Evaluating the impacts of ferry operations on water quality, sediment loads, and the traditional fishery in the Gwich'in Settlement Area, Northwest Territories

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Summary

The Nagwichoonjik (Mackenzie River) and the Teetł'it Gwinjik (Peel River) are fundamental to historical and present land use and culture of Dinjii Zhuh, the Gwich'in Peoples, among them the Teetł'it and Gwichya Gwich'in, who today reside mostly in the communities of Teetł'it Zheh (Fort McPherson) and Tsiigehtchic respectively. The Dempster Highway crosses both of these rivers at locations near these communities, connecting them to the northern Northwest Territories, as well as to southern Canada. The Department of Infrastructure operates ferries during the open-water season, which allow vehicles travelling on the Dempster to cross the Peel and Mackenzie rivers near Fort McPherson and Tsiigehtchic, respectively. Each year, the Department of Infrastructure uses gravel fill to build out landings, which allow vehicles to drive onto the ferries.

The addition of gravel sediment to build these ferry landings has been an ongoing concern for the Gwich'in, especially in the communities of Fort McPherson and Tsiigehtchic. Specifically, there are concerns that gravel from ferry landings could be degrading water quality, harming fishing opportunities, and altering river morphology downstream. Previous reports concluded that ferry operations were not impacting downstream water quality or 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, we utilized a multidisciplinary study design that included Western Scientific sampling on both rivers in 2018 and 2019, and Traditional Knowledge collection in 2019.

For the Traditional Knowledge portion of our project, our team reviewed existing documentation of Traditional Knowledge and gathered further Traditional Knowledge in Fort McPherson and Tsiigehtchic through interviews and community meetings. In total, we conducted 23 semi-directive interviews with Gwich'in knowledge holders, with 16 community member participants in Fort McPherson and 11 in Tsiigehtchic. The interviews started with questions about general environmental changes and fish health, leading subsequently to concerns related to the operation of the ferries. We also worked with the Tetlit and Gwichya Gwich'in Renewable Resource Councils to update and implement a fish harvest survey that was completed by 17 fishers from Fort McPherson and 10 from Tsiigehtchic.

Our collection of Traditional Knowledge showed that knowledge holders in both communities expressed concerns that gravel from the ferry landings was contributing to changes on the rivers, but they also acknowledged large climate-driven sediment inputs upstream (i.e. permafrost thaw slumps, landslides and other erosion). Knowledge holders also expressed a diverse range of concerns that were not considered during the initial design of our study, including: interference with fishing opportunities, ferry cleaning residues entering the rivers, and oil spills. Most Gwich'in harvesters participating in the study did not notice changes to the health or abundance of important fish stocks, like Łuk zheii (Broad Whitefish) and Sruh (Inconnu), but harvesters in Tsiigehtchic have been impacted by the physical presence of the ferry landings due to the alteration of traditional fishing locations.

For the Western Scientific work, we visited the Peel and Mackenzie rivers after spring ice break-up to collect water quality data. Samples of river water were collected to measure turbidity (water clarity) and the amount of total suspended solids (mud and sand travelling in the water). In addition, bed load samples were collected to measure the amount of sand, gravel, and other materials traveling along the bottom of the river, and benthic macroinvertebrates (bugs) were

collected from shallow areas along the shoreline to determine if changes in water quality related to ferry landings might have affected habitat quality for organisms living in the rivers. We collected our water, bed load, and invertebrate samples upstream and downstream of the ferry landings, both before and after the construction of the landings each spring.

Based on our scientific work, we were not able to detect alterations in turbidity, total suspended solids, or bed load sediments downstream as a result of the granular material placed for the landings. All these variables changed through time in relation to river discharge but did not differ significantly between upstream and downstream sites. We did observe differences in the abundance and richness (number of types) of benthic macroinvertebrates among sites, but these differences did not demonstrate an impact from ferry operations.

Our results suggest that downstream movement of materials from the ferry landings are having little impact on the Peel and Mackenzie rivers. However, it is clear that ferry operations have had some impact on Gwich'in traditional use areas on the Mackenzie, have generated concerns about pollution, and have impacted some community members' sense of well-being. Based on these results, we have developed recommendations for both the communities and the Department of Infrastructure. It is our hope that these recommendations will help to address the remaining concerns about ferry operations in a cooperative manner that can balance community concerns with the operational realities faced by the Department of Infrastructure.

Key recommendations

We offer the following recommendations for both the Department of Infrastructure and the communities of Fort McPherson and Tsiigehtchic. These recommendations are described in more detail in Chapter 4. We recommend that:

1. *The Department of Infrastructure continue to limit the quantity of material used for all five ferry landings and continue to recover, store, and reuse material when possible*. These actions will limit the downstream movement of materials.
2. *The Department of Infrastructure limit the length and width of ferry landings as far as possible within the necessary parameters for ferry operations*, so as not to exacerbate sediment deposition downstream. If possible, this could include a reduction in the length of the landing on the Fort McPherson side of the Mackenzie River.
3. *The Department of Infrastructure explore ways to coordinate ferry operation in the fall to avoid interfering with the fall ice fishery or spawning Broad Whitefish populations*. Ideally, communication between ferry operations and fishers could help to inform operational decisions at this time of year.
4. *The Department of Infrastructure and the two Renewable Resource Councils engage to develop a new communication plan as a way of improving relationships*. It is our belief that an improved communication plan could mitigate the concerns that Gwich'in communities have with ferry operations, including landing material use, ferry cleaning, and spills. For the Department of Infrastructure, this could mean considering multiple forms of outreach. For the Renewable Resource Councils, this could mean identifying community members who are prepared to support information sharing and recruitment for meetings with the Department of Infrastructure, thereby ensuring that more people learn about the Department of Infrastructure policies and have an opportunity to voice their concerns and ideas.

5. *Monitoring of granular material use in ferry landing construction be continued by the Department of Infrastructure, including greater communication and transparency; while the Department of Infrastructure and Renewable Resource Councils seek the involvement of other government agencies and/or further research collaborations to enable broader environmental monitoring at these important fishing locations*. We suggest continued annual use of the fish catch survey, and also the possibility of community-based water monitoring programs for the Mackenzie and Peel rivers at these two important fishing locations.

Acknowledgements

This study was supported in many ways by a diverse number of people. First and foremost, we would like to thank the Gwichya and Teetł'it Gwich'in communities of Tsiigehtchic and Fort McPherson for welcoming and hosting us in their traditional territory. Special gratitude is due to all the research participants, who welcomed us to their homes or their fish camps, where they shared their perspectives and Traditional Knowledge with us.

Other collaboration, feedback and support came from various quarters. We would particularly like to thank the Renewable Resource Council Coordinators who supported the project, Gina Vaneltsi-Neyando and Laura Nerysoo for the Teetł'it Gwich'in RRC and Roxanne MacLeod for the Gwichya Gwich'in RRC. Their collaboration, and the wider support and engagement from the members of the RRCs, was fundamental for the design and completion of the study. Similarly, Sharon Snowshoe provided invaluable feedback and assistance as Director for the Gwich'in Department of Cultural Heritage, with additional insight and support from Heritage Specialist, Kristi Benson. Sarah Lord, Fisheries and Forestry Biologist with the Gwich'in Renewable Resources Board was a supportive and valuable source of feedback and advice, especially regarding design of the fish harvest survey. We could not have carried out the Traditional Knowledge documentation and fish surveys without the knowledge and experience of our community-based research assistants, Bella Charlie in Fort McPherson and Geraldine Blake in Tsiigehtchic. Similarly, the Western Science data collection was made possible by expert logistical support from boat operators, most notably Ernest Vittrekwa in Fort McPherson and Herbert Andre in Tsiigehtchic. There are others in the communities that also helped with river transport, food, information and advice; though they are too many to name here, this does not diminish our gratitude for their contributions.

Needless to say, support from the GNWT was also crucial. Merle Carpenter, Regional Superintendent for the GNWT Department of Infrastructure, played a fundamental role in making the study possible—not only by providing information and feedback but also by coordinating our access to vehicles and other logistical support. In addition, key project oversight and extensive feedback on the final report was provided by Jon Posynick, Manager of Environmental Affairs, Design and Technical Services; and Alexis Campbell, Environmental Analyst. Finally, the friendly and able staff at the Aurora Research Institute also deserve much thanks for their logistical support, especially as we relied extensively on their excellent facilities for the Western science portion of the study.

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Figure A2.4.4 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%.

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Chapter 1: Introduction

1.1 Ferry operations in the Gwich'in Settlement Area

1.1.1 Infrastructure, environmental change and Indigenous livelihoods

The Dempster Highway is an all-season gravel highway, opened in 1979, that connects Dawson City, Yukon to Inuvik, Northwest Territories. The highway crosses the Teetł'it Gwinjik (Peel River) near the Gwich'in community of Teetł'it Zheh (Fort McPherson). Further northeast, it crosses the Nagwichoonjik (Mackenzie River) and Tsiigehnjik (Arctic Red River) next to the Gwich'in community of Tsiigehtchic. 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 throughout the season and can be eroded by high water events throughout the summer, so construction and maintenance is ongoing (P. McLaughlin, GNWT, personal communication). Both crossings are at important fishing locations that form part of traditional livelihoods for the Gwich'in Indigenous People.

Gwich'in Traditional Knowledge holders have observed dramatic changes to the Peel and Mackenzie rivers over the past 2-3 decades, especially an increasing frequency of sand and gravel bars on the Peel River and varying sediment deposition on the Mackenzie River. These changes are making it much more difficult and dangerous to navigate the rivers and, in some cases, interfere with setting nets in traditional fishing locations, having a direct impact on Gwich'in livelihood. 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). In light of existing changes and potential impacts, Gwich'in communities have raised concerns about the ongoing construction and maintenance of the ferry landings, since some of the gravel placed in the river to build the landings is eroded and lost downstream. However, Traditional Knowledge holders also 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 the direct impacts of human activity like infrastructure construction and maintenance in and around 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 compound the impacts of other human activities.

Despite conclusions in previous studies that material from ferry landings is not significantly altering water quality (GeoNorth-Ross-AMEC, 2003; GNWT, 2017), many members of the Gwich'in communities of Fort McPherson and Tsiigehtchic have remained concerned about ferry operations. For example, community meetings held by the Department of Infrastructure in 2015 reveal concerns about traditional use areas, fish, and spills from the ferry (GNWT, 2015). In an effort to further inform the issue and address these concerns prior to the process for water licence renewal, Dr. Derek Gray and Dr. Alex Latta were contracted by the Department of Infrastructure, Government of the Northwest Territories to conduct an independent study building on previous studies and monitoring programs. They were joined by master's student Matthew Teillet, who was central to all aspects of the research and completed his thesis as one output of the project. Two other members of the research team contributed their local expertise and networks to the project as community-based research assistants: Bella Charlie in Fort McPherson and Geraldine Blake in Tsiigehtchic.

This report outlines our team's investigation into the impacts of the ferry operations using approaches from both the natural and social sciences. We took a collaborative approach to knowledge production, looking to Traditional Knowledge holders in the communities as well as Western science to address our core questions. Our methods will be discussed further below, but we can summarize our approach with three basic questions, linked to the methods employed, as follows:

1. What changes are Traditional Knowledge holders witnessing in the river environment and if they have concerns related to the ferry operations, what are they? To answer this question, we conducted Traditional Knowledge interviews.
2. Can scientific measurement detect increased sediment in the water, or its impacts on river ecology, as a result of the construction and operation of the ferries? To answer this question, we collected water, sediment and biological samples on the rivers.
3. What can a combination of scientific and Traditional Knowledge methods tell us about the abundance of fish stocks? To answer this question, we conducted surveys with fishers.

1.1.2 Background: Place, people and institutions

The Mackenzie River is the longest river in Canada, originating from Great Slave Lake and flowing to the Beaufort Sea. It receives water from major tributary basins that stretch much further south, east and west, including the Peace, Athabasca, Great Slave, Liard, Great Bear and Peel—in total encompassing a drainage basin of 1.8 million square kilometres (Mackenzie River Basin Board, 2020). As one of these sub-basins, the Peel River is much smaller but of major regional significance. It has its headwaters in the Ogilvie Mountains, draining a watershed covering 73,600 square kilometers, mostly in the northern Yukon (Kokelj et al., 2013). It is joined by six major tributaries before its confluence with the Mackenzie, near the beginning of the Mackenzie delta.

Both the Mackenzie and the Peel rivers are fundamental to historical and present land use and culture of Dinjii Zhuh, the Gwich'in Peoples, whose traditional territory spans thousands of square kilometres across the settler-state jurisdictions of Northwest Territories and Yukon (in Canada) and Alaska (in the United States). Fishing camps along these rivers have been used throughout Gwich'in history (Thompson & Millar, 2007; Wishart, 2009; 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 (Thompson & Millar, 2007; Wishart, 2009, 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; Wishart, 2009). 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 (Wishart, 2009, 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 many Gwich'in harvesters still catch hundreds of fish each during every fishing season (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).

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, 2017a) but have traditionally used lands throughout the Teetł'it Gwinjik (Peel River) watershed (Wray & Parlee, 2013). Similarly, many Gwichya Gwich'in now live in Tsiigehtchic (pop. 172; Statistics Canada, 2017b) but their historical territory spans much of the eastern area of the Gwich'in Settlement Area, including the Khaii Luk (Travaillant Lake) watershed, the Tsiighenchik (Arctic Red River) watershed and parts of the Nagwichoonjik (Mackenzie River) (Wishart, 2009). Fort McPherson is located twelve kilometres by road north of the location where the Abraham Francis

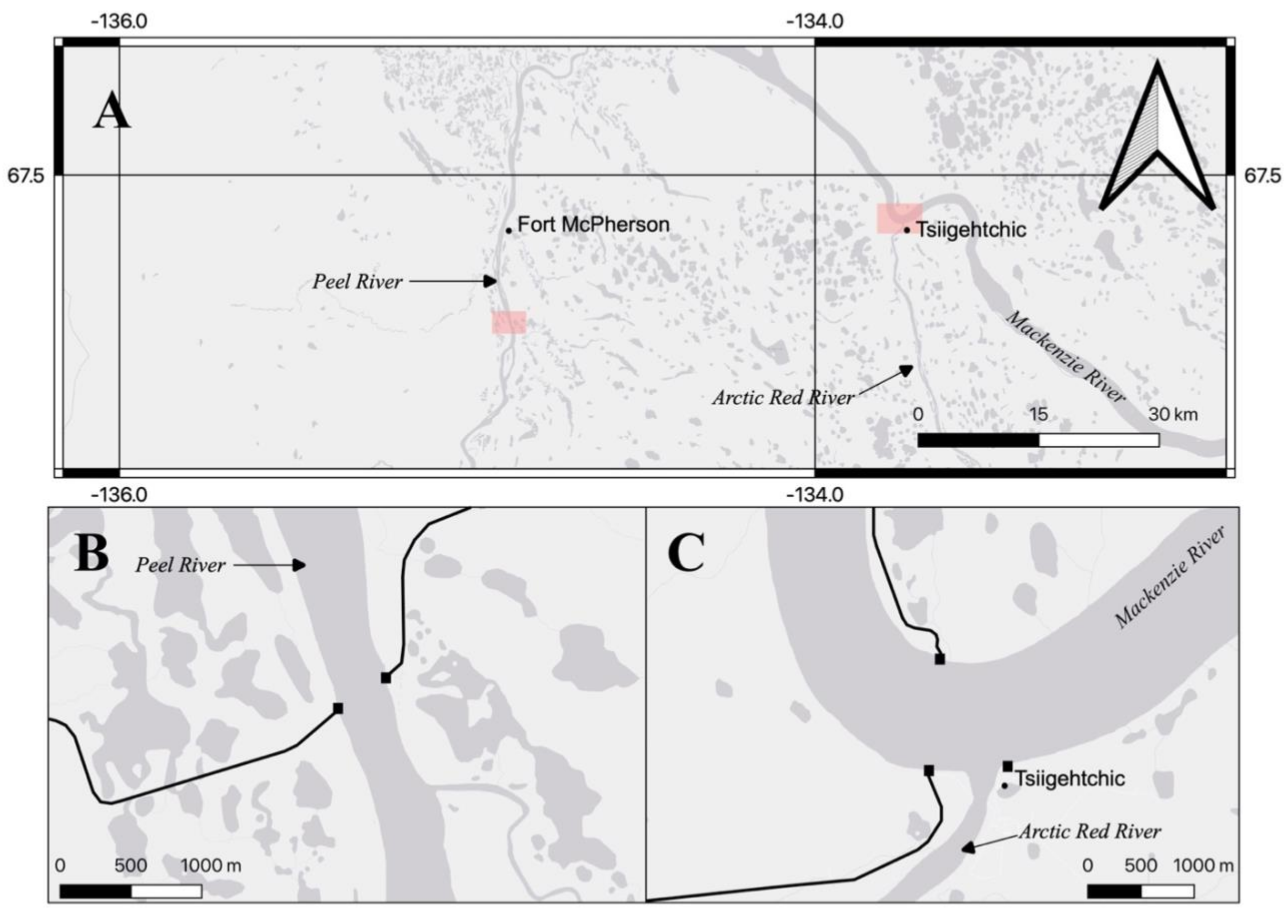

Figure 1.1 Overview of Dempster Highway crossing the Peel and Mackenzie rivers (Panel A), and close-up views of the river crossings on the Peel River (Panel B) and the Mackenzie River (Panel C).

ferry transports Dempster Highway traffic across the Peel River (Figure 1.1 A, B). Tsiigehtchic is located on the southern shore at the confluence of the Arctic Red River and the Mackenzie, where the Louis Cardinal ferry plies the waters between westbound and eastbound landings on the Dempster Highway, as well as a landing in Tsiigehtchic (Figure 1.1 A, C).

The *Gwich'in Comprehensive Land Claim Agreement* (Gwich'in Tribal Council & Indian and Northern Affairs Canada, 1992), signed in 1992 by Gwich'in representatives and the governments of Canada and the Northwest Territories, provides a crucial context for the operation of the ferries and for this study. The Gwich'in Settlement Area encompasses over 56 000 km^2 of the Northwest Territories, including parts of the upper Mackenzie River basin and the Mackenzie Delta, as well as the Peel and Arctic Red rivers. Building on Treaty 11, signed between the Crown and representatives of several Dene First Nations in 1921, the comprehensive land claim was negotiated to set out land and resource rights and ownership, provide economic and other benefits for Gwich'in communities, outline the parameters for a future self-government agreement, and promote the continuity of Gwich'in livelihoods and culture through shared decision-making over land, water and wildlife management. To achieve some of these objectives, the *Gwich'in Comprehensive Land Claim Agreement* created a framework for Gwich'in organizations, including local Renewable Resource Councils (RRCs) and Designated Gwich'in Organizations (DGOs), as well as co-management organizations such as the Gwich'in Renewable Resources Board and the Gwich'in Land and Water Board.

Water licensing is outlined within the Agreement, but the Gwich'in Land and Water Board was not fully realized until the subsequent passage of the *Mackenzie Valley Resource Management Act* (MVRMA) in 1998 (GLUPB, 2015; Government of Canada, 1998). The Act provided the Land and Water Board with water licensing jurisdiction within the Gwich'in Settlement Area. 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* (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 (Government of Canada, 2009a).

1.1.3 Dempster Highway ferries operations and water licensing

After the *Mackenzie Valley Resource Management Act* was passed in 1998, the Gwich'in Land and Water Board had the power to grant water licenses in the Gwich'in Settlement Area, and that is when Gwich'in concerns regarding ferry operations were first officially recorded. At that point, the Department of Infrastructure (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). License renewal applications from 2015 outline that these water licenses were required due to the maintenance of 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 Department of Transportation, 2015a, 2015b). Type B water licenses for ferry operations in the Gwich'in Settlement Area have been approved in 2004, 2010, 2015 and 2021(Mackenzie Valley Land and Water Board, 2021a, 2021b, 2015a, 2015b). The Department of Infrastructure has proposed to extend licensing renewal to every 25 years for ferry operations

(GNWT Department of Transportation, 2015a, 2015b), but in 2015 they were only granted 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 Gwich'in Settlement Area. 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, the Department of Infrastructure 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 the Department of Infrastructure created the Local Area Monitoring Plan (LAMP). At this time, the Department of Infrastructure 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 the Department of Infrastructure records. The Department of Infrastructure also commits to limit the amount of material used annually on each of the five ferry landings to a maximum of 500 m^3 per landing (GNWT Department of Transportation, 2015a, 2015b). In 2016, the Department of Infrastructure published a Sedimentation Report regarding the ferry landings, which summarizes current practices surrounding the ferry landings and plans for future work (GNWT Department of Transportation, 2016). Finally, pursuant to water licensing in 2015 and the recommendations of the LAMP study, the present study was contracted by the Department of Infrastructure in 2017 to re-examine the potential impacts of sediment from the landings on the aquatic environment.

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

Location	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

Note: Negative numbers indicate that the Department of Infrastructure removed more material from the landings than was put down. Data adapted from GNWT Department of Transportation (2016) and personal communication with P. McLaughlin, Department of Infrastructure, GNWT.

1.1.4 Review of previous studies into ferry operations in the Gwich'in Settlement Area

The Department of Infrastructure has commissioned two previous studies into the potential impacts of ferry operations in the Gwich'in Settlement Area. In 2001, the Department of Infrastructure contracted GeoNorth-Ross-AMEC to conduct an Aquatic Effects Study. The study, published in 2003, combined 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 (mapping the depths of the river bottom), water quality, fish stocks and habitat, and benthic macroinvertebrates (insect larva, worms and other small animals living submerged in the river bed). Assessments using aerial photos before and after 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 Traditional Knowledge 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 multidisciplinary study including various elements, 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 activity 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 greater depths.

Following the GeoNorth-Ross-AMEC (2003) report, concern about ferry landing material and ferry operations continued. In response to concerns raised in the context of the next round of water licensing, in 2010, the Department of Infrastructure 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 Department of Transportation, 2017). 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 report (GNWT Department of Transportation, 2017) offered recommendations for future monitoring, including sampling turbidity and total suspended solids throughout the water column of each river. It also recommended that fish harvest data continue to be collected with the inclusion of an effort calculation.

1.2 Major areas of knowledge informing the study

We provide more detailed methodological information at the start of each of the subsequent chapters in this report. However, we conclude this introduction by reviewing some of the bodies of key knowledge that inform this study and that readers may wish to pursue further in order to understand how the study is related to other work being done in this field.

1.2.1 Traditional Knowledge

Traditional Knowledge has long been the basis for Gwich'in stewardship of their traditional territory. Originally ignored by Western approaches to environmental management, more recent approaches have sought to combine Traditional Knowledge and Western science as a powerful method to understand environmental change and to assist with resource management in the Northwest Territories (B. L. Parlee, Goddard, Łutsël K'é Dene First Nation, & Smith, 2014). Nomenclature and definitions of Traditional Knowledge vary throughout the literature (e.g. Houde, 2007; McGregor, 2009b), but it 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). Indigenous communities have strong connections to the land and are therefore sensitive to and impacted by changes in their environment (B. L. Parlee et al., 2014).

Intertwining Traditional Knowledge and Western science in 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 Traditional Knowledge is passed from generation to generation, it presents a much longer-term record of environmental change and can fill gaps in the often time-limited studies undertaken by Western scientific researchers (Houde, 2007; Mantyka-Pringle et al., 2017). Traditional 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) without needing to rely on Western approaches to data collection. At the same time, Western science can sometimes measure changes that cannot be perceived by human senses, and therefore can often build on Traditional Knowledge observations to provide explanations for how or why changes are occurring. Therefore, the combination of Traditional Knowledge and scientific research in resource management can lead to a better overall 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). Indeed, many Traditional Knowledge holders readily integrate scientific information into their understandings of natural systems, and Western Scientists are increasingly recognizing the importance of paying closer attention to Traditional Knowledge.

Several past studies in the Gwich'in Settlement Area provide excellent examples of how combining Traditional Knowledge and Western science can improve understanding and management tools. In one example, Thompson & Millar (2007) drew on Gwich'in Traditional Knowledge to chart the migration patterns and spawning location of subsistence fish species in the Mackenzie and Arctic Red rivers. In another example, Cott et al. (2018) worked with Gwich'in harvesters to link Western scientific and Traditional Knowledge methods for identifying healthy and safe Burbot livers. There are a multitude of other studies conducted in Gwich'in territory that have collected Traditional Knowledge with respect to fisheries (e.g. Greenland & Walker-Larsen, 2001; Thompson, 2008; Wishart, 2013). Ultimately, decisions about how to manage natural resources can be better supported using multiple forms of knowledge (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).

1.2.2 Review of the impacts of added sediment on biota

The movement of sediments in lotic (moving fresh water) 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 (human caused) 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, 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 (Table 1.2; Carson, Jasper, & Conly, 1998) and 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).

Table 1.2 Estimated 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

1.2.3 Fish and sediment

Salmonids dominate the fish caught in the upper Mackenzie River system and are important for subsistence fisheries that are central to the economy and culture of the Teetł'it and Gwichya Gwich'in. Economically and culturally important salmonids in the area include Łuk zheii (Broad Whitefish, *Coregonus nasus*, also referred to locally as Whitefish), Dalts'an (Lake Whitefish, *C. clupeaformis*, also referred to locally as Crookedback), Sruh (Inconnu, *Stenodus leucichthyes*, also referred to locally as Coney), and Treeluk (Arctic Cisco, *C. autumnalis*, also referred to locally as Herring) (Stewart, 1996; Thompson & Millar, 2007) (See Table 1.3). 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. Thompson and Millar (2007) found a wider range in migratory times on the Mackenzie River than 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.

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*

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).

1.2.4 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 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 between larger sediment particles. (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 of invertebrates) 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, Somers, Craig, & Reynoldson, 2007; Rosenberg & Wiens, 1978).

1.3 Study timeline and community involvement

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. Those relationships formed the basis for our research license to begin gathering Western Scientific data for this study in May 2018. Community members were involved in sampling as river experts, guides, and logistical support. During this same data gathering period, we engaged RRCs and other community members around the design of the Traditional Knowledge and fish survey portions of the study. In Tsiigehtchic, we held an informal meeting with members of the RRC. In Fort McPherson, a member of the RRC introduced us to active fishers and other Traditional Knowledge holders at their places of residence. Engagements over research design continued via contact with the RRCs during the rest of that year.

In May 2019, Western science sampling continued, again with the support of community members. We also held community meetings to provide an update on the Western science portion of the study and launch the Traditional Knowledge documentation. In Fort McPherson, the meeting was attended by 25 community members and in Tsiigehtchic the meeting was attended by 20 community members. These meetings were a crucial touchpoint for the team as we reflected on our growing understanding of the main questions and issues, and how our study could contribute to resolving some of them. Traditional Knowledge documentation was completed that May, with the help of our community-based research assistants. Those research assistants were also central to the completion of the fish surveys in Fort McPherson (December of 2019) and Tsiigehtchic (February of 2020).

A community meeting in Tsiigehtchic in February of 2020 provided an opportunity for feedback on the study findings, including our summary of Traditional Knowledge highlights, before we began writing the final report. Attendance at this meeting was lower, with about 10 people present. Sadly, the President of the Teetł'it Gwich'in RRC passed away during that February research visit, which meant that our community meeting in Fort McPherson had to be cancelled. Following that, the public health measures around COVID-19 prevented our planned return to the region in April 2020. The Department of Infrastructure requested and received a one-year extension to its water licence application to provide time for the end-of-project community engagement in Fort McPherson to take place.

An extended period of outreach in the subsequent months sought ways of sharing results with community members in Fort McPherson. A 25-minute audio summary was recorded for the community radio station, but Tetlit Gwich'in RRC staff were stretched thin and despite their best intentions, this segment was never aired. As the deadline to submit the report neared, we provided a two-page summary of the study findings, which was circulated to all of the surviving traditional knowledge holders who had participated in the research (two had sadly passed away) and also made available to others via the Tetlit Gwich'in Council office. We also arranged to remotely attend an RRC meeting. That meeting was then postponed, so we met with two members of the RRC to share the results and hear their feedback. The Executive Director of the Tetlit Gwich'in Council also provided written feedback after reading the results summary. While this end-of-project debriefing was less than adequate, it is all that was possible in light of the COVID-19 pandemic. A summary of community feedback is included in Appendix 3.

1.4 Structure of this report

In Chapter 2, we describe the documentation and analysis of Gwich'in Traditional Knowledge and also present the results of the fish harvest survey. Traditional Knowledge is reviewed as it pertains to river morphology, fishing opportunities, and ferry operations. Although the fish harvest survey is not itself a traditional approach to knowledge, it was conducted with knowledge holders and incorporated opportunities for their observations. As another element that involved the close collaboration of harvesters, it seemed to belong in this section of the report. In Chapter 3, we describe the collection and analysis of data pertaining to the Western Scientific portion of this study. This includes measures of water quality, sediment loads, and benthic macroinvertebrates 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 4, we synthesize information from Chapters 2 and 3 to draw conclusions and make recommendations to the affected communities and to the Department of Infrastructure.

Chapter 2: Using Traditional Knowledge to identify the impacts of ferry operations in the Gwich'in Settlement Area, Northwest Territories

2.1 Introduction

In this chapter, we outline the methods used to engage with Gwich'in communities and document Gwich'in Traditional Knowledge, as well as what we learned through those processes about the impacts of ferry operations on river morphology, fishing opportunities, and Gwich'in livelihood. Traditional Knowledge is often referred to by other names, such as Traditional Ecological Knowledge, Indigenous Knowledge or Indigenous Science. We use "Traditional Knowledge" without prejudice to the other available terms. There is no single accepted understanding of what such knowledge entails, but we were guided by the definition provided by the Gwich'in Tribal Council, (2011) in their document titled, *Conducting Traditional Knowledge Research in The Gwich'in Settlement Area: A Guide for Researchers.* There, Traditional Knowledge is defined as follows:

> *The Gwich'in recognize and value the fact that living on the land for many millennia has provided them with an extensive body of knowledge, values, beliefs and practices that many people today refer to as traditional knowledge. This knowledge, which has been passed down orally and through personal experience and spiritual teachings, is the foundation of Gwich'in identity and survival. It continues to have relevance today and draws its' strength from being used, revised and continuously updated to take into consideration new knowledge. (1)*

This definition draws our attention to a broader understanding of knowledge than what is found in Western science. Traditional Knowledge is relational, as well as being integrally interwoven with culture and way of life.

The *Guide for Researchers* is based on the GTC Traditional Knowledge Policy, which outlines the ethical documentation and use of Gwich'in Traditional Knowledge in research (GTC, 2004). The guide/policy, along with our research agreement with the GTC's Department of Cultural Heritage, the Research Ethics Board review process at Wilfrid Laurier University and the requirements of the NWT Scientific Research License process, guided our documentation and interpretation of Gwich'in Traditional Knowledge for this study. This included seeking feedback on study design from the Tetlit Gwich'in and Gwichya Gwich'in RRCs; holding community meetings at different stages of the research; interacting informally with community members at events, during our data collection on the rivers and around town; publicizing the research by going on local radio; and hiring community-based research assistants. In one key aspect our study fell short: we had hoped to hire research assistants who were fluent in the Gwich'in language, but both of the assistants recommended to us by the RRCs had only partial language ability. All of our research participants were able to discuss the topics with us in English, but with several of the elders we believe they may have been able to express themselves more fully in their mother tongue.

Indigenous scholars have pointed to various concerns about how Traditional Knowledge is often treated in research. One central critique, noted for instance by McGregor (2009), is around failures to acknowledge that Traditional Knowledge is embedded in specific Indigenous languages and worldviews, as well as moral responsibilities to multiple relationships within Creation. Building on this critique, Whyte, (2013) defines Traditional Knowledge as "systems of responsibilities that arise from particular cosmological beliefs about the relationships between living beings and non-living things or humans and the natural world" (5). We perceive that this kind of understanding is implicit also in the Gwich'in understanding of Traditional Knowledge, since the reference to "spiritual teachings" is a direct link to that system of relationships and responsibilities that McGregor and Whyte both highlight. It is easy to see why understanding Traditional Knowledge this way makes conventional approaches to its "collection" by researchers problematic. Such collection essentially attempts to extract information from knowledge holders in ways that abstract it from their lived experience, interpretive frameworks and moral obligations to their human and non-human relations.

In some ways, our study is no different from the many others that seek to draw on Traditional Knowledge as a body of knowledge to shed light on a specific research question. However, as we will explain further in describing our methods below, we decided to engage knowledge holders not merely as sources of environmental observations about the health of the fishery but also as people involved in community discussions about the interactions between the ferries and the traditional fishery. Such discussions hinge precisely on relationships and responsibilities to care for the land, and were indeed the original context where the research question emerged through the expression of community concerns. In sum, we wanted to know how knowledge holders viewed the issue that our study sought to address, and what informed those views. This approach had marked implications for our findings and recommendations.

2.2 Methods

This portion of the study employed social science methods, rooted most strongly in Human Geography but also influenced by approaches from Anthropology and Sociology. An effort was made to adapt those approaches to Indigenous ways of knowing (see e.g. Louis, 2007; Simonds & Christopher, 2013), most notably through an emphasis on relationship building, respect for Indigenous worldviews and an effort to engage communities as collaborators in knowledge production.

There are three main methods described in this section: background research with Gwich'in Traditional Knowledge records, interviews, fish surveys and aerial photos. Fish surveys are not part of Traditional Knowledge, but because these surveys engaged Traditional Knowledge holders and included opportunities to share Traditional Knowledge observations, we felt it was best to include them in this section of the report. Traditional Knowledge holders encouraged us to consult aerial photos in relation to their accounts about the river, which is why those are included in this section of the report.

It is also important here to emphasize the overall role of our interactions with the Renewable Resource Committees (RRCs), the GTC Department of Cultural Heritage, the Gwich'in Renewable Resource Board and community members in both study design and interpretation of results. May 2018 visits to Tsiigehtchic and Fort McPherson were crucial for attuning our study design to community needs and concerns. May 2019 community meetings provided another round of orientation to community perspectives and concerns just before we started conducting interviews. The list of prospective interviewees was generated by the RRC Coordinators, with additional input from members of the RRCs.

2.2.1 Gwich'in Traditional Knowledge records

In preparation for the research, we conducted a comprehensive background review of existing Gwich'in Traditional Knowledge records. Several documents containing Gwich'in Traditional Knowledge, including the original study completed by GeoNorth-Ross-AMEC (2003) on ferry operations in the Gwich'in Settlement Area, were provided by the Department of Infrastructure, GNWT. Other sources of Gwich'in Traditional Knowledge 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 Traditional Knowledge sources informed study design by providing the research team with an understanding of the cultural, environmental, and economic context for ferry operations. During the course of the study, the GTC Department of Cultural Heritage provided over 100 documents from their Traditional Knowledge repository, discovered through a keyword search of "ferry" and "fish" within the same line (Appendix 1.1). 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.

2.2.2 Interviews

The proposed interview questions were formulated after prior engagement with harvesters and RRC members in both Tsiigehtchic and Fort McPherson, and finalized 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 2.1).

Table 2.1 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?

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 1.2) and 11 in Tsiigehtchic (Appendix 1.3). 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. Where Traditional Knowledge holders agreed to have their names used in research outputs, we have included that information when quoting the knowledge and perspectives 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 in the findings as "anonymous #".

We transcribed each interview verbatim. A printed copy of each participant's transcribed interview was offered to participants in February 2020 for their records and for correction if they wished. Key themes were identified through keyword searches documented in Table 2.2. 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. As suggested by several study participants, we also examined historical and current aerial photos of the area to help visualize some of the changes that were described in the interviews around the Fort McPherson landing on the Mackenzie River.

Table 2.2 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"	"herring"	"removal"
"mud"	"new"	"wash"
"clear"	"health"	
"shallow"		

The Traditional Knowledge holders interviewed were familiar with different stretches of the two rivers, with some having a broader knowledge and others mostly familiar with the immediate locations where they always set their nets. This and other factors led to often different observations and levels of concern about the ferries. Given such variance, we engage in some degree of comparison when discussing what we heard from different participants as we report and interpreted the findings. For instance, when numerous knowledge holders mentioned a particular concern, we note that as a way of giving it emphasis.

A final methodological note relates to the verification process used for this part of the study. Our community-based research assistants distributed the interview transcripts back to the study participants, with the invitation to review the transcripts and contact them to request any changes. We did not receive any requests for changes. The second method of verification was to hold community meetings to share the study results and hear community feedback before the report was finalized. As indicated in the introduction, although a community meeting was held in Tsiigehtchic in February 2019, events (passing of the Chair of the RRC, followed by the COVID-19 pandemic) prevented us from holding a meeting in Ft. McPherson.

Verifying Traditional Knowledge results would ideally involve all those who had participated in the interviews in a discussion of the findings, including an effort to reach consensus in areas where there were discrepancies in knowledge holders' interpretations of environmental conditions, fish health or impacts of the ferries on the rivers. Clearly, this opportunity for discussion among knowledge holders was not possible in the case of Ft. McPherson. Even in the meeting we held in Tsiigehtchic, only some of the knowledge holders we interviewed were in attendance. As a result, despite having documented considerable Traditional Knowledge, it is more of a challenge to confidently report findings from that knowledge. To partly compensate for this, and without wishing to suggest that Traditional Knowledge needs to be quantified in order to give it validity, our discussion of findings does rely to some degree on the frequency of different observations or interpretations across different knowledge holders to distill our conclusions.

2.2.3 Aerial photos

We were encouraged by Traditional Knowledge holders in Tsiigehtchic to compare present and historic aerial photos of the ferry landing on the Fort McPherson side of the Dempster Highway crossing in order to provide visual corroboration of their own accounts about changes in the river since ferry operations began. The 2003 Aquatic Effects Study (GeoNorth-Ross-AMEC, 2003) had already included aerial photos in their analysis, so we consulted those photos again as part of our own analysis.

2.2.4 Fish harvest surveys

To further understand fishing use in the area and to continue the dataset started by the Department of Infrastructure, we collected fish harvest records using a protocol that significantly modified the approach in the previous LAMP monitoring (GNWT Department of Transportation, 2011, 2017). We also saw this part of the study as a way to reach more fishers for their Traditional Knowledge observations about fish health and abundance, and we included questions with that aim. We suggest that the surveys represent one example of how Traditional Knowledge and Western science can be successfully intertwined to gain an overall clearer picture of the health of the aquatic environment.

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 settling on a final version of the modified fish survey. In our initial study design it was proposed that fish harvesters would fill out daily or weekly logs of their catch across the fishing season. It seemed to us that the previous catch surveys conducted as part of the Department of Infrastructure's Local Area Monitoring Plan, which sought harvester catch estimates at the end of the fishing season, might not capture information accurately. However, feedback from the RRCs alerted us that this would be impractical and that likely very few harvesters would participate. The time absorbed by this consultation, including additional concerns about survey fatigue and overlap with the annual Arctic Borderlands data collection, meant that no fish surveys were collected for the 2018 fishing season.

There were two main adjustments in the new survey tool that emerged from these consultations. The first incorporated a basis for calculating an approximate catch per unit effort (CPUE). To estimate CPUE we sought to gauge both the amount of time spent fishing over the summer and fall seasons and the size and number of nets used. Fishers were asked to describe their nets and the approximate number of days that they were in the water for more than 12 hours. A basic estimation of CPUE for each species was calculated using this formula:

$$CPUE = \frac{C}{(fn)}$$

where C is total catch of a species by a fisher, f is the total amount of hours spent fishing and n is the total surface area of net deployed. 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 second modification to the fish survey was to incorporate more explicit requests for open-ended harvester feedback about fish health and abundance, thereby more deliberately incorporating Traditional Knowledge observations alongside the quantitative measures in the survey. The original Local Area Monitoring Plan survey tool and our modified survey can be found in Appendices 1.4.1 and 1.4.2.

2.3 Results

In the results we try to use the words of knowledge holders as much as we can to ground the observations we make about the Traditional Knowledge documented in the study. It is important to note that in most instances the quotes shared here merely illustrate the kinds of observations recorded about each topic; space does not allow for a more systematic and exhaustive listing of relevant parts of the interview transcripts.

2.3.1 Traditional Knowledge records

The Gwich'in Traditional Knowledge that was accessed from the Department of Cultural Heritage archives and other sources demonstrates that concern about the ferry operations has been long-standing (Appendix 1.1). 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[ly] no more eddy. (Gabe Andre, 1996, Tsiigehtchic)*

This particular location on the Mackenzie River is the predominant object of concern in existing documentation of Traditional Knowledge, with both Teetł'it and Gwichya Gwich'in describing significant changes there in interviews from 1996, 1999, 2001, 2003 (Kendo, 1999; 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 2.2) on the Mackenzie River is discussed by two of the four knowledge holders in Tsiigehtchic. These individuals made similar observations to those made by Gabe Andre in the quote 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 return to these 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 spent at the crossing waiting for the ferry.

Moving beyond the Traditional Knowledge register to other related documentation of community concerns, in 2015 the GNWT Department of Infrastructure (then the Department of Transportation), met with community members in Tsiigehtchic and Fort McPherson to discuss ferry operations in preparation for the water licence renewal request (GNWT Department of Transportation, 2015a, 2015b). During this consultation, there were calls for more communication with the community, with interest in biannual meetings and more information on the LAMP study. There were multiple comments about oil and gas spills on the ferry and a perceived lack of communication with the community when one does happen. One attendee in Tsiigehtchic expressed concerns about ferry landing location, claiming that ferry operations were getting closer to a fish camp. A community member in Fort McPherson argued that community-based monitors or some other measures are needed to reassure the community that the granular materials at the landings are being placed and removed according to the stated policies. As explored further below, such issues seem to be symptomatic of broader community concerns about the ferry operations, not all of them directly related to the granular materials used on the ferry landings and the associated water licence.

2.3.2 Interviews

A list of the key terms that were used for thematic analysis of the transcribed interviews is listed above in Table 2.2. Environmental change was discussed at length during every interview. There was near 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.

> *I've noticed that the ice was very thin. Whereas, let's say, 20-30 years ago the thickness of the ice was about, 4-5 feet thick. And now, it looks like it was just maybe, almost close to 3 feet. (Agnes Mitchell, 2019, Tsiigehtchic)*
>
> *When the ice used to move we used to have four or five feet of thick ice, you know? Now, you see little two or three-foot ice coming down the river. And it's all candle ice too, like this past spring when the ice moved, it's just straight candle ice. (Abraham Wilson, 2019, Fort McPherson)*

For the knowledge holders who mentioned these changes in ice thickness, they are a cause of concern and are associated with other changes. For instance, Agnes Mitchell went on to mention that the Mackenzie is shallower than it was in the past. The thinning ice is also concerning because it is understood as one of the clearest forms of evidence that climate is changing. Right after discussing ice thickness, Abraham Wilson went on to speak about the climate emergency declaration in Old Crow, asserting that all Gwich'in communities should be declaring a climate emergency and speaking about the threats to spawning habitat as creeks banks collapse.

This concern over riverbank failures and landslides was underlined by several knowledge holders, many of whom also linked it to observations about increased abundance of sandbars.

In 2015 during a rainy period there were 15 landslides that happened between Tsiigehtchic and Tree River, three small ones and the rest medium to very large. (Julie-Anne Andre, 2019, Tsiigehtchic)

You go up the Peel, every hill [has a] landslide…and it goes right down, some of it goes right to the shore…. There's lots of sandbars and there's lots of stumps. (Mary Effie Snowshoe, 2019, Fort McPherson)

When I'm travelling in the rivers there's lots of slides now…. There's lots of movement in the channels, like up in the Arctic Red and the Mackenzie River… lots of sandbar movements. (Herbert Andre, 2019, Tsiigehtchic)

The increase of sandbars is noted as increasing the challenge for river navigation. For instance, Herbert Andre discussed how his grandfather used to be able to drive his boat right into Tree River (upstream on the Mackenzie from Tsiigehtchic) and that he always set a net there. Now there is a sandbar there that stretches way out into the Mackenzie. Several knowledge holders also commented on how increased sediment is affecting the water itself.

When I was younger [the river water] used to be blue. Little bluer than it is now. Now it's like cocoa. (Walter Vittrekwa, 2019, Fort McPherson)

This is of concern to knowledge holders both from the point of view of personal consumption (several reported being able to drink right from the river in the past, where now they cannot) but also in terms of what it might mean for fish.

In addition to broader environmental changes, participants in the study also observed changes to fish species and stocks. Although there are fewer people fishing in the Gwich'in Settlement Area than historically, it is clear that fishing is still an important part of Gwich'in livelihood and many harvesters fish near ferry operations on both rivers (Figure 2.1 and Figure 2.2).

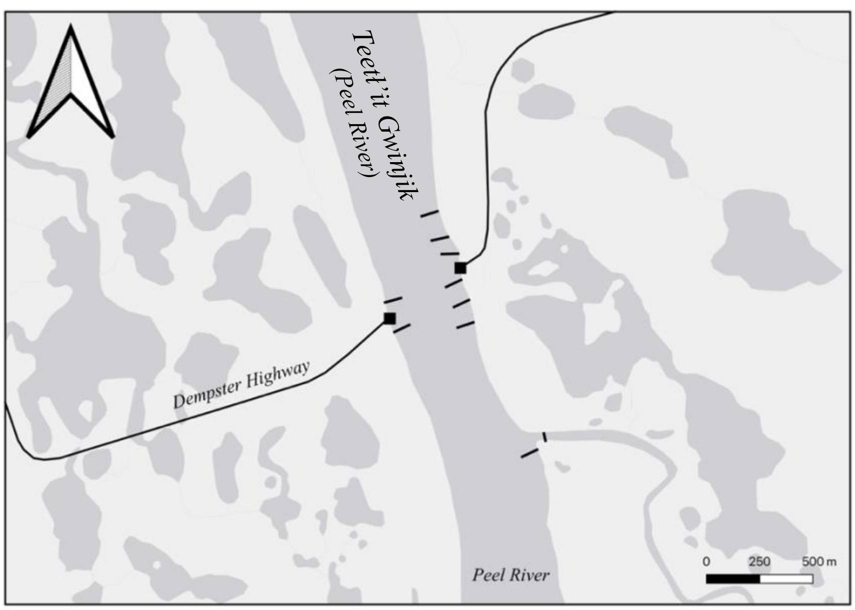

Figure 2.1 Map of the Peel River study reach. The black squares denote the ferry landings. The short black lines denote net-setting areas identified by harvesters, not individual net locations.

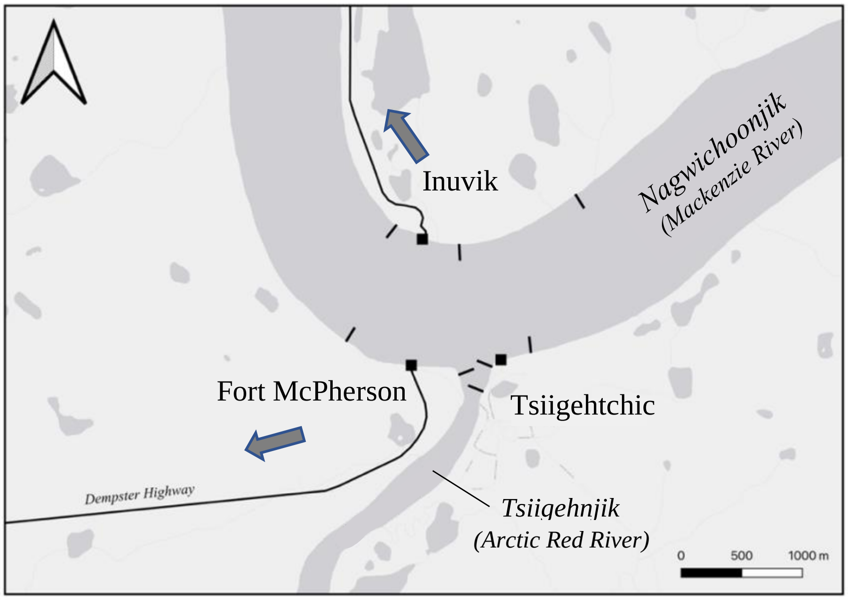

Figure 2.2 Map of the Mackenzie River study reach. The black squares denote the ferry landings and are labelled based on their respective community access. The short black lines denote net-setting areas identified by harvesters, not individual net locations.

With few exceptions, the knowledge shared with us describes Whitefish (Broad Whitefish), Coney (Inconnu), and Crookedback (Lake Whitefish) populations being at historic levels, with some study participants suggesting that there may be more fish or that some of the fish may be larger in size than before. However, environmental changes have impacted fish and fishing opportunities—something noted especially by Teelit Gwich'in Knowledge holders about the Peel River. Several interviewees described how an increase in warm summer days makes fishing more difficult, as fish swim deeper to find colder waters.

> *Every year it's the same for me. If high water comes up, that's when we're low on fish too, huh? When [it's] high water, that's when we don't get fish easy. As soon as the water [is] going down, we set nets; we get our fish back. (Emma Kay, 2019, Fort McPherson)*

> *But last summer was so hot, you know, [it] was poor fishing. Too hot, huh? You know when it's hot like that, the fish stay way down where the water's cold. (Abe Peterson, 2019, Fort McPherson)*

Abe Peterson went on to discuss distinctions between the fish overwintering in the river and those that overwinter in lakes and come down into the river via creeks after spring break-up. He and other knowledge holders noted that the fish that come down the creeks are better for eating. This is one factor in the quality of the fish, but another widely noted one is again related to rising water temperature. Knowledge holders report this is causing the flesh to be softer and even to spoil completely, making it necessary to check fish nets much more frequently than in the past.

> *Whitefish…used to be like solid….Now you cut it, it's like, just like soft and you try to cut it crossways…it's just like you might say it's…come apart or something. Too soft, like. Maybe it's due to the water; waters seem to be getting warmer every year…. Back in the days, pretty cold the water. Now you have to…look at your net every two hours or one hour. Catch them and you take them out right there. That*

way they'll stay cold, skin them right away. (Walter Vittrekwa, 2019, Fort McPherson)

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. There is general agreement that this is due to a decline in sled dog teams and thus less of a need for the Herring to feed them, which has led harvesters to use larger mesh size to catch only species used for human consumption. Therefore, the state of Herring stocks is unknown to Gwich'in knowledge holders. One participant commented that she never sees suckers anymore and these used to be relatively common. In terms of fish health, there was near consensus that apart from the issue of soft flesh the fish are healthy. That said, there were participants in Tsiigehtchic that commented on changes in fish health issues that they have observed.

I've been starting to see a little white worm in the flesh. Also lampreys inside the gills—I've seen more of those in the past few years. (Julie-Anne Andre, 2019, Tsiigehtchic)

Lots of time we get fish that don't look too good…. One time we cut [into a] fish; it had a big white thing inside the guts. (Irene Kendo, 2019, Tsiigehtchic)

After the discussion about concerns regarding the impacts of environmental change on the rivers and fish, the interviews were directed towards ferry operations. Here, we divide our discussion into two parts, since there were important differences to the concerns raised in relation to the two crossings. In Ft. McPherson, there was a difference of opinion among knowledge holders about whether the material being used to construct and maintain ferry landings was contributing to long-term build-up of sand bars. Some saw a clear link.

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 gets washed away..." (Anonymous #1, 2019, Fort McPherson)

Others suggested instead that the increased sand and gravel bars are mostly or entirely a result of broader changes in the land and climate.

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)

I can't understand why they blame,…why they blame the ferry. I think, look at the weather, look at the season. It's all different. It's a change... (Eileen Koe, 2019, Fort McPherson)

It is important to note that those knowledge holders who shared this opinion spoke of the fact that sandbars are increasing upstream of the ferry landing as well, where several of those who linked the ferry landings to the increased sand bars reported that their use of the river is almost exclusively downstream from the landings. We suggest that this difference of opinion can at least partly be explained by this difference of land use, though our inability to hold a community meeting to properly verify the knowledge and seek a consensus limits our ability to draw firm conclusions in this regard.

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 or fuel spills. These concerns were voiced by roughly a third of knowledge holders that we spoke to, mostly regarding residue from vehicles that is washed off the ferry deck into the river.

> *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)*

> *What I see, what should happen is they should stop washing the deck off on the ferry. It's a real big concern, that. Nobody say nothing. You're washing oil and whatnot off the truck, right into the eddies. Sure, it keeps the boat clean but how about our stomach? And them eddies, when they wash the deck, it goes into them eddies and it stays in there. And that's really bad, that. (Ernest Vittrekwa, 2019, Fort McPherson)*

The concern is that deckhands hose the deck of the ferry to keep it clean and if there is an unnoticed spill, it gets washed into the river. Beyond this perceived risk of incremental contamination, one participant also mentioned that a major spill would threaten their fish. On the basis of first-hand observations around previous spills, he shared his impression that response times and crew training is inadequate. It is an issue that he had also raised in a community meeting with Department of Infrastructure staff that happened to take place shortly after a spill in 2015 (See "Consultation Overview" in Department of Transport, 2015). He recounted the following incident during the interview.

> *A couple of years ago they had a oil spill at the ferry crossing. It was just down here where I got net. That spill happened…the previous night, nobody knew about it. The captain is there, he didn't know how to contain the spill... Anyways, I got down there 7 o'clock in the morning cause that oil slick all over that eddy. So I started ringing people, phoning people, and the wildlife officer came up here and put some booms around that eddy. (Abraham Wilson, 2019, Fort McPherson)*

Moving our focus to Tsiigehtchic, only two knowledge holders mentioned similar concerns about deck cleaning and spills, but there was again fairly widespread concern about the impact of ferry landing material on the river. Although Abe Peterson lives in Fort McPherson, he used to live in Tsiigehtchic and reported concerns about management of the granular material placed for the landings there.

> *You know there's tons and tons of gravel they haul every spring. Every time the water gets high, it just washes that gravel away. Where it's going to, you don't know? Yeah, it's years and all that gravel, you know? (Abe Peterson, 2019, Tsiigehtchic)*

As in Fort McPherson, some knowledge holders in Tsiigehtchic connected the erosion of ferry landing materials with nearby sandbars downstream.

> *That pit run washes away. Like one day, if there's a wind? It pounds against that ferry landing and it get washed into the river. Maybe this one is creating a sandbar here [pointing to map downstream of Inuvik landing] and this one here I know for sure this one is here [pointing to map downstream of McPherson landing] because this is pretty strong current here and every time they pour that, not the*

shale but that pit run stuff in there it gets washed down. (Herbert Andre, 2019, Tsiigehtchic)

Along these same lines, another knowledge holder specifically mentioned that travel to downstream fishing camps is much harder now due to the long gravel bar that stretches out into the river from the curve just down from the Inuvik landing (Anonymous, 2019, Tsiigehtchic).

Beyond these concerns about erosion and deposition of materials, several knowledge holders in Tsiigehtchic mentioned an additional issue around the physical extent of the ferry landings, saying that they are extending farther outward into the river than in the past, or that the ferry's use of multiple landings expands the extent of the shoreline unavailable for fishing. At the Inuvik landing on the Mackenzie River, one knowledge holder reported a direct and long-standing interaction between the ferry operations and her family's traditional fishing camp:

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).

Concerns about the impacts of ferry landings on fishing opportunities were especially frequent and pronounced in relation to the Fort McPherson landing on the Mackenzie River (Figure 2.3), which is adjacent to a traditional fishing area immediately 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 raised frequently by knowledge holders and was also mentioned at the pre-season and post-season meetings in Tsiigehtchic. The change to this particular fishing area on the Mackenzie was even noted by knowledge holders in Fort McPherson, who historically have fished there as well, especially for the fall fishery.

[That] used to be a good eddy in that bay. Now it's all sandbar, it's all covered.... Now it's no more bay, it's all filled in, huh? That's from all that gravel they're hauling there. (Abe Peterson, 2019, Fort McPherson)

In fact, Interviewees state that the infilling of this fishing location with silt is especially detrimental to the fall fishery. Fishers must now walk further out on the ice to find deeper locations to set their nets, which is less safe, or instead fish in the mouth of the Arctic Red, which becomes very crowded. 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.

These issues of access to fishing sites were absent in interviews with Traditional Knowledge holders about the Peel River crossing. While there were concerns about the need for better communication to avoid potential interactions between ferry operations and nets placed close to the Peel River landings, it seems that this potential for interactions may in fact arise due to increased fishing opportunities at that site. This is substantiated by an observation from Ernest Vittrekwa, who repeated what he had reported 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 [we] 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. [The river] used to just run directly through. Since they put that ferry landing in, [we] can set nets on both sides. (Ernest Vittrekwa, 2019, Fort McPherson)*

2.3.3 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 about the fishing location downstream of the Fort McPherson landing (Figure 2.3). The 1967 and 1971 photos show the area before the construction of the ferry landing, while 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 more convex-shaped shoreline in 1971. The images corroborate the observations made by Traditional Knowledge holders in the community about how that curve in the river has filled in with sediment.

2.3.4 Fish harvest surveys

In Fort McPherson, the community-based research assistant circulated surveys to harvesters to fill out at the end of the fall fishing season in December

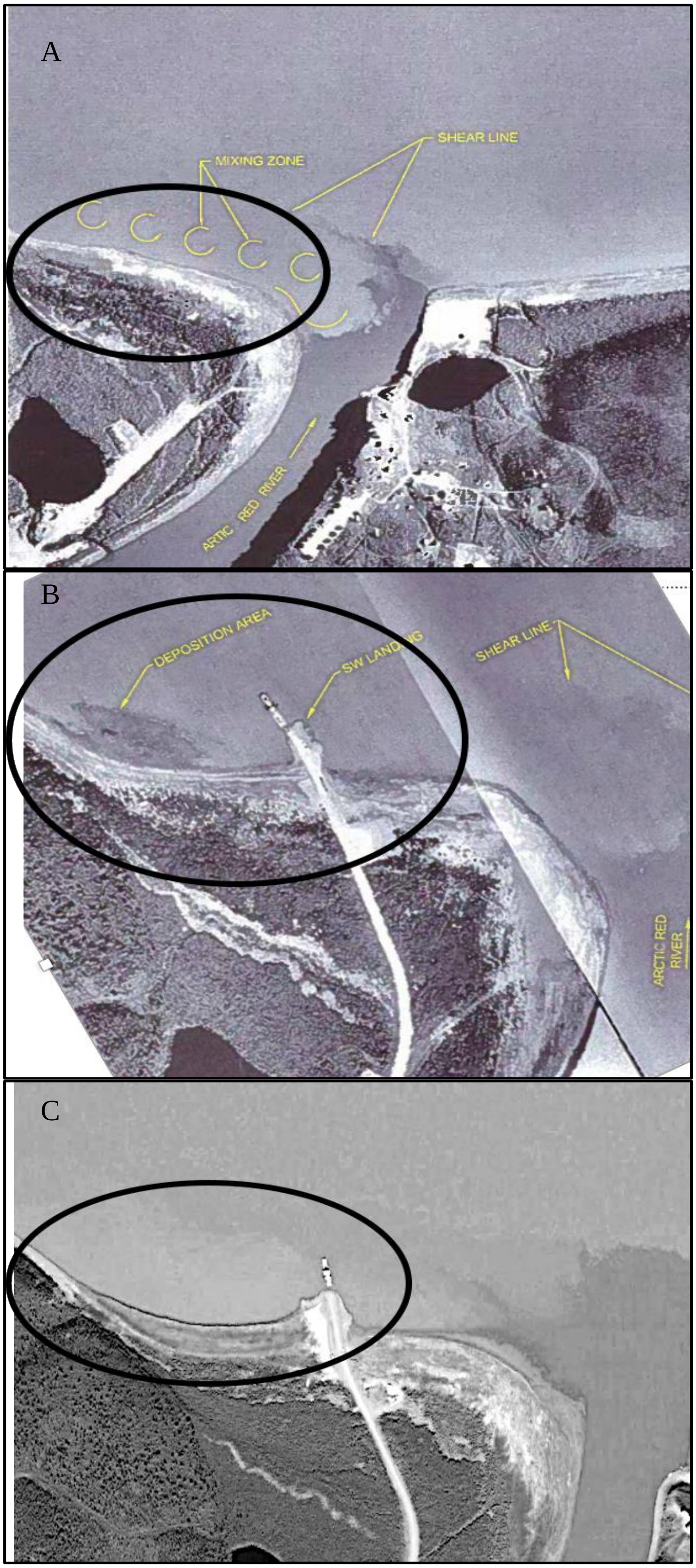

Figure 2.3 Aerial photos of the Fort McPherson landing (circled) on the Mackenzie River taken in A) 1971, B) 1985, and C) 2004. The first photo is before ferry operations began. Photos A) and B) were adapted from GeoNorth-Ross-AMEC (2003), including arrows and labels placed by the authors of that study. Photo C) was taken from Google Earth©.

2019, with 17 participants reporting a total catch of 12,513 fish (see Table 2.3 for results). 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 downstream within 500 m of ferry operations, and two further than 500 m downstream of ferry operations.

Table 2.3 Fish harvest data for main target species fished 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 Department of Transportation (2017).

Year	Broad Whitefish	Lake Whitefish	Northern Pike	Burbot	Inconnu	Total Fish	Average fish per harvester
2011	5159	155	246	64	1238	6862	286
2012	3323	333	189	11	980	4836	242
2013	3930	1005	307	98	1260	6600	314
2014	7526	697	433	159	3743	12558	419
2015	3179	812	206	92	1180	7269	383
2019*	6381	2857	373	412	2490	12513	736

In total, across the five major target species, the 17 fishers from Fort McPherson caught 12,513 fish in the Peel River and spent an estimated 12,948 hours fishing in 2019. Whitefish (Broad Whitefish) accounted for more than half of the fish caught, with a total of 6381. Crookedback (Lake Whitefish) and Coney (Inconnu) also accounted for large proportions of the total catch, with 2857 and 2490 caught respectively. Factoring in time fished, and also square footage of net, Whitefish had the highest catch per unit effort (CPUE) (see Table 2.5). No comparisons with previous years are possible given that this was not part of the LAMP methodology. 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. One harvester accounted for more than half of the fish caught, recording that they caught 7185 fish, with 2136 hours fished on an estimated 600 square feet of net in the 2019 fishery.

Table 2.4 Catch per unit effort (CPUE) calculated from data reported by 17 participants, who fished on the Peel River between May and November 2019. CPUE was calculated by dividing the number of fish caught by the number of square-foot hours of fishing (i.e. area of net multiplied by duration in the water).

Species	Broad Whitefish	Lake Whitefish	Northern Pike	Burbot	Inconnu
2019 Catch	6381	2857	373	412	2490
CPUE	0.00256	0.00204	0.00039	0.00091	0.00136

In Tsiigehtchic, the community-based research assistant deemed that there was survey fatigue during late fall, so surveys were completed while the rest of the research team was back in the community in February 2020, with only ten participants. Both the overall and catch/person numbers in Tsiigehtchic were significantly higher than those of previous surveys (see Table 2.5 for results). It is possible that holding the survey several months after the end of the fishing season had an impact on the accuracy of the data reported. All participants reported using 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.

Table 2.5 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 Department of Transportation (2017).

Year	**Broad Whitefish**	**Lake Whitefish**	**Northern Pike**	**Burbot**	**Inconnu**	**Total Fish**	**Average fish per harvester**
2011	7300	2472	112	49	2014	11947	427
2012	7207	3254	106	126	1821	12514	596
2013	5402	1426	159	333	1232	8552	407
2014	3916	723	10	9	55	4713	393
2015	1518	833	37	9	582	2979	298
2019*	4902	3947	395	267	2772	13075	1308

In total, across the five main target species the 10 fishers reported catching 13 075 fish in the Mackenzie and Arctic Red rivers. Only 7 of the 10 fishers reported time fished, so the 4508 total hours overall recorded for 2019 is lower than the actual total. 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. The three harvesters that did not report time fished were removed from the calculation of CPUE, making it a small sample size. Together with the late survey completion in Tsiigehtchic, this gives us little confidence in the CPUE outcomes. Whitefish had the highest CPUE (see Table 2.6). Again, no comparisons with previous years are possible given that this was not part of the LAMP methodology. Of the 10 fishers surveyed, 4 indicated that fish were more abundant in 2019 than previous years and the other 6 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.

Table 2.6 Catch per unit effort (CPUE) calculated from data reported by 7 participants, 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. CPUE was calculated by dividing the number of fish caught by the number of square-foot hours of fishing (i.e. area of net multiplied by duration in the water).

Species	Broad Whitefish	Lake Whitefish	Northern Pike	Burbot	Inconnu
Catch	4902	3947	395	267	2772
CPUE	0.00760	0.00257	0.00041	0.00019	0.00253

2.4 Discussion

2.4.1 Ferry operations in the Gwich'in Settlement Area

Various kinds of concerns related to the ferry operations on the Mackenzie and Peel rivers have been expressed by the Gwichya and Teetł'it Gwich'in for decades. *It seems reasonable to expect that expression of concern will continue, even if many of the issues are successfully dealt with; the very existence of the ferries, despite the indispensable service they provide to the communities, makes for a significant infrastructure footprint in the midst of traditional fishing locations*.

In previous Traditional Knowledge documentation, concerns about the Mackenzie ferry operations have been more pronounced, but many participants in this study and attendees at the community research meetings in Fort McPherson made it clear that similar concerns about the Peel crossing have been long-standing. At the same time, *it is important to note that there was a notable difference of opinion amongst knowledge holders about one of the most central questions in this study: whether there is a specific link between ferry landings and the growth of downstream sandbars*. The following discussion reflects on some of the nuances around this question, but also addresses the wider array of questions and concerns that were raised by study participants.

The most common observation regarding ferry operations on the Mackenzie River is the alteration of a traditional fishing location downstream of the Fort McPherson landing (Figure 2.3). Traditional Knowledge both in existing documentation and 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 has 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 provides 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 (e.g., Tipping et al. 1993).

While Traditional Knowledge and aerial photos seem to indicate that the alteration of the fishing location is due to the ferry landing, there may also be other factors. 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, Kaluthota, Philipsen, Rood, & Zanewich, 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 impossible, based on the information sources available to us, to conclusively pinpoint the cause of the deposition of sediment on the popular fishing location, we hypothesize that it could be a product of both influences: 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*.

Many Gwich'in have been affected by changes to the fishing area next to the Fort McPherson ferry landing on the Mackenzie, but fishing continues in other locations around the Mackenzie ferry landings (Figure 2.2). In these other locations *ferry operations have also impacted fishers in different ways, from reduced privacy at fish camps to concerns about how the activity of the ferry during freeze-up may interfere with the egg fishery, when pre-spawning female fish are harvested specifically for their eggs*. The most notable additional case of negative interaction between ferry operations and the fishery is that of a harvester who had to relocate their primary fishing location as ferry operations got closer to their fishing camp and eventually overlapped with where they used to set their nets. 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 they were "struggling" with this interaction, interviews and informal interactions with others in the community suggested that this harvester may have been understating the impacts.

Concerns about impacts on specific fishing locations appear limited to harvesters from Tsiigehtchic, and indeed the ferry landings on the Peel River have created eddies that serve as popular net locations. 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, and Tsiigehtchic was also a historic fishing location of significant importance for the Gwichya Gwich'in in their seasonal round of habitation and harvesting between the Richardson Mountains and the Mackenzie River, that predates the permanent settlement there (GTC Department of Cultural Heritage, 2020). This is opposed to fishers in Fort McPherson, who gained greater ease of 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 provide increased fishing opportunities. This was also mentioned by Traditional Knowledge holders in our interviews.

While knowledge holders from Fort McPherson did not express explicit concerns about fishing opportunities or locations, we have noted their significant concerns about ferry landing material.

Our research reveals divergent interpretations about whether that material contributes significantly to increasing sand and gravel bars downstream. Riverbank failures in tributaries and on the Peel River main stem have been increasingly observed by knowledge holders that were interviewed in Fort McPherson, and individuals who made these observations tended to downplay the importance of the ferry landings to changes in the river. Previous Western science studies concur with these Traditional Knowledge observations of a general increase in sediment inputs to the Peel River system (e.g. Chin, Lento, Culp, Lacelle, & Kokelj, 2016a; Kokelj et al., 2013).

The other concern most frequently raised about the ferry operations on the Peel River was around cleaning of the ferry decks, with Traditional knowledge holders fearful of what ongoing inputs of chemicals from vehicles on the ferry may mean for the aquatic ecosystem. *Our study was not able to directly investigate such concerns. We are also unable to comment on concerns about the response capacity in case of major spills, which would undoubtedly be difficult to contain, given the fast-moving water*. It is worth noting that Department of Transport staff committed to following up on the concerns expressed at their 2015 meeting with community members (See "Consultation Overview" in Department of Transport, 2015). In addition, due to a range of comments during the review process, a revised Spill Contingency Plan was submitted along with the final version of the 2015 licence renewal application (Department of Transport, 2015). Department of Infrastructure staff confirm that spill kits are available on site, and training requirements are mandated by Transport Canada. There is also a spill hotline to call if community members notice a spill before the ferry crew. *The gap between the assurances around preparedness from the Department of Infrastructure and the expressions of concern from community members is difficult to reconcile*.

Most of the concerns our study documents are not new, so there is a history of attempts to address them that is worth noting as part of this discussion. Efforts to understand potential impacts from the ferry landings were made in the Local Area Monitoring Plan (LAMP) by conducting annual bathymetric mapping, fish catch surveys with harvesters in both communities, and physical examinations of the extent of the landings to monitor the amount of material used (GNWT Department of Transportation, 2011, 2017). Physical examinations estimated the volume of material present in pre- and post-ferry season by calculating length, width, and height of the landings. In theory, such measurement would permit tracking of changes to location and size of landings over time, but the LAMP reports caution that measurements were not reliable due to variable river depth across survey dates.

In accordance with annual reporting requirements for water licensing, the Department of Infrastructure also records annual amounts of granular material placed and withdrawn across the operating season (Mackenzie Valley Land and Water Board, n.d.). This takes place as part of a policy allowing a maximum of 500 m^3 of material to be placed per landing, per year, and requiring removal of as much material as possible in the fall. *This policy has likely lowered the amount of sediment lost to each river during the spring freshet and may have also limited the physical extent of the landings. In fact, looking to annual reports over the past five years, the documentation indicates that there has been a significant net removal of materials from the rivers at most landings*.

Despite these recorded efforts to manage granular materials carefully, only 4 of the 16 people that we interviewed in Fort McPherson had knowledge of the removal policy. Knowledge of the policy was much higher in Tsiigehtchic, where 11 of the 12 participants knew of the policy. This can perhaps be explained by the close proximity of the landings from Tsiigehtchic, making activities there more visible. *Many of the study participants who did know about the policy expressed different kinds of concern about it, perhaps the most frequent being that the gravel removed from the landings was piled in areas that were later flooded, washing away the stored gravel*. Indeed, we observed piles of recovered gravel coming into contact with spring freshet waters during our data collection in May of 2018 and 2019. This, combined with a lack of knowledge among community members about Department of Infrastructure reporting on gravel use and recovery, seemed to contribute to a lack of confidence in mitigation efforts.

Given the various gaps identified between stated Department of Infrastructure policies and the perceptions held by a significant number of the study participants about the effectiveness of current practices around management of granular material, spill response capacity and related issues, it may be beneficial for the Department of Infrastructure to pursue further relationship-building efforts with the communities. This could include finding ways to effectively communicate the policies that are in place and to ensure that specific observations of problematic practice are brought forward in a timely way for further investigation. One participant in the research underlined this need for better relationships as a matter of respect, both for the people and for the land, in these historically important locations where the ferry crossings are located (Abraham Wilson, 2019, 8 Mile).

2.4.2 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 Department of Transportation, 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 roughly match what was predicted based on previous data collected by the LAMP (GNWT Department of Transportation, 2017). The 27 harvesters that were surveyed in 2019-20 caught more fish on average than harvesters surveyed between 2011 and 2015 (Table 2.3 and Table 2.4). *There is no way to further compare 2019 data to previous surveys as there was no estimation of catch per unit 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 any potential impacts of ferry operations on fish stocks difficult to separate from factors operating in other parts of fish migration. In addition, long-term data collection would be necessary for fish surveys to contribute any reliable information about the health of those stocks.

As already discussed, we made modifications to the previous LAMP survey. The most significant change was to ask fishers to share information about net size and time fished in order to estimate the amount of effort that they were using throughout the season. Variability in responses, especially around net sizes, makes us suspect that the catch per unit effort results are unreliable. Working with fishers to measure their nets would be necessary in the future for this aspect of the effort measurement to be useful. Regarding time, post-season approximations of the duration that nets are in the water is also likely inaccurate. Nevertheless, it is the only option available if harvesters are unlikely to keep daily logs. *Even if the resulting fish harvest estimates are inaccurate, repeated over ten or more years they could provide useful information about long-term trends—information that would supplement Traditional Knowledge observations about whether stocks are healthy or declining*. We also modified the fish survey to more explicitly solicit Traditional Knowledge observations about fish health, size, abundance and related information. For instance, harvesters in Tsiigehtchic noted an increased abundance of Chum Salmon and reported it in their surveys, corroborating information that we had collected with our interviews. Comments from fish harvesters also 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.

2.4.3 Limitations to the study

We believe the information that we catalogued from interviews makes a valuable contribution to Gwich'in Traditional Knowledge records, especially in terms of documenting knowledge holders' concerns about ferry operations. However, there were shortcomings to this portion of the study that are worthy of note, in addition to the challenges with final community verification meetings already mentioned.

As southern Canadian researchers, our commute to the region 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 made multiple visits during open water season, building relationships and further understanding community concerns regarding ferry landings. GeoNorth-Ross-AMEC researchers (2003) were based in the Northwest Territories and participated in multiple Gwich'in events throughout the summer. The geographical distance also contributed to the relative weakness of our verification processes, since we did not have as many opportunities as we would have liked to discuss our findings with the research participants and other community members.

Other limitations relate to the nature of the interviews themselves. As already noted, despite our best intentions, we did not have the capacity to conduct interviews in Gwich'in. It is our understanding that most participants were comfortable being interviewed in English. However, participants may have been reluctant to communicate any discomfort to us. Moreover, language is an important part of culture and identity (Sachdev, 1995; Sachdev, Arnold, & Yapita, 2006). For those participants fluent in Gwich'in, the Traditional Knowledge we documented likely lost certain nuances by being expressed in English instead of their mother tongue (Denzin, Lincoln, Smith, & Battiste, 2014).

The formality of interviews may have also contributed to discomfort for our participants. Despite engaging knowledge holders in a relaxed and informal way, we noted that the informed consent process, the interview structure and the recording equipment generated a degree of formality that may have impeded the communication of certain aspects of knowledge (Collignon, 2006). Some participants seemed comfortable with the process, but we noticed that others were somewhat nervous during interviews, even though they were more relaxed during informal conversations before and after. We still had relatively rich and informative conversations with most of the knowledge holders who participated in the research, but if we had been able to spend more time with them, such discomforts would have been more effectively mitigated.

Chapter 3: Using Western Scientific methods to identify impacts of ferry operations in the Gwich'in Settlement Area, Northwest Territories

3.1 Introduction

In this chapter, we address two main objectives: 1) To learn about the effects of ferry landing construction and maintenance on water quality and sediment loads in the Mackenzie and Peel rivers; and 2) To examine if the invertebrates (bugs) that live on the bottom of the rivers show evidence of changes due to ferry operations. We predicted that if ferry landing material or action from human activity on the landings was altering water quality there would be increases in turbidity (decreased water clarity) and total suspended solids (increased sediment suspended in the water) downstream of the landings. We also predicted that the addition of sediment to build ferry landings would alter the particle size distribution in the bed load downstream of the landings. This would mean that the size of individual grains of sediment would be different due to the movement of sediments from the ferry landings to downstream locations. For the invertebrates, we predicted that changes to water quality and sediment loads downstream of the landings would alter communities by decreasing total abundance, richness (number of different types), and the abundance of sensitive invertebrates.

Testing these predictions allowed us to bring Western Scientific methods to bear alongside the Traditional Knowledge documented in the previous chapter to answer the central questions of this study. In particular, this part of the study helped shape our concluding interpretations of contrasting Traditional Knowledge accounts about whether the ferry landings are major contributors to observed growth of sand and gravel bars in the Peel and Mackenzie rivers.

3.2 Methods

3.2.1 Study sites

Peel River

We established a two-kilometer study reach of the Peel River that was roughly located at what is called 8 Mile or Nataiinlaii and is 10 km south of Fort McPherson, NT (Figure 3.1; 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 3.1). 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

We 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 3.1). The reach is characterized by a large meander (Figure 3.1). The deepest part of the stream (called the 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 million tonnes of sediment in suspension and along the bed (Carson et al., 1998). The Arctic Red River contributes 7.3 million tonnes 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).

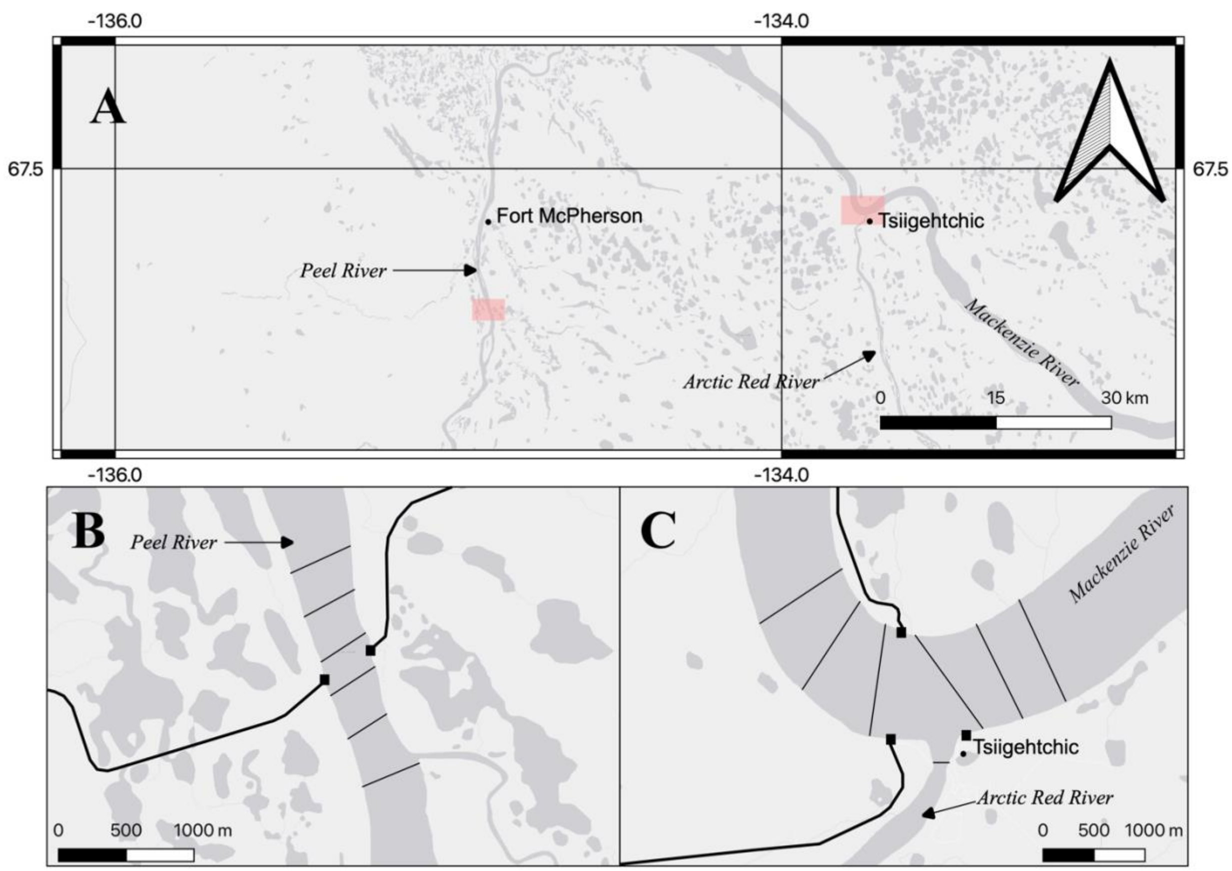

Figure 3.1 A) Map of the scientific study area, B) inset of the Peel River and two ferry landings, and C) inset of the Mackenzie and Arctic Red rivers and three ferry landings. Black lines on each river denote sampling transects. Note: all rivers flow north (upwards on the map).

3.2.2 Data collection and analysis

<u>Sampling design</u>

We conducted fieldwork shortly after ice breakup in 2018 and 2019 at the ferry crossings of the Peel River and the Mackenzie rivers. We chose this period to collect samples due to the high discharge of the rivers during spring and the increased construction activity at this time. We implemented a modified before-after-control-impact (BACI) design to monitor water quality, bed load sediments, and invertebrate communities. The idea of a BACI design, is that data are collected before and after a disturbance at two types of sites: 1) Sites affected by the disturbance of interest; and 2) Sites that are not affected by the disturbance that can serve as control sites. We collected samples 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. We 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 3.1). We sampled one additional transect in the Arctic Red River near its confluence with the Mackenzie River. The use of equipment that collected depth-integrated samples means that we were able to sample the whole water column from the bottom of the stream to the top in each sample. In 2019, we collected invertebrates and sediment at sites 500 m upstream and downstream of the ferry landings on each river. We also collected invertebrates at sites directly downstream, directly upstream, and on each ferry landing (e.g. Figure 3.2). During analysis, we pooled invertebrate sites into three location treatments: upstream, ferry, and downstream sites.

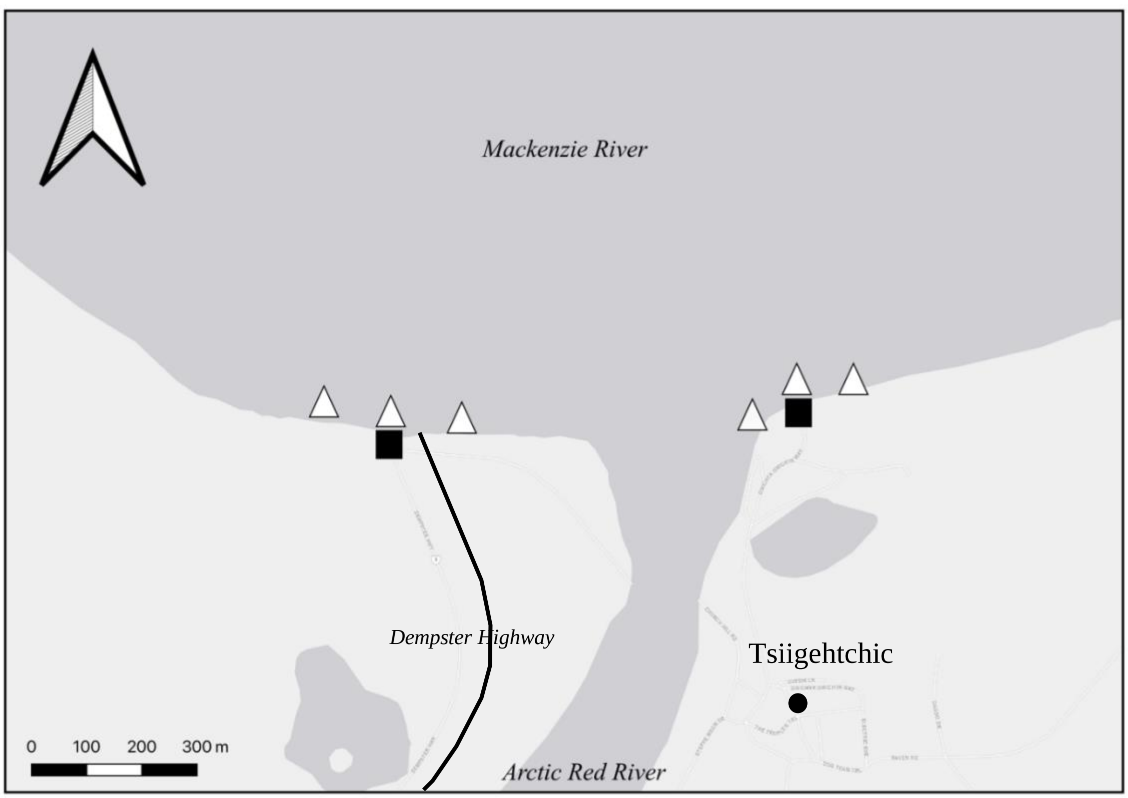

Figure 3.2 Map showing an example of the design for invertebrate collections on the Mackenzie River. Black squares denote ferry landings and white triangles denote invertebrate collection sites. Triplicate invertebrate samples were collected at each site.

Water quality and sediment analysis

We collected depth-integrated water quality samples along transects using a U.S. DH-2 sampler (Rickly Hydrological Co., Inc.). The DH-2 is a torpedo-shaped device that is slowly lowered through the water as it gradually fills a plastic bag with stream water (Figure 3.3). We measured turbidity (water clarity) using a LaMotte portable turbidity meter, and total suspended solids (TSS) using USEPA method 160.2 (1971). The turbidity meter measured water clarity by shining light through a sample to detectors that measure how much of the light was scattered. The more light that is scattered, the higher the turbidity. For total suspended solids, the method involves filtering sediments from a water sample, drying them, and weighing them to determine how much sediment is in a known quantity of water (usually 1 litre). We also measured turbidity 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. We 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). Bed load refers to sediment that moves along the bottom of a stream but is too heavy to lift higher into the water column. The BL-84 looks like a large metal boat anchor with a mesh net attached (Figure 3.3). When lowered to the stream bottom, the open end of the net faces opposite to the direction of movement of the water, and captures sand, gravel, and larger rocks moving along the river bottom. We also collected sediment from the shoreline at a depth of 0-3 cm with a hand shovel at a water depth of approximately 0.5 m. We air-dried bed load and shoreline sediment samples and sorted them using a RX-29 Ro-Tap® sieve shaker (Geneq, Inc.) following the Wentworth scale (Wentworth, 1922). To use the sieve shaker, we stacked together sieves that had meshes with different sized openings, from large to small. Sediment was then placed in the largest sieve on top, and then the sediment shaker vibrated to cause the sediment to fall through the sieves. We then weighed how much sediment was in each sieve so that we could determine how much of the sediment was made up of large versus small grained materials. We 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). The cumulative particle sizes (d_{10}, d_{50}, d_{90}) are a summary of the percent volume of sediment particles that fall below 10, 50, or 90%. We also converted bed load into a rate following the Federal Interagency Sedimentation Project (1990) so that we could estimate how much bed load was moving down the stream over time. To calculate the rate of bed load movement, we used discharge data from the Water Survey of Canada stations 10MC002 and 10LC014 on the Peel and Mackenzie rivers, respectively.

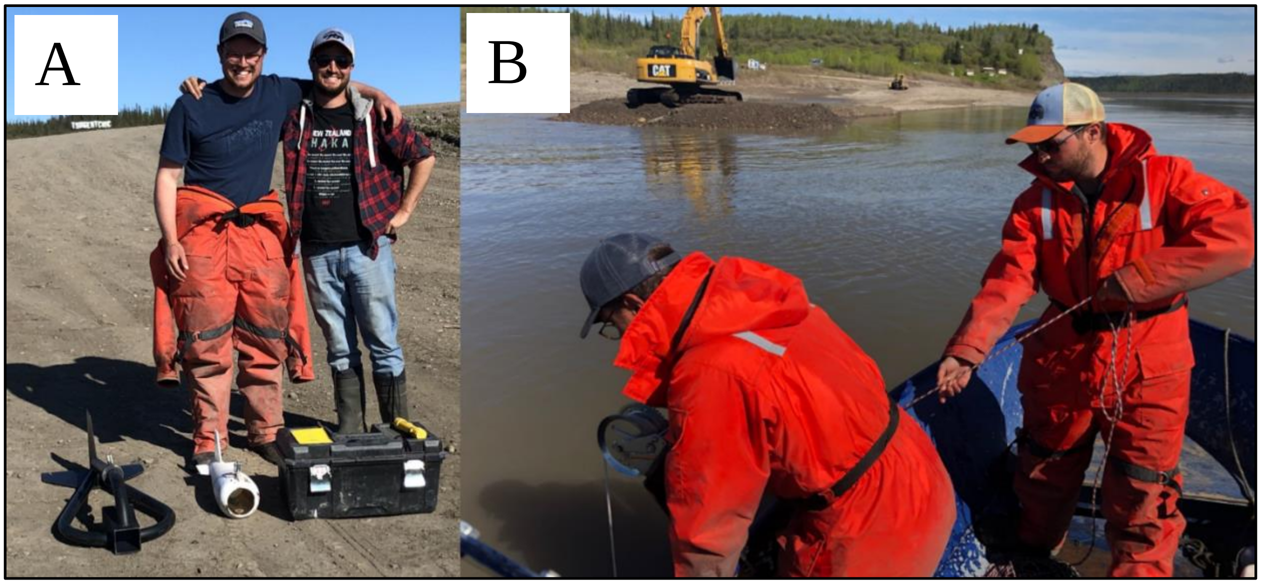

Figure 3.3 Panel A: Researcher Matthew Teillet (left) and assistant Thomas Pretty (right) at The Tsiigehtchic ferry landing on the Mackenzie River. The US BL-84 Bedload Sampler is located on the bottom left and the U.S. DH-2 water sampler is located next to it (left of the toolbox). Panel B: Using a winch to pull the BL-84 from the river bottom.

We analyzed our turbidity, TSS, and bed load particle size metric data using a repeated-measures analysis of variance (ANOVA). The repeated-measures ANOVA is a statistical method that allows researchers to test for differences among sites as well as through time. In our case, we tested for differences between upstream and downstream sites, as well as through time. To appropriately use ANOVA models, some assumptions must be tested. We tested for normality of the ANOVA residuals using a Shapiro-Wilks test and homogeneity of variances using Levene's test ($p < 0.05$ in both cases). Since these tests indicated the our data violated these ANOVA assumptions, we transformed non-normal variables using an ordered quantile transformation (orderNorm) in the R package BestNormalize (Peterson & Cavanaugh, 2019). We 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, we performed a linear regression on log-transformed turbidity and discharge data. We tested the assumption of normality using a Shapiro-Wilks test. We performed all statistical tests in R for Mac version 3.6.1 (R Development Core Team, 2019).

All studies have limitations in terms of their ability to detect differences among sites or through time. The ability of a study to detect true differences is called the statistical "power" of the study. Studies with a larger number of sites, or more samples collected per site, tend to have a higher power than studies that collect few samples (replicates). Studies may also have high power for detecting large differences among sites but have low power for detecting small differences. In cases where a study fails to detect a difference in a variable among sites, or through time, it is important to consider the power of the study, because studies with low power may fail to detect a real difference. To examine the power of our study, we performed simulations to determine how much power we had to detect differences in turbidity, TSS, and the median particle size of the bed load samples. We calculated statistical power by performing simulations based on observed variability in our actual data. We analyzed power in two different scenarios. First, we simulated datasets that had known differences (between 5-90%) between upstream and downstream sites and consisted of 15 values at each location. The proportion of times out of 1000 iterations that the simulation found a significant difference in upstream versus downstream values was the statistical power. This simulation indicated the power we had to detect differences at our actual sample size (15 sites upstream, 15 downstream). We also simulated a dataset that used varying sample sizes (from 3-45) and calculated the power we would have had to detect a 5%, 10%, and 20% difference between upstream and downstream sites. This simulation allowed us to consider how differences in the number of sites sampled upstream versus downstream might affect statistical power. Following convention from previous studies, we considered a power above 0.8 to be high (Cohen, 1992).

Benthic macroinvertebrates

We collected invertebrates following a modified version of Environment and Climate Change Canada's Canadian Aquatic Biomonitoring Network (CABIN) approach (Environment and Climate Change Canada, 2012). Sediment near the shoreline at a depth between 0.5-1 m was disturbed using a kicking motion while we traveled in a zigzag pattern for 3 minutes at each site. We held a D-shaped net with 500 μm mesh downstream of our kicking in order to collect dislodged or drifting organisms. We collected three replicate samples at each site. We sorted and then identified samples to order or family, depending on the taxa, following Ontario Benthos Biomonitoring Network protocol (Appendix 2.1; Jones et al., 2007). Invertebrate 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 repeated-measures ANOVA. The ANOVA allowed us to test for differences between sites (upstream, downstream, ferry landing) and through time. Rarified richness values were used to ensure that estimates of taxa richness were not biased by the number of individuals identified at each site, as richness values tend to be higher when more individuals are identified (Gotelli & Colwell, 2001). When ANOVA output was significant ($\alpha = 0.05$), we performed Tukey's honestly significant difference (HSD) test to determine where differences existed. We tested the assumptions of normality of residuals and homogeneity of variances for the ANOVA 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, we conducted a principal component analysis (PCA). 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).

Maps of the river bottom

Maps of the bottom for each river were created to assist in sample collection and to serve as a reference for future studies of change. Depth data were collected using a Hummingbird Helix 5 chartplotter (depth finder) with CHIRP digital sonar (Compressed High-Intensity Radar Pulse). The chartplotter used a transducer that worked with CHIRP frequencies at 85 kHz and 200 kHz. The chartplotter was set to record depths at 5 second intervals (trackpoint interval) and the boat maintained speeds between 5-8 km/h. An outline of the shoreline of each river was constructed by slowly navigating along the shoreline at depths of ~1 m. Bathymetry for the center of the river was then collected by traversing the width of the rivers in sequential transects spaced no more than 25 m apart. Depth data collected with the Helix 5 was then imported into Reefmaster (https://reefmaster.com.au/), a program that interpolates depth data to create bottom contour maps. In Reefmaster, track points were inspected, and suspicious data points (outliers) were removed before creation of the contour maps. Approximate shorelines were added using satellite imagery. Depth data for the Peel River were collected June 9-15th, 2018 and on the Mackenzie June 10-12th 2018.

3.3 Results

3.3.1 Sediment analysis and water quality

Between 2018 and 2019, we 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 2.2 and Appendix 2.3). Turbidity and TSS measurements were significantly different between sampling dates on the Peel (Table 3.1; $p < 0.0001$) and Mackenzie rivers (Table 3.2; $p < 0.0001$). There was no significant interaction between location and time for turbidity (Figure 3.5; p-values > 0.05) or TSS (Figure 3.5; p-values > 0.05). Turbidity data from the two Manta+ probes was related to discharge (linear regression, $R^2 = 0.847$, $p < 0.001$) and was higher upstream of the ferry landings ($t = -3.78$, $df = 622$, $p < 0.001$). However, for the Peel River there were two instances on June 3 when downstream turbidity was notably higher than upstream turbidity (Figure 3.6). 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 3.6). Without concurrent observations of activity in the river at those times, we could not evaluate the potential causes of these transient increases in turbidity on the Peel.

Over the course of this study, we collected bed load sediments nine times at 30 sites on the Peel River and six times at 33 sites on the Mackenzie River (Appendix 2.2 and Appendix 2.3). 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 were no significant differences between locations (upstream/downstream) and there were no significant interactions 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 3.1 and 2.2; Figure 3.7; p-values > 0.05).

We conducted our statistical power simulation on turbidity, TSS, and d_{50} values from each river to determine the power we had to detect a 5%, 10%, and 20% change in downstream measurements Appendix 2.4). We had a high power (>0.8; Cohen, 1992) to detect a 20% change in turbidity on both rivers and TSS on the Peel River. We had a low power (<0.5) 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. We also had a low power to detect a <20% difference in median bed load particle size (d_{50}) on both rivers.

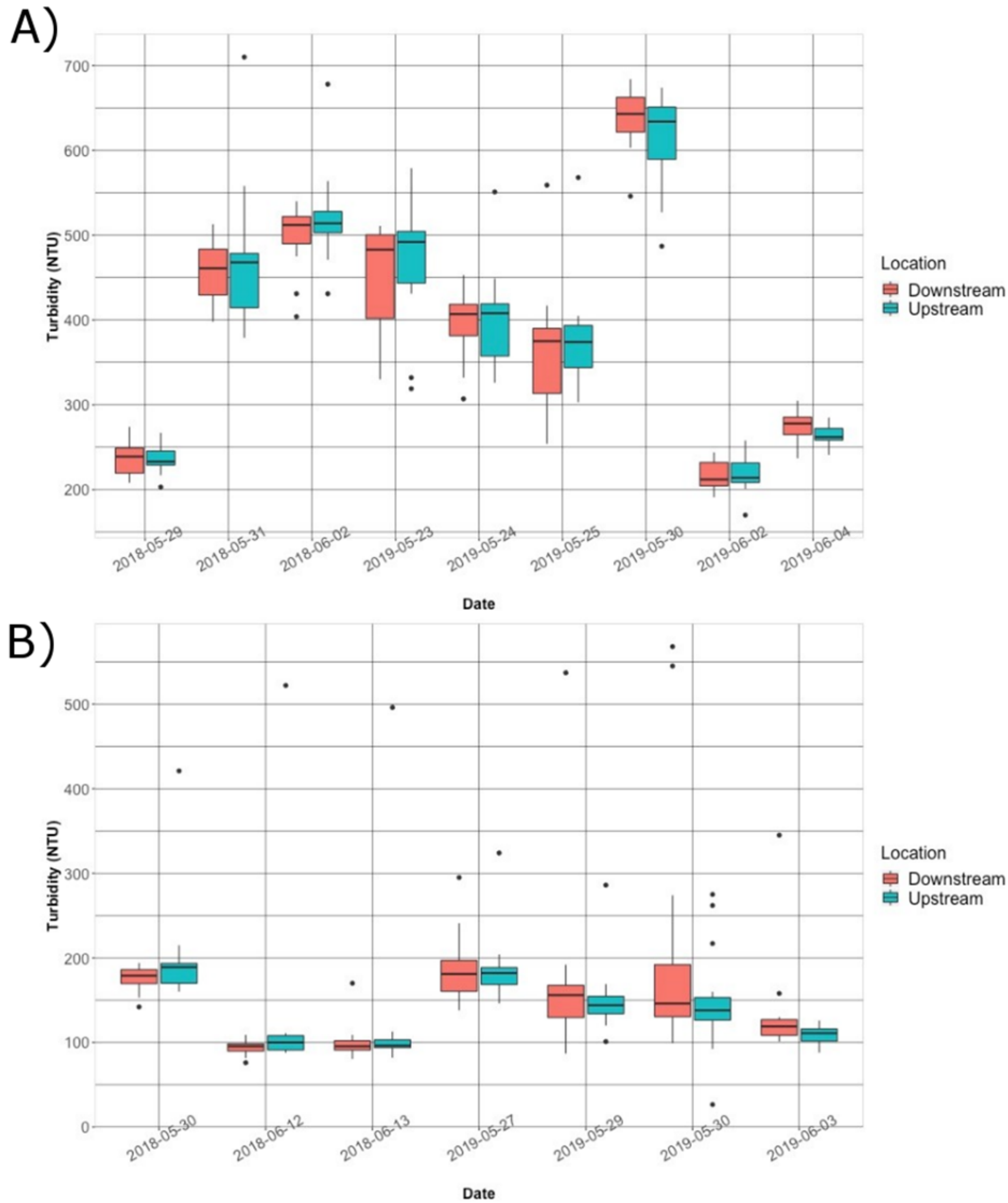

Figure 3.4 Turbidity measurements collected upstream and downstream of the ferry landings on the A) Peel River and B) Mackenzie River. Outliers are represented by points outside of boxplot while boxplots represent the variation in the dataset.

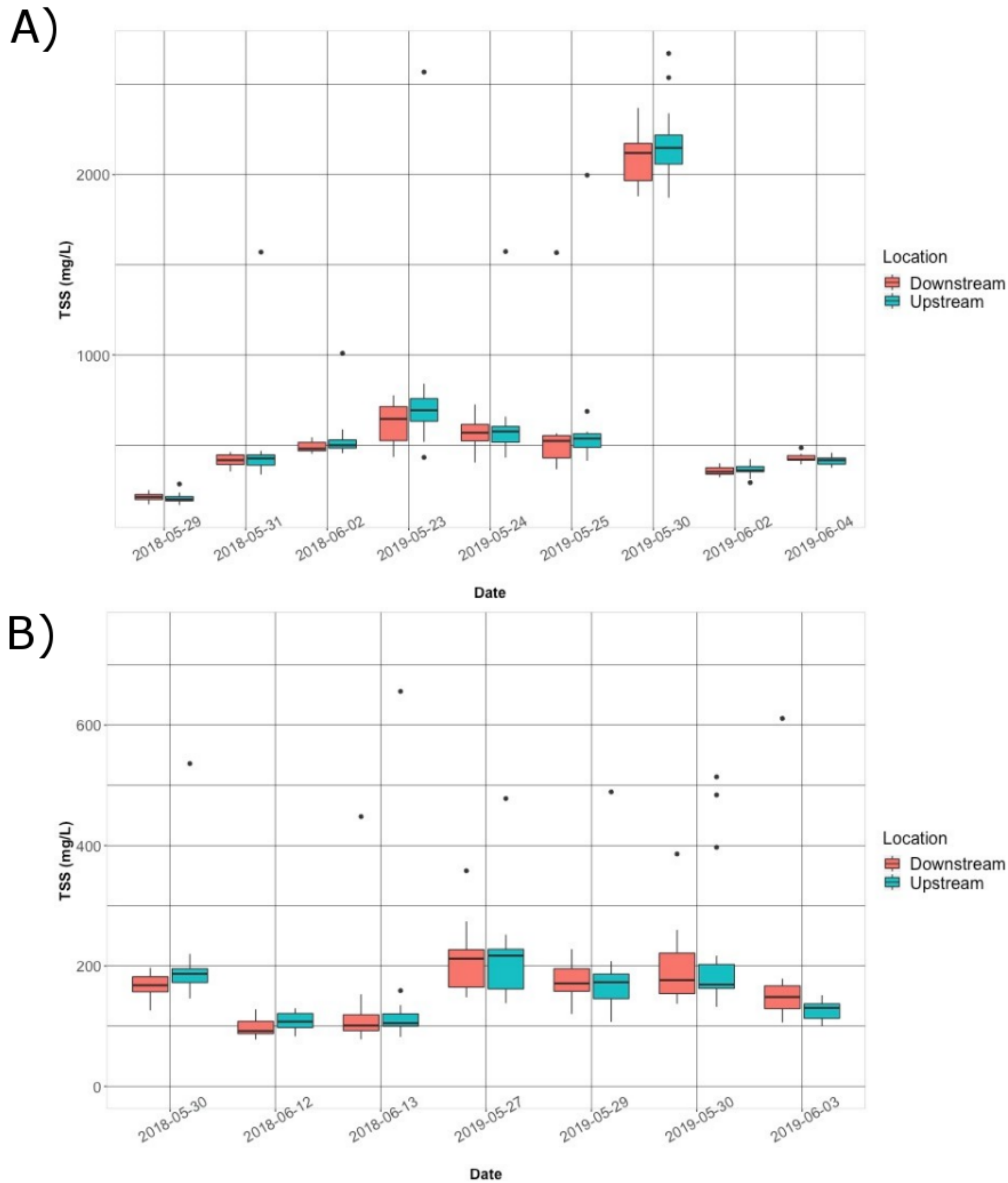

Figure 3.5 Total suspended solids measurements collected upstream and downstream of the ferry landings on the A) Peel River and B) Mackenzie River. Outliers are represented by points outside of boxplot while boxplots represent the variation in the dataset.

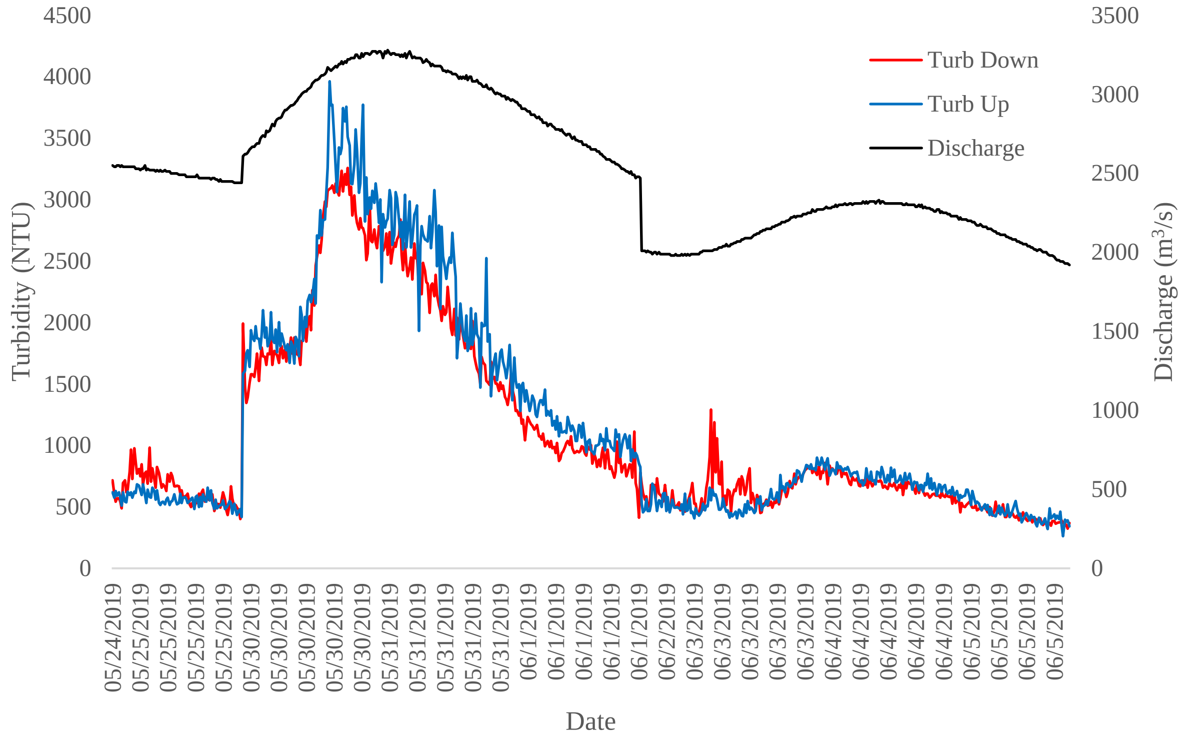

Figure 3.6 Turbidity data from the Peel River from May 24, 2019 to June 6, 2019 aligned with discharge data from Water Survey of Canada station 10MC002. Note: data missing between May 25 and May 30 as well as June 1 and June 3.

Table 3.1 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 3.2 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		0.14	0.72
		Time	1, 11	0.01	0.91
		Location*Time		0.00	0.98
Bed load, d_{50}	OrderNorm	Location		0.08	0.78
		Time	1, 11	0.37	0.55
		Location*Time		0.02	0.88
Bed load, d_{90}	OrderNorm	Location		1.05	0.33
		Time	1, 11	0.19	0.67
		Location*Time		0.59	0.46
Bed load, %sand	OrderNorm	Location		0.01	0.93
		Time	1, 11	0.12	0.73
		Location*Time		0.34	0.57
Bed load, rate	OrderNorm	Location		1.47	0.25
		Time	1, 11	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*

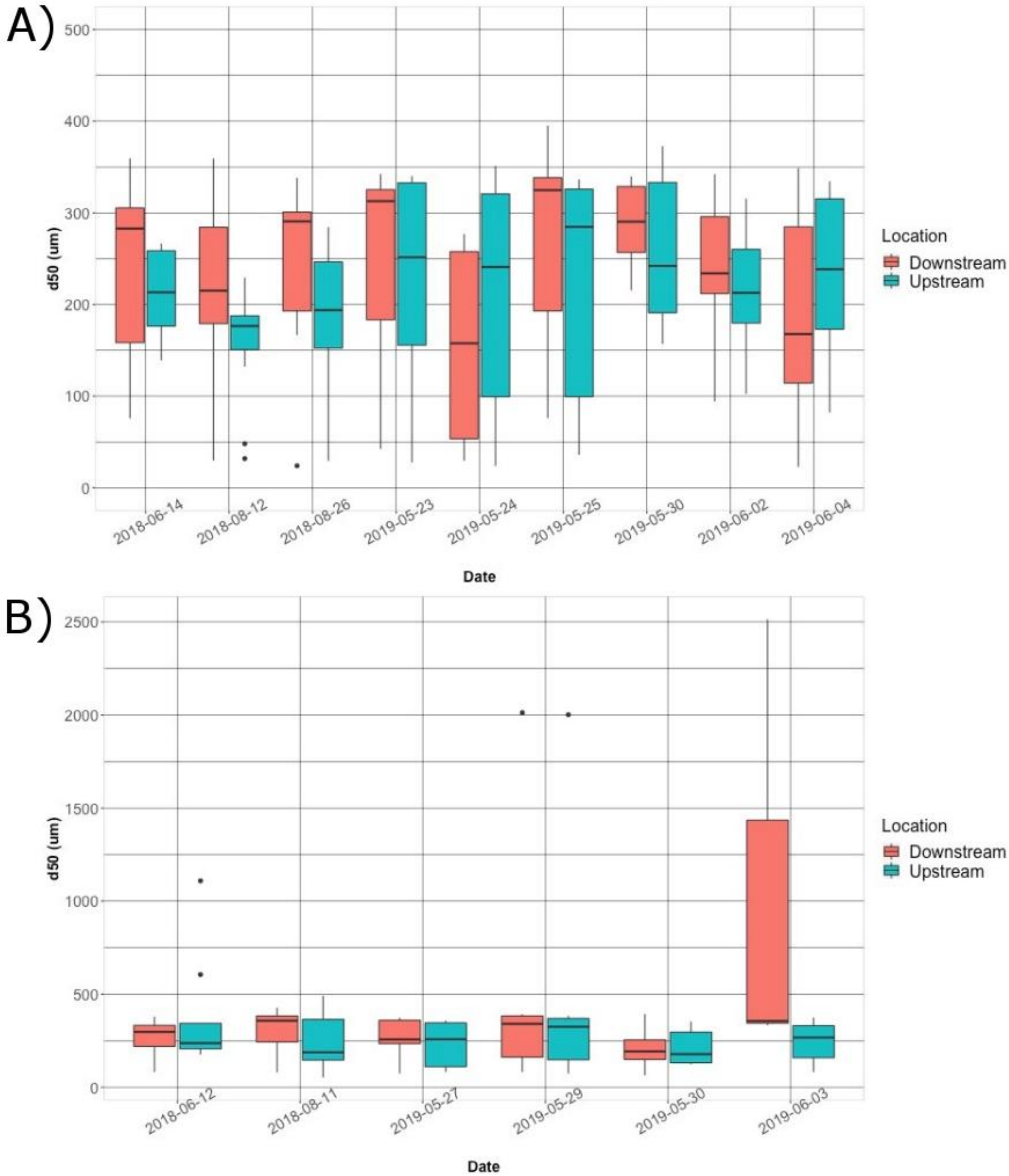

Figure 3.7 Median particle size of bed load sediments collected upstream and downstream of the ferry landings on the A) Peel River and B) Mackenzie River. Outliers are represented by points outside of boxplot while boxplots represent the variation in the dataset.

3.3.2 Invertebrates

In total, we counted 956 individuals in 15 taxonomic groups across the 60 triplicate samples taken in the Peel River (Appendix 2.1). 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 we observed in a single sample from the Peel River was 88 individuals, and no samples had an abundance >100. In the Mackenzie River, we counted 3140 individuals belonging to 15 taxa (Appendix 2.1). 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 3.1; Figures 3.8A and 3.9A; p-values > 0.05). Total abundance differed depending on an interaction between sites and time in the Mackenzie River (Table 3.2; Figure 3.8B; 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 3.2; Figure 3.9B; 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 3.2; Figure 3.10B; 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). The percentage of sensitive species (EPT, or Ephemeroptera, Plecoptera, Trichoptera) on both rivers and chironomid percentage on the Peel River did not differ between upstream, ferry landing, and downstream sites through time (Table 3.1 and 2.2; Figure 3.11; p > 0.05).

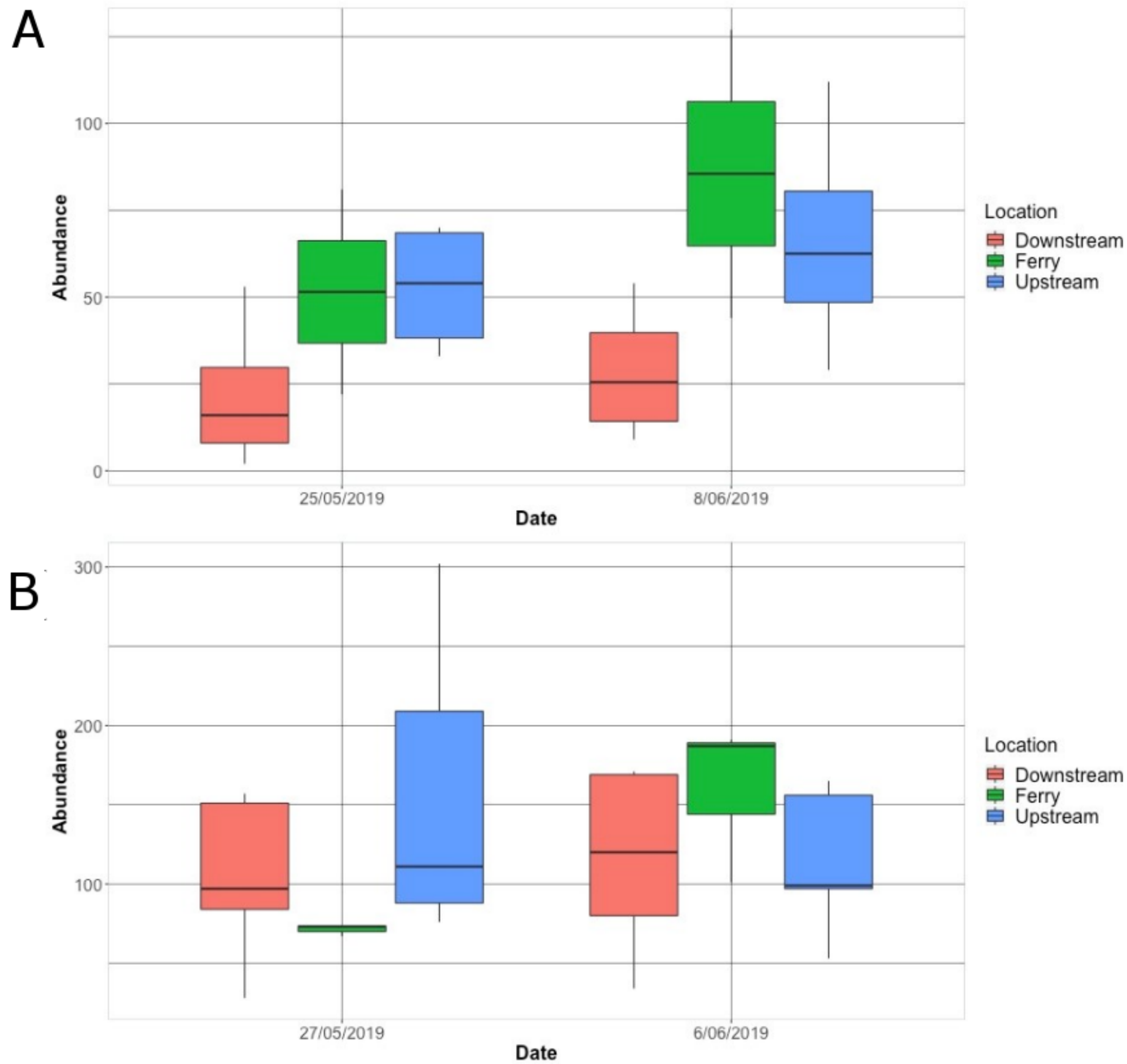

Figure 3.8 Total benthic macroinvertebrate abundances from sites relative to location and time samples on the A) Peel River and B) Mackenzie River. Outliers are represented by points outside of boxplot while boxplots represent the variation in the dataset.

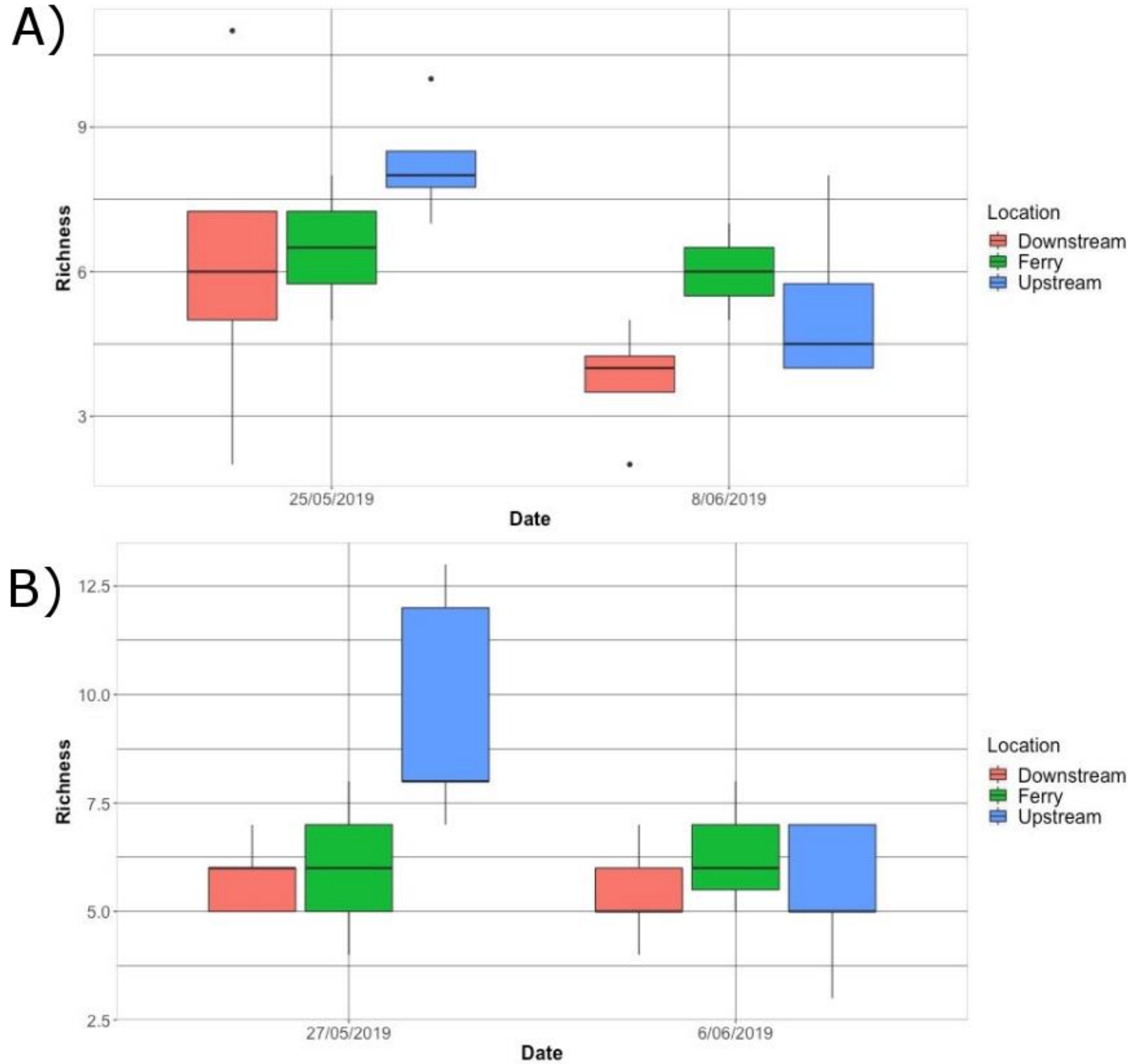

Figure 3.9 Benthic macroinvertebrate taxonomic richness from sites relative to location and time samples on the A) Peel River and B) Mackenzie River. Outliers are represented by points outside of boxplot while boxplots represent the variation in the dataset.

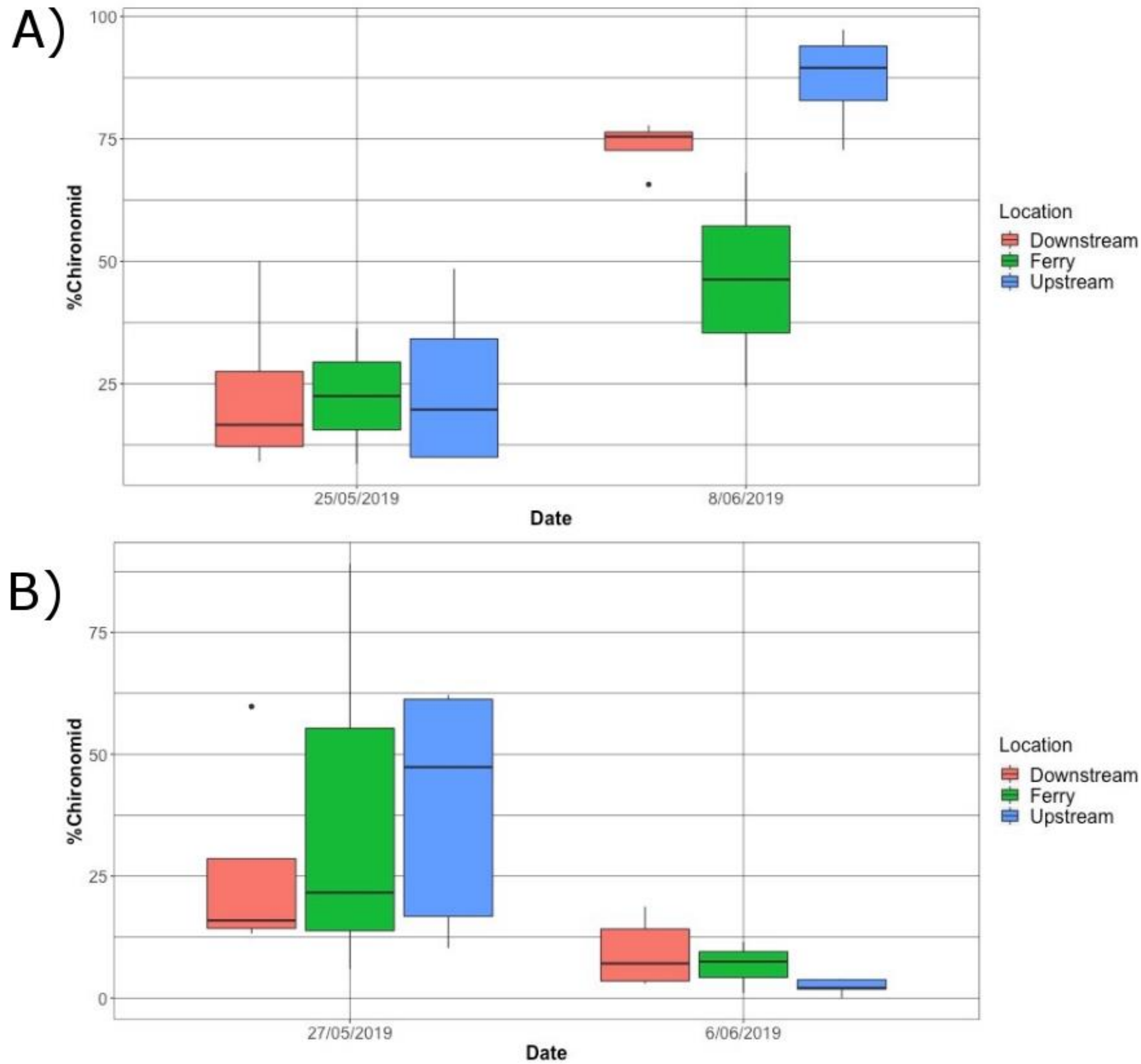

Figure 3.10 Percent Chironomidae from sites relative to location and time samples on the A) Peel River and B) Mackenzie River. Outliers are represented by points outside of boxplot while boxplots represent the variation in the dataset.

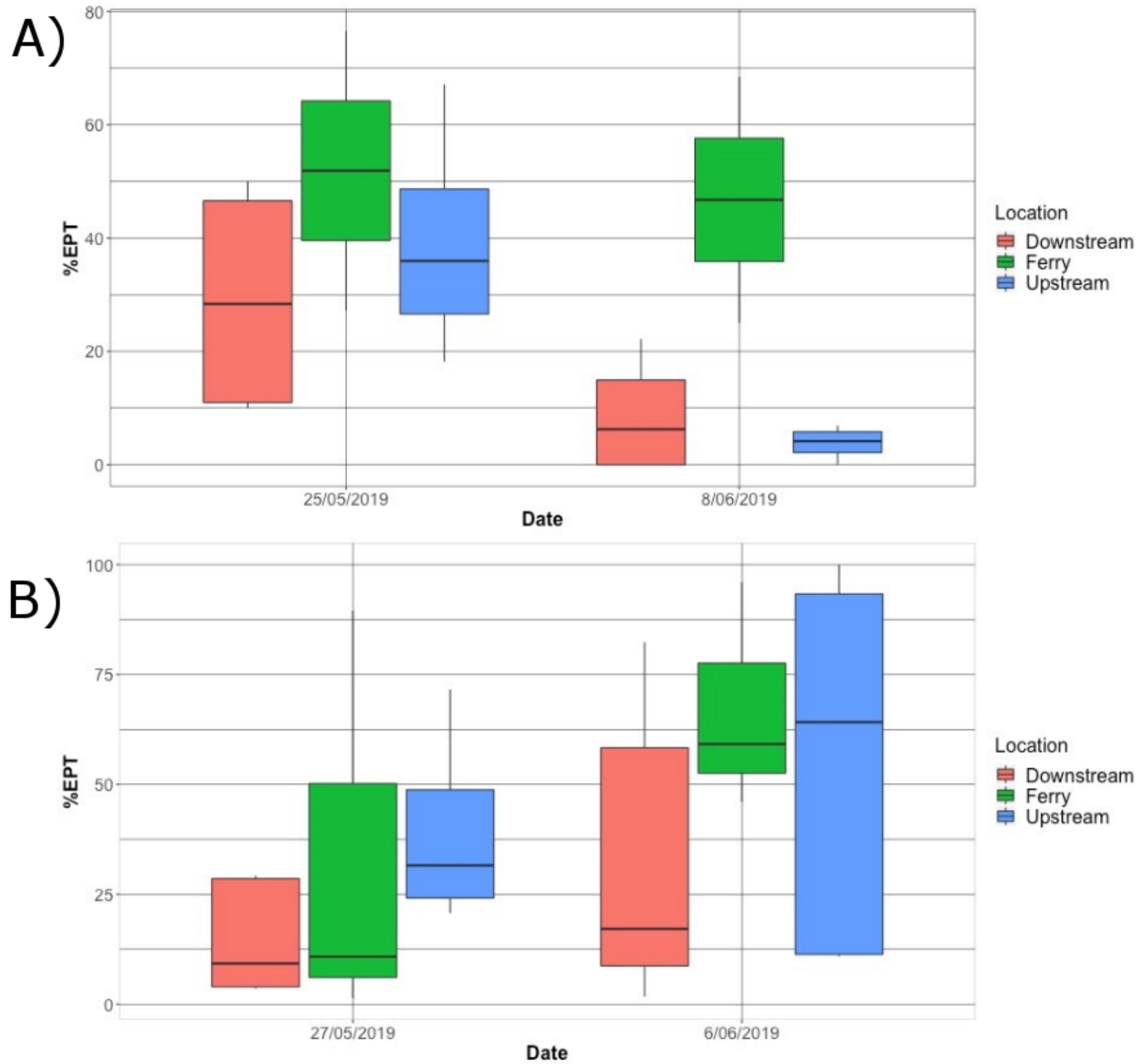

Figure 3.11 Percent sensitive taxa (EPT; Ephemeroptera, Plecoptera, and Trichoptera) from sites relative to location and time samples on the A) Peel River and B) Mackenzie River. Outliers are represented by points outside of boxplot while boxplots represent the variation in the dataset.

Invertebrate communities in the Peel River were structured along PCA axis 1, which accounted for 41.6% of the variation (Figure 3.12A). 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 3.12B). 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, we redefined the sites by substrate sediment type (Figure 3.13). 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 3.13).

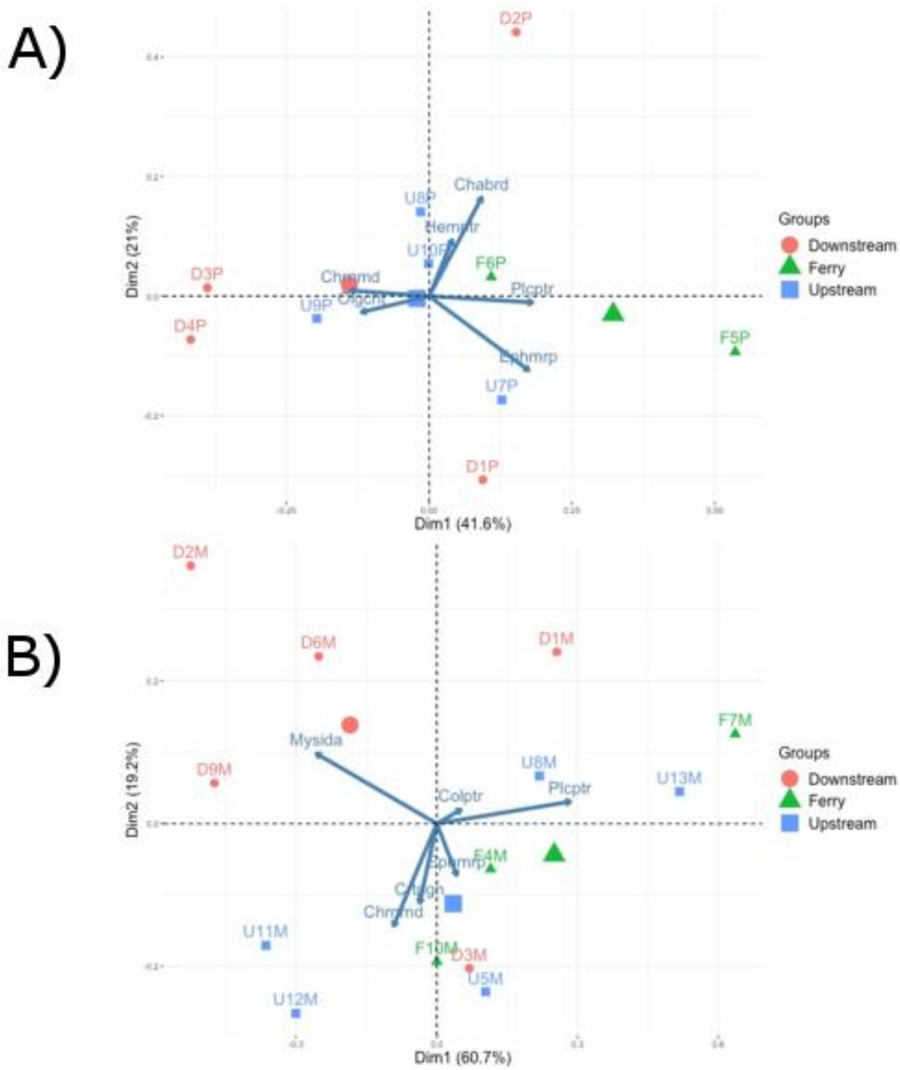

Figure 3.12 PCA biplot illustrating variation in BMI communities at A) 10 sites on the Peel River and B) 13 sites on the Mackenzie River with respect to location. Sites beginning with D represent downstream sites, F represent ferry landing sites, and U represent upstream sites. Large symbols on the biplot represent the mean for each category.

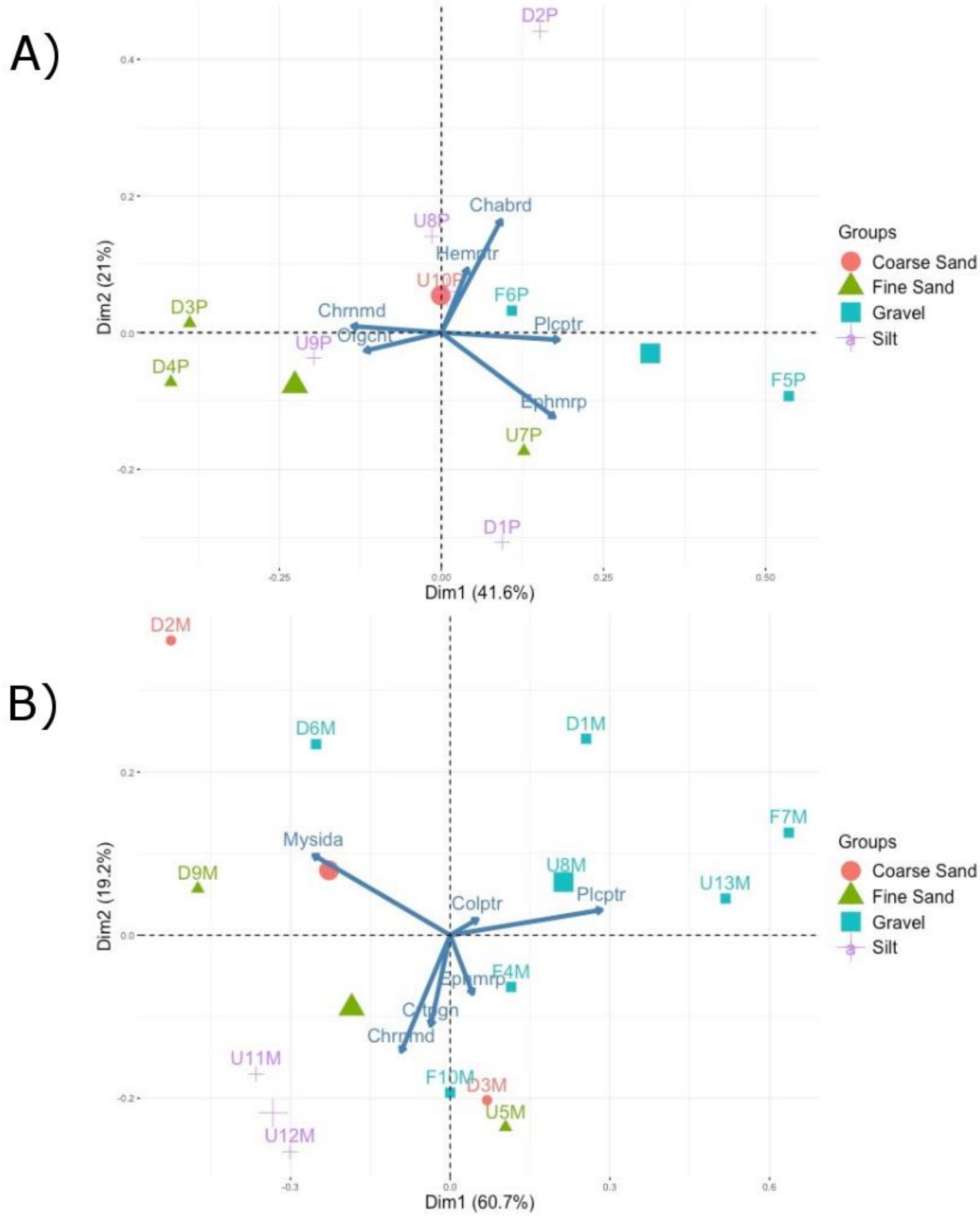

Figure 3.13 PCA biplot illustrating variation in BMI communities at A) 10 sites on the Peel River and B) 13 sites on the Mackenzie River with respect to median particle size of the substrate. Sites beginning with D represent downstream sites, F represent ferry landing sites, and U represent upstream sites. Large symbols on the biplot represent the mean for each category.

3.3.3 Bathymetric maps

Bottom maps of each river were constructed and added to a satellite image from Google Earth. The map of the Peel River is shown in Figure 3.14 and that for the Mackenzie is in Figure 3.15.

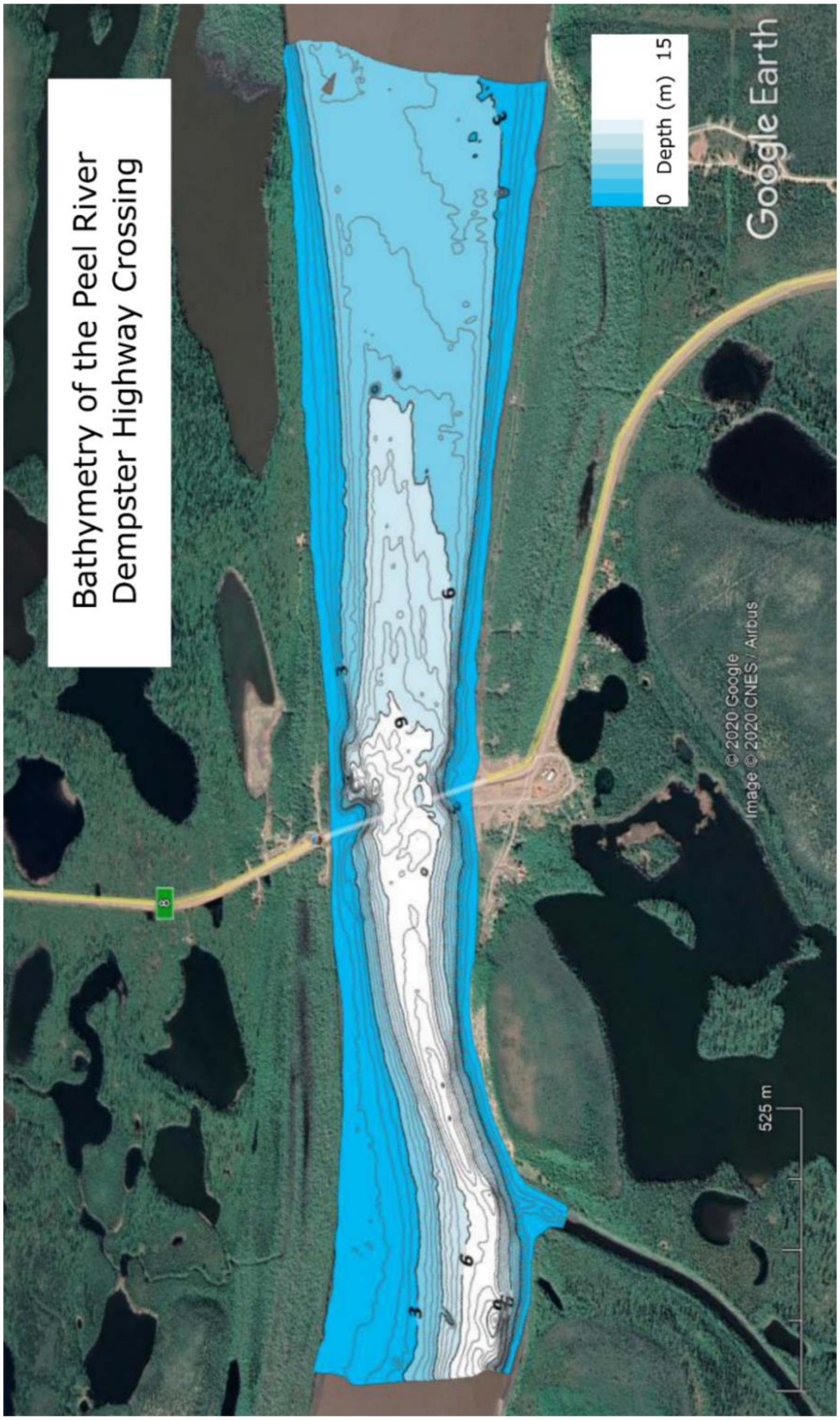

Figure 3.14 Bathymetric map of the Peel River at the Dempster Highway ferry crossing. Numbers represent the depth of the river in meters. Depth data were collected in June 2018.

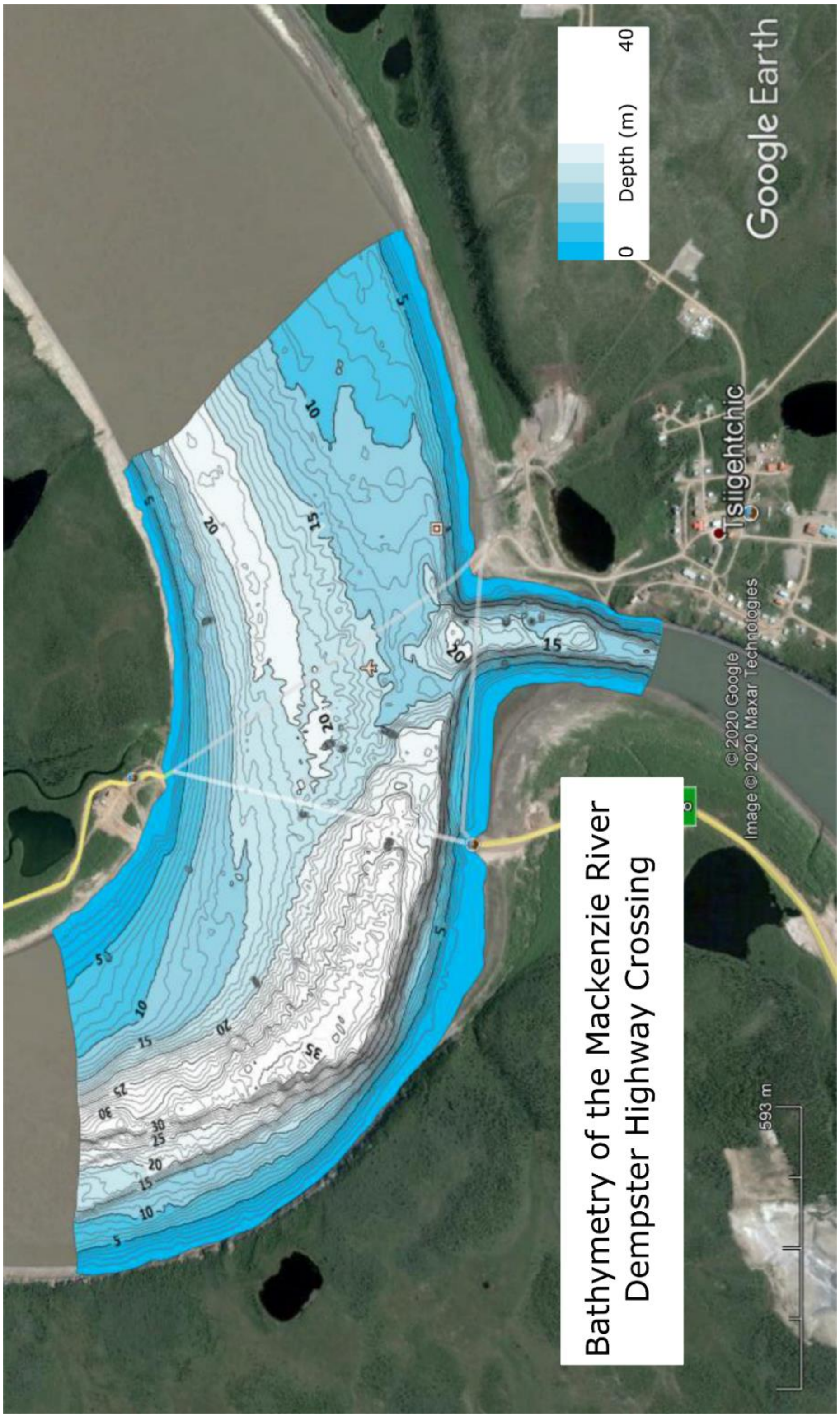

Figure 3.15 Bathymetric map of the Mackenzie River at the Dempster Highway ferry crossing. Numbers represent the depth of the river in meters. Depth data were collected in June 2018.

3.4 Discussion

3.4.1 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, we used metrics that summarized suspended sediment load and bed load. Our 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 we 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. Our 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 our 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 sample collection. Based on these results, we believe that researchers interested in examining sediment movement in these rivers should examine bed load more closely in future studies.

Our 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 Gwich'in Settlement Area, 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 our study sites on the Peel and Mackenzie. Both observations by GeoNorth-Ross-AMEC (2003) and Golder Associates (2004) were likely samples taken close to the ferry boat as it was operating on or near the landings. *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, our 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 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 our sampling design (or almost any other with a feasible number of samples) would be unable to detect a difference in bed load or water quality due to erosion from the ferry landings. Consequently, we believe that future studies examining aspects of water quality other than sediment movement may be a better use of time and resources.

3.4.2 Invertebrates

In order to investigate the potential cumulative impacts of added sediment downstream of ferry landing sites on the Peel and Mackenzie rivers, we compared invertebrate communities among sites upstream, downstream, and on the ferry landings. We 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). *We found no statistically significant differences in invertebrate 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 invertebrates after the construction of the ferry landings could be explained by a number of hypotheses including a recovery of invertebrates after ice breakup (Prowse & Culp, 2003), decreased discharge (Gibbins et al., 2007) and natural variation between sampling sites. Richness (number of different types) of invertebrates 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 invertebrate richness between upstream and downstream locations was one of our predicted outcomes; however, the fact that 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 3.10B). 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, we 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. The timing of chironomid emergence is highly variable among years, but within each year it is often occurs at the same time (i.e. in synchrony) in many parts of the Arctic (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). We sampled invertebrates 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 invertebrate abundances in our PCAs. Invertebrate 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 3.11B). 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 3.13). 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.

Our results showed that the abundance of invertebrates 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 that only found eight individuals in a three minute traveling kick net sample on the Mackenzie River (Environment and Climate Change Canada, 2018a). While it seems that invertebrate 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 invertebrate communities (Figure 3.5A). 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 invertebrates (Scott et al., 2011); however, coarse substrates were found to be naturally occuring at both upstream and downstream sites.

3.4.3 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.

While our 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), more significant erosion of material from the landings may occur during such events. 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.

Chapter 4: Conclusions and recommendations

4.1 Conclusions

The Gwich'in communities of Fort McPherson and Tsiigehtchic have longstanding concerns about ferry operations on the Peel and Mackenzie rivers. Specifically, these concerns have been 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 in the past (GeoNorth-Ross-AMEC, 2003; GNWT Department of Transportation, 2011), but concern has continued to be expressed by many community members (GNWT Department of Transportation, 2015a, 2015b). When our research team was contracted to further investigate these concerns, we initiated a multidisciplinary study to assess the impacts of ferry landing material. Our study was comprised of two main parts: (a) documentation of Traditional Knowledge drawing on methods from the social sciences and (b) Western science drawing on methods from limnology, ecology, and fluvial geomorphology. Engagement with knowledge holders in the two communities also supported the collection of fish harvest survey data, which combined Western approaches and Traditional Knowledge observations. *Although our study was initially focussed only on examining the impacts of ferry landing material, our interactions with the two communities quickly revealed that this was only part of a more complex picture*. This significantly shaped our approach to the Traditional Knowledge portion of the study, which we expanded to include broader questions and concerns about interactions between the ferries and fishing.

With respect to the relationship between landing materials and changes to river morphology, especially the increase in sand and gravel bars, there was a division of opinion among Traditional Knowledge holders. Some saw a direct link between eroded landing materials and growing deposition downstream, but others observed broader changes in the rivers and suggested that an overall increase in transported sediment is more likely the cause. Here, the Western science portion of the study complemented the Traditional Knowledge we documented and helped us to understand the river processes better.

Our scientific sampling found no significant differences in water quality and sediment loads between upstream and downstream sites. 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 total suspended solids. 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*.

To strengthen our conclusions, we turned to overall calculations of how much material the landings potentially contribute to the rivers compared with how much material these rivers transport due to natural processes. *Even taking the worst-case scenarios for material lost from the landings, they contribute only a tiny fraction of the sediments that these river systems wash downstream every year*. Moreover, *both Traditional Knowledge and Western science tell us that climate change is driving increased sediment loads*, with permafrost thaw and other processes related to climate change causing slumps, landslides and increased erosion up the main stems of both rivers and in major tributaries.

While it remains possible that the ferry landings are producing very localized effects from eroded materials, the implications for the two rivers seem different in this respect. Traditional Knowledge holders note that the Peel River landings generated new eddies, but any localized increase in deposition that could result from these eddies does not seem to interfere with fishing. On the other hand, Traditional Knowledge 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, and *it is probable that the infill of an important fishing location directly downstream from the landing is to some degree influenced by the presence of the Fort McPherson landing*.

Other aspects of our study addressed whether there are any observable impacts from the ferry landings on the aquatic environment and fish. *Traditional Knowledge holders mostly reported that fish are healthy and fish stocks are comparable to historical levels*, though they observed other changes, such as the increase in non-native species (unlikely to be related to ferry operations). Although our Western science data collection did not include any direct examination of fish health, we conducted sampling of invertebrate communities both upstream and downstream of the ferry landings, since such communities are sensitive to increased sedimentation and therefore serve as a good indicator of whether the ferry landings are impacting the aquatic environment. *Our analysis of benthic macroinvertebrates confirmed that ferry operations do not alter total abundance, taxonomic richness, or the proportion of sensitive taxa*.

Overall, both Department of Infrastructure annual reporting on placement of granular material (Mackenzie Valley Land and Water Board, 2021a, 2021b, 2015a, 2015b) and local observation suggest that a varying amount of material may be eroded from ferry landings on both rivers. However, *the results from our study, combined with the results from GeoNorth-Ross-AMEC (2003) and the LAMP (GNWT Department of Transportation, 2017), suggest that the erosion of material from ferry landings on the Peel and Mackenzie rivers has a negligible impact on water quality and river morphology*. Given the fact that our Western science analysis lacked the power to detect minor changes, the question arises of whether further study is called for. *Considering 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, within a reasonable budget for environmental monitoring*.

Given the importance of the traditional fishery, *it would make more sense to devote resources to pursuing broader water and fish monitoring efforts that could identify cumulative impacts of climate change and other factors on the health of the fishery*. This would require the involvement of other GNWT departments and funding sources, such as the Community-Based Water Monitoring Program and the Cumulative Impacts Monitoring Program, led by the Department of Environment and Natural Resources. While such monitoring would fall outside the purview of the Department of Infrastructure, their active collaboration could contribute positively to relationships with the communities.

We conclude by noting some of the other concerns about fishing-ferry interactions that we learned about through our analysis of existing Traditional Knowledge documentation and interviews with knowledge holders. *Many of the concerns raised by participants in the research do not relate directly to the water licence, and are arguably tangential to the main question the* *study sought to answer. Nevertheless, it is clear that communities have consistently seen water licence discussions as a space in which to raise concerns that are important to them. This suggests that they may not be finding other avenues for their concerns to be considered.*

These additional concerns expressed by participants included a loss of privacy for fish camps close to the landings, ferry impact on ice during the egg fishery, and interaction between ferries and net locations—most notably the interference with a family's traditional fishing location on the Mackenzie River. Despite the Department of Infrastructure's consistent efforts to be in compliance with regulations, we also heard fairly widespread concerns over the potential impacts of ferry cleaning and spills. Although we did not investigate these concerns in the Western Scientific portion of our study, *it is clear from the research with Traditional Knowledge holders that ferry operations have affected livelihood and sense of well-being for a significant number of these study participants*. While these broader effects go far beyond the scope of this study, community participants saw them as closely related. In this light, we suggest that efforts by both the Department of Infrastructure and Renewable Resource Councils to improve channels of communication could be the basis for stronger relationships, where a broad range of issues can be raised and resolved more readily.

4.2 Recommendations

In this section, we make a number of recommendations to the Department of Infrastructure, the communities of Fort McPherson and Tsiigehtchic, and to other departments in the government of the Northwest Territories whose mandates overlap with the range of issues addressed in the study. Our recommendations are based on the results from this study, our interpretations of previous studies and the academic literature, and also personal communications with representatives from the Department of Infrastructure, the Gwich'in Renewable Resources Board, members of the Tetlit and Gwichya Gwich'in Renewable Resources Boards, Fisheries and Oceans Canada, and other researchers.

4.2.1 Ferry landings and operations

1. We recommend that the Department of Infrastructure continue to limit the quantity of material used for all five ferry landings in the Gwich'in Settlement Area and continue to recover, store, and reuse material when possible. Care should be taken to ensure that stored and recovered material is above the upper water line of spring flooding.

2. As far as possible within the safe operating parameters for the ferries, the Department of Infrastructure could also limit the length and width of ferry landings, so as to avoid exacerbating deposition downstream. A standardized periodic calculation of landing footprint sizes would assist in this regard, helping to identify any changes over time. In particular, we suggest that a reduction in the length of the Fort McPherson landing on the Mackenzie River may reduce deposition in the important fishing location north of the landing.

3. Finally, in the interest of avoiding interference with the traditional fall ice fishery or spawning Broad Whitefish populations, we recommend consideration of potential limits or alterations of ferry operations at this time of year, in communication and coordination with fishers.

4.2.2 Communication

4. We recommend that the Department of Infrastructure and the Renewable Resource Councils in both communities engage over a period of time to develop a new communication plan. This could help the Department of Infrastructure reach more community members with its annual reporting, while also allowing Gwich'in harvesters and Traditional Knowledge holders to voice concerns and feel that those concerns lead to productive conversations and potential solutions. Overall, an improved communication plan could mitigate the concerns that Gwich'in communities have towards ferry operations, including landing material use, ferry cleaning, and spills. It could also provide a basis for coordinating between operators and fishers to minimize fishing-ferry interactions, such as in the above-mentioned fall fishery.

As part of this new communication effort, we encourage the Department of Infrastructure to engage both Gwich'in organizations and Gwich'in community members and harvesters not only through annual meetings, but also through more informal face-to-face interactions. Plain language posters and radio announcements could also be considered, though we recognize that resource limitations may make a more sophisticated communication strategy difficult to sustain. In turn, the Renewable Resource Councils could identify community members who are prepared to support information sharing and recruitment for meetings with the Department of Infrastructure. This would help ensure that, when important conversations occur, more people take part to learn about the Department of Infrastructure policies and to voice their concerns and ideas.

4.2.3 Continuation of monitoring

Throughout our engagement with the communities of Fort McPherson and Tsiigehtchic there were calls for our study to be longer, and it was clear that participants in both communities saw the importance of ongoing monitoring.

5. We recommend that the Department of Infrastructure continue to record data on ferry landing construction and share that information more proactively with the communities. Continued monitoring of the amount of material used to build landings each season is important to document the effective implementation of efforts to limit any impacts on the rivers. Monitoring the physical extent of the ferry landings annually, as outlined in the original LAMP design (GNWT department of Transportation, 2011), will ensure that landings do not extend further than necessary into the Peel and Mackenzie rivers. Greater transparency with methods and reporting going forward, including publishing this information in community-oriented posters, could be an important part of the aforementioned communications plan.

With respect to broader environmental monitoring at these locations, we recommend the continued use of our fish harvest survey—or some adapted version of it—as it is an inexpensive tool that can be used to track changes in subsistence fish stocks. The fish survey incorporates Traditional Knowledge and involves community members in its coordination. We have updated our fish survey based on its performance in 2019 (Appendix 1.4.3). Most of the new changes to the fish survey were minor and made the survey more accessible, but we also improved the ability to calculate effort by clarifying and modifying that part of the survey. While the Department of Infrastructure is not the most appropriate agency to conduct fish surveys in the long term, we suggest it would be in their interest to collaborate with RRCs and other branches of government to see this need addressed.

Finally, and again pointing to the need for collaboration or even leadership from other branches of territorial and federal government, as well as the communities themselves, we recommend a role for community-based monitoring to build knowledge around the cumulative impacts of environmental change on the traditional fisheries on the Peel and Mackenzie rivers. Ferry operations are but one small part of historical changes to these river systems, and continued efforts to ensure the safe management of transportation infrastructure and services requires a better overall understanding of how the rivers systems are being altered due to climate change and other impacts of economic development. The members of our research team would be happy to play a role in supporting the development of such a monitoring initiative.

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Appendices

Appendix 1: Supplementary material for Chapter 2

Appendix 1.1. 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/Interviewer	Interview year	Knowledge holder
Gwich'in Environmental Knowledge Project	GRRB	1996	Gabe Andre
			Irene Kendo
Gwichya Gwich'in Googwandak transcripts	Noel Andre	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 1.2. 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	Mary-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 1.3. Knowledge holders and harvesters that were interviewed about the Mackenzie River ferry operations. One knowledge holder was excluded from the list due to their request 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 1.4: Fish harvest surveys

Appendix 1.4.1. The fish harvest survey developed as part of the Local Area Monitoring Plan (GNWT Department of Transportation, 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.

Appendix 1.4.2. 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?

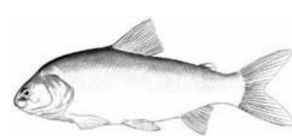
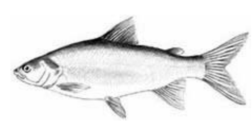
   Mackenzie River ☐ Arctic Red River ☐ Peel River ☐

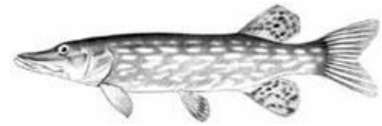
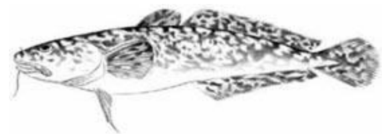
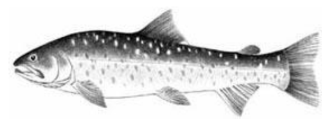
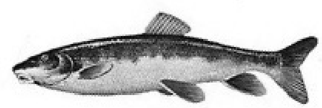
2. Where are your main fishing locations in relation to ferry landings on this river (you may leave this blank if you prefer not to share such information)?

   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 1.4.3. 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)?

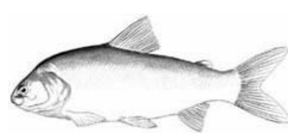
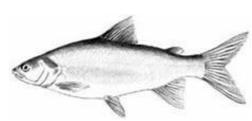
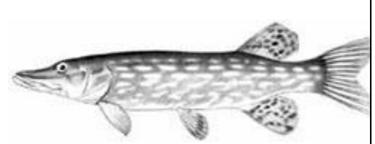
   Upstream of ferry landings ☐

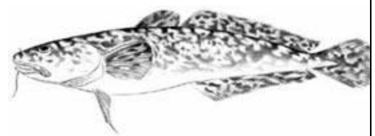
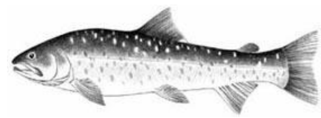
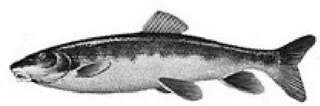
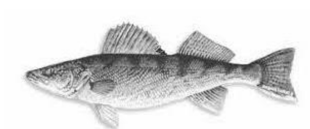
   Downstream, within 1000 feet ☐

   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.

____

____

____

____

Appendix 2: Supplementary material for Chapter 3

Appendix 2.1. 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 2.2. 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 2.3. 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 2.4. Figures for power analysis.

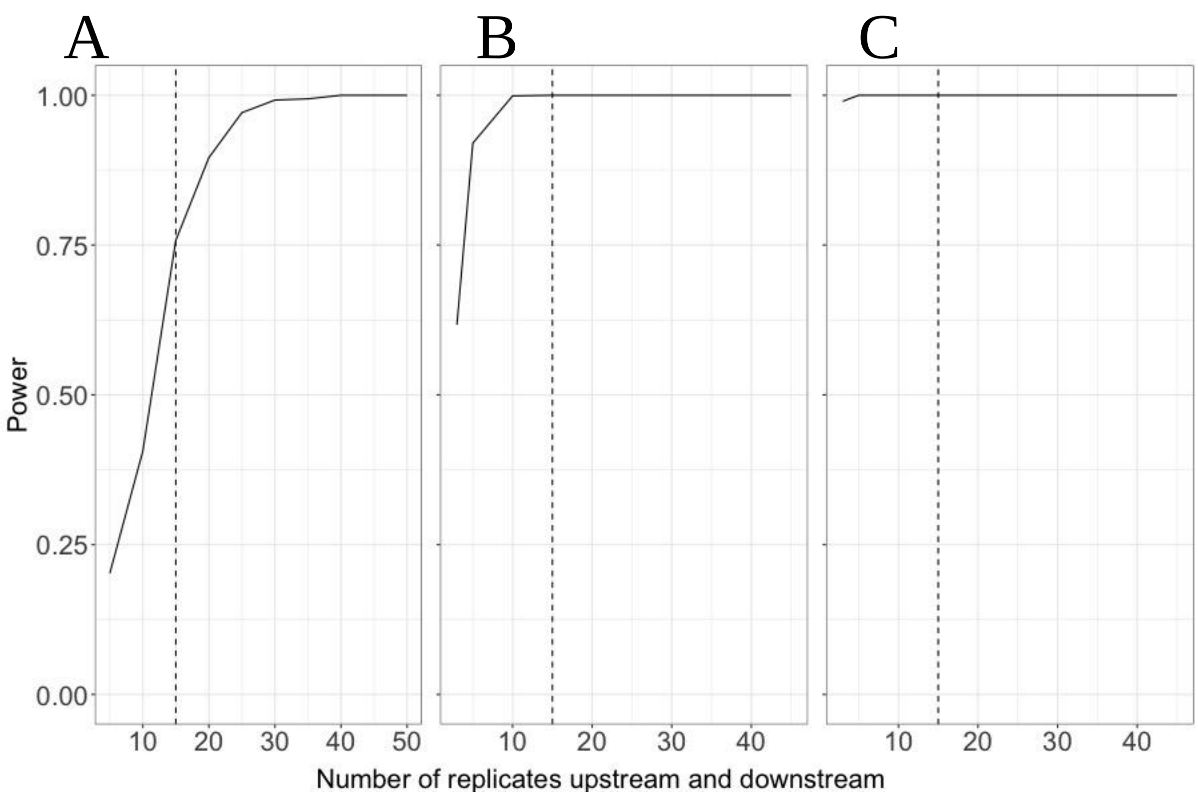


Figure A2.4.1 Relationship between number of replicate turbidity measurements upstream and downstream of the ferry landings on the Peel River and the power to detect a statistical difference between the upstream and downstream sites. The dashed line represents actual number of samples taken upstream and downstream. A) 5% difference in turbidity between upstream and downstream locations, B) 10%, C) 20%.

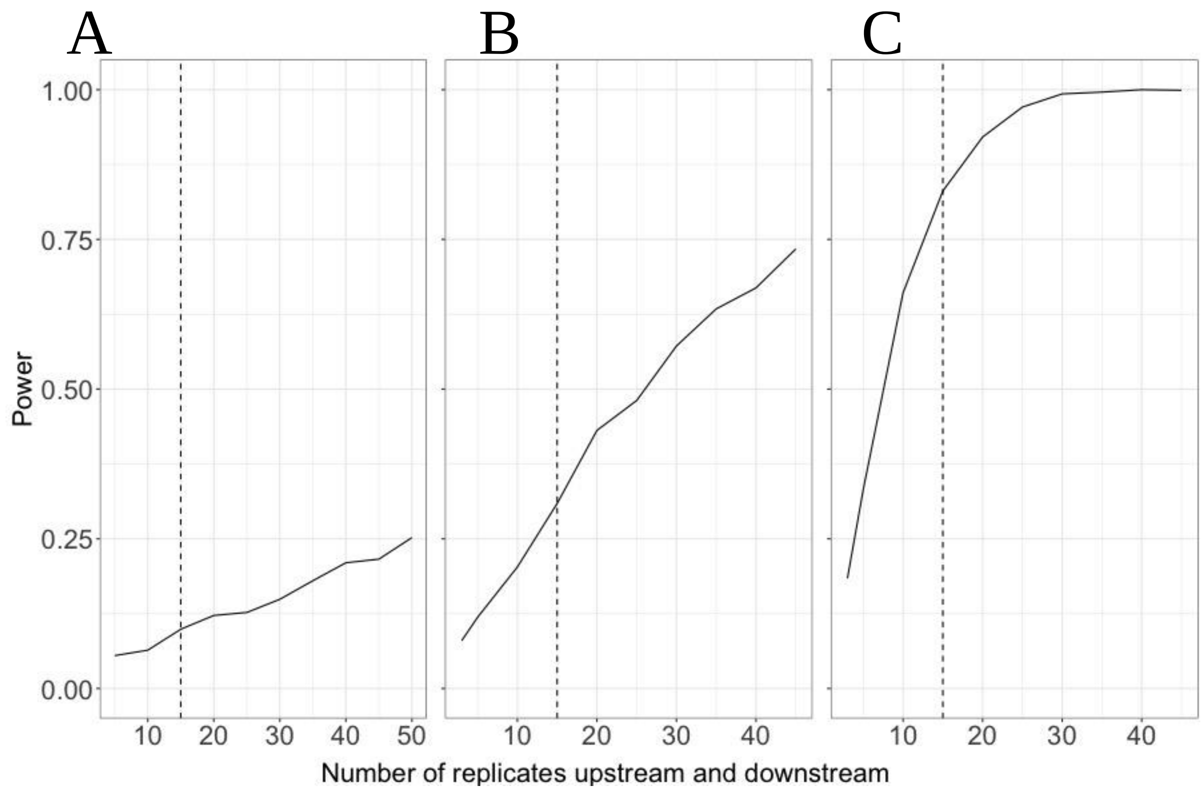


Figure A2.4.2 Relationship between number of replicate turbidity measurements upstream and downstream of the ferry landings on the Mackenzie River and the power to detect a statistical difference between the upstream and downstream sites. The dashed line represents actual number of samples taken upstream and downstream. A) 5% difference in turbidity between upstream and downstream locations, B) 10%, C) 20%.

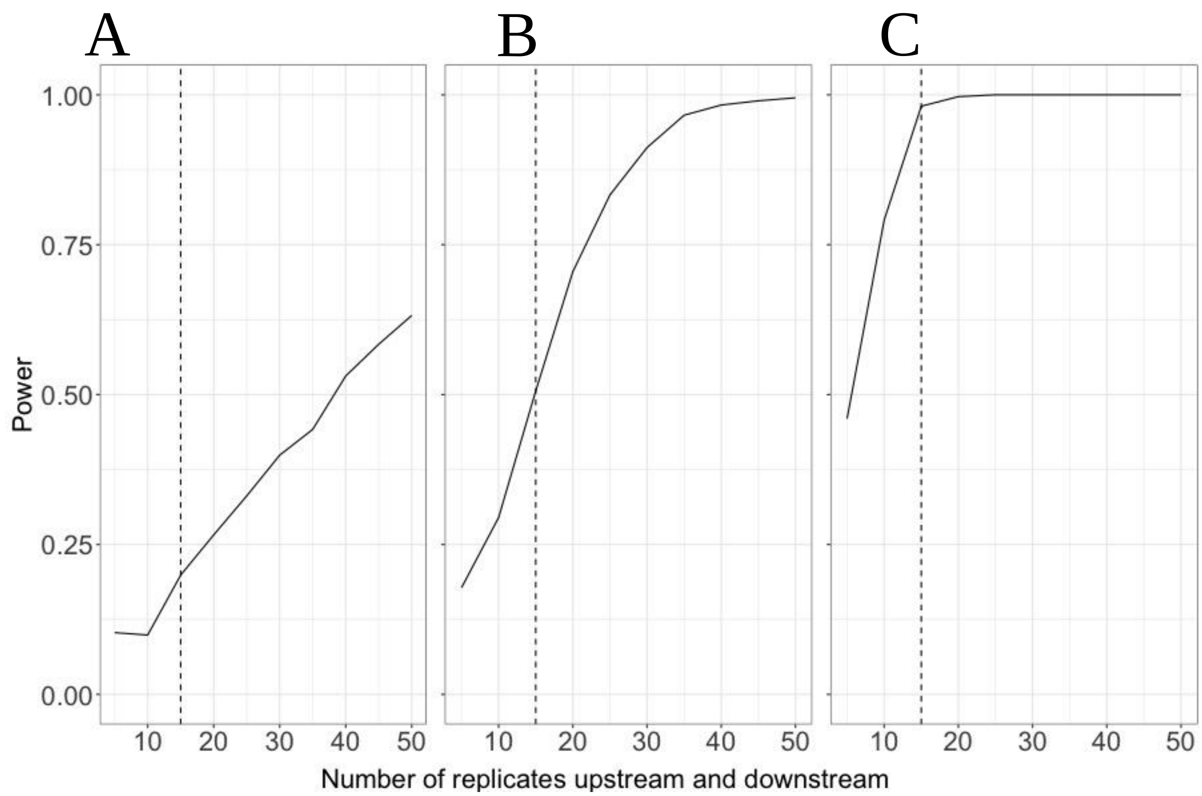


Figure A2.4.3 Relationship between number of replicate total suspended solids (TSS) measurements upstream and downstream of the ferry landings on the Peel River and the power to detect a statistical difference between the upstream and downstream sites. The dashed line represents actual number of samples taken upstream and downstream. A) 5% difference in TSS between upstream and downstream locations, B) 10%, C) 20%.

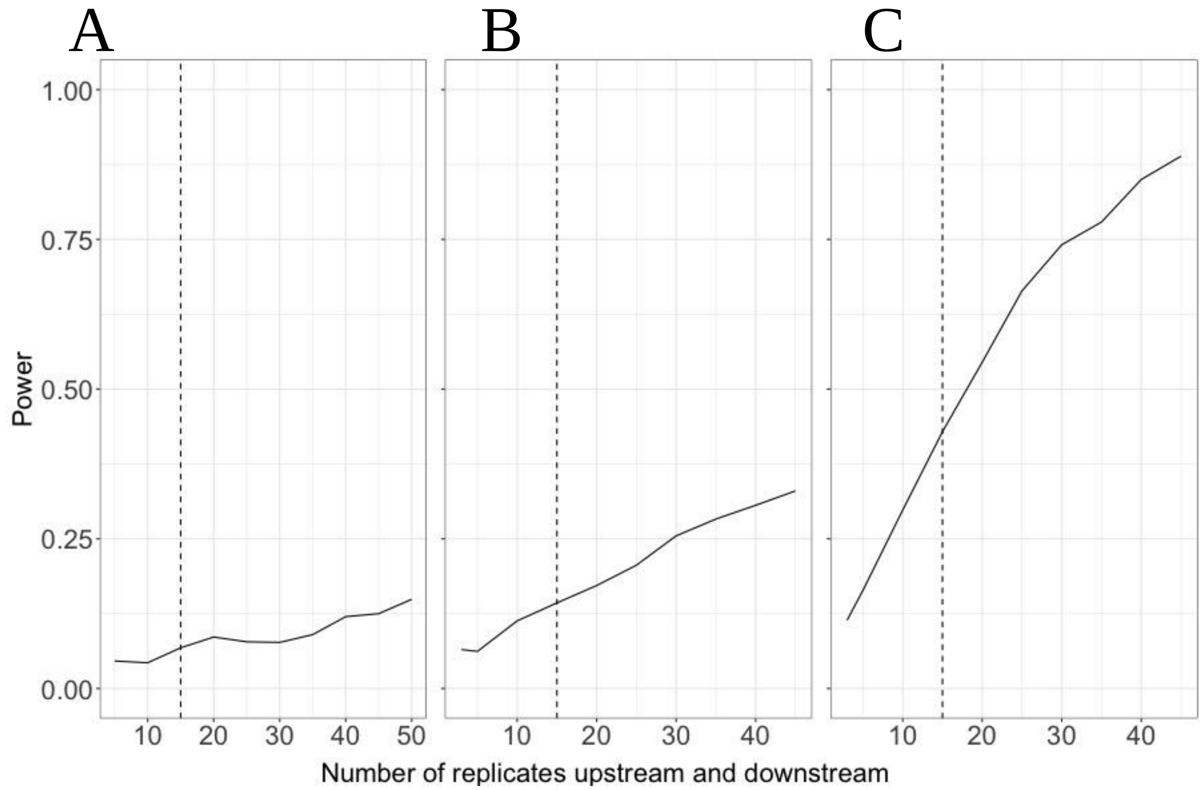


Figure A2.4.4 Relationship between number of replicate total suspended solids (TSS) measurements upstream and downstream of the ferry landings on the Mackenzie River and the power to detect a statistical difference between the upstream and downstream sites. The dashed line represents actual number of samples taken upstream and downstream. A) 5% difference in TSS between upstream and downstream locations, B) 10%, C) 20%.

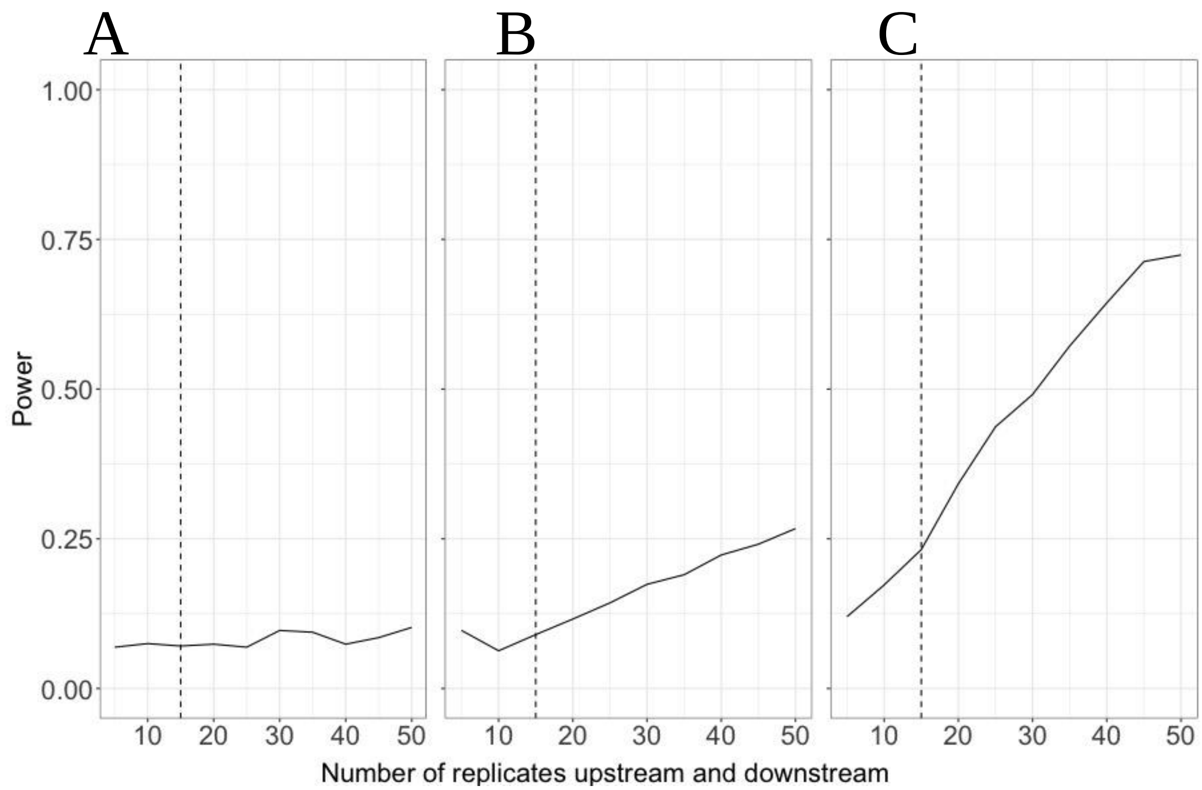


Figure A2.4.5 Relationship between number of replicate bed load median particle size measurements (d_{50}) measurements upstream and downstream of the ferry landings on the Peel River and the power to detect a statistical difference between the upstream and downstream sites. The dashed line represents actual number of samples taken upstream and downstream. A) 5% difference in median particle size between upstream and downstream locations, B) 10%, C) 20%.

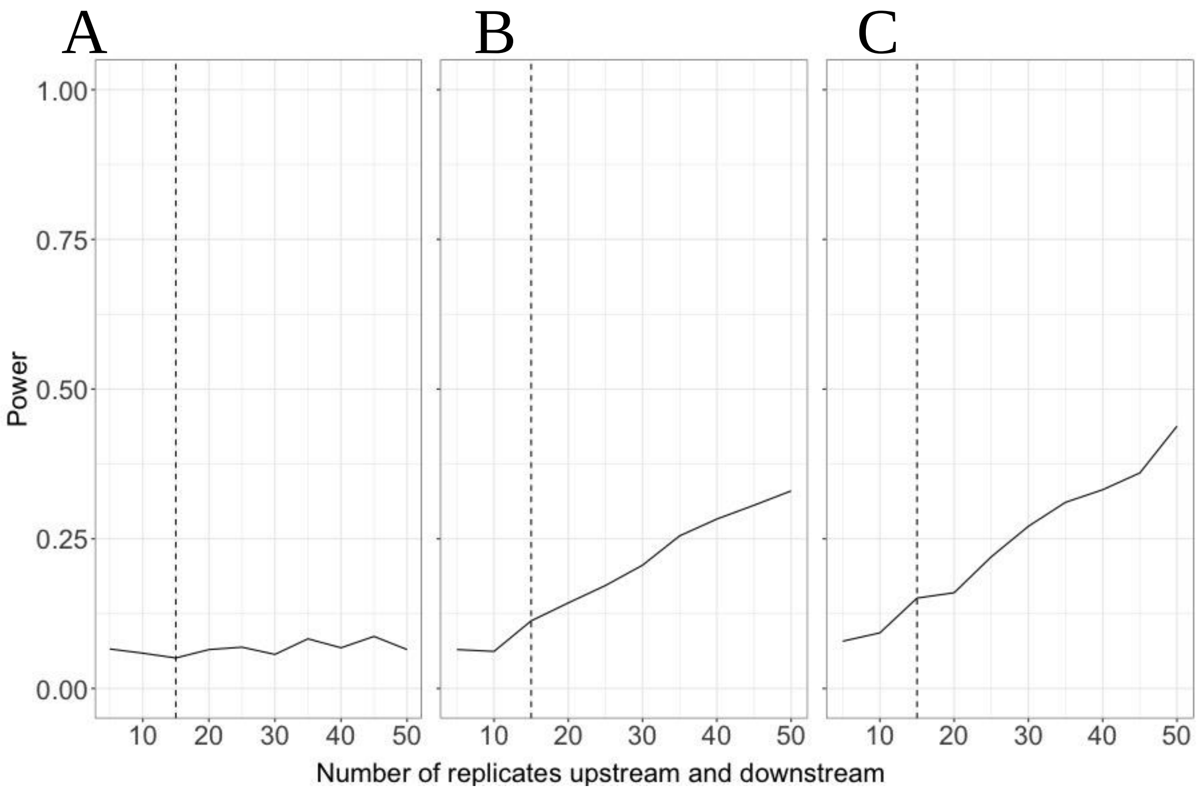


Figure A2.4.6 Relationship between number of replicate bed load median particle size measurements (d_{50}) measurements upstream and downstream of the ferry landings on the Mackenzie River and the power to detect a statistical difference between the upstream and downstream sites. The dashed line represents actual number of samples taken upstream and downstream. A) 5% difference in median particle size between upstream and downstream locations, B) 10%, C) 20%.

Appendix 3 Community feedback on the summary of study outcomes

As outlined in the introduction, community engagement for review of study findings was a key part of the study methodology. A community meeting was held in Tsiigehtchic during researcher travel to the region in February 2020, but due to the death of a former chief during the planned community visit to Fort McPherson, and then to the long-term travel restrictions and other impacts of the COVID-19 pandemic, community feedback from Fort McPherson was limited. A brief summary of the feedback received from both communities is included here.

Feedback from the communities on the research findings was mixed. In Tsiigehtchic it was expressed by several participants that two years was too short a period of study to reach sound conclusions, and that a longer study period was required. One participant challenged the study design, saying it was flawed because it did not compare the parts of the rivers affected by the landings with control sites elsewhere on the rivers. That person asserted that the study needed to be redone. There was some degree of satisfaction among participants that wider concerns about the ferry landings had been heard and documented. The area of deposition directly downstream from the Fort McPherson landing on the Mackenzie River was again mentioned as a focal point of concern, along with the overall footprint size of the Inuvik-side landing, given that several different approaches are used throughout the season.

The two Tetlit Gwich'in RRC members who met with the researchers to hear the summary of findings expressed general satisfaction with the findings and recommendations. In spite of this, and effectively expressing disagreement with the findings, one of the participants spoke at length about the sedimentation of the Peel River channels downstream of the landings, linking this to the erosion of materials from the landings. This same participant drew attention to the way that haste to open the ferries after spring break-up often means that gravel is being dumped into deep and fast-moving water, washing away almost as soon as it is put in place. These comments echoed others documented in the report about community member perceptions that the stated goal of reducing the amount of material lost to the rivers is not always reflected in practice. The Executive Director of the Tetlit Gwich'in Council provided written feedback based on her reading of the 2-page results summary provided to the community. Based on her own lifelong experience on the river she noted various environmental changes, such as riverbank erosion, lakes breaking out into the river, and the increase of willows. Most relevant to this study, she noted that the river is much shallower near Fort McPherson, but gets deeper as you move downstream towards Aklavik. On this basis she indicated that she strongly believes the material from the ferry landings is having an impact.