Fish movement through a nature-like fishpass within a small Arctic stream

By

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Abstract

Resource development can lead to the harmful alteration, disruption, or destruction of fish habitat. During Diavik Diamond Mine, Inc.’s (DDMI) development of its facilities at Lac de Gras (LDG), NWT, DDMI destroyed two small headwater lakes and associated streams. To help offset this loss, DDMI developed a two-phase habitat compensation program, the M-Lakes and West Island Stream (WIS) projects, located in the LDG catchment, where fishpasses were installed to improve ecosystem connectivity and potentially increase each system’s productive capacity.

A collaboration involving the University of Alberta, Fisheries and Oceans Canada, and DDMI worked to design, construct, and evaluate the effectiveness of the WIS nature-like fishpass, a modification of a 420-m headwater lake-outlet stream. The fishpass was designed to improve fish migration through the stream, which was naturally characterized by a series of small cascades and a poorly defined channel, preventing fish passage. My main objective was to evaluate the ability of fish to move throughout the modified stream. Successful movement would provide native fishes, particularly Arctic Grayling (*Thymallus arcticus*), access to spawning and rearing habitat.

To conduct my evaluation, I PIT-tagged adult Arctic Grayling (n = 90), installed three paired antenna arrays, and manipulated stream flow to track fish movement during background (low) flow, and two manipulated (medium and high) flow regimes. A second experiment used the mark and recapture of fin-clipped young-of-year Arctic Grayling to determine the ability of these fishes to migrate downstream through the fishpass at naturally low summer flows.

These field experiments revealed that the WIS fishpass established connectivity, albeit imperfectly. Although adult grayling could traverse through the most challenging lower part of the fishpass at medium and high flows, typical of their spring spawning season, I did identify a bottleneck to movement, particularly upstream movement. The section of stream that had the steepest gradient and a V notch structure created where two large rocks came together had the fewest recorded movement events and lowest passage efficiency. Noticeably more grayling moved during the hours of lower light (6pm to 6am), however, neither fish size nor in-stream water temperature affected movement. Young-of-year (YOY) grayling stocked at two upstream pools effectively migrated downstream throughout the steepest, and likely most challenging sections of WIS at the low summer flows that characterize Barrenlands streams when the YOY would be expected to move from their natal stream to their overwintering lake.

Although the bottleneck section needs improvement, DDMI's WIS compensation project achieved the goal of modifying a stream to provide grayling access to a previously unreachable habitat that could then be used for spawning and rearing. My research revealed that a base discharge of 10L/sec in a channel that was approximately one meter wide with a slope of less than 5 percent, would promote adult grayling movement. This discharge (or greater) was observed for a period of approximately 22 days in the spring of 2013, therefore, under comparable flows there would be time available for adult grayling to ascend, spawn, and descend West Island Stream. I also determined that YOY grayling could successfully navigate downstream at low summer flows of 1L/sec, with some of this movement occurring in the hyporheic zone through the hyporheic flow. PIT tags and antennas proved to be a valuable system for studying fish movement, allowing me to remotely record and document grayling movement, which mostly occurred at night.

Preface

This thesis is an original work by Duane Fredric Noddin. The research project, of which this thesis is a part, received research ethics approval from the Animal Care and use Committee under: “Improving habitat connectivity to enhance productive capacity of Arctic freshwater ecosystems” No. 688/03/12 on 1 May 2011. The project was renewed as No. 688/03/13 on 1 April 2012, and also renewed under “Enhancing productive capacity and understanding biodiversity of arctic freshwater ecosystems” No. 764/03/13 on 1 April 2012. This project was subsequently renewed as AUP00000034 on 19 March 2013.

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My education and the people who have helped me along the way, have come full circle. Because of this research, I learned a ton, I had tremendous experiences, culminating with me securing full time work as a biologist. This outcome reflects strongly on the U of A, and on Diavik, showing that where great relationships exist, people can achieve, advance, and succeed.

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List of Abbreviations

ANOVA: analysis of variance

DDMI: Diavik Diamond Mines Inc

HADD: harmful alteration, disruption, or destruction

LDG: Lac de Gras

M-Lakes: Mainland Lakes

MS-222: tricaine methanesulfonate

NNL: no net loss

PIT: passive integrated transponder

SWS: Schlumberger Water Services

The Act: Canadian Fisheries Act

WIS: West Island Stream

YOY: young-of-year

1.0 Introduction

Human development often leads to the Harmful Alteration, Disruption, or Destruction (HADD) of habitat, including aquatic habitat. Prior to 2013, the Canadian *Fisheries Act* (the Act), along with the Policy for the Management of Fish Habitat, set out the legal framework and policy objectives to address impacts to fish and fish habitat that experienced an unavoidable HADD (DFO 1986). Under these circumstances, the Act required compensation for damaged habitat (DFO 1986). The goal of compensation was to achieve “No Net Loss” (NNL), whereby restored or created habitat would increase the productive capacity of a habitat system (DFO 1986) to a level equivalent to, or greater than the habitat that was lost (Harper and Quigley 2005).

Amendments to the Fisheries Act (DFO 2013a and b) shifted the focus from protecting fish and fish habitat (Brouha 1993, Hutchings and Post 2013), to providing for “the sustainability and ongoing productivity of commercial, recreational, and Aboriginal fisheries” (DFO 2013b). Under the current Act, where potential harm is projected to impact the productivity of a commercial, recreational, or Aboriginal fishery, offsetting measures are required to mitigate potential negative effects. Regardless of whether offsetting or habitat compensation measures are required, the management tools for either have remained largely the same. The restoration of damaged, creation of new, or enhancement of existing habitats, including the improvement of connectivity to functioning natural habitats, continue to be viable avenues of remediation for managers.

Resource managers often face uncertainty when undertaking compensation projects (Minns and Moore 2003). Given our incomplete understanding of ecosystem function, particularly acute for fish and fish habitat in Arctic environments (Power 1997, Birtwell et al. 2005), it is important to study and evaluate compensation projects to further our collective understanding. Gaps in our knowledge are illustrated by Quigley and Harper (2006), who noted that two-thirds of reviewed compensation projects fail to achieve NNL. Roni et al. (2008), in their review of the effectiveness of various stream rehabilitation techniques, identified complexities involved in attempting to improve instream habitat. They suggested that scale, watershed processes, and watershed conditions all play important roles in determining whether or not a given rehabilitation project will succeed, regardless of time and money invested. Based on historically successful rehabilitation projects, Roni et al. (2002, 2008) further suggested a hierarchy of offsetting options. In particular, they suggested that habitat protection, improvements in water quality and flow, and improving habitat connectivity, including the use of fishpasses, should all precede the addition of instream structures and nutrient enhancements. By improving our understanding of the relationships between habitat, and the fish that live in them, we should improve our ability to integrate and adapt compensation objectives with field conditions, likely resulting in the greater success of future projects.

Fishpasses

Fishpasses can establish or restore connectivity between otherwise isolated water systems (Larinier 2001) and, following Roni et al. (2002, 2008), should be an important tool in habitat compensation. Historically, fishpasses have been based on standardized designs and constructed using materials such as concrete, wood, and metals (Katopodis et al. 2001). These structures were often targeted to help economically valuable fish such as salmonids move up and down a river past a barrier (Larinier 1998). For example, the popular pool-and-weir fishpass is designed to allow targeted fish to by-pass a steep and/or high-discharge barrier through a series of step pools (Clay 1995). Such fishpass designs may facilitate the movement of strong swimming and leaping fish, such as salmonids, but could be barriers to fish that lacked strong swimming and leaping abilities (Katopodis et al. 2001).

Management objectives for fishpasses have broadened, and there is a trend toward creating fishpasses made of natural materials found on-site, and designed to mimic conditions of natural streams (Jungwirth 1996, Katopodis et al. 2001, Hatry et al. 2013). The idea of such “nature-like” fishpasses is not new, and fishways made of stone or wood were being built in the early 1900’s (Bruce 1934; Katapodis 2012). Nature-like fishpasses, however, did not start becoming common until the 1990’s. Tsujimoto and Horikawa (1997) introduced the concept of ecological fishways, another term used for nature-like fishpasses, and argued how these fishways could enhance ecological connectivity for many fish species, not just commercially valuable fish. Around the same time period, in Australia, rocky-ramp fishways, a type of nature-like fishpass that places boulders along a slope to interrupt flow and create a hydraulically favourable environment for fish passage, were installed and subsequent evaluation deemed the project successful (Harris et al. 1998). This was followed by the installation of a rocky-ramp fishway on the Margaret River, also in Australia, which successfully re-established connectivity among fish habitats for multiple fish species (Beatty et al. 2007). In another early study, a nature-like fishway incorporated bypass channels, which are dedicated channels that circumvent a barrier to fish movement such as a dam, without interfering with the original function of that dam (Eberstaller et al.1998). This fishway/bypass combination led to the successful passage of multiple fish species, enhancing ecological connectivity (Eberstaller et al. 1998). As well, Rawer-Jost et al. (1998) showed that invertebrates could ascend a nature-like rock-ramp fishway, further enhancing ecological connectivity, not just fish movement.

In an effort to encourage discussion on nature-like fishpass design, Gebler (1998) detailed the designs, costs, and construction materials of his nature-like fishpasses, and how he monitored each fishpass. Subsequently, Katopodis (2005) created an ecological toolkit that took costs, scale, site conditions, fish species, and other aquatic biota into account to design effective fishpasses for different conditions. Katopodis (2005) looked at fishpasses in general, including nature-like fishpasses, and took into account factors such as fish migration, fish behaviour, swimming performance, fishpass hydraulics, and flow management, with the aim of maintaining the ecological integrity of the system. Katopodis (2012) subsequently noted that fishpass design works best when biologists and engineers work together.

This idea was also promoted by Castro-Santos et al. (2009, 2012), who submitted a guideline for fishpass research that keyed in on the paucity of biological data available to fishpass designers and suggested that additional investigations would likely produce more effective fishpasses. Castro-Santos suggested investigating questions already raised in the literature (e.g. how turbulence structure influences swimming performance and how morphology, fish behaviour, or fish hormonal levels affect fish passage) and using the answers to refine and create an adaptive management framework that would enhance future fishpass designs. Technical parameters also started making their way into nature-like fish way designs, with Wang and Hartlieb (2011) keying in on hydraulic conditions. Their research suggested that water depth and boulder arrangements played a more critical role for fish passage than water velocity.

Beyond being aesthetically pleasing, nature-like fishpasses are designed to allow passage of more fish species across a greater variety of discharge rates, and therefore should experience greater passage efficiencies than those of traditional fishpasses (Bunt et al. 2012). Nature-like fishpasses work best where stream gradients are less than 5% and there is an abundance of natural materials on hand (Larinier 2001; Franklin et al. 2009). Franklin et al.'s study showed a fishpass efficiency of 94% with gradients of 5%, but efficiency fell to 40.6% where the fishpass gradient increased to 6.7%. Indeed, subsequent laboratory experiments on a rocky-ramp fish way with a 5% slope demonstrated hydraulically favourable habitats for fish resting and fish movement (Breton et al. 2013).

Fishpass efficiencies also vary between fish species, fishpass locations, and fishpass types, including nature-like and engineered fishpasses (Noonan et al. 2012). On the River Eman, 90 – 100% of the salmonids that located and entered the nature-like fishpass, passed through (Calles and Greenberg 2005). At a broader scale, using PIT tags, these researchers identified 10 species, including the weaker-swimming Tench (*Tinca tinca*), Perch (*Perca fluviatilis*), and Burbot (*Lota lota*), that moved through the River Eman's fishpass, with an overall passage efficiency of 74%. In contrast to the above, Calles and Greenberg (2007) did not see high passage efficiencies for cyprinids or juvenile brown trout, although subsequent sampling suggested that these fish were using the fishpasses as habitat, and therefore were not seeking to pass through them.

Although passage efficiencies were high for fish that entered the River Eman's fishway, Calles and Greenberg (2005) found that only about 50% of the brown trout in the River Eman located the fishpass, suggesting that the attraction efficiency of nature-like fishpasses may be a potential challenge. To increase attraction efficiencies, Lindmark and Gustavsson (2008), created an attraction channel, which constricted discharge and increased velocity.

Despite such case studies evaluating nature-like fishpasses, most nature-like fishpasses are built *ad hoc* on-site with little information available regarding design guidelines, or how to adapt designs to reflect the habitat needs and swimming abilities of particular fish species (Katopodis et al. 2001; Haro et al. 2008, Courtice et al. 2014). A review of published fishpass assessments (Noonan et al. 2012) showed that the best predictors of fishpass success include the order of the fish involved (e.g., Salmoniformes, Cypriniformes, Perciformes, Clupeiformes, Petromyzontiformes), the fishpass type (e.g., pool and weir, pool and slot, nature-like, Denil, and fish lock/elevator), and the length of the fishpass (short for Denil, an average of 14.2 m, and longer for all other fishpasses averaging 175 – 202 m). Salmonids had the highest passage efficiencies across studies, with the pool and weir, the pool and slot, and the nature-like fishpasses recording the highest passage efficiencies, while the Denil and fish lock/elevator had the lowest upstream passage efficiencies regardless of fish species (Noonan et al. 2012). Field experiments studying fish movement within modified streams and relating movement (or lack thereof) to the hydraulics of a stream would help provide valuable information as to what water characteristics encourage or hinder movement (Katopodis et al. 2001). Clearly, as Katopodis (2012) and Castro-Santos et al. (2009, 2012) have noted, fish biologists and hydraulic engineers need to work together to continue to improve on fishpass designs.

Fishpasses and DDMI's Habitat Compensation

During the development of its facilities at Lac de Gras (LDG) in Canada's Northwest Territories, Diavik Diamond Mine, Inc. (DDMI) destroyed two small headwater lakes and associated streams. Accordingly, to comply with their *Fisheries Act* requirements, DDMI developed a two-phase compensation project that would install several fishpasses to improve connectivity within two systems of headwater lakes and their outlet streams, to increase the productive capacity of those systems (DDMI 1998). The first phase (the M-Lakes project) was expected to establish connectivity among three small lakes, and those lakes with Lac de Gras, via three short fishpasses, allowing fish to access and use the uppermost lake (M3L), which was believed to be fishless, and therefore unexploited. The second phase of this compensation program (the West Island project) involved creating a longer fishpass out of West Island Stream (WIS), allowing fish to access and use this stream, something that was not naturally possible due to a combination of a set of impassable cascades located immediately upstream of WIS's mouth with Lac de Gras and poorly defined channel structure further upstream (Golder Associates 2001). The projects were staggered so that the M-Lakes project would be completed first, followed by the West Island project. Although considerable energy, money, and effort was put into the M-Lakes compensation project, it met with marginal success (Courtice et al. 2014, Cahill et al. 2015). The information gained through its assessment, however, was valuable and ultimately improved the WIS fishway design.

Lessons Learned from M Lakes

To enhance connectivity among the three lakes, the M-Lakes project saw pool and weir fishpasses installed in two of the streams, using five gabion style weirs per stream, while a choke-and-pool nature-like fishpass was constructed at the third. The fishpasses were meant to improve connectivity among lakes, and specifically to facilitate the migration of Arctic Grayling (*Thymallus arcticus*), which routinely use small headwater streams for spring spawning (Northcote 1982, 1995). The major factor contributing to the project's limited success was the installation of the gabion-style weirs, which proved unsuitable for small catchment areas that limit the hydrology of headwater lake basins (Baki et al. 2012; Courtice et al. 2014). In short, there simply was not enough water to maintain flows sufficient to encourage fish to seek, and then pass over, the gabion weirs (Cahill et al. 2015). In light of this knowledge, the middle section of all gabion weirs were notched to enhance and concentrate water flow over the weirs and promote fish passage. This modification met with marginally more success (Cahill et al. 2015).

In contrast, the choke-and-pool nature-like fishpass effectively passed numerous adult Arctic Grayling upstream and downstream, and likely facilitated their successful spawning (Cahill et al. 2015). Ninespine Stickleback (*Pungitius pungitius*) were also observed successfully spawning in the stream (Fred Noddin, unpublished data).

Compared to the gabion weirs, the choke-and-pool nature-like fishpass was a superior design for promoting fish passage in these low gradient, low flow, Arctic headwater streams.

To detect fish in the fishpasses, electrofishing, direct observation, and a combination of PIT tags and solar-powered antenna arrays were used at M-Lakes. Although fish were detected by all three methods, it became readily apparent that the PIT tags and antenna arrays were superior. The antenna arrays could continuously track the movements of larger fish, especially at night, into and through the streams, even in the remote setting of the M-Lakes (Cahill et al. 2016).

As noted earlier, because of barriers and poor flows, there was very limited use of WIS by fish prior to any channel modification (Table 1), all of which was restricted to the extreme upper and lower portions of the stream. The West Island Stream compensation project was initially designed to be a fishpass using 20 + gabion weirs. Given the lessons learned from the M Lakes project, it was recommended that the gabion-weirs be abandoned and a nature-like design be utilized for the entire fishpass. This would involve channelization of the stream, including a re-routing of the channel around the steep cascade section near Lac de Gras, and then (re)placement of rock and wood from the catchment to create a hydraulically passable stream for multiple fish species, at a variety of discharges, with Arctic Grayling, a spring-spawning, strong swimming salmonid (Scott and Crossman 1973), being the primary target species.

Channelization of the WIS stream bed would consolidate flow, potentially extending passable in-stream water levels further into the season. Construction of a properly designed nature-like fishpass, without gabion weirs, was expected allow fish passage throughout the stream, even during periods of relatively low flows, reducing the need for fish to jump over barriers, as in the gabion weir design.

The recommended nature-like fishpass was constructed at WIS during late summer 2012 (Courtice et al. 2016). Due to logistical constraints, only general hydrologic measurements of the WIS fishpass (Courtice et al. 2016), together with limited observations and trapping of fish (see below), were made in 2013. Instead, plans were developed for single-season evaluations in 2014 of the ecohydraulics of the modified WIS (Kupferschmidt 2015) and its ability to pass fish, particularly by Arctic Grayling.

Objectives of my Research

It was improbable that I would confirm grayling spawning within WIS given that there were no grayling native to WIS (F. Noddin, pers. obs.). Therefore, I conducted a flow manipulation movement study several weeks after the Arctic Grayling spawning season in this region, using fish brought in from M-lakes, to determine if, and how effectively, grayling could move up and down the fishpass. For logistical reasons, I selected the lowermost 90 m of the WIS nature-like fishpass for the study. This stream reach had the steepest gradient (ca. 4%) and likely posed the greatest challenge for migrating fish. I hypothesized that if grayling were able to navigate this reach of the fishpass, they should be able to access the entirety of the WIS channel, giving WIS the potential to function as a spawning stream.

Fish surveys were conducted at three flow conditions, two of which were achieved through flow augmentation using mechanical pumping, to determine the ability of adult Arctic Grayling to move up- and downstream. These discharges ranged from those common during spring freshet spawning season to substantially reduced flows typical of summer, when Young-of-Year (YOY) grayling migrate from their natal stream to their over-wintering habitat (Northcote 1995, Jones et al. 2003a). Therefore, in addition to quantifying the abilities of adults to move up and down the nature-like fishpass, I also evaluated whether YOY grayling could migrate downstream and out of WIS and into Lac de Gras at summer flow levels. To assess this, I imported marked YOY grayling from a nearby stream within the LDG catchment, released them at two points within WIS, and then tracked their movement to see if, and how quickly these YOY fish navigated downstream.

Results from my studies on fish movement in WIS were not intended to reveal whether a spawning run would occur and be successful, but rather to address whether both a spawning run and out-migration of YOY are possible, two key components of successful spawning/rearing habitat. I hypothesized that if both of these components proved successful, the WIS fishway could provide important conditions needed to serve as spawning/rearing habitat, facilitating an increase to the productive capacity of the Lac de Gras ecosystem. Finally, while addressing these compensation issues, I used the PIT tag – antenna array system and water pumps to investigate if and how stream gradient, fish size, and the time of day influence grayling movement at three different discharges.

2.0 Materials and Methods

2.1 Study Area

This study area (ca. 64°29'N, 110°10'W; Figure 1), is located within the Lac de Gras watershed (Northwest Territories, Canada) in a geographic region known as the Barrenlands (Environment Canada 1991; Krajick 2001). The area is characterized by cool temperatures (mean annual temperature -12°C), low annual precipitation (200 to 300 mm, 50% as snow), and a continuous permafrost layer (Environment Canada 1991). Falling within the Southern Arctic ecozone, Lac de Gras is approximately 100 km north of the tree line, 300 km NE of Yellowknife, and lies approximately 450 m above sea level. The combination of glacial activity and low topographic relief (ca. 50 m) has resulted in a landscape that is approximately 21% covered by water (Jones et al. 2003a). The numerous lakes and streams that drain into Lac de Gras contribute to the headwaters of the Coppermine River, a notable river system flowing north into the Arctic Ocean.

Field work was carried out over the summer 2014 at the West Island compensation site, the M-lakes compensation site, and the Reference 6 lake and stream system (Figure 1). The West Island compensation site (64.527° N 110.436° W), a catchment of 30.08 ha (Baki et al. 2012) approximately 8 km west of the Diavik Diamond Mine site, incorporates West Island Lake (WIL), a small (13.65 ha) headwater lake, and West Island Stream (WIS), a 420 m outlet stream flowing from WIL into the 577 km^2 Lac de Gras (Wedel et al. 1988). The M-lakes compensation site (64.490° N 110.181° W), approximately 3 km east of Diavik mine, comprises three small lakes and their outlets. Reference 6 (two lakes and their outlets) is located at 64.448° N 110.138° W, approximately 8 km to the southeast of Diavik.

WIS had an average slope of 1.8 percent (Golder Associates 2012). However, the lowermost 40-m reach was characterized by steep gradients of individual channels ranging from 9.1 to 12.8 percent, including a series of cascades that were considered impassable to fish (Golder Associates 2012) (Figures 2 and 3). The remainder of the original WIS, characterized by braiding, shallow overland flow (Figures 4 and 5) with the propensity to dry up during mid-late summer, was considered unsuitable and/or inaccessible for fish.

Prior to its habitat modification (described below), only Ninespine Stickleback (*Pungitius pungitius*), Burbot (*Lota lota*), and Slimy Sculpin (*Cottus cognatus*) had been detected in WIS (Table 1). These species were restricted to the lowermost 15 m of WIS, downstream of an impassable series of cascades. Slimy Sculpin were also detected in the uppermost 15 meters of WIS, immediately downstream of the outlet of WIS from WIL.

During the summer of 2012 construction work began on WIS. The stream was channelized and lengthened by 40 m in the lowermost section to overcome the steeper gradients of the cascades area, resulting in a gradient of 3.8 percent (Golder Associates 2012). Instream structures such as rocky ramps, choke-pools, rock weirs, and wood were added to provide hydraulically favourable conditions to allow fish passage over a range of flows (Courtice et al. 2016).

Following construction, the lowermost 90 m of WIS still represented the steepest overall stream gradient and was considered the most challenging section for fish passage. If adult Arctic Grayling could pass this steepest section, it was expected that they would be able to navigate the rest of the stream, where gradients were lower.

2.2 Field Methods – West Island Stream

Initial Assessment - Prior to the introduction of Arctic Grayling, I determined the extent of use by native fishes of the modified WIS. Visual surveys were conducted three times between June 4 and July 10, 2014. Prior to each survey, block nets (3 mm mesh) were placed at the top and bottom of WIS to prevent fish from moving out of, or into the stream during the survey. Two observers wearing polarized sunglasses started at the downstream block net and ascended the stream, one on each bank, independently identifying fish (to species) and recording their location until the upstream block net was reached. At the top of the stream the observers would change sides, and descend the stream, again recording fish observed and their location.

During this initial assessment period, I electrofished WIS twice using three-pass depletion (Zippin 1956). Prior to electrofishing, block nets were installed as described above. A Smith-Root LR-24 backpack electrofisher, equipped with a circular anode, was used by a crew of two. Each pass of the survey started at the downstream block net and progressed to the upstream block net. The electrofisher was set at 600 V DC, with captured fish identified to species, measured (TL +/- 1 mm) and the location of capture recorded. Fish were retained in a 5 gallon pail until the electrofishing was complete and then returned to their point of capture.

Additionally, I placed 22 Gee minnow traps throughout the length of WIS on four separate days, leaving them to fish overnight. All traps were subsequently retrieved, and captured fish were identified, measured, and their location recorded. Subsequently, the fish were returned to the stream at the site of their capture.

Adult Movement: Fish collection and PIT tagging – During the summer 2014, adult grayling were captured from M Lakes by angling. Grayling greater than 20 cm (n = 90) were retained for the flow manipulation movement study. Upon capture, these grayling were anaesthetized using tricaine methanesulfonate (MS-222; Western Chemical Inc., Ferndale Washington) and tagged with a uniquely coded, half duplex Passive Integrated Transponder (PIT) tag. PIT tags were 23 mm long, ca. 3.5 mm in diameter, weighed ca. 0.3g, and were inserted along the mid ventral line into the peritoneal cavity via a small incision made by scalpel (Figure 6) (Jepsen et al. 2002). The location of the incision was ≤ 1 cm anterior to the pelvic fins. Scalpels were sterilized in 90 % ethanol between fish to reduce the potential for infection or disease transmission (CBFWA 1999).

After tagging, fish were placed in one of two 4’ x 4’ x 8’, 1/8” mesh fish holding pens (Figure 7) at M Lakes and given a minimum of 15 minutes to recover. Up to a maximum of 15 fish were kept in each holding pen, for each flow condition until the targeted sample size (n=30) was reached (ca. 1 day). The 30 fish were then transported by helicopter to WIS using Rubbermaid plastic totes and portable aerators. The grayling exposed to the three flows averaged 29 to 33 cm TL.

At WIS, three antenna arrays, each outfitted with two pass-through antennas and one OregonRFID™ PIT reader, were installed into the lowermost 90 m of WIS (Figure 1). Antennas, ca. 75 cm diameter, were constructed using three consecutive wraps of eight-gauge wire (Cahill 2015), and antenna pairs were located at (a) 25 and 36 m, (b) 45 and 52 m, and (c) 68 and 80 m upstream of Lac de Gras (Figures 8- 10). Each reader system was powered by one 30W solar panel and a 90A·h ceramic plate 12V battery. Antenna detection efficiency was tested by using a drone Styrofoam fish with an inserted PIT tag. The drone was placed upstream of an antenna and allowed to float down and pass through the antenna. This procedure was conducted for each individual antenna 10 times during the season. All antennas picked up the drone PIT tag 10 out of 10 times, with an average read range of 0.71 m - 1.20 m on each side of the antenna.

The portion of stream located between two individual antennas was defined as a stream section, for a total of five sections under study. These sections were identified as 25 – 36m, 36 – 45m, 45 – 52 m, 52 – 68m, and 68 – 80 m. The antennas were placed at specific locations so I could evaluate grayling movement through a variety of stream features and key fish structures, like the rocky ramp, the choke and pool, and gentle or steep gradients. Characteristics of each stream section are further detailed in Table 2. For each flow (1L/sec, 9.9 L/sec, and 21.9 L/sec; Table 3), 30 PIT-tagged Arctic Grayling were stocked into WIS, six individuals per pool, at pools located 32, 38, 60, 70, and 85 m upstream of Lac de Gras (Figures 8-10). Block nets were placed at 10 m and 96 m above Lac de Gras so that the grayling were contained within the study area (Figures 8 and 10). Upon stocking into WIS, each grayling's PIT tag number and release location were recorded. Grayling were given 48 hours to move about within the study section. At the end of the 48-hour period, grayling were recaptured by dip netting, performed by an individual wearing polarized glasses, starting at the bottom block net and working upstream. Location of capture and tag number of each fish were recorded. The captured fish were then placed in a holding pen located in Lac de Gras, immediately in front of the WIS outlet. They were then reloaded into totes with aerators and flown by helicopter back to M lakes, where they were released.

Flow, Discharge, and Temperature – In-stream SWS Mini-Diver pressure loggers (Diver – Schlumberger Water Services) were placed at 12, 32, 74, 112, 249, and 345 m upstream of Lac de Gras, recording water levels and temperatures every 10 minutes. The depth data were used in conjunction with direct discharge measurements to develop a depth-discharge rating curve. An SWS was placed on shore, near the stream, to account for atmospheric pressure. Pools located 33, 38, 68, 72, and 85 m upstream of LDG were hydraulically sampled on a 0.1m by 0.1m horizontal sampling plane along the stream's cross section. The stream was split into a minimum of 8 sections across the bank width. A FlowTracker (SonTek) acoustic Doppler velocimeter (ADV) measured point velocities at 60 percent of water depth, at a sampling rate of 1 Hz for 40 s (Kupferschmidt 2015). A larger number of sampling cells, as recommended by Harrelson et al. (1994), was not practical given the stream's narrow width. From these data, a stage vs. discharge rating curve was developed for each hydrostatic logger, which allowed us to convert hydrostatic pressure data into stream discharge (Kupferschmidt 2015).

Stream Flow Manipulation – The ability of grayling to move within the lowermost 100 m of the nature-like fishpass was evaluated over three discharge levels. The first discharge level, 1 L/sec, represented the natural background flow at the time of the experiment, July 6 to July 9, 2014. This flow is substantially less than what would be experienced by grayling during early spring when spawning typically occurs (Northcote 1995; Courtice et al. 2016). Two higher discharge levels were the product of pumping. A Gordon Rump 10 Series Model 14A2-TS2 S/G diesel centrifugal pump drew water from Lac de Gras through 90 m of 4-inch diameter lay flat hosing and released it in the WIS channel 98 m upstream of Lac de Gras. Using a 3-inch intake hose, a discharge of 9.8 L/sec was achieved, which became the experiment's medium flow. This discharge was observed in WIS during 2013 on June 21(Courtice et al. 2016), shortly after the typical grayling spawning period in Barrenlands streams (Jones et al. 2003a). By using a 4-inch intake hose, the discharge was increased to 22 L/sec, becoming the experiment's high flow. This flow was observed during 2013 in WIS on ca. June 10, during the average grayling spawning season (Jones et al. 2003a, Courtice et al. 2016). The medium flow experiment was carried out from July 10, 2014 to July 12, 2014. The high flow experiment was conducted from July 13, 2014 to July 15, 2014. Grayling movements for each discharge were evaluated for 48 hours.

Young-of-year Movement - On July 26, 2014, with flows in WIS at the natural background discharge level of 1.0 l/sec, 55 YOY Arctic Grayling (31 to 56 mm TL, mean = 40.5 mm) were captured by dip net from the upper Reference 6 stream and transported in two 19 L pails, unaerated, by helicopter to WIS (transit time < 10 min). At WIS, 28 individuals were given a partial fin clip (Figure 11) of the upper caudal fin, and placed into the pool at 68 m above Lac de Gras. The remaining 27 individuals were given a partial fin clip of the lower caudal fin and placed into the pool at 38 m above Lac de Gras.

Block nets were set up at 90 m and 10 m above Lac de Gras to contain the YOY grayling. This section of WIS was selected as it represents the steepest stream gradient, had the highest vertical drop of 18.5 cm, and likely the most challenging hydraulic environment for YOY fish to pass downstream. I assumed that if YOY grayling could successfully navigate downstream in this section, they could navigate down other sections of WIS, where gradients are gentler and hydraulic conditions more favorable.

The reasoning behind having YOY stocked at two sites was twofold. First, if the upper YOY stocked at 68 m could make it to 38 m, where the lower YOY were stocked, and the lower YOY could make it to the downstream pool just in front of the lower block net, then it should be possible that a YOY grayling could migrate down through the entirety of the WIS fishpass. Secondly, if the upstream YOY were for some reason, blocked from further downstream movement prior to reaching the lower stocking site, then we would still be able to assess the lower stream migration potential, because we had stocked the one group at 38 m.

Upon release, the YOY were monitored visually for 15 minutes to determine if any of the fish did not survive the capture, transport, and restocking. During the following week, I sampled WIS four times. With the aid of polarized sunglasses, the YOY were easy to locate and once located, they were captured by dip net. Point of capture, time since release, and the fin clip were recorded for each fish. For the first three samplings, the YOY fish were returned to their point of capture. For the final sampling, the YOY were removed and returned to R6, the reference stream they were originally caught.

Lastly, a full length survey of WIS was conducted during low summer flows from August 2-4, 2014. Sections that had vertical drops, which could be migration barriers, were identified and the height of these drops were measured.

2.3 Data Analysis

For this study, I defined movement of adult Arctic Grayling as passage of a tagged grayling from one PIT tag antenna to an adjacent antenna, in either an upstream or downstream direction. Should a grayling be detected only at a single antenna location for the duration of that movement study, no movement was credited to that fish. Available movement is a reflection of a grayling being detected at one PIT antenna, and the position of other antennas in relation to the first. If there was one or more antennas downstream of the initial PIT antenna, then there was the potential to detect a grayling moving downstream, therefore downstream movement (as defined here) was available. Similarly, if there was a PIT antenna upstream of the original antenna, then upstream movement was available to that fish. Thus, for the lowermost PIT antenna, located 25 m above Lac de Gras, the only available option for fish to move would be to move upstream and be detected at the 36 m antenna. For fish that were detected at the uppermost antenna, 80 m above Lac de Gras, the only movement available was downstream to the 68 m antenna. For fish detected at any of the four PIT antennas located between the uppermost antenna (80 m) and the lowermost antenna (25 m), movement was available in both upstream and downstream directions. Comparing the number of times a grayling moved in one direction or the other relative to the number of times up or downstream movement was available allowed me to establish whether up or downstream passage at a particular antenna location was effective, or if there were apparent bottlenecks within the fishpass, indicated by low numbers of actual passage events in a particular direction relative to the total number of movements available to them.

The amount of movement by an individual during each flow manipulation was the total number of times a grayling was detected at one antenna and then subsequently detected at an adjacent antenna. For example, if a grayling was initially detected at the 25 m antenna, and then detected at the 36 m antenna that would count as one movement. If that fish was then detected back at 25 m, and then again at 36 m, that would be two additional movements, for a total movement of three.

Relationships between discharge, stream temperature, stream gradient, time of day, size of fish, the location of a movement, its direction, available movement, and the amount of movement (the total number of times a grayling was detected moving from one antenna to another antenna within a specific discharge) were examined to evaluate grayling movement in the newly created WIS nature-like fishpass. For all tests I chose a critical p value of 0.05 to indicate significance.

Adult grayling - I conducted a 3 x 3 Chi Square Test to assess if there were differences in the overall pattern of grayling movement. I compared upstream movement, downstream movement, and no movement across Background, Medium, and High Flows. I then used a General Linear Model (Minitab 2013) to determine if total movement (per fish) varied between stream sections for each discharge. I transformed (log (x +1)) the variables because the untransformed data were not normal and the variances were not homogenous. Stream sections are defined as the portion of stream that starts at one antenna and finishes at an adjacent antenna, e.g., the lowermost stream section I examined was from 25 m to 36 m upstream from Lac de Gras. Thus, I examined five stream sections in total (Figure 10). I used the Tukey pairwise comparison Method with 95% confidence to assess differences between sections.

To determine if size of fish was related to movement, I conducted linear regressions for each discharge, comparing the length of grayling to the number of times these grayling moved. I also used a polynomial regression on transformed data (log (x+1)) to determine if stream temperature was related to movement separately for the high and medium flows, comparing water temperature, separated into 0.1 degree increments, to the amount of fish movement for each temperature increment. To determine if there were diel patterns to fish movement, I used a Chi square test to compare the overall observed movements of adult grayling for the time frame from 6am to 6pm against the overall observed movements of adult grayling for the time frame 6pm to 6am, the time periods examined by Cahill et al. (2016).

To see if there were potential bottlenecks to upstream movement in WIS by grayling, I recorded the number of times grayling were detected at each of the five lowermost PIT antennas (25, 36, 45, 52, and 68 m), compared to the number of times they were detected at the antenna immediately upstream. I then used a G test, with multiple comparisons, to determine if there were differences in successful upstream passages among the five locations.

Young of Year Grayling – I conducted a single factor ANOVA followed by a post hoc Tukey test to see if the overall average distance moved (upstream or downstream) by YOY grayling, stocked at either 38 m or at 68 m above Lac de Gras, differed among recapture days. I then used a T-test to determine if the final net average movement for YOY was significantly greater than zero for both the 38 m and the 68 m groups.

3.0 Results

3.1 Initial Assessment Prior to Stream Manipulation

The initial assessment conducted prior to our stream discharge manipulation used field observation (June 27 and July 5, 2014), minnow trapping (June 4, June 5, June 28, and July 3, 2014), and electrofishing (June 7, and June 27, 2014). The results revealed that several fishes native to the WIS catchment were using the nature-like fishpass prior to flow manipulations (Table 4). Among the smallest fishes, Ninespine Stickleback (*Pungitius pungitius*) and Slimy Sculpin (*Cottus cognatus*) were limited to the lowermost 33 m of WIS, likely populating the stream from Lac de Gras. At the upstream end of WIS, Slimy Sculpin were captured in the uppermost 77 m, immediately downstream of WIL. In contrast, Young-of-year Burbot were observed throughout the length of WIS, probably originating from WIL. Among larger fishes, juvenile Arctic Grayling, juvenile Round Whitefish, and juvenile Lake Trout were also observed occupying pools in the lower reaches of WIS, with some trout and grayling being observed up to 85 m above Lac de Gras. Like the small-bodied fishes, the weaker swimming whitefish were never observed beyond 33 m upstream of Lac de Gras. In addition to these 2014 pre-manipulation samples, a single adult grayling was captured 286 m above Lac de Gras during a July 2013 electrofishing survey (unpublished data).

3.2 Stream Flow Manipulation

During the flow manipulation experiment, stream temperatures in the lower WIS averaged 12.8°C at base flow (1 $L \cdot sec^{-1}$), but were ca. 2.6°C cooler during the pumping periods, due to the addition of cooler water from Lac de Gras (Kupferschmidt 2015; Table 3). During the background flow there were two fatalities when adult grayling became stranded in shallow water. There were no fatalities recorded at the medium flow, and one recorded at high flow, when a fish was removed opportunistically by a fox (Kupferschmidt, pers. obs.).

The proportion of stocked adult grayling that moved differed significantly under the three flow regimes ($x^2 = 51.8086$, df = 4, $P < 0.001$). In particular, there were significantly fewer individuals that moved (upstream and downstream) at background vs. medium and high flows (Figure 12). Because of the lack of grayling movement at the background flow, subsequent analyses of movement involved only the medium and high flows.

A preliminary GLM analysis with section, flow, and the interaction between section and flow as factors determined that only section was significant (GLM, F(section) = 11.30, F(flow) = 0.78, F(section*flow) = 0.96, p(section) < 0.001, p(flow) = 0.378, p(section*flow) = 0.43). With this information we dropped flow and ran our final model using only section and determined grouping information using Tukey pairwise comparison method with 95% confidence (GLM, F = 11.32, p < 0.001) (Figure 13). The results showed three groupings, with significantly more movement in the lowermost section, 25-36 m, and the least movement in sections 36-45 m, 52-68 m, and 68-80 m. The remaining sectin, 45-52 m, experienced intermediate movement (Figure 13).

I found significant differences among sections in how often Arctic Grayling successfully ascended upstream from one PIT antenna to the next relative to the number of times grayling had the opportunity to swim upstream for both the medium (G(w) = 146.76, df = 4, $P < 0.001$) and high flows (G(w) =145.05, df = 4, $P < 0.001$). For both flows, a multiple comparison test identified the 25 – 36 m section as having the highest success (high flow 71/86 = 82.56%, medium flow 83/101= 82.18%), whereas the 36 to 45 m section had the lowest success (high flow 8/95 = 8.42%, medium flow 9/106 = 8.49%) (Figures 14 and 15).

There was no significant relationship between amount of movement and fish size at medium flow ($r^2 = 0.006$, df = 28, $P = 0.678$) and only a marginally significant relationship at high flow ($r^2 = 0.111$, df = 28, $P = 0.071$) (Figures 16 and 17). Polynomial regression of temperature vs movement showed that the cubic models were significant I found that both the quadratic and cubic models were significant, providing the highest R2 for both medium flow ($F_{3,57} = 15.76$, $P < 0.001$) and high flow ($F_{3,57} = 14.34$, $P < 0.001$) (Figures 18 and 19) For both flows I found higher movement frequencies at intermediate temperature (ca. 12°C and 10°C at medium and high flows respectively. I also found that Grayling moved significantly more during the evening to night hours (6pm to 6am) than in the morning to afternoon (6am to 6pm) hours (X2 = 10.485, df = 1, $P = 0.0012$) (Figure 20). Closer examination of the data showed that the bulk of movement occurred between 12 noon to 12 midnight, with the peak of movement occurring between 6 to 9 pm for both flows.

3.3 Young of Year

Young-of-year grayling were released at 38 m (n = 27) and 68 m (n = 28) above Lac de Gras and monitored four times over a one-week period. After one week, 25 of the 27 YOY released at 38 m were recaptured, and 27 of the 28 YOY released at 68 m were recaptured, with their recapture locations recorded. The YOY not recaptured (two released at 38 m and one released at 68 m) were not included in subsequent analysis. Although a few fish moved upstream from their release points, there was a net movement downstream for both groups (Figure 21); some fish in each group travelled successfully all the way down to the block net, 10 m above Lac de Gras. Fish released at 68 m moved an average of 13.3 m downstream over the week, while the fish released at 38 m moved an average of 9.7 m downstream. Final net downstream movement, both for the 38 m ($t = -5.08$, $df = 25$, $P < 0.001$) and 68 m ($t = -3.55$, $df = 24$, $P = 0.001$) groups, was significantly greater than zero. Net movement did not differ among days for the group released at 38 m (One way ANOVA: $F_{3,98} = 0.28$, $P = 0.843$), while there were marginal differences in movement rates for the YOY released at the 68 m pool ($F = 2.44$, df (3,88), $P = 0.07$). A post-hoc Tukey’s test show that the net movement on the first day (July 27, 2014) was significantly ($P < 0.05$) less than movement on the final day (August 2, 2014).

A full length survey of WIS was conducted Aug 2-4, 2014, at low summer flows (approx.1L/sec). The survey revealed 5 locations were small waterfalls may impede

YOY downstream movement. The tallest of these waterfalls were 18.5 cm and there were two of them, located at 43 m and 155 m above LDG. These were followed by a 15.5 cm falls at 228 m and 14.5 cm falls 35 m above LDG. Finally there was an 8.5 cm falls 73 m above LDG. Of these falls, YOY successfully migrated downstream over the 18.5 cm falls and the 14.5 cm falls located 43 m and 35 m above LDG respectively.

4.0 Discussion

The 2009 and 2010 assessment, prior to stream modification, revealed that limited numbers and species of fish naturally used WIS, and only in the upper- and lowermost 15 meters, close to their source lakes (WIL and Lac de Gras, respectively (M. Hulsman, unpublished data; Table 1). The rest of the stream was not accessible to fish due to braiding, shallow overland flow, and a series of cascades, all considered barriers to fish movement. After stream and channel modification, the initial post-construction assessment showed that fish continued using WIS. Many fish, particularly the smaller species (Ninespine Stickleback, Slimy Sculpin) or juveniles of larger species (Burbot, Round Whitefish, Arctic Grayling, Lake Trout) were restricted to the lower 33-38 m and/or upper 80 m of WIS, close to their source lakes (Lac de Gras and WIL, respectively). However, some juvenile Lake Trout and Arctic Grayling successfully migrated upstream from Lac de Gras through the entirety of the steepest, and likely most challenging, stream reach (the lowermost 90 m). All these observations suggested that the fishpass was navigable (at least to somewhat larger fish), that it was attracting fish, and that some fish were using it.

Notably, one adult grayling was captured 286 m above Lac de Gras. Because extensive sampling efforts over several years (2010 to 2014) (short set gill netting, angling, and electro-fishing) did not reveal the presence of Arctic Grayling in WIL (M. Hulsman, C. Cahill, and W. Tonn, unpublished data), this fish most likely came from Lac de Gras. Furthermore, the stream channel above 286 m is characterized by gentle gradients that should pose no challenges to fish movement, suggesting that some grayling, the target species of the WIS fishpass, could navigate the entire length of the newly created fishpass.

In both 2013 and 2014, prior to flow manipulations, I observed substantial numbers of young-of-year (YOY) Burbot migrating downstream from WIL and tracked their progress as they made their way downstream through the entire WIS and into Lac de Gras. This was a critical observation, because Burbot are considered to be poor swimmers relative to grayling (Deegan et al. 2005; Jones et al. 1974). Therefore, the observation of YOY Burbot successfully migrating downstream through WIS provided strong circumstantial evidence that YOY grayling should also be able to use and move throughout WIS, including end-of-summer migrations downstream out of WIS to overwinter in Lac de Gras, as is typical of Barrenlands stream populations (Jones et al. 2003a), since these streams, including WIS, freeze solid during the Arctic winter.

After the initial assessment, the WIS flow manipulation experiment revealed several interesting results. First, grayling were resistant to move out of pools at the summer background flow of 1 L/sec, but when discharge was elevated to 9.8 L/sec, grayling movement was pronounced, and this movement was maintained when discharge was elevated again, to 22 L/sec. This suggests that even though grayling often use shallow streams (< 1m deep) (Northcote 1995, Stewart et al. 2007), they appear to need a certain base discharge before they will move. This idea of movement being associated with discharge was echoed by Bryant et al. (2009) for Dolly Varden and Cutthroat Trout and by Cahill et al. (2016) for Arctic Grayling.

In addition to discharge, water velocity and seasonal timing such as the approach of a fish spawn, can trigger movement (Huntsman 1948, Asplund and Sodergren 1974, Callihan et al. 2015). Note, however, that while fishpasses can facilitate Arctic Grayling movement, grayling will typically move if slopes are less than 4% and water velocity does not exceed 60 cm/sec (Vincent 1962, Jones et al. 1974, Deegan et al. 2005). Grayling, however, are capable of burst speeds of 162 cm/sec to 213 cm/sec per the Stewart et al. (2007) study, while Behlke et al. (1998) found that Grayling could pass through a 33.5 m culvert with average velocities up to 194 cm/sec. Courtice et al. (2016) found the most challenging sections to fish passage in WIS exhibited maximum velocities of 140 to 190 cm/sec, well within the capabilities of adult Arctic Grayling.

In northern environments, the snowmelt-related spring freshet has been considered the general environmental cue for Arctic Grayling to migrate into streams and spawn (Witkowski and Kowalewski 1988; Northcote 1995; Stewart et al. 2007). Freshet at this latitude begins quickly, dissipates fast, and its timing is variable from year to year (Bowling et al. 2003; Jones et al. 2003a; Courtice et al. 2014, 2016). Therefore, the window of time available for spawning is typically short, approximately 5 – 10 days (Jones et al. 2003b; Cahill et al. 2016). Cahill et al. concluded that for their 25-m nature-like fishpass, increased water depth, as a proxy for increased stream discharge, triggered movement up into a spawning channel at this time. I would expect a similar trigger in WIS, as it is only ca. 12 km from Cahill et al.'s study sites, within the Lac de Gras watershed.

Although occurring outside of the spawning season, my whole-stream field experiment echoed the findings of Cahill et al. (2016). At the summer baseline discharge of approximately 1 L/sec, adult grayling moved very little, staying in the pools into which they were stocked. In WIS, horizontal velocities from the pools under study were near zero at low flows, while at medium and high flows all pools studied had portions of water at or above 30 cm/sec (Kupferschmidt 2015). Among the pools in the lower 90m, only the pools located at 33 m and 38 m above Lac de Gras were of sizes suitable for fish (ca. 30 cm x 10 cm) that had portions at near zero velocities, with the larger deeper pool at 33 m being heavily favoured by fish (Kupferschmidt 2015).

At the low background discharge level, grayling trying to move could become stranded in the shallow waters available between pools; such stranding actually accounted for the loss of two fish (Fred Noddin, pers. obs.). With limited water depths at this low mid-summer stream discharge, the potential for predation also likely increases (Power 1987; Harvey and Stewart 1991) and could contribute to fish remaining in the deeper water of their 'home' pool. This idea is further supported by other studies that tie fish movement to discharge (Bryant et al. 2009; Heim et al. 2015).

Clearly, conditions that affect movement, including the movement toward spawning habitat in these small Barrenlands streams, is directly related to the seasonal short-term discharge created by freshet. The timing, duration, and the intensity of the freshet is strongly influenced by the timing, rate, and total amount of snowmelt in the catchment area during spring (Baki et al. 2012; Courtice et al. 2014). An understanding of the catchment area required to reach and maintain a stream flows of at least 9.9 L/sec (the medium flow in my experiment) would enhance a manager's ability to evaluate potential compensation sites where the goals of the compensation program would be to increase fish movement and provide access to spawning habitat.

There was little or no relationship between total fish movement and grayling size across the size range of fish I used (20-41 cm TL). This result is consistent with Cahill et al. (2016), who also found no relationship for grayling > 15.0 cm FL. Ultimately, it is grayling from Lac de Gras that are expected to establish the founding population for WIS and there is potential that some of those fish will be larger than the fish I used from M-lakes given that LDG is a much bigger lake. With the caveat associated with extrapolating beyond the sizes used in my study, there is no indication that the discharges available in WIS during its freshet would limit the ability of larger grayling from entering and using the stream.

Besides life history cues associated with, e.g., spawning, fish movement often increases with increased stream temperatures (Ford et al. 1995; Heim et al. 2015). Although WIS is a lake outlet stream, which may mute diel temperature fluctuations (Jones et al. 2003a; Cahill et al. 2016), an expansive shallow-water area (< 3m) in the upstream lake and/or direct daytime heating of these shallow headwater streams (my study site was ca. 350 m downstream of WIL) can translate into diel temperature fluctuations of ca. 10 ^{o}C (Baki et al. 2012). Stream temperature in WIS varied by ca. 6 ^{o}C during my study, however, and nearly half (2.6 ^{o}C) of that variation could be accounted for by my pumping colder Lac de Gras water into WIS to artificially increase flow rates. There was a relationship between temperature and movement, with movement being most pronounce at intermediate temperatures, however, these intermediate temperatures, which were around 10°C and 12°C, were the temperature condition that was most available to the grayling during the manipulation, and was likely the reason why movement was most pronounced at these values. As well, Deegan et al. (2005) found that metabolic rates of young Arctic Grayling increase sharply above ca. 12°C.

One significant finding, however, was the relationship between grayling movement and time of day. Similar to Cahill et al. (2016), I found that a majority of fish movement occurred during the lower light periods, 6 pm to 6 am. It is plausible that with reduced light, the perceived risk of predation may also be reduced (Power 1987), therefore promoting greater fish movement. As well, much of my field observations and work occurred during regular daylight hours, and perhaps our presence at the stream, however minimal, was enough to disturb the fish and keep them in their pools.

Movement was also not distributed equally throughout the five stream sections examined. Most of the movement occurred in the lowermost stream section (between PIT antennas 25 m and 36 m). This section was characterized by a low gradient (ca. 2%) and contained two of the stream's largest pools, allowing fish both ease of passage and plenty of holding water in which to rest.

In contrast, one of the most challenging sections for fish passage was between 36 m and 45 m, with a passage efficiency of only 8.4%. This section had both the steepest gradient (ca 3.8%) and a narrow "V" shaped slot-like structure where two large rocks were placed together (Figure 22), through which fish rarely moved, upstream or down. Understanding that this section posed a bottleneck for upstream migration should facilitate the building of better fishpasses in the future. My recommendation would be to avoid structures that create particularly narrow “V” slots, which should help ensure that fish do not get pinched into the tight space created near the bottom of the “V”. Otherwise, placing boulders near each other to constrict stream flow is a common and widely practiced technique; these structures help maintain stream depth and stream velocity, even at reduced flows (Courtice et al. 2014), which then encourage and facilitate fish passage for a longer period of time (Cahill et al. 2015). The section between 52 and 68 m was also challenging, and the likely reason for this was the 3 meter portion of stream that exhibited a large, expansive, and shallow flow, which likely deterred fish passage.

While I was able to assess various aspects of Arctic Grayling movement, little of this would have been possible without the installation and use of field PIT antennas and PIT tags. When combined with a solar panel recharge system, the antennas were able to operate continuously, even when crews were not in the field. The PIT tagging monitoring system has tremendous value, including remotely monitoring fish movement in small streams, and can help answer many questions relating to fish movement and fish life history (Zydlewski et al. 2006).

PIT tags have been used to assess movement behaviour and habitat use of salmonids (e.g. Rainbow Trout and Cutthroat Trout) in fast flowing streams to gain a better understanding of how fish use a network of streams within a given watershed (Connolly et al. 2005). Their use has contributed valuable data on fish life history, e.g., helping to determine the timing of spawning runs (Achord et al. 1996) and the outmigration of juvenile fish (Adams et al. 1997, 1998; Achord et al. 2012). They have also helped establish spillway survival rates (Eppard et al. 2005). PIT tagging has indeed been a valuable addition to the study of fish and fish movement.

Young-of-year grayling introduced from a nearby reference stream were observed feeding in and migrating downstream, even through the steepest sections of WIS, including vertical drops. In fact, they successfully migrated downstream over drops of 14.5 - 18.5 cm, located at 43 m and 35 m respectively. Being able to successful migrate over these falls suggests that all vertical drops present in WIS can be successfully navigated by YOY grayling and therefore, there were no vertical drop barriers to their downstream migration. Furthermore, the visual confirmation of feeding behaviour and the fact that these fish appeared to easily survive a week during the WIS study, suggests that the stream can be effectively used for rearing.

Small stream nature-like fishpasses, guided by ecological engineering, can enhance waterway connectivity and facilitate fish movement (Calles and Greenberg 2005; Palmer et al. 2005), which often leads to greater overall productivity (White 1996; Roni et al. 2008). Nature-like fishpasses can improve passage efficiencies for a wider variety of fish species when compared to other, more traditionally engineered fishpass designs such as the pool and weir (Calles and Greenberg 2007; Steffensen et al. 2013). With properly built nature-like fishpasses, fish need not have to jump over weir-like structures to move from one location to another, which was likely a contributing factor to the lack of fish passage at the V-notch structure in our study. This increased access to aquatic habitats can contribute to (or preserve) a more complex, and therefore a likely more resilient, fish community. Well-constructed nature-like fishpasses operate successfully at a variety of discharge rates, improving their functionality by lengthening the period of time during which fish can migrate up and down a channel (Courtice et al. 2014). This is often important in headwater streams in Arctic environments, where passable conditions during spring freshet can be quite limited temporally (Baki et al. 2012).

While the benefits of successful stream habitat improvement are generally acknowledged (increased productivity, higher biomass, greater connectivity, enhanced community complexity (Hunt 1969; Hunt 1976; Bradshaw 1996; Scruton 1996; Courtice et al. 2014)), it is important to note that measures of restoration success may be interpreted differently based on the temporal scale at which projects are being evaluated (Hunt 1976; Bond and Lake 2003; Marttila et al. 2016), with the anticipated benefits not necessarily immediately evident from short-term monitoring (Hunt 1976; Jones et al. 2003b; Nilsson et al. 2014). For example, the Barrenlands fishway studied by Scrimgeour et al. (2014) had only partially converged in structure and function with nearby natural streams, even 14 years after construction, given the short low-Arctic growing season. I expect that this too, will be the case for WIS, where no spawning population had yet established themselves. At the time of this study, evidence of a couple of Grayling using the stream were discovered. However, more time will be needed for enough Grayling to find the stream before a self-sustaining population of fish can be founded. Therefore, like what has been echoed in the Nilsson (2014) study, the desired results may require a longer-term mindset before full productivity goals may be achieved.

Hindsight and Insights

Work in remote northerly locations can be a logistical challenge, where time, funds, and resources can be limited. Oftentimes this work is done in partnership with an industry where mobilization, set up, and field work occurs at a company site. The relations you have with their staff, most typically their environment staff, are often key to the outcome of your field season. Invest time and energy into this relationship and your time on site will likely go much smoother and be far more productive. I would recommend you consider the following:

1. Request to be on site up to two weeks ahead of your planned field work. Find out about required training, induction, and the certificates you will require prior to going to site, and what you will need to do at site. Ask to receive training for certificates for any equipment you may use regularly. For us that meant obtaining our drivers and our boating certificates. Build this into your schedule. Most of the material you will learn at site is built around site orientation and safety standards.
2. Test out your equipment before trying to use it. For our project we were installing PIT tags and antenna arrays, so we went through the entire set up and functioning process of our systems in a large field lab on the mine site. We were able to trouble shoot our equipment so we could ensure it was fully functional before heading out into the field.
3. Add value to your presence, get your PAL. A lot of remote field work requires the accompaniment of a wildlife monitor. You can help by ensuring you and your crew have firearms training and having earned your possession and acquisition

licence (PAL). Besides having the certificate, you should also know and understand how to safely use these firearms. Within your crew you can then be your own wildlife monitor, thereby reducing the need for the company to either hire, or reassign someone from their department to your project. This will save them time and resources and they will appreciate it.

4. Add value to your presence, be your own supervisor. For this project we were based at a mine site, however, we did our work at remote sites, which requires that there be at minimum one wildlife monitor, and one supervisor. We asked if we could study for and take the Mine Supervisor, Level 1 test. We were granted this, to which all our crew studied for and were successful at getting our entry level Supervisor certificate. Now our crew could be a self-contained unit, where we had the ability to go off site, and be our own supervisor and wildlife monitor. This freed the host organization from having to provide up to two additional full time personnel to our project.
5. If you are pumping water, you will likely need a water permit. This one caught the mine staff and our research team by surprise, but thankfully Diavik flew out NWT mine inspector Tracy Covey (part of that investment into good relations) within the week, to our site and we had our water permit approval done the same day.
6. The value of volunteers. While it was not formally written, we approached management from the mine to approve a request to bring several volunteers during the labour intensive part of our project. They approved our request and

we were able to bring up several additional people to help out, which ultimately reduced worker fatigue and improved comradery.

7. Monitor fatigue. Field work is long hours, lots of days in a row, and little rest in between. Add in challenging weather and lots of biting insects. Therefore, keep a close eye on each other and if possible, build in a short day, or if possible, a day off for each crew member. A bit of personal time, an ability to sleep in, goes a long ways toward keeping morale high, and everyone motivated.
8. Build on the experience of others. Most of the work we do in the field has been done by someone else. Talk to this person, learn from them. If possible meet them face to face. They will give you countless tips and tricks that will make your work immensely easier. I spent a great deal of time with Chris Cahill, who built PIT tag antenna arrays very similar to mine and his advice helped me with how I was going to set up my experimental design, and how I was going to put my antenna systems together, including bear fences around your equipment.

And finally, take a moment to enjoy where you are. It just makes sense to take time and connect to these places, because they truly are special and for us, we are fortunate that for a period of time, we get to work and play there.

5.0 Conclusion and Recommendations

Important lessons learned from my Barrenlands whole-stream experiment included:

1. It may take longer than two seasons for a founding population of Arctic Grayling to find and use a newly created nature-like fishpass. While I found a single adult grayling using WIS in 2013, and a juvenile grayling in 2014, more time will be

needed to properly evaluate whether grayling will naturally establish a founding population, and to what extent they are using the fishway for spawning and rearing young-of-year.

In light of this, I highly recommend that the monitoring of northern projects go beyond the initial time frame of a couple years. Recovery of habitat after modification occurs slowly in the north, so while it is sensible to have an initial two year assessment and monitoring period, I suggest that longer term project evaluations be built into the workings of such proposed projects. To garner true value of the long term success of such projects, I would ask for site follow up at 5 and at 10 years post modification to see how well the modifications are holding up, and whether the intended functions of a fishpass are being maintained. If there is no long term success, then there is no point attempting the modification in the first place. Also, there could be a different suite of challenges uncovered at those time intervals that may not be immediately evident within the scope of a two year evaluation.

Superficially, the Ekati nature-like fishpass (Jones et al. 2003b) could be considered a contradiction to my first point. At Ekati, grayling migrated into, spawned, and recruited young-of-year in the first year after fishpass construction. This fishpass, however, replaced the one and only natal spawning stream for an existing population resident in the downstream lake, and the location of the fishpass was close to where the previous stream existed. In short, there was an established grayling population that had nowhere else to go. In contrast, there was no pre-existing grayling population that had used WIS, therefore, WIS requires a brand new founding population that first needs to find WIS, before spawning and rearing can be expected.

2. PIT tagging and the use of in-stream antenna arrays are excellent, moderately easy means to evaluate fish movement, even at remote field sites.
3. At least some adult Arctic Grayling could successfully navigate the most challenging sections of the WIS nature-like fishpass at flows of 10-22 L/sec, which gives grayling a window of ca. 22 days to move into and out of the fishway during the spawning season, based on recorded flow rates in WIS during 2014 (June 4-26). This period corresponds to the timing of grayling spawning in nearby reference streams, suggesting that the period of suitable discharge would be sufficient to accommodate a spawning run.
4. The steepest section of the fishpass (36 m - 45 m upstream of Lac de Gras) was considered a bottleneck for fish movement. While this stream section was the steepest (ca. 4%), a single “V” shaped wedge channel created between two opposing rocks appeared to be the main reason behind this bottleneck. Of the grayling that reached the 36-m antenna, < 9% successfully made it upstream to the 45-m antenna; whether the attempts of the other 91% to pass this structure failed or whether they simply did not make the attempt cannot be determined from the PIT detection system.
5. The stream section from 52 to 68 m above Lac de Gras could also be considered a bottleneck to movement, although to a lesser degree than the V-notch. This section was characterized by gentle gradients, however, there was a area of the stream, ca. three meters long, where the stream current velocity

slowed, the channel widened, became very shallow, and silted in. Two grayling were stranded and lost in this area at low flows, and it is a likely reason why there was low passage efficiency by grayling through this section at medium and high flows.

The YOY results suggests that, should spawning and hatching occur successfully in WIS, rearing and the eventual outmigration of YOY grayling would also be successful. The West Island Stream project provided a rare opportunity to experimentally evaluate a compensation project at a whole-stream scale. The findings from my study advanced our knowledge of small Arctic headwater streams, the capabilities of Arctic Grayling, the use of a nature-like fishpass in an Arctic setting, the effectiveness of PIT tagging and the value (and limitations) of such projects as a compensation tool. Such information should help managers make informed decisions on how best to design, implement, oversee, and evaluate future compensation projects. The results from this study should ultimately lead to the development of better strategies for the care and protection of fish and fish habitat.

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Appendices

Table 1. Summary of catch results for the 2009 and 2010 fish sampling program at West Island Stream (Mark Hulsman and W. Tonn, unpublished data). Dip net, minnow trap, and electrofishing sampling methods were used in both years to catch fish

Sampling Date	YOY Burbot	Juvenile Lake Trout	Ninespine Stickleback	Slimy Sculpin	Arctic Grayling	Round Whitefish
July 1, 2009			4	2		
Aug 8, 2010	6			2		

Table 2 – Summary of stream characteristics for each stream section.

Stream Section	Length (m)	Gradient	Stream Characteristics
25-36 m	9	1.2 %	Gentle slope. One prominent pool at 33 m, and a smaller pool at 29m. A rocky ramp structure lies at 34-36 m. At low flows the rocky ramp had a 14.5 cm drop.
36-45 m	11	3.8 %	Steepest slope, pool at 41 m, V-notch (a rock weir) at 43 m. At low flows the V-notch had an 18.5 cm drop.
45-52 m	7	3.6 %	Rock weir at 47 m with a pool at 46 m. Bottom is mostly gravel and cobble
52-68 m	16	2.7 %	Mostly riffles, two pools (68 m & 60 m). A 3 m section (54 m to 57 m) has broad shallow flow that has silted in.
68-80 m	12	2.3 %	Channel mostly riffles with two pools (70 m and 72 m). Substrate is mostly gravel and cobbles. A rock weir at 73 m.

Table 3 – Summary of discharge and temperature conditions for the flow manipulation movement experiment.

Flow Condition	Start Time	Mean Flow (l/s)	Mean Water Temperature (^{o}C)	Mean Fish Length (mm)
Background Flow	July 6, 2014 2:30 PM	1.0 (SD = 0.1)	12.8 (SD = 3.1)	330 (SD = 32)
Medium Flow	July 10, 2014 6:30 PM	9.9 (SD = 0.1)	10.2 (SD = 1.3)	300 (SD = 32)
High Flow	July 13, 2014 7:00 PM	21.9 (SD = 0.1)	10.2 (SD = 1.5)	290(SD = 39)

Table 4. Summary of fish sampling methods, sampling dates, and species captured at West Island Stream during 2014, prior to stream flow manipulations.

Method	Sampling Date	YOY Burbot	Juvenile Lake Trout	Ninespine Stickleback	Slimy Sculpin	Arctic Grayling	Round Whitefish
Visual Surveys	June 27, 2014		2	14	1		
	July 5, 2014	18		6	1	1	
Electrofishing	June 7, 2014			2	2		1
	June 27, 2014		2	19	9		
Minnow Traps	June 4, 2014						
	June 5, 2014						
	June 28, 2014			14	2		
	July 3, 2014	3		29		1	

Figure 1. Map showing location of the study area (red dot in insert), Lac de Gras, NWT, (Google Maps, 2015) and the compensation project's three study sites. A 370-m nature like fishpass was created in the 430-m West Island Stream (WIS) to enhance fish movement and habitat use. M Lakes provided the adult Arctic Grayling (*Thymallus arcticus*) used at WIS, to assess their ability to move throughout WIS under varying discharges. Reference 6 streams provided young-of-year Arctic Grayling to assess their ability to migrate down WIS at low flows, typical of late summer conditions. Also shown is the site of the Diavik Diamond Mine.

Figure 2. Prior to habitat modification, West Island Stream at spring freshet. The steep cascades section was considered impassable by fish, muting further upstream migration and habitat use. Photo by Mark Hulsman.

Figure 3. Prior to habitat modification, West Island Stream at low flow. The lower cascades section. Photo by Mark Hulsman.

Figure 4. Prior to habitat modification. A diffuse channel from overland flow at WIS. Photo by Mark Hulsman.

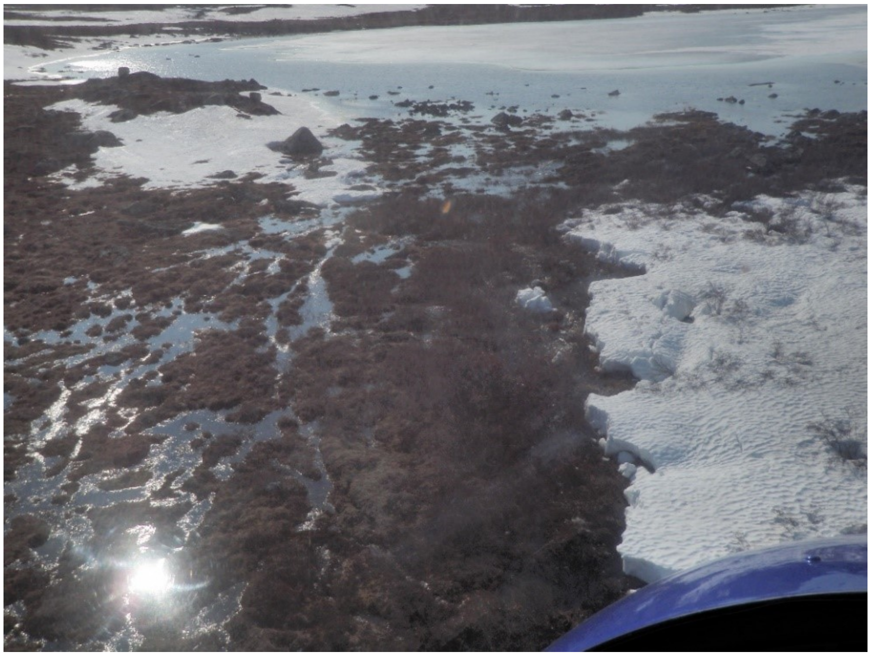

Figure 5. Prior to habitat modification. Photo from standing height. A view of the extensive braiding and broad overland flow of WIS. Photo by Mark Hulsman.

Figure 6. An adult Arctic Grayling, and the 23 mm half-duplex Passive Integrated Transponder (PIT) tag (red arrow), which was inserted into the body cavity, along the mid ventral line (blue arrow), halfway between the two pelvic fins, of the adult grayling used in the flow manipulation movement experiment.

Figure 7. Fish holding pen, 8’x4’x4’ with 3/8” mesh.

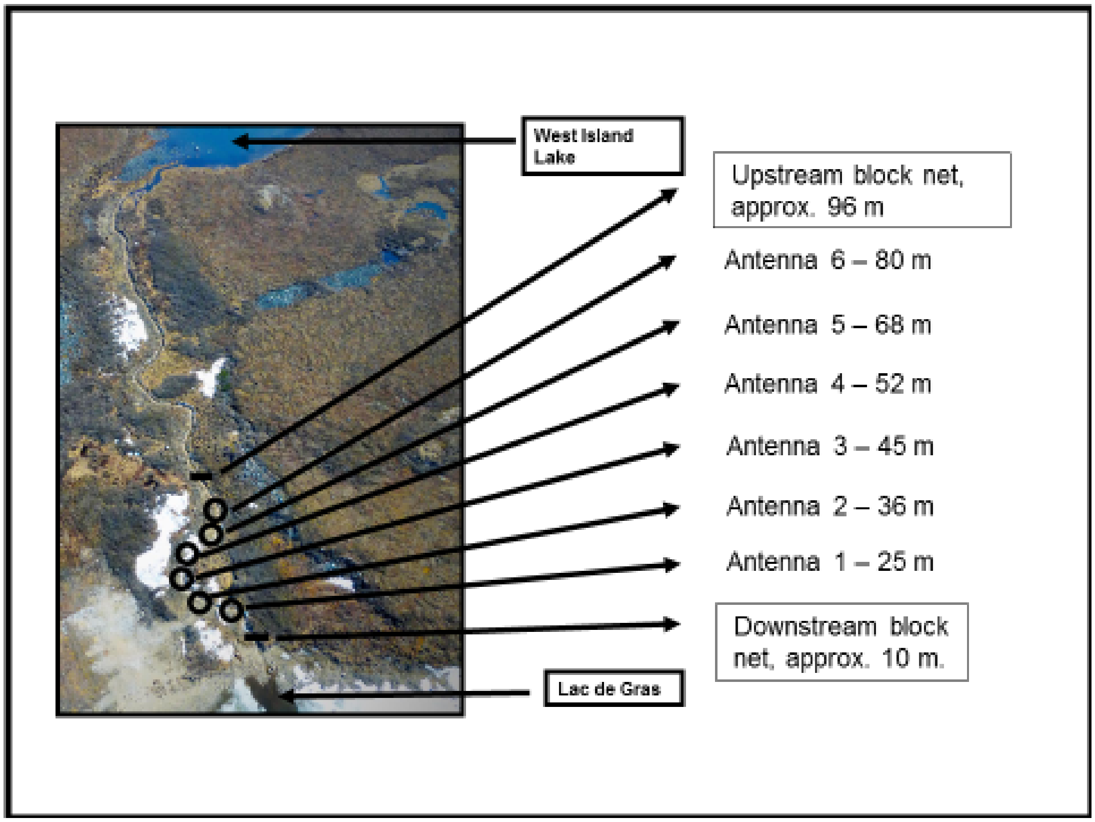

Figure 8. Aerial photo of West Island Stream (WIS), flowing 420 m from West Island Lake (top) to Lac de Gras (bottom). Locations (meters upstream of Lac de Gras) of antennas and block nets used for adult Arctic Grayling in the flow manipulation experiments are also shown.

Figure 9. Photograph looking upstream at two pass-through antennas in WIS (red arrows). The closest antenna in the photo is at 25 m upstream of Lac de Gras, while the antenna further upstream and toward the top of the photo is at 36 m upstream.

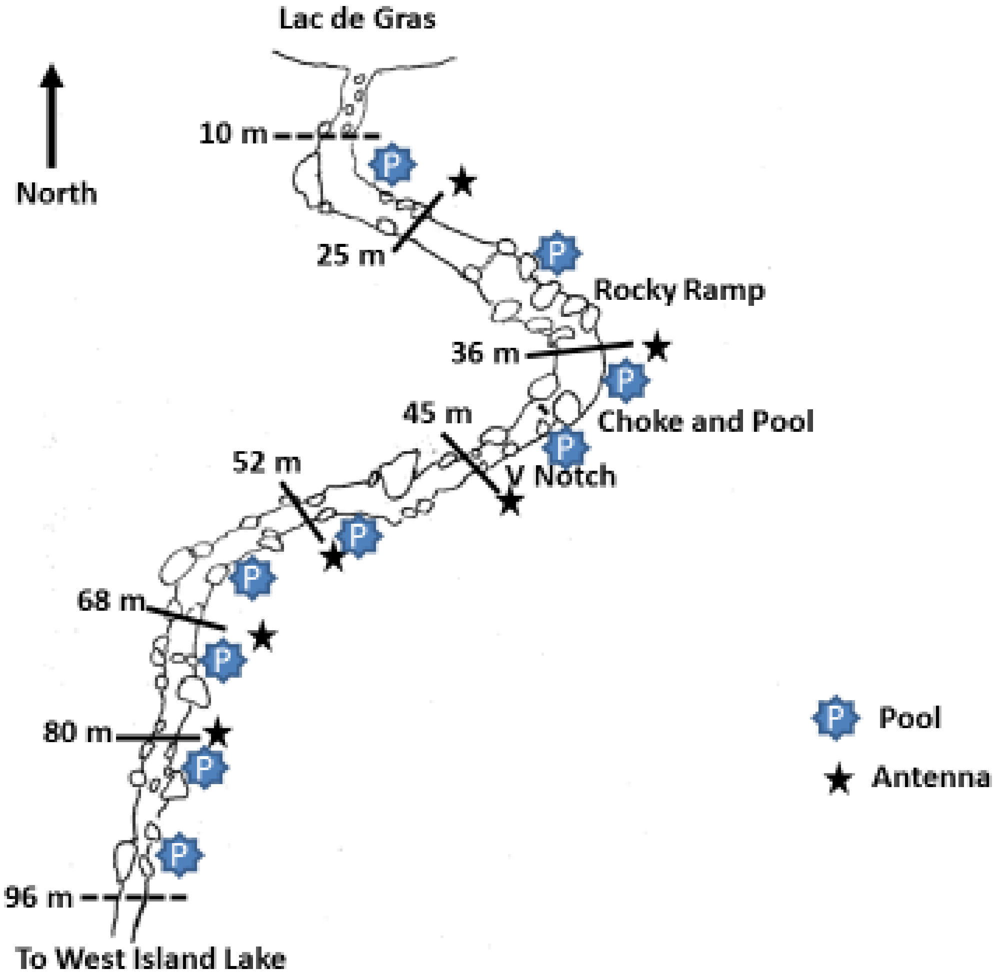

Figure 10. Diagram of the flow-manipulation study area of West Island Stream. The stream flows from West Island Lake to Lac de Gras. Block nets were placed at 10 m and 96 m (dashed lines) to contain movement of adult Arctic Grayling to within the study area. Major boulders, pools, antennas, and fishpass structures are identified, including a Rocky Ramp, Choke and Pool, and V-Notch structures. The V-Notch structure falls within the steepest section (36-45-m) of the fishpass, which experienced the lowest passage efficiency.

Figure 11. A young-of-year (YOY) Arctic Grayling with a partial upper-caudal fin clip (red arrow). This identified the fish as being released at the upstream release site, 68 m from Lac de Gras.

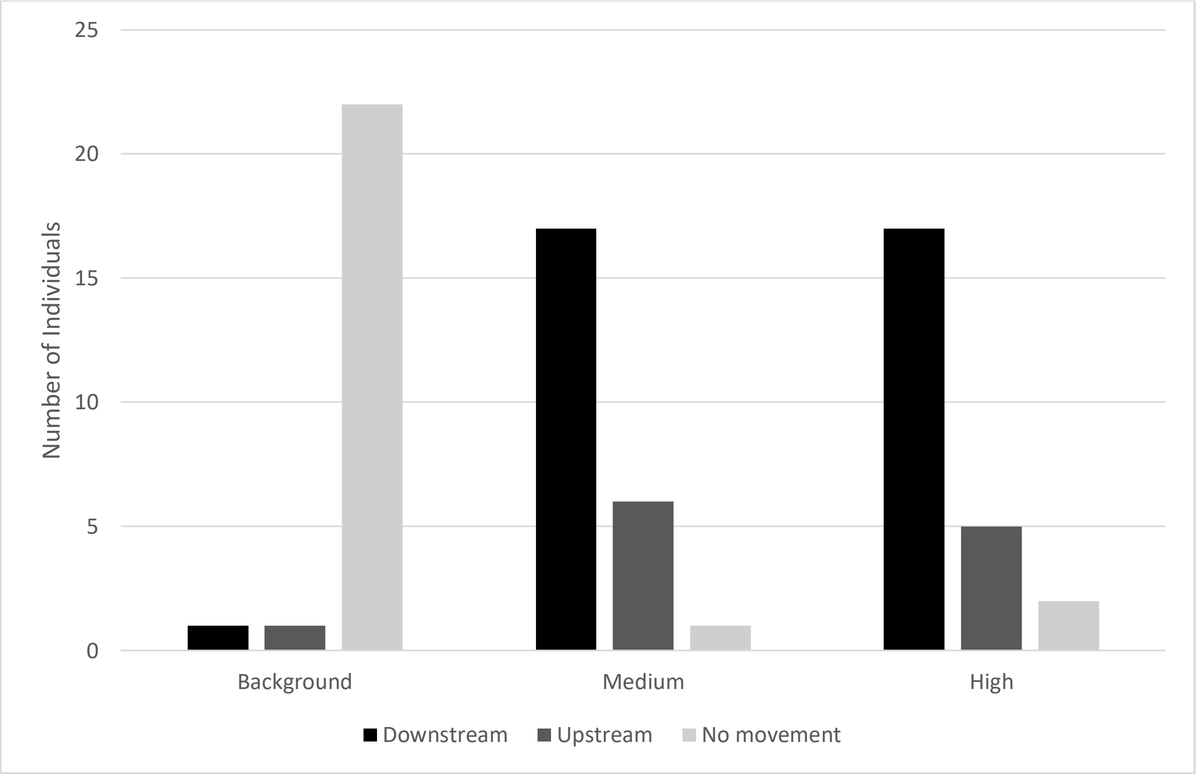

Figure 12. A summary of adult grayling movement direction from the point of release to the point of recapture, with the recapture of the stocked grayling being conducted at the end of each flow study period. No movement indicates that the grayling were recaptured in the same pool they were originally released.

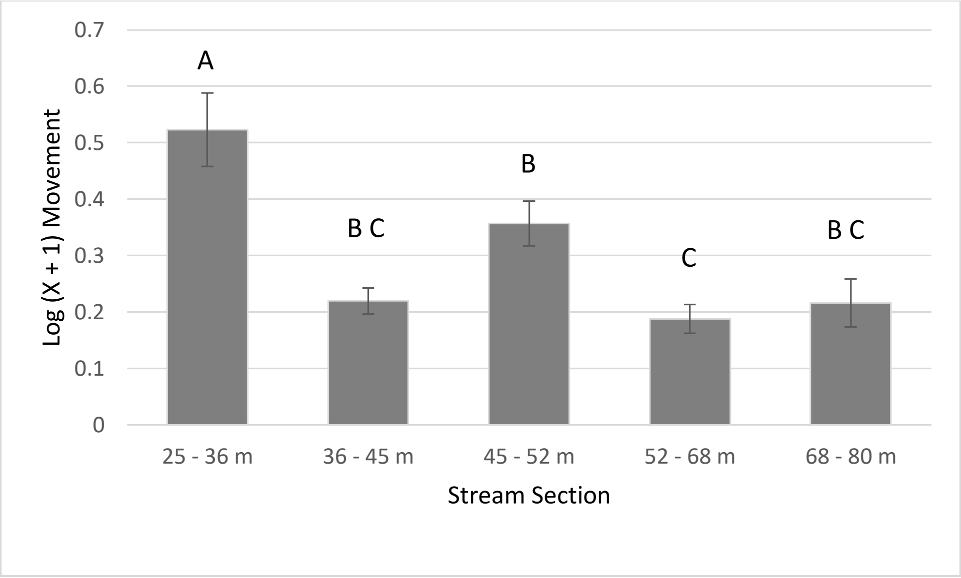

Figure 13. The average number (log (x + 1) transformed) of movements per adult Arctic Grayling differed among the five monitored stream sections at medium and high discharges (combined) (GLM, $F = 11.32$, $df_{(section)} = 4$, $df_{(error)} = 295$, $p < 0.001$). A preliminary analysis indicated that neither flow nor the interaction between stream section and flow was significant. Grouping information (A, B, and C) using Tukey pairwise comparisons and 95% confidence. Error bars are 1 standard error.

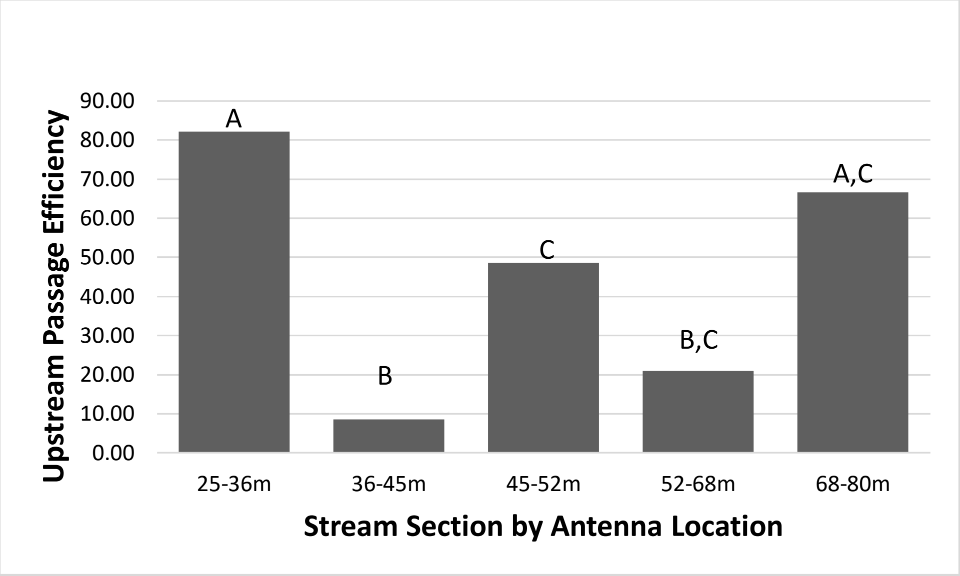

Figure 14. Upstream passage efficiency per section at the Medium discharge, i.e., the percentage of times that a grayling, when detected at the downstream antenna of a stream section, successfully swam upstream to the upstream antenna of that section. The letters A, B, and C denote groups that are statistically different (G test with multiple comparisons).

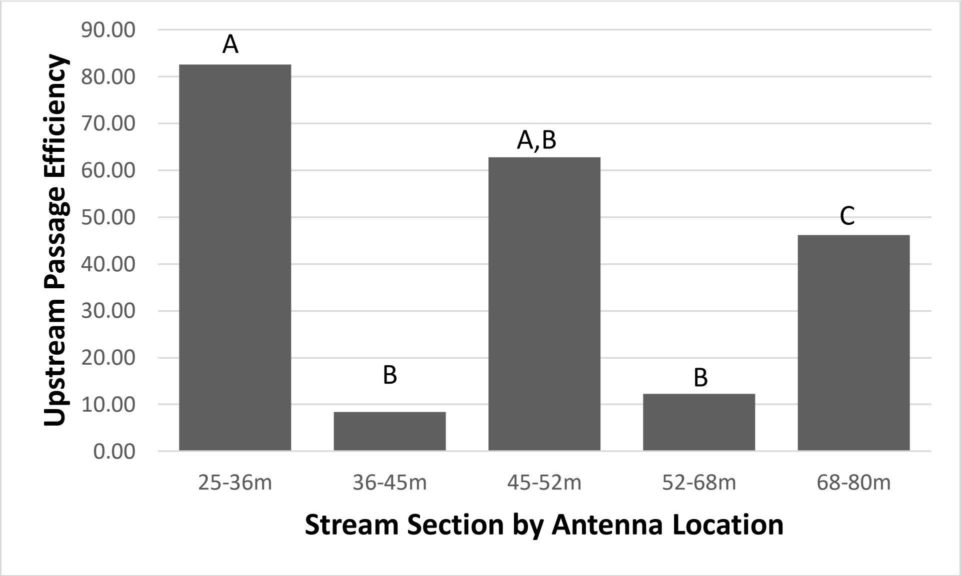

Figure 15. Upstream passage efficiency per section at the High discharge, i.e., the percentage of times that a grayling, when detected at the downstream antenna of a stream section, successfully swam upstream to the upstream antenna of that section. The letters A, B, and C denote groups that are statistically different (G test with multiple comparisons).

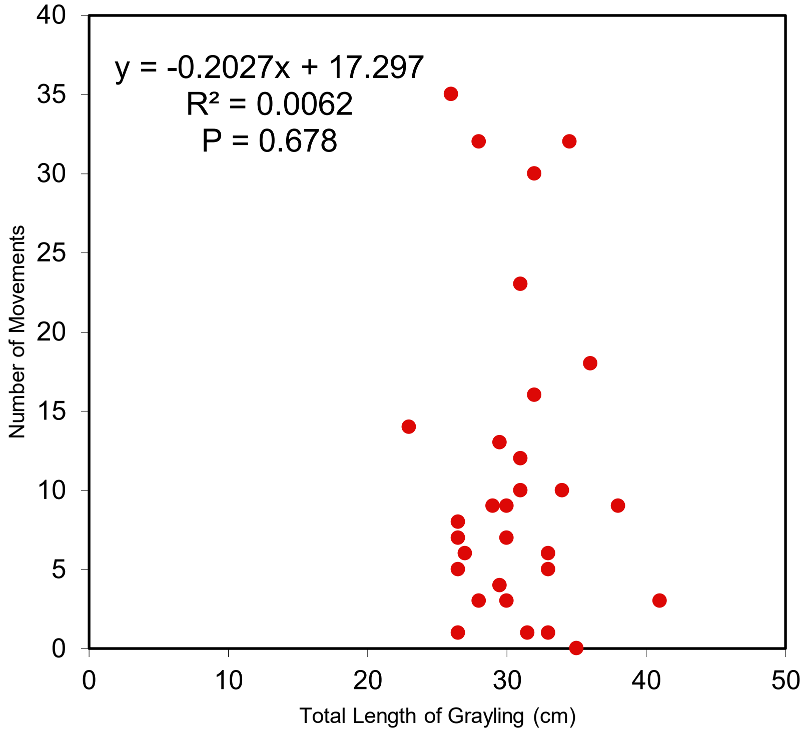

Figure 16. The relationship between total movements of Arctic Grayling and total length (cm) of Arctic Grayling at Medium discharge.

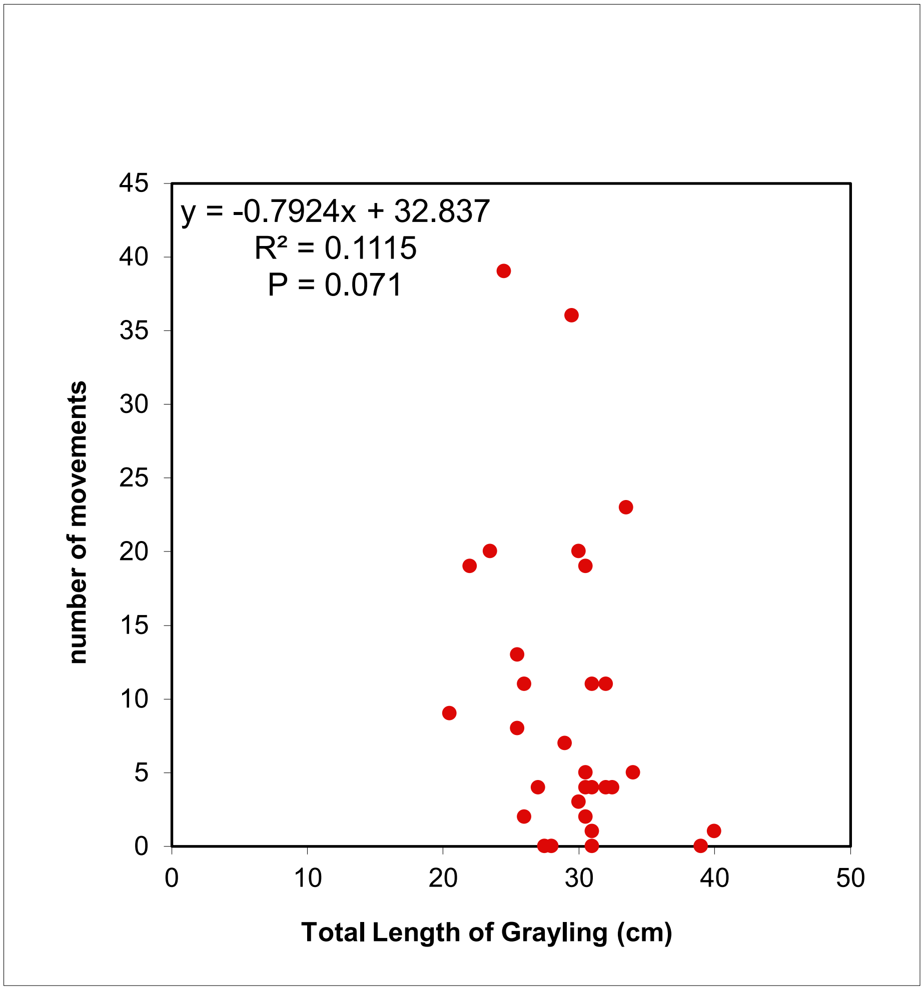

Figure 17. The relationship between total movements of Arctic Grayling and total length (cm) of Arctic Grayling at High discharge.

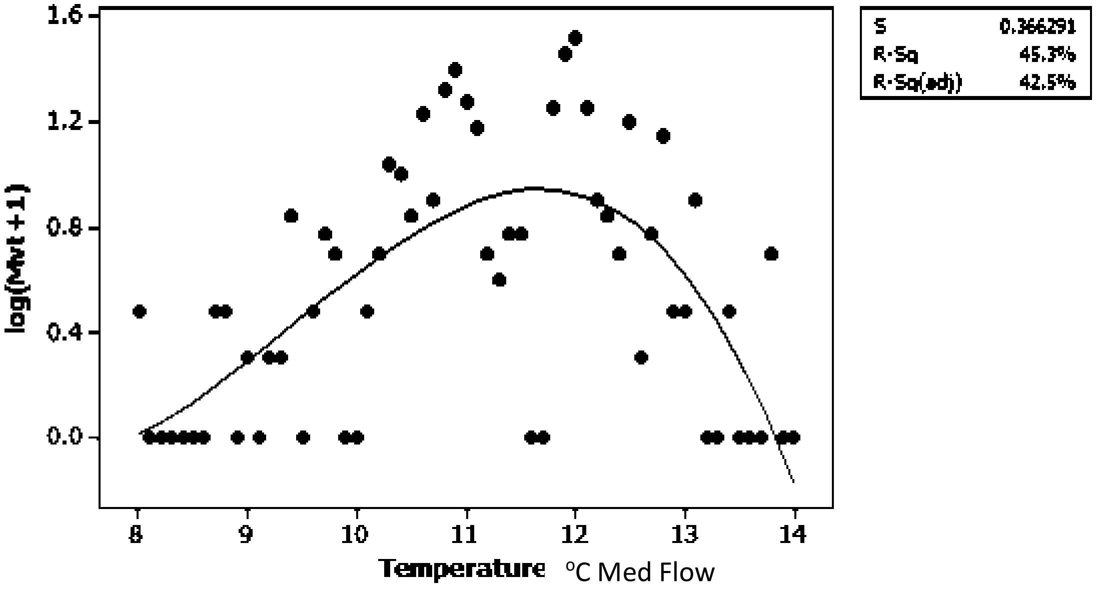

Figure 18. A cubic model polynomial regression showing a significant relationship between temperature (°C) and transformed (log (x +1)) movement at medium flow ($F_{3,57} = 15.76$, $P < 0.001$). (Log (Mvt + 1)) = 16.32 – 5.732 Temperature + 0.6436 Temperature **2 – 0.02274 Temperature**3. Highest movement frequencies are at intermediate temperatures, ca. 12°C.

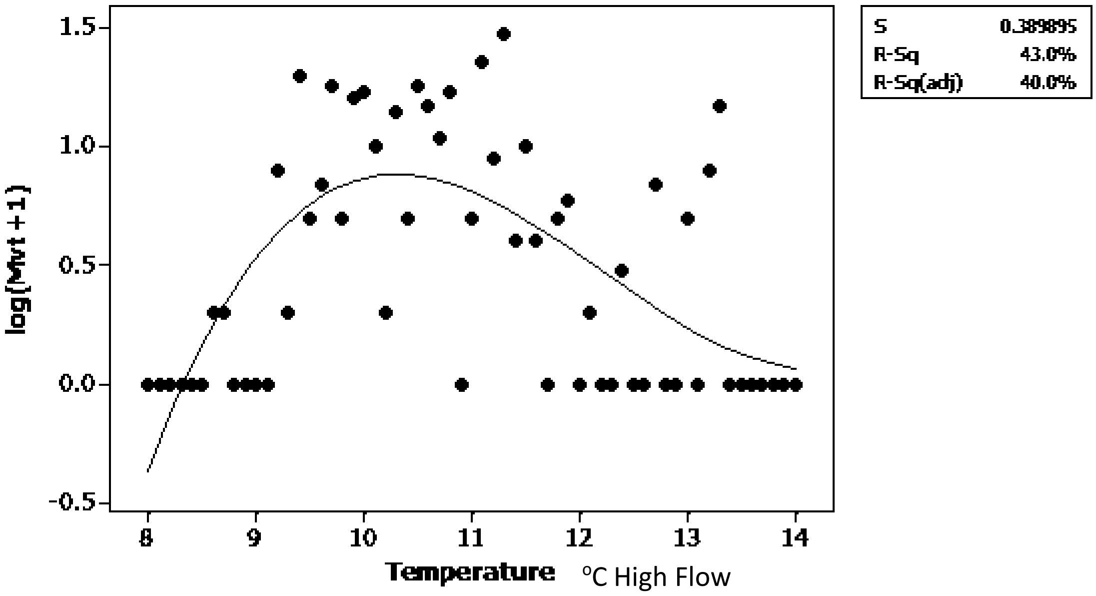

Figure 19. A cubic model polynomial regression showing a significant relationship between temperature (°C) and transformed (log (x +1)) movement at high flow ($F_{3,57} = 14.34$, $P < 0.001$). (Log (Mvt + 1)) = 49.23 + 12.85 Temperature – 1.078 Temperature **2 + 0.02940 Temperature**3. Highest movement frequencies are at intermediate temperatures, ca. 10°C.

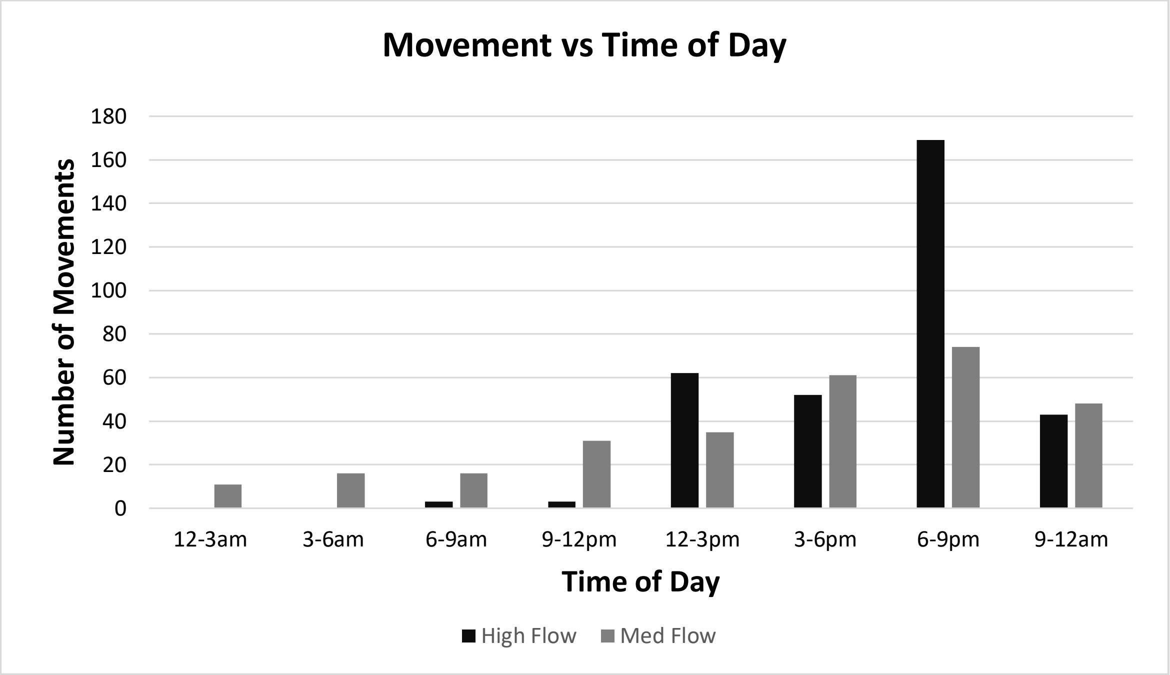

Figure 20. The distribution movements of adult Arctic Grayling, as grouped into three hour time blocks, during the Medium and High flows.

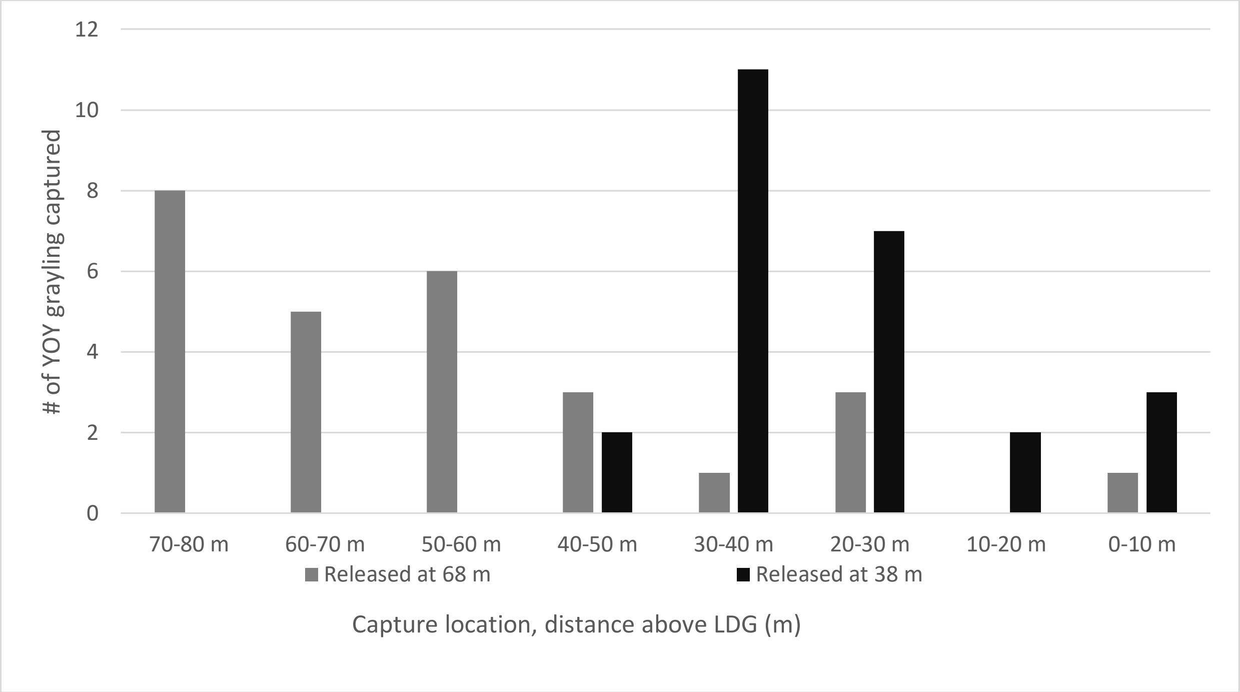

Figure 21. Young-of-year (YOY) movement in the lower 80 m of WIS from July 26, 2014 to August 2, 2014. Several YOY grayling stocked at the 68 m pool (blue bars) were able to migrate through all potential fish barriers with one swimming all the way downstream to the lower block net, 10 m above Lac de Gras. Similarly, three YOY grayling stocked from the pool at 38 m (orange bars) also migrated all the way downstream to the block net area. All YOY were alive at time of capture.

Figure 22. A photograph of the V notch created by the two large boulders, at low summer flow.