

Spatial Ecology of Arctic Grayling in the Parsnip Core Area

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Executive Summary

Flooding of the Upper Peace after construction of the W.A.C. Bennett Dam in 1967 resulted in a considerable loss of riverine habitat to Arctic grayling (*Thymallus arcticus*). The decrease in available habitat, alteration of natural hydrology and evidence of drastic reductions in population size caused great concern for the sustainability of Arctic grayling populations in the Williston Reservoir Watershed. The recent review by Stamford et al. (2017) and monitoring framework by Hagen and Stamford (2017) highlighted a number of critical information gaps related to the spatial ecology of Arctic grayling such as: (1) the unknown distribution of Arctic grayling within the streams of the different core areas (*sensu* Stamford et al. 2017); and (2) the lack of understanding of Arctic grayling migrations. Furthermore, it is unknown whether populations of bull trout (*Salvelinus confluentus*) are limiting the abundance of Arctic grayling and their spatial distribution.

The goal of this project is to investigate the spatial ecology of sub-adult and adult Arctic grayling and their interactions with bull trout in the Parsnip River mainstem and tributaries, a core area of Arctic grayling populations in the Williston Reservoir Watershed.

The information gathered in this study will fill in data gaps that were identified as moderate and high immediacy for the Parsnip core area (data gaps 5.1.3a-i in Table 6 of Stamford et al. 2017) and will also be relevant to other core areas in the Williston Reservoir Watershed (2.3.1b-c and 2.3.5 in Table 1 of Stamford et al. 2017). Therefore, the outcomes of this study will primarily address the Priority Actions 1b-3 and 1b-4 of the Streams Action Plan (FWCP 2014). However, given that the study will collect data on bull trout, it will also contribute information to address Priority Actions 1c-3 and 1c-4 of the Streams Action Plan (FWCP 2014).

This report refers to project activities in Years 1 and 2 of 4. The methods used to address the study objectives include: acoustic telemetry, capture-recapture, temperature data logging, stable isotope analysis and spatial modeling.

A total of 63 fish (50 Arctic grayling and 13 bull trout) were tagged in 2018, mostly in the Anzac River. A total of four tagged Arctic grayling and one tagged bull trout were recaptured by anglers and reported to our team. In 2019, a total of 87 fish (62 Arctic grayling and 25 bull trout) were tagged (14 Arctic grayling and 9 bull trout in the Hominka River, 10 and 4 in the Missinka River, 20 and 6 in the Table River, 18 and 6 in the Anzac River). Six Arctic grayling were recaptured in the same streams they were tagged in on earlier dates (one in the Anzac River, four in the Hominka River, one in the Missinka River).

In 2018, we deployed 55 acoustic receivers in the Parsnip River watershed and one in the lower Pack River. In the Parsnip River watershed, receivers were deployed along the Parsnip River, Anzac River and Table River as well as a few hundred metres into the lower section of the Misinchinka River. In 2019, we deployed 26 additional acoustic receivers in the Parsnip River watershed and two additional receivers in the lower Pack River. Expansion of the telemetry array in 2019 focused on the Hominka and Missinka Rivers. However, some receivers were deployed in the Anzac, Table and Parsnip Rivers to replace lost receivers or bolster the sampling design.

In 2018, a total of 48 temperature data loggers were deployed throughout the Parsnip River watershed to monitor water temperature and most ($n = 41$) were deployed in association with acoustic receivers. Thirty-two air temperature data loggers were installed 2 metres off the ground on stable vegetation zero metres and 10 metres from the stream. In 2019, 39 new water temperature loggers were deployed in the Parsnip watershed and most were deployed in association with acoustic receivers. Two new air temperature loggers were deployed. Two new water temperature loggers were deployed in the lower Pack River, both in association with acoustic receivers. In the fall of 2019, data from 51 water temperature loggers and 31 air temperature loggers were downloaded. The mean summer (June 16, 2019 - August 31, 2019) water temperature in the Parsnip River was 10.76°C ($\pm 1.67^{\circ}\text{C}$). Mean summer air temperature was 12.42°C ($\pm 2.07^{\circ}\text{C}$). The summer detection temperatures of Arctic grayling and bull trout were 11.30°C ($\pm 1.32^{\circ}\text{C}$) and 10.4°C ($\pm 1.09^{\circ}\text{C}$) respectively, and the average difference in detection temperature was 1.18°C ($\pm 0.74^{\circ}\text{C}$).

In 2019, preliminary telemetry results indicate that both Arctic grayling and bull trout rely on the Parsnip River mainstem for overwinter residencies. Arctic grayling move into the tributaries beginning in April, and become widespread across the watershed by June. Bull trout move into the tributaries beginning in June, and become widespread across the watershed by July. Bull trout had a larger range of distribution than Arctic grayling. Individual detection history data ranged from spatiotemporally limited ($n = 1$ detection at 1 site over 1 day) to diverse ($n = 67,451$ detections spanning 7 sites over 404 days for Arctic grayling, and $n = 47,825$ detections across 12 sites over 373 days for bull trout). Species overlap coefficients ranged from no overlap (0.000) to high overlap (0.801 at Table River 24). Telemetry system performance was assessed at five sites, and detection efficiency ranged from 0.03 - 0.67, identifying a need for a predictive model of detection efficiency to be implemented in 2020.

In 2018, a total of 89 samples (adipose fin, muscle, invertebrates, plants, particulate organic matter) were obtained for stable isotope analysis of carbon ($\delta^{13}\text{C}$) and nitrogen ($\delta^{15}\text{N}$). In the summer of 2019, the sample size was expanded to a total of 183 samples. This larger sample size has allowed us to conduct preliminary analyses on general dietary relationships between Arctic grayling and bull trout in the Parsnip watershed as well as investigate differences in grayling diets between main tributaries. Bull trout were found to occupy a larger dietary niche in comparison to grayling. Arctic grayling from the

Missinka River exhibited the smallest dietary niche, whereas the Arctic grayling from the Hominka River occupied the largest amount of niche space. When comparing results between tributaries, there seems to be a core dietary preference shared between Arctic grayling from all four tributaries sampled.

The project successfully completed objectives for the 2019 field season including expansion of the acoustic telemetry and temperature monitoring array, increasing the sample size for tagged bull trout and stable isotope analysis. In 2020 four key objectives will be focused on:

1. Continued expansion of the temperature monitoring array to encompass more variability in the elevation of temperature logger sites in undersampled, smaller watersheds.
2. Increase numbers of Arctic grayling and bull trout tagged.
3. Deploy additional sentinel tags and characterize river geomorphology at receiver sites to develop a predictive model of detection efficiency.
4. Increasing size and variety of stable isotope samples to include terrestrial invertebrates and a wider sample of the fish community present in the study system.

With the increasing amount of road access within the watershed as a result of expanded industrial activity, we believe these project objectives can feasibly be completed within the 2020 field season. Additionally, because the telemetry array is complete we will no longer have to focus our early summer field work on acoustic receiver deployment (except for replacement of lost or damaged receivers) and more time will be spent on tagging, deployment of sentinel tags, river geomorphology characterization, data download and sampling for stable isotope analysis.

We have engaged in six outreach activities presenting project objectives and preliminary results to local stakeholders and First Nations communities in the project area.

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1. Introduction

The construction of the 183-m high W.A.C. Bennett Dam in 1967, forming the Williston Reservoir flooded roughly 350 km of the Peace, Finlay, and Parsnip River valleys (Hagen and Stamford 2017). Arctic grayling (*Thymallus arcticus*) in the Upper Peace watershed show a fluvial life history form and appear to not use the reservoir (Clarke *et al.* 2007). Therefore, flooding of the Upper Peace resulted in a considerable loss of riverine habitat. Prior to impoundment, Arctic grayling were widespread and abundant in tributary streams of the Upper Peace. However, presently Arctic grayling are restricted to just eight of the larger watersheds in the Williston Reservoir watershed (Hagen and Stamford 2017). The decrease in available habitat, alteration of natural hydrology (change from large flowing rivers to reservoir) and evidence of drastic reductions in population size cause great uncertainty about the sustainability of Arctic grayling populations in the Williston Reservoir Watershed (Stamford and Taylor 2005). The recent review by Stamford *et al.* (2017) and monitoring framework by Hagen and Stamford (2017) highlighted a number of critical information gaps related to the spatial ecology - the causes and consequences of a species distribution over time and space (Hastings *et al.* 2011) - of Arctic grayling (*Thymallus arcticus*). For example, two important spatial ecology data gaps identified in the review are: (1) the unknown distribution of Arctic grayling within the streams of the different core areas (*sensu* Stamford *et al.* 2017); and (2) the lack of understanding of Arctic grayling migrations.

Knowledge of a species' spatial ecology is fundamental to the effective development and implementation of enhancement and conservation programs (Allen and Singh 2016, Ogburn *et al.* 2017). To identify critical habitats and potential limiting factors (e.g. habitat conditions, human impacts, interspecific interactions), these programs often require detailed information derived from spatial ecology studies describing where, when and why individuals move and are distributed in space (Cooke *et al.* 2016). Although the description of distribution and migrations is a necessary step in understanding the spatial ecology of Arctic grayling, it is not sufficient to determine its drivers. Both abiotic and biotic factors play an important role in influencing the spatial ecology of species (Royle *et al.* 2017). Among abiotic factors, the spatio-temporal availability of thermal habitats is one of the most important drivers of fish distribution and migrations in freshwater environments (Lucas and Baras 2001, Isaak *et al.* 2010). Despite the general perception that the thermal environment in running freshwater is homogeneous, streams actually exhibit substantial thermal variability at small (10 to 100 m) and large (> 1,000 m) spatial scales due, for example, to the variability in riparian vegetation shade and groundwater input along their extension (Kurylyk *et al.* 2015). Temperature has a strong potential to limit Arctic grayling populations, as highlighted by (Stamford *et al.* 2017), and it is known that the occurrence of Arctic grayling and bull trout is negatively related to water temperature (Hawkshaw *et al.* 2014, Isaak *et al.* 2010). Therefore, a full description of the distribution and migrations of Arctic grayling in the Williston Reservoir Watershed require a detailed characterization of the distribution of thermal habitats. Spatial stream

network modeling (SSNM) provides high resolution predictions of temperature patterns over large spatial extents and their application to animal occurrence data has become more widespread (Isaak *et al.* 2014). A novel combination of telemetry detection data and spatial modeling will provide a detailed characterization of Arctic grayling and bull trout thermal ecology and available thermal habitat.

Biotic interactions (e.g. resource competition, predation) also influence the distribution and migrations of freshwater fishes (Lucas and Baras 2001). In the Williston Reservoir Watershed, Arctic grayling co-occur with bull trout (*Salvelinus confluentus*) in streams of several core areas and there is a strong potential for age-dependent overlap in resource use. For example, as juveniles, both species prey heavily on terrestrial drift, aquatic insects and other invertebrate prey and individuals larger than 150 mm will increasingly include fish as prey (Stewart *et al.* 2007a,b). Arctic grayling feeding behaviour also appears to be related to the degree of competition for prey resources (Stewart *et al.* 2007b). Overlap in prey resource use and/or risks of predation by larger bull trout on smaller Arctic grayling, therefore, may significantly influence the spatial ecology of Arctic grayling in ways that limit the potential growth of its populations (Stamford *et al.* 2017).

2. Objectives and Linkage to FWCP Action Plans and Priority Actions

The goal of this project is to investigate the spatial ecology of sub-adult and adult Arctic grayling and their interactions with bull trout in the Parsnip mainstem and tributaries, a core area of Arctic grayling populations in the Williston Reservoir Watershed. Specifically, the objectives are to:

- i. Investigate the migrations of sub-adult and adult Arctic grayling among the Parsnip mainstem, tributaries and a nearby watershed (Pack River);
- ii. Describe and define the distribution and thermal habitat use of sub-adult and adult Arctic grayling;
- iii. Determine the overlap in distribution patterns of sub-adult and adult Arctic grayling and bull trout;
- iv. Determine the patterns of resource use and the resulting trophic relationship between Arctic grayling and bull trout.

The information gathered in this study will fill in data gaps that were identified as moderate and high immediacy for the Parsnip core area (data gaps 5.1.3a-i in Table 6 of Stamford *et al.* 2017) and will also be relevant to other core areas in the Williston Reservoir Watershed (2.3.1b-c and 2.3.5 in Table 1 of Stamford *et al.* 2017). Therefore, the outcomes of this study will primarily address the Priority Actions 1b-3 and 1b-4 of the Streams Action Plan (FWCP 2014). However, given that the study will collect data on bull trout, it will also contribute information to address Priority Actions 1c-3 and 1c-4 of the Streams Action Plan (FWCP 2014), particularly by filling in high immediacy data gaps 5.1a and 5.1b outlined in Table 5.1c in Hagen and Webber (2019).

3. Study Area

The project was conducted in the Parsnip River core area (watershed), with a focus on five streams in 2019: Parsnip River, Anzac River, Table River, Hominka River, and Missinka River.

3.1. Parsnip River

The Parsnip River system (54.769403°, -122.501018°) has a watershed area of 5,612 km² (Hagen *et al.* 2015). Total river length is 175 km, and the majority of this is low gradient. The river has a wide channel with many meanders, large gravel bars and clay banks. Substrate is a mix of cobble, gravel and fines. The Parsnip River and its major tributaries drain a mountainous area in the Hart Ranges of the Rocky Mountains, which lies east of the Rocky Mountain Trench. The Parsnip has turbid water as a result, and high peak flows from late-May to early June. Substantial glacial influence occurs in the Upper Parsnip River. However, in late summer downstream of the Missinka River (54.578597°, -122.034947°), turbidity improves to be relatively clean (Hagen *et al.* 2015). The highest flows occur in late May, and the lowest flows occur during the period from September to March (Blackman 2002a). Discharge and temperature information is available from a Hydrometric Data gauge located above the confluence with the Misinchinka River confluence (Station 07EE007, Water Survey of Canada). Maximum discharge in 2018 at 1,250 m³ · s⁻¹ occurred mid-May and minimum discharge at 25 m³ · s⁻¹ occurred in mid-October. Maximum temperature in 2018 reached 20 °C in mid-August.

3.2. Anzac River

The Anzac River system (54.902632°, -122.280257°) drains a 939 km² watershed and is 78 km in length with an average gradient of 0.7% (Blackman 2002a). The stream drains a mountainous region of the Hart Ranges in the Rocky Mountains, on the East side of the Parsnip mainstem. Watershed elevation ranges from 730 m at the confluence with the Parsnip River to 2,495 m in the headwaters (Beaudry *et al.* 2000). The upper river is characterized by bedrock canyons with a moderate gradient (1-2%). The lower river lies in a wide unconfined valley. As the river nears the Parsnip River confluence it creates large meanders, many oxbows and has a low gradient (<0.5%) (Blackman 2002a). Snowmelt causes high river turbidity and flows in the spring months, however the Anzac is low and clear in the late summer months and fall. Substrate is mainly composed of clean cobble and gravel. No hydrometric data is available for the Anzac River.

3.3. Table River

The Table River system (54.755545°, -122.090737°) drains a 506 km² watershed and is 56 km in length with an average gradient of 0.7% (Blackman 2002a). The stream drains a

mountainous region of the Hart Ranges in the Rocky Mountains, on the East side of the Parsnip mainstem. Watershed elevation ranges from 725 m at the confluence with the Parsnip River to 2500 m in the headwaters (Beaudry et al. 2000). The upper river has a moderate gradient (1-2%). The lower river has a low gradient (<0.5%) and contains many oxbows, side channels and abandoned channels (Blackman 2002a). No hydrometric data is available for the Table River.

3.4. Hominka River

The Hominka River system (54.696944°, -121.837500°) drains a 433 km² watershed (Hagen et al. 2015). The stream drains a mountainous region of the Hart Ranges in the Rocky Mountains, on the East side of the Parsnip mainstem. Watershed elevation ranges from 669 m at the confluence with the Parsnip River to 2,100 m in the headwaters. The upper watershed is confined by steep slopes which quickly ascend to alpine terrain, and the river has a moderate gradient (3-5%). The lower river is sinuous, low gradient (<0.5%) and drains many adjoining marsh wetlands (Beaudry et al. 2000). No hydrometric data is available for the Hominka River.

3.5. Missinka River

The Missinka River system (54.596666°, -121.737500°) drains a 434 km² watershed (Hagen et al. 2015). The stream drains a mountainous region of the Hart Ranges in the Rocky Mountains, on the East side of the Parsnip mainstem. Watershed elevation ranges from 740 m at the confluence with the Parsnip River to 2,346 m in the headwaters. The upper river is entrenched, confined by steep valley walls, and the river has a moderate gradient (1-3%). The lower river is sinuous, low gradient (<0.5%) with a wide alluvial floodplain (Beaudry et al. 2000). No hydrometric data is available for the Missinka River.

4. Methods

The methods used to address the study objectives include: acoustic telemetry, capture-recapture, temperature data logging, stable isotope analysis and spatial stream network modeling. Arctic grayling and bull trout were captured by angling. Captured fish were tagged (acoustic transmitters, and/or PIT [Passive Integrated Transponder] and anchor tags), sampled for muscle and dorsal fin tissue (stable isotope analysis), and released. Fish tagged with acoustic transmitters have been continuously monitored by an array of acoustic receivers deployed throughout the Parsnip River watershed and in the Pack River. A small subset of the captured fish was sacrificed for stomach contents. Other fish caught by angling and electrofishing were also sacrificed for stable isotope analysis (to fully characterize the food webs where Arctic grayling and bull trout are located). Separate data loggers were deployed to monitor both air and water temperature throughout the Parsnip watershed.

4.1. Fish Capture and Tagging

Captured Arctic grayling and bull trout > 230 g were surgically tagged with acoustic transmitters. For surgical tag implantation, the fish were sedated by electro-anaesthesia (Ward et al. 2017, Abrams et al. 2018) using electric gloves attached to a Transcutaneous Nerve Stimulation (TENS) 3000 unit (Koalaty Products Inc., Tampa, USA), while kept in a V-shaped trough filled with ambient water. A small incision (20-30 mm) was made on the ventral midline 30-50 mm posterior to the pectoral fins and an acoustic tag (V9, Vemco, Bedford, Canada) and a PIT tag (12mm HDX, Oregon RFID) were inserted into the peritoneal cavity. The incision was closed with 3-4 simple interrupted sutures (Wagner et al. 2011). The tags as well as the tagging instruments were all disinfected in a bath of Virkon (Lanxess, Germany) for 10 minutes and rinsed with distilled water. The fish were also externally tagged with an anchor tag (below the dorsal fin), measured (fork length), weighed and sampled for muscle and fin tissue. After processing, the fish were placed into a recovery bag filled with ambient water and released at the capture site after regaining equilibrium and responding vigorously when grabbed by the tail.

To augment spatial information on Arctic grayling and bull trout, additional fish were captured and tagged with anchor and/or PIT (8mm FDX or 12mm HDX) tags, including fish < 230 g. The captured fish were immobilized by hand and quickly handled in a V-shaped trough filled with ambient water, where they were externally tagged with an anchor tag (below the dorsal fin) and PIT tag (injected into the abdominal cavity), measured (fork length), weighed, and sampled for muscle tissue and adipose fin tissue. The location of capture or recapture of tagged fish was recorded with a GPS. In an effort to increase the number of recaptures, local First Nations and recreational anglers have been asked to report the capture of any tagged fish as well as the date/time and spatial coordinates of capture (see Appendix 1). We have been working with the Angler's Atlas to use their MyCatch app and their capacity to reach out to thousands of anglers in BC to request that any tagged fish caught by anglers be reported along with the relevant information (date/time, location, and tag number).

Fish handling and tagging protocols were approved by the UNBC Animal Care and Use Committee (Protocol number: 2018-06). Permits to capture and tagging fish in this study were issued by the BC Ministry of Forests, Lands, Natural Resource Operations and Rural Development (Fish Collection Permit numbers: [PG18-356580](#) and [PG19-523435](#))

4.2. Monitoring of Acoustic Tagged Fish

Receivers were deployed in clusters of 2-4 receivers spaced 0.5-2 km from one another, while distributing the receiver clusters widely in the watershed (Royle et al. 2014). The acoustic receivers were moored (concrete block, cable and duckbill anchors) on the streambed with the hydrophones facing the surface. Given the narrow width of the

streams (10-60 m) in the area and typical high detection efficiency of acoustic receivers at short distances (< 50 m), only one receiver was deployed at each location (approximately 5-20 m from one of the banks). Due to the large size of the study area, difficult access to the sites and seasonally high water, data collected by acoustic receivers from 2018-2019 were downloaded during the 2019 field season. Data collected by acoustic receivers from 2019 - 2020 will be downloaded during the 2020 field season.

In addition to the 55 acoustic receivers in the Parsnip River watershed and one in the Pack River that were deployed in 2018, we deployed 26 additional acoustic receivers in the Parsnip River watershed and two additional receivers in the lower Pack River (Figure 1). Eight receivers were lost between 2018 and 2019. One receiver deployment was vandalized by the public and was retrieved and sent to Vemco for repair. The vandalized receiver site was not replaced. The other seven receivers were lost due to sediment movement burying the receiver or exposing the anchors. The losses occurred in the Table River (4), Anzac River (2) and Parsnip River (1). Of the seven sites which were lost to natural disturbances, two sites were deemed feasible for replacement, one in the lower Table River and one in the Upper Anzac River. Vemco receivers were redeployed at these sites because habitat nearby (within 100 m) was found to be more likely to retain deployments (slow glides with >60% large cobble sediment type). Our receiver deployment focus since 2018 has shifted from pool habitat to slow, deep run/glide habitat. This is because pools were found to be associated with sediment deposition and small, mobile sediments when compared to stable runs with large sediment sizes (>20cm diameter). After accounting for unreplaced losses, Arctic grayling and bull trout tagged with acoustic transmitters are now being continuously monitored by an array of 75 receivers (VR2W, Vemco, Bedford, Canada) deployed in the Parsnip mainstem, Anzac River, Table River, Missinka River, Misinchinka River, Hominka River, and in the lower Pack River. Due to the clustered deployment strategy and large geographical scope of the telemetry array, these losses, although unfortunate due to lost data, will not affect our ability to carry out the project objectives.

Because the 2019 field season included deployments of new acoustic tags receivers, all analyses and visualizations were treated as preliminary and are meant to guide the actions of the 2020 field season. Analyses were conducted in R and visualizations were conducted with R base packages as well as R packages 'riverdist' (Tyers 2012) for visual mapping and 'overlap' (Ridout and Linkie 2009) for overlap plots. Analyses and visualizations of the data had four scopes: individual, species, location, and infrastructure.

4.2.1. Scope: Individuals

Individuals were assessed by movement and distribution across the entire study period (defined as all available data on an individual and varies based on the time and date the individual was tagged and the array of receivers deployed and active at the time of surgery). Individual movements were explored by maps, abacus plots, and histograms.

Maps provided visualizations of the extent of distribution through space, abacus plots visualized distribution through time and space, and histograms described the probability distributions of detections across the landscape for each individual based on their detection histories. These probability distributions will be used to inform a spatial capture-recapture (SCR) model in the next phase of the project and may influence infrastructure modifications in the 2020 field season. A scatterplot provided a visualization of minimum distances moved. Because detection efficiencies of acoustic receivers are influenced by individual animal behavior, the rate at which a fish is moving can influence the probability it is detected by reducing the time it is within range of a receiver (Melnychuk 2012). As such, fish in times of high and/or rapid movement (such as migrations) may pass an acoustic receiver undetected, only to be detected later at a more distant location. These instances create visible peaks in the scatterplot, which can be viewed as a proxy measurement of migration timings in a preliminary exploration of the data. This method is limited in that there are many other variables that can cause a missed detection along a migration, many of these non-behavioral and environmentally induced (Melnychuk 2012). It was, however, included as one limited tool in an effort to lend credence to competing processes underlying the observed data.

4.2.2. Scope: Species

Species were assessed by distribution over two timeframes: by month and by Arctic grayling life history periods. Visual distribution by month provided insight on the distribution of each species through space and time unbiased by prior information about what we would expect to see based on knowledge of species behaviors. The time frame “Arctic grayling life histories” is broken into spawning, feeding, and overwintering periods based on the work of Blackman (2002b). Visualization of these metrics provides two insights: 1) if and how current distribution patterns compare to historical data and 2) if and how Arctic grayling and bull trout distributions differ during these distinct periods of an Arctic grayling’s life history, a key indicator to any possible interactions between the two species.

4.2.3. Scope: Location

Assessments of location were explored in the preliminary data to provide insights into species distribution through time. In order to shed light on objective iii (Determine the overlap in distribution patterns of sub-adult and adult Arctic grayling and bull trout), this analysis was conducted to provide insights into specific areas within the Parsnip watershed prone to having both species present at the same time. Using package ‘overlap’ (Ridout and Linkie 2009), the data was analyzed visually and quantitatively by built-in functions to plot relative densities of each species detections over time by generating a ‘coefficient of overlap’ at each site (the proportion of time both species were present within detection range of an acoustic receiver over the entire study period). These methods provided useful visualizations on when different species use specific sites

throughout the study period. Periods of overlap indicate periods where interactions between the species is possible.

4.2.4. Scope: Infrastructure

Infrastructure performance, specifically the detection efficiency (DE) of the acoustic receivers themselves, was also assessed in these preliminary data, although it is of no biological relevance (Melnychuk 2012). DE is defined as the proportion of transmissions successfully logged by an acoustic receiver to the number of possible transmissions based on the transmission frequency of the sentinel tags (Brownscombe et al. 2019). By placing sentinel tags near (30 - 150 m) five receivers, we were able to calculate detection efficiencies for two acoustic receivers in the Parsnip River, two in the Table River, and one in the Anzac River. These numbers will 1) provide insights into how many detections were successfully logged versus how many were possibly missed; and 2) will be used in the implementation of a spatial capture-recapture (SCR) model in the next phase of the project.

4.3. Temperature Monitoring

Air and water temperature data loggers (DS1921Z, Maxim Integrated, San Jose, USA; MX2203 and MX2201, Onset, Bourne, USA) were deployed throughout the study area in the 2018 and 2019 field seasons. Water temperature loggers were attached to acoustic receiver moorings or boulders in the stream following methods outlined by Isaak *et al.* (2013). Air temperature loggers were installed 2 m off the ground on stable vegetation 0 m and 10 m from the stream. Temperature data was downloaded at the same time as the acoustic receivers in September and October of 2019.

Data collection and cleaning was conducted according to methods outlined by Sowder and Steel (2012). Some temperature logging records were incomplete for a variety of reasons including battery failure, exposure to air and logger malfunctions. All data files missing records between April 1, 2019 - October 31, 2019 were imputed using a regularized iterative Principal Component Analysis algorithm implemented in the missMDA package in R statistical software (Josse and Husson 2016, R Core Development Team 2020), creating a complete time series of air and water temperature for each location. The missMDA minimizes and provides the mean square error of prediction (MSEP) for imputation using leave-one-out cross validation. The data loggers recorded a variety of sub-daily measurements, so data was aggregated into daily values.

Theory behind a new class of spatial stream network model (SSNM) has recently been developed and the use of SSNMs has grown rapidly (Isaak *et al.* 2014). Specialized toolsets are required to fit spatial models to stream networks, which calculate a variety of watershed attributes including stream network distance, flow direction and landscape contributing areas. The spatial tools for the analysis of river systems (STARS) toolbox used in ArcGIS (ESRI 2009) provides an efficient framework for preprocessing hydrology

layers (Peterson and Ver Hoef 2014). Once topological network relationships are finalized using the STARS toolbox, the SSN package in R statistical software will be used to generate the spatial statistical model of temperature for the Parsnip watershed (Ver Hoef *et al.* 2014, R Core Development Team 2011).

4.4. Sampling and processing for stable isotope analysis

In addition to fin and muscle tissue sampled from tagged fish, two whole Arctic grayling were sacrificed (following UNBC Animal Care and Use Committee guidelines) upon capture in 2019. Muscle was sampled from above the lateral line and anterior to the dorsal fin, whereas fin tissue was taken from the adipose fin. Samples from sacrificed fish included liver, otolith and stomach contents in order to maximize data collected. Supplementary sampling of aquatic macro-invertebrates, other potential prey fish, periphyton, particulate organic matter (POM), macrophytes, and terrestrial vegetation was conducted for stable isotope analyses at seven sites. This supplemental sampling occurred at sites distributed in both upper and lower reaches of the Anzac, Table, Hominka and Missinka Rivers (Figure 2). Sampling for mature fish was done via 2 man-hours of angling when reaching the site. Macro-invertebrates were sampled by conducting three rounds of 30 second kicknets in shallow riffles. Collected macro-invertebrates were then identified and stored for processing by genera. Potential prey fish such as sculpin (*Cottus sp.*) and burbot (*Lota lota*) were captured via electrofishing, using a backpack electrofisher (LR-24, Smith-Root, Vancouver, WA, USA) along stream margins, using conservative settings (100v, 40Hz, 10% duty cycle) and adjusted for optimal capture. Periphyton was collected by scrubbing large river rocks in a five gallon bucket filled with river water. The suspended periphyton was then stored in a one liter bottle until processing. Terrestrial vegetation was sampled from stream banks, selecting for most abundant plant species.

In the laboratory, all collected material was kept in a -30°C freezer until processing for stable isotope analysis. Periphyton samples were filtered using a vacuum filtration system fitted with a fibreglass filter. All samples were dried in a standard laboratory convection oven set at 50°C for a minimum of 48 hours and then ground to a powder using a mortar and pestle. Samples were sent to the Environmental Isotope Laboratory, University of Waterloo (Waterloo, ON) where they will be analyzed (ongoing) using a Delta Plus Continuous Flow Stable Isotope Ratio Mass Spectrometer (Thermo Finnigan, Bremen, Germany) coupled to a Carlo Erba elemental analyzer (CHNS-O EA1108, Carlo Erba, Milan, Italy). Stable carbon ($\delta^{13}\text{C}$) and nitrogen ($\delta^{15}\text{N}$) isotope analyses can be used to evaluate consumer dietary ecology, both at the individual and community level (Post 2002, Bearhop *et al.* 2004), as they integrate prey resource use over time (Bearhop *et al.* 2004). Results of analysed samples were received in early February of 2020. Total ellipse area (TA) and standard ellipse area corrected for a small sample size (SEA_c), were calculated on both species to provide insight on trophic positioning (Jackson *et al.* 2011, Layman *et al.* 2007).

5. Results and Outcomes

Data collected by acoustic receivers and temperature data loggers in 2019-2020 will be downloaded during the 2020 field season. Therefore, below we only provide a detailed description of data collected from July 1, 2018 to October 31, 2019 including number of fish captured, tagged and/or sampled for stable isotope analysis, receivers and temperature loggers deployed, data downloads, preliminary analysis and community outreach. Data from 2018-2019 field seasons were stored in a PostGreSQL relational database (Appendix 2).

5.1. Fish Capture, Tagging and Recaptures

A total of 87 fish (62 Arctic grayling and 25 bull trout) were tagged in 2019, (14 Arctic grayling and nine bull trout in the Hominka River, 10 and four in the Missinka River, 20 and six in the Table River, 18 and six in the Anzac River) (Figure 2). All fish were tagged with acoustic transmitters, PIT tags and anchor tags, except for 18 Arctic grayling and four bull trout, which were tagged with PIT and anchor tags only.

Among tagged Arctic grayling, 29 were identified as females (mean \pm 1 SD: 552.4 \pm 143.1 g for weight; 33.4 \pm 2.7 cm for fork length), 23 were identified as males (mean \pm 1 SD: 641.3 \pm 125.9 g for weight; 35.8 \pm 2.9 cm for fork length), and 10 could not have the sex determined (mean \pm 1 SD: 562.0 \pm 159.0 g for weight; 33.5 \pm 2.9 cm for fork length).

Among tagged bull trout, three were identified as females (mean \pm 1 SD: 1,666.7 \pm 1,234.2 g for weight; 50.2 \pm 19.1 cm for fork length), nine were identified as males (mean \pm 1 SD: 2,123.3 \pm 1,335.6 g for weight; 55.0 \pm 15.6 cm for fork length), and 13 could not have sex determined (mean \pm 1 SD: 2,340.0 \pm 1,138.4 g for weight; 58.9 \pm 9.4 cm for fork length).

Six Arctic grayling were recaptured by project staff. Among recaptured grayling, three were recaptured in the Hominka River, and one each were recaptured in the Anzac, Table and Missinka Rivers. Additionally, two Arctic grayling and two bull trout were recaptured in the Table River by a group of anglers from Prince George, British Columbia. Of the two bull trout (both tagged in 2019), one was recaptured 7 km upstream from its original tagging location (32 days later) and the other was recaptured at the same location where it was tagged one week earlier. Both Arctic grayling were recaptured at their tagging locations. However, one was tagged in August 2019 and the other in August 2018.

5.2. Acoustic Telemetry Monitoring

5.2.1. *Scope: Individual*

Data retrieved during the 2019 download season (second field season; first download season), provided detection histories for 91 of the 118 acoustic tags deployed in Arctic grayling. Because the deployment of acoustic tags is ongoing through the end of the 2020 field season, detection histories at the end of the first download season ranged from spatiotemporally limited ($n = 1$ detection at 1 site over 1 day) to diverse ($n = 67,451$ detections spanning seven sites over 404 days). Seventy-one Arctic grayling spent at least part of the year in the Parsnip mainstem (Appendix 3.II). Of the 20 that did not, 15 were temporally limited ($n < 10$ detections) with no overwinter data available (i.e. tagged in 2019) and five are candidates to be classified as compromised acoustic tags (i.e. malfunctioning, shed or mortality) if no further data is recovered in the 2020 download season. Preliminary results show that the tagged Arctic grayling exhibit high fidelity to one of the monitored tributaries, with only three individuals migrating between more than one tributary over the monitoring period. No individuals have been recorded visiting three tributaries in one season. Minimum distance moved between detections for Arctic grayling ranged from 0 - 49 km, with no movements longer than 20 km happening overwinter (Appendix 3.IV).

Data retrieved during the 2019 download season provided a detection history for 21 of the 29 acoustic tags deployed in bull trout. Detection histories at the end of the 2019 download season ranged from spatiotemporally limited ($n = 1$ detection at 1 site over 1 day) to diverse ($n = 47,825$ detections across 12 sites over 373 days). Sixteen bull trout spent at least part of the year in the Parsnip mainstem (Appendix 3.II). Of the five that did not, three were temporally limited with no overwinter data available (i.e. tagged in 2019) and two are candidates to be classified as compromised acoustic tags (i.e. malfunctioning, shed or mortality) if no further data is recovered in the 2020 download season. Much of the spatial extent of bull trout in the Parsnip River watershed overlaps with Arctic grayling with two notable exceptions: 1) bull trout were detected further upstream than the maximum extent of Arctic grayling detection; and 2) five of the bull trout detection histories show an apparent outmigration towards Williston Lake between August 6 - Sept 21, 2019 (with one making the same apparent migration earlier on July 15). Minimum distance moved between detections for bull trout ranged from 0 - 62 km, with no movements longer than 20 km happening overwinter (Appendix 3.IV).

5.2.2. *Scope: Species*

Arctic grayling were detected in the Parsnip River mainstem during the winter months (November - March), with a regular residency in the lower Anzac River (Appendix 3.V). From April - May, they were detected in the middle reaches of the Anzac and Table Rivers. From June to September, they were detected in the upper reaches of both rivers

and widespread in the Parsnip mainstem. Data from the 2019 download season was too limited to include the Missinka and Hominka Rivers in this exploratory analysis.

Bull trout were detected in the Parsnip River mainstem from November – May with a regular residency in the lower Anzac River (Appendix 3.VI). From December 1, 2018 - February 28, 2019, detections of tagged bull trout were limited to only the confluence of the Table and Parsnip Rivers. For the month of June, detections in the middle-reaches of the Hominka and Anzac Rivers were recorded. From July – September, they are ubiquitous in the watershed with the notable exception of no tagged bull trout being recorded in the Anzac River in September 2019.

We visually compared the distributions of species over the periods defined in the methods as overwintering, Arctic grayling spawning, and Arctic grayling feeding to determine the potential for species interactions during different key times in Arctic grayling's phenology (Appendix 3.VII). Arctic grayling and bull trout were observed in highly similar locations in the overwinter period of December and January. During the period of Arctic grayling spawning (May 1 – June 15), Arctic grayling were found to be typically higher in the tributaries than the bull trout. During the Arctic grayling feeding period (June 16 – August 31), both species are widespread in the watershed, but bull trout were recorded typically higher in the tributaries than the Arctic grayling.

5.2.3. Scope: Location

Overlap frequency analysis varied greatly among acoustic receivers (coefficient of overlap of 0.001 at acoustic receiver ANZR07 to 0.801 at acoustic receiver TBLR24). In the Anzac River, most sites had no winter detections except those in the lower reaches (Appendix 3.VIII). The Hominka River had periods of species overlap in the lower reaches in August and September. The Parsnip River had widespread activity at all times of the year. The Table River had well-defined periods of overlap in the middle reaches of the river around September.

5.2.4. Scope: Infrastructure

Detection efficiency achieved by acoustic receiver PARR058 ranged from 0.41 – 0.67, PARR111 ranged from 0.06 – 0.11, TBLR16 ranged from 0.12 to 0.20, TBLR24 ranged from 0.03 – 0.05, and ANZR08 ranged from 0.14 – 0.23 (Appendix 3.IX).

5.3. Temperature Monitoring

In 2019, 39 new water temperature logging stations were deployed in the Parsnip and most (n = 21) were deployed in association with acoustic receivers (Figure 1). Two new air temperature logging stations were deployed in 2019 to capture temperature data from the upper Missinka watershed. Two new water temperature loggers were deployed in the lower Pack River, both in association with acoustic receivers. In the fall of 2019, data from 51 water temperature loggers and 31 air temperature loggers were downloaded.

After data cleaning was complete and missing data were imputed using the approach by Josse and Husson 2016, a complete time series of mean daily temperature values from April 1, 2019 - October 31, 2019 was created for 46 sites (MSEP = 0.1960). Incomplete air temperature data from 21 of the air logging sites was also imputed following the same method (MSEP = 0.780).

The mean summer (June 16, 2019 - August 31, 2019) water temperature in the Parsnip River was 10.76°C ($\pm 1.67^\circ\text{C}$), whereas mean summer air temperature was 12.42°C ($\pm 2.07^\circ\text{C}$). August 2019 mean and maximum data values at 47 water temperature logger sites show an elevational temperature gradient common in Rocky Mountain streams (Figures 3 and 4). This elevational gradient was accompanied by a strong seasonal shift in temperatures peaking in July and August (Table 1). Mean air and water temperature in three phenologically significant seasons (spring spawning, summer feeding and fall overwintering migrations) were compared to temperature at Arctic grayling acoustic detections (Figure 5). Arctic grayling detection temperatures tracked mean water temperature across these seasons. However, Arctic grayling were on average detected at slightly warmer temperatures (about 1.64 °C warmer) than the mean water temperature available in the watershed.

The summer detection temperature of Arctic grayling (11.30°C $\pm 1.32^\circ\text{C}$) was warmer than that of bull trout (10.4°C $\pm 1.09^\circ\text{C}$), with a mean difference of 1.18°C $\pm 0.74^\circ\text{C}$ (Figure 6). Detection temperatures of the two species tracked closely across the whole temperature time series, however notable changes in detection temperature variability relative to the other species can be seen in their key migration periods (Figure 7). Although data from summer 2018 were limited due to ongoing deployment of equipment, preliminary analysis of detection temperatures between August 2018 (n = 42,181) and August 2019 (n = 88,325) was still possible. August 2018 mean water temperature was 13.4°C ($\pm 1.42^\circ\text{C}$), whereas mean grayling and bull trout detection temperatures in 2018 were 13.9 °C ($\pm 1.02^\circ\text{C}$) and 10.9°C ($\pm 0.67^\circ\text{C}$) (Figure 8). August 2019 mean water temperature was 10.9°C ($\pm 1.18^\circ\text{C}$), whereas mean grayling and bull trout detection temperatures in 2019 were 11.1 °C ($\pm 1.45^\circ\text{C}$) and 10.4°C ($\pm 1.03^\circ\text{C}$) (Figure 8).

5.4. Stable Isotope Analysis

A total of 183 samples were obtained for stable isotope analysis of carbon ($\delta^{13}\text{C}$) and nitrogen ($\delta^{15}\text{N}$) from 2018 to 2019 (Figure 2). Samples included adipose fin tissue (n = 76), muscle tissue (n = 17), prey fish (n = 35), invertebrates (n = 15), terrestrial vegetation (n = 32) and aquatic vegetation or periphyton (n = 8). A large variety of samples is important to reduce uncertainty in dietary sources as well as provide insight into food web structure as small sample sizes can skew results of metrics (Layman et al. 2007). Further, having samples representative of many different food sources will help generate a larger, more holistic food web characterization by the end of the project. Preliminary analyses on differences in summer diets of bull trout and Arctic grayling have been conducted as well as investigation into grayling diet variation by tributary. Stable isotope

biplots fitted with 95% ellipses were used to determine dietary niche size of Arctic grayling and bull trout (Figure 9) as well as differences in grayling diets by tributary (Figure 10). When comparing bull trout and Arctic grayling dietary breath (TA), bull trout were found to occupy a larger dietary niche in comparison to grayling ($TA_{\text{bull}} = 24.07$, $TA_{\text{grayling}} = 9.91$). SEA_c also confirmed this relationship ($SEA_{c \text{ bull}} = 9.17$, $SEA_{c \text{ grayling}} = 2.05$). These data indicate that bull trout are consuming a large range of prey while Arctic grayling are exhibiting more specialized dietary preferences (Figure 9).

Arctic grayling from the the Missinka River exhibited the smallest TA and SEA_c ($TA = 1.66$, $SEA_c = 1.57$) (Table 2), whereas the Arctic grayling from the Hominka River occupied the largest amount of niche space ($TA = 5.44$) and standard ellipse area ($SEA_c = 2.50$) (Table 2). When comparing results between tributaries, there seems to be a core dietary preference shared between Arctic grayling from all four tributaries sampled (Figure 10). Ellipse shape may be influenced by outlying fish who consume different prey than the rest of our sample but this bias should be reduced in future analyses as the sample size increases.

5.5. Community Outreach

We have engaged in six outreach activities in 2019:

- i. First Nations Engagement: McLeod Lake Elders Council Meeting in Prince George on May 23, 2019. MSc Student Bryce O'Connor presented the project objectives and work completed in the 2018 field season. Thirty minute presentation with an extended question period after. The presenter urged the council to communicate our need for a First Nation technician to help with the summer field season. Attendance was approximately 30 people. The presentation was successful in gaining the project some recognition within the community in McLeod Lake.
- ii. Public announcement at International Fly Fishing Film Festival hosted by the Polar Coachmen Fly Fishing Club at the University Northern of British Columbia on February 2, 2019. MSc student Bryce O'Connor outlined the study area, project objectives, methods and proponents. The main goal was to emphasize the mark-recapture component and urge recreational anglers to participate in the project by reporting the capture of any tagged fish. Bryce stressed responsible fish handling and care while identifying tag numbers. Posters displaying information about the project and tag location on the fish were available for attendees to view at intermission and after the films (see Appendix 2). Attendance was approximately 60 people.
- iii. Public announcement at Iron Fly Prince George: Fly Tying Meets Iron Chef hosted by Kate Watson at Trench Brewing and Distilling on March 7, 2019. MSc student Bryce O'Connor outlined the study area, project objectives, methods and proponents. The main goal was to emphasize the mark-recapture component and

urge recreational anglers to participate in the project by reporting the capture of any tagged fish. Bryce stressed responsible fish handling and care while identifying tag numbers. Posters displaying information about the project and tag location on the fish were available for attendees to view throughout the evening (see Appendix 2). Attendance was approximately 40 people.

- iv. McLeod Lake Annual General Meeting: Project members accompanied biologists from FLNRORD and FWCP staff to the Annual General Meeting in McLeod Lake on August 9, 2019. Our booth adjacent to the FWCP and FLNRORD booths gained attention and allowed us to further disseminate information about the project and our need for help with summer field work.
- v. Poster Presentation: NRES Graduate Student Poster Presentation and Reception at UNBC Winter Garden on January 17, 2020. MSc students Bryce O'Connor and Joseph Bottoms presented individual posters outlining their complementary preliminary findings on the thermal and spatial ecology (respectively) of Arctic grayling in the Parsnip watershed. Posters displaying information about the project were available for attendees to view for approximately two-and-a-half hours. See posters in Appendix 2. Attendance of the event (alongside 17 additional graduate students) was approximately 60 people.
- vi. First Nations Engagement: McLeod Lake Indian Band Community Meeting at McLeod Lake Indian Band Main Administrative office on March 3, 2020. MSc student Joseph Bottoms presented the project objectives, preliminary findings, and next steps to community members in McLeod Lake. He also presented the opportunity to involve a First Nations technician on the project in the 2020 field season. Presentation was condensed to approximately 15 minutes plus question and answer time at the end of the evening. Attendance was approximately nine people.

6. Discussion

6.1. Acoustic Telemetry Monitoring

6.1.1. Scope: Individual

Visual compilation of individual fish data allowed for a few insights to be teased from the preliminary data. Individual fish behavior varied widely in our dataset. The data did follow a general rule that the more detections in an individual's history, the greater the extent of their distribution (Appendix 3.II). This is encouraging, as in the 2020 field season we will have a much more temporally complete dataset with many more possible detections along a fully established receiver array.

Most individuals whose migrations cover many receivers throughout the year displayed residency periods near multiple receivers. This asks the question of those individuals that do not. The dataset is limited by the practicality of deploying and maintaining a receiver array with adequate resolution to track all fish at all times. However, further exploration into the data can confirm if these conspecifics display residency behaviors. While the spatial resolution cannot be increased, the temporal resolution can be increased to determine periods where individuals reside between two acoustic receivers (yet in the detection range of neither).

The detection data showed that individuals of both species are highly mobile during all parts of the year except over winter (Appendix 3.II). This provided insight into overwintering behavior, as movements greater than 10 km between detections were rare, and none were found over 20 km. However, during the rest of the year, there is not a clear temporal pattern in the minimum distances moved other than they are greater than in winter. The purpose of this analysis was to visualize the relationship between distance travelled between detections and time of year. Error is introduced into these visualizations every time an acoustic receiver 'misses' a detection along a migration route (i.e. a large minimum distance travelled may be plotted as a result of multiple missed detections along a migration route). It is based on the idea that fish in migratory periods are more likely to move past a receiver site without being detected than those displaying residency behavior as they are present in the detection range for a shorter period of time. Delineating these detection efficiency errors from true movements may become apparent after the 2020 download season provides a more complete dataset. Alternate methods into exploring the data may be necessary, such as visualizing the time periods between detections at different receivers.

6.1.2. Scope: Species

Visual comparison of species distribution by month reinforced some of the ideas discussed above. While individual Arctic grayling seem to keep their summer migrations to one tributary, the abundance of the species across the watershed suggests that each tributary with receivers may be exploited by Arctic grayling. When the 2020 download data is in, this will guide further questions into annual behaviors of individuals as they age, and how habitat selection changes as the fish goes through life.

Both species were found to have a regular overwinter residency in the lower Anzac River in addition to the Parsnip mainstem. When visualizing the data based on Arctic grayling life history periods of overwintering, spawning, and feeding, an interesting pattern emerged. The Arctic grayling are the first to leave their overwintering sites in the Parsnip mainstem, for a time occupying higher reaches in the tributaries than the bull trout. When the bull trout leave their overwintering sites, they overlap with and eventually pass the Arctic grayling to occupy the highest reaches of the tributaries that Arctic grayling never use. As this overlaps with the timing and location of the thermal refugia in the summer,

this will become a critical question when integrating the Spatial Capture-Recapture model and the Spatial Stream Network model.

6.1.3. Scope: Location

The first set of preliminary data showed promise for the utility of the overlap plots. Overwinter absences of all fish can be seen clearly, with upper tributaries being vacated sooner than lower tributaries as winter approaches. Interestingly, the data that showed an absence of any tagged bull trout in the Anzac River in September of 2019 coincided with high levels of species overlap in the Table River. Further investigations into the data will be able to tease apart this observation by tracking individual movement dates (i.e. tracking the bull trout as they leave the Anzac River to see if they enter the Table River). These overlap plots are limited in that they do not have the capacity on their own to determine direction of movement or abundance of individuals, but they will be valuable tools that tell us where to focus specific questions that will be addressed with the spatial capture-recapture model.

6.1.4. Scope: Infrastructure

Detection efficiencies are an inherent challenge in telemetry studies. The hydrology of the Parsnip watershed is highly dynamic, which makes finding a location that meets the ideal deployment site criteria (e.g. long, deep [$> 2\text{m}$] section with slow currents) for acoustic receivers rare. As such, detection efficiencies are a real challenge when dealing with these data. Indeed, system performance ranged from 3 - 67% detection efficiency throughout the study period. This identified a need to create a predictive model of detection efficiency, which we will implement in the 2020 field season using the methods described in Brownscombe et al. (2019). New aspects of field work will include manually measuring detection efficiency at increasing distances from each receiver, describing site characteristics (depth, substrate, discharge, diel periods) and using sentinel tags to plot detection efficiency variance through time. These data will be combined with machine learning to describe system performance through a predictive model.

6.2. Temperature Monitoring

Temperature loggers deployed in 2019 bolstered the existing sampling design in the Anzac, Table and Parsnip Rivers, and expanded the array into the Hominka, Missinka and other smaller (unnamed) watersheds. Temperature monitoring array expansion is a necessary step to create an accurate autocovariance function required to build the SSNM (Som *et al.* 2014). The drawbacks of this spatial model's large minimum sample size are greatly outweighed by the benefits of a temperature map which can supply the information needed to support regionally significant resource conservation decisions (Isaak *et al.* 2014). In order to enhance the models predictive ability, expansion of the temperature monitoring array will continue in 2020 to include higher elevation areas in the Colbourne Creek, Reynolds Creek and Misinchinka River.

Data imputation using the missMDA R package was an effective method to complete time series of temperature data when technological failure occurred due to logger issues or natural events. Data inadequacies often inhibit complete dataset analysis and the low MSE of the imputation is a positive indication of its utility (Isaak *et al.* 2018). Shifting our preference to the MX 2201 Onset temperature logger model in summer 2020 should alleviate some of the incomplete data issues, however data imputation will remain an important tool for future data analysis.

Preliminary analysis suggests that although a temperature gradient was present in the Parsnip River, it did not hold temperatures which were unfavourable for Arctic grayling. The mild water temperatures ($10.76\text{ }^{\circ}\text{C} \pm 1.67^{\circ}\text{C}$) in summer 2019 were consistent with reported temperature preferences for adult Arctic grayling (Figure 5). Additionally, grayling were never detected above 14.5°C which is their purported upper avoidance temperature in Williston Reservoir tributaries (Ballard and Shrimpton 2009). The widespread availability of coldwater habitat ($< 14.5^{\circ}\text{C}$) in the watershed is a possible cause for the wide ranging Arctic grayling distribution revealed by preliminary analysis of telemetry data (Figures 3, 5, Appendix 3.V). This observation is contrary to past reporting and professional opinion which states that grayling occupy habitat in the upper tributaries of the Parsnip River during the summer feeding season (Blackman 2002b). Even in this mild year, Arctic grayling were detected at temperatures approaching 14.5°C (Figure 5, 6). This would suggest that Parsnip River Arctic grayling are vulnerable to decreases in available thermal habitat in unseasonably warm years or under predicted increases in mean temperature that are likely in all climate change scenarios (IPCC 2014). Detection temperatures of Arctic grayling in August 2018 revealed a higher detection temperature which may be indicative of thermal habitat residency under warmer conditions (Figure 8). This could indicate selection of warmer water temperatures to maximize growth, or a limitation in available coldwater habitat (CWH). Given the limitations of data from 2018 including a small sample size, and skewed date range towards the colder fall months, this observation should be taken with caution until additional data is collected.

The difference between 2019 summer detection temperatures of Arctic grayling and bull trout ($1.18\text{ }^{\circ}\text{C} \pm 0.74\text{ }^{\circ}\text{C}$) suggests these two species occupy different, but overlapping thermal niches (Figure 6). Extreme climatic conditions could decrease thermal habitat overlap between the two species. Comparison of August 2018 and 2019 detection temperatures between the two species indicates a wider spread in thermal habitat selection under warmer conditions (Figure 8). In both years, Arctic grayling detection temperature tracked mean water temperature closely. However, mean bull trout detection temperature varied little (0.5°C). Indeed, in other regions, it has been shown that bull trout occupy colder water temperatures and will experience different

repercussions to changes in available CWH than species at lower trophic levels with wider thermal niches (Isaak *et al.* 2015). Arctic grayling in the Big Hole River in Montana have a much broader thermal niche than reported here, occupying water at temperatures as high as 26°C (Byorth *et al.* 1996). Other literature suggests an intermediary upper avoidance temperature of 18°C (Coutant 1977). Studies from the Williston Reservoir however suggest Arctic grayling are rarely found at temperatures above 14.5°C (Ballard and Shrimpton 2009).

Parsnip grayling detection temperatures at or over 14.5°C raise concerns about possible interactions with unfavourable thermal habitat in the watershed. Using the value of 14.5°C from past regional reports we predict grayling will have reductions in preferred thermal habitat in the near future. However other thermal preferences listed in the literature give hope to the ability of Arctic grayling to be plastic in the face of rising temperatures. There is also evidence that dynamic temperature regimes may benefit Arctic grayling across multiple life history stages. Warmer, low discharge years provide better habitat to juvenile grayling, while colder, high discharge years benefit adult grayling (Deegan *et al.* 1999). Shifting water temperature regimes will have varied impacts at multiple spatial scales for multiple species and life stages. This is concerning given the predicted change in temporal and spatial availability of thermal habitat under novel climatic conditions (Waldock *et al.* 2018). Parsnip River Arctic grayling and bull trout have differing abilities to latitudinally track shifting climates due to the differences in their movement ecology and the flooding of the Williston Reservoir, which limited riverine habitat. A longer time series of temperature and detection data spanning multiple summers will give stronger insight into spatial variation in CWH availability and both species temperature selection.

Critical next steps in analysis of temperature data include the preprocessing of the hydrological layers using the STARS toolbox to fit the SSNM. Temperature at acoustic detections will allow us to build thermal response curves for Arctic grayling and bull trout, from which CWH patches can be quantified. The influence of CWH patches on Arctic grayling and bull trout movement will be assessed to better understand the effect of water temperature on occurrence probability. Using the SSNM, predictions will be made about the size of CWH patches in the year 2070. These predictions will be created from predicted air temperature data which is freely available from the Pacific Climate Impacts Consortium.

6.3. Stable Isotope Analysis

Basic metrics for quantification of trophic breadth have provided insight into the relationship between Arctic grayling and bull trout in the Parsnip as well as dietary preferences of Arctic grayling in the four main tributaries during the summer. Bull trout were found to occupy an extremely large niche in comparison to Arctic grayling

throughout the Parsnip system (Figure 9). This may be due to the fact Arctic grayling are suspected to be primarily surface feeders while bull trout consume aquatic invertebrates as well as a variety of fish found in the Pack and Parsnip rivers (Northcote 1993). It is suspected that the relatively large variation in trophic breadth among Arctic grayling from the four study tributaries (Figure 10) may be related to differing availability of aquatic invertebrates. Indeed, some rivers (e.g. Hominka) seemed to have a higher abundance of aquatic invertebrates than other tributaries (I. Clevenger, pers. obs.).

In order to better understand overall dietary trends, larger sample sizes of both study species, as well as samples of kokanee and terrestrial invertebrates will be taken in 2020 to reduce uncertainty in sources of dietary contributions. Metrics such as standard deviation of nearest neighbor distance and mean distance to centroid (currently underway) will provide information on more nuanced aspects of dietary relationships such as the distribution of trophic niches. Additionally, dietary contributions could be quantified into percent of diet in order to determine the importance of dietary inputs. Cutting et al. (2016) found that amphipoda and hemiptera were large contributors to grayling diet. Amphipoda are not likely to be found in the Parsnip system as they are typical of freshwater lakes. However, this may allude to the importance of benthic invertebrates in Arctic grayling diets. Sampling lacked terrestrial invertebrates such as hemiptera and diptera which are hypothesized to be an important source of nutrients for adult grayling (Northcote 1993). This data gap will be addressed in the 2020 field season.

7. Recommendations

In the third year of the project (field season of 2020), we will:

- Download existing temperature data loggers and expand the temperature monitoring network to include higher elevation areas in the Colbourne Creek, Reynolds Creek and Misinchinka River.
- Download existing acoustic receivers and replace any that may be lost or damaged.
- Continue tagging Arctic grayling and bull trout by distributing tags among the four main tributaries that are being monitored (Anzac, Table, Hominka and Missinka Rivers).
- Deploy additional sentinel tags throughout the watershed and collect data on river geomorphology at receiver deployment sites for the development of a predictive model of detection efficiency.
- Continue the collection of samples for stable isotope analysis from all main tributaries (Anzac, Table, Hominka and Missinka Rivers) and expand the collection to include terrestrial insects.

8. Acknowledgements

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Table 1. Monthly 2019 spring-fall water temperature summary metrics.

Month	Mean	Maximum	Minimum	SD
April	1.94	5.3	-0.29	1.20
May	4.79	10.86	0.99	1.43
June	8.31	14.15	4.10	1.99
July	11.17	15.04	7.85	1.44
August	10.85	15.99	7.17	1.62
September	8.78	13.69	2.10	2.36
October	3.28	6.30	0.00	1.39

Table 2. Preliminary metrics calculated using SIBER quantifying trophic niche space occupied by Arctic grayling from the four main tributary sampled in the Parsnip River watershed. Samples were taken over the summer field seasons of 2018 and 2019.

	Anzac River	Hominka River	Missinka River	Table River
Total Area	2.48	5.44	1.66	3.11
Standard Ellipse Area	1.90	2.50	1.57	1.57

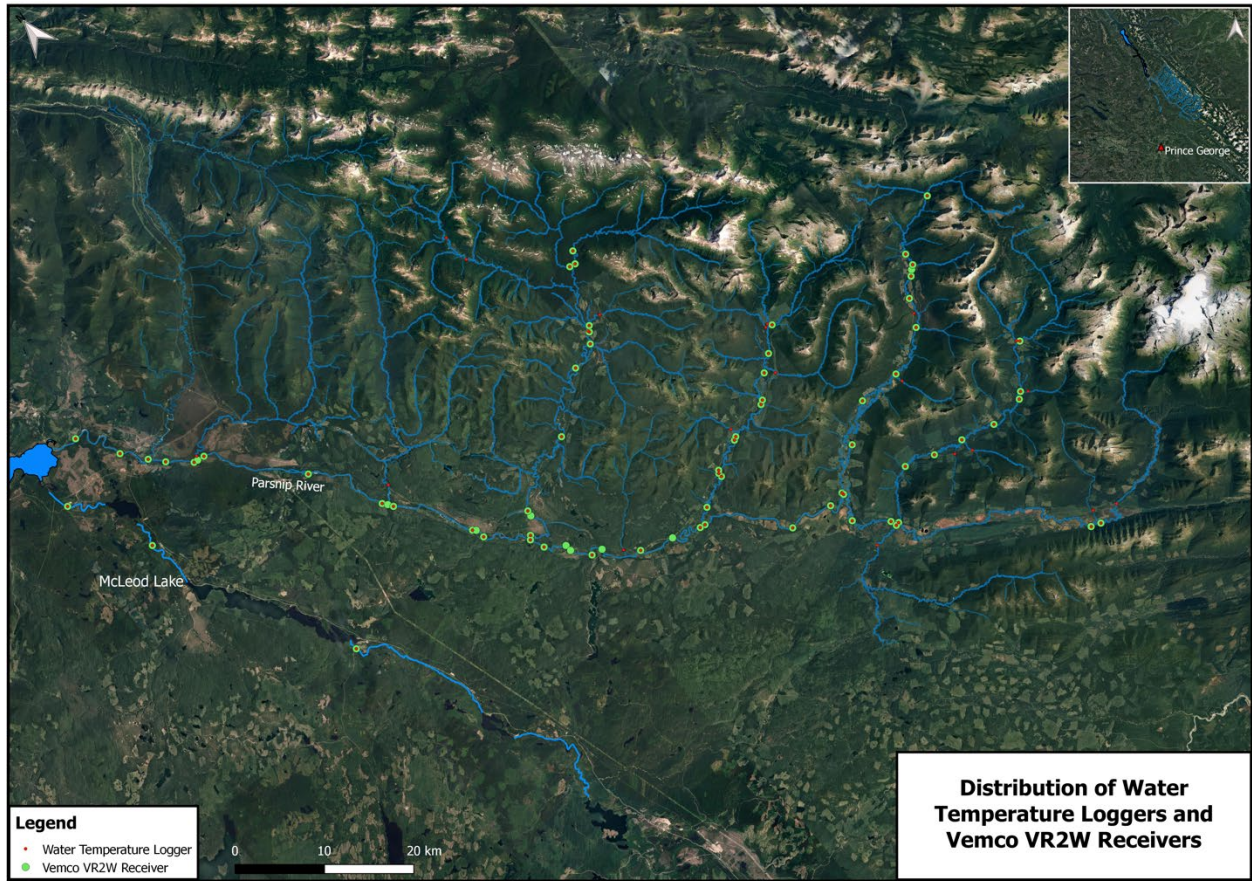


Figure 1. Location of all temperature loggers and Vemco VR2W acoustic receivers in the Parsnip River and Pack River Watersheds.

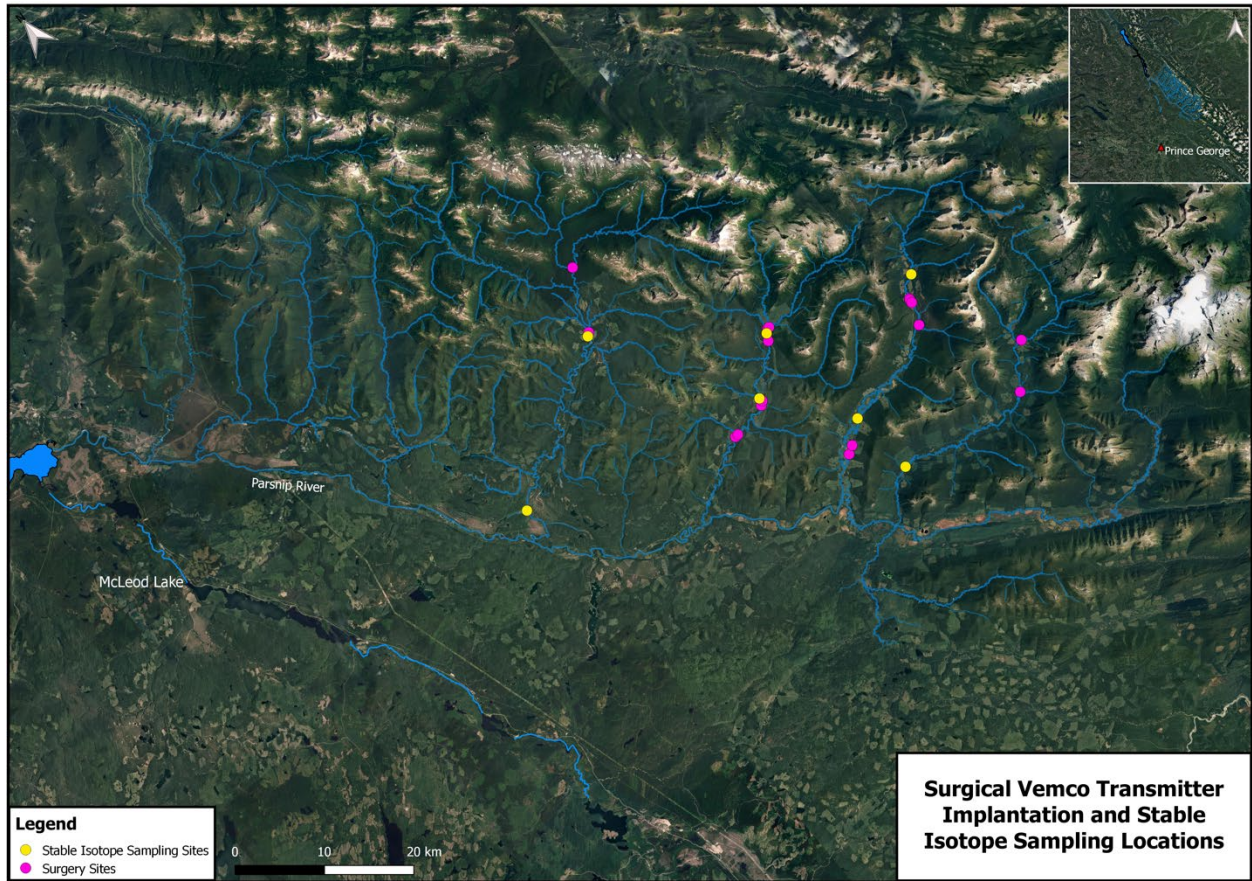


Figure 2. Locations of tag implantation surgery sites, and stable isotope sampling sites as of January 2020.

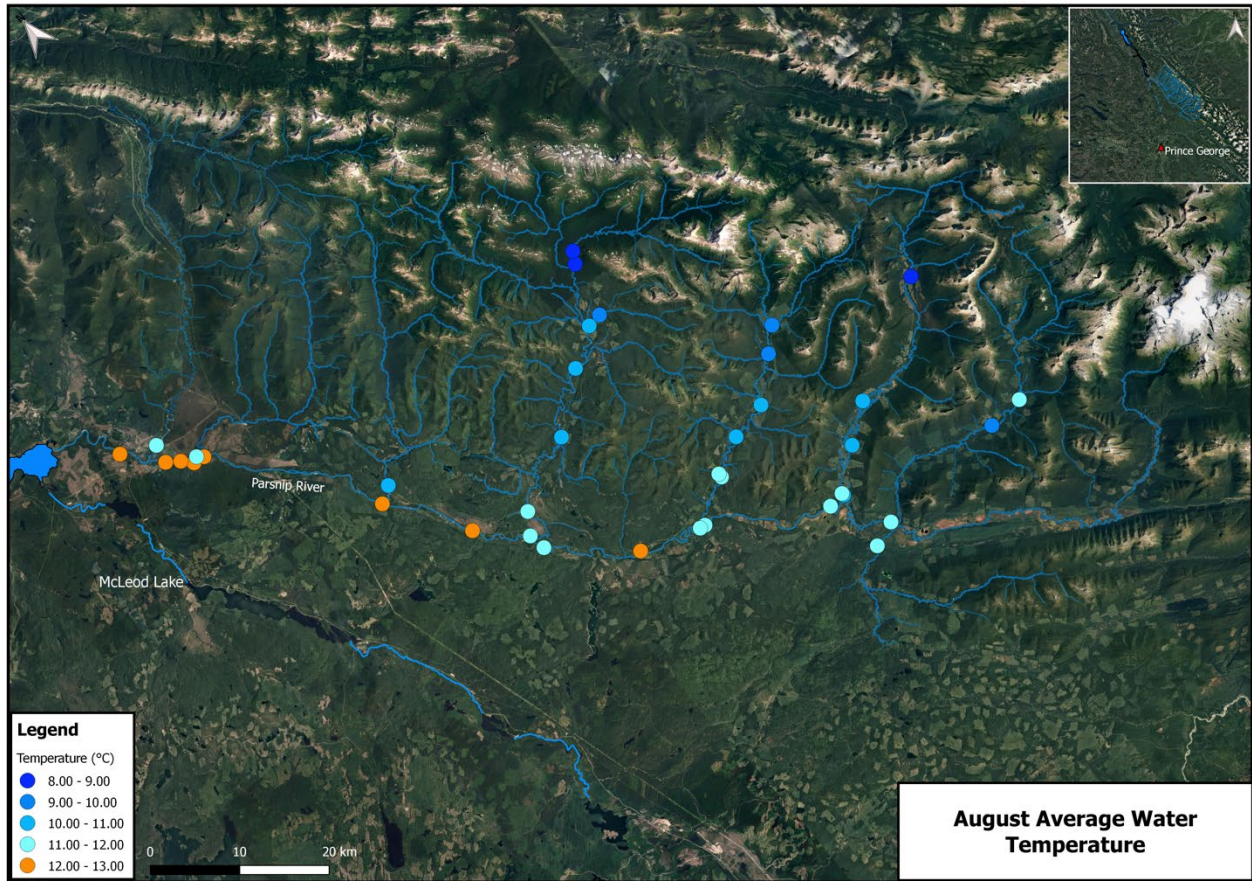


Figure 3. August 2019 mean water temperature at data logger sites (n = 46) within the Parsnip River watershed.

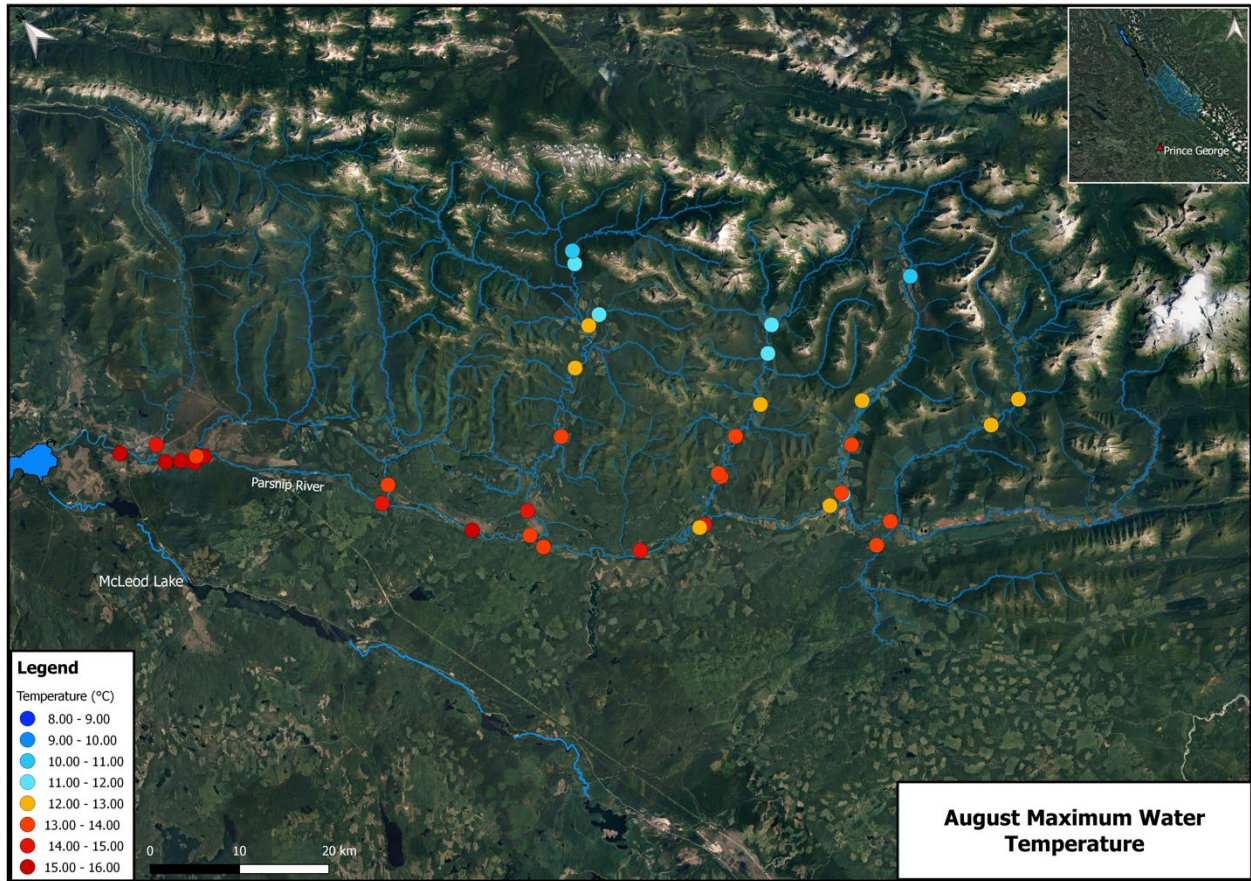


Figure 4. August 2019 maximum water temperature at logging sites ($n = 46$) within the Parsnip River watershed.

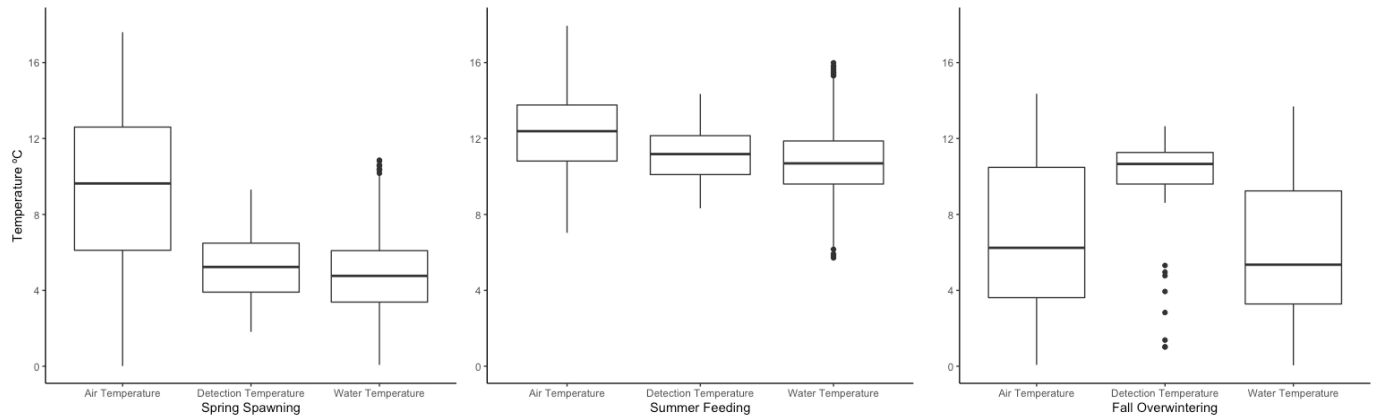


Figure 5. Boxplots depicting air temperature, Arctic grayling detection temperature (mean daily temperature at acoustic detection) and water temperature across three time series: Spring Spawning (April 17, 2019 - June 15, 2019), Summer Feeding (June 16, 2019 - August 31, 2019), and Fall Overwintering (September 1, 2019 - October 31, 2019). Thick horizontal line represents the median, lower and upper edges of the box represent the 25th and 75th percentile and the whiskers extend to a length that is equal to 50% of the interquartile range.

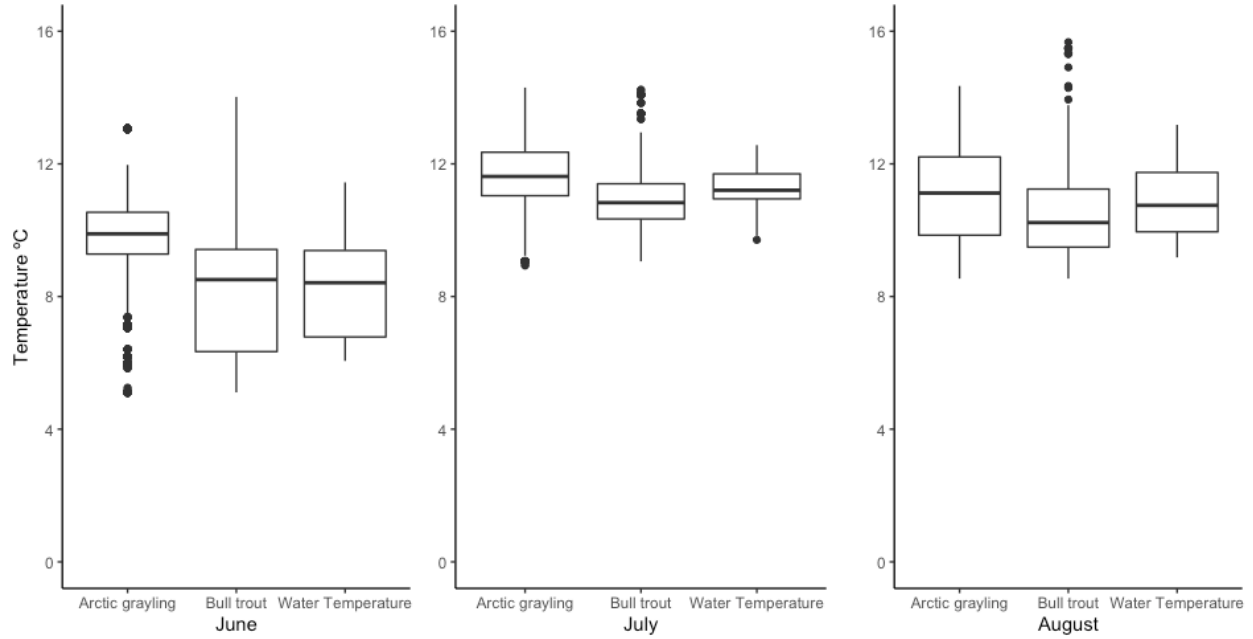


Figure 6. Boxplots depicting detection temperature (mean daily temperature at acoustic detection) of Arctic grayling and bull trout and water temperature in the summer of 2019. Thick horizontal line represents the median, lower and upper edges of the box represent the 25th and 75th percentile and the whiskers extend to a length that is equal to 50% of the interquartile range.

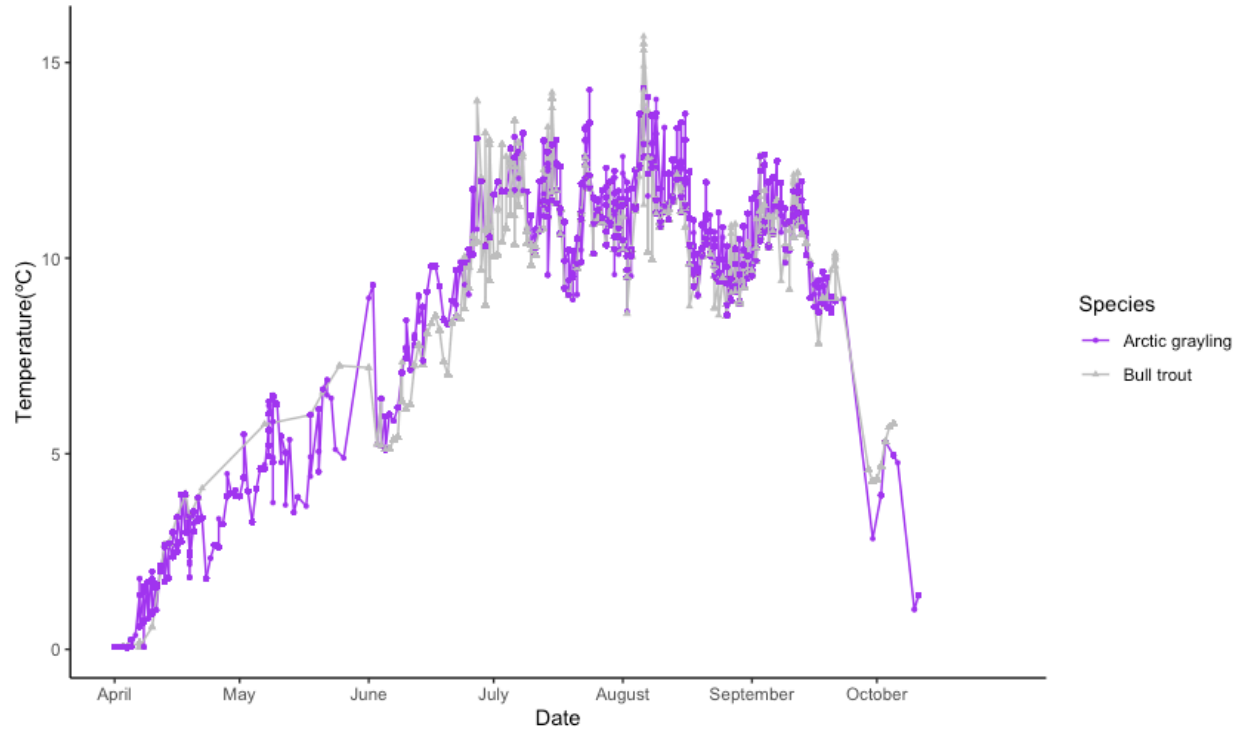


Figure 7. Temperature at detections of Arctic grayling and bull trout from April 01, 2019 to October 31, 2019.

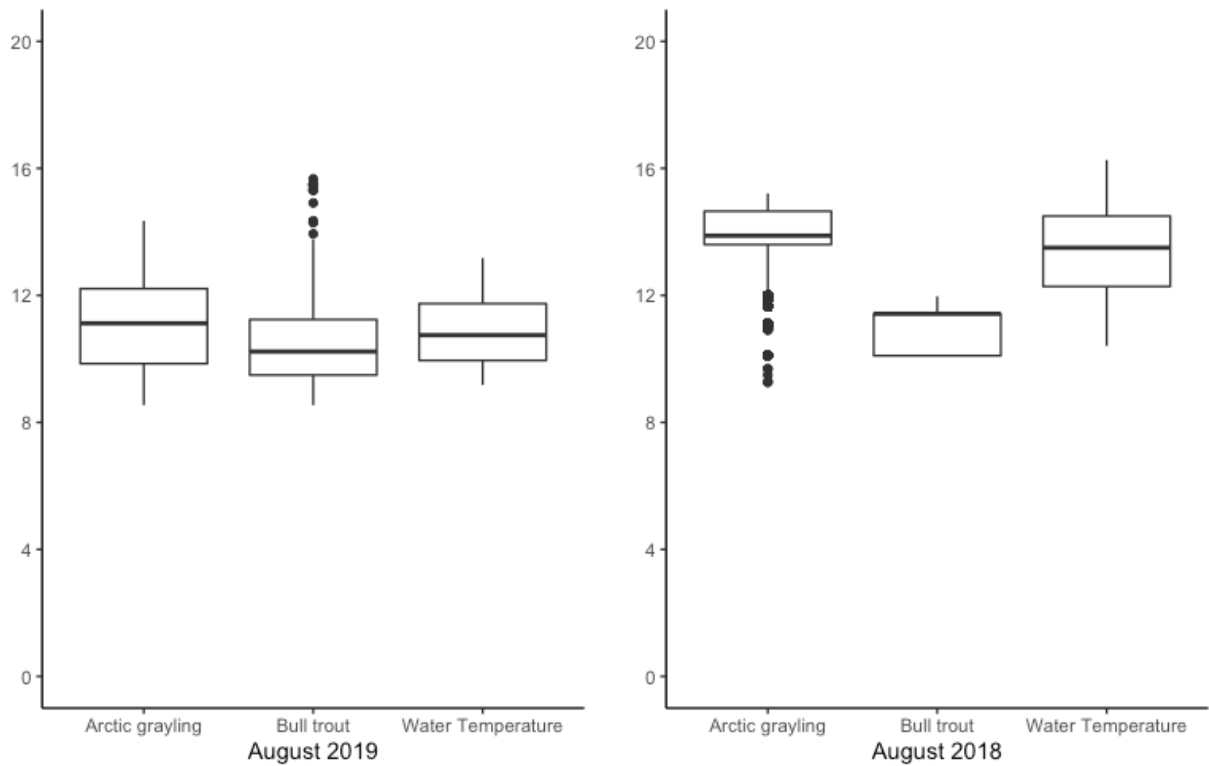


Figure 8. Boxplots depicting detection temperature (mean daily temperature at acoustic detection) of Arctic grayling, bull trout and water temperature in August 2018 and 2019. Thick horizontal line represents the median, lower and upper edges of the box represent the 25th and 75th percentile and the whiskers extend to a length that is equal to 50% of the interquartile range.

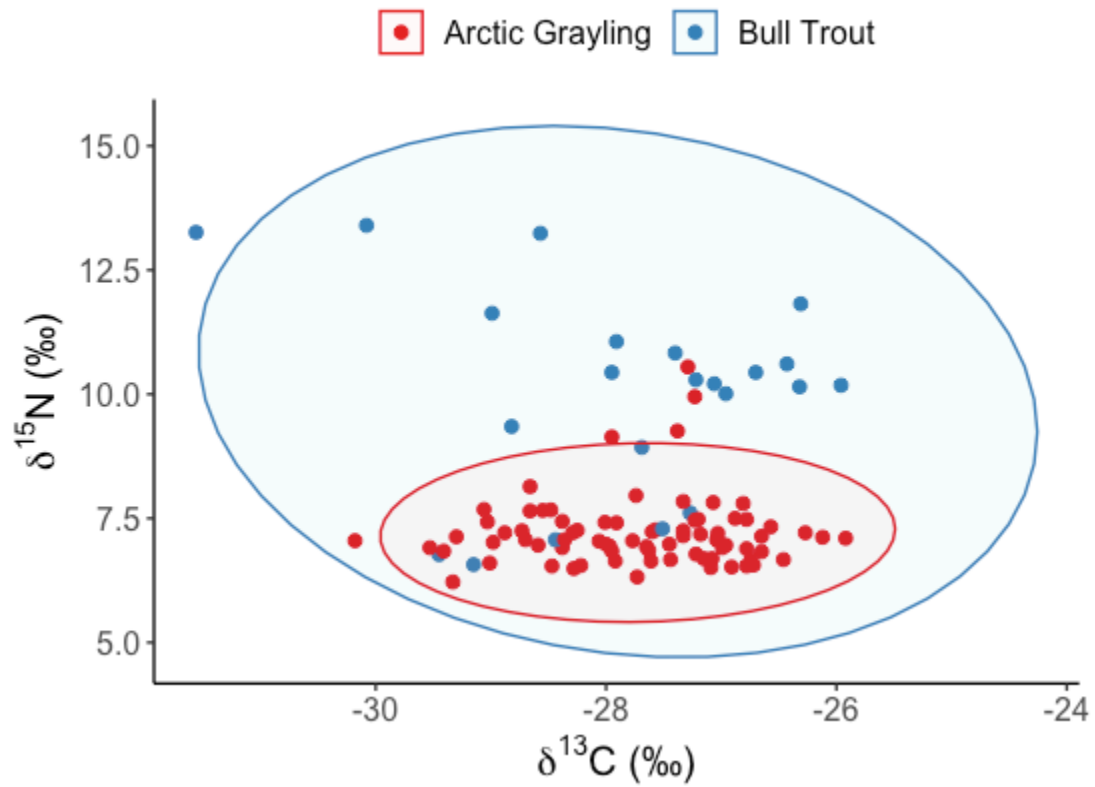


Figure 9. Isotope biplot fitted with 95% ellipses quantifying summer isotopic niche occupied by both Arctic grayling and bull trout within the Parsnip River watershed. Isotopic signatures were derived from adipose tissue collected over the 2018 and 2019 field seasons.

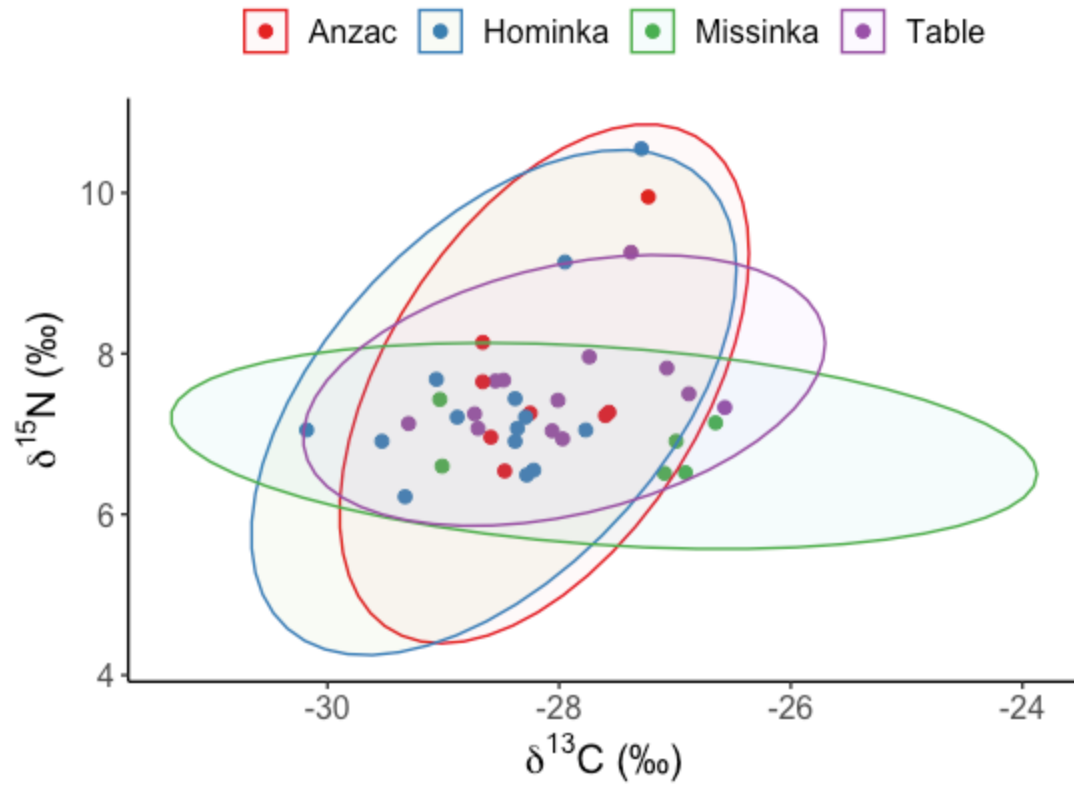


Figure 10. Isotope biplot fitted with 95% ellipses representing summer isotopic niche occupied by Arctic grayling in upper tributaries of the Parsnip River watershed. Isotopic signatures were derived from adipose tissue collected over the 2018 and 2019 field seasons.