-education and personal experiences, I can do my part as an ally and an academic student to spread the truths of past and modern-day colonialism. I also hope to contribute my skills and knowledge towards efforts that dismantle colonial ideas and systems.

I also have an in-depth understanding of the importance of environmental health and how it relates to our health as people. Growing up, seeing the destruction of vital habitats and their impact on surrounding communities has motivated me to dedicate my time to understanding ecological restoration practices and to challenge people to rethink their relationships with the environments around them and the world.

I acknowledge that despite holding allyship and holding strong spiritual and environmental values, I come from a white, westernized background, which limits my understanding of Indigenous peoples' experiences, cultural practices, knowledges and ways of interacting with the world. I have also been predominantly educated in Western sciences, which can limit a deeper understanding of Indigenous sciences.

This project was started by Camp Onakawana in order to better understand the risks that mercury posed to themselves and other members of Moose Cree First Nation. I was invited onto the project a year later as a master's student and was given the opportunity to learn about the experiences that Moose Cree community members have had in their territory, as well as to determine mercury concentrations in fish samples collected by the community. With these knowledges combined, I was able to create an outline for risk assessments that demonstrates the importance of working with communities who are the most impacted by contaminants like mercury throughout the duration of risk assessment projects

ACKNOWLEDGEMENTS

I would like to acknowledge the Moose Cree Community for inviting myself and my team onto their territory to learn from community harvesters and Knowledge Holders. I am grateful for the hospitality and friendship offered by Camp Onakawana and the Moose Cree First Nation Lands and Resources Department. This project would not be possible without the generously donated fish samples from community harvesters and the knowledge shared by community members. I am grateful for the fish beings who contributed to the project, and to the environment and peoples who support their well-being. It's also important to recognize the Tozer family, who reached out about their concerns for mercury in the territory, which started the project. Our research would not be possible without them.

I would like to give special recognition to my supervisor Dr. Mary-Claire Buell for always encouraging me, inspiring me, believing in me and for pushing me to grow into the student I am today. Without her hard work and dedication towards environmental toxicology, environmental forensics and community involvement, much of the work in my lab, including this project, would not be possible.

Furthermore, I would like to thank my colleagues in TRACE Lab for their advice and constant support. I would like to especially thank Chloe Lauer, Jessica Cook, Nathalie Kuria Auma Omondi, and Rebbeca Reimer who have provided me with assistance, guidance, and friendships that grounded me during my project.

Additionally, I would like to thank this projects funders, Indigenous Services Canada and First Nations Environmental Contaminants Program.

Comparisons between years at certain sites would not have been possible without the data acquired from the Government of Ontario website through Satyendra Bhavsar. Visualization of sample sites and a broader understanding of various environments and elements in the territory was also possible thanks to the training and guidance from the MaDGIC department at Trent University.

I would like to give recognition to James Wilkes, who recommended this work to me and who was an important teacher who gave me the foundational knowledge needed to take part in this project.

Lastly, I would like to thank my committee members Dr. Holger Hintelmann and Dr. Chris Furgal as well as Alex Litvinov and Stephen McGovarin for their advice, comments, and recommendations which helped guide the direction of my thesis. I would like to give special recognizing to Dr. Holger Hintelmann for providing me with funding during my time in my Environmental Life Science Graduate program.

Table of Contents

LIST OF FIGURES

Figure 2.3: Consumption recommendations for walleye in the Moose Factory Area (A) and Moose River Crossing (B). To use this table, find your weight in the left-hand column (round down to the closest weight). Then, read across to the "number of servings per week" column to see how many servings you can eat. One serving equals 227 g (Government of Ontario, 2024), or about two hand-sized fillets. Sensitive populations (children, women of child-bearing age, and subsistence consumers) should follow the same steps using the tables on the right. Note: these tables apply only to walleye from the specified locations and within the listed size range (15–20 inches).

Figure 2.4: Ontario government walleye samples from years 1980, 1999, 2015, 2016 and 2017, as well as walleye from the current study collected in 2022 for the Moose Cree Mercury project. A) Moose Factory Area. B) Abitibi River.

Figure 2.5: Reported changes in the environment where light orange represents greater/more changes and dark orange represents fewer/less changes. The second chart shows the percentage of reported changes in fish observed by survey participants.

Figure 2.6: An interdisciplinary framework for preliminary assessments of fish contamination and risk assessment.

consumers). Panel A) is the Moose Factory Area, B) the Mouth of the Abitibi River, C) Moose River Crossing, D) Harricana River, E) Abitibi River. The solid orange regression lines show significant relationships.

LIST OF TABLES

ABBREVIATIONS

DOC: Dissolved organic carbon

FITw: Food Intake Tolerance per week

Hg: Mercury

lbs: Pounds

MECP: Ministry of the Environment, Conservation and Parks

mg/kg ww: milligrams/ kilogram, wet weight

MMHg: Methylmercury

OFCG: Ontario Fish Consumption Guide

oz: Ounces

ppm: Parts per million

TDI: Tolerable daily intake

μg/kg bw/day: micrograms/ kilogram, body weight/ day

GLOSSARY

ᐃᓕᓕᐧᐊᐢᑭᕀ: Moose Cree.

Anoxic: An absence or deficiency of oxygen.

Anthropogenic disturbances: Human-caused disturbances.

Bioaccumulation: The buildup of a chemical or contaminant in the tissues of an organism over time, often absorbed faster than the body can eliminate it.

Biomagnification: the process by which a contaminant or contaminants increase in concentration in the higher levels of a food chain, leading to higher contaminant concentrations in predators compared to lower trophic species.

Cultural harm: Limitations, restrictions, or barriers placed on communities that can infringe on their right to practice their cultures.

Local Ecological Knowledges: Unique, place-specific understandings of local environments, including plants, animals, and their interactions on local lands and waters, developed and shared by local people through direct, long-term observation and interaction with their surroundings.

Turtle Island: North and Central America.

CHAPTER 1:

Literature Review and Introduction

1.1 Mercury

Since the colonization of Turtle Island, anthropogenic impacts on the lands have sharply increased the mobilization of contaminants like mercury in aquatic ecosystems. Mercury is a natural element found around the world that is often known for its toxic effects on the human body in high doses or from prolonged chronic exposure (Harada 1995; Park & Zheng, 2012). It doesn't serve any known biological purpose and can be distributed into ecosystems through natural and unnatural means, such as through the discharge of industrial waste or land disturbances (Park & Zheng, 2012). On a global scale, industrial activities have generally elevated air pollutants, including mercury, with a large portion of these pollutants travelling to northern regions due to long-distance transport and their ability to accumulate in higher latitudes (Pirkle et al., 2016). When mercury is exposed to anoxic areas within aquatic ecosystems, it can become methylated by sulfur or iron-reducing microbes into a more toxic form of mercury known as methylmercury (MMHg) (Harding et al., 2018). Once the mercury is converted to MMHg it becomes biologically available to organisms and can bioaccumulate and biomagnify up the food chain (Harding et al., 2018). Oftentimes, top predator species accumulate higher MMHg levels than non-predatory species (Rohonczy et al., 2019).

Piscivore fish species such as walleye (*Sander vitreus*) and northern pike (*Esox lucius*) often accumulate higher concentrations of MMHg in their tissues than herbivore and omnivore fish species do (Pirkle et al., 2016; Harding et al., 2018). Once MMHg enters their bodies, it concentrates in the liver, kidneys, the brain, and muscle tissues (Dopierala & Fischer, 2023). It can remain in their bodies for multiple years after exposure has occurred (Blanchfield et al., 2021). Multiple biological and environmental factors have been shown to influence the process of MMHg accumulation, such as seasonal variability, the sex of a fish, temperature and their overall diets (Christie & Regier, 1988; Hartman & Margraf, 2006; Gewurtz et al., 2011a; Pirkle et al., 2016; Zupo et al., 2019).

Northern parts of Canada, including Northern Ontario, have been shown to have greater mercury burdens than southern regions of Ontario despite having fewer land disturbances (Pirkle et al., 2016). A study by Gandhi et al. (2014) found that concentrations of mercury in walleye from Northern Ontario locations generally had higher mercury concentrations than Southern Ontario walleye, with a median mercury concentration of approximately 0.4 µg/g wet weight (ww) for 40 cm (15.7 inch) walleye from Northern Ontario (Gandhi et al., 2014). The 50 cm (19.6 in) walleye showed a median of approximately 0.6 µg/g ww, and lastly, the 60 cm (23.6 in) walleye showed an approximate 1.0 µg/g ww from 2000-2012 (Gandhi et al., 2014). Southern parts of Ontario were sampled for mercury concentrations in walleye at 108 locations (Gandhi et al., 2014). Data collected from 2000-2012 showed median mercury in walleye 40 cm

(15.7 inch) was approximately 0.35 μg/g ww; median concentrations were approximately 0.55 μg/g ww for walleye 50 cm (19.6 inch), and 60 cm (23.6 inch) walleye had a median mercury concentration of approximately 0.8 μg/g ww (Gandhi et al., 2014).

Median mercury concentrations in walleye from northern and southern parts of Ontario in the same size classes from 1970-1985 were found to have slightly higher mercury concentrations than walleye from 2000-2012 (Gandhi et al., 2014). Another study done in the James Bay region of Quebec that sampled a majority of their fish in the 1990's found that walleye ranging from 15-100 cm (5.9-39.3 in) had concentrations of mercury that averaged at 0.60 Hg/kg (0.60 μg/g ww), walleye from 20-125 cm (7.87-47.2 in) averaged at 0.85 Hg/kg (0.85 μg/g ww) and walleye >25-125 cm (9.84-49.2 in) had average mercury concentrations ranging from 1.30 Hg/kg (1.30 μg/g ww) (Moriarity et al., 2020).

People who frequently consume fish that contain high traces of MMHg often face human health impacts associated with it (Calder et al., 2016). Chronic exposure to elevated levels of MMHg can increase the chances of developing illnesses such as neurodevelopmental disorders, cardiovascular issues, kidney damage, cancer and in severe cases, Minamata disease (Harada 1995; Fernandes Azevedo et al., 2012; Karagas et al., 2012; Park & Zheng, 2012). Indigenous communities are often the most susceptible to mercury exposure due to frequent consumption of fish from lands and waters that have been disrupted through anthropogenic disturbances (Hoover, 2013; Calder et al., 2016; Juric et al., 2017). For example, in the 1980s, the James Bay Cree (*Eeyou Istchee*) community experienced symptoms such as tremors and limited hand-eye coordination due to the high levels of MMHg in their land-based fish (Beuter & Edwards, 1998;

Moriarity et al., 2020). As a result, a fish consumption advisory was created to limit fish consumption in the community (Moriarity et al., 2020).

1.2 Mitigation Approaches to Mercury Exposure Through Fish Consumption

To limit the health risks associated with mercury, consumption guidelines are often created (Health Canada, 2007). Currently there are multiple guidelines in Canada for mercury including, the allowable level of mercury contamination in market fish (0.5 ppm), the guideline for daily water exposed to mercury intake (0.001 (mg/L) (0.001 ppm), and the total allowable daily intake guideline for total mercury intake from food (0.47 μg/kg bw per day for the general population and 0.20 μg/kg bw/day for sensitive populations like woman and children) (Health Canada, 2007; Government of Ontario, 2024). The total daily allowable intake guideline is used by Health Canada when fish consumption advisories/ recommendations are created (Health Canada, 2007).

Consumption advisories use risk mitigation strategies that limit the consumption of contaminated fish using a human health risk model (Hoover, 2013). Fish consumption advisories were first adopted in the 1970s in North America throughout parts of the Great Lakes due to concerns around MMHg (Imm et al., 2005). The advisories were initially created for people who consume sport-caught fish, and the advisories were meant to be temporary (Imm et al., 2005). In 2001, Health Canada posted its first fish guideline for mercury contamination, which identified a standard consumption recommendation of less than 0.5 ppm for the general population (Health Canada, 2007). The Health Canada guideline set a baseline recommendation limit that assisted the creation of site-specific consumption recommendations that have mainly been carried out by the Government of Ontario.

The Ontario Fish Consumption Guideline (OFCG) provides recommendations on the allowable monthly intake of different species of fish in certain areas of Ontario. This approach to risk mitigation has been generally accepted as adequate for the general population, assuming the general population is food secure and largely dependent on grocery store items. For Indigenous populations, fish consumption guides do not offer the same benefits as they do for the general population. Instead, they can add limitations to their overall land-based food intake, resulting in poorer health outcomes, food insecurity, severed connections to traditions and culture, fewer opportunities to pass down knowledges and techniques to future generations and an overall lower quality of life (Hoover, 2013; Keshavarz et al., 2023). In addition to these shortcomings, consumption guidelines have been challenged in scientific literature in various ways (Jones 1999; El-Hayek, 2007; Hoover, 2013). For example, guidelines generally don't account for region-specific risks, which can limit spatial and temporal differences for mercury across regions (El-Hayek, 2007). They also do not consider the potential for cumulative impacts when multiple contaminants are present (El-Hayek, 2007). There are limited considerations for population diversity and vulnerabilities associated with various groups of people (i.e. socioeconomic status, life stage, etc.) (EPA, 1999; Hoover, 2013; Lowitt et al., 2024). The Ontario consumption guide only tests the muscle part of the fillet, which limits people’s ability to understand mercury concentrations in other parts of the fish that they consume. There is a lack of consideration for cumulative exposure from multiple species, locations, or other environmental pathways. For mercury specifically, Jones (1999) has also argued that the Health Canada guideline only accounts for exposure levels and doesn't consider the absorption rates of different chemical forms of mercury.

While it is not possible to address all the limitations of current fish consumption advisories within a single study, community-based, localized approaches represent a critical first step toward more effective and contextually relevant risk assessment. Focusing on a specific case study allows for the integration of Local Ecological Knowledges, cultural practices, and site-specific exposure patterns, particularly in relation to contaminants such as mercury. These approaches can generate more reliable and representative data, improve the relevance of consumption guidance, and build trust through community engagement. In doing so, they lay the groundwork for more adaptive, inclusive, and responsive frameworks that better reflect both health risks and the socio-cultural importance of fish consumption.

Acquiring trust takes time, patience and the ability to value more than data for an assessment. It requires a level of humanity where risk assessors really take the time to understand the communities' needs and perspectives. It also requires an understanding of the colonial harm that has and continues to impact Indigenous communities. Trust through understanding community perspectives and needs can limit the potential cultural harms colonial research practices have on communities. Cultural harm includes any limitations, restrictions, or barriers placed on communities that can infringe on their right to practice their cultures. For example, fish consumption advisories can limit the consumption of fish and the practice of fishing, which can harm a community's ability to pass down knowledge on navigation in the territory, how to set nets, and how to clean and cook harvested foods (Hoover., 2013)

To limit harm to communities that rely on land-based foods, it's important to work with them, locate important fishing areas, and identify possible alternatives for piscivorous fish that can be overly contaminated with mercury (EAGLE Project, 2001; Hoover, 2013). The OFCG has not included Indigenous perspectives in their consumption advisory tables for the Moose River and surrounding areas and as a result, they have missed vital information such as, important traditional hunting locations where fish should be sampled, what species are consumed the most frequently by community members and omit observations related to fish and consumption that Moose Cree community members have made over the years. In order to address these gaps and to limit cultural harm often brought forth by consumption advisories/guidelines, my thesis focuses on a case-based study in Moose Cree First Nation Territory that aimed to develop and implement a community-based approach to understanding the risks of MMHg in the Moose River Watershed.

1.3 Moose Cree First Nation and Moose Cree First Nation Territory

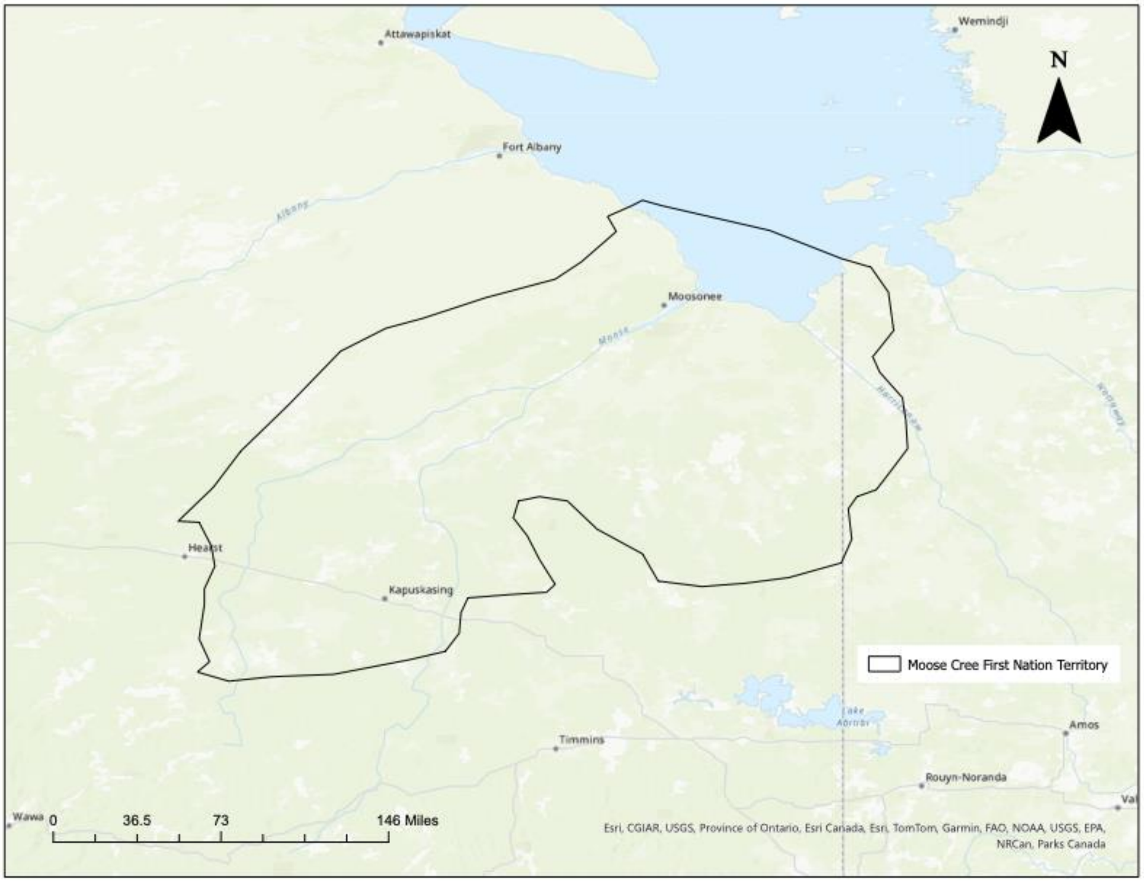

Figure 1.1: ᐃᓕᓕᐗᐢᑭᕀ | Ililiwaskiy (Moose Cree First Nation) territory. The black outline depicts the general outline of the territory, but is not an absolute boundary.

The ᐃᓕᓕᐗᐢᑭᕀ | Ililiwaskiy (Moose Cree) Territory is located in James Bay, Ontario, Canada. It is a remote community that requires a five-hour train ride from Cochrane, Ontario, to reach Moosonee, where a majority of the Moose Cree population resides. Within the territory, multiple fishing and hunting camps have been handed down to family members over generations. Traditional camps in the territory have been utilized since time immemorial and remain significantly important areas for fishing, hunting, connection and knowledge sharing. The Moose Cree community holds a strong relationship with fish since fish make up a staple part of their diet, with many members consuming multiple species of fish, such as walleye, northern pike, and lake sturgeon, all year round. In recent years, community members have voiced growing concerns around mercury levels in fish found within their territory. Contaminants like mercury threaten the community's ability to consume fish and therefore threaten their food sovereignty rights and cultural fishing practices. Contaminants like mercury, therefore infringe on fishing rights outlined in Treaty 9 (Government of Canada, 2013). Oftentimes, infrastructure projects like mines and hydroelectric dams can influence mercury levels in fish (Mailman et al., 2006). Heightened concentrations of carbon deposition and the creation of anoxic zones create a suitable environment for methylation to occur (Mailman et al., 2006).

The Moose Cree Territory holds an abundance of natural resources that are presently being utilized. Extractive projects in the territory have provided some benefits to the community through employment opportunities, energy and power generation, and economic benefits. A road has recently been proposed to provide easier transportation to and from the community, as well as to open the area for resource extraction activities. A road would allow the community to benefit economically from extraction projects. However, extraction projects also hold the potential to cause harm to the Moose Cree communities' way of life since they often contribute to increased levels of contaminants like mercury present in the animals, fish and waters and harm community foodways, food sovereignty, and traditional practices. It is, therefore, important to find a balance between resource extraction and protecting Indigenous rights and traditional practices. Mitigation strategies could also be used to limit possible consequences from land disturbances. For example, a common practice in Quebec includes the removal of vegetation before flooding occurs from hydroelectric projects, which reduces rates of methylation (Bilodeau et al., 2020).

1.4 Land Disturbance and Its Influence on Mercury in Moose Cree First Nation Territory

Land disturbances like logging, landfills, mining and hydroelectric dam development have influenced the mobilization of mercury in aquatic ecosystems (Calder et al., 2016). Most specifically, hydroelectric dam development contributes to an increase of MMHg in aquatic ecosystems. An influx of organic material and the creation of anoxic zones from flooding initiate the decomposition process, where specialized bacteria can methylate mercury (Calder et al., 2016; Mailman et al., 2006).

The Moose Factory area currently has two hydroelectric dams in close proximity to each other, residential areas, a hospital, a decommissioned landfill and an airport. The Moosonee Gov't Wharf dam, located in Moosonee, was established in the 1960s, and the other dam was established in 1999. The Abitibi River has more than six hydroelectric dams located along it, with the most recent one established in 2017. From the 1950s to the 1980s, mass logging also occurred from Moose River Crossing to Island Falls in the Abitibi River (Preston and Long, 1998). Other logging activities, forest fires, roads, aggregate pits, mines and petroleum wells have also disrupted the Moose River watershed.

1.5 Land Disturbance and Development Influence on Navigation

The Moose Cree community and surrounding communities in the James Bay region, such as Taykwa Tagamou Nation, and Eeyou Istchee (Chisasibi Cree Nation) have been negatively impacted by changes to the land since the colonization of their territory's, with hydroelectric dam development driving some of the most significant impacts to the land, waters and cultural practices like hunting and fishing (Berkes, 1988; Preston and Long, 1998). An article written by Preston and Long noted that a Taykwa Tagamou Nation (formerly known as New Post First Nation) community member noticed increased water flow from the Island Falls generating station that had been eroding away the riverbanks, transforming the land, and disrupting grave sites in the Abitibi River (1998). Furthermore, sand bars had been observed appearing on the land, and there had been an overall decrease in spirituality and cultural practices such as setting nets and navigating the land in the Taykwa Tagamou Nation Territory (Preston and Long, 1998).

Sandbars often increase due to erosion and deposition from natural or anthropogenic-based land disturbances (Shampa et al., 2024). Rivers experience natural water level fluctuations and turbidity, which are often driven by weather and seasonal changes in Canada (Bonsal et al., 2019). Rivers may even experience low water levels due to droughts from a lack of precipitation or elevated water levels due to flooding from snowmelt or heavy rainfall events (Niaman et al., 2008; Bonsal et al., 2019). Recently, climate change has increased the frequency of flooding in the winter and spring, while also lowering summer water flow in some parts of Canada (Bonsal et al., 2019). However, land use changes driven by anthropogenic activities like logging, mining, and hydroelectric activity can often dramatically alter natural water fluctuations and often in a shorter span of time (Bipa et al., 2024). For example, hydropeaking from hydroelectric dams allows a sudden release of water that often impacts the flow of the water, vegetation, and biota downstream (Bipa et al., 2024). Hydropeaking also significantly increases the level of erosion in aquatic ecosystems, which can transport silt and sediment to other parts of the river (Bipa et al., 2024). Alternatively, when dams reduce their flow rates, they can limit nutrient and water flow downstream (Yang et al., 2025). Lower water levels and altered turbidity can alter the temperature of the water, which can increase stress on biological organisms and can make it more difficult to fish (ędra & Wiejaczka, 2018). Multiple cases can be found in the literature where Indigenous communities face significant consequences from hydroelectric development. For example, in the Chisasibi Cree Territory, hydroelectric dams have also increased mercury levels in the water, increased erosion and altered water level fluctuations, which resulted in a decline of hunting and fishing in the Chisasibi Cree Territory (Berkes, 1988).

1.6 Importance of Fish

For many Indigenous communities located across North America, fish is an important traditional food source that provides food security, especially since Indigenous communities experience high rates of food insecurity (Hoover, 2016). Food insecurity in Indigenous communities often arises due to consumption advisories on harvested foods and higher-than-average grocery store prices (Hoover, 2016; Shafiee et al., 2022). Many communities face consumption limitations on traditional foods such as fish due to elevated contaminants in their territories (Hoover, 2016; Shafiee et al., 2022). A traditional diet or traditional food refers to local foods that have been harvested from the land and waters over generations (Trichopoulou et al., 2007). According to Elliott et al. (2012), the practice of hunting, fishing and consuming meats such as fish allows First Nations communities to consume a more traditional diet that offers higher levels of nutrients, less fat, sodium, and fewer carbohydrates than grocery store items that offer fewer health benefits (Kuhnlein et al., 2004). Another study by Kuhnlein et al. (2004) found that peoples from Inuit communities in Canadian Arctic regions who consumed fewer traditional foods like fish and meat showed an overall decrease in their energy, and higher rates of obesity. A transition away from local traditional diets to westernized diets has also resulted in a higher frequency of diabetes and chronic diseases in Indigenous communities (Keshavarz et al., 2023).

It's important for Indigenous communities to continue to consume traditional foods like fish so that they can continue to receive the health benefits their traditional foods offer. Fish produce a variety of health benefits due to their fatty acid content, which lowers risks associated with diseases such as cardiovascular health issues and neurodevelopmental issues (Gil & Gil, 2015). Fish also offers protein, high levels of vitamin B12 and B2, and micronutrients like iodine, selenium, and vitamin D (Karagas et al., 2012).

Moose Cree community members value fish for its cultural importance, its relationship to the community, and for survival (Lescord et al., 2024). Many fish are considered culturally important in Moose Cree First Nation, such as walleye, northern pike, and lake sturgeon. Culturally important foods include foods that have been harvested from territorial lands and waters over generations, as well as the knowledges associated with them (Trichopoulou et al., 2007). Some examples of the knowledges tied to culturally important foods in Moose Cree First Nation include knowing the names of food in Moose Cree, knowing when to go out to catch certain foods, navigation on the land and waters, catching, cleaning, preparing and cooking land-based foods.

"The fish come in the river here certain times of the year. Like for instance, we set our nets in the river during the summer. When a certain flower blooms here."

-Male Moose Cree Fish Harvester

Generational hunting and fishing on the land has allowed Moose Cree community members to sustain their community, limit mental health related issues, carry out traditional practices, pass down intergenerational knowledge such as how to navigate rivers, when to set nets, how to catch fish, clean, prepare and cook fish, and it has continued their overall relationship with the land and water. However, mercury contamination in fish found within the Moose Cree Territory and fish consumption advisories has the potential to threaten these relationships.

1.7 Objectives

The overall goal of this thesis is to investigate the issue of mercury with a focus on MMHg in Moose Cree Territory and provide a case study example of how community knowledge and chemical data together can reflect the impacts of mercury on cultural practices connected to fishing. The objectives are to:

1. Quantify concentrations of mercury in culturally important fish species, including walleye, northern pike and lake sturgeon, from sites of importance to the Moose Cree people.

2. Document impacts on Moose Cree relationship with fish and the influence of mercury as one of those impacts.
3. Develop a process for assessing the risks of mercury that brings together Indigenous and Western Science.
4. Understand trends in mercury loads within fish from culturally relevant fishing sites.

Chapter 2 explores objectives 1 to 3. This chapter weaves together knowledge shared by Moose Cree community members and the data collected through fish sampling.

Chapter 3 provides an in-depth analysis of the mercury data collected, further exploring objective 1 and addressing objective 4.

Chapter 4 provides concluding remarks and recommendations for future studies.

CHAPTER 2:

Understanding the Relationships Between Land Disturbance, Mercury, and Traditional Practices in the Moose Cree Territory:

A Foundation for Risk Assessment

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ABSTRACT

The ᐃᓕᓕᐧᐊᐢᑭᔾ| Ililiwaskiy (Moose Cree First Nation Territory) in the James Bay region of Ontario, Canada, and like many Indigenous communities across the globe, has experienced decades of industrial activity impacting its ecosystems. Community concerns regarding mercury levels in culturally significant fish species led to an interdisciplinary research initiative. This study combined scientific analysis and community knowledge to assess mercury concentrations in three traditionally consumed fish species—walleye (*Sander vitreus*), northern pike (*Esox lucius*), and lake sturgeon (*Acipenser fulvescens*).

Researchers engaged with Moose Cree members through workshops, fish sampling training, interviews, and surveys on fish consumption and land/water relationships. Over 180 fish were sampled from six locations. Walleye showed the highest mercury levels, with many samples exceeding Health Canada's guidelines, particularly for walleye over 15 inches., and the 0.2 ppm guideline for subsistence consumers, women, and children. Community interviews underscored the cultural importance of fish and observed environmental changes, as well as changes seen in fish and fishing in the territory.

This project revealed not only elevated mercury in traditional food sources but also broader impacts on land-based practices and food security. The findings emphasize the need to rethink water management planning and how contaminant risks from resource extraction are assessed and mitigated. Ultimately, the project supports Moose Cree First Nation leadership in advancing land stewardship and sustaining cultural connections to traditional foods and the land. It also illustrates a collaborative risk assessment process

that could be used broadly for bringing together Indigenous knowledge with scientific inquiry to address environmental health concerns.

Key Words: Mercury; Fish; Consumption; Indigenous Knowledge; Cumulative Effects

2.1 INTRODUCTION

Contamination of Indigenous traditional food sources is a substantial health and culturally disruptive global issue. Mercury contamination is responsible for approximately 80% of fish consumption advisories in countries such as the United States (EPA, 2001). The goal of risk assessments and subsequent fish consumption advisories and guidelines is to reduce exposure to contaminants and to limit negative human health impacts (Cleary et al., 2021; Lowitt et al., 2024). Fish are sampled for total mercury, and then concentrations are compared to total allowable daily intakes set by health and/or environmental agencies (Health Canada, 2007; Government of Canada, 2019; Government of Ontario, 2024). From there, recommendations are made for how many fish can be eaten per week or month (Government of Ontario, 2024). For sites with high levels of mercury found in fish, this can result in very few to zero fish being recommended for consumption. The elimination of traditional foods like fish in Indigenous communities has been shown to increase rates of diabetes, cardiovascular issues and other diet-related chronic health diseases (Browne et al., 2020). Indigenous communities can also be impacted culturally since a loss of knowledge around hunting, fishing, cleaning fish, and cooking can often occur after learning that their food is unsafe for consumption (Hoover, 2013; Lowitt et al., 2024).

Assessing the risks of contaminants like mercury requires an understanding of traditional practices, fish consumption, and changes that have been observed by community members. Without an understanding of community relationships with the land, water and fish, consumption advisories miss valuable information pertaining to cumulative impacts of change and direction to not eat the fish can perpetuate colonial harm that can sever relationships between community, land, water and the beings who share the land and waters (Hoover, 2013; Lowitt et al., 2024). To avoid this, it is necessary to create a process for evaluating and mitigating risk that includes the communities impacted by mercury elevation (Brunet et al., 2020; Dellinger et al., 2022; Houde et al., 2022).

Fish is an important traditional food source to the ᐃᓕᓕᐧᐊᐢᑭᕀ | Ililiwaskiy (Moose Cree First Nation) peoples (Lescord et al., 2024). Fish offer a variety of health benefits; their fatty acid content lowers risks associated with cardiovascular health, cancer, and neurodevelopmental health (Karagas et al., 2012; Calder et al., 2019; Charkiewicz et al., 2025). Fish offers protein, high levels of vitamin B12 and B2, omega-3 fatty acids and micronutrients like iodine, selenium, and vitamin D (Karagas et al., 2012; Calder, 2017; Calder et al., 2019; Noreen et al., 2025). Mercury is a non-essential element that can often impact the health benefits associated with fish (Park & Zheng, 2012; Noreen et al., 2025). Frequent chronic exposure to elevated levels of mercury in fish can increase the chances of developing neurological issues, kidney damage, cancer, cardiovascular difficulties and in severe cases, Minamata disease (Harada 1995; Fernandes Azevedo et al., 2012; Park & Zheng, 2012; Charkiewicz et al., 2025). Impacts from extractive and hydroelectric activities influence mercury methylation rates in the environment, increasing the bioaccumulation and biomagnification of mercury in fish (Calder et al., 2016). Methylation occurs when mercury is converted by microbial organisms to a more neurotoxic and biologically available form of mercury (methylmercury) (Calder et al., 2016). Methylmercury (MMHg) can accumulate in the tissues of organisms and biomagnify up the food chain, where predatory species like walleye (*Sander vitreus*) accumulate higher concentrations than lower trophic species (Stewart et al., 2008; Rohonczy et al., 2019; Government of Canada, 2021). People who regularly consume fish from waters in areas with increased hydroelectric dam development are often exposed to increased levels of MMHg and are therefore more susceptible to experiencing negative health impacts (Calder et al., 2016). Currently, Moose Cree First Nation has over ten hydroelectric dams within their territory, which includes the Moose River watershed.

This project investigated how mercury is part of a dynamic food and land relation system and explored its connection to the web of impacts created from land use and resource extraction activities in Moose Cree Territory. Our objectives were to 1. Determine the mercury concentrations in traditionally consumed fish, 2. Determine if there are differences in mercury burdens in fish between six culturally important fishing locations, 3. Bring together community knowledge and chemical data on mercury to explore its connection to the diverse threats impacting cultural practices and food systems in Moose Cree First Nation Territory. By working closely with Moose Cree Lands and Resources Department and community members this project demonstrates a holistic approach to understanding the impacts and risks associated with elevated mercury in traditionally consumed fish.

2.2 METHODS

2.2.1 Project Launch and Sampling Design

In 2022, our team hosted an open house with Moose Cree First Nation community members to introduce our project. To ensure our project focused on important areas to the Moose Cree First Nation, the open house included a mapping workshop where community members, including anglers/harvesters, women, and Elders, were invited to identify key locations that should be prioritized in the study. Large maps of the territory were provided, as well as small individual maps. Community members who attended the open house marked on the maps areas that were important to them for this project. The project team members digitized these maps using QGIS, creating shapefiles that were layered on top of each other. Areas with the highest density of circles were selected as the primary sampling locations for this study. In total, our team selected six (6) primary sites.

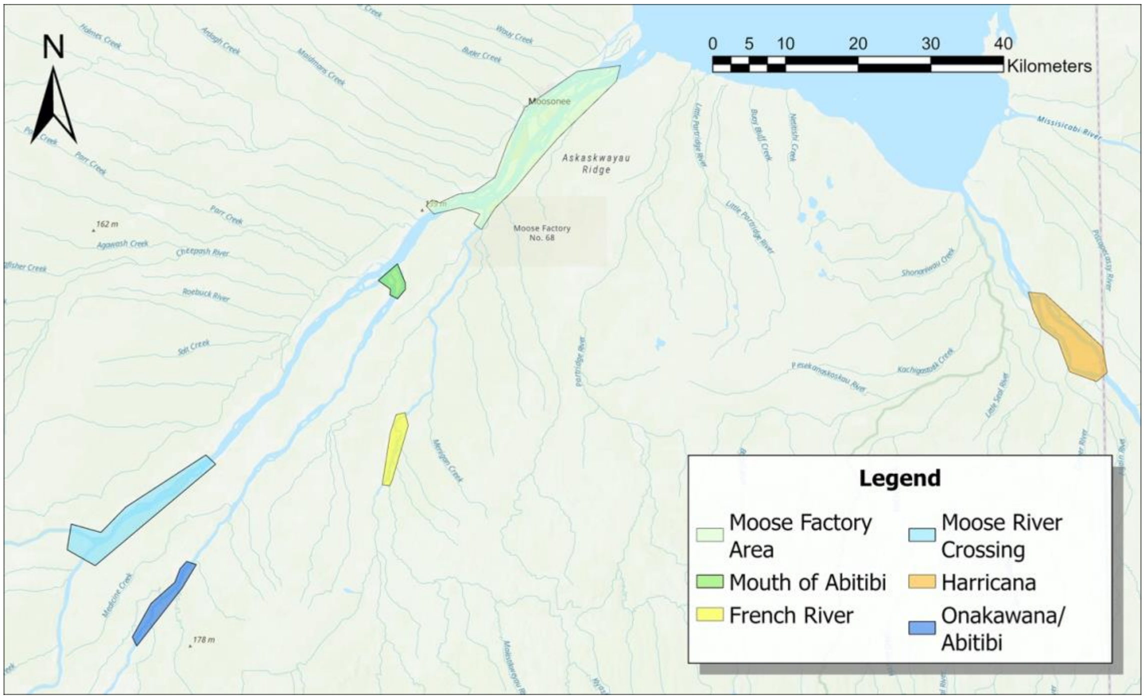

Figure 2.1: Sampling areas for mercury study in the Moose Cree Territory. Regions included Moose Factory Area, the Mouth of the Abitibi River, the French River, the Harricana River, and the Onakawana/ Abitibi River.

2.2.2 Fish Collection and Analysis

Three fish were chosen for sampling: walleye (*Sander vitreus*), northern pike (*Esox lucius*), and lake sturgeon (*Acipenser fulvescens*). All three species are culturally important fish species due to the significant roles they have had in assisting the survival of the Moose Cree community over generations. These three species are frequently consumed by the community and are cooked in various ways, such as frying, boiling or smoking. To identify mercury concentrations in the three fish species, community members were trained on sampling protocols in a workshop provided in the community following the project launch open house. This protocol includes measuring the total length, fork length, and weight of fish. Harvesters were taught how to take a skinless-boneless muscle sample from behind the dorsal fin and proper storage protocols. Harvesters were also asked to write down the species and location caught when processing the fish. The fish were mostly caught during the late summer months/ early fall (i.e. 72% of fish were caught August-October). Fish tissue was stored in Ziploc bags on ice and eventually in the freezer at approximately -20°C until shipment from the band office to a certified lab, ALS Laboratories (alsglobal.com) for total mercury analysis.

ALS Labs Sample Preparation:

Approximately 1g of homogenized tissue was weighed and transferred to a digestion vessel. A 10:1 mixture of concentrated HNO_3 and concentrated HCl, and 1mL of 30% hydrogen peroxide was added to each digestion vessel. The sealed digestion vessels were loaded onto a Microwave autosampler, and each sample was treated with microwave energy. Each sample was stirred until the resultant digestate was clear and homogeneous. Subsamples from the bulked digestates were further digested for mercury analyses. These samples were treated with nitric acid, sulfuric acid, potassium permanganate and potassium persulfate (per EPA SW846 method 7471B), before instrumental analysis.

Instrumental Analyses:

Mercury was determined via Cold Vapour Atomic Absorption (CVAA) (Teledyne/CETAC M7600.2 mercury analyzer) after in-line stannous chloride reduction of the secondary digestates to evolve elemental mercury (see EPA SW846 method

7471B). Instrument calibrations were relative to responses from commercially sourced and certified standards (Inorganic Vantures, Product #: CGHG1).

QA/QC:

Each batch of samples (each batch representing ≤20 samples) was prepared to include both a positive and negative control sample: a laboratory method blank and a laboratory control sample (spiked blank matrix) (Inorganic Vantures, Product # NLHG1).

Note that this entire process was completed by a Canadian Association for Lab Accreditation (CALA) laboratory.

2.2.3 Community Interviews and Surveys

Understanding Moose Cree First Nation's relationship with traditionally harvested fish is essential for determining any risks associated with fish mercury burdens and for informing mitigation strategies. It was also essential for ensuring that any risk messaging did not perpetuate the severing of the relationship with the land, water, and fish. To achieve this, we conducted semi-structured interviews and surveys with Moose Cree 14 fish harvesters and Knowledge Holders (2 women and 12 men). A call for participation was put out by Moose Cree Lands and Resources Department personnel and was intended to target Knowledge Holders who are active harvesters living in the territory. Out of the 14 participants, eight were 31-49 years old, three were 65 years old, two were 50-64, and one participant was 18-30 years old. Due to the limited representation of women in the study, we acknowledge that the results may be influenced by gender bias in the knowledge obtained.

Surveys and interviews were reviewed and given ethics approval by Trent University's ethics committee (protocol number: 27916). Informed consent letters were provided to each participant. These letters outlined that the Moose Cree community would have ownership of the survey and interview data and that it would be used for this study in partnership with Trent University. Participants had the option to read the form or to have it read out loud to them before deciding if they would like to continue.

Interviews were conducted with fourteen Moose Cree community participants, with twelve male participants and two female participants. Participants were given the choice to be recorded or to have notes taken on paper and pen. The interviews consisted of thirteen questions. Data from the interviews was then transcribed in Otter AI, where common themes were manually highlighted and moved into an Excel table. Quotes were placed under five common themes that included: family history with fish and the land; importance of fish and relationship; hunting and fishing on the land; preparation and cooking; and changes in fish, water, land and people. All themes were present in every interview and were acknowledged as important to all participants.

Surveys were conducted with all of the participants who participated in the interviews. The surveys had twenty-three questions regarding personal and family fish consumption preferences and habits, observed impacts on the local environment, and observed impacts on fishing in the territory.

2.2.4 Statistical Analysis

To assess potential differences in the data between sample sites and between sampling years, analysis of covariance (ANCOVA) models with fish length as a covariate were conducted using RStudio (version 1.2.5042; R Core Team, 2024). Prior to analysis, assumptions were assessed using the car package for running normality checks on residuals. As needed, mercury and length data were log-transformed to meet the assumptions of normality and homogeneity of variances. ANCOVA models were performed using the aov() and lm() functions from base R. When statistically significant differences were detected ($p < 0.05$), post hoc pairwise comparisons were conducted using the emmeans package, with estimated marginal means adjusted for the covariate (length). A Bonferroni correction was applied to control for Type I error in multiple comparisons.

Linear and power regression models were evaluated using Microsoft Excel and R to assess the relationship between variables (mercury and length). In Excel, linear regressions were conducted using the LINEST function and the Regression Tool within the Data Analysis Toolpak, which provided the coefficient of determination (R^2) and corresponding p-values for each model. A p-value threshold of <0.05 was used to determine statistical significance. To further evaluate model fit, power regressions were performed in R using the *lm()* function applied to log-transformed data. Linear regression models typically demonstrated superior fit compared to power models based on higher R^2 values (see Table S1, Supplemental Material); as such, linear regressions were used for further interpretation of the data.

Fish Consumption Guideline Calculations:

To calculate guidelines, we applied the following formulas adapted from the Assembly of First Nations (AFN), Chiefs of Ontario and Health Canada (HC) 2001:

Total Daily Intake

The Canadian tolerable daily intake (TDI) has been created by toxicological risk assessments on mercury in Canada (Health Canada, 2007). TDI stands for the maximum amount of mercury that can be ingested daily over a lifetime without adverse health effects (Government of Alberta, 2016). The TDI value for women of childbearing age and for children is 0.2 µg/Hg/Kg bw/d (Health Canada, 2007). The TDI value for adults who are not of reproductive age is 0.47 µg/Hg/kg/bw/day.

Food Intake Tolerance (FITw)

FIT represents the portions of fish that can be safely consumed weekly in accordance to published TDI. Weekly was chosen as a time interval based on informal feedback from the community on the easiest time interval to track. The FITw (in g/week) formula is as follows:

Equation 1:

FITw= TDI *7* Body Weight(kgbw) / a*length^{b} (mg/kg) * Serving size

The Components That Are Comprised Within FITw is as Shown:

- TDI (µg/kgbw/day) is the total daily intake of fish that can be consumed daily without exceeding guidelines.
- Diet is the proportion of specific fish tissue contaminant that is consumed, supporting the guideline calculation.

- Body weight (kg): The weight of human body.
- Length: The length of the fish.
- a and b: Regression coefficients for every fish species' relationship between length, contaminant, and sample location.

Note: $a*length^b$ should typically only be used when the relationship between length and mercury concentration is strong and significant. When this is not the case, the average concentration of a given size class may be used and is explored further in our results and discussion.

2.3 RESULTS

2.3.1 Chemical Data:

We evaluated mercury concentrations in fish at 6 culturally important fishing locations in the Moose Cree Territory. Our results brought together Western science with Moose Cree perspectives on what they have noticed on their territory, while also assessing the use of the Ontario fish consumption guideline among participants.

Out of the 186 fish that were used for this study, Moose Factory Area had 28 walleye, 2 sturgeon and 8 northern pike. Moose River Crossing had 44 walleye, 13 northern pike, and 5 sturgeon. Abitibi River/ Onakawana had 22 walleye, 11 northern pike, and 3 sturgeon. The Mouth of the Abitibi River had 13 walleye, 17 northern pike, and 4 sturgeon; the Harricana sight had 9 walleye, and the French River had 7 northern pike samples. Species with fewer than three individuals at a sample site were not added to the figures due to limited data.

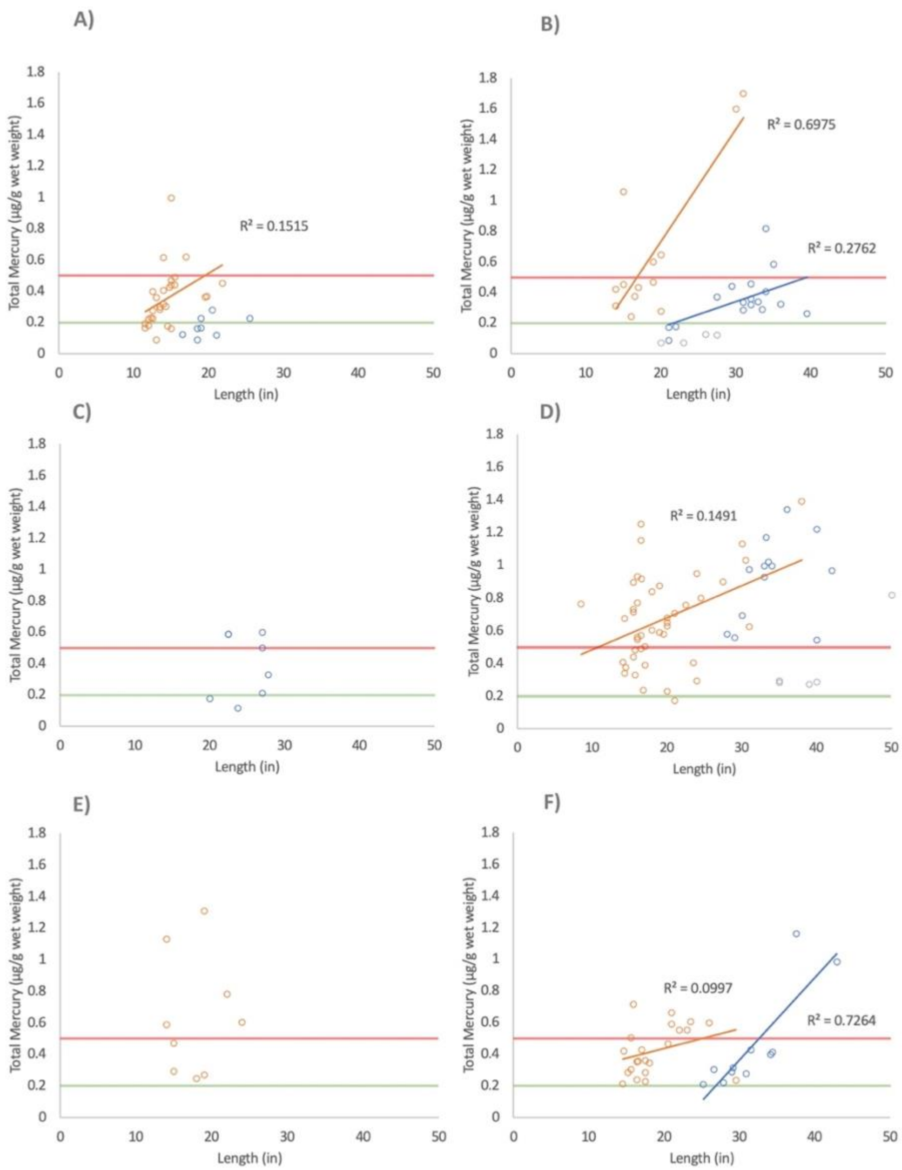

Figure 2.2: Mercury (µg/g) concentrations and length (in) of fish at six traditional fishing locations. Orange dots represent walleye, blue dots represent northern pike, and grey dots represent lake sturgeon. The red line represents the 0.5 ppm Health Canada guideline for the general population, and the green line shows the 0.2 ppm Health Canada guideline for sensitive populations (women, children, and subsistence consumers). Solid lines represent significant linear relationships, and dotted lines represent insignificant relationships.

Pannel A) Moose Factory Area (northern pike: n=8, walleye: n=28) B) the Mouth of the Abitibi River (sturgeon: n=4, northern pike: n=17 walleye n=13), C) French River (northern pike: n=8) D) Moose River Crossing (sturgeon: n= 5, northern pike: n=13, walleye: n= 44 E) Harricana River (walleye n=9 F) Abitibi River/Onakawana (sturgeon: n=3, northern pike: n=11, walleye: n=22).

Linear regressions between fish length and concentration of mercury in walleye were considered significant ($p < 0.05$) at the Moose Factory Area (p 0.041), Mouth of Abitibi River ($p < 0.001$), Moose River Crossing (p 0.014) sites, whereas the Harricana River (p 0.921) and Abitibi River/Onakawana (p 0.152) were not significant. Where significant regressions were observed, many were considered weak relationships ($R^2 < 0.3$) as seen in *Figure 2.2.*

At all of the sites where walleye were caught, at least one or more fish below 15 inches exceeded the sensitive population guideline (0.2 ppm), with the smallest walleye exceeding this guideline being only 8.5 inches. Pike that surpassed the sensitive population guideline had mercury concentrations in fish that ranged from 19 to 42.9 inches, and the site D sturgeon that surpassed the sensitive population guideline ranged from 35 to 50 inches.

A)

Fish Consumption Recommendation: Near Moose Factory

Walleye

15-20 inch fish

General Population		Sensitive Population	
Your weight (pick closest number without going over)	Number of servings per week	Your weight (pick closest number without going over)	Number of servings per week
90 lbs	1	150 lbs or less	0
150 lbs	1		
200 lbs	2	Greater than 150 lbs	0
250 lbs	3		

Ontario Guideline for this fish species, fish size and location is:
General Population: 4/ month; Sensitive Population: 0
Note: Ontario assumes all people weigh 70kg or ~ 154 lbs

B)

Fish Consumption Recommendation: Moose River Crossing

Walleye

15-20 inch fish

General Population		Sensitive Population	
Your weight (pick closest number without going over)	Number of servings per week	Your weight (pick closest number without going over)	Number of servings per week
90 lbs	0	150 lbs or less	0
150 lbs	1		
200 lbs	1	Greater than 150 lbs	0
250 lbs	2		

Figure 2.3: Consumption recommendations for walleye in the Moose Factory Area (A) and Moose River Crossing (B). To use this table, find your weight in the left-hand column (round down to the closest weight). Then, read across to the “number of servings per week” column to see how many servings you can eat. One serving equals 8 oz (227 g) (Government of Ontario, 2024), or about two hand-sized fillets. Sensitive populations (children, women of childbearing age, and subsistence consumers) should follow the

same steps using the tables on the right. Note: these tables apply only to walleye from the specified locations and within the listed size range (15–20 inches).

Consumption recommendations were created for sites that had more than 15 walleye caught (Gewurtz., 2011). Moose Factory walleye consumption recommendations indicate that people in the general population who weigh 90 lbs or less can safely consume one serving of 15–20-inch walleye per week, 200 lbs can consume two a week, and 250 lbs can consume 3 walleye a week that are 15-20 inches. For the Moose River Crossing Area, consumption recommendations for the general population indicate that people who weigh 90 lbs or less should not consume walleye 15+ inches on a weekly basis. People who weigh 150-200 lbs can safely consume one 15–20-inch walleye per week, and people who weigh 250 lbs can consume two 15–20-inch walleye a week. Both of the consumption tables indicate that people in the sensitive population who weigh more or less than 150 lbs should not consume any walleye 15 inches or larger at these sites per week.

Table 1: Average mercury concentrations, standard deviations, median, and number of walleye at each location between 10-15 inches, 15-20 inches, 20-25 inches and 25+ inches.

Site Name	10-15	15-20	20-25	25 +
Moose Factory Area	0.33, ± 0.19, x̃ 0.29, 22	0.48, ± 0.23, x̃ 0.44, 9	0.45, NA, x̃ NA, 1	NA
Mouth of Abitibi River	0.56, ± 0.34, x̃ 0.44, 4	0.51, ± 0.25, x̃ 0.45, 9	0.46, ± 0.26, x̃ NA,2	1.65, ± 0.07, x̃ NA, 2

Moose River Crossing	0.45, ± 0.15, x̃ 0.39, 4	0.65, ± 0.25, x̃ 0.61, 27	0.60, ± 0.24, x̃ 0.67, 10	1.01, ± 0.28, x̃ 1.03, 5
Harricana River	0.62, ± 0.36, x̃ 0.53, 4	0.52, ± 0.45, x̃ 0.29, 5	0.69, ± 0.12, x̃ NA, 2	NA
Abitibi/ Onakawana	0.32, ± 0.15, x̃ NA, 2	0.37, ± 0.13, x̃ 0.35, 12	0.57, ± 0.07, x̃ 0.57, 6	0.42, ± 0.26, x̃ NA, 2

NA= not applicable, i.e. no samples were collected within that size class, or sample size was not large enough to display a median (<4) and/or standard deviation.

At a few sites, mean Hg for specific length classes had standard deviations approaching the mean (e.g. Harricana 15–20: 0.52 ± 0.45 mg/kg) (see Table 1), indicating high variability in mercury concentrations among walleye from that site in that length class. This level of dispersion suggests that the data are likely non-normally distributed, limiting our ability to rely on parametric tests to interpret the data and develop risk messaging for these specific length classes at these sites; as such, caution should be taken when applying the data.

Average concentrations were very similar across all of the sites (*Table 1*), however, after accounting for length using ANCOVA ($p < 0.001$, df=4, F=4.95), followed by a posthoc test, there was a significant difference between Moose River Crossing and the Abitibi/Onakawana site ($p < 0.001$) and between the Moose Factory Area and Moose River Crossing ($p < 0.001$) sites.

Concentrations of mercury in walleye samples from this study (2022) were also compared to the walleye samples collected by the Ontario Government in 1999, 2015, 2016 and 2017 around the Moose Factory Area, or Moosonee Area (*Figure 2.4*. A). No significant difference were found between years at this site (p >0.05, df =4; F=0.194). The concentrations of mercury in walleye collected by the Ontario Government in 1980 at the Abitibi site were also compared to the data collected from this study; for this comparison, significant differences in mercury burden in fish between the two study years were observed (p <0.001, df=1, F=31.4).

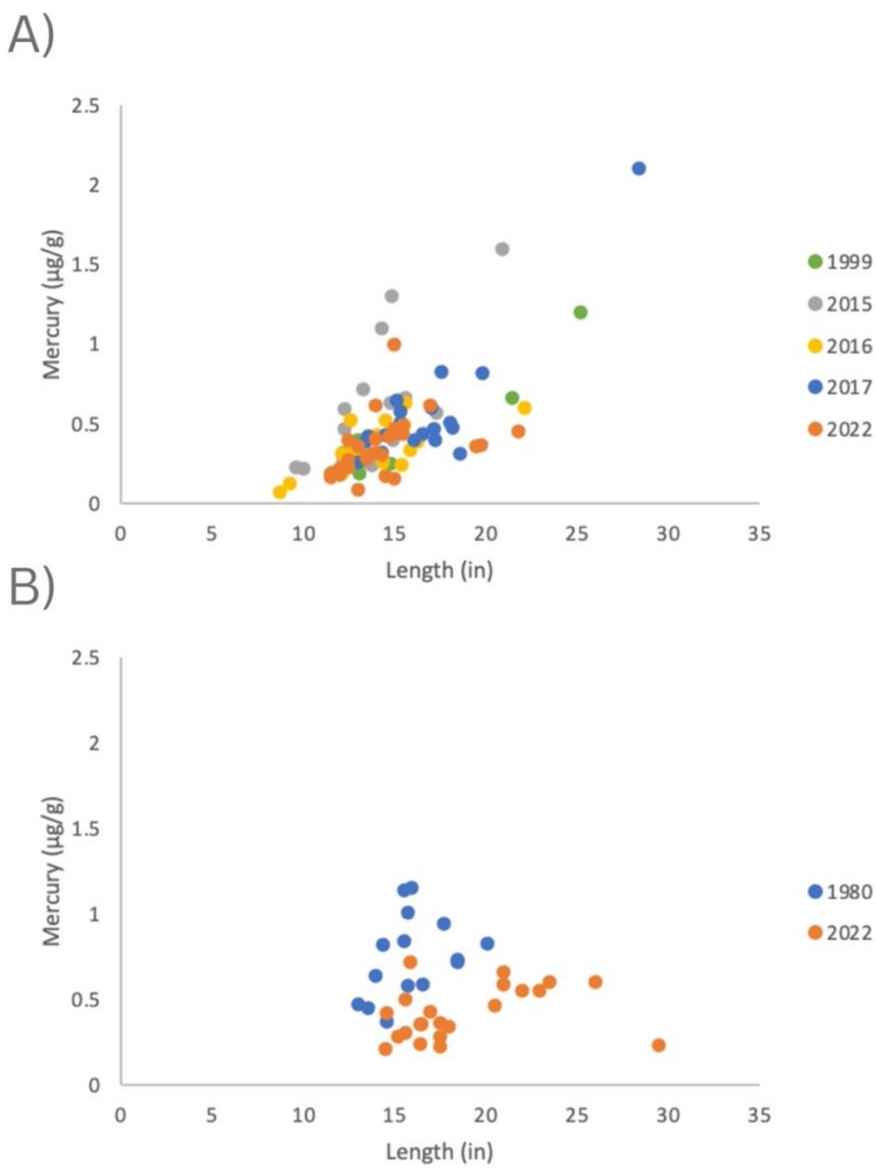

Figure 2.4: Ontario government walleye samples from years 1980, 1999, 2015, 2016 and 2017, as well as walleye from the current study collected in 2022 for the Moose Cree Mercury project. A) Moose Factory Area. B) Abitibi River.

2.3.2 Survey and Interview Data:

Within our survey, we asked participants to indicate if they were aware of or used the Ontario Fish Guide. 17% of participants indicated that they use the Ontario Fish Consumption Guideline for areas in the territory, while the majority of the participants indicated that they do not use the Ontario Fish Consumption Guideline. 58% of the participants stated that they do not know about the Ontario Fish Consumption Guideline. 17% of participants indicated that they know about the fish consumption guide but that they chose not to follow it, and 8% percent of participants indicated that they don't know how to use the Ontario Fish Consumption Guide.

Surveys showed that 43% of participants try to limit their consumption to once a month. Some interviewees stated that they have limited their fish consumption because they know about the high mercury levels in the territory. Other community members who participated in the survey prefer to consume fish more regularly, with 14% of interviewees stating they consume fish more than twice a week, and 7% stated that they consume fish once a week. Community members who selected the manual entry option for their answers (i.e. participants were given the option to manually add additional details about their fish consumption habits) (36%) also mentioned that they will consume fish once or twice a month, twice a month, twice or three times a month, when their body needs it, and that their consumption depends on how much fish are harvested. Survey and interview participants expressed the importance of fish and how it's more than just food for the community.

"I don't know how to explain that connection that you have with the food that you gather, especially the food, and to share it, how important that is, and especially for the older people to be able to continue to eat [fish and traditional foods]."

- Female Moose Cree Fish Harvester

The survey and interviews also explored several themes to understand if impacts, including chemical (i.e. mercury), physical or other impacts, were of concern to the participants. The surveys and interview data shown consisted of questions that focused on whether participants have noticed changes in the waterways, their ability to carry out harvesting practices and if they have noticed changes in fish caught within the territory. *Figure 2.5* displays the percentage of community members who have seen greater/more or fewer/less changes in the Moose Cree Territory. 50% of survey participants indicated that water level fluctuation is happening more frequently. 50% of participants indicated sandbars were showing up more frequently, while 21% mentioned that they had observed fewer sandbars. 57% of participants indicated more difficulty boating in rivers, while 21% had less difficulty boating in rivers. Fewer animal sightings in the territory were reported by 42% of participants, and 36% of participants indicated that they are experiencing a greater difficulty accessing their fishing grounds, while 21% indicated that they are having less difficulty accessing fishing grounds. *Figure 2.5* indicates the percentages of participants who have noticed changes in fish within the territory. 36% of participants selected that they have noticed changes in the skin of the fish and have seen more injuries on fish, 50% have noticed changes with the colours of the fish, 29% selected that they have noticed more deformities. It should be noted that it is typically expected that a minimum of 20-25% of the population participate in order to achieve a representative sample size (Wu et al, 2022), therefore, the survey data should be viewed as baseline data.

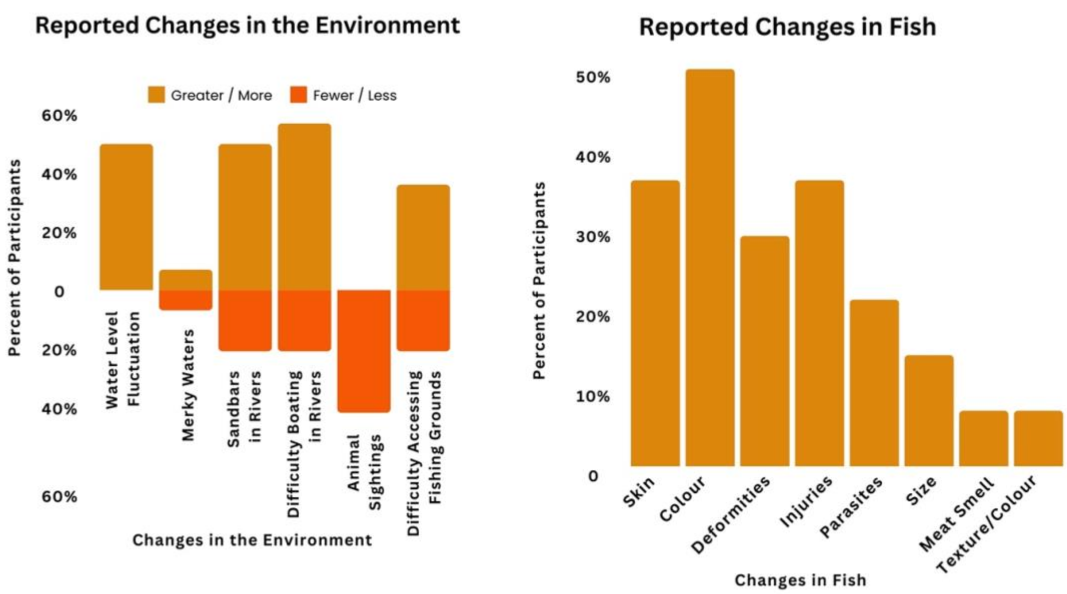

Figure 2.5: The percent of participants who reported changes in the environment, where light orange represents greater/more changes and dark orange represents fewer/less changes. The second chart shows the percentage of reported changes in fish observed by survey participants.

Every participant and community member we interviewed had a connection to fish and fishing and reported frequently eating fish. This connection ran much deeper than just acquiring the taste or the health benefits of the fish they catch. Fishing is a way to connect to their families, friends and those who have come before them. A majority of participants stressed how fish allows for the continuation of generational practices and traditions on the land, as well as passed down Moose Cree techniques for catching fish, cleaning fish, preparing fish and cooking it. Some community members mentioned family inherited camps and locations where they share fond memories with grandparents, parents and their sons and daughters. Interviewees described fishing as a way to connect with the land and water, learn safety and how to navigate the water, assist with mental health-related issues, a way to spend time with family and friends, to pass down generational knowledge and that fishing assists community members who have fallen ill or are no longer physically able to fish on their own. Although the majority of participants appear to be cautious of their fish consumption, the survey data can suggest that it is important for community members to continue their regular consumption of fish due to their tightly woven generational relationship with fish and their frequent consumption of fish in the territory. Consumption advisories should have a section for weekly consumption of fish rather than monthly, which could provide an easier way to remember the number of fish that have been consumed in a given period of time.

2.4 DISCUSSION

2.4.1 Assessing the Risk of Mercury Concentrations in Traditionally Consumed Fish

All six fishing locations in the 2022 data found mercury levels that exceeded Health Canada guidelines for sensitive populations in walleye and northern pike at varying lengths (*Figure 2.2*). Heightened mercury concentrations in fish pose both a health risk and a cultural risk for practices such as the harvesting, cleaning and consumption of fish in the Moose Cree community. It is also important to note that 83% of the Moose Cree community members who participated in the surveys indicated that they don't use the Ontario fish consumption guide due to not knowing about it, not understanding how to use it or choosing not to use it for reasons such as a distrust for the Ontario Government. These results demonstrate a need for the creation of community-based fish consumption advisories moving forward.

Currently, the Ontario Government has created fish advisories for several areas across Ontario, predominantly for informing sport fishers on safe consumption (i.e how many fish are safe to eat per month). The Government of Ontario monitors several chemicals, including mercury. The Ontario fish advisories for the Moose River watershed were last updated in 2014 according to their website (https://www.ontario.ca/https://www.ontario.ca/), and mercury is identified as the chemical influencing the consumption recommendations for this region. There are several limitations to their approach: Ontario consumption advisories assume that the people reading the advisory weigh 154 lbs, which can limit the consideration for people who weigh greater or less than 154 lbs. The Government of Ontario also has limited or no recorded data in many traditionally important Moose Cree fishing locations, such as Camp Onakawana and Moose River Crossing. Many locations in the Moose Cree Territory have not been resampled in years, including the Abitibi area, which last sampled walleye for mercury in the 1980s. Consumption advisories made by the Ontario Government also consider monthly fish intake rather than weekly intake. Individuals are unlikely to track their monthly consumption of fish but often recall weekly consumption (Hoover, 2013). A weekly advisory could relieve some of the additional burden of tracking. This is particularly useful for community members who regularly consume fish more than once a month.

While our consumption recommendation calculations were made on a weekly basis and factored in various weights, the outcomes resulted in similar recommendations to the Ontario Government for sites where both our study and the Ontario Government have sampled. For example, the Government of Ontario guideline indicates that 18–20-inch walleye in the Moose Factory area should not be consumed by sensitive populations (Government of Ontario, 2021a). Similarly, our data advises that sensitive populations should not consume a serving of walleye between 15-20 inches or more at this location (*Figure 2.3*).

Restrictions on fish consumption can deeply impact people's connection to fish. Our interviews indicated that fish are incredibly important to the Moose Cree people.

"It's one of our sustenance, and what we do is we eat fish throughout the year. For instance, we have different seasons for geese, but we fish pretty much all year round."

- Male Moose Cree Fish Harvester

A study by Hoover (2013), who worked with the Mohawk community of Akwesasne, located on the Saint Lawrence River near the Ontario, Montreal and United States of America borders, learned of a similar importance of fish and fishing, where it was strongly tied to Akwesasne culture and that community members would regularly consume fish every week (Hoover, 2013). However, when fishing advisories were implemented in the 1980s due to anthropogenic activities on the land, it impacted the community's fish consumption and eroded away parts of their culture that had been passed down for generations (Hoover, 2013). Many community members had become afraid of consuming the fish altogether due to the fish contamination advisories (Hoover, 2013). The community's language (known as Kanyen'kéha) had been impacted, especially words related to fish and fishing, and skills meant for fishing, such as how to create nets for catching the fish, had disappeared (Hoover, 2013; Government of Québec, 2025). This study provides further evidence of the importance of fish and fishing and the harm that land disturbances and consumption advisories can have on Indigenous communities and their cultures.

2.4.2 Modifying Fish Consumption Recommendations and Size of Fish in Moose Cree Territory

The assumption that mercury burden increases with increasing length didn't always hold true in our study. This is somewhat problematic for risk messaging as well as consumption calculations for the development of guidelines, as both are predicated on this relationship (see *Equation 1*). For risk messaging, the lack of relationship with length presents a challenge, as length is often used as an accessible proxy for contaminant burden when communicating safe consumption guidelines to the public; length is also discussed by harvesters as a factor influencing whether they keep a fish or not. If mercury concentrations do not reliably correlate with length, advisories based on size thresholds may be misleading, potentially underestimating risk for smaller fish with high mercury levels, or overestimating risk for larger fish with lower-than-expected concentrations. This inconsistency complicates efforts to provide clear, actionable guidance to communities and resource users who depend on fish for food, cultural practices, and livelihoods. At some sites we found a significant linear relationship between length and mercury, however these relationships were often very weak (Moose Factory Area:

walleye R^2=0.15, Abitibi River/ Onakawana: walleye R^2= 0.09, northern pike R^2= 0.72, Moose River Crossing: walleye R^2= 0.14, Mouth of Abitibi: walleye R^2= 0.69, northern pike R^2= 0.27) (*Figure 2.2*), and five sites had several small walleye with mercury concentrations that exceeded that of larger fish. This weak relationship may be a product of small to medium sample sizes. Additionally, the relationship between length and mercury in walleye can be influenced by several factors, which can reduce the strength of the relationship. This includes diet, age-length misalignment, habitat variability, and individual metabolic rates. According to a study done by Wiener et al. (1990), environmental factors in aquatic ecosystems, such as the pH level, can create higher mercury variation in walleye. Temperature can also influence the growth of walleye (Christie & Regier, 1988). A study done by Christie & Regier (1988), found that the optimal temperature range for walleye growth is between 18-22°C and that in colder temperatures, walleye can take a longer time to grow which means smaller walleye may be older than they appear in areas that experience colder climates (Christie & Regier, 1988; Peat et al., 2015). Simoneau et al. (2005) further confirmed that walleye in the Quebec Abitibi area were found to grow more slowly than walleye found at other sites in their study. They suggested that their observations further display how environmental factors play a role in mercury accumulation (Simoneau et al., 2005). These studies elaborate on the complexity of environmental and biological factors that can influence mercury levels found in walleye at varying sizes. For example, in a study by Gewurtz et al., (2011), walleye were demonstrated as one of the few fish where sexual dimorphism plays a key/significant role in pollution bioaccumulation. Mercury and PCBs were shown to be significantly different in male vs. female walleye; a combination of lipid content, growth rate, age at maturity and energy allocation to gonad development were all important factors influencing bioaccumulation (Gewurtz et al 2011). With this in mind, it is important to consider how biological and environmental factors can influence different species of fish that could be sampled in the future. It is also important to note that, rather than length, fish age analysis would support data interpretation and the variability that may occur in mercury found in fish from Northern Ontario (Chételat et al., 2021). Future studies in the Moose Cree Territory should be done to investigate the relationship between mercury burden in fish and water quality parameters such as dissolved organic carbon (DOC), pH, temperature, and conductivity. Sampling for water quality should occur during fish harvesting events and potentially seasonally at the locations where fish are being monitored for mercury. In addition to investigating water quality parameters, continuous monitoring efforts for multiple fish species, along with multi-evidence-based approaches for consumption advisories, could further assist in the creation of community-based consumption guides. Such approaches could work to reduce cultural harm and would aim to provide alternatives for species of fish that could have lower mercury concentrations in them compared to predatory fish species. Data from these monitoring programs can also assist in the assertion of land rights and the protection of culturally important fishing locations in the territory. Simplifying data, converting existing data to the Moose Cree language, creating audio options for guides, and regular in-person communication could be highly beneficial to the community when communicating fish consumption advisories.

2.4.3 Differences in Mercury Burdens Between Six Culturally Important Fishing Locations

Significant differences were identified between Moose River Crossing and the Abitibi/Onakawana site, as well as between the Moose Factory Area and Moose River Crossing. The Moose River Crossing site was found to have the highest mean concentrations of mercury in walleye when compared to the other sites (*Table 1*). The Moose River Crossing site is downstream from five active hydroelectric dams located on the Mattagami River. The watershed surrounding the site has also been disturbed by a landfill in the process of being decommissioned, multiple historic petroleum wells, an active train crossing, and an active temporary winter road, which may be contributing to the mercury burdens in fish caught from this site (Government of Ontario, 2024; Ontario Geohub, 2025; Ontario Northland, 2025). There are many factors that may contribute to the observed higher mercury concentrations in walleye at Moose River Crossing. It is possible that there are higher methylation rates of divalent mercury in the tributaries/watersheds of that area, and/or there could be influences from the anthropogenic activities within the watershed. It is also worth noting that Moose River Crossing appeared to have median mercury concentrations (15-16 in, 0.64 µg/g, n=10; 19-20 in, 0.64 µg/g, n=6) that exceeded the median mercury concentrations in walleye found in Northern Ontario in the same length classes reported by Gandhi et al. (2014). The study done by Gandhi et al. (2014), found that mercury concentrations in walleye from 453 Northern Ontario locations that were 15.7 inches long averaged at approximately 0.4 µg/g (minimum/ median), and 0.7 µg/g (maximum) from 2000-2012. The 50 19.6-inch walleye had a median of 0.6 µg/g (1.3 µg/g maximum) (Gandhi et al., 2014).

When the Government of Ontario data was compared to the 2022 data from this study, it indicated that mercury concentrations in walleye from around the Moose Factory area haven't experienced any significant changes over the years that data was collected (1999-2022), *Figure 2.6*. Our data shows concentrations at this site surpassing the guideline for sensitive populations from fish that were 12 inches and above (*Figure 2.2*, Panel A). Similarly, in 2018, Lennox et al., found that walleye 13-14 inches upstream and downstream of the Moose River (including the Moose Factory Area) exceeded the guideline for sensitive populations at a concentration of approximately 0.4 µg/g wet weight.

The Abitibi River data showed a significant change between the data that was gathered in the 1980s and the data from our study (2022). The data indicated that mercury levels have declined since the 1980s in the Abitibi River. However, mercury concentrations are shown to be above the Health Canada Guidelines for sensitive populations, and some samples were above the general population guideline (*Figure 2.2*). From the 1920s-1970s, the Abitibi River experienced multiple land disturbances, including the construction of multiple hydroelectric dams, logging activities, and the construction of the railroad and roads for mining or natural resource access (Preston & Long, 1999; Government of Ontario, 2021b). In reservoirs, methylmercury concentrations influenced by hydroelectric dams generally peak 5-8 years after impoundment and can take 15 to over 20 years to return to baseline levels in fish (Calder et al., 2016). Data from *Figure 2.6* shows that mercury levels are lower than they were in the 1980s, indicating that peak mercury levels from early land disturbances have since declined. A study by Brouard et al. (1990), in the James Bay region of Quebec, found that mercury levels post hydroelectric dam took 20 years to return to baseline levels for non-piscivorous fish (whitefish), whereas the piscivorous fish (northern pike) took 30 years to return to baseline levels. Another study by French et al. (1998), found that fish mercury levels around Newfoundland hydroelectric dam sites remained elevated for up to 60 years following impoundment. Despite long waiting periods, the data from the Abitibi River site may indicate that mercury concentrations are declining. Erosion and flooding from hydroelectric projects and recent development projects likely continue to influence mercury in fish from the Abitibi River despite having lower levels from the 1980s (Calder et al., 2016).

2.4.4 Bringing Together Community Knowledge and Chemical Data on Mercury to Explore Its Connection to the Diverse Threats Impacting Cultural Practices and Food Systems in Moose Cree First Nation Territory

By investigating mercury levels in fish, through an interdisciplinary approach (i.e. interviews, surveys and chemical data collection) it became apparent that it is not just mercury impacting the Moose Cree people's relationship with their traditional food sources. Our results indicate that development projects have significantly impacted the Moose Cree community's relationship to their land, water, and traditional food. Project participants emphasized that water levels are changing in the rivers, that they're experiencing difficulties navigating by boat in the territory and that sandbars have been noticed more frequently than they had been when they were younger, making it difficult to carry out cultural practices on the land, including fishing and hunting for food, fewer family camping trips and limitations on educational opportunities for the youth (*Figure 2.4*). Boat motors have also been damaged more frequently due to the lower water levels and increased sandbars, making fishing and hunting more costly for the community, already faced with higher-than-average prices in Ontario. Other community members who could not participate in formal surveys and interviews due to time constraints but who have attended project events such as the project open house, training sessions and/or the return of results open house and feast, have also mentioned similar observations that interview participants have noted such as changes in water levels, increased sandbars, fewer animal sightings, difficulties navigating transportation costs and observations of poor fish health.

Similarly, when La Grande hydroelectric complex was developed in Québec, it impacted multiple First Nations communities, including the Cree Nation of Chisasibi, the Cree Nation of Wemindji, the Cree Nation of Eastmain and the Cree Nation of Mistissini (Senécal & Égré., 1999). Not only were community members impacted by mercury from the hydroelectric complex, they also experienced impacts to the rivers such as flooding, low flow rates (up to 90% reduced flow in some areas in the Cree Nation of Eastmain), and a rapid increase of flow in rivers (Senécal & Égré., 1999). The changes to the rivers impacted their ability to fish, hunt, set up traplines and navigate the lands and waters (Senécal & Égré., 1999). In areas where flow rates and water levels had decreased, community members expressed that fish no longer tasted as good as they used to (Senécal & Égré., 1999). Areas that had previously been used for fishing and hunting for thousands of years had become damaged or lost entirely (Senécal & Égré., 1999). Another study written by Preston and Long (1999) noted that a Taykwa Tagamou Nation member noticed increased water flow from the Island Falls generating station that had been eroding away the riverbanks, transforming the land, and disrupting grave sites in the Abitibi River. Furthermore, he had noticed sandbars appearing on the land and an overall decrease in shamanism and cultural practices in his territory (Preston and Long, 1999). This case study further highlights how land disturbances from hydroelectric activity can disturb Indigenous people's ability to navigate land and water, and how the consequences of flooding, lower water levels, and drastic increases in the flow of rivers can impact a community's cultural practices and ways of life.

Project participants also noted that fewer animals are being spotted on the land, and fewer fish are caught in areas that used to have an abundance of different species. Other areas in the territory have seen an increase of certain fish species, according to interviewees. However, most of the interviewees agreed that fish have declined over their lifetimes or have declined from previous generations. Rare occurrences of fish die-offs were also mentioned by members of the Moose Cree First Nation. Members of the Moose Cree First Nation often trap their fish after the fish have spawned and will release larger fish to allow them to restock their populations. This co-dependent relationship has been carried out for multiple generations. According to some interviewees, fish populations were extremely abundant generations ago, before significant land disturbances occurred on the land and in the rivers.

"When we went fishing a long time ago, we caught 200, or over 200 Fish!... We don't even get 20 now when we try. They don't come anymore. I don't know what happened to the white fish. Fish don't seem to be coming in anymore."

- Moose Cree Elder on their experience catching fish at one of their family's traditional hunting camps as a young person, compared to today.

Survey data also noted the changes that are being seen with the fish (*Figure 2.4*). Changes to the colour and skin of fish, as well as more frequent fish injuries, have been observed by many Moose Cree interviewees. An article by Depew et al., (2012) found that rainbow trout showed skin discoloration when exposed to methylmercury during a lab-based study. However, the discoloration in fish found in the Moose River watershed should be further investigated to better understand the changes that are being seen, to rule out other factors that could be present. Studies have found that fish injuries and mortalities can increase when a water system is disturbed by a hydroelectric dam (Brown et al., 2014; Crew et al., 2017). Disruptions from water level fluctuations, pressure changes, turbine mortality/injury, screen/rack impingement, behavioural and operational entrainment/ impingement risk and turbidity/ rapid flow alterations can all contribute to increased fish mortalities and injuries (Brown et al., 2014; Crew et al., 2017). Similar quantification studies should be conducted in Moose Cree Territory to understand how hydroelectric dams contribute to the significant fish injuries that have been observed by community members.

2.4.5 The Creation of a Process for Informing Risk Assessment

Tengö et al., (2014), found that multiple evidence-based approaches ensure the capture of community perspectives and the participation of peoples with multiple experiences and knowledges. Our study aimed to create a multiple evidence-based approach to assess the risk of mercury in fish and develop fish consumption advisories with the Moose Cree First Nation community.

Our process emphasized community knowledge and involvement throughout the entire research cycle (*Figure 2.6*). Our team was committed to ensuring that, as we investigated mercury, we approached it from multiple perspectives using both Western and Indigenous science so that the story of mercury wasn't understood in isolation but as a node in a complex web of impacts from resource extraction and land use activities. To fully understand and assess the risks of mercury, our research highlights that there is a need to understand Moose Cree relationships with the land and the impacts that community members have noticed and feel from industry.

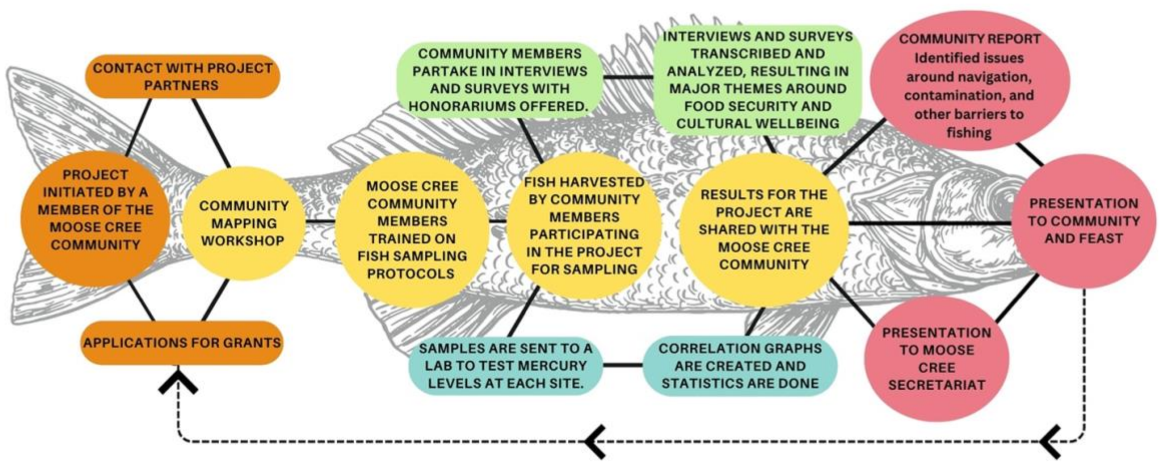

Figure 2.6: An interdisciplinary framework for preliminary assessments of fish contamination and risk assessment.

Our approach emphasized building community capacity and knowledge mobilization. Our responsibility as researchers included creating space for multiple community voices so that the knowledge generated could best benefit Moose Cree First Nation.

5 CONCLUSION

Indigenous communities in North America rely on land-based foods for physical, cultural and mental well-being. Such traditional land practices have allowed Indigenous communities like Moose Cree First Nation to carry out their land-based teachings since time immemorial. Fish and fishing are central to Moose Cree culture, health, and well-being, yet concerns about contamination, particularly from hydroelectric development and resulting environmental changes, have reduced access to fishing, disrupted intergenerational knowledge transfer, and impacted community confidence in consuming fish. Our data is clear: popular areas for fishing have mercury concentrations in walleye that greatly restrict consumption. It is also clear that data from Moose Cree Territory doesn’t always follow the “larger the fish, the more mercury trend” as the relationship between fish and length was weak at some of our sampling sites. This makes it difficult to develop reliable guidelines. Future monitoring programs could improve our ability to advise on mercury risks and understanding of mercury concentration by collecting fish age structures and developing studies that include gonad identification, gonad stage development, and mark recapture monitoring.

Based on these results, we recommend that efforts be made in Ontario by the Ontario Government and hydroelectric companies to ensure that the hydroelectric dam impacts on river navigation are reduced, and that significant efforts are made to ensure hydroelectric development impacts on fish mercury burdens (i.e. erosion and flooding) are also reduced and mitigated. Our results also indicate that access to fishing support (boats, gas, nets, training) should be a priority to ensure intergenerational opportunity for the Moose Cree community.

By working closely with Moose Cree First Nation, the story of mercury and fish has expanded into a story about the diverse impacts of land disturbances and how it has impacted everyday life and cultural practices in the territory. It also serves as an example that illustrates the multiple perspectives, observations and experiences different peoples have, which creates a greater understanding of the impacts on the Moose Cree community. Ultimately, our approach creates an informed direction for the creation of fish consumption advisory tables and consumption guides with the communities that are the most impacted by the mercury concentrations in fish, and by listening to community members, a greater understanding of land-based impacts can be understood. This greater understanding can therefore create a steppingstone for sustainable solutions in collaboration with Indigenous communities and land developers.

CHAPTER 3:

Assessing Mercury in Walleye in Moose Cree Territory:

A Case Study

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ABSTRACT

In northern Ontario, Canada, the methylation of inorganic mercury to the more toxic form of mercury, monomethylmercury (MMHg), poses risks as MMHg biomagnifies in aquatic food webs, especially in predatory fish such as walleye (Sander vitreus). This study, conducted in collaboration with Moose Cree First Nation, investigates the spatial and seasonal patterns of mercury in walleye across five culturally significant fishing locations in the Moose River watershed, along with historical and quantitative analyses.

Walleye were caught and sampled by community members at sites selected through participatory workshops, and total mercury concentrations were measured in muscle tissue samples. Results revealed some spatial variability in mercury burden, with slightly higher concentrations found at sites near hydroelectric development. Seasonal analysis at Moose River Crossing did not show significant differences in mercury levels; however, sample sizes for seasons were limited. Regression analyses demonstrated a weak and inconsistent relationship between fish length and mercury concentration, challenging the assumption of existing fish consumption advisories that larger fish accumulate more mercury.

The findings from this study highlight the need for higher-resolution, locally driven risk assessment and mitigation for mercury monitoring in northern river systems.

3.1 INTRODUCTION

Since the 1960's, mercury (Hg) has become a major human health concern, sitting as one of "the ten leading chemicals of concern" in environments around the world (World Health Organization, 2020; Basu et al., 2023). Mercury becomes especially concerning in aquatic environments where specialized microbes can transform it into MMHg, a more toxic form of mercury that can bioaccumulate and biomagnify in organisms (Al- Sulaiti et al., 2022). As MMHg makes its way through the food chain, larger predatory species like walleye (*Sander vitreus*) often accumulate higher concentrations than lower trophic species since they consume many organisms that have already accumulated traces of MMHg (Simoneau et al., 2005; Al- Sulaiti et al., 2022). People who consume predatory species like walleye can therefore accumulate the MMHg that the fish carry in their bodies.

To counteract the negative health impacts that MMHg can have on people who consume fish, Governments often create fish consumption guides in areas where MMHg levels have surpassed the respective guidelines (Government of Ontario, 2021a). Fish consumption guides recommend the number of a particular fish species that people can safely consume over a specified period of time. They were originally created with recreational harvesters in mind and were meant to be temporary (Imm et al., 2005). Since their initial creation, they have become problematic for Indigenous peoples who rely on the consumption of fish from the areas where the consumption guides have been created (EAGLE Project, 2001; Hoover, 2013). For Indigenous peoples who rely on land-based foods as their main source of sustenance, contaminated fish can threaten their health and ability to exercise their territorial rights.

3.1.1 Shortcomings of Process for Monitoring Mercury in Fish for the Development of Fish Consumption Recommendations

There are several limitations to the development of fish consumption recommendations and this has been acknowledged widely in the literature, from debate around how Total Allowable Daily intake is calculated, limitations to single contaminant assessments and cumulative effects considerations to debate about what is considered a true serving size it is clear there is much room for further research (Jones, 1999; Health Canada, 2007; World Health organization, 2008; Viera et al., 2015; Kim et al., 2016). Given the current state of the science and what is currently considered an acceptable approach to the development of fish recommendations, there are limitations that can be immediately addressed by more localized monitoring programs that engage communities most reliant on fish for their well-being. For example, fish contaminant monitoring programs often lack community involvement during their creation, which limits knowledge sharing and inquiries about community concerns; they also often miss important traditional fishing locations, which may have greater or lesser potential for high mercury burdens compared to sites in the area that are targeted by scientists carrying out fish contaminant monitoring programs. Additionally, contaminant monitoring programs can take up to several years or more before the subsequent fish consumption guides are updated, limiting the information that's available to a community during that time. Fish contaminant monitoring programs are also frequently made with fish samples collected during the summer months. This sampling strategy doesn’t account for seasonal MMHg differences within different fish species, which leaves a question about the possibility for seasonal differences between certain species. Lastly, the application of fish contaminant monitoring program data to create fish consumption guides relies on the assumption that length is a strong predictor of the mercury burden found in various species of fish, which is not always the case (Gewurtz et al., 2011a).

The objectives of this study were to address these limitations on a local scale focusing on walleye, through a case study in Moose Cree First Nation Territory by 1. determining if there are differences in mercury loadings in walleye between culturally significant fishing locations in the Moose River watershed; 2. determining if there are seasonal differences in walleye caught from one of the fishing sites that are fished year round, Moose River Crossing; 3. determining if there are significant changes in the mercury burden in walleye over time using both Government and this study's data; 4. assessing the relationship between length and mercury burden in walleye from the Moose River watershed

3.2 METHODS

3.2.1 Study Site

The ᐃᓕᓕᐧᐊᐢᑭᐩ | Ililiwaskiy (Moose Cree) Territory is located in James Bay, Ontario, Canada. The Moose River watershed drains an area of approximately 109,000 km² (McCrea & Merriman, 1981). Its three main tributaries include the Missinaibi River, the Mittagami River and the Abitibi River, which eventually drain into the Moose River and into James Bay (McCrea & Merriman, 1981). The Moose Cree peoples are largely populated around Moosonee and on Moose Factory Island. However, the entire territory is utilized for hunting, fishing, and other traditional practices.

Sampling locations within the watershed were determined by the Moose Cree People through an interactive workshop during the project launch (see chapter 2 for details). *Figure 3.1* displays the fishing locations where walleye were caught.

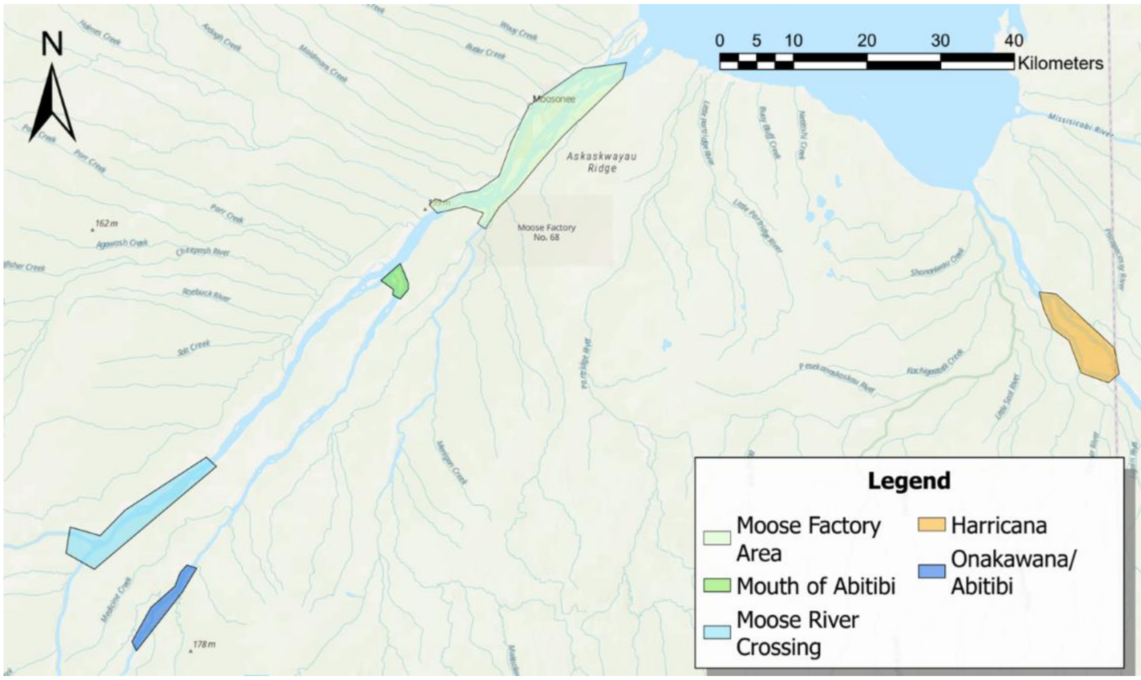

Figure 3.1: Sampling areas for mercury study in the Moose Cree Territory. Regions included Moose Factory Area, the Mouth of the Abitibi River, the Harricana River, and the Onakawana/ Abitibi River.

3.2.2 Sampling

Moose Cree harvesters were trained on fish sampling and hired to catch fish at the 5 locations identified in *Figure 3.1*. Total length, fork length, location, date, and species were recorded. A small portion of the muscle tissue was preserved on ice and transported to the band office until shipment to a certified lab by the Moose Cree First Nation Lands and Resources Department.

Samples were homogenized and sub-sampled prior to being placed on a hot block digestion, where HNO3, HCl, and H2O2 were added to digest the samples following the new perspectives method added to the British Columbia lab manual to improve interlaboratory consistency-metals in animal tissue and vegetation (Government of British Columbia, 2023). All samples were analyzed by ALS Laboratories for total mercury and percent moisture. Over 180 samples were sent to the lab for analysis by ICP/MS. Mercury analysis was done through CVAAS (cold vapour atomic absorption spectrometry). Northern pike and sturgeon samples were limited at many of our sample sites, whereas walleye samples were abundant; therefore, walleye is the species we focus on in this paper. All available government sampling years up until 2022 were identified. There were two government sites near two of our study's sites (Moose Factory area and the Abitibi River), which were used for comparisons between years.

3.2.3 Data Analysis

Our site location data and our seasonal data were tested for normality and homogeneity of the variances using R Studio. Data was transformed where necessary to meet the assumptions of the parametric tests used to analyze the data. ANCOVAs were performed to determine if there are differences between sites (Objective 1) and seasons (Objective 2). A comparative analysis assessing similarities or differences for mercury in walleye between the Ministry of the Environment, Conservation and Parks (MECP) data and our data was performed (Objective 3). A series of regressions were also used to assess the relationship between length and mercury burden in walleye (Objective 4).

3.3 RESULTS AND DISCUSSION

3.3.1 Differences in Mercury Burden in Walleye Between Sites

The results from the ANCOVA indicated that there is a difference in the mercury concentrations from sampled fish between the Moose Factory Area and the Moose River Crossing site (p 0.001) and a difference between the Moose River Crossing site and the Onakawana/Abitibi River site ($p < 0.001$). Differences between the other sites were not significant ($p > 0.05$). It is important to note that some sites had small sample sizes, which could be corrected in the future to better determine site differences at locations such as the Harricana River site and the Mouth of the Abitibi site.

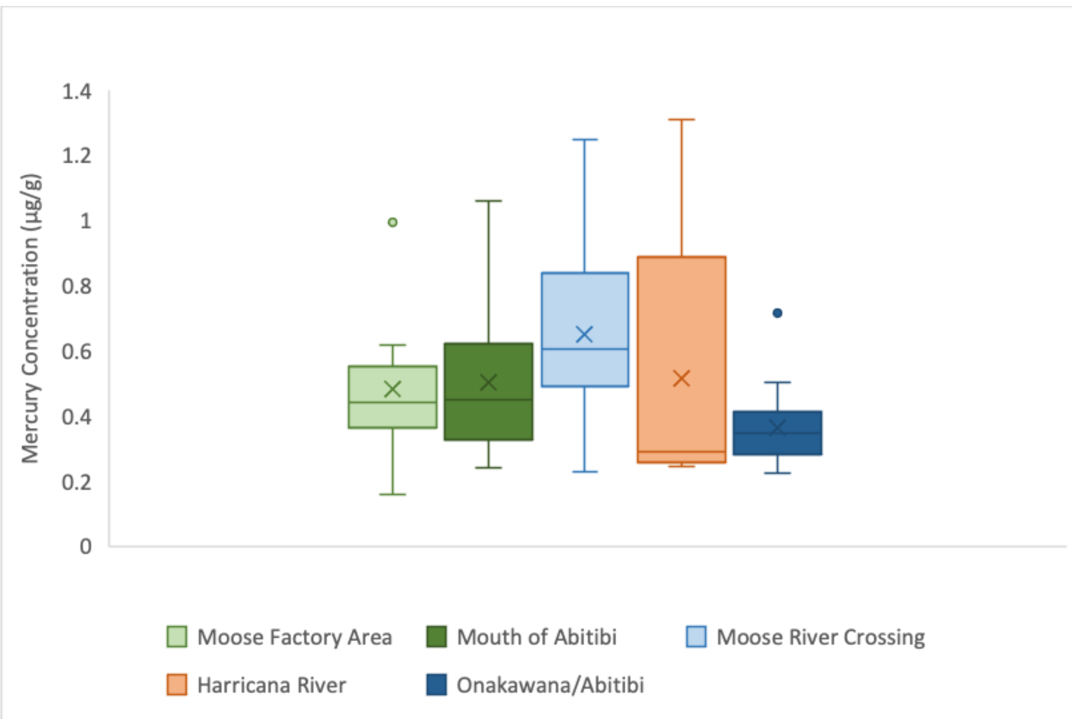

Figure 3.2: Average mercury content (marked by x) in walleye 15-20 inches at each of the five sites. Where Moose Factory Area n=9, Mouth of Abitibi n=9, Moose River Crossing n=27, Harricana River n=5 and Onakawana/Abitibi n=12.

Northern ecosystems in Canada experience higher levels of mercury than southern Canadian ecosystems do (Pirkle et al., 2016). The higher levels of mercury in northern areas of Canada are largely influenced by a higher latitude compared to the south, where global currents often push air pollutants (Pirkle et al., 2016). Atmospheric mercury pollutants can travel long distances and accumulate in colder climates (Pirkle et al., 2016; Government of Canada, 2022). Human activities such as logging, mining, and the implementation of hydroelectric dams can also greatly influence the levels of mercury found in a local environment since they often increase rates of erosion and the release of organic material (Calder et al., 2016; Pirkle et al., 2016). Concentrations of mercury in fish are typically higher in regions with frequent anthropogenic disturbances compared to those that experience limited disturbances (Garcia & Carignan, 2000; Evans & Talbot, 2012). Habitats such as peatlands and bogs accumulate more mercury than other habitats and are often sources of methylmercury in aquatic habitats around them (Sun et al., 2023). The James Bay area, where Moose Factory is located, is known to have the second-largest peatland complex in the world (Holmquist et al., 2014). Peatlands and bogs generate a higher potential for hydrogen (pH) than other wetlands do (Talbot et al., 2017). They accumulate organic matter and have anoxic conditions with extremely low flow rates, allowing them to slowly accumulate and hold larger levels of atmospheric mercury and naturally occurring mercury over time compared to other wetlands (Talbot et al., 2017). The anoxic, or low oxygen conditions in peatlands allow a specialized type of bacteria to convert mercury into methylmercury, allowing it to be taken up by organisms like aquatic insects and fish (Hu et al., 2020). Although bogs and peatlands are generally landlocked, they are still able to slowly leach out mercury over time (Talbot et al., 2017; Hu et al., 2020). They also have the potential to release larger amounts of mercury into the atmosphere during flooding events or fires (Rein & Huang., 2021). Concentrations of mercury in walleye between lengths of 8-38 (in) with the majority of the fish 14-19 (in) found in this study ranged from 0.1 µg/g ww to 1.7 µg/g ww where the average ($\bar{x}$) = 0.5 µg/g ww), this is within the previously reported range for the local ecosystem (i.e. northern peatlands) (Gandhi et al., 2014; Lennox et al., 2018; Moriarity et al., 2020); however the site that had the highest concentrations of mercury (Moose River Crossing, walleye 8.5-35 (in), range= 0.2-1.4 µg/g ww [$\bar{x}$ = 0.7 µg/g ww]) is the closest of the five sites to a large series of hydroelectric development on the territory, suggesting that hydroelectric impacts may be contributing to fish mercury burdens. The Moose River has been disturbed largely by hydroelectric dam development projects. Moose River Crossing has also been disturbed by logging that occurred from the 1950’5-1980’s (Preston and Long, 1999); as well as from roads, a railroad, aggregate pits, a landfill and petroleum wells. The Moose Factory area has two hydroelectric dams in close proximity to each other, residential areas, a decommissioned landfill, a hospital, and an airport. The Abitibi River has more than six hydroelectric dams located along it, with the most recent one established in 2017. Significant differences were only found between Moose River Crossing and the Moose Factory Area, as well as between Moose River Crossing and the Abitibi River site.

3.3.2 Seasonal Differences in Mercury Burden in Walleye

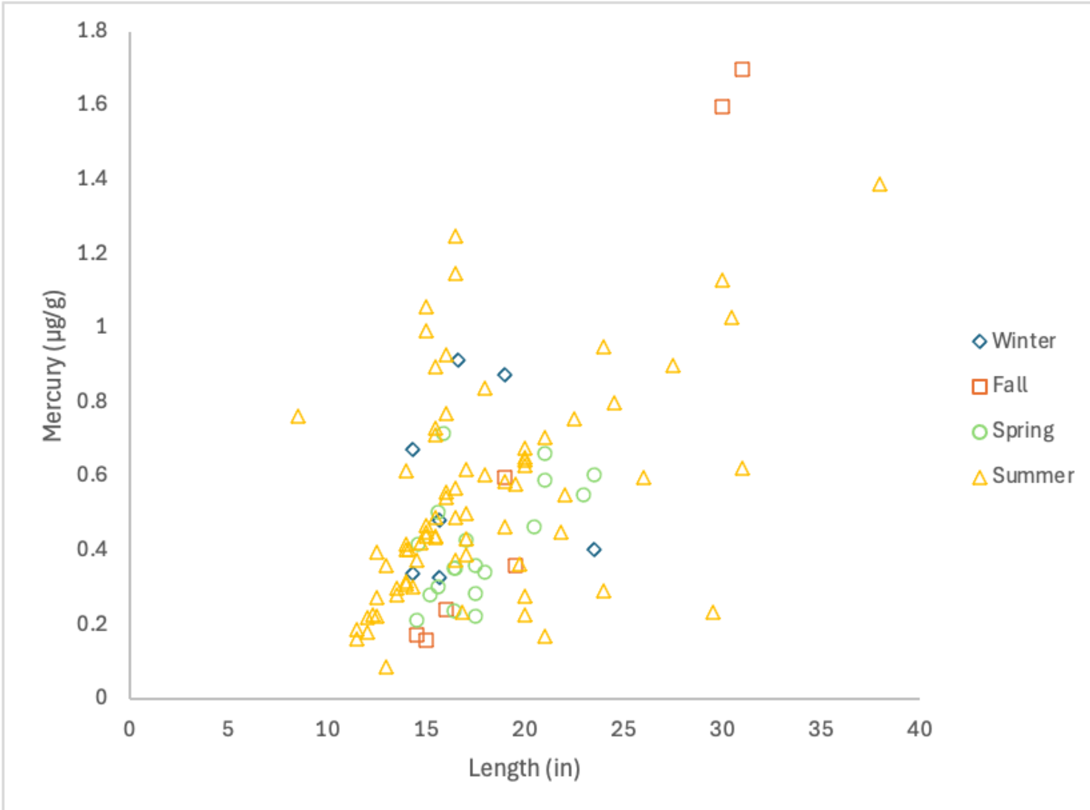

Figure 3.3: All walleye data and the corresponding seasons they were caught in. The blue diamond represents winter (n=7), the red square shows fall/autumn (n=7), the green circle represents spring (n=19), and the yellow triangle represents summer months (n=74).

Results exploring the seasonal data showed that in the case of walleye, there were no significant differences between seasons at the Moose River Crossing site (p 0.07) (Figure 3.3.). Other sites in this study had limited comparative data (<5) in certain seasons and were therefore excluded from ANCOVA tests.

Some studies have suggested that mercury accumulation changes in fish depending on the season, but this seasonal change is not always seen (Piro et al., 2023; Mills et al., 2018). In some instances, short-term environmental changes may not be detectable in fish tissue mercury (Mills et al., 2018). Mercury excretion rates are low, so brief decreases in mercury intake from fish diets may not always show a difference in mercury concentrations between seasons (Mills et al., 2018). Sampling timing, frequency of sampling, and limited sample sizes can also affect the detection of seasonal variation for mercury in fish tissues (Gewurtz et al., 2011b; Mills et al., 2018).

The Moose River Crossing site had the greatest number of walleye mercury samples within this study; however seasonal variation may not have been detected due to there being a limited sample size for the winter season (n=7), whereas the summer season had a higher sample size (n=37). Studies have suggested that seasonal changes can be detected and that mercury in fish is often the highest in the spring when compared to summer or fall months (Ward and Neumann 1999; Farkas et al. 2003; Moreno et al. 2015). Further analysis should be carried out to confirm whether mercury levels in fish are significantly altered by seasons in the Moose River watershed.

Our study indicated that small-sized fish were often found to have high concentrations of mercury in them, similar to many larger fish. Temperature can influence the growth of walleye (Christie & Regier, 1988). A study done by Christie & Regier (1988), found that the optimal temperature range for walleye growth is between 18-22°C and that in colder temperatures walleye can take a longer time to grow which means smaller walleye may be older than they appear in areas that experience colder climates and longer winters (Christie & Regier, 1988; Peat et al., 2015). Simoneau et al. (2005), further confirmed that walleye in the Quebec Abitibi area were found to grow slower than walleye found at other sites in their study. They suggested that their observations further display how environmental factors play a role in mercury accumulation (Simoneau et al., 2005). These studies elaborate on the complexity of environmental and biological factors that can influence mercury levels found in walleye at varying sizes.

It is important to consider how biological and environmental factors, such as seasonal differences, can influence different species of fish that could be sampled in the future. The results for mercury in walleye showed that there were no significant seasonal differences found. The sample size for this study was small compared to sample sizes from studies that have found seasonal differences (Hartman & Margraf., 2006; Zhang et al., 2012). A larger quantity of walleye samples at Moose River Crossing would be needed in future studies to confidently address whether there could be a seasonal difference in fish mercury levels at this site. Other traditionally consumed fish species should also be considered when determining fish mercury seasonal differences.

3.3.3 Mercury Concentrations at Similar Latitudes and Longitudes in Ontario

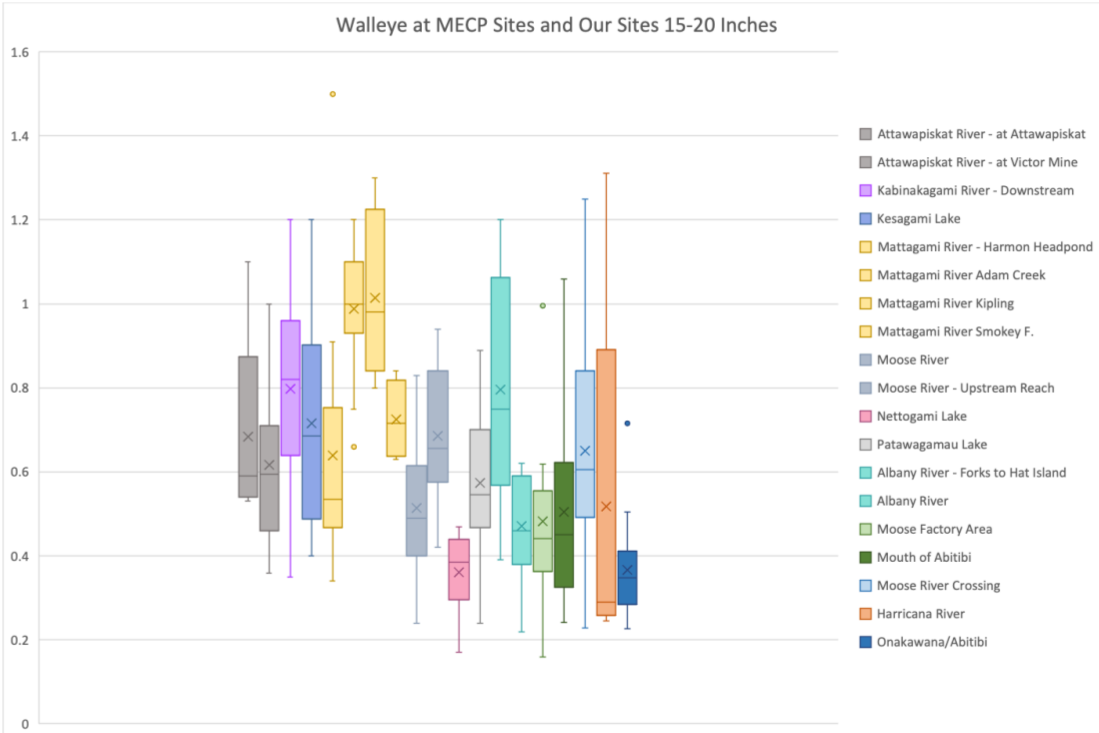

Figure 3.4: Ministry of the Environment, Conservation and Parks (MECP) mercury concentrations in 15–20-inch walleye (from 2005-2018) beside our study locations 15–20-inch walleye.

Mercury concentrations in walleye analyzed by the MECP at various sites within a latitude of 50.00000 to 53.00000 and a longitude of -84.00000 to -79.00000 show similar averages when compared to the sites in this study. It should be noted that most of the MECP locations had sample sizes <20, leaving room for high variability in the data shown in *Figure 3.4* (Attawapiskat River at Attawapiskat n=5, Attawapiskat at Victor Mine n=12, Kabinakagami River n=27, Kesagami Lake n=18, Mittagami River Harmon Headpond n=14, Mittagami River Adam Creek n=11, Mittagami River Kipling n=4, Mittagami River Smokey Falls n=6, Moose river n=21, Moose River Upstream Reach n=10, Nettogami Lake n=14, Patawagamau Lake n=12, Albany River Forks to Hat Island n=12, Albany River n=11, Moose Factory Area n=9, Mouth of Abitibi n=9, Moose River Crossing n=27, Harricana River n=5 and Onakawana/Abitibi n=12). The area chosen within the ranges of the selected latitudes and longitudes highlights the areas that are the most similar to the sites within this study. These locations share similar atmospheric ranges, temperatures, ecotypes, and geology.

MECP data show a variety of disturbed and undisturbed sampling locations. While many sites have experienced minor levels of disturbances, sites such as those on the Attawapiskat River, Mittagami River, and the Kabinakagami River have experienced significant impacts. The Attawapiskat River is mostly undisturbed but saw some disturbances from De Beers Victor diamond mine from 2008 till 2019, when it was eventually shut down (De Beers, 2024). The mine produced mercury effluent, which continues to be monitored by De Beers (De Beers, 2024). The Mittagami River has been largely disturbed by four major hydroelectric facilities (Little Long Rapids Generating Station, Smokey Falls Generating Station, Harmon Generating Station and Kipling Generating Station (Ontario GeoHub, 2025). Mittagami River could therefore be experiencing higher concentrations of mercury in fish than sites with fewer or no hydroelectric disturbances. The Kabinakagami River has experienced heavy logging with many clear-cut areas. Kabinakagami Lake was also disturbed by a historic gold mine that shut down in 1934 (GeologyOntario; Government of Ontario, 2021c). Sections of the Kabinakagami River might see slight differences in mercury concentrations when compared to sites without disturbances; however, more data is needed to support this theory. Overall, the locations from the MECP data set showed similar averages to those seen in the data from this study.

3.3.4 Relationship Between Length and Mercury Burden in Walleye

Linear regressions between fish length and concentration of mercury in walleye were considered significant ($p < 0.05$) at the Moose Factory Area (p 0.041), Mouth of Abitibi River ($p < 0.001$), Moose River Crossing (p 0.014) sites, whereas the Harricana River (p 0.921) and Abitibi/Onakawana site (p 0.152) were not significant. Where significant regressions were observed, they were considered weak relationships ($R^2 < 0.3$) as seen in *Figure 3.2.* At all of the sites where walleye were caught, there were fish that exceeded the sensitive population guideline that were less than 15 inches long. Hg concentrations that exceeded the sensitive population guideline for sites with walleye ranged from 8.5 to 38 inches.

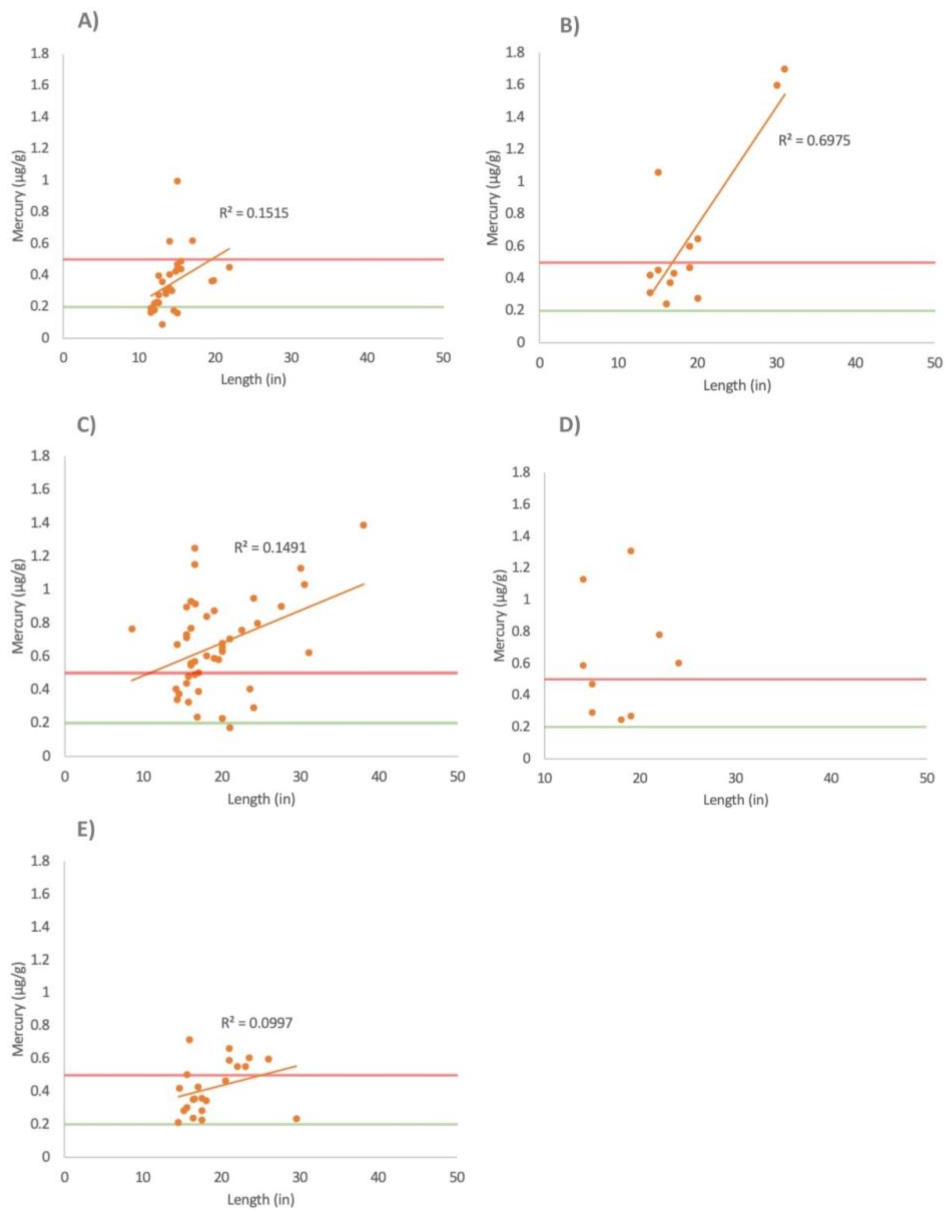

Figure 3.5: Mercury (µg/g) levels in different lengths (in) of fish at traditional fishing locations. Orange dots represent walleye. The red line represents the 0.5 ppm Health Canada guideline for the general population, and the green line shows the 0.2 ppm Health Canada guideline for sensitive populations (women, children, and subsistence consumers). Panel A) is the Moose Factory Area, B) the Mouth of the Abitibi River, C)

Moose River Crossing, D) Harricana River, E) Abitibi River. The solid orange regression lines show significant relationships.

Using regression models, we found that smaller-sized fish appeared to have mercury concentrations that were similar to larger fish caught at the same site in the study. In the literature, it is often cited that larger fish will have higher levels of mercury than smaller fish of the same species (Dang & Wang, 2012). As a fish grows, it can consume larger prey items (Dang & Wang, 2012). Larger fish are often assumed to be older than small-bodied fish, which would give them more time to accumulate Hg. However, the size of the fish doesn't always give a true estimation of the age of the fish. Colder climates can slow the growth of certain species of fish while also extending their lifespans (Quist et al., 2003). For example, a study by Quist et al (2003) found that walleye grow at a slower rate in northern latitudes when compared to walleye in southern latitudes. While other species such as northern pike thrive in colder environments (Craig & Babaluk., 1989). Another study by Lavigne et al (2010) demonstrated that slower-growing walleye and northern pike populations have higher Hg concentrations at a standardized length than faster-growing individuals do. A study done by Selch et al (2019) has also found that male walleye grow slower than female walleye by about a year. Their slower growth and faster metabolic rate mean that contaminants like mercury have a longer amount of time to accumulate in the tissues of the fish (Madenjian et al., 2016; Selch et al., 2019). Therefore, a male walleye the same size as a female walleye could have slightly higher levels of mercury in them (Selch et al., 2019). Another study by Madenjian et al (2016) found that contaminants like PCBs and Hg accumulate differently in fishes of different sexes and species. It is therefore important to consider the sex of a fish when assessing a species for mercury levels.

Our study has indicated that the length-to-mercury burden relationship is weak at all sites and insignificant at 1 out of 5 of the sites. Data was transformed and power regressions were also run to see if power models were better suited to the data, as seen in Neff et al., (2012) and Gandhi et al., (2014). Power regressions and transformation did not improve the relationship (see Appendix X, Table 1). This suggests that the region where our case study took place does not follow the "larger fish higher mercury" rule and that fish aging structures may be a more appropriate metric for predicting mercury burden. This becomes problematic for risk messaging as length is used to help the general public predict how many fish are safe to eat. Our results, therefore, suggest a different approach needs to be considered when converting fish mercury data to fish recommendations in this region.

3.4 CONCLUSION

Our study aimed to work in collaboration with Moose Cree First Nation in order to gain insights on how to approach the creation of a community-based fish monitoring program that can inform local fish consumption recommendations. The results from this study revealed the need for continued monitoring of mercury in the Moose Cree watershed. Differences between sites demonstrate the need for higher resolution monitoring that targets areas of cultural significance that are frequently fished for sustenance. Changes in Mercury over time were observed at the Abitibi site. Further investigation should be conducted to understand how land use changes, such as hydroelectric development, may contribute to upward trends in fish mercury burdens. The limited relationship between length and mercury burden in walleye suggests that the assumption that the bigger the fish, the higher the mercury burden does not always hold true. This has implications for fish consumption advisories, which rely on a length to mercury concentration relationship for calculating allowable intakes.

Together, we were able to better understand the current status of mercury in walleye at five culturally important fishing locations, determine if concentrations have changed at two of the studied sites, determine if mercury burdens varied at different sites and if seasonal variability showed any significance at one of the sites in our study. Our work created an outline for future monitoring in Moose Cree Territory so that a community-based fish consumption guide could eventually be created for the community.

CHAPTER 4:

Conclusions and Future Work

Mercury is a non-essential, natural metal that is found globally in small quantities (Driscoll et al., 2013). Anthropogenic air pollutants have greatly increased the quantities of mercury found in certain areas of the world, including northern parts of Ontario and Canada (Pirkle et al., 2015). Land disturbances from activities such as logging, mining and hydroelectric activity influence the mobilization of mercury into nearby watersheds (Driscoll et al., 2013; Pirkle et al., 2015; Calder et al., 2016). Once in the water, mercury can methylate in anoxic zones filled with specialized bacteria that convert mercury into methylmercury (Calder et al., 2016; Mailman et al., 2006). Methylmercury bioaccumulates and biomagnifies, leaving predators such as walleye and the people who consume them susceptible to accumulating high levels of mercury from their diets (Calder et al., 2016). Mercury at high concentrations in the body can result in health implications such as increased neurodevelopmental issues, cardiovascular issues, increased rates of cancer, and other chronic diseases (Harada 1995; Fernandes Azevedo et al., 2012; Park & Zheng, 2012).

Fish contaminant monitoring programs are often created to mitigate the impacts of mercury on the body (Health Canada, 2007). However, risk analysis practices used to construct consumption guides often miss important information such as a wider variety of weight classes, important fishing locations for Indigenous populations, a wider selection of traditionally consumed fish species and most importantly, Indigenous involvement, Knowledges and their voices. They can also take multiple years to update the concentrations found at their sampling locations. It is therefore important to work closely with Indigenous communities like Moose Cree First Nation to understand community concerns and to better understand the impacts that mercury can have at important fishing locations within Indigenous territories.

This study aimed to provide a baseline analysis of mercury concentrations in three traditionally consumed fish species (walleye [*Sander vitreus]*, northern pike [*Esox lucius]*, and lake sturgeon [*Acipenser fulvescens]*), in the traditional territory of Moose Cree First Nation, while understanding a need for collaborative efforts and understandings during the process of risk analysis.

Our results indicated that mercury concentrations at all six of our sample sites surpassed the Health Canada guidelines for the general population and for subsistence populations (*Figure 2.2*). The data we collected was also mostly within the ranges of mercury found at other locations in the northern parts of Ontario (Gandhi et al., 2014; Lennox, 2018; Moriarity et al., 2020). The site that had the highest concentrations of mercury in fish (Moose River Crossing, $\bar{x}$ = 0.7 μg/g ww) is the closest of the five sites to a large portion of hydroelectric development on the territory, suggesting that hydroelectric impacts may be contributing to fish mercury burdens. Our interview and survey data have also identified the diverse impacts that hydroelectric dams have had on Moose Cree First Nation harvesters, with multiple concerns stated regarding fluctuating/ lower water levels, the creation of sand bars and difficulty navigating by boat in the rivers (*Figure 2.5*). Other concerns were brought up regarding fewer fish at previously abundant harvesting locations and discoloured fish at certain sites, which could be due to a number of reasons and should be further studied.

Chapter 2 focused on overall mercury concentrations in walleye, northern pike, and sturgeon at the six sample sites in our study (*Figure 2.2*). A consumption recommendation for walleye 15-20 inches was created for Moose River Crossing and the area near Moose Factory, which included a variety of recommendations based on consumer weight classes as well as a weekly consumption recommendation (*Figure 2.3*).

Chapter 2 also investigated whether mercury burdens in walleye have changed over time. Government of Ontario data was compared with our study's data at two similar locations (*Figure 2.4*). The Abitibi River/ Onakawana site showed lower mercury concentrations compared to the concentrations recorded in 1980, while the Moose Factory area showed no significant changes over the years mercury data in walleye was retrieved (1999-2022).

Survey and interview results with 14 Moose Cree harvesters were shared regarding changes or observations to the environment, fish and fishing in the territory that they have made over their lives (*Figure 2.5*). In the interviews, prominent impacts on people's ability to fish due to water levels, navigation, and increasing sightings of sand bars were discussed frequently and in greater depth than other topics. Interviews emphasized the cultural importance of fish, fishing and access to traditional fishing sites (Figure 4.1)

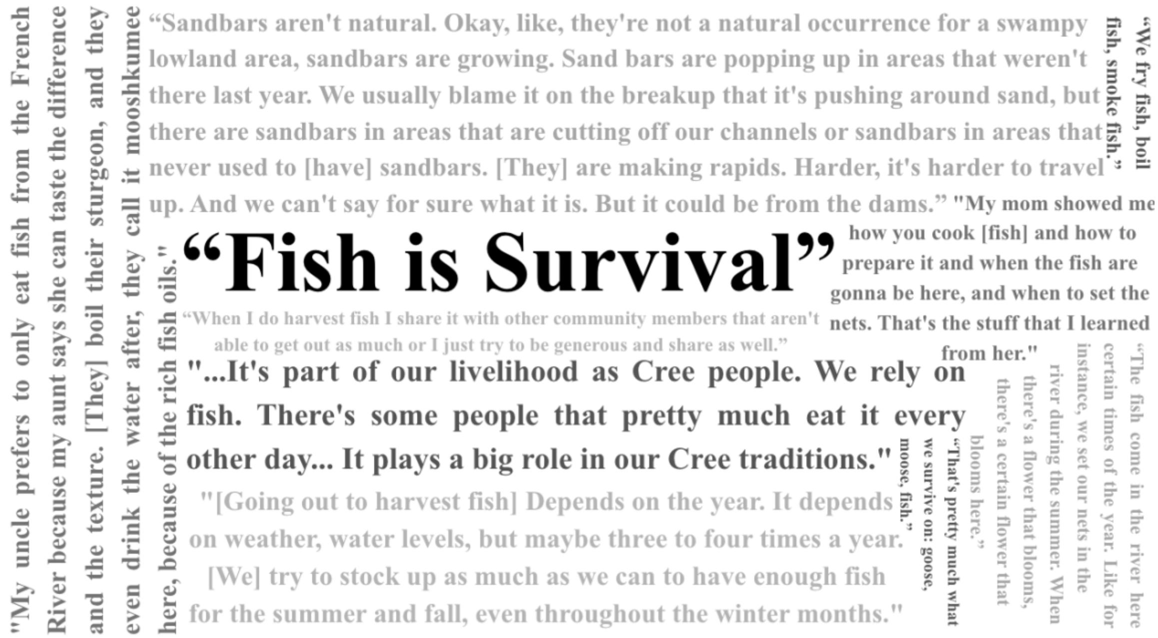

Figure 4.1: Quotes from community fish harvesters in Moose Cree First Nation.

Lastly, an interdisciplinary framework for preliminary assessments of fish contamination and risk assessment was developed to act as a guide that addresses limitations in traditional risk assessments (*Figure 2.6*).

Chapter 3 focused on mercury data for walleye at five sample sites (*Figure 3.5*), which assesses the relationship between length and mercury burden in walleye from the Moose River watershed. Weak linear regressions identified length as a weak representation of age for mercury concentrations found in walleye in Moose Cree Territory.

Multiple natural and unnatural sources were outlined as factors that can influence mercury concentrations in the Moose Cree Territory. The walleye data from this study was compared to known mercury averages from Northern Ontario in the literature and from MECP data. No dramatic deviations were seen from the expected averages. However, significant site differences were identified at the Moose River Crossing site (p 0.001), which carries the largest hydroelectric dam burden, compared to other sites in this study. Differences between sites demonstrate the need for higher resolution monitoring that targets areas of cultural significance that are frequently fished for sustenance.

No significant seasonal differences were identified for walleye in this study (p 0.07). However, seasonal differences in Northern Ontario walleye have been shown to be significant in the literature (Hartman & Margraf, 2006; Zhang et al., 2012). Seasonal differences for mercury burdens in walleye identified in the literature indicate a need for further research in Moose Cree Territory.

Traditional risk assessments often limit involvement with communities that are the most impacted by contaminants in the areas they sample from, which limits an understanding of the ways people experience risks (Checker, 2007). Advisories created from traditional risk assessments may also unintentionally lead to social, cultural and physical harm to the communities they're created for (Hoover, 2013). This standard for sampling poses limitations on community voices from people who know their land better than anyone else, which disregards possible concerns around commutive impacts (Checker, 2007). Community involved and informed risk assessments could, therefore, improve sampling methods for risk assessments in Indigenous communities, which could limit the harm that they pose.

Our work has brought together chemical data and community data, which has created an outline for future monitoring in Moose Cree Territory that can overcome some of the limitations of conventional risk assessments.

Conventional risk assessments hold a variety of limitations that can often approach monitoring efforts with a limited understanding of the needs and concerns of local communities (Arsenault et al., 2019). Through our collaboration with Moose Cree First Nation, we were able to listen to concerns around mercury in fish, coordinate workshops, training sessions, and open houses, as well as conduct surveys and interviews. Our time working together ultimately outlined the importance of community leadership and collaboration within the risk assessment process. Not only did it provide us with an understanding of how mercury has impacted Moose Cree community members' relationship with their traditional foods, but it also shone a light on the impacts that hydroelectric dams have had on the community's ability to practice their traditional fishing and hunting practices.

At the same time, we were also able to analyze mercury samples, which provided the community with recent results for mercury levels in fish. The inclusion of community engagement and collaboration has allowed the community to develop the skills they need to perform their own monitoring efforts so that they can continue to understand the contaminant presence in their territory without having to rely on outside sources who may not understand the locations or species the Moose Cree community hopes to target.

By working closely with the Moose Cree Community, we have opened an opportunity for scientists to understand the importance of community collaboration and how it can bring forth perspectives that aren't often considered in conventional risk assessments. By working closely with community members during risk assessments, community members have more control over where they would like monitoring to occur and what species they would like to test. Allowing community members to get more involved in risk assessments done in their territories provides the community with a greater opportunity to learn about contaminants in their territory, which can ultimately support how the community manages and communicates risk.

Through the inclusion of workshops, sampling training sessions, open houses, community sampling, surveys and interviews, we were better able to understand the concerns and needs that Moose Cree First Nation community harvesters had regarding fish, fishing and mercury. Our process (*Figure 2.6*) allowed us to understand that concerns for mercury in fish are equally tied to concerns around the impacts of hydroelectric activity on the land and how it has posed limitations on the Moose Cree community's ability and right to navigate and fish within their traditional territory. Utilizing our process to involve community knowledge holders can remove the limitations and knowledge gaps that Western-based research can have during risk assessment processes, which can generate more effective localized risk mitigation strategies. Involving community members in environmental risk assessments empowers them with the knowledge and experience needed to address current challenges and proactively develop strategies to prevent future risks in their communities (Checker, 2007).

4.1 Project Outcomes

Data from our study was presented to Moose Cree First Nation community members in Moose Factory on June 19, 2024, and was later published in a report for the community (Miceli et al., 2025). The findings from our project have since been used to generate the next steps for water management planning in the territory, as it clearly identified that hydroelectric activities have resulted in major changes to the river system that are impacting the Moose Cree peoples' way of life. Moose Cree Lands and Resources Department, in partnership with Dr. Buell, has received a second round of funding from FNECP to expand this project and fill gaps identified by the research outlined in this thesis. The data in this study will therefore be further built upon with upcoming research.

4.2 Next Steps

Grants have been received for future work in the territory. The data collected in the upcoming study will be added to the existing data from this study. The locations in this study will be analyzed for mercury again, with the addition of other important traditional harvesting locations, including inland lakes. The study will also aim to sample a wider variety of traditionally consumed fish species to account for mercury levels in omnivore and herbivore fish species.

Future studies in Moose Cree Territory that aim to assess mercury burdens in fish should test multiple culturally important harvesting locations in the territory. They should also account for fish age rather than the length of a fish. Sampling for fish caught during multiple seasons could also identify if seasonal differences are present in certain species of fish in the territory.

Another important area of research that is needed is to obtain a greater understanding of the averages for northern Ontario mercury concentrations at undisturbed locations so that possible differences in mercury levels could be better understood in areas that have experienced significant disturbances from things like mines, logging and hydroelectric activity.

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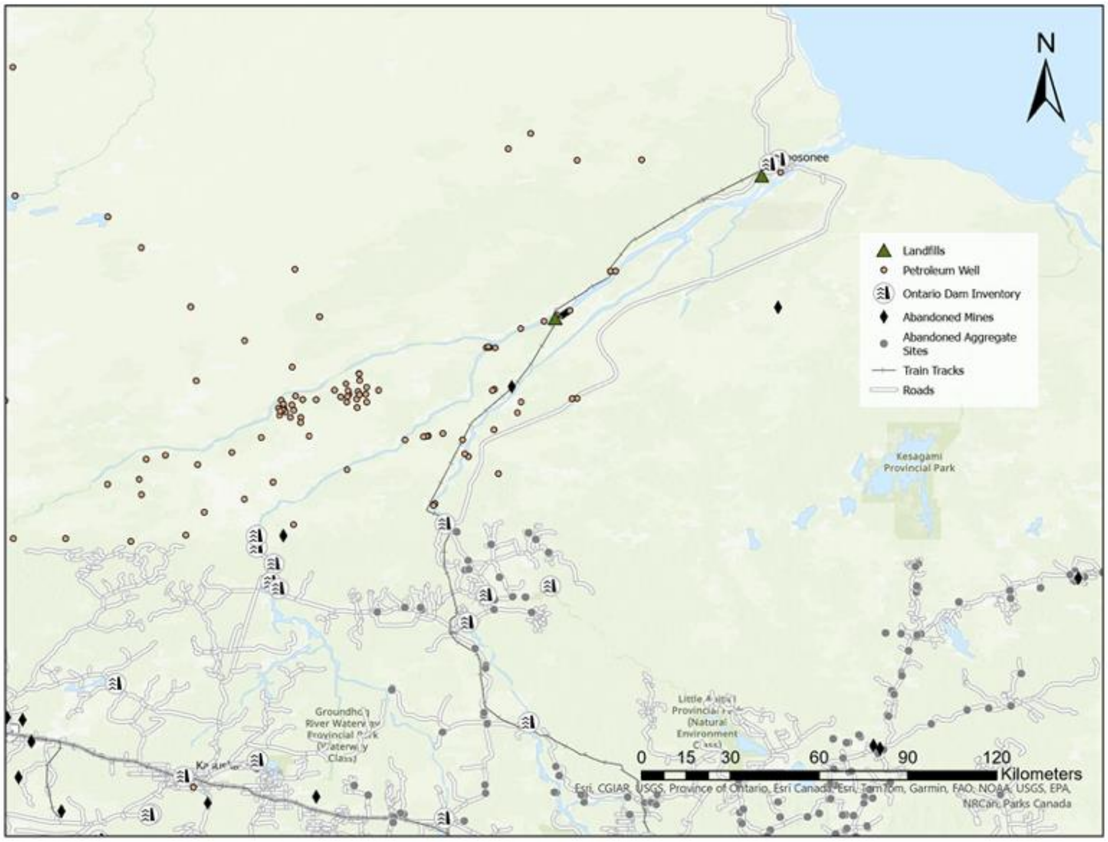
APPENDICES:

Site	Linear Regression R2	p value	Power Regression R2	Sample Size
Near Moose Factory	0.1515	0.041	0.1350	28
Mouth of Abitibi	0.6975	<0.001	0.7369	13
Moose River Crossing	0.1602	0.014	0.1279	37
Harricana River	0.0015	0.921	0.0008	9
Onakawana/Abitibi *	0.0997	0.152	0.0198	22

Supplementary Figure 1: Linear relationship data for each site location within the study.



Supplementary Map 1: Disturbances in and around the Moose Cree First Nation Territory. NOTE: Some known disturbances (ex: the hydroelectric dam at Moose River Crossing) were not seen in some of the government of Ontario's data sets.

Appendix 1: Interview Questions.

Q25 What history has your family had with fish?

Q26 Did you and your family currently or previously have many areas where you would collect fish?

Q27 Can you share ways your family cooked fish in the past or that you use today?

Q28 How often would your family travel out to collect fish?

Q29 Did these activities include hunting for other animals (e.g., moose, set trap lines)?

Q30 Did your family ever share with you teachings about the fish and the rivers?

Q31 If Yes to question 31, are there teachings you would like to share?

Q32 Are there teachings around fish or the waters that you still remember today that have been told to you when you were a youth?

Q33 Can you characterize your relationship with fish?

Q34 Do you have any connection to any specific fish or fish location?

Q35 Do you feel that some people have lost their connection to fish?

Q36 If yes to question 35, why do you think that connection has been lost?

Appendix 2: Survey

Default Question Block

Thank you for your interest in participating in our research project aimed at understanding levels of mercury in fish from Moose Cree First Nation Traditional Territory. With this study we will be producing a fish consumption guide specifically for the Moose Cree First Nation community members. As a participant in this research, you will be asked to share your fish consumption habits as well as share the general locations from where the fish you eat are caught. This research is being conducted by Moose Cree First Nation in collaboration with Camp Onakawana, and Trent University. The Principal Investigator (PI) is Dr. Mary-Claire Buell Assistant Professor at Trent University. Dr. Buell has spent the last 10 year monitoring contaminants in several lakes and rivers examining the effects and potential effects on traditional/native fish species. We recognise that knowledge from community members on how frequently they and their households consume fish and as well as their understanding of where fish they are consuming are frequently caught and the characteristics of these fish over time will help inform how we evaluate the potential risks of mercury in fish from Moose Cree First Nation Territory. Therefore, we would be happy for your participation in this research.

The survey is expected to last approximately twenty (20) minutes. If you participate you will be asked about basic demographic information such as gender, age range, years of experience in your present role/occupation and size of household. You will be asked twenty-two (22) multiple choice questions. Your participation in this survey is voluntary. This means that you are free not to participate and can withdraw your participation at any point without consequence. Upon withdrawal, your data will be destroyed as well. We anticipate that there will be minimal risks associated with your participation in this research.

You can skip any question, or fully end your survey at any time of your choosing. Your data will be anonymized and your name will not be attached to the data. The data will be stored until you and/your community receives a final report on findings of the research and until the master's student's thesis and other publications are completed. Following the completion of the final report, thesis and publications.

With permission from Moose Cree Band Council, the findings of this research may also be used for presentations at conferences. You may not experience any direct benefit as a result of your participation in this study. However, you may value the opportunity to give your views and share your observations; and, we hope that there will be future benefits to the Moose Cree First Nation community as a result of what is learned in this research.

At the end of the survey you will be provided an opportunity to share your contact information so that you can be entered into a draw for a $100 gift card. This is completely optional. Your contact information will not be linked to your survey responses and will only be used for the sole purpose of the draw.

This study has been reviewed and approved by the Trent University Research Ethics Board. Please direct questions pertaining to this review to Anna Kisiala, Coordinator, Research Conduct and Reporting, Trent University, Phone: 705-748-1011 ext 7866, Email: annakisiala@trentu.ca.).

If you would like to discuss this research further or if you have any questions, Dr.Mary-Claire Buell can be contacted by phone 705-748-1011 ext 6748, or by email (maryclairebuell@trentu.ca).

○ I have read and understood the information above and I would like to continue with the survey and consent to the use of the data provided

Please select the option that best describes your age

○ 18-30 yrs

○ 31-49 yrs

○ 50-64 yrs

○ 65 yrs or over

Please select the option that best describes your gender

○ Male

○ Female

○ Non-binary / third gender

○ Prefer not to say

What household roles do you often find yourself participating in?

☐ Fish harvesting

☐ Meal Preparation

☐ Meal consumer

☐ Other (Please specify)

How many persons make up your household?

○ 1

○ 2

○ 3

○ 4

○ 5

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○ 6
○ 7
○ Over 8 people

How many adult females (over 18) live in your household ?

○ 0
○ 1
○ 2
○ 3
○ 4
○ 5 or greater

For the adult females (over 18) in your household, how many are in each of the following weight categories? Please write the number in the space provided below.

☐ 0- 75 lb
☐ 76-100 lb
☐ 101-150 lb
☐ 151-200 lb
☐ 201-250 lb
☐ greater than 250 lb

For the adult females (over 18) in your household, how many are in each of the following age categories? Please write the number in the space provided below.

☐ 18-30 yrs
☐ 31-49 yrs
☐ 50-64 yrs
☐ 65 and over yrs

How many adult males (over 18) live in your household ?

○ 0
○ 1
○ 2
○ 3
○ 4
○ 5 or greater

For the adult males (over 18) in your household, how many are in each of the following weight categories? Please write the number in the space provided below.

☐ 0- 75 lb
☐ 76-100 lb
☐ 101-150 lb
☐ 151-200 lb

☐ 201-250 lb

☐ greater than 250 lb

For the adult males (over 18) in your household, how many are in each of the following age categories? Please write the number in the space provided below.

☐ 18-30 yrs

☐ 31-49 yrs

☐ 50-64 yrs

☐ 65 and over yrs

How many youth and children (under 18 yrs) live in your household ?

◯ 0

◯ 1

◯ 2

◯ 3

◯ 4

◯ 5 or greater

For the youth and children (under18) in your household, how many are in each of the following weight categories? Please write the number in the space provided below.

☐ Not Applicable

☐ 0- 75 lb

☐ 76-100 lb

☐ 101-150 lb

☐ 151-200 lb

☐ 201-250 lb

☐ greater than 250 lb

For the youth and children (under 18) in your household, how many are in each of the following age categories? Please write the number in the space provided below.

☐ Not applicable

☐ 0-2 yrs

☐ 3-5 yrs

☐ 6-10 yrs

☐ 10- 15 yrs

☐ 16-18 yrs

Do you eat fish?

◯ No

◯ Yes

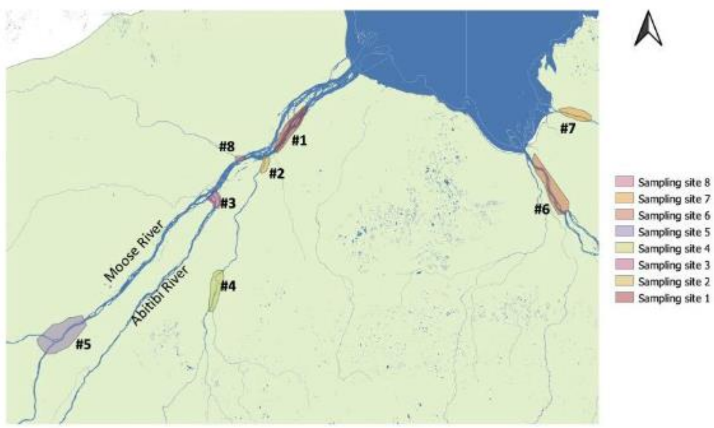
How often do you eat fish?

- ◯ Once a week
- ◯ Twice a week
- ◯ More than twice a week
- ◯ Once a month
- ◯ Rarely ever
- ◯ I do not eat fish
- ◯ other (please specify)

How do you obtain the fish that you eat? (Select all that apply)

- ☐ Self Caught
- ☐ Purchased or given to from fisher
- ☐ Buy from store
- ☐ other (Please Specify)

Fish Sampling Sites - Moose Factory First Nation



Within the last year, did you or anyone in your household fish from any of the following locations? Select all that apply.

- ☐ Site 1
- ☐ Site 2
- ☐ Site 3
- ☐ Site 4
- ☐ Site 5
- ☐ Site 6
- ☐ Site 7
- ☐ Site 8
- ☐ Other sites not highlighted on map

What type of fish do you eat at home? Please select all that apply.

- ☐ Walleye [Pickerel]

☐ Pike
☐ Sturgeon
☐ Brook Trout
☐ Lake Whitefish
☐ Cisco
☐ Don't know
☐ Species not on list (please specify)

What type of fish do you eat most often? Please rank the fish from 1 to 7 based on how often they are eaten; where 1 represents the fish eaten least often and 7 represents the fish eaten most often.

☐ Walleye [Pickerel]
☐ Pike
☐ Sturgeon
☐ Brook Trout
☐ Lake Whitefish
☐ Cisco
☐ Species not on list (please specify) ________________
☐ Don't know

What is the portion size of fish you eat per meal? Please note that two hand-sized fillets are approximately one 8 ounce (227g) serving.

◯ Less than 8 ounces (less than one serving)
◯ 8 ounces (one serving)
◯ 16 ounces (two servings)
◯ 24 ounces (three servings)

○ 32 ounces (four servings)

○ More than 32 ounces (more than four servings)

What parts of the fish do you eat? (Please select all that apply).

☐ Flesh (ie fillet)

☐ Head

☐ Skin

☐ Back Meat

☐ Tail Meat

☐ Tail

☐ Caviar

☐ Abdomen meat

☐ KAMA

☐ whole fish

☐ Innards (guts)

☐ other (please specify)

How is the fish prepared? Please select all that apply.

☐ Deepfried

☐ Panfried

☐ Baked

☐ Smoked

☐ Dried

☐ Other not on list (please specify)

In which months do you consume the most fish?

○ December, January, February

○ March, April, May

○ June, July, August

○ September, October, November

○ I generally consume the same amount of fish throughout the year

Have you noticed any differences in the appearance of fish ? Please check the circles where you have seen changes in fish. (Please select all that apply)

- ☐ Skin
- ☐ Fat content
- ☐ Appearance (color)
- ☐ Deformities
- ☐ Injuries
- ☐ Parasites
- ☐ Changes in size (bigger or smaller)
- ☐ Does the meat smell different
- ☐ Have you seen changes in the diet of fish (eating different fish or bugs)
- ☐ flesh texture/color has changed
- ☐ other (please specify)

Block 1

Have you noticed any changes to fish movements/populations? Please select all that apply.

- ☐ Fish size changes
- ☐ New species observed
- ☐ Declining fish catches at specific areas
- ☐ Increasing fish catches at specific areas
- ☐ Fishing spots have changed
- ☐ Change in fish migrations
- ☐ Spawning areas have changed
- ☐ Please specify any other not listed above.

Please select any of the following where you have noticed changes

- ☐ Water levels have been fluctuating more frequently
- ☐ Water is less merky
- ☐ Water is more merky
- ☐ More sand bars in river
- ☐ Less sand bars in rivers
- ☐ Its been easier to boat in rivers
- ☐ Its been harder to boat in rivers
- ☐ Have there been any animals that you have seen less of lately
- ☐ Have there been any animals that you have seen more of lately
- ☐ Has it been easier to access fishing grounds
- ☐ Has it been harder to access fishing grounds
- ☐ Other

Block 2

Does the Ontario Fish Consumption Guide help determine the amount of fish you eat?

- ○ Yes
- ○ No; I do not know about the Ontario Fish Consumption Guide
- ○ No; I am familiar with the Ontario Fish Consumption Guide but do not know how to use it
- ○ No; I am familiar with the Ontario Fish Consumption Guide but choose not to follow it