Migration timing and overwintering habitat of anadromous Arctic Char (*Salvelinus alpinus*) near Kugluktuk, Nunavut

by

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Author's Declaration

I hereby declare that I am the sole author of this thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Abstract

Arctic Char (*Salvelinus alpinus*) is a key component of subsistence diets in Inuit communities across the Arctic. The Hamlet of Kugluktuk, in the Kitikmeot region of Nunavut, relies on the Coppermine River to support an important fishery of anadromous (i.e., sea-run) Arctic Char, which feed in the ocean in summer and return to freshwater in fall to spawn and overwinter. Arctic Char is a highly plastic species, and while the exhibited diversity of life history strategies and migration patterns likely contributes to their persistence across a challenging landscape, it also necessitates population-level information to identify stressors and effectively manage subsistence fisheries. The migration patterns of Arctic Char using the Coppermine River and surrounding area are poorly understood, and overwintering movements and habitat use in fluvial environments in general are largely unknown for Arctic Char. To address these knowledge gaps, acoustic transmitting tags were surgically implanted in 164 healthy adult Arctic Char captured in the Coppermine River and Coronation Gulf in 2018 and 2019. An array of forty-seven acoustic receivers was deployed in freshwater and marine environments during the 2018 and 2019 ice-free seasons, with a subset left to detect 2018 winter movements in the Coppermine River. Consistent with local knowledge, telemetry data indicate that some Arctic Char do not overwinter in typical (i.e., lacustrine) habitats, and instead overwinter in the Coppermine River below Kugluk Falls (a substantial migration obstacle). Overwintering in fluvial environments is likely energetically costly and hazardous in a dynamic system such as the Coppermine River, which experiences substantial surface ice accumulation, slush, anchor ice, and hanging dams. Within the lower reaches of the Coppermine River, net downstream movement in winter was observed for ten (37%) individuals and five individuals were observed to enter the marine environment prior to river break-up in the spring. Under-ice movement into the marine environment has not been previously documented for Arctic Char, and this behavior suggests that the fitness benefit gained through early spring migration to rich ocean feeding grounds may outweigh the risks associated with fluvial overwintering. Following summer marine feeding, adult anadromous Arctic Char that migrated above Kugluk Falls entered freshwater earlier than those overwintering below Kugluk Falls, indicating that the length and difficulty of the migratory pathway affect fall migration timing. Particularly for those individuals overwintering below Kugluk Falls, smaller individuals entered freshwater later than larger individuals, likely due to the potential for proportionately greater gains in body condition for smaller individuals in the marine environment. This descriptive study helps further understanding of the variation in migration patterns and life history tactics employed by Arctic Char in the region. The high inter-individual and inter-annual variability that was observed in migration destination and timing provide a basis for future research on drivers of these patterns, such as spawning status, environmental cues, and population dynamics. Results will help in the management of local fisheries and in ensuring the future sustainability of this important food source.

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1. Introduction

Arctic Char (*Salvelinus alpinus*) is a large, long-lived fish species in the family Salmonidae that occupies a unique niche in Arctic ecosystems. The species is cold-adapted, has a circumpolar distribution, and is the most northern freshwater fish in the world (Scott and Crossman 1973; Johnson 1980); it is the only freshwater fish found at latitudes higher than 75°N (Power and Reist 2018). Arctic Char are terminal predators in the majority of Arctic freshwater ecosystems where they are found (Johnson 1980), and their lifespan may exceed thirty years (Johnson 1980; Power and Reist 2018). Arctic Char often feed opportunistically on a wide variety of prey from benthic (bottom), pelagic (water column), and profundal (deep) habitats (Johnson 1980) in freshwater ecosystems, and young-of-year and juvenile Arctic Char in freshwater lakes and streams may be predated upon by birds such as loons (*Gavia* spp.) and terns (*Sterna paradisaea*), or cannibalized by adults (Scott and Crossman 1973; Johnson 1980; Power and Reist 2018). In marine ecosystems, sea-run Arctic Char prey on fish such as Capelin (*Mallotus villosus*), while smaller individuals prey on invertebrates and smaller fish species (Power and Reist 2018). Seals (Phocidae) prey on sea-run adult Arctic Char in marine and estuarine ecosystems (Scott and Crossman 1973; Johnson 1980).

In addition to their ecological importance, Arctic Char are an important subsistence food fish for Inuit communities across the Canadian Arctic (Van Oostdam et al. 2005). Arctic Char confer many nutritional benefits to human consumers, as they are an excellent source of protein, fatty acids, and nutrients (Van Oostdam et al. 2005). In a comprehensive study of wildlife harvesting in Nunavut, the Nunavut Wildlife Management Board reported that Arctic Char were harvested more frequently and in greater abundance than other fish species; almost nine times more Arctic Char were harvested in Nunavut than Lake Trout (*Salvelinus namaycush*), the second most commonly harvested fish species (Priest and Usher 2004). With high food prices and limited economic opportunities, traditional or country foods, such as Arctic Char, have significant nutritional, economic, social, spiritual, and cultural value (Collings et al. 1998; Nuttall et al. 2005). Harvesting traditional foods requires comprehensive and detailed knowledge of the local environment and species (Nuttall et al. 2005), and helps to maintain indigenous knowledge and cultural practices (Power 2008). Acquiring accurate data from which to monitor Arctic Char is thus of critical importance to northern community members, regulators, and scientists, especially in light of their importance to current and future food security and the fact that their resilience to environmental change is largely unknown.

1.1 Life History

Arctic Char typically spawn in freshwater in September or October at a temperature of ~4°C (Scott and Crossman 1973). Spawning substrate ranges from gravel with intermittent boulders to coarse sand (Johnson 1980). Arctic Char are iteroparous, and typically reproduce multiple times over their lifespan (e.g., Johnson 1980). They may spawn annually in the southern extent of their range (Scott and Crossman 1973). Due to high energetic investment, they do not usually spawn every year in northern regions, and spawning intervals of two to four years are common (Power and Reist 2018). Eggs typically hatch in April, and juveniles rear in freshwater (e.g., Johnson 1980).

Arctic Char are facultatively anadromous, and may remain in freshwater year-round for their entire life cycle, or adopt an anadromous (i.e., sea-run) life history (Johnson 1980). After an initial period of 2-11 years rearing in freshwater (Power and Reist 2018), anadromous individuals migrate to the ocean to feed in summer and return to freshwater to spawn and overwinter (Figure 1). Arctic Char have only been observed using the marine environment in winter at one location in Norway, where ocean temperatures were typically > 2°C, and warmer than the nearby river environment (Jensen and Rikardsen 2012). It is thought that Arctic Char elsewhere must overwinter in freshwater as they have lower salinity tolerance at colder temperatures (Wandsvik and Jobling 1982; Finstad et al. 1989).

Ocean waters in temperate and Arctic regions are typically more productive and offer greater foraging opportunities than freshwater systems (Gross et al. 1988). An anadromous life history can thus result in higher growth rates and higher net fitness relative to a freshwater-resident life history (Gross et al. 1988; Rikardsen et al. 2000; Gulseth and Nilssen 2001). Over 90% of the diet of anadromous Arctic Char in the central Canadian Arctic is derived from marine sources (Swanson et al. 2011), and individual fish from one Norwegian river system were shown to almost double their weight over a relatively brief period of marine foraging (forty-four days; Mathisen and Berg 1968). Anadromous Arctic Char are thought to cease feeding while they overwinter in freshwater, or to feed at low levels (Moore and Moore 1974; Boivin and Power 1990; Rikardsen et al. 2003).

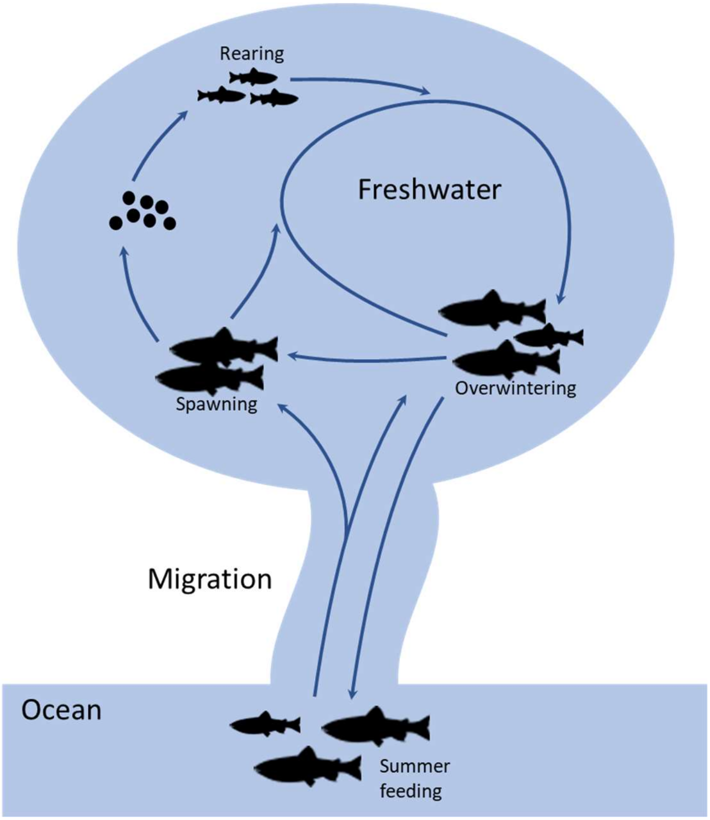

Figure 1: Typical life history strategies of Arctic Char. Adults may be residents, remaining in freshwater year-round, or may be anadromous, migrating to the ocean to feed during the summer months and returning to freshwater to spawn and overwinter. Some anadromous individuals may skip marine migrations for one or more years.

Individuals experience substantial decreases in body mass and lipid content overwinter (Mathisen and Berg 1968; Jørgensen et al. 1997); char at Nauyuk Lake in the central Canadian Arctic were observed to lose 30-46% of their energy reserves over a single winter (Dutil 1986). The marine feeding period is thus of critical importance to anadromous Arctic char in regaining body condition, and in facilitating overwinter survival (Jensen et al. 2018) and reproductive output (Tallman et al. 1996).

Energetic costs associated with anadromy include expenditures during long distance movement, as well as required changes in physiology to accommodate the transition between freshwater and saltwater (Gross et al. 1988). There may also be a higher risk of mortality associated with migrations (Gross et al. 1988; Quinn et al. 2016; Jensen et al. 2019), and anadromous Arctic Char are typically shorter-lived than freshwater residents (Power and Reist 2018). In areas where there are harvesting pressures from subsistence and commercial fisheries, it is the anadromous life history type that is more frequently targeted (Gyselman 1994; Roux et al. 2011; Tallman et al. 2019), because these individuals are easier to capture when moving through constricted (e.g., narrow, shallow) migratory corridors, and because fish are concentrated in areas near river mouths during spring marine entry and fall freshwater entry.

Arctic Char exhibit considerable plasticity in life history, and both among- and within- population variability in life history strategy is common. Some populations are partially anadromous (both resident and anadromous life history types are observed), and offspring may adopt a different life history strategy than their parents (Nordeng 1983). Primary productivity in freshwater lakes has been linked to prevalence of anadromy; Arctic Char in more productive lakes are less likely to migrate to sea, presumably because the net fitness benefit of migrating from more productive lakes is lower (Nordeng 1983; Finstad and Hein 2012). Warmer water temperatures may also reduce the prevalence or frequency of anadromy, as migration becomes more energetically costly and recovery from fatigue takes longer (Gilbert and Tierney 2018). Similarly, Arctic Char may be less likely to adopt an anadromous life history if migration distances are longer or stream gradients are higher (Kristoffersen 1994; Finstad and Hein 2012). Not all anadromous Arctic Char make annual migrations to the ocean (Radtke et al. 1996). In some populations, skipped ocean migrations occur during spawning years (e.g., Johnson 1980). Other authors have suggested that skipped migrations occur when energy reserves are insufficient to allow migration (Radtke et al. 1996) or environmental conditions are unfavourable (Power and Reist 2018), although these relationships remain untested.

Plasticity in life history strategy and migration patterns has likely allowed Arctic Char to persist across a range of climatic conditions and to exploit a wide variety of environments (e.g., Johnson 1989; Beddow et al. 1998; Harwood and Babaluk 2014; Gilbert et al. 2016). Plasticity in life history also manifests in variability in trophic ecology, growth rates, and reproductive traits, and this variability poses challenges for developing fisheries management plans and for predicting effects of stressors across the vast geographic range of the species. Improved knowledge of population-specific life history has been suggested to be key in determining sustainable harvest limits and managing local Arctic Char fisheries in the Canadian Arctic (Roux et al. 2011). Conventional methods of establishing and managing sustainable harvest limits require accurate estimates of population abundance, which are extraordinarily costly to acquire in the Canadian Arctic. Further, population estimates may be invalid if the stock being managed is comprised of multiple populations (e.g., Gyselman 1994; Moore et al. 2016), if life history is unknown, or if there are multiple life history types within the population that cannot be differentiated visually. Site-specific population data are relatively rare in the Canadian Arctic, and genetic structure and dispersal are only beginning to be understood in even the best-studied systems (e.g., Moore et al. 2016; Harris et al. 2016).

1.2 Fall Migration Timing

In addition to variability in the prevalence and frequency of anadromy, timing of entry into freshwater in the fall varies within and among anadromous populations of Arctic Char. Gaining knowledge of factors that affect migration timing is important for local communities and fisheries managers, because anadromous char are typically harvested as they migrate between summer feeding grounds in the marine environment and spawning and overwintering habitats in freshwater environments. Timing of freshwater entry may be influenced by several biotic factors. Several authors have reported that females often enter freshwater before males (Grainger 1953; Dempson and Green 1985), and that larger fish return earlier than smaller fish (Johnson 1980; Dempson and Green 1985; Dempson and Kristofferson 1987; Berg and Jonsson 1989; Gulseth and Nilssen 2000), although other authors have found no relationship between timing of freshwater entry and size or sex (e.g., Moore et al. 2016).

The timing of fall freshwater entry may vary among years for a given individual, due to variability in migration destination, climatic factors, and/or local physical characteristics of the migratory pathway. Although salmonids are well-known for their high fidelity to natal river systems, Arctic Char in some areas may only exhibit strong fidelity in spawning years; overwintering migration destination in non-spawning years can occur at different sites or even different watersheds (Guðjónsson 1987; Gyselman 1994; Moore et al. 2013; Spares et al. 2015; Gilbert et al. 2016). Moore et al. (2017) found that non-spawning char in one area of the central Canadian Arctic were more likely to overwinter in rivers with shorter migratory routes and lower gradients than their natal systems. It thus appears that in non-spawning years and in some systems, char overwinter at sites that are easier to access and therefore less energetically costly to reach, allowing them to maintain more of the benefits of ocean migration (Moore et al. 2017). Char have also been observed to begin migration earlier when travel routes pass through areas that become affected by low water conditions in the fall (Gilbert et al. 2016). It is therefore possible that char that migrate to destinations via longer or more challenging (e.g., higher gradient) routes enter freshwater earlier to take advantage of more favorable hydrological conditions prior to winter freeze-up, but data on this assertion are limited.

1.3 Overwintering Ecology

Understanding overwintering ecology of fish is important in informing fisheries management and habitat conservation (Cunjak 1996), and has long been identified as a critical knowledge gap (Hubbs and Trautman 1935). In the Arctic, fish species that overwinter in freshwater must have sufficient food availability or energy stores to allow survival over the long (up to nine months) ice-covered season, and require appropriate temperature and oxygen conditions. Causes of overwintering mortality include starvation and thermal stress (Hurst 2007). Availability of overwintering habitats, particularly in shallow ecosystems, is reduced by ice formation, and movement between habitats can become restricted (Craig 1989). While our understanding of how ice processes affect physical aspects of winter fish habitat has improved (Huusko et al. 2007; Brown et al. 2011), little is known regarding fish ecology in winter relative to ice-free periods.

Arctic Char are fall spawners and typically spawn and overwinter in lakes (Johnson 1980; Power and Reist 2018). Spawning may also occur in streams that do not freeze to the bottom during the winter. These sites are often characterized by groundwater inputs, and rearing juveniles may overwinter in streams rather than lakes (e.g., Siikavuopio et al. 2009). Less commonly, adults may also overwinter in rivers or estuaries that are sufficiently deep to prevent freezing and where frazil or anchor ice conditions are minimal. Although rare, overwintering in fluvial environments has been observed across much of the range of Arctic Char, including the western Canadian Arctic in the Northwest Territories (Harwood and Babaluk 2014), the eastern Canadian Arctic in Labrador (Beddow et al. 1998), and Norway (Jensen and Rikardsen 2012).

Despite their Arctic distribution, the majority of studies on Arctic Char migration patterns and habitat use have focused on the brief ice-free season, likely for logistical reasons. Although a few studies have been conducted on juveniles overwintering within streams (e.g., Siikavuopio et al. 2009), all winter studies of adults have occurred in lakes (Klemetsen et al. 2003; Svenning et al. 2007; Mulder et al. 2018a, 2018b, 2019). Evidence from studies of overwintering within lake systems suggests that Arctic Char occupy thermal niches that minimize net energy loss; the thermal range occupied by char overwintering in lakes has been reported to vary between 0.2-2.0°C (Klemetsen et al. 2003; Mulder et al. 2018b), which is at or above the 0.2°C lower thermal limit for feeding (Elliott and Elliott 2010) but sufficiently cold to reduce metabolic costs. Evidence from lacustrine studies also suggests that Arctic Char minimize energy expenditure in winter by reducing movement and remaining relatively stationary (Mulder et al. 2018a), except for diel movements that are likely associated with foraging during daylight hours (Mulder et al. 2019). These two tactics of minimizing energy expenditures (thermal habitat selection and movement reduction) may be more challenging in fluvial systems, where fish must maintain position in flowing water and mixing of the water column prevents the formation of distinct thermal niches in areas without groundwater inputs. However, few studies have been conducted in large, ice-covered rivers for salmonids in general (Huusko et al. 2007), and to my knowledge the only overwintering study of adult char in a river system or estuary was conducted by Jensen and Rikardsen (2012), who did not have locational data and instead inferred habitat use from temperature and salinity measurements. There is thus a clear knowledge gap in the overwintering movements and habitat use of Arctic Char in large, fluvial systems.

1.4 Study Rationale and Local Context

Kugluktuk is a small hamlet in the Kitikmeot region of western continental Nunavut (Figure 2). Inuit comprise the majority (94%) of the population of 1500 (Statistics Canada 2017). Similar to other communities in Nunavut, Arctic Char is the main fish species harvested in the area, followed by whitefish (*Coregonus* spp.) (Priest and Usher 2004). Although exploratory commercial fisheries were present in the past, these are no longer operational and fishing is principally for personal consumption. The Coppermine River flows immediately to the east of Kugluktuk, and Kugluk (or Bloody) Falls is located approximately 15 km upstream of the river mouth. The Coppermine River has historically supported much of the important subsistence char fishery for the community. Harvested char are typically anadromous, and in the past many were harvested in the fall using spears as they migrated upstream at Kugluk Falls (Scott and Crossman 1973). At present, anadromous char are largely caught by gill nets and some angling as they move past Kugluktuk and through the lower reaches of the river (Prno 2019).

The nearest suitable lakes for overwintering anadromous char in the Coppermine River watershed are the Dismal Lakes, located > 160 river kilometres upstream from the Coronation Gulf (Figure 2). This is considerably farther than overwintering lakes used by other populations of Arctic Char in the region (0.2-50.4 km; Gyselman 1994; Gilbert et al. 2016; Moore et al. 2017). In addition to ascending Kugluk Falls, migration to the Dismal Lakes requires traversing several other sets of rapids and 30 km along the Kendall River, which connects the Dismal Lakes to the main stem of the Coppermine River (Figure 2). The Kendall River is a relatively shallow river; the deepest areas measure 2.0-3.2 m during spring freshet in June and water levels decrease rapidly through July and August (Wedel et al. 1988; Environment Canada 2008). Water levels in some reaches of the Kendall River may restrict the passage of adult fish. Avoidance of this long and challenging migratory pathway by overwintering in the Coppermine River may result in a net fitness benefit, and local fishers report catching Arctic Char by setting nets through the ice in the Coppermine River below Kugluk Falls in November and December. With a watershed area of 50 800 km^2 (Wedel et al. 1988), large discharge (summer average of 473 m^3/s; Coulombe-Pontbriand et al. 1998), and deep channels (up to 14 m; this study), the Coppermine River provides a unique opportunity to examine char migration cues and habitat use in a large fluvial system that has variable habitat and the potential for multiple and atypical (i.e., non-lacustrine) overwintering sites.

Following discussions in 2017, the University of Waterloo, the Kugluktuk Hunters and Trappers Organization, and Fisheries and Oceans Canada (DFO) established a partnership to study Arctic Char in the Kugluktuk area. This project aims to address community concerns regarding the subsistence char fishery in Kugluktuk, with an emphasis on identifying and characterizing migration patterns and overwintering habitat used by Arctic Char. Community priorities and gaps in the scientific literature regarding Arctic Char migration cues and salmonid overwintering in fluvial systems guided development of research questions and the methodological approach of this study.

1.5 Methods for Investigating Migration and Habitat Use: Aquatic Acoustic Telemetry

Studies of fish habitat use and migration patterns can be conducted in several ways, including direct (e.g., mark-recapture, photography) and indirect (e.g., chemical tracers, gene flow) techniques. Telemetry is a direct technique that entails automatic transmission of remote data to a receiver, which may be either an autonomous recorder or a handheld device, such as a radio antenna. The first application of telemetry in the aquatic environment occurred in 1964, and involved tracking migrations of adult Chinook Salmon (*Oncorhynchus tshawytscha*) using ultrasonic transmitters (Stasko and Pincock 1977). These early transmitters were large and heavy, and their use was restricted to large-bodied animals. Technology has since improved and enabled advances in tracking numerous animals in a variety of aquatic ecosystems (Hussey et al. 2015). Ultrasonic, now referred to as acoustic, telemetry is one widely used method that employs sound waves to transmit information to hydrophone receivers.

Acoustic telemetry is comparatively affordable, as transmissions are typically recorded by autonomous receivers and do not require overflights, as is often necessary in radio telemetry campaigns that cover large landscapes. Acoustic tags transmit a coded signal, which allows for tracking of individual animals (Heylen and Nachtsheim 2018). Improvements in battery technology have resulted in decreases in tag size, such that they may be used in smaller aquatic organisms, such as fish. Acoustic tags are highly versatile and are effective in both freshwater and saltwater; thus, they can be used in anadromous species, such as Arctic Char. In contrast, radio transmitters only work in freshwater (Cooke et al. 2012). Acoustic telemetry has been used successfully elsewhere in the Arctic to characterize Arctic Char movement patterns (Spares et al. 2015; Moore et al. 2016, 2017; Harris et al. 2020), and can be used to investigate habitat use, population range, stock mixing, and how organism movement may be related to environmental factors (Crossin et al. 2017).

1.6 Study Objectives

Knowledge of animal movement ecology is crucial to achieving effective management of harvested species and development of conservation plans (Allen and Singh 2016). An understanding of population- and location-specific life history has been shown to be important in management of a commercial fishery for Arctic Char in Cambridge Bay, Nunavut (Harris et al. 2016). The migration cues and patterns of Arctic Char using the Coppermine River and surrounding areas are poorly understood, and overwintering movements and habitat use of char, and salmonids in general, are largely unknown in large, ice-covered fluvial systems. Given these knowledge gaps, and the importance of Arctic Char both ecologically and as a subsistence food source, the overall goal of my research was to describe the spring and fall migration patterns and overwintering habitat of Arctic Char near Kugluktuk, Nunavut. I used acoustic telemetry to address two specific objectives:

Objective 1: Identify overwintering locations and winter movements of Arctic Char within the Coppermine River.

If Arctic Char were detected overwintering in the fluvial environment of the Coppermine River, I expected that fish would preferentially overwinter in deep areas, where available under-ice habitat was anticipated to be greater and water velocity lower. I also expected fish to reduce movement and remain in one section of the river to conserve energy, similar to what has been observed for char overwintering in lakes (Mulder et al. 2018a).

Objective 2: Investigate if and how timing of fall entry into freshwater is affected by fish size and migration destination for anadromous Arctic Char in the Coppermine River.

If a relationship was observed between timing of freshwater entry and migration destination, I expected that individuals with a longer or more difficult (e.g., high gradient) migratory pathway would enter freshwater first. Based on previous observations in other regions (Johnson 1980; Dempson and Green 1985; Dempson and Kristofferson 1987; Berg and Jonsson 1989; Gulseth and Nilssen 2000), I expected larger individuals to return to freshwater earlier in the fall than smaller individuals.

Knowledge gained through this research will allow the community of Kugluktuk to enact more informed management of their subsistence fishery. This research will also be of interest to the larger scientific community, as large knowledge gaps regarding migration cues and overwinter ecology exist for Arctic Char, especially for Arctic Char that do not overwinter in lakes.

2. Methods

2.1 Study Location

The Hamlet of Kugluktuk, formerly known as Coppermine, has a population of approximately 1500 (Statistics Canada 2017) and is located on the Coronation Gulf in the western Kitikmeot region of continental Nunavut (67°49`N,115°06`W) (Figure 2). Human activity in the area has been documented to date back > 3000 years, to the pre-Dorset people (McGhee 1970). Kugluktuk is located in an area of continuous permafrost in the Arctic tundra region. The climate is characterized by long, cold, dry winters (daily average temperatures of -24.5 to -27.7 °C and monthly average precipitation of 8.4 to 10.4 mm) and short, cool, moist summers (3.3 to 10.9 °C and 37.8 to 45.1 mm) (Environment Canada 2010). The average date of sea ice break-up in the Coronation Gulf near Kugluktuk, determined over a thirty year period from 1981 to 2010, is 02 July (Canadian Ice Service 2018). The average date of freeze-up is 22 October, yielding a relatively brief ice-free season.

The Coppermine River originates at Lac de Gras, in the boreal or subarctic region of the Northwest Territories ~325 km north of Yellowknife (64°50`N,109°30`W), and flows ~845 km northwest before entering the Coronation Gulf immediately to the east of Kugluktuk (Wedel et al. 1988). The overall slope of the river is minimal, measuring only 0.6 m/km (Wedel et al. 1988). The hydrological regime of the Coppermine is subarctic nival. The lower reaches have a mean peak discharge during spring freshet of 1330 m^3/s, whereas mean summer discharge is 473 m^3/s (Coulombe-Pontbriand et al. 1998). Minimal flows are sustained during the winter months, with lake storage in the upper Coppermine providing the primary contribution to the mean winter discharge of 118 m^3/s (Coulombe-Pontbriand et al. 1998).

The Coppermine River has historically supported an important subsistence char fishery for the community of Kugluktuk. Approximately 15 km upstream of the river mouth lies Kugluk (or Bloody) Falls (Figure 2). Kugluk Falls is a cascade that is passable, but poses a substantial obstacle, for migrating Arctic Char. Although other river systems in the area are known to support char (Government of Nunavut 2010), the downstream reaches of the Coppermine River, from Kugluk Falls to the river mouth, serve as the primary freshwater fishing locations for Kugluktuk community members (Prno 2019).

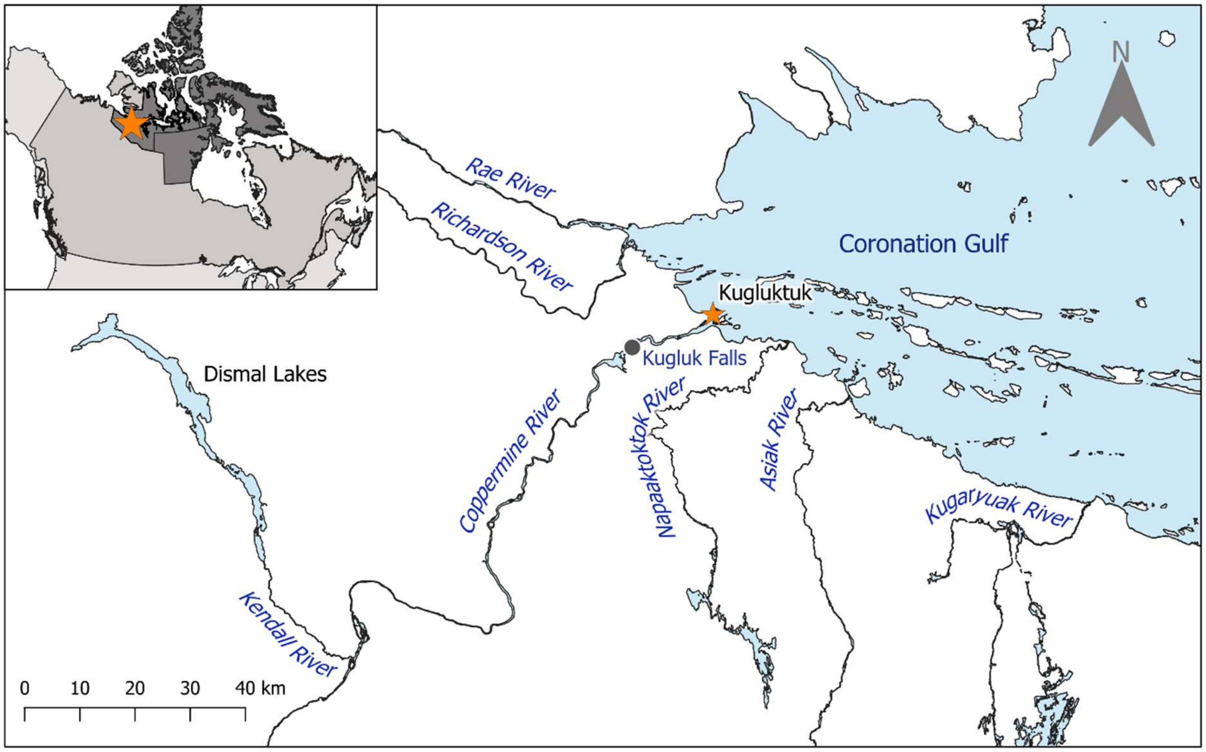

Figure 2: Map of the study area. The Hamlet of Kugluktuk is located in the western Kitikmeot region of continental Nunavut. The study area focuses on the Coppermine River, and extends into the Coronation Gulf from the Rae and Richardson rivers in the west to the Kugaryuak River in the east. Kugluk (or Bloody) Falls, located ~15 km upstream of the Coppermine River mouth, is a large cascade that is passable, but poses a substantial obstacle, for migrating Arctic Char. The nearest suitable lakes for overwintering Arctic Char in the Coppermine River watershed are the Dismal Lakes, ~160 km upstream from the Coronation Gulf.

2.2 Fish Capture and Tagging

All fish captures and tagging were conducted under Animal Utilization Project Protocols 18-07 and 30071, which were approved by the University of Waterloo Animal Care Committee, as well as FWI-ACC-2019-30, which was approved by the Fisheries and Oceans Canada Freshwater Institute Animal Care Committee. A total of 165 healthy, adult Arctic Char were live-captured in the Coppermine River and Coronation Gulf from 08-23 August in 2018 (n=48) and from 19 July-08 September in 2019 (n=117). Char were captured using 127 mm (5 inch) mesh monofilament gill nets (n=151), 51 mm (2 inch) mesh gill nets (n=1), angling (n=11), and dip-netting (n=2). Captured fish were monitored in 75 L fish crates before and after surgeries. Water in crates was held at ambient temperature with aerators, and water was changed frequently. Individual fork length was measured to the nearest millimeter and adipose fins were clipped prior to surgeries for use in a related project.

During surgery, fish were electro-immobilized using a TENS 3000 unit (Roscoe Medical, Middleburg Heights, OH), with one electrode held on the dorsal surface posterior to the opercula and one on the dorsal surface of the caudal peduncle. Pulse width was 30 µS, pulse rate was 150 Hz, and the unit was run in modulation mode with a constant timer and an initial current setting of 5 mA. Water was pumped continuously over the gills for the duration of the tagging procedure (typically less than four minutes), and fish recovered immediately upon removal of the electrodes.

Acoustic tags (V16T, diameter 16 mm, length 98 mm, weight 34 g, Vemco, InnovaSea Systems, Halifax, NS) were surgically implanted into the coelomic cavity. The interval between tag transmissions randomly varied between 60 and 180 seconds. Tags transmitted both tag ID and fish body temperature. Char with fork lengths < 600 mm were weighed to verify that tags were < 2 % of body mass (body mass > 1700 g) (Winter 1996). Surgeries were performed by a single surgeon. Tags were inserted through a 3-3.5 cm incision that was made on the ventral surface, ~1 cm right of the midline, and ending 4-5 cm anterior to the pelvic girdle. Incisions were closed with 2-3 simple interrupted sutures with square knots in a 3-2 pattern, using 3-0 PDS II violet absorbable monofilament sutures with 26 mm, ½ circle, taper point needles. Fish were held and observed for ~15 minutes post-surgery to ensure adequate recovery before release.

2.3 Deployment and Retrieval of Acoustic Receivers

An array of omnidirectional acoustic monitoring receivers (Vemco, InnovaSea Systems, Halifax, NS) was deployed in the Coppermine River and Coronation Gulf (Figure 3). Three models of receiver were deployed. VR2AR receivers were moored autonomously at the river or ocean bottom and subsequently retrieved using self-contained buoys and an automatic release mechanism. VR2Tx and VR2W receivers were attached to surface floats for manual retrieval.

Receivers were deployed with hydrophone (sensor) tips located ~1-1.5 m above river or ocean bottom along migration corridors (e.g., Coppermine River) identified by local fishers. As char typically travel in nearshore areas rather than through deep, open waters (Spares et al. 2012; Moore et al. 2016), receivers were also placed along the coast of the Coronation Gulf, offshore from landscape features where it was suspected char would pass when traveling from one area or basin to another. Detection ranges were estimated at the time of receiver deployment by travelling a known distance from the receiver, lowering a range testing tag with the same design specifications as the tags implanted into fish, and verifying it was detected by the receiver. This testing ensured that receivers were appropriately placed to gate areas of particular interest (i.e., they could detect tag transmissions over the full width of the area), such as the Coppermine River, and therefore minimize the likelihood of fish passing undetected.

Thirty receivers were deployed in 2018 between 28 July and 17 August (Figure 3). Receivers were removed and data downloaded during 21-29 September, immediately prior to river freeze-up. A subset of seven VR2AR receivers was redeployed after downloading data to detect overwintering movements, including six in the Coppermine River below Kugluk Falls and one at First Point, in the

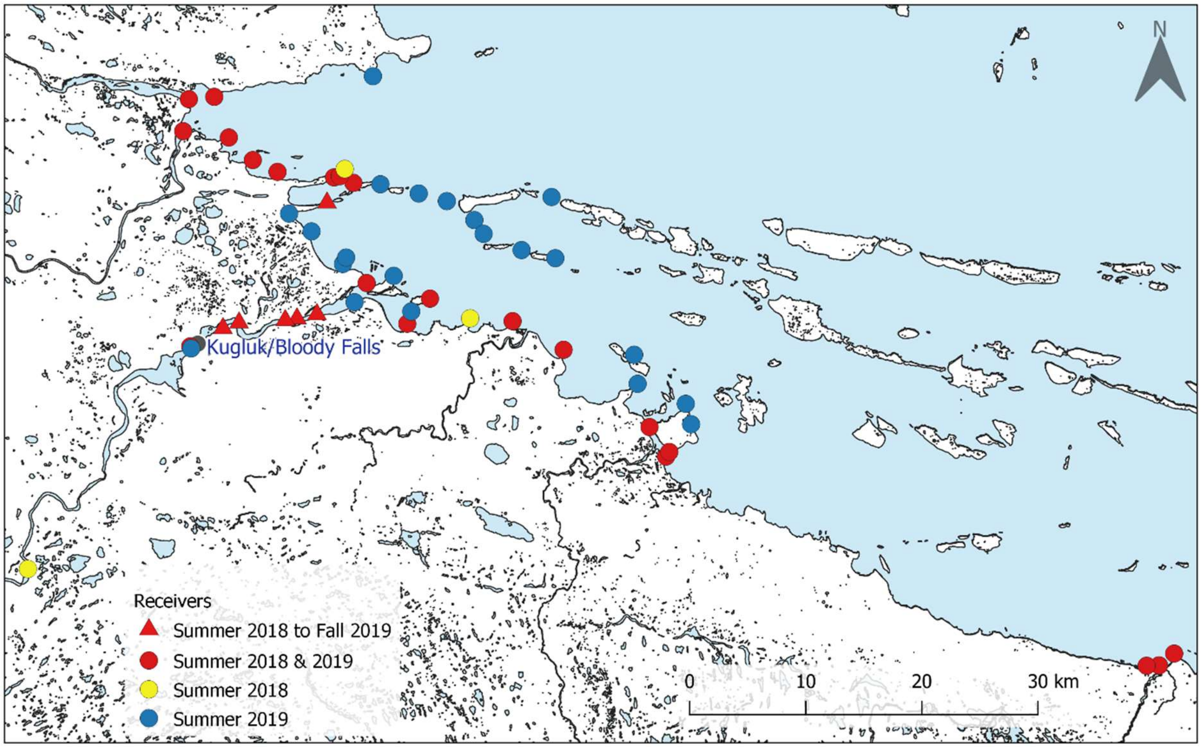

Figure 3: Map of receiver locations. Symbols indicate the time period each receiver was deployed and data are available. Receivers marked with a red triangle were left in place over the winter of 2018 and successfully retrieved in 2019, including five in the Coppermine River and one at First Point, approximately 7 km northwest of the river mouth.

Coronation Gulf (located approximately 7 km northwest of the river mouth; Figure 4). From 07-17 July 2019, non-overwintering receivers were redeployed and additional receivers installed to expand the array coverage to a total of forty-seven receivers (Figure 3). Receivers were again retrieved and data from the 2019 summer field season were downloaded between 22-30 September 2019.

On 31 January 2020, after drilling through the ice, a VR100 with transponding hydrophone (Vemco, InnovaSea Systems) was used to communicate with a receiver at the river mouth (Figure 4). The VR100 cannot be used to download full receiver data records, but it is able to obtain the date and time the receiver last detected an individual fish in a watch list. This method of obtaining detection data is limited in that the maximum number of fish on the watch list is 128, and only information from the most recent detection of each fish is obtained. However, this partial exchange of information is beneficial in cases when receiver retrieval and download are not possible (such as when they are under ice), particularly if there is a risk of receiver loss.

2.4 Detection Data

All receiver log and detection data were imported into VUE software version 2.6.2 (Vemco, InnovaSea Systems). The VUE VRL File Editor was used to account for receiver clock drift and to correct recorded times. The VUE False Detection Analysis Tool was used to identify potential cases of interference between transmitter signals or incomplete transmissions. All flagged detections were manually reviewed and invalid observations removed. Following this preliminary processing, all subsequent data manipulation, analyses, and visualization were conducted using R version 3.6.1 (R Core Team 2019).

A complete dataset of observations was created by merging data from fish tagging, recapture, and harvest records with data from receiver detection records, and assigning locations to each observation. Detection data were simplified into residence periods (start, end, and length of time a tag was detected continuously at a given location). The maximum residence period observed during the ice-free season, provided that the individual was subsequently detected on another receiver, was determined. Fish that had a most recent residence period greater than this maximum residence period were flagged as mortalities or cases of tag shedding/expulsion.

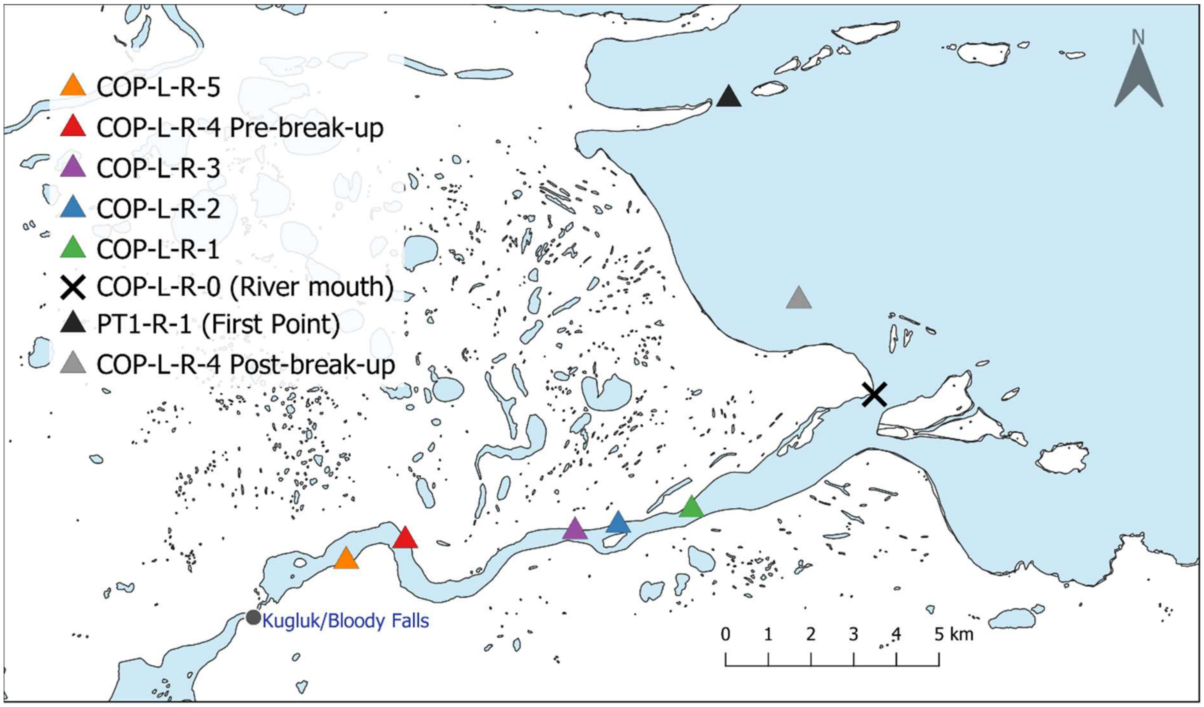

Figure 4: Map of overwintering receivers in the Coppermine River and First Point. Receivers in the Coppermine River are numbered sequentially from 0 (river mouth) to 5 (farthest upstream). Receiver COP-L-R-0 (**X**) was not re-located in the spring of 2019; no overwinter data are available for the river mouth. The post-break-up location of COP-L-R-4 indicates its resting position from 20 June – 02 September 2019, after it broke free of its mooring and was transported into the Coronation Gulf during river break-up on 19 June.

2.5 Environmental Data

In addition to recording transmissions from fish tags, VR2AR and VR2Tx receivers recorded temperature (°C), depth (m), tilt (°), and noise (mV) hourly. HOBO Water Temperature Pro v2 Data Loggers (Onset Computer Corporation, Bourne, MA, USA) were used to record hourly temperatures at VR2W moorings, as these receivers lack internal logging capabilities. Fish body temperatures (transmitted by acoustic tags) often varied from the temperatures that were recorded by receivers near the river- or ocean-bed, so tag temperatures were used as a measure of the thermal habitats occupied by fish. Receiver logs were used to identify disturbances (e.g., changes in tilt) and aided in characterizing the under-ice environment (e.g., noise, depth of water/ice) of the overwintering receivers. A vertical profile of temperature and salinity conditions was collected at First Point on 22 March 2019 using a SonTek Castaway-CTD (Xylem, San Diego, California).

2.6 Data Analysis

2.6.1 Identification of Migration Destination

For the purpose of this study, the Coppermine River was divided into areas of interest in relation to Kugluk Falls: Above Falls and Below Falls. The migration destination of an individual for a given year was classified as Above Falls if it was detected at a receiver above Kugluk Falls in the fall of that year. As the migration destination variable was intended to differentiate between a long, difficult migratory route (Above Falls) and a shorter, easier route (Below Falls), the migration destination was classified as Above Falls for individuals that migrated above the falls, even if they subsequently returned below the falls within the same study year (n=2). In 2018, an individual was classified as overwintering Below Falls if it was detected on at least one receiver below the falls during the ice-on period (freeze-up on 01 October 2018 to river break-up on 19 June 2019). Tags returned from char captured by harvesters through the ice during this period were also classified as Below Falls.

Overwintering detection data were not available for 2019, so the number of fish overwintering below the falls could not be determined using direct detection data. Instead, the 2019 migration destinations of individuals were classified as Below Falls or Unknown by modeling detection data from fall 2018 and applying the model to detection data from fall 2019. A generalized linear model was used to model 2018 data. The response variable was binomial (0 = no detections overwinter Below Falls (Unknown migration destination), 1 = detections overwinter Below Falls). Two individuals migrating Above Falls in 2018 were excluded from the model. The number of days between receiver retrieval date (22 September 14:00) and previous detection within the river was a continuous explanatory variable. Since longer periods between last detection and receiver retrieval date were observed for the uppermost two receivers below the falls, a categorical explanatory variable was added for receiver location (Upper = two upstream receivers at COP-L-R-5 and COP-L-R-4; Lower = three downstream receivers at COP-L-R-3, COP-L-R-2, and COP-L-R-1, as well as the river mouth, Figure 4). The accuracy of the model was tested using k-fold cross validation with five folds. A predicted Below Falls probability ≥ 0.75 was selected as the threshold, to maximize the proportion of true positives (mean = 0.88, standard deviation (SD) = 0.11) while minimizing the proportion of false positives (mean = 0.10, SD = 0.22; Appendix D). Parameters estimated from the model were applied to the 2019 detection data to estimate the probability that an individual was overwintering Below Falls. Individuals with predicted Below Falls presence values > 0.75 were classified as overwintering Below Falls. The remaining individuals were classified as Unknown migration destination, and removed from subsequent analyses.

2.6.2 Identification of Date of Fall Freshwater Entry

Date of freshwater entry for each fish was estimated using the date of first detection at the river mouth, provided that at least one detection or tagging event had been previously recorded in the marine environment and all subsequent detections for that year were within the Coppermine River. If there were multiple detections of an individual at the river mouth receiver, and if > 24 hours elapsed between subsequent detections, the initial detection at the river mouth was assumed to reflect the fish passing within the receiver detection radius rather than true freshwater entry and use of the river environment. In these cases, the start of the final residence period at the river mouth was used as the entry date.

2.6.3 Modeling Date of Fall Freshwater Entry

General linear models were used to relate date of fall freshwater entry to the continuous variable of individual fork length, and the categorical variable of migration destination (Above Falls, Below Falls). Individuals were included in the model only if their migration destination was known or estimated (see 2.6.1). For individuals with freshwater entry dates in both study years (n=9), only the first year was included.

Migration year was initially included as a random factor in linear mixed effects models. The full model with no random factor and the full model with random intercept were fit with restricted maximum likelihood (REML), using the package nlme in R (Pinheiro et al. 2019) and following Zuur et al. (2009). A likelihood ratio test was used to compare the two models, with the p value adjusted to account for testing on the boundary (Zuur et al. 2009). The fit of the random intercept model was not significantly better than the fixed effects model (L<0.001, df=1, p=0.5). To investigate whether this was due to uneven sample sizes (only one fish was observed entering freshwater and migrating above the falls in 2018), the same test was conducted on Below Falls observations only, with a single predictor variable of fork length. Again, the fit of the random intercept model was not significantly better than the fixed effects model (L=1.39, df=1, p=0.12). Thus, the random intercept was removed from the final model set and both years of data (2018 and 2019) were combined.

The final model set was fit using maximum likelihood (ML) estimation. Models were compared using Akaike's Information Criterion with a second-order bias correction (AICc), to avoid overparameterization due to low sample size relative to number of parameters (Anderson 2008). AICc values were calculated using the R package MuMIn (Barton 2019), and adjusted R^2 values were estimated using the lm function in base R.

2.6.4 Identification of Spring Ocean Entry

The receiver located at the river mouth was lost during winter 2018, so no dates of last detection in freshwater in spring 2019 are available. Instead, dates of ocean entry were estimated by detections on the overwintering receiver at First Point and at the opportunistic (re)location of COP-L-R-4 in the marine environment (Figure 4). The mooring of receiver COP-L-R-4 was damaged over the winter, and the receiver was carried into the Coronation Gulf during river break-up on 19 June 2019. The receiver buoys were damaged and became detached in the Gulf, which caused the receiver to sink and remain stationary approximately three kilometres from the river mouth, where it was able to detect marine entry of char in late June. Due to the date of arrival (20 June 2019 09:00) of this receiver at its spring location and the substantial distance (~7 km) between the river mouth and the First Point receiver, identified dates of spring ocean entry are likely overestimates.

2.7 Mapping

All maps in this document were created using QGIS version 3.10.2 (QGIS Development Team 2020). Shapefiles of Canada and Nunavut regional boundaries were obtained from Statistics Canada (2016) and the United States boundary from the United States Census Bureau (2017). Nunavut community and landmark place names were retrieved from the Canadian Geographical Names Data Base (Natural Resources Canada 2011). All waterbody shapefiles were obtained from the CanVec hydrographic series (Natural Resources Canada 2015).

3. Results

3.1 Fish tagging

Of the 165 Arctic Char tagged in this study, only one did not recover following surgery (dark brown in Figure 5, Fall 2019). Fork lengths of tagged individuals ranged from 539-889 mm (mean = 709 mm, standard deviation (SD) = 66 mm). Tag:body mass ratio values ranged from 0.4-1.8%; all were below the 2% rule-of-thumb (Winter 1996), and far below the ratios observed to affect growth, behavior, and survival in other salmonids (e.g., Chittenden et al. 2009; Ammann et al. 2013; Collins et al. 2013; Smircich and Kelly 2014; Newton et al. 2016; Darcy et al. 2019).

After removal of false detections and known or suspected mortalities (see Section 2.4), there were 341 665 transmissions representing 147 individual char detected by the receiver array over the study period (08 August 2018 to 30 September 2019). Four of these char were detected by the receiver array but were harvested by subsistence fishers within twenty-four hours of release and before movement patterns could be discerned. Of the eighteen individuals that were not included in the final dataset, one did not survive surgery, eleven were never detected, five were suspected to have shed their tags or were mortalities following release, and one was a confirmed mortality (Figure 5).

3.2 Overwintering Receivers

Six receivers were deployed within the Coppermine River in winter 2018. With the exception of the receiver at the river mouth, all overwintering river receivers were successfully retrieved in 2019 (Figure 4). Receiver COP-L-R-5 remained attached to its mooring, but lost both buoys (one during fall deployment and one overwinter) and required retrieval by a remote operated vehicle (ROV, operated by CompleteWaters, Hamilton, ON). Receiver COP-L-R-4 lost one buoy, detached from its mooring, and was transported to the Coronation Gulf during spring break-up, where the second buoy was damaged, causing the receiver to sink. This receiver was relocated when its transmissions were detected by a different receiver and was later retrieved by the ROV. Detections from this receiver while in the marine environment enabled the identification of ocean entry in spring 2019 (Section 2.6.4). Receiver COP-L-R-3 also became detached from its mooring and was retrieved by a

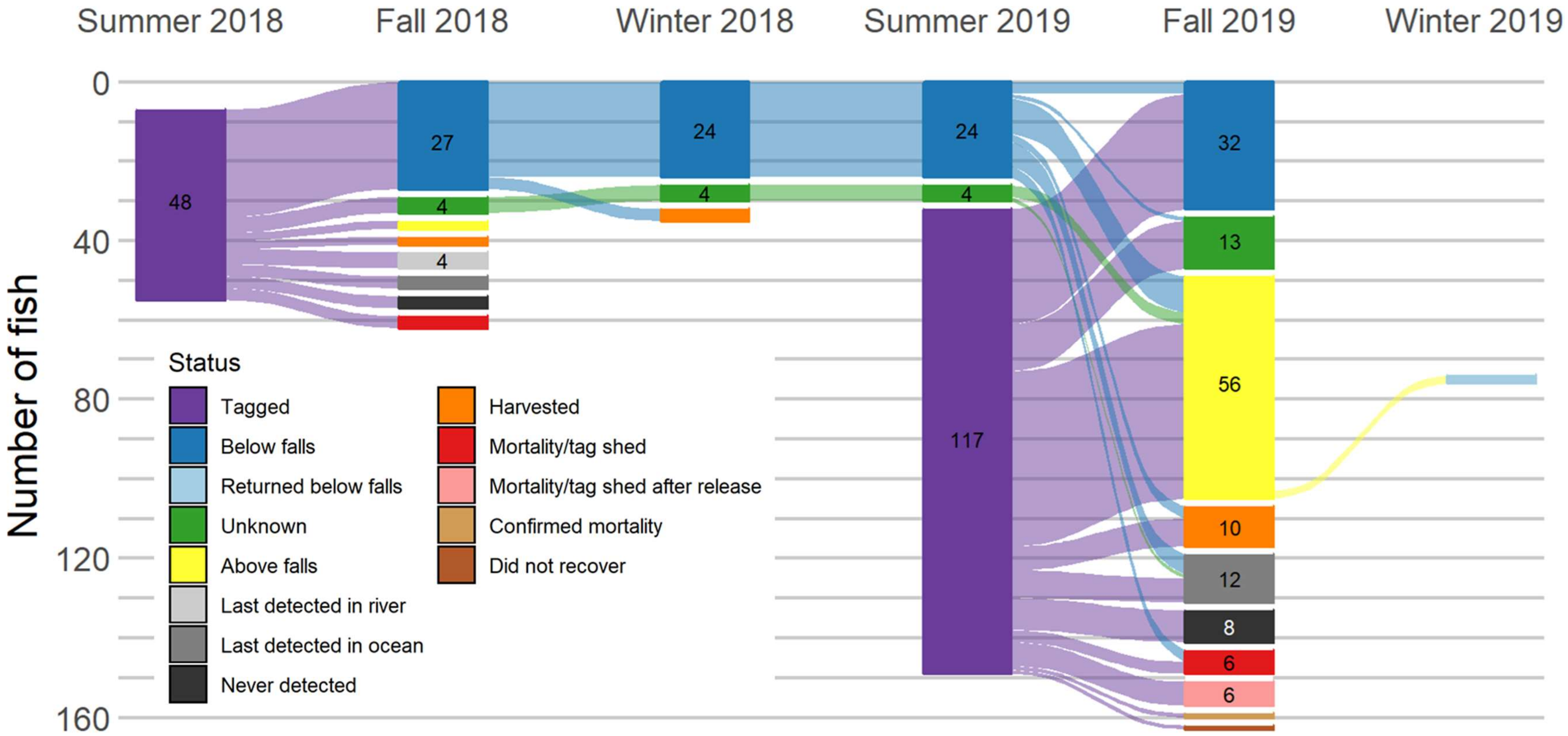

Figure 5: Status of tagged fish by season of study. Summer represents the earliest known status of an individual in a given ice-free season. Fall represents either fall migration destination (Above Falls, Below Falls, or Unknown) or fate over the ice-free months (e.g., Harvest or Mortality/tag shed prior to freeze-up). Winter represents ice-covered periods. Tallies are only shown for values > 4 to prevent cluttering.

local fisher after being transported to the Coronation Gulf during spring break-up. The remaining two receivers (COP-L-R-2 and COP-L-R-1) were undamaged for the duration of the winter season and break-up.

3.3 Migration Destination

In 2018, two Arctic char were detected migrating above the falls, on 28 and 31 August (yellow bar in Figure 5, Fall 2018). One of these fish was also detected on 06 September at a receiver located approximately thirty kilometres upstream of Kugluk Falls. Twenty-seven individuals were detected overwintering below the falls, three of which were harvested through the ice in October and November by local fishers (blue and orange bars, respectively in Figure 5, Fall 2018). Four individuals were detected below the falls in August and September, before the ice-covered period, but were not subsequently detected over the winter months. These individuals were then detected in the marine environment in June 2019; however, their 2018 migration destinations remain unknown (green bar in Figure 5, Fall 2018). It is possible that these fish overwintered but remained undetected below the falls, or they may have moved above the falls or into the marine environment without being detected by receivers at either location. Twelve additional char had unknown migration destinations: two were harvested before their migration destinations were identified (orange), three were mortalities or potential cases of tag shedding within the river (red), four were last detected within the river in August or September of 2018 and never subsequently detected (light grey), and three were last detected in the marine environment in August or September (dark grey in Figure 5, Fall 2018).

In 2019, fifty-six char migrated above the falls between 23 July and 22 September (yellow bar in Figure 5, Fall 2019). Forty-five individuals were last detected within the Coppermine River, below Kugluk Falls. Based on modeling of 2018 detection dates and locations and applying the model to 2019 data, thirty-two individuals were estimated to be overwintering below the falls in 2019 (blue bar in Figure 5, Fall 2019). Model estimates of the probability the remaining thirteen individuals were overwintering Below Falls were less than 0.75, and the migration destinations of these fish were classified as Unknown (Appendix D). Migration destination (either Above Falls, Below Falls, or Unknown) in 2019 could not be determined for thirty-one char tagged in 2019, or for twelve char tagged in 2018 and detected in spring 2019. Of these forty-three fish, fourteen were last detected in the ocean and may be overwintering elsewhere (dark grey), eight were confirmed harvested (orange), one was a confirmed mortality (light brown), twelve were potential mortalities or cases of tag shedding (red and pink), and eight were not detected in 2019 (black bar in Figure 5, Fall 2019).

Of twenty-four individuals known to have overwintered below the falls and not harvested through the ice in 2018, six were harvested or likely mortalities in 2019 (orange and red Fall 2019 bars, coming from blue Summer 2019 bar in Figure 5). An additional five were last detected in the marine environment in 2019 (dark grey), and may be overwintering within an alternate river system. One was last detected within the river in the fall of 2019, but was not estimated by the model to be overwintering below the falls and migration destination remains Unknown (green). Three were estimated by the model to be overwintering below the falls in 2019 (blue), and nine were detected passing above the falls between 23 July and 25 August (yellow).

3.4 Overwinter Detections

Twenty-seven tagged char were detected on at least one river receiver downstream of the falls during the winter of 2018, which was defined as the period between 01 October 2018 (ice was forming) and 19 June 2019 (river break-up). In early October, ten char were detected at COP-L-R-5 and sixteen were detected at COP-L-R-4. No fish were detected on either of these receivers after 10 October, except for three individuals detected at COP-L-R-5: one was detected briefly in early February, another was detected briefly in mid-March and then immediately before river break-up on 18 June, and one was consistently detected from mid-March to mid-May (Figure 6). As winter progressed, detections of fish decreased or ceased at each receiver in an upstream to downstream pattern. Detections largely ceased at COP-L-R-3 by 30 November, at COP-L-R-2 by 15 December, and at COP-L-R-1 by 19 February. During the periods that fish were detected by river receivers, fish body temperatures ranged from -0.14 to 0.33°C, and 99.98% of detected temperatures were < 0.02°C.

3.5 Overwinter Movement

Of the twenty-seven fish detected below Kugluk Falls over the winter of 2018, twelve were detected by one or both of the two upstream receivers (COP-L-R-4 and COP-L-R-5) and fifteen were detected by one or more of the three downstream receivers (COP-L-R-1, COP-L-R-2, COP-L-R-3) in early October (Figure 7). During the period that detections continued to be recorded regularly by the

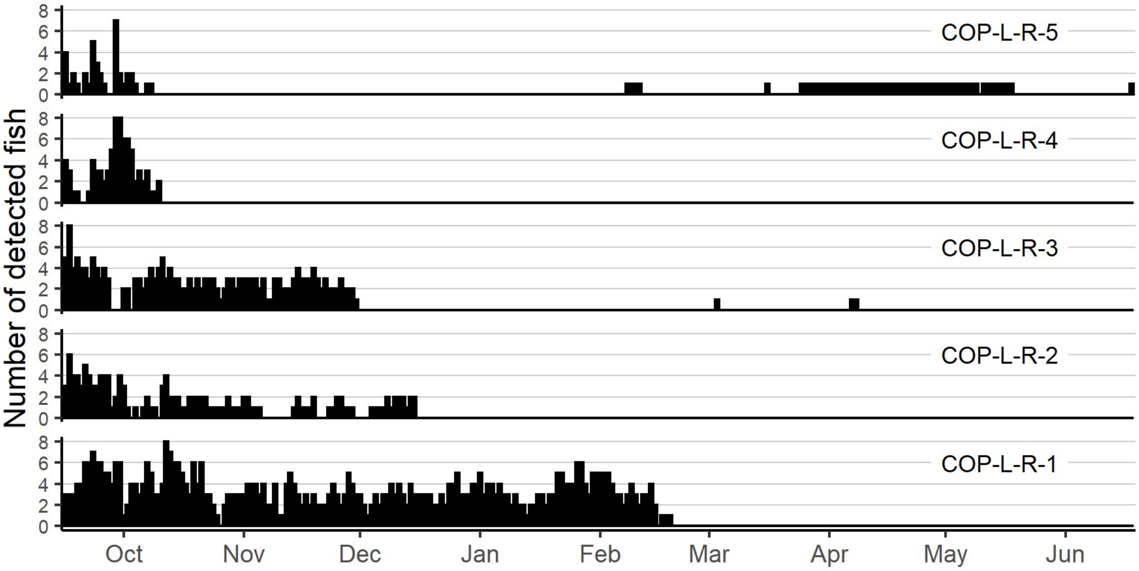

Figure 6: Number of unique fish that were detected each day on river receivers from late fall (15 September) to river break-up (19 June). The winter period is considered to begin on 01 October, when ice was beginning to form in the Coppermine River and Coronation Gulf, and end at river break-up. Receivers are presented in order from upstream to downstream and are located along an approximately 8 km stretch of river, ranging from 2 km below Kugluk Falls (COP-L-R-5) to 5 km above the river mouth (COP-L-R-1).

downstream receivers (November to mid-February; Figure 6), 67% of individuals were detected by a single receiver (Figure 7), which suggests minimal movement between receivers. Although detections had largely ceased on the other receivers, receivers COP-L-R-3 and COP-L-R-5 continued to sporadically detect fish from mid-February to May (Figure 6). Two individuals were recorded at COP-L-R-3 in March and April; both of these fish had been previously recorded at that same location in late December and had not been detected elsewhere (Figure 7). An additional three individuals were recorded at COP-L-R-5: two in February and March, after being last detected in early October in the same area, and one that was detected consistently from March until May. These late winter detections also suggest minimal winter movements.

Overwinter movement was observed during two periods. First, four of the fish detected at the upstream receivers traveled downstream to the three lower receivers in early October (Figure 7). Second, limited movement of these four fish and the fifteen downstream fish was observed among the three lower receivers until 14 December. Between October and 14 December, ten individuals displayed net downstream movement and one displayed net upstream movement (Figure 7). After

14 December, detections in the lower section were only recorded on the most downstream receiver (COP-L-R-1), with the exception of the aforementioned two individuals at COP-L-R-3.

Figure 7: Winter 2018 detections of twenty-seven tagged char overwintering within the Coppermine River, below Kugluk Falls. Each horizontal line (vertical axis) represents one individual tagged char. Individual fish ID labels are not shown to prevent cluttering. Coloured bars indicate timing, duration, and location of overwintering detections. Three individuals were harvested by local fishers through the ice at unknown locations below the falls, indicated by black points.

Overwintering detection data are not available for 2019. Limited data obtained by communicating with the river mouth receiver (**X** in Figure 4) through the ice on 31 January 2020 shows, however, that at least seven individuals were detected at the river mouth over the winter months. Four individuals had previously been detected in late August and September 2019 at receiver COP-L-R-4, before being detected near the river mouth between 05 October and 07 December. A fifth individual was previously detected at receiver COP-L-R-3 on 06 September 2019 and was most recently detected at the river mouth on 12 November. Most interestingly, two individuals were detected migrating above the falls on 30 July and 09 August 2019, and were most recently detected at the river mouth on 09 October and 02 October, respectively.

3.6 Receiver Logs

Depth logs from receivers that were deployed overwinter in the river indicated that at locations closer to the river mouth, such as at receiver COP-L-R-1, the surface height was relatively constant throughout winter (Figure 8). However, at the two receivers located closest to Kugluk Falls, COP-L-R-4 and COP-L-R-5, there were 4-7 m increases in surface height above the receivers, and measurements were more variable. Local community members have observed large build-ups of ice at certain locations within the Coppermine River, including the stretch of river below Kugluk Falls where these two receivers were placed. Increases in surface heights above the two upstream receivers (COP-L-R-5 and COP-L-R-4) were likely due to ice accumulation caused by periods of over-ice flow from Kugluk Falls that subsequently froze, as well as potential stress cracks and buckling from ice dams.

By examining noise, depth, and tilt records in the receiver logs, it was possible to identify disturbance events or periods when high noise levels may have impacted the ability of receivers to detect tagged fish. Detections largely ceased at the two most upstream receivers, COP-L-R-4 and COP-L-R-5, on 10 October when ice was beginning to accumulate as inferred from depth logs (Figure 9b, dashed line). Noise levels also suggested there were under-ice disturbances at these receivers prior to 10 October (Figure 9a). Other evidence of disturbance included the damage of one buoy from each receiver, as well as the broken mooring of COP-L-R-4 (identified in Figure 9). Visual inspection after physical retrieval of COP-L-R-4 by ROV suggested that the receiver and cable were

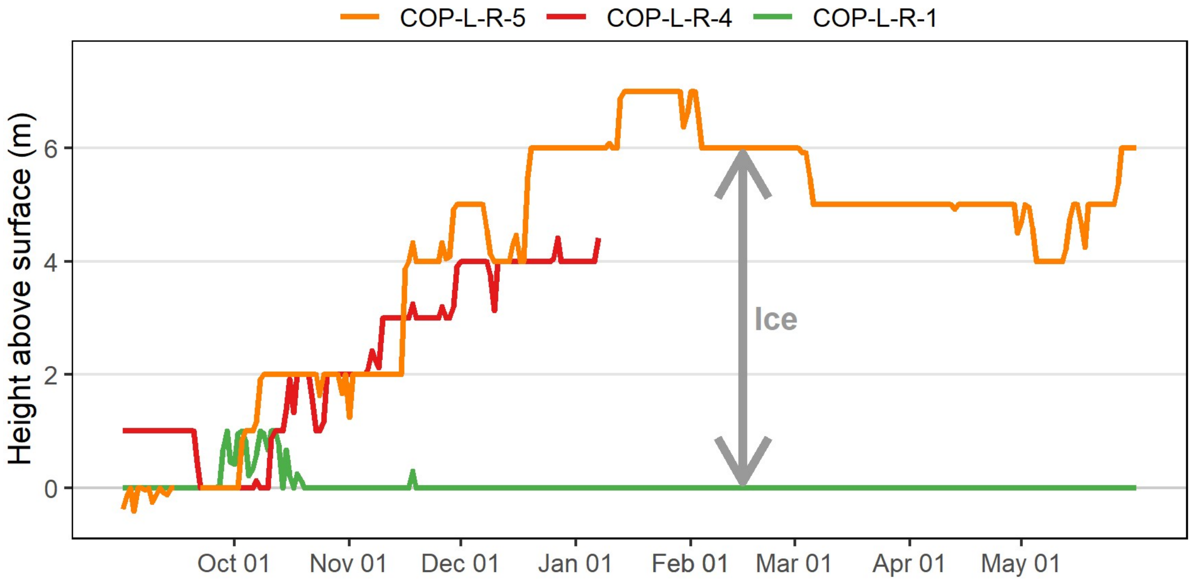

Figure 8: Average daily water depth measurements from three receiver logs, including the two located furthest upstream and closest to Kugluk Falls (COP-L-R-4 and COP-L-R-5), and the furthest downstream (COP-L-R-1) for reference. COP-L-R-4 logs are only displayed until the estimated date it broke free of its mooring (08 January 2019). Measurements are adjusted so that 0 m represents the surface of the water as recorded in late September, prior to river freeze-up. Values greater than 0 m indicate either an increase in water level or build-up of ice above the receiver. Note that the resolution of receiver measurements is 1 m, so rounding errors may occur when actual levels are near thresholds between two increments. Also note that depths are recorded as the equivalent depth of seawater, which is more dense than the freshwater found within the Coppermine River and substantially more dense than ice. Therefore, changes represented here are underestimates of the true changes in surface level.

subject to considerable friction and force, which corroborates the inference of substantial under-ice disturbances from receiver logs.

Depth measurements were less variable for the three downstream receivers, tilt angles remained relatively constant (Figure 10), and no buoys were damaged on any of these receivers, suggesting there was relatively less ice-build up, ice dams, buckling, or movement in this section of the river. The one major disturbance identified was associated with the mooring of receiver COP-L-R-3. Similar to COP-L-R-4, the visual inspection of the point of failure indicated sustained vibration and friction at this receiver location. The time of mooring detachment can be identified from decreasing depths that were recorded by the receiver as it ascended from the river bottom to the surface, below ice

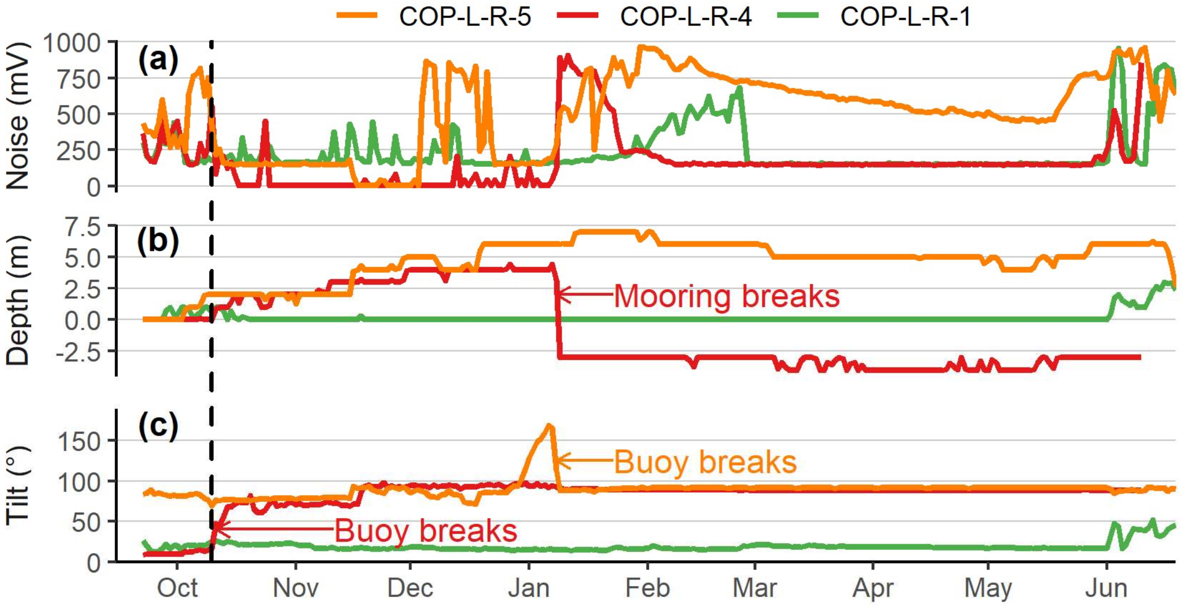

Figure 9: Receiver logs of (a) noise, (b) depth, and (c) tilt for upstream receivers (COP-L-R-4 and COP-L-R-5), with downstream receiver COP-L-R-1 for reference. The vertical black dashed line indicates the date when detections ceased at both upstream receivers, with the exception of three individuals detected on COP-L-R-5 between February-April 2019.

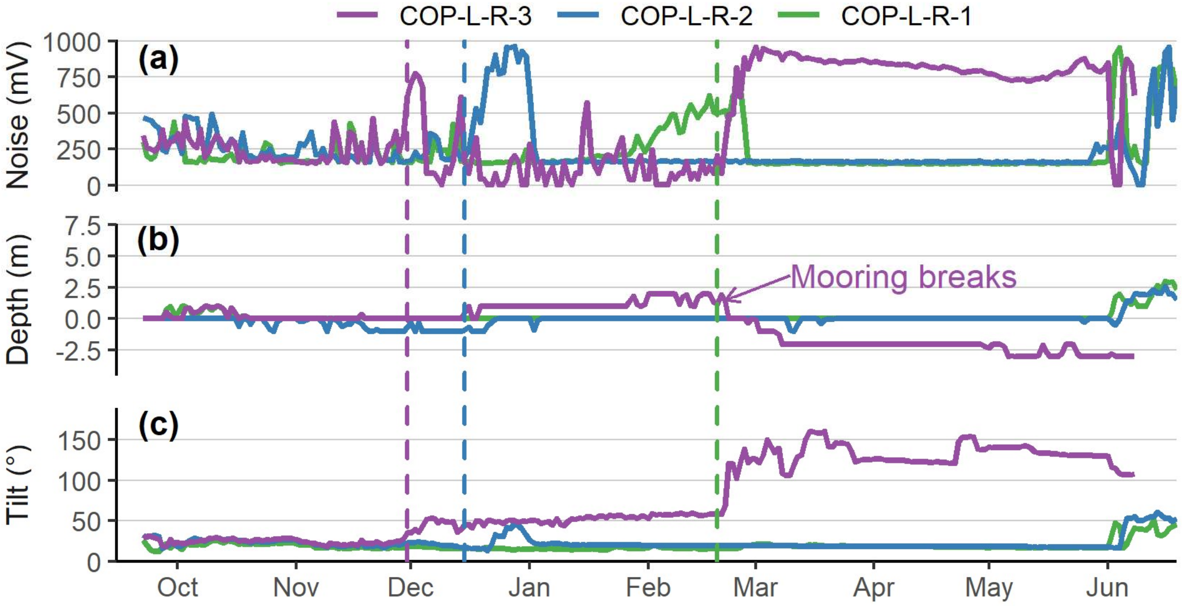

Figure 10: Receiver logs of (a) noise, (b) depth, and (c) tilt for three downstream receivers. Vertical dashed lines indicate dates when fish detections ceased at each receiver, with the exception of two single detections in March and April from two unique individuals on receiver COP-L-R-3.

(Figure 10). Leading up to this time, increases in ice depth and receiver tilt were observed, as well as greater variability in noise.

Following the failure of the COP-L-R-3 mooring, the receiver tilt records show the hydrophone was oriented downwards, and noise was consistently high (Figure 10). Despite the unfavourable receiver orientation and elevated noise levels, this receiver was able to detect two individuals, one on 03 March and one on 07 April (Figure 6). Noise levels at this time were similar to those observed at COP-L-R-5 when it also recorded mid-winter detections (March through May, Figure 9). On 22 March 2019, an attempt was made to communicate with receiver COP-L-R-3 after drilling through the ice; however, communication was not possible as the water column was comprised of slush or unconsolidated frazil ice. The high noise levels observed at this time on both COP-L-R-3 and COP-L-R-5 were likely associated with slush flowing beneath the ice. Although slush was only observed at this single point in time, similar conditions are likely persistent and occur every year, as an historic hydrological station near Kugluk Falls had to be re-located due to slush ice conditions over multiple years (Coulombe-Pontbriand et al. 1998). Under-ice slush would reduce the detection range of the receivers; detections may still be possible, but within a more restricted radius.

During the period that receivers COP-L-R-3 and COP-L-R-5 recorded elevated noise levels (March through May), the remaining three receivers (COP-L-R-1, 2, and 4) recorded low, less variable noise levels and consistent tilt angles (Figure 9 and Figure 10), suggesting that they were frozen into anchor ice (COP-L-R-1 and 2) or surface/hanging ice (COP-L-R-4). This likely prevented the receivers from detecting tag transmissions, and no fish were detected by these receivers during this period. Ice surrounding these receivers likely melted in early June, when higher noise levels and increased variability in depth and tilt measurements were evident on all river receivers prior to break-up on 19 June (Figure 9 and Figure 10). With the exception of this period in early June, the temperatures at all receivers stayed constant at approximately 0°C (Appendix E).

3.7 Freshwater Entry

Fall freshwater entry dates into the Coppermine River were identified for twenty-eight individuals in 2018 and fifty-four individuals in 2019. Sample sizes in models of fall freshwater entry date were reduced, however, because migration destinations were unknown or could not be estimated for ten individuals. Data from both 2018 and 2019 were included in the models (see Section 2.6.3), but only the first year (2018) was included in the models when entry dates were identified for an individual in both 2018 and 2019 (n=9). This was done to improve balance of sample sizes between years and migration destinations. The final sample size was sixty-three (n=24 from 2018, n=39 from 2019).

For individual fish that were included in the models, date of freshwater entry in 2018 ranged from 12 August to 08 September, with a median of 22 August. In 2019, the range was 22 July to 13 September with a median of 30 July. The overall range was 22 July to 13 September and the overall median was 13 August. Fish tagging did not take place in 2018 until 08-23 August, one week later than the median entry date in 2019, so individuals with early entry dates in 2018 were likely missed by tagging efforts. The fork lengths of individuals included in the models ranged from 539-885 mm, with a median of 686 mm. Thirty-three individuals were detected migrating above the falls, and thirty were detected (2018) or estimated (2019; Section 2.6.1) to be overwintering below the falls.

Migration destination was the strongest predictor of fish entry date, and explained over half the variation when included in a linear model as the single explanatory variable (Model 1 in Table 1). Individuals migrating above Kugluk Falls entered freshwater earlier than those overwintering below the falls. There was a relatively early pulse of fish entering the river observed in July 2019, and all these individuals migrated above the falls (Figure 11). A potential second pulse of fish appeared to enter the river on approximately 10 August, and several individuals migrated above the falls. After mid-August, the majority of fish that entered freshwater were detected or estimated through

Table 1: *A priori* linear model set, relating date of fall freshwater entry to the categorical variable migration destination (Above Falls, Below Falls) and continuous variable fork length (n=63). AICc scores were used to rank models, and models are presented in order of increasing AICc values (decreasing rank).

Model		AICc	ΔAICc	-2LogLikelihood	Model Likelihood	Model Weight	Adjusted R^2
M3	Destination + Fork Length	460.23	0.00	451.54	1.00	0.45	0.54
M1	Destination	460.49	0.26	454.08	0.88	0.39	0.53
M4	Destination*Fork Length	462.24	2.02	451.19	0.36	0.16	0.54
M2	Fork Length	506.68	46.46	500.28	0.00	0.00	0.03
M0	1 (Null)	507.11	46.88	502.91	0.00	0.00	-

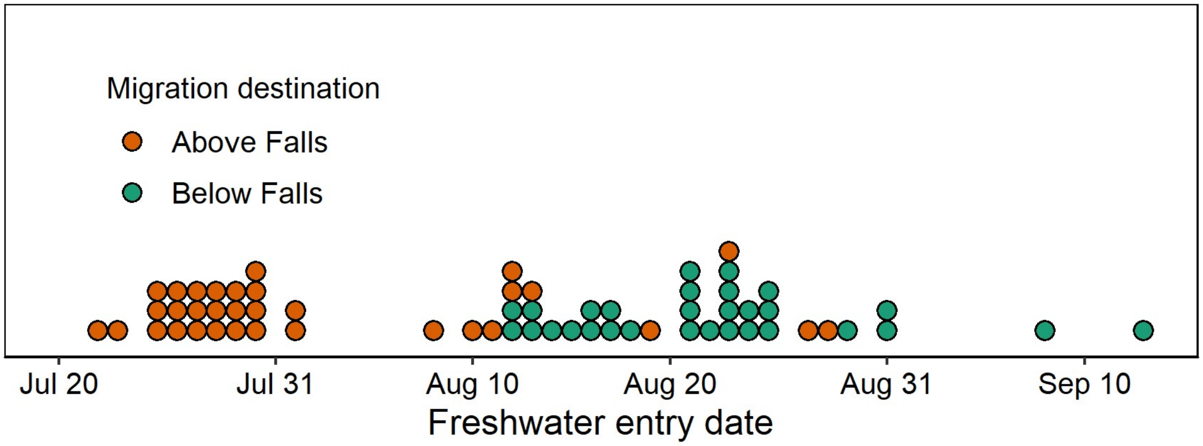

Figure 11: Dates of fall entry into freshwater for char included in linear models, grouped by migration destination (Above Falls, Below Falls). Each dot represents an individual fish. A clear peak of fish entering the river is observed in July, with all these individuals migrating above the falls. A second pulse of fish entering freshwater was observed around 12 August and a third pulse was observed around 23 August.

modeling to use the lower reaches of the Coppermine River for overwintering (Figure 11). For individuals detected migrating above the falls, date of passage above the falls (measured as the earliest date of detection on a receiver above the falls) was highly correlated with date of freshwater entry (Pearson's r=0.89, Figure 12), suggesting that fish displayed directed upstream movement after entering the river.

Date of freshwater entry was negatively related to fork length; smaller fish entered freshwater later. However, fork length was not a strong predictor of fish entry date (adjusted R^2=0.03, Model 2 in Table 1) and including fork length in a model that also included destination only marginally improved model AICc (Models 1 and 3 in Table 1). This may be due to the fact that the relationship between fork length and entry date appears to vary over the course of the season (Figure 13). Fork length appears to be less important earlier in the season, for the first run of char that migrate above the falls. Later in the summer, a negative relationship is evident between fork length and entry date, regardless of migration destination. Model results indicate limited support for an interaction between destination and fork length (Model 4 in Table 1); however, the standard error of the estimated coefficient for the interaction term included zero (Appendix F). The uncertainty in this term is likely driven by the ten individuals that entered freshwater later in the season but migrated above the falls (Figure 13).

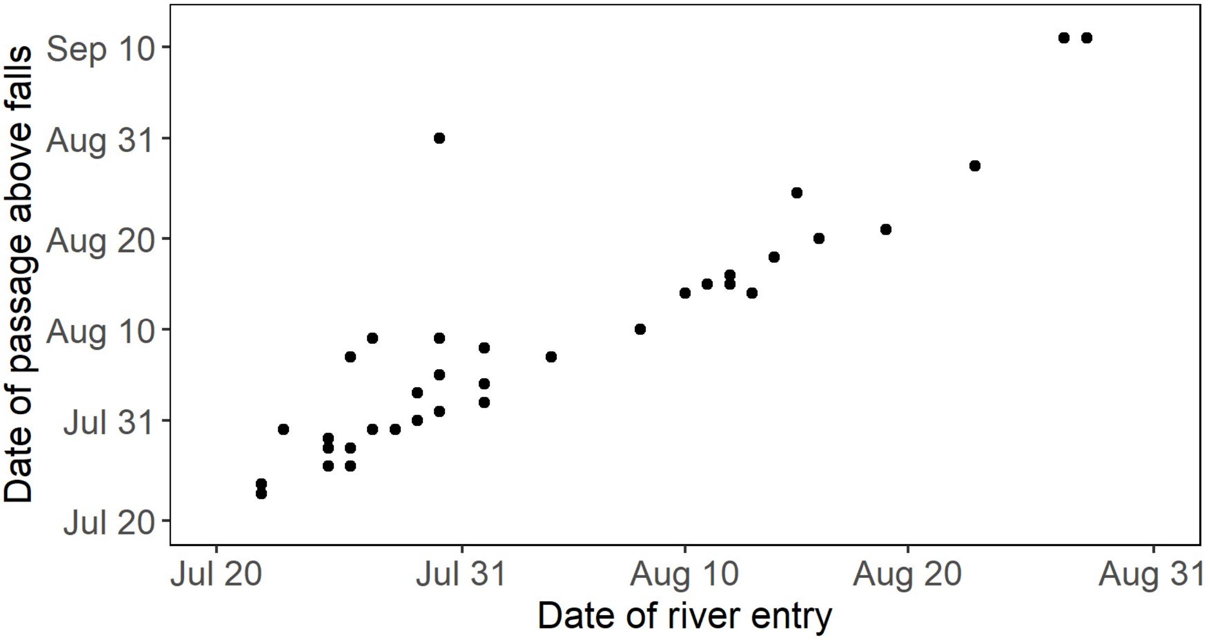

Figure 12: Relationship between date of fall freshwater river entry and date of passage above Kugluk Falls. Date of passage above the falls was determined by the earliest time an individual was detected at receivers located above the falls. River entry and passage above falls were highly correlated (Pearson's r = 0.89).

3.8 Spring Marine Entry

Three of the twenty-seven individuals that were recorded overwintering below the falls in 2018 were harvested within the river (orange bar in Figure 5, Winter 2018), and one individual was detected as a potential mortality or case of tag shedding in the marine environment in the spring (red bar in Figure 5, Fall 2019). The remaining twenty-three char that overwintered below the falls in 2018 were subsequently detected in the marine environment in spring 2019 (Figure 14). Due to the relocated COP-L-R-4 receiver not being present at its marine location until after river break-up, as well as the relatively large distance between the river mouth and the First Point receiver (~7 km), all dates of marine entry are likely underestimates.

One of the fish that overwintered below the falls in 2018 was first detected on 14 July at Four Mile Bay, approximately 6.5 km (4 mi) west of the river mouth (Table 2; 4MB-R-1 in Appendix B). A second was first detected on 26 July by receivers at the Kugaryuak River, approximately 70 km east of the Coppermine River (Figure 2). These two individuals were not detected until after marine

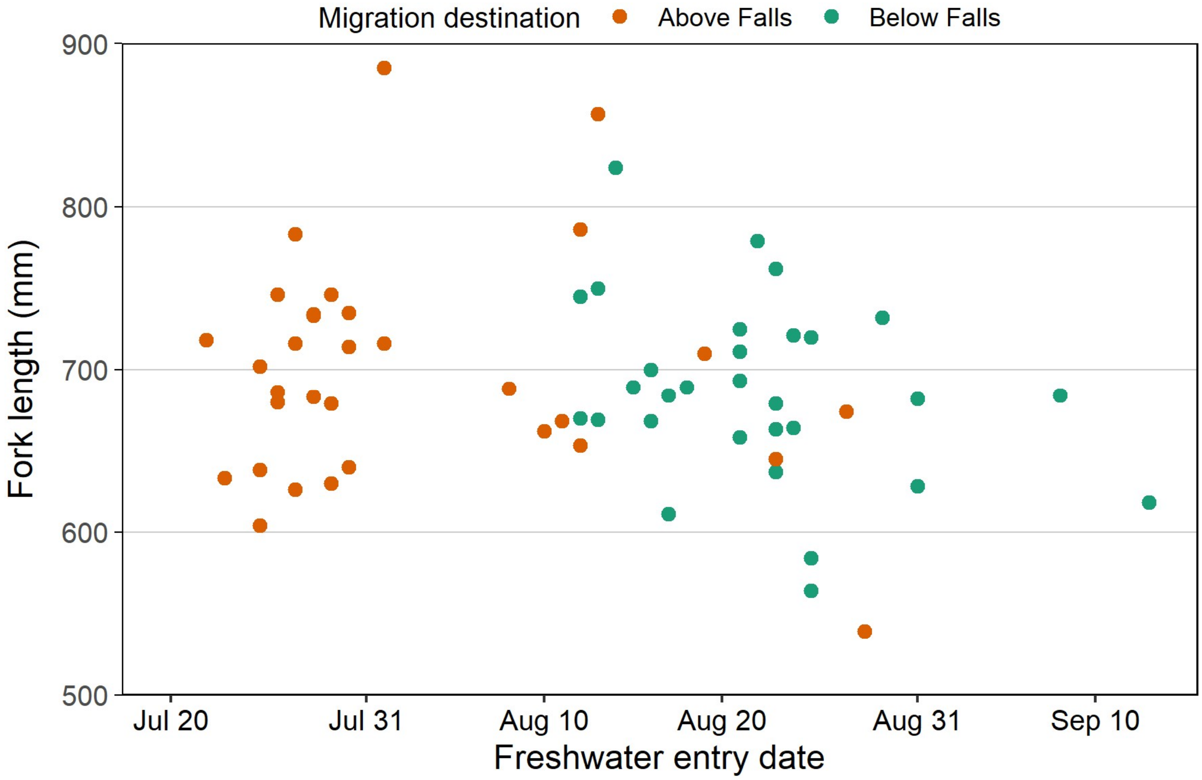

Figure 13: Individual fork length and dates of fall freshwater entry for char included in linear models, grouped by migration destination (Above Falls, Below Falls)**.** There is no obvious relationship between fork length and freshwater entry date for fish that entered freshwater early in the season (July). Later in the season, a negative relationship is apparent between fork length and entry date; smaller individuals enter freshwater later.

receivers had been deployed for the 2019 season, and thus marine entry dates were not estimated, as these fish had evidently been using the marine environment for some time prior to detection.

Five individuals were first detected in the marine environment prior to river break-up on 19 June (Figure 14, Table 2). All five early entrants were detected at First Point, which is located approximately 7 km northwest of the river mouth, thus requiring substantial under-ice travel. The body temperatures of these five individuals prior to river break-up ranged from -0.14—1.28°C. Mean body temperatures during this period ranged from 0.07—0.49°C, with an overall mean of 0.30°C and standard deviation of 0.26°C.

Sixteen individuals were first detected in the marine environment after river break-up. These were all detected within two weeks, and the majority within one week, of river break-up (Figure 14). Two

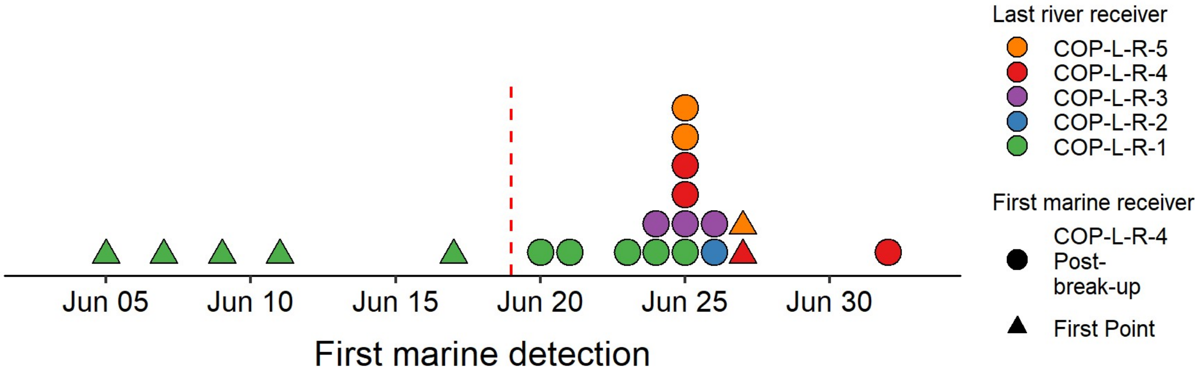

Figure 14: Dates that char overwintering below the falls in 2018 were first detected in the marine environment in spring 2019. Each point represents an individual char and the red dashed line indicates the date of river break-up (19 June). Colour indicates the river receiver where each char was last detected before entering the marine environment. Circles represent char that were first detected in the marine environment at the re-located COP-L-R-4 receiver; triangles represent char that were first detected at First Point. Not shown are two individuals that were first detected in mid- to late-July at distances that indicated they were likely missed or did not swim past receivers nearer to the river mouth.

Table 2: First marine detections in spring 2019 of tagged char that overwintered in 2018 in the Coppermine River below Kugluk Falls. River break-up occurred on 19 June. Four Mile Bay is located 6.5 km west of the river mouth.

First Marine Detection	**Time Period**	**Number of Fish**
First Point	Pre-break-up	5
First Point	Post-break-up	2
Relocated COP-L-R-4	Post-break-up	14
Four Mile Bay	14 July	1
Kugaryuak River	26 July	1

were detected at First Point and fourteen were first recorded by the opportunistically relocated COP-L-R-4 receiver, after it had broken free of its mooring and was transported to the marine environment (Table 2; see Figure 4 for a map of receiver locations). The loss and later relocation of this receiver was serendipitous, as marine entry dates of these fourteen char would not otherwise have been possible to estimate. Body temperatures at the time of first marine detection of the individuals that were first detected at the relocated COP-L-R-4 receiver ranged from 4.41-10.22°C, with median of 9.20°C.

The eight fish with the earliest marine detections were last detected in freshwater at COP-L-R-1, the receiver closest to the river mouth (Figure 14). In general, the individuals detected overwinter in the lower reaches of the river were the first detected in the marine environment. Those detected at COP-L-R-4 and COP-L-R-5 were not detected in the Coronation Gulf until 25 June or later, at least six days after river break-up.

4. Discussion

4.1 Causes of Mortality and Undetected Fish

The percentage of tagged char that was detected moving through the receiver array (90%) compares favorably with other acoustic telemetry studies of Arctic Char (39-93%; Spares et al. 2015; Moore et al. 2017; Mulder et al. 2018a; Harris et al. 2020), and the percentage of tagged char identified as potential mortalities or cases of tag shedding (8%) was substantially lower than the 48-79% tag expulsion rate that has been observed by other researchers (Jensen and Rikardsen 2012; Mulder et al. 2018b). Overall, low inferred rates of mortalities and tag expulsions suggest that there were no undue adverse effects from surgeries to implant tags, and that char were largely able to recover and retain tags following the procedure.

The percentage of tags that was returned by local fishers over the two years of the study (9%) was modest relative to a study in nearby Cambridge Bay, where four of only nine tagged char (44%) were harvested in the local fishery (Bégout Anras et al. 1999), but is approaching the 5% considered by Fisheries and Oceans Canada to be a sustainable annual harvest rate for exploited char populations when detailed population-specific data are lacking (Tallman 2011). Anadromous fish often experience higher mortality rates in the marine environment and along migratory pathways (Gross et al. 1988; Quinn et al. 2016); estimated marine mortality rates from a Norwegian study ranged from 20-40% a year (Jensen et al. 2016). Harvest and mortality rates estimated here are likely underestimates because tagged individuals that were never detected (6.7%) or last detected in the marine environment (9.1%) could be undetected mortalities or unreported harvests (Appendix G).

It is possible that some individuals were not detected or were last detected in the marine environment because they migrated to rivers other than the Coppermine. Authors of a study of Arctic Char at Nulahugyuk Creek, approximately 160 kilometres northwest along the coastline from Kugluktuk, observed that char did not return to this natal watershed for 4-5 years after their first migration to sea (Gilbert et al. 2016). Char have never been observed to overwinter in the ocean, and individuals that did not return to Nulahugyuk Creek thus likely overwintered in non-natal systems until they reached sexual maturity. An annual stream restoration and floy tagging program takes place at Nulahugyuk, and some char with these floy tags have been captured by fishers in the

Coppermine River (Amanda Dumond, Manager of Kugluktuk Hunters and Trappers Organization, pers. comm.). The upstream migration at Nulahugyuk Creek is the earliest recorded Arctic Char migration from saltwater to freshwater, and takes place from mid-June to late-July each year (Gilbert et al. 2016). It is thought that char enter Nulahugyuk Creek early because that is the only time when water levels are sufficiently high to allow passage of adult fish; migration barriers and fish strandings have been observed to occur in this system due to low summer water levels (discharges of 0.03-6 m^3/s; Gilbert et al. 2016). In contrast, connectivity remains high throughout the ice-free season in the Coppermine River, where the average summer discharge is 473 m^3/s (Coulombe-Pontbriand et al. 1998). It is possible that some individuals overwinter below Kugluk Falls, enter the marine environment under ice early in the spring, and migrate to Nulahugyuk Creek or alternate spawning streams. If this is the case, it may be that fish use overwintering habitat below Kugluk Falls to minimize energy costs associated with longer migratory pathways, avoid potential stranding in other watersheds with lower discharges, and/or to allow early out-migration in the spring. Fates of undetected char remain speculative; further identification of mortality/tag shedding rates and migration to other river systems would require extending receiver coverage both temporally (i.e., additional years of study) and spatially (e.g., include Nulahugyuk Creek).

4.2 Under-ice Ecology of Arctic Char

4.2.1 Fluvial Overwintering

The detection of Arctic Char within the Coppermine River during winter 2018 corroborates local indigenous knowledge that char overwinter within the lower reaches of the Coppermine River. Other populations of Arctic Char that overwinter in fluvial environments have been documented in the literature (e.g., Beddow et al. 1998; Jensen and Rikardsen 2012; Harwood and Babaluk 2014), but are relatively rare. The fluvial overwintering habitats used by other populations include a river system that remains ice-free due to disturbance from a hydroelectric plant (Jensen and Rikardsen 2012), large, extremely deep (> 30 m) pools within a river (Beddow et al. 1998), or areas with sufficient groundwater input that, despite being shallow (< 3 m), do not freeze to the bottom (Harwood and Babaluk 2014). Overwintering habitats below Kugluk Falls in the Coppermine River are dissimilar from these other documented locations, in that they are of moderate depth

(3.8-14.1 m), have spatially uniform water temperatures, which suggests that there are no substantial groundwater inputs (Kugluktuk Ikaarvik youth group, unpubl. data), and are fully ice-covered. They also likely experience large-scale under-ice disturbances, including scouring, anchor ice, hanging dams, and substantial formation of slush, as indicated by noise, tilt, and surface height data collected by receivers.

Despite physical conditions that would pose challenges for overwintering fish, there are several potential reasons for a portion of the local Arctic Char population(s) to overwinter within the river below Kugluk Falls. First, fish may intentionally overwinter within the lower reaches of the Coppermine River to avoid the likely strenuous passage above Kugluk Falls or long migration to the Dismal Lakes under potentially unfavourable hydrological conditions. Another benefit of overwintering below Kugluk Falls is the potential for earlier access to the marine environment and associated food sources. As marine feeding is associated with nutrition and fecundity benefits (Gross et al. 1988; Tallman et al. 1996; Rikardsen et al. 2000; Gulseth and Nilssen 2001), fish that overwinter nearer to the ocean and have earlier access to marine food resources would likely experience higher gains in condition and fitness by the end of the ice-free season. It is thus likely energetically advantageous to overwinter at locations closer to the marine environment.

It is also possible that individuals enter the river with the intent of migrating to the upper reaches, but are unable to ascend Kugluk Falls. Failure to migrate above the falls may be due to poor body condition, unfavourable environmental conditions (e.g., water level, discharge, temperature), fishing pressure, or injury from snagging. Some individuals could thus be forced to overwinter below the falls. Further investigation of movement patterns during fall migration (e.g., speed, directedness of travel) may allow identification of intended migration destination and provide additional insight into the factors influencing the occurrence of fluvial overwintering within the Coppermine River.

4.2.2 Overwintering Habitat and Movement

While overwintering within the lower reaches of the Coppermine River may be energetically advantageous due to a short migration and close proximity to rich marine feeding grounds, there may also be energetic costs associated with overwintering in the river. One tactic to minimize metabolic costs that is employed by char that overwinter in lakes is the selective occupation of a cold thermal niche relative to available habitat (Mulder et al. 2018b). As there is mixing of the water column and no known groundwater inputs in the lower reaches of the Coppermine River, char overwintering within the river are likely unable to select a preferred thermal habitat. The body temperatures of char overwintering within the Coppermine River (99.98% < 0.02 °C) were lower than those observed in lakes (0.2-2.0°C; Klemetsen et al. 2003; Mulder et al. 2018b), and below the 0.2°C lower thermal limit for feeding (Elliott and Elliott 2010). Char that overwinter in the Coppermine River would likely thus have low metabolic costs due to the cold temperature, but they are likely unable to take advantage of any feeding opportunities.

Another energy conservation tactic observed for char overwintering in lakes is a reduction in movement (Mulder et al. 2018a). Although fish overwintering in fluvial systems must display some movement to maintain position in flowing water or avoid ice accumulation, reduced winter movement has been observed in salmonids that overwinter within rivers, including Atlantic Salmon (*Salmo salar*) kelts (Komadina-Douthwright et al. 1997), Cutthroat Trout (*Oncorhynchus clarkii*; Jakober et al. 1998), and Rainbow Trout (*Oncorhynchus mykiss*; Muhlfeld et al. 2001). Consistent with these studies, evidence of reduced winter movement suggests that at least some fish remained restricted to a relatively small spatial area, likely in pockets of suitable habitat, for the duration of the winter. It is possible that additional fish exhibited reduced movement, but that detections were obscured by slush causing high noise levels and reducing detection radii.

It was expected that fish would preferentially overwinter in deep areas, where available under-ice habitat was anticipated to be greater and water velocity lower. Other salmonids that overwinter in fluvial environments, such as Brook Trout (Chisholm et al. 1987), Brown Trout (*Salmo trutta*; Heggenes et al. 1993; Lindstrom and Hubert 2004), and Cutthroat Trout (Lindstrom and Hubert 2004) have been observed to preferentially overwinter in lower velocity areas, likely due to reduced energy expenditures. However, more fish were detected overwinter in a section of the Coppermine River with the highest summer velocities (receiver COP-L-R-5, personal observation) than in the section that contained a large, deep pool (~18 m, receiver COP-L-R-4, Appendix B), where unexpected ice accumulation and under-ice disturbances were inferred from receiver logs and damage. The accumulation of ice and restriction of river channels may be greater in areas with lower water velocity (Huusko et al. 2007; Brown et al. 2011), and previous authors have noted that accumulation of frazil ice in deep pools can result in less under-ice fish habitat than predicted or compared to shallower areas (Cunjak 1996; Komadina-Douthwright et al. 1997). Selection of overwintering habitat in large Arctic rivers without groundwater input may therefore involve trade-offs between inhospitable ice conditions in areas with low water velocity and increased energy costs in areas with higher velocities, but further research with more detailed hydrological data is required.

Challenging under-ice conditions driven by Kugluk Falls likely resulted in both a reduction in receiver detection radii and downstream movement of fish to more suitable habitat. In early October, ice build-up and under-ice disturbances coincided with timing of downstream fish movement from the receivers closest to Kugluk Falls. Similar movements to avoid ice accumulation and buckling in early winter have been observed for other salmonids overwintering in rivers with dynamic ice conditions, such as Brook Trout (Lindstrom and Hubert 2004), Bull Trout (*Salvelinus confluentus*; Jakober et al. 1998), and Cutthroat Trout (Brown 1999; Lindstrom and Hubert 2004). Later in the winter, the accumulation of frazil ice crystals and formation of anchor ice or hanging dams, as inferred from receiver logs, appeared to follow an upstream to downstream temporal pattern. This suggests that habitat became progressively unsuitable or smaller over the course of the winter, with lower sections of the river affected later in the season. This temporal and spatial pattern of ice accumulation may have caused the net downstream fish movement (n=10) observed here. This result is consistent with local indigenous knowledge that char move downstream over the course of the winter to feed near the river mouth (Prno 2019).

4.2.3 Marine Entry

Individuals that were last detected overwinter at the lowermost receivers in the Coppermine River were detected in the marine environment earlier than those overwintering closer to Kugluk Falls. Although it has been suggested that Arctic Char enter the marine environment while rivers remain frozen (Grainger 1953), it has otherwise been observed by western scientists that char do not enter the marine environment until after river break-up (Mathisen and Berg 1968; Moore 1975; Dempson and Green 1985; Gulseth and Nilssen 2000; Spares et al. 2015). In contrast, detections at First Point before spring break-up confirmed that movement into the marine environment occurred while the river and Coronation Gulf remained ice-covered, corroborating local observations that char can be caught through cracks in the sea ice in April to mid-June (Prno 2019; Eric Hitkolok, local fisher, pers. comm.). The only documented location where Arctic Char used the marine environment in winter was in Norway, where it was suggested that accumulation of frazil ice within the freshwater environment promoted winter use of the marine environment (Jensen and Rikardsen 2008). This may also be the case in the Coppermine River. However, the marine habitat used by char in Norway was not ice covered and was typically warmer than the nearby river environment (> 2°C; Jensen and Rikardsen 2012). In contrast, fish recorded by the First Point receiver before river break experienced much colder temperatures (-0.14 to 1.28°C) and traveled approximately 7 km under ice from the mouth of the Coppermine River. To my knowledge, under-ice travel of this distance and use of the marine environment by Arctic Char at these cold temperatures has not previously been documented.

Winter use of the marine environment is unusual for Arctic Char, as they have lower salinity tolerance at colder temperatures (Wandsvik and Jobling 1982; Finstad et al. 1989). However, temperature and salinity tolerances have been shown to vary seasonally. Previous authors have reported that in June, when char were acclimated to spring photoperiod conditions, fish were more tolerant of high salinities (Arnesen et al. 1992), or of both high salinities and low temperatures (Finstad et al. 1989), than in other seasons. Similarly, Aas-Hansen et al. (2005) found that Arctic Char captured through the ice in freshwater in late winter (May and June) had greater osmoregulatory capacity (i.e., salinity tolerance) and greater liver metabolic capacity (in preparation for feeding season) relative to earlier in the winter (April). This suggests that char undergo physiological adaptations in response to seasonal cues and prior to entering saltwater that may allow individuals to travel under the ice under cold, marine conditions in June.

An alternate explanation is that char detected at First Point before break-up in June were exploiting a pocket of freshwater under the ice surface. Temperature and salinity measurements at First Point on 22 March 2019 show a layer of 0 °C freshwater from the water surface until a sharp halocline at a depth of approximately 3 m (Appendix H). Although similar measurements are not available for the period in June when char were detected in the area, it is likely this freshwater layer persisted or increased in volume due to greater discharge from the Coppermine River prior to break-up. A layer of water with salinity ranging from 15-22 practical salinity units (PSU) has been observed in the marine environment at nearby Cambridge Bay at river break-up, when freshwater inputs would be expected to be high (Harris et al. 2020). This is much more saline than the 0-1 PSU observed at First Point under ice, and may explain why char were observed moving within the marine environment before ice break-up near Kugluktuk but not in other regional studies. Little is known of oceanographic processes in the region, particularly during the winter months, and future work characterizing the marine environment will greatly improve our understanding of under-ice movements of Arctic Char.

4.3 Variation in Migration Destination of Arctic Char

The high level of inter-individual variability in migration destination that I observed may reflect multiple sympatric char populations that use the Coppermine River and surrounding marine areas. Such stock mixing has been observed in the nearby Cambridge Bay fishery, where Arctic Char from different populations are known to use the same marine environments during summer (Dempson and Kristofferson 1987; Moore et al. 2016). Identification of spawning locations is necessary to determine if multiple, reproductively isolated populations of Arctic Char use the Coppermine River watershed.

It is possible that one population consistently overwinters and also spawns below the falls, after an extended period of feeding in the ocean. Although it is uncommon for Arctic Char to spawn in fluvial environments, it has been documented elsewhere (Dempson and Green 1985; Cunjak et al. 1986; Elliott and Baroudy 1995; Harwood and Babaluk 2014). Where fluvial spawning has been observed, it is either in more southerly areas of the species' range, in more moderate climates (Dempson and Green 1985; Elliott and Baroudy 1995), or in areas where there is groundwater upwelling (Cunjak et al. 1986; Harwood and Babaluk 2014). Such habitats are unknown in the lower reaches of the Coppermine River, and overwinter ice conditions and scouring during spring break-up likely make the area risky for incubation and hatching. However, gravel beds suitable for spawning are present and some local fishers have reported catching post-spawning females (still with eggs) through the ice (Allen Niptanatiak, Government of Nunavut Conservation Officer, pers. comm.). Others, however, have indicated that it is rare to catch males in spawning colours below the falls (Eric

Hitkolok and Adam Panioyak, local fishers, pers. comm.). The occurrence of spawning below the falls and in fluvial habitat close to marine food sources remains to be confirmed.

Although Arctic Char typically spawn and overwinter in lakes, the nearest suitable lakes are the Dismal Lakes, which are > 160 km from the Coronation Gulf and substantially farther than other lakes in the region (0.2-50.4 km; Gyselman 1994; Gilbert et al. 2016; Moore et al. 2017). Interestingly, two individuals were detected migrating above Kugluk Falls in summer 2019, but then returned below the falls to overwinter. Although two-step migrations have been documented elsewhere, where char migrate to spawning areas and then move downstream or even into adjacent river systems to overwinter (Beddow et al. 1998; Jensen and Rikardsen 2008), the length and difficulty of a two-step migration to and from the Dismal Lakes would be unprecedented. Instead, it is more likely that these individuals migrated upstream to spawn in fluvial habitats above Kugluk Falls, and moved downstream to areas that were more suitable for adult overwintering or to position themselves closer to the ocean for earlier marine entry. If this is a common occurrence, it may also explain the local observations of post-spawning females below Kugluk Falls. Further investigation of spawning locations in this system is necessary to identify the drivers of inter-individual variation in migration destination.

In addition to inter-individual variability, inter-annual (for individuals detected in both 2018 and 2019) variability in migration destination was also observed. Observed differences among years in migration destination may be related to the spawning status of tagged individuals. Evidence of overwintering in non-natal habitats in non-spawning years has been noted in other populations of Arctic Char (Moore et al. 2013; Spares et al. 2015; Gilbert et al. 2016); dispersal in non-spawning years has been suggested to be more likely if the migratory pathway to spawning grounds is long or has a higher gradient (Moore et al. 2017), as is the case for the upper reaches of the Coppermine River. Char may thus overwinter below Kugluk Falls only in non-spawning years. Overwintering below the falls in the year prior to spawning may confer a fitness benefit, as marine feeding can commence earlier and result in a greater increase in body condition prior to upstream fall migration and spawning. Further investigation is required to test this assertion.

The inter-individual and inter-annual variation observed here has important implications for fisheries management, as delineating and characterizing populations is key to ensuring the future sustainability of Arctic Char stocks in the Coronation Gulf. Longer movement studies, genetic analyses, and/or otolith microchemistry would further understanding of population dynamics in this understudied region.

4.4 Migration Timing

Fall entry of Arctic Char into the Coppermine River occurred over a longer period of time and followed different patterns than elsewhere, including nearby Cambridge Bay. The timing of entry into freshwater is compressed in Cambridge Bay, and typically ranges from 10 August to 15 September, with a clear peak in entry timing that ranges from 27 August to 10 September (McGowan 1990). In contrast, the date of fall freshwater entry into the Coppermine River system ranged from 22 July to 13 September, and several peaks in the number of fish entering freshwater were observed. Additional years of monitoring are required to understand if peaks can be appropriately delineated and if timing is consistent among years. Differences in migration patterns among regions may be due to physical differences between the Coppermine River and river systems near Cambridge Bay. With a watershed area of 50 800 km^2 (Wedel et al. 1988), the Coppermine River is approximately 3.4 times the size of the largest river system near Cambridge Bay (Moore et al. 2016). The migratory pathways are also relatively short near Cambridge Bay (3.6-50.4 km, mean 18 km; Moore et al. 2017) and typically lead to single destinations (i.e., lakes), whereas the large size and variable habitats of the Coppermine River allow for multiple migration destinations and overwintering habitats, which may in turn drive the inter-individual and inter-annual variability that I observed in timing of freshwater entry.

The difficulty of the migratory pathway may affect date of freshwater entry, as individuals migrating above the falls were observed to enter the river earlier than those estimated to be overwintering below the falls. Arctic Char are less likely to employ an anadromous life history strategy in areas where the migration pathway is difficult (e.g., high gradient) or long (Finstad and Hein 2012). In a study of migration timing near Cambridge Bay, Moore et al. (2016) found that at least 20% of the variation in the timing of fall freshwater entry was related to the river system where the individuals had been tagged and were thought to originate from. However, these authors did not investigate effects of migration destination on timing of freshwater entry, which may be important, especially because low fidelity to natal systems in non-spawning years has been observed for char in these systems (Moore et al. 2017). Freshwater entry timing is known to vary among populations and among destination tributaries within the same river system for other salmonids, for example, Chinook Salmon (Keefer et al. 2004; Strange 2012; Quinn et al. 2016), but variability in entry timing has not been directly attributed to migration route characteristics. A relationship between freshwater entry date and the length and difficulty of the migratory pathway has not previously been observed for char or other salmonids using the same river system.

There was an overall negative relationship between individual fork length and freshwater entry date; smaller fish were found to enter the Coppermine River later. This contrasts with findings from Cambridge Bay, where no relationship was found between entry date and size (Moore et al. 2016), but is consistent with other studies that have observed large char entering into freshwater earlier in the fall than smaller char (Dempson and Green 1985; Mulder et al. 2018a). Smaller fry of another salmonid, Arctic Grayling (*Thymallus arcticus*), have been observed to stay later in summer feeding streams than larger individuals, risking entrapment from ice freeze-up for nutritional benefits (Heim et al. 2016). Arctic Char with shorter fork lengths may thus enter freshwater later, due to the proportionately greater potential for growth in the marine environment for smaller fish and associated fitness benefits (Quinn et al. 2016).

The strength of the relationship between size and entry date appeared to be inconsistent over the course of the ice-free season. No correlation was evident earlier in the year, when all the fish that entered freshwater migrated above the falls. The negative relationship between size and entry date was stronger later in the summer season, and did not appear to be affected by migration destination; smaller individuals entered freshwater later, even when those individuals migrated above the falls in late summer. It is possible there are two runs of char that migrate above Kugluk Falls to different destinations in the upper reaches of the Coppermine River. The first run may migrate over a greater distance or through areas of low flow, and therefore need to enter the river earlier to improve the rate of migration success, regardless of size. Conversely, the second run may be migrating a shorter distance and have different migration cues. Further research is required to more accurately identify migration destinations in the upper reaches of the Coppermine River and additional drivers of migration timing (e.g., temperature, water level, tidal cycle).

5. Summary and Conclusions

Although overwintering of Arctic Char in fluvial environments has been observed in several locations across the Arctic (Beddow et al. 1998; Harwood and Babaluk 2014; Jensen et al. 2016), it is not commonly observed, and within-river winter movements remain virtually unstudied. There are undoubtedly numerous costs and benefits to fitness for Arctic Char that overwinter in the lower Coppermine River. One potential benefit is avoiding the energy expenditure associated with a long and difficult migration above Kugluk Falls. However, due to high flows and dynamic ice conditions, both through the winter months as well as during spring break-up, char are unlikely to be able to employ energy conservation tactics in the river that have been observed elsewhere in lakes, such as remaining relatively stationary and seeking sheltered locations at thermal optima. These costs, along with a potentially higher risk of mortality, may be outweighed by the advantage of being closer to the marine environment, which allows for earlier access to rich marine feeding grounds.

Arctic Char is a highly plastic species (Nordeng 1983; Klemetsen 2010). This plasticity has likely allowed them to exploit a wide variety of challenging environments throughout the circumpolar Arctic. In this study, I observed high inter-individual variability in timing of freshwater entry, migration destination, and overwintering habitat. I also observed substantial inter-annual variability in the life history tactics employed within individuals. Additional research is required to investigate how natal system, spawning status, and potential environmental cues may affect variability in migration destination and overwintering ecology both within and among individuals.

Many biological (e.g., sex, size) and environmental (e.g., water level, temperature, characteristics of migratory pathway) factors have been suggested to influence the timing of Arctic Char migrations to freshwater in fall. There is conflicting evidence regarding the importance of some of these variables, whereas others remain untested. I found that timing of freshwater entry was related to migration destination. Individuals that migrated above the falls entered the Coppermine River earlier than those overwintering below the falls. It thus appears that individuals with a longer and more difficult migratory pathway enter freshwater earlier than other individuals using the same system. Migration timing was also size-dependent, particularly later in the ice-free season. Smaller fish entered freshwater later than larger individuals, likely due to smaller individuals risking adverse environmental conditions to prolong access to productive feeding opportunities in the marine environment.

Results from this study help to further knowledge of migration patterns and overwintering ecology for Arctic Char. The insights gained from this study, combined with future work characterizing the environmental cues of char migration in the region, will aid our understanding of why some individuals enter freshwater early and do not take advantage of the full ice-free season in the marine environment. This will be important for predicting the impacts of climate and other changes on this ecologically and culturally important fish species. Also, as the Coppermine River is the largest fluvial system within the region, it may provide overwintering habitat for char populations from other rivers in non-spawning years. Improving our understanding of the variation in life history tactics employed by different char stocks that seasonally mix within the region will be important in managing local fisheries and ensuring the future sustainability of an essential subsistence food source.

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Appendix A: Raw Data from Tagging Activities

Table A-1: Information collected at time of capture for tagged char, including length, weight, tagging location, date, and capture method. Note that the same Tag ID may be used for more than one fish, in cases where tags were returned by local fishers and subsequently re-deployed.

Fish ID	Species	Fork length (mm)	Weight (g)	Station Name	Latitude	Longitude	Date	Time (MDT)	Gear	Tag ID
8262	ARCH	670	NA	YCO-E-C-1	67.80722	-114.9197	08-Aug-18	14:00	Gill net, 5 inch	14607
8263	ARCH	750	NA	YCO-E-C-1	67.80722	-114.9197	08-Aug-18	14:00	Gill net, 5 inch	14609
8265	ARCH	689	NA	KIK-C-1	67.78676	-114.35754	09-Aug-18	14:00	Gill net, 5 inch	14606
8266	ARCH	710	NA	KIK-C-1	67.78676	-114.35754	09-Aug-18	14:00	Gill net, 5 inch	14608
8267	ARCH	700	NA	KIK-C-1	67.78676	-114.35754	09-Aug-18	14:00	Gill net, 5 inch	14613
8268	ARCH	669	NA	KIK-C-1	67.78676	-114.35754	09-Aug-18	14:00	Gill net, 5 inch	14610
8269	ARCH	738	NA	KIK-C-1	67.78494	-114.35202	09-Aug-18	14:00	Gill net, 2 inch	14611
8270	ARCH	824	NA	KIK-C-1	67.78676	-114.35754	09-Aug-18	14:00	Gill net, 5 inch	14612
8272	ARCH	611	NA	KIK-C-1	67.78676	-114.35754	13-Aug-18	14:00	Gill net, 5 inch	14615
8273	ARCH	689	NA	KIK-C-2	67.79832	-114.37265	13-Aug-18	14:00	Gill net, 5 inch	14614
8274	ARCH	668	NA	KIK-C-2	67.79832	-114.37265	13-Aug-18	14:00	Gill net, 5 inch	14616
8275	ARCH	684	NA	KIK-C-2	67.79832	-114.37265	13-Aug-18	14:00	Gill net, 5 inch	14617
8276	ARCH	688	NA	KIK-C-2	67.79832	-114.37265	13-Aug-18	14:00	Gill net, 5 inch	14629
8279	ARCH	786	NA	COP-L-C-1	67.76168	-115.30699	15-Aug-18	12:00	Angling	14628
8280	ARCH	700	NA	COP-L-C-1	67.76168	-115.30699	15-Aug-18	13:00	Gill net, 5 inch	14627
8281	ARCH	857	NA	COP-L-C-1	67.76168	-115.30699	16-Aug-18	14:00	Gill net, 5 inch	14626
8282	ARCH	734	NA	COP-L-C-1	67.76168	-115.30699	16-Aug-18	14:00	Gill net, 5 inch	14625
8283	ARCH	737	NA	COP-L-C-1	67.76168	-115.30699	16-Aug-18	14:00	Gill net, 5 inch	14624
8285	ARCH	772	NA	COP-L-C-2	67.75769	-115.33029	18-Aug-18	14:00	Gill net, 5 inch	14622
8286	ARCH	710	NA	COP-L-C-2	67.75769	-115.33029	18-Aug-18	14:00	Gill net, 5 inch	14623
8287	ARCH	693	NA	4MB-C-1	67.85591	-115.2775	19-Aug-18	14:00	Gill net, 5 inch	14620
8288	ARCH	836	NA	4MB-C-1	67.85591	-115.2775	19-Aug-18	14:00	Gill net, 5 inch	14621
8289	ARCH	673	NA	4MB-C-1	67.85591	-115.2775	19-Aug-18	14:00	Gill net, 5 inch	14618
8290	ARCH	658	NA	4MB-C-1	67.85591	-115.2775	19-Aug-18	14:00	Gill net, 5 inch	14619
8291	ARCH	688	NA	4MB-C-1	67.85591	-115.2775	19-Aug-18	14:00	Gill net, 5 inch	14640
8293	ARCH	564	2200	4MB-C-1	67.85591	-115.2775	19-Aug-18	14:00	Gill net, 5 inch	14641
8295	ARCH	584	NA	4MB-C-1	67.85591	-115.2775	20-Aug-18	14:00	Gill net, 5 inch	14639
8296	ARCH	637	NA	4MB-C-2	67.85477	-115.26343	20-Aug-18	14:00	Gill net, 5 inch	14638
8297	ARCH	725	NA	4MB-C-2	67.85477	-115.26343	20-Aug-18	14:00	Gill net, 5 inch	14637
8298	ARCH	779	NA	4MB-C-2	67.85477	-115.26343	20-Aug-18	14:00	Gill net, 5 inch	14636
8299	ARCH	721	NA	4MB-C-1	67.85591	-115.2775	21-Aug-18	14:00	Gill net, 5 inch	14634
8300	ARCH	664	NA	4MB-C-1	67.85591	-115.2775	21-Aug-18	14:00	Gill net, 5 inch	14635
8301	ARCH	645	NA	4MB-C-1	67.85591	-115.2775	21-Aug-18	14:00	Gill net, 5 inch	14632
8302	ARCH	762	NA	4MB-C-1	67.85591	-115.2775	21-Aug-18	14:00	Gill net, 5 inch	14633
8303	ARCH	663	NA	4MB-C-1	67.85591	-115.2775	21-Aug-18	14:00	Gill net, 5 inch	14630
8304	ARCH	712	NA	OldMOT	67.82942	-115.10586	22-Aug-18	11:30	Gill net, 5 inch	14631
8305	ARCH	712	NA	OldMOT	67.82942	-115.10586	22-Aug-18	11:30	Gill net, 5 inch	14643
8306	ARCH	638	NA	OldMOT	67.82942	-115.10586	22-Aug-18	13:30	Gill net, 5 inch	14642
8307	ARCH	719	NA	BargeDock	67.82517	-115.1324	22-Aug-18	14:30	Gill net, 5 inch	14645

Fish ID	Species	Fork length (mm)	Weight (g)	Station Name	Latitude	Longitude	Date	Time (MDT)	Gear	Tag ID
8309	ARCH	745	NA	BargeDock	67.82517	-115.1324	22-Aug-18	14:00	Gill net, 5 inch	14644
8310	ARCH	720	NA	BargeDock	67.82517	-115.1324	22-Aug-18	14:00	Gill net, 5 inch	14646
8311	ARCH	696	NA	BargeDock	67.82517	-115.1324	22-Aug-18	14:00	Gill net, 5 inch	14647
8314	ARCH	850	NA	BargeDock	67.82517	-115.1324	23-Aug-18	14:00	Gill net, 5 inch	14649
8315	ARCH	651	NA	BargeDock	67.82517	-115.1324	23-Aug-18	14:00	Gill net, 5 inch	14648
8317	ARCH	707	NA	BargeDock	67.82517	-115.1324	23-Aug-18	14:00	Gill net, 5 inch	14651
8318	ARCH	679	NA	BargeDock	67.82517	-115.1324	23-Aug-18	14:00	Gill net, 5 inch	14650
8319	ARCH	731	NA	BargeDock	67.82517	-115.1324	23-Aug-18	14:00	Gill net, 5 inch	14652
8320	ARCH	866	NA	BargeDock	67.82517	-115.1324	23-Aug-18	14:00	Gill net, 5 inch	14653
8535	ARCH	626	2200	ASK-W-C-2	67.80132	-114.48729	19-Jul-19	12:20	Angling	14654
8536	ARCH	653	2700	ASK-W-C-2	67.80132	-114.48729	19-Jul-19	13:10	Angling	14655
8537	ARCH	618	2200	KIK-C-1	67.78676	-114.35754	19-Jul-19	14:00	Gill net, 5 inch	14656
8538	ARCH	633	2500	KIK-C-1	67.78676	-114.35754	19-Jul-19	14:00	Gill net, 5 inch	14657
8539	ARCH	718	2800	5MI-C-1	67.89212	-115.14735	20-Jul-19	14:00	Gill net, 5 inch	14658
8540	ARCH	640	2500	PT2-C-1	67.89586	-115.20771	20-Jul-19	19:00	Angling	14659
8541	ARCH	810	5000	5MI-C-1	67.89212	-115.14735	22-Jul-19	15:00	Gill net, 5 inch	14661
8543	ARCH	797	3800	KIK-C-1	67.78676	-114.35754	23-Jul-19	12:50	Gill net, 5 inch	14660
8544	ARCH	693	3200	KIK-C-1	67.78676	-114.35754	23-Jul-19	12:50	Gill net, 5 inch	14663
8545	ARCH	604	2100	KIK-C-1	67.78676	-114.35754	23-Jul-19	13:10	Gill net, 5 inch	14662
8547	ARCH	675	3300	KIK-C-1	67.78676	-114.35754	23-Jul-19	14:10	Gill net, 5 inch	14665
8548	ARCH	702	3100	KIK-C-1	67.78676	-114.35754	23-Jul-19	14:46	Gill net, 5 inch	14664
8549	ARCH	680	3300	KIK-C-1	67.78676	-114.35754	23-Jul-19	15:18	Gill net, 5 inch	14666
8550	ARCH	746	4300	KIK-C-1	67.78676	-114.35754	24-Jul-19	13:39	Gill net, 5 inch	14667
8551	ARCH	686	3000	KIK-C-1	67.78676	-114.35754	24-Jul-19	14:32	Gill net, 5 inch	14669
8552	ARCH	616	2300	BargeDock	67.82517	-115.1324	25-Jul-19	15:32	Gill net, 5 inch	14668
8553	ARCH	746	3700	BargeDock	67.82517	-115.1324	25-Jul-19	15:32	Gill net, 5 inch	14670
8554	ARCH	714	3400	KIK-C-1	67.78676	-114.35754	26-Jul-19	13:42	Gill net, 5 inch	14671
8555	ARCH	683	2900	KIK-C-1	67.78676	-114.35754	26-Jul-19	13:54	Gill net, 5 inch	14672
8556	ARCH	783	4700	KIK-C-1	67.78676	-114.35754	26-Jul-19	14:07	Gill net, 5 inch	14673
8559	ARCH	716	4000	KIK-C-1	67.78676	-114.35754	26-Jul-19	14:50	Gill net, 5 inch	14674
8561	ARCH	630	3100	KIK-C-1	67.78676	-114.35754	26-Jul-19	16:07	Gill net, 5 inch	14675
8563	ARCH	616	2400	KIK-C-1	67.78676	-114.35754	26-Jul-19	16:31	Gill net, 5 inch	14676
8566	ARCH	679	2900	PT2-C-1	67.89586	-115.20771	27-Jul-19	16:50	Gill net, 5 inch	14677
8567	ARCH	734	3200	PT2-C-1	67.89586	-115.20771	27-Jul-19	16:50	Gill net, 5 inch	14678
8568	ARCH	733	3300	PT2-C-1	67.89586	-115.20771	27-Jul-19	17:15	Gill net, 5 inch	14679
8569	ARCH	735	3600	HWK-C-1	67.86176	-115.24017	29-Jul-19	11:12	Gill net, 5 inch	14680
8570	ARCH	735	3800	BargeDock	67.82517	-115.1324	29-Jul-19	13:54	Gill net, 5 inch	14681
8571	ARCH	771	3200	COP-L-C-0	67.82195	-115.07698	29-Jul-19	16:38	Gill net, 5 inch	14683
8573	ARCH	885	6900	BargeDock	67.82517	-115.1324	31-Jul-19	12:25	Gill net, 5 inch	14682
8574	ARCH	716	3500	BargeDock	67.82517	-115.1324	31-Jul-19	13:40	Gill net, 5 inch	14685
8847	ARCH	662	3600	BargeDock	67.82517	-115.1324	09-Aug-19	11:30	Gill net, 5 inch	14687
8852	ARCH	668	3100	BargeDock	67.82517	-115.1324	10-Aug-19	12:55	Gill net, 5 inch	14688
8853	ARCH	803	4300	COP-F-C-1	67.7389	-115.3721	12-Aug-19	15:12	Gill net, 5 inch	14686

Fish ID	Species	Fork length (mm)	Weight (g)	Station Name	Latitude	Longitude	Date	Time (MDT)	Gear	Tag ID
8854	ARCH	889	6800	COP-F-C-1	67.7389	-115.3721	12-Aug-19	15:12	Gill net, 5 inch	14689
8855	ARCH	726	4100	COP-F-C-1	67.7389	-115.3721	12-Aug-19	15:12	Gill net, 5 inch	14684
8856	ARCH	841	5700	COP-F-C-1	67.7389	-115.3721	12-Aug-19	15:40	Gill net, 5 inch	14690
8857	ARCH	687	3600	COP-F-C-1	67.7389	-115.3721	12-Aug-19	15:51	Gill net, 5 inch	13365
8858	ARCH	597	2300	COP-F-C-1	67.7389	-115.3721	12-Aug-19	16:00	Gill net, 5 inch	13366
8859	ARCH	665	2800	COP-F-C-1	67.7389	-115.3721	12-Aug-19	16:19	Gill net, 5 inch	13363
8860	ARCH	619	3000	COP-F-C-1	67.7389	-115.3721	12-Aug-19	16:51	Gill net, 5 inch	13364
8862	ARCH	636	2200	COP-F-C-1	67.7389	-115.3721	13-Aug-19	14:30	Angling	13362
8863	ARCH	705	3200	COP-F-C-1	67.7389	-115.3721	13-Aug-19	14:50	Gill net, 5 inch	13361
8864	ARCH	646	3100	COP-F-C-1	67.7389	-115.3721	13-Aug-19	15:01	Gill net, 5 inch	13360
8865	ARCH	663	3000	COP-F-C-1	67.7389	-115.3721	13-Aug-19	15:12	Gill net, 5 inch	13359
8866	ARCH	667	3000	COP-F-C-1	67.7389	-115.3721	13-Aug-19	16:41	Gill net, 5 inch	13358
8868	ARCH	719	4000	COP-F-C-1	67.7389	-115.3721	13-Aug-19	16:50	Gill net, 5 inch	13357
8869	ARCH	655	2800	COP-F-C-1	67.7389	-115.3721	13-Aug-19	16:59	Gill net, 5 inch	13356
8870	ARCH	651	2600	COP-F-C-1	67.7389	-115.3721	13-Aug-19	17:09	Gill net, 5 inch	13355
8871	ARCH	711	4600	BargeDock	67.82517	-115.1324	14-Aug-19	13:20	Gill net, 5 inch	13374
8873	ARCH	779	4240	OldMOT	67.82942	-115.10586	15-Aug-19	15:00	Gill net, 5 inch	13373
8874	ARCH	667	3020	OldMOT	67.82942	-115.10586	15-Aug-19	15:00	Gill net, 5 inch	13372
8875	ARCH	716	3000	OldMOT	67.82942	-115.10586	15-Aug-19	15:00	Gill net, 5 inch	13371
8876	ARCH	565	1860	WSandbar	67.83674	-115.10374	15-Aug-19	15:00	Gill net, 5 inch	13370
8877	ARCH	684	3230	WSandbar	67.83674	-115.10374	15-Aug-19	15:00	Gill net, 5 inch	13369
8878	ARCH	617	2640	WSandbar	67.83674	-115.10374	16-Aug-19	11:15	Gill net, 5 inch	13368
8879	ARCH	629	2690	COP-L-C-4	67.76219	-115.30662	16-Aug-19	14:25	Angling	13367
8880	ARCH	724	2840	COP-L-C-4	67.76219	-115.30662	16-Aug-19	15:30	Angling	13721
8881	ARCH	670	3250	COP-L-C-4	67.76219	-115.30662	16-Aug-19	16:30	Gill net, 5 inch	13722
8882	ARCH	568	1970	COP-L-R-5	67.7552	-115.3393	17-Aug-19	12:45	Angling	13719
8883	ARCH	696	3230	COP-L-C-4	67.76219	-115.30662	17-Aug-19	14:24	Angling	13714
8884	ARCH	695	2930	COP-L-C-4	67.76219	-115.30662	17-Aug-19	14:00	Angling	13717
8885	ARCH	715	3140	COP-L-C-4	67.76181	-115.32527	17-Aug-19	12:00	Gill net, 5 inch	13720
8912	ARCH	628	3590	4MB-C-1	67.85477	-115.26343	23-Aug-19	16:36	Gill net, 5 inch	13718
8913	ARCH	674	2900	4MB-C-1	67.85477	-115.26343	23-Aug-19	17:08	Gill net, 5 inch	13715
8914	ARCH	658	2440	COP-L-C-4	67.7583	-115.3001	25-Aug-19	16:00	Gill net, 5 inch	13716
8915	ARCH	685	3730	COP-L-C-4	67.7583	-115.3001	25-Aug-19	16:30	Gill net, 5 inch	13713
8916	ARCH	863	8530	COP-L-C-4	67.7583	-115.3001	25-Aug-19	17:00	Gill net, 5 inch	13712
8918	ARCH	706	3530	COP-L-C-4	67.7583	-115.3001	26-Aug-19	15:30	Gill net, 5 inch	13711
8919	ARCH	717	3820	COP-L-C-4	67.7583	-115.3001	26-Aug-19	15:30	Gill net, 5 inch	13723
8920	ARCH	641	2660	COP-L-C-4	67.7583	-115.3001	26-Aug-19	15:30	Gill net, 5 inch	13724
8921	ARCH	714	3630	COP-L-C-4	67.7583	-115.3001	26-Aug-19	15:30	Gill net, 5 inch	13727
8922	ARCH	715	3510	COP-L-C-4	67.7583	-115.3001	26-Aug-19	15:30	Gill net, 5 inch	13725
8923	ARCH	710	4900	COP-L-C-4	67.7583	-115.3001	26-Aug-19	17:30	Gill net, 5 inch	13726
8925	ARCH	682	3270	4MB-C-1	67.85477	-115.26343	27-Aug-19	13:30	Gill net, 5 inch	13728
8926	ARCH	732	4020	4MB-C-1	67.85477	-115.26343	27-Aug-19	16:15	Gill net, 5 inch	13730
8927	ARCH	539	1850	4MB-C-1	67.85477	-115.26343	27-Aug-19	17:00	Gill net, 5 inch	13729
8928	ARCH	742	4170	COP-L-C-3	67.77391	-115.21997	28-Aug-19	12:30	Angling	13731
8929	ARCH	560	2250	4MB-C-1	67.85477	-115.26343	29-Aug-19	15:20	Gill net, 5 inch	13732

Fish ID	Species	Fork length (mm)	Weight (g)	Station Name	Latitude	Longitude	Date	Time (MDT)	Gear	Tag ID
8930	ARCH	803	4430	4MB-C-1	67.85477	-115.26343	29-Aug-19	16:11	Gill net, 5 inch	13734
8931	ARCH	837	NA	COP-F-C-1	67.7389	-115.3721	30-Aug-19	13:11	Gill net, 5 inch	13733
8932	ARCH	780	NA	COP-F-C-1	67.7389	-115.3721	30-Aug-19	13:23	Gill net, 5 inch	13735
8933	ARCH	725	NA	COP-F-C-1	67.7389	-115.3721	30-Aug-19	13:35	Gill net, 5 inch	13736
8934	ARCH	723	NA	COP-F-C-1	67.7389	-115.3721	30-Aug-19	13:45	Gill net, 5 inch	13738
8935	ARCH	745	NA	COP-F-C-1	67.7389	-115.3721	30-Aug-19	13:55	Gill net, 5 inch	13737
8936	ARCH	757	NA	COP-F-C-1	67.7389	-115.3721	30-Aug-19	14:29	Gill net, 5 inch	13740
8937	ARCH	721	NA	COP-F-C-1	67.7389	-115.3721	30-Aug-19	14:38	Gill net, 5 inch	13739
8938	ARCH	784	NA	COP-F-C-1	67.7389	-115.3721	30-Aug-19	14:50	Gill net, 5 inch	13742
8939	ARCH	654	NA	COP-F-C-1	67.7389	-115.3721	30-Aug-19	15:01	Gill net, 5 inch	13741
8940	ARCH	729	NA	COP-F-C-1	67.7389	-115.3721	30-Aug-19	15:12	Gill net, 5 inch	13744
8941	ARCH	752	NA	COP-F-C-1	67.7389	-115.3721	01-Sep-19	14:06	Gill net, 5 inch	13743
8942	ARCH	724	NA	COP-F-C-1	67.7389	-115.3721	01-Sep-19	14:18	Gill net, 5 inch	13745
8943	ARCH	809	NA	COP-F-C-1	67.7389	-115.3721	01-Sep-19	14:28	Gill net, 5 inch	13746
8944	ARCH	745	NA	COP-F-C-1	67.7389	-115.3721	01-Sep-19	14:39	Gill net, 5 inch	13757
8946	ARCH	748	NA	COP-F-C-1	67.7389	-115.3721	01-Sep-19	15:12	Gill net, 5 inch	13755
8947	ARCH	780	NA	COP-F-C-1	67.7389	-115.3721	01-Sep-19	15:23	Gill net, 5 inch	13756
8948	ARCH	721	NA	COP-F-C-1	67.7389	-115.3721	01-Sep-19	15:37	Gill net, 5 inch	13753
8949	ARCH	745	NA	COP-F-C-1	67.7389	-115.3721	01-Sep-19	15:48	Gill net, 5 inch	13754
8950	ARCH	710	NA	COP-F-C-1	67.7389	-115.3721	01-Sep-19	15:59	Gill net, 5 inch	13751
8951	ARCH	681	NA	COP-F-C-1	67.7389	-115.3721	01-Sep-19	16:10	Gill net, 5 inch	13752
8952	ARCH	740	NA	COP-F-C-1	67.7389	-115.3721	05-Sep-19	14:50	Gill net, 5 inch	13747
8953	ARCH	742	NA	COP-F-C-1	67.7389	-115.3721	05-Sep-19	15:01	Gill net, 5 inch	13748
8954	ARCH	> 700	NA	COP-F-C-1	67.7389	-115.3721	05-Sep-19	15:21	Gill net, 5 inch	13749
8955	ARCH	843	NA	COP-F-C-1	67.7389	-115.3721	05-Sep-19	15:35	Dip net	13750
8956	ARCH	714	NA	COP-F-C-1	67.7389	-115.3721	05-Sep-19	16:18	Gill net, 5 inch	13758
8957	ARCH	697	NA	COP-F-C-1	67.7389	-115.3721	05-Sep-19	16:30	Gill net, 5 inch	13759
8958	ARCH	731	4170	COP-F-C-1	67.7389	-115.3721	06-Sep-19	12:10	Dip net	13760
8960	ARCH	713	4070	COP-F-C-1	67.7389	-115.3721	08-Sep-19	14:17	Gill net, 5 inch	13713
8961	ARCH	721	4090	COP-F-C-1	67.7389	-115.3721	08-Sep-19	14:32	Gill net, 5 inch	13371
8962	ARCH	680	3830	COP-F-C-1	67.7389	-115.3721	08-Sep-19	14:43	Gill net, 5 inch	14618
8963	ARCH	737	NA	COP-F-C-1	67.7389	-115.3721	08-Sep-19	16:20	Gill net, 5 inch	14635
8964	ARCH	775	NA	COP-F-C-1	67.7389	-115.3721	08-Sep-19	16:29	Gill net, 5 inch	14616
8965	ARCH	774	NA	COP-F-C-1	67.7389	-115.3721	08-Sep-19	16:38	Gill net, 5 inch	14652
8966	ARCH	751	NA	COP-F-C-1	67.7389	-115.3721	08-Sep-19	16:46	Gill net, 5 inch	14617
8967	ARCH	756	NA	COP-F-C-1	67.7389	-115.3721	08-Sep-19	16:54	Gill net, 5 inch	14639
8968	ARCH	682	NA	COP-F-C-1	67.7389	-115.3721	08-Sep-19	17:05	Gill net, 5 inch	14630

Appendix B: Receiver Deployment and Retrieval Data

Table B-1: Deployment and retrieval dates, times, and locations for all receivers with data available at time of writing.

Type	ID	Station Name	Latitude	Longitude	Depth (m)	Date deployed (MDT)		Date retrieved (MDT)	
VR2AR	548200	4MB-R-1	67.85629	-115.27006	8.9	13-Jul-19	12:43	23-Sep-19	10:50
VR2AR	548196	7MI-E-R-1	67.9268	-114.76061	47.2	17-Jul-19	17:51	30-Sep-19	10:00
VR2AR	548031	7MI-S-R-1	67.89266	-114.90007	45.7	17-Jul-19	15:29	30-Sep-19	10:53
VR2AR	547986	7MI-W-R-1	67.90073	-114.96566	51.5	17-Jul-19	15:19	30-Sep-19	11:06
VR2W	122038	ASK-E-R-1A	67.7576	-114.385	2.6	05-Aug-18	13:12	22-Sep-18	13:05
VR2Tx	482101	ASK-E-R-1A	67.75729	-114.38439	2.6	09-Jul-19	13:03	19-Sep-19	17:00
VR2W	122037	ASK-E-R-1B	67.76173	-114.38138	3.5	05-Aug-18	13:34	22-Sep-18	13:00
VR2Tx	482042	ASK-E-R-1B	67.76173	-114.38138	3.4	09-Jul-19	13:18	24-Sep-19	15:30
VR2W	122040	ASK-W-R-1	67.77493	-114.43022	3.7	05-Aug-18	12:34	22-Sep-18	14:07
VR2Tx	482044	ASK-W-R-1	67.77609	-114.43455	3.3	09-Jul-19	12:32	24-Sep-19	15:52
VR2AR	548195	ASK-W-R-2	67.8059	-114.48264	48.8	17-Jul-19	16:47	24-Sep-19	16:03
VR2AR	548027	COD-E-R-1	67.88064	-114.78908	52.1	17-Jul-19	17:29	30-Sep-19	12:28
VR2AR	548236	COD-E-R-2	67.88195	-114.71762	58.2	17-Jul-19	17:21	30-Sep-19	12:15
VR2AR	548032	COD-W-R-1	67.88442	-114.87378	39.6	17-Jul-19	17:39	30-Sep-19	10:45
VR2AR	547640	COP-L-R-0	67.82185	-115.07583	8.5	29-Jul-18	14:31	21-Sep-18	11:53
VR2AR	548237	COP-L-R-0	67.82207	-115.07532	8.4	07-Jul-19	13:51	22-Sep-19	15:16
VR2AR	548199	COP-L-R-0B	67.80489	-115.08849	3.7	13-Jul-19	12:11	22-Sep-19	15:23
VR2AR	547639	COP-L-R-1	67.78746	-115.1553	4.9	28-Jul-18	14:15	21-Sep-18	12:21
VR2AR	547639	COP-L-R-1	67.78746	-115.1553	4.6	21-Sep-18	12:28	21-Jul-19	17:20
VR2AR	547704	COP-L-R-1	67.78746	-115.1553	3.9	11-Sep-19	12:04	22-Sep-19	15:53
VR2AR	547641	COP-L-R-2	67.77986	-115.19212	3.8	28-Jul-18	16:00	21-Sep-18	12:35
VR2AR	547641	COP-L-R-2	67.77986	-115.19212	4.0	21-Sep-18	12:43	21-Jul-19	17:04
VR2AR	548239	COP-L-R-2	67.78001	-115.19183	4.1	07-Jul-19	11:37	22-Sep-19	16:17
VR2AR	547636	COP-L-R-3	67.77594	-115.21426	8.7	29-Jul-18	13:35	21-Sep-18	12:49
VR2AR	547636	COP-L-R-3	67.77594	-115.21426	8.8	21-Sep-18	12:56	09-Jun-19	0:00
VR2AR	548234	COP-L-R-3	67.77601	-115.21322	8.7	07-Jul-19	11:58	22-Sep-19	16:36
VR2AR	547637	COP-L-R-4	67.7638	-115.30361	14.1	29-Jul-18	12:40	21-Sep-18	13:09
VR2AR	547637	COP-L-R-4	67.7638	-115.30361	13.5	21-Sep-18	13:14	10-Jun-19	4:00
VR2AR	548238	COP-L-R-4	67.76395	-115.30347	13.7	07-Jul-19	12:26	22-Jul-19	13:10
VR2AR	548238	COP-L-R-4	67.76393	-115.30362	12.8	23-Jul-19	15:01	22-Sep-19	17:02
VR2AR	547704	COP-L-R-5	67.75598	-115.3318	5.2	29-Jul-18	11:50	21-Sep-18	13:27
VR2AR	547704	COP-L-R-5	67.75598	-115.3318	5.2	21-Sep-18	13:33	04-Sep-19	12:25
VR2AR	547641	COP-L-R-5	67.75598	-115.3324	3.5	04-Sep-19	12:35	22-Sep-19	17:26

Type	ID	Station Name	Latitude	Longitude	Depth (m)	Date deployed (MDT)		Date retrieved (MDT)	
VR2Tx	482105	COP-U-R-1	67.7351	-115.38538	4.6	15-Aug-18	19:00	29-Sep-18	17:15
VR2AR	547702	COP-U-R-1	67.7351	-115.38538	3.8	29-Sep-18	17:22	17-Jul-19	13:00
VR2Tx	482102	COP-U-R-1	67.7351	-115.38538	5.2	17-Jul-19	13:07	25-Sep-19	15:00
VR2AR	547702	COP-U-R-1B	67.73383	-115.38235	7.3	21-Jul-19	14:45	25-Sep-19	15:00
VR2Tx	482043	COP-U-R-4	67.53216	-115.57001	5.8	17-Aug-18	14:15	17-Jul-19	16:40
VR2AR	547638	KIK-W-R-0	67.78711	-114.354	27.7	09-Jul-19	14:11	24-Sep-19	15:13
VR2AR	548231	KIK-W-R-1	67.80128	-114.3761	26.5	09-Jul-19	14:18	24-Sep-19	15:03
VR2AR	548232	KIK-W-R-2	67.82686	-114.50605	14.5	09-Jul-19	14:29	24-Sep-19	16:24
VR2Tx	482041	KUG-E-R-1	67.71555	-113.27296	12.4	04-Aug-18	15:56	25-Sep-18	13:30
VR2W	125029	KUG-E-R-1	67.71543	-113.27386	13.0	15-Jul-19	13:25	24-Sep-19	17:00
VR2AR	547703	KUG-L-R-0	67.70361	-113.29658	11.9	04-Aug-18	13:45	25-Sep-18	12:20
VR2AR	548201	KUG-L-R-0	67.70361	-113.29658	12.4	15-Jul-19	13:30	24-Sep-19	13:47
VR2Tx	482051	KUG-W-R-1	67.7008	-113.32095	6.9	04-Aug-18	16:30	25-Sep-18	11:16
VR2W	125028	KUG-W-R-1	67.7008	-113.32095	6.8	15-Jul-19	13:46	24-Sep-19	13:58
VR2AR	547637	LOST_COP-L-R-4	67.8363	-115.1314	24.0	20-Jun-19	15:00	02-Sep-19	17:00
VR2AR	548033	MRK-R-1	67.90021	-115.02572	59.7	17-Jul-19	15:11	30-Sep-19	11:19
VR2Tx	482045	NAP-E-R-1	67.81532	-114.64835	6.3	05-Aug-18	15:40	21-Sep-18	16:24
VR2Tx	482051	NAP-E-R-1	67.81532	-114.64835	6.2	09-Jul-19	12:00	26-Sep-19	11:00
VR2Tx	482049	NAP-W-R-1	67.82557	-114.76562	14.5	05-Aug-18	16:34	25-Sep-18	16:00
VR2AR	547703	NAP-W-R-1	67.82568	-114.76437	15.7	09-Jul-19	11:39	26-Sep-19	12:13
VR2AR	547638	PT1-R-1	67.87289	-115.2015	33.5	30-Jul-18	11:35	22-Sep-18	16:56
VR2AR	547638	PT1-R-1	67.87289	-115.2015	33.2	22-Sep-18	17:09	07-Jul-19	14:30
VR2AR	548230	PT1-R-1	67.87301	-115.202	34.1	07-Jul-19	14:36	23-Sep-19	11:08
VR2Tx	482050	PT1-R-2	67.89364	-115.16126	9.7	30-Jul-18	17:09	22-Sep-18	13:44
VR2AR	548235	PT1-R-2	67.89364	-115.16126	9.4	07-Jul-19	14:50	23-Sep-19	13:21
VR2AR	548030	PT1-R-3	67.89859	-115.10702	49.1	17-Jul-19	15:01	23-Sep-19	13:37
VR2Tx	482042	PT2-R-1	67.89336	-115.20277	14.4	30-Jul-18	14:09	22-Sep-18	16:49
VR2AR	547636	PT2-R-1	67.89336	-115.20277	14.7	10-Jul-19	12:57	23-Sep-19	11:25
VR2Tx	482044	PT2-R-2	67.89556	-115.19198	16.6	30-Jul-18	15:48	22-Sep-18	16:42
VR2AR	548202	PT2-R-2	67.89544	-115.19165	17.3	10-Jul-19	13:04	23-Sep-19	11:48
VR2Tx	482102	PT2-R-3	67.90201	-115.18659	5.5	13-Aug-18	18:00	22-Sep-18	13:50
VR2AR	547702	RAE-L-R-0	67.91889	-115.53655	6.8	03-Aug-18	17:05	22-Sep-18	14:27
VR2Tx	482105	RAE-L-R-0	67.91893	-115.53608	7.3	10-Jul-19	15:35	24-Sep-19	12:58
VR2Tx	482047	RAE-N-R-1	67.92639	-115.48779	5.0	13-Aug-18	16:37	22-Sep-18	14:15
VR2Tx	482047	RAE-N-R-1	67.92677	-115.48327	5.1	10-Jul-19	15:52	24-Sep-19	12:50
VR2AR	548028	RAE-N-R-2	67.97748	-115.18604	21.0	17-Jul-19	14:40	24-Sep-19	12:08
VR2W	125029	RIC-E-R-1	67.89944	-115.43442	3.3	03-Aug-18	15:23	22-Sep-18	15:16
VR2Tx	482041	RIC-E-R-1	67.8991	-115.43442	3.1	10-Jul-19	14:45	04-Sep-19	7:00

Type	ID	Station Name	Latitude	Longitude	Depth (m)	Date deployed (MDT)		Date retrieved (MDT)	
VR2W	125028	RIC-E-R-2	67.88803	-115.37358	2.3	03-Aug-18	13:26	22-Sep-18	16:18
VR2Tx	482050	RIC-E-R-2	67.88803	-115.37358	2.2	10-Jul-19	14:25	24-Sep-19	15:31
VR2Tx	482101	RIC-E-R-3	67.88478	-115.31775	3.3	02-Aug-18	11:00	22-Sep-18	16:27
VR2Tx	482045	RIC-E-R-3	67.88483	-115.3166	2.9	10-Jul-19	13:45	24-Sep-19	15:40
VR2Tx	482039	RIC-L-R-1	67.89377	-115.52838	4.6	13-Aug-18	15:40	22-Sep-18	14:50
VR2Tx	482039	RIC-L-R-1	67.89441	-115.52847	4.7	10-Jul-19	15:15	24-Sep-19	13:10
VR2W	122040	SND-E-R-1	67.83323	-115.02675	7.9	13-Jul-19	15:20	19-Aug-19	11:20
VR2W	122040	SND-E-R-1	67.83323	-115.02675	7.9	19-Aug-19	11:27	26-Sep-19	13:20
VR2Tx	482049	TRE-R-1	67.66597	-111.85237	3.5	09-Jul-19	16:00	25-Aug-19	20:00
VR2W	122035	YCO-E-R-1A	67.80072	-114.97203	6.3	12-Aug-18	22:30	21-Sep-18	15:35
VR2W	122036	YCO-E-R-1A	67.80048	-114.97195	6.0	11-Jul-19	12:11	22-Sep-19	12:00
VR2AR	547987	YCO-E-R-1B	67.81057	-114.97125	21.3	11-Jul-19	12:20	26-Sep-19	12:44
VR2W	122036	YCO-E-R-2	67.82423	-114.94174	5.8	12-Aug-18	23:30	21-Sep-18	15:22
VR2W	122038	YCO-E-R-2	67.82362	-114.94095	6.6	11-Jul-19	12:48	26-Sep-19	12:30
VR2W	122034	YCO-E-R-3	67.8184	-114.85139	6.2	12-Aug-18	21:30	21-Sep-18	15:47
VR2AR	548233	YCO-W-R-1	67.83081	-115.134	7.6	13-Jul-19	12:28	19-Aug-19	11:05
VR2AR	548233	YCO-W-R-1	67.83081	-115.134	7.6	19-Aug-19	11:10	23-Sep-19	14:14
VR2W	122034	YCO-W-R-2	67.84806	-115.21516	4.0	13-Jul-19	13:00	23-Sep-19	14:01

Appendix C: VR100 Data

Table C-1: Tagged fish detected at the river mouth receiver in fall and winter 2019. Data were retrieved from this receiver using the VR100 on 31 January 2020.

Fish ID	Tag ID	Date last detected		Number of detections	Station and date of previous detection
8293	14641	27-Nov-19	11:50	564	COP-L-R-4, 14-Sep-19
8309	14644	02-Dec-19	16:51	366	COP-L-R-4, 16-Sep-19
8538	14657	09-Oct-19	7:22	3417	Above Falls, 30-Jul-19
8574	14685	02-Oct-19	22:45	151	Above Falls, 09-Aug-19 and 23-Sep-19
8870	13355	05-Oct-19	14:40	264	COP-L-R-4, 22-Sep-2019
8914	13716	07-Dec-19	12:31	307	COP-L-R-4, 27-Aug-19
8882	13719	12-Nov-19	16:43	8	COP-L-R-3, 06-Sep-19

Appendix D: Detailed Methods for Estimating 2019 Below Falls Overwintering Locations

Overwintering detection data are not available for 2019, so the number of fish overwintering below the falls could not be determined using direct detection data. Instead, individuals with the migration destination of Below Falls were estimated for 2019. This was done by modeling detection data from fall 2018 and applying the model to detection data from fall 2019.

River detection data from the fall of 2018 were truncated to only include detections prior to 22 September 16:00 MDT (the equivalent date and time that river receivers were retrieved in 2019). Detections from the two individuals that migrated above Kugluk Falls in 2018 were excluded. A generalized linear model was used to model 2018 data (n=38), using the glm function in R. The response variable was binomial (0 = no detections overwinter Below Falls (Unknown migration destination), 1 = detections overwinter Below Falls). Individuals with Unknown migration destinations may have overwintered within the Coppermine River but outside of receiver coverage, moved undetected above the falls or into a different river system, been harvested with no tag returned, or undetected mortalities/tag expulsions. The number of days between receiver retrieval date (22 September 16:00 MDT) and previous detection within the river was a continuous explanatory variable. Since greater intervals between last detection and receiver retrieval date were observed for the uppermost two receivers below the falls, a categorical explanatory variable was added for receiver location (Upper = two upstream receivers at COP-L-R-5 and COP-L-R-4; Lower = three downstream receivers at COP-L-R-3, COP-L-R-2, and COP-L-R-1, as well as the river mouth).

Estimated β coefficients for the generalized linear model are presented in Table D-1. The accuracy of the model was tested using k-fold cross validation. Observations were randomly divided into five folds, with seven observations per fold (five Below Falls and two Unknown migration destinations). Four folds were combined to create a training dataset, and the resulting model applied to a test dataset (the fifth fold). This was repeated five times; each fold was used once as the test dataset. Metrics of classification accuracy were calculated for each model and for two thresholds of Below Falls probability (0.5 and 0.75; Table D-2). A threshold of 0.5 was more accurate in predicting both migration destinations (Accuracy in Table D-2); however, accurate model classification of Below Falls migration destinations was of the most interest as it was used in a subsequent modeling exercise. After examining only observations with predicted Below Falls migration destinations, a predicted Below Falls probability ≥ 0.75 was selected as the threshold, to maximize the proportion of true positives while minimizing the proportion of false positives (Table D-2).

The full dataset was used to create the final model. Estimated model parameters were applied to the 2019 detection data (excluding individuals who had migrated above the falls) using the predict function in R (Table D-2). This resulted in thirty-two fish estimated to overwinter below Kugluk Falls in 2019, with a minimum predicted Below Falls value of 0.82 (Table D-3).

Table D-1: Estimated β coefficients for generalized linear model with binomial response variable (0 = no detections overwinter below falls (Unknown overwinter location); 1 = detections overwinter Below Falls). The continuous explanatory variable Time Interval was the time difference in days between receiver retrieval date and last previous detection. The categorical explanatory variable River Section refers to receiver location (Upper = COP-L-R-5 and 4; Lower = COP-L-R-1,2, and 3, as well as the river mouth). Note the model equation is on the logit scale and resulting predictions must be converted to the linear scale.

Parameter	Coefficient	Standard Error
Intercept	2.39	0.83
Time Interval	-0.25	0.10
River Section (Upper)	2.63	1.78

Table D-2: Classification accuracy of logistic model with binomial response variable (0 = Unknown, 1 = Below Falls overwintering location), using k-folds cross validation with five folds. Accuracy metrics were calculated for two thresholds (0.5 and 0.75) and are presented as mean (standard deviation). Note that True Positives represent fish that overwintered Below Falls and were correctly identified by the model as Below Falls. Similarly, False Positives represent fish with Unknown overwintering location that were mis-identified by the model as Below Falls.

Threshold	Accuracy	True Positives	False Positives
0.50	0.91 (0.13)	0.96 (0.09)	0.2 (0.27)
0.75	0.89 (0.12)	0.88 (0.11)	0.1 (0.22)

Table D-3: Model predictions of overwintering location (Below Falls or Unknown) for individuals detected in the lower Coppermine River in fall 2019. Time Interval is the time between last detection in the river and 22 September 16:00 MDT (date of receiver retrieval). Fish were estimated to be overwintering below the falls if the model prediction was > 0.75.

Fish ID	Time Interval (days)	River Section	Prediction	Overwintering Location
8944	0	Upper	0.99	Below Falls
8949	0	Upper	0.99	Below Falls
8964	0	Upper	0.99	Below Falls
8950	0.05	Upper	0.99	Below Falls
8926	0.21	Upper	0.99	Below Falls
8939	0.75	Upper	0.99	Below Falls
8960	0.80	Upper	0.99	Below Falls
8862	1.06	Upper	0.99	Below Falls
8958	1.18	Upper	0.99	Below Falls
8965	2.30	Upper	0.99	Below Falls
8954	2.85	Upper	0.99	Below Falls
8877	5.92	Upper	0.97	Below Falls
8309	6.29	Upper	0.97	Below Falls
8293	8.57	Upper	0.95	Below Falls
8863	8.76	Upper	0.94	Below Falls
8912	0	Lower	0.92	Below Falls
8916	0	Lower	0.92	Below Falls
8923	0	Lower	0.92	Below Falls
8934	0	Lower	0.92	Below Falls
8936	0	Lower	0.92	Below Falls
8940	0	Lower	0.92	Below Falls
8943	0	Lower	0.92	Below Falls
8946	0	Lower	0.92	Below Falls
8864	0.09	Lower	0.91	Below Falls
8919	0.18	Lower	0.91	Below Falls
8937	0.77	Lower	0.90	Below Falls
8298	1.22	Lower	0.89	Below Falls
8537	1.32	Lower	0.89	Below Falls
8968	12.69	Upper	0.86	Below Falls
8925	2.80	Lower	0.84	Below Falls
8871	13.62	Upper	0.83	Below Falls
8961	13.78	Upper	0.82	Below Falls
8953	16.68	Upper	0.69	Unknown
8952	16.72	Upper	0.69	Unknown
8287	8.89	Lower	0.54	Unknown
8929	9.20	Lower	0.52	Unknown
8884	19.91	Upper	0.50	Unknown
8951	20.45	Upper	0.46	Unknown
8948	20.79	Upper	0.44	Unknown
8914	26.25	Upper	0.17	Unknown
8882	15.89	Lower	0.16	Unknown
8921	19.46	Lower	0.07	Unknown
8880	24.81	Lower	0.02	Unknown
8856	40.65	Upper	0.01	Unknown
8860	40.80	Upper	0.00	Unknown

Appendix E: Overwinter Receiver Temperature Logs

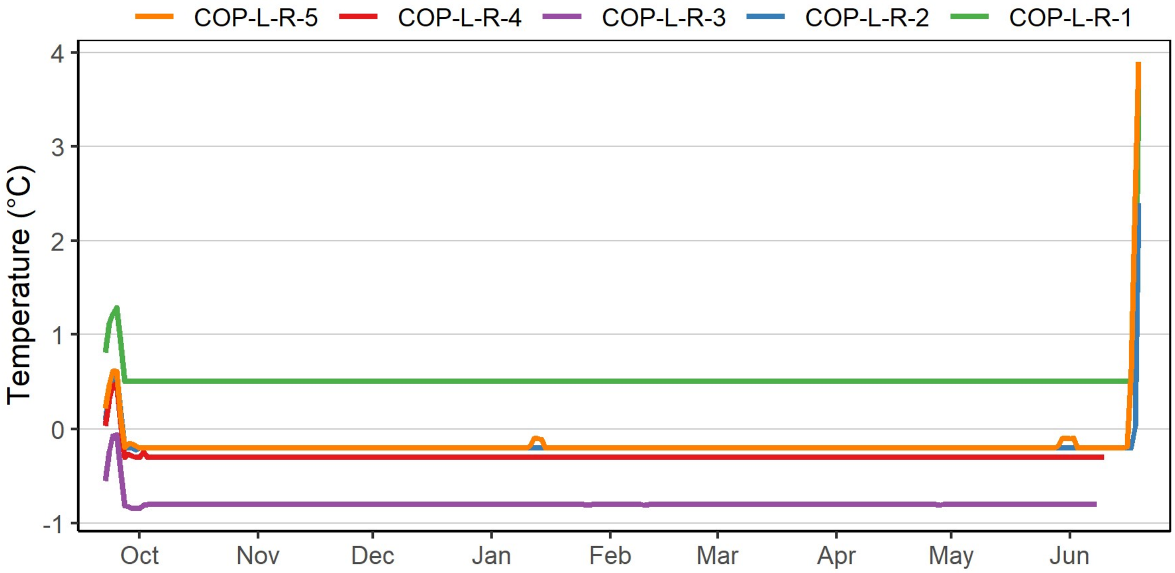

Figure E-1: Temperature logs of river receivers from 22 September 2018 (as surface ice was beginning to accumulate) to 19 June 2019 (river break-up). Receivers are numbered sequentially along the river channel, with COP-L-R-1 closest to the river mouth and COP-L-R-5 the closest to Kugluk Falls. Note that receiver COP-L-R-2 recorded the same temperatures as receiver COP-L-R-5 and is largely obscured. Temperatures recorded by the receivers follow the same thermal patterns, and differences in magnitude are likely due to individual calibration rather than differences in river temperature.

Appendix F: Linear Model Set and β Coefficients

Table F-1: *A priori* linear model set, relating date of fall freshwater entry to the categorical variable migration destination (Above Falls, Below Falls) and continuous variable fork length (n=63). AICc scores were used to rank models, and models are presented in order of increasing AICc values (decreasing rank). β-coefficients for migration destination apply to Above Falls destinations only. Note the standard error of the interaction (Above Falls*Fork Length) β-coefficient overlaps zero.

Model		AICc	ΔAICc	-2LogLikelihood	Model Likelihood	Model Weight	Adjusted R^2	Estimated Coefficents (+/- Standard Error)			
								Intercept	Above Falls	Fork Length	Above Falls*Fork Length
M3	Destination + Fork Length	460.23	0.00	451.54	1.00	0.45	0.54	253.31 (12.56)	-18.93 (2.26)	-0.03 (0.02)	-
M1	Destination	460.49	0.26	454.08	0.88	0.39	0.53	233.73 (1.65)	-19.26 (2.28)	-	-
M4	Destination*Fork Length	462.24	2.02	451.19	0.36	0.16	0.54	262.41 (20.40)	-33.70 (26.07)	-0.04 (0.03)	0.02 (0.04)
M2	Fork Length	506.68	46.46	500.28	0.00	0.00	0.03	253.11 (18.34)	-	-0.04 (0.03)	-
M0	1 (Null)	507.11	46.88	502.91	0.00	0.00	-	223.64 (1.66)	-	-	-

Appendix G: Causes of Mortality and Undetected Fish

Table G-1: Potential causes of mortality and undetected fish, that may have impacted estimates of mortality, harvest, and tag expulsion rates. Tagged fish that were never detected or ceased being detected by the receiver array may have experienced one of these events, or may have moved outside of the study area.

Event	Description	Local context	Impact on study
Tag expulsion	Sutures fail and tags are expelled through the incision site before it has healed. Studies that were able to quantify the proportion of tag expulsions report expulsion rates of 48-79% [1,2].	No reported fish were recaptured with incisions and missing tags. Tags detected in a stationary position (8%) were identified as possible tag expulsions. Tags expelled outside of receiver coverage would not be detected.	Underestimated tag expulsion rate
Harvest; tag not found	Fish is harvested, but fisher does not find the tag.	Many harvested char in the Kugluktuk area are processed into biffi, or dried fish. This involves fileting the fish while they are whole, so the viscera and any implanted tags are not removed. A fisher may not realize they have captured a tagged char if the incision site has healed.	Underestimated harvest rate
Harvest; unreported	Fisher retrieves tag, but does not know where to return it.	One tag was reported to another group that studies fish in the area; additional tags may have been similarly mis-directed or unreported.	Underestimated harvest rate
Harvest; snagging	Hooks are dragged through the water in an attempt to pierce, or snag, the fish in the body rather than the mouth. A harvesting study in the Sylvia Grinnell River near Iqaluit, Nunavut found snagging was an effective way of catching many fish in a short period of time and may even result in more captures than gill netting [3].	Impacts from snagging in Kugluktuk may be similar to those in the Sylvia Grinnell River, in that fish are easily snagged as they congregate in one location (staging to ascend Kugluk Falls). Snagging is increasingly discouraged within the community of Kugluktuk, but remains prevalent. Retrieved tags from snagged char may not be returned, due to the negative perception of snaggers within the community, including project partner the Kugluktuk Hunters and Trappers Organization. Snagging can also result in injury to fish, affecting their ability to successfully migrate upstream.	Underestimated harvest rate Mis-match of entry date and observed migration destination (early entry to migrate above falls; overwintered below falls following injury)

Event	Description	Local context	Impact on study
Ghost fishing	Gill nets that are broken or lost can continue to entrap fish, including char.	In the fall of 2017, eighty-two nets were counted within a 13 km section between the river mouth and Kugluk Falls (Allen Niptanatiak, Government of Nunavut Wildlife Conservation Officer, pers. comm.). Under-ice nets may be lost if they are left too long and freeze solidly into place.	Underestimated mortality rate
Predation	Ringed seals (*Pusa hispida*) are known to feed on Arctic Char [4,5].	Ringed seals are common in the area. One ringed seal was observed in the Coppermine River in late September 2018, approximately 12 km upstream from the river mouth, indicating that the risk of increased predation often associated with anadromy can extend beyond the marine environment and into freshwater.	Underestimated mortality rate

1 Jensen, J.L.A., and Rikardsen, A.H. 2012. Archival tags reveal that Arctic Charr Salvelinus alpinus and Brown Trout Salmo trutta can use estuarine and marine waters during winter. J. Fish Biol. 81(2): 735–749.

2 Mulder, I.M., Morris, C.J., Dempson, J.B., Fleming, I.A., and Power, M. 2018b. Overwinter thermal habitat use in lakes by anadromous Arctic Char. Can. J. Fish. Aquat. Sci. 75(12): 2343–2353.

3 Kristofferson, A.H., and Sopuck, R.D. 1983. The effects of exploitation on the Arctic charr population of the Sylvia Grinnell River, Northwest Territories. Can. Manuscr. Rep. Fish. Aquat. Sci. 1721: v + 35.

4 Gjertz, I., and Lydersen, C. 1986. The ringed seal (Phoca hispida) spring diet in northwestern Spitsbergen, Svalbard. Polar Res. 4(1): 53–56.

5 Harris, L., Yurkowski, D., Gilbert, M., Else, B., Duke, P., Ahmed, M., Tallman, R., Fisk, A., and Moore, J. 2020. Depth and temperature preference of anadromous Arctic Char Salvelinus alpinus in the Kitikmeot Sea, a shallow and low-salinity area of the Canadian Arctic. Mar. Ecol. Prog. Ser. 634: 175–197.

Appendix H: Castaway Temperature and Salinity Data

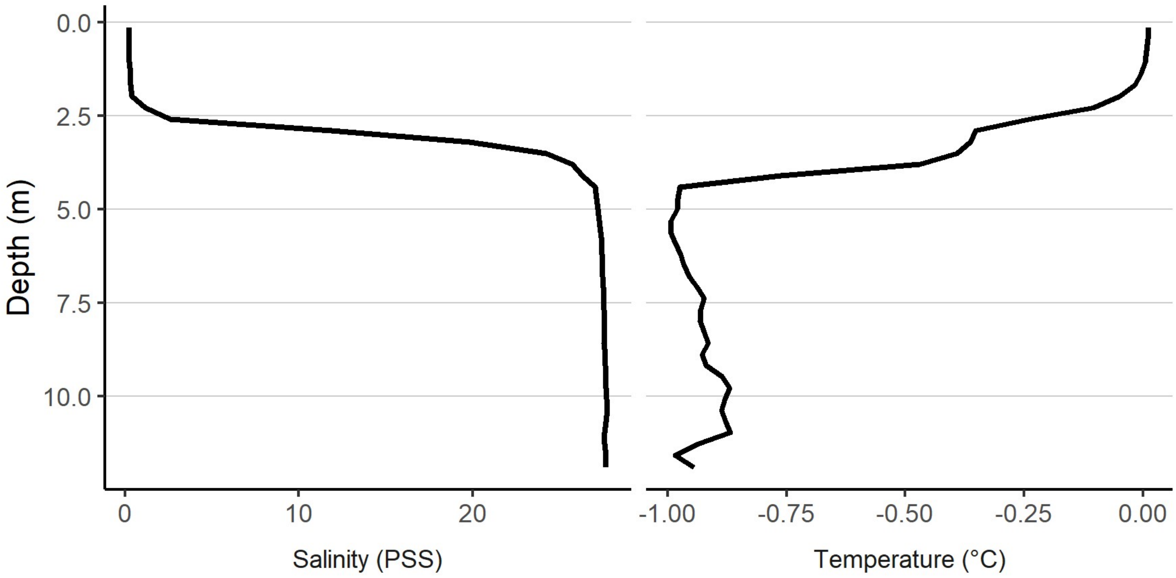

Figure G-1: Temperature and salinity profiles at First Point receiver, taken using a SonTek Castaway on 22 March 2019. Salinity is measured on the Practical Salinity Scale (PSS). Note the presence of a thermo- and halocline at a depth of approximately 3 m below the ice surface.