Bridge River Project Water Use Plan

Carpenter Reservoir and Middle Bridge River Fish Habitat and Population Monitoring

Implementation Year 6

Reference: BRGMON-04

Study Period: October 2017 to September 2018

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Bridge-Seton Water Use Plan

Implementation Year 6 (October 2017-September 2018):

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Reference: BRGMON-4

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Executive Summary

The objectives of BRGMON-4 are to collect comprehensive information of the life history, biological characteristics, distribution, abundance, and composition of the fish community (with focus on Bull Trout, Rainbow Trout, kokanee, and Mountain Whitefish) in Carpenter Reservoir and the Middle Bridge River, and to assess the effects of reservoir elevations (i.e., BC Hydro operations) on fish populations. Monitoring in 2018 (Year 6 of the 10-year monitoring program) consisted of:

- tributary electroshocking surveys to enumerate juvenile salmonids and compare the characteristics of Rainbow Trout that migrate to Carpenter Reservoir with those that remain as tributary residents;
- Bull Trout movement monitoring using acoustic telemetry tagging and PIT tag recapture data;
- adult Bull Trout abundance estimation via a three-week mark-recapture program consisting of gill netting, boat-based electroshocking, and angling throughout the reservoir;
- collection of length, weight, and age data for Bull Trout, Rainbow Trout, kokanee, and Mountain Whitefish during mark-recapture sampling activities; and
- kokanee spawner enumeration surveys in Carpenter Reservoir tributaries.

BRGMON-4 will answer the following management questions using a weight of evidence approach:

MQ1: What are the basic biological characteristics of fish populations in Carpenter Reservoir and Middle Bridge River?

We collected length, weight, and age data from all fish captured during field sampling programs to develop comprehensive time series of biological characteristics. Biological data were used to determine temporal variability in body condition, create Age-Length-Keys (ALKs), and fit von Bertalanffy growth models for various species captured in the Carpenter Reservoir and its tributaries. We estimated Bull Trout abundance in Carpenter Reservoir (2016 through 2018) using CJS mark-recapture modelling. Preliminary results suggest that Bull Trout populations ranged from 1,829 (SD 668) in 2016 to 2,883 (SD 1,052) in 2017.

MQ2: Will the selected alternative (N2-2P) result in positive, negative, or neutral impact on abundance and diversity of fish populations?

It is challenging to determine whether N2-2P affected fish populations in Carpenter Reservoir given the highly variable nature of reservoir elevations, the time lag between operational decisions and population-level effects, and a lack of consistent historic fish population data. Elevations in the reservoir vary due to management priorities in other areas of the system and with natural environmental fluctuations. We compared average elevations in the first two weeks of April (a proxy for growing season productivity) and summer elevations (representing habitat volume) between pre-and post-N2-2P periods (2002-2011 vs 2012-2018). We observed a trend towards higher April elevations (and therefore higher productivity according to BRGMON-10 modelling results) and lower mean summer elevation (and therefore lower summer habitat volume) post-N2-2P relative to pre-N2-2P. Therefore, although N2-2P did not specify a new operating regime of the

reservoir, the WUP alternative and recent high flow modifications may have impacted reservoir elevations.

MQ3: Which are the key operating parameters that contribute to reduced or improved productivity of fish populations in Carpenter Reservoir and the Middle Bridge River?

Data collected to date suggest fish populations in Carpenter Reservoir may be affected by minimum and maximum reservoir elevation, and the timing and extent of reservoir filling and drawdown. Low summer elevations and low minimum spring elevations contract habitat volumes and reduce the accessibility of large tributary confluences in the western portion of the reservoir, which typically offer thermal refugia for Bull Trout and Mountain Whitefish. In 2016 through 2018, there is preliminary evidence of negative effects of low elevations on fish populations; Bull Trout showed reduced movement, particularly into and out of the Middle Bridge River, and there was a reduction in fish condition (a measure of fish health) for almost all species. Although sampling methods do not target kokanee in the reservoir, limiting our ability to make inferences, historic data from the early 1990s suggest kokanee can also be negatively affected by low reservoir elevations. High flows through Terzaghi Dam in 2016 and 2017 led to the entrainment and mortality of kokanee, further indicating a negative effect of reservoir operations.

MQ4: Is there a relationship between specific characteristics of in-stream flow in the Middle Bridge River that contribute to reduced or improved productivity of fish populations in Carpenter Reservoir and the Middle Bridge River?

Consistently high turbidity in the Middle Bridge River makes it difficult to assess fish populations and determine the effects of reservoir operations; however, Kokanee and Mountain Whitefish spawning surveys combined with hatch date calculations suggest that the direct risk of egg dewatering in the Middle Bridge River from Lajoie Dam operations is low. Egg dewatering risk is likely low because stage heights remain relatively consistent throughout important spawning and incubation periods (i.e., late summer to early February). The spawning and incubation success of these species may still be affected by the management of Lajoie Dam. Because of management at Lajoie Dam, the Middle Bridge River has more stable winter water temperatures relative to Carpenter Reservoir tributaries, and hatch dates are estimated to be earlier in the Middle Bridge River as a result. Also, the Middle Bridge River substrates have higher levels of fine particulate matter in interstitial spaces (due to flow management), which can impact egg settling (Mountain Whitefish) and redd digging (kokanee).

MQ5: 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 population in both areas, or can existing constraints be relaxed?

Preliminary evidence suggests that low summer elevations and low early spring elevations may result in decreased reservoir productivity and overall habitat volume, which may be detrimental to fish populations in Carpenter Reservoir. Increasing reservoir elevations in the early spring (to promote increased reservoir productivity) and in the summer (to increase overall habitat volume and access to large tributary inflows) may therefore improve habitat conditions and productivity of fish populations. Continued monitoring will help to determine whether operation of Carpenter Reservoir and Lajoie Dam can be adjusted to improve fish populations in the reservoir and in the river.

We recommend continued monitoring in 2019 to build upon data collected in years 1 through 6. Monitoring in 2019 will consist of acoustic monitoring of adult Bull Trout, Bull Trout abundance estimation via mark-recapture sampling, collection of length, weight, and age data for Bull Trout, Rainbow Trout, kokanee, and Mountain Whitefish, and kokanee spawning surveys. We recommend expanding kokanee spawning surveys by marking the locations of observed spawning and/or redds, and performing peak counts on additional spawning tributaries throughout the reservoir.

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Status of BRGMON-4 objectives and management questions (2018, year 6)

Study Objectives	Management Questions	Management Question Status
1: Collect comprehensive information on the life history, biological characteristics, distribution, abundance, and composition of the fish community in Carpenter Reservoir and Middle Bridge River.	1: What are the basic biological characteristics of parameters of fish populations in Carpenter Reservoir and Middle Bridge River?	The monitoring program has developed a database of biological characteristics for fish species in the reservoir and Middle Bridge River (Bull Trout, Rainbow Trout, Mountain Whitefish, and kokanee) that will answer MQ 1. Biological metrics being collected include length, weight, condition, age, relative species density, relative abundance, spawn timing and location, and habitat use. These metrics are used to create length-weight models, fish condition, and length-at age models.
2: Provide information required to link the effects of reservoir operation on fish populations.	2: Will the selected alternative (N2-2P) result in positive, negative, or neutral impact on abundance and diversity of fish populations?	The monitoring program is developing time series of biological characteristics for fish populations in Carpenter Reservoir and the Middle Bridge River. Biological time series will be compared to reservoir elevations before and after N2-2P and productivity indices as modelled by BRGMON-10 to infer the effect of the selected alternative on 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?	Reservoir elevations have been highly variable throughout BRGMON-4, and there is evidence that variable elevations may have resulted in changes in the biological characteristics of fish populations in the reservoir. It is challenging to identify specific factors that affect fish populations due to the complex nature of the reservoir and river ecosystems and the long life-span of fish species. The monitor is developing an understanding of the characteristics and preferences of fish species in Carpenter Reservoir and will answer Management Question 3 using a weight of evidence approach.
	4: Is there a relationship between specific characteristics of the in-stream flow in the Middle Bridge River that contribute to reduced or improved productivity of fish populations in Carpenter Reservoir and the Middle Bridge River?	Mountain Whitefish spawner surveys and hatch date calculations paired with winter Middle Bridge River stage heights suggest flow release schedules at Lajoie Dam do not result in significant dewatering of Mountain Whitefish eggs or kokanee and Bull Trout redds in the river. Middle Bridge River flow and temperature have the potential to affect fish productivity in the river, and this monitor will continue to investigate these effects using a weight of evidence approach. Operations of Lajoie Dam also affect fish productivity in the reservoir due to their effect on reservoir elevations, which is considered by Management Question 3 of this monitor.

	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 management question will be answered considering the results of Management Questions 1 through 4. Preliminary results of BRGMON-4 and results from BRGMON-10 suggest that reservoir elevations affect fish habitat in the reservoir and, therefore, refinements to operations may improve fish populations. Specific refinements will be developed in the final years of BRGMON-4 based on the answers to Management Questions 1 through 4.

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1 Introduction

1.1 Background

The Bridge River power project, located in the Bridge River Valley of southwestern British Columbia (Figure 1-1), was initiated in the 1920s and completed in 1960 with the construction of Terzaghi Dam (BC Hydro 2014). Terzaghi Dam impounds approximately 50 km of the Bridge River valley and created Carpenter Reservoir, the primary reservoir for power generation at the Shalalth powerhouse. Two tunnels, Bridge 1 and Bridge 2, carry water through Mission Mountain to Shalalth for power generation, before discharging Bridge River water into Seton Lake and subsequently the Fraser River. A second dam upstream of Carpenter Reservoir, Lajoie Dam, impounds the upper Bridge River as Downton Reservoir and regulates flows in the middle Bridge River between Lajoie Dam and Carpenter Reservoir. Construction of the Bridge River generating system significantly altered flow in the Bridge River and resulted in substantial impacts to aquatic ecosystems and cultural resources throughout the valley.

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 adopted for Carpenter Reservoir at the end of the snowmelt season in mid-August; however, it was expected this target would likely be exceeded due to other higher priority constraints (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). Although these expected outcomes were not explicit in the final BRCC report, it appears that N2-2P was expected to benefit fish populations in both the middle Bridge River and Carpenter Reservoir.

Beginning in 2016, the operations of the Bridge River hydroelectric complex were modified due to safety concerns at LaJoie Dam and repair requirements at Bridge 1 and 2 generating stations. High flows from Terzaghi Dam into the Lower Bridge River were required to reduce Downtown Reservoir elevations to a modified maximum elevation (734 m) that accounted for safety concerns at Lajoie Dam. To move water out of Downton and Carpenter Reservoirs in 2016 through 2018, Lower Bridge River discharges surpassed 6 m^3/s (the maximum flow treatment prescribed during the WUP) for extended periods of time and reached maximums above 90 m^3/s in all years. These high flows resulted in dramatic changes to habitat in the Lower Bridge River and Downton Reservoir, and affected elevations in Carpenter Reservoir. Particularly in 2017 and 2018, minimum and maximum elevations in Carpenter Reservoir were low relative to previous years and habitat volume in the reservoir was reduced. Due to the lower habitat volume, the residence time of water in Carpenter Reservoir likely declined, along with water temperatures and reservoir productivity.

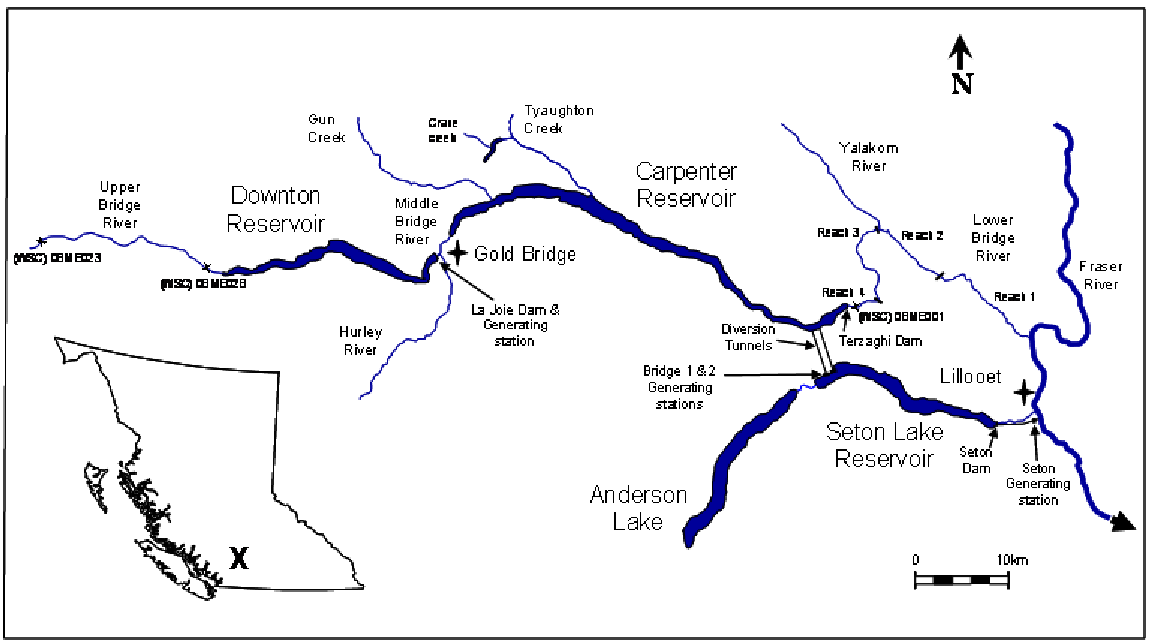

Figure 1-1 Bridge River power system near Lillooet, British Columbia.

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 (Appendix A). 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; Limnotek 2018).

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.

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 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 tested 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. The current approach will focus on Bull Trout, kokanee, Rainbow Trout and Mountain Whitefish. Select life stages of these species were chosen because they are (a) abundant, ecologically important, and/or sensitive to habitat changes, and (b) possible to assess using methods tested during the monitoring period.

The primary objective of BRGMON-4 is to determine whether operating parameters for Carpenter Reservoir (i.e., maximum and minimum elevation, and the rates of filling and drawdown) and Lajoie Generating Station (i.e., in-stream flow releases and subsequent Middle Bridge River stage heights) affect fish populations in Carpenter Reservoir and the Middle Bridge River. This monitor will inform 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.

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, operating within minimum and maximum elevation objectives of 606.55 m and 651.08 m, respectively 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., Downton 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 Carpenter Reservoir Operating Parameters

BC Hydro continuously monitors operating parameters throughout the Bridge River Power System. The two operating parameters most applicable to answering the BRGMON-4 management questions are Carpenter Reservoir elevation and in-stream flow releases at Lajoie Dam. Carpenter Reservoir elevations can be summarized as various metrics, including daily elevations, annual maxima and minima, and the rates of reservoir filing and drawdown (the rate of change in elevation). In-stream flow releases from Lajoie Dam affect stage height and flows in the Middle Bridge River, which also subsequently influence reservoir elevation. Additional operating parameters affect the reservoir and river, including Downton Reservoir elevations (upstream of Carpenter Reservoir and Lajoie Dam), and in-stream flow releases from Terzaghi Dam (downstream of Carpenter Reservoir). We focus on elevation because an estimate of reservoir elevation for a given day or time period reflects the combined influence of all these operating parameters.

We acquired Carpenter Reservoir elevations, and in-stream flow releases from Terzaghi and Lajoie Dams from BC Hydro Power Records to qualitatively examine the change in operating parameters between monitor years. We determined the minimum and maximum elevations for all monitor years as well as the timing and rate of filling and drawdown and compared these parameters with observations of fish populations throughout the monitoring period. We also obtained historic Carpenter Reservoir elevation data from 1954 to present to determine how operating parameters have changed since the construction of Terzaghi Dam.

We compared average reservoir elevation for the 10 years prior to N2-2P (i.e., pre-WUP; 2002-2011) with conditions from 2012 to present (i.e., post-WUP) to determine whether conditions relevant to fish populations changed in Carpenter Reservoir immediately following the implementation of N2-2P. There is no pre-defined pre-WUP period, and we selected 10 years, the total length of BRGMON-4 monitoring, to represent the most relevant management regime prior to the WUP implementation. The two elevation parameters that were compared were mean elevation from July through September and mean elevation for the first two weeks of April. Mean elevation in July through September represents full pool habitat volume, while mean elevation in the first two weeks of April is correlated with growing season productivity in the reservoir (i.e., higher elevations in early April are associated with higher growing season productivity; see details in Limnotek 2018). Adequate habitat volume and reservoir productivity are important for fish growth and productivity, and changes in these parameters between pre- and post-WUP periods would suggest that changes in fish populations would have likely also occurred.

2.3 Bull Trout Abundance

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.

2.3.1 Mark-Recapture Field Program

The mark-recapture field program began in 2015 and was run in each subsequent monitoring year. The 2018 mark-recapture period occurred between June 25 and July 12. In 2015 and 2016, the mark-recapture program occurred in late July (at maximum reservoir elevation), but 2016 acoustic data indicated that Bull Trout undergo spawning migrations at this time (Putt et al. 2017), and surface water temperatures in late July exceeded preferred Bull Trout tolerances. We moved the program ~1-month earlier to avoid the spawning migration and reduce the potential for temperature-related handling stress, while still ensuring a high volume of reservoir habitat.

Multiple capture methods were used to target all habitat types and allow the abundance estimate to be applied to the entire study area (i.e., Carpenter Reservoir). A combination of angling at creek mouths, shoreline overnight electrofishing, and shoreline and pelagic short-set gill netting was used to mark and recapture Bull Trout. 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:

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

for species *i* using gear *j*.

2.3.2 Mark-Recapture Modelling

We used the Cormack Jolly-Seber (CJS) open-mark recapture model to estimate Bull Trout abundance in Carpenter Reservoir from 2015 through 2018 (Seber 1982, Pollock et al. 1990, Schwarz and Arnason 1996). In open mark-recapture models, the probability of a fish being captured in a sampling event is determined by two parameters: the apparent survival (φ) 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. 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 model, 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 the first year because there is no recapture probability (p) estimated for the first sampling event.

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 (φ) and capture probability (p):

$$AIC_c = 2k + 2\ln(\hat{L}) + \frac{2k(k+1)}{n-k-1} \quad \text{Eq 4}$$

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 the best-fit CJS model 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 Cormack 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 has been used to quantify immigration and emigration during the mark-recapture period.
Each marked animal present following the *i*th sampling event has equal survival probability (ϕ_i) until the (*i+1*)th sampling event	Marks were only applied to healthy individuals (i.e., fish without outwards signs of disease or injury) and all individuals were held until completely recovered (i.e., have regained equilibrium) 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 tagging (particularly fin ray scars). 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. In the rare event that a fish showed clear signs of handling but no PIT was detected, it was assumed a recapture and given a new tag code.
All samples are instantaneous	To be considered instantaneous, the duration of the sampling period should be <10% of the interval between sampling periods (Lebreton et al. 1992). The mark recapture program will be kept below 30 days to satisfy this criterion.

2.4 Bull Trout 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. 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.

2.4.1 Bull Trout Acoustic Tagging

Twenty Bull Trout were angled from May 28 to June 25, 2018 at the confluences of Viera, Marshall, Cedarvale, Keary, 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, a tag burden accepted as having negligible effects to fish performance or health (Winter, 1983). 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 that was 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.

2.4.2 Acoustic Receivers

Two telemetry gates (VR2W-69 kHz coded acoustic receivers; Vemco) were installed in Carpenter Reservoir in 2015 and maintained into 2018: one at the Jones Creek confluence (six receivers) and one at the boundary of the reservoir and the Middle Bridge River (four receivers; Figure 2-1). 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 ~1 m off the reservoir bottom (with the transducer oriented upwards) and marked with floats that became submerged as pool elevation increased, while receivers in the Middle Bridge River were attached directly to bottom anchors. At a maximum pool elevation of 648 m, maximum water depth at the reservoir gate site was ~30 m with receivers located at depths ranging from 5 m to 30 m. The location of the reservoir gate became part of the Middle Bridge River at an elevation of ~617 m, causing the receivers to become dry (this occurred in 2017 and 2018). Water depths in the Middle Bridge River were more consistent, ranging from 1 m to 2 m depending on discharges from Lajoie Dam and the Hurley River. Receivers in the reservoir were installed at a low 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 2017 will be presented in this report, while movement data from the current reporting year (2018) will be presented in 2019.

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 (i.e., millions of detections). 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. In 2018 we performed long-term range testing of the reservoir gate using a sentinel tag installed in May of 2017 and recovered it in June of 2018. The sentinel tag allowed us to monitor the detection range of each receiver in response to changing reservoir conditions (e.g., reservoir elevation, temperature, and turbidity).

2.4.3 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.

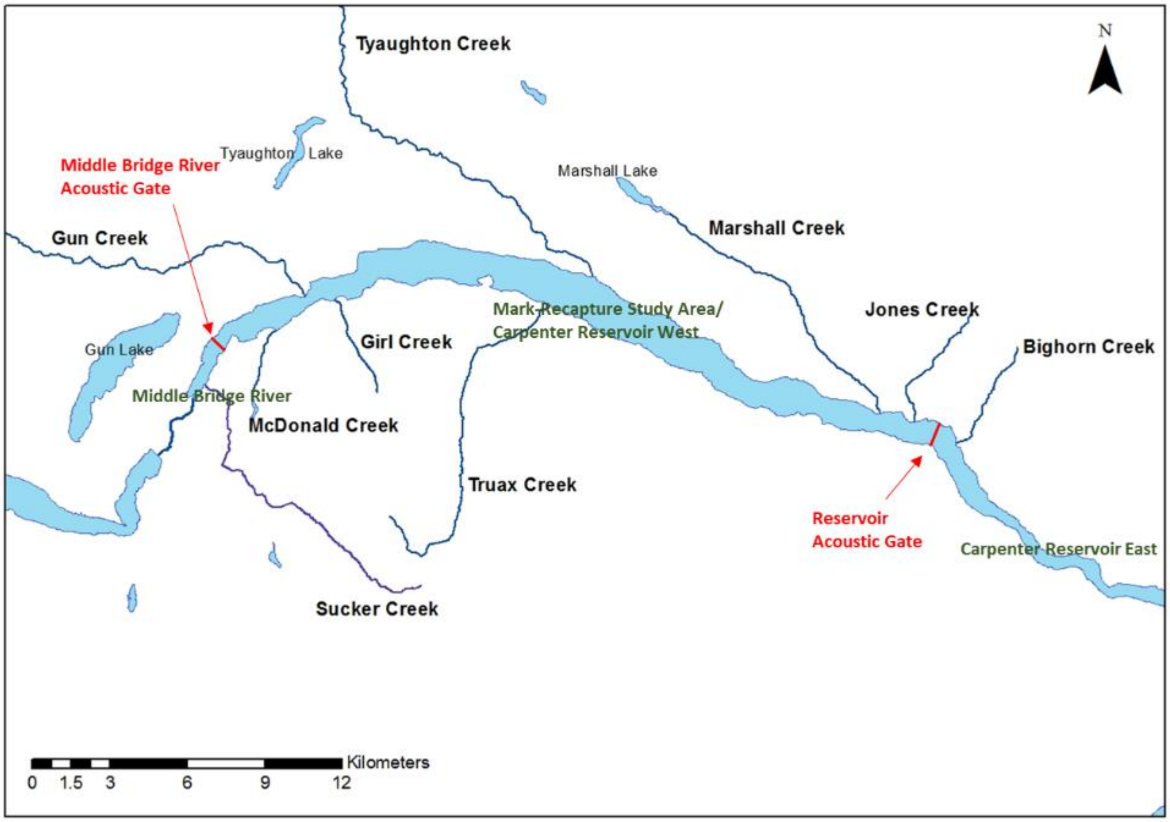

Figure 2-1 Major Carpenter Reservoir tributaries and the locations of acoustic telemetry gates.

2.5 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 2012 to 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 concurrent with the open mark-recapture program for Bull Trout. We compared shoreline electroshocking counts from 2001 to counts obtained during BRGMON-4. We could not compare CPUE values because of methodological differences including varying survey objectives, the number of dippers, the timing of surveys, and reservoir conditions during surveys. Despite these variations, comparing electroshocking counts across years may inform changes in species density and distribution in Carpenter Reservoir.

2.6 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.

2.6.1 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 newly emerging Rainbow Trout juveniles that were too small to sample for scales (<50 mm fork length; assumed to be 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 2-2). 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).

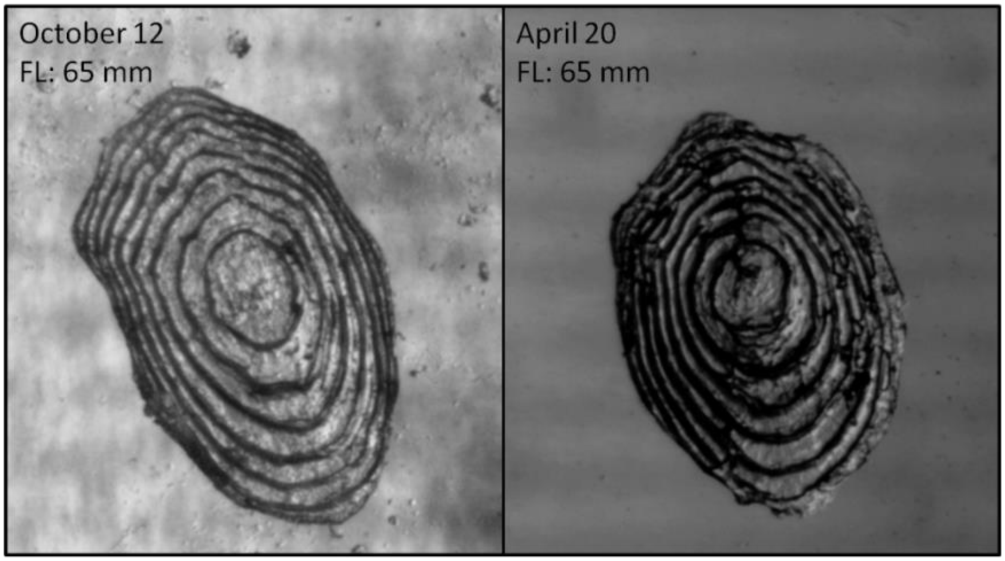

Figure 2-2 Scales assessed as age-0 collected from two Rainbow Trout captured during tributary electroshocking. The scale collected on April 20 (right) has undergone a winter of growth and should be classified as age-1; however, winter growth annuli are almost impossible to distinguish.

2.6.2 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):

$$W_i = \alpha L_i^{\beta} 10^{\epsilon_i} \qquad \text{Eq 5}$$

$$\log(W_i) = \log(\alpha) + \beta \log(L_i) + \epsilon_i \qquad \text{Eq 6}$$

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).

$$K_F = \frac{W * 10^N}{L^3} \qquad \text{Eq 7}$$

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).

2.6.3 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:

$$L_t = L_\infty\left[1 - \exp\left(-K(age - t_0)\right)\right] + \varepsilon \qquad \text{Eq 8}$$

where L_t is length-at-age at time t, L_∞ is the asymptotic length, K is a growth coefficient, t_0 is the time at which length is theoretically zero, and ε is the residual error. The growth model was fit iteratively for the parameters L_∞, K, and t_0 using a minimum sums of squares optimization (Ogle 2016b). We fit the von Bertalanffy growth model to all fish groupings listed above.

2.6.4 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).

2.7 Reservoir Tributaries and Middle Bridge River Spawner Assessments

2.7.1 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, Macdonald Creek, Marshall Creek, Sucker Creek, Truax Creek, and the Middle Bridge River. 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 surveyor). The visual survey length below the maximum reservoir elevation boundary was variable in each tributary as reservoir elevation increased, while the survey lengths above the maximum pool level remained consistent and ranged from ~50 m to 140 m. The length of accessible stream below the maximum pool elevation was measured during each visual survey to assess the rate of stream length decrease, and again in early November when the reservoir was at approximately full pool. 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, 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 below the maximum pool elevation of 648 m (potentially spawning in areas at risk of flooding) and fish observed above the maximum pool elevation (unlikely to be affected by flooding). We also took weekly stream-length measurements within the drawdown zone of Girl Creek, Marshall Creek, and Truax Creek to determine the amount of habitat that became flooded with increasing reservoir elevation. In Marshall Creek and Girl Creek we returned when the reservoir had reached full pool to record the maximum extent of stream length loss.

Temperature data loggers were reinstalled in Marshall Creek, Gun Creek, Macdonald Creek, Truax Creek, and the Hurley River and Middle Bridge River in the spring of 2018 to monitor temperature profiles through the summer and during the fall kokanee migration period. Temperature loggers were installed in the water column, not at redd depth, but we assume that water column and redd-depth temperatures are equivalent (i.e., no groundwater effects). We determined the 50% hatch dates (the date at which 50% of eggs have hatched) 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. Average migration timings from the tributaries were used as a surrogate for the Middle Bridge River.

2.7.2 Rainbow Trout Tributary Electroshocking

Monthly backpack electroshocking surveys began in 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, Table 2-2, Figure 2-1). 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 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 (Table 2-2). The above-drawdown portion of Tyaughton Creek is inaccessible and could not be included in the electroshocking surveys. In 2018 we repeated electroshocking in Marshall Creek, Macdonald Creek, and Gun Creek. We did not perform electroshocking in Tyaughton Creek due to low captures in 2017, and we did not repeat electroshocking in Truax Creek in 2018 due to access issues.

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.

Juvenile Rainbow Trout are almost exclusively captured during tributary electroshocking and are rarely captured in the reservoir during BRGMON-04. This makes it hard to compare growth in the two habitats and to determine at what age Rainbow Trout typically migrate from the tributaries to the reservoir. Densities of juvenile Rainbow Trout are likely low in the reservoir; however, sampling methods in the reservoir to date have not targeted smaller age classes. To attempt to capture juvenile Rainbow Trout in the reservoir (as opposed to within tributaries) we piloted three nights of overnight minnow trapping proximate to Marshall and Tommy Creeks (three traps per site). Minnow trapping occurred during the Bull Trout mark-recapture period to coordinate with sampling crews making daily trips to the reservoir. Minnow trapping was unsuccessful as only one Redside Shiner was captured in all traps, and will not be considered as a method for capturing juvenile Rainbow Trout in the reservoir.

Table 2-2. Tributary electroshocking sites from 2016 through 2018. Grey shaded bars indicate a tributary was electroshocked.

	2016	2017	2018
Marshall Creek	■	■	■
McDonald Creek	■	■	■
Truax Creek	■	■	
Tyaughton Creek		■	
Gunn Creek		■	■

3 Results

3.1 Carpenter Reservoir Operating Parameters

In 2018, Carpenter Reservoir elevation was characterized by a low minimum elevation and the lowest fall maximum elevation observed during BRGMON-4 (Figure 3-1). The reservoir reached a minimum elevation of 615.3 m on April 20, 2018, which was the same minimum elevation reached in 2017 and the lowest elevation on BRGMON-4 record. The reservoir filled rapidly during the first three weeks of May but remained low through the summer and fall relative to the previous six years of operation. A maximum elevation of 641.2 m was reached on November 3, 2018, 1.8 m lower than any other year of BRGMON-4. Rapid filling in May corresponded with heightened discharge from Lajoie Dam (from 25 cms to 70 cms; Figure 3-2) and the natural freshet period in the region. Similarly, the decline in filling rate in early June corresponded with discharges of ~100 cms from Terzaghi Dam into the Lower Bridge River and a decline in local inflows to the system (data not shown). Reservoir elevation in 2018 remained within normal operating conditions specified for the reservoir of a minimum elevation of 606.6 m and a maximum elevation of 651.1 m.

We compared Carpenter Reservoir elevation parameters for the 10-year period prior to WUP implementation to the WUP period (2011-2018) to determine whether conditions in the reservoir had changed after the WUP implementation. There was a trend of higher average elevation in the first two weeks of April and lower mean summer elevation in the post-WUP period relative to the pre-WUP period; however, there was substantial variation in both time periods (Figure 3-3; Figure 3-4).

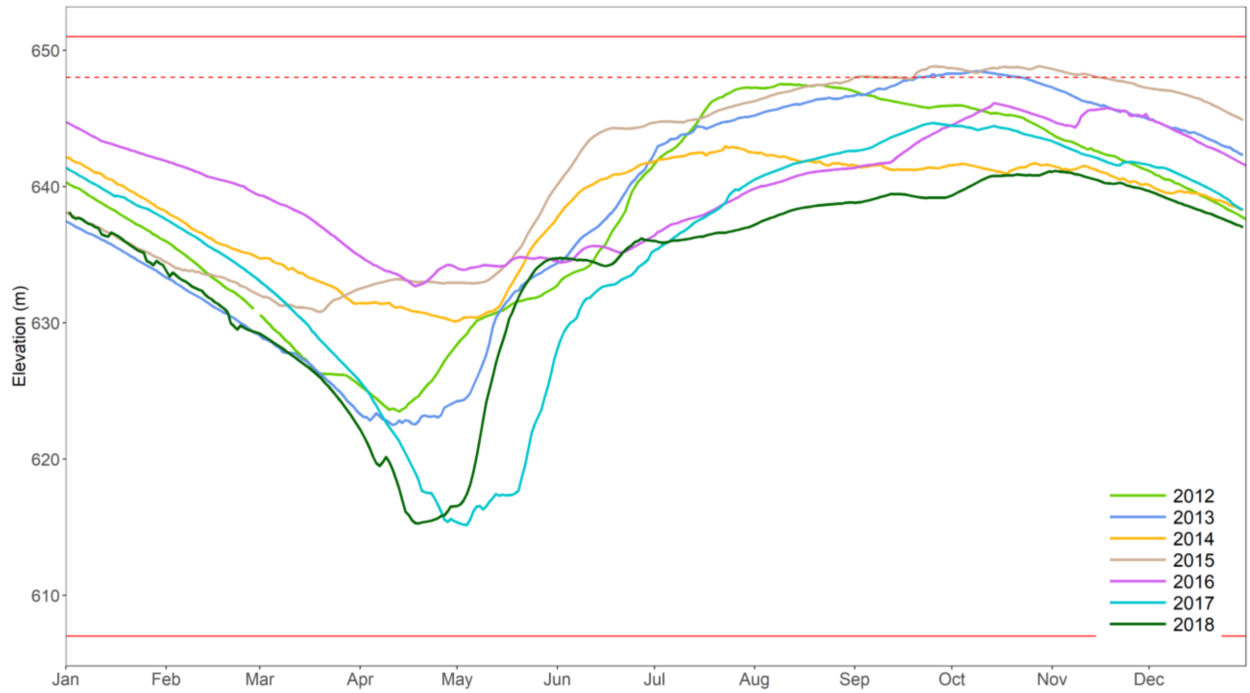

Figure 3-1 Carpenter Reservoir elevations from 2012 to 2018. Solid red lines represent maximum and minimum operational targets of 606.55 m and 651.08 m, respectively, and dashed red line represents the soft operational maximum target of 648 m.

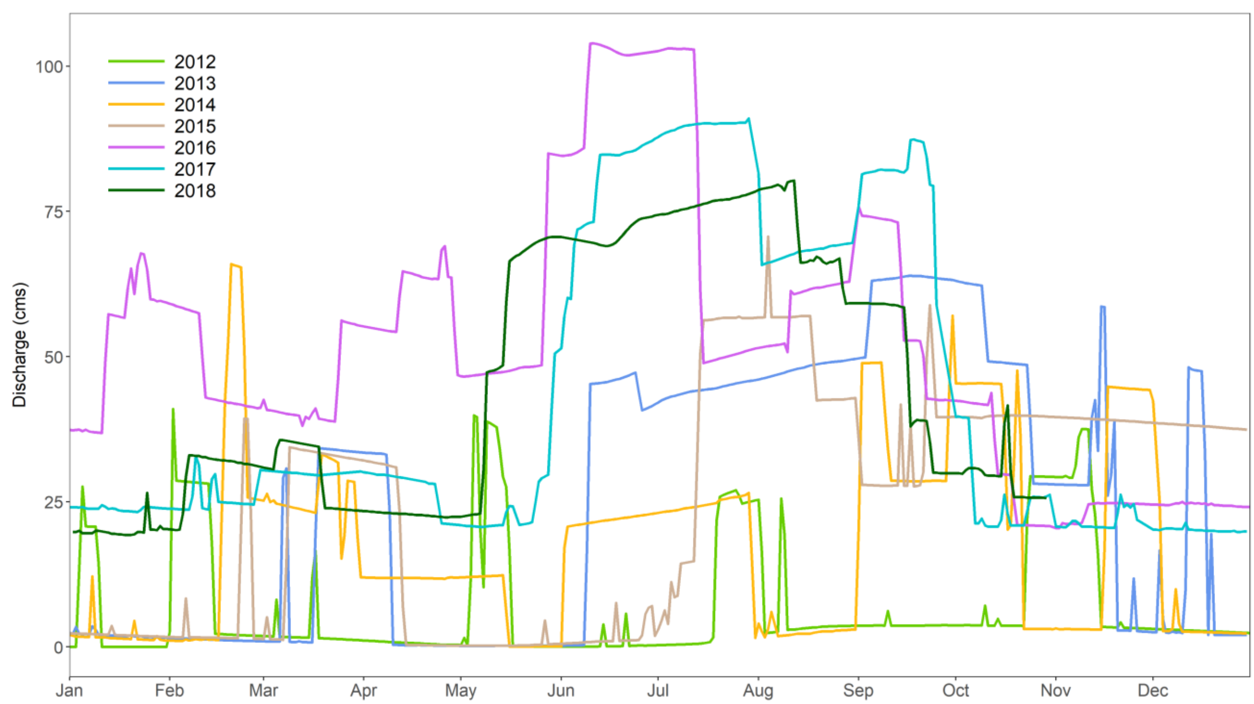

Figure 3-2 In-stream flow releases from Lajoie Dam to the Middle Bridge River from 2012 to 2018.

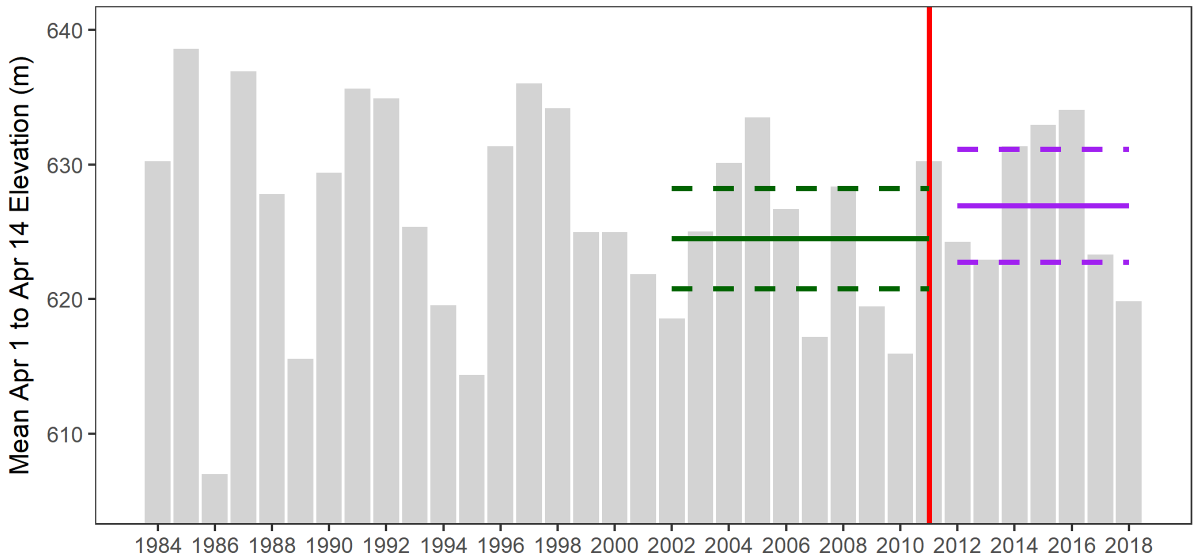

Figure 3-3 Historic average Carpenter Reservoir elevation from April 1 to April 14. Green lines show mean elevation (dashed lines represent 95% confidence intervals) from 2002 to 2011, while purple lines show mean elevation (and 95% confidence intervals) from 2012 to 2018.

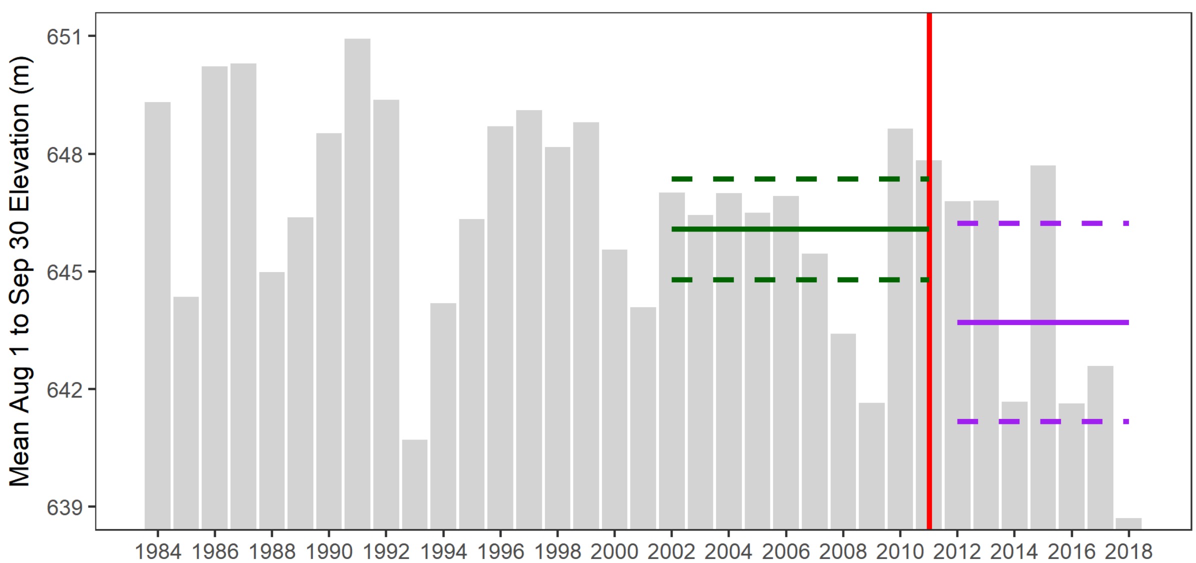

Figure 3-4 Historic average Carpenter Reservoir elevation from August 1 to September 30. Green lines show mean elevation (dashed lines represent 95% confidence intervals) from 2002 to 2011, while purple lines show mean elevation (and 95% confidence intervals) from 2012 to 2018.

3.2 Bull Trout Abundance Estimation

The 2018 mark-recapture program took place in Carpenter Reservoir from June 25 to July 12 (Figure 3-5). A total of 152 Bull Trout were captured during the mark-recapture program via angling, gill netting, and boat electroshocking, 20 of which (13.2%) were recaptured from previous marking periods (Table 3-1). The greatest effort (60.0 hours) was spent angling, while 5.0 hours were spent electroshocking, and 14.2 hours were spent gill netting. Electroshocking had the highest Bull Trout CPUE (Figure 3-6) and 98 Bull Trout were caught using this method, compared to 67 Bull Trout and 6 Bull Trout captured via angling and gill netting, respectively. CPUE was relatively consistent for each capture method across the four years of the designated mark-recapture program (Figure 3-6).

The mean fork length of Bull Trout captured during the 2018 mark-recapture program was 418.1 mm (SD 91.4 mm), the largest of any mark-recapture period so far (Table 3-2). Average fork length for Bull Trout captured during the mark-recapture program differed from 2015 to 2018 (ANOVA F value 18.0, p-value 2.5e-11; Figure 3-7), and a Tukey's test indicated that mean fork lengths in 2018 were higher than in 2015 through 2017 (using a significance level of 0.05).

Age data suggest the age distribution of Bull Trout captured during the annual mark-recapture program is shifting towards more mature Bull Trout (Figure 3-8). In 2015 the mark-recapture catches were dominated by Bull Trout aged 4 and 5, while in 2018, the catches were dominated by Bull Trout aged 6 and older.

Table 3-1 Mark-recapture capture summary data for Carpenter Reservoir Bull Trout (2015 to 2018).

Year	Mean (min and max) Reservoir Elevation (m)	Total Number Caught	Number Recaptures	Recapture Percentage
2015 (Jun 29 – Jul 31)	645.2 (644.6-646.1)	270	-	-
2016 (Jul 17 – Aug 13)	639.5 (638.1-640.6)	144	5	3.5
2017 (Jun 19 – Jul 7)	634.3 (632.9-635.9)	227	10	4.4
2018 (Jun 25 – Jul 12)	636.0 (635.9-636.2)	152	20	13.2

Table 3-2 Fork lengths (mm) of Bull Trout captured during mark-recapture sampling in Carpenter Reservoir (2015-2018).

	Fork Length (mm)				
Year	N	Mean	St. Dev	Min	Max
2015	269	363.1	61.1	174	540
2016	140	379.4	74.6	241	605
2017	227	388.3	77.0	220	695
2018	152	418.1	91.4	162	622

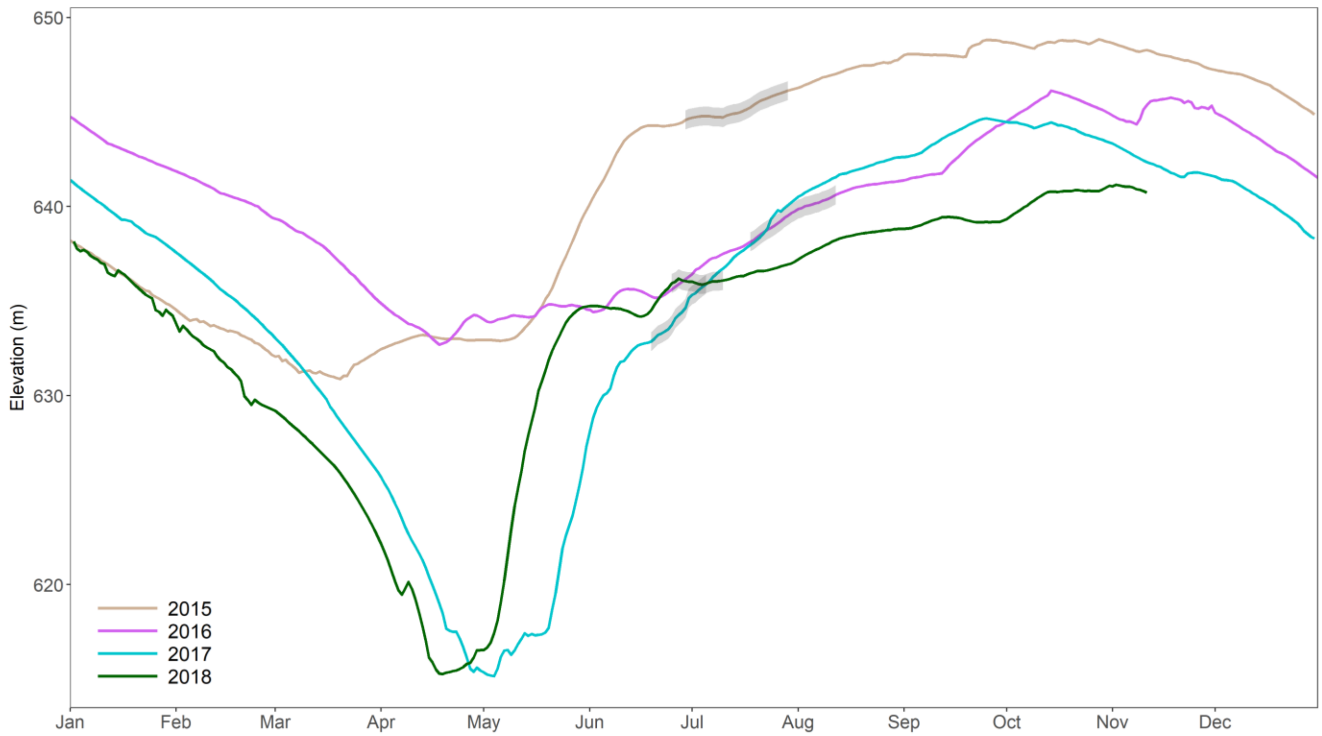

Figure 3-5 Carpenter Reservoir elevations (2015-2018) with annual Bull Trout mark-recapture periods highlighted in grey. Mark-recapture sampling occurred in July in 2015 and 2016 but was moved to early June in subsequent years to reduce temperature-related handling stress.

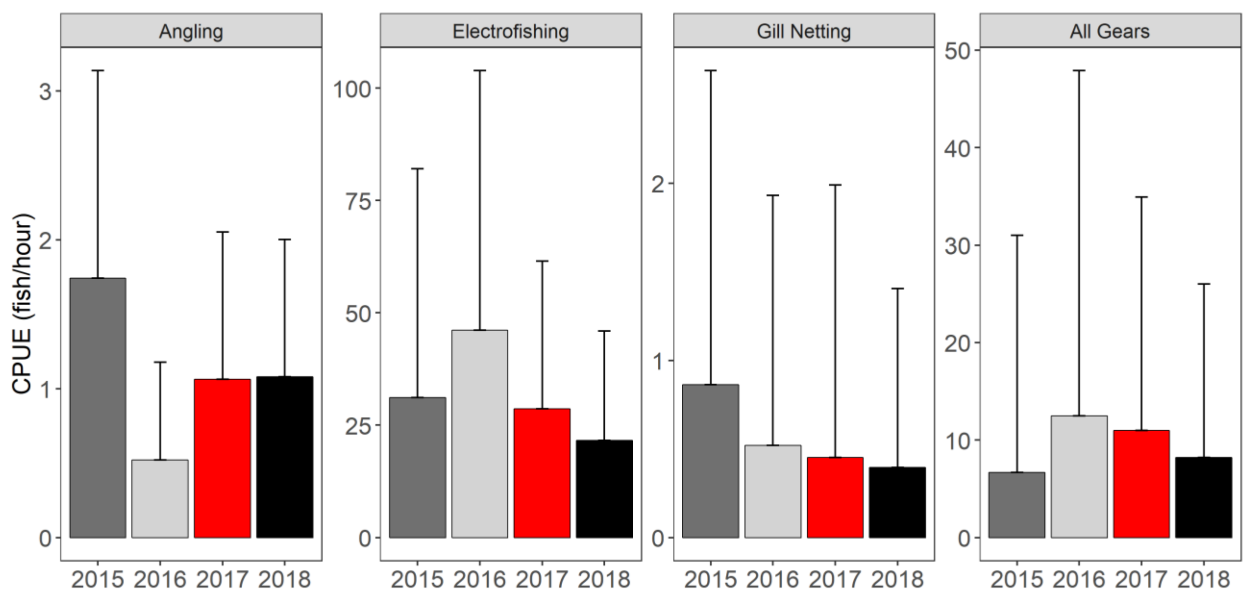

Figure 3-6 Gear-specific mean CPUE (in fish/hour) with standard deviations for Bull Trout captured during the mark-recapture program. Scales are free to show variation among gear types.

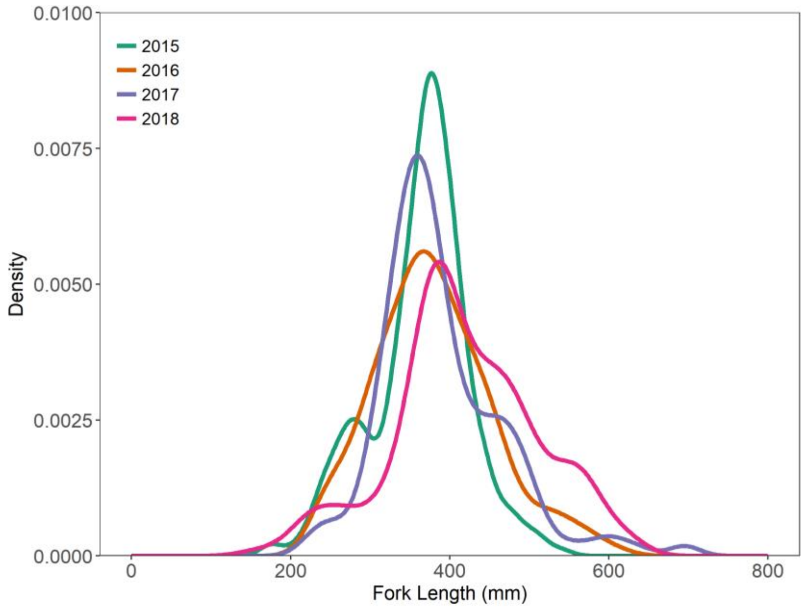

Figure 3-7 Probability density function (from kernel density estimation) of fork lengths for Bull Trout captured during the Carpenter Reservoir mark-recapture program.

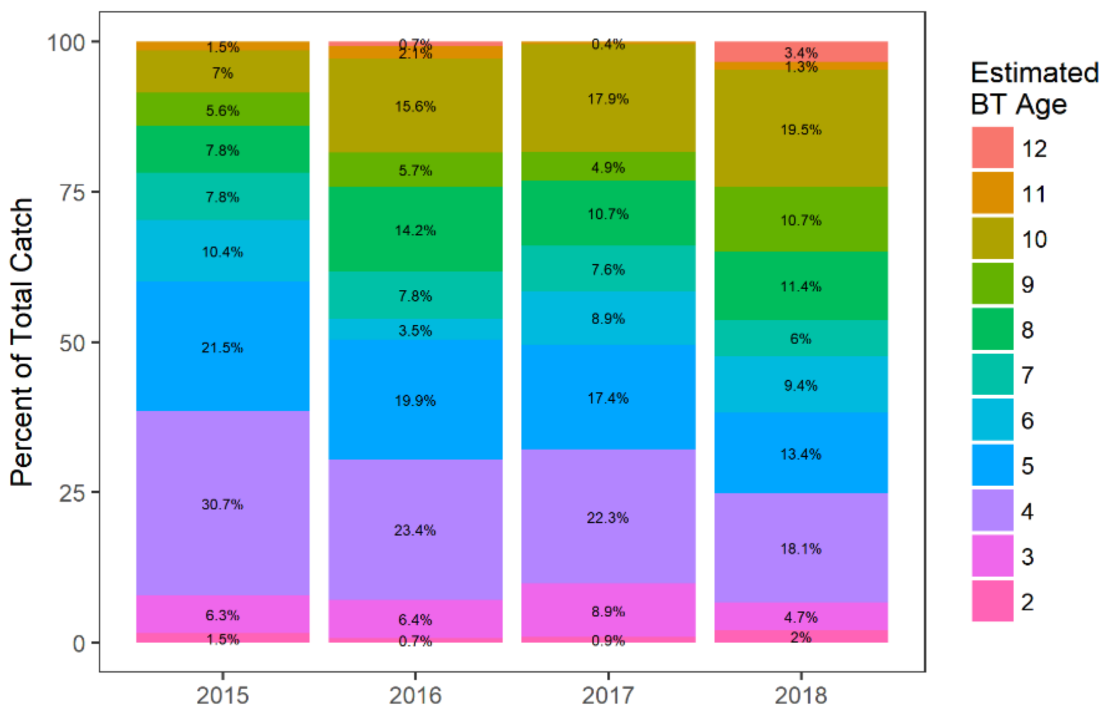

Figure 3-8 Bull Trout captures during annual mark-recapture sampling in Carpenter Reservoir separated into age classes estimated using Bull Trout Age Length Key (ALK).

3.2.1 Mark-Recapture Modelling

The CJS model was used to estimate Bull Trout survival and capture probability, and an index of annual abundance was calculated for 2016 through 2018 (abundance cannot be calculated for 2015 because there is no value of capture probability for this year). The CJS model with the highest AICc support was that with fixed capture probability (p_{fixed}) and time-varying survival ($\varphi_{time\text{-}varying}$; Table 3-3). The fixed survival model was within two AICc points and was therefore indistinguishable from the top model; however, we selected the fixed capture probability because we hypothesize that survival/emigration may vary among mark-recapture years due to physical variation in the reservoir. Capture probability and year-specific survival parameter estimates for the fixed capture probability model are shown in Table 3-4.

Parametric bootstrapping (1,000 simulations) was used to evaluate the goodness-of-fit of the fixed capture probability CJS model (Figure 3-9). Bootstrapping results suggest a moderate fit to the mark-recapture data. Both survival and capture probability parameters were relatively unbiased (i.e., the mean bootstrapped values were similar to the estimated parameters) but capture and survival probabilities were imprecise (i.e., a broad distribution of possible parameter values was generated during bootstrapping). We used CJS capture probabilities simulated during parametric bootstrapping in Equation 2 to calculate annual abundance in 2016 through 2018. The simulated CJS abundance of adult Bull Trout in Carpenter Reservoir was 1,829 individuals (SD 668) in 2016, 2,883 (SD 1,052) in 2017, and 1,931 (SD 705) in 2018.

Table 3-3 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
$\varphi_{time\text{-}varying}$, p_{fixed}	**4**	**311.59**	**0**
φ_{fixed}, $p_{time\text{-}varying}$	4	312.20	0.61
$\varphi_{time\text{-}varying}$, $p_{time\text{-}varying}$	6	315.55	3.96
φ_{fixed}, p_{fixed}	2	315.68	4.09

Table 3-4 Parameter estimates, standard errors, and 95% confidence limits for the CJS model with fixed capture probability. φ = survival probability, *p* = capture probability.

Parameter	Estimate	Standard Error	Lower Confidence Interval (2.5%)	Upper Confidence Interval (97.5%)
$\varphi_{Year\ 2015\text{-}2016}$	0.23	0.08	0.11	0.43
$\varphi_{Year\ 2016\text{-}2017}$	0.56	0.18	0.23	0.84
$\varphi_{Year\ 2017\text{-}2018}$	0.67	0.07	0.53	0.79
P_{fixed}	0.09	0.02	0.06	0.14

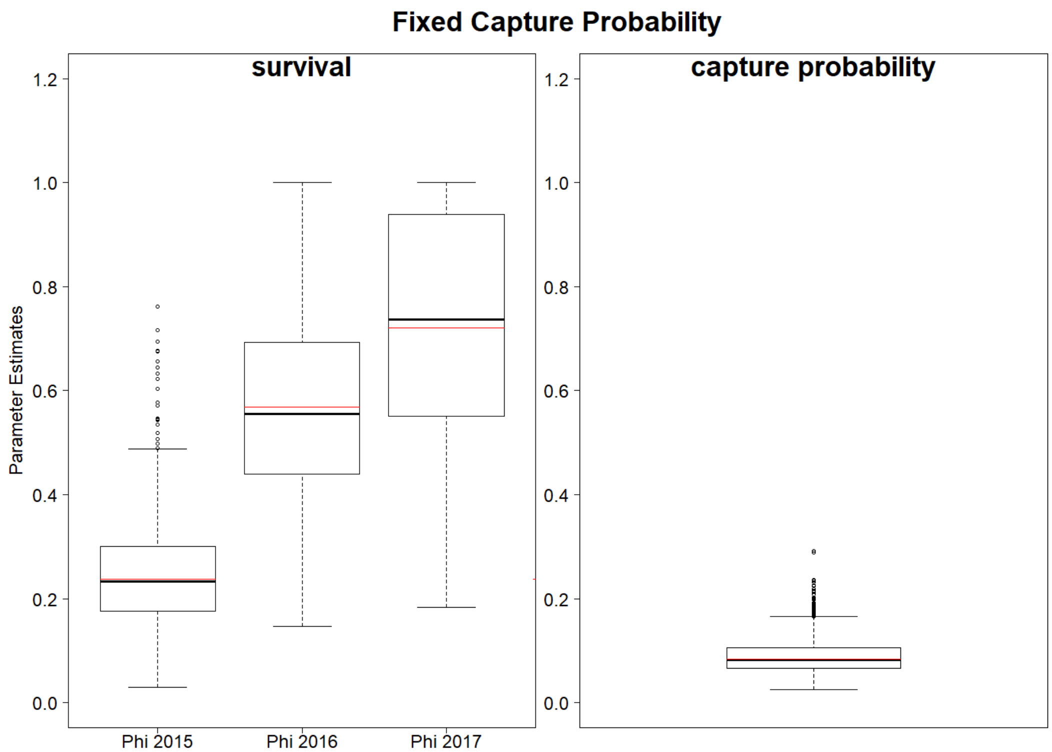

Figure 3-9 Parametric bootstrapping (n = 1000) parameter estimates for the CJS model with fixed capture probability. Red lines are the true parameters.

3.3 Mark-recapture By-catch Capture Data

We calculated CPUE for all gear types and by-catch species during the mark-recapture period (Figure 3-10) to serve as a density index across mark-recapture years for all species captured during the program. CPUE should be used cautiously when comparing to CPUE from other time periods, as all capture activities during the mark-recapture period are targeted towards the capture of adult Bull Trout. The 2015 and 2016 mark-recapture periods occurred in late July, while the 2017 and 2018 mark-recapture periods occurred in late June. These timings explain why kokanee were captured in 2015 and 2016 but rarely in 2017 and 2018: kokanee stage at creek mouths in preparation for spawning in late July. Mountain Whitefish and Rainbow Trout CPUE decreased in 2018 relative to 2017. The 2018 Rainbow Trout CPUE was the lowest of all mark-recapture periods to date despite program timing and reservoir elevation being similar between the two years.

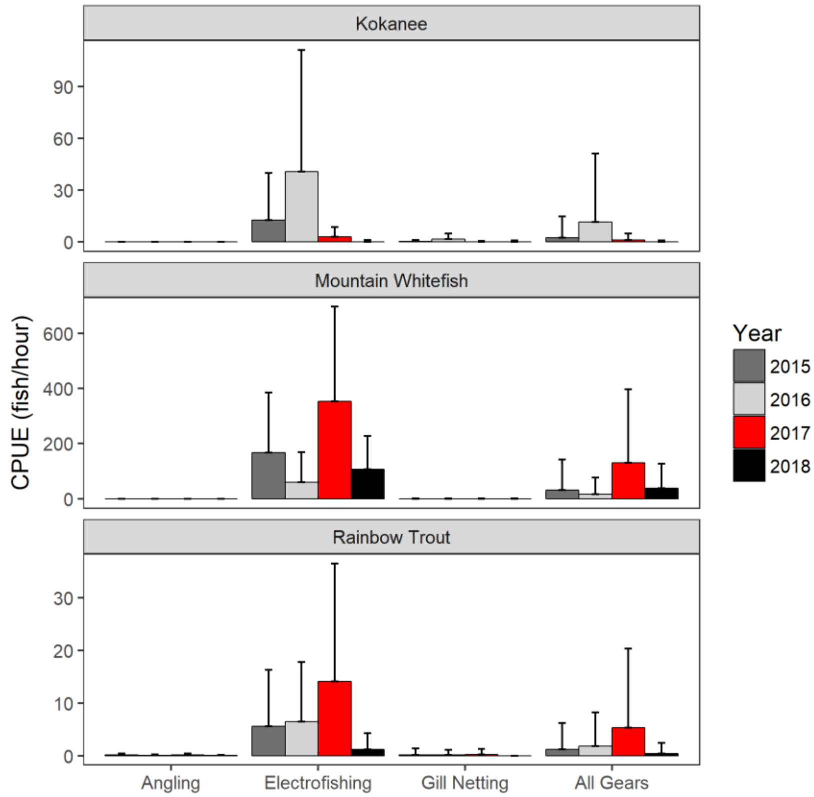

Figure 3-10 Gear-specific CPUE (in fish/hour) and standard deviations for all by-catch species captured during the mark-recapture program.

3.4 Bull Trout Movement Analysis

3.4.1 Characteristics of Acoustic-Tagged Fish

Approximately 20 Bull Trout were tagged annually from 2015 to 2018 with an acoustic transmitter. We aimed to tag Bull Trout with weights > 550 g to minimize tagging effects, and 2018 was the only year we were able to meet this weight target for all acoustic surgeries (Table 3-5). The mean size of Bull Trout tagged with acoustic transmitters was highest in 2018 compared to 2015 through 2017. Bull Trout tagged in 2018 ranged from age 3 to age 10, and age distributions (modeled using Age-Length-Keys developed in 2016; Putt et al. 2017) were similar among the four years (not shown).

Table 3-5 Fork lengths (mm) and weights (g) of acoustic Bull Trout in Carpenter Reservoir (2015-2018).

	Fork Length (mm)					Weight (g)				
Year	**N**	**Mean**	**St. Dev**	**Min**	**Max**	**N**	**Mean**	**St. Dev**	**Min**	**Max**
2015	20	446.6	38.0	400	519	15	675.8	132.9	508	975
2016	18	435.8	45.9	363	520	18	886.6	367.7	478	1638
2017	20	419.7	64.2	333	542	20	752.3	377.5	353	1523
2018	20	483.2	42.9	394	585	16	1059.8	336.0	768	1924

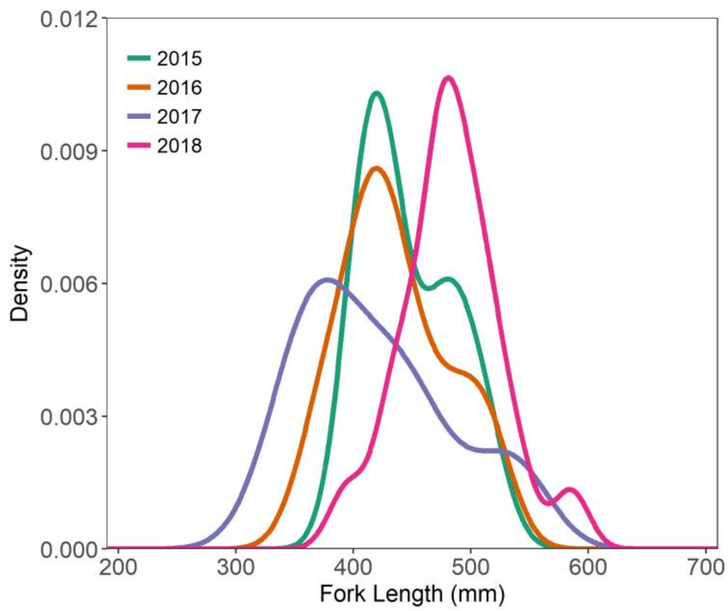

Figure 3-11 Probability density function (from kernel density estimation) of fork lengths for acoustic-tagged Bull Trout in 2015 through 2018.

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 2015 through 2017 acoustic survey periods (Table 3-6). Detection efficiencies in 2016 and 2017 were similar and higher than in 2015. Two additional receivers were added to the Middle Bridge River acoustic gate in 2016, which likely explains the increases efficiency at this gate in 2017.

In 2017 we installed a sentinel tag proximate to the reservoir receiver gate to monitor seasonality in detection efficiency at this gate. Detection percentage was high (>80%) for almost all receivers within 600 m of the sentinel tag, suggesting that the reservoir gate design is very robust. One receiver located 430 m from the sentinel tag failed to detect the sentinel tag at any point throughout the study period. The receiver detected tagged Bull Trout during this period and was therefore functioning properly, suggesting that it was somehow physically shielded from the sentinel tag. Across all receivers, detection percent (i.e., the percent of sentinel tag transmissions detected by a receiver) was high (>90%) during full pool, summer conditions (August through September) but declined in October and November (Figure 3-12). Detection percent recovered in January but subsequently declined in the spring (February through early April) as reservoir elevation declined. The sentinel tag was not deployed in May and June; however, these months are characterized by minimum reservoir elevations, and it is likely that detection percentages would remain relatively low. Variations in detection percentage were exacerbated at the two receivers that were furthest from the sentinel tag. The decrease in detection percentage in the fall was potentially related to decreasing water temperatures (during fall turnover) and increasing turbidity in the reservoir.

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

Year	Gate	Movements Detected	Movements Missed	Detection Efficiency
Jun 2015 – Apr 2016	River and Reservoir Gate Combined	33	36	48%
	River Gate	15	21	42%
	Reservoir Gate	18	14	56%
Apr 2016 – Apr 2017	River and Reservoir Gate Combined	55	28	66%
	River Gate	17	9	65%
	Reservoir Gate	38	19	67%
Apr 2017 – Apr 2018	River and Reservoir Gate Combined	85	38	69%
	River Gate	19	6	76%
	Reservoir Gate	66	29	69%

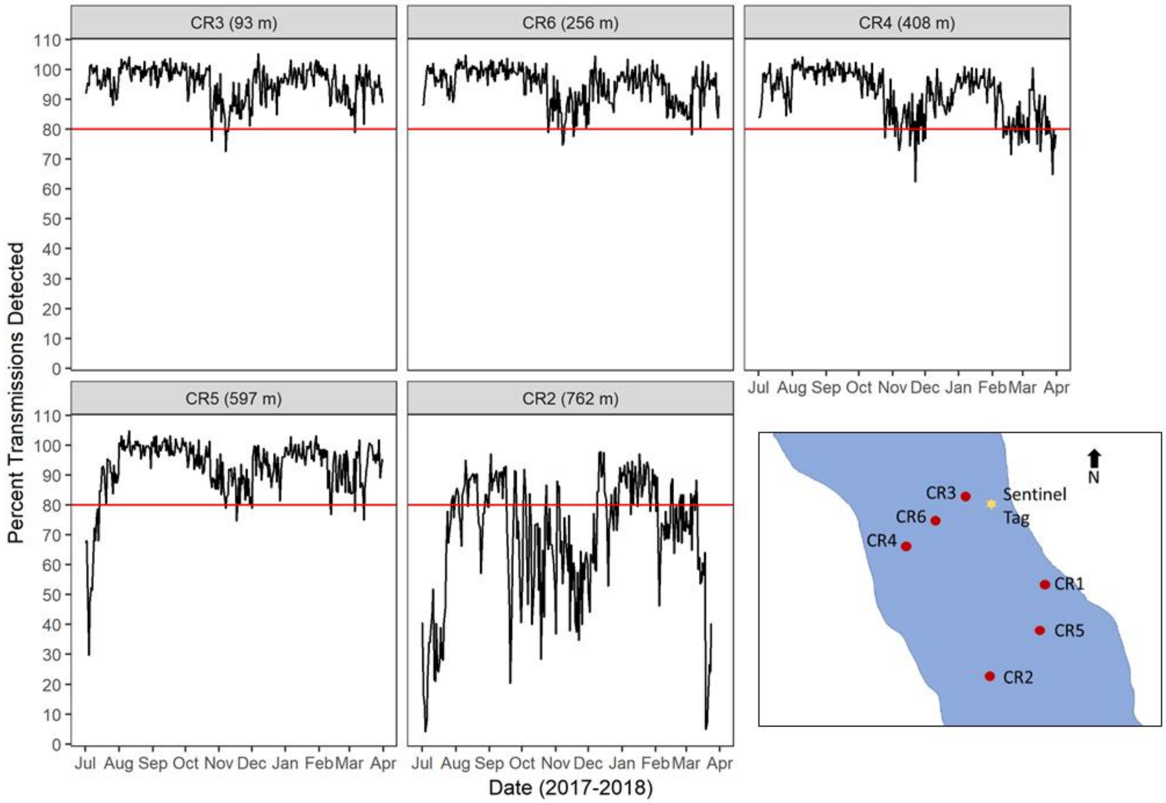

Figure 3-12 Detection efficiency of receivers in the Carpenter Reservoir acoustic gate to detect a sentinel tag in place from July 2017 to April 2018. The straight-line distance of each receiver from the sentinel tag is listed in the title bars, and the red line represents the 80% (high) detection probability line. An inset map provides the physical location of the six receivers and the sentinel tag.

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. We collected and downloaded the acoustic receivers in June of 2018 and subsequently redeployed them for future downloading in June of 2019. There is a one-year lag between the acoustic data reported here and the other analyses described in this report.

Of the 20 Bull Trout tagged in the spring of 2017, 17 were detected during the 2017 acoustic monitoring period (April 2017 to April 2018; Figure 3-13 and Figure 3-14). We also detected seven Bull Trout that were tagged in 2016, two of which were not detected in the 2016 acoustic monitoring period, and two Bull Trout that were tagged in 2015 (tags deployed in 2015 were scheduled to deplete their battery by June of 2018 and were not included in the analysis).

We saw very few movements into and out of the Middle Bridge River in 2017 (Figure 3-13 and Figure 3-14). Eight Bull Trout migrated into the Middle Bridge River in late summer and early fall, suggesting possible spawning migrations. The remaining Bull Trout remained within the reservoir and made movements between its eastern and western halves. Heavy movement periods appeared to be late summer and late fall; however, movement between the two reservoir portions occurred throughout the monitoring period.

The mark-recapture period is highlighted in Figure 3-13 and Figure 3-14. In 2017, 46% of Bull Trout (n = 13) detected over the year were within the western half of the reservoir during the mark-recapture period, while 54% (n = 11) were within the eastern half of the reservoir. Reservoir elevation was relatively low (mean elevation 634 m) during the 2017 mark-recapture period compared to previous years and the acoustic gate was near to the boundary of the Middle Bridge River and the reservoir. In 2015, when reservoir levels were high (mean elevation 645 m) relative to other monitoring years, during the mark-recapture period there were almost no Bull Trout located in the eastern half of the reservoir, and ~25% of tagged Bull Trout were consistently detected in the Middle Bridge River. These two contrasting years may suggest that when elevation is high, Bull Trout prefer western reservoir habitat and are more likely to undergo spawning migrations into the Middle Bridge River. Conversely in low elevation years, Bull Trout spend more time in the eastern portion of the reservoir and are less likely to undergo spawning migrations into the Middle Bridge River.

We observed some consistent movement patterns for tags detected in multiple years. For example, Tag 4113 (estimated to be age 10 in 2017) moved into the Middle Bridge River in November of both 2016 and 2017. The remaining tags detected in both years (Tags 4112 [age 11], 34802 [age 7], 34803 [age 6], and 34804 [age 7]) moved between the two halves of the reservoir but did not undergo movements into the Middle Bridge River in either of the two years.

Combined, the three years of acoustic monitoring suggest a potential contraction of the migration period into the Middle Bridge River has occurred as the years have progressed. In 2015, Bull Trout moved into the Middle Bridge River from mid-July to mid-January. In 2016, movements occurred from late July to mid-January, and in 2017, detections occurred from September to December. In all years, most detections were in mid-October. We have also seen preliminary evidence of fewer tagged Bull Trout migrating into the Middle Bridge River (i.e., 11/20 migrated into the river in 2015, 5/18 in 2016, and 8/20 in 2017), which agrees with declining catch rates of Bull Trout at western tributaries such as Macdonald Creek during mark recapture angling.

Figure 3-13 End location of Bull Trout movement events from April 2017 to April 2018 in Carpenter Reservoir and the Middle Bridge River for all fish detected (tags released in Year 2, 3, and 4). Coloured bars represent end location of individual events. The Year 5 mark-recapture study period is shown within the red rectangle. Ages on the right represent the estimated age of each Bull Trout for the current monitoring year.

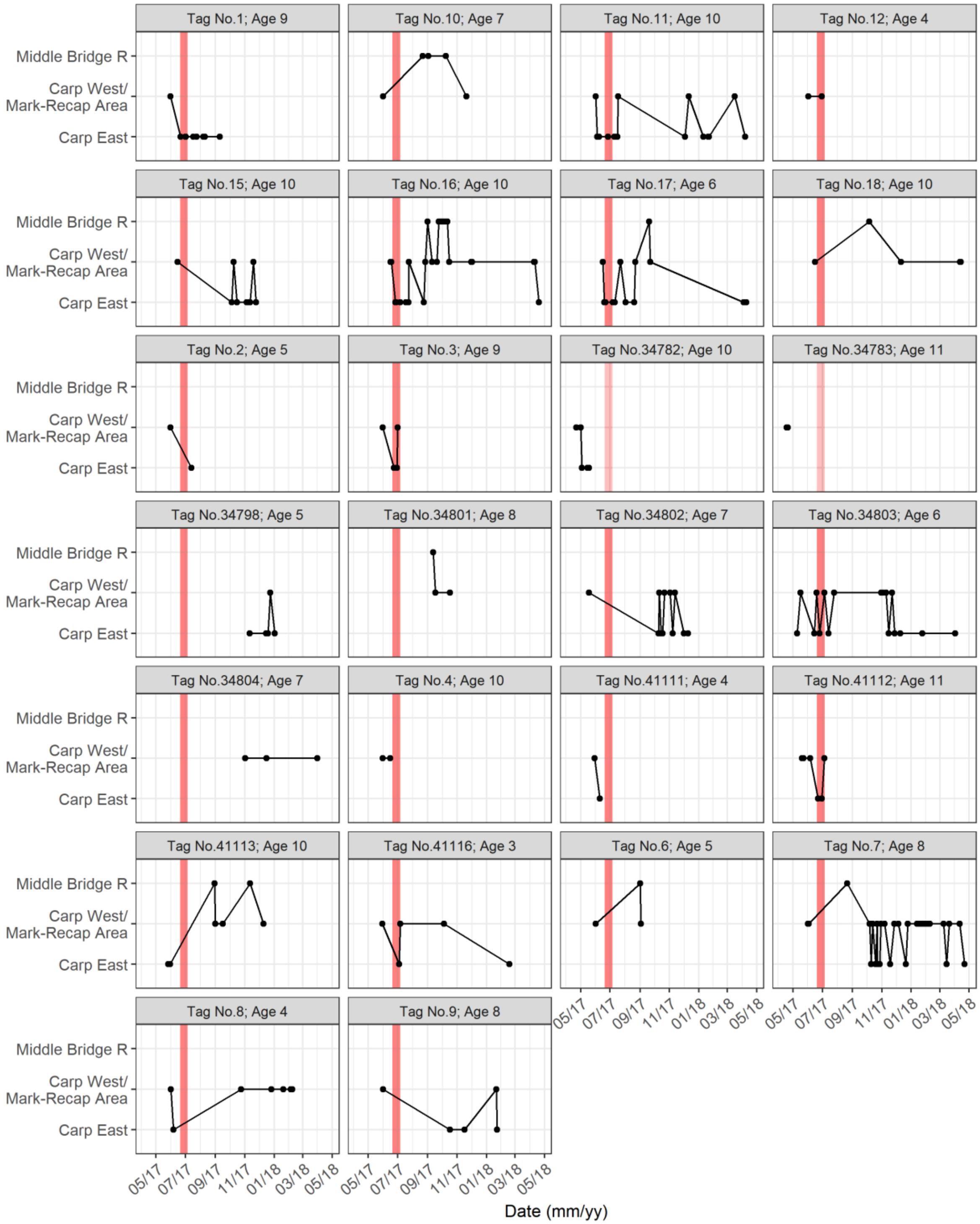

Figure 3-14 End location of individual movement events for acoustic Bull Trout in Carpenter Reservoir and the Middle Bridge River (April 2017 to April 2018). The mark-recapture period is in red. Lines are used to connect locations visually and do not represent exact location. Ages represent the estimated age of each Bull Trout for the current monitoring year.

3.4.4 Bull Trout Position Data

The 2017-2018 Bull Trout acoustic data were analyzed by VEMCO to determine individual fish positions proximate to the reservoir acoustic gate from June 10, 2017 to April 21, 2018. Positions could be calculated due to the presence of a stationary sentinel tag within the detection range of the acoustic gate. The reservoir acoustic gate detected 11 Bull Trout during the study period, eight of which could be positioned by the VEMCO positioning system (VPS). Detections occurred almost constantly throughout the study period except for the period from early August to mid-October. The August to October period had very few Bull Trout detections, corresponding with the warmest temperatures in the reservoir. Bull Trout generally prefer water temperatures <12°C (McPhail 2007), and water temperatures throughout the water column exceeded 12°C by mid-August at a BRGMON-10 sampling site 1.5 km west of the gate (Figure 3-15). August to October also corresponds with the Bull Trout spawning period. Bull Trout spawn in tributaries of the reservoir and in the Middle Bridge River, and acoustic Bull Trout undergoing spawning migrations may not have been present in the reservoir at this time. Most VPS detections occurred along the reservoir margins; however, mid-reservoir detections were common, particularly for fish that remained within the area of the gate for multiple days in a row. There were very few linear movements through the gate area, suggesting that Bull Trout forage in the vicinity of the acoustic gate.

The Bull Trout movement behaviours identified by the VPS data help to explain the relatively low efficiency of the reservoir acoustic gate for detecting Bull Trout crossing events (Table 3-6). Although the efficiency of the receivers to detect a sentinel tag was very high throughout the year (>80%; Table 3-6), the efficiency of the gate to detect crossing events was lower (~60%; Table 3-6). If the movement pattern of a Bull Trout proximate to the acoustic gate was random or circular (e.g., foraging or holding behaviour) instead of linear (i.e., migrating behaviour), the gate may have failed to accurately determine the beginning and end (and corresponding locations) of the detection event. The VPS data demonstrated that directed crossing movements were infrequent in the vicinity of the reservoir gate relative to foraging and holding behaviour, which could explain why crossing efficiency for the gate was lower than the sentinel tag detection efficiency for individual receivers.

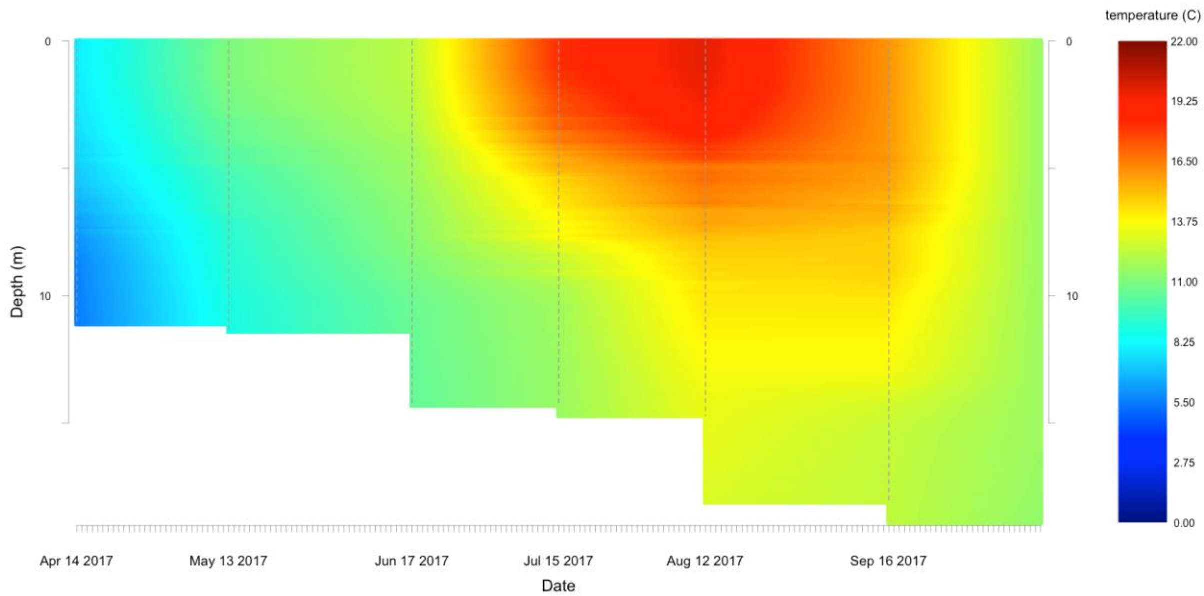

Figure 3-15. Water temperatures at BRGMON-10 sampling station C6 from April 2017 to October 2017. Dashed lines represent sampled water temperatures, and water temperatures for dates between the dashed lines are linear approximations. Data and figure are from BRGMON-10.

3.4.5 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 2018. Recapture locations highlight variable behavioural patterns of Bull Trout in Carpenter Reservoir and the Middle Bridge River. Of the 271 Bull Trout captured more than once during BRGMON-4, 41% 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 = 159) 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 (38%) of Bull Trout recaptured in multiple years were captured at the same location each time (e.g., Tag 584851 [estimated age 7 in 2017] was angled from Truax Creek once per year from 2015 to 2017). Of the fish captured at different locations, 34% were captured within a 10 km radius of their release location, while 28% were captured at locations >10 km apart. For example, Tag 586062 was captured two springs in a row at Keary Creek (at age 6 and age 7) via shoreline electroshocking and once in the fall (at age 6) at Truax Creek via angling. Some fish travelled large distances within or between years; for example, Tag 657920 was captured at Tyaughton Creek (~35 km, riverine habitat) in the spring of one year (at age 6) and close to Terzaghi Dam (~km 0, lacustrine habitat) in the subsequent spring. 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 fish tagged in Carpenter Reservoir 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.

Movement Category	Count	% Total	% Detected multiple years
Caught multiple years at same location	61	23%	38%
Caught multiple years >10 km apart	45	16%	28%
Caught multiple years <10 km apart	53	20%	34%
Only recapped within same week of one	112	41%	NA

3.5 Shoreline Electroshocking in Carpenter Reservoir

We compared shoreline electroshocking counts between a single historic (i.e., 2001/pre-WUP) survey and surveys completed during BRGMON-4 (i.e., mark-recapture electroshocking in 2015 through 2018. During BRGMON-4, all electroshocking took place west of Cedarvale Creek (km 13) and east of Truax Creek (km 35), and we only draw comparisons to historic electroshocking within this area.

Bull Trout counts were relatively consistent throughout BRGMON-4 and between BRGMON-4 and the historic survey in 2001 (Figure 3-16; zero counts are represented by coloured circles) 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 Bull Trout were spawning in or migrating to the Middle Bridge River or predating 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 2018 (Figure 3-17). Almost all Rainbow Trout were captured at tributary confluences except proximate to Terzaghi Dam during historic surveys in 2001, where Rainbow Trout were captured in steep and shallow shoreline habitat. In 2017, there were higher counts of Rainbow Trout during tributary electroshocking, which was partially attributed to the earlier timing of the electroshocking survey in that year (i.e., the timing corresponds with Rainbow Trout staging for spawning). In 2018 the survey timing remained the same, but Rainbow Trout counts were substantially lower at tributary confluences.

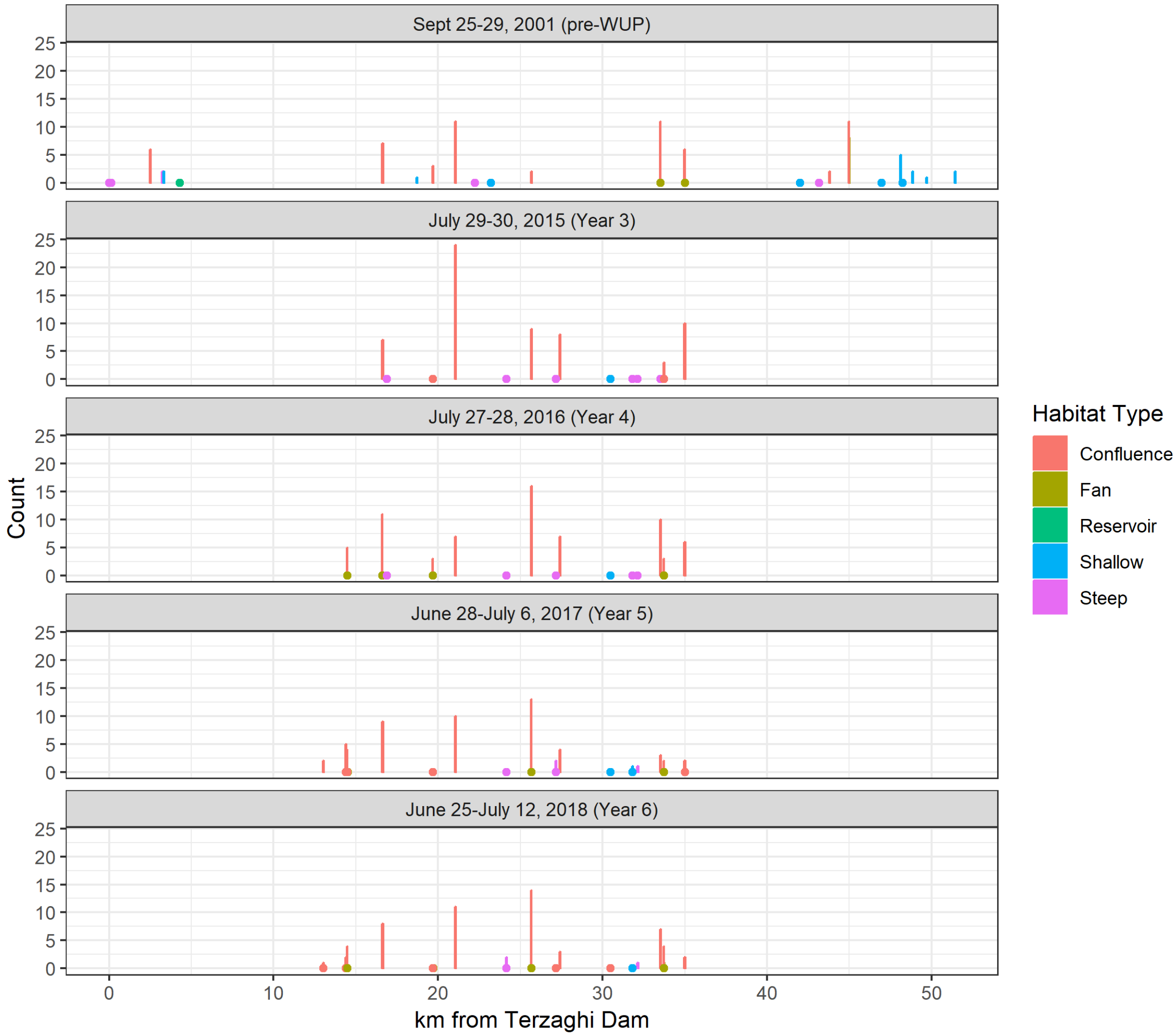

Figure 3-16 Bull Trout counts from Carpenter Reservoir shoreline electroshocking surveys in 2001 (pre-WUP) and 2015-2018 (BRGMON-4). Zero counts are represented by solid points.

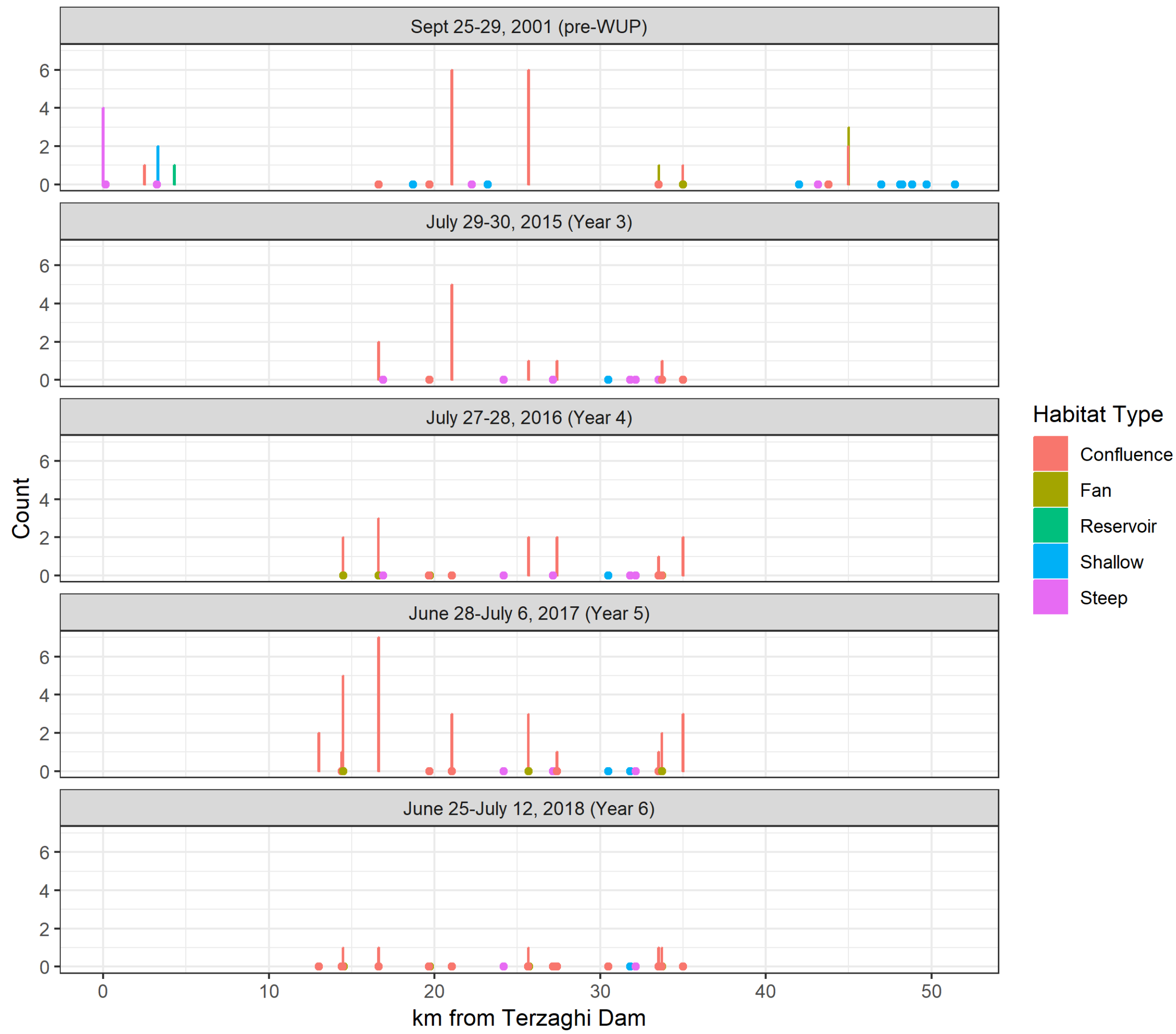

Figure 3-17 Rainbow Trout counts from Carpenter Reservoir shoreline electroshocking surveys. Zero counts are represented by solid points.

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 of 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 2013 through 2018 (all sampling occasions).

	Bull Trout	Rainbow Trout	Mountain Whitefish	Kokanee
2013	432	92	311	3
2014	210	66	249	2
2015	369	45	86	27
2016	253	133	354	91
2017	317	202	255	18
2018	214	160	269	3
Total	1,795	698	1,524	144

Table 3-9 Ageing structures analysed in 2014 through 2018 of BRGMON-4.

Species	Scales Aged	Otoliths Aged	Fin Rays Aged	Total Structures Aged
Bull Trout	9	10	74	93
Kokanee	52	0	0	52
Mountain Whitefish	194	31	0	225
Rainbow Trout	408	2	0	410

3.6.1 Bull Trout

Lengths and weights of Bull Trout captured in Carpenter Reservoir from 2013 to 2018 were highly correlated (adjusted R-squared for 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 3-18; ANOVA p-value 0.08, DF 5, F 1.95). We examined the length-to-weight relationship 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 0.77) and the addition of year to the length-weight model was highly significant (Figure 3-18; ANOVA p-value <0.001, DF 5, F 10.45). 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 2013 through 2018 for Bull Trout age 3 to 6 (Figure 3-19; ANOVA p-value <0.001, DF 5, F 9.18), and a Tukey's HSD test indicated the condition of Bull Trout ages 3 to 6 was lower in 2017 relative to 2013 through 2016 (2018 was statistically similar to all previous years). We also examined the change in condition of Bull Trout within the top 5% of fork lengths captured in the reservoir each year (not shown). For the top 5% of Bull Trout, condition increased in 2016 through 2018 relative to 2013 through 2015.

A total of 93 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 613 mm and fasted adult growth in ages 3 to 6 (Figure 3-20, Table 3-10). A Bull Trout ALK was used to estimate the proportion of Bull Trout in each age class and to estimate ages of unaged fish (Figure 3-21).

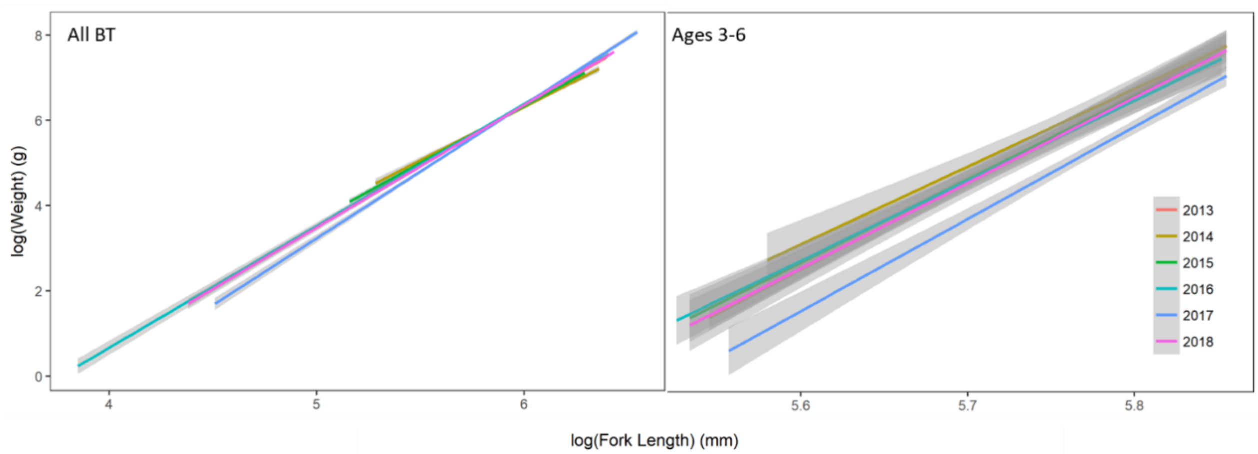

Figure 3-18 Logarithmic length-weight relationships for Bull Trout in 2013 through 2018. Shaded grey area represents linear model 95% confidence interval.

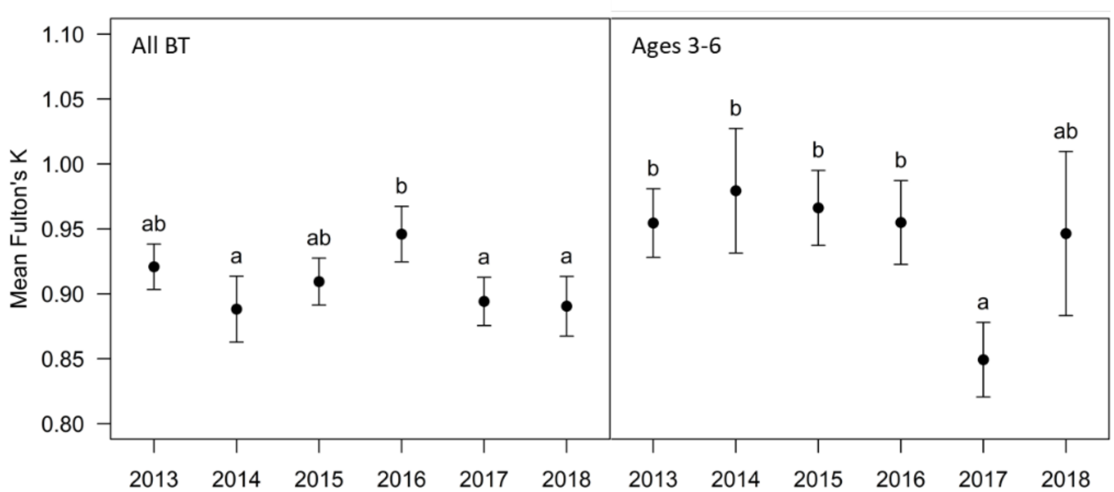

Figure 3-19 Mean annual condition factor (and 95% CI) for Bull Trout in Carpenter Reservoir. Means with the same significance letter are statistically equal.

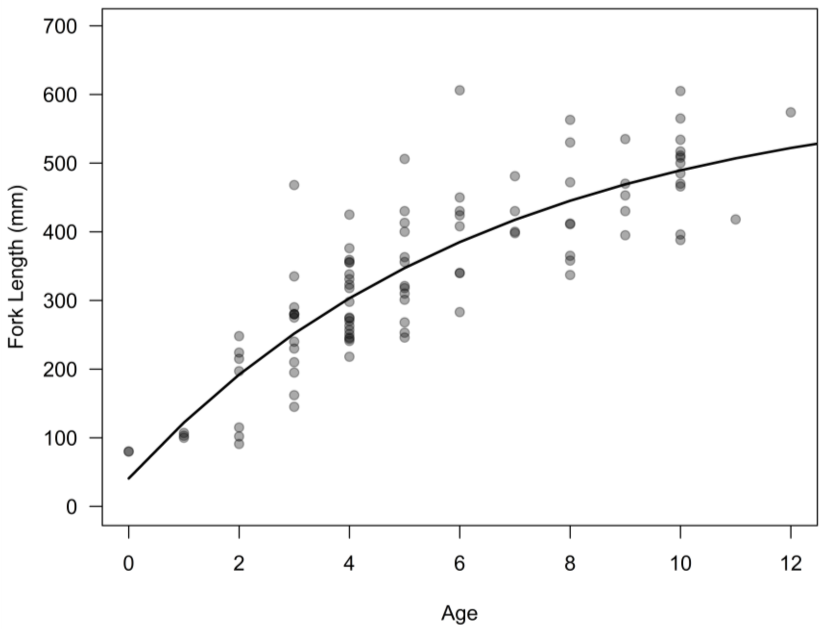

Figure 3-20 Von Bertalanffy growth model for Bull Trout fork length (mm) and observed ages (all study years combined). Transparency shows point overlap.

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}	612.58	0.71
K	0.15	0.00
T_0	-0.50	0.00

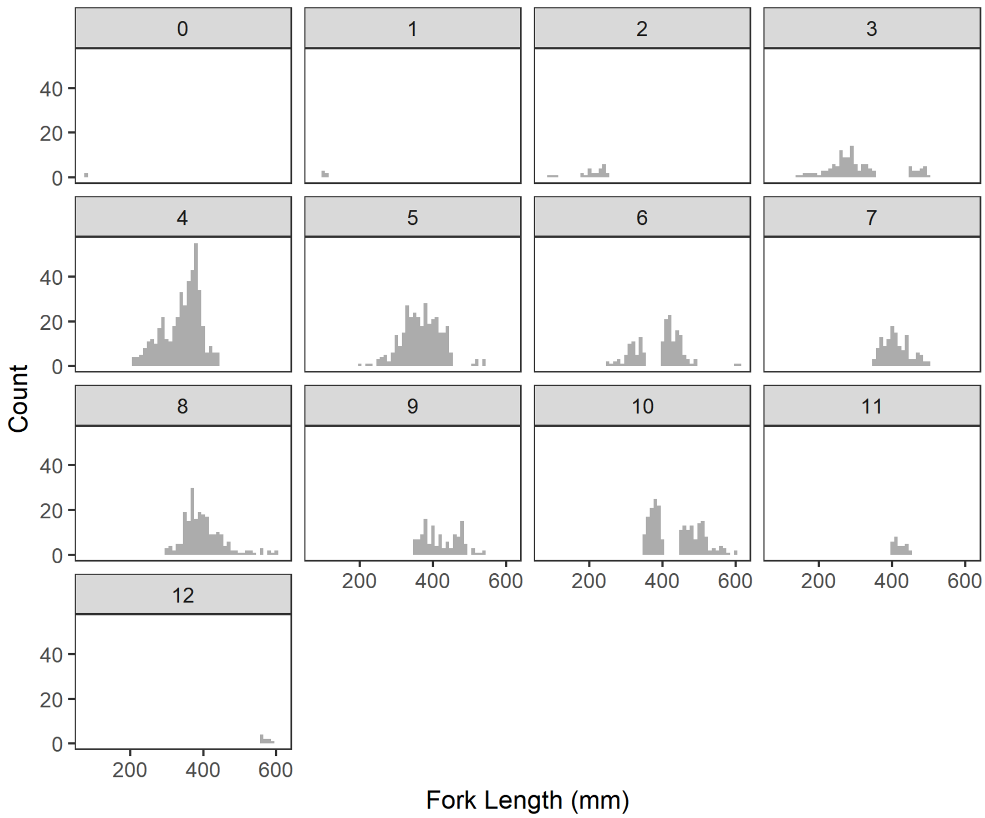

Figure 3-21 Length-frequency histogram for all BRGMON-4 Bull Trout by age (observed and ALK-estimated combined).

3.6.2 Rainbow Trout

Lengths and weights of Rainbow Trout captured only in Carpenter Reservoir in 2013 through 2018 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 3-22; ANOVA p-value <0.001, DF 5, F 16.71). An ANOVA of annual mean K_F was significant (Figure 3-23; p-value <0.001, DF 5, F 8.62), and a Tukey's HSD indicated that condition factors during the 2013 to 2015 period were higher relative to the 2016 to 2018 period. For Rainbow Trout caught only in the tributaries (during electroshocking in 2016 through 2018), year was not a significant addition to the length-weight relationship (ANOVA p-value 0.68, DF 2, F 0.39), and an ANOVA of mean K_F was not significant (p-value 0.18, DF 2, F 1.73).

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 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 condition factors of only age 3 and age 4 Rainbow Trout captured in the reservoir (n = 51) and in the tributaries (n = 37) between 2016 through 2018. Mean K_F for age 3 and 4 Rainbow Trout captured in the reservoir was significantly different in 2016 through 2018 (p-value 0.02, DF 2, F 4.00; highest in 2016, lowest in

2017, and both overlapped with 2018), while there was no difference between mean K_F of tributary fish of the same age (ANOVA p-value 0.20, DF 2, F 1.70).

A total of 410 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: fish captured in the reservoir (reservoir only), stream-residents captured upstream of the Marshall Creek waterfall (tributary residents), and a combination of tributary juveniles and all reservoir captures (Figure 3-24, 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 3-25).

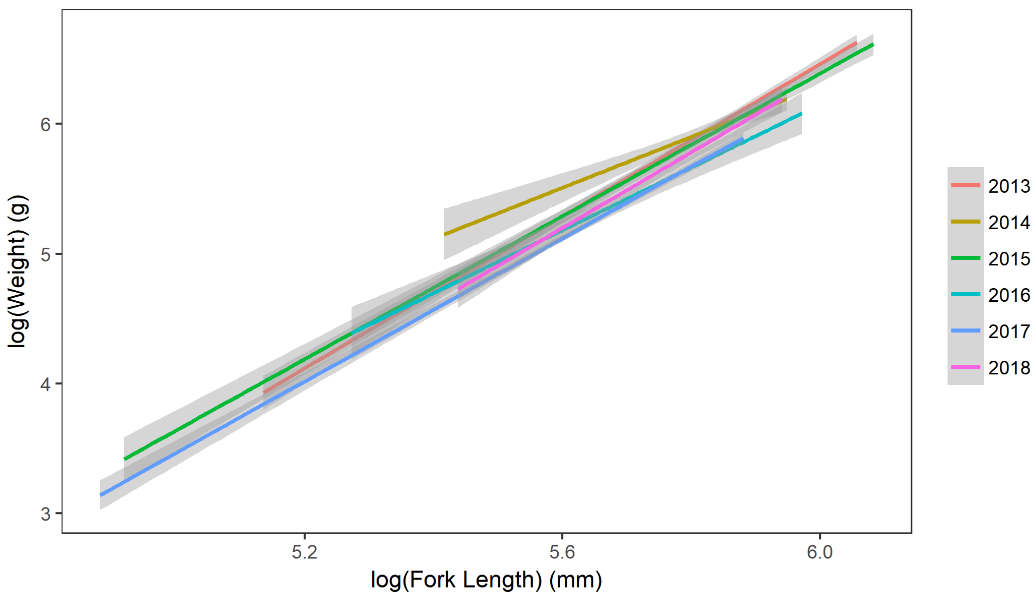

Figure 3-22 Logarithmic length-weight relationships for Rainbow Trout (captured only in Carpenter Reservoir) in 2013 through 2018. Shaded grey area represents linear model 95% confidence interval.

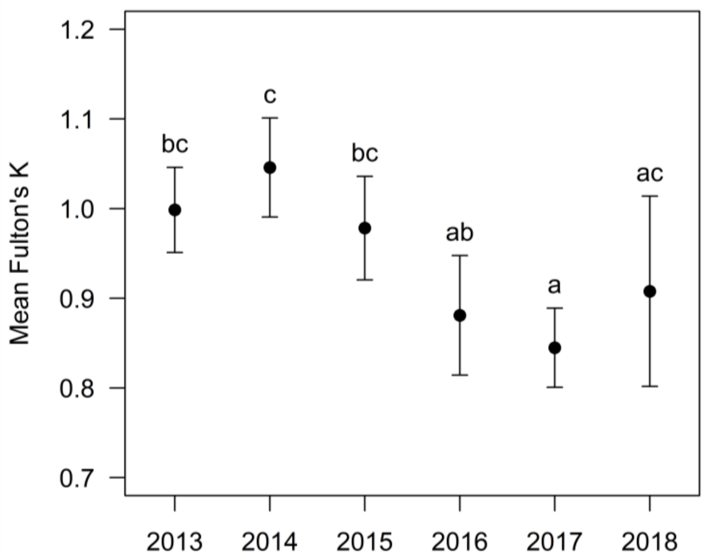

Figure 3-23 Mean annual condition factor (with 95% CI) for Rainbow Trout (Carpenter Reservoir only). Means with the same significance letter are statistically equal.

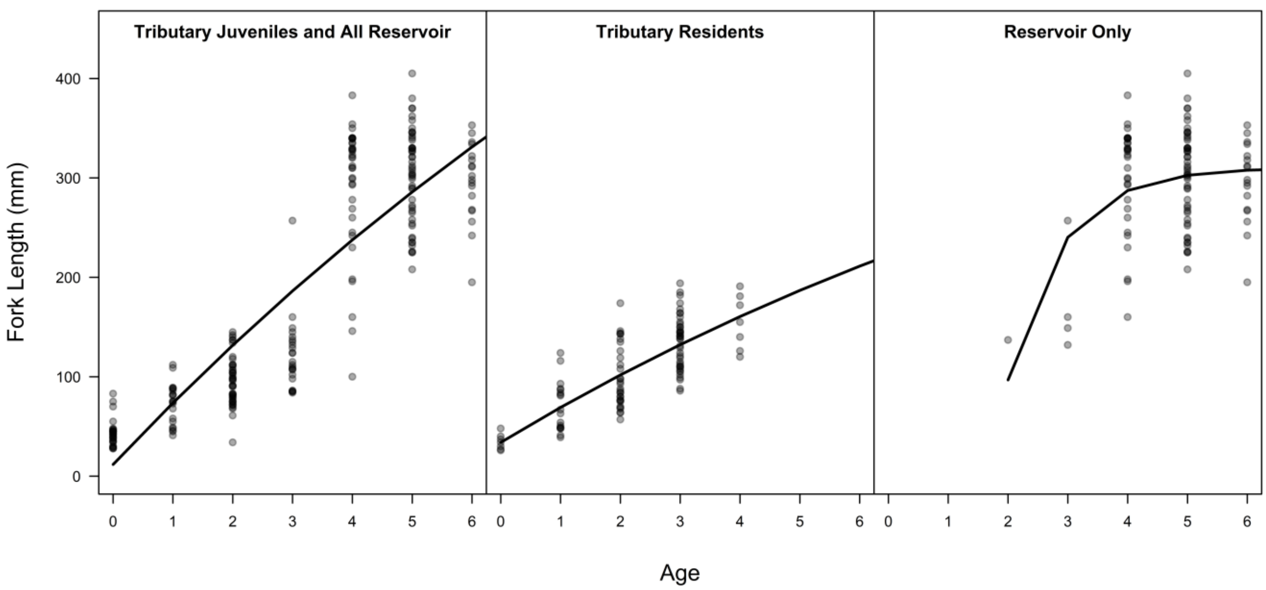

Figure 3-24 Von Bertalanffy growth models for Rainbow Trout fork length (mm) and observed ages separated by life-history type (all study years combined). Transparency shows point overlap.

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}	1,036.51	3.16	533.71	16.65	310.20	0.13
K	0.06	0.00	0.07	0.00	1.12	0.00
T_0	-0.18	0.00	-0.90	0.01	1.66	0.00

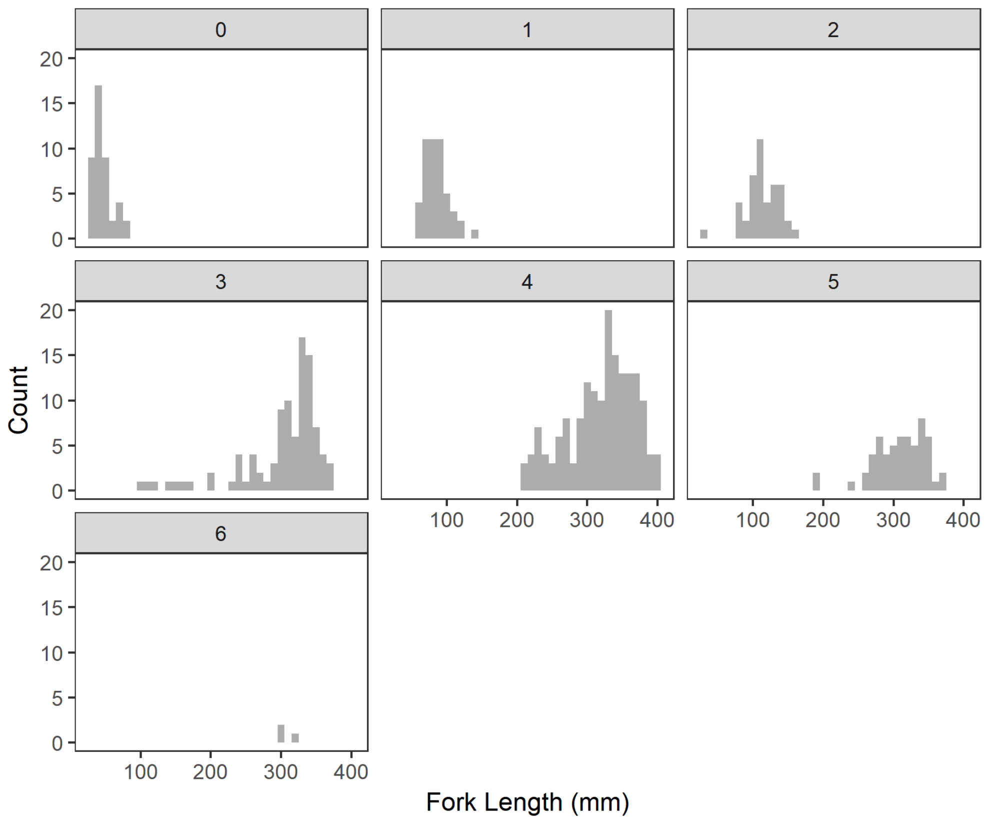

Figure 3-25 Length-frequency histogram for all BRGMON-4 Rainbow Trout by age (observed and ALK-estimated combined).

3.6.3 Mountain Whitefish

Lengths and weights of Mountain Whitefish captured in Carpenter Reservoir in 2013 through 2018 were highly correlated (adjusted R-squared all years 0.94), and the addition of a year variable to the length-weight model was significant when compared to the intercept-only model (Figure 3-26; ANOVA p-value <0.001, DF 5, 49.92). An ANOVA of annual mean K_F was significant (p-value <0.001, DF 5, F 10.25), and showed a decline in condition in 2016 and 2017 followed by a high condition year in 2018 (Figure 3-27).

A total of 225 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 3-28, 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 3-29).

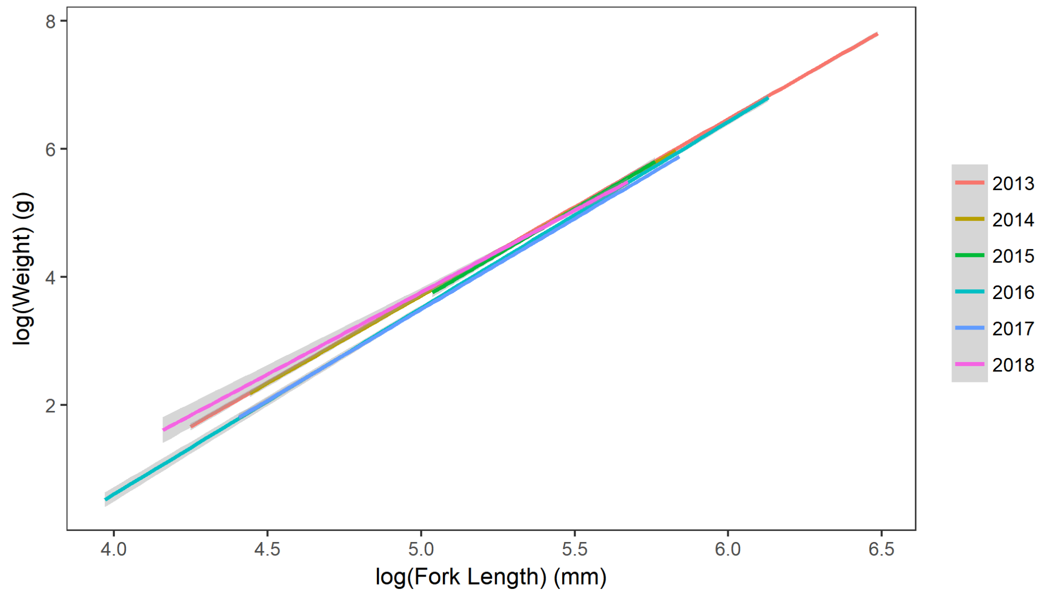

Figure 3-26 Logarithmic length-weight relationships for Mountain Whitefish in 2013 through 2018. Shaded grey area represents linear model 95% confidence interval.

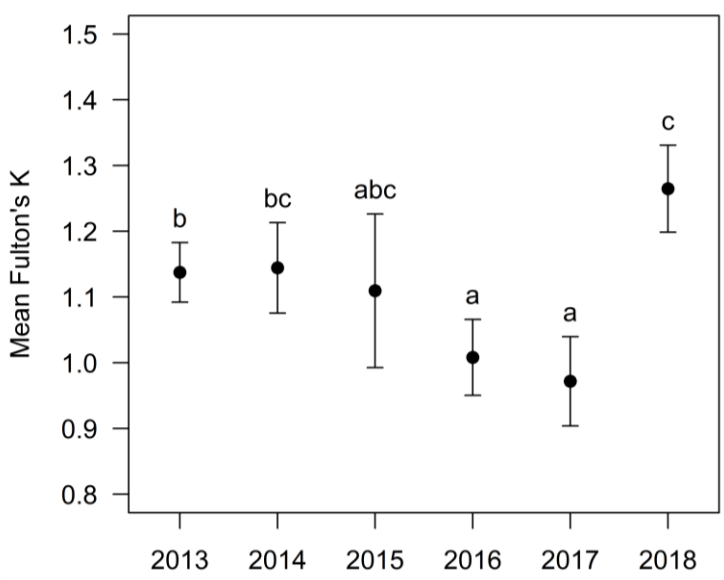

Figure 3-27 Mean annual condition factor (with 95% CI) for Mountain Whitefish in Carpenter Reservoir. Means with the same significance letter are statistically equal.

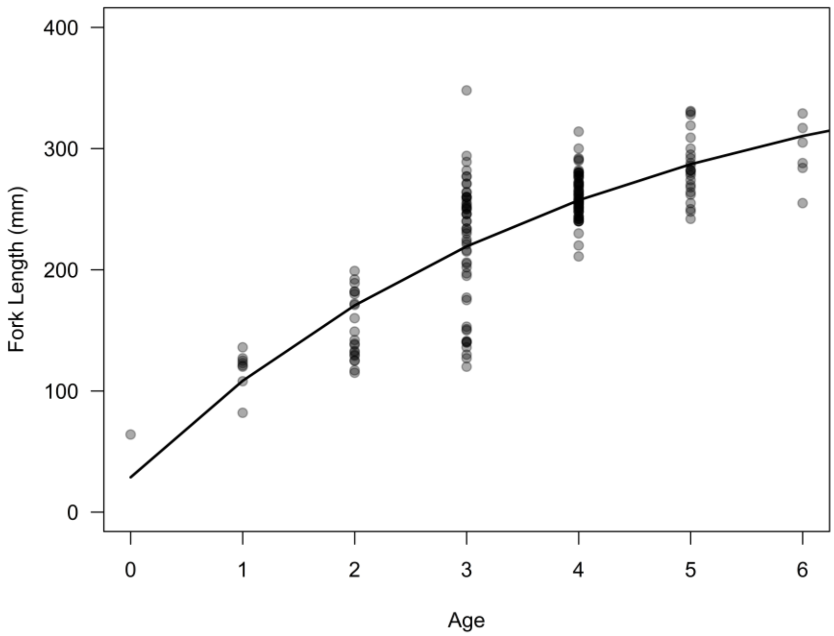

Figure 3-28 Von Bertalanffy growth model for Mountain Whitefish fork length (mm) and observed ages (all study years combined). Transparency shows point overlap.

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}	393.94	0.88
K	0.25	0.00
T_0	-0.31	0.01

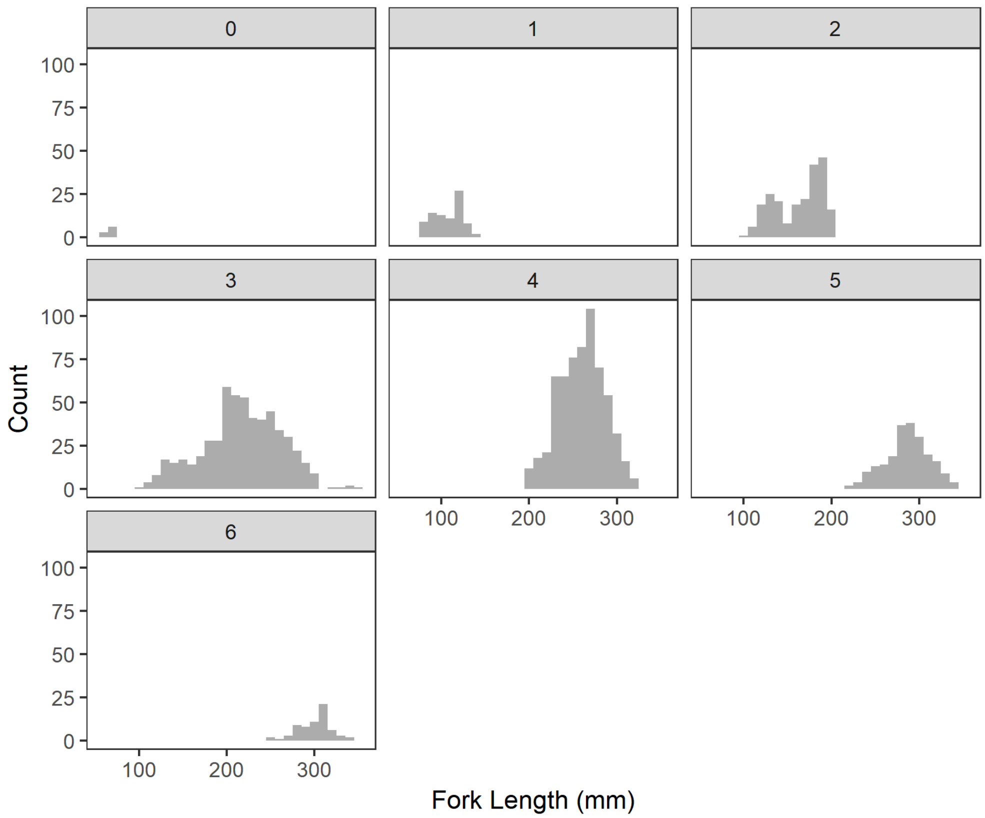

Figure 3-29 Length-frequency histogram for all BRGMON-4 Mountain Whitefish by age (observed and ALK-estimated combined).

3.6.4 Kokanee

Lengths and weights of kokanee captured in Carpenter Reservoir in 2013 through 2018 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 3-30; ANOVA p-value <0.001, DF 5, F 12.52). An ANOVA of annual mean K_F was significant (p-value <0.001, DF 5, F 9.78), and a Tukey's HSD test indicated that condition in 2016 through 2018 was lower (with some overlap) than condition in 2013 through 2015 (Figure 3-31).

A total of 52 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 3-32).

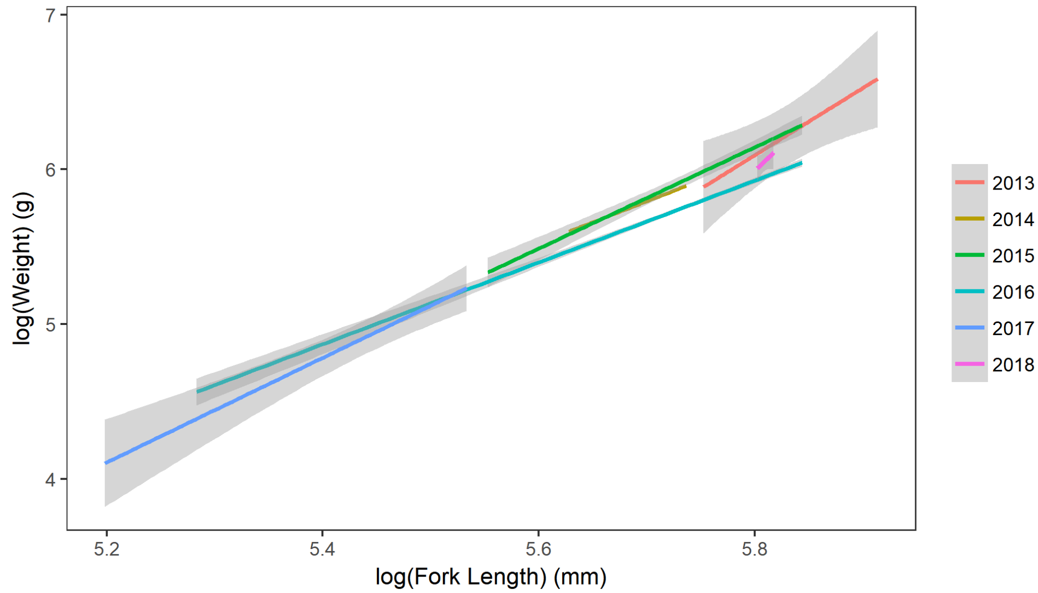

Figure 3-30 Logarithmic length-weight relationships for kokanee in 2013 through 2018. Shaded grey area represents linear model 95% confidence interval.

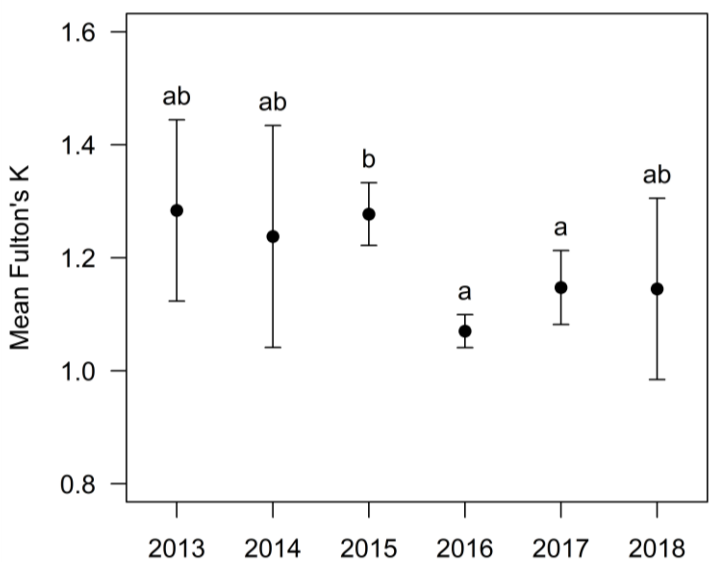

Figure 3-31 Mean annual condition factor (with 95% CI) for kokanee in Carpenter Reservoir. Means with the same significance letter are statistically equal.

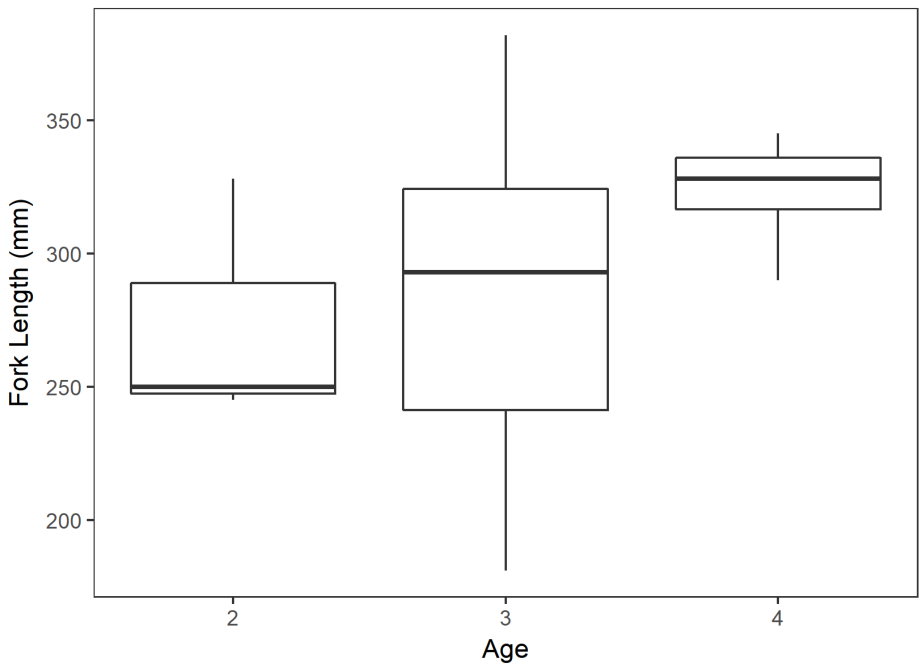

Figure 3-32 Boxplots of fork length (mm) for each age class of kokanee observed in Carpenter Reservoir.

3.7 Tributary Surveys in the Carpenter Reservoir Watershed

3.7.1 Kokanee spawner assessments

In 2018, kokanee were observed from August 16 to September 6, with counts peaking on August 23 in Truax Creek and August 30 in Marshall Creek (Figure 3-33). The highest spawner counts were observed in Truax and Marshall Creeks, with very few kokanee being observed in any other tributary. No kokanee were observed in Sucker Creek, likely because a high flow event washed out a spawning area present at the tributary outflow (almost all kokanee observed in Sucker Creek since 2014 had been observed in this area). 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 3-34). Combined spawner counts in 2018 were the lowest on record from 2014 to 2018, but were similar to counts in 2016 (Figure 3-34).

We measured the amount of potential spawning habitat below the drawdown zone boundary that became flooded with increasing reservoir elevation in Girl Creek, Marshall Creek, and Truax Creek. In Marshall Creek, the length of the creek in the drawdown zone decreased by 81 m from the start of kokanee spawning to maximum reservoir elevation, while in Girl Creek it decreased by 60 m (Figure 3-35). Due to the steep gradient of Carpenter Reservoir tributaries, the amount of habitat lost with elevation increase is quite substantial; however, the quality of the habitat in the drawdown zone is low relative to the habitat above the maximum reservoir elevation (Appendix B), and we would not expect kokanee to spawn in high numbers within the drawdown zone. The percentage of kokanee sighted within the drawdown area of the reservoir was 2% in Marshall Creek and 13% in Truax Creek. In Macdonald Creek, Girl Creek, and Sucker Creek, spawner counts were too low (<10 fish) to compare within and above the maximum elevation boundary.

Mean daily temperature at the onset of the kokanee spawning migration (August 16, 2018) was 8.7°C in Marshall Creek, 13.0°C in Macdonald Creek, and 9.9°C in the Middle Bridge River. At peak count, water temperature was 8.0°C in Marshall Creek, 10.5°C in Macdonald Creek, and 9.6°C in the Middle Bridge River. Using a 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 from the 2017-2018 winter period (Figure 3-37; temperature data are not yet available for 2018-2019) and kokanee spawning dates from 2018. We also calculated the 50% hatch dates for the Middle Bridge River, where kokanee are known to spawn; however, migration timing in the Middle Bridge River is uncertain because kokanee cannot be observed due to high turbidity.

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 3-37). Macdonald Creek is also relatively warm compared to snowmelt-fed creeks, but its unregulated nature results in temperatures that are less stable and colder 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 June.

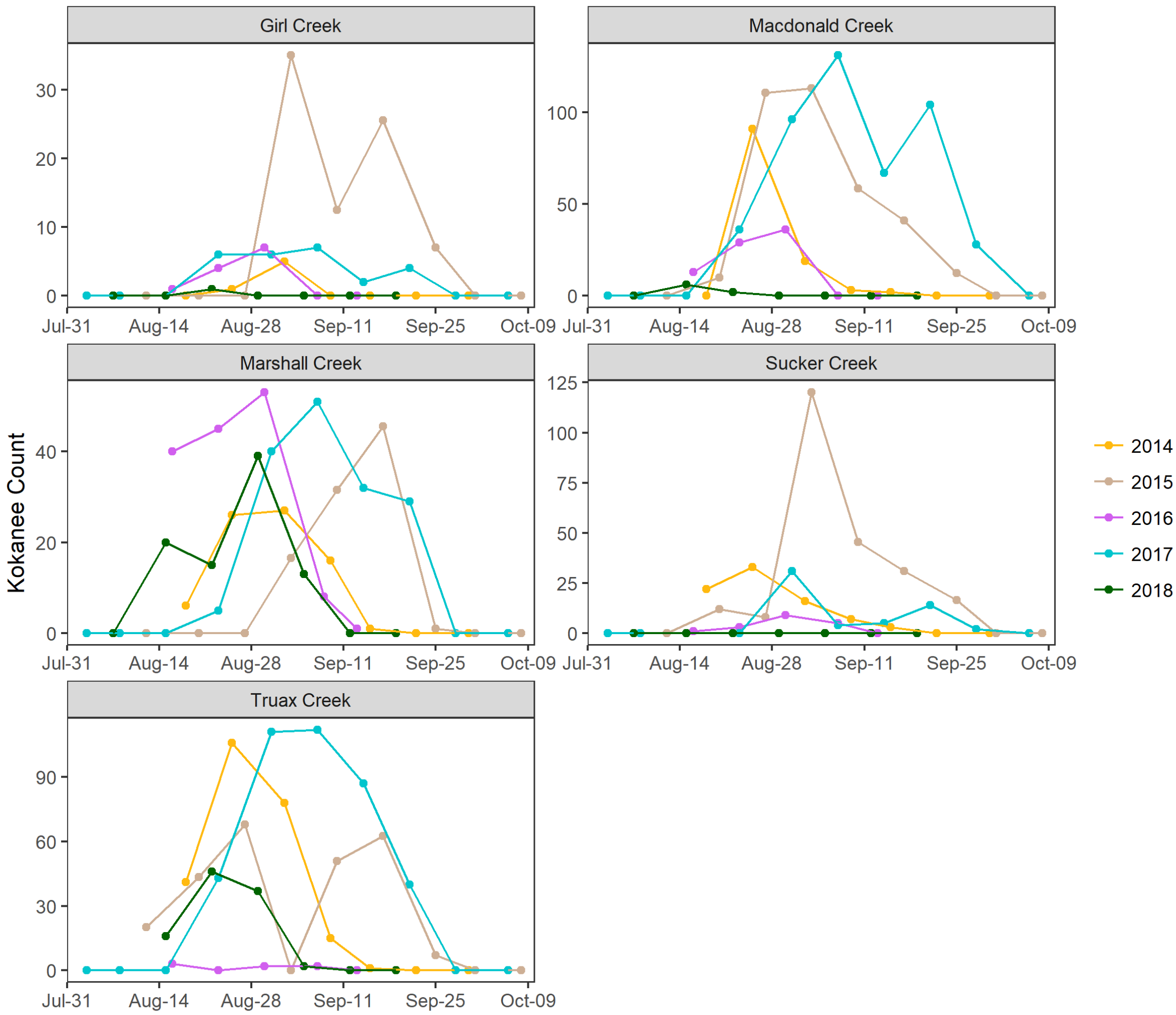

Figure 3-33 Tributary-specific kokanee spawner counts from visual surveys in 2014 through 2018.

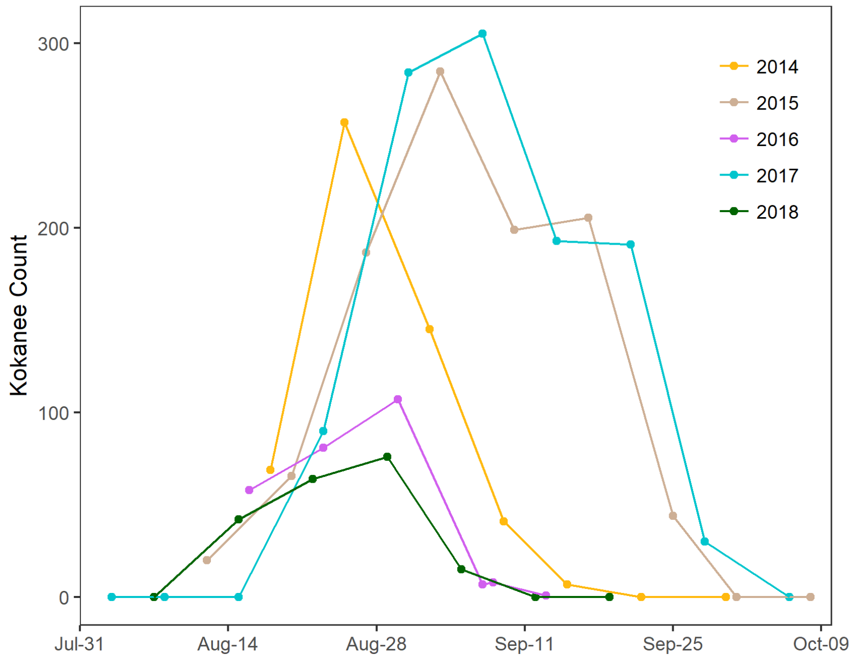

Figure 3-34 Counts of kokanee in Carpenter Reservoir tributaries (Truax, Girl, Macdonald, Sucker, and Marshall Creeks combined) in 2014 to 2018.

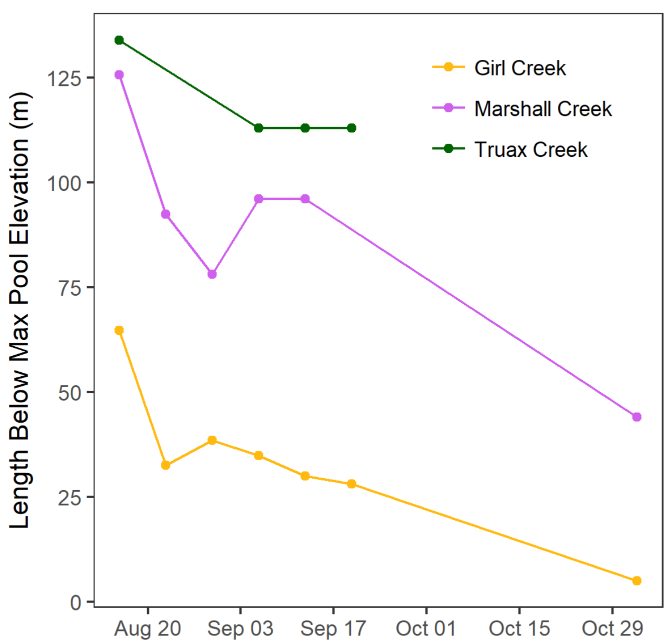

Figure 3-35 Stream-lengths within the drawdown zone of Carpenter Reservoir (i.e., below the maximum pool elevation boundary) through the kokanee spawning period. In Marshall

Creek and Girl Creek a final measurement was taken in early November at the 2018 maximum pool elevation.

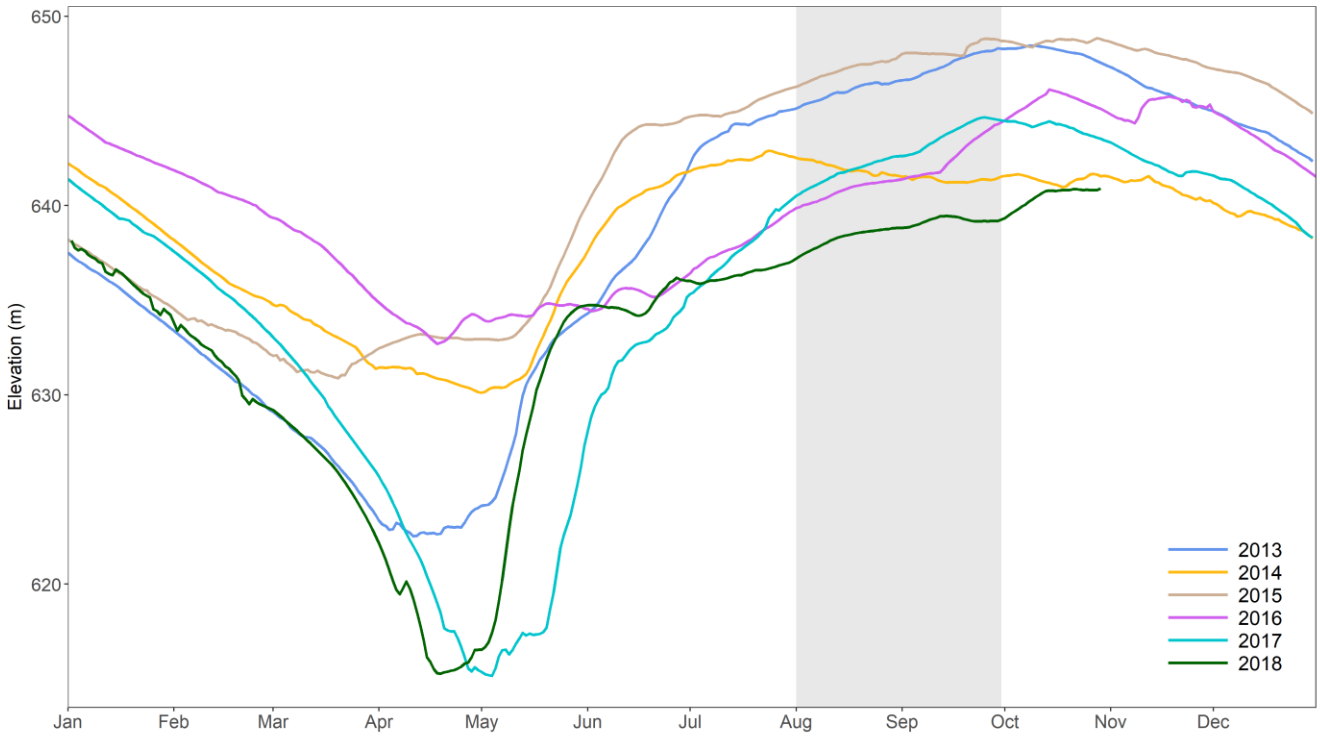

Figure 3-36 Carpenter Reservoir elevation (2013 through 2018) during the approximate kokanee spawning window (August 1 to September 31; shaded in grey) in the Carpenter Reservoir.

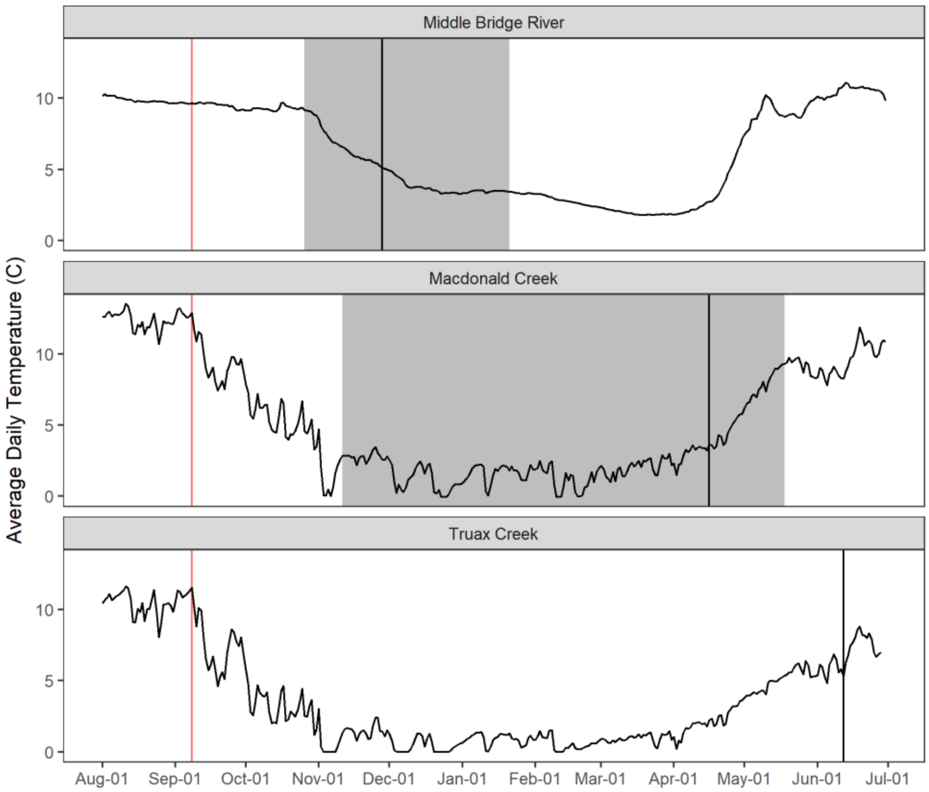

Figure 3-37 Kokanee peak 50% hatch date (black line) and estimated 50% hatch window (shaded grey area). Hatching dates were calculated using the peak kokanee migration date from 2018 (red line) and the maximum and minimum extent of the migration (not shown). The 50% hatch window for Truax Creek could not be calculated due to insufficient temperature data.

3.7.2 Tributary Electroshocking Assessment in Carpenter Reservoir Tributaries

We performed a third 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 Macdonald Creek, Marshall 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). In each electroshocking year we captured more Rainbow Trout above the maximum pool elevation (Figure 3-38), particularly in Marshall Creek and Macdonald Creek, where there is a tributary-resident Rainbow Trout population.

Table 3-13 Total catches by species during Carpenter Reservoir tributary electroshocking in Year 6.

Tributary	Bull Trout	Kokanee	Mountain Whitefish	Rainbow Trout	Sculpin
Macdonald	0	0	8	56	29
Marshall	1	0	0	81	1
Gun	9	0	2	10	14

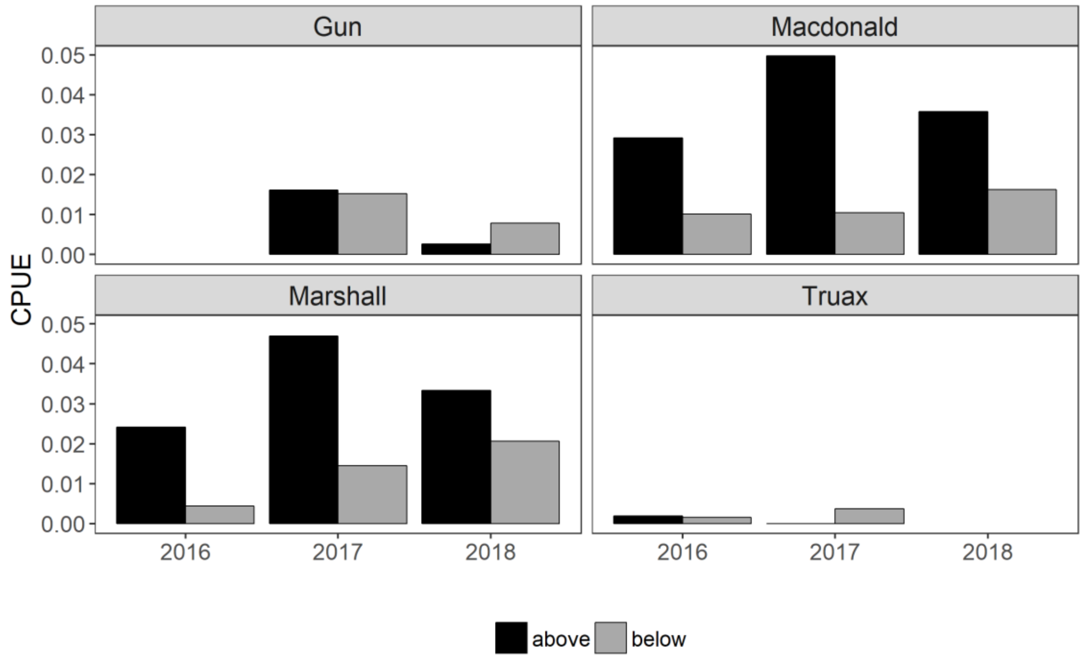

Figure 3-38 Annual captures of Rainbow Trout above and below the maximum elevation boundary in Gun (not sampled in 2016), Macdonald, Marshall, and Truax Creeks (not sampled in 2018).

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. We captured Rainbow Trout above the drawdown zone boundary in April through August and below the drawdown boundary in June through September. We captured primarily Rainbow Trout ages 1 through 4 until August, when we first observed the emergence of YOY Rainbow Trout (Figure 3-39). In 2016 and 2017, YOY Rainbow Trout were not observed in Macdonald Creek until September. In Macdonald Creek, age 4 and age 5 Rainbow Trout were only captured above the reservoir drawdown boundary, suggesting these fish are tributary residents.

We captured two Bull Trout in Macdonald Creek in 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 2017 or 2018 and it does not appear that Macdonald Creek is a Bull Trout spawning tributary. Mountain Whitefish (ages 0 to 3) were captured in all three years of tributary electroshocking, suggesting Mountain Whitefish may spawn in Macdonald Creek or upstream in the Middle Bridge River. In 2018 in Macdonald Creek we did not recapture any Rainbow Trout tagged in previous years, but one age 2 individual was captured on two separate occasions above the drawdown zone boundary.

Figure 3-39 Counts of Rainbow Trout captured in Macdonald Creek both above and below the drawdown zone boundary in 2016 through 2018 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. We captured Rainbow Trout both above and below the drawdown zone during almost every sampling occasion (Figure 3-40). Capture rates were relatively stable and higher above the drawdown zone relative to the drawdown zone 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). As in Macdonald Creek, YOY Rainbow Trout appeared in Marshall Creek in August, compared to September in previous years.

Rainbow Trout captured within the drawdown zone ranged from age-0 to age-6, while those caught above the drawdown zone ranged from age 0 to age 4. Adult Rainbow Trout of the same age were larger in the reservoir population relative to the resident population. We recaptured four Rainbow Trout above the waterfall that had been tagged in previous years and two Rainbow Trout were captured on two separate occasions in 2018. One recaptured fish was tagged in September of 2016 and recaptured in April of 2018, and on both occasions was assessed as age 2 (grew 8 mm). Another recaptured fish was tagged in the summer of 2017 and recaptured in the spring of 2018, and on both occasions was assessed at age 1 (grew 6 mm). The small increase in fork length and deposition of growth rings of these recaptures highlights the low growth rates of Rainbow Trout in Carpenter Reservoir tributaries, particularly during cool winter periods.

We captured a small number of Bull Trout below the drawdown zone boundary in all years, including an age 2 Bull Trout in September of 2018. 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.

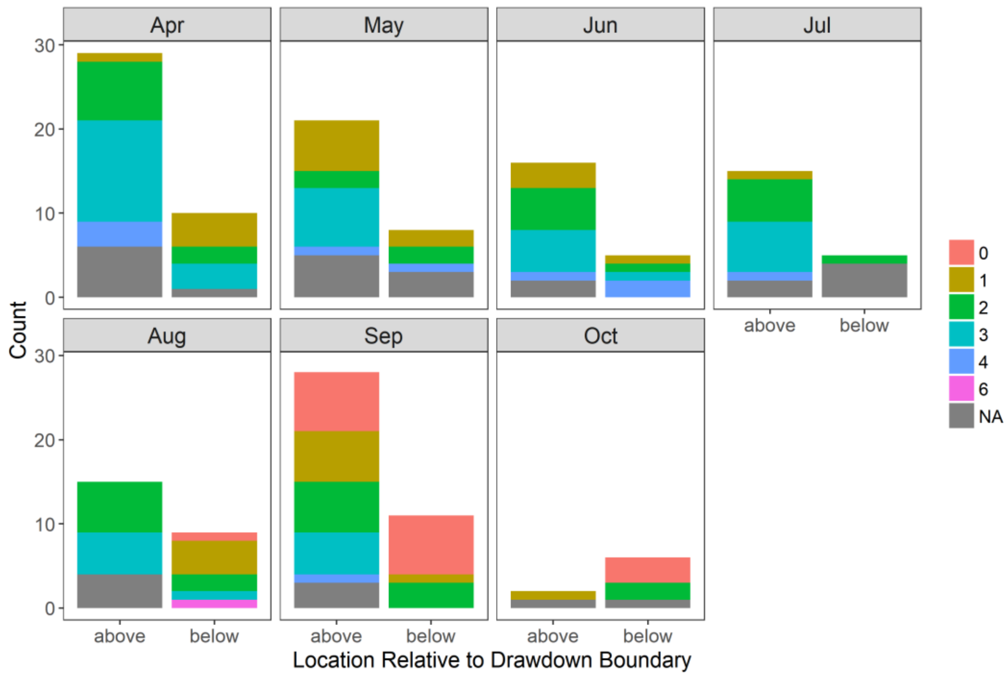

Figure 3-40 Counts of Rainbow Trout captured in Marshall Creek both above and below the drawdown zone boundary in 2016 through 2018 combined. Colors represent scale ages.

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 (data not shown), which may be due to similar habitat characteristics between the two zones. Rainbow Trout catch rates were lower in 2018 relative to 2017. We captured a YOY Rainbow Trout in September of 2017 and in August and October in 2018, 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 of 2016 with a length of 155 mm (likely age-1 or age-2), and one age 0 Bull Trout (80 mm) in 2018, 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.

3.7.2.1 Rainbow Trout Growth

We compiled length and age data from tributary electroshocking in 2016 through 2018 to examine juvenile Rainbow Trout growth (Figure 3-41). 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. Pooling data from all years, 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). For age 1 Rainbow Trout, sample sizes permitted us to examine the effect of year on the growth model (for all tributaries pooled); however, an ANOVA comparing the model with and without a year component suggested the addition of year was not a significant improvement to the results (p-value 0.05, DF 2, F 3.76).

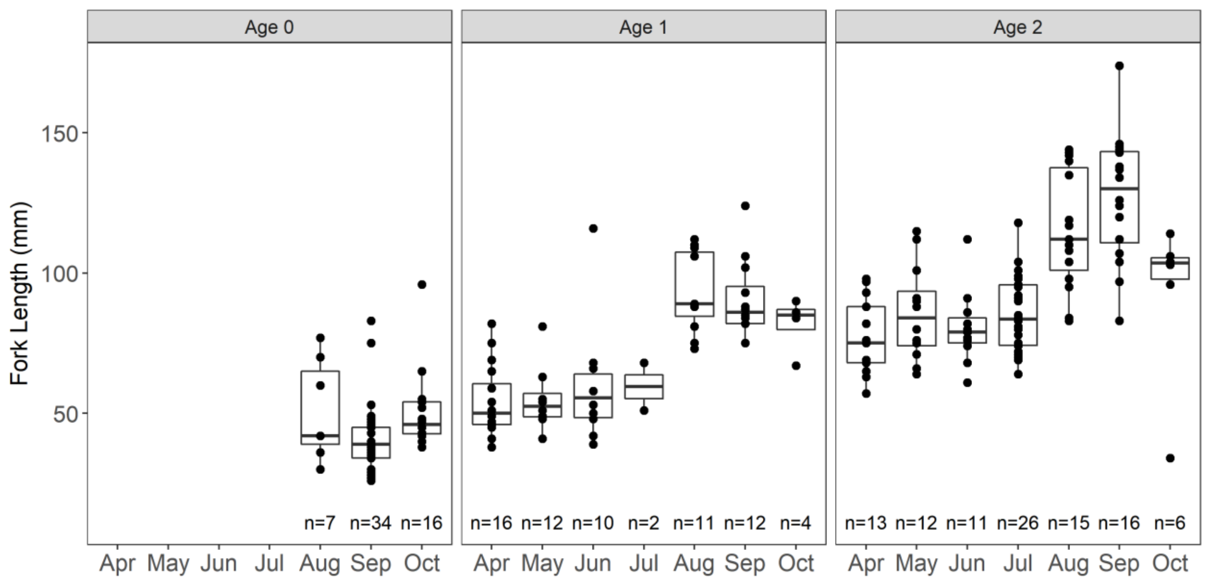

Figure 3-41 Length boxplots of age-0 to age-2 Rainbow Trout captured in Macdonald, Marshall, Truax, and Gun Creeks during 2016 to 2018 tributary electroshocking.

3.7.2.2 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 and peak in mid-June, and we first observe emerging YOY in August in most tributaries. Tributary electroshocking results indicate successful Rainbow Trout spawning in Marshall, Macdonald, Gun, and Truax Creek (there is likely additional spawning in tributaries not electroshocked). According to tributary temperature data collected in 2018, the average daily temperatures at peak migration (June 18, 2018) were 8.8°C in Truax Creek, 9.4°C in Gun Creek, 9.5°C in Marshall Creek, and 11.9°C in Macdonald Creek.

Rainbow Trout visual spawner surveys (in 2014 through 2016) were relatively unsuccessful due to low spawner counts, 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 2018 for Gun, Marshall, and Macdonald Creeks (Figure 3-42). Hatch timing was relatively similar between the three tributaries, primarily due to the short ATU requirement of Rainbow Trout.

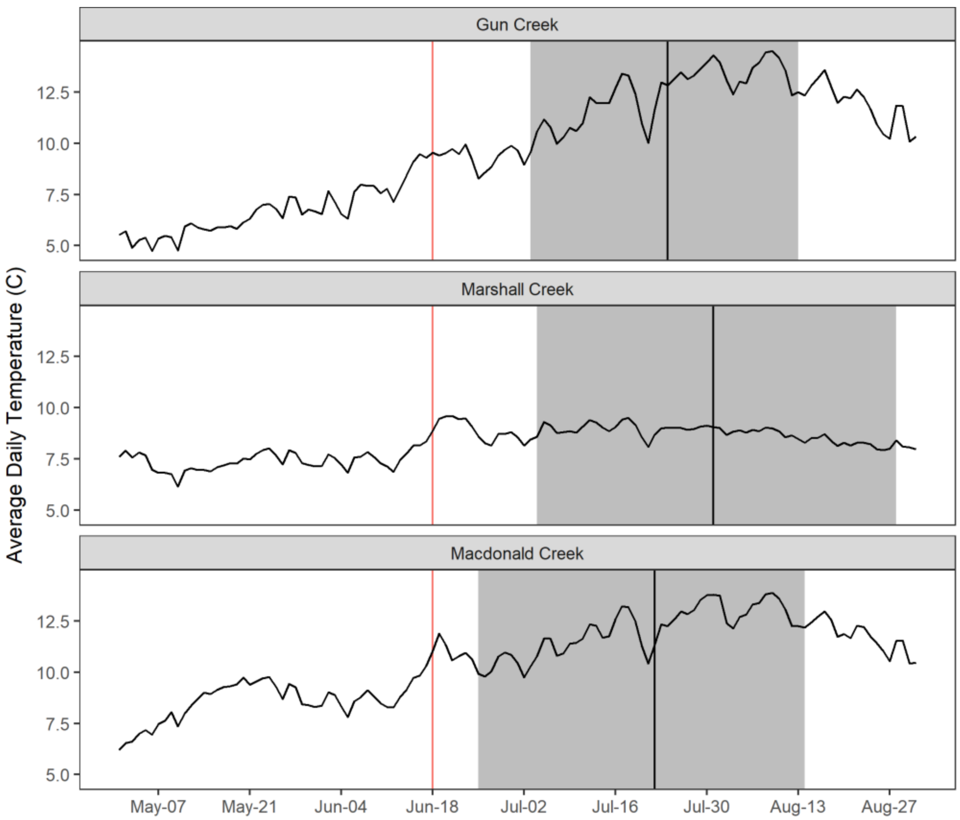

Figure 3-42 Rainbow Trout peak 50% hatch date (black line) and estimated 50% hatch window (shaded grey area). Hatching dates were calculated using the peak Rainbow Trout migration date from 2016 (red line) and maximum and minimum extent of the migration (May 15-July 15; not shown).

4 Discussion

The primary objectives of BRGMON-4 are to collect information on the life history, biological characteristics, abundance, and composition of the fish community in Carpenter Reservoir and the Middle Bridge River, and assess the effects of reservoir operations on these fish populations. Data collected in 2018 of the 10-year monitoring program builds on data and understanding gained in 2012 through 2017 and helps to direct monitoring in future years.

4.1 Carpenter Reservoir Operating Parameters

Operating parameters in Carpenter Reservoir were variable from 2012 to 2018, particularly in regard to minimum and maximum elevation, and the rate of reservoir filling in the spring. In 2017 and 2018, minimum elevation was low relative to 2012 through 2016. Despite similar minimum elevations, reservoir conditions were quite different between 2017 and 2018. In 2017, the reservoir remained at minimum elevations for an extended time period, and in 2018, elevation during summer months was the lowest observed during BRGMON-4.

We focus on two time periods to examine the effect of reservoir elevation on fish in Carpenter Reservoir: the beginning of April, and July through October. Modelling results from BRGMON-10 suggest that reservoir elevation at the beginning of April is a determining factor of productivity during the reservoir growing season. In years with low elevation in April, reservoir productivity is likely to be lower due to a more turbid surface layer that becomes isolated during thermal stratification. Elevations in July through October provide an indication of habitat quantity and quality in the reservoir. Low summer elevations reduce habitat volume in two ways: first, the physical volume of the reservoir (depth, length, and width) is lower, and second, the number of large, cool tributaries that flow directly into the reservoir is reduced (thereby eliminating clear cool confluences with optimal Bull Trout habitat and foraging conditions). According to these two indicators, habitat conditions in Carpenter Reservoir were poor in 2018 relative to previous years. Elevations in early April and during the summer were relatively low, suggesting potentially low growing season-productivity and habitat quantity and quality for fish in the reservoir. The implications of these effects are discussed below in the context of the management questions.

4.2 BRGMON-4 Management Questions

4.2.1 Management Question 1: What are the basic biological characteristics of parameters of fish populations in Carpenter Reservoir and Middle Bridge River?

The Carpenter Reservoir fish community consists of Bull Trout, Rainbow Trout, Mountain Whitefish, kokanee, Redside Shiner, Bridgelip Sucker, and Coastrange Sculpin. Bull Trout is the dominant predator in the reservoir and likely the main piscivorous fish. Large Rainbow Trout sometimes consume small fish; however, given the small size of Rainbow Trout in Carpenter Reservoir (generally <400 mm) and the relatively low density of juvenile fish and minnows, Rainbow Trout likely subsist primary on insects and crustacea such as daphnia. Catch data from BRGMON-4 suggest Carpenter Reservoir is currently dominated by Bull Trout and Mountain Whitefish. This is not surprising given that Kokanee and Rainbow Trout rely heavily on lacustrine habitat, which is small and inconsistent in Carpenter Reservoir due to elevation fluctuations. In contrast, Bull Trout and Mountain Whitefish are generally more adaptable to riverine conditions and are less constricted at low reservoir elevations, which allow them to dominate the fish community in Carpenter Reservoir.

Fish distribution and habitat use varies in Carpenter Reservoir according to season and the habitat available as a result of reservoir elevation. In the summer at full pool (i.e., when Carpenter

Reservoir most resembles a lake ecosystem), kokanee and Rainbow Trout inhabit the thermally-stratified, lacustrine portion of the reservoir proximate to Terzaghi Dam. This portion of the reservoir offers thermal refuge from warm surface waters and has higher densities of zooplankton prey relative to eastern areas (Limnotek 2018). At full pool, Bull Trout and Mountain Whitefish can be found throughout the margins of the reservoir, but generally congregate at large, cool tributary inflows, many of which are near the western boundary of the reservoir. CPUE data and Bull Trout movement data (from acoustic tagging) suggest Bull Trout distributions shift westward in the reservoir as elevations increase in early summer and western habitats become more available.

Kokanee spawn in Carpenter Reservoir tributaries in August and September, and immature individuals rear in the eastern lacustrine habitat in the winter. At low pool in the spring, kokanee become constricted within lacustrine habitat proximate to Terzaghi Dam and generally do not utilize more western riverine habitat. In contrast, Rainbow Trout are more distributed throughout the reservoir in the spring as they migrate towards tributaries in preparation of spawning. This correlation between minimum elevation and spawning timing suggests Rainbow Trout may be less vulnerable to reduced lacustrine habitat at extreme drawdowns. In contrast to kokanee and Rainbow Trout, Bull Trout and Mountain Whitefish do not rely on lacustrine habitat and are distributed throughout the reservoir and the Middle Bridge River at minimum pool in the spring. Despite their broader habitat preferences, Bull Trout and Mountain Whitefish are still vulnerable to extreme reservoir drawdowns. Habitat in the drawdown region of the reservoir is of relatively poor quality as it is highly turbid, has virtually no cover or shoreline vegetation, and offers limited foraging opportunities. Bull Trout may also be indirectly affected by extreme drawdowns if they result in a decrease in abundance or condition of prey species (i.e., juvenile Rainbow Trout and kokanee and Redside Shiners).

Productivity and predator-prey interactions in Carpenter Reservoir likely affect the size distributions of fish in the reservoir. Carpenter Reservoir is classified as an oligotrophic water body with relatively low productivity (Limnotek 2018). The Bull Trout community in Carpenter Reservoir is characterized by large numbers of mid-sized fish (~300-400 mm in length), with relatively few large, older individuals (>400 mm). This Bull Trout size distribution is likely related to low productivity and corresponding low prey densities in the reservoir. Rainbow Trout in the reservoir are also generally small, which may be related to low reservoir productivity and cooler rearing conditions in tributaries. Rainbow Trout spawning tributaries are cold and peak spawning occurs later in the year relative to typical spawn timings for Rainbow Trout (McPhail 2007). Scale ageing data from Carpenter Reservoir tributaries suggest that juvenile Rainbow Trout undergo almost negligible growth during the winter of their first year. In addition, tributary electroshocking data indicates Rainbow Trout may rear for multiple years in the tributaries (as opposed to leaving following their first winter), which would further reduce juvenile growth rates and decrease the mean size-at-maturity of Rainbow Trout in Carpenter Reservoir.

Length, weight, and age data have been collected annually to develop age-length-keys and growth models for Bull Trout, Rainbow Trout, Mountain Whitefish, and kokanee. ALKs and von Bertalanffy growth models have successfully been developed for Bull Trout and Mountain Whitefish, which can be compared to models from other systems, and to growth models that may be developed for

Carpenter Reservoir under potential future monitoring programs. For example, we estimated that the asymptotic length of Bull Trout in Carpenter Reservoir is 605 mm, while in Seton Lake asymptotic length was estimated to be 695 mm (Burnett and Parkinson 2018), suggesting growth is slower in Carpenter Reservoir relative to Seton Lake. Insufficient data are available to model kokanee length and age, and almost all kokanee captures consist of mature individuals captured at tributary confluences prior to spawning migrations. Pre-spawning fork lengths provide an indication of the size-at-maturity of kokanee in Carpenter Reservoir, which can be compared to other systems or future monitoring programs in lieu of growth models.

Carpenter Reservoir Rainbow Trout age and growth modelling was challenging due to the unique growth characteristics of Rainbow Trout in rearing tributaries and in the reservoir. Rainbow Trout undergo almost no growth during their first winter due to the cold temperatures in rearing tributaries (i.e., often approaching zero for extended periods during the winter). Typically, Rainbow Trout migrate to rear in lake ecosystems after one winter (McPhail 2007); however, Rainbow Trout may rear in Carpenter Reservoir tributaries for multiple years before migrating to the reservoir. Rainbow Trout scales are difficult to age due to slow growth rates during tributary rearing; growth rings are very close together and winter growth is almost indistinguishable from summer growth. Once Rainbow Trout migrate to the warmer reservoir habitat their growth rate increases; however, this period of rapid growth occurs at different ages in Carpenter Reservoir depending on how many years the individual reared in the tributary environment. Because Rainbow Trout migrate to the reservoir at different ages, there is substantial overlap in fork length distributions for mid-aged Rainbow Trout. This overlap combined with low captures of large Rainbow Trout make it difficult to model growth rates in the reservoir, and particularly to determine the asymptotic (or theoretical maximum) fork length of Carpenter Reservoir Rainbow Trout.

4.2.2 Management Question 2: Will the selected alternative result in positive, negative, or neutral impact on abundance and diversity of fish populations?

The WUP alternative, N2-2P, did not prioritize management of Carpenter Reservoir or Lajoie Dam (BC Hydro 2011), and constraints on minimum and maximum reservoir elevation remained at 606.6 m and 651.1 m, respectively. N2-2P was followed to 2015, then in 2016 modified operations were implemented to address safety risks at Lajoie Dam. Although modified operations did not change the constraints on Carpenter Reservoir elevation, reservoir elevations were affected due to changes in constrains on Downton Reservoir elevation. It is challenging to determine whether N2-2P affected fish populations in Carpenter Reservoir because of the highly variable nature of elevations in the reservoir and because of a lack of consistent historic fish population data. Elevation constraints are very broad for the reservoir, and Carpenter Reservoir has been operating within the WUP targets since the mid 1980s. Elevations in the reservoir vary due to management priorities in other areas of the system, and due to natural environmental fluctuations (e.g., annual freshet conditions). These sources of variation are difficult to separate, and combined with the lag time between operational decisions and population-level effects, make it challenging to determine how reservoir management affects fish populations.

A substantial barrier towards determining the effect of N2-2P on Carpenter Reservoir fish populations is the lack of consistent pre-WUP data. Several historic studies (generally consisting of one year or one sampling event) provide insight into the status of fish populations prior to the alternative (e.g., shoreline electroshocking, gill netting, spawning surveys, and hydroacoustic surveys; see Section 1.2). The short duration of historic surveys and the highly variable nature of reservoir elevations before and after N2-2P suggest historic surveys are not an accurate representation of average conditions prior to N2-2P, and cannot be compared to post-WUP data collected during BRGMON-4.

Variable reservoir elevations may impact fish behaviour, fish condition and habitat availability. Therefore, to assess potential impacts of N2-2P on fish populations, we performed a preliminary examination into historic Carpenter Reservoir elevations. In the 1980s the reservoir was operated closer to the minimum and maximum elevation constraints than in future years, and summer maximums have generally declined across the historic record. These trends are preliminary and reservoir elevations have been highly variable throughout the historic record (i.e., there are no clear management regime changes). When comparing reservoir parameters between pre- and post-WUP periods (i.e., 2002-2011 vs 2012-2018), we observed a general trend towards higher average elevation in the first two weeks of April and lower mean summer elevation in the post-WUP period relative to the pre-WUP period. These preliminary observations suggest that although N2-2P did not specify a new operating regime for Carpenter Reservoir, the WUP alternative and the high flow modifications have resulted in a different operation regime relative to the pre-WUP period.

4.2.3 Management Question 3: Which are the key operating parameters that contribute to reduced or improved productivity of fish populations in Carpenter Reservoir and Middle Bridge River?

The effects of operating parameters on fish productivity in Carpenter Reservoir and the Middle Bridge River is difficult to determine due to the size of Carpenter Reservoir, the large degree of variation in reservoir elevation, and the lag time between reservoir elevations and population-level effects to fish. Despite these constraints, preliminary data and insights from BRGMON-4 suggest fish populations in the reservoir may be affected by minimum and maximum reservoir elevation, and the timing and extent of reservoir filling and drawdown rates.

Low summer elevations in 2016 through 2018 may be affecting the condition, relative abundance, and distribution of Carpenter Reservoir Bull Trout. Bull Trout are adaptable to both reservoir and river conditions; however, their preferred habitat becomes constricted in Carpenter Reservoir in the summer, and this constriction is exacerbated by low summer elevations. During the summer, Carpenter Reservoir Bull Trout appear to prefer tributary confluences throughout the reservoir, which are productive inflows into the reservoir and provide thermal refuge from high summer water temperatures. In the shallow western portions of the reservoir, where thermal stratification does not occur, these thermal refugia are particularly important. Historic evidence (Chamberlain et al 2001) and acoustic data suggest Bull Trout move towards western reaches of the reservoir as elevations increase, likely taking advantage of tributary confluences and cool inflows from the Middle Bridge River. When summer elevations are low, access to many large tributaries (e.g., Truax

Creek, Gun Creek, Tyaughton Creek) is restricted, which compounds the overall decrease in habitat that occurs when the reservoir is at a lower volume. Low summer elevations lead to reduced habitat availability and increased competition between adult Bull Trout.

BRGMON-4 data provide some evidence that the low summer elevations and low minimum spring elevations have resulted in population-level changes to Carpenter Reservoir Bull Trout. In 2016, the first year with low summer elevations, there was a decline in Rainbow Trout and Mountain Whitefish condition (i.e., forage species). We did not see a corresponding decline in condition for Bull Trout in 2016, but in 2017 there was a decline in condition of Bull Trout aged 3 to 6 (an important age for growth). In 2018, summer reservoir levels remained low, but conditions of Bull Trout, Rainbow Trout and Mountain Whitefish increased to some degree. Although this change in condition may provide evidence of elevation-related population effects, condition factor may not fully reflect changes to fish health and overall body composition. Although Fulton's condition factor is effective at non-lethally evaluating coarse condition efficiently, it may not reflect the complex changes to food webs that can occur with habitat alterations (Blackwell et al. 2000). These results are preliminary, but weight of evidence suggests that habitat contraction in Carpenter Reservoir may have resulted in poor conditions for Bull Trout, and a decrease in the condition and subsequent decrease in numbers of mid-sized individuals.

Low summer and early fall elevations in the reservoir also appear to be restricting Bull Trout movements into and out of the Middle Bridge River. Since the acoustic program began in 2015, we have seen preliminary evidence of a decline in the number of Bull Trout that migrate into the Middle Bridge River in the late summer of each year and an increase in the number of movements observed at the mid-reservoir acoustic gate. In 2015 and 2016, Bull Trout were detected making potential spawning migrations into the Middle Bridge River in July and August, but in 2017 this movement pattern was absent (Bull Trout were not detected moving into the Middle Bridge River until September, suggesting possible predation behaviour as opposed to spawning behaviour). When elevations are low, the western portion of the reservoir is highly turbid and fast flowing, and provides poor habitat for Bull Trout and their prey species. Due to poor habitat conditions and/or a general decline in body condition, of the Bull Trout may be avoiding spawning migrations into the Middle Bridge River and instead spawning in Carpenter Reservoir tributaries (with limited spawning sites; Griffith 1999), or forgoing spawning until conditions improve. Although these data are preliminary, this scenario would lead to a decline in the Bull Trout population in future years.

Condition of Rainbow Trout in Carpenter Reservoir was lower in 2016 through 2018 relative to 2013 through 2015, and in 2018 there was a sharp decline in the number of Rainbow Trout captured during the Bull Trout mark recapture program. As with Bull Trout, declining Rainbow Trout condition and numbers may be related to the decline in overall habitat volume in Carpenter Reservoir, particularly in 2017 and 2018. A similar pattern occurred with Mountain Whitefish, but condition of Mountain Whitefish was statistically higher in 2018 than in any other year of BRGMON-4. Increasing condition coupled with decreasing indices of abundance may indicate density-dependent processes are occurring in the reservoir. As abundances decline, the remaining population may have access to higher quality and quantity of food and habitat, resulting in an increase in their health and condition. Condition and relative abundance data for fish species in

Carpenter Reservoir highlight the complex nature of the ecosystem and the challenges inherent in determining how reservoir operations affect fish populations. Although there are multiple interactions between species and years that are difficult to account for, the weight-of-evidence suggests that reservoir conditions in recent years have been relatively poor for many fish species, resulting in some degree of decreasing body condition, constricted movement patterns, and declining indices of abundance for fish species.

The effect of reservoir operations on kokanee is more difficult to interpret than for other species because BRGMON-4 sampling methods and timing do not target kokanee. The primary index of kokanee abundance is spawner counts performed in August and September of each year, which have been highly variable among years and tributaries since 2014. Kokanee rely heavily on lacustrine habitat for most of their lifespan, and we would expect that years with low minimum and maximum reservoir elevation would contract kokanee habitat and negatively affect kokanee populations. For example, low minimum elevations (<610 m) in Carpenter Reservoir in the mid-1990s resulted in the near extinction of the Carpenter Reservoir kokanee population (Griffith 1999). Despite low minimum reservoir elevations in 2017 and 2018 and entrainment of kokanee through the Terzaghi Dam in 2016 and 2017, kokanee counts did not consistently decline in 2016 through 2018. We may see a delayed effect of sub-optimal conditions in future cohorts mature and migrate to monitored spawning tributaries (e.g., 81% of kokanee entrained in 2016 [for which lengths could be determined] were estimated to be age 1+ or 2+; McHugh et al. 2017). Alternatively, the limited scope of kokanee sampling in this monitor may not represent an accurate indication of the overall population in the reservoir. Given the contraction of lacustrine habitat and the decline in kokanee observed in the 1990s, kokanee abundance will likely decline with continued low minimum elevations.

Kokanee spawner surveys and observations of redds and paired kokanee suggest that kokanee rarely spawn within the drawdown zone of Carpenter Reservoir tributaries, and the risk of redd inundation is therefore low. Qualitative habitat surveys performed in 2016 support this finding as habitat within the drawdown zone is generally highly braided and shallow and has little to no riparian cover (Appendix B). Although the risk of redd inundation is low, poor habitat conditions within the drawdown zone may still affect kokanee spawning success as kokanee must migrate through the drawdown zone to reach upstream spawning habitats. Shallow braided tributaries require more energy for migration, and a lack of cover increases the predation risk for migrating kokanee. These risks are exacerbated when reservoir elevations are low during the kokanee spawning period and the drawdown zone is longer. Kokanee spawning also occurs in the Middle Bridge River, and access to the Middle Bridge River remains unrestricted regardless of reservoir elevation. Poor spawning conditions in Carpenter Reservoir tributaries may shift kokanee spawner distributions into the Middle Bridge River; however, the quality of spawning habitat in the Middle Bridge River is unknown (we are currently unable to monitor kokanee spawning in the Middle Bridge River due to low visibility),

4.2.4 Management Question 4: Is there a relationship between specific characteristics of the in-stream flow in the Middle Bridge River that contribute to reduced or improved productivity of fish populations in Carpenter Reservoir and the Middle Bridge River?

There are limited opportunities to monitor fish in the Middle Bridge River due to high turbidity in the river throughout the year. Also, the effect of conditions in the Middle Bridge River and in Carpenter Reservoir are confounded as most species spend at least part of their life cycle in both habitats. Due to the difficulties in monitoring in the Middle Bridge River, the effect of operations at Lajoie Dam are primarily captured relating to how they affect elevations in Carpenter Reservoir (Management Question 3), and how conditions in the Middle Bridge River affects spawning and incubation.

Spawning Mountain Whitefish have been monitored in the Middle Bridge River via spawner angling surveys in several years beginning in 2009 (Tisdale 2010, Putt et al. 2018). Spawn timing and hatch calculations suggest Mountain Whitefish spawn in the Middle Bridge River in mid- to late-November and hatch in early February. Middle Bridge River stage heights are relatively stable over this period and there are generally few rampdowns at Lajoie Dam. Tisdale and BRGMON-4 both concluded that the direct risk to egg dewatering from Lajoie Dam operations is low. Kokanee spawn in the Middle Bridge River in September and hatch in early December, and the risk of dewatering kokanee redds due to Lajoie Dam operations is also likely low.

Despite the low risk of population-level effects from egg or redd dewatering in the Middle Bridge River, operations at Lajoie Dam have the potential to impact fish in the river and in Carpenter Reservoir. Winter water temperatures are more stable and elevated in the Middle Bridge River, resulting in faster hatch dates, particularly for kokanee. Earlier emergence could expose alevin to different flow rates and food sources relative to those emerging later in the tributaries. In addition to temperature-related effects, management of Lajoie Dam affects the amount of turbidity in the Middle Bridge River and the amount of fine particulate matter in Middle Bridge River substrate. Regulated flow regimes (with infrequent high flow events) result in armouring of substrates (i.e., interstitial spaces become filled with particulate), and may affect spawning success of fish species that spawn there (Meibner et al 2018). We observed armoured substrate and sandy substrate in many areas of the Middle Bridge River during Mountain Whitefish egg mat surveys in 2013 and 2016. Mountain Whitefish are broadcast spawners and rely on eggs settling into interstitial spaces. In armoured substrate like in the Middle Bridge River, fewer eggs may successfully settle into the substrate and incubate. Similarly, fish that dig redds, such as kokanee, may be challenged to dig redds in the armoured substrate, resulting in fewer spawning events, shallower redds, and decreased spawning success (Sear 1993).

4.2.5 Management Question 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?

Management Question 5 will be answered using insights from answers to Management Questions 1 through 4. Preliminary evidence suggests that low summer elevations and low early spring elevations may result in decreased reservoir productivity and overall habitat volume, which may be detrimental to fish populations in Carpenter Reservoir. Increasing reservoir elevations in the early spring (to promote increased reservoir productivity) and in the summer (to increase overall habitat volume and access to large tributary inflows) may therefore improve habitat conditions and productivity of fish populations. A greater understanding of Management Questions 1 through 4 through continued monitoring will help to determine whether operation of Carpenter Reservoir and Lajoie Dam can be adjusted to improve fish populations in the reservoir and in the river.

4.2.6 Conclusions and Recommendations

Data collected from during BRGMON-4 suggest fish populations in Carpenter Reservoir and the Middle Bridge River are affected by operation of the Bridge River power system. We recommend continued monitoring in 2019 to build upon data collected in years 1 through 6 and answer the five management questions using a weight of evidence approach. Monitoring in 2019 will consist of acoustic monitoring of adult Bull Trout, Bull Trout abundance estimation via mark-recapture sampling, collection of length, weight, and age data for Bull Trout, Rainbow Trout, kokanee, and Mountain Whitefish, and kokanee spawning surveys. We recommend expanding kokanee spawning surveys by marking the locations of observed spawning and/or redds, and performing peak counts on additional spawning tributaries throughout the reservoir.

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Appendix A

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

Author(s)	Sampling Period	Description	Notes and Primary Findings	Reference
Griffith, R.P.	1995-1996	- Inventoried fish and fish habitat in tributaries (25 locations) - Gill netted on 4 occasions, primarily near the diversion tunnels - Monitored limnology in the reservoir	- Spawning habitat area was limited by accessible stream length, availability of spawning substrate, and lack of cover - Concluded the standing stock of fish in tributaries was below theoretical juvenile rearing capacity - High gill net catches were obtained for Bull Trout and Rainbow Trout relative to other regional lakes but lower kokanee density relative to 1993 - Water residence time is low in the reservoir, likely resulting in relatively low abundance of phytoplankton and zooplankton	Griffith, R.P. 1999. Assessment of fish habitat and production in Carpenter Lake Reservoir relative to hydroelectric operations. Prepared for B.C. Hydro, Kamloops BC. 216 p.
Tisdale, G.A.E.	1999	- Rainbow Trout spawning assessment in 17 tributaries (based tributaries on those identified by Griffith 1999) - Performed stream walks, assessed migration barriers, and monitored temperature and turbidity	- Spawning Rainbow Trout were observed in 6 tributaries - Peak spawning occurred from June 11 to July 23, 1999 - A total of 125 Rainbow Trout were observed, 75% of which were in Marshall Creek (may be an important spawning location).	Tisdale, G.A.E. 2000. 1999 Carpenter Lake Reservoir Rainbow Trout Spawning Assessment (Onorhynchus mykiss). Prepared for B.C. Hydro and Power Authority, Kamploops, B.C. 45 p.
Unknown	2000	- Performed 92 cross-sectional acoustic transects in September of 2000 at a water surface elevation of 645 masl	- Analysed number of fish per transect and depth of fish - Concluded that more fish were present in the Eastern portion of the reservoir - Did not verify species during transects, so no abundances were estimated	Unpublished
Chamberlain, M.W. et al	2000-2001	- Used radio telemetry to track movements of Bull Trout in the Middle Bridge River and the reservoir - Quantified the effects of an experimental drawdown of the Middle Bridge River on	- Described Bull Trout movement (small sample size) - Monitored Middle Bridge River ramp-down in late July/early August - Increased stranding risk occurred but spawning	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.

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

Appendix B

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

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