Bridge River Project Water Use Plan

Carpenter Reservoir and Middle Bridge River Fish Habitat and Population Monitoring

Implementation Year 4

Reference: BRGMON-4

Study Period: October 2015 to September 2016

Annika Putt, Caroline Melville, Dani Ramos-Espinoza and Douglas Braun

May 2017

Bridge-Seton Water Use Plan

Implementation Year 4 (October 2015-September 2016):

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Reference: BRGMON-04

Annika Putt, Caroline Melville, Dani Ramos-Espinoza and Douglas Braun

Prepared for: St'at'imc Eco-Resources

May 2017

ST'ÁT'IMC

Suite 215 - 2323 Boundary Road | Vancouver, BC | Canada | V5M 4V8
1121A Enterprise Way | Squamish, BC | Canada | V8B 0E8
604 428 8819 | info@instream.net

Executive Summary

The Carpenter Reservoir and Middle Bridge River fish habitat and population monitor (BRGMON-04) examines how the operation of BC Hydro facilities affects fish populations in the Carpenter Reservoir watershed. BRGMON-04 aims to develop an understanding of fish populations and biological characteristics in Carpenter Reservoir and the Middle Bridge River, and determine whether changes in fish populations over the monitoring period are related to the operation of Downton Reservoir and Carpenter Reservoir, and generating facilities in the Bridge River power generating system. Monitoring in Year 4 included a pilot short-set gill netting program in four reservoir habitat zones, acoustic tagging and tracking of Bull Trout in the reservoir and into the Middle Bridge River, a second year of the Bull Trout open mark-recapture program, visual surveys for spawning kokanee, and monthly juvenile electroshocking surveys in three Carpenter Reservoir tributaries.

The short-set gill netting program took place during two time periods in Carpenter Reservoir (full pool and low pool) in four different types of reservoir habitat. The four types of habitat (eastern pelagic, mid-reservoir pelagic, eastern littoral, and western littoral) were selected to include habitat throughout the reservoir that became watered/dewatered at different reservoir elevations. The objective of the gill netting was to identify preferred habitat areas for all reservoir species, with emphasis on Mountain Whitefish. Although gill netting results provided valuable presence and absence information for Carpenter Reservoir fish species, catch rates were insufficient to determine preferred habitat. Short-set gill netting will not be considered for future monitoring years.

A subsample of Bull Trout were tagged in Year 4 within the Carpenter Reservoir mark-recapture study area, located between Jones Creek and the boundary of the reservoir and the Middle Bridge River. A telemetry gate, consisting of two rows of acoustic VR2W receivers, was positioned at each end of the mark-recapture study area to determine when tagged Bull Trout moved into and out of the mark-recapture area. The primary objective of the acoustic tracking was to verify the assumption that no one-way movement of Bull Trout occurred during the mark-recapture study period. Acoustic data were not available for Year 4 due to the timing of receiver recovery and downloading, and Year 3 data were analyzed in this report. During the Year 3 mark-recapture period (June 30 to July 31, 2015), 31% of tagged Bull Trout moved east to west (i.e., towards the Middle Bridge River), suggesting that a Bull Trout spawning migration occurred during the mark-recapture sampling period. Sampling during the migration period may have violated the model assumption of equal capture probabilities for all Bull Trout during the study period. In future years, the mark-recapture period will be moved earlier in the year to avoid sampling during a spawning migration. Although the acoustic telemetry was effective at verifying the mark-recapture assumptions, detection efficiency was low at both the river and reservoir gates, and the final locations of tagged Bull Trout are uncertain.

The Year 4 Bull Trout open mark-recapture sampling period took place from July 18 to August 12, 2016. Recapture percentages in Year 4 were lower relative to Year 3, and CPUE by gear type varied between the two years. An open mark-recapture model requires three years of data and we used Bull Trout capture data from Years 1 and 2 in addition to Years 3 and 4 to model Bull Trout population abundance. The POPAN formulation of the Jolly-Seber open mark-recapture model was fit to several candidate models and evaluated using AICc model selection. The POPAN model with fixed capture probability and time-varying survival and entrance probabilities was selected as the best fit model.

Goodness-of-fit testing suggested the POPAN Jolly Seber and the simpler Cormack Jolly Seber open population models did not fit the Bull Trout mark-recapture data with high accuracy and precision. Goodness-of-fit issues could be related to the small number of mark-recapture events and the inclusion of data from Years 1 and 2 in the models (i.e., data obtained prior to the mark-recapture modelling program being initiated). Poor model fits could also be related to unequal capture probabilities resulting from the sampling period occurring during a Bull Trout spawning migration. Both the Year 3 and Year 4 mark-recapture periods took place in late summer, potentially during the Bull Trout spawning migration. The Year 5 mark-recapture period will be moved earlier in the year (i.e., into late June) to avoid the Bull Trout migration timing. The mark-recapture model and sampling will continue to be refined to improve Bull Trout population estimates.

Monthly electroshocking surveys in Marshall Creek, McDonald Creek, and Truax Creek aimed to determine whether Rainbow Trout successfully spawn in Carpenter Reservoir tributaries. Rainbow Trout spawning was identified in Marshall and McDonald Creeks. Young-of-year Rainbow Trout were captured in September and age 1 Rainbow Trout were captured during spring sampling in both creeks. Very little evidence of Rainbow Trout spawning was observed in Truax Creek; however, one young-of-year Bull Trout was captured in May, suggesting Bull Trout spawning occurs in this tributary. Catch rates were low for all species during electroshocking and the sampling will be repeated in Year 5 to increase sample sizes and determine juvenile growth rates, particularly for Rainbow Trout.

Year 4 of BRGMON-04 provided valuable data to build on knowledge and understanding acquired in Years 1 through 3, and historically. Following completion of Year 4 monitoring, current data are insufficient to draw conclusions regarding the effects of BC Hydro operations on fish and fish productivity in Carpenter Reservoir and the Middle Bridge River. Future monitoring years will strengthen existing data and methodologies and improve and modify monitoring to address data gaps and uncertainties. The monitor design and approach will focus on using a weight of evidence approach to address the management questions, incorporating multiple sources of both direct and indirect data.

Status of BRGMON-04 objectives and management questions following Year 4 (2015-2016)

Study Objectives	Management Questions	Management Question Status
1: Collect comprehensive information on the life history, biological characteristics, distribution, abundance, and composition of the fish community in Carpenter Reservoir and Middle Bridge River.	1: What are the basic biological characteristics of parameters of fish populations in Carpenter Reservoir and Middle Bridge River?	All monitoring activities in Years 1 through 4 provided data towards answering MQ1. Our understanding of biological characteristics will continue to develop as the monitor progresses and data gaps are identified and filled. Specific methods to date include: - Bull Trout abundance estimated via an open mark-recapture model - Bull Trout behavioural data from radio and acoustic telemetry surveys - CPUE index values (shoreline electroshocking) for all species - Gill netting CPUE in multiple habitats repeated at low pool and full pool conditions - Length, weight, and age data for Mountain Whitefish, Bull Trout, Rainbow Trout, and kokanee - Growth sampling in select reservoir tributaries - Spawner surveys of kokanee and Rainbow Trout in reservoir tributaries
2: Provide information required to link the effects of reservoir operation on fish populations.	2: Will the selected alternative (N2-2P) result in positive, negative, or neutral impact on abundance and diversity of fish populations?	We are currently compiling historic research, historic reservoir elevations, and modeled pre-WUP productivity (BRGMON-10) to describe pre-WUP conditions in Carpenter Reservoir. The change between pre- and post-WUP reservoir conditions will be compared to the magnitude and variation of physical and biological parameters during the monitoring period. Where possible, multiple sources of evidence will be weighed to determine if the N2-2P condition affected the abundance and diversity of fish populations.
	3: Which are the key operating parameters that contribute to reduced or improved productivity of fish populations in Carpenter Reservoir and Middle Bridge River?	All monitoring activities in Years 1 through 4 provide data that will be used to answer MQ3. Data being collected include: - Quantitative time series data (e.g., Bull Trout spawner abundance, length, weight, and age data for all species, spawner counts) - Presence-absence data (e.g., identifying successful spawning of Rainbow Trout in tributaries vulnerable to inundation) - Habitat characteristics (e.g., physical measurements, habitat surveys) - Spawning locations and migration timing (e.g., telemetry systems, visual surveys) - Historic biological and physical data for the Carpenter Reservoir watershed - Modeled productivity from the BRGMON-10 WUP monitor All available data sources will be combined to identify pathways through which

		operating parameters (e.g., reservoir elevation, annual maximum and minimum elevations and timings, rates of elevation change, flow rates from Lajoie Dam, etc.) can affect fish populations in the reservoir and river including when fish populations are most vulnerable to operational effects, and whether the effects are more pronounced in certain species or age classes.
	4: Is there a relationship between specific characteristics of the in-stream flow in the Middle Bridge River that contribute to reduced or improved productivity of fish populations in Carpenter Reservoir and the Middle Bridge River?	Data are being compiled that will be used to answer MQ4 via a weight-of-evidence approach: - Historic Mountain Whitefish spawner surveys and egg mat deployment in the Middle Bridge River (performed by G.E. Tisdale) - Mountain Whitefish spawner surveys and egg mat deployment will be repeated in Year 5 of BRGMON-04 - Historic stable isotope data describing energy pathways in the Middle Bridge River and Carpenter Reservoir (Leslie 2003) - Stage height and temperature in the Middle Bridge River and flow from Lajoie Dam are being monitored in BRGMON-04 and by BC Hydro - Stranding surveys are being directed by BC Hydro during Lajoie ramping events
	5: Can refinements be made to the operation of Carpenter Reservoir and management of in stream flow releases from Lajoie Generating Station into the Middle Bridge River to improve protection or enhance fish populations in both of these areas, or can existing constraints be relaxed?	MQ5 will be answered using the results of MQ 1 through 4.

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1 Introduction

1.1 Background

The Bridge River power project, located in the Bridge River Valley of southwestern British Columbia (Figure 1-1), was initiated in the 1920s and completed in 1960 with the construction of Terzaghi Dam (BC Hydro 2014). Upon completion, the Bridge River generating system (consisting of three dams and four generating facilities) was the largest generator of power in British Columbia and today contributes 6-8% of BC Hydro's total generating capacity. Construction of the Bridge River generating system significantly altered flow in the Bridge River and resulted in substantial impacts to aquatic ecosystems throughout the valley. Lower Bridge River flows ceased below the dam (apart from periodic spill releases), and as such, a four-kilometer section of channel remained dewatered before being fed by groundwater and tributary inflows further downstream. A flow agreement implemented in 2000 resulted in an average flow release of 3.0 m^3s^{-1} from Terzaghi Dam that continuously watered the Lower Bridge River channel. The average annual discharge was increased to 6.0 m^3s^{-1} in May 2011.

The Bridge River Valley is an important cultural and sustaining resource for the St'át'imc Nation, and BC Hydro facilities in the valley have greatly altered their use of the watershed. A Water Use Planning (WUP) process was initiated in 1999 in response to concerns of environmental and social impacts from power generation. In 2003, a multi-stakeholder consultative committee (Bridge River Consultative Committee, hereafter BRCC) presented recommendations for an alternative operating strategy (N2-2P) aimed to balance fish and wildlife health, recreational opportunities, flood management, water security, and power generation. A draft WUP was developed in 2003 following recommendations from the BRCC, and a final WUP was accepted in 2011 (BC Hydro 2011).

Uncertainties in the biological and physical characteristics of regional reservoirs, lakes, and rivers hindered the development of explicit population-level performance measures for managing the Bridge River power system. Qualitative performance measures aided in the development of the current operating strategy; however, there were significant uncertainties regarding the effects of operations on biological parameters. The WUP recommended comprehensive environmental monitoring in the Bridge River Valley to address uncertainties and to monitor impacts of the alternative operating strategy (BC Hydro 2011). Recommendations to monitor fish and fish habitat in Carpenter Reservoir and the Middle Bridge River led to the development of the BRGMON-04 monitoring program (BC Hydro 2015).

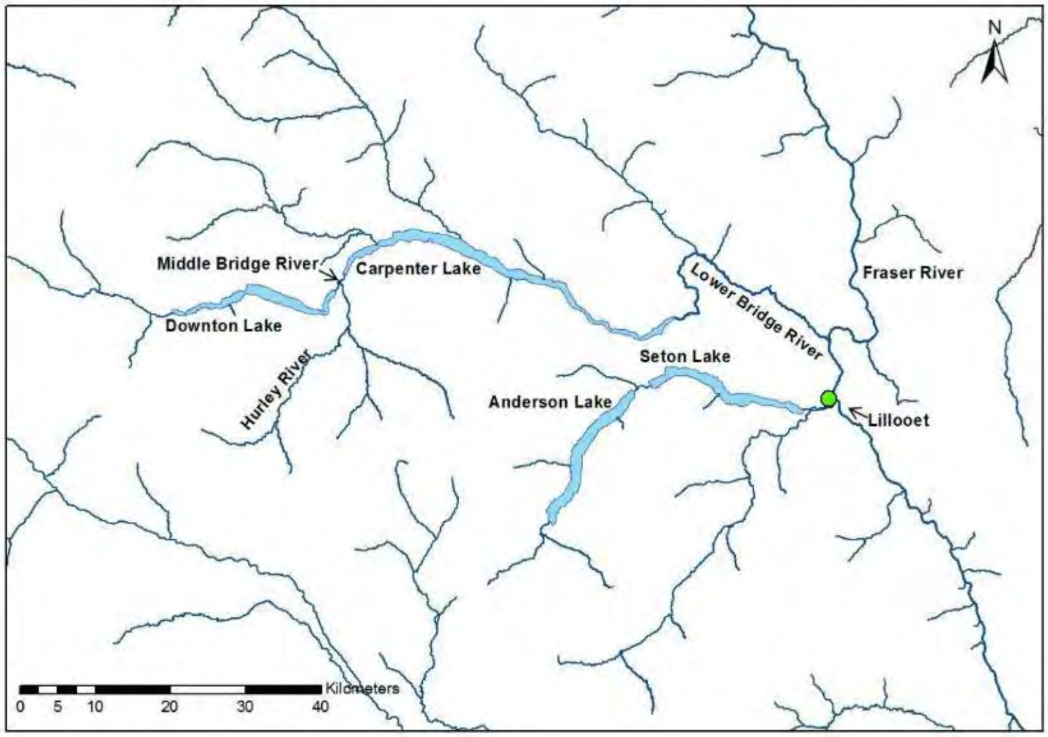

Figure 1-1 Bridge River power system near Lillooet, British Columbia.

1.2 Previous Research in Carpenter Reservoir and the Middle Bridge River

There have been several preliminary investigations into Carpenter Reservoir fish populations and reservoir productivity in recent decades (Table 1-1). R.P. Griffith & Associates and Limnotek Research and Development Inc. (hereafter, 'Limnotek') assessed fish and fish habitat and limnological conditions in the reservoir in 1995 and 1996 (Griffith 1999), including (a) identification and assessment of stream spawning habitat using closed-site electroshocking, and (b) fish indexing gill net surveys in pelagic areas of the reservoir. Counts of Rainbow Trout and Bull Trout were low in Carpenter Reservoir tributaries, and habitat investigations suggested limited stream-lengths accessible to fish (due to steep gradients and barriers to passage), limited spawning substrate in streams, and lack of cover in streams heavily affected by reservoir drawdown.

Gill netting near the Bridge 1 and Bridge 2 diversion tunnels in the eastern pelagic portion of the reservoir (bottom and mid-water depths) yielded high catches of Rainbow Trout and Bull Trout, and low catches of kokanee. Gill netting during high and low reservoir elevations suggested that Bull Trout and Rainbow Trout were less reliant on pelagic habitat than kokanee and occupy western (i.e., more fluvial) portions of the reservoir during low pool conditions. Limnological surveys found low densities of zooplankton and phytoplankton in Carpenter Reservoir, possibly due to a short water retention time in the reservoir (Perrin and Macdonald 1997; Harding et al 2017-in review).

In 1999 and 2000, Chamberlain et al. (2001) examined the impacts of hydro operations on Bull Trout and kokanee migrations, life histories, and critical life history stages. Two years of Bull Trout radio telemetry occurred and tributary spawner surveys were conducted to obtain relative kokanee spawner counts. Radio telemetry indicated that Bull Trout migrate into the western portion of the reservoir as it fills in the spring and summer, and occupy the eastern portion of the reservoir during the winter (Chamberlain et al. 2001). No kokanee were observed in the 11 tributaries during visual surveys, and only 2 kokanee carcasses were observed (in Gun Creek). Preliminary investigations of reservoir productivity by Limnotek led to a light-based productivity model that suggested Carpenter Reservoir productivity increased from the Terzaghi Dam to the Middle Bridge River (unpublished, referenced in Chamberlain et al. 2001).

Energetic food webs in Carpenter Reservoir and the Middle Bridge River were examined in 2001 using stable isotopes to identify the primary energy sources of fish species in the reservoir (Leslie 2003). Samples were collected across 5 months from the reservoir, the Middle Bridge River, and reservoir tributaries. Isotope ratios were developed for terrestrial plants, zooplankton, reservoir chironomids, fish tissues, and macroinvertebrate drift in inflows. Stable isotope signatures in fish throughout the Carpenter Reservoir watershed most resembled reservoir chironomidae and Middle Bridge River macroinvertebrate drift, rather than zooplankton or tributary sources. Carbon signatures in reservoir chironomidae and Middle Bridge River macroinvertebrate drift could not be separated and it was not possible to determine which energy source was most important for fish productivity. Despite these uncertainties, the stable isotope analysis provided valuable insight into energy production in the reservoir and Middle Bridge River, and was used during the WUP process to evaluate the effects of alternative operating strategies on Carpenter Reservoir productivity.

Much of the historic sampling in Carpenter Reservoir and the Middle Bridge River (both published studies [e.g., Griffith 1999, Chamberlain et al. 2001, Leslie 2003] and unreported data collection [e.g., hydroacoustic sampling in 2000]) was completed in the early 2000s during the development of the WUP monitors. Preliminary research into fish populations and productivity in Carpenter Reservoir highlighted uncertainties in biological and physical characteristics of the system and the effects of BC Hydro operations on fish productivity. The Carpenter Reservoir and Middle Bridge River Fish Habitat and Population Monitoring Program (BRGMON-04) was developed during the WUP process to address these uncertainties. BRGMON-04 will build on previous research to develop an understanding of Carpenter Reservoir and Middle Bridge River fish populations and to determine how BC Hydro operations affect fish productivity.

Table 1-1 Summary of previous research and available data for Carpenter Reservoir and the Middle Bridge River.

Author/ Contributor(s)	Sampling Period	Description	Notes and Primary Findings	Reference
Griffith, R.P.	1995-1996	- Inventoried fish and fish habitat in tributaries (25 locations) - Gill netted on 4 occasions, primarily near the diversion tunnels - Monitored limnology in the reservoir	- Spawning habitat area was limited by accessible stream length, availability of spawning substrate, and lack of cover - Concluded the standing stock of fish in tributaries was below theoretical juvenile rearing capacity - High gill net catches were obtained for Bull Trout and Rainbow Trout relative to other regional lakes but lower kokanee density relative to 1993 - Water residence time is low in the reservoir, likely resulting in relatively low abundance of phytoplankton and zooplankton	Griffith, R.P. 1999. Assessment of fish habitat and production in Carpenter Lake Reservoir relative to hydroelectric operations. Prepared for B.C. Hydro, Kamloops BC. 216 p.
Tisdale, G.A.E.	1999	- Rainbow Trout spawning assessment in 17 tributaries (based tributaries on those identified by Griffith 1999) - Performed stream walks, assessed migration barriers, and monitored temperature and turbidity	- Spawning Rainbow Trout were observed in 6 tributaries - Peak spawning occurred from June 11 to July 23, 1999 - A total of 125 Rainbow Trout were observed, 75% of which were in Marshall Creek (may be an important spawning location).	Tisdale, G.A.E. 2000. 1999 Carpenter Lake Reservoir Rainbow Trout Spawning Assessment (Onorhynchus mykiss). Prepared for B.C. Hydro and Power Authority, Kamploops, B.C. 45 p.
Unknown	2000	- Performed 92 cross-sectional acoustic transects in September of 2000	- Analysed number of fish per transect and depth of fish - Concluded that more fish were present in the Eastern portion of the reservoir - Did not verify species during transects, so no abundances were estimated	Unpublished
Chamberlain, M.W. et al	2000-2001	- Used radio telemetry to track movements of Bull Trout in the Middle Bridge River and the reservoir - Quantified the effects of an experimental drawdown of the Middle Bridge River on fish populations and habitat	- Described Bull Trout movement (small sample size) - Monitored Middle Bridge River ramp-down in late July/early August - Increased stranding risk occurred but spawning effects were not quantified	Chamberlain, M.W., O'Brien, D.S., Caverly, A., and A.R. Morris. 2001. 2000 Middle Bridge River Bull Trout (Salvelinus confluentus and Kokanee (Oncorhynchus nerka) Investigation. British Columbia Ministry of Environment, Lands and Parks, Fisheries

		- Enumerated kokanee in the Middle Bridge River and reservoir tributaries	- No kokanee were observed in any streams	Branch, Southern Interior Region.
Leslie, K.	2001	- Sampled stable isotopes from trophic groups in Carpenter Reservoir, the Middle Bridge River, and reservoir tributaries over 5 months - Qualitatively assessed food web dynamics in Carpenter Reservoir from variations in stable isotope enrichment ratios	- Stable isotope signatures of fish in the reservoir were more like reservoir chironomidae and Middle Bridge River macroinvertebrate drift than tributary production or reservoir zooplankton. - The carbon signatures of river drift and reservoir chironomidae could not be distinguished; could not discern whether fish were more dependant on river inputs or reservoir littoral inputs	Leslie, K. 2003. Use of stable isotope analysis to describe fish food webs in a hydroelectric reservoir. Research Project submitted for requirements of the degree of Master of Resource Management. Simon Fraser University Report No.336. 100 p.
Higgins, P., Korman, J., et al.	2001	- Performed shoreline boat electroshocking in CR in late September 2001. - Indexing performed at 29 sites around the reservoir.	- CPUE of Bull Trout, Rainbow Trout, and Bridgelip Sucker was evenly distributed amongst the reservoir tributary outflows - Mountain Whitefish CPUE was highest in the Middle Bridge River and at tributaries in the western portion of the reservoir - Redside Shiner CPUE was highest at tributary confluences in the eastern portion of the reservoir	Unpublished
Tisdale, G.A.E.	2005 and 2009	- Deployed spawning mats in the MBR to collect Mountain Whitefish eggs. - Angled Mountain Whitefish weekly, and sampled for age, sex, maturity, and length.	- Identified peak spawn timing and approximate hatch date for Mountain Whitefish in the Middle Bridge River - Existing flow regime did not appear to have impacted Mountain Whitefish or their spawning habitat for the 2007-2009 period	Tisdale, G.A.E. 2005. 2005 Middle Bridge River Rocky Mountain Whitefish (Pros opium williamsoni) Exploratory Spawning Assessment October 5, 2005 – December 22, 2005. Prepared for B.C. Hydro and Power Authority. 37 p. Tisdale, G.A.E. 2010. 2009 Middle Bridge River Rocky Mountain Whitefish (Prosopium williamsoni) Exploratory Spawning Assessment October 4, 2009 – December 21, 2009. Prepared for B.C. Hydro and Power Authority, Shalalth B.C. 40 p.

1.3 Management Questions

BRGMON-04 addresses five primary management questions identified during the WUP process (BC Hydro 2012)[1]:

1. What are the basic biological characteristics of parameters of fish populations in Carpenter Reservoir and its tributaries?
2. Will the selected alternative (N2-2P) operation result in positive, negative, or neutral impact on abundance and diversity of fish populations?
3. Which are the key operating parameters that contribute to reduced or improved productivity of fish populations in Carpenter Reservoir and Middle Bridge River?
4. Is there a relationship between specific characteristics of the in-stream flow in the Middle Bridge River that contributes to reduced or improved productivity of fish populations in Carpenter Reservoir and Middle Bridge River?
5. Can refinements be made to the operation of Carpenter Reservoir and management of in-stream flow releases from Lajoie Generating Station into the Middle Bridge River to improve protection or enhance fish populations in both areas, or can existing constraints be relaxed?

1.4 Key Water Use Decision Affected

BRGMON-04 will inform key management decisions relating to minimum and maximum elevations for Carpenter Reservoir, minimum elevations for Downton Reservoir, and management of releases from Lajoie Generating Station. During the WUP process, a higher priority was placed on reducing spills in the Lower Bridge River and protecting anadromous fish species than protecting species resident to the reservoir (BC Hydro 2011). Whitefish egg dewatering in the Middle Bridge River was identified as an issue of concern during the WUP process, and a deeper drawdown of Downton Reservoir was adopted to reduce egg dewatering in the Middle Bridge River during winter months (BC Hydro 2011). BRGMON-04 aims to determine whether operating parameters for Carpenter and Downton Reservoirs and in-stream flow releases from Lajoie Generating Station have a negative effect on fish populations and fish habitat, and whether current management practices can be refined to reduce negative impacts or enhance reservoir fish populations.

1.5 Monitoring Approach

BRGMON-04 aims to resolve current data gaps and uncertainties in the Carpenter Reservoir watershed through the collection of comprehensive fish populations and habitat condition data. The first two years of monitoring (Year 1 by Tisdale Environmental Consultants [TEC] and Year 2 by InStream Fisheries Research Inc. [IFR]) highlighted deficiencies in the original hypotheses and methodological approaches outlined in the TOR. Carpenter Reservoir is a large and remote reservoir and it is unrealistic to monitor all species and life stages in both the reservoir and the Middle Bridge River. Methods used in other reservoir WUP monitors (e.g., boat electrofishing, fly-over spawner surveys, hydroacoustic transects; Sebastian and

[1] An amendment to the terms of reference (TOR) was completed in 2015, during which the BRGMON-04 hypotheses were modified. The management questions were not modified during the amendment.

Weir 2014, Zwart et al. 2013, Sebastian et al. 2003) are ineffective or cost-prohibitive for BRGMON-04 due to the system's size, remote access, high turbidity, and large fluctuations in reservoir elevation.

The TOR was amended in March 2015 (based on monitoring in Years 1 and 2) to include revised hypotheses and modifications to the original methodologies (BC Hydro 2015). Management questions will be answered either directly via a targeted monitoring program, or indirectly through a weight-of-evidence approach. The TOR focuses on species and life stages that are; (a) abundant, ecologically important, and/or sensitive to habitat changes, and (b) possible to assess using methods tested during BRGMON-04 monitoring.

2 Methods

2.1 Study Site

Carpenter Reservoir is located 40 km upstream of the confluence of the Bridge and Fraser Rivers and is bound to the west by the Middle Bridge River and Lajoie Dam and to the east by Terzaghi Dam. Carpenter Reservoir water is diverted through two tunnels near the eastern end of the reservoir that discharge into Seton Lake via the Shalalth power generating facility. Reservoir elevation is controlled by BC Hydro and changes substantially during annual cycles in the reservoir. At low pool (April), the boundary of the Middle Bridge River and Carpenter Reservoir moves eastward and the volume of Carpenter Reservoir decreases. As the reservoir fills in the spring, the boundary of the river and reservoir moves westward and reservoir length and volume increase. At full pool, generally reached in the late summer, the reservoir is 50 km long and 1 km wide with a total surface area of approximately 4,620 ha (Perrin and Macdonald 1997). The maximum depth at full pool is 55 m in the lacustrine portion adjacent to Terzaghi Dam. There are approximately 20 major tributary inflows to Carpenter Reservoir, but 5 sub-basins contribute a majority (85%) of the catchment area (Perrin and Macdonald 1997). The main drainages are the Upper Bridge River (i.e., Downtown Lake and the Middle Bridge River), the Hurley River, Tyaughton Lake, Marshall Lake, and Gun Lake. The largest tributaries drain upstream lakes, while numerous smaller tributaries drain snowfields and steep mountainous terrain.

2.2 Gill Net Surveys

A pilot short-set gill netting program was used in Year 4 to examine species composition and distribution in Carpenter Reservoir during full pool and low pool conditions. A successful program would obtain sufficient catches to determine preferred habitat areas for fish species in the reservoir. Mountain Whitefish are an abundant forage fish species and potential food source of Bull Trout in the reservoir, and their behaviour and habitat preferences have not been identified. Determining Mountain Whitefish distribution was the primary goal of the pilot program.

Four habitat types were defined in Carpenter Reservoir with varying physical and biological characteristics: deep pelagic habitat (in the eastern portion of the reservoir close to the Terzaghi Dam), low elevation littoral habitat, high elevation littoral habitat, and mid-reservoir pelagic habitat. Because these habitats are located at different elevations, they become flooded and dewatered at different times. Western reservoir littoral habitat is the first to dewater as reservoir elevation decreases, followed by eastern reservoir littoral habitat. The mid-reservoir pelagic habitat is in the original river channel and would remain watered during deep drawdown as part of the Middle Bridge River. The eastern reservoir pelagic habitat is located close to the Terzaghi Dam in the deepest portion of Carpenter Reservoir and represents lacustrine habitat that would also remain watered during minimum elevations (~ 50 m deep at full pool). One site was identified and surveyed in each of the four habitat types using short-set gill netting (Figure 2-1).

Short-set gill netting occurred in the four habitat zones at low pool (April 26-28, 2016) and full pool (September 21-23, 2016) elevations (Figure 2-1). During the low pool survey in April, high elevation littoral habitat was dewatered and could not be sampled. Resource Inventory Committee (RIC) standard gill nets 91.2 m long, 2.4 m deep with six different mesh sizes (25, 89, 51, 76, 38, and 64 mm stretched mesh) were distributed throughout each habitat type to fish as much area as possible. In littoral habitats, gill nets were set perpendicular to shore along the reservoir bottom, while in pelagic and mid-reservoir habitats a mixture of bottom, mid-water, and surface sets were used. The goal was to perform 10 sets of 20 minutes in each habitat type for a total of 200 minutes of sampling per site. All captured fish were weighed, measured, and sampled for age structures (fin rays were collected from Bull Trout and scales were collected from Mountain Whitefish, kokanee, Rainbow Trout, and Redside Shiners).

Catch per unit effort (CPUE) was used to summarize gill net captures. CPUE is an index of abundance that can be compared between habitat zones and reservoir elevations to infer habitat use and preferred habitat for fish species in the reservoir during the time of sampling. Once habitat preference is determined, the area of preferred habitat in the reservoir can be calculated and compared during different reservoir conditions. CPUE was calculated for each species in the four habitat zones during full pool and low pool using the equation:

$$CPUE_{ijx} = \frac{Catch_{ijx}}{Time(hours)} \qquad \text{Eq 1}$$

For species i at pool level j in habitat zone x. Length, weight, and age data collected during gill netting were combined with data collected during the Bull Trout mark recapture program (discussed in Section 2.3.2) to describe the biological characteristics of all species in Carpenter Reservoir.

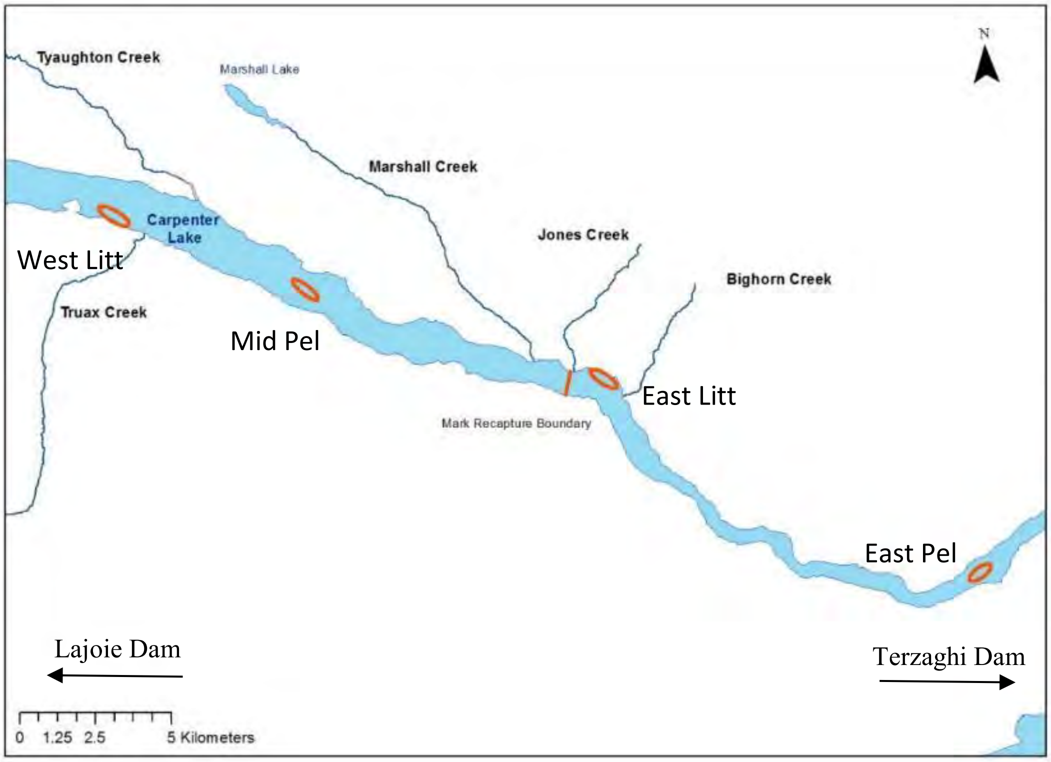

Figure 2-1 Carpenter Reservoir short-set gill netting areas: eastern reservoir littoral (East Litt), western reservoir littoral (West Litt), mid-reservoir pelagic (Mid Pel), and eastern reservoir pelagic (East Pel).

2.3 Bull Trout Abundance and Movement Analysis

An open mark-recapture model was used to estimate annual Bull Trout abundance in Carpenter Reservoir. Open mark-recapture models account for fish movement into and out of the monitoring area via births, deaths, immigration, and emigration. Fish are captured each year and marked with a unique identifier (passive integrated transponder [PIT] tag). The sampling is repeated in subsequent years and both marked and unmarked animals are captured. Marked animals are recorded and released, and unmarked animals are tagged and released. The mark-recapture in Carpenter Reservoir has two main components: an intensive annual mark-recapture period in Carpenter Reservoir, and acoustic telemetry in the reservoir and Middle Bridge River.

2.3.1 Movement Analysis

Acoustic telemetry was used to define the mark-recapture study area, verify mark-recapture model assumptions about Bull Trout movement during and between mark-recapture periods, and determine habitat use and behaviour of Bull Trout in Carpenter Reservoir and the Middle Bridge River. During the mark-recapture program, acoustic telemetry was used to monitor Bull Trout movement into and out of the study area, which was restricted to the western half of Carpenter Reservoir to maximize catch rates. Any one-way movement of Bull Trout during the mark-recapture period would violate the model assumption of equal capture probability.

Eighteen Bull Trout were angled from June 7-10, 2016 at the confluences of Gun and Truax Creeks (within the mark-recapture study area) and tagged with acoustic transmitters (V13 transmitters, Vemco; 2-year battery life). To minimize adverse tagging effects, Bull Trout > 550 g were selected so that the tag weight (in air) was < 2% of the total fish weight (in air). Bull Trout were angled using roe as bait and held in swim tubes prior to surgery. Bull Trout were anaesthetized in dark coolers using clove oil (diluted to 10-parts ethanol, 1-part clove oil) until fish lost equilibrium and exhibited weak opercular motion. Tags were surgically implanted into the abdominal cavity using a small incision on the mid-ventral line, which was closed using two monofilament sutures (Wagner et al. 2011). Fish recovered in a dark cooler monitored for temperature and oxygen, and released when active and upright.

Two telemetry gates (VR2W-69 kHz coded acoustic receivers; Vemco, Bedford, Nova Scotia) were installed at the eastern and western boundaries of the study area in June 2015: one at the Jones Creek confluence[2] (six receivers) and one at the boundary of the reservoir and the Middle Bridge River (four receivers; Figure 2-2). The telemetry gates separate the distance between the Lajoie and Terzaghi Dams into three sections:

1. **Carpenter Reservoir East**: From the Terzaghi Dam to the reservoir acoustic gate at the Jones Creek confluence (17.5 km)
2. **Carpenter Reservoir West** (i.e., the mark-recapture study area): From the reservoir acoustic gate at the Jones Creek confluence to the Middle Bridge River gate (31 km)
3. **Middle Bridge River**: From the Middle Bridge River gate to the Lajoie Dam (4.5 km, not including habitat in the Hurley River)

Reservoir receivers were suspended in the water column and marked with floats that became submerged as pool elevation increased, while receivers in the Middle Bridge River were attached directly to bottom anchors (Figure 2-3). The Middle Bridge River acoustic receivers were recovered in November 2016; however, reservoir receivers will not be recovered until 2017, when the reservoir drafts sufficiently to access submerged floats. Due to the timing of receiver recovery, acoustic data from Year 3 will be analyzed in the current Year 4 annual report and acoustic data collected in Year 4 data will be analyzed in the Year 5 annual report.

Acoustic receivers record the tag number and the time of detection but cannot determine signal strength, distance, depth, or direction of travel. To obtain direction of travel, each acoustic gate was composed of two lines of receivers. If a Bull Trout was detected by one line of receivers followed by a second line of receivers, the starting location, ending location, and direction of movement through the gate could be determined. Each receiver can detect tag transmissions within a limited area (i.e., detection range), and the number and spacing of receivers in each line determines how effectively the gate can detect a tag that moves from one side to the other (i.e., detection efficiency). Detection efficiency can also be affected by environmental conditions including temperature, turbidity, suspended solids, depth changes, vegetation growth, flow, and biofouling (Kessel et al. 2014).

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[2] The reservoir gate was moved 1 km east in June 2016 to reduce detection of tags holding at Marshall Creek.

The reservoir gate was positioned to maintain an 80% minimum detection range based on range testing performed in June 2015 (BRGMON-04 Year 3 Summary Report, Putt et al 2016b). Range testing in the Middle Bridge River indicated that detection range was lower in the river relative to the reservoir (~5% at 60 m from the test tag, or the full width of the river). Two additional receivers were installed in the river in Year 4; however, further range testing indicated the additional receivers failed to increase detection range to a minimum standard of 80% across the width of the river. Detection range was ~10% at 25 m to 50 m from the test tag and declined to zero at 60 m to 80 m from the test tag.

Acoustic detections were summarized as 'events' to condense the large volume of acoustic data. We defined an event as the period during which a Bull Trout was detected consistently by a gate, followed by a period with no detections. Several different time periods were tested to define events, and 24 hours was chosen as a biologically realistic and computationally practical definition (i.e., if a Bull Trout was not detected for 24 hours or longer, the next detection would be considered the beginning of a new event). The length of the time period between events helps to condense detection data but does not substantially affect detection efficiency of the gates. Events included the one-way movement of Bull Trout across gates (crossing events), or movements towards and away from gates without crossing (vicinity events). The initial and final detections in each event were used to determine the starting and ending location of each tagged fish. Events were summarized to describe the movement and position of individual Bull Trout as well as the proportion of Bull Trout in each study area at different time periods.

Despite receiver overlap, the acoustic gates were not 100% successful at detecting crossing events. Missed crossing events were identifiable when a tag appeared on the other side of a gate without a crossing event being detected. We calculated the number of successful crossing events relative to the number of missed crossing events to determine the detection efficiency of the acoustic system. Detection efficiency was calculated for both the river and reservoir gates during full (February to June) and low pool (July to January) conditions. The detection efficiency of the last event cannot be determined until the fish is detected by another gate, and the final position of each tag is inherently uncertain.

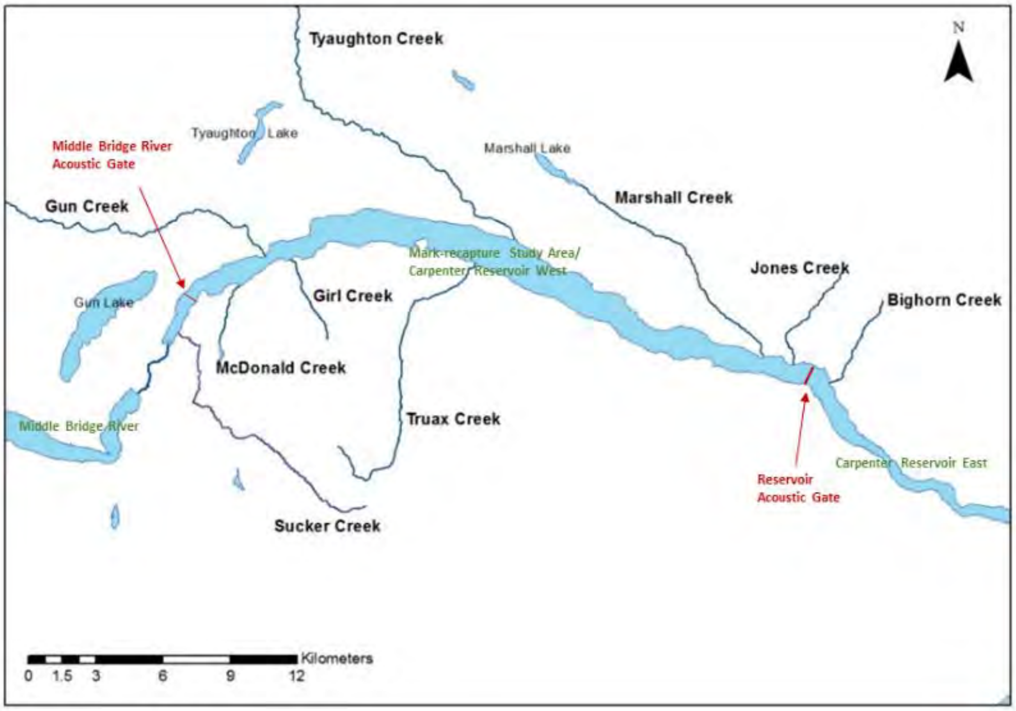

Figure 2-2 Carpenter Reservoir tributaries and the locations of acoustic telemetry gates bounding the mark-recapture study area.

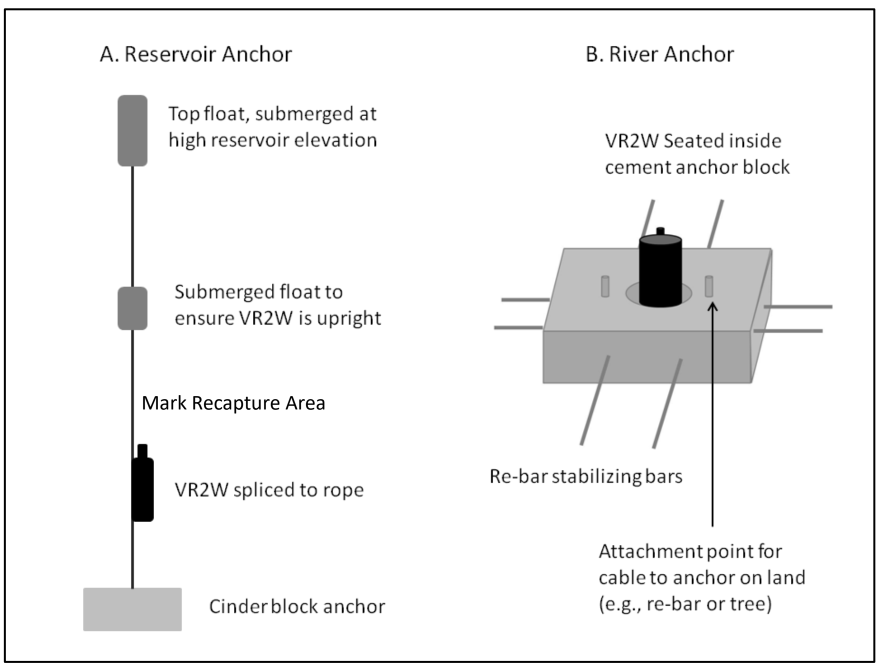

Figure 2-3 Anchor systems for receivers in Carpenter Reservoir (A) and the Middle Bridge River (B)

2.3.2 Mark-Recapture

An intensive period of Bull Trout marking and recapture occurred between July 18 and August 12, 2016. Multiple capture methods were used to target all habitat types and allow the abundance estimate to be applied to the entire mark-recapture study area. A combination of angling at creek mouths (~16 days[3]), shoreline overnight electrofishing (2 days), and shoreline and pelagic short-set gill netting (~3 days; 9.17 hours total soak time) was used to mark and recapture Bull Trout. All Bull Trout were PIT tagged and released at their capture location, and lengths, weights, and age structures (pectoral fins) were collected. Biological data and age structures were also collected from by-catch species (Rainbow Trout, Mountain Whitefish, and kokanee) to calculate CPUE and build on existing length, weight, and age databases. Environmental data were recorded whenever possible (i.e., water temperature, water visibility, weather, sample duration, location coordinates), and method-specific characteristics were recorded for gill netting (i.e., net type, net depth, habitat type sampled, soak time) and electrofishing (i.e., site length, site depth, time spent electroshocking).

2.3.2.1 Mark-Recapture Modelling

POPAN model

The POPAN formulation of the Jolly-Seber open population mark-recapture model was used to estimate annual Bull Trout abundance in the upper portion of Carpenter Reservoir (Seber 1982, Pollock et al. 1990, Schwarz and Arnason 1996). The model has four major assumptions that are applicable to BRGMON-04 (Table 2-1; common to most open mark-recapture models). The POPAN model estimates the apparent survival (φ) and capture probability (p) of both marked and unmarked fish, allowing the total abundance to be estimated. Simpler formulations of the Jolly-Seber model, such as the Cormack Jolly-Seber method (CJS), only model marked animals and therefore do not directly estimate total abundance. In addition to survival and capture probability, the POPAN formulation estimates a super population (*N*) containing all fish ever entering a population, and the probability of entrance (PENT) into the population (*b*; Table 2-2). In an open model, the survival parameter is often referred to as "apparent survival" as it includes both mortality and emigration (Schwarz and Arnason 1996). Similarly, the probability of entrance accounts for individuals that are recruiting from the population as well as new immigrants to the study area.

A three-part multinomial likelihood function (covering all capture histories) is used to estimate the parameters in Table 2-2 (Schwarz and Arnason 1996):

$$L = P(first\ capture|\{p_i\},\{\varphi_i\}\{b_i\})\ \cdot P(recapture|\{p_i\},\{\varphi_i\})\cdot\ P(loss\ on\ capture|\{v_i\}) \qquad \text{Eq 2}$$

The likelihood function (Eq 2) includes the probability that a fish enters from the super population (*N*) and is captured during a sampling event (*first capture*), the probability of recapture in subsequent sampling events (*recapture*), and the probability that the fish dies during a capture event (*loss on capture*). The model can be time-dependent (i.e., unique parameters are estimated for each sampling

[3] A day unit in this case represents one day (8 hrs) of effort by one field crew. For example, if two crews were angling for 8 hours at separate locations, this would be considered two days of effort.

event) or parameters can be fixed across time periods. Not all parameters are identifiable in models with time varying survival because of parameter confounding (e.g., the survival and catchability from the final event cannot be distinguished; for more information on parameter identifiability see Schwarz and Arnason 1996).

The POPAN formulation does not directly estimate N_i (annual abundance) or B_i (annual births); however, these parameters can be derived using parameters estimated in Table 2-2 and Equations 3, 4 and 5:

$$N_1 = b_0 * N \qquad \text{Eq 3}$$

$$B_{i=2,3,\ldots K} = b_{i-1} * N \qquad \text{Eq 4}$$

$$N_{i=2,3,\ldots K} = N_{i-1} * \varphi_{i-1} + B_i \qquad \text{Eq 5}$$

Mark-recapture models were evaluated in R Project Software using the packages RMark (Laake 2013), which provides an interface between R and the mark-recapture software MARK (White and Burnham 1999), and marked (Laake et al 2013). AICc model selection (adjusted for small sample sizes) was used to evaluate candidate models that included both fixed and time-varying survival (φ), capture probability (p), and entrance probability (b).

$$AIC_c = 2k + 2\ln(\hat{L}) + \frac{2k(k+1)}{n-k-1} \qquad \text{Eq 6}$$

where k is the number of parameters in the model, n is the number of observations, and $\hat{L}$ is the likelihood for the candidate mark-recapture model. The model with the lowest AICc value was selected as the preferred model of the set. More information on AICc in MARK can be found in White and Burnham (1999) and Cooch and White (2006).

Three mark-recapture events are required to model open-mark recapture data, and to generate abundance estimates we included Bull Trout tagging data from Years 1 and 2 in the models. Location, gear type, and capture date were recorded in Years 1 and 2 (prior to the implementation of the mark-recapture program), which allowed us to compile tagging data that closely matched the mark recapture program in Years 3 and 4; however, including data from Years 1 and 2 may violate the assumption of equal capture probability and bias estimates of abundance. The mark-recapture program was designed in Year 3 to distribute gear types and effort throughout the study area and to concentrate effort over a two-week period. Effort was not recorded in Years 1 and 2 and the only method of capture was angling, which may bias capture probabilities in Years 1 and 2. In addition, the mark-recapture program consists of concentrated marking and recapture periods, while in Years 1 and 2 angling took place sporadically throughout the summer; only fish whose tagging dates overlapped with mark-recapture periods in Years 3 and 4 were selected during modeling. The effect of including Years 1 and 2 will be evaluated in Year 5, after three years of designated mark-recapture data have been collected.

We used parametric bootstrapping to examine the goodness-of-fit of POPAN models using a simulation estimation procedure:

1. POPAN mark-recapture parameters were estimated for candidate models using RMark (Laake 2013) and AICc model selection.

2. Parameters from the top two models were used to simulate 100 mark-recapture datasets using simulation methods developed by Laake (2016).
3. POPAN model parameters were estimated for each of the 100 simulated datasets using the same parameter specifications as the original estimation (i.e., fixed or time-varying conditions were consistent between simulation and estimation).
4. Estimated parameters were compared to true parameters to assess goodness-of-fit.

Goodness-of-fit was considered high if the true parameter fell within the range of estimated parameters. If the true parameter lay outside of the 95% confidence interval for the simulation-estimation, the probability of observing the original mark-recapture data was low given the true parameters. We determined bias of simulated parameter estimates relative to the best fit parameter using the equation:

$$relative\ bias\ (\%) = 100 * \frac{\sum_{i=1}^{n} |\hat{x}_i - x|}{n} \qquad \text{Eq 7}$$

where $\hat{x_\iota}$ is the parameter estimate for the ith simulation and x is the true estimated parameter from the data. A lack of fit can signify incorrect model specification or violations to model assumptions, and the goodness-of-fit characteristics can indicate what data characteristic may be responsible for the lack of model fit.

Cormack Jolly-Seber Model

We fit the Cormack Jolly-Seber model (CJS) to the Bull Trout open mark-recapture data to compare the estimates of survival and catchability between the two formulations (CJS model equations are described in Cormack 1964). Survival and catchability are modelled in the same way in the POPAN and CJS models, and the behaviour of the CJS model parameters may help to interpret model fitting issues of the more complex POPAN model. The CJS model estimates survival and capture probability for only marked fish, and does not estimate annual abundance. CJS model fitting and goodness-of-fit testing was performed in R using the packages RMark (Laake 2013) and marked (Laake et al. 2013).

Table 2-1 Assumptions of the Jolly-Seber open mark-recapture model.

Assumption	Applicability to BRGMON-4 Bull Trout Mark Recapture
Each animal in the population at the time of the *i*th sample has equal capture probability (p_i)	This assumption can be violated if only certain age classes or habitats are sampled, if animals do not evenly distribute during the sampling period, or if animals immigrate or emigrate from the study area during the mark-recapture period. To minimize the risk of violating this assumption, multiple capture methods were distributed as evenly as possible throughout the mark-recapture period to target as many habitat areas and size classes of Bull Trout as possible. Acoustic telemetry data will be used to quantify immigration and emigration during the mark-recapture period.
Each marked animal present following the *i*th sampling event has equal survival probability (ϕ_i) until the ($i+1$)th sampling event	Marks were only applied to healthy individuals and all individuals were held until completely recovered to eliminate capture-related mortality. Proper handling techniques for all capture methods were used by field staff during the mark-recapture program.
Marks are not lost or missed	All fish were scanned with a PIT reader and examined for other signs of handling (e.g., fin ray scar, gill net scar, etc.). All PIT tags were inserted carefully following standard protocols to reduce tag loss from improper insertion. PIT tag loss rates can be <5% (e.g., Ombredane et al. 1998) when inserted properly.
All samples are instantaneous	To be considered instantaneous, the duration of the sampling period should be <10% of the interval between sampling periods (Lebreton et al. 1992). The 25-day mark recapture program in Year 4 was 7% of the interval between the previous sampling period.

Table 2-2 Estimated parameters in the POPAN formulation of the Jolly-Seber model.

p_i	The probability a fish is captured in event *i*
φi	The probability a fish survives between event *i* and *i*+1
N	The super population from which all fish ever caught are contained within
b_i	The probability that a fish enters the population from *N* between sample event *i* and *i*+1 and survive to event *i*+1
v_i	The probability that a fish will be released

2.4 Analysis of Biological Data

Species-specific length, weight, and age data were used to describe biological characteristics of Carpenter Reservoir Bull Trout, Rainbow Trout, Mountain Whitefish, and kokanee. Biological data will be used to describe the characteristics of species in the reservoir and determine whether these characteristics change over the course of the monitoring period.

2.4.1 Ageing Analysis

Ageing structures were collected from Bull Trout, Rainbow Trout, kokanee, Mountain Whitefish, and Redside Shiners. Scales were collected from Rainbow Trout, kokanee, and Mountain Whitefish above the lateral line and immediately below the dorsal fin. Scales were mounted on glass slides and read under magnification by two independent analysts to determine fish age (Zymonas and McMahon 2009). Fin rays were sampled from Bull Trout (the first 2-3 rays from the left pectoral or pelvic fin) and a random subset (n = 74) covering all fork lengths was aged by North South Consultants (Winnipeg, Manitoba).

Otoliths (a calcified structure located in the brain cavity of the fish) were collected opportunistically from accidental mortalities. Otoliths are often considered a more accurate method of fish ageing, and can help verify scale and fin ages. All otoliths were examined under magnification by two independent analysts to identify growth annuli and estimate age (Zymonas and McMahon 2009).

2.4.2 Length vs Weight and Body Condition

Length and weight are generally highly correlated for species within a particular system, and the relationship can be used to monitor gross changes in fish health and growth. Log-linear regression modeling was used to describe the annual length (L) vs weight (W) relationships for each species (Ogle 2016a):

$$W_i = \alpha L_i^{\beta} 10^{\epsilon_i} \quad \text{Eq 8}$$

$$\log(W_i) = \log(\alpha) + \beta \log(L_i) + \epsilon_i \quad \text{Eq 9}$$

where α and β are intercept and slope parameters, and ε is multiplicative model error.

Fulton's Condition Factor (K_F) was also calculated to describe the annual body condition of fish in Carpenter Reservoir (Anderson and Neumann 1996).

$$K_F = \frac{W * 10^N}{L^3} \quad \text{Eq 10}$$

where *W* is weight in grams, *L* is length in millimeters, and *N* is an integer that scales the condition factor close to a value of one (*N*=5 for Carpenter Reservoir salmonids).

2.4.3 Von Bertalanffy Growth Model

Paired lengths and ages were used to fit von Bertalanffy growth functions for Rainbow Trout, Mountain Whitefish, and Bull Trout (von Bertalanffy 1938). Note that there were not enough age classes to fit the von Bertalanffy model to kokanee. Sufficient data was not available to produce annual growth models, and data were pooled from all study years for von Bertalanffy model fitting. The von Bertalanffy growth model is defined by the nonlinear model equation:

$$L_t = L_\infty\left[1 - \exp\left(-K(age - t_0)\right)\right] + \varepsilon \quad \text{Eq 11}$$

where L_t is length-at-age at time t, L_∞ is the asymptotic length, K is a growth coefficient, t_0 is the time at which length is theoretically zero, and ε is the residual error. The growth model was fit iteratively for the parameters L_∞, K, and t_0 using a minimum sums of squares optimization in the statistical environment R (R Development Core Team 2015).

2.4.4 Age-Length Keys

Age-length keys (ALKs) were developed for Bull Trout, Rainbow Trout, and Mountain Whitefish in Carpenter Reservoir to allow age estimation for all fish captured. An ALK is a probability matrix specific to a population that determines the probability that a fish from each length class is part of each age class and vice versa (Guy and Brown 2007; Ogle 2016a). These probabilities are used to develop theoretical proportions of fish from each length class that should be assigned to each age class, and are used to estimate ages for unaged fish in a population (Isermann and Knight 2005). ALK analysis was performed using ages pooled from all years in the Fisheries Stock Assessment (FSA) package in R (Ogle 2016b).

2.5 Reservoir Tributaries and Middle Bridge River Spawner Assessments

2.5.1 Tributary Visual Surveys

Visual surveys of kokanee spawning were conducted in Carpenter Reservoir tributaries to estimate migration timing and duration and determine peak spawning dates for each tributary. Visual surveys took place in Girl Creek, Jones Creek, McDonald Creek, Marshall Creek, Sucker Creek, Truax Creek, and the Middle Bridge River (Figure 2-2). The tributaries surveyed were all tributaries accessible by vehicle and for which turbidity was low enough to allow for fish observation. The survey length in each tributary extended form the confluence to the most upstream accessible location (i.e., before upstream passage was too difficult for surveyors). The visual survey length below the drawdown boundary was variable in each tributary as reservoir elevation increased, while the survey lengths above the drawdown zone remained consistent and ranged from ~50 m to 140 m. The Middle Bridge River was too turbid to obtain kokanee counts but spawners were observed rolling near the water surface, which confirmed their presence.

All tributaries (apart from the Middle Bridge River) measured less than 5 m across and crews surveyed the full wetted width from one bank. Two observers walked each tributary in a downstream direction, surveying a consistent stream length each week. Observers recorded the number of adult kokanee, number of redds, weather conditions (temperature and percent cloud cover), water clarity (good, moderate, or poor), discharge level (high, moderate, low, dry), and the presence of additional species. Kokanee counts were separated into fish observed within the reservoir drawdown zone (potentially spawning in areas at risk of flooding) and fish observed above the drawdown zone (unlikely to be affected by flooding). Surveys began prior to the estimated start of spawning and continued weekly until no fish were observed. Spawner counts were examined for individual tributaries and across all tributaries for each survey to examine broader spawn timings and overall spawner indices for Carpenter Reservoir kokanee.

2.5.2 Rainbow Trout Tributary Electroshocking

Monthly backpack electroshocking surveys were used to determine whether Rainbow Trout spawning occurred in tributaries of Carpenter Reservoir (Marshall Creek, McDonald Creek, and Truax Creek[4]; within and above the drawdown zone) or whether seeding occurred from upstream lakes (i.e., Marshall and McDonald Lakes, Figure 2-2). Tributary electroshocking was used to assess spawning because adult spawner surveys were unsuccessful at determining successful spawning locations in reservoir tributaries. Successful spawning was defined as the presence of multiple life stages, beginning with emerging fry (age 0) and progressing to age 1 and 2 parr. Observing parr alone would suggest fry emerged further upstream or elsewhere and seeded downstream areas.

Each month, two 50 m lengths of stream were electroshocked in each tributary, one above and one below the drawdown zone elevation. In Marshall Creek, the drawdown zone was bounded by a large waterfall that restricted upstream fish passage, and the above-drawdown site was located upstream of the waterfall. Surveyors walked the 50-m length in an upstream direction, sampling the entire width of the stream and collecting all species. When upstream passage was restricted (e.g., by debris), the sampling was suspended and moved upstream where access could be re-established. When reservoir elevations increased and within-drawdown stream length were less than 50 m, the full drawdown zone was sampled and survey length was recorded.

All fish were anaesthetized, weighed, and measured. Rainbow Trout, Bull Trout, and kokanee with fork length >75 mm and <150 mm were implanted with a PIT tag in the ventral stomach cavity, while fish with fork length >150 mm were PIT tagged in the dorsal musculature. To determine monthly juvenile growth rates, scale samples were collected from all Rainbow Trout, Mountain Whitefish, kokanee, and juvenile Bull Trout, and fin rays were collected from adult Bull Trout.

3 Results

3.1 Physical Conditions in Carpenter Reservoir and the Middle Bridge River

Carpenter Reservoir elevation was compiled from 2010 to 2016 to examine the annual variation in reservoir operations. From 2010 to 2016, Carpenter Reservoir typically attained a maximum elevation in September and drafted at a slow, steady rate to a minimum level in April (Figure 3-1). Historic minimum elevation varied by approximately 20 m, while the range in maximum elevation was approximately 10 m (Figure 3-1). In 2016, the minimum Carpenter Reservoir elevation was <635 m, the highest minimum elevation since 2010 (Figure 3-1). High minimum elevation was the result of an abnormally early freshet combined with a reduction in reservoir storage capacity in Downton Reservoir. This was followed by a below-average inflow from the Middle Bridge River that kept reservoir levels relatively low throughout the summer. Discharge from Lajoie and Terzaghi Dams in 2016 are shown in Figure 3-2 and Figure 3-3, respectively. Flow release from Terzaghi Dam reached a maximum of almost 100 cms in 2016, while in 2015 the maximum flow release was < 25 cms (not shown).

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[4] Jones Creek was initially included as the fourth tributary but was removed due to heavy scouring from winter debris flows that removed spawning substrate.

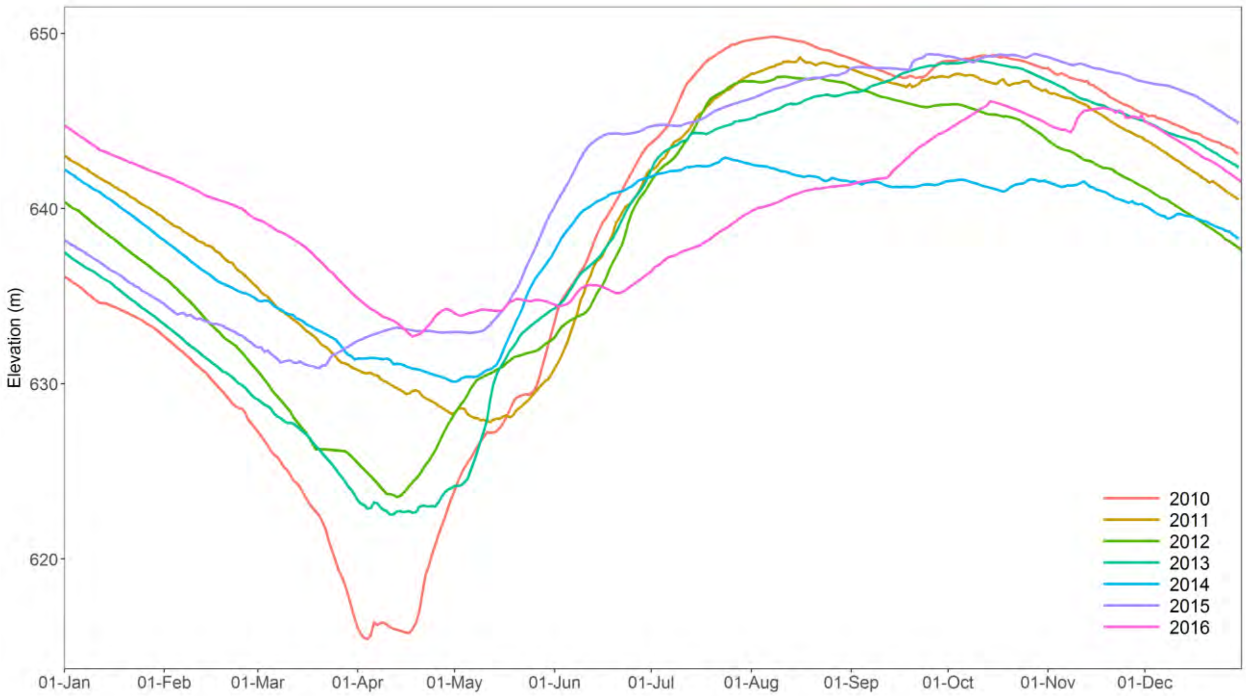

Figure 3-1 Carpenter Reservoir elevation from 2010 to 2016.

Figure 3-2 Flow release (cms) from Lajoie Dam in 2016.

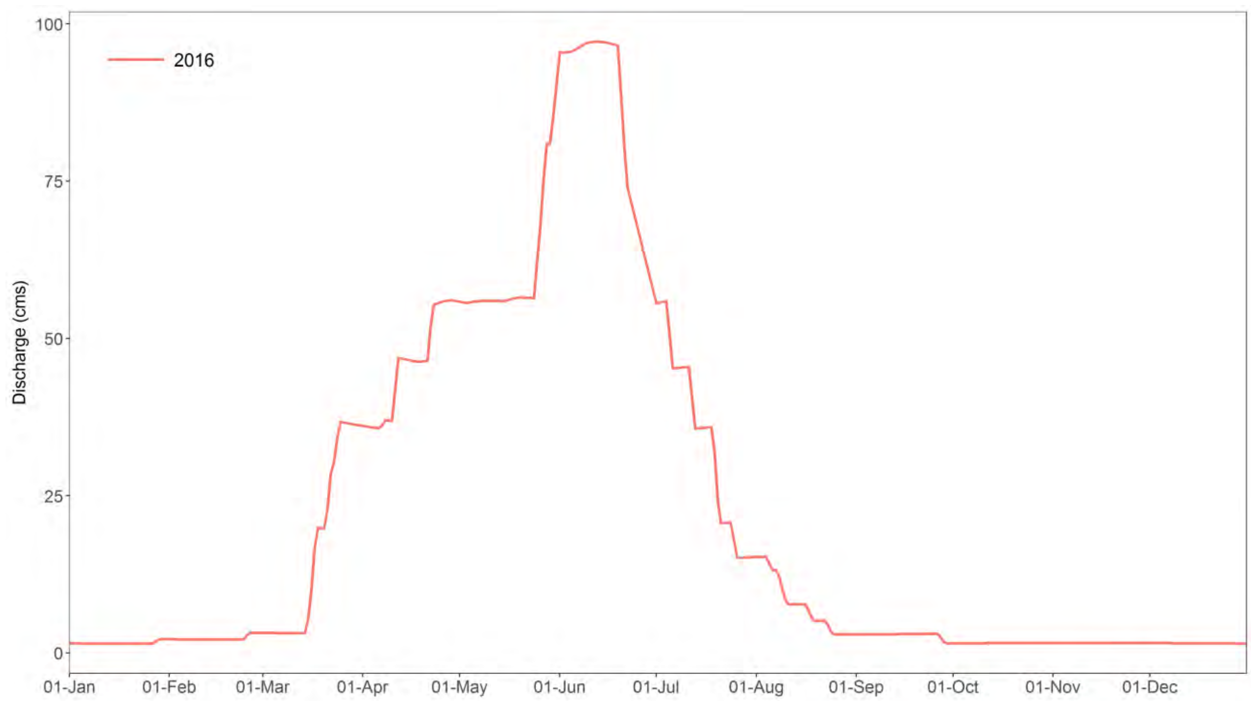

Figure 3-3 Flow release (cms) from Terzaghi Dam in 2016.

3.2 Short-Set Gill Netting

Pilot short-set gill netting was conducted in four habitat zones at full pool and low pool to identify species distribution and critical habitat. Gill netting took place April 26 to 28 and September 20 to 23, 2016[5] when reservoir elevations were 634 m (low pool) and 643 m (full pool), respectively. We were not able to reach the proposed goal of 200 minutes (3.3 hours) of gill netting per site; however, the total effort in each habitat area was relatively consistent within sampling periods (Table 3-1). Mean CPUE was calculated by habitat type and reservoir elevation (Figure 3-4); however, statistical comparisons between CPUE were not calculated due to small sample sizes, and preferred habitat areas could not be determined because of low catch rates.

Littoral habitats generally had higher CPUE values than pelagic habitats, and CPUE was higher during low-pool surveys (Figure 3-4). CPUE for all species was relatively low for surface and mid-water sets (relative to littoral sets), with only small catches of Redside Shiner (adults age 2 and 3) and Bull Trout in surface sets. CPUE of Redside Shiners generally increased from east to west, while Bridgelip Sucker CPUE decreased from east to west (Figure 3-4). Mountain Whitefish CPUEs were highest in littoral areas, particularly at low pool conditions when habitat area was restricted (Figure 3-4).

[5] The Western Reservoir Littoral habitat was dewatered in April and thus was not sampled during the low pool sampling period.

Table 3-1 Number of sets and total effort (h) for pilot short-set gill netting.

Gill Net Zone	Low Pool Number of Sets	Total Effort (h)	Full Pool Number of Sets	Total Effort (h)
Eastern Reservoir Littoral	6	2.79	9	3.58
Western Reservoir Littoral	NA	NA	8	3.18
Mid Reservoir Pelagic	6	2.58	7	3.10
Eastern Reservoir Pelagic	6	2.28	5	2.00[6]

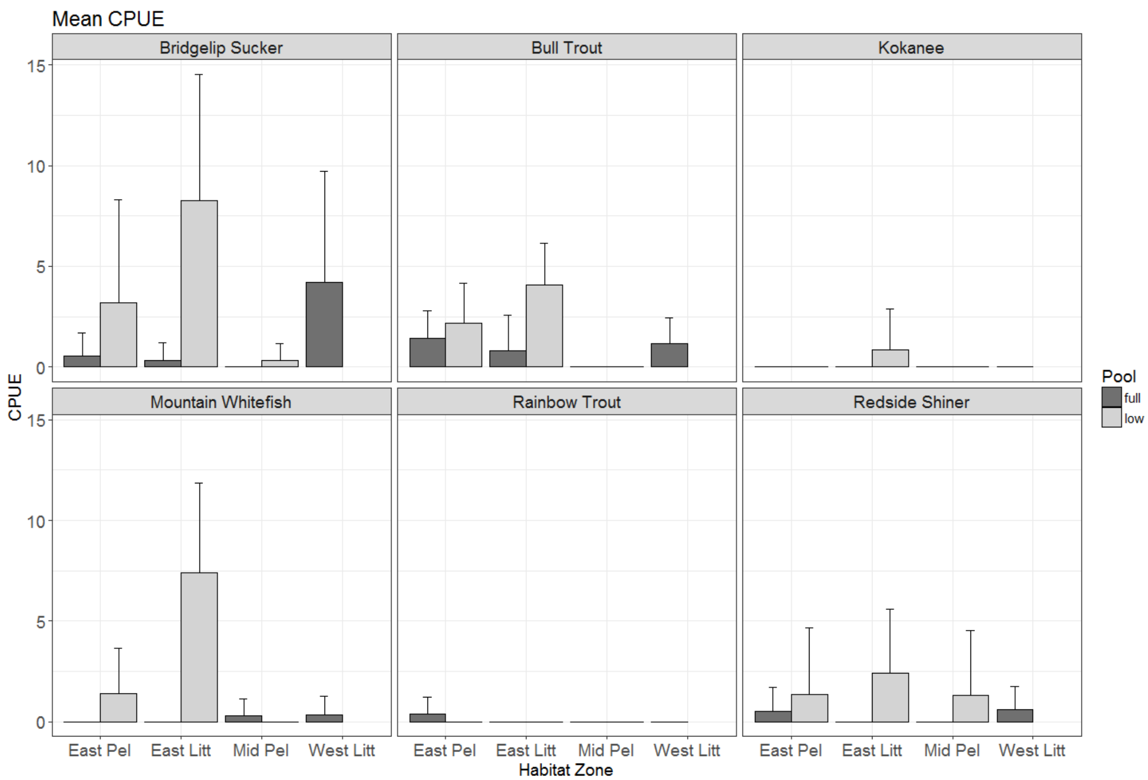

Figure 3-4 Mean short-set gill net CPUEs in Carpenter Reservoir at full pool and low pool conditions. The Western Littoral habitat was dewatered and not sampled at low pool conditions.

3.3 Bull Trout Abundance Estimation and Movement Analysis

3.3.1 Movement Analysis

Acoustic telemetry was used in Carpenter Reservoir to monitor Bull Trout movement and determine whether Bull Trout immigrated or emigrated from the mark-recapture study area during the mark-recapture period. In June of Year 3 (2015), 20 Bull Trout were tagged with acoustic transmitters at the Marshall, Gun, and Truax Creek outflows (mean fork length 446.6 mm, SD 38 mm, range 400 mm to 519 mm). Tagging was repeated in June of Year 4 (2016), and an additional 18 Bull Trout were tagged at the

[6] Surveys were shortened due to unsafe boating conditions on the reservoir.

three creek mouths (mean fork length 436 mm, SD 46 mm, range 363 mm to 520 mm). Due to the timing of receiver recovery and downloading, the analysis herein contains acoustic data from Year 3 (June to September 2015) and the winter of Year 4 (January to April 2016) and refers only to Bull Trout tagged in Year 3 (2015). Of the 20 Bull Trout tagged in Year 3, 16 (80%) were detected by an acoustic receiver between June 2015 and April 2016. The four tags that were not detected in Year 3 either remained within the area they were tagged in (i.e., the mark recapture zone) or were deceased. These two states cannot be separated so we did not include these tags in the movement analysis.

The open mark-recapture period in Year 3 occurred from June 30 to August 12, 2015 (shown as the red rectangle in Figure 3-5, Figure 3-6, and Figure 3-7). During the mark recapture period, 8 (50%) of the 16 tagged Bull Trout detected in Year 3 remained within the mark-recapture zone (MRZ) for the entire survey duration (Figure 3-5, Figure 3-6, and Figure 3-7). The other 8 Bull Trout were detected by the acoustic telemetry gates during the mark-recapture period (Figure 3-5, Figure 3-6, and Figure 3-7):

- Two Bull Trout moved out of the MRZ and into the eastern portion of the reservoir (one returned to the MRZ during the mark-recapture period while the second did not return until August 14, 2015)
- Five Bull Trout moved out of the MRZ and into the Middle Bridge River
- One Bull Trout moved into the MRZ from the eastern portion of the reservoir

The five Bull Trout that moved out of the MRZ and into the Middle Bridge River (i.e., east to west) during the Year 3 mark recapture period (31% of the 16 total tags) were likely migrating towards the Middle Bridge River or western tributaries (e.g. Gun Creek) to spawn. This potential spawning migration was observed by the acoustic gates from early July to mid-November, during which 11 (69%) of the tagged Bull Trout detected in Year 3 migrated into the Middle Bridge River (i.e., crossed the Middle Bridge River acoustic gate). Of the fish that moved into the Middle Bridge River, four were detected moving back into the reservoir. The remaining Bull Trout (n=7) were not detected moving back into the reservoir, suggesting they either remained in the river (alive or dead) or their return migration was not detected by either telemetry gate.

The number of missed crossing events and the ratio of successful to missed crossing events was calculated for the reservoir and river gates (i.e., Table 3-2). Between June 2015 and April 2016, 52% of all potential events were missed (i.e., detection efficiency was 48%). Detection efficiency was lower at the river gate relative to the reservoir gate, and detection efficiency at full pool (July through January) was lower for both gates (Table 3-2).

Table 3-2 Detection efficiency of acoustic gates in Carpenter Reservoir and the Middle Bridge River (June 2015 to April 2016).

	June 2015 – April 2016	**Low Pool (Jan–Jul)**	**Full Pool (July-Dec)**
River and Reservoir Gate Combined	48%	60%	47%
River Gate	42%	-	43%
Reservoir Gate	56%	75%	52%

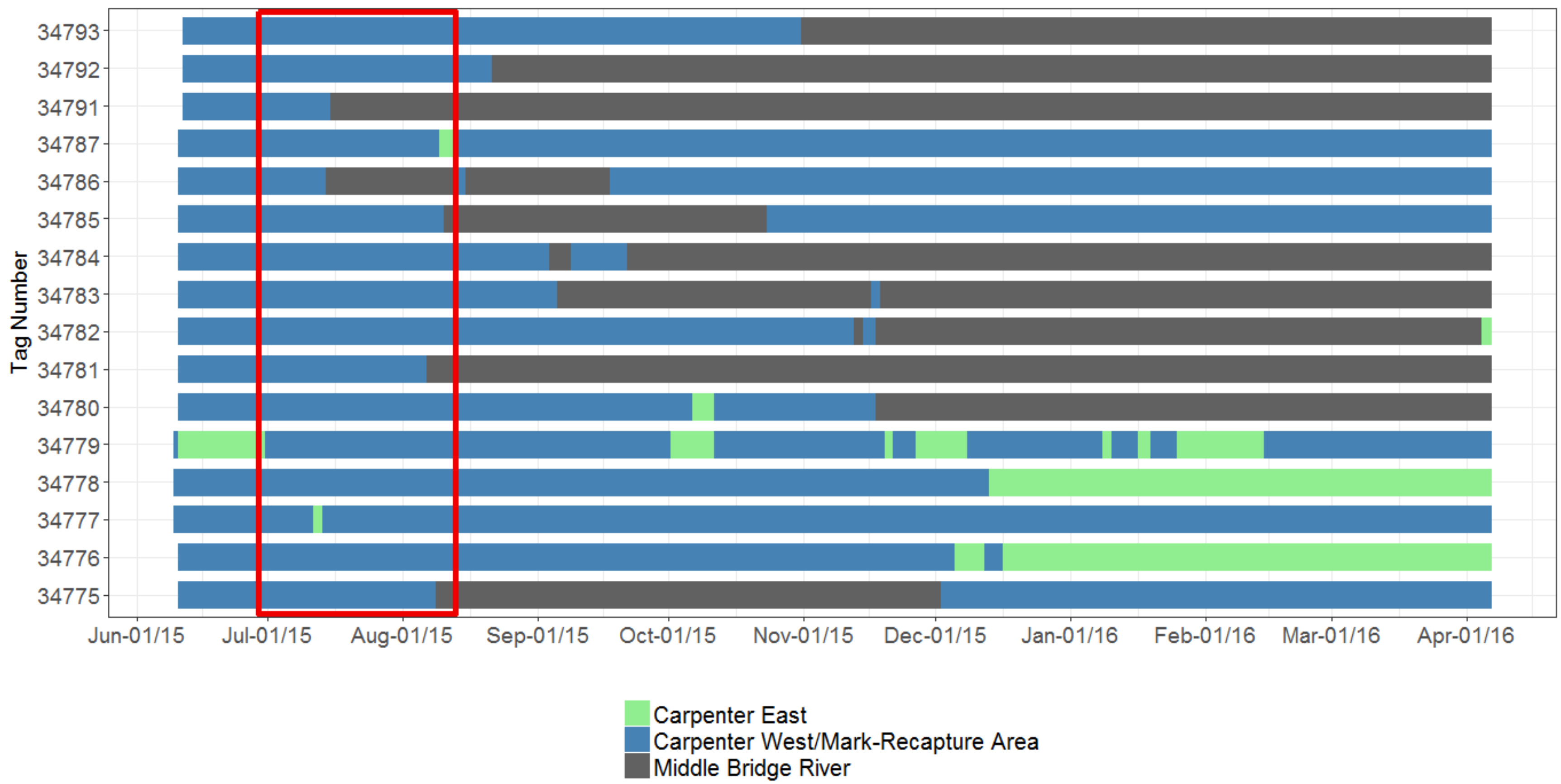

Figure 3-5 End location of acoustic-tagged Bull Trout movement events from June 2015 to April 2016 in Carpenter Reservoir and the Middle Bridge River. Coloured bars represent end location of individual events. The initial end location is the release location of tagged fish. The mark-recapture study period is shown within the red rectangle.

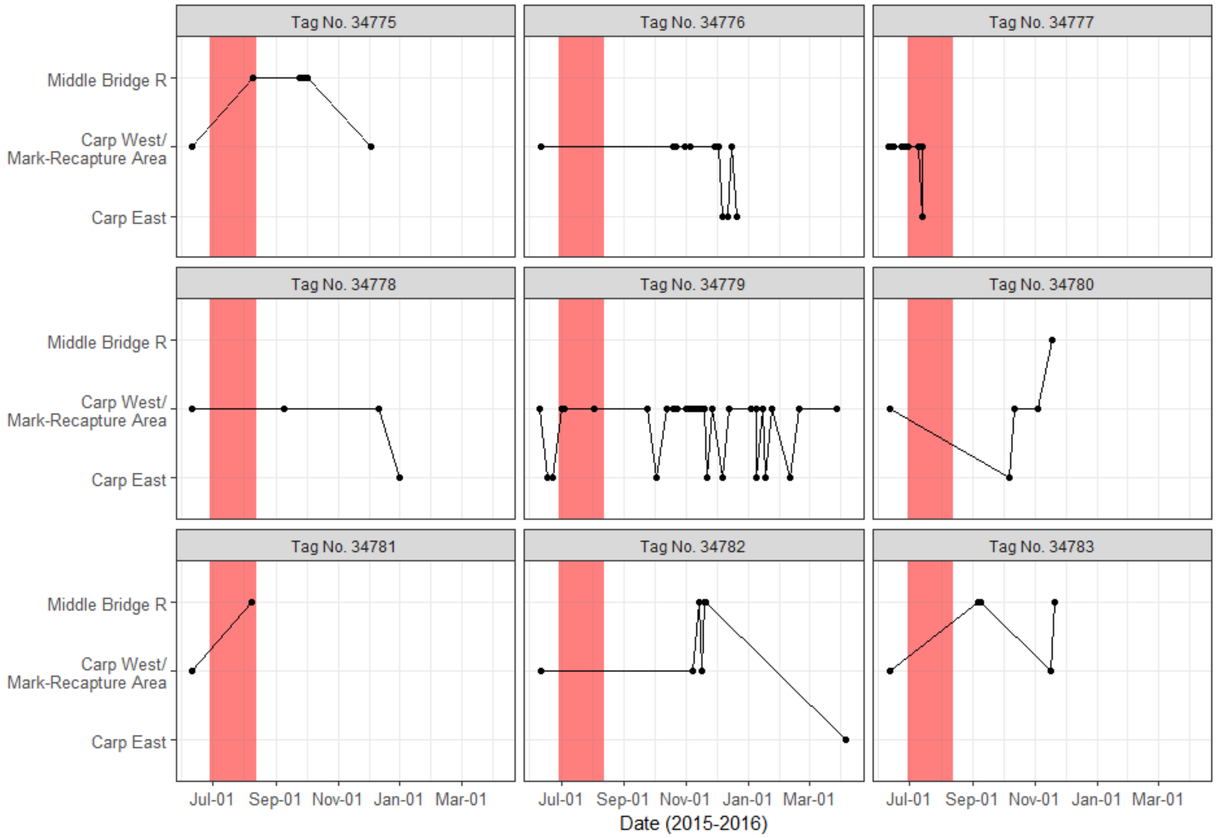

Figure 3-6 End location of individual movement events for acoustic-tagged Bull Trout in Carpenter Reservoir and the Middle Bridge River from June 2015 to April 2016. The mark-recapture period is highlighted in red. The initial end location is the release site. Connecting lines are used to connect locations visually and do not represent exact location.

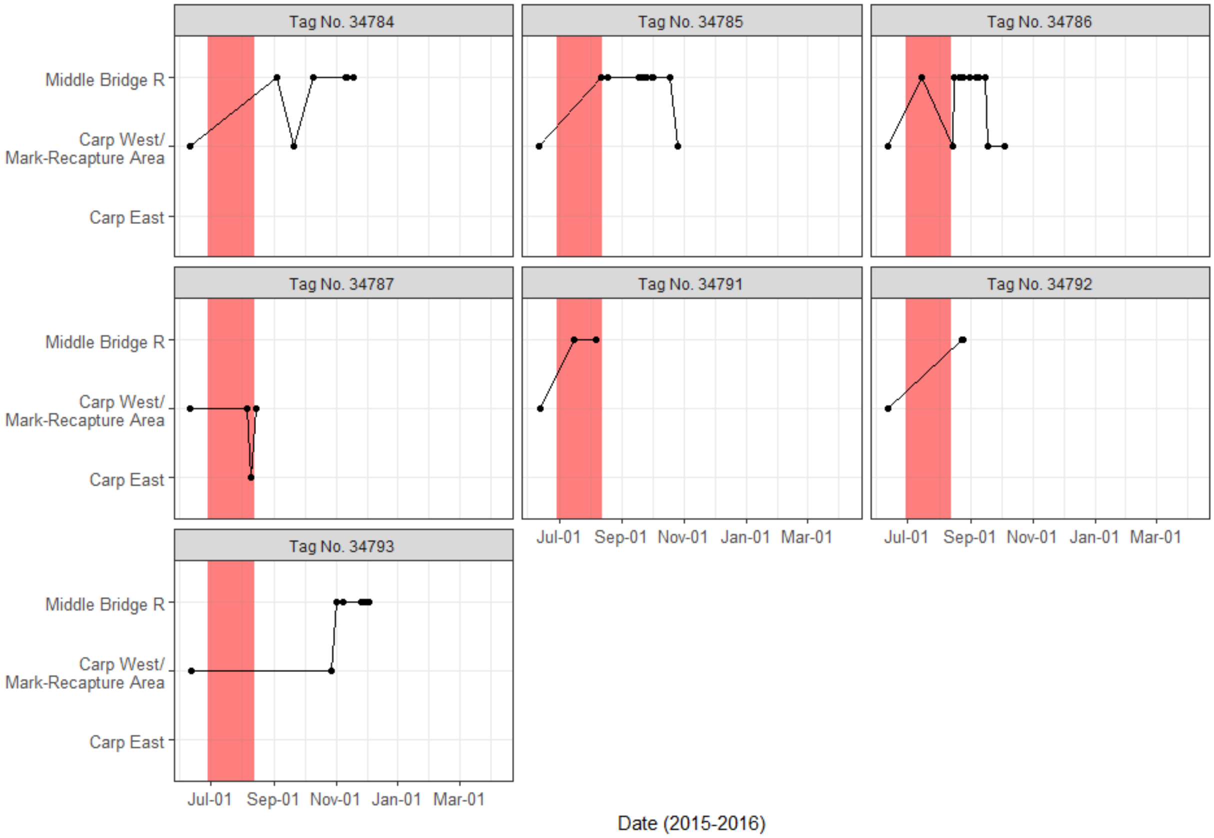

Figure 3-7 End location of individual movement events for acoustic-tagged Bull Trout in Carpenter Reservoir and the Middle Bridge River from June 2015 to April 2016. The mark-recapture period is highlighted in red. The initial end location is the release site. Connecting lines are used to connect locations visually and do not represent exact location.

3.3.2 Mark-Recapture

An open mark-recapture program was conducted in Carpenter Reservoir to estimate Bull Trout abundance within the mark-recapture study area. The Year 4 open mark-recapture period occurred over a three-week period from July 18 to August 12, 2016. A total of 125 Bull Trout were tagged during this period, 5 of which (4%) were recaptured from previous marking periods (Table 3-3). Of the 125 unique Bull Trout captured in Year 4, 12 (9.6%) were captured more than once during the Year 4 mark-recapture period (fish captured multiple times within the mark-recapture are only counted once during modelling). In comparison, 34 (13.1%) of the 260 Bull Trout captured during the Year 3 mark-recapture period were capture more than once within the Year 3 study period.

We attempted to perform the mark-recapture period at full pool in each of the study years, and therefore mark-recapture periods occurred across different time periods (Table 3-3). Full pool elevation is not consistent in the reservoir, and elevation patterns varied within and among mark-recapture periods (Figure 3-8).

Table 3-3 Mark-recapture data for Carpenter Reservoir Bull Trout in Years 1 through 4 (2013-2016).

Year	Total Number Caught	Number Recaptures	Recapture Percentage
Year 1 (Jun 19 – Aug 20)	182	-	-
Year 2 (Jun 19 – Aug 20)	49	6	12.2
Year 3 (Jun 29 – Jul 31)	260	16	6.2
Year 4 (Jul 17 – Aug 13)	125	5	4.0

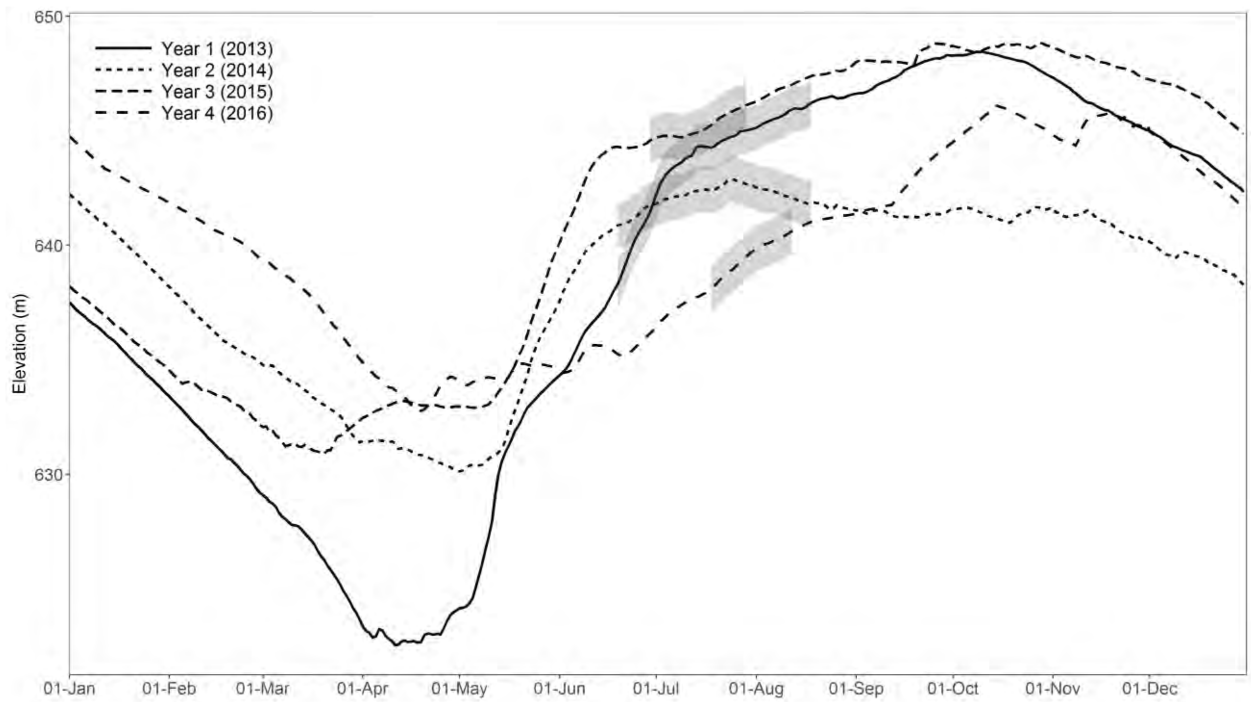

Figure 3-8 Carpenter Reservoir elevations during open mark-recapture periods (Years 1 through 4). Grey shaded bars represent the unique mark-recapture dates in each year.

CPUE was calculated for all gear types and species during the mark-recapture period (Table 3-4, Figure 3-9). Angling CPUE was zero for Mountain Whitefish and kokanee, and angling was only successful for capturing Bull Trout and Rainbow Trout (Figure 3-9). Electroshocking was an efficient method of capture for all species except Rainbow Trout, for which gill netting CPUE was highest (Figure 3-9). Bull Trout-specific CPUEs were calculated for Years 3 and 4 (Figure 3-10), and total effort was summarized by gear type and study year (Figure 3-11, effort data were not available for Years 1 and 2). Bull Trout CPUE was highest for electrofishing (Figure 3-10), but electrofishing effort was relatively low (Figure 3-11). In contrast, Bull Trout CPUE was low for angling but effort was high and angling resulted in the greatest total captures of Bull Trout (Table 3-4).

Table 3-4. Catch per unit effort (CPUE) values (fish/hour) separated by angling (an), electrofishing (ef) and gill netting (gn) for Bull Trout (bt), Rainbow Trout (rb), Mountain Whitefish (mw), and kokanee (ko) in the Carpenter Reservoir mark-recapture study area.

				Bull Trout			Rainbow Trout			Mountain Whitefish			Kokanee		
Year	**Gear**	**Effort (h)**	**No. Event**	**Count**	**Mean CPUE**	**SD CPUE**	**Count**	**Mean CPUE**	**SD CPUE**	**Count**	**Mean CPUE**	**SD CPUE**	**Count**	**Mean CPUE**	**SD CPUE**
Year 3	an	125.51	22	239	1.91	1.39	12	0.10	0.22	0	0.00	0.00	0	0.00	0.00
Year 3	ef	1.93	13	54	32.74	54.10	8	5.24	10.98	331	191.35	233.90	23	15.43	29.74
Year 3	gn	13.45	46	13	0.86	1.77	2	0.17	1.18	6	0.40	1.92	4	0.28	0.95
Year 3	all	140.89	81	306	6.26	24.03	22	0.97	4.73	337	30.94	114.84	27	2.64	12.84
Year 4	an	118.50	24	72	0.52	0.66	15	0.08	0.17	2	0.00	0.00	0	0.00	0.00
Year 4	ef	1.58	13	58	54.00	63.57	7	5.53	9.56	98	78.03	122.29	63	58.01	82.27
Year 4	gn	9.18	38	5	0.52	1.41	1	0.15	0.95	6	0.66	1.59	17	1.75	3.23
Year 4	all	129.26	75	135	10.18	33.37	23	1.11	4.51	106	14.44	58.59	80	11.40	40.44

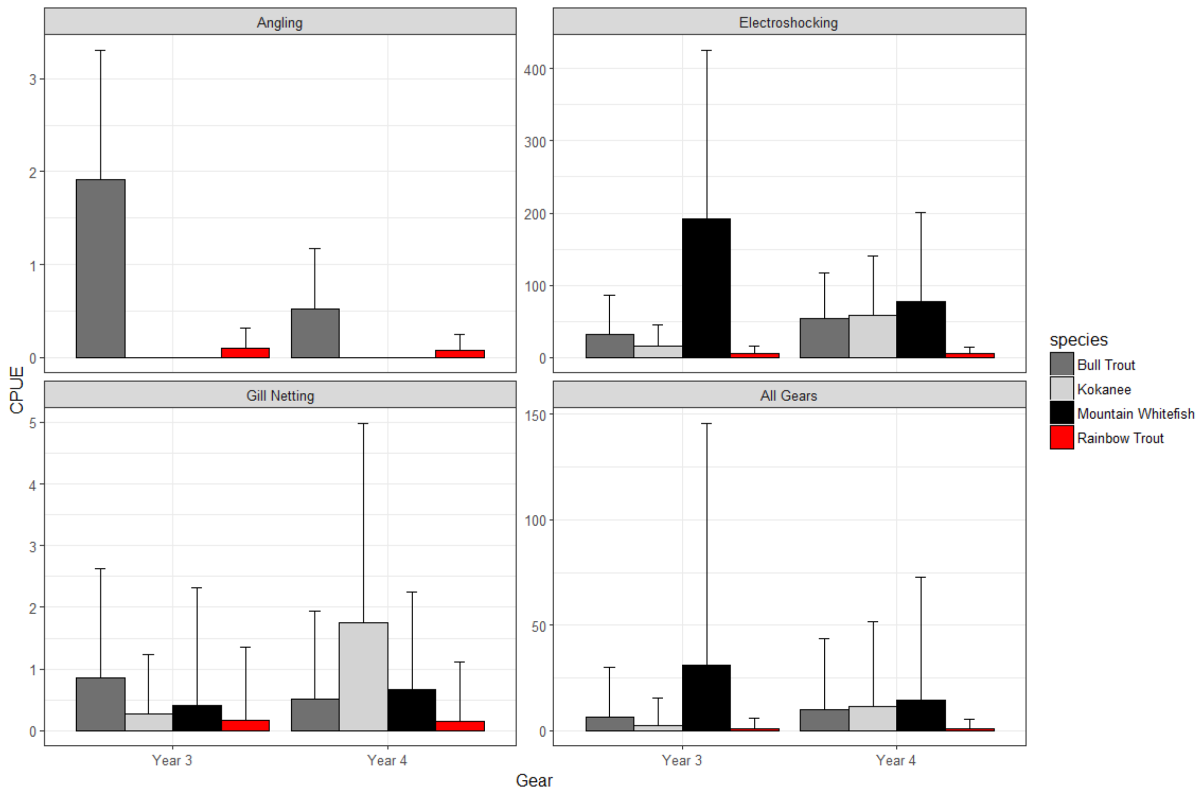

Figure 3-9 Mean CPUE by capture method during the Bull Trout mark recapture period. Y-axis scales vary by capture method and error bars represent standard deviation.

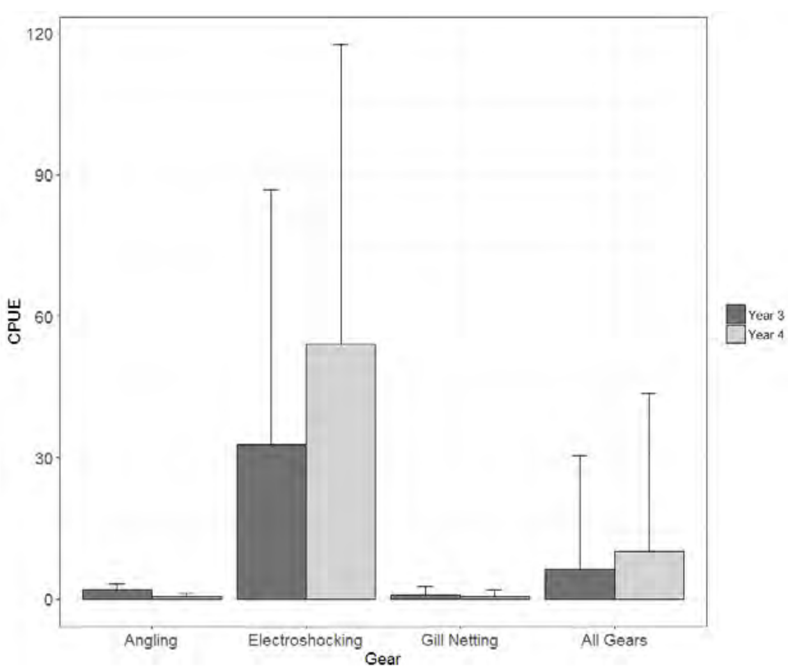

Figure 3-10 Mean Bull Trout mark-recapture CPUE for Years 3 and 4 (2015 and 2016).

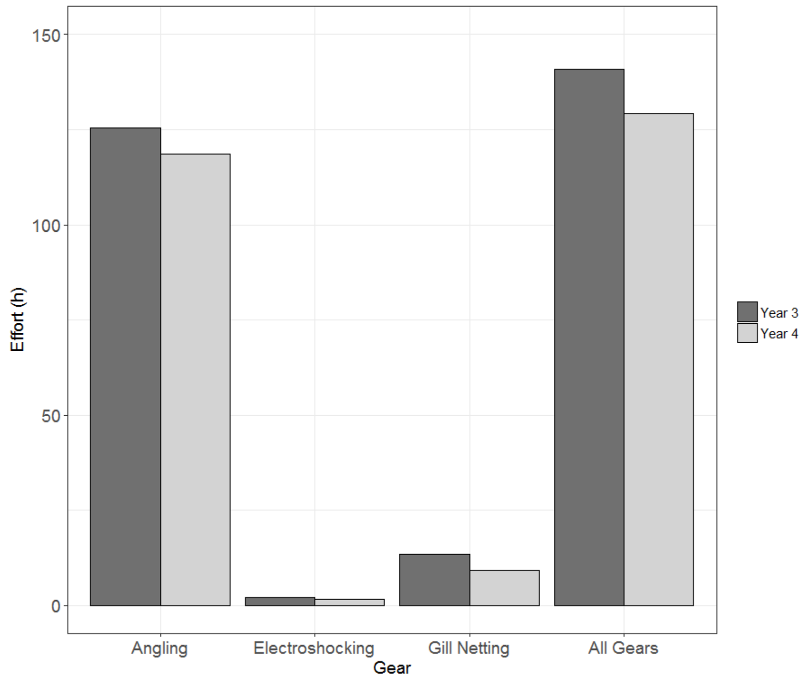

Figure 3-11 Total mark-recapture effort by gear type in Years 3 and 4 (2015 and 2016).

POPAN Jolly-Seber Model

The POPAN Jolly-Seber model was used to estimate annual Bull Trout abundance in the Carpenter Reservoir mark-recapture study area for Years 1 through 4. The fits of 8 candidate models were compared using AICc, and the top three models were those with fixed entrance probability (b_{fixed}), fixed capture probability (p_{fixed}), and fixed survival probability (φ_{fixed}; Table 3-5). These three models were within 2.2 AICc points of each other with a parameter difference of 1, suggesting virtually equal fits. We selected the fixed capture probability model to discuss here (i.e., the best-fit model) because all parameters were identifiable in this model and abundance estimates (desired output) could be derived for all years[7] (Table 3-6). The fixed capture probability model estimated Year 4 adult Bull Trout abundance in the mark-recapture study area to be 737 individuals. Parameter estimates for the top POPAN models were characterized by low precision and large confidence intervals, which in turn led to low precision in derived population estimates for Years 1 through 4 (Figure 3-12).

Goodness-of-fit Testing

Parametric bootstrapping (1,000 simulations) was used to evaluate the goodness-of-fit of the fixed capture probability POPAN model (Figure 3-13). Survival from Year 2 into Year 3 (φ_{2014}) and the probability of

[7] In the model with fixed entrance probability, abundance in the initial and final capture periods cannot be estimated due to parameter confounding (see Schwartz and Arnason, 1996).

entrance in Year 2 were moderately biased (>10%) relative to the model estimate, and all parameters were characterized by some degree of bias (Table 3-7). Bootstrapping results suggest a relatively poor model fit to the mark-recapture data. Goodness-of-fit was examined for the three top models according to AICc (not presented), and all models were characterized by low precision and high bias for some parameters and study years.

Table 3-5 AICc of POPAN open mark-recapture model estimates for Carpenter Reservoir Bull Trout. φ = survival probability, *p* = capture probability, and *b* = entrance probability.

Model	Number of Parameters	AICc	Delta AICc
$\varphi_{\text{time-varying}}$, $p_{\text{time-varying}}$, b_{fixed}	7	254.5	0.00
$\varphi_{\text{time-varying}}$, p_{fixed}, $b_{\text{time-varying}}$	8	256.7	2.2
φ_{fixed}, $p_{\text{time-varying}}$, $b_{\text{time-varying}}$	8	257.3	2.8
$\varphi_{\text{time-varying}}$, $p_{\text{time-varying}}$, $b_{\text{time-varying}}$	9	257.9	3.4
φ_{fixed}, $p_{\text{time-varying}}$, b_{fixed}	7	263.8	9.3
φ_{fixed}, p_{fixed}, $b_{\text{time-varying}}$	6	279.3	24.8
$\varphi_{\text{time-varying}}$, p_{fixed}, b_{fixed}	6	330.4	75.8
φ_{fixed}, p_{fixed}, b_{fixed}	4	439.5	184.9

Table 3-6 Parameter estimates, derived population estimates, standard errors, and 95% confidence limits for the POPAN model with fixed capture probability. φ = survival probability, *p* = capture probability, *b* = entrance probability, *Ns* = super-population abundance, and *N* = annual abundance.

Parameter	Estimate	Standard Error	Lower Confidence Interval (2.5%)	Upper Confidence Interval (97.5%)
$\varphi_{\text{Year 1}}$	0.240	0.088	0.109	0.448
$\varphi_{\text{Year 2}}$	1.000	0.000	0.000	1.000
$\varphi_{\text{Year 3}}$	0.089	0.046	0.031	0.230
P_{fixed}	0.170	0.051	0.091	0.294
Ns	2942.18	780.83	1837.95	5022.67
$b_{\text{Year 2}}$	0.014	0.033	0.000	0.628
$b_{\text{Year 3}}$	0.417	0.030	0.359	0.478
$b_{\text{Year 4}}$	0.204	0.024	0.161	0.256
$N_{\text{Year 1}}$	1073.56	332.46	592.98	1942.51
$N_{\text{Year 2}}$	297.27	69.52	159.83	552.90
$N_{\text{Year 3}}$	1525.49	453.74	862.12	2699.29
$N_{\text{Year 4}}$	737.12	231.29	404.28	1343.97

Table 3-7 Relative bias for parameter estimates from parametric bootstrapping goodness-of-fit testing of the fixed capture probability POPAN model.

Parameter	Relative Bias
φ_{2013}	7.8%
φ_{2014}	16.3%
φ_{2015}	3.4%
p_{fixed}	7.2%
b_{2014}	19.4%
b_{2015}	7.6%
b_{2016}	4.6%

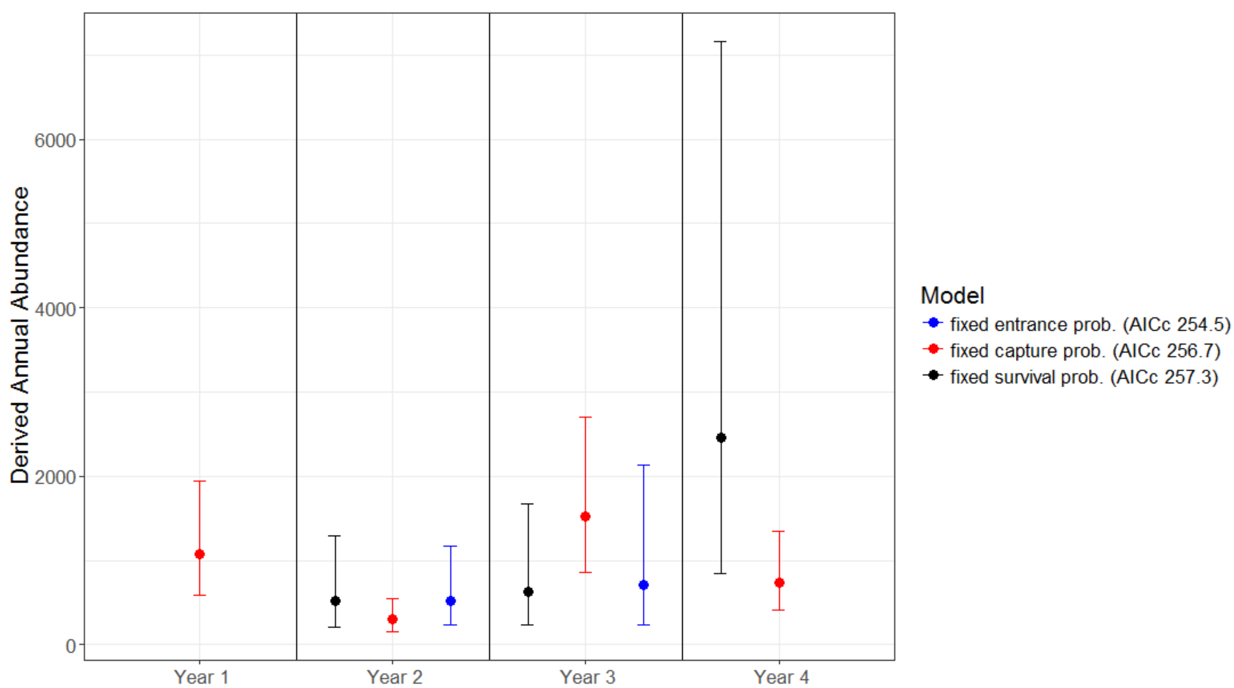

Figure 3-12 Derived population estimates and 95% confidence intervals for the 3 top POPAN models. Annual abundance could not be determined for all years in all models due to parameter confounding.

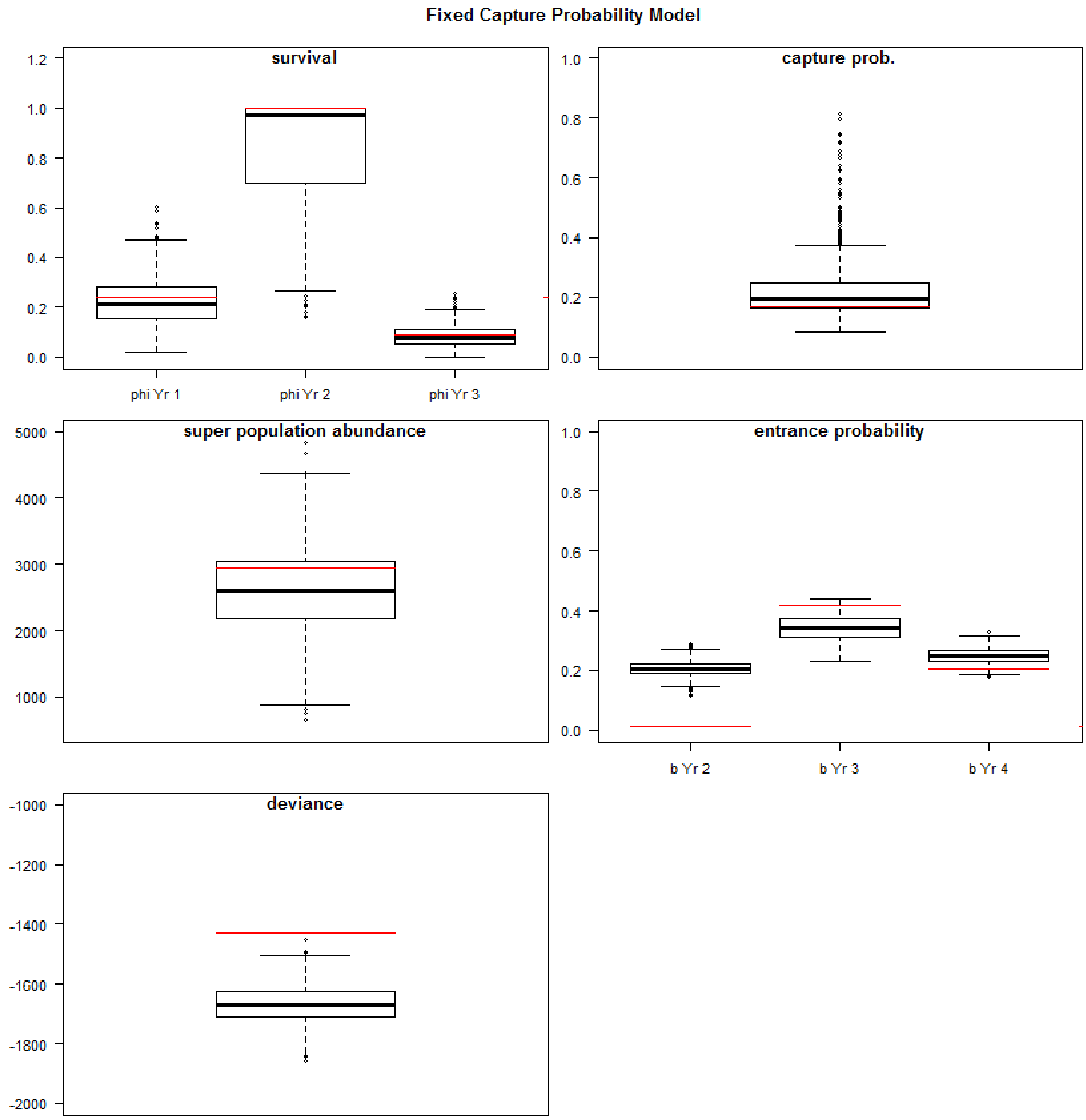

Figure 3-13 Parametric bootstrapping (n = 1000) parameter estimates for the POPAN model with fixed capture probability. Red lines are true parameters.

Cormack Jolly-Seber Model

The Cormack Jolly-Seber (CJS) model was also used to estimate Bull Trout survival and catchability (the CJS model does not estimate abundance) and were compared to the estimates of these parameters from the POPAN model. Four candidate models were evaluated (Table 3-8) and the model with the highest AICc support included a fixed catchability parameter (p_{fixed}) and time varying survival ($\varphi_{\text{time-varying}}$). The second-fit model (i.e., fixed survival and time-varying catchability) was within 1 AICc point of the best model; however, we evaluated the fit of the fixed catchability model for consistency with the best-fit POPAN model. Survival and catchability estimated by the p-fixed model were identical to those estimated by the fixed-p POPAN model, which is expected as they are modelled similarly in both derivations. Goodness-of-fit testing via parametric bootstrapping agreed with relative bias and precision issues identified during POPAN goodness-of-fit testing (Figure 3-14).

Table 3-8 AICc values for CJS open mark recapture models. φ = survival and p = capture probability.

Model	Number of Parameters	AICc	Delta AICc
$\varphi_{\text{time-varying}}$, p_{fixed}	4	222.2	0.0
φ_{fixed}, $p_{\text{time-varying}}$	4	222.8	0.6
$\varphi_{\text{time-varying}}$, $p_{\text{time-varying}}$	6	225.7	3.5
φ_{fixed}, p_{fixed}	2	240.5	18.3

Table 3-9 Parameter estimates and standard errors for the CJS model with fixed capture probability. φ = survival and p = capture probability.

Parameter	Estimate	Standard Error	Lower Confidence Interval (2.5%)	Upper Confidence Interval (97.5%)
$\varphi_{\text{Year 1}}$	0.242	0.09	0.11	0.45
$\varphi_{\text{Year 2}}$	1.000	0.00	0.00	1.00
$\varphi_{\text{Year 3}}$	0.090	0.05	0.03	0.23
p	0.168	0.05	0.09	0.29

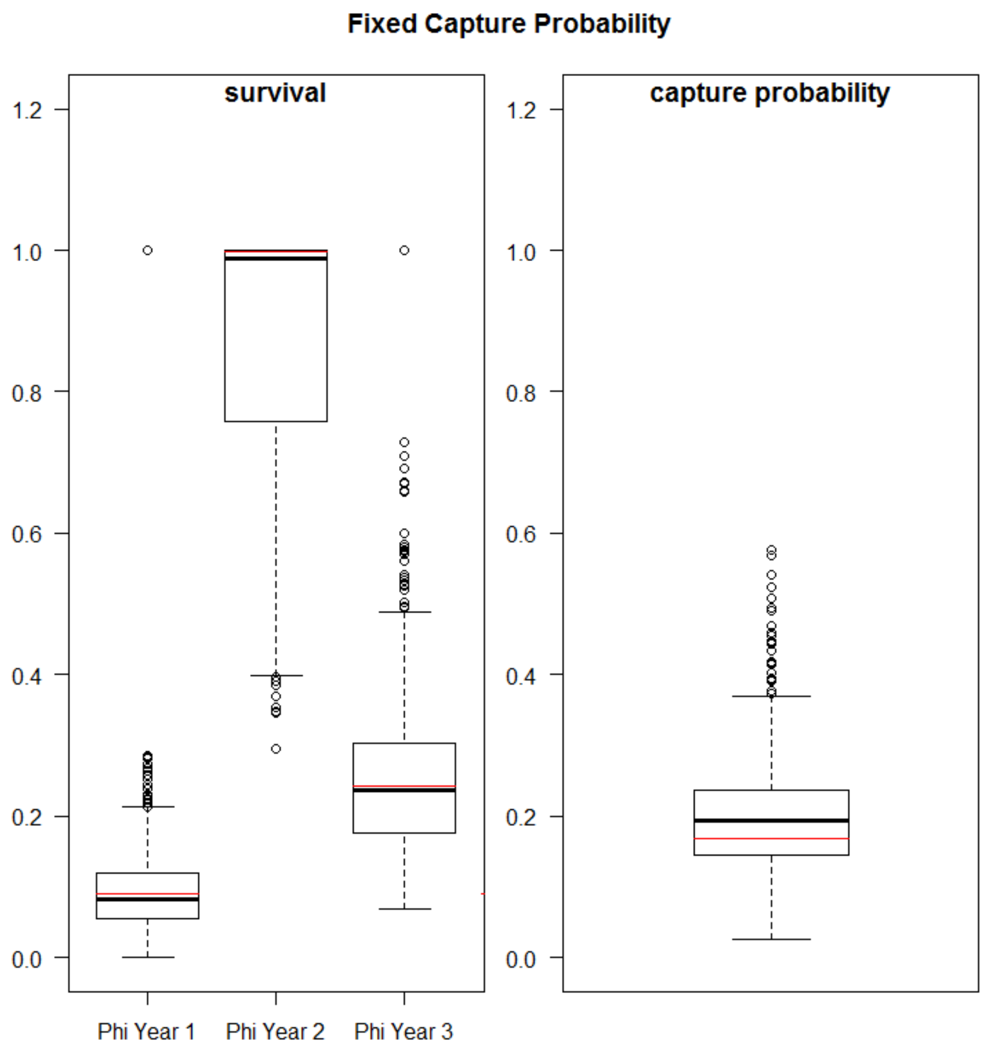

Figure 3-14 Parametric bootstrapping (n = 1,000) parameter estimates for the CJS model with fixed capture probability. Red lines are the true parameters.

3.4 Biological Characteristics

Species-specific length, weight, and age data are being collected throughout BRGMON-04 to describe biological characteristics of fish species in the Carpenter Reservoir watershed. Ages were determined for scales (kokanee, Rainbow Trout, Mountain Whitefish), fin rays (Bull Trout), and otoliths (accidental mortalities) collected during Years 2 through 4 (Table 3-10). Scale ages of juvenile Rainbow Trout were somewhat unique in Carpenter Reservoir due to minimal growth rates over the first winter. Juvenile Rainbow Trout typically do not develop scales until ~50 mm in length, and age determination is dependent on observing clearly defined annuli. In Carpenter Reservoir tributaries, juvenile Rainbow Trout experience their first winter without developing identifiable growth rings, leading to their mis-classification as age 0 fish (a juvenile that has survived one winter should be classified as age 1 based on

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winter growth annuli). We accounted for this underestimation in juvenile Rainbow Trout ages by adding 1 year to individuals captured after at least one winter of growth.

Table 3-10 Ageing structures analysed in Years 2 through 4 of BRGMON-04.

Species	Scales Aged	Otoliths Aged	Fin Rays Aged
Bull Trout	7	10	74
Kokanee	35	0	0
Mountain Whitefish	131	31	0
Rainbow Trout	154	2	0

3.4.1 Bull Trout

A total of 1,205 Bull Trout have been captured in Carpenter Reservoir in Years 1 through 4, of which 919 were PIT tagged. The mean condition factor (K_F) for Bull Trout in Year 4 was 0.96 with a standard deviation of 0.19 (Table 3-11), and length and weight were highly correlated in all study years (Figure 3-15). A total of 91 Bull Trout were aged in Year 4 by IFR (otoliths and juvenile scales) and North South Consultants (fin rays; Figure 3-16). Estimated Bull Trout ages ranged from 0 to 12 years. A von Bertalanffy growth model was successfully fit to Bull Trout length and age data (Table 3-12, Figure 3-17). A Bull Trout age length key was used to estimate the proportion of Bull Trout in each age class and to estimate ages for unaged fish (Figure 3-18).

Table 3-11 Condition factor of Bull Trout captured in Carpenter Reservoir in Years 1 through 4.

Year	Fish Count	Mean Condition Factor (K_F)	SD Condition Factor
1	432	0.92	0.15
2	210	0.89	0.15
3	368	0.91	0.21
4	193	0.96	0.19

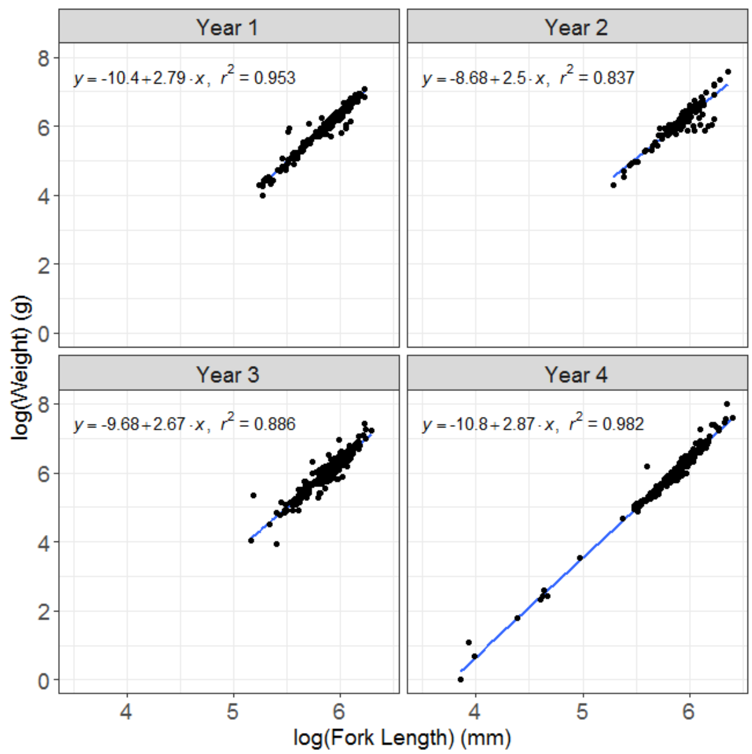

Figure 3-15 Length-weight relationships for Carpenter Reservoir Bull Trout by study year.

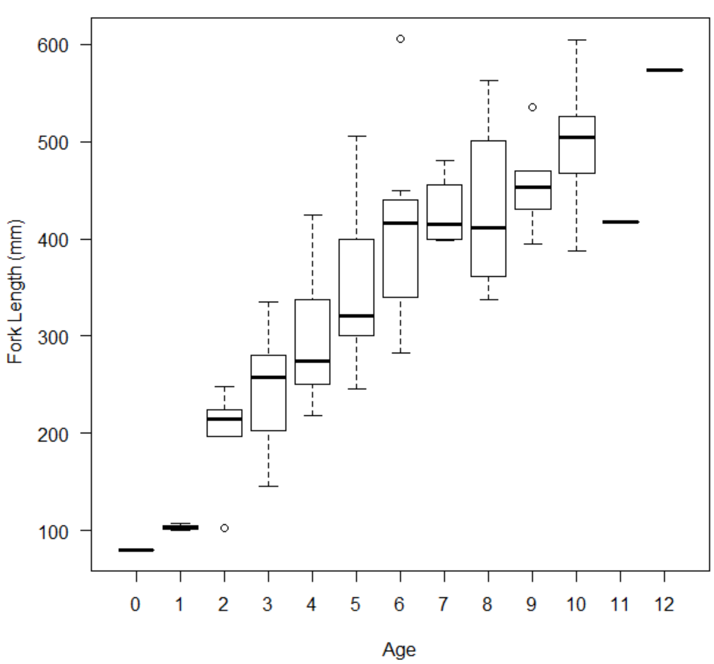

Figure 3-16 Bull Trout length-at-age (observed ages) in Carpenter Reservoir (all study years combined).

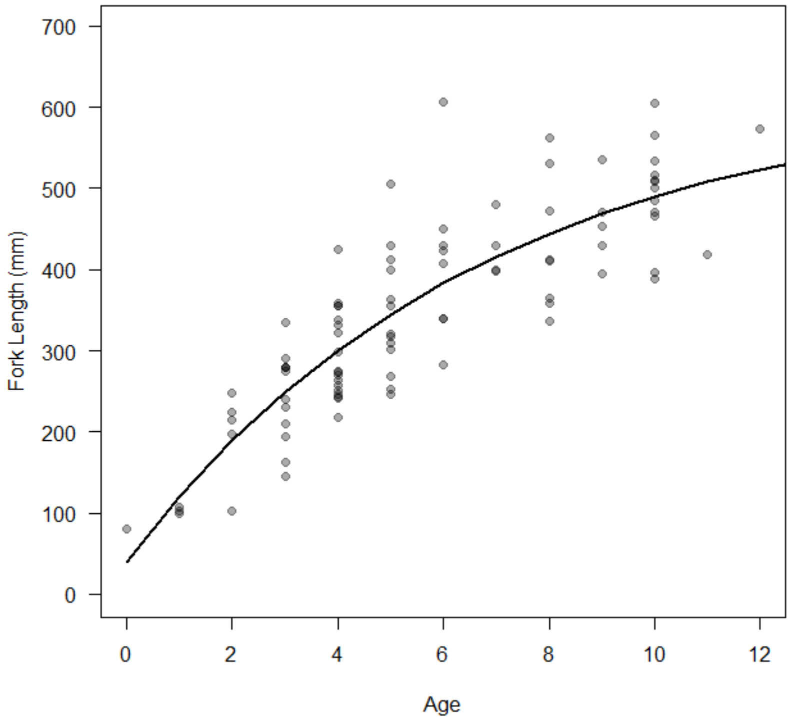

Figure 3-17 Von Bertalanffy growth model for Bull Trout fork length (mm) and observed ages (all study years combined). Transparency shows point overlap.

Table 3-12 Von Bertalanffy parameter estimates for Bull Trout (all study years combined).

Parameter	Estimate	SE
L_{inf}	620.43 mm	0.81
K	0.15	0.00
t_0	-0.44	0.01

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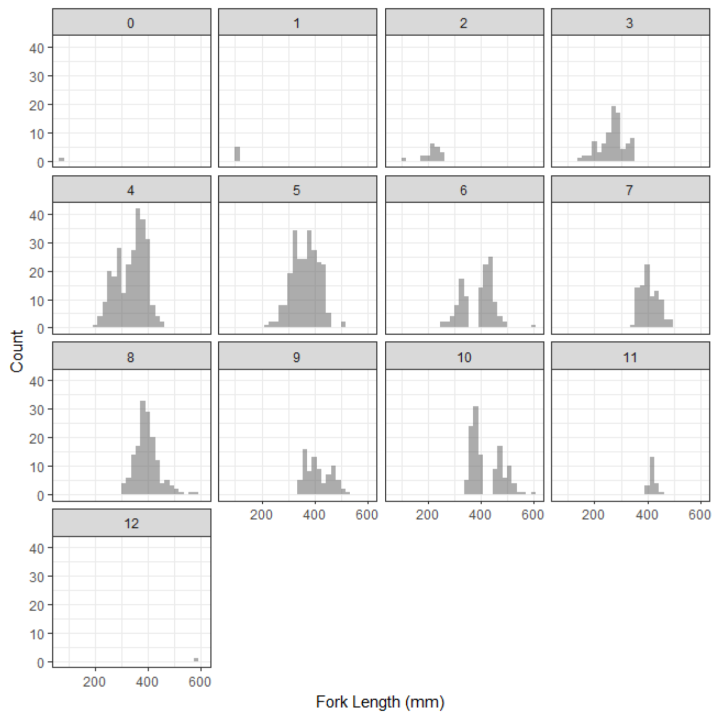

Figure 3-18 Length-frequency histogram for Bull Trout by age (observed and ALK-estimated combined).

3.4.2 Rainbow Trout

A total of 324 Rainbow Trout have been captured in Carpenter Reservoir in Years 1 through 4, of which 236 were PIT tagged. The mean condition factor (K_F) for Rainbow Trout in Year 4 was 1.10 with standard deviation of 0.25 (Table 3-13), and length and weight were highly correlated in all study years (Figure 3-19). A total of 156 Rainbow Trout (a combination of otoliths and scales) were aged by IFR (Figure 3-20), with estimated ages ranging from 0 to 7 years. A von Bertalanffy growth model was fit to Rainbow Trout length-at-age data (Table 3-12, Figure 3-17). An ALK was developed for Rainbow Trout and used to estimate the proportion of Rainbow Trout in each age class and to assign ages to unaged fish (Figure 3-22).

Table 3-13 Condition factor of Rainbow Trout captured in Carpenter Reservoir Years 1 through 4.

Year	Fish Count	Mean Condition Factor (K_F)	SD Condition Factor
1	92	1.00	0.14
2	66	1.05	0.37
3	45	0.98	0.13
4	120	1.10	0.25

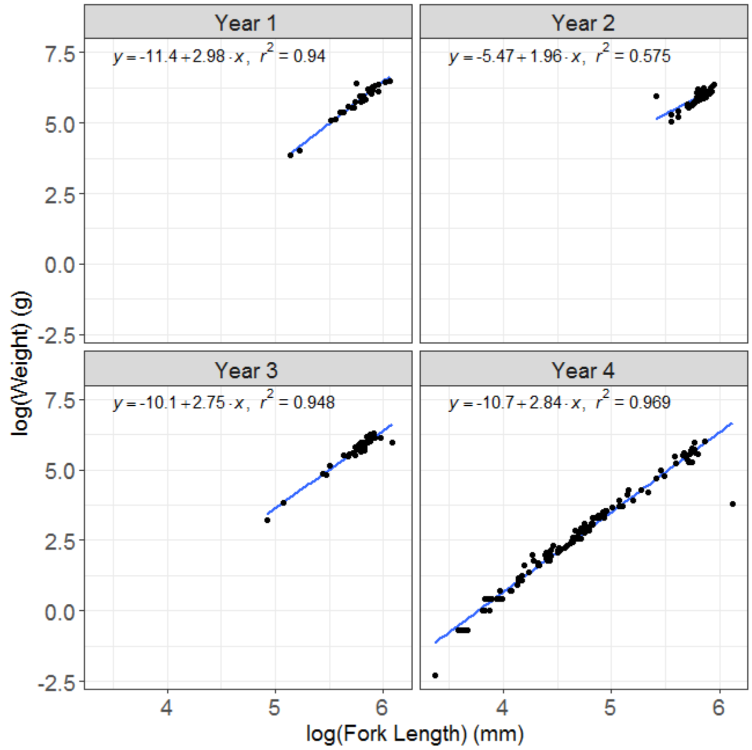

Figure 3-19 Length-weight relationships for Carpenter Reservoir Rainbow Trout by study year.

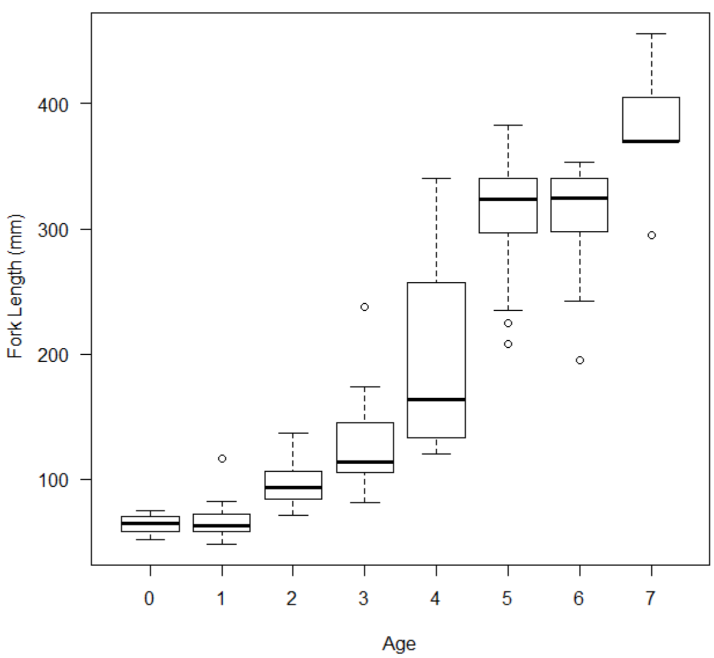

Figure 3-20 Rainbow Trout length-at-age in Carpenter Reservoir (all study years combined)

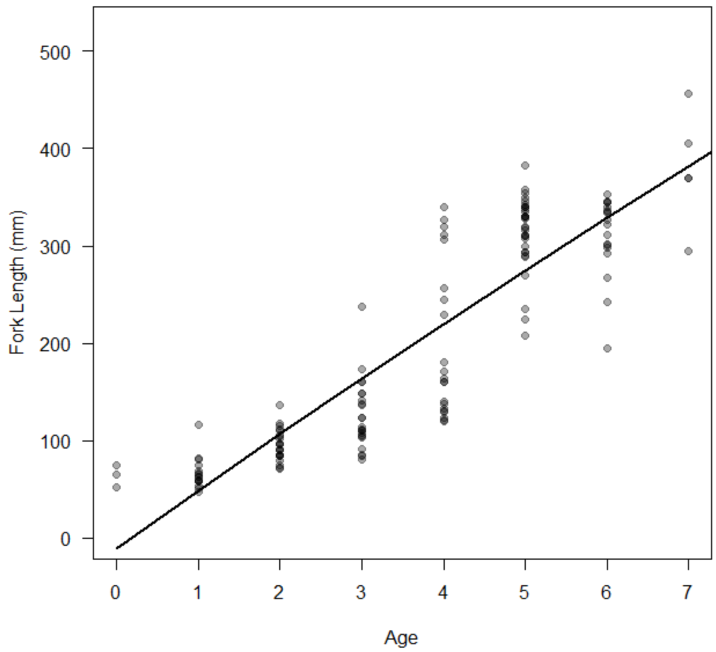

Figure 3-21 Von Bertalanffy growth model for Rainbow Trout fork length (mm) and observed ages (all study years combined). Transparency shows point overlap.

Table 3-14 Von Bertalanffy parameter estimates for Rainbow Trout (all study years combined).

Parameter	Estimate	SE
L_{inf}	3472.68 mm	31.75
K	0.017	0.000
t_0	0.176	0.002

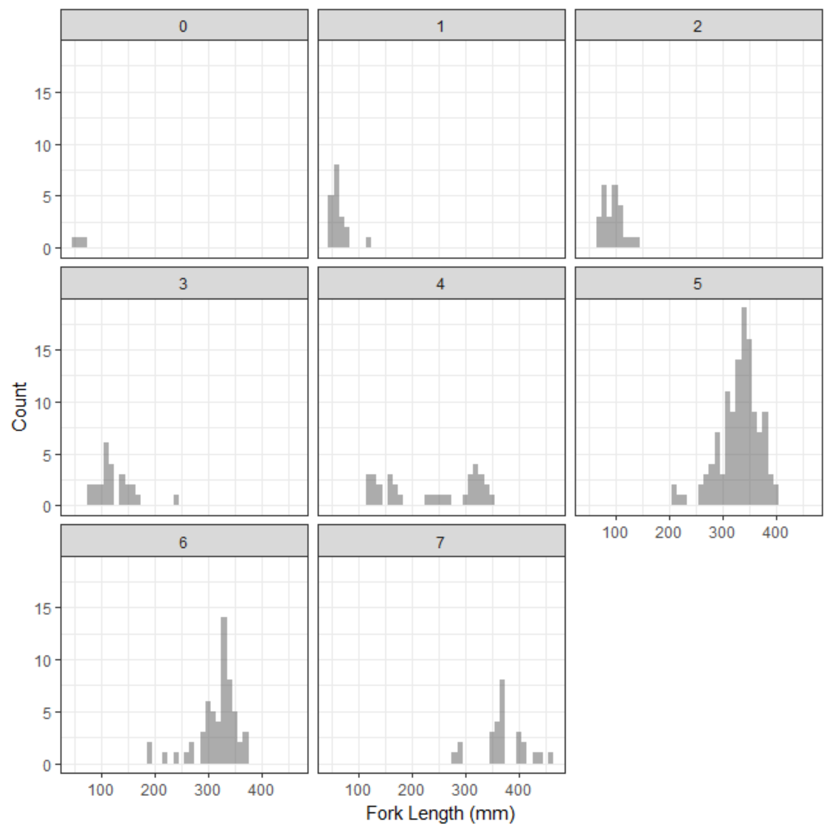

Figure 3-22 Length-frequency histogram for Rainbow Trout by age (observed and ALK-estimated combined).

3.4.3 Mountain Whitefish

A total of 821 Mountain Whitefish have been captured in Carpenter Reservoir over the four-year study period, 216 of which were PIT tagged. The mean condition factor (K_F) for Year 4 was 0.95 with standard deviation 0.14 (Table 3-15), and length and weight were highly correlated in all study years (Figure 3-23). A total of 50 Mountain Whitefish (scales and otoliths) were aged by IFR (Figure 3-24). Estimated Mountain Whitefish ages ranged from 1 to 6 years. A von Bertalanffy growth model was fit to Mountain Whitefish length-at-age data (Table 3-16; Figure 3-25). A Mountain Whitefish ALK was used to estimate the proportion of Mountain Whitefish in each age class and to assign ages to unaged fish (Figure 3-26).

Table 3-15 Characteristics of Carpenter Reservoir Mountain Whitefish Years 1 through 4.

Year	Fish Count	Mean Condition Factor (K_F)	SD Condition Factor
1	311	1.16	0.23
2	249	1.14	0.26
3	86	1.11	0.15
4	175	0.95	0.14

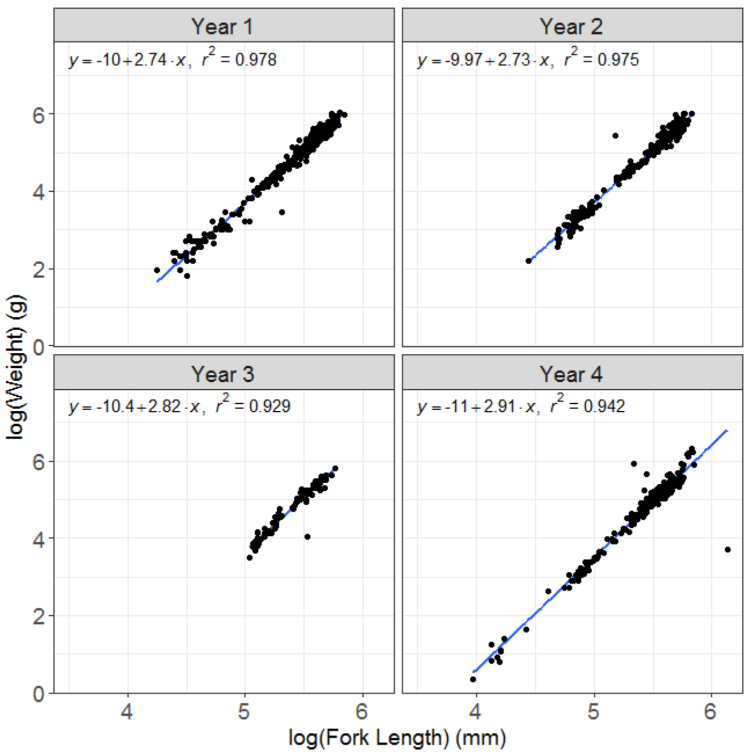

Figure 3-23 Length-weight relationships for Mountain Whitefish by study year.

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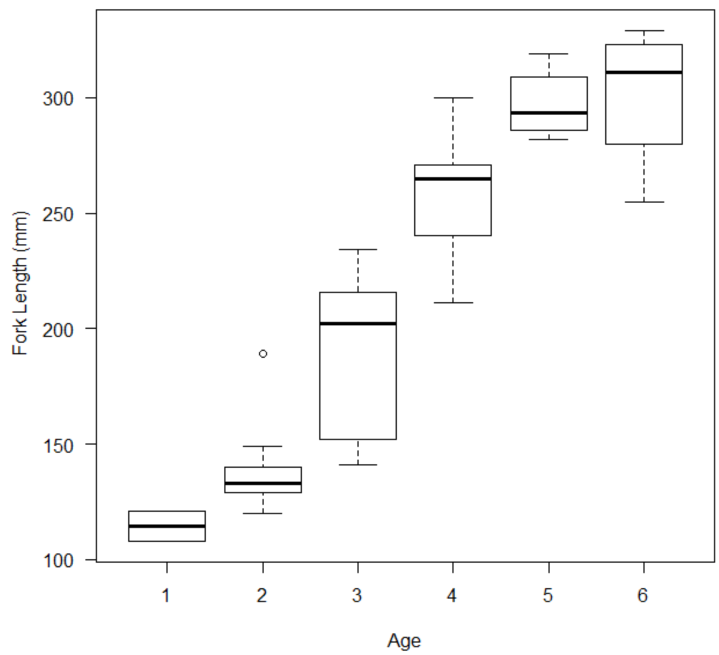

Figure 3-24 Mountain Whitefish length-at-age in Carpenter Reservoir (all study years combined).

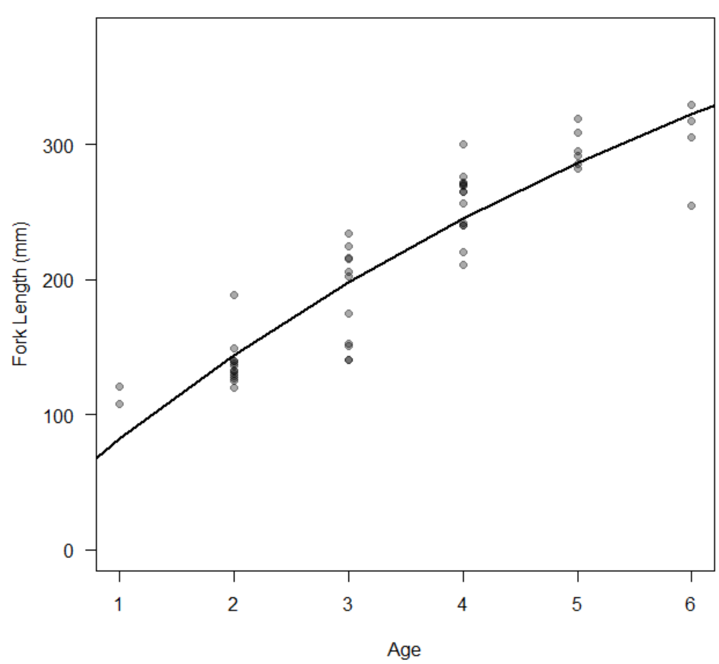

Figure 3-25 Von Bertalanffy growth model for Mountain Whitefish fork length (mm) and observed ages (all study years combined). Transparency shows point overlap.

Table 3-16 Von Bertalanffy parameter estimates for Mountain Whitefish (all study years combined).

Parameter	Estimate	SE
L_{inf}	566.36 mm	4.96
K	0.14	0.00
t_0	-0.14	0.01

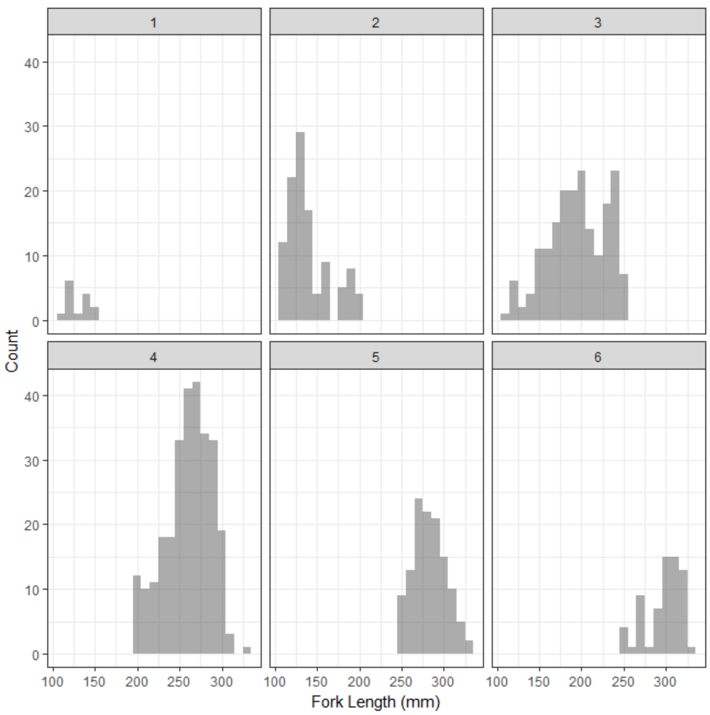

Figure 3-26 Length-frequency histogram for Mountain Whitefish by age (observed and ALK-estimated combined).

3.4.4 Kokanee

A total of 116 kokanee have been captured in Carpenter Reservoir in Years 1 through 4. The mean condition factor (K_F) of kokanee was 1.07 in Year 4 with a standard deviation of 0.08 (Table 3-17), and length and weight were highly correlated for all years with sufficient data (Figure 3-27). A total of 35 kokanee (scales and otoliths) were aged by IFR (Figure 3-28). We did not fit a von Bertalanffy model or an age-length-key to kokanee due to the limited number of age classes present in the aged subsample. Most kokanee captured during monitoring were adult spawners (between 3 and 4 years old) holding in preparation of spawning migrations.

Table 3-17 Characteristics of kokanee Captured in Carpenter Reservoir in Years 1 through 4.

Year	Fish Count	Mean Condition Factor (K_F)	SD Condition Factor
1	3	1.28	0.14
2	2	1.24	0.03
3	21	1.28	0.11
4	13	1.07	0.08

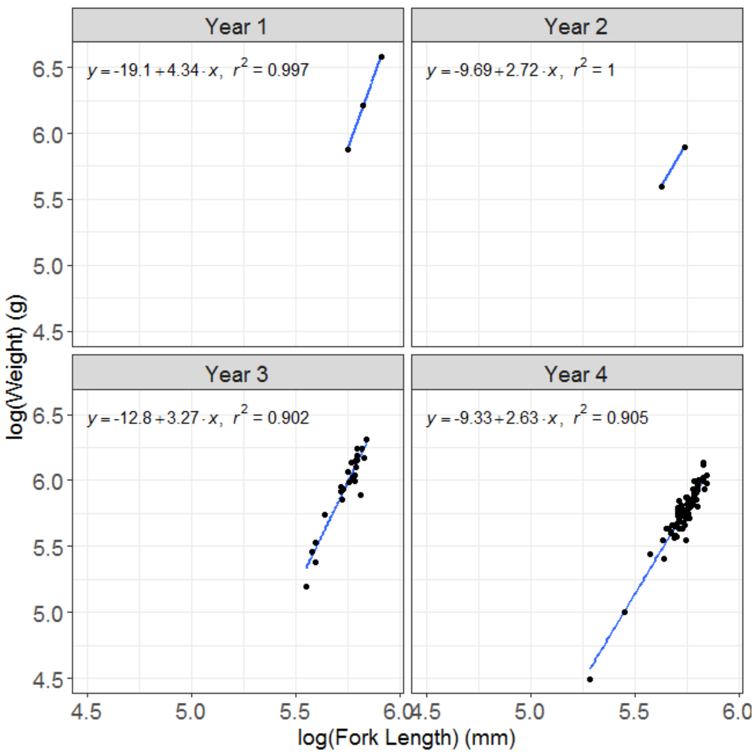

Figure 3-27 Length-weight relationships for kokanee in Carpenter Reservoir by study year.

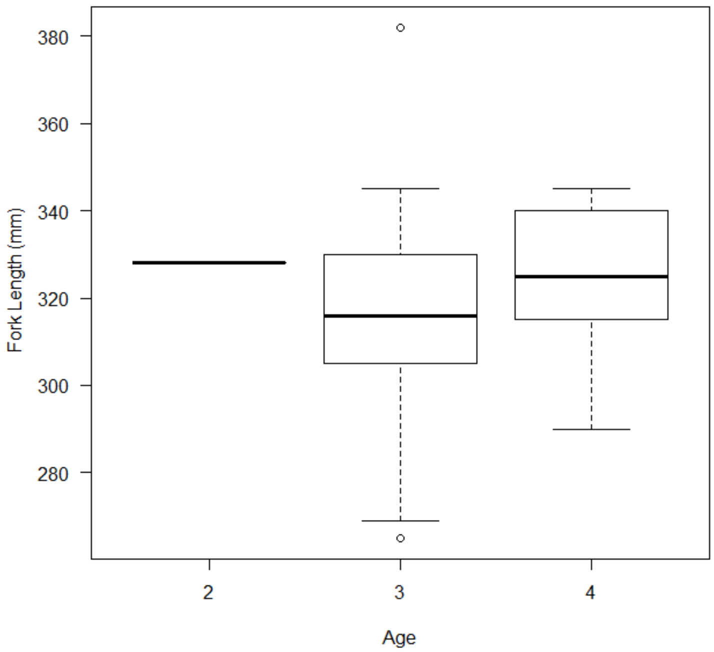

Figure 3-28 Kokanee length-at-age in Carpenter Reservoir (all study years combined).

3.5 Reservoir Tributary and Middle Bridge River Spawner Assessments

3.5.1 Tributary Visual Surveys

Kokanee spawner surveys in Years 1 through 4 recorded approximate annual migration timings (Table 3-18) and relative spawner abundance in Carpenter Reservoir tributaries (Figure 3-29). In Year 4, kokanee were observed during the initial survey (August 16) in Marshall Creek, Truax Creek, and McDonald Creek, suggesting the migration began prior to the monitoring period (i.e., no initial zero counts were obtained). No identifiable spawning behaviour was observed in any of the tributaries during the Year 4 visual surveys, suggesting kokanee spawn upstream of the monitored stream areas.

Tributary-specific kokanee spawner counts were not consistently high in any one tributary, and the relative timing of initial, final, and peak counts was variable among tributaries. Variability in spawner counts was expected due to the unique physical characteristics of each tributary and differences in the quantity and quality of spawner habitat (Table 3-19). Spawner counts from weekly surveys (August through September) were summed across all tributaries to obtain an index of spawner abundance (only tributaries surveyed in all years were included in annual totals; Figure 3-30). It is difficult to compare spawner counts between tributaries and years due to the absence of initial zero counts; however, it appears that the kokanee spawning migration occurred earlier in Year 4 relative to Years 2 and 3, and the total spawner count may have been lower. Physical conditions were also variable between survey years:

reservoir elevation was lower (Figure 3-31) and tributary mean daily water temperatures were higher in Year 4 relative to Year 3 (Figure 3-32).

Kokanee counts were distinguished between above and within the drawdown zone to evaluate the potential risks of elevation fluctuations on spawning and migrating kokanee. In Girl Creek in Year 4, 100% of kokanee observed over the spawning period were counted within the drawdown zone[8], while this percentage was 71% in Truax Creek, 41% in McDonald Creek, 4% in Marshall Creek, and 0% in Sucker Creek. Counts in the drawdown zone were higher in Year 4 relative to Year 3, likely because reservoir elevation was lower in Year 4 and the volume and duration of drawdown zone habitat was therefore larger. Despite kokanee being observed in the drawdown zone, no spawning behaviour was noted in drawdown areas and kokanee likely were staging and later migrated further upstream to spawn.

Table 3-18. Kokanee spawner date of arrival, date last observed, date of peak count, and peak count in Carpenter Reservoir tributaries.

Study Year	First Date Observed	Last Date Observed	Date of Peak Count	Peak Count (all tribs combined)	Tributaries with Kokanee Observed
Year 1 (2013)	Sep 6	Sep 6	Sep 6	14	McDonald, Sucker
Year 2 (2014)	Aug 19	Sep 16	Aug 26	257	McDonald, Sucker, Girl, Truax, Marshall
Year 3 (2015)	Aug 13	Sep 26	Sep 11	345	McDonald, Sucker, Truax, Girl, Marshall, Jones
Year 4 (2016)	Aug 16	Sep 13	Aug 30	107	McDonald, Sucker, Truax, Girl, Marshall

[8] This high percentage is somewhat misleading due to a large pool located in the Girl Creek drawdown zone that is used as a holding area by migrating kokanee (kokanee can be easily enumerated in this pool but may spawn further upstream in Girl Creek or the Middle Bridge River).

Table 3-19 Qualitative assessment of kokanee spawning habitat quality and quantity in Carpenter Reservoir tributaries.

Tributary	Habitat Quality: Low Pool	Habitat Quality: Full Pool
Girl Creek	- Generally low flows and low turbidity - Kokanee often hold in a large clear pool at the outflow - Drawdown zone is steeper relative to other tributaries - At low elevations debris barriers exist that may limit fish passage	- Habitat quality is generally improved - Debris barriers are removed at full pool - Elevation gradient lessened at full pool
McDonald Creek	- Generally moderate flows with consistent riffle habitat - Low turbidity - High quality spawning habitat throughout the drawdown zone	- Habitat quality remains the same except in years of high maximum elevation - Only a small portion of habitat is flooded due to the proximity of McDonald Creed to the Middle Bridge River - In low elevation years, almost no change in habitat area would occur
Marshall Creek	- Moderate flows in the drawdown zone at low elevations - All habitat is in the drawdown zone due to a waterfall restricting stream length - Drawdown zone habitat quality is poor downstream of the highway (exposed mudflats) - Drawdown habitat quality is high upstream of the highway (high woody debris content, riffles and pools)	- Habitat quality improves as the mud flat habitat is flooded (exposure is reduced), but decreases at high full pool elevations - All habitat is flooded at high full pool elevations (such as occurred in 2015) - Although all habitat is flooded, the tributary forms a pronounced channel and a backwatered portion remains in which spawners are observed
Sucker Creek	- Moderate flows and low turbidity - Kokanee are often observed holding at the tributary outflow (may be holding to migrate up Sucker Creek or up the Middle Bridge River)	- Habitat quality does not change - Sucker Creek is located in the Middle Bridge River upstream of the reservoir-river boundary and inundation does not occur
Truax Creek	- Higher flows relative to other tributaries and moderate turbidity - Habitat quality in the drawdown zone is poor (shallow, braided, exposed mudflats)	- Habitat quality improves as the mud flat habitat is flooded (exposure is reduced) - Spawning habitat quality is low directly above the drawdown zone (high flows and lack of appropriate substrate), but improves further upstream of the tributary confluence

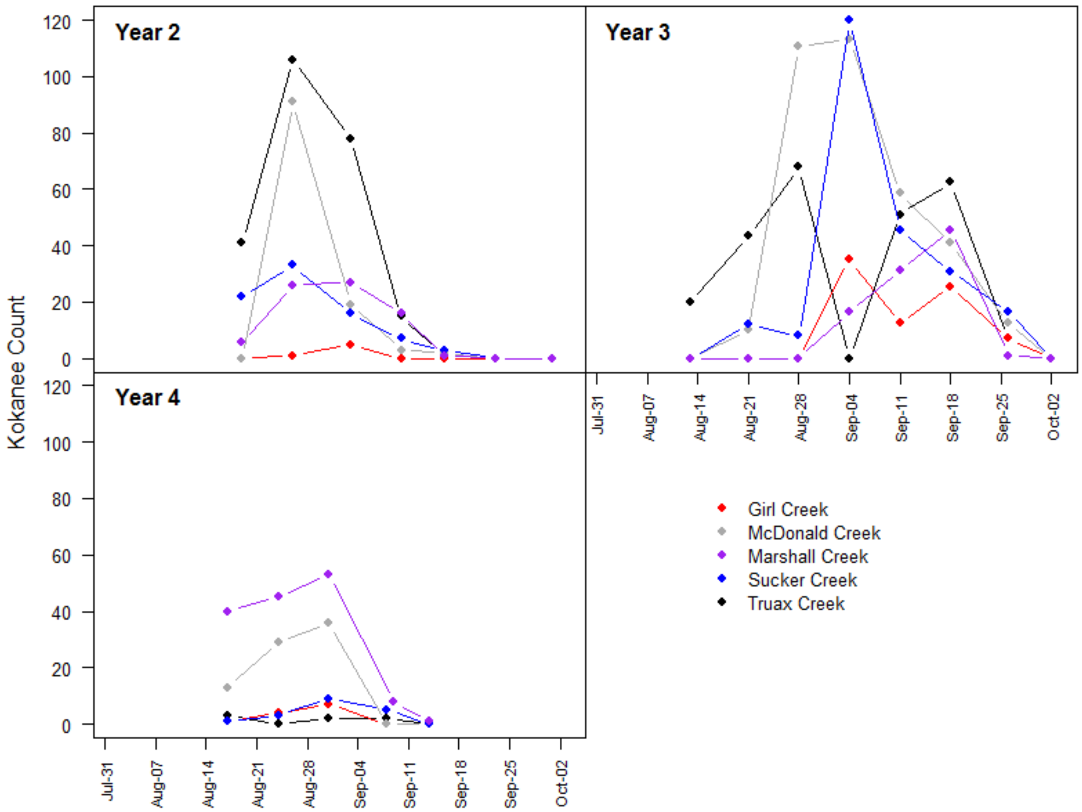

Figure 3-29. Kokanee spawner counts from visual surveys in Years 2 through 4 (2014-2016).

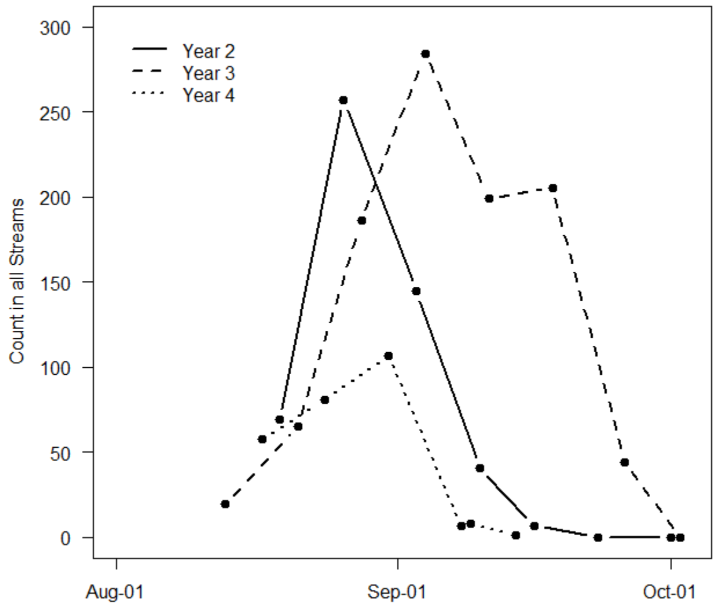

Figure 3-30 Counts of kokanee in Carpenter Reservoir tributaries (Truax, Girl, McDonald, Sucker, and Marshall Creeks combined) in Years 2 through 4 (2014 to 2016).

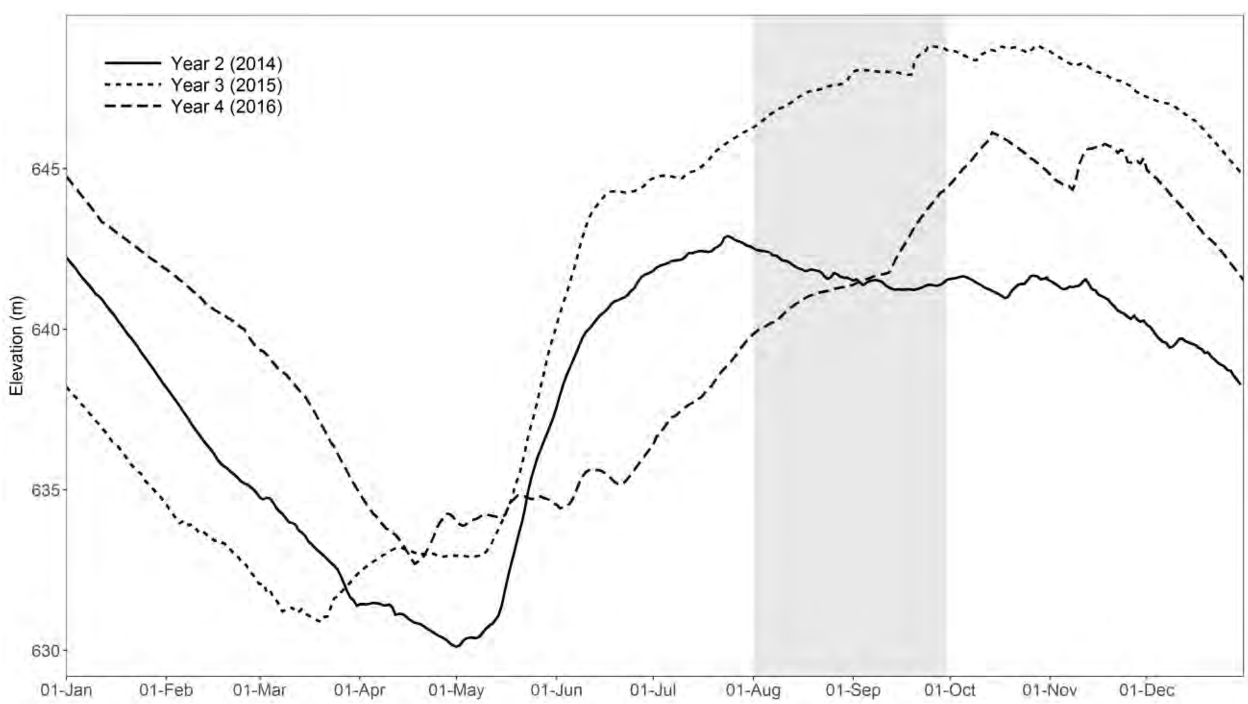

Figure 3-31 Carpenter Reservoir elevation (Years 2 to 4; 2014 to 2016) during the approximate kokanee spawning window (August 1 to September 31; shaded in grey) in the Carpenter Reservoir watershed.

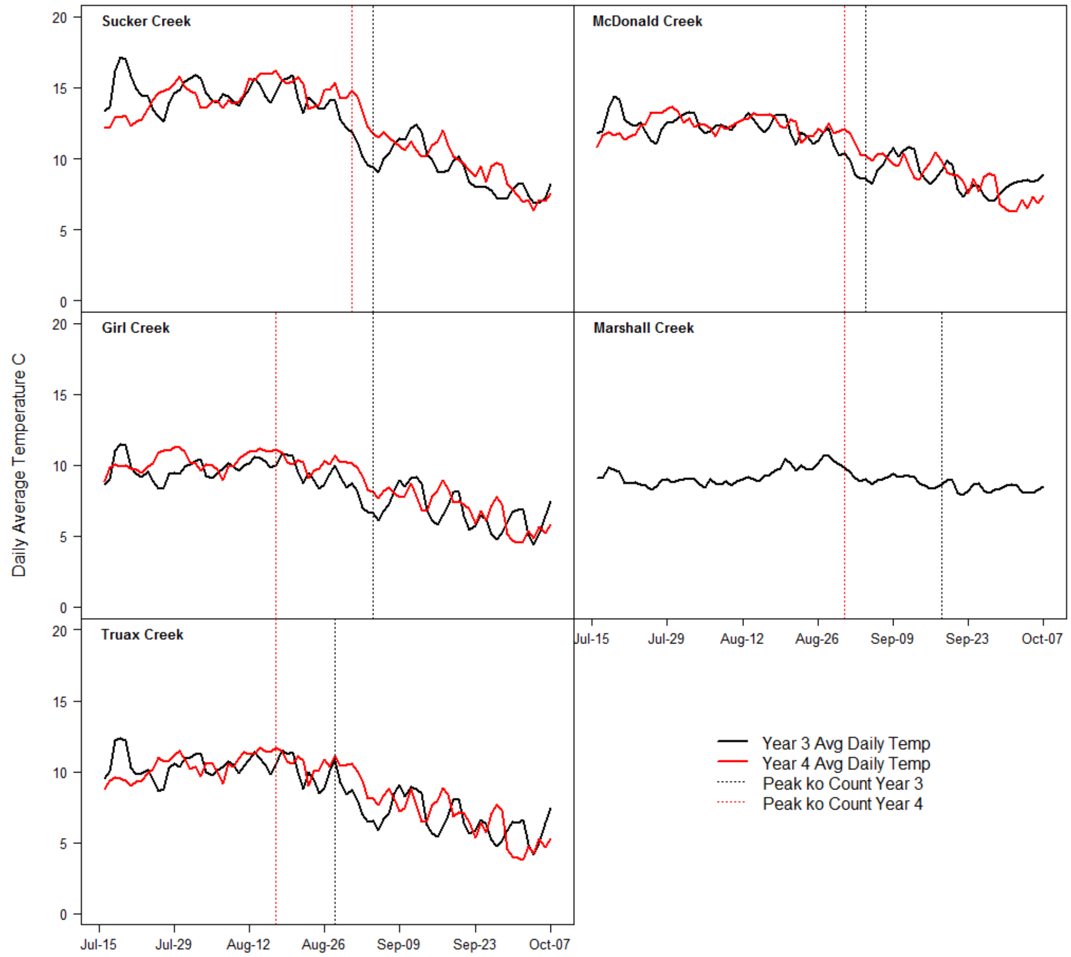

Figure 3-32 Average daily temperature in Carpenter Reservoir tributaries in Years 3 (2015) and 4 (2016).

3.5.2 Tributary Electroshocking Assessment

Backpack tributary electroshocking surveys occurred monthly from April to October in three Carpenter Reservoir tributaries (McDonald Creek, Marshall Creek, and Truax Creek) to identify tributaries with successful Rainbow Trout spawning. Electroshocking CPUE was highest for Rainbow Trout in Marshall Creek (Figure 3-33), and highest for sculpin in McDonald and Truax Creeks (not shown). In both Marshall and McDonald Creeks, Rainbow Trout CPUE was higher above the drawdown zone relative to within the drawdown zone. In Marshall Creek, no fish other than Rainbow Trout were captured above the waterfall barrier (Figure 3-33). One young-of-year (Y-O-Y) Bull Trout was captured in May in Truax Creek and several age 1 Bull Trout were captured in August and September, suggesting Truax Creek is a spawning tributary for Bull Trout. No Y-O-Y Mountain Whitefish were observed during electroshocking.

Y-O-Y Rainbow Trout were captured in Marshall, McDonald and Truax Creeks beginning in September. The presence of Y-O-Y Rainbow Trout suggests successful spawning in all three surveyed tributaries.

Juvenile catch rates were relatively higher in Marshall and McDonald Creeks, and only one Y-O-Y Rainbow Trout was captured in Truax Creek. Juvenile growth rates could not be determined for Rainbow Trout due to small sample sizes; length distributions for age 0 and age 1 Rainbow Trout are shown in Figure 3-34.

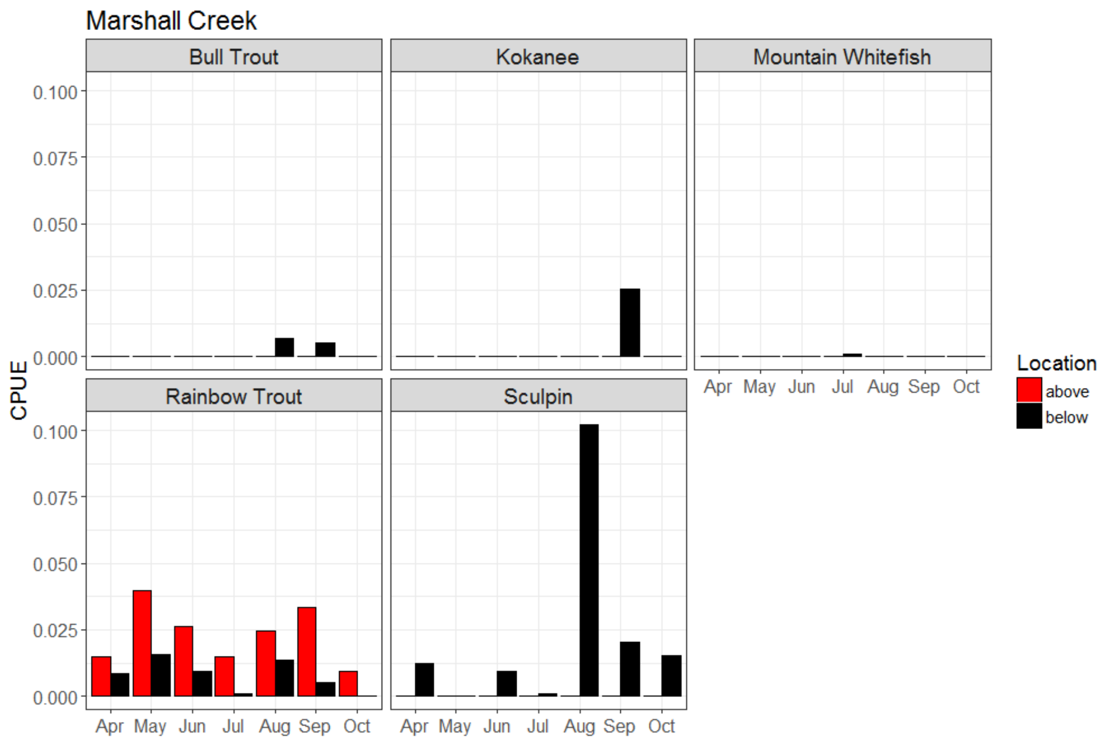

Figure 3-33 Electroshocking CPUE for all species above and below the reservoir drawdown zone in Marshall Creek (Year 4 [2016] April through October)

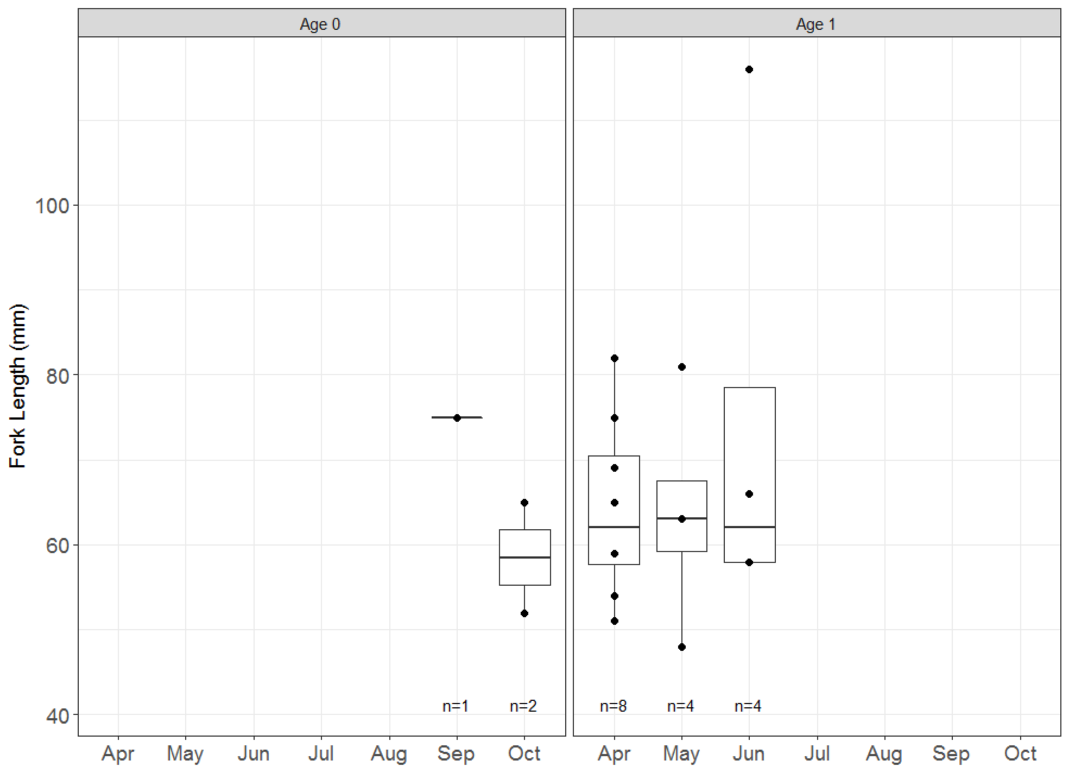

Figure 3-34 Length boxplots of age 0 and age 1 Rainbow Trout captured in McDonald, Marshall, and Truax Creeks from April to October during Year 4 (2016) tributary electroshocking.

3.5.3 Tributary Temperature Monitoring

Temperature data loggers (Onset HOBO TidbiT V2; 1-hour sample frequency) were installed in Marshall Creek, Gun Creek, Sucker Creek, McDonald Creek, Girl Creek, Truax Creek, the Hurley River, and the Middle Bridge River in September 2014 to monitor annual temperature profiles in reservoir tributaries. Additional thermographs were installed in Keary Creek, Tyaughton Creek, and the Middle Bridge River (downstream site) in the spring of 2015 as part of BRGMON-10. Average daily and monthly temperatures were calculated in each tributary for the 2015 and 2016 calendar years (Year 3 is 2015 and Year 4 is 2016; Figure 3-35, Figure 3-36).

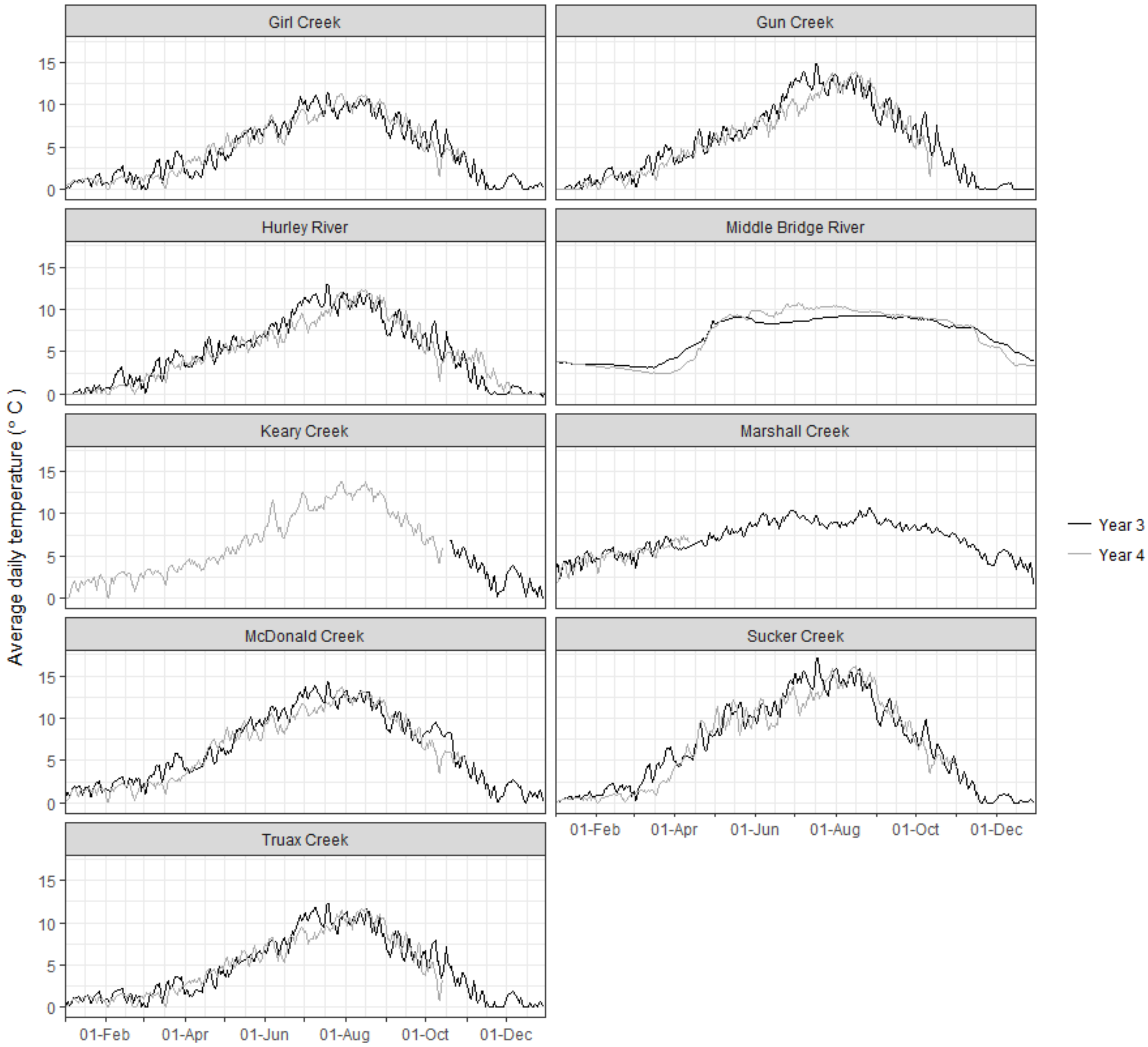

Figure 3-35 Mean daily temperatures in Carpenter Reservoir tributaries Years 3 (2015) and 4 (2016).

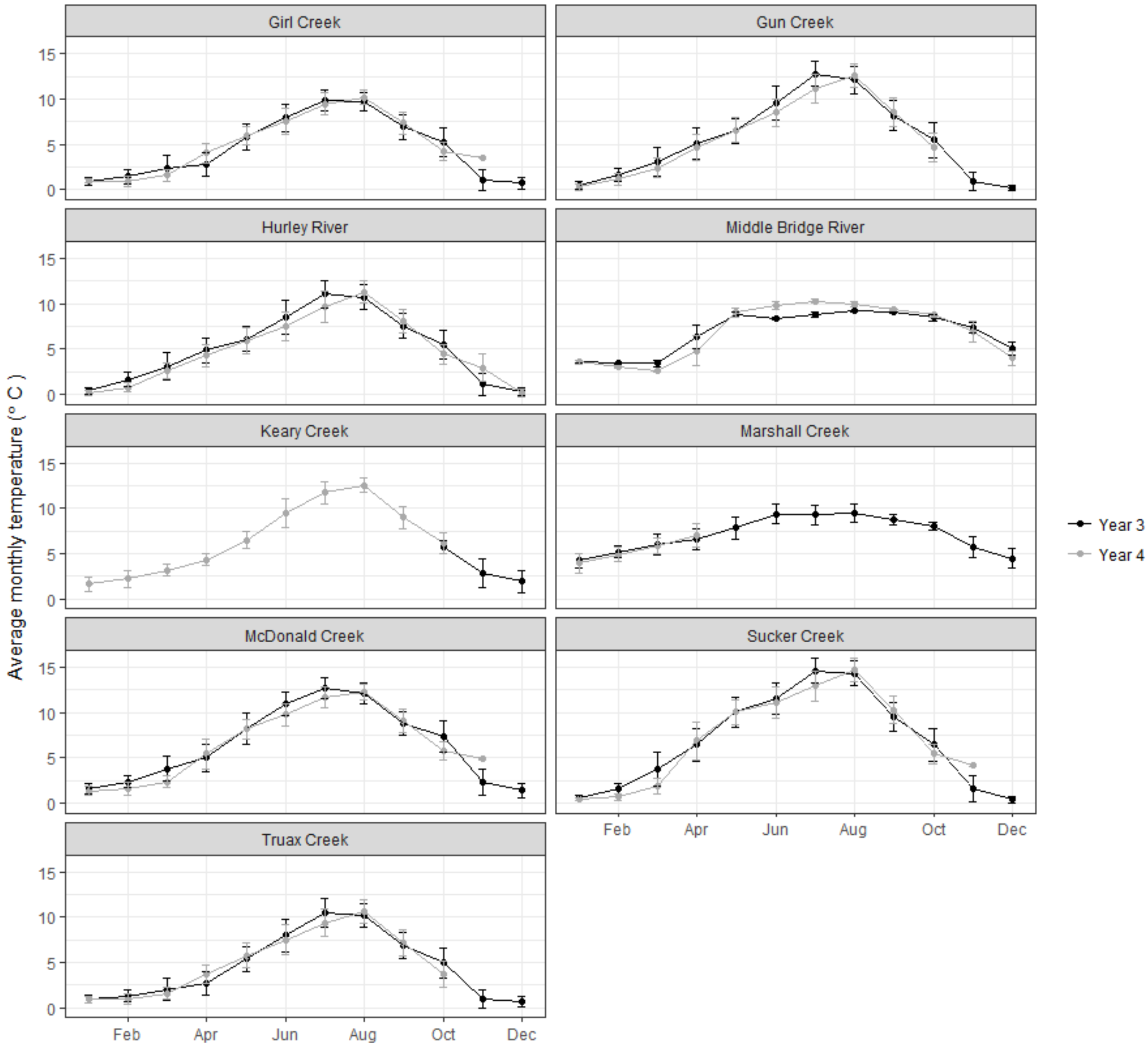

Figure 3-36 Mean monthly temperatures of Carpenter Reservoir tributaries in Years 3 (2015) and 4 (2016). Error bars represent standard deviation.

4 Discussion

The primary objective of BRGMON-04 is to monitor the response of fish and fish habitat in Carpenter Reservoir and the Middle Bridge River to BC Hydro operations of Lajoie and Terzaghi Dams. Data collected in Year 4 of the 10-year monitor builds on data and understanding gained in Years 1 through 3 and helps to direct monitoring in future years.

4.1 Physical Conditions in Carpenter Reservoir and the Middle Bridge River

Physical conditions in Carpenter Reservoir were somewhat abnormal in 2016 (Year 4) relative to the past 7 years of operations. Minimum elevation in Carpenter Reservoir was the highest since 2010 and high discharges of almost 100 cms occurred from Terzaghi Dam during July of 2016. High reservoir elevations and high flows out of Terzaghi Dam are expected to impact fish populations in the reservoir, the degree to which will be investigated in future years of BRGMON-04. High reservoir elevations resulted in a greater proportion of lacustrine habitat in the winter and early spring of 2016. Carpenter Reservoir contains fish that prefer lacustrine habitat, such as kokanee, Redside Shiner, and Rainbow Trout, as well as those that prefer riverine habitat, such as Mountain Whitefish. The relative distribution of fish in Carpenter Reservoir may have been affected by shifting habitat proportions and the timing of habitat availability in the reservoir.

High flows from Terzaghi Dam resulted in the entrainment of kokanee through the dam and into the Lower Bridge River (kokanee were observed in the plunge pool downstream of the dam), and the entrainment of other species may also have occurred. It is important to understand how relatively abnormal operating conditions, such as in 2016, affect fish populations in Carpenter Reservoir and the success of BRGMON-04 monitoring methods. Gross changes in fish populations will likely be identified using time series methods in BRGMON-04 including kokanee visual surveys and the Bull Trout mark-recapture program. The affect of operational changes on the success of BRGMON-04 methods will continue to be evaluated to determine whether methodological changes may be required to account for changing conditions in Carpenter Reservoir and the Middle Bridge River.

4.2 Short-Set Gill Netting

The pilot short-set gill netting program in Year 4 aimed to describe species distributions in four different categories of Carpenter Reservoir habitat and determine preferred habitat for Mountain Whitefish. Previous surveys in Carpenter Reservoir used hydroacoustic methods to examine lacustrine distributions (unpublished), shoreline electroshocking to assess littoral distributions (e.g., Higgins et al. unpublished, Putt et al 2016a, Putt et al 2016b), and overnight gill netting to determine entrainment risk near Carpenter Reservoir diversion tunnels (Griffith 1999). No previous research has attempted to survey both littoral and lacustrine habitats under different operational conditions (i.e., reservoir elevations) using a standard method, as was the goal of the short-set gill netting.

Short-set gill netting data and historic hydroacoustic and shoreline electroshocking surveys suggest that fish species in Carpenter Reservoir use habitat in accordance with theoretical preferences as it becomes available with changing operational conditions. Since 2010, annual maximum and minimum reservoir elevations have varied considerably (e.g., the difference between maximum and minimum elevation was 35 m in 2010 and <15 m in 2014 and 2016; Figure 3-1). Not only do habitat conditions vary significantly in the reservoir and Middle Bridge River, the degree to which habitat varies and the timing of variations is different in each year. Bull Trout are mobile and adaptable to different habitat conditions, which is reflected in short-set gill netting and shoreline electroshocking CPUE. Bull Trout CPUE is highest in productive, thermally optimal habitats including tributary confluences and the boundary of the reservoir and Middle Bridge River, and are consistently found in these habitats from April to October. In contrast, Rainbow Trout and kokanee are more reliant on lacustrine habitat and are generally only captured in littoral areas prior to spawning migrations. Lacustrine species are more vulnerable to reservoir drawdown and kokanee and Rainbow Trout populations appear to fluctuate to a greater degree than Bull Trout in the Carpenter Reservoir watershed. For example, gill netting and stream surveys performed in 1994 and 1995 encountered high numbers of Rainbow Trout and almost no kokanee (Griffith 1999), whereas BRGMON-

04 monitoring in Years 1 through 4 found low Rainbow Trout catches (gill netting and shoreline electroshocking) and substantial numbers of kokanee spawners (stream surveys).

Although the pilot gill netting provided valuable qualitative insight into species presence and absence in the four habitats, catches were too low to quantify critical habitat for any species. Catch rates could be increased using overnight gill net sets; however, overnight sets would result in high mortality rates and would interfere with tagging programs in the reservoir. In addition, gill netting in Carpenter Reservoir is challenging and hazardous due to large volumes of submerged debris and high winds travelling through the narrow valley. Short-set gill netting will not be repeated in Year 5 due to hazardous conditions and the inability of gill netting to identify critical habitat areas for any species. Species distributions and habitat preferences will continue to be investigated using CPUE data from electroshocking during the Bull Trout mark-recapture period. Additional methods such as hydroacoustic surveys may be evaluated in future years to determine habitat preference for all species under varied reservoir conditions (see recommendations).

4.3 Bull Trout Abundance Estimation and Movement Analysis

4.3.1 Bull Trout Open Mark-Recapture Abundance Estimation

Goodness-of-fit testing indicated that POPAN open mark-recapture models could not accurately or precisely fit Bull Trout mark-recapture data from Years 1 through 4. The top four models of the candidate set differed by 3.4 AICc points with a parameter difference of 2, suggesting virtually equal fit (Table 3 5). In addition, the behaviour of the top three models (each with one fixed parameter) was similar: large fluctuations in annual capture data were accounted for by large fluctuations in the two time-varying parameters. This model-fitting behaviour resulted in substantial differences in parameter estimates amongst the top models. Ideally, all model parameterizations should produce relatively consistent parameter estimates or trends in time-varying parameter estimates, and inconsistencies suggest the model cannot determine the true characteristics of the population. Mark-recapture models with time-varying parameters may be biologically-appropriate for Bull Trout in Carpenter Reservoir considering the annual variation in environmental conditions that occurs in the watershed. Time-varying models can account for changes in population dynamics (e.g., survival, birth rates, immigration and emigration, etc.) as well as changes in effort and habitat characteristics (Budy et al 2017). CPUE variations between Years 3 and 4 suggest capture probability may vary among years in Carpenter Reservoir, and large fluctuations in annual reservoir maxima and minima may affect annual survival and the probability of entrance into the population.

Mark-recapture model uncertainty may be related to insufficient mark-recapture data or unequal capture probabilities within mark-recapture periods (Table 3-3). Additional years of mark-recapture data could increase the accuracy and precision of model estimates and interpret goodness-of-fit testing results. In Year 4 we used data from Years 1 and 2 to obtain sufficient mark-recapture events (i.e., three periods) to run the open population models. Years 1 and 2 were not designed within the mark-recapture framework, and their inclusion may be responsible for the large fluctuations in capture rates and subsequent uncertainties in model results. Following Year 5, mark-recapture models of Years 1 through 5 and Years 3 through 5 will be compared to determine how the inclusion of Years 1 and 2 affected model results.

Acoustic telemetry gates detected a one-way migration (from east to west) of Bull Trout during the open mark-recapture study period, which may have resulted in the model assumption of equal catchability being violated during the Year 3 program. A portion of Bull Trout may have been foraging during the study period while others were migrating in preparation of spawning, and their susceptibility to different capture methods likely varied. Angling CPUE was lower in Year 4 relative to Year 3 despite similar gill netting and electroshocking CPUE (Figure 3-10), suggesting Bull Trout were (a) less susceptible to angling due to behavioural differences, or (b) angling success was affected by physical conditions in the reservoir (e.g., elevation, Figure 3-8). In Year 5, the mark-recapture program will take place in late June (approximately one month earlier than in Years 3 and 4) to avoid sampling during the Bull Trout spawning migration. Moving the mark-recapture period may affect catch rates and recapture percentages because the reservoir will not have reached its maximum elevation (physical conditions may be substantially different); however, meeting the assumption of equal capture probabilities is critical for open mark-recapture modelling and will be prioritized in Year 5.

In Year 5, the mark-recapture program will be expanded to include the eastern portion of the reservoir (i.e., from Jones Creek to the Terzaghi Dam). The mark-recapture study area was originally restricted to the western half of the reservoir to allow for sufficient effort distribution throughout the study area and to maximize catch rates. Mark-recapture CPUE suggests Bull Trout are almost exclusively found at tributary confluences and in thermally optimal littoral areas during summer months. In Year 5, effort in pelagic areas will be reduced (where Bull Trout CPUE is low) and tributary confluences and littoral areas in the eastern half of the reservoir will be included in the study. This will allow for a whole-reservoir estimate of adult Bull Trout abundance to be generated for Carpenter Reservoir using an open mark-recapture modelling framework.

4.3.2 Bull Trout Movement Analysis

Acoustic telemetry successfully detected a migration of Bull Trout westward through Carpenter Reservoir and into the Middle Bridge River beginning in July and extending into late October. This migration pattern agrees with radio telemetry data from Chamberlain et al. (2001), where radio-tagged Bull Trout were found to move into the Middle Bridge River in early summer. Not all Bull Trout tagged in Year 3 moved into the Middle Bridge River (31% remained in the reservoir), indicating that Bull Trout spawning likely also occurs in other Carpenter Reservoir tributaries. Incidental captures of juvenile Bull Trout agree with this hypothesis: a Y-O-Y Bull Trout was captured in Truax Creek during Year 4 tributary electroshocking, and Y-O-Y Bull Trout have also been observed in sub-catchments of Gun and Tyaughton Creeks (Griffith 1999). Acoustic data suggest that Bull Trout movement patterns and behaviour are highly variable in Carpenter Reservoir, a finding consistent with Chamberlain et al. (2001). Some tagged Bull Trout crossed acoustic gates multiple times during the year, some were detected by a gate only once (potentially while undergoing a spawning migration), and some were detected continuously by a gate for an extended period (Figure 3-5).

Detection efficiency (i.e., the ability of a gate to successfully detect the movement of a Bull Trout through the gate) was 56% at the reservoir gate and 42% at the river gate over the Year 3 acoustic monitoring period. Although some Bull Trout were detected migrating from the river back to the reservoir, several Bull Trout either remained in the river or their return migration was not detected by the river gate due to low detection efficiency. Missed crossing events cannot be identified until a subsequent event is detected, and the detection efficiency from Year 3 may change with the addition of Year 4 data. For example, one Bull Trout (tag 34782) was detected moving into the Middle Bridge River in mid-November and was subsequently detected on the eastern side of the reservoir gate in April of 2016, suggesting both the river and reservoir gates failed to detect the movement of the tag as it migrated eastward through the reservoir.

Improving detection efficiency at both acoustic gates will be prioritized during Year 5. Biofouling and debris interference may have affected the detection range of individual receivers, particularly those in the Middle Bridge River. Decreased detection ranges of individual receivers would subsequently lower the overall efficiency of the Middle Bridge River gate. In Year 5, acoustic receivers in the Middle Bridge River will be inspected and cleaned monthly to reduce biofouling and ensure receivers are located as deep as possible to maximize detection range. At the reservoir gate, changing physical conditions (e.g., turbidity, reservoir depth, thermocline development) may have affected the detection ranges of individual receivers and subsequently reduced the overall detection efficiency of the gate. A sentinel tag will be installed near the reservoir gate in the spring of Year 5 and will remain in place throughout the year, transmitting at a known interval. The sentinel tag can be used to determine how annual fluctuations in the detection range of individual receivers may affect detection efficiency of the reservoir gate.

Detection efficiency at the reservoir gate may also be related to the overlap between detection ranges of the two lines of receivers, which results in both sides of the gate detecting the same tag transmissions. Depending on the location of the tag, tag collisions, etc., the final transmissions from a tag may be detected by both lines of receivers or by the line of receivers furthest from the true location, leading to an incorrect interpretation of the tag's final position. We anticipated this issue and increased the spacing of the two lines of receivers in Year 4 from 350 m to 550 m to reduce the overlap of tag detection by both lines of receivers. The effectiveness of increasing the space between the two lines of receivers will be evaluated when Year 4 acoustic data are analyzed in Year 5, and the spacing between the two lines of receivers may be increased further if necessary.

The low detection efficiency of the acoustic gates did not directly influence the Year 4 open mark-recapture model results, but may have led to incorrect conclusions related to the open mark-recapture model assumption (Table 2-1). Missed crossing events may have resulted in incorrectly assuming Bull Trout remained within the study area (i.e., the proportion of tagged Bull Trout that migrated towards the Middle Bridge River may have been larger than assumed) or may have resulted in overestimating the proportion of fish that left the study area (i.e., Bull Trout may have migrated into the study area from the Middle Bridge River). Despite these uncertainties, acoustic telemetry indicates that a portion of tagged Bull Trout moved westward (towards the Middle Bridge River) during the Year 3 mark-recapture period. The timing of this potential migration agrees with radio telemetry data of Chamberlain et al (2001) as well as adfluvial migration patterns of Bull Trout throughout British Columbia (McPhail 2007). Although the exact movement patterns of Bull Trout are uncertain, acoustic telemetry suggests a Bull Trout spawning migration may have occurred during the mark-recapture period that may be partially responsible for bias in mark-recapture estimates.

4.4 Biological Characteristics

Biological data including length, weight, and age were collected for all species in Year 4, adding to a growing database of biological characteristics in Carpenter Reservoir and the Middle Bridge River. Age-length-keys and von Bertalanffy growth models were fit to Bull Trout, Rainbow Trout, and Mountain

Whitefish length and age data. During von Bertalanffy modelling, low sample sizes at minimum and maximum ages and fork lengths and uncertainty in the ages of median-length fish (particularly for Rainbow Trout) resulted in uncertainty and model fitting issues for some species. For Rainbow Trout and Mountain Whitefish, a larger sample size of older/larger fish is needed to obtain a more accurate estimation of the von Bertalanffy L_{inf} parameter. Length and age relationships for all species will be improved with the collection of additional data in future monitoring years. Completed time series of biological characteristics will be analyzed to determine whether fish populations in Carpenter Reservoir changed over the 10-year monitoring period, and/or whether changes in biological characteristics were related to the operation of Terzaghi and Lajoie Dams.

4.5 Kokanee Tributary Visual Surveys

Tributary visual surveys during Years 2 through 4 of BRGMON-04 and historic surveys suggest kokanee undergo population cycles in the Carpenter Reservoir watershed. Tributary electroshocking by Griffith (1999) in September 1995 and by Chamberlain et al. (2001) in August and September 2000 found almost no spawning or migrating kokanee, whereas adult spawners were frequently encountered by BRGMON-04 in Years 1 through 4. Kokanee rely heavily on lacustrine habitat when not spawning or migrating, and years of extreme drawdown may result in high entrainment rates of density-related mortality of adult kokanee. Extreme drawdowns in the mid-1990s may explain the low kokanee numbers observed by Griffith (1999) and Chamberlain et al. (2001). Spawner enumerations during BRGMON-04 would indicate that the kokanee population has increased from low densities during the late 1990s.

We observed a greater proportion of kokanee spawners in the drawdown zones of surveyed tributaries in Year 4 relative to Year 3. Higher counts in the drawdown zone reflect a lower maximum reservoir elevation in Year 4 that resulted in a larger amount of drawdown habitat being available to kokanee during their spawning migration. No evidence of spawning behaviour was observed by kokanee in the drawdown zone, and kokanee likely migrate further upstream to spawn. Although kokanee likely spawn upstream where redds would not be affected by inundation or dewatering, the presence of a large drawdown zone may still be problematic to kokanee spawners. Drawdown areas are highly braided and void of cover, exposing spawners to both increased predation risk and increasing the time during which they are vulnerable to predation.

4.6 Rainbow Trout Tributary Electroshocking Surveys

Monthly tributary electroshocking surveys in Year 4 identified successful Rainbow Trout spawning in Marshall, McDonald, and Truax Creeks due to the presence of age 0 Rainbow Trout. Rainbow Trout CPUE was substantially higher in McDonald and Marshall Creeks relative to Truax Creek (only one Y-O-Y was captured in Truax Creek), potentially due to the presence Rainbow Trout lakes upstream of both tributaries. Resident populations of Rainbow Trout may occur in Marshall and McDonald Creeks, as evidenced by small-bodied spawners. We could not confirm whether seeding from upstream populations occurred in Marshall or McDonald Creeks, but the presence of Y-O-Y Rainbow Trout above the Marshall Creek waterfall migration barrier suggests that seeding is possible from upstream lakes and/or stream resident Rainbow Trout populations.

Rainbow Trout tributary electroshocking will be continued in Year 5 to increase sample sizes of juvenile age classes and calculate juvenile growth rates. A larger sample size is also needed to confirm Rainbow Trout spawning success in the tributaries, determine whether resident stream populations are present in tributaries (using length-weight relationships), and determine whether seeding may be occurring from populations upstream from Carpenter Reservoir. Additional ageing analysis may help to determine growth characteristics of Y-O-Y Rainbow Trout in Carpenter Reservoir streams. In Year 4 we corrected for unidentifiable growth over the first winter for all Rainbow Trout; however, this correction may not be appropriate if some Y-O-Y produce identifiable growth patterns in their first winter. If sufficient age classes are identified, individual length-at-age relationships will be examined for Rainbow Trout in Marshall and McDonald Creeks to determine whether these creeks support resident populations whose growth characteristics differ from fish captured in Carpenter Reservoir.

5 Status of Monitoring and Recommendations

While minor refinements continue to improve BRGMON-04 methods and analyses, larger methodological changes could be considered to target uncertainties in fish and fish habitat in Carpenter Reservoir and the Middle Bridge River. Whether methodological changes are necessary depends on monitoring priorities identified by BC Hydro towards answering key management questions. Alternative methods are briefly presented here for future discussion and consideration:

- **Identifying critical Bull Trout spawning locations.** The relative importance of Bull Trout spawning in Carpenter Reservoir tributaries, the Middle Bridge River, and the Hurley River is currently unknown. We propose to use a combination of acoustic and radio telemetry (fixed stations and mobile tracking) to monitor spawning migrations at a fine spatial scale and identify critical spawning habitat. This will inform when, and to what degree, Bull Trout spawning may be affected by reservoir operations.
- **Identifying energy pathways in Carpenter Reservoir.** The relative importance of different energy sources to fish production in Carpenter Reservoir has important implications for how reservoir management may be manipulated to increase productivity. Stable isotope analyses can be used to trace energy movements through food webs and determine critical energy sources for each species. A limited stable isotope sampling program completed by Leslie (2003) could be expanded (both spatially and temporally) to identify energy pathways in the watershed. Stable isotope sampling and processing is labour intensive and would require additional resources or major changes to the current BRGMON-04 monitoring program.
- **Density and distribution of fish species in Carpenter Reservoir.** Pilot short-set gill netting failed to determine species distributions and critical habitat in Carpenter Reservoir during different physical conditions. Hydroacoustic sampling is often used to determine fish density and distribution in lakes and reservoirs, and a hydroacoustic survey was performed in Carpenter Reservoir in 2000 prior to BRGMON-04 monitoring. Hydroacoustic surveys could be repeated in Carpenter Reservoir under different conditions to obtain a comprehensive understanding of fish distribution and densities in the reservoir under different reservoir conditions. Hydroacoustic sampling and analysis is intensive and would likely require additional resources than currently available in BRGMON-04.

BRGMON-04 will use a weight-of-evidence approach incorporating multiple sources of direct and indirect evidence to answer management questions outlined in the TOR. To date, the monitor is on track to answering all management questions to the most robust degree possible given the extent of the system and the limited monitor duration. Time series data and short term surveys are being compiled to increase understanding of fish species and habitat in the reservoir and Middle Bridge River, and minor adjustments continue to refine the monitoring approach and improve the quality of results. Large methodological changes could be considered (as described above) to prioritize certain management questions and data gaps, upon the discretion of current management requirements. A summary table on page iv of this report provides detailed descriptions relating methods in Year 4 to each BRGMON-04 management question.

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