# Bridge River Project Water Use Plan

## Carpenter Reservoir and Middle Bridge River Fish Habitat and Population Monitoring

## Implementation Year 5

## Reference: BRGMON-4

**Study Period: October 2016-September 2017**

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**March 1, 2018**

# Bridge-Seton Water Use Plan

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## Carpenter Reservoir and Middle Bridge River Fish Habitat and Population Monitoring

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Prepared for: St'át'imc Eco-Resources

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## Executive Summary

The objectives of the Carpenter Reservoir and Middle Bridge River Fish Habitat and Population Monitor (BRGMON-4) are to collect comprehensive information of the life history, biological characteristics, distribution, abundance, and composition of the fish community in Carpenter Reservoir and the Middle Bridge River, and to provide information required to link the effects of reservoir operations on fish populations. Specific monitoring activities in Year 5 (2016-2017) included Bull Trout abundance estimation using an open-mark recapture model in the reservoir; monitoring of Bull Trout movement behavior through acoustic telemetry; shoreline electroshocking indexing of Bull Trout, Rainbow Trout, kokanee, and Mountain Whitefish; abundance indices of kokanee spawning in Carpenter Reservoir tributaries; backpack electroshocking in tributary habitat above and within the reservoir drawdown area; and Mountain Whitefish spawning surveys (egg mats and angling) in the Middle Bridge River.

The Bull Trout mark-recapture study area was expanded in Year 5 (2017) to include the entire reservoir (as opposed to the western half as in previous years) and data from Years 1 through 4 were retrospectively adjusted for the mark-recapture analysis. The top-ranked mark-recapture model (i.e., with a fixed capture probability) indicated a Year 5 Bull Trout population of 1,237 (SE 337). The estimated Bull Trout mark-recapture abundance ranged from 291 individuals in Year 2 (SE 84) to 1,530 (SE 400) in Year 3 for the top-ranked model. Mark-recapture results are preliminary and additional years of data are required to refine the modelled abundance estimate and link Bull Trout abundance to management of Carpenter Reservoir and the Middle Bridge River.

Year 5 (2017) acoustic data will not be available until early 2018; however, acoustic data from Year 4 (2016) suggest Bull Trout may have remained in the reservoir and undergone fewer movements into and out of the Middle Bridge River compared to Year 3 (2015). This change in behaviour may be related to lower maximum reservoir elevations in 2016, which concentrated suitable foraging habitat in the eastern half of Carpenter Reservoir. Although we did not observe a decline in mark-recapture Bull Trout abundance, continued low maximum reservoir elevations could lead to reduced Bull Trout productivity because of decreased habitat volume and increased competition for prey.

Results from shoreline electroshocking indexing (and biological data collected therein) in Years 1 through 5 (2012-2017) suggest that reservoir elevation significantly affects the distribution and condition of fish in Carpenter Reservoir. Reservoir elevation and lacustrine habitat area were lower in Years 4 and 5 (2016 and 2017) relative to previous monitoring years. Elevation was particularly low in 2017 (Year 5), when the reservoir was reduced to ~615 masl (the lowest elevation observed during BRGMON-4) and remained low for an extended period. Fish densities generally shifted east in Years 4 and 5 towards

the contracted lacustrine habitat, and a decrease in Fulton's condition factor occurred for Bull Trout, Rainbow Trout and Mountain Whitefish. Bull Trout condition was significantly lower in Year 5 relative to Years 1 through 4 (Tukey's HSD p-value <0.001), and lower in Years 4 and 5 relative to Years 1 through 3 for both Rainbow Trout (p-value 0.01) and Mountain Whitefish (p-value <0.001). The delay in decreasing condition factor for Bull Trout relative to Rainbow Trout and Mountain Whitefish may indicate that reservoir operations directly affected forage species condition and indirectly affected Bull Trout condition because of decreased prey quality.

Kokanee spawner counts in Year 5 (2016) did not indicate a decrease in kokanee spawner abundance despite entrainment of kokanee in the spring of 2015 and 2016 (due to modified operations of Lajoie Dam and Carpenter Reservoir). The number of kokanee entrained was uncertain and potentially too small to cause a reduction in kokanee productivity. If the entrained kokanee were mostly immature, however, a delayed effect may be detected in Year 6 or 7 of BRGMON-4. We performed detailed spawner and redd surveys during peak spawning in Carpenter Reservoir tributaries and determined that a majority of paired kokanee and identifiable redds were located above the allowable maximum reservoir elevation. Considering that kokanee are primarily spawning in higher elevation areas, reservoir filling during spawning and incubation is not likely to substantially affect kokanee productivity in the reservoir.

Mountain Whitefish angling and egg mat surveys were completed in the Middle Bridge River in 2005, 2009, 2011, 2012, and again in 2016 (Year 5 of BRGMON-4). Migration timing, peak spawner counts, and 50% hatch dates were relatively consistent among years, but egg mats deployed in 2017 were unsuccessful at collecting Mountain Whitefish eggs (compared to captures in previous years). The decline in egg counts does not suggest a crash in the Mountain Whitefish population (due to comparable adult captures in all survey years), but was more likely related to the increased prevalence of sand and fines at the egg mat site locations compared to the primarily cobble and gravel substrates recorded in previous years. Stage heights in the Middle Bridge River were consistent throughout the Mountain Whitefish egg incubation period, suggesting management of Lajoie Dam did not affect Mountain Whitefish productivity in Year 5.

Data from Year 5 (2016-2017) of BRGMON-4 builds on previous monitoring in Carpenter Reservoir and the Middle Bridge River. Continued monitoring will help determine whether changes in fish indices and habitat characteristics are related to the management of Carpenter Reservoir and the Middle Bridge River. Due to the complex nature of Carpenter Reservoir and the broad scope of the BRGMON-4 management questions, developing a long-term dataset of biological characteristics is key for answering the management questions. For Year 6 we recommend repositioning acoustic monitoring systems to inform

Bull Trout lacustrine habitat use and residency time at high-use tributary confluences. We also recommend considering targeted monitoring in the Middle Bridge River to pinpoint critical Bull Trout spawning habitat, stable isotope methods to identify energetic pathways in the Carpenter Reservoir watershed, and hydroacoustic surveys to determine densities and distributions of all reservoir fish species.

## Status of BRGMON-4 objectives and management questions following Year 5 (2016-2017)

| Study Objectives | Management Questions | Management Question Status: Contributions from Year 5 |
|---|---|---|
| 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? | This question is being answered through the collection of baseline biological data for select fish species in Carpenter Reservoir (Bull Trout, Rainbow Trout, Mountain Whitefish, and kokanee). Metrics being described include:<br>- Condition factor and length vs. weight relationships<br>- Von Bertalanffy growth coefficients and asymptotic lengths<br>- Index of abundance for Bull Trout (the top predator; mark-recapture estimate)<br>- CPUE index values for all species (shoreline electroshocking)<br>- Tributary spawner abundance indices for kokanee<br>- Bull Trout movement behavior (spatial CPUE, acoustic tagging, PIT tags)<br>- Forage fish distributions (spatial CPUE) |
| 2: Provide information required to link the effects of reservoir operation on fish populations. | 2: Will the selected alternative result in positive, negative, or neutral impact on abundance and diversity of fish populations? | In Year 5 (2016-2017), we compiled historic data from shoreline electroshocking surveys in 2001, Mountain Whitefish spawning surveys in the Middle Bridge River, and previously-published scientific research in Carpenter Reservoir. These data provide insight into conditions prior to the implementation of N2-2P. A weight-of-evidence approach is being used to understand how the revised operating regime has affected fish in Carpenter Reservoir. |
| | 3: Which are the key operating parameters that contribute to reduced or improved productivity of fish populations in Carpenter Reservoir and Middle Bridge River? | Reservoir elevation was relatively low in Years 4 and 5 (2015-2017), and preliminary results suggest low reservoir elevation affected the distribution and condition of fish in Carpenter Reservoir. Low elevation and high discharge into the Lower Bridge River also caused entrainment of kokanee (and possibly other species) through Terzaghi Dam. Despite contracted fish distributions and a decrease in condition, we did not observe a corresponding decline in the abundance indices of Bull Trout or kokanee spawners in Years 4 and 5. |
| | 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 | In Year 5 (2016-2017), we repeated Mountain Whitefish spawner surveys completed by TEC in 2005, 2009, 2012, and 2013. Egg mats were unsuccessful at capturing eggs in Year 5 at index sites from previous years, and in-stream flow likely altered substrate characteristics at the index sites since the most recent survey (2013). The Middle Bridge River stage height remained relatively stable |

| | |
|---|---|
| populations in Carpenter Reservoir and the Middle Bridge River? | throughout the Mountain Whitefish incubation period, minimizing the risk of egg dewatering (in the surveyed area) and decreased Mountain Whitefish productivity due to Lajoie Dam operations. A stranding event (resulting in the mortality of kokanee spawners) occurred in the eastern portion of the Middle Bridge River in September of Year 5 (2016-2017), possible due to a combination of natural water level declines and a ramp down at Lajoie Dam. The stranding event was estimated to kill ~80 kokanee spawners, which is not likely to have affected kokanee productivity in the reservoir. |
| 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? | This question will be answered using the results of management questions 1 through 4. |

## Acknowledgements

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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 at that time. Today, the Bridge River complex 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 Terzaghi Dam (apart from periodic spill releases), and a four-kilometer section of channel remained dewatered before being fed by downstream groundwater and tributary inflows. A flow agreement implemented in 2000 resulted in an average flow release of 3.0 $m^3$ $s^{-1}$ from Terzaghi Dam that continuously watered the Lower Bridge River channel. The average annual discharge was increased to 6.0 $m^3$ $s^{-1}$ in May 2011.

The Bridge River Valley is an important cultural and sustaining resource for the St'át'imc First 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. The initial WUP was completed in 2001, and in 2003, a multi-stakeholder consultative committee (Bridge River Consultative Committee 2003, hereafter BRCC) performed a review of more than 20 proposed alternative operating strategies outlined in the WUP process. The BRCC provided recommendations to BC Hydro, and in 2011 a final WUP was accepted that implemented an alternative operating strategy (N2-2P) that aimed to balance fish and wildlife health, recreational opportunities, flood management, water security, and power generation (BC Hydro 2011). 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-4 monitoring program (BC Hydro 2015).

N2-2P did not include substantial changes to the normal operating conditions of Carpenter Reservoir. The operating objectives for minimum and maximum reservoir elevation remained at 606.55 m and 651.08 m, respectively. A soft maximum elevation target of 648 m was suggested for Carpenter Reservoir at the end of the snowmelt season in mid-August; however, BC Hydro conceded this would likely be exceeded due to higher priorities elsewhere (Carpenter Reservoir elevations are of low priority in the Bridge River power system; BC Hydro 2011). The WUP included new recommendations for discharge from Lajoie Generating Station into the Middle Bridge River. A minimum flow schedule was developed relating discharge to Downton Reservoir elevations (with a minimum discharge of 5.7 $m^3$ $s^{-1}$), and maximum ramping rates of 2.5 cm $hr^{-1}$ and 15 cm $day^{-1}$ were recommended.

The extent to which N2-2P was expected to affect fish species in Carpenter Reservoir and the Middle Bridge River is unclear. The WUP stated that "for Carpenter Lake reservoir, the proposed conditions in [the] Water Use Plan are not expected to impact fish or fish habitat" (BC Hydro 2011). In contrast, an explicit objective of the BRCC during the WUP review was to maximize abundance and diversity of fish in all parts of the power system, and expected outcomes included improvements in Mountain Whitefish (*Prosopium williamson*) egg survival in the Middle Bridge River, and a 30% improvement in the fisheries index of Carpenter Reservoir (BRCC 2003). The BRCC report does not detail how or why the 30% improvement target was developed, and this target was not mentioned in the final WUP document.

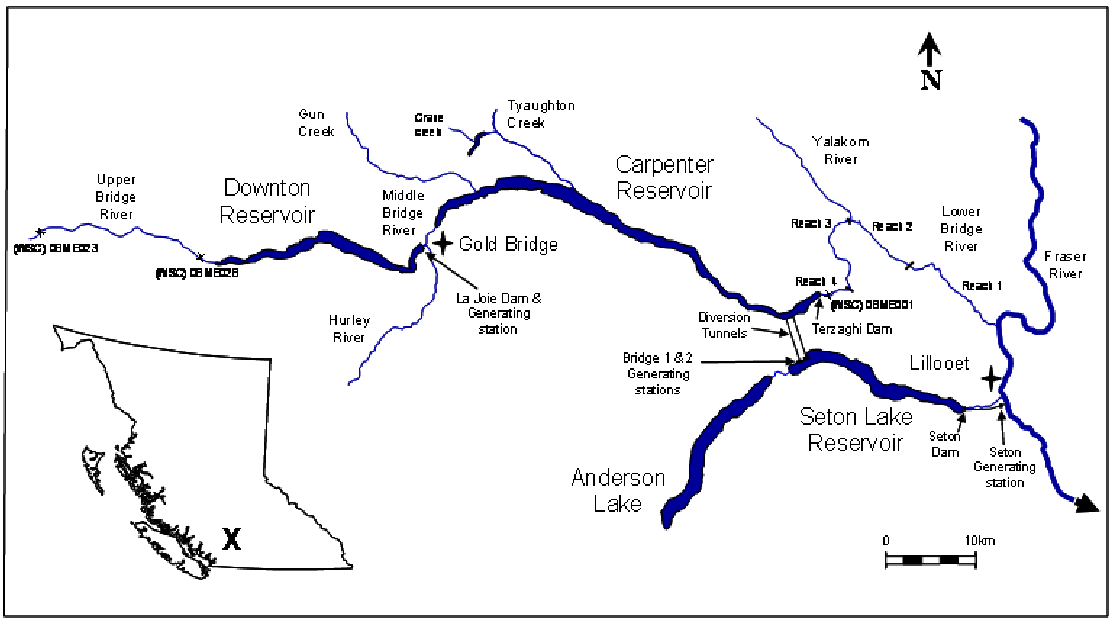


**Figure 1-1 Bridge River power system near Lillooet, British Columbia**.

## 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 (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 gillnet surveys in pelagic areas of the reservoir. Rainbow Trout (*Oncorhynchus mykiss*) and Bull Trout (*Salvelinus confluentus*) catches 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.

Gillnetting near the Bridge 1 and Bridge 2 diversion tunnels in the eastern pelagic portion of Carpenter Reservoir (bottom and mid-water depths) yielded high catches of Rainbow and Bull

Trout, and low catches of kokanee (*Onchorhynchus nerka*). Gillnetting during high and low reservoir elevations suggested Rainbow and Bull 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 residence time in the reservoir (Perrin and Macdonald 1997; Harding et al. 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. Chamberlain (2001) also performed two years of Bull Trout radio telemetry and kokanee tributary spawner surveys. 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 two kokanee carcasses were observed (in Gun Creek).

Energetic food webs in Carpenter Reservoir and the Middle Bridge River were examined in 2001 using stable isotopes to identify primary energy sources for fish species in the reservoir (Leslie 2003). Samples were collected across five 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 were indistinguishable, and it was not possible to determine which of the two energy sources most influenced fish 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-4) was developed during the WUP process to address these uncertainties. BRGMON-4 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)<br>- Gill netted on 4 occasions, primarily near the diversion tunnels<br>- Monitored limnology in the reservoir | - Spawning habitat area was limited by accessible stream length, availability of spawning substrate, and lack of cover<br>- Concluded the standing stock of fish in tributaries was below theoretical juvenile rearing capacity<br>- High gill net catches were obtained for Bull Trout and Rainbow Trout relative to other regional lakes but lower kokanee density relative to 1993<br>- 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)<br>- Performed stream walks, assessed migration barriers, and monitored temperature and turbidity | - Spawning Rainbow Trout were observed in 6 tributaries<br>- Peak spawning occurred from June 11 to July 23, 1999<br>- 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 at a water surface elevation of 645 masl | - Analysed number of fish per transect and depth of fish<br>- Concluded that more fish were present in the Eastern portion of the reservoir<br>- 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<br>- Quantified the effects of an experimental drawdown of the Middle Bridge River on | - Described Bull Trout movement (small sample size)<br>- Monitored Middle Bridge River ramp-down in late July/early August<br>- 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 |

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| | | fish populations and habitat<br>- 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<br>- 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.<br>- 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.<br>- 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<br>- Mountain Whitefish CPUE was highest in the Middle Bridge River and at tributaries in the western portion of the reservoir<br>- 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.<br>- 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<br>- 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.<br><br>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-4 addresses five management questions identified during the WUP process (BC Hydro 2012):

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?

Carpenter Reservoir is a large and complex system, and BGRMON-4 is the first long-term research study to take place in the reservoir. The terms of reference (TOR) provided initial hypotheses and methods towards answering the management questions, but the TOR was modified considering insights from Years 1 and 2 (2012-2014). Initial monitoring indicated that many of the proposed methods were poorly suited for Carpenter Reservoir and hypotheses including all species could not be answered in the scope of BRGMON-4 (see details in Putt et al. 2016a). The TOR was amended in March 2015 to include revised hypotheses and modifications to the original methodologies (BC Hydro 2015). Additional years of monitoring indicated that the revised hypotheses did not adequately answer the management questions, and the hypotheses were removed from project planning and reporting.

BRGMON-4 will inform the management of minimum and maximum elevations in Carpenter Reservoir, minimum elevations in Downton Reservoir, and management of releases from Lajoie Dam. The monitor 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 and fish habitat, and whether current management practices can be refined to reduce negative impacts or enhance reservoir fish populations. Management questions will be answered through a weight-of-evidence approach. BRGMON-4 will focus 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 the monitoring period.

# 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 (Figure 1-1). Native fish in Carpenter Reservoir include Bull Trout, Rainbow Trout, Mountain Whitefish, Redside Shiner (*Richardsonius balteatus*), Bridgelip Sucker (*Catostomus columbianus*), and Coastrange sculpin (*Cottus aleuticus*). In the early 1970s, roughly 1,153,000 kokanee (a non-native species) were stocked in Carpenter Reservoir by the Province of British Columbia (likely for recreational purposes) and are still present in the reservoir (Chamberlain et al. 2001).

Carpenter Reservoir water is diverted through two tunnels near the eastern end of the reservoir that discharge into Seton Lake via the Bridge 1 and Bridge 2 generating stations in Shalalth. Reservoir elevation is controlled by BC Hydro and changes substantially during annual cycles in the reservoir. At low pool (generally 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 4,620 ha (Perrin and Macdonald 1997). The maximum depth at full pool is 55 m in the lacustrine portion adjacent to Terzaghi Dam.

Carpenter Reservoir becomes thermally stratified around June and achieves fall turnover by mid to late October. Thermal stratification is more pronounced in the eastern, lacustrine portion of the reservoir and lessens closer to the boundary of Carpenter Reservoir and the Middle Bridge River. Cold, turbid waters flow into the reservoir via the Middle Bridge River and sink to create a dense, turbid layer along the reservoir bottom and a warm, less turbid layer at the surface (Perrin et al. 2016). Primary productivity is relatively low in Carpenter Reservoir due to high turbidity and short water residence times, and productivity is generally concentrated in warm, clear water at the top of the water column. During years of extreme reservoir drawdown, lacustrine habitat quality and quantity decrease, and the length of the Middle Bridge River increases. Lower reservoir elevations also result in shorter water residence times, which can decrease zooplankton productivity in the reservoir (i.e., if residence times become shorter than the zooplankton lifespan; Perrin et al. 2016).

There are approximately 20 major tributary inflows to Carpenter Reservoir, but five sub-basins contribute to the 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 Middle Bridge River Mountain Whitefish Spawning Assessment

### 2.2.1 Mountain Whitefish

Mountain Whitefish spawn in the Middle Bridge River from mid-November to late-December and peak hatching occurs in early- to mid-February (Tisdale 2010, McPhail 2007). Spawning and rearing success may be impacted by ramp-downs occurring at the upstream Lajoie Dam during the winter and spring. Mountain Whitefish are broadcast spawners and their eggs settle into interstitial areas of small cobble areas. Incubating eggs or newly hatched individuals could be desiccated and killed if a ramp down of Lajoie Dam causes water levels to drop in the Middle Bridge River. Determining the incubation timing and 50% hatch dates for Mountain Whitefish in the Middle Bridge River (calculated using accumulated thermal units, ATU) is important for predicting the times during which Mountain Whitefish are vulnerable to dewatering as a result of operations at Lajoie Dam.

Mountain Whitefish spawning in the Middle Bridge River was assessed in Year 5 (2016) with egg mat and angling surveys modelled after spawning assessments completed by Tisdale Environmental Consultants Inc. (TEC) in the Middle Bridge River in 2005, 2009, 2012, and 2013 (Tisdale 2010, 2013). Egg mats are passive samplers consisting of a porous furnace filter material into which Mountain Whitefish eggs settle and can be enumerated. When placed in low elevation areas, egg mats can indicate whether eggs would be at risk of desiccation following operation-related ramp downs, and also help to determine spawning and incubation timing. Weekly angling surveys were performed in November and December of 2016 to identify the timing of peak female ripeness and the mean age of spawners. Mountain Whitefish were angled weekly from November 1 to December 29, 2016 using single cured salmon eggs. Angling effort was initially distributed evenly among the five egg mat sites, but was later restricted to Sites 2 and 4 to maximize captures (relatively few fish were caught at the other three sites; Figure 2-1). A minimum of 30 Mountain Whitefish were captured during each survey and assessed for weight, fork length, age (via scale ageing analysis), sex (if possible), and sexual maturity. Sexual maturity was separated into three categories:

1. Not Ripe: No eggs or milt expelled via hand extraction.
2. Ripe: Eggs or milt expelled via hand extraction.
3. Spawned: Fish showed spawning characteristics, but abdomen was loose and little to no eggs or milt were expelled via hand extraction.

Egg mats were installed on November 1 at five sites in the river to measure weekly egg deposition, water depth, velocity, temperature, and turbidity (Figure 2-1; TEC 2010). We used spawning mats built by TEC consisting of furnace filter material attached to an angle iron frame measuring 0.77 by 0.92 m. To deploy the mats, two technicians waded into the river and positioned the mats alongside hydraulic seams. Rope was used to attach the mats to onshore anchor points. Egg mats were carefully removed each week and the number of Mountain Whitefish eggs attached to both sides were recorded before all eggs were removed and the mats were redeployed in the same locations.

Physical measurements of depth, velocity, turbidity, and water temperature were recorded weekly at each egg mat site. Velocity was the average of three velocity measurements collected via a Swoffer Model 2100 Current Velocity Meter at 60% of the maximum depth (Swoffer Instruments Inc., Washington, USA). Water temperature was measured using a hand-held waterproof thermometer and turbidity was the average of three measurements taken using a pre-calibrated Hanna Instruments turbidity meter (HI 93703, Hanna Instruments, Vancouver, Canada). Temperature loggers (TidbiT HOBO v2, Hoskin Scientific, Burnaby, Canada) deployed in the Middle Bridge River at Site 2 (Figure 2-1) and in the Hurley River ~50 m upstream from the confluence of the Middle Bridge and Hurley Rivers recorded hourly water temperature throughout the survey period.

The number of Mountain Whitefish, the proportion of ripe females, and combined weekly egg counts were summarized and compared to data collected by TEC in 2012 and 2013, and conclusions from surveys in 2009 (TEC 2010; 2005 and 2009 data were not available for direct comparison). We did not assess the sex of immature fish and therefore proportions of ripe females are relative to all Mountain Whitefish sampled in a survey. To determine when incubating eggs and newly hatched Mountain Whitefish are vulnerable to desiccation due to Lajoie Dam ramp downs, Middle Bridge River temperature data from the winter of 2015/2016 were used to calculate 50% hatch dates (based on spawning dates in 2016) using an ATU requirement of 327. We used 327 ATUs (from the lower Columbia River) because water temperatures in the Middle Bridge River are similar to those reported in the Columbia River during Mountain Whitefish egg incubation (R.L. & L 2001) and for consistency with ATU analysis by TEC (TEC 2010).

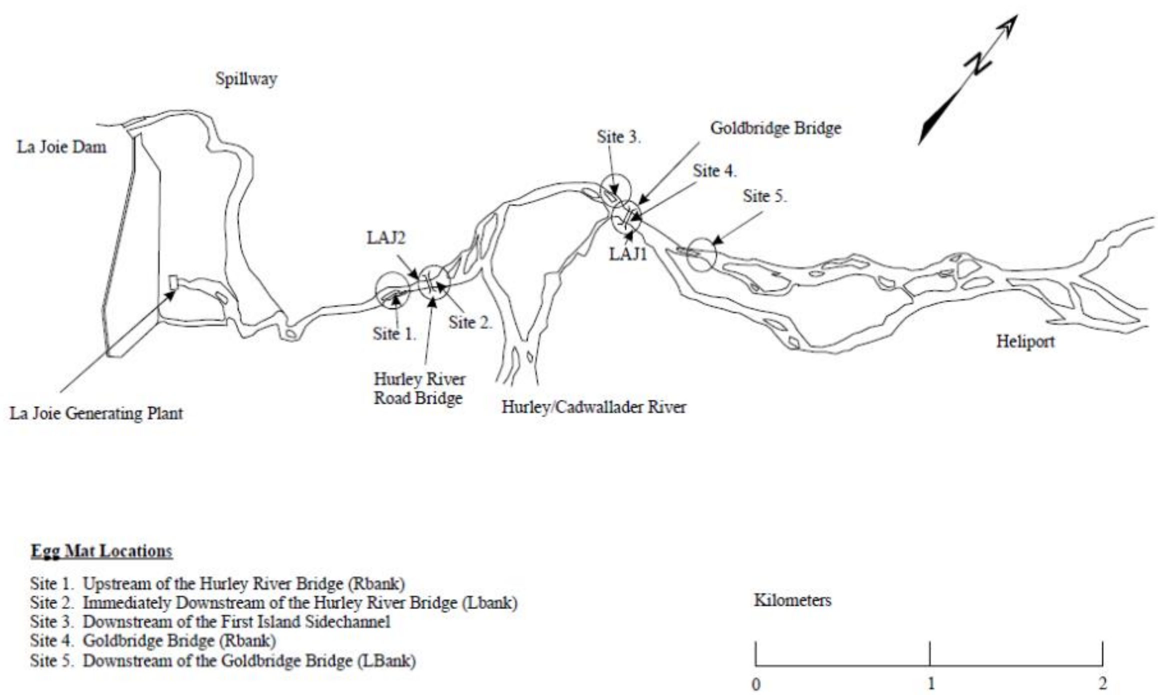


**Figure 2-1 Location of egg mat spawning sites on the Middle Bridge River identified by Tisdale Environmental Consultants Inc (Source: Figure 2 from TEC 2013).**

## 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). During subsequent sampling events, marked animals are recorded and released, and unmarked animals are tagged and released. The relative proportions of marked and unmarked Bull Trout are used in mark-recapture modelling to determine the survival and capture probabilities of the population and estimate the population size during each sampling event. 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 Mark-Recapture Field Program

The Year 5 mark-recapture period occurred between June 19 and July 7, 2017. The mark-recapture period was originally scheduled to correspond with maximum reservoir elevation in late July (to maximize available Bull Trout habitat); however, acoustic analysis from Year 4 (2016) indicated that Bull Trout migrate from Carpenter Reservoir into the Middle Bridge River during this period (Putt et al 2017). To avoid sampling during this migration period, we moved the Year 5 mark-recapture period ~1-month earlier than in Year 4. In 2017, we also expanded the mark-recapture study area to the entirety of Carpenter Reservoir (from the Gun Creek confluence to Terzaghi Dam). We had previously restricted the mark-recapture area to the western half of the reservoir; however, relatively low reservoir elevations in 2017 decreased habitat volume and site access in the original study area. To obtain adequate Bull Trout captures for mark-recapture modelling, we expanded the study to include the entire reservoir area. Bull Trout sampling outside of the original mark-recapture area occurred in Years 1 through 4 (2013-2016), and we were able to expand the scope of previous years to include all years in the mark-recapture analysis.

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 (~14 days[1]), shoreline overnight electrofishing (2 days), and shoreline and pelagic short-set gill netting (~3 days; 11.5 hours total soak time) was used to mark and recapture Bull Trout in 2017. All Bull Trout were PIT tagged and released at their capture location, and we collected lengths, weights, and age structures (pectoral fins). 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. CPUE (fish captured per hour of sampling) was calculated for all species and gear types using the equation:

[1] 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.

$$CPUE_{ij} = \frac{Catch_{ij}}{Time(hours)} \quad \text{Eq 1}$$

for species *i* using gear *j*.

Environmental data were recorded whenever possible (i.e., water temperature, water visibility, weather, sample duration, location coordinates), and method-specific characteristics were recorded for gillnetting (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 Mark-Recapture Modelling

We used two closely-related formulations of an open mark-recapture model to estimate Bull Trout abundance for Years 1 through 5 (2013-2017): the Cormack Jolly-Seber (CJS) model and the POPAN model (Seber 1982, Pollock et al. 1990, Schwarz and Arnason 1996). The two formulations estimate population abundance (our desired output) using slightly different methods (explained below). We tested the fit of multiple parameterizations of both formulations to ensure a comprehensive analysis. The models will be refined in future years as more mark-recapture data are collected and our understanding of Bull Trout behaviour grows. In future years we may also add additional parameters to the model (e.g., size classes) or apply Bayesian methods to inform parameters and describe uncertainty.

In all open mark-recapture models the probability of a fish being captured in a sample event is determined by two parameters: the apparent survival ($\varphi$) from sampling period $i$ to $i$+1 and the capture probability ($p$) within the $i^{th}$ sampling event. In an open model, the survival parameter is 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.

The survival and capture probabilities are used to build probability expressions for each of the possible encounter histories over the $K$ capture occasions. In the CJS formulation, multinomial maximum likelihood estimation is then used to derive estimates of apparent survival and capture probability for the population, where the likelihood is the sum of the probabilities of each possible encounter history and the binomial probability of loss on capture (see details and variance estimation procedures in Cooch and White 2006). The model can be time-dependent (i.e., unique survival and capture probability parameters are estimated for each sampling event) or parameters can be fixed across all time periods. In the CJS formulation, the apparent survival and capture probabilities are only modelled for marked fish, and the total number of fish in the population ($N$) at sampling event $i$ is not directly estimated. Instead, abundance and the standard error of abundance are calculated using estimated capture probabilities:

$$\hat{N}_i = \frac{n_i}{\hat{p}_i} \quad \text{Eq 2}$$

$$se(\hat{N}_i) = \frac{n_i(se[p_i])}{{p_i}^2} \quad \text{Eq 3}$$

where $n_i$ is the total number of fish (marked and unmarked) captured in period $i$ and $\hat{p}_i$ is the predicted recapture probability for period $i$ (Davidson and Armstrong 2002). An estimate of $N$ cannot be determined for 2013 because there is no recapture probability ($p$) estimated for the first sampling event.

In contrast to the CJS formulation, the POPAN model estimates the apparent survival and capture probability of both marked and unmarked fish, allowing the total abundance to be estimated. The multinomial maximum likelihood ($L$) function consists of three parts: the recapture of marked individuals and the binomial probability of loss on capture (identical to the CJS formulation), and the probability of first capture. The probability of first capture includes a new parameter ($b$), the probability of entrance from a super-population ($N$). The superpopulation is not the total population of Bull Trout in the reservoir, but instead represents a theoretical population that includes all fish (marked or unmarked) that have ever entered the population (see details in Cooch and White 2006, Schwarz and Arnason 1996).

$$L = P(first\ capture|\{p_i\},\{\varphi_i\}\{b_i\}) \cdot P(recapture|\{p_i\},\{\varphi_i\}) \cdot P(loss\ on\ capture|\{v_i\}) \qquad \text{Eq 4}$$

Not all parameters are identifiable in POPAN models with time-varying capture probabilities because of parameter confounding, and therefore not all parameters are estimated in each model parameterization (e.g., the survival and catchability from the final event cannot be distinguished; for more information on parameter identifiability, see Schwarz and Arnason 1996).

In the POPAN formulation, annual abundance ($N_i$) and births ($B_i$) are derived using the parameters estimated in Table 2-2 and the following equations:

$$N_1 = b_0 * N \qquad \text{Eq 5}$$

$$B_{i=2,3,\ldots K} = b_{i-1} * N \qquad \text{Eq 6}$$

$$N_{i=2,3,\ldots K} = N_{i-1} * \varphi_{i-1} + B_i \qquad \text{Eq 7}$$

AICc model selection (adjusted for small sample sizes, Burnham and Anderson 2002) was used to evaluate candidate models that included both fixed and time-varying survival ($\varphi$), capture probability ($p$), and entrance probability ($b$; POPAN formulation only):

$$AIC_c = 2k + 2\ln(\hat{L}) + \frac{2k(k+1)}{n-k-1} \qquad \text{Eq 8}$$

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 highest AICc support (i.e., the lowest AICc value) was selected as the preferred model.

We used parametric bootstrapping to examine the goodness-of-fit of POPAN and CJS models using a simulation estimation procedure (see Putt et al. 2017, Laake 2016). 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. 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.

All mark-recapture models were evaluated in R Project Software (R Core Development Team 2017) 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).

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

| 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 ($\phi_i$) 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). For example, the 25-day mark recapture program in 2016 was 7% of the interval between the previous sampling period. |

**Table 2-2 Estimated parameters in the POPAN and Cormack Jolly-Seber formulations of the Jolly-Seber model. Parameters unique to the POPAN model are italicized.**

| | |
|---|---|
| $p_i$ | The probability a fish is captured in event *i* |
| $\varphi i$ | 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 |

### 2.3.3 Movement Analysis

Acoustic telemetry was used to verify mark-recapture model assumptions about Bull Trout movement during and between mark-recapture periods. A key assumption of the open mark-recapture model is that fish have equal capture probabilities during the mark-recapture sampling period (Table 2-1). We used acoustic telemetry to determine if a one-way movement (i.e., migration) of Bull Trout occurred during the mark-recapture study period. Bull Trout exhibiting migratory behaviours would have different capture probabilities than non-migratory individuals, thereby violating the model assumptions and likely biasing capture probabilities and abundance estimates.

*Bull Trout Acoustic Tagging*

Eighteen Bull Trout were angled from May 31 to June 16, 2017 at the confluences of Mission, Strawberry, Marshall, and Truax Creeks, and tagged with acoustic transmitters (V13 transmitters, Vemco, Bedford, Nova Scotia; 2-year battery life, 13 mm diameter, 48 mm length, transmission rate 20-60 s). To minimize adverse tagging effects, our goal was to tag only Bull Trout > 550 g to ensure that tag weight (in air; 11 g) was < 2% of the total weight of fish 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 they lost equilibrium and exhibited weak opercular motion. Tags were surgically implanted into the abdominal cavity using a small incision on the mid-ventral line closed using two monofilament sutures (Wagner et al. 2011). Fish recovered in a dark cooler monitored for temperature and oxygen and were released when active and upright.

*Acoustic Receivers*

Two telemetry gates (VR2W-69 kHz coded acoustic receivers; Vemco) were installed in Carpenter Reservoir in 2015 and maintained into 2017: one at the Jones Creek confluence (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: 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. Since the installation of acoustic gates in 2015, the number and position of receivers has been modified to increase gate effectiveness, increase detection efficiency, and account for low elevation events. In 2015, six receivers making up the reservoir gate were installed just east of the Marshall Creek confluence and two receivers were installed in the Middle Bridge River near Sucker Creek. In 2016, the reservoir gate was moved ~500 m east to reduce detections of tagged Bull Trout holding at Marshall Creek, and two additional receivers were installed at the Middle Bridge River gate to increase detection efficiency. In the spring of 2017, the boundary of Carpenter Reservoir and the Middle Bridge River was downstream of the reservoir gate, resulting in almost all reservoir receivers becoming stranded. We recovered the dry receivers on April 22, 2017 and reinstalled two receivers in the flowing water as close to their original location as possible. The remaining four receivers were reinstalled on June 12, 2017, following sufficient reservoir elevation increase.

Receivers were installed at low reservoir elevation and subsequently became submerged for most of the year. Receivers in the reservoir could not be recovered until the following spring when winter ice had melted and the reservoir drafted sufficiently to access submerged floats. Due to the timing of receiver recovery, there is a one-year time lag in acoustic telemetry reporting. Movement data from Year 4 will be presented in this report, while movement data from the current reporting year (Year 5) will be presented in Year 6.

*Detection Efficiency*

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). The reservoir gate was positioned to maintain an 80% minimum detection probability at the maximum extent of the detection range based on range testing performed in June 2015 (Putt et al. 2016b). We could not achieve such a high detection efficiency in the river, likely due to low water depths, high turbidity, and bio-fouling of the hydrophones. Range testing in the Middle Bridge River indicated that detection efficiency is ~10% at 30-50 m from a receiver.

Acoustic detections were summarized as ‘events’ to condense the large volume of acoustic data (nearly two million detections collected since 2015). 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 time between events helped to condense detection data but did not substantially affect the detection efficiency of the gates. Events included the one-way movement of Bull Trout across gates (defined as ‘crossing events’), or movements towards and away from gates without crossing (defined as ‘vicinity events’). The initial and final detections in each event were used to determine the start and end 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 range 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 conditions (July to January). 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.

*Movement of PIT-tagged Bull Trout*

During all BRGMON-4 fish sampling events, Bull Trout were tagged with a unique PIT tag. Unique PIT tags allow recaptures to be identified for mark-recapture modelling, but also provide growth and location data when tagged Bull Trout are recaptured during subsequent sampling occasions. We performed a preliminary examination of specific recapture locations of Bull Trout encountered multiple times during BRGMON-4. Location data can be combined with broad-scale movement patterns identified in the acoustic monitoring program to inform Bull Trout behavioural patterns in Carpenter Reservoir.

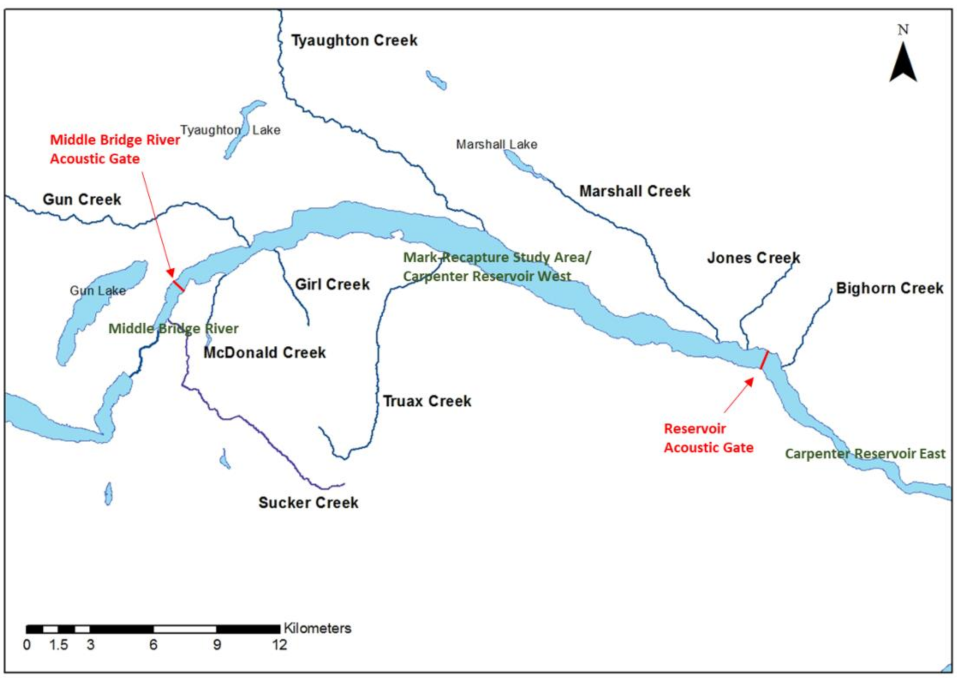


**Figure 2-2 Carpenter Reservoir tributaries and the locations of acoustic telemetry gates.**

## 2.4 Analysis of Shoreline Electroshocking CPUE

Shoreline electroshocking indexing was proposed in the original BRGMON-4 TOR to describe seasonal and annual variation in relative abundance, growth, and distribution of all species in Carpenter Reservoir. The proposed indexing program was modeled after shoreline electroshocking completed in September 2001 (Korman, unpublished) that was used to inform decisions during the

WUP process. In BRGMON-4 Years 1 and 2 (2012-2014), we determined that shoreline electroshocking was inconsistent in Carpenter Reservoir due to highly variable spatial and temporal turbidity (i.e., we could not determine electroshocking efficiency) and alternative indexing methods were pursued (e.g., a Bull Trout open mark-recapture program). To maintain consistency, we continued an annual shoreline indexing survey as part of the open mark-recapture program for Bull Trout. Although the sample timing and reservoir conditions vary between electroshocking surveys, comparing electroshocking results across years may inform changes in species density and distribution in Carpenter Reservoir.

Electroshocking effort is dependent on the total seconds shocked, the total meters shocked, the number of technicians (dippers) collecting stunned fish, and the dipping protocol. Bull Trout and Rainbow Trout captures were prioritized by dippers during BRGMON-4, positively biasing the CPUE values for these species and negatively biasing CPUE for all other species. To account for this bias, we used counts to compare catches among years. Almost all stunned Bull Trout, Rainbow Trout, and kokanee are netted during BRGMON-4 electroshocking, and in 2001, three to four dippers were used through most of the sampling period. Because Bull Trout, Rainbow Trout, and kokanee catches are generally low at each site, we assume that almost all individuals of these species would have been captured by three to four dippers, making count a more comparable index than CPUE.

## 2.5 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.

### 2.5.1 Ageing Analysis

Ageing structures were collected from Bull Trout, Rainbow Trout, kokanee, Mountain Whitefish, and Redside Shiners. Scales were collected from the area 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 archived for future ageing. Otoliths (a calcified structure located in the brain cavity of the fish) were collected opportunistically from accidental mortalities and examined under magnification by two independent analysts to identify growth annuli and estimate age (Zymonas and McMahon 2009).

During tributary electroshocking, we captured Rainbow Trout juveniles that were too small to sample for scales. Rainbow Trout typically do not develop scales until ~50 mm in length. Although we could not obtain scales from Rainbow Trout <50 mm, we assumed these fish were age-0. We captured these newly emerging fish in August through September and again in April through June. Rainbow Trout undergo minimal growth while overwintering in Carpenter Reservoir tributaries in their first few years of life, and the young-of-the-year (YOY) that emerged in the fall of one year were nearly indistinguishable from those captured in the following spring (both in appearance and during scale ageing; Figure 2-3). These Rainbow Trout were misclassified as age-0 during scale ageing due to the lack of identifiable growth (Minard and Dye 1998). In standard ageing procedures, a juvenile that has survived one winter should be classified as age-1 based on winter growth annuli (Minard and Dye 1998). We accounted for this underestimation in juvenile Rainbow Trout ages by adding one year to all Rainbow Trout captured after at least one winter of growth. This assumes that all Rainbow Trout captured during BRGMON-4 reared for at least one winter in the tributaries, which is likely accurate considering Rainbow Trout life history characteristics (McPhail 2007).

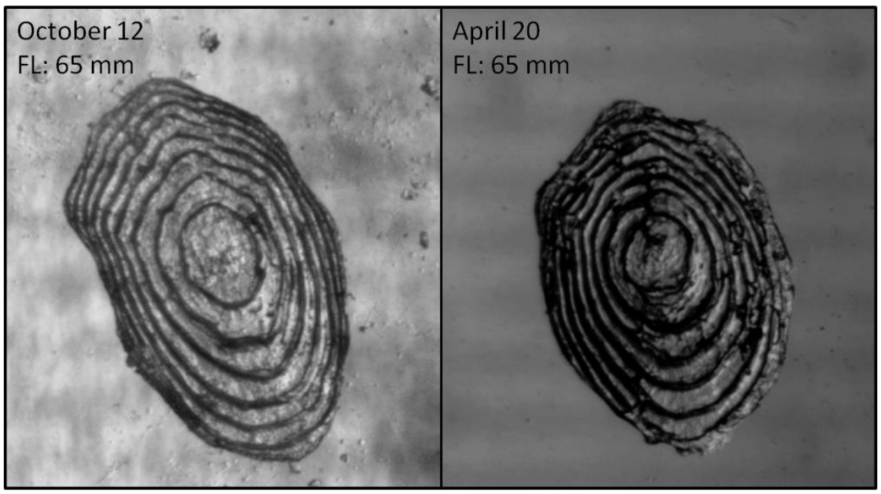


**Figure 2-3 Scales assessed as age-0 collected from two different Rainbow Trout captured during Carpenter Reservoir tributary electroshocking. The scale collected on April 20 (right) has undergone a winter of growth and should be classified as age-1; however, winter growth annuli are almost impossible to distinguish.**

### 2.5.2 Length vs Weight and Body Condition

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

$$W_i = \alpha L_i^{\beta} 10^{\epsilon_i} \quad \text{Eq 9}$$

$$\log(W_i) = \log(\alpha) + \beta \log(L_i) + \epsilon_i \quad \text{Eq 10}$$

where α and β are intercept and slope parameters, and ε is multiplicative model error. We examined the effect of year on the length-weight relationship by comparing the length-weight model above to a model including a year variable using one-way analysis of variance (ANOVA) testing (alpha 0.05; modelling completed using R package FSA, Ogle 2016b).

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

$$K_F = \frac{W * 10^N}{L^3} \qquad \text{Eq 11}$$

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). We compared the mean $K_F$ values between years using a one-way ANOVA (alpha = 0.05), and then used Tukey's pairwise hypothesis testing (Tukey's Honest Significant Difference-HSD) to determine which mean $K_F$ values were statistically different (Ogle 2016a, 2016b).

For Bull and Rainbow Trout, we examined the length-weight relationships and $K_F$ values for population subsets. For Bull Trout, we isolated adults between 200 mm and 350 mm in length (approximately ages 3 to 6). These Bull Trout represent potential adult spawners that are still undergoing measurable annual growth (have not reached asymptotic length) and their growth may be more affected by reservoir conditions than for older, slow-growing individuals. Rainbow Trout were separated into three categories for length and weight modelling: Rainbow Trout caught in the reservoir only, Rainbow Trout caught above the drawdown boundary in Marshall Creek (i.e., a stream-resident population isolated from Carpenter Reservoir), and a combination of all Rainbow Trout caught in the reservoir and juvenile Rainbow Trout caught in the tributaries (i.e., juveniles that will likely migrate to the reservoir).

### 2.5.3 Von Bertalanffy Growth Model

Paired lengths and ages were used to fit von Bertalanffy growth functions for Rainbow Trout (stream-residents only, reservoir captures only, and tributary juveniles with all reservoir captures), Mountain Whitefish, and Bull Trout (von Bertalanffy 1938). Species-specific growth models will allow us to describe growth characteristics and compare growth parameters to other systems in the region. Sufficient data were 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:

$$L_t = L_\infty\left[1 - \exp\left(-K(age - t_0)\right)\right] + \varepsilon \qquad \text{Eq 12}$$

where $L_t$ is length-at-age at time $t$, $L_\infty$ is the asymptotic length, $K$ is a growth coefficient, $t_0$ is the time at which length is theoretically zero, and $\varepsilon$ is the residual error. The growth model was fit iteratively for the parameters $L_\infty$, $K$, and $t_0$ using a minimum sums of squares optimization (Ogle 2016b). We fit the von Bertalanffy growth model to the three population types of Rainbow Trout listed above.

### 2.5.4 Age-Length Keys

Age-length keys (ALKs) were developed for Bull and Rainbow Trout, and Mountain Whitefish in Carpenter Reservoir to allow age estimation for all fish captured (Ogle 2016b). 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).

## 2.6 Reservoir Tributaries and Middle Bridge River Spawner Assessments

### 2.6.1 Tributary Visual Surveys

Visual surveys of kokanee spawning were conducted in Carpenter Reservoir tributaries to estimate migration timing and spawning 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 survey length in each tributary extended from the confluence to the most upstream accessible location (i.e., before upstream passage was too difficult for surveyors; Table 2-3). 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.

On September 12, 2017, detailed redd surveys were performed in Truax, Macdonald, Gun, and Marshall Creeks in addition to the weekly kokanee spawner count. The redd surveys coincided with the peak count of kokanee spawners in the four tributaries surveyed and aimed to determine whether spawning behaviour and/or redds could be directly observed. During the redd survey, two observers walked in an upstream direction within the weekly spawner count stream length and noted evidence of kokanee pairs, digging behaviour, and observable redds. The redd surveys were repeated on October 11, 2017, after the completion of the run, to determine if redds could still be observed once water levels had decreased further and kokanee were no longer present in the tributaries.

We determined the 50% hatch dates for kokanee based on the onset, peak, and end of the spawning migration counts, and an ATU requirement of 680 (at 7.5°C; DFO 1997). The 50% hatch dates identify the time period during which incubating eggs or newly emerged kokanee juveniles would be vulnerable to inundation in the event of increasing reservoir elevation. Kokanee are also known to spawn in the Middle Bridge River (Putt et al. 2017), although visual surveys cannot be completed due to high turbidity. We calculated the 50% hatch timing for kokanee in the Middle Bridge River to determine when kokanee eggs and newly emerged juveniles could be dewatered during ramp down events at the Lajoie Dam. We used average migration timings from the tributaries as a surrogate for the Middle Bridge River because visual surveys could not be completed in the river. BRGMON-4 proposed redd stranding assessments during Lajoie Dam ramp down events in the winter of 2016/2017 (Year 5); however, IFR was not informed of any scheduled ramp down events from late October to early February and no ramping surveys were performed during this period. A kokanee stranding event occurred on September 29, 2017 in the Middle Bridge River (although technically Year 6 this event is summarized in this report), and SER technicians performed a stranding assessment and fish salvage on October 2 and 3, 2017.

**Table 2-3 Coordinates (UTM 10U E/N) of above-drawdown visual surveys in Carpenter Reservoir tributaries.**

| Tributary | Downstream Boundary | Upstream Boundary | Approx. Length (m) |
|---|---|---|---|
| Truax Creek | 0525341/5637123 | 0525314/5637088 | 55 |
| Girl Creek | 0517079/5637667 | 0517185/5637586 | 120 |
| Macdonald Creek | 0514609/5636685 | 0514582/5636570 | 125 |
| Sucker Creek | 0511876/5634575 | 0511945/5634531 | 85 |
| Marshall Creek | 0537997/5623240 | 0537985/5632448 | 115 |

### 2.6.2 Rainbow Trout Tributary Electroshocking

Monthly backpack electroshocking surveys began in Year 4 (2016; April through October) to determine whether Rainbow Trout spawning occurred in tributaries of Carpenter Reservoir (Marshall Creek, McDonald Creek, and Truax Creek; within and above the drawdown zone) or whether seeding occurred from upstream lakes (i.e., Marshall and McDonald Lakes, Figure 2-2). Successful spawning was defined as the presence of multiple life stages, beginning with emerging fry (age-0) and progressing to age-1 and age-2 parr. Observing parr alone would suggest fry emerged further upstream or elsewhere and seeded downstream areas.

Electroshocking surveys were repeated in Year 5 (2017) with the addition of Gun Creek, a large tributary suspected to be a spawning tributary for Rainbow and Bull Trout, and Tyaughton Creek, a highly turbid Bull Trout spawning tributary. The above-drawdown portion of Tyaughton Creek is inaccessible and could not be included in the electroshocking surveys. In Truax Creek, the above-drawdown area was only shocked in April of 2017 due to a combination of bear activity, high discharges, and high densities of kokanee spawners in all other months. Sampling of the Truax Creek drawdown area was also suspended in May and August due to bear activity. In Macdonald Creek, electroshocking did not take place in September due to high densities of kokanee spawners and redds. No tributaries were electroshocked in October due to water temperatures dropping below 5°C.

Two 50-m lengths of stream were electroshocked in each tributary during each monthly survey: one above and one below the drawdown zone boundary. 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 stunned fish. 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 lengths >75 mm and <150 mm were implanted with a PIT tag in the ventral stomach cavity, while fish with fork lengths >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 in Year 5 (2015) was anomalous relative to previous years of BRGMON-4 (Figure 3-1). The reservoir reached its minimum elevation (615.16 m) on May 5, 2017, two to three weeks later than previous minimum elevations (in 2012-2016), and maximum elevation (644.67 m) was reached on September 26. The minimum elevation was ~17 m lower than 2016, and ~7 m lower than 2015 (the lowest year on BRGMON-4 record); however, 2015 maximum and minimum elevations were within the normal operating conditions of the reservoir (606.55 m to 651.08 m). Reservoir elevation rose slowly throughout the spring, and a substantial portion of Carpenter Reservoir remained riverine into late August, when the boundary of the river and reservoir reached the Gun Creek fan. The prolonged minimum elevation in Carpenter Reservoir was a result of the 2016 modified minimum drawdown of Downton Reservoir. Low minimum elevations in Carpenter Reservoir and high discharges from Lajoie Dam (to draw down Downton Reservoir) resulted in high flows from Terzaghi Dam into the Lower Bridge River. Discharges in the Lower Bridge River peaked at 127 cms on June 27, 2017 (Figure 3-2), and we observed kokanee entrainment through Terzaghi Dam (entrainment also occurred due to high flows in 2016). We did not adjust monitoring activities in 2015 despite the modified operational regime; however, if the new operating regime is continued, the effect of the modifications on BRGMON-4 monitoring will be evaluated to determine whether the current methods will successfully address the management questions.

Stage heights in the Middle Bridge River were relatively consistent at ~0.5 m from January to May of 2017 (Figure 3-3). Stage heights increased in June and remained at ~0.8 m until late September, at which point they decreased to base flows (0.4 m) for the remainder of the year. Middle Bridge River stage heights in the winter of 2017 were lower and more stable than 2016, with no substantial ramping events occurring in 2017 until late April.

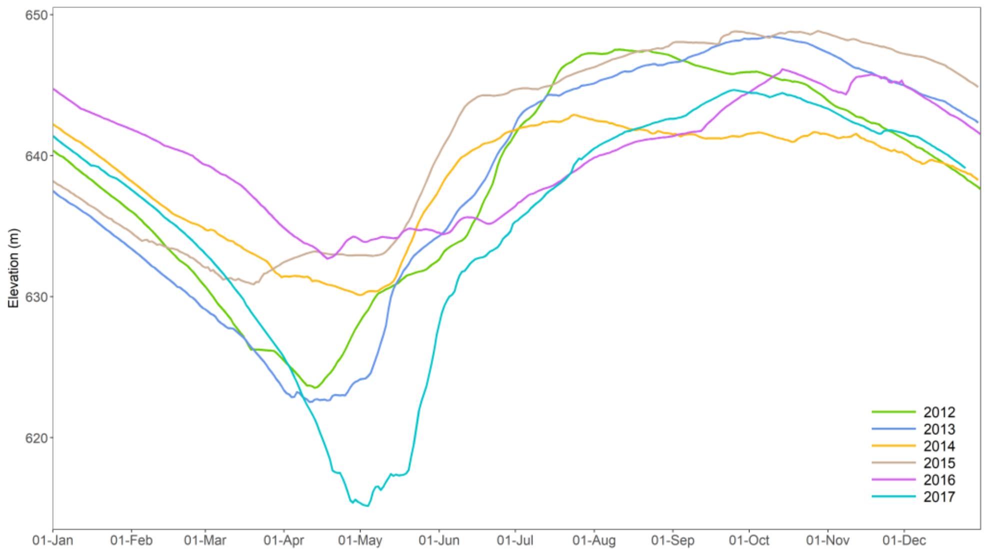


**Figure 3-1 Carpenter Reservoir elevations 2013 to 2017 (Years 1 through 5).**

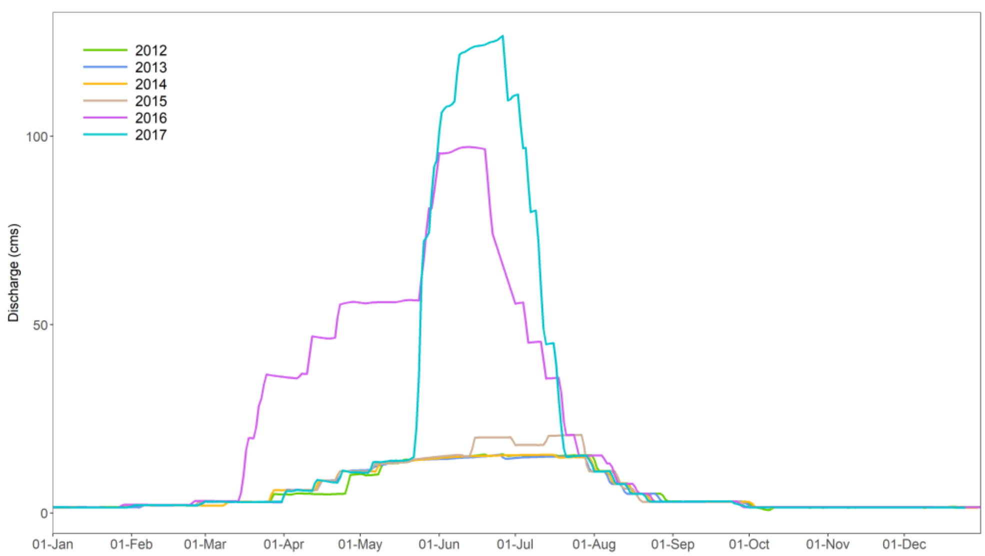


**Figure 3-2 Discharge from Terzaghi Dam to the Lower Bridge River from 2013 to 2017 (Years 1 through 5).**

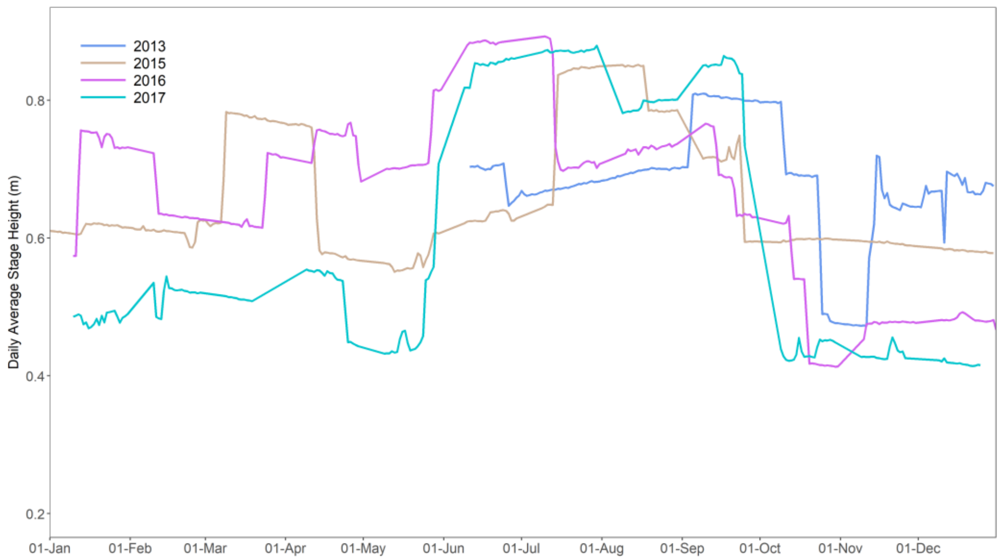


**Figure 3-3 Middle Bridge River average daily stage height. A continuous dataset for Years 1 through 5 (2013 to 2017) is not available.**

## 3.2 Middle Bridge River Mountain Whitefish Spawning Assessment

Spawning mats were deployed in the Middle Bridge River and combined with weekly Mountain Whitefish angling surveys to determine spawning dates for Mountain Whitefish. Mountain Whitefish spawner surveys were also performed in 2005, 2009, 2012 (Year 1), and 2013 (Year 2; TEC 2013). Raw data were available for 2012 and 2013 and published results were available for 2009 (no data or report was available for 2005).

A total of 87 Mountain Whitefish were angled from the Middle Bridge River at the Hurley and Goldbridge bridges from October 26 to December 7, 2016. The first ripe female was captured on November 2 and ripe females were captured until December 7, the final day of capture (Figure 3-4). Peak catches of Mountain Whitefish occurred on November 23, while the greatest proportion of ripe females occurred on November 22. Migration timing in 2009 (TEC 2010) and Years 1 and 2 (2012-2013) of BRGMON-4 (TEC 2013) were similar to 2016 (Year 5), with the onset occurring in late October and peak catches in the last two weeks of November. Ripe female counts peaked in the last week of November in 2012 but in the third week of November in 2013 and 2016; however, low catch rates may confound peak dates for ripe females and we suspect the timing was similar in all three years. Mountain Whitefish fork length distributions were compared between years, and average lengths for both males and females were smaller in Year 5 relative to Years 1 and 2 (Figure 3-5). Mean fork lengths in Year 5 were also smaller than Mountain Whitefish captured in 2009 (not shown); the mean fork length for male Mountain Whitefish was 286.8 mm (SE 2.07 mm) in 2009 and the mean fork length for females was 292.2 mm (SE 1.62 mm; TEC 2010).

At the onset of the Mountain Whitefish migration in Year 5 (October 26, 2016), mean daily temperature in the Middle Bridge river was 8.6 °C, and at peak count (November 22) the temperature was 5.9°C. Using a migration onset on October 26, peak spawning on November 22, and ATU requirement of 327 for Mountain Whitefish incubation, 50% hatch may have begun by mid-December and peaked on February 7, 2017 (Figure 3-6). For 2009, 2012, and 2013, TEC estimated 50% hatch to begin in early- to mid-January and peak near the third week of February (TEC 2010 and 2013). Estimated hatch timing for Mountain Whitefish was earlier in 2016 relative to previous years because we based ATU calculations on the onset of migration, rather than the first date eggs were observed on spawning mats. In 2016, we deployed five egg mats in the Middle Bridge River, but only 18 Mountain Whitefish eggs were captured by the mats (compared to hundreds per week in previous years) and egg mat data could not be used to inform spawn and egg deposition timing for the Middle Bridge River.

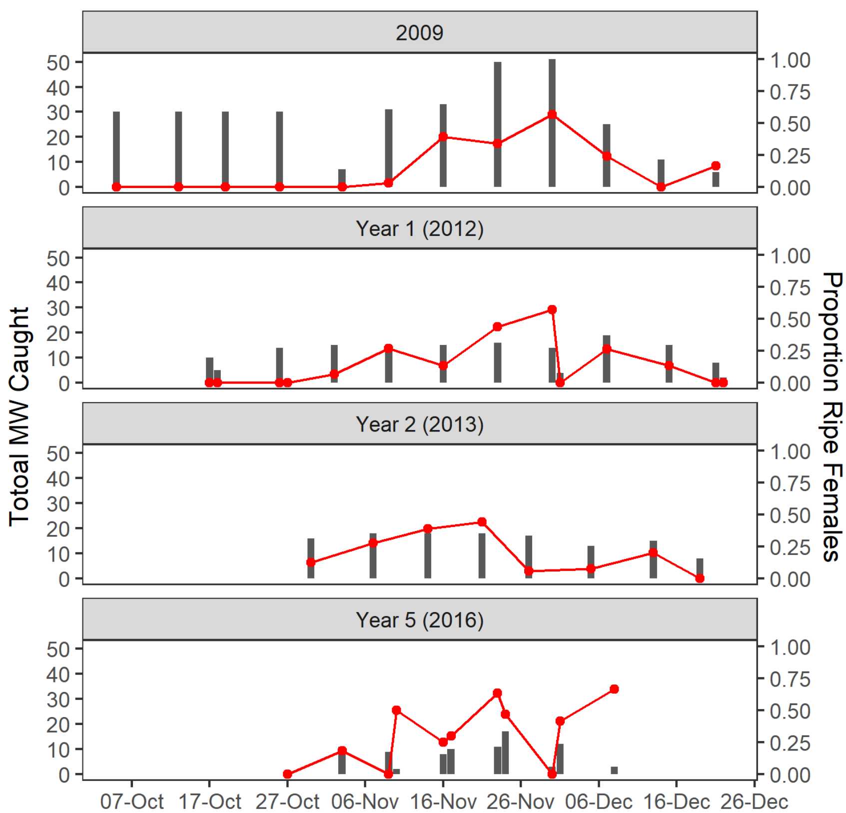


**Figure 3-4 Proportion of ripe female Mountain Whitefish captured during Middle Bridge River spawning assessments from 2009 to 2016 (red lines). Total catches are shown as grey bars.**

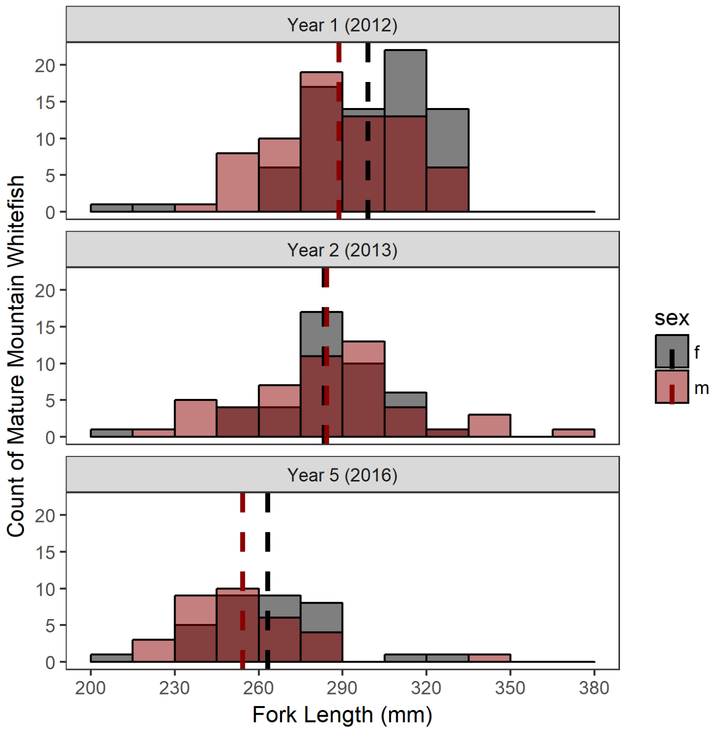


**Figure 3-5 Fork lengths of mature male and female Mountain Whitefish captured during Middle Bridge River spawning assessments in 2012, 2013, and 2016. Dashed lines represent mean fork length.**

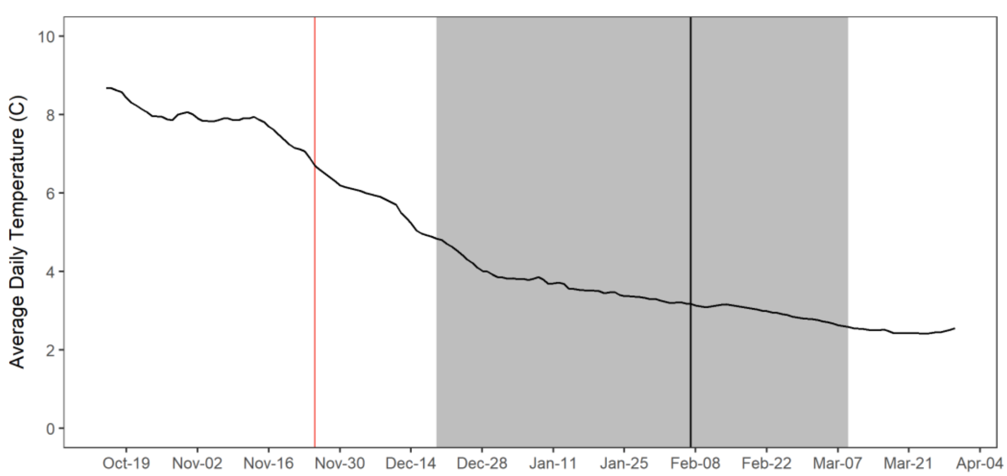


**Figure 3-6 Mountain Whitefish 50% hatch date range (shaded grey area) and peak hatch date (black line) for Year 5 (2016; ATU requirement of 327). Peak spawning is shown by the red line.**

## 3.3 Bull Trout Abundance Estimation

An open mark-recapture program was conducted in Carpenter Reservoir to estimate adult Bull Trout abundance from Terzaghi Dam to the boundary of the reservoir and the Middle Bridge River. The Year 5 (2017) open mark-recapture period occurred over two weeks from June 19 to July 7, 2017, approximately one month earlier than previous mark-recapture periods (Years 3 and 4; 2015-2016). The mark-recapture program occurred earlier to avoid sampling during a Bull Trout spawning migration and reduce handling stress from high water temperatures in warm summer months. Prolonged and low minimum elevations resulted in the lowest reservoir elevations experienced during a mark-recapture period in Carpenter Reservoir (Figure 3-7).

A total of 216 Bull Trout were captured using various methods during the Year 5 (2017) open mark-recapture period, 10 of which (4.6%) were recaptured from previous marking periods (Table 3-1). The greatest effort (over 100 hours) was spent angling, which delivered the highest total captures of Bull Trout, while <15 hours were spent each gill netting and electroshocking. Electroshocking was the most efficient capture method, with mean CPUE values of >25 Bull Trout per hour, compared to ~1 Bull Trout per hour for angling (Figure 3-8). Angling CPUE varied in Years 3 through 5 despite relatively constant effort; however, mean CPUE for all gear types combined was similar across the three years (Figure 3-8).

The mean fork length of Bull Trout captured during the Year 5 (2017) mark-recapture program was 390.8 mm (SD 77.0 mm), the largest of any mark-recapture period so far. The distribution of fork lengths was relatively narrow in Year 5 (Figure 3-9); we captured fewer Bull Trout with fork lengths <300 mm and more Bull Trout >500 mm compared with previous years. Fork length distributions for recaptured Bull Trout (not shown) were similar to all captured Bull Trout shown in Figure 3-9.

**Table 3-1 Mark-recapture capture summary data for Carpenter Reservoir Bull Trout in Years 1 through 5 (2013-2017).**

| Year | Total Number Caught | Number Recaptures | Recapture Percentage |
|---|---:|---:|---:|
| Year 1 (Jun 19 – Aug 20, 2013) | 222 | - | - |
| Year 2 (Jun 19 – Aug 20, 2014) | 49 | 7 | 14.3 |
| Year 3 (Jun 29 – Jul 31, 2015) | 270 | 19 | 7.0 |
| Year 4 (Jul 17 – Aug 13, 2016) | 144 | 6 | 4.2 |
| Year 5 (Jun 19 – Jul 7, 2017) | 216 | 10 | 4.6 |

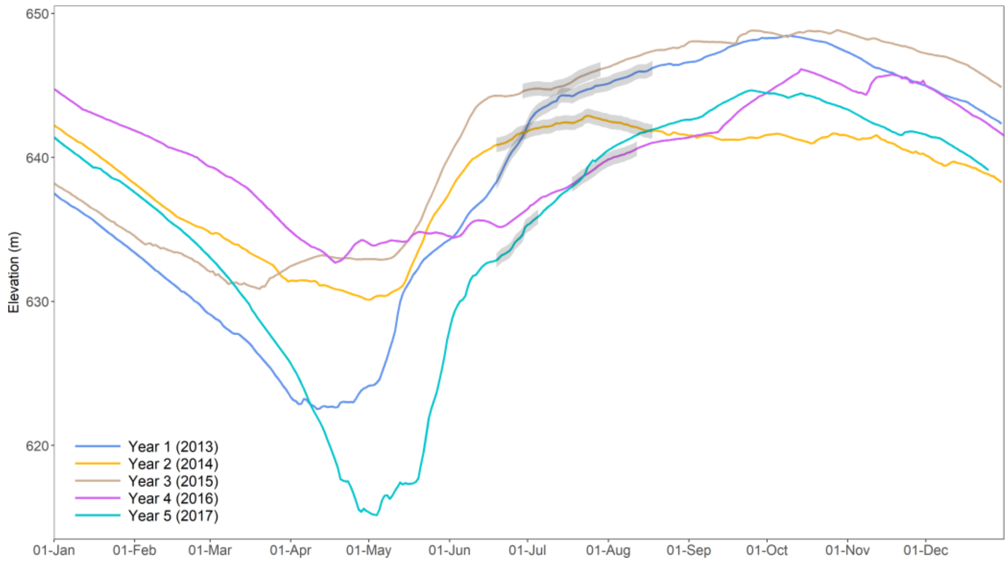


**Figure 3-7 Carpenter Reservoir elevations for Years 1 through 5 (2013-2017) with open mark-recapture sampling periods highlighted in grey.**

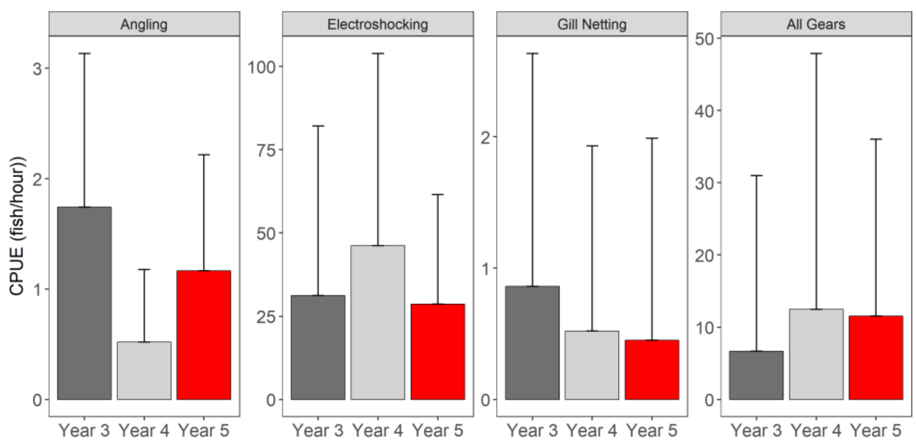


**Figure 3-8 Gear-specific mean CPUE (in fish/hour) with standard deviations for Bull Trout captured during the mark-recapture program. Scales are free to show variation among gear types.**

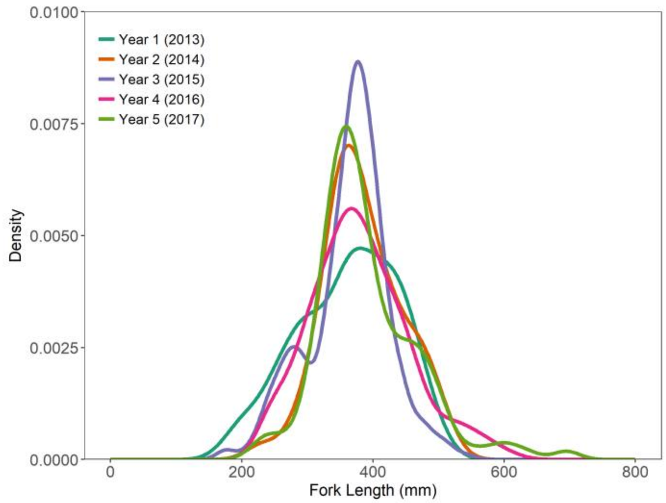


**Figure 3-9 Fork length density distributions for Bull Trout captured during the Carpenter Reservoir mark-recapture program.**

### 3.3.1 Mark-recapture CPUE of by-catch species

We calculated CPUE for all gear types and by-catch species during the mark-recapture period (Figure 3-10). CPUE for by-catch species should be used cautiously when comparing to CPUE from other time periods, as all capture activities during this period are targeted towards capture of adult Bull Trout. Mountain Whitefish were the most commonly encountered by-catch species, primarily captured via shoreline electroshocking. Relatively few kokanee were captured in Year 5 (2017), likely due to the earlier timing of the mark-recapture program. In years when the program was later, kokanee were more vulnerable to capture as they were staging at the creek mouths prior to undertaking spawning migrations. Mountain Whitefish and Rainbow Trout electroshocking CPUE both increased in Year 5. The Year 5 mark-recapture program occurred in late June of 2017 compared to July in 2015 and 2016. In June, we would expect Rainbow Trout to be congregated at tributary confluences as part of their spawning migrations, where they would be vulnerable to electroshocking. The increase in Mountain Whitefish CPUE may be related to a higher proportion of riverine habitat in Year 5 due to the low reservoir drawdown, which is the preferred habitat of Mountain Whitefish.

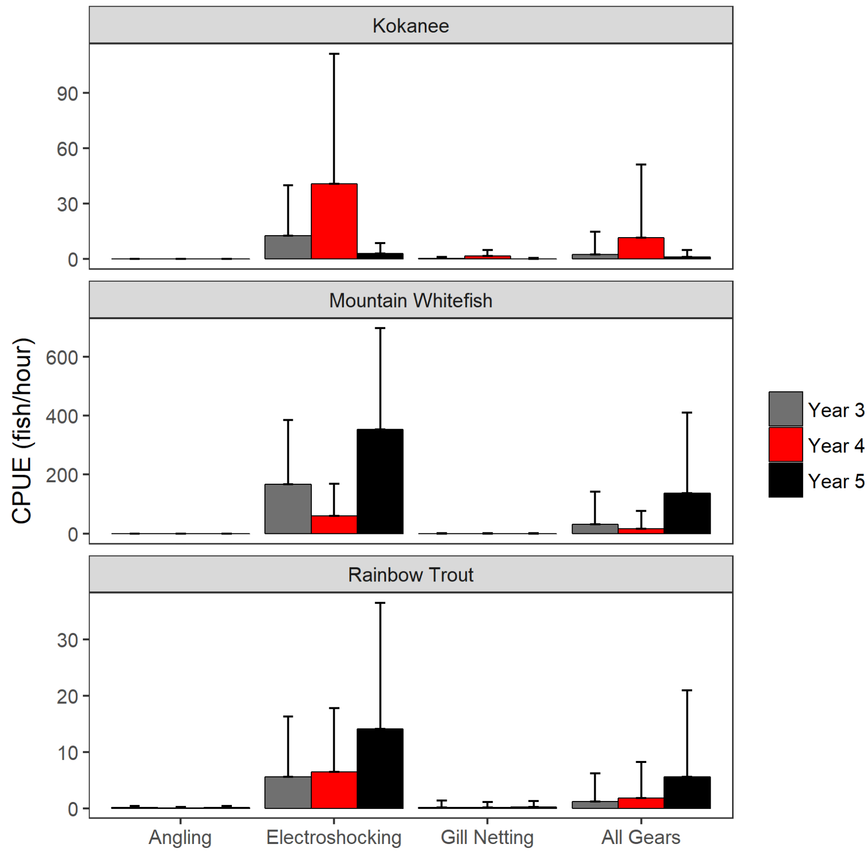


**Figure 3-10 Gear-specific CPUE (in fish/hour) and standard deviations for all by-catch species captured during the mark-recapture program.**

### 3.3.2 Mark-Recapture Modelling

*POPAN Jolly-Seber Model*

The POPAN Jolly-Seber model was used to estimate an index of annual Bull Trout abundance in Carpenter Reservoir in Years 1 through 5. The fits of eight candidate models were compared using AICc (Table 3-2), and the top three models were those with fixed entrance probability ($b_{fixed}$; i.e., births and immigration combined), fixed capture probability ($p_{fixed}$), and fixed survival probability ($\varphi_{fixed}$; i.e., survival and emigration combined). The top two models were within two AICc points of each other with a parameter difference of one, suggesting virtually equal fits. We selected the fixed capture probability model as the best-fit model because all parameters were identifiable and abundance estimates (the desired output) could be derived for all years[2] (Table 3-3). Also, because the physical nature of the study area is variable among years, we suspect that survival/emigration

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[2] 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).

and the entrance of new individuals from the super population are more accurately described by time-varying parameters. The fixed capture probability model estimated Year 5 (2017) adult Bull Trout abundance in Carpenter Reservoir to be 1,237 individuals (SD 337). Parameter estimates for the top POPAN models were characterized by relatively low precision and large confidence intervals, which in turn reduced precision of the annual population estimates (Figure 3-11).

Parametric bootstrapping (1,000 simulations) was used to evaluate the goodness-of-fit of the fixed capture probability POPAN model (Figure 3-12). Bootstrapping results suggest a relatively poor model fit to the mark-recapture data. Entrance probabilities were highly biased, likely because of variable survival probabilities estimated by the POPAN model.

**Table 3-2 AICc of POPAN open mark-recapture model estimates for Carpenter Reservoir Bull Trout. φ = survival probability, *p* = capture probability, and *b* = entrance probability. The model selected as the top model is shown in bold.**

| Model | Number of Parameters | AICc | Delta AICc |
|---|---|---|---|
| $\varphi_{\text{time-varying}}$, $p_{\text{time-varying}}$, $b_{\text{fixed}}$ | 9 | 395.73 | 0.00 |
| **$\Phi_{\text{time-varying}}$, $p_{\text{fixed}}$, $b_{\text{time-varying}}$** | **10** | **396.96** | **1.23** |
| $\varphi_{\text{fixed}}$, $p_{\text{time-varying}}$, $b_{\text{time-varying}}$ | 10 | 398.57 | 2.84 |
| $\varphi_{\text{time-varying}}$, $p_{\text{time-varying}}$, $b_{\text{time-varying}}$ | 12 | 398.98 | 3.25 |
| $\varphi_{\text{fixed}}$, $p_{\text{time-varying}}$, $b_{\text{fixed}}$ | 8 | 408.65 | 12.92 |
| $\varphi_{\text{fixed}}$, $p_{\text{fixed}}$, $b_{\text{time-varying}}$ | 7 | 425.04 | 29.31 |
| $\varphi_{\text{time-varying}}$, $p_{\text{fixed}}$, $b_{\text{fixed}}$ | 7 | 490.59 | 94.86 |
| $\varphi_{\text{fixed}}$, $p_{\text{fixed}}$, $b_{\text{fixed}}$ | 4 | 612.49 | 216.76 |

**Table 3-3 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%) |
|---|---|---|---|---|
| $\varphi_{Year\ 1}$ | 0.23 | 0.07 | 0.12 | 0.40 |
| $\varphi_{Year\ 2}$ | 1.00 | 0.00 | 0.00 | 1.00 |
| $\varphi_{Year\ 3}$ | 0.12 | 0.05 | 0.05 | 0.24 |
| $\varphi_{Year\ 4}$ | 0.32 | 0.12 | 0.14 | 0.59 |
| $P_{fixed}$ | 0.17 | 0.05 | 0.10 | 0.28 |
| $Ns$ | 4131.37 | 937.99 | 2745.57 | 6535.15 |
| $b_{Year\ 2}$ | 0.00 | 0.02 | 0.00 | 1.00 |
| $b_{Year\ 3}$ | 0.30 | 0.02 | 0.26 | 0.35 |
| $b_{Year\ 4}$ | 0.16 | 0.02 | 0.12 | 0.20 |
| $b_{Year\ 5}$ | 0.23 | 0.02 | 0.19 | 0.28 |
| $N_{Year\ 1}$ | 1271.16 | 345.33 | 753.45 | 2144.59 |
| $N_{Year\ 2}$ | 291.03 | 84.38 | 166.77 | 507.88 |
| $N_{Year\ 3}$ | 1529.70 | 400.49 | 923.49 | 2533.83 |
| $N_{Year\ 4}$ | 830.96 | 227.35 | 490.76 | 1406.98 |
| $N_{Year\ 5}$ | 1236.79 | 336.73 | 732.28 | 2088.90 |

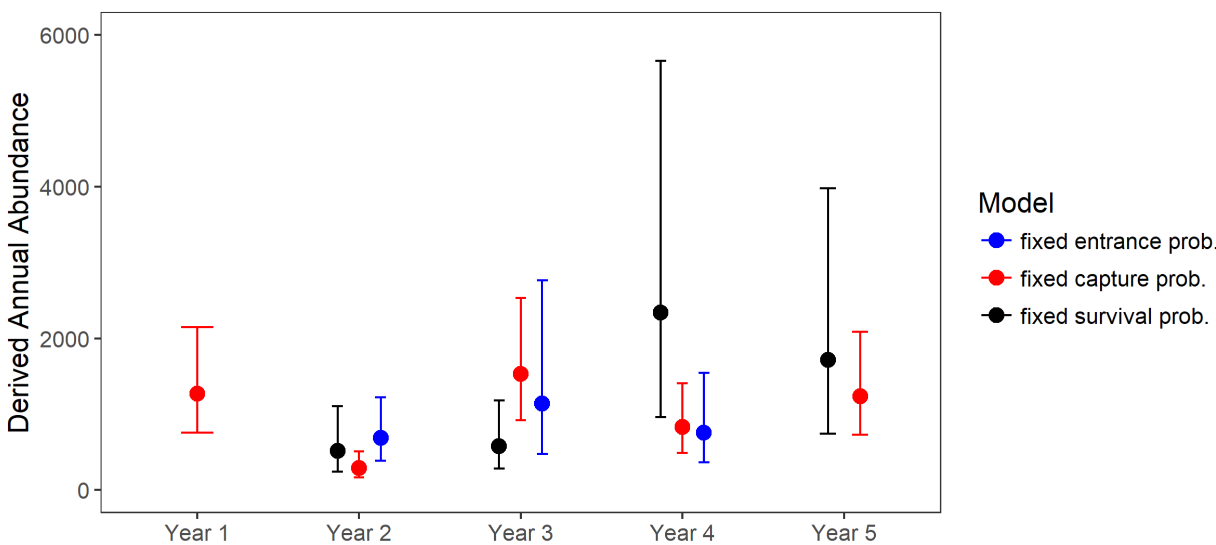


**Figure 3-11 Derived population estimates and 95% confidence intervals for the top three POPAN models. Annual abundance could not be determined for all years in all models due to parameter confounding.**

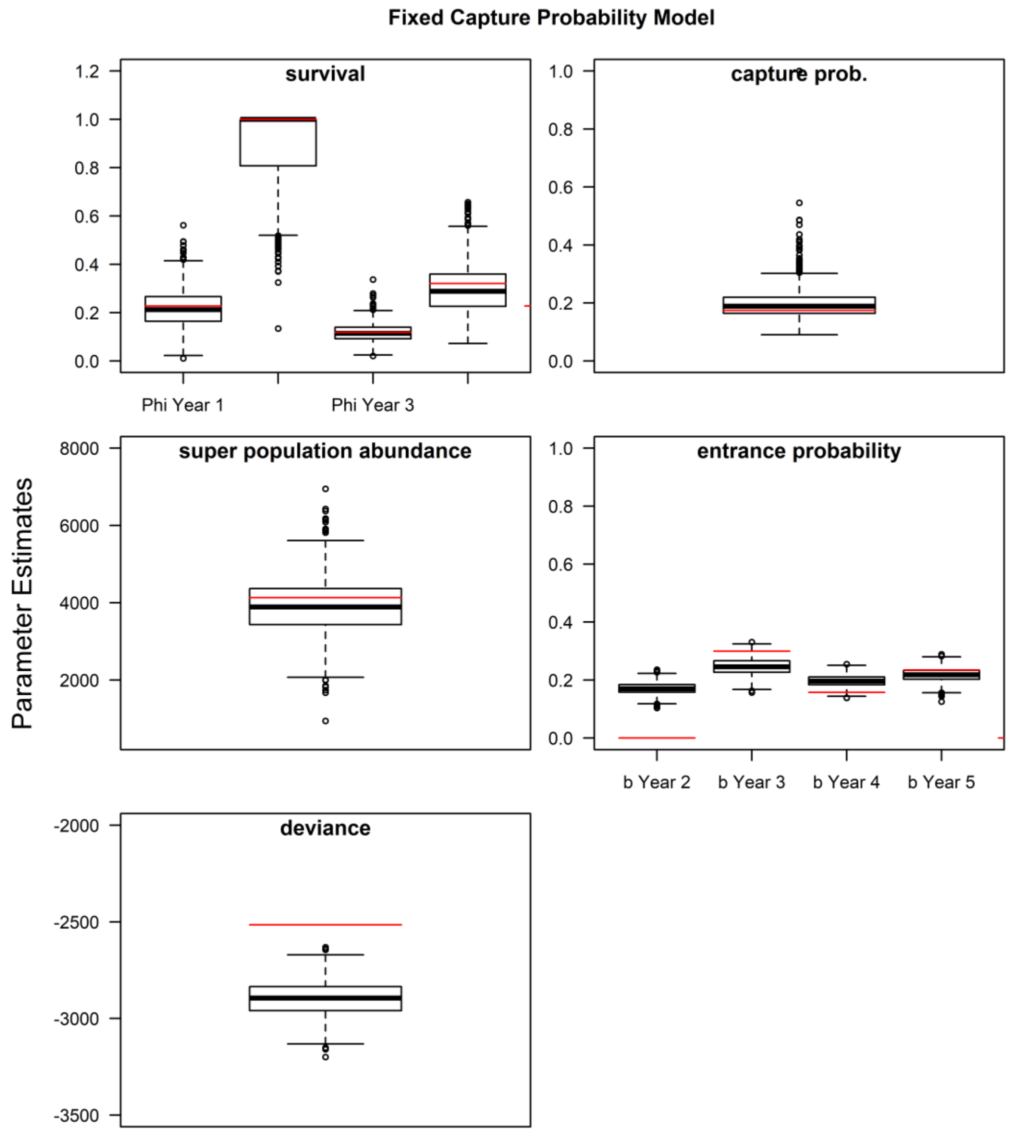


**Figure 3-12 Parametric bootstrapping (n = 1,000) parameter estimates for the POPAN model with fixed survival probability. Red lines are true parameters.**

*Cormack Jolly-Seber Model*

The Cormack Jolly-Seber (CJS) model was also used to estimate Bull Trout survival and capture probability, and an index of annual abundance was calculated for Years 2 through 5. The CJS model with the highest AICc support was that with fixed capture probability ($p_{\text{fixed}}$) and time-varying survival ($\varphi_{\text{time-varying}}$; Table 3-4). The fixed survival model was within 2 AICc points and was therefore indistinguishable from the top model; however, we selected the fixed capture probability model for consistency with POPAN modelling and because survival/emigration may vary among mark-recapture years due to physical variation in the reservoir. The POPAN and CJS models estimate capture probability and survival using the same processes, and parameter estimates for these parameters are shown in Table 3-3.

Goodness-of-fit testing via parametric bootstrapping (1,000 simulations) agreed with relative bias and precision issues identified during POPAN goodness-of-fit testing (Figure 3-13). We used CJS capture probabilities (*p*) simulated during parametric bootstrapping in Equation 2 to calculate annual abundance in Years 2 through 5 (Figure 3-14). The CJS model estimated the abundance of adult Bull Trout in Carpenter Reservoir to be 1,244 (SD 414) in Year 5 (2017).

**Table 3-4 AICc values for CJS open mark recapture models. φ = survival and *p* = capture probability. The model selected as the top model is shown in bold.**

| Model | Number of Parameters | AICc | Delta AICc |
|---|---|---|---|
| **$\varphi_{\text{time-varying}}$, $p_{\text{fixed}}$** | **5** | **352.91** | **0.00** |
| $\varphi_{\text{fixed}}$, $p_{\text{time-varying}}$ | 5 | 354.52 | 1.61 |
| $\varphi_{\text{time-varying}}$, $p_{\text{time-varying}}$ | 8 | 357.07 | 4.16 |
| $\varphi_{\text{fixed}}$, $p_{\text{fixed}}$ | 2 | 375.46 | 22.54 |

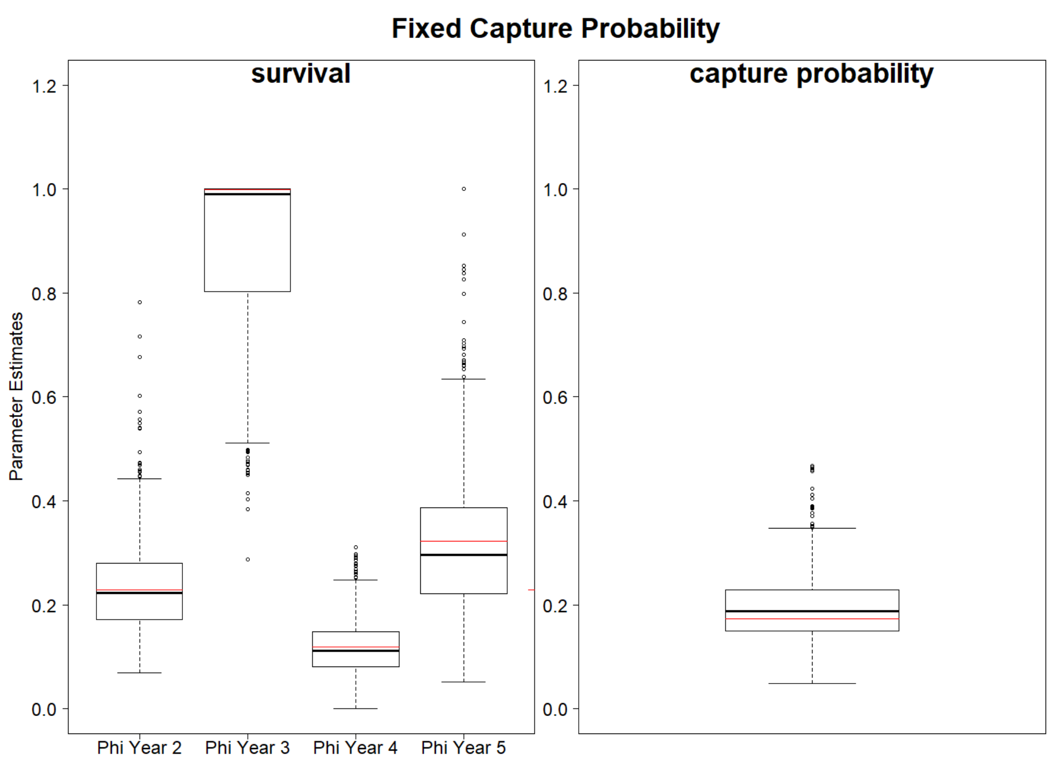


**Figure 3-13 Parametric bootstrapping (n = 1,000) parameter estimates for the CJS model with fixed capture probability. Red lines are the true parameters.**

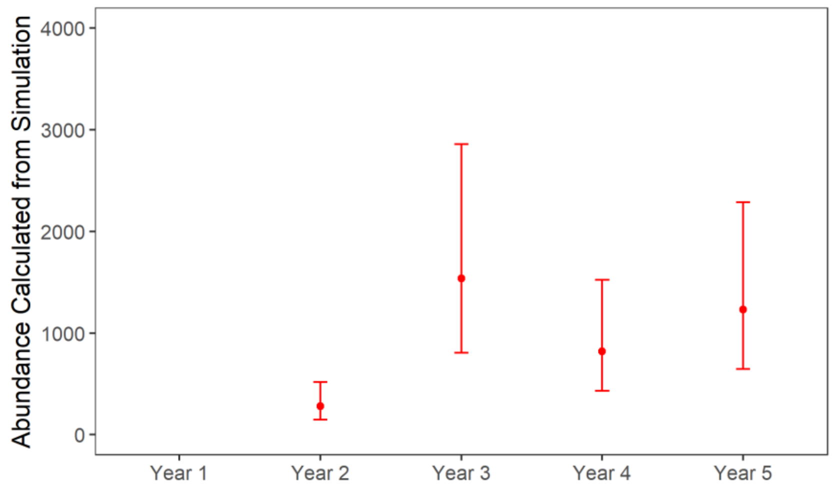


**Figure 3-14 Mean and 95% confidence intervals for annual abundance of Bull Trout during the mark recapture program. Abundances were calculated with Equation 2 using CJS capture probabilities (*p*) simulated using parametric bootstrapping (n = 1,000).**

## 3.4 Bull Trout Movement Analysis

### 3.4.1 Characteristics of Acoustic-Tagged Fish

Approximately 20 Bull Trout were tagged annually in Years 3 through 5 (2015-2017) with an acoustic transmitter. We aimed to tag Bull Trout with weights >550 g to minimize tagging effects; however, slightly underweight fish were tagged in all three years (Table 3-5). It was particularly difficult in Year 5 to capture adequately-sized Bull Trout for acoustic tags, and the mean size of acoustic-tagged Bull Trout in Year 5 was lower than in previous years (Figure 3-15). Tagged Bull Trout ranged in age from 3 to 11 (Figure 3-16), and age distributions (modeled using Age-Length-Keys developed in Year 4; Putt et al 2017) were similar among the three years (not shown).

**Table 3-5 Fork lengths (mm) and weights (g) of acoustic-tagged Bull Trout in Carpenter Reservoir, Years 3 through 5.**

| | | Fork Length (mm) | | | | Weight (g) | | | |
|---|---|---|---|---|---|---|---|---|---|
| Year | N | Mean | St. Dev | Min | Max | Mean | St. Dev | Min | Max |
| Year 3 (2015) | 20 | 446.6 | 38.0 | 400 | 519 | 675.8 | 132.9 | 508 | 975 |
| Year 4 (2016) | 18 | 435.8 | 45.9 | 363 | 520 | 886.6 | 367.7 | 478 | 1638 |
| Year 5 (2017) | 20 | 419.7 | 64.2 | 333 | 542 | 752.3 | 377.5 | 353 | 1523 |

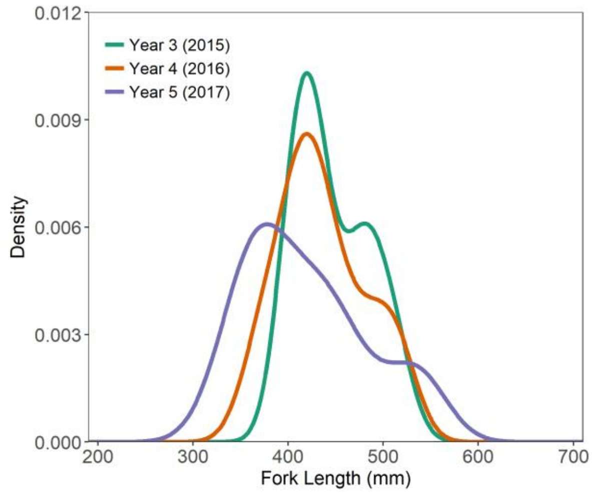


**Figure 3-15 Fork length density distributions for acoustic-tagged Bull Trout in Years 3 through 5.**

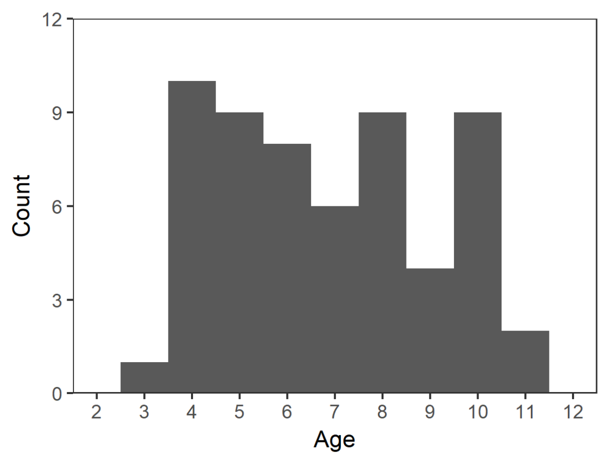


**Figure 3-16 Age distributions (modelled using an Age-Length-Key) for acoustic-tagged Bull Trout in Carpenter Reservoir (Years 3 through 5 pooled).**

### 3.4.2 Detection Efficiency

The number of missed crossing events and the ratio of successful to missed crossing events was calculated for the reservoir and river gates for the Year 3 (2015) and Year 4 (2016) acoustic survey periods (Table 3-6). Detection efficiency was higher in Year 4 relative to Year 3, with the increase in efficiency largely occurring at the river gate due to the addition of two receivers in Year 4.

**Table 3-6 Detection efficiency of acoustic gates in Carpenter Reservoir and the Middle Bridge River (June 2015 through April 2017) separated by pool level.**

| Study Year | Gate | Movements Detected | Movements Missed | Detection Efficiency |
|---|---|---|---|---|
| Year 3: Jun 2015 – Apr 2016 | River and Reservoir Gate Combined | 33 | 36 | 48% |
| | River Gate | 15 | 21 | 42% |
| | Reservoir Gate | 18 | 14 | 56% |
| Year 4: Jun 2016 – Apr 2017 | River and Reservoir Gate Combined | 55 | 28 | 66% |
| | River Gate | 17 | 9 | 65% |
| | Reservoir Gate | 38 | 19 | 67% |

### 3.4.3 Movement of Tagged Bull Trout

Acoustic telemetry gates were used to monitor Bull Trout movement and determine the direction and timing of Bull Trout migrations between the eastern and western portions of Carpenter Reservoir and into and out of the Middle Bridge River. In Years 3 and 4 (2015 and 2016), the study area of the mark-recapture program was restricted to the western half of the reservoir, while in Year 5 (2017) the study area was expanded to include the entire reservoir. In the current Year 5 analysis, we retrospectively expanded the study area for Years 2 through 4 to the entire reservoir. Due to the timing of receiver recovery and downloading, the analysis herein contains acoustic data from September 2016 to May 2017 and refers to Bull Trout tagged in Years 3 and 4. Of the 20 Bull Trout tagged in Year 3, nine were redetected in Year 4. Of the 19 fish tagged in Year 4, eight were detected in Year 4.

In Year 4 (2016), seven of the eight acoustic Bull Trout tagged and detected in Year 4 were positioned within the western half of the reservoir (i.e., the original study area used during Year 3 and Year 4) during the mark-recapture sampling period. One Bull Trout had migrated into Carpenter East in early July and remained in Carpenter East during the mark-recapture period (Figure 3-17, Figure 3-18). Figure 3-17 shows the continuous location (post event) of tags released only in Year 4, while Figure 3-18 shows the end locations (not continuous) of tags released in Year 4 (2016) and tags released in Year 3 (2015) that were redetected in Year 4. Because the detection efficiencies of the acoustic gates were not 100%, we could not make assumptions about the end locations of Year 3 Bull Trout (n = 9) until they were redetected in Year 4. Only one Year 3 Bull Trout was redetected prior to or during the Year 4 mark-recapture (allowing us to infer its location and movement). This Bull Trout was detected moving into the Middle Bridge River from Carpenter West during the mark-recapture period.

From June 2016 to May 2017, ten of the 17 acoustic-tagged Bull Trout detected in Year 4 (i.e., released in 2015 and 2016) moved between the eastern and western portions of Carpenter Reservoir and did not migrate into or out of the Middle Bridge River (Figure 3-18). Five Bull Trout moved into the Middle Bridge River in the fall of 2016 and may have spawned there, while the remaining Bull Trout may have spawned in Carpenter Reservoir tributaries, were not detected during their fall migration (i.e., due to gate inefficiencies), or did not spawn in 2016.

We compared the movement behaviours of Bull Trout tagged in Year 3 (2015) that were redetected in Year 4 (2016; n = 9). Many of the fish redetected in Year 4 (2016) exhibited similar movement behaviours in the two years (see Putt et al. 2017):

- Tag 34775 moved from Carpenter Reservoir West to the Middle Bridge River in August of both years
- Tag 34780 moved from Carpenter Reservoir West to the Middle Bridge River in December of both years
- Tag 34776 moved from Carpenter Reservoir West to Carpenter Reservoir East in both years

Although their movement patterns were not the same in both years, many of the Bull Trout were detected in the same vicinity in both study years. For example, Tags 34793, 34783, and 34784 were only detected by the river gate (i.e., moved between the Middle Bridge River and Carpenter Reservoir West), while Tags 34779 and 34777 were only detected by the reservoir gate (i.e., moved between Carpenter Reservoir East and Carpenter Reservoir West). Only one tag (34780) was detected by different gates in the two years: in Year 3 (2014-2015) it was detected by both gates while in Year 4 (2015-2016) it was detected only at the river gate. We examined the ages of acoustic-tagged Bull Trout, but we were not able to detect consistent patterns in movement behaviour by age.

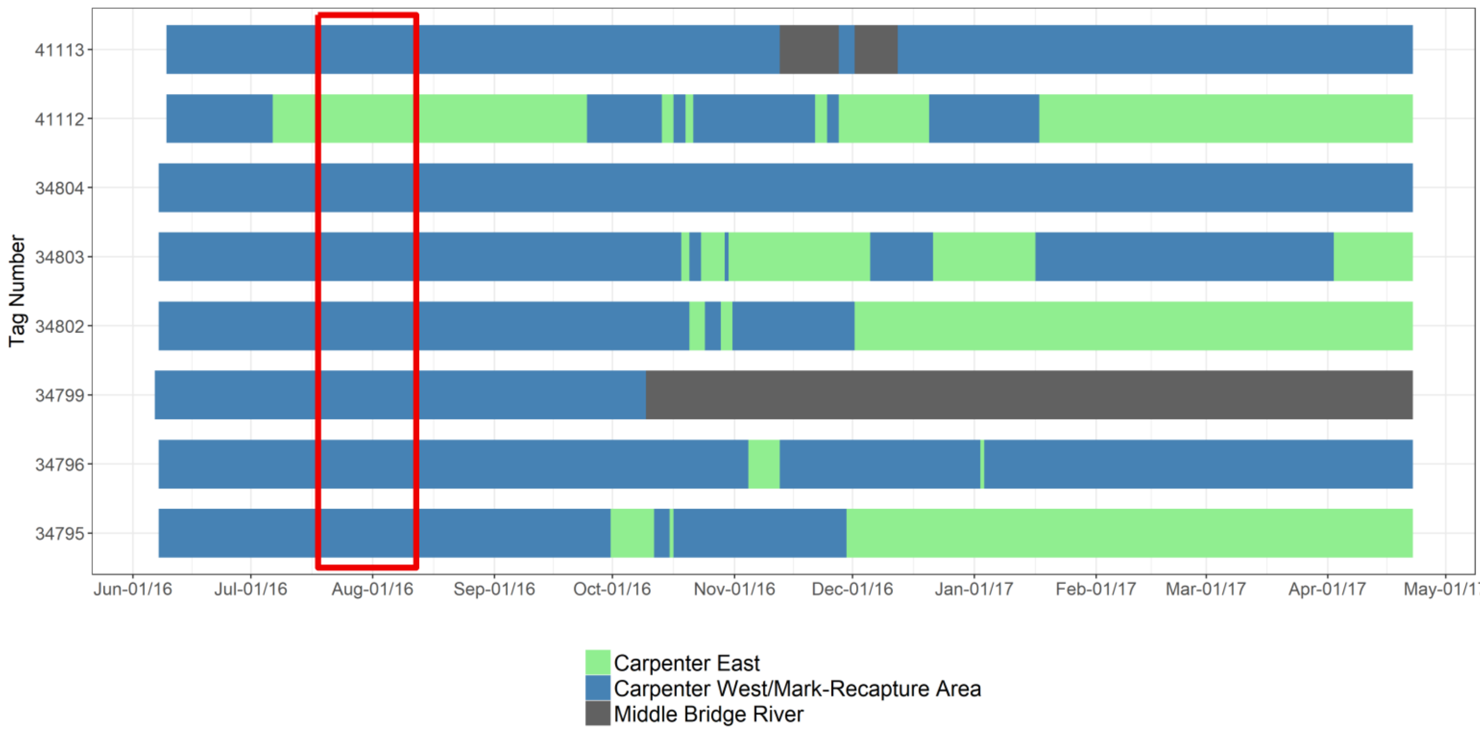


**Figure 3-17 End location of Bull Trout movement events from April 2016 to May 2017 in Carpenter Reservoir and the Middle Bridge River (tags released in Year 4 only). Coloured bars represent end location of individual events. The Year 4 mark-recapture study period is shown within the red rectangle.**

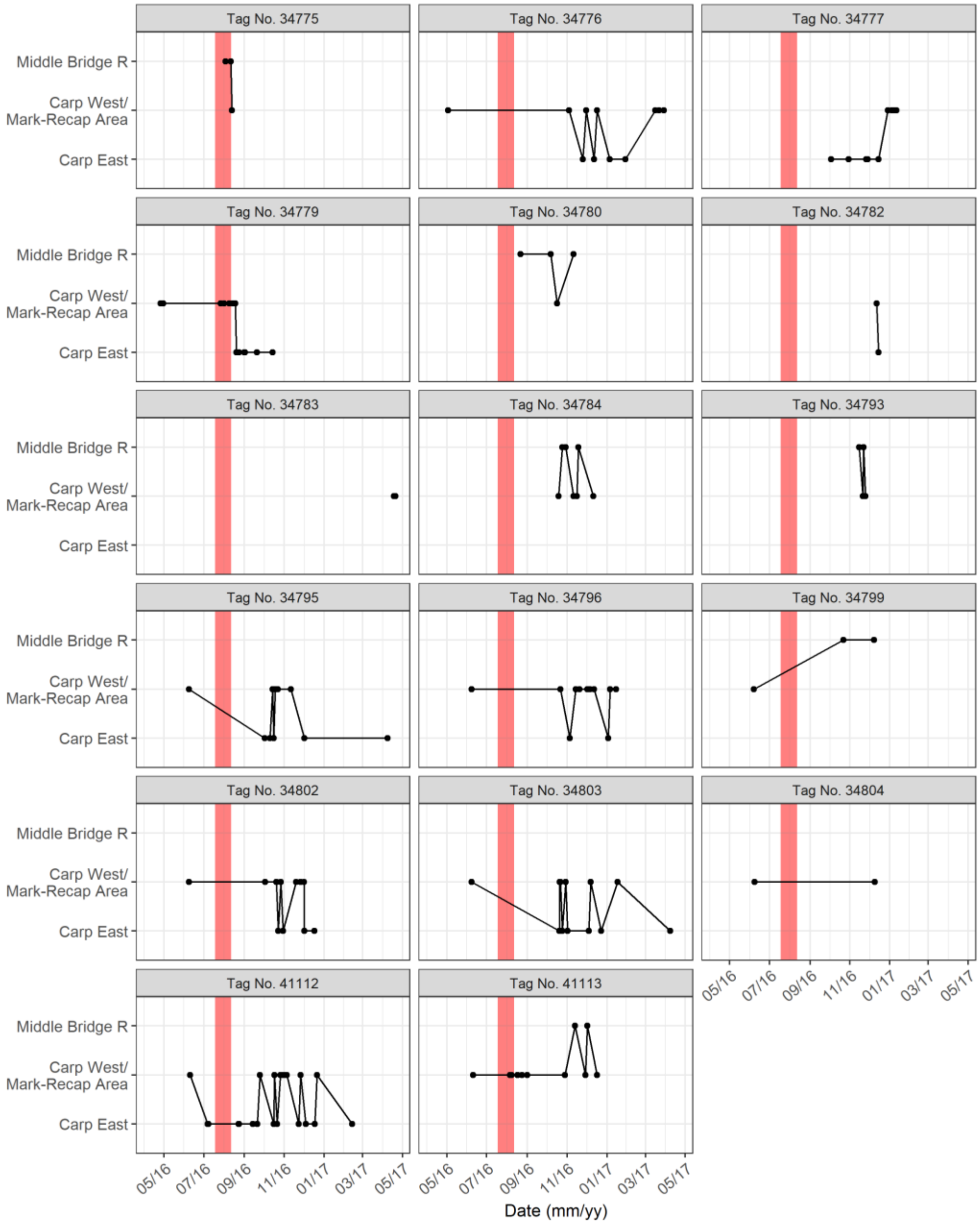


**Figure 3-18 End location of individual movement events for acoustic Bull Trout in Carpenter Reservoir and the Middle Bridge River (June 2015 to April 2016). The mark-recapture period is in red and lines are used to connect locations visually and do not represent exact location.**

### 3.4.4 Movement of PIT-Tagged Bull Trout

We examined the capture locations of PIT-tagged Bull Trout encountered multiple times in Carpenter Reservoir from December 2012 to September 2017. Recapture locations highlight variable behavioural patterns of Bull Trout in Carpenter Reservoir and the Middle Bridge River. Of the 223 Bull Trout captured more than once during BRGMON-4, 34% were recaptured within the same week of tagging and proximate to their release location. We removed these immediate recaptures and partitioned the remaining Bull Trout recaptures (n = 147) into: recaptures in multiple years at the exact same location, recaptures within 10 km of their release location, and recaptures >10 km from the release location (Table 3-7).

A large number (44%) of Bull Trout recaptured in multiple years were captured at the same location each time (e.g., Tag 584851 was angled from Truax Creek once per year from 2015 to 2017; Appendix B). Of the fish captured at different locations, 27% were captured within a 10 km radius of their release location, while 30% were captured at locations >10 km apart. For example, Tag 586062 was captured two springs in a row at Keary Creek via shoreline electroshocking and once in the fall at Truax Creek via angling (Appendix B). Some fish travelled large distances within or between years; for example, Tag 657920 was captured at Tyaughton Creek (~km 35, riverine habitat) in the spring of one year and close to the Terzaghi Dam (~km 0, lacustrine habitat) in the subsequent spring (Appendix B). Bull Trout acoustic data and PIT tag recaptures suggest that Bull Trout utilize Carpenter Reservoir habitat (as opposed to Middle Bridge River habitat) to a greater degree than previously hypothesized. Particularly, it appears that Bull Trout often return to similar areas in the reservoir each year, and that Bull Trout spawning locations may be variable depending on reservoir conditions.

**Table 3-7 Percentage of recaptured fish that were recaptured in the same location, within 10 km of their original tagging location, and more than 10 km from their original tagging location from December 2012 to September 2017.**

| Movement Category | Count | % Total | % Detected multiple years |
|---|---|---|---|
| Caught multiple years at same location | 64 | 29% | 44% |
| Caught multiple years >10 km apart | 44 | 20% | 30% |
| Caught multiple years <10 km apart | 39 | 18% | 27% |
| Only recapped within same week of one | 76 | 34% | NA |

## 3.5 Shoreline Electroshocking in Carpenter Reservoir

We compared shoreline electroshocking counts between a historic (i.e., 2001/pre-WUP) survey and surveys completed during BRGMON-4 (i.e., mark-recaputre electroshocking in Years 3 to 5, 2015-2017). Almost all captures of Bull Trout, Rainbow Trout, and kokanee occurred at tributary confluences between the log boom to the east and Gun Creek to the west. During BRGMON-4, electroshocking does not occur east of the log boom or west of Gun Creek and we cannot draw comparisons between catches in these areas.

Bull Trout counts were relatively consistent throughout BRGMON-4 and between BRGMON-4 and the historic survey in 2001 (Figure 3-19) despite variable survey timing and reservoir conditions. This agrees with angling observations, where Bull Trout are consistently captured at tributary confluences from early spring through late fall. Bull Trout were also captured west of Gun Creek in 2001, suggesting possible spawning or predation on pre-spawning kokanee (kokanee spawn in the Middle Bridge River in late September). Rainbow Trout counts were low relative to Bull Trout, but captures generally occurred in similar locations for both species, particularly in 2015 through 2017 (Figure 3-20). Almost all Rainbow Trout were captured at tributary confluences except proximate to Terzaghi Dam, where Rainbow Trout were captured in steep and shallow shoreline habitat. We compared fork length distributions for Bull Trout and Rainbow Trout captured during shoreline electroshocking in 2001 and during BRGMON-4 (not shown) and found average fork lengths to be consistent across all surveys.

Kokanee counts were higher during late summer surveys (i.e., Year 3 [2014] and Year 4 [2015]) relative to the late spring survey in Year 5 (2016; Figure 3-21). The variation in timing of shoreline electroshocking surveys makes it difficult to separate potential changes in kokanee abundance from behavioural changes due to sample timing. Kokanee are lacustrine during the winter and spring and migrate to tributary confluences and the Middle Bridge River in late summer, making them most vulnerable to shoreline electroshocking (resulting in higher counts) in late July through September.

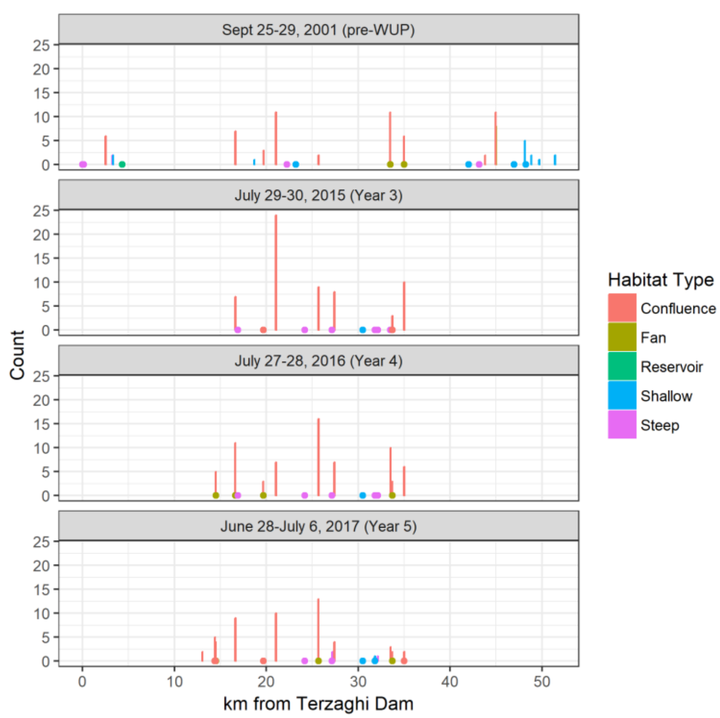


**Figure 3-19 Bull Trout counts from Carpenter Reservoir shoreline electroshocking surveys. Zero counts are represented by solid points.**

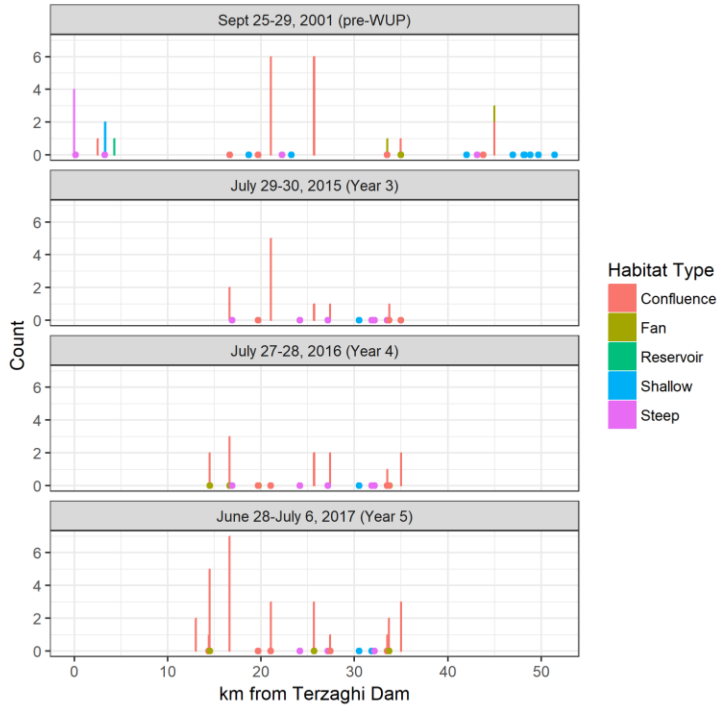


**Figure 3-20 Rainbow Trout counts from Carpenter Reservoir shoreline electroshocking surveys. Zero counts are represented by solid points.**

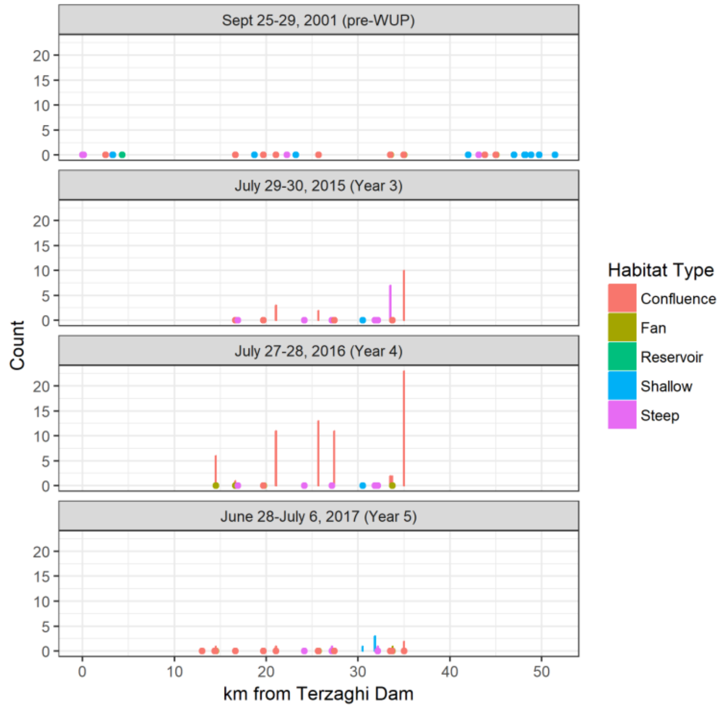


**Figure 3-21 Kokanee counts from Carpenter Reservoir shoreline electroshocking surveys. Zero counts are represented by solid points.**

## 3.6 Biological Characteristics

Species-specific length, weight, and age data were collected to describe biological characteristics of fish species in the Carpenter Reservoir watershed (Table 3-8). Ages were determined for scales (kokanee, Rainbow Trout, Mountain Whitefish), fin rays (Bull Trout), and otoliths (accidental mortalities, all species) collected during Years 2 through 5 (Table 3-9).

**Table 3-8 Count of fish in Carpenter Reservoir sampled for biological characteristics (length, weight, and potential ageing structure) in Years 1 through 5 (all sampling occasions).**

| | Bull Trout | Rainbow Trout | Mountain Whitefish | Kokanee |
|---|---|---|---|---|
| Year 1 (2012-2013) | 432 | 92 | 311 | 3 |
| Year 2 (2013-2014) | 210 | 66 | 249 | 2 |
| Year 3 (2014-2015) | 369 | 45 | 86 | 27 |
| Year 4 (2015-2016) | 253 | 133 | 354 | 91 |
| Year 5 (2016-2017) | 317 | 202 | 255 | 18 |
| Total | 1,491 | 538 | 1,255 | 141 |

**Table 3-9 Ageing structures analysed in Years 2 through 5 of BRGMON-4.**

| Species | Scales Aged | Otoliths Aged | Fin Rays Aged | Total Structures Aged |
|---|---|---|---|---|
| Bull Trout | 8 | 10 | 74 | 92 |
| Kokanee | 50 | 0 | 0 | 50 |
| Mountain Whitefish | 162 | 31 | 0 | 193 |
| Rainbow Trout | 288 | 2 | 0 | 290 |

### 3.6.1 Bull Trout

Lengths and weights of Bull Trout captured in Carpenter Reservoir in Years 1 through 5 were highly correlated (adjusted R-squared all years 0.93). The addition of a year variable to the length-weight model was not significant when compared to the intercept-only model (Figure 3-22; ANOVA p-value 0.06, DF 4, F 2.24). We examined the length-to-weight relationships and condition factors of Bull Trout with lengths between 200 mm and 350 mm, or approximately age 3 to age 6. The relationship between length and weight was highly correlated for ages 3 through 6 (adjusted R-squared 0.79) and the addition of year to the length-weight model was highly significant (Figure 3-22; ANOVA p-value <0.001, DF 4, F 12.60). Annual variation in the slope of the length-weight relationship suggests that the mean weight between years increases at a different rate with each unit increase in length. There was a significant difference between mean condition factor ($K_F$) values in Years 1 through 5 (Figure 3-23; p-value <0.001, DF 4, F 11.13), and a Tukey's HSD test indicated the condition of Bull Trout ages 3 to 6 was lower in Year 5 (2016-2017) relative to Years 1 through 4 (all comparisons including Year 5 had p-value <0.001).

A total of 92 Bull Trout have been aged by IFR (otoliths and juvenile scales) and North South Consultants (fin rays; Table 3-9), and 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, which shows an asymptotic length of ~600 mm and fastest adult growth in fish ages 3 to 6 (Figure 3-24, Table 3-10). A Bull Trout ALK was used to estimate the proportion of Bull Trout in each age class and to estimate ages for unaged fish (Figure 3-25).

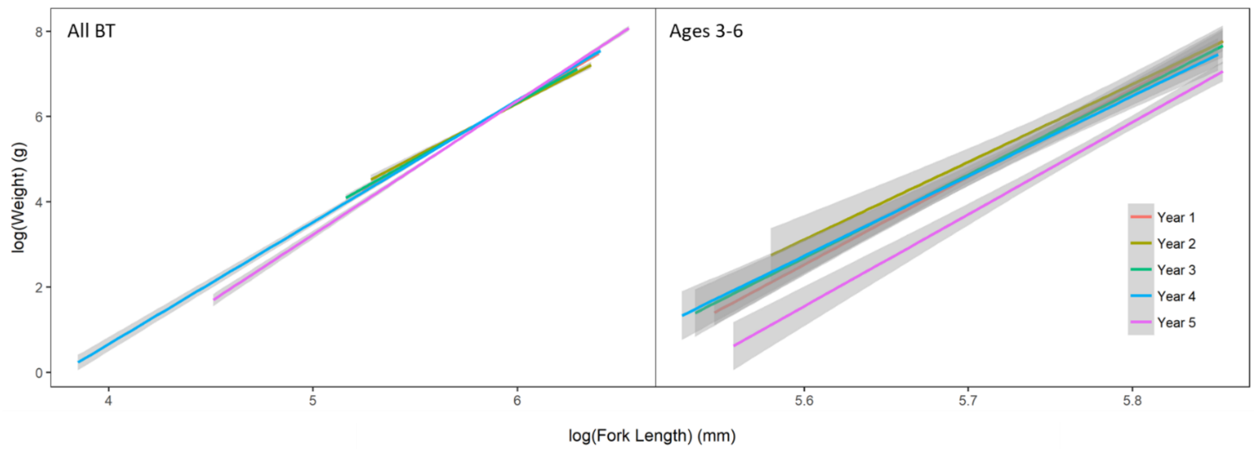


**Figure 3-22 Logarithmic length-weight relationships for Bull Trout in Years 1 through 5. Shaded grey area represents linear model 95% confidence interval.**

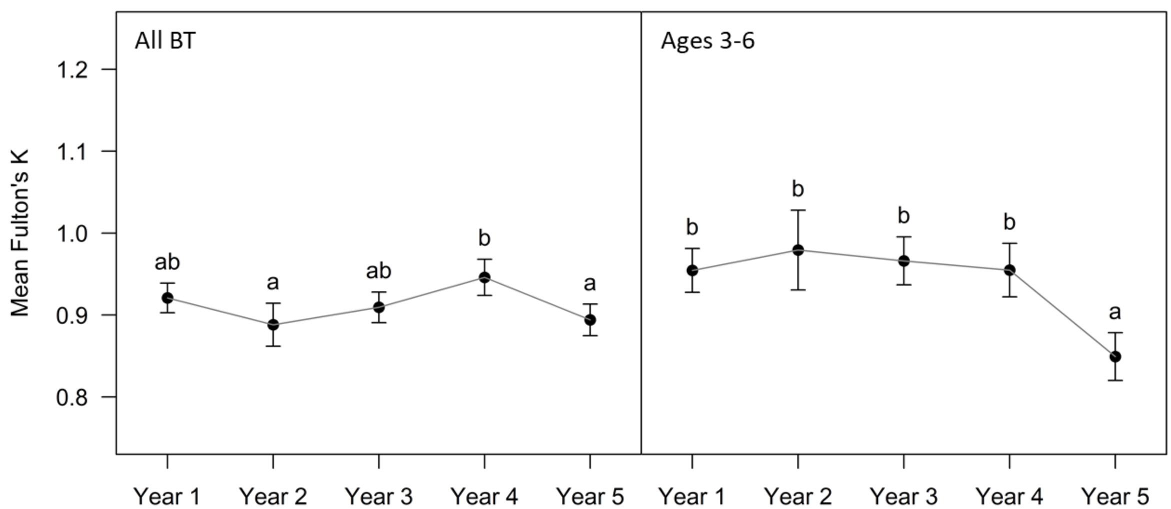


**Figure 3-23 Mean annual condition factor (and 95% CI) for Bull Trout in Carpenter Reservoir. Means with the same significance letter are statistically equal.**

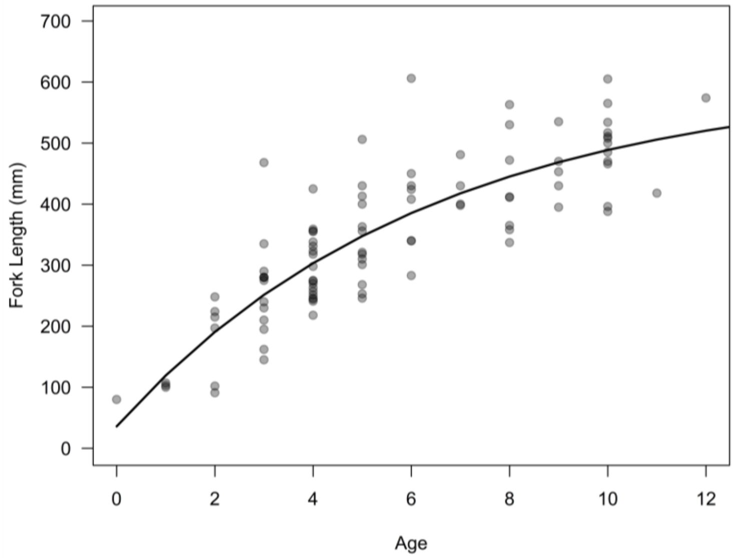


**Figure 3-24 Von Bertalanffy growth model for Bull Trout fork length (mm) and observed ages (all study years combined). Transparency shows point overlap.**

**Table 3-10 Von Bertalanffy parameter estimates for Bull Trout (all study years combined), where $L_{inf}$ is the asymptotic growth, K is the growth coefficient, and $T_0$ is the time at which length is theoretically zero.**

| Parameter | Estimate | SE |
|---|---|---|
| $L_{inf}$ | 605.42 | 0.73 |
| K | 0.16 | 0.00 |
| $T_0$ | -0.39 | 0.01 |

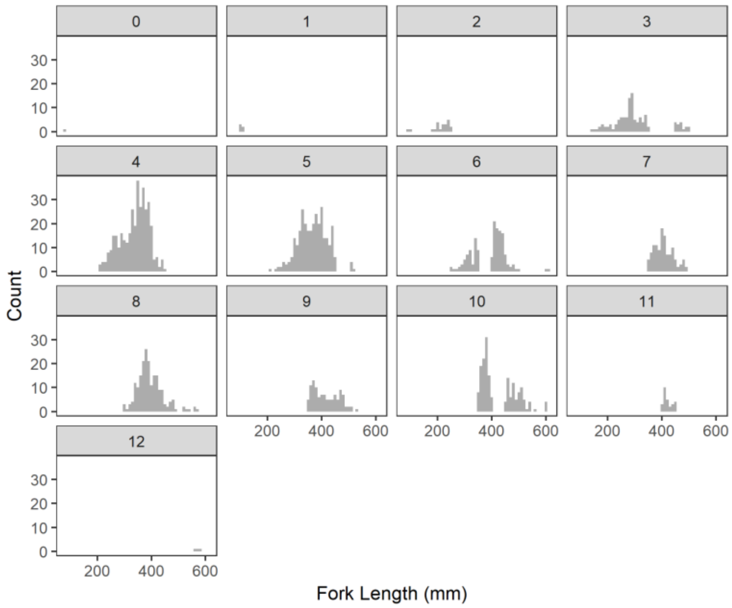


**Figure 3-25 Length-frequency histogram for all BRGMON-4 Bull Trout by age (observed and ALK-estimated combined).**

### 3.6.2 Rainbow Trout

Lengths and weights of Rainbow Trout captured only in Carpenter Reservoir in Years 1 through 5 were highly correlated (adjusted R-squared all years 0.90), and the addition of a year variable to the length-weight model was highly significant when compared to the intercept-only model (Figure 3-26; ANOVA p-value <0.001, DF 4, F 20.26). An ANOVA of annual mean $K_F$ was significant (p-value <0.001, DF 4, F 10.27), and a Tukey's HSD indicated that condition in Years 4 and 5 (2015-2017) was significantly lower than in Years 1 through 3 (2012-2015; p-values comparing Years 4 and 5 to Years 1 through 3 all <0.05; Figure 3-27). For Rainbow Trout caught only in the tributaries (during electroshocking in Years 4 and 5), year was not a significant addition to the length-weight relationship (p-value 0.79, DF 1, F 0.07) and an ANOVA of annual mean $K_F$ was not significant (p-value 0.90, DF 1, F 0.02).

Rainbow Trout age distributions were generally younger in the tributaries than in the reservoir, which may bias comparisons of $K_F$. The oldest tributary-residents were age 3 and 4 and very few juveniles were captured in the reservoir, either because no juveniles were present in the reservoir, or they were not vulnerable to current capture methods. We compared the condition factors of only age 3 and age 4 Rainbow Trout in the reservoir (n = 70) and in the tributaries (n = 33) between Years 4 and 5. Mean $K_F$ for age 3 to 4 Rainbow Trout captured in the reservoir was significantly lower in Year 5 compared to Year 4 (ANOVA p-value 0.01, DF 1, F 7.25), while there was no difference between mean $K_F$ of tributary fish of the same age (ANOVA p-value 0.58, DF 1, F 0.31).

A total of 280 Rainbow Trout have been aged by IFR (otoliths and scales; Table 3-9), and estimated Rainbow Trout ages ranged from 0 to 6 years. We fit three von Bertalanffy growth models to Rainbow Trout length and age data separated into: reservoir only fish, stream-residents captured upstream of the Marshall Creek waterfall, and a combination of tributary juveniles and all reservoir captures (Figure 3-28, Table 3-11). The three von Bertalanffy models highlight the variation in growth characteristics of different categories of Rainbow Trout and indicate that growth is slower in the tributaries. An ALK using data from tributary juveniles and all reservoir captures was used to estimate the proportion of Rainbow Trout in each age class and to estimate ages for unaged fish (Figure 3-29).

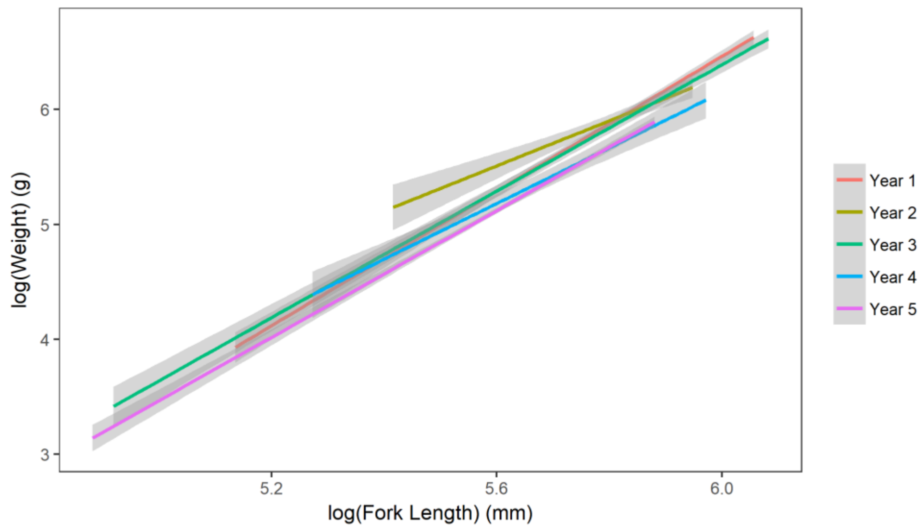


**Figure 3-26 Logarithmic length-weight relationships for Rainbow Trout (captured only in Carpenter Reservoir) in Years 1 through 5. Shaded grey area represents linear model 95% confidence interval.**

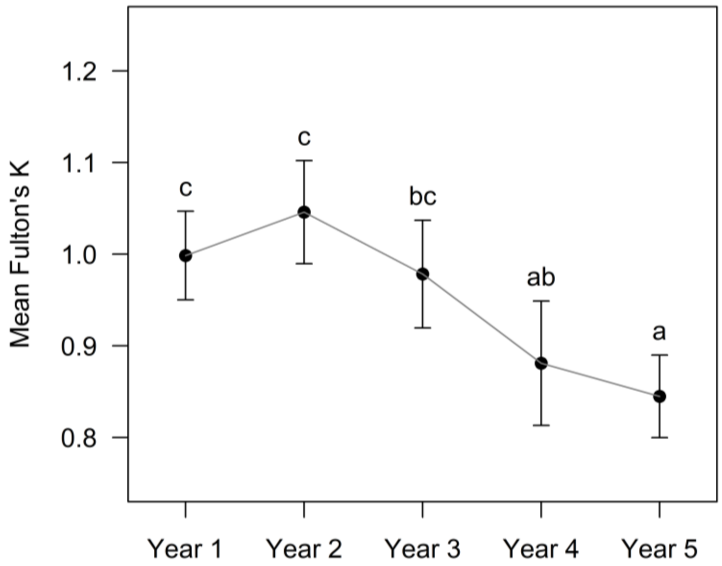


**Figure 3-27 Mean annual condition factor (with 95% CI) for Rainbow Trout (Carpenter Reservoir only). Means with the same significance letter are statistically equal.**

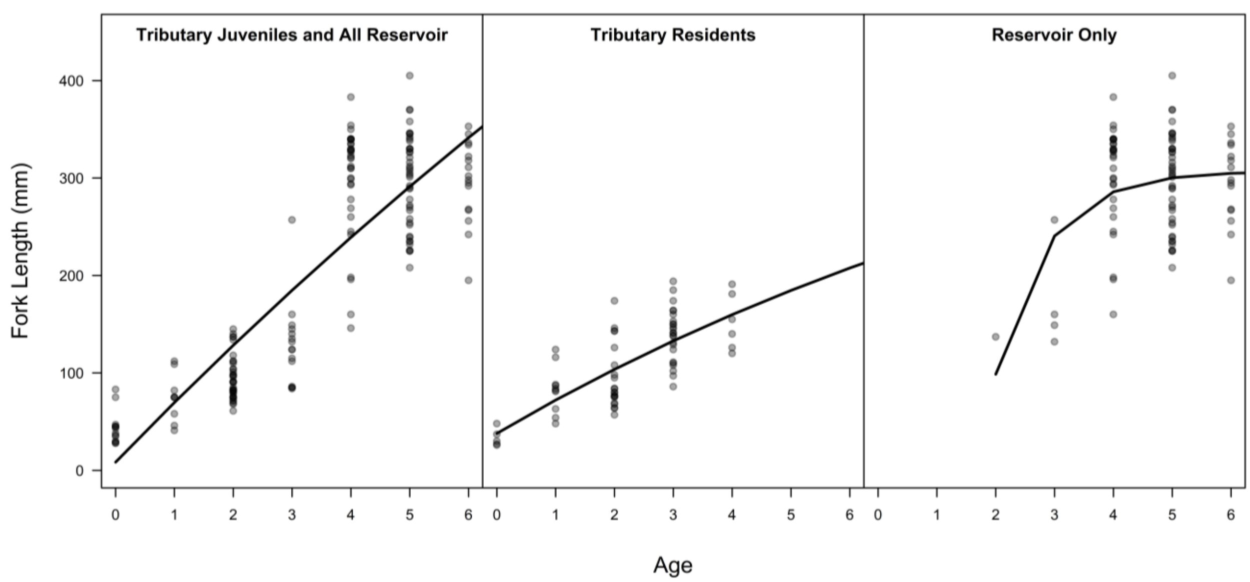


**Figure 3-28 Von Bertalanffy growth models for Rainbow Trout fork length (mm) and observed ages separated by life-history type (all study years combined). Transparency shows point overlap.**

**Table 3-11 Von Bertalanffy parameter estimates for Rainbow Trout (all study years combined) separated by life-history type, where $L_{inf}$ is the asymptotic growth, K is the growth coefficient, and $T_0$ is the time at which length is theoretically zero.**

| Parameter | Tributary Juveniles and All Reservoir | | Tributary Residents Estimate | | Reservoir Only | |
|---|---|---|---|---|---|---|
| | Estimate | SE | Estimate | SE | Estimate | SE |
| $L_{inf}$ | 1,583.43 | 13.34 | 485.87 | 19.20 | 307.03 | 0.13 |
| K | 0.04 | 0.00 | 0.08 | 0.00 | 1.14 | 0.00 |
| $T_0$ | -0.14 | 0.00 | -1.02 | 0.02 | 1.66 | 0.00 |

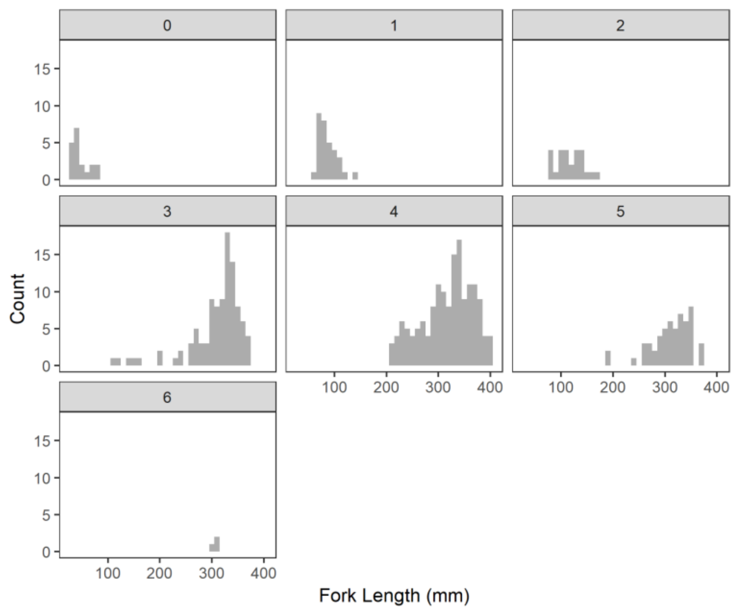


**Figure 3-29 Length-frequency histogram for all BRGMON-4 Rainbow Trout by age (observed and ALK-estimated combined).**

### 3.6.3 Mountain Whitefish

Lengths and weights of Mountain Whitefish captured in Carpenter Reservoir in Years 1 through 5 were highly correlated (adjusted R-squared all years 0.96), and the addition of a year variable to the length-weight model was significant when compared to the intercept-only model (Figure 3-30; ANOVA p-value <0.001, DF 4, F 79.91). An ANOVA of annual mean $K_F$ was significant (p-value <0.001, DF 4, F 48.60), and a Tukey's HSD test indicated that condition in Years 4 and Year 5 (2015-2017) was significantly lower than in Years 1 through 3 (2012-2015; all comparisons of Years 4 and 5 to Years 1 through 3 had p-values <0.001; Figure 3-31).

A total of 162 Mountain Whitefish have been aged by IFR (otoliths and scales; Table 3-9), and estimated Mountain Whitefish ages ranged from 1 to 6 years. A von Bertalanffy growth model was fit to Mountain Whitefish length and age data (Figure 3-32, Table 3-12). A Mountain Whitefish ALK was used to estimate the proportion of Mountain Whitefish in each age class and to estimate ages for unaged fish (Figure 3-33).

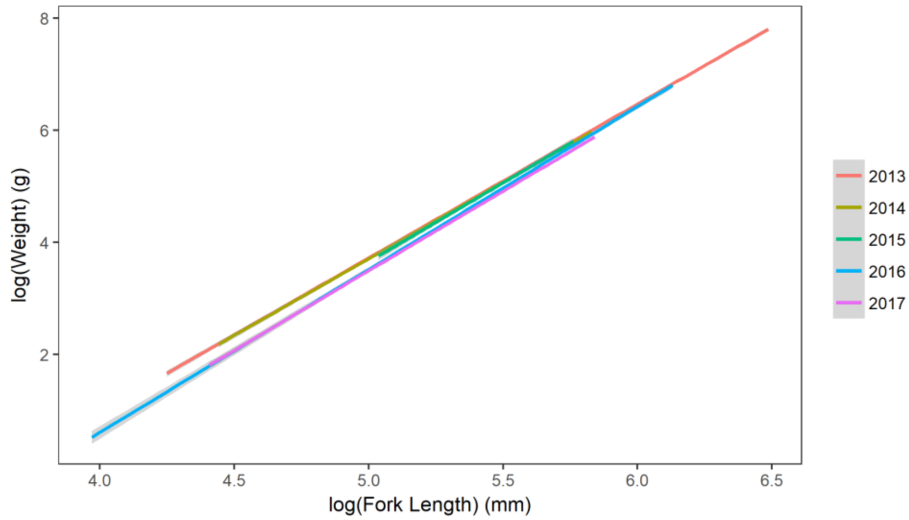


**Figure 3-30 Logarithmic length-weight relationships for Mountain Whitefish in Years 1 through 5. Shaded grey area represents linear model 95% confidence interval.**

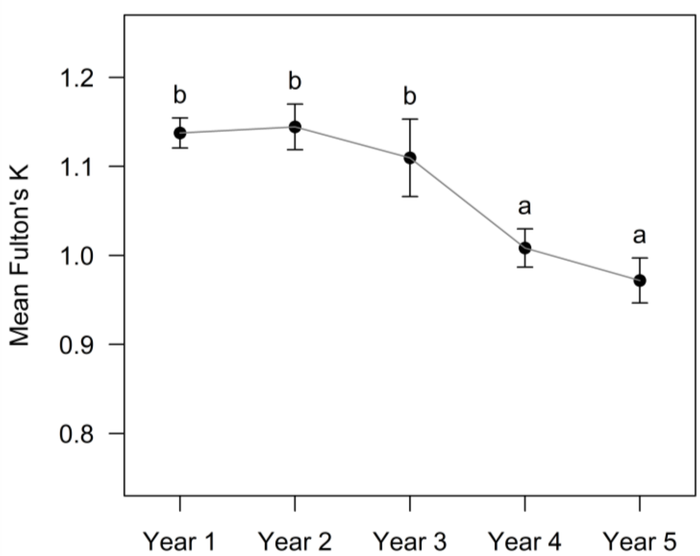


**Figure 3-31 Mean annual condition factor (with 95% CI) for Mountain Whitefish in Carpenter Reservoir. Means with the same significance letter are statistically equal.**

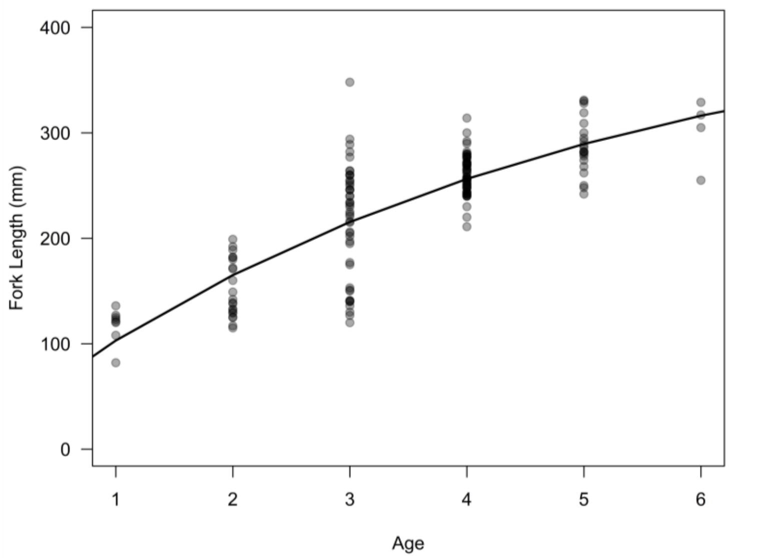


**Figure 3-32 Von Bertalanffy growth model for Mountain Whitefish fork length (mm) and observed ages (all study years combined). Transparency shows point overlap.**

**Table 3-12 Von Bertalanffy parameter estimates for Mountain Whitefish (all study years combined), where $L_{inf}$ is the asymptotic growth, K is the growth coefficient, and $T_0$ is the time at which length is theoretically zero.**

| Parameter | Estimate | SE |
|---|---|---|
| $L_{inf}$ | 431.38 | 1.51 |
| K | 0.21 | 0.00 |
| $T_0$ | -0.30 | 0.01 |

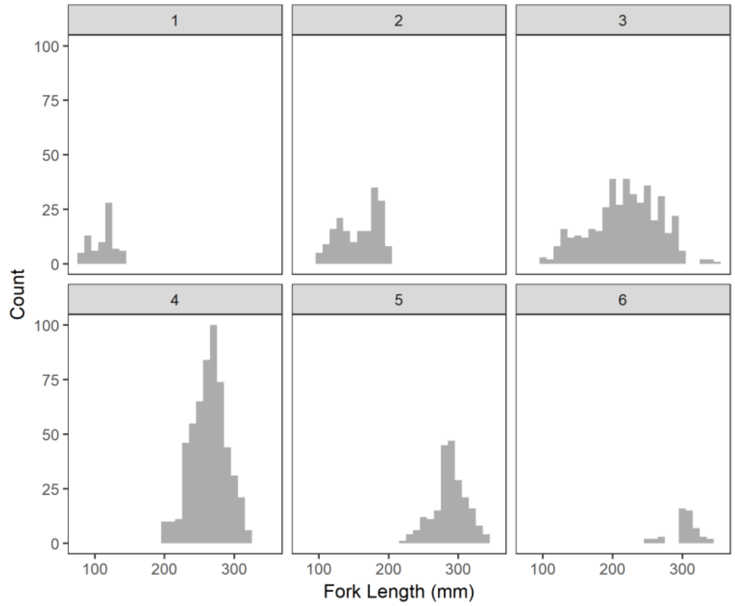


**Figure 3-33 Length-frequency histogram for all BRGMON-4 Mountain Whitefish by age (observed and ALK-estimated combined).**

### 3.6.4 Kokanee

Lengths and weights of kokanee captured in Carpenter Reservoir in Years 1 through 5 were highly correlated (adjusted R-squared all years 0.90), and the addition of a year variable to the length-weight model was significant when compared to the intercept-only model (Figure 3-34; ANOVA p-value <0.001, DF 4, F 15.4). An ANOVA of annual mean $K_F$ was significant (p-value <0.001, DF 4, F 12.04), and a Tukey's HSD test indicated that condition in Years 4 and 5 was significantly lower than in Year 3 (p-values <0.05; Figure 3-35), but not significantly lower than in Years 1 and 2.

A total of 50 kokanee have been aged by IFR (scales; Table 3-9). Estimated kokanee ages ranged from 2 to 4 years. A von Bertalanffy growth model was not fit to kokanee length-at-age data due to the lack of juvenile age and length data (length-at-age boxplots are shown in Figure 3-36).

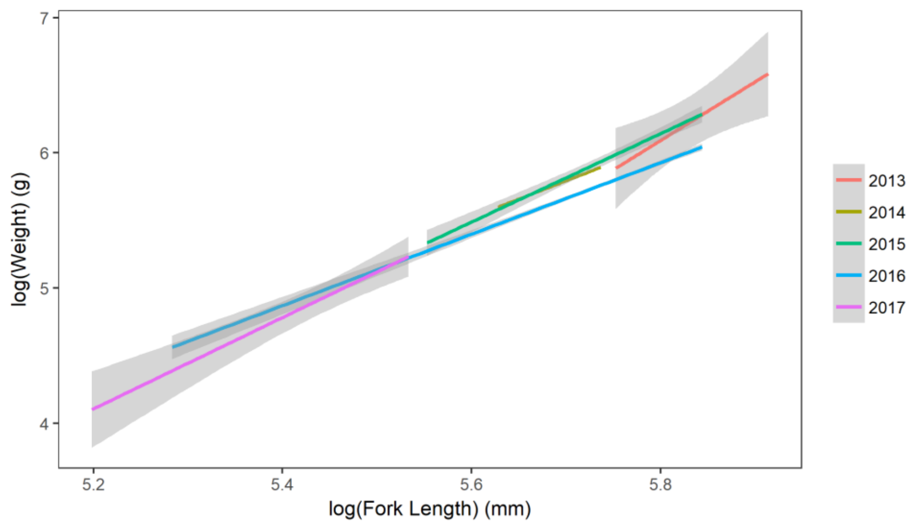


**Figure 3-34 Logarithmic length-weight relationships for kokanee in Years 1 through 5. Shaded grey area represents linear model 95% confidence interval.**

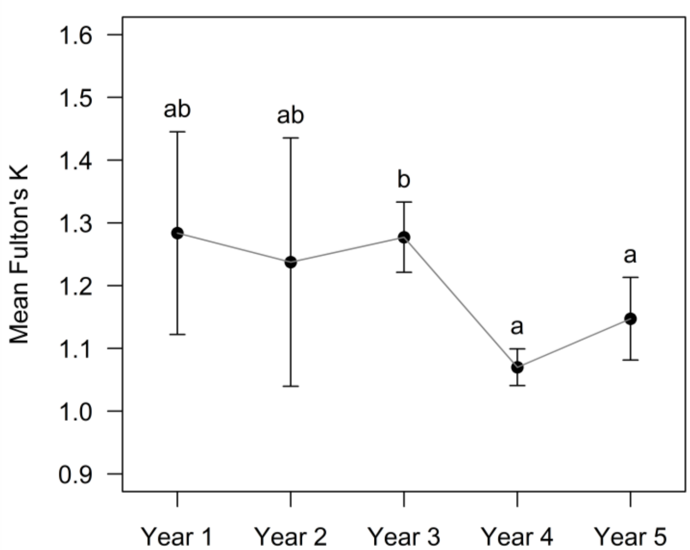


**Figure 3-35 Mean annual condition factor (with 95% CI) for kokanee in Carpenter Reservoir. Means with the same significance letter are statistically equal.**

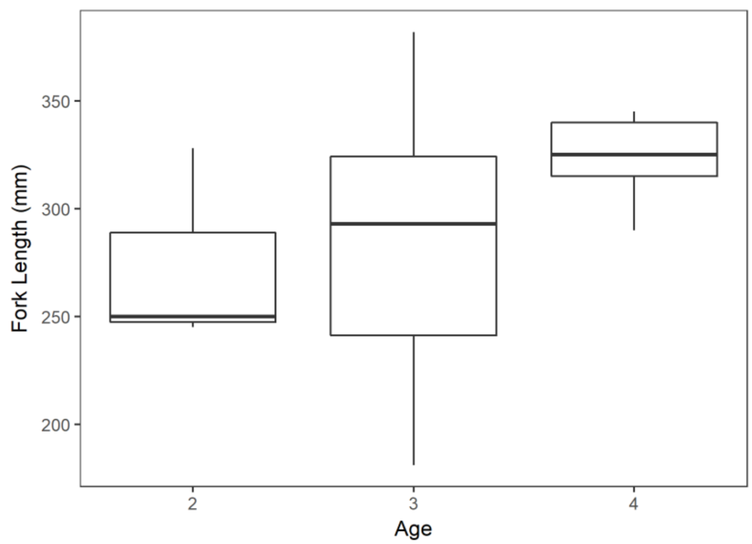


**Figure 3-36 Boxplots of fork length (mm) for each age class of kokanee observed in Carpenter Reservoir.**

## 3.7 Tributary Surveys in the Carpenter Reservoir Watershed

### 3.7.1 Kokanee spawner assessments

Kokanee spawner surveys in Years 2 through 5 (2013-2016) measured approximate migration timings and relative spawner abundances in Carpenter Reservoir tributaries (Figure 3-37). In Year 5 (2017), kokanee were observed from August 16 to September 29, with counts peaking on September 8. The highest spawner counts were observed in Truax and Macdonald Creeks, followed by Marshall Creek, and peak migration timing was relatively consistent amongst the tributaries (Figure 3-38). Variability in spawner counts is expected due to the unique physical characteristics of each tributary and differences in the quantity and quality of spawner habitat (Appendix A). Weekly spawner counts were summed across all tributaries to obtain an index of spawner abundance (only tributaries surveyed in all years were included in annual totals; Figure 3-37). Combined spawner counts in Carpenter Reservoir tributaries were similar to Year 3 (2015) and higher relative to Year 4 (2016).

Kokanee counts were partitioned into above and within the drawdown zone (i.e., the maximum allowable elevation of 650 masl) to evaluate the potential risks of fluctuations in reservoir elevation to spawning and migrating kokanee (redds within the drawdown zone are vulnerable to flooding). In Girl Creek, 71% of kokanee observed during all visual surveys combined were located within the drawdown, compared to 42% in Macdonald Creek, 4% in Marshall Creek, and 40% in Truax Creek. In Year 4 (2016), the proportion of kokanee observed in the drawdown zones of Macdonald and Marshall Creeks was almost identical to Year 5 (2017), while the proportion of kokanee in the drawdown zone in Year 5 (2017) decreased by 29% in Girl Creek and 31% in Truax Creek relative to Year 4 (2016). Variations in the distribution of kokanee may be partially related to reservoir elevation during the migration period (Figure 3-39).

Temperature data loggers were reinstalled in Marshall Creek, Gun Creek, Macdonald Creek, Truax Creek, the Hurley River, and the Middle Bridge River in May 2017 to monitor temperature profiles through the summer and during the fall kokanee migration period (Figure 3-40). Mean daily temperature at the onset of the kokanee spawning migration was 7.7°C in Marshall Creek, 10.7°C in MacDonald Creek, and 8.1°C in Truax Creek. At peak count, water temperature was 8.3°C in Marshall Creek, 11.7°C in Macdonald Creek, and 10.2°C in Truax Creek.

Using a kokanee 50% hatch ATU of 680 (at 7.5°C; DFO 1997), we estimated the hatching period based on the onset, peak, and end of the observed migration in Truax and Macdonald Creeks using continuous temperature data for the 2015/2016 winter period (Figure 3-41; temperature data were not available for 2016/2017). We also calculated the 50% hatch dates for the Middle Bridge River, where kokanee are known to spawn; however, because kokanee cannot be observed due to high turbidity, migration timing in the Middle Bridge River is uncertain.

Peak hatch dates were highly variable for kokanee in Truax Creek, Macdonald Creek, and the Middle Bridge River due to the large ATU requirements for kokanee and temperature differences among the tributaries. Warmer and more stable temperatures in the Middle Bridge River (regulated by BC Hydro) resulted in earlier estimated peak hatch dates and a relatively short hatch window (Figure 3-41). Macdonald Creek is also relatively warm, but its unregulated nature results in temperatures that are less stable than the Middle Bridge River. The 50% hatch period for Macdonald Creek was estimated to begin in October but the hatching window extended over a 6-month period. Truax Creek is snowmelt-fed and colder than the other tributaries, resulting in a later estimated hatching period and a peak 50% hatch date in early May.

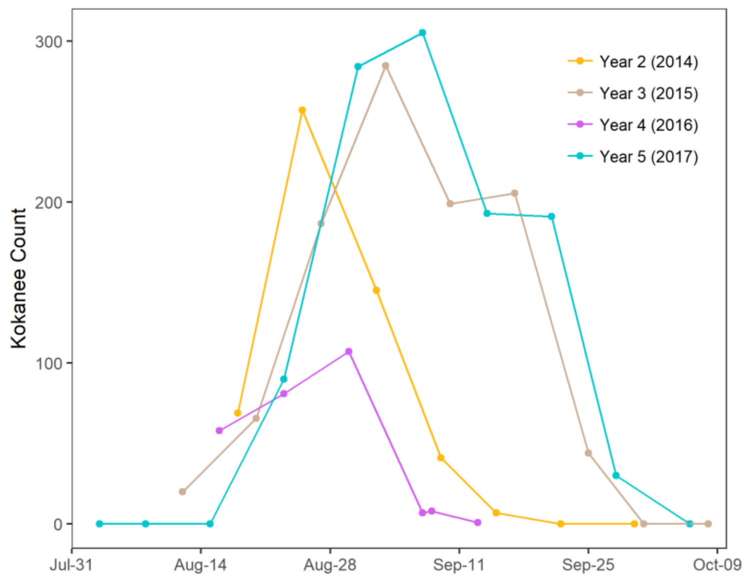


**Figure 3-37 Counts of kokanee in Carpenter Reservoir tributaries (Truax, Girl, Macdonald, Sucker, and Marshall Creeks combined) in Years 2 through 5 (2014 to 2017).**

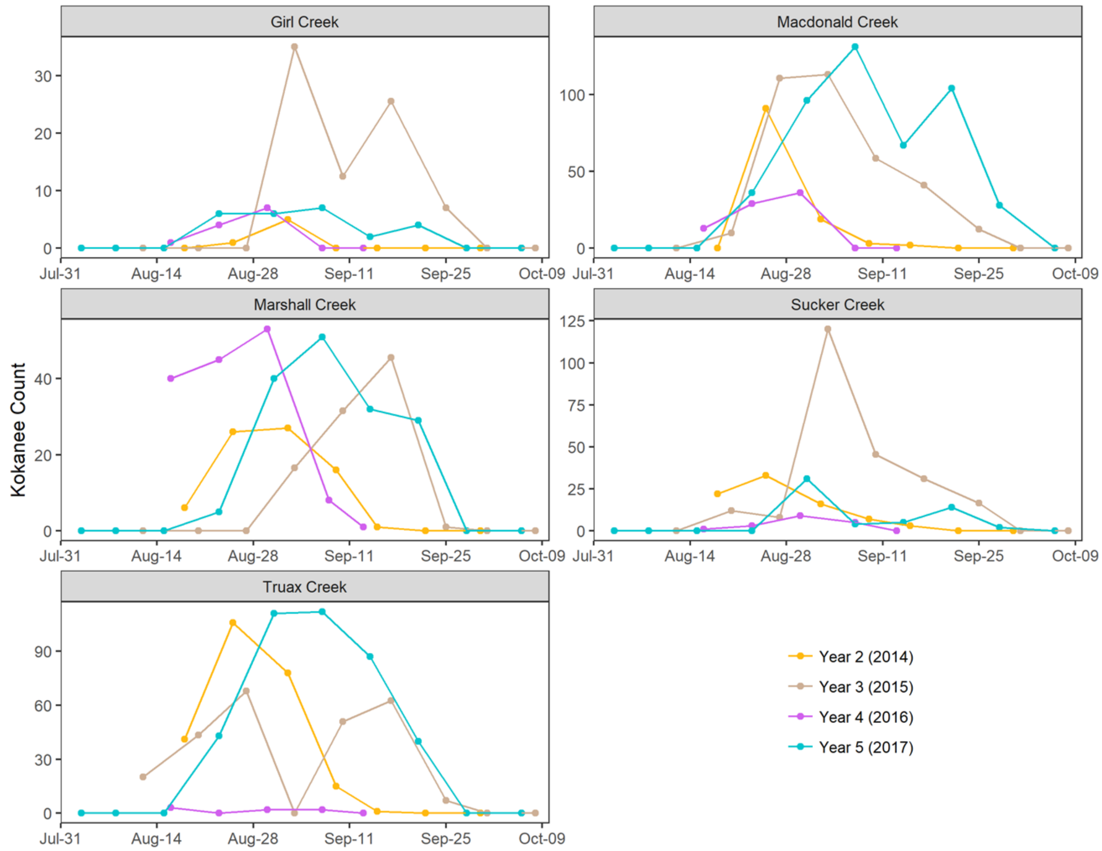


**Figure 3-38 Tributary-specific kokanee spawner counts from visual surveys in Years 2 through 5.**

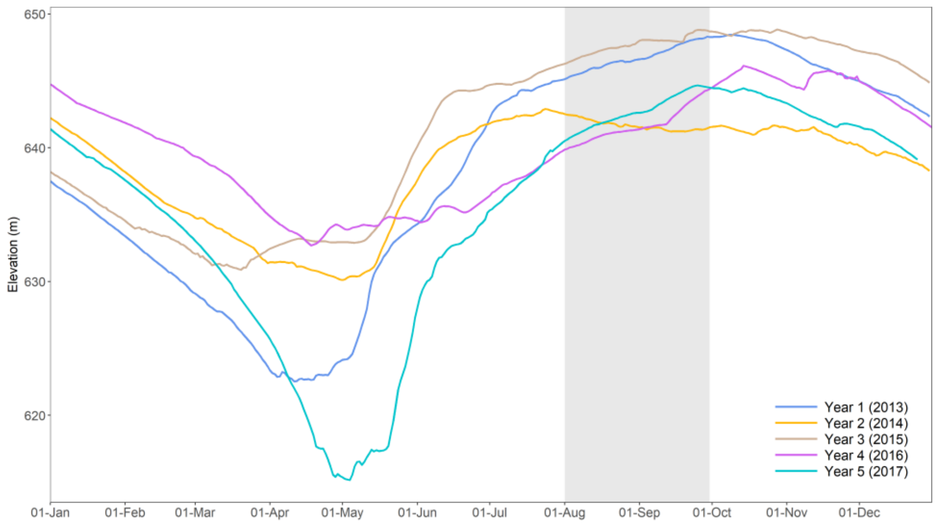


**Figure 3-39 Carpenter Reservoir elevation (Years 2 to 5; 2014 to 2017) during the approximate kokanee spawning window (August 1 to September 31; shaded in grey) in the Carpenter Reservoir.**

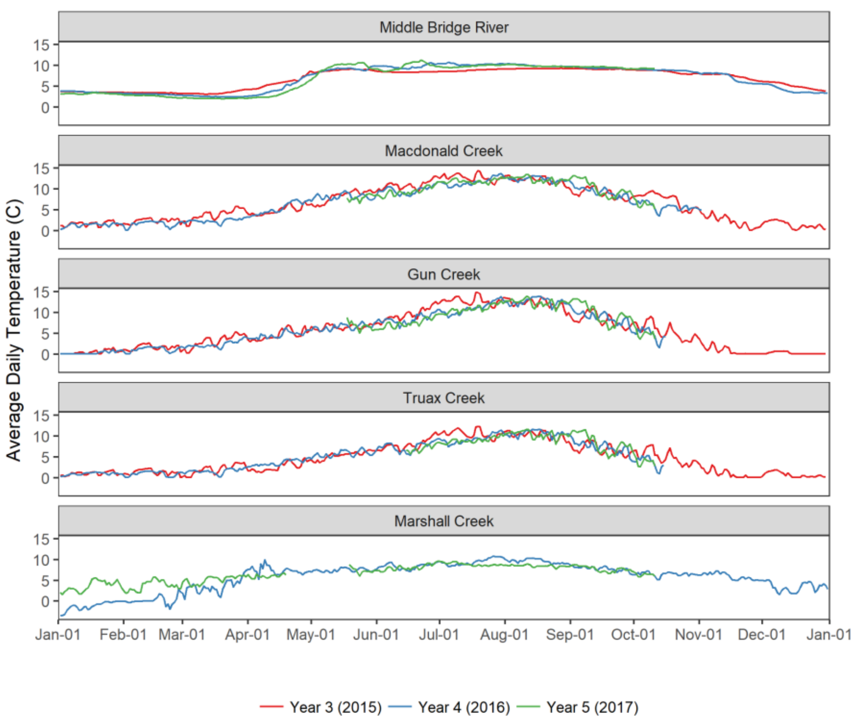


**Figure 3-40 Average daily temperatures in Carpenter Reservoir tributaries.**

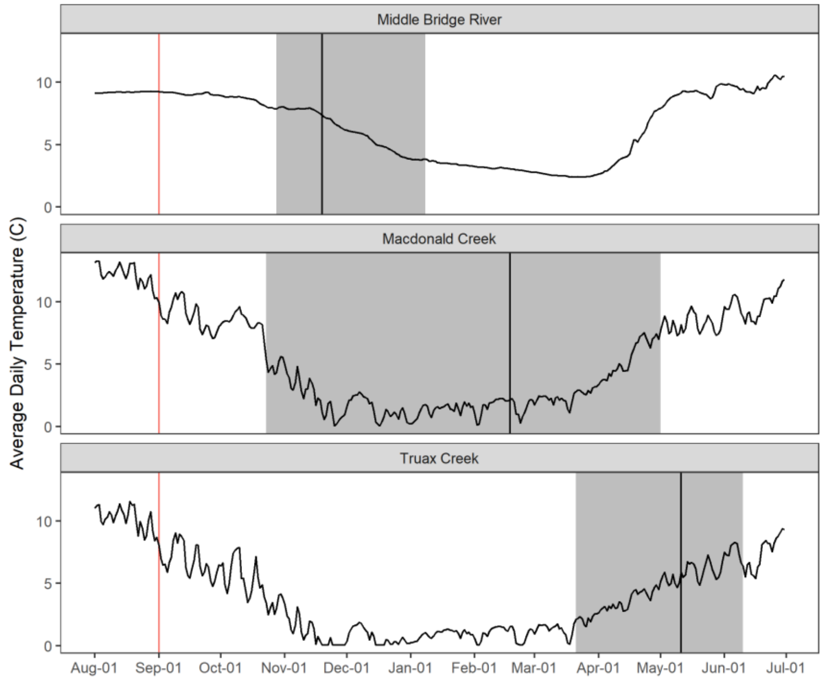


**Figure 3-41 Dates of 50% hatch (shaded grey area) and peak 50% hatch (black line) for kokanee in Carpenter Reservoir tributaries. The red line is the peak migration date in Year 5 (2017).**

*Detailed Kokanee Redd Surveys*

On September 12, 2017, detailed redd surveys were performed in Truax, Macdonald, Gun, and Marshall Creeks in addition to the weekly kokanee spawner count. Paired kokanee and redds were observed in all tributaries surveyed. On September 12, reservoir elevations were close to the maximum level reached in 2017, and the below-drawdown habitats were almost entirely flooded in Marshall and Truax Creeks. Due to the similar timing of peak spawning and peak reservoir elevations, redds observed during the September 12 survey were not likely flooded during incubation.

In Truax Creek, paired kokanee were observed both above and below the drawdown area in almost all isolated patches of appropriate substrate. We observed higher densities of paired kokanee above the drawdown zone, likely due to increased woody debris and cover relative to the drawdown zone. In Macdonald Creek, one redd was identified within the drawdown zone, and paired kokanee and 10 redds were observed above the drawdown zone boundary. As observed in Truax Creek, the habitat above the drawdown zone was of higher quality than below the drawdown boundary, corresponding to higher spawner and redd densities. Gun Creek flows into Carpenter Reservoir via a heavily-braided fan with numerous side channels, and paired kokanee and redds were observed in isolated patches of high quality spawning gravel. We could not assess spawners upstream of the Gun Creek drawdown zone to high flows and turbidity. In Marshall Creek, paired kokanee and 20 redds were observed below the Marshall Creek waterfall. In years of high maximum elevation (such as Year 4/2015 of BRGMON-4), all Marshall Creek habitat can become backwatered by the reservoir and affect spawning and incubation of kokanee.

The redd surveys were repeated on October 11, 2017 to determine if redds could be identified without the presence of spawning kokanee. Although redds were observed on September 12, we could not definitively identify redds on October 11 due to high flows, turbulence, and a lack of periphyton growth on surrounding substrate. Redd counts and spawner surveys completed during peak counts may still be useful for determining how reservoir management affects kokanee spawning success. When reservoir elevation is low during peak spawning, redds or paired kokanee observed within the drawdown zone could indicate incubating redds are vulnerable to inundation in the event of increasing reservoir elevation.

### 3.7.2 Kokanee Stranding Event in the Middle Bridge River

On September 29, 2017, a Goldbridge resident reported ~80 stranded kokanee in the Middle Bridge River close to the Sucker Creek confluence (Figure 3-42). A ramp down of Lajoie Dam had occurred the week before the stranding event, but the reported site was not included in the stranding assessment protocol. The stranding may have occurred because of the ramp down, but was more likely related to colder temperatures reducing inflows from the Hurley River (or a combination of the two mechanisms). On October 2 and 3, a crew consisting of BC Hydro and SER personnel performed a stranding assessment at the site and recovered only one kokanee (spawned out female), suggesting that heavy predation occurred on the stranded kokanee. Also salvaged were 38 Bridgelip Suckers, 101 Coastrange Sculpin, four Rainbow Trout (seven juvenile and one adult), three Bull Trout (one juvenile and two adult), 35 Mountain Whitefish, and ~300 Redside Shiners. Within the shallow isolated areas, the technicians were unable to identify kokanee redds (small scour areas were observed but could not be definitively attributed to kokanee); however, the crews were able to confirm the presence of clean, small gravels that were suitable for kokanee spawning.


**Figure 3-42 Location of isolated pools observed in September 2017 in the Middle Bridge River (source: Google Earth Images).**

### 3.7.3 Tributary Electroshocking Assessment in Carpenter Reservoir Tributaries

We performed a second year of monthly tributary electroshocking in Carpenter Reservoir tributaries, with the goal of shocking two 50 m sections (above and below the drawdown zone) in Truax Creek, Macdonald Creek, Marshall Creek, Tyaughton Creek and Gun Creek. Rainbow Trout and sculpin were the most frequently captured species, with smaller catches of Bull Trout, kokanee, and Mountain Whitefish (Table 3-13).

**Table 3-13 Total catches by species during Carpenter Reservoir tributary electroshocking in Year 5 (2016-2017).**

| Tributary | Bull Trout | Kokanee | Mountain Whitefish | Rainbow Trout | Sculpin |
|---|---|---|---|---|---|
| Macdonald | 0 | 3 | 4 | 37 | 134 |
| Marshall | 1 | 0 | 2 | 56 | 10 |
| Truax | 1 | 0 | 3 | 2 | 3 |
| Gun | 1 | 9 | 10 | 32 | 114 |
| Tyaughton | 2 | 0 | 2 | 0 | 35 |

*Macdonald Creek*

Macdonald Creek is a relatively warm tributary (avg August temperature of ~12.3 C compared to ~10.5 C in Truax Creek) fed by a small upstream lake with a known population of resident Rainbow Trout. The confluence of Macdonald Creek is located on the western end of Carpenter Reservoir and is often part of the Middle Bridge River. Because of its western location, Macdonald Creek is less affected by reservoir elevation management, and the drawdown zone is only flooded in years with extreme elevation maxima. We captured Rainbow Trout both above and below the drawdown zone during almost every sampling occasion, and Rainbow Trout capture rates were relatively high compared to Truax and Gun Creeks (but similar to Marshall Creek). We captured primarily Rainbow Trout ages 1 through 3 until August, when we first observed the emergence of YOY Rainbow Trout (Figure 3-43).

We caught more than two times the number of Rainbow Trout above the drawdown zone relative to below in almost every sampling occasion on Macdonald Creek. Habitat quality is higher above the drawdown zone, and we also found evidence that a resident population of Rainbow Trout is present in Macdonald Creek: age 3 and 4 Rainbow Trout were smaller in the resident population relative to the reservoir population, and we recaptured two Rainbow Trout in Year 5 (2017) that had been tagged in Year 4 (2016) above the drawdown zone. One individual was tagged at age-1 and had grown 13 mm (from September 2016 to May 2017), while a second individual was tagged at age-2 and had grown 13 mm (from August 2016 to July 2017). We also captured two Rainbow Trout twice in the same year: one age-4 fish was captured in both April and July of 2017, and one age-1 fish was captured in September and October of 2016. Rainbow Trout captured in Macdonald

Creek ranged in age from 0 to 4 in both years; however, captures of age-0 (YOY) Rainbow Trout were higher in Year 4 relative to Year 5.

We captured two Bull Trout in Year 4 (2016; one juvenile age-2 and one mature adult [tagged at the confluence of Tyaughton Creek in 2014]) but no Bull Trout were captured in Year 5 (2017) and it does not appear that Macdonald Creek is a Bull Trout spawning tributary. We also captured Mountain Whitefish in both years (ages 1 to 3) and adult kokanee spawners in September.

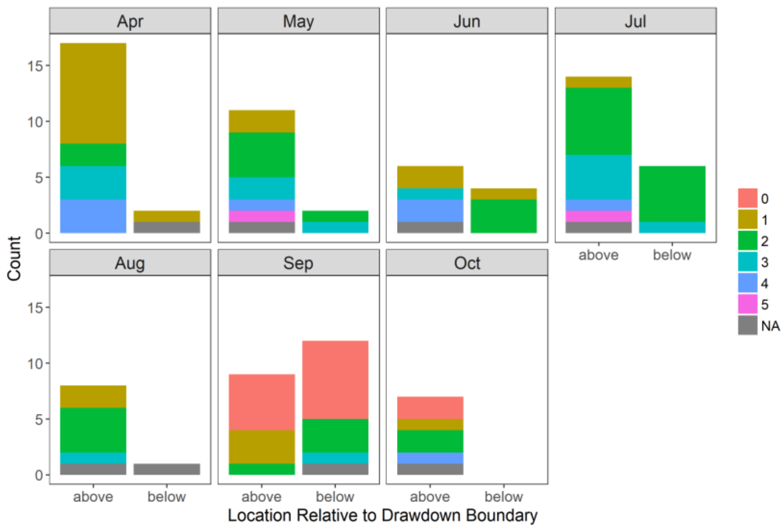


**Figure 3-43 Counts of Rainbow Trout captured in Macdonald Creek both above and below the drawdown zone boundary in Years 4 and 5 combined. Colors represent scale ages.**

*Marshall Creek*

Marshall Creek is fed by an upstream lake and is characterized by a large waterfall located just upstream of the confluence with Carpenter Reservoir. The waterfall creates a plunge pool and a relatively deep, channelized stream that can be almost entirely backwatered in years of high reservoir elevation. Due to the channelized nature of the creek, clear outflow waters remain present in the tributary even at maximum reservoir elevations, but tributary depths increase and flows decrease. We captured Rainbow Trout both above and below the drawdown zone during almost every sampling occasion, and Rainbow Trout capture rates were relatively high compared to Truax and Gun Creeks (but similar to Macdonald Creek). Capture rates were relatively stable and higher above the drawdown zone relative to the drawdown zone (in all months) and the above-drawdown zone population is resident to Marshall Creek (two-way movement cannot occur between the reservoir and the upstream habitat due to the waterfall barrier).

Rainbow Trout captured within the drawdown zone ranged from age-0 to age-6, while those caught above the drawdown zone ranged in age from 0 to 4. Adult Rainbow Trout of the same age were larger in the reservoir population relative to the resident population. In Year 5 (2017), we recaptured a Rainbow Trout above the waterfall that had been tagged at age-3 in the same location (growth of 15 mm from July 2016 to May 2017). We captured an age-1 Rainbow Trout above the drawdown zone in June (which had emerged the previous year) and recaptured the same fish in August (growth of 7 mm).

We captured a small number of adult Bull Trout below the drawdown zone in both years. One Bull Trout (age-4) captured in Marshall Creek in September of 2016 was tagged at the tributary confluence in June of the same year. Kokanee spawners were observed in the fall of both years and small numbers of adult Mountain Whitefish were also captured in each year.


**Figure 3-44 Counts of Rainbow Trout captured in Marshall Creek both above and below the drawdown zone boundary in Years 4 and 5 combined. Colors represent scale ages.**

*Truax Creek*

Truax Creek is a cold and steep tributary fed entirely by snowmelt, and is characterized by relatively high spring and summer flows. In Year 5 (2017), we were not able to sample the tributary in May, August, and October due to a combination of bear activity, high flows, and high densities of kokanee spawners. We captured an age-0 Rainbow Trout in Truax Creek (confirming the occurrence of adult spawning), but Rainbow Trout capture rates were low relative to Marshall and Macdonald Creeks and we did not capture Rainbow Trout in each month.

We did not find evidence of a tributary-resident population of Rainbow Trout in Truax Creek. No Rainbow Trout individuals tagged in Year 4 (2016) were recaptured in Year 5 (2017). We did catch one age-2 Rainbow Trout twice in Year 5 (2017), once in September and once in October. We captured Mountain Whitefish in both years, both mature adults and immature fish of age-1. We also captured a number of juvenile Bull Trout including an age-0 individual in Year 4 (2016), suggesting Truax Creek is a Bull Trout spawning tributary.

*Gun Creek*

Gun Creek is a large, high-gradient tributary that drains a large upstream Rainbow Trout lake (Gun Lake). We added Gun Creek to the sampling program in Year 5 (2017) because it is suspected to be a spawning tributary for both Rainbow and Bull Trout. We captured Rainbow Trout in Gun Creek both above and below the drawdown zone in almost all months. Catches of all species were relatively similar above and below the drawdown zone in Gun Creek, which may be due to similar habitat characteristics between the two zones. Rainbow Trout catch rates were higher than those in Truax Creek but lower than Macdonald and Marshall Creeks. We captured a YOY Rainbow Trout in September, suggesting that Rainbow Trout successfully spawn in the tributary. We did not observe evidence of a resident population of Rainbow Trout in Gun Creek, and most Rainbow Trout were juveniles from age 0 to 3.

We captured one small Bull Trout in Gun Creek in August with a length of 155 mm (likely age-1 or age-2), indicating Bull Trout spawning likely occurs in the tributary. We captured many age-2 and age-3 Mountain Whitefish both above and below the drawdown zone. Gun Creek is very close to the Middle Bridge River (known Mountain Whitefish habitat), which likely explains why this tributary had the highest catches of Mountain Whitefish of all tributaries sampled.

*Tyaughton Creek*

Tyaughton Creek drains Tyaughton Lake via a steep canyon and is thought to be an important Bull Trout spawning location (Griffith 1999). When Tyaughton Creek nears Carpenter Reservoir, the angle lessons dramatically and the tributary picks up extremely high turbidity levels due to a fine, muddy substrate. We captured two Bull Trout in the drawdown zone of Tyaughton Creek in July (no above-drawdown habitat was sampled due to accessibility issues). The fork lengths of the two Bull Trout were 51 and 189 mm, possibly age-0 and age-1 or 2, respectively. The presence of these immature Bull Trout suggest Tyaughton Creek is a spawning location for Bull Trout. We also captured two age-2 Mountain Whitefish in the tributary, one in June and one in July.

#### ***3.7.3.1 Rainbow Trout Growth***

We compiled length and age data from tributary electroshocking in Years 4 and 5 to examine juvenile Rainbow Trout growth (Figure 3-45). Mean length-at-age for age-0 to age-2 Rainbow Trout was variable throughout the sampling months, but a positive trend in fork length was observed from April to October. We used linear modelling to estimate the average growth per month for both age-1 and age-2 Rainbow Trout in all Carpenter Reservoir tributaries combined. Model slopes predict monthly growth from April to October to be 6.3 mm for age-1 Rainbow Trout (adjusted R-squared 0.56) and 7.6 mm for age-2 Rainbow Trout (adjusted R-squared 0.63). We pooled data from all tributaries to obtain an adequate sample size for growth rate calculations. Tributary-specific growth rates will be examined with additional electroshocking data collected in future years.

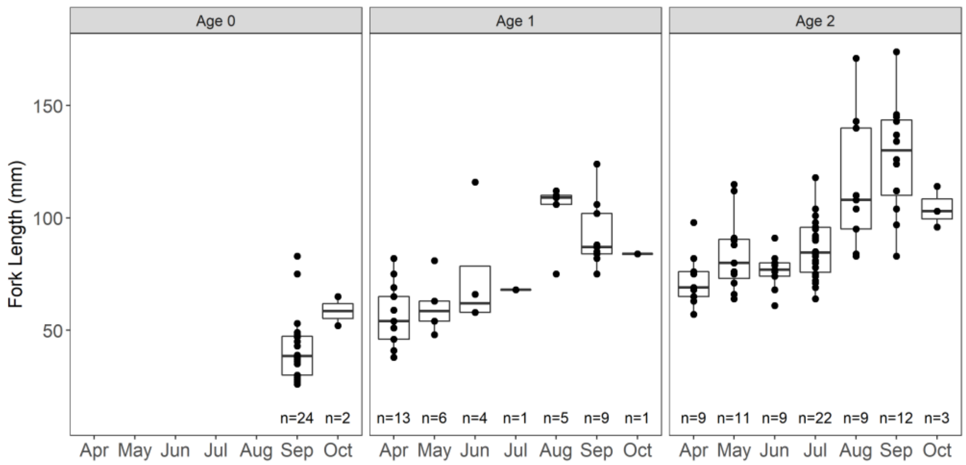


**Figure 3-45 Length boxplots of age-0 to age-2 Rainbow Trout captured in Macdonald, Marshall, Truax, and Gun Creeks during Year 4 and Year 5 tributary electroshocking (2016 and 217).**

### *3.7.3.2 Rainbow Trout ATU Calculations*

Adult spawner surveys (BRGMON-4 and TEC unpublished) in Carpenter Reservoir and in Downton Reservoir (Sneep 2015a) suggest spawning migrations begin in mid-May (May 15) and peak in mid-June (June 18), and we first observed emerging YOY in August in most tributaries. Tributary electroshocking results indicate successful Rainbow Trout spawning in Marshall, Macdonald, Gun, and Truax Creeks. According to tributary temperature data collected in Year 5 (2017), the average daily temperatures at peak migration were 6.8°C in Truax Creek, 7.7°C in Gun Creek, 8.2°C in Marshall Creek, and 9.7°C in Macdonald Creek.

Rainbow Trout visual spawner surveys were relatively unsuccessful, and detailed timing information is not available for each tributary. We used a peak spawning date of June 18 across all tributaries (migration onset was May 15 and the end of migration was July 15) and an ATU requirement of 390 (at 10°C) to estimate the timing of Rainbow Trout 50% hatch in Gun, Marshall, Macdonald, and Truax Creeks (Figure 3-46). Temperature data were from Year 4 (2016) because temperature loggers were not installed at the onset of the spawning migration in Year 5 (2017).

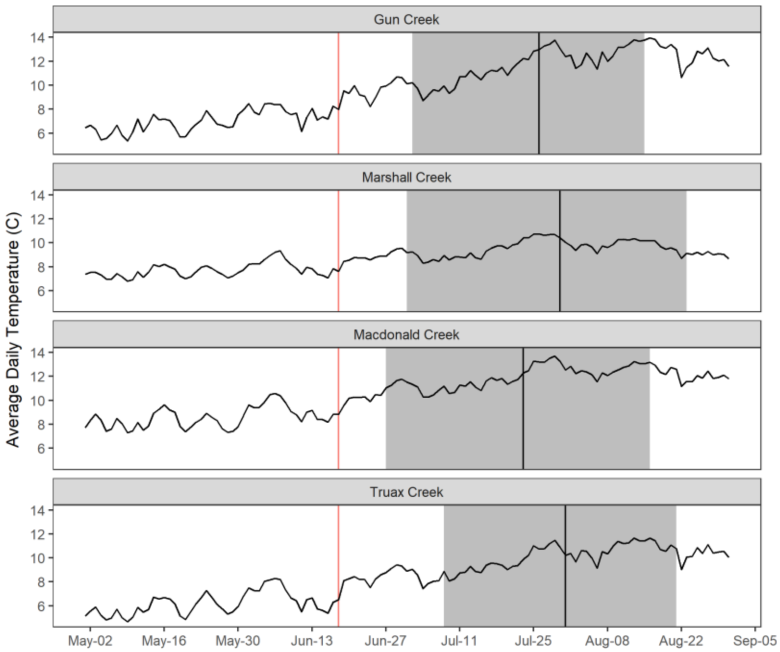


**Figure 3-46 Rainbow Trout 50% hatch timing for Carpenter Reservoir tributaries using average spawn timings and temperature data from Year 4. The red line is the peak hatch date (June 18), the black line is the peak estimated 50% hatch and the grey shaded area shows the range in 50% hatch from migration onset (May 15) to completion (July 15).**

# 4 Discussion

The primary objective of BRGMON-4 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 5 (2016-2017) of the 10-year monitoring program builds on data and understanding gained in Years 1 through 4 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 have varied throughout BRGMON-4 (2012 to 2017), and reservoir elevations in Year 5 (2017) followed a unique trajectory relative to Years 1 through 4. Minimum elevation was low relative to previous years and the reservoir was maintained at minimum levels for a longer period. Prolonged low elevation resulted in an expansion of riverine habitat and a contraction of lacustrine habitat proximate to Terzaghi Dam. Kokanee, a lacustrine species during the summer, were concentrated in this contracted habitat and were entrained through Terzaghi Dam into the Lower Bridge River during high flow releases (>120 cms) in June and July. Kokanee entrainment was also observed in Year 4 (2016), when Lower Bridge River discharge was ~100 cms. Kokanee entrainment through Terzaghi Dam was not quantified in either year and the population-level effect on Carpenter Reservoir kokanee is still unknown. The effect of kokanee entrainment on kokanee productivity may be delayed due to the age classes of entrained fish, and additional years of visual survey data will likely show whether entrainment resulted in population-level effects. Entrainment of other species was not observed in Years 4 or 5, and no Carpenter Reservoir PIT tags were detected on PIT arrays at the counter site and the Reach 3-4 break in the Lower Bridge River from October 6 to November 29, 2015 (the PIT antenna was not operational during the high flow periods in June and July when entrainment occurred). Entrainment of other species may have occurred through Terzaghi Dam; however, kokanee were particularly vulnerable due to their reliance on lacustrine habitat during the elevated discharge periods in June and July of Years 4 and 5 (2016 and 2017).

Prolonged low elevations in Carpenter Reservoir likely affected the distribution patterns of several species in Carpenter Reservoir. During the summer and fall, Carpenter Reservoir Bull Trout typically congregate at tributary confluences to seek thermal refuge and prey on small tributary fish. In the summer of Year 5 (2017), tributary confluences west of Tommy Creek (~ 5 km west of Marshall Creek) were still part of the Middle Bridge River, and densities of all species at these western tributaries were lower than in previous years. Tributaries that flow into the Middle Bridge River generally have much smaller pools of clear, cold water at their confluence, which generally have high densities of adult Bull Trout and adult Rainbow Trout. Also, the Middle Bridge River itself is relatively poor fish habitat when it flows through the Carpenter Reservoir drawdown area from Gun Creek to the confluence with the reservoir (i.e., high turbidity, muddy substrate, no cover, etc.), particularly for Bull Trout prey species (kokanee, Rainbow Trout, and Redside Shiners). In years of low reservoir elevation, forage species likely concentrate further east towards Terzaghi Dam due to habitat suitability, and Bull Trout move east in response. The effects of elevation-related habitat contractions are particularly relevant to reservoir productivity and management decisions in the reservoir, and BRGMON-4 activities will continue to inform habitat preferences and behavioural responses in Carpenter Reservoir and the Middle Bridge River.

## 4.2 Mountain Whitefish Spawning Assessment

Mountain Whitefish spawning assessments were completed by TEC in the Middle Bridge River in 2005 and 2009, and were repeated in Year 1 (2011), Year 2 (2012), and Year 5 (2016) of BRGMON-4. Migration timing, peak spawner counts, and 50% hatch dates were relatively consistent among years. Male and female Mountain Whitefish captured during Year 5 were smaller in length relative to previous surveys in 2009, 2012, and 2013. Biological data suggest Mountain Whitefish condition has declined in Carpenter Reservoir and the Middle Bridge River in the last two years, which may explain the decrease in average fork lengths of spawning Mountain Whitefish in Year 5.

Despite using the same egg mat equipment and deployment sites as TEC, egg mats in Year 5 (2016) were unsuccessful as an egg collection method. We do not see decreased egg mat catches as an indication of overall declines in Mountain Whitefish spawning because catches of adult spawners were comparable to previous surveys. In Year 5, the substrate at spawning mat sites was characterized by high levels of sand and fines compared to boulder, cobble, and gravel in previous surveys. Sand and fines are unsuitable for Mountain Whitefish spawning, which likely explains poor egg mat catches in Year 5 relative to previous years. Mountain Whitefish were likely spawning in other areas of the Middle Bridge River (rather than a dramatic decline in spawning), as the peak spawner counts in Year 5 were similar to previous surveys. Flow characteristics in the Middle

Bridge River may have altered the distribution of substrate since the previous Mountain Whitefish surveys, through a combination of high flows and substrate mobilization and low flows and substrate-armouring. Although egg mats may be used to assess egg deposition at suitable sites in the Middle Bridge River, they cannot be used at fixed sites as an indexing tool unless substrate and flow characteristics remain fixed.

Middle Bridge River stage heights were not available for all years of BRGMON-4; however, data from 2015 through 2017 suggest stage heights were relatively consistent throughout the Mountain Whitefish egg incubation period. Under these stable stage-height conditions, the effect of Lajoie Dam operation on Mountain Whitefish egg-dewatering is negligible. Lajoie operation may still affect Mountain Whitefish spawning success if it results in heavily armoured substrates (i.e., when fines fill interstitial spaces) or other flow-related substrate changes, such as substrate transport. We observed high levels of armoured substrate during surveys in the Middle Bridge River, which could decrease Mountain Whitefish egg survival by preventing eggs from settling into interstitial spaces.

Mountain Whitefish spawner surveys performed previously by TEC and in Year 5 (2016) informed spawning and incubation timing and adult spawner characteristics, but did not quantify egg deposition, determine the location of suitable spawning substrate, or assess spawning success. The Year 5 surveys support the conclusion by TEC that Mountain Whitefish egg stranding risk is low in the Middle Bridge River under BC Hydro's current operating conditions; however, egg stranding would likely occur in the event of ramp-downs during the incubation and hatching periods (December through February). Our conclusions should only be applied to the area proximate to the Hurley and Goldbridge bridges. Mountain Whitefish spawning has not been assessed further east towards the confluence with Carpenter Reservoir and the effect of Lajoie Dam operations outside of the current study area is unknown.

## 4.3 Bull Trout Abundance Estimation

Preliminary mark-recapture modelling results suggest Bull Trout abundance in Carpenter Reservoir has remained relatively stable in Years 1 through 5 (2013-2017), with a mean abundance of ~1,000 fish. Although we have found evidence that the condition of Bull Trout may have declined in Years 4 and 5, we have not observed a decline in overall Bull Trout abundance. With only three years of dedicated mark-recapture modelling, it is too soon to draw conclusions regarding trends in Bull Trout abundance in Carpenter Reservoir. Mark-recapture modelling with be refined with additional years of data, and movement data (PIT and acoustic tags) will help to interpret changes in abundance relative to physical conditions in the reservoir.

We expanded the mark recapture study area in Year 5 (2017) to include the entirety of Carpenter Reservoir from Terzaghi Dam to the Gun Creek confluence. Reservoir elevations were relatively low during the Year 5 mark-recapture period, and Bull Trout CPUE at previously-productive tributaries in the western portion of the reservoir were almost zero. Bull Trout tend to congregate at tributary confluences that flow into Carpenter Reservoir and form clear, deep pools of cool water with suitable prey. To increase our capture and recapture rates, we expanded the boundary of the mark-recapture program to access more tributaries flowing into the reservoir, rather than into the drawdown zone. Adjusting the study area boundary of an open mark-recapture program would typically violate model assumptions; however, we sampled tributary confluences throughout the reservoir in Years 1 through 4 and were able to include these data in the Year 5 analysis. Recapture percentages for Years 1 through 4 and Bull Trout CPUE in Years 3 through 5 were similar with and without the boundary expansion, and parameter estimates did not change substantially between models using the original and expanded areas.

Preliminary insights into Bull Trout behaviour in Carpenter Reservoir suggest the expansion of the mark-recapture study area may improve the accuracy of the abundance estimate and provide a more intuitive measure of Bull Trout abundance in the reservoir. Bull Trout tend to congregate at tributary confluences throughout the reservoir in the warm summer months and are rarely observed in pelagic habitat (according to electroshocking and gill netting CPUE). We originally restricted the mark-recapture study area to focus effort, increase recapture rates, and cover more habitat areas, but catches were almost zero outside of tributary confluences. Although these zeros are informative, maintaining a high level of effort outside tributary confluences does not further inform the mark-recapture model. Reducing effort in mid-reservoir areas and focusing on tributary confluences throughout the reservoir provides a reservoir-wide abundance estimate without requiring additional days of sampling, and focuses the model to reflect emerging behavioural patterns.

Goodness-of-fit testing indicated that open mark-recapture models had relatively low accuracy and precision when fitting Bull Trout capture data from Years 1 through 5. Survival probabilities were particularly biased from simulated means, particularly in Years 1 and 2, which took place prior to the design and implementation of the mark-recapture program. Sampling dates, method type, and effort were controlled in mark-recapture Years 3 through 4, but were not controlled for or even recorded in Years 1 and 2. Methodological inconsistencies, changing personnel, and different sampling dates between Years 1 and 2 and Years 3 through 5 could be responsible for model fitting issues and low accuracy and precision. As additional years are added to the mark-recapture dataset, we will examine the effect of removing Years 1 and 2 on model fit, accuracy, and precision.

## 4.4 Bull Trout Movement

Acoustic data from Year 4 (2015-2016) suggest that Bull Trout may have remained in the reservoir and undergone fewer movements into and out of the Middle Bridge River than in Year 3 (2015-2016). In Year 3, 80% of acoustic-tagged Bull Trout were detected at least once by the acoustic arrays in Carpenter Reservoir and the Middle Bridge River, but in Year 4, only 42% of Bull Trout tagged in Year 4 were redetected. Under the assumption that all acoustic-tagged Bull Trout survived tagging and were not removed from the reservoir, the remaining 58% of Year 4 acoustic Bull Trout either did not move past an acoustic gate, or a gate failed to detect their movement. Although the acoustic gates are not 100% efficient at detecting Bull Trout movement, it is unlikely that a Bull Trout could move past a gate and not be detected by at least one receiver. Acoustic-tagged Bull Trout may have remained near their original release location, thereby avoiding detection by all gates.

Contrary to in Year 3 (2014-2015), the acoustic gates did not detect a substantial migration of Bull Trout into the Middle Bridge River during the late summer months (despite similar detection efficiencies between the two years), and a greater amount of movement occurred between the eastern and western portions of the reservoir. Carpenter Reservoir elevation was higher in Year 4 (2016) than Year 5 (2017; by 5 m in June and July), which corresponds to a substantial amount of Bull Trout habitat. When reservoir elevation is high, cold-water thermal refugia form at tributary confluences further west towards the Middle Bridge River (e.g., Gun, Girl, Truax, and Tyaughton Creeks), and a larger sink of cool water is available in the shallower western portion of the reservoir. Western-reservoir habitat is more suitable in years of higher elevation, and we would expect Bull Trout to move into these areas. Bull Trout movement into the western portion of the reservoir may be delayed or nonexistent when reservoir elevation is lower, as indicated by Year 4 (2015-2016) acoustic data. Reservoir elevation was also low in Year 5 (2017), and movement data from Year 5 will further inform Bull Trout movement behaviour in the reservoir.

Bull Trout movement into the Middle Bridge River in the late summer may indicate a spawning migration. Bull Trout typically spawn in August through September, and movement into and out of the river from July through October could be spawning-related. We also detected several Bull Trout migrating into the Middle Bridge River in November and December. Mountain Whitefish spawn in the Middle Bridge River from mid-October through December, and ATU calculations suggest kokanee hatch in the Middle Bridge River from November through January. Bull Trout movement into and out of the Middle Bridge River in the winter is likely related to foraging opportunities on kokanee juveniles and/or Mountain Whitefish eggs.

Acoustic data and PIT tag recapture locations suggest that Bull Trout in Carpenter Reservoir may exhibit diverse behavioural types, but that individual Bull Trout maintain similar behaviours among years. PIT tag recaptures indicate Bull Trout reside at the same tributary confluence year after year, and many of the acoustic Bull Trout detected in both Year 3 and 4 (2014-2016) displayed similar movement patterns and movement timings between the two years. Further analysis of the acoustic telemetry data is required to determine the residence times of Bull Trout at tributary confluences, and to support movement patterns identified by the acoustic gates. The gates were operated in Year 5 (2017; to be downloaded in spring of 2018), but receivers will be redeployed in new locations in Year 6 (2018). Some receivers will be positioned proximate to Terzaghi Dam to determine lacustrine habitat use, while others will be positioned near major tributary confluences to determine residence time and site fidelity. Additional years of acoustic data and recapture information from PIT tags will further inform Bull Trout behaviour and the effect of reservoir operation on Bull Trout movement.

## 4.5 Shoreline Electroshocking in Carpenter Reservoir

We compared counts of Bull Trout, Rainbow Trout, and kokanee from shoreline electroshocking surveys completed in 2001 and during BRGMON-4. Relative catches of Bull Trout were similar across all surveys, with the highest catches occurring at mid-reservoir tributary confluences. These tributary confluences represent ideal habitat for Bull Trout, which are consistently captured at these confluences during angling and electroshocking surveys from April to October. Counts at these confluences may be biased somewhat high because of their suitability for boat electroshocking. Tributaries at the eastern end of the reservoir are steeper and plunge deep into the reservoir, making them hard to shock (fish scatter under and around the boat), while mid-reservoir tributaries are more channelized and form a natural corral for electroshocking (fish are driven further towards the confluence). Counts of Bull Trout west of Gun Creek in September of 2001 (this area is not electroshocked during BRGMON-4) may support the hypothesis that the Middle Bridge and Hurley Rivers are important Bull Trout spawning areas, or may represent Bull Trout that are resident to the Middle Bridge River. Acoustic movement analyses suggest that a portion of Bull Trout migrate into the Middle Bridge River in the late summer, possibly as part of a spawning migration. Additional information is needed to determine whether the Middle Bridge and Hurley Rivers are critical Bull Trout spawning habitat and whether a resident population of Bull Trout resides in the Middle Bridge River.

In contrast to surveys completed during BRGMON-4, no kokanee were captured during the 2001 pre-WUP electroshocking survey. The absence of kokanee during the 2001 survey may be related to a crash in kokanee populations following extreme reservoir drawdowns in the mid-1990s (as suggested by Chamberlain et al. 2001, Griffith 1999). The highest counts of Rainbow Trout occurred during Year 5 (2017), possibly due to the earlier timing of this survey. Rainbow Trout congregate at tributary confluences from April to early July, corresponding with spawning periods in the tributaries. Following spawning, Rainbow Trout likely move into lacustrine portions of Carpenter Reservoir, where they are less vulnerable to shoreline electroshocking. Surveys proximate to Terzaghi Dam in 2001 (in areas not electroshocked during BRGMON-4) yielded Rainbow Trout captures in steep shoreline habitat, shallow shoreline habitat, and at tributary confluences, providing further evidence that Rainbow Trout prefer lacustrine habitat during warm summer periods.

## 4.6 Biological Characteristics

*Condition*

Biological data (length, weight, and age) were collected for all species in Year 5 (2017), adding to a growing database of biological characteristics in Carpenter Reservoir and the Middle Bridge River. Preliminary analyses suggest that the condition of both forage fish and piscivorous fish in Carpenter Reservoir has declined in the last two years, corresponding with low maximum reservoir elevations and delayed reservoir filling. For Bull Trout, the top predator in Carpenter Reservoir, the decrease in condition was more pronounced for spawners aged 3 to 6 which are still undergoing relatively high annual growth (i.e., have not reached asymptotic length). The decrease in condition of Bull Trout could be related to a similar decrease in the condition of prey species (kokanee, Rainbow Trout, and Mountain Whitefish), or a decrease in the abundance of prey species, particularly kokanee and Redside Shiners. Kokanee populations may have declined following entrainment through Terzaghi Dam in Years 4 and 5 (2016 and 2017), and the abundance of Redside Shiner may have decreased due to a contraction of littoral habitat (Redside Shiners are not frequently seen in the Middle Bridge River). Bull Trout condition may also have been affected by elevated competition at tributary confluences, which are fewer in number at lower reservoir elevations.

Condition also declined in Years 4 and 5 (2016 and 2017) for kokanee, Mountain Whitefish, and Rainbow Trout. Such a decline could be related to low reservoir elevations contracting habitat and increasing competition and predation, or due to a reduction in food sources. Forage fish species in Carpenter Reservoir feed on zooplankton and chironomids in the reservoir, and macroinvertebrate drift from the Middle Bridge River and Carpenter Reservoir tributaries. Although preliminary results from BRGMON-10 suggest zooplankton production per square meter in Carpenter Reservoir was similar in Years 3 and 4 (the two survey years for BRGMON-10; Perrin et al. 2016), reservoir elevation and total zooplankton habitat area were lower in Year 4 (and in Year 5). Zooplankton production also declines as water residence time becomes shorter, which occurs as reservoir elevations decrease and outflow rates increase (Perrin et al. 2016). We did not see a corresponding decrease in condition in Rainbow Trout in Carpenter Reservoir tributaries, suggesting that conditions in the reservoir, rather than conditions common to both habitats, were responsible for the decrease in condition of forage fish species.

*Growth*

Von Bertalanffy growth models were fit to length and age data for Bull Trout, Rainbow Trout, and Mountain Whitefish. Although growth parameters are dependent on system-specific conditions (physical and biological), the estimated asymptotic length of Bull Trout in Carpenter Reservoir may be low relative to other lake-dwelling and migratory populations in western North America (Caskenette et al. 2016, Erhardt and Scarnecchia 2016, Harris et al. 2016). Although additional data for large-bodied Bull Trout are needed to strengthen the growth relationship, BRGMON-4 observations and catch data suggest that the Carpenter Reservoir Bull Trout population is characterized by large numbers of small adults <45 cm. We rarely capture large Bull Trout >50 cm, which are characteristic of lake-dwelling populations (such as Seton Lake; Sneep 2015b). The smaller asymptotic length of Bull Trout in Carpenter Reservoir (relative to other systems) may be related to physical conditions such as turbidity and productivity that can affect Bull Trout survival and growth (Erhardt and Scarnecchia 2016, Harris et al. 2017).

Mountain Whitefish von Bertalanffy growth parameters from Carpenter Reservoir and the Middle Bridge River were similar to those of Mountain Whitefish in the Columbia River, a large regulated river in south-eastern British Columbia. Growth coefficients were lower in the Carpenter Reservoir system (0.21) compared to the Columbia River from 2001 to 2016 (0.2-0.45; Golder et al. 2016, 2017). Mountain Whitefish up to 50 cm in length were captured in the Columbia River, while the largest Mountain Whitefish captured in Carpenter Reservoir was <350 mm. The slow growth of Carpenter Reservoir Mountain Whitefish may be related to lower habitat quality in Carpenter Reservoir. BRGMON-4 will continue to develop growth and condition models for Carpenter Reservoir and examine the effect of reservoir operations on annual growth parameters of Mountain Whitefish.

Rainbow Trout appear to exhibit multiple behavioural types in the Carpenter Reservoir watershed (i.e., stream-residents and those that move to the reservoir after rearing), and the von Bertalanffy growth model requires further refinement to accurately describe growth of Rainbow Trout in the reservoir and its tributaries. During tributary electroshocking, we captured Rainbow Trout aged 1 to 3 in Gun, Macdonald, Marshall, and Truax Creeks, suggesting juveniles may rear in Carpenter

Reservoir tributaries longer than typical of the species (fry typically migrate during the fall of their first year or following their first winter). Rainbow Trout may rear in Carpenter Reservoir tributaries for an extended period because of high Bull Trout predation at tributary confluences, and/or slow growth in their first year. Newly emerged Rainbow Trout YOY exhibit slow growth due to cool water temperatures and a later spawning period relative to Rainbow Trout spawning populations in warmer systems. In contrast, juvenile Rainbow Trout in Downton Reservoir appear to spend very little time rearing in tributaries and migrate to the reservoir shortly after emergence (Jeff Sneep, pers. comm.). The difference between juvenile migration behaviour in the two reservoirs is likely related to two mechanisms: (1) many tributaries of Downton Reservoir are small and become dry in the fall and winter, whereas tributaries in Carpenter Reservoir are larger and provide year-round Rainbow Trout habitat, and (2) there are no predators in Downton Reservoir, compared to high Bull Trout predation at tributary confluences in Carpenter Reservoir.

We captured a small number of age-2 and age-3 Rainbow Trout in Carpenter Reservoir, which were generally bigger than their tributary counterparts. We suspect Rainbow Trout juveniles migrate from the tributaries to the reservoir over a broad range of age classes, with some individuals moving into the reservoir after one winter while others reside in the tributaries for up to three years before migrating to the reservoir. Current BRGMON-4 sampling methods do not target juvenile Rainbow Trout in the reservoir, which may bias the von Bertalanffy growth relationship. Juvenile Rainbow Trout that migrate to Carpenter Reservoir at a younger age likely experience faster growth in the reservoir relative to fish of the same age rearing in the tributaries, and additional sampling of reservoir juveniles is needed to fully understand the growth of Carpenter Reservoir Rainbow Trout. In Year 6 (2018), we will perform pilot minnow trapping surveys to target smaller-bodied Rainbow Trout in the reservoir.

Additional age and length data will be collected to expand on growth modelling and inform life history characteristics of all Carpenter Reservoir species. The effect of reservoir elevation and/or additional management parameters may be added to growth modelling, and alternative models may be implemented to more accurately describe growth characteristics for some species. For Rainbow Trout, a simple logistic or Richards model will be examined. The Richards model is an S-shaped growth model that allows for periods of accelerated growth, which may account for higher growth of juvenile Rainbow Trout when they first migrate to the reservoir. We will also explore the use of hierarchical Bayesian growth models to incorporate prior hypotheses of asymptotic growth when length and age data are sparse for older age classes (Harris et al. 2016, He and Bence 2007).

## 4.7 Tributary Assessments in Carpenter Reservoir Tributaries

### 4.7.1 Kokanee spawner surveys

Although spawning timing is similar among the tributaries surveyed, the variable temperatures in the tributaries and the long ATU requirement of kokanee (680) resulted in estimated peak 50% hatch timings that varied by 5 months among streams. In some tributaries, including the Middle Bridge River, hatching was predicted to occur in the winter, while in cooler tributaries (such as Truax Creek) hatching may occur in the spring. The timing of 50% hatch may affect the development of juvenile kokanee and the risk of predation by Bull Trout in the river and in the reservoir. Kokanee that hatch in the spring would likely experience faster growth rates and could be less susceptible to predation when they migrate into the reservoir. Although reservoir elevation can influence the degree to which juvenile kokanee may experience Bull Trout predation, the hatch and development timings are related to natural tributary water temperatures and are not influenced by reservoir operations.

Tributary visual surveys (Years 2 through 5 of BRGMON-4 and historic) suggest kokanee undergo high and low 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-4 in Years 1 through 5. Kokanee rely heavily on lacustrine habitat when not spawning or migrating, and years of extreme drawdown may result in elevated entrainment and mortality of adult kokanee. Extreme drawdowns in the mid-1990s may be responsible for almost no spawners being observed by Griffith (1999) and Chamberlain et al. (2001), and zero captures of kokanee during September 2001 electroshocking (Korman, unpublished). Low reservoir elevation and high discharges from Terzaghi Dam in 2016 and 2017 (Years 4 and 5) resulted in entrainment of kokanee in both years; however, spawner counts remained high. Kokanee entrainment may not have affected spawner population sizes in Years 4 and 5 if the number of entrained kokanee was small relative to the total population size. Alternatively, kokanee spawner numbers may have decreased, but spawner counts failed to detect a decline due to their limited scope (e.g., we were not able to survey the Middle Bridge River [known kokanee spawning habitat] due to high turbidity).

We performed detailed spawner surveys during peak spawning in Marshall, Macdonald, and Truax Creeks to assess spawning behaviour within the drawdown zone. Paired kokanee and redds were observed within the drawdown area in all three tributaries, suggesting incubating kokanee eggs would be at risk of inundation with further elevation increases. Carpenter Reservoir generally increases throughout the spawning period and peaks in early to mid-October, and the elevation increase following peak spawning is typically negligible. The number of paired kokanee and redds was much smaller in the drawdown zone relative to above the drawdown boundary due to the presence of higher quality habitat in upland areas. Although kokanee appear to favour high-quality spawning habitat upstream of the drawdown area, kokanee spawning success could be affected in years of low reservoir elevation. The lower the reservoir at the onset of spawning, the more drawdown habitat available for kokanee spawning, and the greater the potential risk of redds being flooded during spawning or incubation.

Kokanee stranding events such as occurred in the Middle Bridge River in September 2017 (estimated 80 kokanee) would likely have a greater effect on kokanee spawning success than minor redd inundation in the drawdown zone. The stranding event confirms that the Middle Bridge River is an important spawning location for Carpenter Reservoir kokanee. BRGMON-4 will continue to monitor Middle Bridge River stranding events and explore methods of assessing kokanee spawning in the Middle Bridge River.

### 4.7.2 Tributary Electroshocking Assessment in Carpenter Reservoir Tributaries

Monthly tributary electroshocking in Years 4 and 5 (2016 and 2017) identified successful Rainbow Trout spawning in Marshall, McDonald, Truax, and Gun Creeks due to the presence of age-0 Rainbow Trout. Stream resident populations of Rainbow Trout were identified in Marshall and McDonald Creeks, which likely contribute to Carpenter Reservoir Rainbow Trout populations through downstream movement. Growth rates of juvenile Rainbow Trout were low in the tributaries, and YOY Rainbow Trout underwent almost no growth over their first winter.

Tributary electroshocking also identified successful Bull Trout spawning in Truax Creek, and a small Bull Trout (155 mm) was captured in Gun Creek (thought to be an important spawning tributary; Griffith 1999). We did not capture any age-0 Mountain Whitefish in the tributaries, but the presence of juvenile Mountain Whitefish (ages 1 and 2) may suggest Mountain Whitefish spawn in tributaries in addition to the Middle Bridge River. Tributary electroshocking provided important juvenile growth data for von Bertalanffy growth modelling for all species in the reservoir and we recommend continuing a targeted electroshocking program. Additional data will inform Rainbow Trout behavioural types and tributary length, age, and weight distributions can be compared to those from the reservoir to determine whether reservoir operations affect the growth and condition of Rainbow Trout.

# 5 Status of Monitoring and Recommendations

While minor refinements continue to improve BRGMON-4 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 the Middle Bridge River instream flow regime.
- **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 operations may be refined 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-4 monitoring program.
- **Density and distribution of fish species in Carpenter Reservoir.** Pilot short-set gillnetting 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-4 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-4.

BRGMON-4 will continue to use a weight-of-evidence approach incorporating multiple sources of direct and indirect evidence to answer the 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 our understanding of fish and fish 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 5 (2016-2017) to each BRGMON-4 management question.

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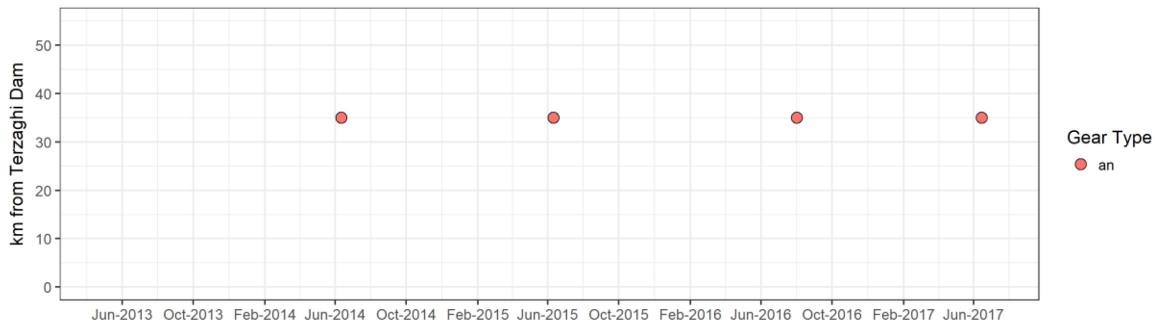
## Appendix A

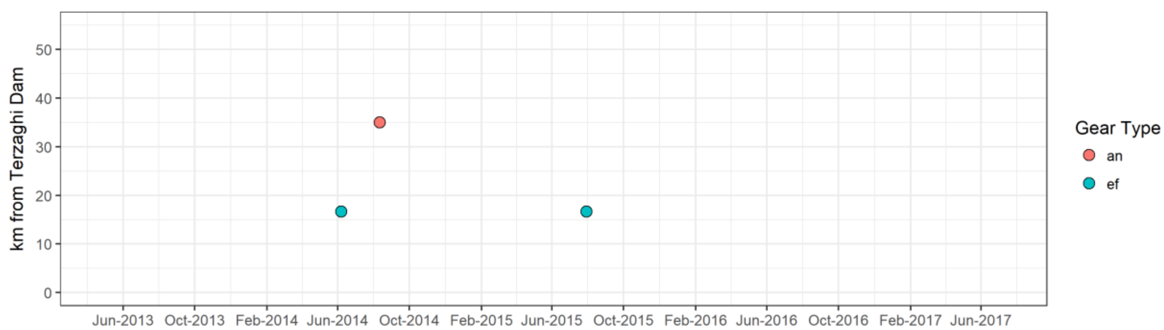
**Qualitative assessment of kokanee spawning habitat quality and quantity in Carpenter Reservoir tributaries.**

| Tributary | Habitat Quality: Low Pool | Habitat Quality: Full Pool |
|---|---|---|
| Girl Creek | - Generally low flows and low turbidity<br>- Kokanee often hold in a large clear pool at the outflow<br>- Drawdown zone is steeper relative to other tributaries<br>- At low elevations debris barriers exist that may limit fish passage | - Habitat quality is generally improved<br>- Debris barriers are removed at full pool<br>- Elevation gradient lessened at full pool |
| McDonald Creek | - Generally moderate flows with consistent riffle habitat<br>- Low turbidity<br>- High quality spawning habitat throughout the drawdown zone | - Habitat quality remains the same except in years of high maximum elevation<br>- Only a small portion of habitat is flooded due to the proximity of McDonald Creed to the Middle Bridge River<br>- In low elevation years, almost no change in habitat area would occur |
| Marshall Creek | - Moderate flows in the drawdown zone at low elevations<br>- All habitat is in the drawdown zone due to a waterfall restricting stream length<br>- Drawdown zone habitat quality is poor downstream of the highway (exposed mudflats)<br>- 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<br>- All habitat is flooded at high full pool elevations (such as occurred in 2015)<br>- 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<br>- 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<br>- 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<br>- 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)<br>- 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 |

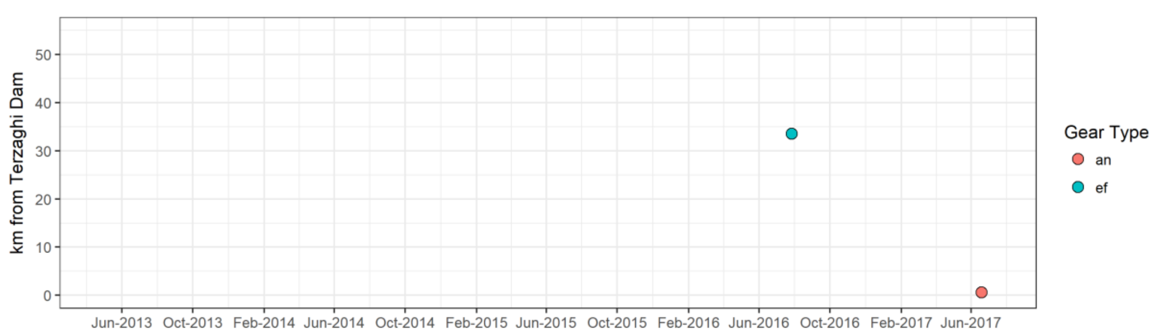
## Appendix B




**Recapture locations of Bull Trout PIT Tag 584851, captured in Truax Creek (via angling) on 4 separate occasions.**




**Recapture locations of Bull Trout PIT Tag 586062, captured in Keary Creek and Truax Creek via angling and electroshocking.**




**Recapture locations of Bull Trout PIT Tag 657920, captured at Tyaughton Creek and near Terzaghi Dam at Viera Creek via angling and electroshocking.**