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Impacts of transportation infrastructure on water quality, sediment loads, and fishing opportunities in the Gwich'in Settlement Area, Northwest Territories

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Abstract

The addition of gravel sediment to build ferry landings on the Peel and Mackenzie Rivers has been an ongoing concern for the Gwich'in communities of Fort McPherson and Tsiigehtchic that depend on the rivers for their livelihoods. Specifically, there are concerns that gravel from ferry landings is degrading water quality, harming fishing opportunities, and altering river morphology downstream. Previous reports concluded that ferry operations were not impacting downstream ecology. However, past studies had methodological shortcomings and community concerns about the ferry landings remain. To study the impact of the gravel landings on water quality, I utilized a multidisciplinary study design that included Western Scientific sampling on both rivers in 2018 and 2019, and Traditional Knowledge collection in 2019. During physical sampling, I collected depth-integrated samples of the water column, bed load samples, and benthic macroinvertebrates at sites upstream and downstream of ferry operations. Our team also reviewed existing documentation of Traditional Knowledge and gathered further Traditional Knowledge in Fort McPherson and Tsiigehtchic through interviews and community meetings. As well, I updated and implemented a fish harvest survey in 2019. I found that gravel from ferry landings did not alter turbidity, total suspended solids, or bed load sediments downstream. I observed differences in the abundance and richness of benthic macroinvertebrates but concluded that the differences found were not related to ferry operations. Knowledge holders in both communities expressed concerns that gravel from the ferry landings was contributing to morphological changes on both rivers but also acknowledged large climate-driven sediment inputs upstream (i.e. permafrost thaw slumps). Knowledge holders also expressed a diverse range of concerns that were not considered during the initial design of my study, including: interference with fishing opportunities, ferry cleaning residues entering the rivers, and oil spills.

Gwich'in harvesters did not notice changes to the popular fish stocks of Broad Whitefish and Inconnu but harvesters in Tsiigehtchic have been impacted by the physical presence of the ferry landings due to the alteration of traditional fishing locations. My results suggest that ferry landing material is minimally impacting the Peel and Mackenzie Rivers, but ferry operations have interfered with Gwich'in traditional use areas, livelihood, and sense of well-being. Based on these results, I provide recommendations for both the communities and the Department of Infrastructure, Government of the Northwest Territories.

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Chapter 1: Introduction

1.1 Background

Over the years, attempts to bolster Canada's economy and develop northern resources have led to a need for more infrastructure projects in Canada's north (Environment and Climate Change Canada, 2010; GeoNorth-Ross-AMEC, 2003; Golder Associates, 2004). The development of these projects, including transportation infrastructure, can cause damage to local environments (Barton, 1977; Brown, Michael Aust, & McGuire, 2013; Maitland, Poesch, Anderson, & Pandit, 2016). Waterways can be disturbed by the construction and maintenance of transportation infrastructure by altering sediment loads and water quality, which can in turn effect biota. In addition, the need to provide means for vehicles to cross river systems has led to the construction and maintenance of ferry landings and ferry services on multiple northern rivers (GNWT, 2018). The development of these forms of infrastructure can cause concern in local communities as to their effects on the natural environment and interference with traditional use areas like fishing camps.

1.1.1 Ferry Operations in the Gwich'in Settlement Area

The Dempster Highway is an all-season road that connects Dawson City, Yukon to Inuvik, Northwest Territories (NT). The gravel highway opened in 1979 and crosses the Peel River (Teetł'it Gwinjik) near the Gwich'in community of Fort McPherson (Teetł'it Zheh), NT and the Mackenzie (Nagwichoonjik) and Arctic Red (Tsiigehnjik) Rivers next to the Gwich'in community of Tsiigehtchic (Tsiigehtshik), NT. Vehicles are transported across the two rivers via government-operated ferries during the open-water season, generally late May to early November. Construction of ferry landings using a mixture of gravel substrate (GNWT, 2015) occurs annually after ice breakup at two locations on the Peel River and three locations on the Mackenzie River. Initial construction of the landings can occur in a day, but landing locations vary slightly throughout the season so construction and maintenance is ongoing (P. McLaughlin, GNWT, personal communication). Highwater events can occur throughout the summer, especially on the Peel River, affecting ferry operations and requiring maintenance of the landings. Material to build and maintain all five landings originates from the local Frog Creek Quarry or Bob's Welding Quarry (P. McLaughlin, GNWT, Personal Communication, 2019).

The Mackenzie River is the longest river in Canada, originating from Great Slave Lake and flowing to the Beaufort Sea. The Gwich'in Settlement Area, which encompasses parts of the upper Mackenzie River basin and the Mackenzie Delta, includes two major tributaries: The Peel and Arctic Red Rivers. The Teetł'it and Gwichya Gwich'in, who now reside mostly in the communities of Fort McPherson and Tsiigehtchic respectively, have fished and traveled on the Peel and Mackenzie Rivers for millennia (GLUPB, 2015; Nolin & Pilon, 1994). Ongoing construction and maintenance of the gravel ferry landings near the communities has raised concerns about potential adverse effects downstream. At the same time, Traditional Knowledge (TK) holders have observed changes to the Peel and Mackenzie Rivers that could be related to the ferry landings. Increasing frequency of bars on the Peel River and varying sediment deposition on the Mackenzie River have affected the livelihood of the Gwich'in. Gwich'in communities, government agencies, and researchers also fear that changes to these rivers could adversely affect fish spawning habitat and fishing opportunities (GeoNorth-Ross-AMEC, 2003; VanGerwen-Toyne, Walker-Larsen, & Tallman, 2008). However, throughout the Traditional Knowledge record, Gwich'in knowledge holders identify climate change as another significant driver of change (e.g. Parlee, 2016; Pulli, 2003). Indeed, as the Arctic warms, river systems experience similar changes to those seen from development within a catchment (e.g. Kokelj et al., 2013 and Lévesque & Dubé, 2007). Therefore, it can be difficult to determine the contribution of climate-related changes versus anthropogenic development in aquatic ecosystems. Furthermore, the impacts of warming and development can act additively to alter river systems (Huntington et al., 2007). For instance, permafrost thaw slumps can greatly increase sediment loads in northern rivers (Kokelj et al., 2013) and potentially confound the impacts of development.

Ferry operations have been investigated and regulated in the Gwich'in Settlement Area since water licensing regulations were enacted in 1998. However, the Gwich'in communities of Fort McPherson and Tsiigehtchic continue to see changes in the Peel and Mackenzie Rivers and remain concerned about ferry operations. Community meetings held by the Department of Infrastructure (INF) in 2015 reveal concerns about traditional use areas, fish, and spills from the ferry (GNWT, 2015). As a result of these concerns, and in relation to the water license renewal process for the ferry operations on the Mackenzie and Peel Rivers, Dr. Derek Gray, Dr. Alex Latta, and I were contracted by the Department of Infrastructure, Government of the Northwest Territories to continue and update previous monitoring programs. My thesis outlines our team's investigation into the impacts of ferry operations using an interdisciplinary approach. Throughout the study, we relied on a collaborative approach to knowledge production, drawing on both Scientific and Traditional Knowledge.

1.1.2 Legal framework for inquiry

In 1992, the Gwich'in Comprehensive Land Claim Agreement (GCLCA) was signed in Fort McPherson, NT by the Gwich'in and the governments of Canada and the Northwest

Territories (Government of Canada, 1992). Flowing from the signing of Treaty 11 in 1921, the GCLCA defined the Gwich'in Settlement Area (GSA) and affirmed rights to land, financial compensation, and self-governance (Government of Canada, 1992). The GCLCA created a framework for Gwich'in organizations, including the Gwich'in Land and Water Board. Water licensing is outlined within the GCLCA but the Gwich'in Land and Water Board was not fully realized until the subsequent signing of the *Mackenzie Valley Resource Management Act* (MVRMA) in 1998 (GLUPB, 2015; Government of Canada, 1998). The MVRMA provided the Land and Water Board with all water licensing jurisdiction within the GSA. Today, the Gwich'in Land and Water Board is guided by the Mackenzie Valley Land Use Regulations (Government of Canada, 2009b) for licensing in federal waters (Type A water license) and the *Waters Act* (GNWT, 2014) for licensing in non-federal waters (Type B water license; GLUPB, 2015). Proponents of activities with potential impacts on the water are required to apply for a water license based on water use or disturbance, or the amount of waste that will be deposited due to the project (GNWT, 2011; Government of Canada, 2009a). Waste can arise from oil and gas exploration, production, processing, and refining; quarrying and gravel washing; hydrostatic testing and cooling; or other industrial activity (Government of Canada, 2009a).

After the MVRMA was passed in 1998, the Gwich'in Land and Water Board had the power to grant water licenses in the GSA and that is when Gwich'in concerns regarding ferry operations were first officially recorded. At that point, INF (then the Department of Transportation) was required to apply for two Type B water licenses from the Gwich'in Land and Water Board for ferry operations on the Peel and Mackenzie Rivers (GeoNorth-Ross-AMEC, 2003). A license renewal application from 2015 outlines that these water licenses were required due to the maintenance of current ferry landings on each river, modifying the bed and bank of the watercourses, and the deposition and potential loss of material (considered waste in the Waters Act) used to maintain the landings (GNWT, 2015). Type B water licenses for ferry operations in the GSA seem to have been approved in 2003, 2010, and 2015 (GeoNorth-Ross-AMEC, 2003; GNWT, 2011, 2015). INF has proposed to extend licensing renewal to every 25 years for ferry operations (GNWT, 2015), but in 2015 they were only given a five year renewal.

Since 1998, the Gwich'in Land and Water Board has been able to impose conditions through water licensing for ferry operations in the GSA. The first notable condition was to conduct an Aquatic Effects Study on the impacts of ferry operations in 2001 (GeoNorth-Ross-AMEC, 2003). In 2003, INF also conducted a Structural Alternatives Study. The study investigated alternatives to the continual construction and maintenance of the ferry landings. The study concluded that due to hydrological and geological constraints, many alternatives (e.g. a bridge) would not be feasible. The next round of water licensing in 2010 required a new monitoring program, which is when INF created the Local Area Monitoring Plan (LAMP). At this time, INF also implemented a gravel removal policy in order to reduce the amount of material lost and reuse as much material as possible. Table 1.1 summarizes the total amount of material placed or recovered since 2011 per landing, according to INF records. INF was also required to limit the amount of material used annually on each of the five ferry landings to a maximum of 500 m^3 (GNWT, 2015). In 2016, INF published a Sedimentation Report regarding the ferry landings, which summarizes current practices surrounding the ferry landings and plans for future work (GNWT, 2016). More recently, pursuant to water licensing in 2015, Dr. Derek Gray, Dr. Alex Latta, and I were contracted by INF to continue and update previous studies and monitoring programs regarding ferry operations on the Peel and Mackenzie Rivers in the GSA.

1.1.3 Review of major inquiries into ferry operations in the GSA

The Department of Infrastructure has commissioned two main inquiries into the physical impacts of ferry operations in the GSA. In 2001, INF contracted GeoNorth-Ross-AMEC to conduct an Aquatic Effects Study. The study, published in 2003, combined physical Western Science with Traditional Knowledge to examine the effects of ferry operations on the Peel and Mackenzie Rivers. Quantitative measurements were taken of flow rate, bathymetry, water quality, fish stocks and habitat, and benthic macroinvertebrates. Assessments using aerial photos pre-ferry landing construction were also made. As part of the Traditional Knowledge portion of the study, researchers interviewed four knowledge holders in Fort McPherson and four in Tsiigehtchic. The final report concluded that the ferry landings were not negatively affecting water quality or fish health in the area (GeoNorth-Ross-AMEC, 2003). The researchers stated that the ferry landings had created eddy currents around the landings but have not affected the overall flow of the Peel and Mackenzie Rivers. Observations of TK holders that were interviewed by GeoNorth-Ross-AMEC do not contradict this finding but do suggest that there is increased sediment deposition in the newly created eddies, which has impacted fishing.

While GeoNorth-Ross-AMEC conducted a large, inclusive, and multidisciplinary study, there were several methodological shortcomings. The original study measured total suspended solids (TSS) in each river but did not measure material transported in the bed load. In addition, the TSS measurements were taken upstream and downstream of the ferry landings, but not before and after the ferry landings had been installed. This experimental design was used to investigate the impacts of the ferry boats but would not have been able to attribute increases in TSS to ferry landing material. Also, water samples were not depth-integrated and may have missed increased TSS concentrations at great depths.

Following the GeoNorth-Ross-AMEC (2003) report, concern about ferry landing material and ferry operations in the GSA continued. In response to concerns raised in the context of the next round of water licensing in 2010, INF developed the Local Area Monitoring Plan (LAMP). The LAMP collected data on river morphology, fish harvesting, and the physical extent of the ferry landings on the Peel and Mackenzie Rivers (GNWT, 2011). Annual collection of harvest records and bathymetric data since 2012 have created a dataset of changes in fish harvesting and river morphology, respectively. However, the LAMP also had several shortcomings. Fish harvest records that were collected from 2011-2015 illustrate that fishing is still an important part of Gwich'in livelihood but there is no attempt to determine catch per unit effort or the state of fish stocks in the Peel and Mackenzie Rivers. The bathymetric data that was collected illustrates that there have been no major changes in river morphology within each study reach since 2011, but was not accurate enough to detect minor, localized changes in morphology downstream of the landings. Although the reach often extends no more than 1 km downstream of the landings, it is important to note that even if a major morphological change were to have occurred downstream, it would have been impossible to attribute it to the ferry landings, due to the multiple factors affecting sediment introduction, transportation, and deposition in the river. The final LAMP (GNWT, 2017) report offered recommendations for future monitoring, including sampling turbidity and total suspended solids throughout the water column of each river. GNWT (2017) also recommended that fish harvest data continue to be collected with the inclusion of an effort calculation.

1.2 Review of the impacts of added sediment on biota

The movement of sediments in lotic environments is a natural process that is observed even in pristine streams. Sediments can either be suspended in the water column or move along the bed of the river. As the discharge of a river increases, more sediment and larger particles can be transported (Prowse, 1993). The quantity of suspended sediments can naturally increase due to erosion, ice breakup, increased discharge, and runoff, but human activity can also greatly disturb the natural sediment regime of a river. Anthropogenic development such as forest harvesting (e.g. Anderson, 1996), road use and construction (e.g. Barton, 1977; Brown et al., 2013), urbanization (e.g. Russell et al., 2017), river modification (e.g. Smith et al., 2016), and agriculture (e.g. Alberto et al., 2016) can impact sediment loads in rivers. Although direct anthropogenic development can alter sediment loads within a river, indirect effects can be seen too. In northern rivers and streams, studies have investigated the effect of thawing permafrost and thermokarst activity, finding significant changes in sediment loads throughout large catchments due to bank failures next to streams (Favaro & Lamoureux, 2015; Kokelj et al., 2013). Interest in understanding sediment loads in rivers stems from the observed impact on the world's oceans (Holmes et al., 2002) and on aquatic organisms (Bruton, 1985; Wood & Armitage, 1997). The Mackenzie River system transports large quantities of sediment to the Arctic Ocean annually (Table 1.2; Carson, Jasper, & Conly, 1998) but the impacts of climate change and development throughout the catchment continue to alter discharge (Yang, Shi, & Marsh, 2015) and sediment loads (Kokelj et al., 2013).

1.2.1 Fish and sediment

Salmonids dominate the fish caught in the upper Mackenzie River system and are important for subsistence fisheries. Economically and culturally important salmonids in the area include Whitefish (Broad Whitefish, *Coregonus nasus*, or Łuk zheii), Crookedback (Lake Whitefish, *C. clupeaformis*, or Dalts'an), Coney (Inconnu, *Stenodus leucichthyes*, or Sruh), and Herring (Arctic Cisco, *C. autumnalis*, or Treeluk; Table 1.3; Stewart, 1996; Thompson & Millar, 2007). These salmonids can demonstrate one of three life history strategies within the region: lacustrine (living in lakes), potamodramous (migratory; freshwater only), and anadromous (migratory; saltwater to freshwater; Reist & Bond, 1988; VanGerwen-Toyne et al., 2008a). Important subsistence fish in the Mackenzie River system are anadromous and make yearly migrations to unique breeding and overwintering areas. Timing of migrations is species-dependent. VanGerwen-Toyne et al. (2008b) concluded that anadromous fish migrate upstream on the Peel River from mid-July until September with many fish migrating downstream after freeze-up. Similarly, Thompson and Millar (2007) used Traditional Knowledge to gather migration data on the Mackenzie River. They found a wider range in migratory times than the study on the Peel River, with migration for anadromous fish starting in June and ending in October (Thompson & Millar, 2007). Potential spawning sites have been identified for several fish in the Mackenzie River (Howland, VanGerwen-Toyne, & Tallman, 2009). The sites are located throughout the Upper Mackenzie River and the Mackenzie Delta, with a potential site adjacent to the Gwich'in community of Tsiigehtchic (Howland et al., 2009). Efforts to identify exact spawning habitat on the Peel River have been attempted but no firm conclusions have been made (VanGerwen-Toyne, Walker-Larsen, et al., 2008). However, VanGerwen-Toyne et al.

(2008b) note that there is some evidence of spawning habitat at and upstream of Fort McPherson in the Peel River.

Salmonid spawning habitat in rivers is often classified by larger sediment particles like gravel. Spawning habitat can be jeopardized by the deposition of finer sediments and the filling of inter-granular spaces (Franssen, Lapointe, & Magnan, 2014). Increases in fine sediments from anthropogenic sources has been shown to degrade salmonid spawning habitat (e.g. Soulsby et al., 2001). Fine sediments occur naturally in the Mackenzie River system in bed load and in suspension (Carson et al., 1998) but human-induced increases could have negative impacts on spawning habitat (DFO, 1998). Fine sediments can also impact other aspects of fish ecology. Increases in suspended sediments can alter the behaviour and physiology of fish (Kjelland, Woodley, Swannack, & Smith, 2015). Salmonids will avoid areas with increased sediments and will even alter migration routes (Carlson et al., 2001). If avoidance is not possible, high concentrations of suspended sediments can even be lethal to fish. Egg and juvenile survival decreases with increasing sediment deposition (Fudge & Bodaly, 1984; Suttle, Power, Levine, & McNeely, 2004).

1.2.2 Benthic macroinvertebrates and sediment

Macroinvertebrates in Arctic streams are subject to harsh climatic conditions, physical disturbances related to freeze/thaw cycles, and low nutrient levels (Irons, Miller, & Oswood, 1993; Prowse & Culp, 2003; Prowse et al., 2006). Perhaps due to the harsh environment of the Arctic, environmental factors are the dominant force structuring macroinvertebrate communities in this region’s streams at both local and regional scales (Scott et al. 2011; Lento et al. 2013).

The importance of local factors in structuring macroinvertebrate communities in Arctic streams highlights the potential impact of a localized disturbance (Lento et al., 2013; Weigel et al., 2003).

Anthropogenic disturbance can drastically alter local environmental factors important for invertebrate communities. One of the most common results of development within a catchment is an alteration of the sediment regime. Deposition of fine sediments can impact macroinvertebrate communities by the infilling of interstices (Schälchli, 1992). As the spaces between substrate sediments are important habitat for foraging and predator avoidance, the infilling of these spaces can impact community diversity (Burdon, Mcintosh, & Harding, 2013; Culp & Davies, 1985; Louhi, Richardson, & Muotka, 2017; Wood & Armitage, 1997). Sediments can also impede the ability of some invertebrates to respire and filter feed (Wood & Armitage, 1997). The addition of sediments to streams can also initiate catastrophic or mass drift within benthic invertebrate communities (Culp, Wrona, & Davies, 1986; Gibbins, Vericat, & Batalla, 2007; Rosenberg & Wiens, 1978). While drift (downstream movement) is a natural ecological process in lotic environments (Townsend & Hildrew, 1976), catastrophic drift can lower macroinvertebrate community diversity (Culp et al., 1986). Both sediments in suspension and in the bed load in rivers can cause drift (Béjar, Gibbins, Vericat, & Batalla, 2017; Culp et al., 1986).

With the increase in sediment disturbance throughout the Arctic due to development and climate change, the need to monitor aquatic communities has risen. Biological monitoring or biomonitoring can be defined as the observation of an organism's response to a stressor to determine if the environment is suitable for life (Cairns & Pratt, 1993). Macroinvertebrates are commonly used to assess the health of aquatic ecosystems because they are sensitive to disturbance and are relatively easy to collect (Rosenberg & Resh, 1993). In Canada, several provincial and federal protocols have been adopted in order to regulate biomonitoring with macroinvertebrates (e.g. Jones et al., 2007; Environment Canada, 2012). There are a number of community descriptors used to compare disturbed areas to control areas, including taxonomic richness and abundance (Bailey et al., 2012). Certain species that are particularly sensitive to additions of sediment are also used for comparison. Ephemeroptera, Plecoptera and Trichoptera (EPT) richness is widely used to assess water quality (Lenat, 1983), but low diversity of EPT organisms in Arctic rivers can limit their use as a community descriptor (Scott, Barton, Evans, & Keating, 2011). The larval form of the Chironomidae family (chironomids) are very abundant in northern streams due to their freeze tolerance (Andrews & Rigler, 1985) and the lack of their invertebrate predators in the Arctic (Scott et al., 2011). As chironomids are also sensitive to sediment disturbances, they can also be a useful bioindicator of the cumulative impacts of changing sediment loads (Béjar et al., 2017; C. Jones et al., 2007; Rosenberg & Wiens, 1978).

1.3 Traditional Knowledge

The documentation of Traditional Knowledge (TK) has become a powerful method to understand environmental change and to assist with resource management in the Northwest Territories (B. L. Parlee, Goddard, First Nation, & Smith, 2014). Nomenclature and definitions vary throughout the literature (e.g. Houde, 2007; McGregor, 2009), but TK in the GSA is defined by the Gwich'in Tribal Council (GTC) as "…that body of knowledge, values, beliefs and practices passed from one generation to another by oral means or through learned experience, observation and spatial teachings, and pertains to the identity, culture and heritage of the Gwich'in," (GTC, 2004). Indigenous communities often have strong connections to the land, and are therefore sensitive to and impacted by changes in their environment (B. L. Parlee et al., 2014). The incorporation of TK into the resource management process allows for a more accurate and holistic perspective on ecological change that better reflects community concerns (Berkes, Berkes, & Fast, 2007; Houde, 2007; Raymond et al., 2010). In addition, as TK is passed from generation to generation, it can fill holes in temporally limited Western Scientific research (Houde, 2007; Mantyka-Pringle et al., 2017). Knowledge holders who have constant interaction with a system can observe changes in their surroundings like water quality (e.g. Mantyka-Pringle et al., 2017) or fish stocks (e.g. Neis et al., 1999; Johannes et al., 2008). Therefore, the combination of TK and scientific research in resource management can lead to a better understanding of the long-term changes occurring in ecological systems and an appreciation for how those changes are impacting local communities (Mantyka-Pringle et al., 2017; Sutherland, Gardner, Haider, & Dicks, 2014).

Our understanding of lotic systems in the Arctic consists of a complex mix of hydrological, ecological, economic, and cultural knowledge. Although TK has been employed by Indigenous peoples for centuries, policy makers have focused on scientific monitoring programs until recently. Management programs have shifted to include multiple forms of knowledge and build on the foundational TK established by Indigenous peoples (Houde, 2007). Kokelj et al. (2012) demonstrated that Inuvialuit knowledge holders knew of the consequences of large environmental disturbances in the Mackenzie Delta ten years before researchers and environmental decision-makers. Furthermore, Thompson & Millar (2007) show that TK can reveal important aspects of fish ecology by documenting Gwich'in TK on the migration patterns and spawning location of subsistence fish species in the Mackenzie and Arctic Red Rivers. In another example, Cott et al. (2018) demonstrate that Gwich'in harvesters can accurately identify healthy and safe Burbot livers. As liver health in fish can be an indicator of pollution, this illustrates the continued relevance of traditional methods within monitoring programs (Cott et al., 2018). There are a multitude of other studies conducted in the GSA that collected TK with respect to fisheries (e.g. Greenland & Walker-Larsen, 2001; Thompson, 2008; Thompson & Millar, 2007; Wishart, 2013). Ultimately, decisions about how to manage natural resources can be better supported using multiple forms of knowledge including Traditional Knowledge and Western Science (D. Armitage, Berkes, Dale, Kocho-Schellenberg, & Patton, 2011; Berkes et al., 2007; Tengö, Malmer, Brondazio, Elmqvist, & Spierenburg, 2012). Deemed the co-production of knowledge, this relies on the involvement of local communities, decision-makers, and researchers to mobilize multiple knowledge types to understand and manage complex social-ecological systems (Tengö et al., 2012).

1.4 Structure of this thesis

For my thesis, I report the details from my multidisciplinary study design that investigated the impacts of ferry operations on the Peel and Mackenzie Rivers in the Gwich'in Settlement Area, Northwest Territories. In Chapter 2, I describe the Western Scientific portion of this study where I examine the physical impacts of the construction and maintenance of ferry landings. I examined water quality, sediment loads, and benthic macroinvertebrate communities before and after the spring construction of the landings at control and impacted sites to determine the significance of eroded material on riverine ecology. In Chapter 3, I describe the collection and analysis of Gwich'in Traditional Knowledge. I summarize the updated Gwich'in Traditional Knowledge record as it pertains to river morphology, fishing opportunities, and ferry operations. I also describe the implementation of a fish harvest survey. In Chapter 4, I synthesize information from Chapters 2 and 3 to draw conclusions and make recommendations to the affected communities and to the Department of Infrastructure.

1.5 Tables

Table 1.1. Total amount of net material used (m^3) per ferry landing on each river in the Gwich'in Settlement Area. Negative numbers indicate that INF removed more material from the landings than placed. Data adapted from GNWT (2016) and personal communication with P. McLaughlin, INF, GNWT.

	2011	2012	2013	2014	2015	2016	2019
Peel River ferry landings	520.0	-955.0	350.7	-300.0	-2220.0	-1400.0	-380.0
Mackenzie River ferry landings	506.0	320.0	236.29	70.0	92.0	-1400.0	-336.0

Table 1.2. Annual sediment contribution (in million tonnes) to the Mackenzie Delta from 1974-1994 (Adapted from Carson et al. 1998).

River	Wash load (mt)	Bed load (mt)	Total (mt)
Mackenzie	103	4	107
Arctic Red	7.3	N/A	7.3
Peel	21	N/A	21

Table 1.3. List of common subsistence fish caught in the Peel and Mackenzie River in the Gwich'in Settlement Area. Adapted from Thompson and Millar (2007).

Gwichya Gwich'in	Teetł'it Gwich'in	Local Name	Common Name	Scientific Name
Łuk zheii	Łuk zheii	Whitefish	Broad whitefish	*Coregonus nasus*
Dalts'in	Dalts'an	Crookedback	Lake whitefish	*Coregonus clupeaformis*
Sruh	Sruh	Coney	Inconnu	*Stenodus leucichthyes*
Treeluk	Treeluk	Herring	Arctic cisco	*Coregonus autumnalis*
Chehluk	Chehluk	Loche	Burbot	*Lota lota*
Eltyin	Eltin	Jackfish	Northern Pike	*Esox lucius*
Dhik'ii	Dhik'ii	Char	Dolly Varden Char	*Salvelinus malma*

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Chapter 2: Using Western Scientific methods to determine the impacts of ferry operations in the Gwich'in Settlement Area, Northwest Territories

2.1 Introduction

In this chapter, I outline the scientific portion of my thesis that aimed to address two main objectives. For my first objective, I investigated the potential impacts of ferry landing construction and maintenance on water quality and sediment loads. I predicted that if ferry landing material or action from human activity on the landings was altering water quality there would be increases in turbidity and total suspended solids (TSS) downstream of the landings. Similarly, I predicted that the addition of sediment on ferry landings would alter the particle size distribution in the bed load downstream of the landings. For my second objective, I used benthic macroinvertebrate communities (BMI) to assess if the cumulative impacts of ferry landing activity were affecting the biota living in the streams. I predicted that changes to water quality and sediment loads downstream of the landings would alter BMI communities by decreasing total abundance, richness, and the abundance of sensitive taxa.

2.2 Methods

2.2.1 Study Site

Peel River

The two-kilometer study reach of the Peel River is roughly located at what is called 8 Mile or Nataiinlaii and is 10 km south of Fort McPherson, NT (Figure 2.1; GLUPB, 2015). Throughout the study reach the Peel River is relatively straight, and ferry landings are situated on each bank in the middle of the study reach (Figure 2.1). A Water Survey of Canada station is located 8 km upstream of the Peel River study reach (station 10MC002) and measures river velocity, depth, and discharge.

The Peel River originates in the mountains of the Yukon and flows into the Mackenzie Delta downstream of Fort McPherson. It is estimated that the Peel River contributes 21 mt of sediment to the Mackenzie Delta each year (Carson et al., 1998). During sampling, the average wetted width of the study reach was 370 m and the approximate mean discharge throughout sampling was 2 768 m^3/s (Water Survey of Canada).

Mackenzie River

I established a two-kilometer study reach on the main stem of the Mackenzie River at the confluence of the Arctic Red River near the community of Tsiigehtchic, NT (Figure 2.1). The reach is characterized by a large meander (Figure 2.1). An apparent thalweg is observed diagonally crossing the river in the middle of the reach with depths of up to 35 m. There are three ferry landings in the centre of the study reach: right shore (to Inuvik), left shore downstream of the confluence of the Arctic Red River (to Fort McPherson), and left shore upstream of the confluence of the Arctic Red River (to Tsiigehtchic). A Water Survey of Canada station located in the reach measures water level and velocity throughout the year (station 10LC014).

The Mackenzie River is the longest river in Canada, spanning over one-fifth of the country (Woo & Thorne, 2016). The majority of the sediments transported by the Mackenzie River are fine suspended clay and silt particles, with larger sand particles making up the bed load (Carson et al., 1998; Davies, 1975). The main stem of the Mackenzie River downstream of the mouth of the Arctic Red River transports 107 mt of sediment in suspension and along the bed (Carson et al., 1998). The Arctic Red River contributes 7.3 mt of sediment annually to the main stem of the Mackenzie River (Carson et al., 1998). Throughout sampling, the average wetted width was approximately one km and the average discharge was 21 526 m^3/s (Water Survey of Canada).

2.2.2 Data collection and analysis

Sampling design

I conducted fieldwork shortly after ice breakup in 2018 and 2019 at the ferry crossings of the Peel River and the Mackenzie River in the GSA. I chose this period to collect samples due to the high erosive discharge of these rivers and the increased construction activity at this time. I implemented a modified before-after-control-impact (BACI) design to monitor water quality, bed load sediments, and invertebrate communities. Samples were collected after ice breakup on multiple days in 2018 and 2019, before and after the initial construction of the ferry landings at sites upstream and downstream on both rivers. I took depth-integrated water samples and sediments moving along the bed of the rivers at transects 50 m, 500 m, and 1 km from the ferry landings (Figure 2.1). One additional transect was sampled in the Arctic Red River near its confluence with the Mackenzie River. Transect distances were limited due to logistical constraints. In 2019, I collected BMI and substrate sediment at sites 500 m upstream and downstream of the ferry landings on each river. I also collected BMI at sites directly downstream, directly upstream, and on each ferry landing (e.g. Figure 2.2). During analysis, I pooled BMI sites into three location treatments: upstream, ferry, and downstream sites.

Water quality and sediment analysis

I collected depth-integrated water quality samples along transects using a U.S. DH-2 sampler (Rickly Hydrological Co., Inc.). Turbidity was measured using a LaMotte portable turbidity meter, and total suspended solids (TSS) was determined for each sample using USEPA method 160.2 (1971). Turbidity was also measured every 15 minutes in the Peel River in May and June 2019 using two Manta+ Trimeter probes (Eureka Water Probes) placed 200 m upstream and downstream of the ferry landings. I collected bed load sediments with a US BL-84 Bedload Sampler (Rickly Hydrological Co., Inc.) following the operating procedure published by the Federal Interagency Sedimentation Project (1990). I collected substrate sediment layers from 0-3 cm with a hand shovel at a water depth of approximately 0.5 m. Bed load and substrate sediment samples were air dried and sorted using a RX-29 Ro-Tap® sieve shaker (Geneq, Inc.) following the Wentworth scale (Wentworth, 1922). I calculated sediment metrics for sorted bed load samples, including the cumulative particle diameter at varying proportions (d_{10}, d_{50}, d_{90}) and percent sand (<2mm, >63µm) using GRADISTAT (Blott & Pye, 2001; Wentworth, 1922). I also converted bed load into a rate following the Federal Interagency Sedimentation Project (1990). Discharge was measured on the Peel and Mackenzie Rivers continuously at Water Survey of Canada stations 10MC002 and 10LC014, respectively.

I analyzed turbidity, TSS, and bed load particle size metrics and rates using a two-factor (before/after construction and upstream/downstream of landings) repeated-measures analysis of variance (ANOVA). The assumption of normality of the residuals for ANOVA was tested using a Shapiro-Wilks test and the assumption of homogeneity of variances was tested using Levene's test ($p < 0.05$ in both cases). I transformed non-normal variables using an ordered quantile transformation (orderNorm) in the R package BestNormalize (Peterson & Cavanaugh, 2019). I analyzed the continuous turbidity data from the probes placed in the Peel River using a paired t-test. In order to examine the variation in the continuous turbidity data, I performed a linear regression on log-transformed turbidity and discharge data. The assumption of normality was examined using a Shapiro-Wilks test. All statistics were performed in R for Mac version 3.6.1 (R Core Team, 2019).

I performed a power analysis by simulation to determine the statistical power I had to detect differences in turbidity, TSS, and the median particle size of the bed load samples. I estimated statistical power by performing thousands of iterations of a simulated dataset based on observed variability in my actual data. I analyzed power in two different scenarios. First, I simulated a dataset that had known differences (between 5-90%) between upstream and downstream values and consisted of 15 values at each location. The proportion of times out of 1000 iterations that the simulation finds a significant difference in upstream and downstream values is the statistical power. This provided the power I had to detect varying differences at my actual sample size. Then, I simulated a dataset that used varying sample sizes (from 3-45) and calculated the power I would have had to detect a 5%, 10%, and 20% difference between upstream and downstream sites. I considered a power above 0.8 to be high (Cohen, 1992).

Benthic macroinvertebrates

I collected BMI following a modified version of Environment and Climate Change Canada's Canadian Aquatic Biomonitoring Network (CABIN) approach (Environment Canada, 2012). Substrate in the littoral zone at a depth between 0.5-1 m was disturbed using a kicking motion while I traveled in a zigzag pattern for 3 minutes at each site. A 500 μm D-net was held downstream in order to collect dislodged or drifting organisms. I collected three replicate samples at each site. Samples were sorted and BMI were identified to order or family, depending on the taxa following Ontario Benthos Biomonitoring Network protocol (Appendix 1.1; Jones et al., 2007). BMI community metrics including rarified taxonomic richness (Hurlbert, 1971), abundance, percent sensitive taxa (EPT or Ephemeroptera, Plecoptera, and Trichoptera), and percent Chironomidae were analyzed using a two-factor (before/after construction and upstream/downstream of landings) repeated-measures ANOVA. Rarified richness values were used to ensure that estimates of taxa richness were not biased by the number of individuals identified at each site (Gotelli & Colwell, 2001). When ANOVA output was significant ($\alpha = 0.05$), I performed Tukey's honestly significant difference (HSD) test to determine where differences existed. Assumptions of normality of residuals and homogeneity of variances for the ANOVA were tested using a Shapiro-Wilks test and a Levene's test, respectively (p-values > 0.05 in both cases). To examine how the relative abundance of taxa differed among sample sites relative to the ferry landings and median particle size of substrate sediments, I conducted a principal component analysis (PCA). A PCA is a dimensionality reduction technique that produces a two-dimensional ordination diagram that can be used to examine similarities in taxa composition among sites (i.e. sites located closer together have more similar communities). To reduce the influence of zeroes in the dataset on the PCA, the PCA was run using Hellinger transformed abundance data (Legendre & Gallagher, 2001). To reduce bias in the PCA due to the influence of rare taxa, taxa present in <20% of sites were removed prior to analysis (Lepš & Šmilauer, 2003).

2.3 Results

Sediment analysis and water quality

Between 2018 and 2019, I measured turbidity and TSS nine times at 30 sites on the Peel River and seven times at 33 sites on the Mackenzie and Arctic Red Rivers (Appendix 1.2 and Appendix 1.3). Turbidity and TSS measurements were significantly different between sampling dates on the Peel (Table 2.1; $p < 0.0001$) and Mackenzie Rivers (Table 2.2; $p < 0.0001$). There was no significant interaction between location and time for turbidity (Figure 2.3; p-values > 0.05) or TSS (Figure 2.4; p-values > 0.05). Turbidity data from the two Manta+ Trimeter probes was related to discharge (linear regression, $R^2 = 0.847$, $p < 0.001$) and was higher upstream of the ferry landings ($t = -3.78$, d.f. = 622, $p < 0.001$). However, there were two instances on June 3 when downstream turbidity was notably higher than upstream turbidity (Figure 2.5). Between 05:45 and 06:45 on June 3, downstream turbidity was recorded to be approximately 200% higher than upstream turbidity. On the same day between 12:00 and 12:30, downstream turbidity was as much as 70% higher than upstream turbidity (Figure 2.5).

Over the course of this study, I collected bed load sediments nine times at 30 sites on the Peel River and six times at 33 sites on the Mackenzie River (Appendix 1.2 and Appendix 1.3). In the Peel River, bed load samples contained an average of 90.1% sand and the average median particle size was 249.6 µm. In the Mackenzie River, bed load samples contained an average of 87.2% sand and the average median particle size was 337.1 µm. Under the Wentworth (1922) particle size classification, this means the average median particle size in the Peel River was fine sand and in the Mackenzie River it was medium sand. When examining the potential effects of ferry landings on bed load sediments, there was no significant interaction between location and time for any of the particle size distribution metrics (*d_{10}*, *d_{50}*, *d_{90}*, %sand, and rate) on either river (Table 2.1 and 2.2; Figure 2.6; p-values > 0.05).

I conducted a statistical power simulation on turbidity, TSS, and *d_{50}* values from each river to determine the power I had to detect a 5%, 10%, and 20% change in downstream measurements (Figures 2.7-2.12). I had a high power (>0.8; Cohen, 1992) to detect a 20% change in turbidity on both rivers and TSS on the Peel River. I had a low power (<0.8) to detect a 20% difference in TSS on the Mackenzie River and a low power to detect a 5% and 10% difference in all variables in both rivers. I also had a low power to detect a <20% difference in median bed load particle size (*d_{50}*) on both rivers.

Benthic macroinvertebrates

In total, 956 individuals in 15 taxonomic groups were counted across the 60 triplicate samples taken in the Peel River (Appendix 1.1). The chironomid family accounted for approximately 47% of individuals across all sites, while Plecopterans and Ephemeropterans accounted for approximately 16% and 13% of individuals, respectively. The highest abundance I observed in a single sample from the Peel River was 88 individuals, and no samples had an abundance >100. In the Mackenzie River, I counted 3140 individuals belonging to 15 taxa (Appendix 1.1). The most abundant taxa were the mysids, accounting for 33% of all individuals. Plecopterans accounted for 29% of individuals counted and chironomids for approximately 21%. Only four samples had an abundance >100 individuals.

The interaction between location relative to the ferry landings and sampling date relative to landing construction was not significant for total abundance and taxonomic richness in the Peel River (Table 2.1; Figures 2.13A and 2.14A; p-values > 0.05). Total abundance differed depending on an interaction between sites and time in the Mackenzie River (Table 2.2; Figure 2.13B; p-value = 0.03). A follow-up Tukey HSD test found no differences among locations and through time; however, differences between ferry landing sites before and after construction were closest to significance ($p = 0.19$). There was a significant interaction between location and time for taxonomic richness on the Mackenzie River (Table 2.2; Figure 2.14B; $p = 0.04$). A subsequent Tukey HSD test of this interaction found that taxonomic richness differed between upstream and downstream sites before construction of ferry landings ($p = 0.03$), upstream sites before and after construction ($p = 0.02$), and downstream sites after construction and upstream sites before construction ($p = 0.01$). Chironomid percentage in the Mackenzie River differed depending on an interaction between sites and time (Table 2.2; Figure 2.16B; $p = 0.01$). A Tukey HSD test found that chironomid percentage differed between downstream sites before and after ferry landing construction ($p = 0.04$), between ferry landing sites before and after construction ($p = 0.03$), and at upstream sites before and after construction ($p < 0.0001$). EPT percentage on both rivers and chironomid percentage on the Peel River did not differ between upstream, ferry landing, and downstream sites through time (Table 2.1 and 2.2; Figure 2.15; $p > 0.05$).

BMI communities in the Peel River were structured along PCA axis 1, which accounted for 41.6% of the variation (Figure 2.17A). Plecopterans and ephemeropterans had high axis 1 scores, while chironomids and oligochaetes had low axis 1 scores. Site categories on the Peel River did not group out clearly on the ordination plot; however, ferry landing sites tended to have the highest axis 1 scores and downstream sites had the lowest. In the Mackenzie River, PCA axis 1 accounted for 60.7% of the variation (Figure 2.17B). Plecopterans had low axis 1 scores, and mysids had high axis 1 scores. Opposite to the Peel River, ferry landing sites tended to have the lower axis 1 scores and downstream sites had higher axis 1 scores. In order to further explain the variation in BMI communities, I redefined the sites by substrate sediment type (Figure 2.18). Gravel sites on the Peel and Mackenzie Rivers had high axis 1 scores while fine sediment sizes had lower axis 1 scores. On both rivers, Plecopterans were associated with gravel sites and chironomids were associated with fine sand sites (Figure 2.18).

2.4 Discussion

Sediment analysis and water quality

In order to investigate the potential erosion and downstream transport of materials used to construct ferry landings in the Peel and Mackenzie Rivers, I used metrics that summarized suspended sediment load and bed load. My BACI sampling design was aimed at detecting differences between upstream control sites and downstream impacted sites, before and after construction began on the landings. The data collected at transects upstream and downstream of the ferry landings showed no differences in turbidity, total suspended solids (TSS), or bed load that could be attributable to the landings. In addition, the turbidity probes I installed to continuously monitor upstream and downstream changes in turbidity on the Peel River also showed very few differences between locations upstream and downstream of the ferry landings. This suggests that little material was moving downstream from the ferry landings, and contradicts previous reports conducted on ferry operations in the Northwest Territories that showed elevated turbidity levels in response to ferry operations (GeoNorth-Ross-AMEC, 2003; Golder Associates, 2004). The continuous turbidity data from the probes in the Peel River showed a strong relationship with discharge, which explains the variability in turbidity and TSS among sampling days, as discharge was variable throughout the periods of sampling. My turbidity measurements were comparable to those taken on both rivers between 2000 and 2018 by Environment and Climate Change Canada (2018b) and GeoNorth-Ross-AMEC (2003). To my knowledge, sediment moving in the bed load has only been quantified for one study on the Mackenzie River, but this study only sampled the suspended bed load and assumed that unsuspended bed load was negligible (Carson et al., 1998). It does seem, however, that the unsuspended bed load sediments are not negligible, with many samples from both rivers having several kg of sandy bed load collected in a 30 second drop. Based on these results, I believe that future estimates of total sediment load in the Peel and Mackenzie Rivers should examine bed load more closely.

My sampling effort had the statistical power to detect >20% differences in turbidity (and TSS on the Peel River); however, future studies would need to increase the sample size in order to detect smaller changes. With respect to ferry operations in the GSA, GeoNorth-Ross-AMEC (2003) found that turbidity increased by up to 15% while the ferry was at rest and departing. A report published by Golder Associates (2004), on the then proposed Deh Cho bridge, found a 33% TSS increase downstream of ferry propeller wash, although TSS concentrations were much lower than ambient concentrations at my study sites on the Peel and Mackenzie. Both observations by GeoNorth-Ross-AMEC (2003) and Golder Associates (2004) are likely instantaneous and localized to times and areas where the ferry boat was operating. Sediment increases of much higher magnitudes can be observed in the Peel and Mackenzie Rivers during ice breakup (Prowse, 1993), thermokarst activity (Kokelj et al., 2013), or periods of high discharge (Carson et al., 1998), suggesting that brief increases of TSS from ferry operations are likely inconsequential in these large, dynamic rivers.

There are at least two possible explanations as to why we did not find an effect of ferry operations on sediment transport. The first has to do with the study objectives, which dictated the timing and locations of turbidity measurements. While previous studies (GeoNorth-Ross-AMEC, 2003; Golder Associates, 2004) were interested in changes to the water quality directly linked to the ferry boats themselves, my study aimed to detect changes to water quality from the erosion of ferry landing material. This difference in objectives meant that previous studies were tracking changes in water quality within close proximity to operating ferries, while our study was conducted at a broader spatial scale with samples taken up to 1 km from the landings. The second explanation involves sediment loads and natural variation. The Peel and Mackenzie Rivers transport large amounts of sediments into the Mackenzie Delta and eventually the Beaufort Sea. There are discrepancies in the literature regarding the annual sediment load of the Mackenzie River. Sediment totals range from 51-220 million tonnes (mt) per year (Gareis & Lesack, 2017; Davies, 1975) with the most widely cited being 124 mt per year (Carson et al., 1998). Of that 124 mt of sediment transported to the Mackenzie Delta annually, 21 mt is contributed by the Peel River (Carson et al., 1998). Although the Department of Infrastructure (GNWT) has reported to have lost up to 500 m^3 (~840 t) of material from ferry landings in some years, that is a small proportion of the total sediment moved by the Peel (0.004%) and Mackenzie (6.94×10^{-4}%) Rivers annually. Given the negligible increase represented by losses of material from ferry landings, it is easy to see why my sampling design (or almost any other with a feasible number of replicates) would be unable to detect a difference in bed load or water quality due to erosion from the ferry landings.

Benthic macroinvertebrates

In order to investigate the potential cumulative impacts of added sediment downstream of ferry landing sites on the Peel and Mackenzie Rivers, I compared BMI communities among sites upstream, downstream, and on the ferry landings. I predicted that if ferry landing material was altering water quality or sediment loads then this would be reflected in the abundance or richness of BMI communities as described in the literature (Béjar et al., 2017; Culp et al., 1986; Rosenberg & Wiens, 1978; Smith et al., 2016; Wood & Armitage, 1997). I found no statistically significant differences in BMI communities in the Peel River with respect to location regardless of timing of sampling. In the Mackenzie River, total abundance differed at the ferry landing sites before and after the construction of the landings; however, the difference was not in the predicted direction, with abundance actually increasing after the construction of the landings. The observed increase in BMI after the construction of the ferry landings could be explained by a number of hypotheses including a recovery of BMI after ice breakup (Prowse & Culp, 2003), decreased discharge (Gibbins et al., 2007) and natural variation between sampling sites. Richness of BMI on the Mackenzie River was higher at upstream sites before construction, but no other differences in richness existed between sampling locations and times. A difference in BMI richness between upstream and downstream locations was one of my predicted outcomes; however, the fact that BMI richness decreased at the upstream site after ferry landing construction makes it difficult to reach any firm conclusions.

On the Mackenzie River, chironomid percentage at downstream, ferry, and upstream sites differed before and after construction (Figure 2.16B). It is important to note that there was a decrease in the relative abundance of chironomids at all locations after the construction of the ferry landings, even upstream sites. For that reason, I cannot conclude that the decrease in chironomid percentage downstream and at ferry landing locations is due to ferry operations. Although no conclusions can be drawn from the downstream differences, they were predicted as it has been shown in the literature that chironomids are sensitive to increases in sediment load.

Chin et al. (2016) found that the chironomid family was sensitive to increased concentrations of TSS from thaw slumping in the Peel Plateau region, Northwest Territories. Other studies found that chironomids make up a large proportion of organisms drifting due to increased sediment loads (Béjar et al., 2017; Culp et al., 1986; Rosenberg & Wiens, 1978). There are also several alternative hypotheses for the observed decrease in chironomid abundance. Chironomid emergence is highly variable and often synchronous in the Arctic (P. D. Armitage, 1995). Emergence is driven by water temperature (Danks & Oliver, 1972) and the water temperature of the Mackenzie River warms rapidly after ice break up, with mean water temperatures increasing from 5 °C in May to 12 °C in June (Yang, Marsh, & Ge, 2014; Yang & Peterson, 2017). I sampled BMI in the Mackenzie River on May 27 and again on June 6, so the decrease in chironomid abundance could be explained by an emergence due to increasing water temperatures.

Locations relevant to the ferry landings did not distinctly group together based on variation in BMI abundances in my PCAs. BMI communities on the Peel River were dominated by chironomids. Chironomids were expected to dominate samples on both rivers due to the high reported abundances in Arctic streams in the literature (e.g. Oswood, 1989; Scott, Barton, Evans, & Keating, 2011). However, this was not the case in the Mackenzie River sites, with chironomids making up the third most abundant taxa. Mysids and plecopterans made up the two most abundant taxa in the Mackenzie River sites (Figure 2.17B). Although there is limited literature on mysid shrimp in this area, they have been observed in the Mackenzie Delta in past studies (Casper, Rautio, Martineau, & Vincent, 2015). Plecopterans and ephemeropterans were associated with sites with gravel substratum in both rivers (Figure 2.18). This observation corresponds with those made by Scott et al. (2011), who found that plecopterans and ephemeropterans were more diverse on coarser substrates throughout streams in the Mackenzie River basin.

My results showed that the abundance of BMI in the Peel and Mackenzie Rivers was fairly low (0-137 individuals per sample). These results matched with those from two past studies in the region: 1) a study by GeoNorth-Ross-AMEC (2003) that found 395 individuals in 30 Ekman grab samples from upstream sites on the Mackenzie and Peel Rivers; and 2) a study by Environment and Climate Change Canada (2018a) that only found eight individuals in a three minute traveling kick net sample on the Mackenzie River (Environment and Climate Change Canada, 2012). While it seems that BMI abundance in the Peel and Mackenzie main stems are low, studies conducted in tributaries of these rivers found much higher abundances. For example, Chin et al. (2016) found a range of nine individuals per sample to 6033 per sample in stream sites in the Peel River watershed, with low abundances corresponding with areas experiencing high TSS loads due to permafrost thaw activity. Chin et al. (2016) found that mean TSS concentrations from moderately to highly disturbed sites were 872.67 mg/L to 2856.33 mg/L respectively. TSS concentrations observed on the Peel River in this study were seen to reach comparable levels to those seen at highly disturbed sites by Chin et al. (2016), suggesting that naturally large sediment pulses constantly disrupt BMI communities (Figure 2.4A). TSS concentrations on the Mackenzie River were much lower than the Peel River but could drastically increase during times of elevated discharge in the spring (Carson et al., 1998; Kennedy et al., 2014) and ice breakup (Prowse, 1993; Prowse & Culp, 2003). There could also be lack of suitable substrate for many BMI (Scott et al., 2011); however, coarse substrates were found to be naturally occuring at both upstream and downstream sites.

Limitations

The Peel and Mackenzie Rivers are wide, deep, swift, and remote, which makes sampling logistically challenging. Sampling equipment was lowered to depths of up to 33 m by a hand-crank winch from 5 m aluminum boats. This limited the number of daily samples that could be collected and in turn lowered the statistical power to detect small differences in water quality or sediment loads.

Although my findings suggest that sediment from the ferry landings is not impacting water quality, sediment loads, or BMI communities, reporting by the GNWT (2015) states that up to 500 m^3 has been lost in the Mackenzie River in some years. While my sampling focused on detecting changes due to the construction and maintenance of the ferry landings in the spring, high-water events throughout the summer and fall were not investigated. During one of these events on the Peel River, flow was observed directly over top of the ferry landing (M. Teillet, personal observation, 2018). Due to the increased discharge during these events and the increased sediment-carrying capacity (Carson et al., 1998), erosion of material from the landings may have occurred. Despite these caveats, we planned our work during a time of high flow when active construction was taking place. We expected the spring construction and maintenance to be the most likely and predictable time to detect eroded sediment from the ferry landings, as this is when loose material is being placed in order to build out the landings.

Conclusions and implications

I investigated the potential effects of ferry landings on the water quality, sediment loads, and BMI communities of the Peel and Mackenzie Rivers. I found no significant differences in water quality and sediment loads between upstream and downstream sites through time. BMI communities on the Peel River also did not differ between sites relevant to the ferry landings through time. BMI community metrics from the Mackenzie River, including total abundance, taxonomic richness, and chironomid percentage, were significantly different between locations and through time, but these differences did not appear to be related to the ferry landings.

Our power analyses showed that our study design had a high power to detect a 20% difference in turbidity between upstream and downstream sites on both rivers, giving us some confidence in our results. However, we had a low power to detect differences in bed load between upstream and downstream locations, and a low power to detect smaller (5-10%) upstream/downstream differences in turbidity or TSS. Issues with low power were caused by high variability among our samples, highlighting the difficulty of quantifying sediment movement in these large, dynamic systems. Given the results of our power analysis, we believe that our study was adequately designed to detect modest changes in water quality due to erosion of sediment from ferry landings (i.e. ≥20%), but inadequate for detecting smaller differences.

In conclusion, my study indicates that the current practices by the Department of Infrastructure related to ferry operations do not appear to be having large impacts on water quality or BMI communities downstream of the landings. Given the small amount of material estimated to be lost from the landings each year relative to the natural sediment loads of these rivers, it may be logistically impossible to detect small differences given a reasonable budget for environmental monitoring. However, since statistical power increases with sample size, ongoing monitoring (perhaps by community-based monitors) would help to increase the number of observations, allowing for more powerful tests in the future. An ongoing monitoring effort would also assist with the detection of changes in water quality, sediment loads, or BMI communities related to climate change and other anthropogenic disturbances in these rivers (e.g. Chin et al., 2016; Kokelj et al., 2013; Rood, Kaluthota, Philipsen, Rood, & Zanewich, 2017).

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2.6 Tables

Table 2.1. Results from two-factor repeated measures analysis of variance tests for all physical variables measured on the Peel River. (*) denotes a significant p-value.

Variable	Transformation	Factor	df	F	p-value
Turbidity	OrderNorm	Location	1, 28	0.14	0.71
		Time		73.11	<0.0001*
		Location*Time		0.40	0.53
TSS	OrderNorm	Location	1, 28	1.26	0.27
		Time		72.33	<0.0001*
		Location*Time		0.28	0.60
Bed load, d_{10}	OrderNorm	Location	1, 11	0.15	0.70
		Time		0.03	0.86
		Location*Time		0.27	0.61
Bed load, d_{50}	OrderNorm	Location	1, 24	0.12	0.73
		Time		1.36	0.25
		Location*Time		0.04	0.85
Bed load, d_{90}	OrderNorm	Location	1, 11	0.01	0.93
		Time		2.23	0.16
		Location*Time		3.13	0.10
Bed load, %sand	OrderNorm	Location	1, 24	0.15	0.71
		Time		4.71	0.04*
		Location*Time		0.38	0.54
Bed load, rate	OrderNorm	Location	1, 23	0.89	0.35
		Time		0.00	0.95
		Location*Time		0.66	0.42
BMI, abundance	Arcsine	Location	2, 7	3.10	0.11
		Time	1, 7	1.64	0.24
		Location*Time	2, 7	0.37	0.71
BMI, richness	Arcsine	Location	2, 7	0.60	0.58
		Time	1, 7	6.74	0.04*
		Location*Time	2, 7	0.28	0.76
BMI, %EPT	Arcsine	Location	2, 7	2.58	0.15
		Time	1, 7	12.52	0.009*
		Location*Time	2, 7	1.46	0.29
BMI, %Chironomidae	Arcsine	Location	2, 7	1.95	0.21
		Time	1, 7	54.46	0.0002*
		Location*Time	2, 7	2.20	0.18

Table 2.2. Results from two-factor repeated measures analysis of variance tests for all physical variables measured on the Mackenzie River. (*) denotes a significant p-value.

Variable	Transformation	Factor	df	F	p-value
Turbidity	OrderNorm	Location	1, 31	1.02	0.32
		Time	1.95, 60.52	96.86	<0.0001*
		Location*Time	1.95, 60.52	3.04	0.06
TSS	OrderNorm	Location	1, 31	0.34	0.56
		Time	1.81, 56.19	75.85	<0.0001*
		Location*Time	1.81, 56.19	0.90	0.40
Bed load, d_{10}	OrderNorm	Location	1, 11	0.14	0.72
		Time		0.01	0.91
		Location*Time		0.00	0.98
Bed load, d_{50}	OrderNorm	Location	1, 11	0.08	0.78
		Time		0.37	0.55
		Location*Time		0.02	0.88
Bed load, d_{90}	OrderNorm	Location	1, 11	1.05	0.33
		Time		0.19	0.67
		Location*Time		0.59	0.46
Bed load, %sand	OrderNorm	Location	1, 11	0.01	0.93
		Time		0.12	0.73
		Location*Time		0.34	0.57
Bed load, rate	OrderNorm	Location	1, 11	1.47	0.25
		Time		5.95	0.03*
		Location*Time		3.42	0.09
BMI, abundance	Arcsine	Location	2, 10	0.32	0.73
		Time	1, 10	0.24	0.63
		Location*Time	2, 10	4.56	0.04*
BMI, richness	Arcsine	Location	2, 10	1.24	0.12
		Time	1, 10	18.57	0.002*
		Location*Time	2, 10	6.31	0.02*
BMI, %EPT	Arcsine	Location	2, 10	1.24	0.33
		Time	1, 10	3.88	0.08
		Location*Time	2, 10	2.12	0.17
BMI, %Chironomidae	Arcsine	Location	2, 10	0.40	0.68
		Time	1, 10	92.50	<0.0001*
		Location*Time	2, 10	7.42	0.01*

2.7 Figures

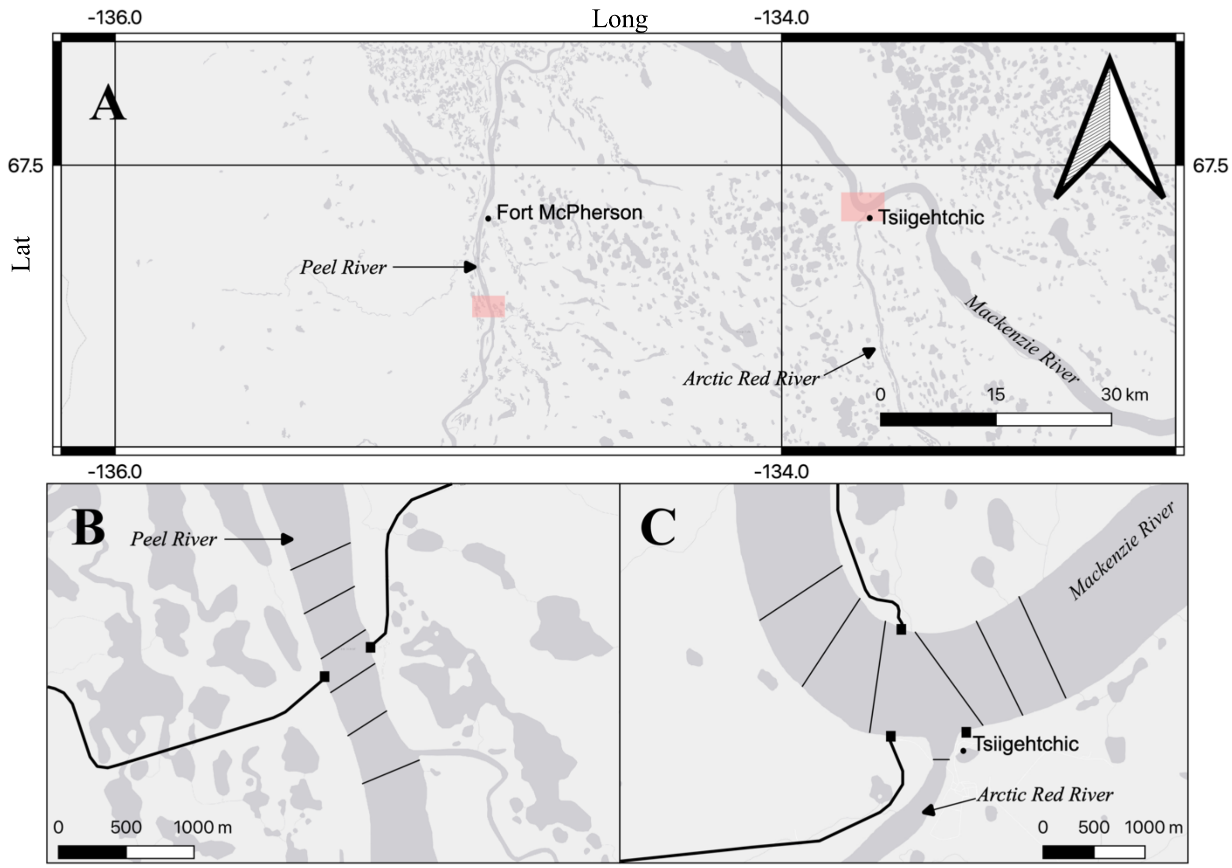


Figure 2.1. A) Map of the scientific study area, B) inset of the Peel River and two ferry landings, and C) inset of the Mackenzie and Arctic Red Rivers and three ferry landings. Black lines on each river denote sampling transects. Note: all rivers flow north (upwards on the map).

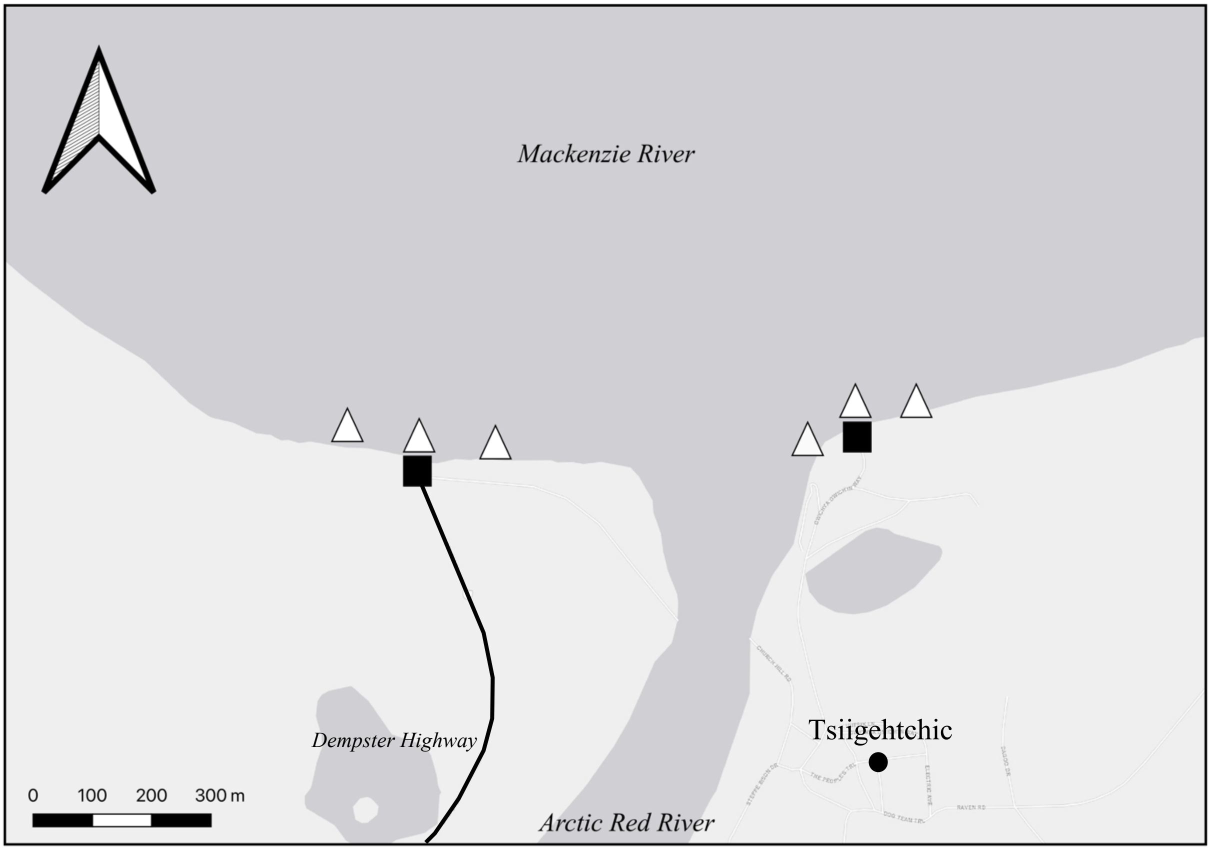


Figure 2.2. Map showing an example of benthic macroinvertebrate (BMI) sample design on the Mackenzie River. Black squares denote ferry landings and white triangles denote BMI collection sites. Triplicate samples were taken at each BMI site.

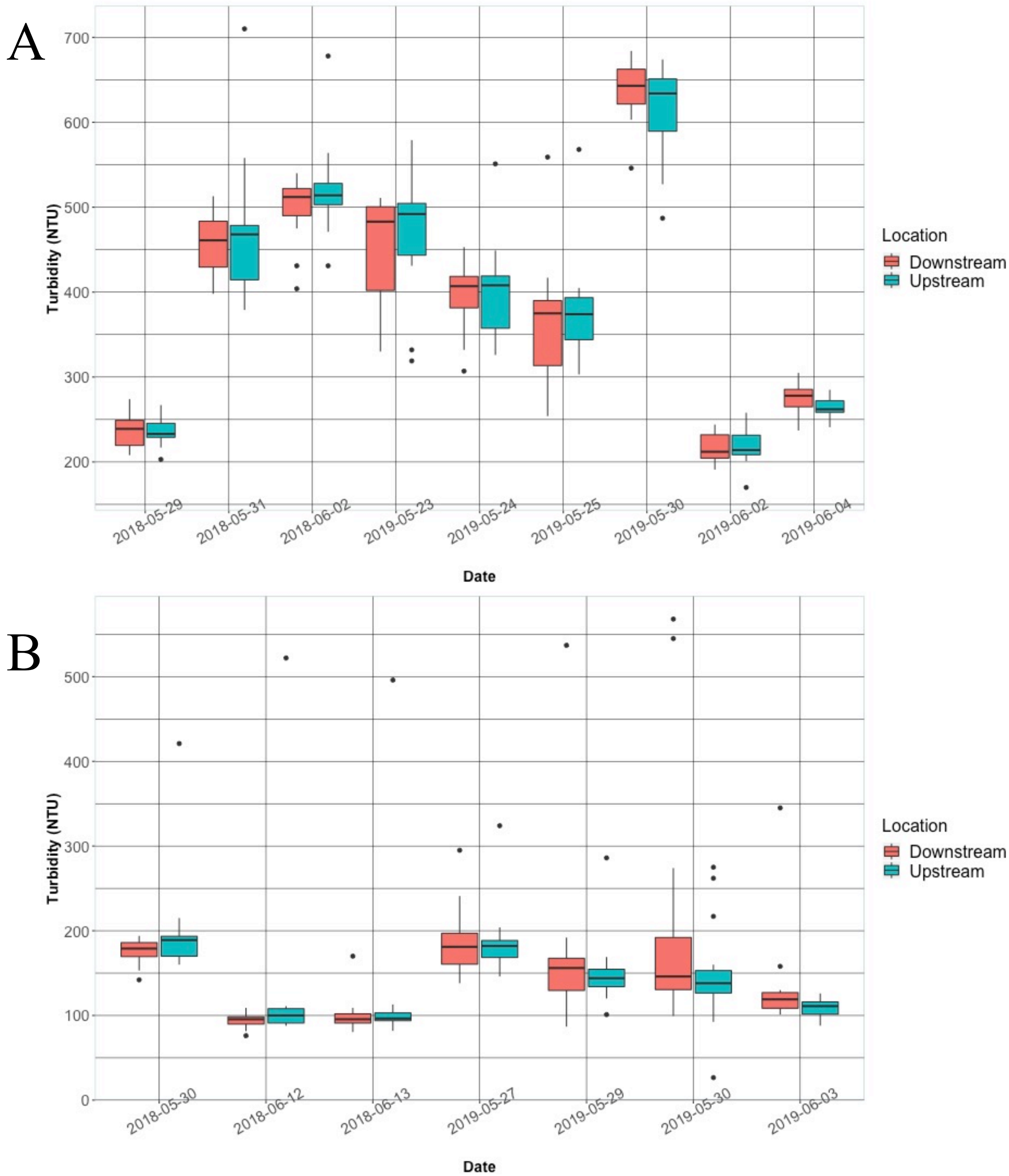


Figure 2.3. Turbidity measurements collected upstream and downstream of the ferry landings on the A) Peel River and B) Mackenzie River. Outliers are represented by points outside of boxplot while boxplots represent the variation in the dataset.

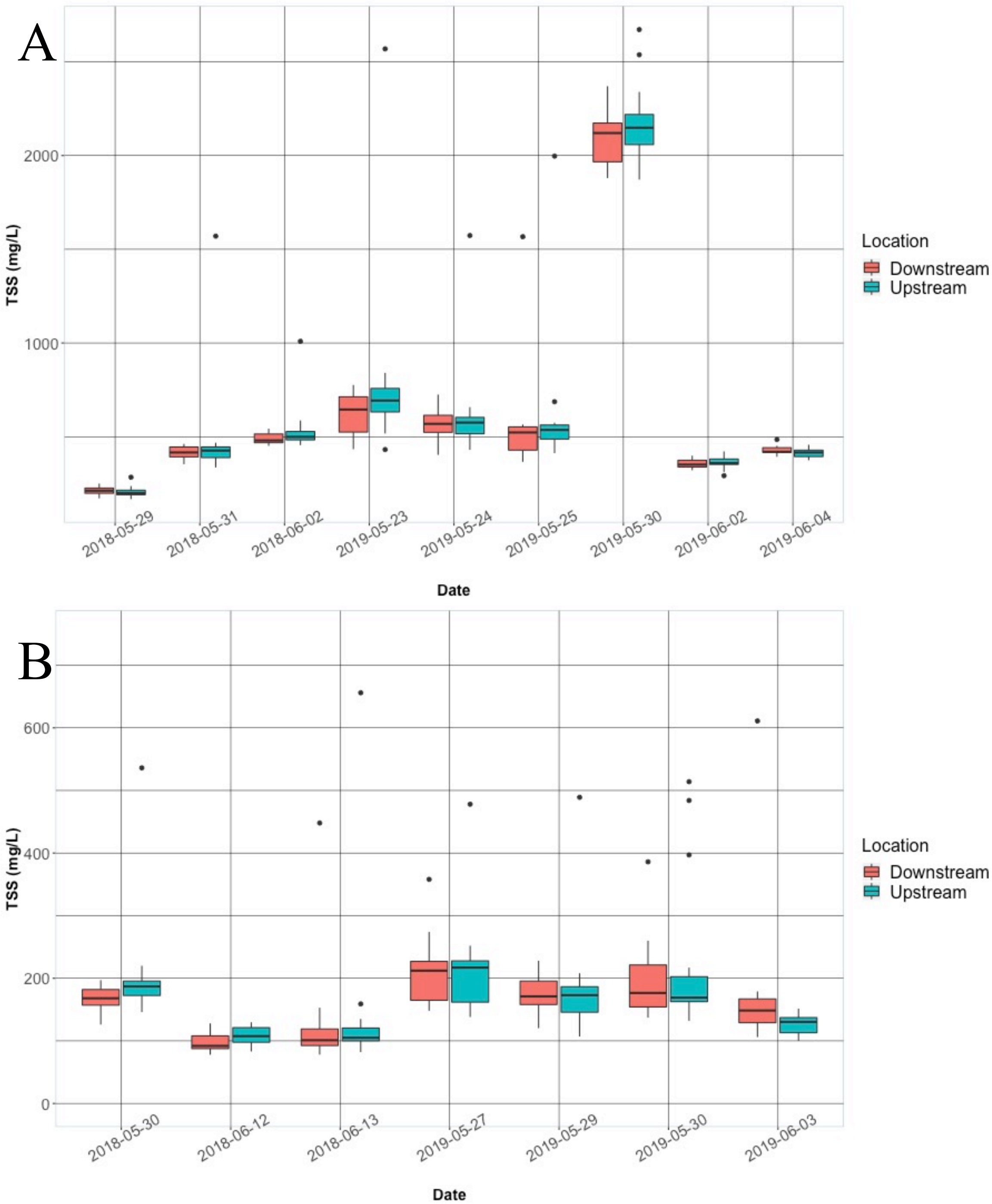


Figure 2.4. Total suspended solids measurements collected upstream and downstream of the ferry landings on the A) Peel River and B) Mackenzie River. Outliers are represented by points outside of boxplot while boxplots represent the variation in the dataset.

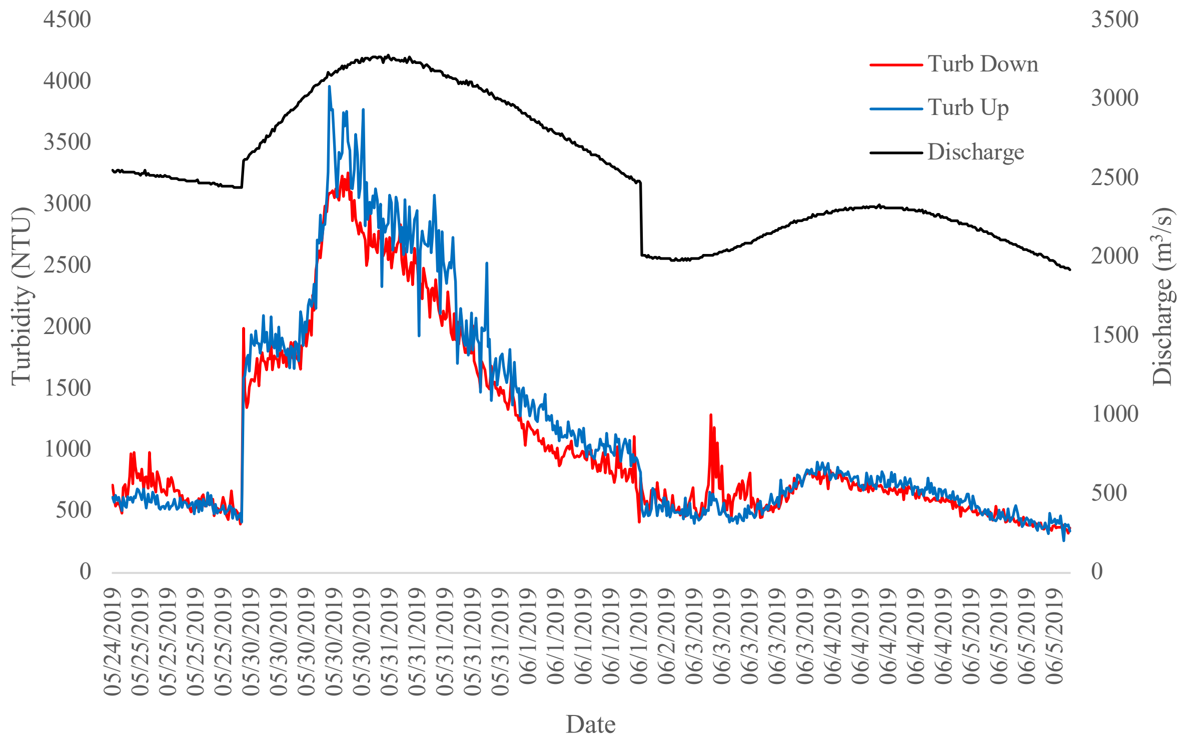


Figure 2.5. Turbidity data from the Peel River from May 24, 2019 to June 6, 2019 aligned with discharge data from Water Survey of Canada station 10MC002. Note: data missing between May 25 and May 30 as well as June 1 and June 3.

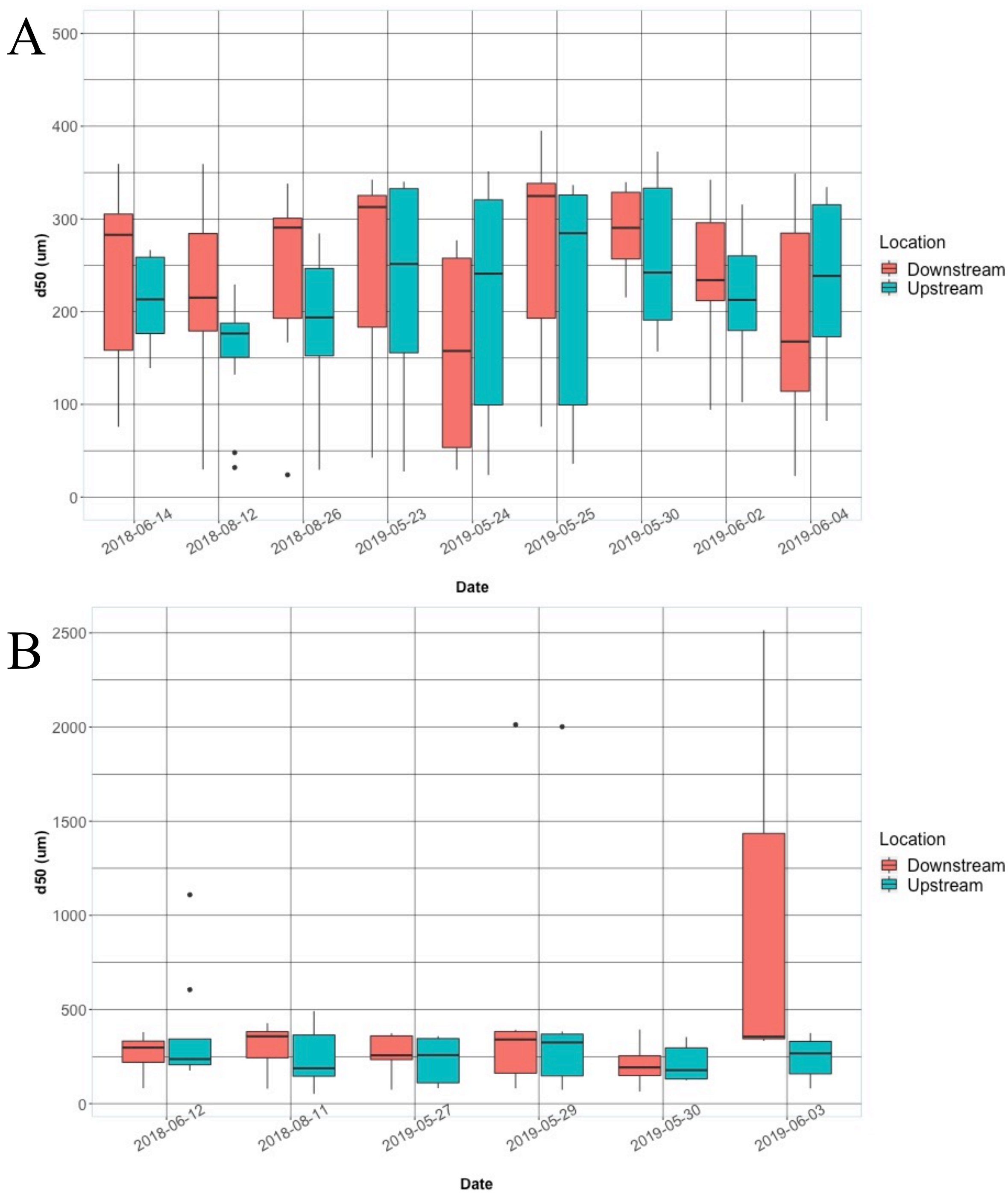


Figure 2.6. Median particle size of bed load sediments collected upstream and downstream of the ferry landings on the A) Peel River and B) Mackenzie River. Outliers are represented by points outside of boxplot while boxplots represent the variation in the dataset.

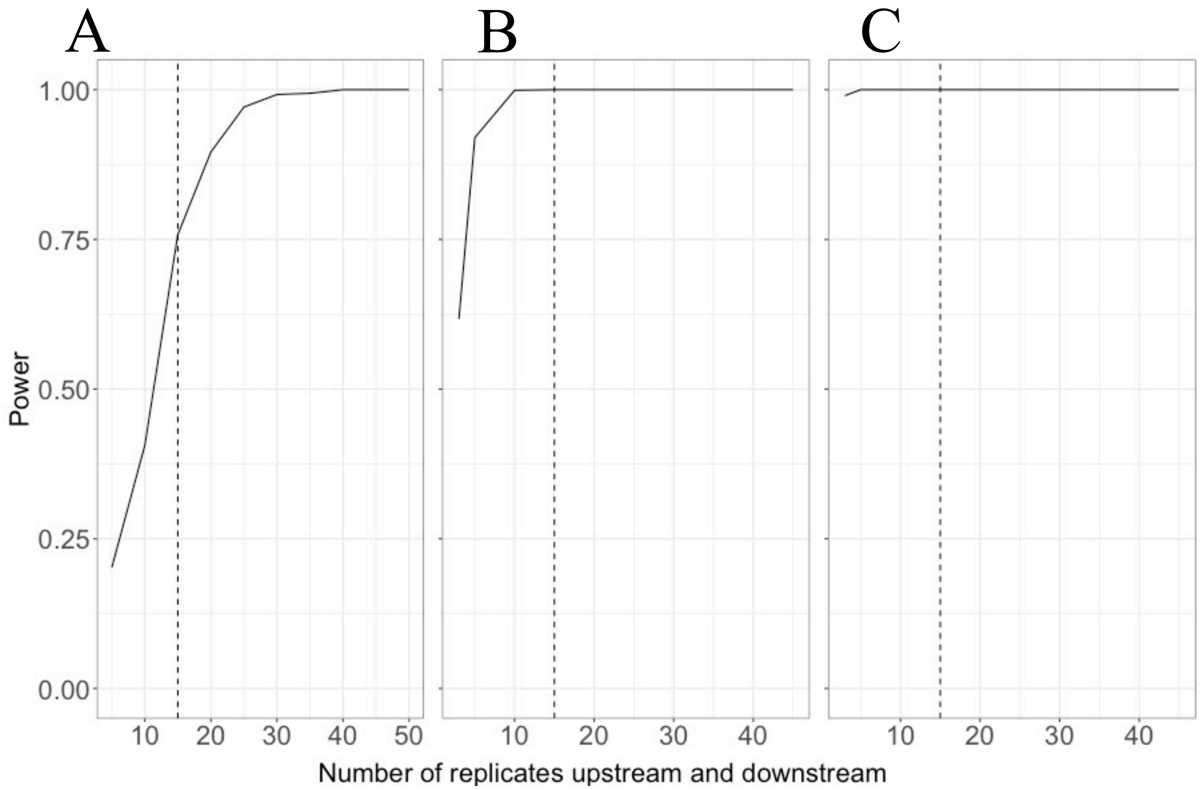


Figure 2.7. Relationship between number of replicate turbidity measurements upstream and downstream of the ferry landings on the Peel River and the power to detect a statistical difference between the upstream and downstream sites. The dashed line represents actual number of samples taken upstream and downstream. A) 5% difference in turbidity between upstream and downstream locations; B) 10%; C) 20%.

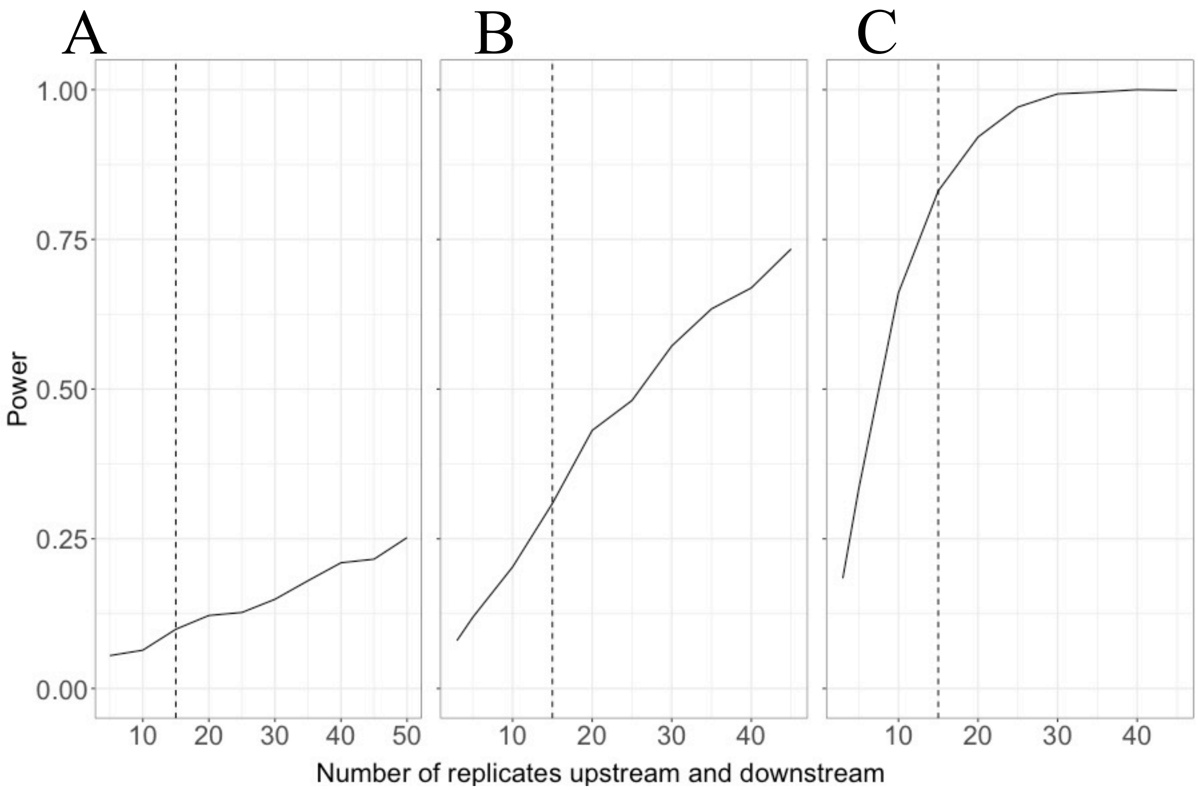


Figure 2.8. Relationship between number of replicate turbidity measurements upstream and downstream of the ferry landings on the Mackenzie River and the power to detect a statistical difference between the upstream and downstream sites. The dashed line represents actual number of samples taken upstream and downstream. A) 5% difference in turbidity between upstream and downstream locations; B) 10%; C) 20%.

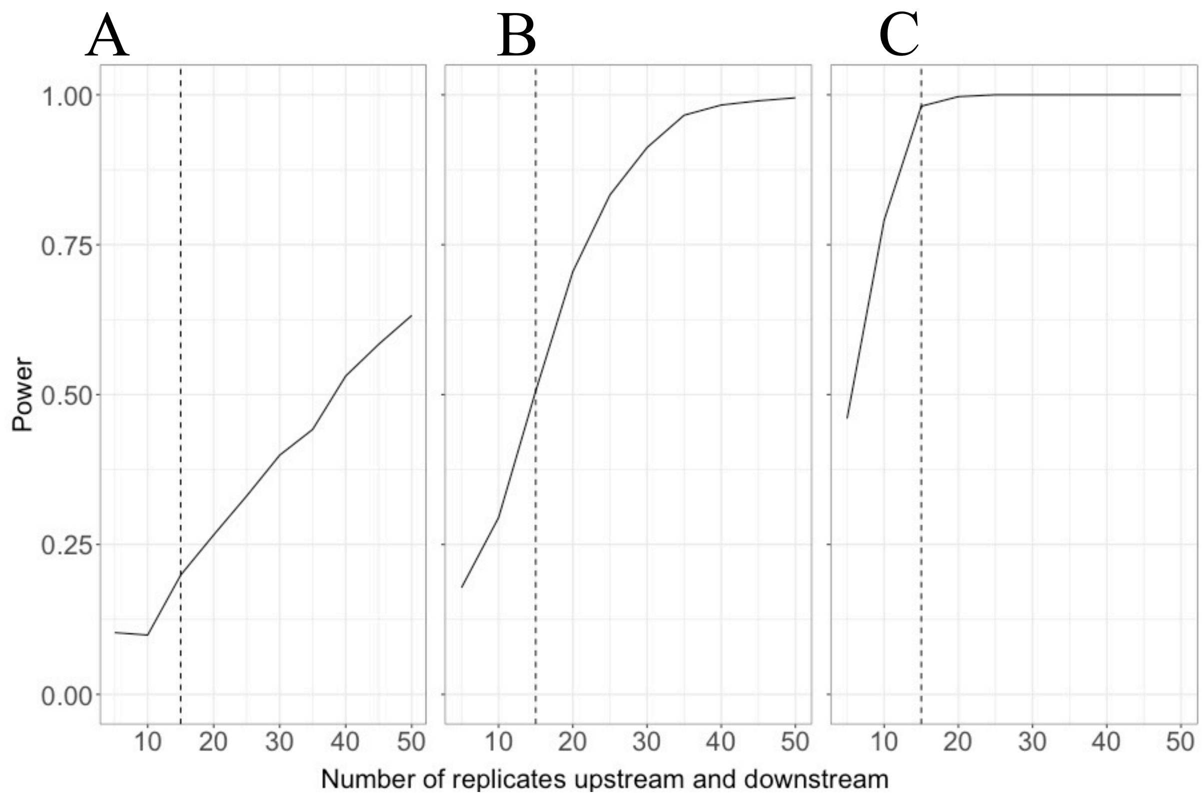


Figure 2.9. Relationship between number of replicate total suspended solids (TSS) measurements upstream and downstream of the ferry landings on the Peel River and the power to detect a statistical difference between the upstream and downstream sites. The dashed line represents actual number of samples taken upstream and downstream. A) 5% difference in TSS between upstream and downstream locations; B) 10%; C) 20%.

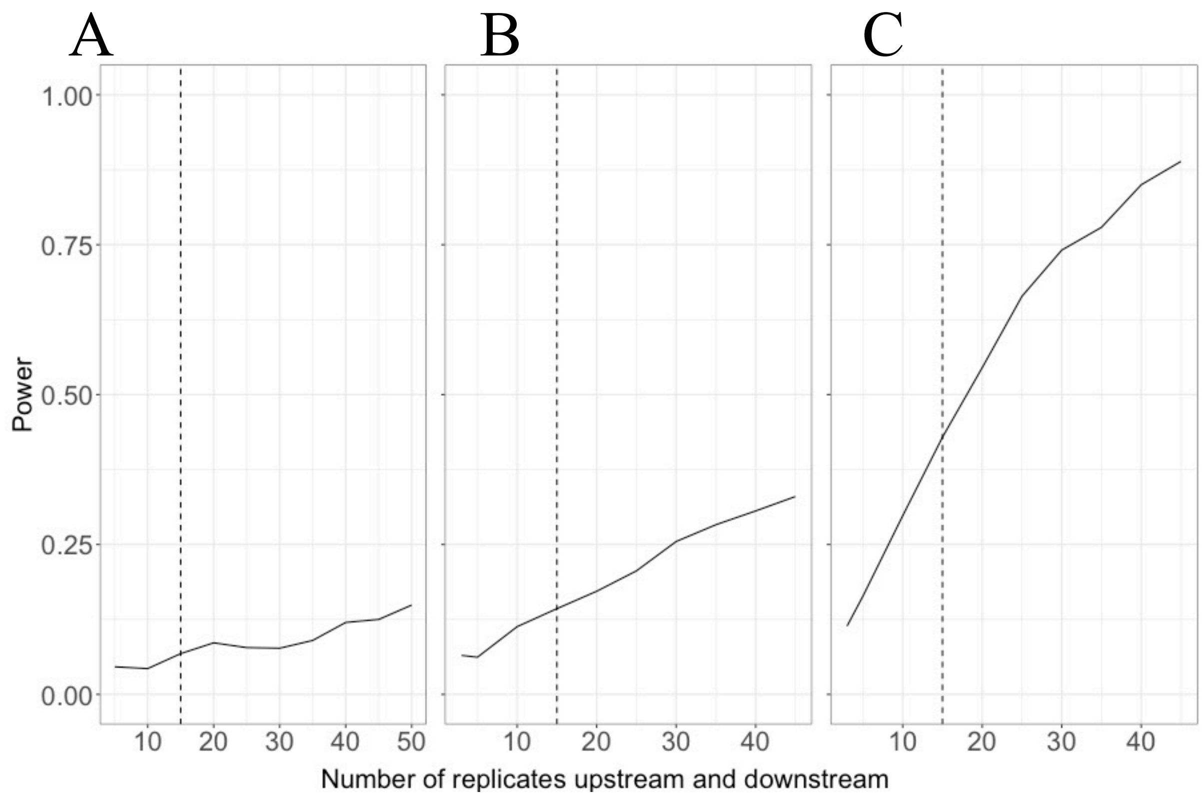


Figure 2.10. Relationship between number of replicate total suspended solids (TSS) measurements upstream and downstream of the ferry landings on the Mackenzie River and the power to detect a statistical difference between the upstream and downstream sites. The dashed line represents actual number of samples taken upstream and downstream. A) 5% difference in TSS between upstream and downstream locations; B) 10%; C) 20%.

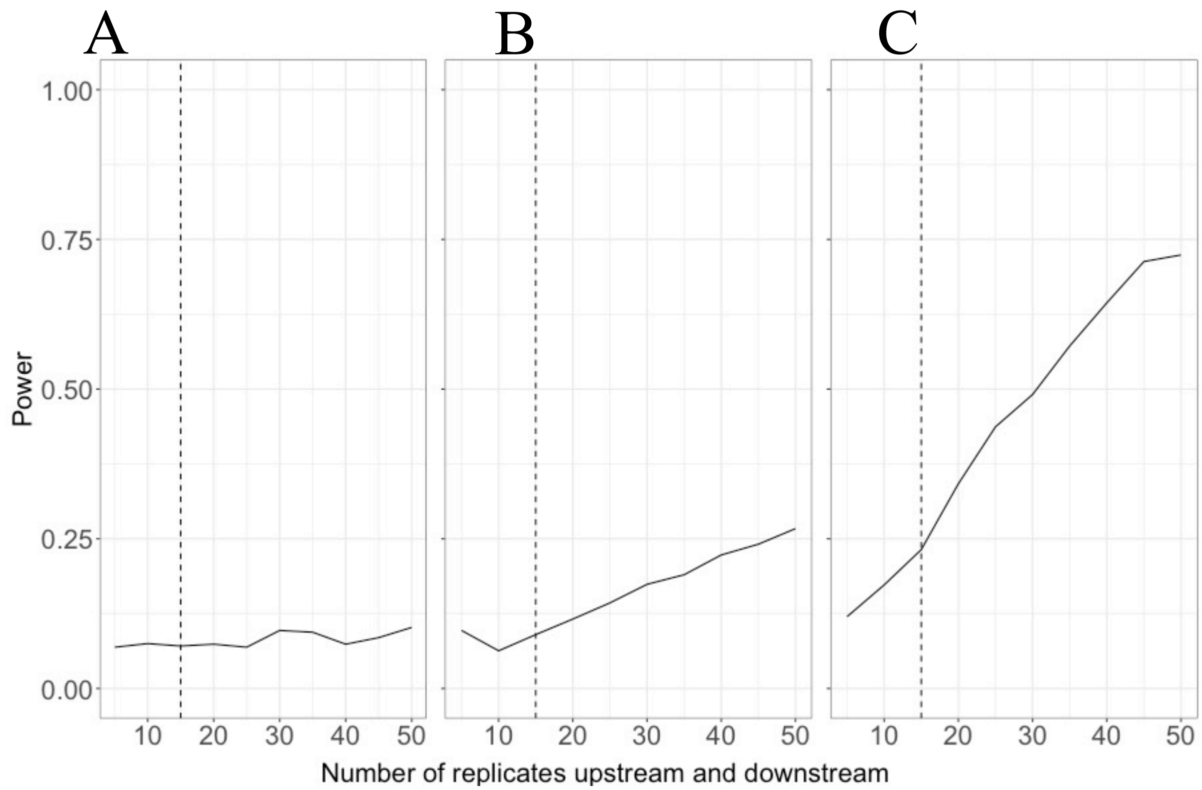


Figure 2.11. Relationship between number of replicate bed load median particle size measurements (*d_{50}*) measurements upstream and downstream of the ferry landings on the Peel River and the power to detect a statistical difference between the upstream and downstream sites. The dashed line represents actual number of samples taken upstream and downstream. A) 5% difference in median particle size between upstream and downstream locations; B) 10%; C) 20%.

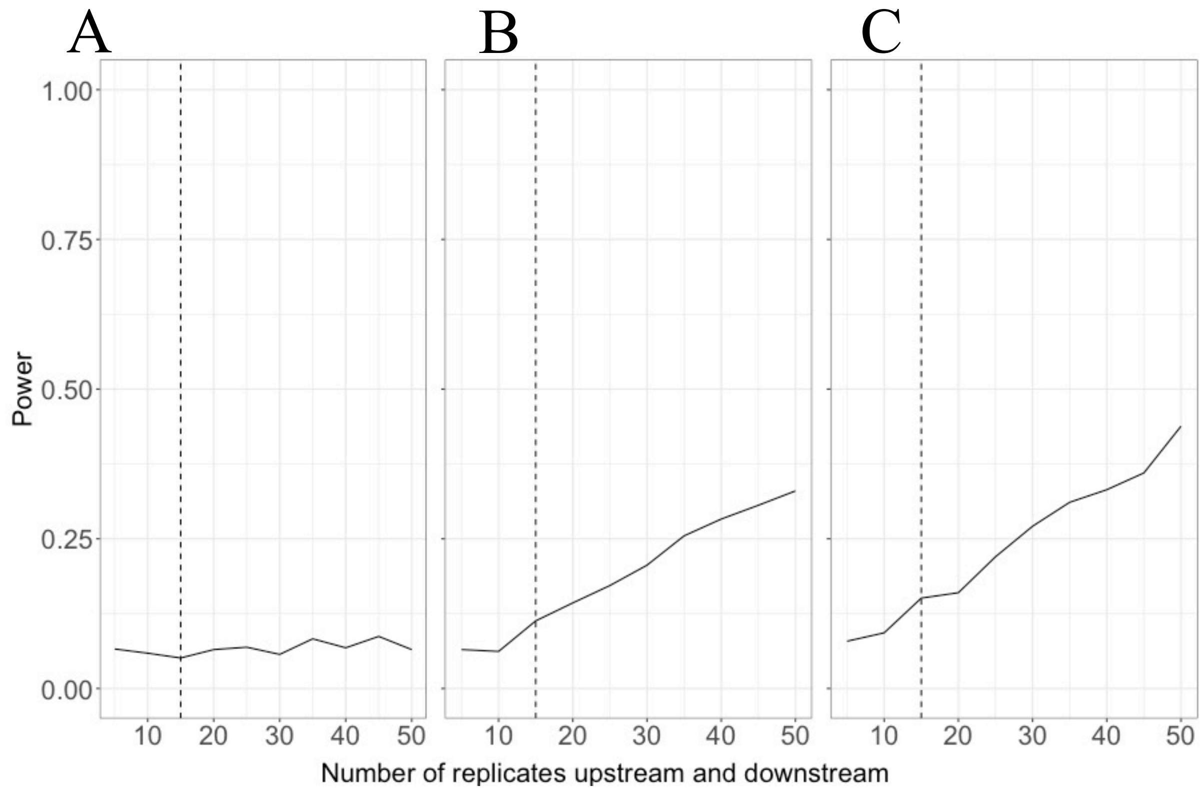


Figure 2.12. Relationship between number of replicate bed load median particle size measurements (d_{50}) measurements upstream and downstream of the ferry landings on the Mackenzie River and the power to detect a statistical difference between the upstream and downstream sites. The dashed line represents actual number of samples taken upstream and downstream. A) 5% difference in median particle size between upstream and downstream locations; B) 10%; C) 20%.

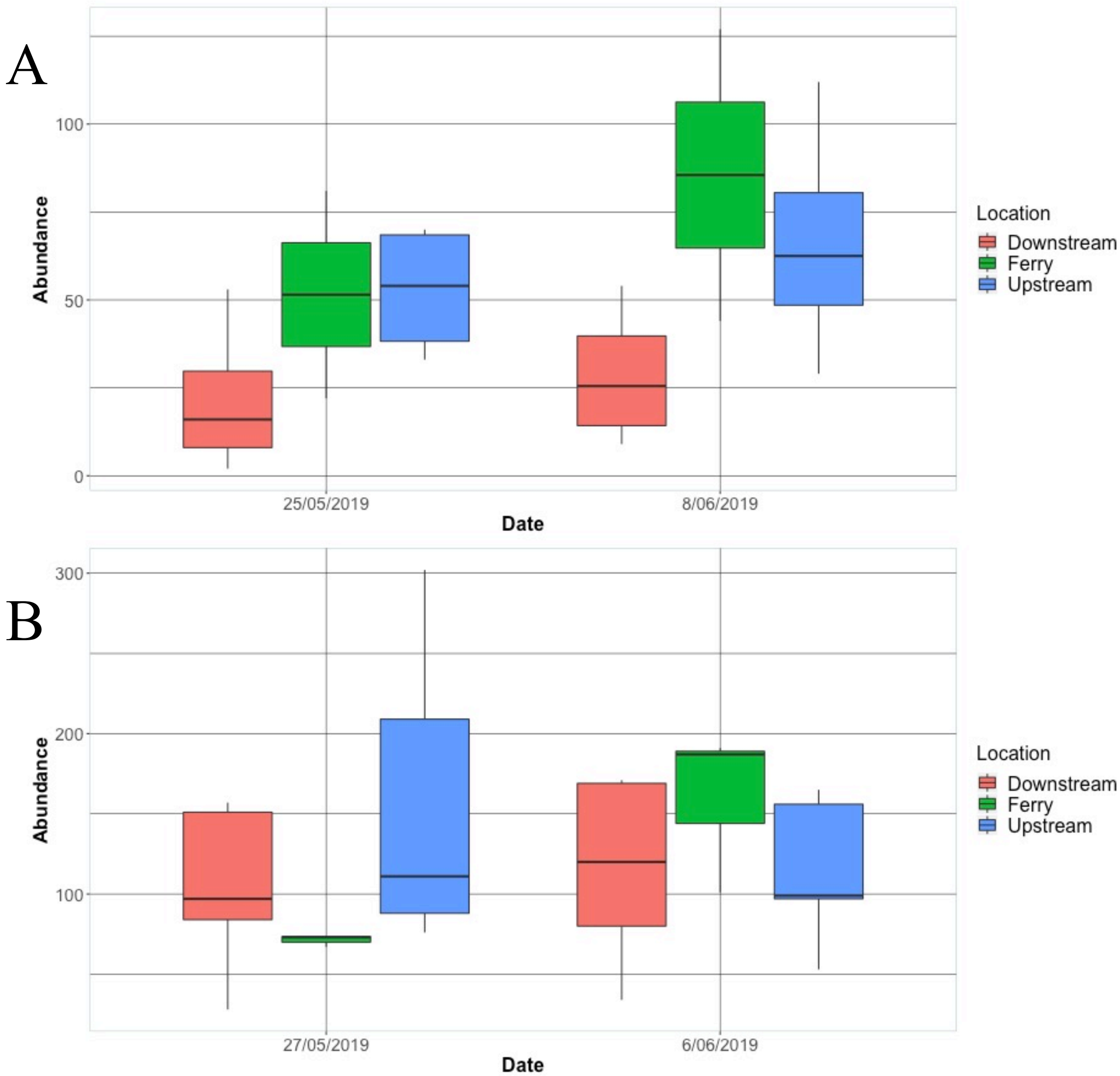


Figure 2.13. Total benthic macroinvertebrate abundances from sites relative to location and time samples on the A) Peel River and B) Mackenzie River. Outliers are represented by points outside of boxplot while boxplots represent the variation in the dataset.

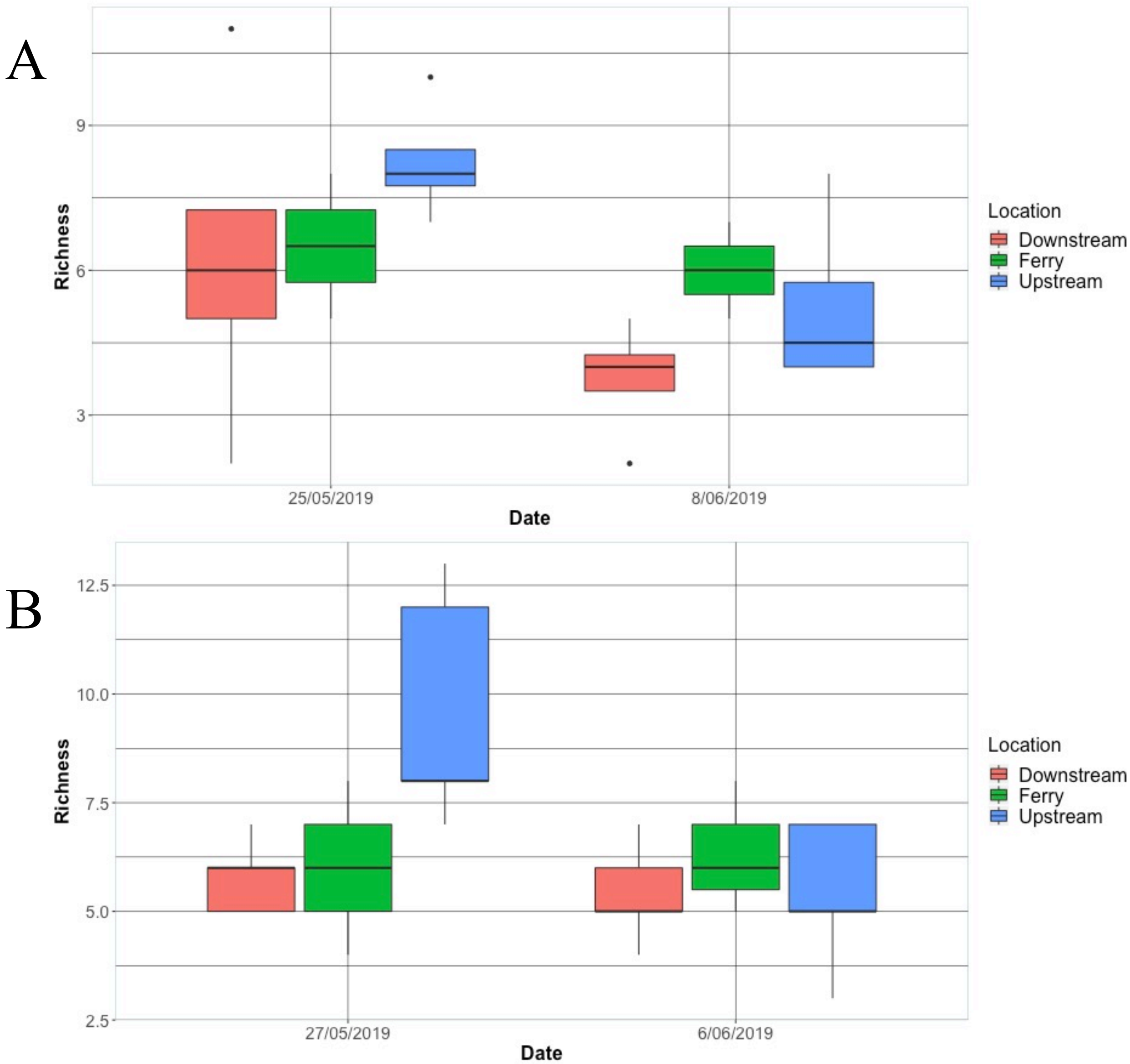


Figure 2.14. Benthic macroinvertebrate taxonomic richness from sites relative to location and time samples on the A) Peel River and B) Mackenzie River. Outliers are represented by points outside of boxplot while boxplots represent the variation in the dataset.

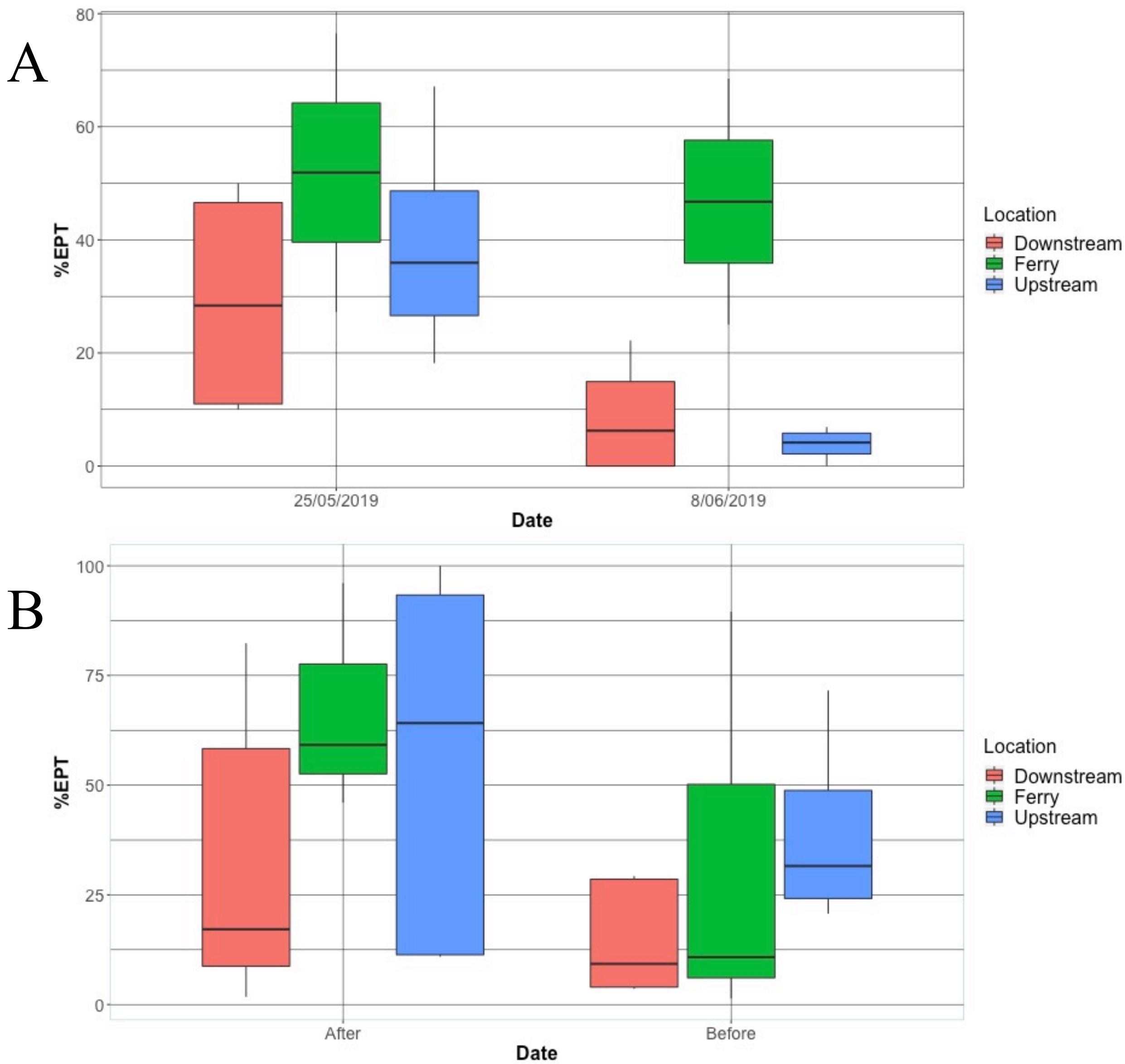


Figure 2.15. Percent sensitive taxa (EPT; Ephemeroptera, Plecoptera, and Trichoptera) from sites relative to location and time samples on the A) Peel River and B) Mackenzie River. Outliers are represented by points outside of boxplot while boxplots represent the variation in the dataset.

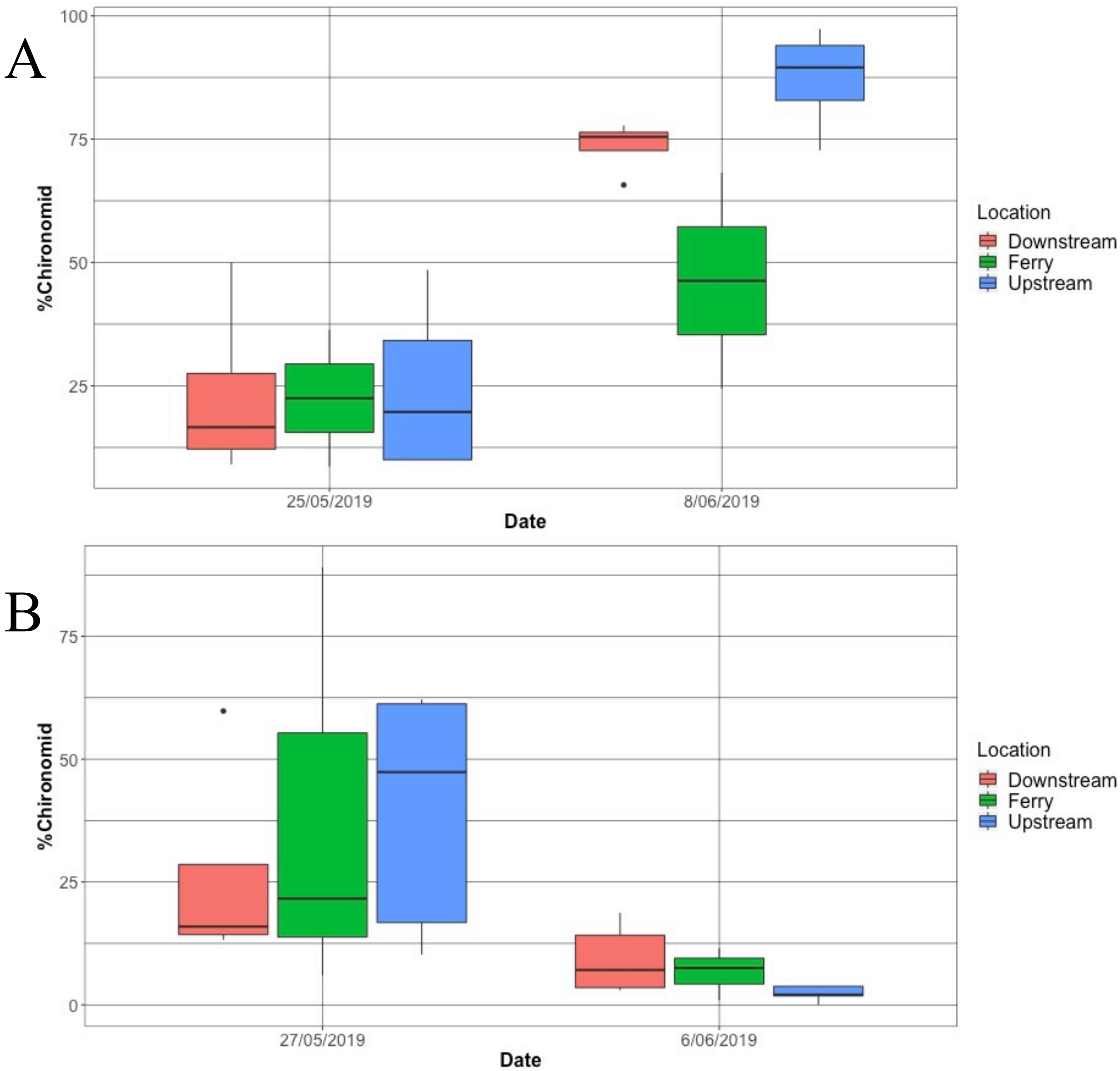
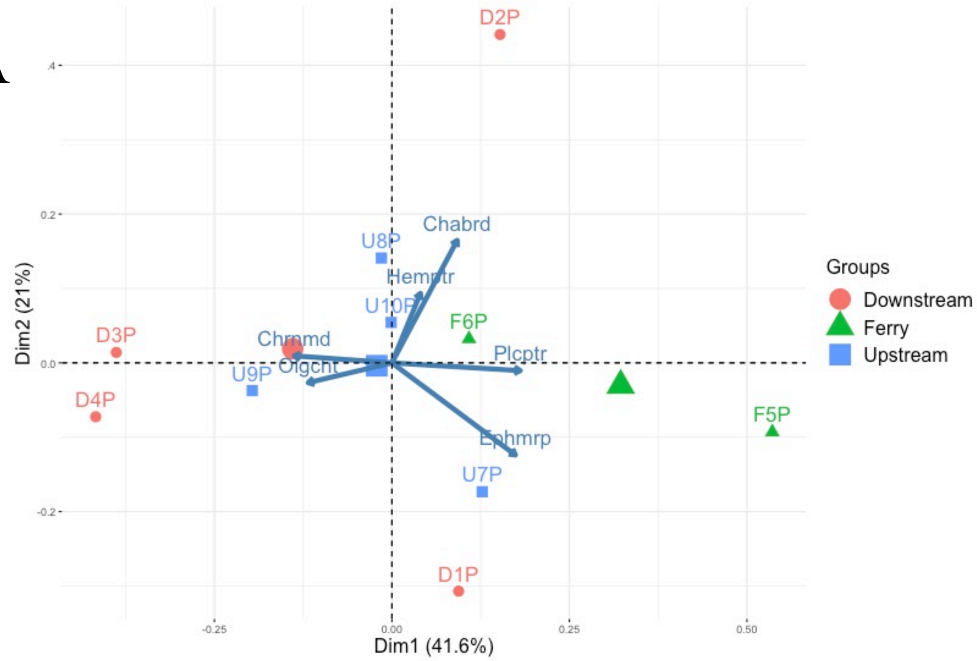


Figure 2.16. Percent Chironomidae from sites relative to location and time samples on the A) Peel River and B) Mackenzie River. Outliers are represented by points outside of boxplot while boxplots represent the variation in the dataset.

A



B

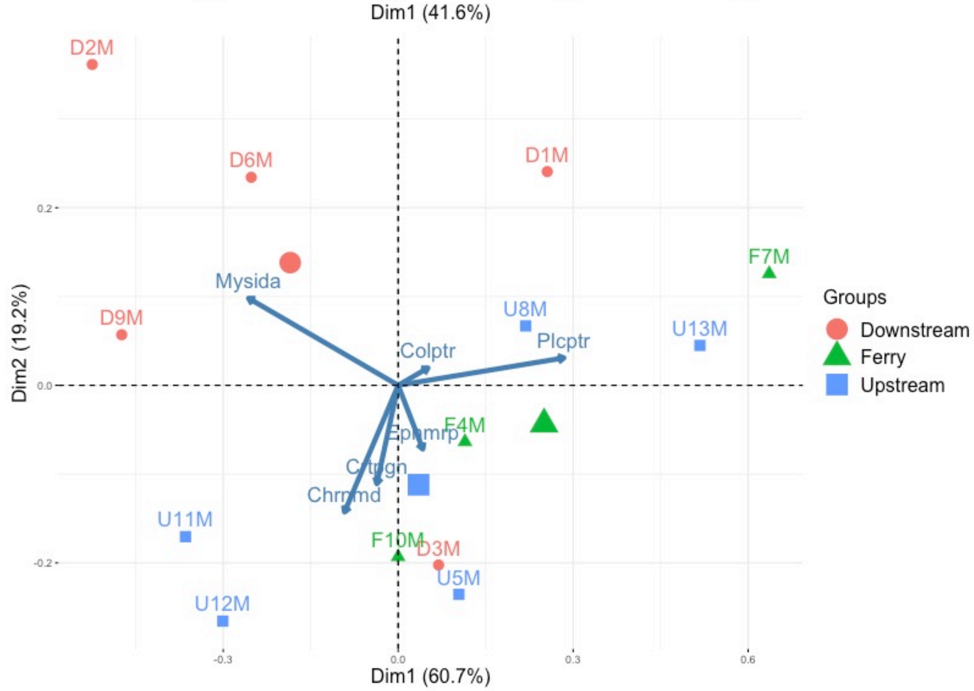


Figure 2.17. PCA biplot illustrating variation in BMI communities at A) 10 sites on the Peel River and B) 13 sites on the Mackenzie River with respect to location. Sites beginning with D represent downstream sites, F represent ferry landing sites, and U represent upstream sites. Large symbols on the biplot represent the mean for each category.

A

B

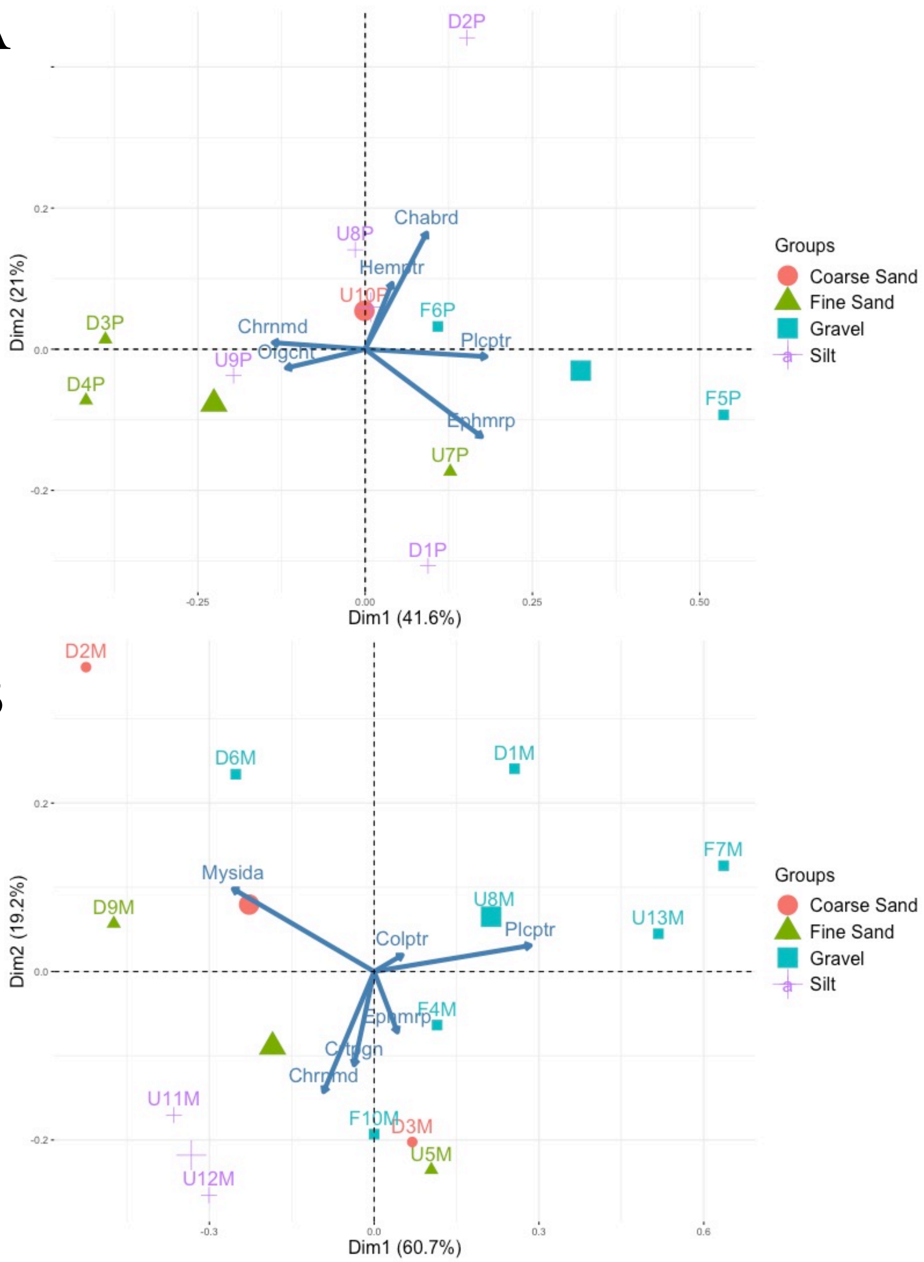


Figure 2.18. PCA biplot illustrating variation in BMI communities at A) 10 sites on the Peel River and B) 13 sites on the Mackenzie River with respect to median particle size of the substrate. Sites beginning with D represent downstream sites, F represent ferry landing sites, and U represent upstream sites. Large symbols on the biplot represent the mean for each category.

Chapter 3: Using Traditional Knowledge to determine the impacts of ferry operations in the Gwich'in Settlement Area, Northwest Territories

3.1 Introduction

In this chapter, I outline the Gwich'in Traditional Knowledge (TK) that was shared with us through interviews from this study and past studies as it pertains to ferry operations in the Gwich'in Settlement Area (GSA). Gwich'in TK is defined by the Gwich'in Tribal Council (GTC) as "that body of knowledge, values, beliefs and practices passed from one generation to another by oral means or through learned experience, observation and spiritual teachings, and pertains to the identity, culture and heritage of the Gwich'in," (GTC, 2004). We analyzed Gwich'in TK to help determine the impacts of ferry operations on river morphology, fishing opportunities, and Gwich'in livelihood.

3.2 Methodology

Study area

The GSA encompasses over 56 000 km^2 of the Northwest Territories (NT) and includes much of the Gwich'in People's traditional lands (GLUPB, 2015). Two of the original Gwich'in cultural groups are the Teetł'it Gwich'in and Gwichya Gwich'in. Most Teetł'it Gwich'in now live in Fort McPherson (pop. 700; Statistics Canada, 2016) but have traditionally used lands throughout the Peel River watershed (Wray & Parlee, 2013). Similarly, many Gwichya Gwich'in now live in Tsiigehtchic (pop. 172; Statistics Canada, 2016) but their historical territory spans much of the eastern area of the GSA (Heine, Andre, Kritsch, Cardinal, & Tsiigehtshik, 2007). The Gwich'in share a strong relationship with the natural environment, and actively participate in decisions on management and use of lands and waters in the GSA (Heine et al., 2007; Wray & Parlee, 2013).

The Peel, Mackenzie, and Arctic Red Rivers all flow through the traditional use areas of the Gwich'in, and Osgood (1970) noted that each Gwich'in subgroup was associated with a river or stream (Wishart, 2013). Fishing camps along these rivers have been used throughout Gwich'in history (Heine et al., 2007; Thompson & Millar, 2007; Wray & Parlee, 2013). For example, Gwich'in fishing artifacts recovered in Tsiigehtchic have been dated to over 1300 years old (Nolin & Pilon, 1994). Traditional knowledge held by the Gwich'in People also supports claims that these fish camps have been used for generations (Heine et al., 2007; Thompson & Millar, 2007; Wishart, 2013). The fish camps were often next to eddies on the Peel and Mackenzie Rivers, where nets were set after ice breakup until the camp was abandoned for the year in the fall. Fish were traditionally caught using gill nets, fish traps, fish wheels, or spears (Greenland & Walker-Larsen, 2001; Heine et al., 2007). Throughout the summer, fish were eaten fresh or dried for consumption in the following winter. Dried fish, or dryfish, was also used as dog food during the fur trade and is still commonly prepared today (Heine et al., 2007; Wishart, 2013). Fishing remains an important activity in Gwich'in communities today and is practiced throughout the year. Fish harvest data collected near Fort McPherson and Tsiigehtchic indicates that Gwich'in harvesters each still catch hundreds of fish every year (GNWT, 2017). The importance of fish, water, and the land to the Gwich'in is also reflected in their concern for it (Wishart, 2013; Wray & Parlee, 2013). Multiple studies have investigated the impacts of climate change and development on fish stocks, including the Aquatic Effects Study (GeoNorth-Ross-AMEC, 2003) and the Local Area Monitoring Plan (GNWT, 2017), both addressing community concerns over potential impacts from ferry operations in the GSA.

The GTC has a Traditional Knowledge Policy that defines Gwich'in TK and outlines the ethical use of Gwich'in TK in research (GTC, 2004). This policy, along with our research license from the Aurora Research Institute and our research agreement with the GTC's Department of Cultural Heritage, guided our documentation and interpretation of Gwich'in TK for this study.

Traditional Knowledge records

In preparation for the research, we conducted a comprehensive background review of existing Gwich'in TK records. Several documents containing Gwich'in TK, including the original study completed by GeoNorth-Ross-AMEC (2003) on ferry operations in the GSA, were provided by the Department of Infrastructure, GNWT. Other sources of Gwich'in TK were found via library database searches and Google Scholar using the search term "Gwich'in + Traditional Knowledge". We also found multiple relevant Traditional Knowledge sources on the Gwich'in Renewable Resources Board website (GRRB, 2019). These TK sources informed study design by providing the research team with an understanding of the cultural, environmental, and economic context for ferry operations in the GSA. During the course of the study, the GTC Department of Cultural Heritage provided over 100 documents from their TK repository, discovered through a keyword search of "ferry" and "fish" within the same line (Appendix 2.1). Together with the earlier background sources, these helped broaden our understanding of the context for community concerns about the ferries and shaped our interpretation of research findings.

Relationship building

Two members of our research team began working within the communities of Fort McPherson and Tsiigehtchic on environmental projects during the summer of 2017. At this time, we began to build relationships with local Renewable Resource Councils (RRC) and community members. Beginning in May 2018, and throughout the Western Scientific (WS) sampling for this study, community members were involved in sampling as river experts, guides, and logistical support. In 2019, WS sampling continued with the help of community members, and researchers began the TK portion of the study. We documented TK in formal interviews and meetings in 2019, with the help of a community-based research assistant in each community. All knowledge that was collected during our meetings and interviews in 2019 is considered TK under the Gwich'in Traditional Knowledge Policy (GTC, 2004).

Community meetings

During the May 2018 community visits, we met informally with members of the Gwichya Gwich'in RRC in Tsiigehtchic, and our research team was supported by a member of the Tetlit Gwich'in RRC to visit the homes of fish harvesters and Traditional Knowledge holders in Fort McPherson for informal discussions. The aim of this early visit was for us to gain a sense of how community members perceived the issues to be addressed by our study and to ask them what kinds of questions we should raise in our interviews the following summer. In May 2019, meetings were held in both Tsiigehtchic and Fort McPherson. Members of local renewable resource councils, the GTC, and the communities were invited to a two-hour meeting at which the research team outlined the project, provided interim results from the 2018 WS data collection, and explained how the TK data collection would proceed. The meetings provided a setting to begin the identification and recruitment of TK holders and harvesters to participate in the TK interviews. Participants also had the opportunity to ask questions about the research and offer input to the project. In Fort McPherson, the meeting was attended by 25 community members and in Tsiigehtchic the meeting was attended by 20 community members.

Interviews

The proposed interview questions were revised after feedback from both RRCs and the GTC Department of Cultural Heritage. Potential participants for the interviews were identified by the RRCs, with a focus on community members who have significant fishing experience and who are recognized holders of Gwich'in Traditional Knowledge. They were approached in community meetings, by phone, or at their homes by the researchers or the community-based research assistants. Interviews followed a semi-directive interview method (Huntington, 1998), starting with questions about general environmental changes and fish health, leading subsequently to ferry-related impacts (Table 3.1). A map of the study area was provided so that knowledge holders could identify past and present fishing locations, as well as pointing out the locations of their main observations about changes to the rivers. Interviews were conducted with the support of the research assistants, who not only helped build trust with participants but also contributed to the interview process. We interviewed 27 Gwich'in knowledge holders, 16 in Fort McPherson (Appendix 2.2) and 12 in Tsiigehtchic (Appendix 2.3). In most cases, knowledge holders were interviewed individually, although four interviews in Fort McPherson had two participants present. Each interview was recorded using a Zoom audio recorder and four interviews were video recorded. The interviews were usually held in the knowledge holders' homes and with at least two researchers present.

We transcribed each interview verbatim. A printed copy of each participant's transcribed interview was offered to knowledge holders in February 2020 for their records and for correction if they wished. Key themes were identified through keyword searches documented in Table 3.2. While choice of search terms was largely shaped by the specific topics on which we sought to gather participants' observations and opinions, we also highlighted additional unanticipated topics and terms to search for across the interview data. Frequent conversations among the research team to debrief following interviews were important for shaping our interpretations of the data as it was collected and as data analysis began. In order to visualize some of the changes that were described in the interviews around the Fort McPherson landing on the Mackenzie River, we also examined historical and current aerial photos of the area.

Where TK holders agreed to have their names used in research outputs, we have included that information when quoting the words they shared with us. In a small number of cases, participants wished to remain anonymous but still agreed that we could use their words, in which case they are noted as "anonymous #".

Fish harvest surveys

To further understand fishing use in the area and to continue the dataset started by INF (Table 3.3 and Table 3.4), we collected fish harvest records using a modified protocol outlined by previous LAMP studies (GNWT, 2011). An extensive period of consultation was undertaken with the RRCs, other community members, and the Gwich'in Renewable Resources Board Fisheries and Forest Biologist, before a final version of the modified fish survey was put in place. The timing of this consultation meant that no fish surveys were collected for the 2018 fishing season. Among other adjustments, the new survey tool incorporated a basis for calculating an approximate catch per unit effort (CPUE) and also provided space to make comments on observed changes in fish abundance or health. Although the calculation of CPUE is not a traditional method, I include it within this chapter as it relates directly to the other harvester-based TK. As an attempt to estimate the amount of time spent fishing over the summer and fall seasons, fishers were asked to approximate the amount of days that their net was in the water for more than 12 hours. A basic estimation of CPUE for each species was calculated using this formula:

$$CPUE = \frac{C}{f}$$

where *C* is total catch of a species by a fisher and *f* is the total amount of hours spent fishing. The mean CPUE was calculated for each species in order to calculate the relative effort needed to catch fish in the Peel and Mackenzie Rivers. The original LAMP survey tool and our modified survey can be found in Appendix 3.1 and Appendix 3.2. Community-based research assistants circulated surveys to harvesters to fill out at the end of the fall fishing season. Harvesters were asked to enumerate their catch from the Peel River or Mackenzie River during the spring/summer and fall/winter of 2019.

3.3 Results

Traditional Knowledge records

The Gwich'in TK from previous inquiries provided insight into multiple concerns regarding ferry operations on the Peel and Mackenzie Rivers (Appendix 2.1). For instance, an interview in 1996 as part of the Gwich'in Environmental Knowledge Project revealed a number of concerns regarding ferry operations (GRRB, 1996). One knowledge holder in Tsiigehtchic associates the weight of the ferry with decreasing fish populations on the Mackenzie River, observing that there are more fish in the morning while the ferry has been parked throughout the night. Also, as a part of the same study, a different Gwich'in knowledge holder discusses their concerns about the ferry landing material and the impact to a fishing location downstream of the Fort McPherson landing on the Mackenzie River:

> Used to be real good for net, now that ferry, the ramp... Every spring they put how many tons of gravel in the river. Half of it, I guess go in that bay and that bay is full now, near no more eddy. (Gabe Andre, 1996, Tsiigehtchic).

Concern about this fishing location on the Mackenzie River remains evident, appearing in interviews from 1999, 2001, 2003 (Heine et al., 2007; Pulli, 2003; Thompson & Millar, 2007), and our interviews from 2019. The Aquatic Effects Study (GeoNorth-Ross-AMEC, 2003), the first investigation into the impacts of ferry operations in the Gwich'in Settlement Area, interviewed four Gwich'in knowledge holders in each community in 2001. The fishing location downstream of the Fort McPherson landing (Figure 3.2) on the Mackenzie River is discussed by two of the four knowledge holders in Tsiigehtchic. These individuals made similar observations to those made in the 1996 interviews mentioned above; the popular fall fishing location had become too shallow and the eddy that had been there previously was no longer useable. Knowledge holders and GeoNorth-Ross-AMEC (2003) suggest that the length of the ferry landings disrupt river flow and promote the deposition of fine sediments downstream.

> Whereas before the mud would keep washing down – now because of the ferry landings, it just sits there. (Dan Andre, 2001, Tsiigehtchic).

We further discuss concerns surrounding fishing opportunities near the Fort McPherson landing on the Mackenzie River later in this section, but it is also worth mentioning other ferry-fishing conflicts that are noted by Gwich'in knowledge holders in previous work. For instance, a

2008 interview for the James Jerome Photo Collection Project documents a privacy concern regarding ferry operations (GSCI, 2008). Two knowledge holders in this interview discuss having to change the location of where they fish and prepare dryfish. Increased traffic and ease of access to ferry landing sites has meant more people at traditional fishing locations, not to mention people in vehicles passing through, including time at the crossing waiting for the ferry. In 2015, the Department of Infrastructure (INF; then the Department of Transportation), GNWT met with 11 community members in Tsiigehtchic to discuss concerns regarding ferry operations on the Mackenzie River (GNWT, 2015). During this consultation, there were calls for more communication between INF and the community, with interest in biannual meetings and more information on the LAMP. There were multiple comments about oil and gas spills on the ferry and how there is a lack of communication with the community when one does happen. One commenter correlated spills with decreasing fish populations. One attendee also expressed concerns about ferry landing location, claiming that ferry operations are getting closer to a fish camp. Employment concerns were also raised, with an attendee citing that at the time there was only one person from Tsiigehtchic working on the ferries. As explored further below, such issues seem to be symptomatic of broader community concerns, as well as sometimes strained relations between communities and INF.

Interviews

Environmental change was discussed at length during every interview. There was virtual consensus across all interviewees that the Peel and Mackenzie Rivers are changing along with the climate. These changes include the decreased thickness and duration of river ice cover, which impacts break-up and flooding in the spring, observations of riverbank failures and landslides, and increased abundance of sandbars. Alice Vittrekwa described:

> I look back and I compare that to today and our elders used to predict how the weather, what kind of weather we're going to have. They could go out and look around and say, "Oh, this week it's going to be warm. All this week." Today, you go to our elders: a big question mark there. Because everything is changing. (Alice Vittrekwa, 2019, Fort McPherson).

A portion of each interview was also spent on fish and observed changes to fish species and stocks. Although there are fewer people fishing in the GSA than historically, it was clear that fishing is still an important part of Gwich'in livelihood and many harvesters fish near ferry operations on both rivers (Figure 3.1 and Figure 3.2). In general, knowledge shared about Whitefish (Broad Whitefish), Coney (Inconnu), and Crookedback (Lake Whitefish) describes populations to be at historic levels, with some interviewees suggesting that populations are larger. Some knowledge holders also mentioned that the aforementioned fish species may be larger in size than before. However, environmental changes have impacted fish and fishing opportunities. Several interviewees discussed that there has been an increase in warm summer days, which makes fishing more difficult as fish swim deeper to find colder waters. Fishers have also seen greater abundances of the non-native Walleye and Dog Salmon (Chum Salmon). Gwich'in fishers rarely catch Herring (Arctic or Least Cisco) anymore; however, there is agreement that this is due to a decline in sled dog teams and thus less of a need for the Herring to feed them. Therefore, the state of Herring stocks is unknown to Gwich'in knowledge holders.

After the discussion about concerns regarding the rivers and fish, the interviews were directed towards ferry operations. A summary of the main findings can be found in Table 3.5. Knowledge holders discussed multiple concerns regarding ferry operations on the Peel River, including material usage on the ferry landings and cleaning of the ferry deck. The most common observation that arose during our interviews in Fort McPherson was that material being used to construct and maintain ferry landings is contributing to morphological changes in the Peel River:

> And that big sandbar, it's growing closer to us. It's getting bigger and wider; there's even willows growing on it. And I think that's got lots to do with all that gravel and everything they put into the [landings], when that get washed away and all this." (Anonymous #1, 2019, Fort McPherson).

Overall, seven of 16 knowledge holders that were interviewed in Fort McPherson attributed material from the ferry landings on the Peel River as the cause of increasing size and frequency of sandbars and decreasing river depth. Some observe that highwater events on the Peel River increase the erosion of material from the ferry landings. Despite the fact that some community members perceive direct links between the landings and growing sandbars, others also noted other sources of sediment throughout the Peel River watershed:

> The landslides or whatever go [in]to creeks in the mountains. I see quite a bit of them. And that, all that material from there goes to the creeks and comes to the river. (Walter Vittrekwa, 2019, Fort McPherson).

The second most common concern that was mentioned in our interviews with the community members of Fort McPherson was over the possibility and history of oil and gas spills. These concerns were voiced by five of the 16 knowledge holders that we spoke to, mostly regarding runoff from vehicles while parked on the ferry.

> All the trucks go on that ferry and then… they [are] stuck on that ferry. [Then they] throw it [the vehicle runoff] into the river. That [does] not look good for me. (Emma Kay, 2019, Fort McPherson).

The concern is that deckhands continually hose the deck of the ferry to keep it clean and if there is an unnoticed spill, it will get washed into the river. One interviewee mentioned that a major spill would threaten their fish and that INF's contingency plan for spills is insufficient. The same participant spoke of a spill incident in 2009 as his own direct experience with this lack of preparation.

> I have concerns about the ferry itself and things that more relate to fish, to me it's going to relate to the fish because of what happened the last couple of years. With the oil spills on the ferry, ferry landing. (Abe Wilson, 2019, Fort McPherson).

Knowledge holders in Tsiigehtchic mentioned similar concerns about ferry landing material and oil spills in the Mackenzie River. However, concern also surrounded the physical extent of the ferry landings, with four of the 12 interviewees describing that the landings are extending farther outward into the river than in the past. Community members in Tsiigehtchic also brought up specific concerns regarding fishing opportunities. Specifically, concerns were regarding the Fort McPherson landing (Figure 3.2) on the Mackenzie River and a popular fishing area downstream:

> Downstream from the McPherson landing, a lot of silt has filled in the bay there where people used to be able to fish right from shore. (Julie-Anne Andre, 2019, Tsiigehtchic).

This impact was mentioned in six of the 12 interviews and was also mentioned at the pre-season and post-season meetings in Tsiigehtchic. Interviewees state that the infilling of this fishing location with silt is a detriment to the fall fishery as well. Fishers must now walk further out on the ice to find deeper locations to set their nets, which is less safe. Participants report that this is exacerbated by ferry operations continuing into the fall during initial freeze up, which creates unsafe ice conditions and also generates a lot of slush that clogs up fishing nets. At the

Inuvik landing on the Mackenzie River, one knowledge holder had the even more immediate problem of needing to relocate a traditional fishing camp due to ferry operations:

> I used to put my net here, but then the ferry, when the water drops, it's difficult for them to land over here so they have to move in here… So, I'm struggling with that. (Margaret Nazon, 2019, Tsiigehtchic).

Out of the 28 Gwich'in knowledge holders that were interviewed, only four did not discuss concerns regarding ferry operations in the GSA. While the majority of what we documented would be classified as concerns about the ferry operations, several positive aspects of ferry operations in the GSA also emerged. One notable thing that was mentioned was that the ferry operations create jobs for community members. Also, Ernest Vittrekwa repeated what he had mentioned in the GeoNorth-Ross-AMEC (2003) study about eddy creation on the Peel River:

> And that ferry landing, I don't know… Only thing I see get out of it is that it created four eddies, for nets. One on each side for both sides. Four eddies. Used to be no eddy across the river for nets. Used to just run directly through. Since they put that ferry landing in, can set nets on both sides. This side too. (Ernest Vittrekwa, 2019, Fort McPherson).

Aerial photos

Using the same materials gathered by GeoNorth-Ross-AMEC (2003), we examined aerial photos taken in 1967, 1971, 1985, and 2012, to further investigate the observations made by knowledge holders in Tsiigehtchic regarding the fishing location downstream of the Fort McPherson landing (Figure 3.3). The 1967 and 1971 photos show the area before the construction of the ferry landing and the 1985 and 2012 photos show the area after. In the photo from 1985, there is a clear depositional zone downstream of the landing that cannot be seen in the precondition photos. The photo from 2012 shows marked changes to the morphology of the shoreline, appearing concave as opposed to the convex-shaped appearing shoreline in 1971. The images corroborate the observations made by TK holders in the community.

Fish harvest surveys

Fish surveys were distributed at the end of the fall fishery in both communities. Information from 17 fishers that harvest on the Peel River was compiled and preliminary catch per unit effort was calculated. Of the 17 people surveyed, all used gill nets with mesh no less than 4.5 inches and two mentioned the use of a fishing rod for ice fishing or to catch Loche (Burbot). Nine harvesters stated that they fish upstream of ferry operations, five that they fish downstream within 500 m of ferry operations, and two that they fish downstream further than 500 m of ferry operations. In total, the 17 fishers caught 12 524 fish in the Peel River and spent an estimated 12 948 hours fishing in 2019. One harvester accounted for more than half of the fish caught, recording that they caught 7185 fish, with 2136 hours fished in the 2019 fishery. Whitefish (Broad Whitefish) accounted for more than half of the fish caught with 6381. Crookedback (Lake Whitefish) and Coney (Inconnu) accounted for large proportions of the total catch, with 2857 and 2490 caught respectively. Accordingly, Whitefish had the highest CPUE at 0.458 fish / hour. The remainder of the fish totals and CPUE estimations can be found in Table 3.6. Of the 17 fishers surveyed, three indicated that fish were more abundant in 2019 than previously, three indicated that they were less abundant, and the other 11 indicated that abundances were the same.

Information was returned from 10 fishers that harvest on the Mackenzie and Arctic Red Rivers in 2019. Of the 10 harvesters that were surveyed, all used gill nets with mesh between 3 and 6 inches, with two stating that they use two nets. Six harvesters stated that they exclusively fish upstream of ferry operations either on the Arctic Red River or upstream on the Mackenzie. Four harvesters reported that they fish at a variety of locations upstream and downstream of ferry operations. In total, the 10 fishers reported catching 13 075 fish in the Mackenzie and Arctic Red Rivers and spent an estimated 4508 hours fishing in 2019. Three harvesters did not report how many days they had fished so the estimation of time spent fishing is lower than actual. Whitefish (Broad Whitefish) was the most caught fish with 4902 caught. Crookedback (Lake Whitefish) and Coney (Inconnu) accounted for the second and third most caught, with 3947 and 2772 caught respectively. Whitefish had the highest CPUE at 1.402 fish / hour and the rest of the fish totals and CPUE estimations can be found in Table 3.7. Of the 10 fishers surveyed, four indicated that fish were more abundant in 2019 than previous years and the other six indicated that abundances were the same as previous years. Seven of the 10 harvesters reported that there were more Salmon (Dog Salmon) in 2019 than previous years.

3.4 Discussion

Ferry operations in the Gwich'in Settlement Area

The Gwich'in community of Tsiigehtchic has had concerns about ferry operations on the Mackenzie River since at least 1996. These concerns were voiced in interviews and meetings documenting TK in 1996, 1999, 2001, 2003, 2008, 2015, and 2019. The nature of the concerns varies somewhat across the two rivers but has similar dimensions.

The most common observation regarding ferry operations on the Mackenzie River is the alteration of a popular fishing location downstream of the Fort McPherson landing (Figure 3.3). TK records and TK shared during our 2019 interviews describe the physical extent of the ferry landing slowing water velocity downstream and creating a deposition zone of fine sediments behind the landing, at the fishing location. This altered the substrate composition and water level of the area, rendering it unusable to Gwich'in fishers. Rather than setting nets from the shore, fishers must now move further into the river to find appropriate depths or shift their fishing to the mouth of the Arctic Red River. Aerial photos of the fishing location appear to show a depositional zone downstream of the landing that cannot be seen in the photos taken before the construction of the landing. This seems to provide further evidence that the physical extent of the Fort McPherson landing on the Mackenzie River could have created this depositional zone, altering an important Gwich'in fishing location. Similar phenomena can be found in the literature. Tipping et al. (1993) found that deposition of fine particles occurred downstream of a gravel bar at times of low discharge in the River Severn, United Kingdom. While TK and aerial photos seem to indicate that the alteration of the fishing location is due to the ferry landing, there is also an alternative hypothesis. The fishing location in question is less than one km away from the confluence of the Arctic Red River, which transports 7.3 million tonnes of sediment to the Mackenzie River annually (Carson et al., 1998). Research by Best (1988) found that due to the separation of flow at a confluence, a bar often forms at the downstream junction corner (i.e. the popular fishing site on the Mackenzie River). Although there are discrepancies in the literature, the discharge of the Mackenzie River has changed over the past decades (Rood et al., 2017; Yang et al., 2015). Changes in the discharge ratio between the Mackenzie and Arctic Red Rivers could increase the separation of flow and increase the size of the depositional zone at the downstream junction zone (Best, 1988). While it is unclear what has caused the deposition of sediment on the popular fishing location, it could be a product of both hypotheses: the physical extent of the landing having exacerbated the changes to the discharge of the Mackenzie and

Arctic Red Rivers, altering the deposition zone downstream of the confluence. Although there have been observed changes to that fishing location, it is important to note that fishers from Tsiigehtchic still fish at other locations around the ferry landings on the Mackenzie River (Figure 3.2).

Many Gwich'in have been affected by changes to the fishing area next to the Fort McPherson ferry landing on the Mackenzie, but ferry operations have also impacted fishers in other ways on the river. The most notable case is that of a harvester who had to relocate their net as ferry operations got closer to their fishing camp. Fishing camps are recognized as a location of cultural value and therefore a heritage resource under the Gwich'in Land Use Plan (GLUPB, 2015). While that particular harvester/knowledge holder noted the relocation as "a struggle", another interviewee indicated that the relocation had significantly reduced that person's time spent fishing. Concerns about impacts on specific fishing locations appear limited to harvesters from Tsiigehtchic.

Those who historically dwelled in Tsiigehtchic likely had little difficulty accessing fishing locations at sites that are now ferry landings, due to their relative proximity to the town. This is opposed to fishers in Fort McPherson, who gained increased access to 8 Mile on the Peel River with the construction of the Dempster Highway and associated ferry operations. Although there were fishing camps in the area historically, GeoNorth-Ross-AMEC (2003) concluded that the ferry landings on the Peel River created new eddies which are popular places to set fishing nets. This was also mentioned by TK holders in our interviews.

While knowledge holders from Fort McPherson did not express explicit concerns about fishing opportunities or locations, there were concerns about ferry landing material. Interviewees noted that highwater events from rainstorms in the summer erode the sediment placed on the landings by INF. It is the observed erosion of ferry landing material, combined with the increasing size of bars downstream, that has some concerned or convinced that the ferry landings are contributing to changes in river morphology. While some express this opinion, others suggest that this is not the case. Riverbank failures in tributaries and on the Peel River main stem have been increasingly observed by knowledge holders that were interviewed in Fort McPherson. Bars have also been observed upstream of the ferry landings. Kokelj et al. (2013) note that greater thermokarst activity due to climate warming in the Peel River watershed has significantly increased solute concentration in the Peel River main stem since 1960. It has been shown that thermokarst activity in the area can greatly increase sediment concentrations in streams and rivers (Chin et al., 2016; Kokelj et al., 2013).

Attempts to mitigate potential impacts from the ferry landings were made in the Local Area Monitoring Plan (LAMP) by examining the physical extent of the landings and monitoring the amount of material that was used on each landing (GNWT, 2011, 2015). These reports determined the length, width, and height of landings on the Mackenzie River to estimate the volume of material making up each landing. In theory, such measurement would provide an opportunity to monitor the length of the landings and the amount of material being used on them; however, there is no indication that this monitoring continued after the first year that it was conducted (GNWT, 2017). Per water licensing, INF also implemented a material limit and removal policy on both rivers in 2011. This policy allowed a maximum of 500 m^3 of material to be placed per landing per year and required removal of as much material as possible in the fall. This policy likely lowered the amount of sediment lost to each river during the spring freshet and limited the physical extent of the landings. However, records were only reported about landings on the Mackenzie River in the water license application (GNWT, 2015) suggesting that the gravel removal policy was designed to appease community concerns in Tsiigehtchic. This also explains why only four of the 16 people that we interviewed in Fort McPherson had knowledge of the removal policy, contrasted with 11 of the 12 people in Tsiigehtchic that knew of the policy.

INF is also aware of the concerns regarding oil spills on the ferry boats, as noted in the application to renew water licenses for ferry operations (GNWT, 2015). Ferry boats have been equipped with spill kits and a spill contingency plan has been put in place with each ferry captain, who is in charge of monitoring for incidents. There is also a spill hotline to call if community members notice a spill before the ferry crew (GNWT, 2015). Although these policies seem to have been in place since 2015, nine out of the 28 knowledge holders that we interviewed in 2019 still have concerns about oil spills or washing contaminated deck water into the river. This brings to question the effectiveness of INF's communication with the communities of Fort McPherson and Tsiigehtchic or a lack of trust between the two parties.

Statement about knowledge

Although we acknowledge that the information that we collected in our interviews is considered Gwich'in TK (GTC, 2004), it is important to note that within that context there are a number of knowledge types present. While TK recognizes deep cultural roots, other types of knowledge relate to short-term experience, observation, and opinion. For instance, the expression of environmental change on the Peel and Mackenzie Rivers by Gwich'in knowledge holders likely drew on TK or local ecological knowledge (Houde, 2007; Olsson & Folke, 2001), while concerns regarding ferry operations may have relied on lay or situated knowledge (Raymond et al., 2010). Lay knowledge refers to the personal interpretation of situations (O. Jones, 1995) and situated knowledge refers to a localized expertise of a site or issue (Raymond et al., 2010). We recognize that these types of knowledge can be shaped by opinion, politics, or hearsay and the knowledge that we collected likely had a diverse range of origins. For example, some knowledge holders held positions that were directly related to ferry operations or the controversy surrounding them (e.g. deckhand on the ferry or appointed official with a Gwich'in organization), so the knowledge that they provided differed from those who observed ferry operations as land users. Recognizing these different kinds of knowledge does not invalidate any of the contributions made by our interview participants, but it does complicate the process of interpreting and arriving at study outcomes, especially when participants make different observations or express divergent interpretations of similar observations.

Fish harvest surveys

As evident in our interviews, fish surveys, and the literature, fishing remains an important part of Gwich'in livelihood (GeoNorth-Ross-AMEC, 2003; GNWT, 2017; Greenland & Walker-Larsen, 2001; Thompson & Millar, 2007; Wishart, 2013). Whitefish, Crookedback, and Coney were the most abundantly caught species in the Peel River in 2019, and the relative abundances match what was predicted based on previous data collected by the LAMP (GNWT, 2017). We made an attempt to update the original LAMP fish survey by incorporating questions that would help track changes in fish stocks on both rivers. The 27 harvesters that were surveyed in 2019 caught more fish on average than harvesters surveyed between 2011 and 2015 (Table 3.3 and Table 3.4). There is no way to further compare 2019 data to previous surveys as there was no estimation of effort in the LAMP surveys. The migratory nature of the popular fish species in the Peel and Mackenzie Rivers (Howland et al., 2009; Thompson & Millar, 2007; VanGerwen-

Toyne, Walker-Larsen, et al., 2008) make assessing the impacts of ferry operations on fish stocks difficult with this type of survey and long-term data is needed to investigate any trends in fish stocks.

The most significant modification to the survey that we used compared to the previous LAMP survey was to ask fishers to estimate the amount of effort that they were using throughout the season. To do this, we asked harvesters to recall how many days they left their nets in the river for more than 12 hours. Although an approximation like this is likely inaccurate and does not always capture fishing practice accurately, we believe that it is the best option if harvesters are unlikely to keep daily logs. Even if the resulting fish harvest estimates are inaccurate, we believe they provide useful information to supplement harvester TK about whether stocks are healthy or declining. In particular, as long as survey collection methodology remained consistent, the data could provide more precise information about long-term trends. That is why we combined both TK and CPUE approaches in our survey. We also modified the fish survey to further include TK by adding several questions about observed changes to the river and fish stocks. For instance, harvesters in Tsiigehtchic noted an increased abundance of Chum Salmon and reported it in their surveys. Comments from fish harvesters in 2019 and 2020 pointed out some weaknesses in the modified survey, so we see it as a work in progress to match data collection needs with patterns of harvester activity and degrees of willingness to keep records of catch information.

Limitations

We believe the information that we catalogued from interviews and meetings in the GSA in 2019 contributed significantly to the Gwich'in TK records. However, there were shortcomings to this portion of the study that are worthy of note. As southern Canadian researchers, our commute to the GSA was long and expensive. This limited the amount of engagement we were able to foster with the communities of Fort McPherson and Tsiigehtchic. Ideally, we would have spent the entire open water season in the communities, building relationships and further understanding community concerns regarding ferry landings. GeoNorth-Ross-AMEC (2003) was based in the Northwest Territories and participated in multiple Gwich'in events throughout the summer.

Another limitation was that despite our efforts to recruit community-based research assistants with fluency in Gwich'in, our research assistants were not in fact fluent and we did not have a translator present in the interviews. Only one knowledge holder spoke in Gwich'in at the beginning of their interview before switching to English, and it is our understanding that most interviewees were comfortable being interviewed in English. However, knowledge holders may have been reticent to communicate any discomfort to us. This was a shortcoming in our interviews as language is an important part of Indigenous culture and identity (Sachdev, 1995; Sachdev, Arnold, & Yapita, 2006). The TK we catalogued likely lost certain nuances by being expressed in English instead of Gwich'in (Denzin, Lincoln, Smith, & Battiste, 2014; Ellis, 2005). Despite our efforts to engage participants in a relaxed and informal way, we also noted that the informed consent process and the interview structure generated a degree of formality that may have impeded the communication of knowledge. In certain instances, we noticed that knowledge holders were somewhat apprehensive during interviews yet were more relaxed during informal conversations before and after the interviews. This has been discussed in the literature and is one of the reasons that some researchers do not recommend formal interviews. Collignon (2006) scrutinized formal interviews based on her experiences with Inuit knowledge holders, claiming that interviews subject them to a way of thinking that is not theirs, which limits the communication of how people actually perceive the land.

Conclusions and implications

We investigated the effects of ferry operations on the Peel and Mackenzie Rivers and Gwich'in livelihood by studying existing documentation of TK and by engaging TK holders to document further ferry-related knowledge and concerns. Concerns regarding ferry operations differ in Fort McPherson and Tsiigehtchic. Knowledge holders in Fort McPherson have noticed morphological changes to the Peel River and some attribute those to sediment eroded from the ferry landings. It is difficult to conclude definitively whether these changes are due to the ferry landings or climate-driven impacts. As I discuss in relation to the scientific data in Chapter 4, it seems most likely that the relationship between landings and changing river morphology argued by some knowledge holders as an interpretation of their land-based observations is in fact quite limited in scope. Community members in Tsiigehtchic have documentation of their concerns regarding ferry operations dating back to 1996. The majority of these concerns and those voiced in our study are related to the fishing area downstream of the Fort McPherson landing on the Mackenzie River. Knowledge holders say that the ferry landing has created a depositional zone that has made the fishing area unusable. This phenomenon is discussed in the literature, but changes to the fishing area could also be driven by climate-related changes to the dynamic confluence of the Arctic Red River with the Mackenzie River. We can conclude that climate-related changes to both rivers could be a source of the altered deposition processes, which could be exacerbated by the physical extent of the ferry landing.

Although ferry operations may not have contributed significantly to observed changes in the Peel and Mackenzie River, there are still impacts for the Gwich'in communities of Fort McPherson and Tsiigehtchic resulting from the placement and operation of the landings. The encroachment on locations of cultural value and the stress of anticipating potential oil spills are impacts that have affected Gwich'in livelihood and sense of well-being. An improved communication plan between INF and each community could go a long way in mitigating further concern regarding ferry operations in the GSA.

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3.6 Tables

Table 3.1. A list of the main discussion topics and associated subcategories that were used in interviews with knowledge holders in Fort McPherson and Tsiigehtchic.

Discussion topics	Subcategories
1. We'd like to know what you've observed in terms of overall changes to the river environment.	A) Have you seen any changes in the behaviour of the river—its depth, times and volumes of flooding, ice cover, shore vegetation? B) What about the quality of the water in the river—its appearance and taste?
2. We hope you can tell us what you might have observed about the health and abundance of fish.	A) Have you seen any changes in fish populations, either numbers or distribution? B) Are you aware of where fish are spawning? Have you seen any changes in this? C) Have you noticed differences in fish size and health, or the quality of the meat?
3. [Only for active fish harvesters] We'd like to know a bit about your fishing practices, especially relative to the ferry landings (we will use maps to aid this discussion):	A) In which locations on the river do you fish? How much time do you spend in each location, what do you catch there, and how important is each location to your overall fish harvest? Has this changed over time? B) Do you consider that any of your main locations may have suffered impacts specifically from the ferry landings? If so, what kind of impacts?
4. Finally, we'd like to know what you've observed regarding the ferry landings and efforts to mitigate their potential impacts.	A) Some people have expressed concern that the materials used for the ferry landing could be harming the fish or interfering with fishing. Do you share those concerns? B) Do you think that efforts to reduce the potential for impacts, for example by recovering and reusing the gravel put down for the landings, have been effective? C) Are there any other aspects of the ferry operations, such as location, maintenance or dates of operation, that concern you in relation to the fishery?

D) Have you participated in any previous meetings or data collection related to this issue conducted by the Department of Infrastructure (formerly Department of Transportation) staff or scientists? Are you aware of the Local Area Management Plan (LAMP) study?

E) (For those who did express concerns): What kinds of actions do you think are required to address the concerns you have about the ferry landings and/or operations?

Table 3.2. A list of search words used to identify themes in transcribed interviews.

Environmental change	Fish health and abundance	Ferry-related concerns
"ice"	"fish"	"gravel"
"flood"	"whitefish"	"ferry"
"bar"	"coney"	"landing"
"slide"	"new"	"removal"
"mud"	"health"	
"clear"		

Table 3.3. Fish harvest data from the Peel River from 2011-2015, 2019. Data collected as part of the LAMP and the current study (*). Data from 2011-2015 adapted from GNWT (2017).

Year	Broad Whitefish	Lake Whitefish	Northern Pike	Burbot	Inconnu	Total Fish	Average fish per harvester
2011	5159	155	246	64	1238	6862	285.92
2012	3323	333	189	11	980	4836	241.80
2013	3930	1005	307	98	1260	6600	314.29
2014	7526	697	433	159	3743	12558	418.60
2015	3179	812	206	92	1180	7269	382.58
2019*	6381	2857	373	412	2490	12513	736.06

Table 3.4. Fish harvest data from the Mackenzie River from 2011-2015. Data collected as part of the LAMP and the current study (*). Data from 2011-2015 adapted from GNWT (2017).

Year	Broad Whitefish	Lake Whitefish	Northern Pike	Burbot	Inconnu	Total Fish	Average fish per harvester
2011	7300	2472	112	49	2014	11947	426.68
2012	7207	3254	106	126	1821	12514	595.91
2013	5402	1426	159	333	1232	8552	407.24
2014	3916	723	10	9	55	4713	392.75
2015	1518	833	37	9	582	2979	297.90
2019*	4902	3947	395	267	2772	13075	1307.50

Table 3.5. Enumeration of concerns regarding ferry operations from 16 knowledge holders in Fort McPherson and 12 in Tsiigehtchic. Concerns were sorted into three general categories. Concerns regarding ferry landings included the physical extent of the landings and/or landing material. Concerns regarding fishing opportunities include the alteration and/or access to traditional fishing locations.

Concern	Fort McPherson	Tsiigehtchic
Ferry landings	11 / 16	7 / 12
Fishing opportunities	0 / 16	10 / 12
Ferry cleaning/spills	7 / 16	2 / 12

Table 3.6. Fish harvest data from 17 fishers who fished on the Peel River between May and November 2019.

Species	Broad Whitefish	Lake Whitefish	Northern Pike	Burbot	Inconnu	Chum Salmon	Dolly Varden Char	Cisco	White Sucker	Walleye
Catch	6381	2857	373	412	2490	122	107	5	148	10
Effort (fish / hour)	0.458	0.253	0.046	0.094	0.189	0.012	0.071	0.000	0.031	0.000

Table 3.7. Fish harvest data from 10 fishers who fished on the Mackenzie and Arctic Red Rivers between May and November 2019. Effort was calculated from only seven harvesters as three did not report the amount of days they had fished in 2019.

Species	Broad Whitefish	Lake Whitefish	Northern Pike	Burbot	Inconnu	Chum Salmon	Dolly Varden Char	Cisco	White Sucker	Walleye
Catch	4902	3947	395	267	2772	671	32	30	35	35
Effort (fish / hour)	1.402	0.334	0.053	0.030	0.334	0.054	0.001	0.006	0.007	0.011

3.7 Figures

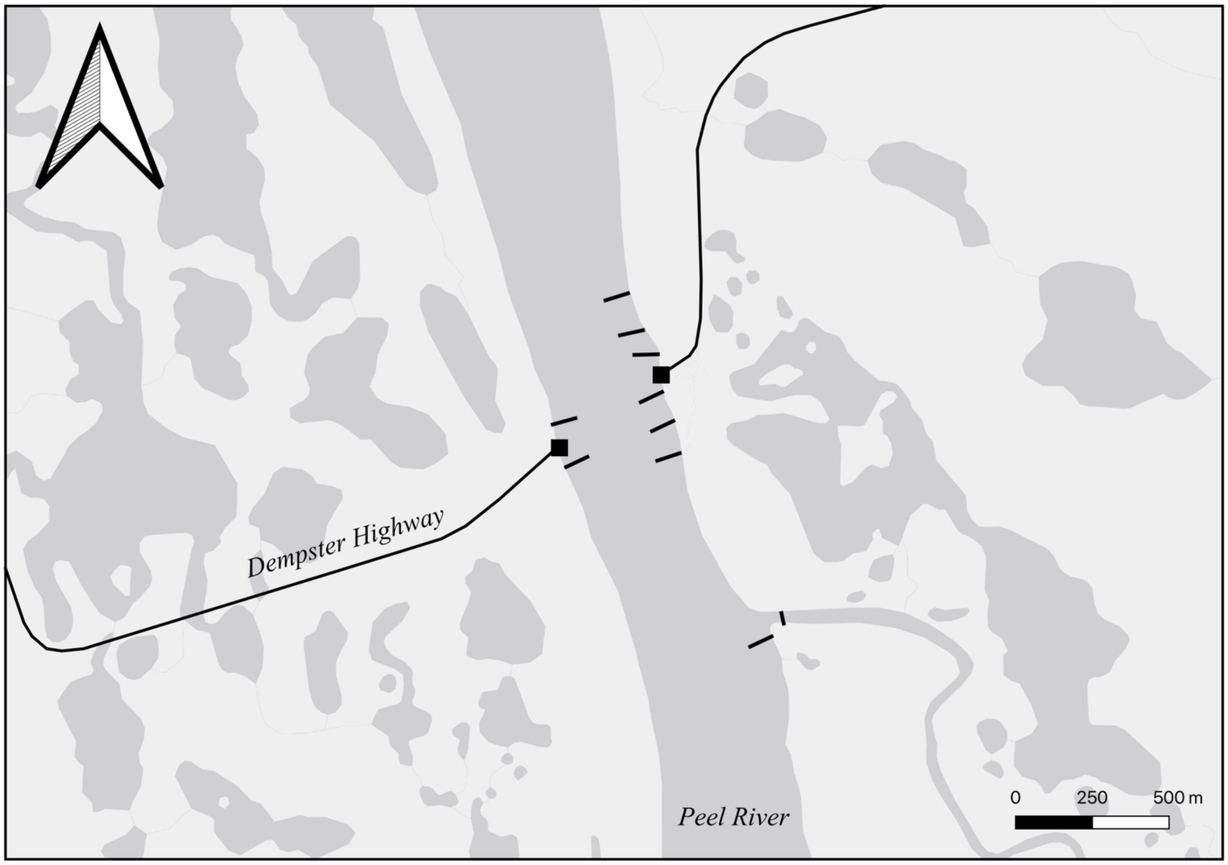


Figure 3.1. Map of the Peel River study reach. The black squares denote the ferry landings and the short black lines denote fishing nets. Fishing net locations were identified by harvesters during interviews.

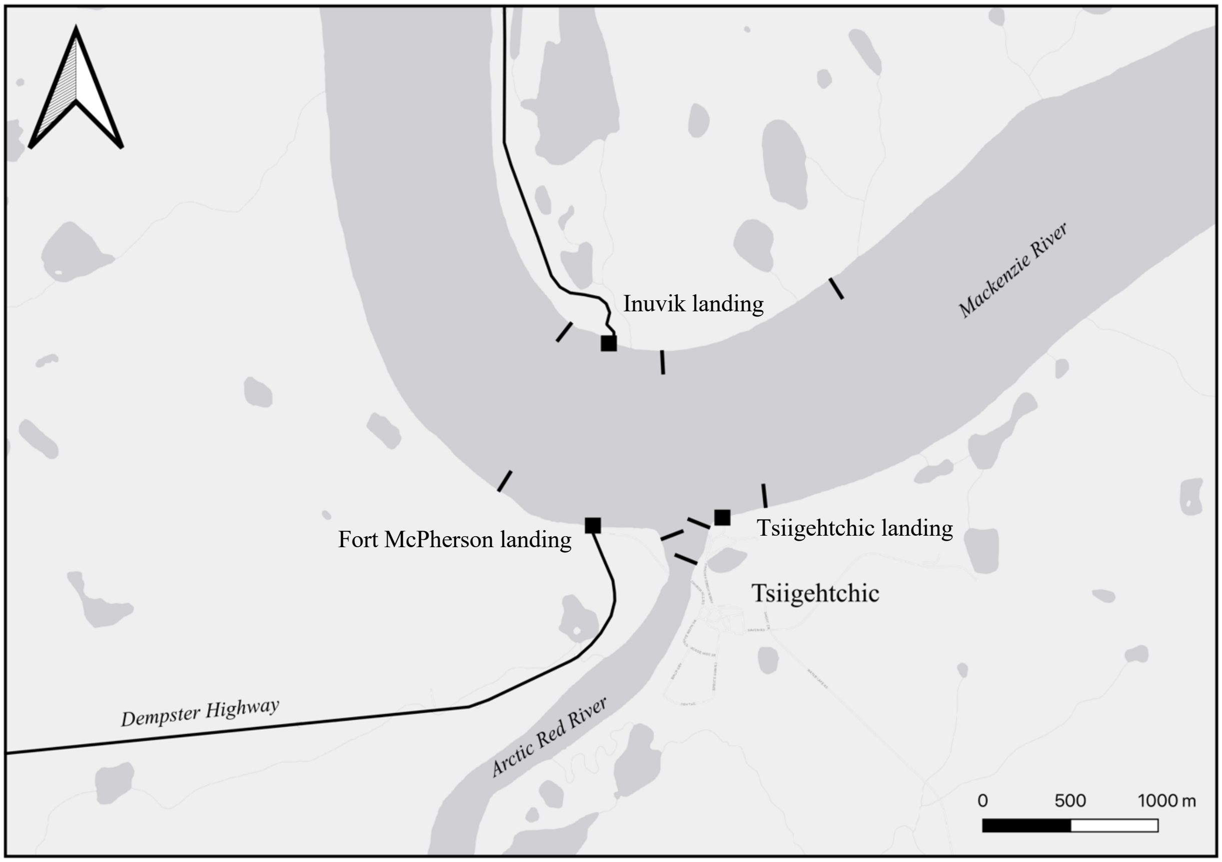


Figure 3.2. Map of the Mackenzie River study reach. The black squares denote the ferry landings and are labelled based on their respective community access. The short black lines denote fishing nets. Fishing net locations were identified by harvesters during interviews.

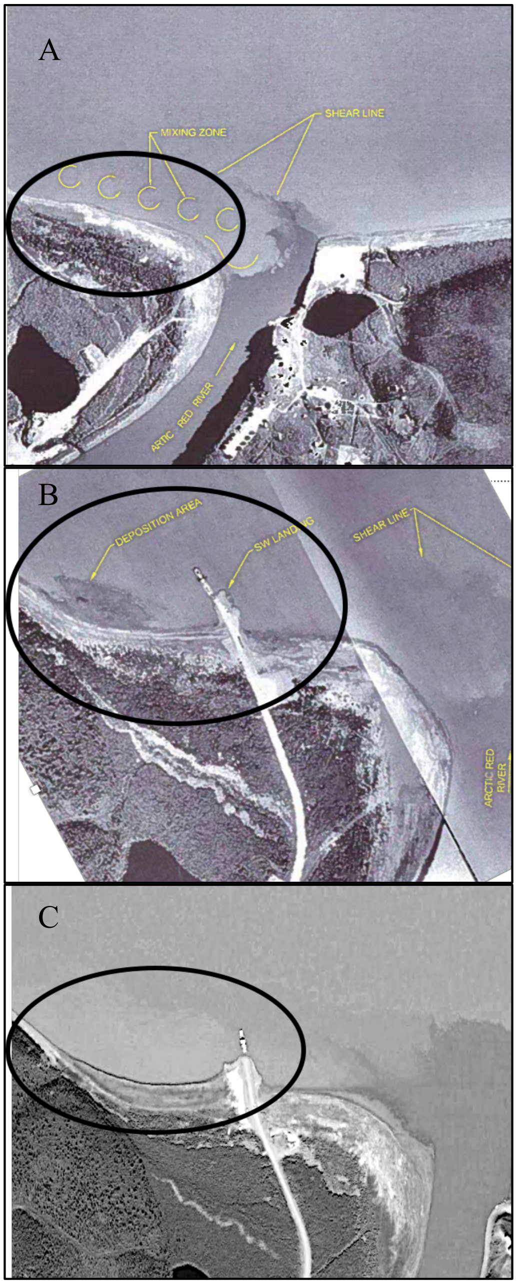


Figure 3.3. Aerial photos of the Fort McPherson landing (circled) on the Mackenzie River taken in A) 1971, B) 1985, and C) 2004. The first photo is before ferry operations began. Photo A) and B) were adapted from GeoNorth-Ross-AMEC (2003) and photo C) was taken from Google Earth©.

Chapter 4: Discussion

4.1 Final conclusions

The Gwich'in communities of Fort McPherson and Tsiigehtchic, Northwest Territories have been concerned about ferry operations on the Peel and Mackenzie Rivers since at least 1996. Specifically, these concerns were centred around changes to river morphology and access to traditional fishing locations. Water licensing mandated the investigation into the effects of ferry operations and ferry landing material (GeoNorth-Ross-AMEC, 2003; GNWT, 2011), but concern amongst the communities remained (GNWT, 2015). When our research team was contracted to further investigate these concerns, we designed a multidisciplinary study to assess the impacts of ferry landing material. Our study was comprised of two main parts: Western Science drawing on methods from limnology, ecology, and fluvial geomorphology and Traditional Knowledge drawing on methods from the social sciences. Although our study was initiated to examine the impacts of ferry landing material, our interactions with Gwich'in communities quickly revealed that ferry landing material was only part of the concern regarding ferry operations.

In the past, the INF has reported that material has been lost from ferry landings on both rivers (GNWT, 2015). However, the results from our study suggest that ferry landing construction and maintenance in the spring does not contribute to significant differences in turbidity, total suspended solids, or bed load sediments. Our analysis of benthic macroinvertebrates confirmed that ferry operations do not alter total abundance, taxonomic richness, or the proportion of sensitive taxa. Gwich'in knowledge holders in Fort McPherson expressed the most concern over ferry landing material and its contribution to bars downstream, but also shared observations that bank failures throughout the watershed are contributing to increased sediment loads. Fewer but similar observations were made in Tsiigehtchic. The results from our study combined with the results from GeoNorth-Ross-AMEC (2003) and the LAMP (GNWT, 2017) suggest that the erosion of material from ferry landings on the Peel and Mackenzie Rivers is inconsequential when compared with natural and climate-induced sediment loads.

Both our study and the previous GeoNorth-Ross-AMEC (2003) study note that the ferry landings have likely resulted in highly localized changes in water flow patterns. TK holders note that the Peel River landings generated new eddies, and aerial photos suggest that the Fort McPherson landing on the Mackenzie River may have helped create a stronger eddy downstream from the Arctic Red and Mackenzie confluence. On the Peel River, any localized increase in deposition that could result from these eddies does not seem to interfere with fishing. However, it is probable that the infill of an important fishing location on the Mackenzie River is to some degree influenced by the presence of the Fort McPherson landing.

As mentioned above, our study was designed to assess the impacts of ferry landing material but throughout the TK portion of our study, other concerns arose. The most common of those concerns were interference with fishing opportunities on the Mackenzie River and ferry cleaning and oil spills on both rivers. Although we did not investigate these concerns in the Western Scientific portion of our study, it is clear from the TK portion that ferry operations and the physical extent of the ferry landings have affected Gwich'in livelihood and sense of well-being.

4.2 Recommendations for the Department of Infrastructure, GNWT and the communities

In this section, I make a number of recommendations to both INF and the communities of Fort McPherson and Tsiigehtchic, based on the results from our study, previous studies, the literature, and personal communications with representatives from INF, the Gwich'in Renewable Resources Board, Fisheries and Oceans Canada, and other researchers.

4.2.1 Ferry landings

The Department of Infrastructure should continue to limit the use of material on all five ferry landings in the GSA and continue to recover, store, and reuse material when appropriate. Care should be taken to ensure that stored and recovered material is above the upper water line of spring flooding. INF should limit the length and width of ferry landings, so as not to exacerbate deposition downstream. If possible, this should include a reduction in the length of the Fort McPherson landing on the Mackenzie River. Ferry operation in the fall should be limited so as to not interfere with the fall ice fishery or spawning Broad Whitefish populations, with close communication between ferry operations and fishers informing operation decisions at this time of year.

4.2.2 Communication

INF should engage over a period of time with both communities to develop a new communication plan. It is my belief that an improved communication plan could mitigate the concerns that Gwich'in communities have towards ferry operations, including landing material use, ferry cleaning, and spills. Improved communication could also create a platform for the Gwich'in to voice concerns and for INF to voice solutions. This could help improve the apparent mistrust between both parties. In addition to formal consultation, I encourage INF to engage both Gwich'in organizations and Gwich'in community members and harvesters on an ongoing basis. In my experience, engagement through meetings is only partly effective. We found that community engagement was best when spending time at the ferry landings and going door-to-door to communicate with community members who may not always attend meetings. Plain language posters and radio announcements should also be utilized. There is also a responsibility on the side of the communities in working to improve relations with INF. Identifying community members who are prepared to support information sharing and recruitment for meetings with INF would help ensure that, when important conversations occur, more people take part to learn about INF policies and to voice their concerns and ideas.

4.2.3 Continuation of monitoring

Throughout engagement with the communities of Fort McPherson and Tsiigehtchic there were calls for our study to be longer, and it was clear that both communities saw the importance of environmental monitoring. Our results also suggest that fishing is still a very important part of Gwich'in livelihood. If monitoring is to continue, I recommend the continued use of our fish harvest survey, as it is an inexpensive tool that can be used to track changes in subsistence fish stocks. The fish survey incorporates TK but also involves community members in its administration. I have updated our fish survey based on its performance in 2019 (Appendix 3.3). Most of the new changes to the fish survey were minor and made the survey more accessible, but I also improved the ability to calculate effort. In the survey for this study (Appendix 3.2), we had a field for harvesters to identify how many days a month their net was in the water for more than 12 hours. After the survey's administration in 2019, it was clear that several harvesters did not understand that field, and also some harvesters leave their nets in for less than 12 hours a day. I updated the field to provide a place for harvesters to estimate how many days they fished per month and then the average amount of hours they fished per day.

In addition to the fish survey, INF should continue to monitor material use on each landing. I recommend that INF continue to monitor the amount of landing material used each season but with an increased precision in measurements. The physical extent of the ferry landings should also be monitored annually as outlined in the original LAMP report, to ensure that landings do not extend further into the Peel and Mackenzie Rivers (GNWT, 2011). INF should aim to be completely transparent with methods and reporting going forward by publishing information online.

If there are calls to investigate the deposition of fine sediment downstream of the Fort McPherson landing on the Mackenzie River, I recommend a computer-based modelling approach. With data available on sediment dynamics and discharge on the Mackenzie and Arctic Red Rivers, it could be possible to model the impacts of the physical extent of the ferry landing and climate-related variation.

If concerns among Gwich'in communities persist after the completion of this study, I recommend that INF hire a community-based monitor in each community. The monitor would be involved in documenting maintenance to the landings, tracking material placement and removal on the landings, and monitoring for spills. Not only would this create job opportunities, but it would allow members of each community to be more involved in ferry operations.

4.3 Integrative biological research

This project draws on multiple disciplines to develop conclusions about the physical and cultural effects of ferry operations in the Gwich'in Settlement Area, Northwest Territories. Strictly within the discipline of biology, I rely on a community ecology approach to examine the cumulative impacts of eroded sediment from ferry landings on the Peel and Mackenzie Rivers. And, as I studied the sediment regime of two large inland rivers, this research also draws on aspects of limnology and fluvial geomorphology. While half of this project focused on physical methodology and Western Scientific analyses, the other half utilized the social sciences to collect and examine Traditional Knowledge from Gwich'in knowledge holders. Within the social sciences, I practiced semi-structured interviewing and survey methods, with additional elements of participant observation that contributed to your overall understanding of local livelihoods and culture. Through informal interactions, meetings, and interviews, I was able to further understand the effect of ferry operations on Gwich'in livelihood and culture. Without the integration of multiple disciplines, my study would not have been as holistic or as impactful.

4.4 References

GeoNorth-Ross-AMEC. (2003). *Aquatic Effects Study for the Ferry Crossings near Tsiigehtchic and Ft. McPherson, NT*.

GNWT. (2011). *Local Area Monitoring Plan*.

GNWT. (2015). *Renewal Application for Water Licence*.

GNWT. (2017). *Local Area Monitoring Plan Summary Report*.

Appendices

Appendix 1: Supplementary material for Chapter 2

Appendix 1.1. Taxonomic resolution used for benthic macroinvertebrate identification and total abundances found in each river. Taxonomic resolutions adapted from the Ontario Benthos Biomonitoring Network (Jones et al., 2007).

Taxonomic Resolution	Taxa	Peel River	Mackenzie River
Phylum	Nematoda	4	0
Subclass	Oligochaeta	20	50
	Acarina	22	5
Order	Coleoptera	7	20
	Amphipoda	1	4
	Hemiptera	14	5
	Ephemeroptera	126	223
	Plecoptera	156	939
	Trichoptera	3	12
	Mysida	0	1046
Family	Chironomidae	457	651
	Tabanidae	40	15
	Ceratopogonidae	63	159
	Tipulidae	5	2
	Chaoboridae	33	6

Appendix 1.2. Sample size, mean, and standard deviation (in parentheses) for water quality and sediment variables sampled on the Peel River in 2018 and 2019.

Variable	N	Upstream	Downstream
Turbidity (NTU)	270	396.03 (138.16)	392.12 (135.29)
TSS (mg / L)	270	692.52 (608.75)	636.69 (537.59)
Bed load, d_{10} (µm)	167	106.50 (68.87)	130.21 (62.30)
Bed load, d_{50} (µm)	167	247.55 (363.88)	243.46 (90.57)
Bed load, d_{90} (µm)	167	548.86 (1054.72)	428.80 (136.08)
Bed load, %sand	167	86 (22)	93 (15)
Bed load, rate (g / s / m)	280	0.19 (0.29)	0.17 (0.28)

Appendix 1.3. Sample size, mean, and standard deviation (in parentheses) for water quality and sediment variables sampled on the Mackenzie River in 2018 and 2019.

Variable	N	Upstream	Downstream
Turbidity (NTU)	228	170.26 (102.31)	153.13 (83.35)
TSS (mg / L)	228	212.99 (207.89)	184.47 (169.92)
Bed load, d_{10} (µm)	83	210.14 (494.55)	168.56 (100.68)
Bed load, d_{50} (µm)	83	300.65 (305.28)	271.28 (116.24)
Bed load, d_{90} (µm)	83	691.39 (646.71)	630.47 (136.08)
Bed load, %sand	83	88 (21)	86 (25)
Bed load, rate (g / s / m)	188	0.12 (0.24)	0.12 (0.23)

Appendix 2: Supplementary material for Chapter 3

Appendix 2.1. Knowledge holders that have discussed ferry operations in previous projects or initiatives and whose words were used in our interpretation of Gwich'in concerns.

Project	Investigator	Year	Knowledge holder
Gwich'in Environmental Knowledge Project	GRRB	1996	Gabe Andre
			Irene Kendo
Gwichya Gwich'in Googwandak	Heine et al.	1999	Irene Kendo
Aquatic Effects Study	GeoNorth-Ross-AMEC	2001	Dan Andre
			Noel Andre
James Jerome Photo Workshop	GSCI	2008	Noel Andre
			Alestine Andre

Appendix 2.2. Knowledge holders and harvesters that were interviewed about the Peel River ferry operations. One knowledge holder was excluded from the list because of a request to remain anonymous.

Location of interview	Knowledge holder
Camp near 8 Mile	Abe and Lucy Wilson
Fort McPherson	Abe Peterson
Fort McPherson	Abraham Stewart
Fort McPherson	Emma Kay
Fort McPherson	Ernest and Alice Vittrekwa
Fort McPherson	Marie-Effie Snowshoe
Fort McPherson	Paul Koe
Fort McPherson	Rosalie Ross
Fort McPherson	Thomas and Eileen Koe
Camp near 8 Mile	Walter Vittrekwa and Lorraine Francis
Fort McPherson	Winnie Prodromidis

Appendix 2.3. Knowledge holders and harvesters that were interviewed about the Mackenzie River ferry operations. Two knowledge holders were excluded from the list due to their requests to remain anonymous.

Location of interview	Knowledge holder
Tsiigehtchic	Agnes Mitchell
Tsiigehtchic	Albert Ross
Tsiigehtchic	George Niditchie
Tsiigehtchic	Herbert Andre
Tsiigehtchic	Irene Kendo
Tsiigehtchic	James Andre
Tsiigehtchic	Julie-Ann Andre
Tsiigehtchic	Louis Cardinal
Tsiigehtchic	Margaret Nazon
Tsiigehtchic	Peter Ross

Appendix 3: Fish harvest surveys

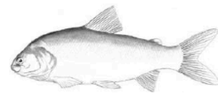
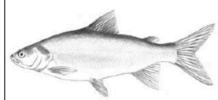
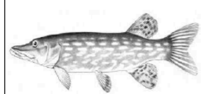
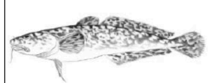
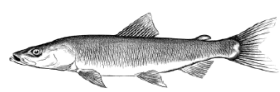
Appendix 3.1. A copy of the fish harvest survey developed as part of the Local Area Monitoring Plan (GNWT, 2011) and used between 2011-2015.

Local Area Monitoring Plan – Fish Harvest Study Questionnaire
What community do you live in? Ft. McPherson_________ Tsiigehtchic________
What river system are you reporting on? Peel River__________ Mackenzie_________
What Time of Year was the Harvesting Spring/Summer ________ Fall/Winter________ *(If you fished in both seasons, please use a separate questionnaire for each reporting season)*
How many times did you fish this year? 1-5_______ 5-10_______ 10-20 _____________
How many of the trips was nothing caught? Number _________________

Using page three of this questionnaire, please plot on the photo image of the river where you caught fish and what type by using the symbol to the right of the fish shown. Each time you place a symbol it represents one fish. If multiple fish of the same type were caught in the same spot, place a number beside the symbol to indicate the amount of fish harvested at that single location.
Example: If you caught three Jack fish the shore of the Peel river, mark the location on the photo as…….**NP3**
If you fished in an area and did not catch anything, mark **X in** the area where you fished on the map

Voluntary information:
PERSON
Name:

CONTACT INFORMATION
Mailing Address:
Age:
Experience in Fishing (years):
General Comments (anything you want to say about fish health, recommendations, concerns):
Would you like a copy if the compiled fish harvest data sent directly to you? (circle one) Yes No
All data is being collected under and subject to the NWT Access to Information and Protection of Privacy Act. Personal information will only be released at with the permission of the individual.

Fish Name	Gwich'in Name	Fish Image	Symbol to Use
Broad Whitefish - *Coregonus nasus*	Luk Zheii		BW
Lake (Humpback) Whitefish - *Coregonus clupeaformis*	Dalts´an		LW
Northern Pike - *Esox lucius*	Eltin		NP
Burbot - *Lota lota*	Chehluk		BT
Inconnu - *Stenodus leucichthys*	Sruh		IU

Appendix 3.2. A copy of the updated fish harvest survey developed for this study and used in 2019.

Tsiigehtchic & Ft. McPherson Fish Harvest Survey 2019

You are invited to participate in a study of the effects of the Dempster Highway ferry landings on water quality and the traditional fishery on the Mackenzie and Peel Rivers. The lead researchers are Derek Gray (Department of Biology, Wilfrid Laurier University) and Alex Latta (Department of Geography and Environmental Studies, Wilfrid Laurier University), assisted by Matt Teillet, a master's student (Department of Biology, Wilfrid Laurier University), and [*name of community RA to be inserted here*], who is a research assistant from your community.

BACKGROUND INFORMATION

The seasonal construction of ferry landings on the Mackenzie and Peel Rivers has raised concerns in Ft. McPherson and Tsiigehtchic. Despite previous studies and management efforts by the Department of Infrastructure (DOI), there are continued worries about impacts on the aquatic environment. Our team is funded by DOI to carry out a two-year, arms-length study of the issue. One part of that study includes water science data collection in 2018 and 2019, another involves Traditional Knowledge and fish harvest data collection during 2019.

In this survey we are asking fisher harvesters to estimate their annual fish catches at the end of the fall fishing season. We are also seeking information about where they fish, what kind of equipment is used and how much time they fish.

RISKS

There are no risks associated with participation in this survey.

BENEFITS

The study will help communities and the DOI better understand the relationship between the ferry landings and the traditional fisheries. We hope that this survey not only provides data for the ferry landings study, but is also employed by the communities to track health of fish stocks over time.

CONFIDENTIALITY

Providing your name in the survey is important so that your names are present in the data for future reference by the GTC Department of Cultural Heritage and/or the GTC Renewable Resources Board. However this is optional and your name will not be used in the research results presented at the end of this study. The survey data will be held in the offices of the RRC and the researchers. After five years, the researchers' copies will be shredded but copies will be given to the GTC Department of Cultural Heritage to deposit with the GTC Dept. of Cultural Heritage Archives.

COMPENSATION

Participants will receive a stipend of $50 for completing the fish-catch survey.

PARTICIPATION

Completion of the fish-catch survey will require about 30 minutes. The community-based research assistant will follow up with you at the end of the season to provide any assistance you might need to complete the survey.

Participation in this survey is voluntary, and you may withdraw from the study at any time without forfeiting any compensation due. If you withdraw from the study, your survey data will be destroyed.

FEEDBACK AND PUBLICATION

The research findings will be shared with the communities in the year-end research meetings, and these meetings will help shape the final report. The Renewable Resource Committee and DGO in each community will receive a copy of the final report, and of any other publications emerging from the research, including conference papers and journal articles (with plain-language summaries).

CONTACT

If you have questions or concerns related to your participation in the study (including any adverse experiences), you may contact Dr. Alex Latta, 75 University Avenue West, Waterloo, Ontario, N2L 3C5 (phone: 519-884-0710 x 3115, email: alatta@wlu.ca).

This project has been reviewed and approved by the University Research Ethics Board (REB 5993 *number to be inserted on approval*), which receives funding from the Research Support Fund. If you feel you have not been treated according to the descriptions in this form, or your rights as a participant in research have been violated during the course of this project, you may contact Jayne Kalmar, PhD, Chair, University Research Ethics Board, Wilfrid Laurier University, (519) 884-1970, extension 3131 or REBChair@wlu.ca.

Background Information

What community do you live in? Tsiigetchic ☐ Ft. McPherson ☐

Providing your name could allow your community's RRC track specific changes in fishing patterns over time. However, if you prefer to remain anonymous you can leave this field blank.

Your name (optional): ________________________________

Please answer the following questions to the best of your ability.

1. Where do you spend the majority of your time fishing?

   Mackenzie River ☐ Arctic Red River ☐ Peel River ☐

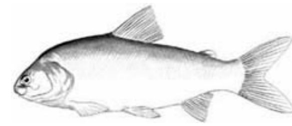
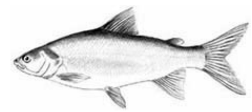
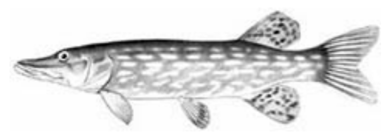
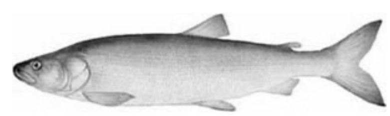
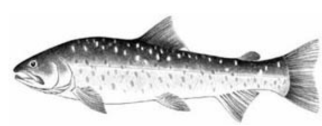
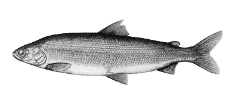
2. Where are your main fishing locations in relation to ferry landings on this river (you may leave this blank if you prefer not to share such information)?

   Upstream ☐ Downstream, within 500 m ☐ Downstream, further than 500 m ☐

3. How many years have you fished at these locations (you may leave this blank if you prefer not to share such information)?

   __________ years

4. Approximately how many fish of the following species did you catch between May and November on the above river?

English Name	Gwich’in Name	Appearance	Amount
Broad Whitefish	luk Zheii		
Lake (Humpback) Whitefish	dalts’an		
Northern Pike or Jackfish	eltin		
Burbot	chehluh		
Inconnu or Coney	sruh		
Salmon	shii		
Char	dhik’ii		
Herring or Cisco	treeluk		

Sucker	daats'at		
Other (____________)			
Other (____________)			

5. How does this year's total fish catch compare to last year's total fish catch?

   More fish this year ☐ Same amount ☐ Less fish this year ☐

6. Did you notice any changes to the abundance of particular species that should be noted?

   ____

7. How much time did you spend fishing this year compared to last year?

   More time this year ☐ About the same amount of time ☐ Less time this year ☐

8. How were the majority of the above fish caught?

   Gill net ☐ Fishing rod ☐ Other ☐ please specify: ___________________

9. If you used a gill net, please answer the following questions and circle the units used, indicating also which kind of fish were targeted with different nets if you used more than one kind of net:

   Net #1
   Length of net: _________ feet / metres

   Height of net: _________ feet / metres

   Size of mesh openings: _________ inches / centimetres

   Used for the following kinds of fish: ____

   Net #2
   Length of net: _________ feet / metres

   Height of net: _________ feet / metres

   Size of mesh openings: _________ inches / centimetres

   Used for the following kinds of fish: ____

   Net #3
   Length of net: _________ feet / metres

   Height of net: _________ feet / metres

Size of mesh openings: _________ inches / centimetres

Used for the following kinds of fish: ____

10. For the following months, please indicate the approximate number of days that your nets were in the water for at least 12 hours, or that you spent 4 or more hours fishing with a line:

	Net #1	**Net #2**	**Net #3**	**Line**
May				
June				
July				
August				
September				
October				
November				

11. Are there any other observations or comments that you would like to share about the health and size of fish stocks during this fishing season? You may also use this space to make suggestions about how to improve the survey in future years.

____

____

____

____

____

Appendix 3.3. Proposed updates to the 2019 fish harvest survey used in this study based on feedback and experience.

Background Information

What community do you live in? Tsiigetchic ☐ Ft. McPherson ☐

Providing your name could allow your community's RRC track specific changes in fishing patterns over time. However, if you prefer to remain anonymous you can leave this field blank.

Your name (optional): ________________________________

Please answer the following questions to the best of your ability.

1. Where do you spend the majority of your time fishing?

   Mackenzie River ☐ Arctic Red River ☐ Peel River ☐

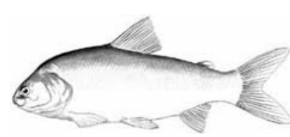
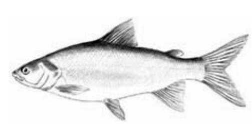
2. Where are your main fishing locations in relation to ferry landings on this river (you may leave this blank if you prefer not to share such information)?

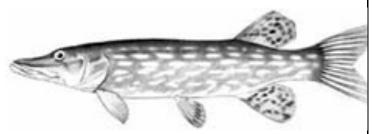
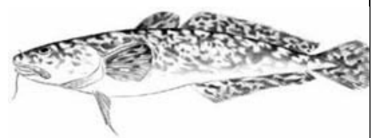
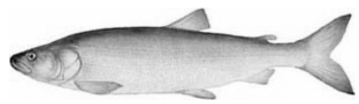
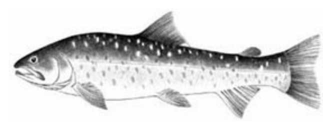
   Upstream of ferry landings ☐
   Downstream, within 1000 feet ☐
   Downstream, further than 1000 feet ☐

3. How many years have you fished at these locations (you may leave this blank if you prefer not to share such information)?

   __________ years

4. Approximately how many fish of the following species did you catch between May and November on the above river?

Common Name	Gwich'in Name	Appearance	Amount	More or less than last year
Whitefish (Broad Whitefish)	luk Zheii			
Crookedback (Lake Whitefish)	dalts'an			

Jackfish (Northern Pike)	eltin			
Loche (Burbot)	chehluh			
Coney (Inconnu)	sruh			
Dog Salmon (Chum)	shii			
Char	dhik'ii			
Herring (Cisco)	treeluk			
Sucker (Longnose Sucker)	daats'at			
Pickerel (Walleye)				
Other (____________)				

Other (____________)				

5. How does this year's total fish catch compare to last year's total fish catch?

   More fish this year ☐ Same amount ☐ Less fish this year ☐

6. Did you notice any changes to the total amount of particular fish that should be noted?

   ____

7. How much time did you spend fishing this year compared to last year?

   More time this year ☐ About the same amount of time ☐ Less time this year ☐

8. How were the majority of your fish caught?

   Net ☐ Fishing rod ☐ Other ☐ please specify: ___________________

9. If you used a net, please answer the following questions and circle the units used, indicating also which kind of fish were targeted with different nets if you used more than one kind of net:

   Net #1
   Length of net: _________ feet

   Height of net: _________ feet

   Size of mesh openings: _________ inches

   Net #2
   Length of net: _________ feet

   Height of net: _________ feet

   Size of mesh openings: _________ inches

   Net #3
   Length of net: _________ feet

   Height of net: _________ feet

   Size of mesh openings: _________ inches

10. For the following months, how many days did you fish and how many hours did you spend fishing a day on average? *Example: I fished for 14 days in June and my net was in the water for about 5 hours a day.*

	Days	**Average hours per day**
May		
June		
July		

August		
September		
October		
November		

11. Are there any other observations or comments that you would like to share about the health and size of fish stocks during this fishing season? You may also use this space to make suggestions about how to improve the survey in future years.

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