Bridge River Project Water Use Plan

Carpenter Reservoir and Middle Bridge River Fish Habitat and Population Monitoring

Implementation Year 9

Reference: BRGMON-4

Study Period: October 2020 – September 2021

Annika Putt, Allison Hébert, Daniel Ramos-Espinoza, and Carson White

InStream Fisheries Research Inc.
215 – 2323 Boundary Road
Vancouver, BC
V5M 4V8

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Annika Putt*, Allison Hebert, Dani Ramos-Espinoza, and Carson White

Prepared for:

St’át’imc Eco-Resources
10 Scotchman Rd
PO Box 798
Lillooet, BC V0K 1V0

BC Hydro
6911 Southpoint Drive
Burnaby, BC V3N 4X8

Prepared by:

Instream Fisheries Research Inc.
1121A Enterprise Way
Squamish BC, V8B 0E8

*Corresponding author

October 6, 2022

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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 and Middle Bridge River discharges (i.e., BC Hydro operations) on fish populations. Monitoring in 2021 (Year 9 of the 10-year monitoring program) consisted of:

1. Bull Trout movement monitoring using acoustic telemetry and Passive Integrated Technology (PIT) tag recapture data;
2. adult Bull Trout abundance estimation via a three-week mark-recapture program consisting of boat-based electroshocking and angling throughout the reservoir;
3. collection of length, weight, and age data for Bull Trout, Rainbow Trout, kokanee, and Mountain Whitefish during mark-recapture sampling activities;
4. kokanee spawner enumeration surveys in Carpenter Reservoir tributaries and two sessions of overnight electrofishing to establish adult kokanee presence and absence;
5. tributary electroshocking to identify juvenile rearing habitat; and
6. monthly limnological sampling to compare growth conditions in the reservoir to those in 2015 and 2016.

BRGMON-4 answers 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 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 growth models for various species captured in Carpenter Reservoir and its tributaries. Preliminary results suggest fish species in Carpenter Reservoir grow slowly and reach lower maximum fork lengths relative to nearby systems, which is expected given relatively low reservoir productivity. We estimated Bull Trout abundance in Carpenter Reservoir (2016 through 2021) using Cormac-Jolly-Seber (CJS) mark-recapture modelling. Preliminary results suggest Bull Trout populations may have declined, with abundance estimates ranging from 2,778 (95% CI: 1,181-6,534) in 2016 to 316 (95% CI: 175-569) in 2019 (the 2021 estimate was 445; CI: 265-748). These biological metrics contribute to a comprehensive database describing Carpenter Reservoir fish species and can be

compared among regimes to determine how management affects fish species in the reservoir and Middle Bridge River (see MQ3).

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. We compared average elevations in the first two weeks of April (a proxy for growing season productivity and similar to the timing of minimum elevation) and summer elevations (representing habitat volume) among pre-N2-2P (2002-2011), N2-2P (2012-2015), and Modified Operations (2017-2021). Our results suggest spring elevations may have increased under N2-2P, while summer elevations remained virtually unchanged. Both have declined (or remained low for multiple years) under Modified Operations. This indicates Carpenter Reservoir is experiencing a trend of declining growing season productivity and full pool habitat volume, which may negatively impact abundance and diversity of reservoir fish populations.

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?

Fish populations in Carpenter Reservoir may be affected by minimum and maximum reservoir elevation, and the timing and rate of filling and drawdown. Monitoring results from BRGMON-10 and this study suggest low minimum elevations in the spring (as have occurred from 2017 to 2020, and a lesser extent in 2021) result in increased sediment loading, later thermocline development, a smaller euphotic zone, lower growing season productivity, and reduced biomass of lacustrine invertebrates. In years with low minimum elevation, there is decreased food availability for all species, and invertebrate drift from the Middle Bridge River and other inflow tributaries becomes more important to the reservoir food web.

Increased sediment loading and elevated turbidity associated with low minimum reservoir elevations may also have sublethal and negative behavioral effects the system's salmonids. There is preliminary evidence of negative effects of Modified Operations in 2016 through 2021 on fish populations; Bull Trout showed reduced movement, particularly into and out of the Middle Bridge River, and there was a temporary reduction in fish condition (a measure of fish health) for almost all species. Although BRGMON-4 sampling does not target kokanee, limiting our ability to make inferences, kokanee spawner counts may be declining in Carpenter Reservoir. We saw no spawners in 2019, one spawner in 2020, and moderate counts in 2021. Overall, Kokanee have declined in Carpenter Reservoir relative to WUP levels (2014-2016), possibly related to low spring elevations and entrainment through Terzaghi Dam (as occurred in 2016 and 2017).

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. Since Modified Operations began in 2016, angling indices suggest a decline in the number of Mountain Whitefish spawners in the Middle Bridge River. The reason for this decline is uncertain due to limited data, but it may be related to a shift in spawning location, decreased juvenile survival, or decreased conditions in the river or reservoir. We performed additional visual surveys of Carpenter Reservoir tributaries during peak spawning dates but did not observe spawning outside of the Middle Bridge River. Discharges from Lajoie Dam remain relatively stable throughout the Mountain Whitefish and kokanee incubation period (November through April), suggesting Lajoie Dam operations are unlikely to negatively affect juvenile survival. Elevated water temperatures result in earlier predicted hatch dates in the Middle Bridge River relative to other systems in British Columbia, but the effect of earlier hatching on juvenile survival is unknown.

Since the onset of Modified Operations in 2016, the Middle Bridge River hydrograph has become more stable, and is characterized by increased discharge from Lajoie Dam in June through October. Changes to the hydrograph may be affecting adult Mountain Whitefish outside of the spawning period, but we do not have data to examine other time periods. Similarly, although conditions in the reservoir may have a negative effect on the abundance of adult Mountain Whitefish, we do not target Mountain Whitefish during reservoir sampling.

Due to challenging sampling conditions in the Middle Bridge River, and the broad scope of BRGMON-4, we have limited data to determine how discharges in the Middle Bridge River affect fish in the river and reservoir. For kokanee, which spawn in the Middle Bridge River and in Carpenter Reservoir tributaries, declining spawner abundance is likely related to decreased reservoir elevations, as kokanee rely heavily on lacustrine habitat during their adult life stage. In contrast, Mountain Whitefish are not dependent on lacustrine habitat, and the reason for declining spawner abundance in the Middle Bridge River is unclear.

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 low summer elevations and low spring elevations (similar to maximum and minimum elevations) decrease reservoir productivity and overall habitat quality and quantity in Carpenter Reservoir. Increasing reservoir elevations in the early spring would likely reduce sediment loading, reduce turbidity, and increase reservoir productivity, while increasing elevations in the summer would increase overall habitat volume and access to large tributary inflows. Both of these management strategies would likely improve habitat conditions and fish productivity. Current data suggest Lajoie Dam operations are not likely to directly affect juvenile survival for Mountain Whitefish and kokanee, and stable discharge releases from November through April should be continued. The effect of the Middle Bridge River hydrograph on adult fish (both resident and of reservoir origin) is not examined during BRGMON-4; therefore, no refinements can be recommended.

BRGMON-4 status of objectives, management questions, and hypothesis after Year 9.

Objectives	Management Questions	Year 9 (2020-2021) 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?	A database of biological characteristics has been developed for key fish species of interest in the reservoir and Middle Bridge River (Bull Trout, Rainbow Trout, Mountain Whitefish, and kokanee; Bridgelip Suckers, Coastrange Sculpin, and Redside Shiners are also present but not targeted by BRGMON-4). 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, fish condition, and length-at age models to better understand fish population characteristics. Bull Trout are the top predator in Carpenter Reservoir, and Mountain Whitefish are likely the most populous forage fish species. Rainbow Trout are present in low numbers, and several tributaries (e.g., Marshall Creek, Macdonald Creek) have resident populations of Rainbow Trout that likely contribute to the reservoir population. Kokanee abundance has declined substantially over the course of the monitor, likely due to a reduction in lacustrine habitat volume resulting from Modified Operations in 2016 through 2021. Preliminary evidence suggests fish grow slowly in Carpenter Reservoir and reach shorter maximum lengths relative to nearby systems. This finding is expected given that Carpenter Reservoir is a relatively low productivity system. In addition, all target species are stream spawners and access to abundant suitable

		spawning habitat is limited in the steep, small tributaries that feed into the reservoir.
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?	Weight of evidence suggests reservoir productivity, habitat volume, and indicators of physical habitat quality (e.g., increased total suspended sediment and turbidity) have declined since the implementation of Modified Operations (2016-2021). This trend of declining productivity and habitat may negatively affect abundance and diversity of fish populations in the reservoir, evidence of which has been observed during this monitor (see MQ3 and MQ4).
	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 preliminary evidence suggests elevations may affect biological characteristics of fish populations in the reservoir. Low elevations (e.g., <620 m) in the spring for multiple consecutive years results in shorter water residence times and higher turbidity, leading to reduced growing season productivity and a decline in food availability for all species. Low reservoir elevation in the spring and summer also restricts the quantity and quality of fish habitat, which may negatively affect fish abundance and productivity. It is challenging to identify specific factors affecting fish populations due to the complex nature of the reservoir and river ecosystems and the long lifespan of fish species.
	4: Is there a relationship between specific characteristics of the in-stream flow in the Middle Bridge River that contribute to reduced or	Mountain Whitefish spawner surveys and hatch date calculations paired with winter Middle Bridge River stage heights suggest discharge release schedules at Lajoie Dam do not result in significant dewatering of Mountain Whitefish eggs or kokanee and redds in the river. A decline in Mountain Whitefish

	improved productivity of fish populations in Carpenter Reservoir and the Middle Bridge River?	spawner indices has occurred since 2016, but the cause is uncertain and may related to river or reservoir conditions. Since 2016, the Middle Bridge River hydrograph has become more consistent, with higher discharges from June through October relative to 2012 to 2015. Since BRGMON-4 sampling does not target Mountain Whitefish in the reservoir or river (outside of the spawning period), we cannot determine whether changes to the hydrograph may be responsible for decreased spawner abundance.
	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?	Preliminary results of BRGMON-4 and results from BRGMON-10 suggest that both minimum and maximum reservoir elevations affect fish habitat in the reservoir. Therefore, refinements to operations that increase both minimum and maximum elevations may improve fish populations. In the Middle Bridge River, stable discharge releases from Lajoie Dam from November through April likely result in a low risk to incubating Mountain Whitefish and kokanee and therefore should be continued. Further recommendations for the Middle Bridge River cannot be made as BRGMON-4 does not sample fish in the river outside of the spawning period.

Acknowledgements

We are grateful to the St’át’imc Nation for allowing this monitoring to be conducted within their territory. We would like to thank St’át’imc Eco Resources (SER) staff for administrative support for this project, and BC Hydro for project funding. Ron James was the lead SER field technician in 2021, and Wes Payne, Kelsey Alec, Bailee Phillips, Doug Mitchell, Rebecca Riley, Ray Bob, Cliff Lesley, and Avaleen Adolf assisted with fieldwork. We would also like to thank Jeff Sneep and Chris Perrin for valuable project input. InStream Fisheries Research staff helped with project design, implementation, analysis, and synthesis.

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1. Introduction

1.1 Background

The Bridge River power project, 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 impounded 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 from Carpenter Reservoir 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, further impounds the Bridge River as Downton Reservoir, and regulates discharge in the Middle Bridge River between Lajoie Dam and Carpenter Reservoir.

The Bridge River Valley is an important cultural and sustaining resource for the St'át'imc First Nation. A Water Use Planning (WUP) process was initiated in 1999 in response to environmental and social concerns resulting from power generation. The initial WUP process outlined 20 proposed alternative operating strategies, which were reviewed by the Bridge River Consultative Committee (BRCC; a multi-stakeholder body). The BRCC provided recommendations to BC Hydro, and a final WUP was accepted in 2011 that implemented an alternative operating strategy (N2-2P) aimed to balance fish and wildlife health, recreation, flood management, water security, and power generation (BC Hydro 2011). The WUP recommended monitoring to address uncertainties and investigate environmental changes in response to the N2-2P operating strategy (BC Hydro 2011). Recommendations to monitor fish and fish habitat in Carpenter Reservoir and the Middle Bridge River (between Carpenter Reservoir and Lajoie Dam) led to the development of BRGMON-4 (BC Hydro 2015).

N2-2P did not include substantial changes to the operating guidelines for Carpenter Reservoir. Minimum and maximum reservoir elevation objectives remained at the licensed limits of 606.55 m and 651.08 m, respectively. A soft maximum elevation target of 648 m at the end of the snowmelt season in mid-August was adopted; however, it was expected this target would be exceeded due to other higher priority constraints (BC Hydro 2011). N2-2P included new operational guidelines for discharge from the Lajoie Generating Station into the Middle Bridge River, which aimed to balance fish habitat in the Middle Bridge River and Downton Reservoir. A minimum discharge schedule was developed relating discharge to elevations in Downton Reservoir (with a minimum discharge of 5.7 m^3/s), and maximum ramping rates of 2.5 cm/h and 15 cm/day were recommended to reduce the likelihood of fish stranding.

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 fish indices of abundance in Carpenter Reservoir (BRCC 2003). Although these expectations were not explicit in the final BRCC report, it appears N2-2P was expected to benefit fish populations in both the river and reservoir.

Beginning in 2016, operations of the Bridge River hydroelectric power system were modified due to safety concerns at Lajoie Dam and repair requirements at the Bridge 1 and 2 generating stations (i.e., the Modified Operations regime). Higher discharges from Terzaghi Dam into the Lower Bridge River were required to draft Downton Reservoir to a modified maximum elevation of 734 m (from 749.81 m) due to safety concerns at Lajoie Dam. To remove water from Downton and Carpenter Reservoirs, Lower Bridge River discharges surpassed 15 m^3/s (the maximum discharge treatment prescribed during the WUP) and peaked at 97-127 m^3/s in 2016 through 2018. Modified Operations dramatically changed habitat in the Lower Bridge River and Downton Reservoir and affected elevations in Carpenter Reservoir. Particularly from 2017 to 2020, minimum spring elevations were low in the reservoir relative to previous years resulting in decreased water volume and reduced habitat availability, as well as reduced habitat quality (as inferred from modelling in Limnotek 2018).

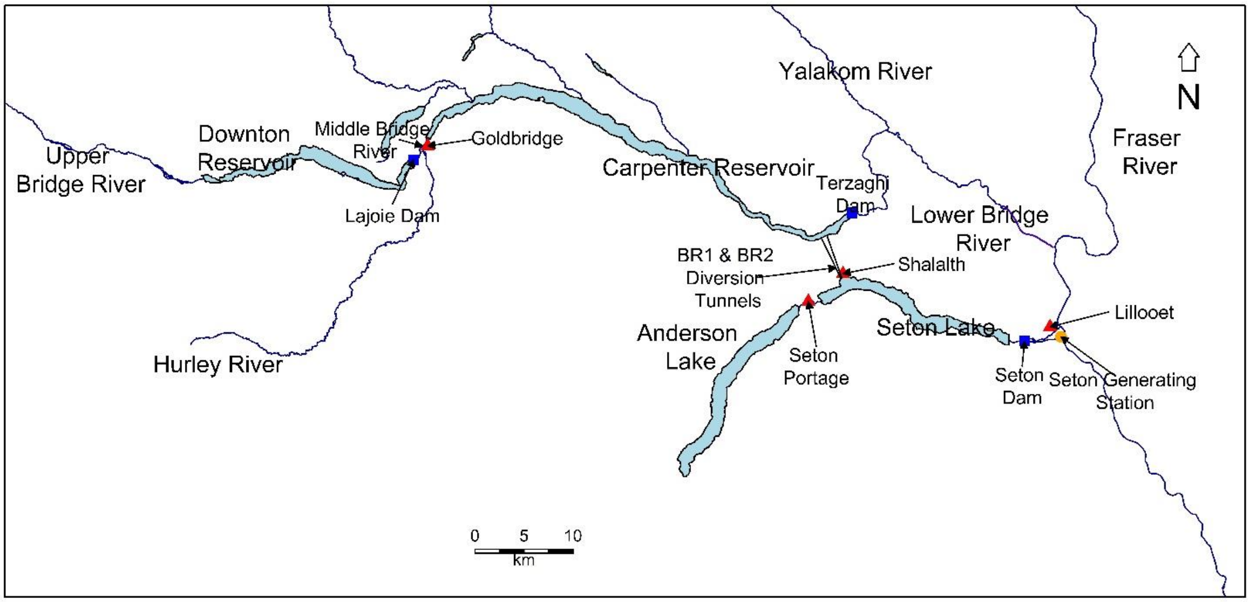


Figure 1.1 Bridge-Seton power system near Lillooet, British Columbia.

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). A fish habitat assessment in 1995 and 1996 included the identification and assessment of stream spawning habitat and pelagic fish indexing using gillnet surveys (Griffith 1999). Rainbow Trout (*Oncorhynchus mykiss*) and Bull Trout (*Salvelinus confluentus*) catches were low in Carpenter Reservoir tributaries. Habitat surveys suggested there were 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 that were 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*).

In 1999 and 2000, Chamberlain et al. (2001) examined the impacts of hydro operations on Bull Trout and kokanee migrations, life history expression, and critical life history stages using radio telemetry (Bull Trout) and tributary spawner surveys (kokanee). Radio telemetry indicated that Bull Trout migrate into the western portion of the reservoir as it reaches full pool in the summer and occupy the eastern portion during winter (Chamberlain et al. 2001). No kokanee were observed in the 11 tributaries surveyed; however, two carcasses were observed in Gun Creek.

Limnological surveys in Carpenter Reservoir have found low densities of zooplankton and phytoplankton, possibly due to a short water residence time in the reservoir (Perrin and Macdonald 1997; Griffith 1999, Limnotek 2018). These limnological findings agree with stable isotope research from 2001 that examined energetic food webs in the reservoir (Leslie 2003). Stable isotopes were collected from the reservoir, Middle Bridge River, and reservoir tributaries. Isotope signatures in fish most resembled reservoir Chironomidae and Middle Bridge River macroinvertebrate drift, rather than zooplankton or macroinvertebrate drift from smaller 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 was completed in the early 2000s during the development of the WUP monitors. Previous research highlighted uncertainties in biological and physical characteristics and the effects of operations on fish productivity in Carpenter Reservoir. BRGMON-4 was developed to address these uncertainties.

1.3 Management Questions

The objective of BRGMON-4 is to determine whether operating parameters for Carpenter Reservoir (maximum and minimum elevations, and rates of filling and drawdown) and Lajoie Generating Station (in-stream discharge releases and subsequent Middle Bridge River stage heights) affect fish populations in Carpenter Reservoir and the Middle Bridge River. This monitor will inform whether management can be refined to reduce negative impacts or enhance reservoir fish populations. Specifically, BRGMON-4 addresses five management questions (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?

BRGMON-4 is the first long-term study to take place in Carpenter Reservoir. The terms of reference (TOR) provided initial hypotheses and methods towards answering the management questions, but the TOR was modified considering insights from 2012 to 2014 (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); however, these revised hypotheses were later deemed unsuitable and were removed from project planning and reporting. The current approach aims to answer the management questions without the use of formal hypotheses, and will focus on Bull Trout, kokanee, Rainbow Trout, and Mountain Whitefish.

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 1970s and 1990s, kokanee were stocked in Carpenter Reservoir by the Province of British Columbia and are still present today (Chamberlain et al. 2001, M. Casselman, pers comm., August 2020).

Carpenter Reservoir elevation is controlled by BC Hydro and changes considerably during annual cycles in the reservoir (up to a licensed maximum drawdown of 44.53 m). As the reservoir is drawn down to 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 and summer, the boundary of the river and reservoir moves westward and reservoir length and volume increase. At full pool, generally reached in late summer, the reservoir is approximately 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 when approaching full pool (i.e., late June or early July) and achieves fall turnover by mid- to late October. Thermal stratification is more pronounced in the eastern portion of the reservoir and lessens closer to the boundary of the Middle Bridge River. Cold, turbid waters from the Middle Bridge River flow into the reservoir and sink to create a dense, turbid layer along the reservoir bottom (Limnotek 2018). Primary productivity is relatively low in Carpenter Reservoir due to high turbidity and short water residence times, and productivity is generally concentrated in warmer, clear surface water. During extreme reservoir drawdowns, lacustrine habitat quality and quantity decrease, the length of the Middle Bridge River increases, and productivity during the growing season decreases (Limnotek 2018).

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 portions of the Bridge River (i.e., Downton Reservoir 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 in the Bridge River Power System; the operating parameters most applicable to BRGMON-4 are Carpenter Reservoir elevation and Middle Bridge River discharge (characterized by in-stream discharge releases at Lajoie Dam). Operations data were provided by BC Hydro.

2.2.1 Carpenter Reservoir Elevations

We summarized elevation parameters for all monitoring years and compared these parameters with fish population data. 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 Carpenter Reservoir elevations for the 10 years prior to N2-2P (i.e., pre-WUP; 2002-2011), from 2012 to 2015 (i.e., post-WUP/N2-2P), and from 2017 to 2021 (i.e., Modified Operations) to determine changes attributed to implementation of N2-2P. We removed 2016 from the analysis because it was a transitional year between N2-2P and WUP and did not represent the operational characteristics of either regime (Matt Casselman, pers. comm. September 2020). There was no defined pre-WUP regime. We selected 10 years, the total length of BRGMON-4, to represent the operations prior to WUP implementation.

Four elevation parameters were compared using analysis of variance (ANOVA): mean elevation from July through September (representing full pool habitat volume), mean elevation for the first two weeks of April (a period correlated with annual growing season productivity in the reservoir; Limnotek 2018), and maximum and minimum elevations. Full pool habitat volume was correlated with maximum elevation (R^2 0.9) and elevation in early April was correlated with minimum elevation (R^2 0.8); however, we present all four parameters due to their utility to BC Hydro managers. Adequate habitat volume and reservoir productivity are important for fish growth and productivity, and changes in these parameters would provide evidence that operations affect fish populations.

In addition to maximum and minimum elevations, the timing of these parameters and rate of change in elevation may also affect the productivity of fish in the reservoir; for example, the timing and rate of reservoir drawdown can affect stranding and entrainment of fish proximate to Terzaghi Dam (Matt Casselman, pers. comm. June 2020). The effects of these parameters on species-specific fish productivity are difficult to determine, particularly due to the interactions between rates of elevation change and maximum and minimum elevations. We do not define or compare elevation timing and rate of change, but these parameters are important to consider, and further analyses may be required.

2.2.2 Middle Bridge River Discharge

Continuous discharge data for the Middle Bridge River were not available for the BRGMON-4 monitoring period. Prior to 2017, stage height data from below Lajoie Dam were available for some years, but no stage-discharge relationship was published. Beginning in late 2017, stage and discharge information became publicly available via Water Survey of Canada (08ME029); however, due to the recent availability of discharge data, discharge could not be compared between operational regimes. Instead, Lajoie Dam discharge data were used to compare conditions in the Middle Bridge River amongst operational regimes.

Lajoie Dam is operated to maintain a minimum discharge schedule based on Downton Reservoir elevations rather than a specific hydrograph. The lack of a defined hydrograph and lack of consistency in discharge releases make it uninformative to quantitatively compare discharge amongst years. Instead, we compared the qualitative characteristics of discharge releases amongst regimes.

2.3 Middle Bridge River Mountain Whitefish Spawning Assessment

Mountain Whitefish spawn in the Middle Bridge River from mid-November to late December and peak hatch occurs early to mid-February (Tisdale 2010, McPhail 2007). Mountain Whitefish are broadcast spawners, and their eggs settle into the interstitial spaces of small cobbles. Incubating eggs or newly hatched individuals could be desiccated and killed if a ramp-down of Lajoie Dam discharge causes water levels to drop in the Middle Bridge River during the winter and early spring. Determining incubation timing and 50% hatch dates (calculated using accumulated thermal units, ATU) is important for predicting when Mountain Whitefish are vulnerable to dewatering.

Mountain Whitefish spawning activity in the Middle Bridge River was assessed in 2020 as well as in 2018 and 2016 using angling surveys modelled after those performed by Tisdale Environmental Consultants Inc. (TEC) in 2005, 2009, 2012, and 2013 (Tisdale 2010, 2013). Angling occurred in November and December to identify the timing of peak female ripeness and the mean age of spawners. Mountain Whitefish were angled weekly from October 28 to December 9, 2020, using single cured salmon eggs. We angled at all five sites (Figure 2.1) but focused primarily on Sites 2 and 4 to maximize captures (relatively few fish were caught at the other three sites). All Mountain Whitefish captured were assessed for weight, fork length, age (via scale ageing analysis), sex (if possible), and sexual maturity. Sexual maturity was separated into three categories:

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

The number of Mountain Whitefish, the proportion of ripe females, and combined weekly egg counts were compared to data from 2009, 2012, 2013, 2016, and 2018 (Tisdale 2010, Putt et al. 2018, Putt et al., 2021). We did not assess the sex of immature fish; therefore, proportions of ripe females were relative to all Mountain Whitefish sampled in a survey. To determine when incubating eggs and newly hatched Mountain Whitefish are vulnerable to desiccation, Middle Bridge River temperature data were used to calculate 50% hatch dates using an ATU requirement of 327. We used 327 ATUs (from the lower Columbia River) because water temperatures in the

Middle Bridge River are similar to those reported in the Columbia River during Mountain Whitefish egg incubation (R.L. & L 2001) and for consistency with ATU analysis by TEC (Tisdale 2010).

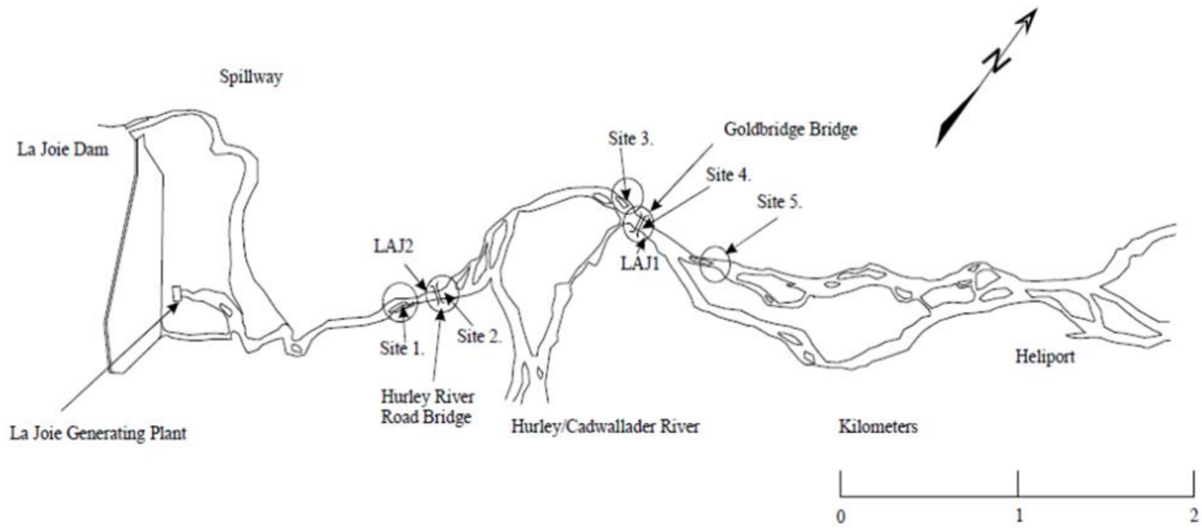


Figure 2.1 Location of Mountain Whitefish sampling sites on the Middle Bridge River identified by Tisdale Environmental Consultants Inc (Source: Tisdale 2013).

2.4 Bull Trout Abundance Estimation

An open mark-recapture model was used in 2015 through 2021 to estimate annual Bull Trout abundance in Carpenter Reservoir. Open mark-recapture models account for fish moving in and out of the study area via births, deaths, immigration, and emigration. Fish were captured annually and marked with a unique identifier (passive integrated transponder [PIT] tag). During subsequent sampling events, marked animals were recorded and released, and unmarked animals were tagged and released. The relative proportions of marked to unmarked fish were used in mark-recapture modelling to determine sampling-specific survival and capture probabilities and population size.

2.4.1 Mark-Recapture Field Program

The 2021 mark-recapture period occurred between June 14 and June 29. In 2015 and 2016, the mark-recapture program occurred later in July (at maximum reservoir elevation), but acoustic data indicated that Bull Trout undergo spawning migrations in July (Putt et al. 2019), and surface water temperatures exceeded Bull Trout tolerances. We moved the program a 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 (angling at creek mouths and overnight electrofishing) were used to target all habitat types (i.e., tributary confluence, tributary fan, shallow shoreline, and deep shoreline) and allow the abundance estimate to be applied to the entire study area (i.e., Carpenter Reservoir). All Bull Trout were PIT tagged and released at their capture location, and we collected fork lengths, weights, and age structures (pectoral fin rays). Biological data and age structures were also collected from Rainbow Trout, Mountain Whitefish, and kokanee to calculate catch-per-unit-effort (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*.

The methods used and timing of the mark-recapture program make it difficult to sample Mountain Whitefish and kokanee in the reservoir (i.e., there are too many Mountain Whitefish to produce an accurate index count, and kokanee are not typically present at tributary confluences in mid- to late June). Pilot gillnetting in 2015 and 2016 was unsuccessful at efficiently capturing Mountain Whitefish and kokanee, and as a result, we have very little data for these two species in the reservoir. Both Mountain Whitefish and kokanee were targeted as adult spawners, during Middle Bridge River angling and tributary visual surveys, respectively.

2.4.2 Mark-Recapture Modelling

We used the Cormack Jolly-Seber (CJS) open-mark recapture model to estimate Bull Trout abundance in Carpenter Reservoir (Seber 1982, Pollock et al. 1990, Schwarz and Arnason 1996). There are several assumptions associated with open mark-recapture models that must be met to ensure the model produces reliable estimates, and we adapted sampling methodologies where necessary to meet these assumptions (Table 2.1).

In open mark-recapture models, the probability of a fish being captured is determined by the apparent survival (φ) from sampling period *i* to *i+1* and the capture probability (p) within the i^{th}

sampling event. The survival parameter is referred to as “apparent survival”, as it includes mortality and emigration (Schwarz and Arnason 1996). Similarly, the probability of entrance accounts for individuals that recruit from the population as well as immigrants to the study area.

Survival and capture probabilities are used to build probability expressions for each of the possible encounter histories over the *K* capture occasions. Maximum likelihood estimation is then used to derive estimates of apparent survival and capture probability for the population (see Cooch and White 2006). The model can be time-dependent (i.e., survival and capture probabilities are estimated for each sampling event) or parameters can be fixed across 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 is calculated using estimated capture probabilities:

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

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

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

The Akaike information criterion for small sample sizes (AICc; Burnham and Anderson 2002) was used to evaluate candidate models that included both fixed and time-varying survival (*φ*) and capture probability (*p*). In AICc selection, the model with the highest AICc support (i.e., the lowest AICc values) is generally selected as the top model; however, in mark-recapture modelling, it is typical to have similar AICc support for multiple models. We used model averaging to estimate survival and capture probabilities using AICc model weights. Confidence intervals for the model-averaged estimates were derived using the Delta-method, or the error propagation method (Cooch and White 2006). The Delta method calculates the linear approximation of each single model variance and combines these approximations to estimate variance for the model-averaged variables.

We used the model-averaged capture probabilities to generate abundance estimates using Equation 2. We then calculated log-normal confidence intervals for the abundance estimates (commonly used in distance abundance sampling; Thomas et al. 2002, Elwen et al. 2009):

$$LnVar = \ln\left(1 + {varN̂}/{\hat{N}^2}\right) \quad \text{Eq 4}$$

$$r = exp\left(1.96 * \sqrt{LnVar}\right) \quad \text{Eq 5}$$

$$UCL = \hat{N} * r \quad \text{Eq 6}$$

$$LCL = {\hat{N}}/{r} \quad \text{Eq 7}$$

where $\hat{N}$ is the model-averaged abundance, $var\hat{N}$ is the variance of the estimated abundance, *UCL* is the upper 95% confidence interval, and *LCL* is the lower 95% confidence interval.

All mark-recapture models were evaluated in R Project Software (R Core Development Team 2017) using the package RMark (Laake 2013), which provides an interface between R and the mark-recapture software MARK (White and Burnham 1999).

Table 2.1 Assumptions of the Cormack Jolly-Seber open mark-recapture model.

Assumption	Applicability to BRGMON-4 Bull Trout Mark-Recapture
Each animal in the population at the time of the i^{th} sample has equal capture probability (p_i)	Violated if limited age classes or habitats are sampled, animals do not evenly distribute, or animals immigrate or emigrate from the study area during the mark-recapture period. We used multiple capture methods, and acoustic telemetry to assess immigration and movement during the mark-recapture period.
Each marked animal present following the i^{th} sampling event has equal survival probability (ϕ_i) until the $(i+1)^{th}$ event	Proper fish handling techniques were used, marks were applied to healthy individuals without outwards signs of disease or injury, and all individuals were held until completely recovered.
Marks are not lost or missed	Fish were scanned for PIT tags and examined for other signs of tagging (particularly fin ray scars). PIT tags were inserted following standard protocols to reduce tag loss. PIT tag loss can be <5% (e.g., Ombredane et al. 1998) with proper technique.
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 was <30 days to satisfy this criterion.

2.5 Bull Trout Movement Analysis

Acoustic telemetry was used in Carpenter Reservoir and the Middle Bridge River to monitor Bull Trout movements. We used two acoustic telemetry gates from the spring of 2015 to spring 2018 to monitor linear movements in the reservoir and into and out of the Middle Bridge River. The gates verified that Bull Trout movements were random within Carpenter Reservoir during the mark-recapture period (i.e., no migration occurred; Putt et al. 2019). Having adequately verified this mark-recapture assumption, we repositioned the receivers in the spring of 2018 to broadly monitor Bull Trout movements throughout the reservoir and the Middle Bridge River.

2.5.1 Acoustic Tagging

In 2021, twenty Bull Trout were angled from May 25 to June 29 at the confluences of Bobb, Nosebag, Keary, Marshall, and Truax Creeks, and tagged with acoustic transmitters (V13 transmitters, Vemco, Bedford, Nova Scotia; 2-year battery life, 13 mm diameter, 48 mm length, transmission rate 20-60 s). To minimize adverse tagging effects, we aimed to tag Bull Trout >550 g to ensure that tag weight (in air; 11 g) was < 2% of the total fish weight in air, a tag burden with negligible effects on fish performance (Winter 1983). Bull Trout were anaesthetized in dark coolers using clove oil (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 with water monitored for temperature and oxygen and were released when active and upright.

2.5.2 Acoustic Receivers

Six acoustic receivers (VR2W-69 kHz; Vemco) were deployed throughout Carpenter Reservoir and four acoustic receivers were deployed in the Middle Bridge River (Table 2.2, Figure 2.2). The river receivers were deployed together to increase detection probability (see Putt et al. 2018), while the receivers in Carpenter Reservoir were deployed singly. Reservoir receivers were suspended in the water column ~1 m off the bottom (with the transducer oriented upwards) and marked with floats, while receivers in the Middle Bridge River were attached directly to bottom anchors. Receivers were recovered on April 14, 2021; therefore, receiver data and analyses presented herein are representative of 2020, Year 8 of BRGMON-4 (2021 data will be recovered in April 2022 and presented in the Year 10 report).

Receivers provided presence-absence data for important locations throughout Carpenter Reservoir and detected fish that moved into the Middle Bridge River. Receivers were spaced relatively evenly along the length of the reservoir, and were stationed proximate to locations or features of interest:

1. Terzaghi Dam (km 0.5): Assessed presence in the deep lacustrine portion of the reservoir and informed the risk of Bull Trout entrainment through Terzaghi Dam.
2. Bridge River 1 (BR1) and Bridge River 2 (BR2) Diversion Tunnels (km 3.5): Assessed presence in the deep lacustrine portion of the reservoir and informed the risk of Bull Trout entrainment through BR1 and BR2.
3. C3/West of Strawberry Creek (km 9.4): Assessed presence in a deep, channelized area between the main spawning tributaries and the lacustrine portion of the reservoir.
4. Keary Creek (km 16.6): Assessed presence at an important spawning and feeding tributary.

5. Tommy Creek (km 25.7): Assessed presence at an important spawning and feeding tributary.
6. Truax Creek (km 35.0): Assessed presence at an important spawning and feeding tributary.
7. Middle Bridge River (km 49.5): Assessed presence in the Middle Bridge River, an important Bull Trout spawning tributary.

The area in Carpenter Reservoir within which a receiver can detect transmitters (the detection range) varies with depth, water temperature, and turbidity (Putt et al. 2019). Range testing in 2015 suggested receivers in Carpenter Reservoir had an 80% detection range of ~300 m at full pool (i.e., 80% of transmissions were detected within 300 m of the receivers), while receivers in the Middle Bridge Reservoir had an 80% detection range of ~10-15 m (Putt et al. 2016b). Of the six receivers deployed in Carpenter Reservoir from 2018-2021, three (Terzaghi, Diversion, and C3) were not subject to dramatic changes in detection range, while the three other receivers (Keary, Tommy, and Truax) were located on shallower tributary fans. The detection range of these shallow receivers decreased as reservoir elevation decreased and was 0 m when the reservoir reached its minimum elevation in early May of 2021. The magnitude of the decrease in detection range was unknown, and we assumed detection range was low at receivers proximate to Keary, Tommy, and Truax from mid-March to late May.

Water depths in the Middle Bridge River were more consistent, and receivers were positioned ~0.5-1.5 m below the water surface depending on discharges from Lajoie Dam and the Hurley River. Due to poor detection range in the Middle Bridge River, four receivers were deployed together (two on each side of the river) to increase the probability of a tag being detected by at least one receiver.

Data from the receiver locations were used to determine how many fish were present at each location throughout the monitoring year, as well as how individual tags moved between the receiver locations.

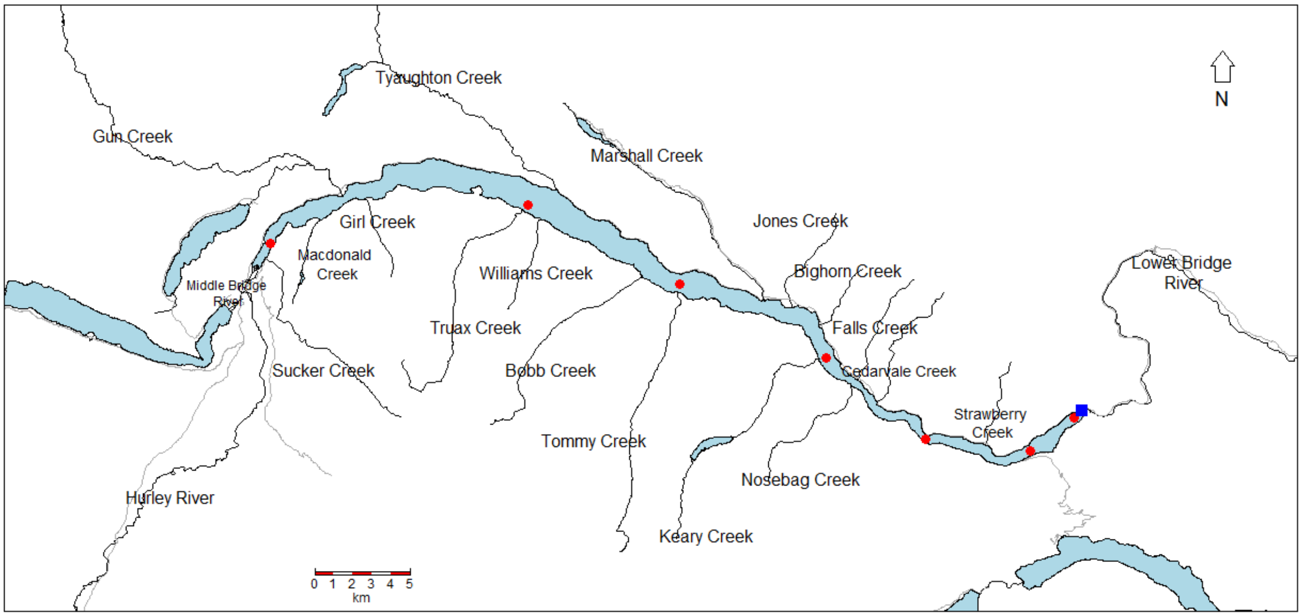


Figure 2.2 Major Carpenter Reservoir tributaries and acoustic telemetry receivers in the reservoir and Middle Bridge River. Red circles show the locations of receiver stations, and the blue square is Terzaghi Dam.

Table 2.2 Carpenter Reservoir and Middle Bridge River acoustic receiver locations, habitat types, and water depths at full pool and low pool.

Receiver Name	Number of Receivers	KM From Terzaghi	Habitat Type	Approximate Depth (m) at Full Pool (~645 m)	Approximate Depth (m) at Low Pool (~615 m)
Terzaghi	1	0.5	Deep	45-55	20-25
BR1 and BR2 Diversion	1	3.5	Deep	45-55	20-25
CR3/West of Strawberry	1	9.4	Deep	30-35	10-15
Keary	1	16.6	Tributary Fan	25-30	0
Tommy	1	25.7	Tributary Fan	20-25	0
Truax	1	35.0	Tributary Fan	10-15	0
Middle Bridge River (MBR)	4	49.5	River	0.5-1.5	0.5-1.5

2.5.3 Movement of PIT-Tagged Bull Trout

During all BRGMON-4 fish sampling events, Bull Trout were tagged with a unique PIT tag. PIT tags allow recaptures to be identified for mark-recapture modelling, but also provide growth and location data when tagged fish were recaptured. We examined 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.

2.6 Analysis of Biological Data

The target species for monitoring of biological data were Bull Trout, Rainbow Trout, Mountain Whitefish, and kokanee. We collected length and weight data for all target species captured, and age was determined for a subset of all species captured. Continuous collection of biological data will determine potential changes over the course of the monitoring period.

2.6.1 Ageing Analysis

Scales collected above the lateral line below the dorsal fin were later mounted on glass slides and age determined under magnification by two independent analysts (Zymonas and McMahon 2009). Scales are not a reliable aging structure for adult Bull Trout, and fin rays (i.e., the first 2-3 rays from the pectoral or pelvic fin) were sampled from Bull Trout. Two fin ray subsets were aged: one subset was primarily from 2014 to 2016 (N2-2P), and a second subset was primarily from 2020 to 20121 (Modified Operations). Otoliths (a calcified structure located in the brain cavity) were collected opportunistically from mortalities of all species and examined under magnification by two independent analysts to identify growth annuli and estimate age (Zymonas and McMahon 2009).

We captured newly emerging Rainbow Trout juveniles that were too small to sample for scales (<50 mm fork length; assumed to be age-0) during backpack electroshocking of select Carpenter Reservoir tributaries in 2016 through 2018 (Putt et al., 2019), and in 2021. We captured emergent fry in August through September and again in April through June. Rainbow Trout undergo minimal growth while overwintering in Carpenter Reservoir tributaries in their first few years of life, and the young-of-the-year (YOY) that emerged in the fall of one year were nearly indistinguishable from those captured in the following spring (both in appearance and during scale ageing; Figure 2.3). These Rainbow Trout were misclassified as age-0 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 by adding one year to all Rainbow Trout captured after at least one winter of growth. This assumes that all Rainbow Trout reared for at least one winter in the tributaries, which was likely accurate considering Rainbow Trout life history characteristics (McPhail 2007).

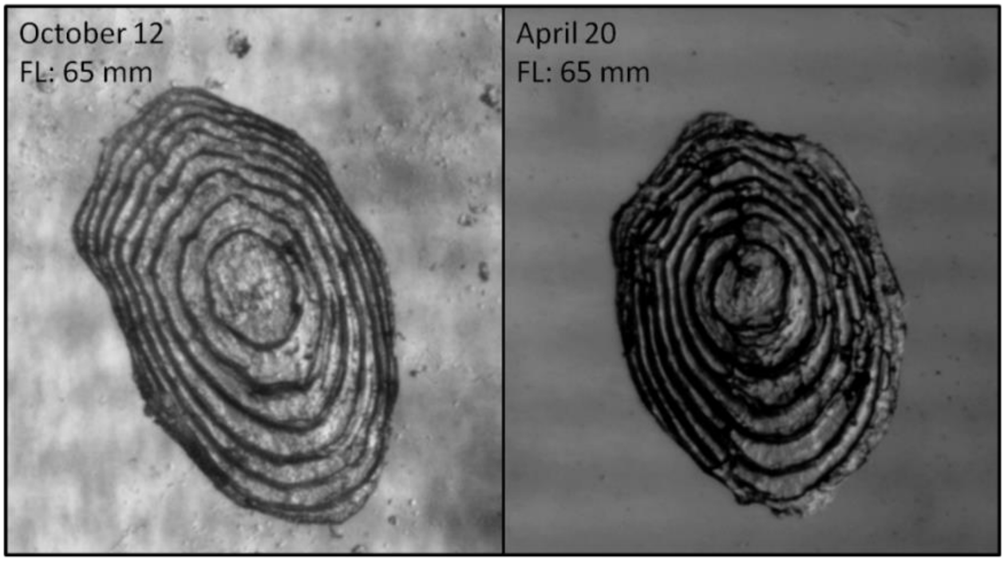


Figure 2.3 Scales assessed as age-0 collected from Rainbow Trout captured during tributary electroshocking. The scale collected on April 20 (right) has undergone a winter of growth and should be classified as age-1; however, winter growth annuli are indistinguishable.

2.6.2 Length vs Weight and Body Condition

The relationship between fish length and weight can be used to monitor gross changes in fish health and growth. Log-linear regression was used to model the annual length (*L*) vs weight (*W*) relationships for each species (Ogle 2016a):

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

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

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

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

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

where *W* is weight in grams, *L* is length in millimeters, and *N* is an integer that scales the condition factor close to a value of one (*N*=5 for Carpenter Reservoir salmonids). We compared the mean condition factor values between years using one-way ANOVA (α = 0.05), and then used Tukey's pairwise hypothesis testing (Tukey's Honest Significant Difference-HSD) to determine which mean condition factor values were statistically different (Ogle 2016a, 2016b).

We examined length-weight relationships for population subsets of Bull Trout, Rainbow Trout, and Mountain Whitefish. For Bull Trout, we isolated adults between 200 mm and 350 mm in length (approximately ages 3 to 6 years) and greater than 350 mm in length (greater than age 6 years). Bull Trout aged 3-6 represent potential adult spawners that are still undergoing measurable annual growth (i.e., have not reached asymptotic length). Rainbow Trout were separated into three categories for length and weight modelling: reservoir captures only, tributary captures only, and reservoir and tributary captures combined. For Mountain Whitefish, we examined biological characteristics of individuals captured in Carpenter Reservoir during the spring and summer field sampling programs, as well as adult spawners captured in the Middle Bridge River during winter angling.

2.6.3 Growth Modeling

Paired lengths and ages were used to fit von Bertalanffy and Gompertz growth functions for Rainbow Trout, Mountain Whitefish, and Bull Trout. Species-specific growth models describe growth characteristics and can be used to compare growth to other systems in the region. Data were pooled from all study years and growth models were fit using the equations:

von Bertalanffy:

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

Gompertz:

$$L_t = L_\infty * exp^{-exp^{[-G(t-t_0)]}} + \varepsilon \qquad \text{Eq 12}$$

In the von Bertalanffy model, 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. In the Gompertz model, *G* is the instantaneous rate of growth at age t_0, and t_0 is the age at which the growth rate begins to decline. Previously, all growth modelling was performed using von Bertalanffy modeling, but high asymptotic lengths suggested this model was not a good fit for BRGMON-4 data. The Gompertz model is often used in systems with slow initial growth, as observed in Carpenter Reservoir tributaries. Using AIC, we compared the fit of von Bertalanffy vs Gompertz growth models for Bull Trout, Rainbow Trout, and Mountain Whitefish. We found higher AIC support for the Gompertz model in all cases, and therefore used Gompertz modelling to describe growth in 2021.

2.6.4 Age-Length Keys

Age-length keys (ALKs) were developed for Bull Trout, Rainbow Trout, and Mountain Whitefish in Carpenter Reservoir to allow age estimation for fish not sampled for ageing structures (Ogle 2016b). An ALK is a probability matrix 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 Tributary Surveys in the Carpenter Reservoir Watershed

2.7.1 Kokanee Spawner Assessments

Kokanee spawning surveys were conducted in Carpenter Reservoir tributaries to estimate migration timing and spawning duration. Visual surveys took place in Girl Creek, Jones Creek, Macdonald Creek, Marshall Creek, Sucker Creek, and Truax Creek. Survey lengths extended from the tributary confluence to the most upstream accessible location (i.e., before upstream passage was too difficult for surveyors). Visual survey lengths below the maximum reservoir elevation boundary were variable as reservoir elevation increased, while survey lengths above the maximum pool level remained constant and ranged from approximately 50 m to 140 m. A GPS track was recorded for each survey to determine the weekly change in stream length below the maximum elevation boundary.

All tributaries (apart from the Middle Bridge River) measured less than 5 m across, and crews surveyed the full wetted width from one bank, recording the number of adult kokanee, number of redds, water clarity (good, moderate, or poor), and discharge level (high, moderate, low, dry). 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).

Temperature data loggers were installed in Marshall Creek, Gun Creek, Macdonald Creek, Truax Creek, and the Hurley River and Middle Bridge River in spring 2020 to monitor temperature profiles through the summer and during the fall kokanee migration period. Although temperature loggers were not installed at redd depth, we assumed that water column and redd-depth temperatures were equivalent (i.e., no groundwater effects). Temperature data have been used in previous reports to estimate 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 period during which incubating eggs or newly emerged kokanee juveniles would be vulnerable to inundation from increasing reservoir elevation. We could not calculate 50% hatch dates for 2019 and 2020 because we did not observe spawners; however, 50% hatch dates from 2018/2019 are included in the results. Hatch dates will be estimated for 2021/2022 once temperature loggers are recovered in spring 2023.

2.7.2 Monthly Tributary Electroshocking

Monthly backpack electroshocking surveys occurred in Carpenter Reservoir tributaries in 2016, 2017, 2018, and 2021. These surveys were intended to determine which species spawn in Carpenter Reservoir tributaries (Marshall Creek, McDonald Creek, Gun Creek, and Truax Creek), and describe juvenile Rainbow Trout growth in the watershed. Although all sampling years were within the Modified Operations period, reservoir operations were variable (Figure 3.1) and 2016 and 2021 represent the first and sixth years of Modified Operations, respectively.

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. We used general additive models (GAMs) to evaluate whether juvenile Rainbow Trout growth differed among sampling years.

2.8 Targeted Kokanee Electroshocking

Targeted overnight boat-based electroshocking occurred on August 5 and August 10, 2021, at the request of BC Hydro, as an attempt to confirm the presence of kokanee in Carpenter Reservoir. In 2019 and 2020, few to no kokanee were captured during field sampling or observed during tributary surveys, resulting in concern that kokanee may have been extirpated from the reservoir. We electroshocked all accessible tributary confluences on both sampling occasions to target kokanee staging for spawning. Kokanee, Bull Trout, and Rainbow Trout were enumerated, weighed, measured, and sampled for age structures.

2.9 Monthly Limnological Sampling

Detailed limnological sampling occurred in 2015 and 2016 in the Carpenter Reservoir watershed as part of BRGMON-10: Carpenter Reservoir Productivity Model Validation and Refinement (Limnotek 2018). The objective of BRGMON-10 was to determine how reservoir operations affect biological production in Carpenter Reservoir, using physical and biological sampling, regression modelling, and scenario modelling with the CE-QUAL-W2 hydrodynamic model. CE-QUAL-W2 was used to predict the effect of different operational scenarios on reservoir productivity. Data from 2015 and 2016 were used to parameterize the model; however, both years were characterized by high spring water elevations relative to Modified Operations (2017 to 2021). We repeated a portion of the limnological sampling in 2021 to describe physical conditions, nutrient availability, and zooplankton/phytoplankton biomass in the reservoir under Modified Operations, and to determine whether CE-QUAL-W2 scenario conclusions agreed with new empirical data.

Carpenter Reservoir was sampled monthly from May to October. Water sampling, Secchi disc readings, zooplankton and phytoplankton sampling occurred at two stations, C2 and C6, previously established by BRGMON-10 (Figure 2.4). Water samples were collected from the surface and from 2 m off the reservoir bottom using a General Oceanics Niskin sampler. Water samples were also collected from the surface of eight tributaries: Keary Creek, Marshall Creek, Tyaughton Creek, Truax Creek, Gun Creek, the Middle Bridge River downstream of the Hurley River, and the Middle Bridge River at its confluence with Carpenter Reservoir (Figure 2.2). Water samples were filtered and preserved on site (as needed), stored on ice, and then shipped to ALS Environmental (Burnaby, BC) for analysis of pH, turbidity, total suspended solids, alkalinity, ammonia, nitrate, total nitrogen, orthophosphate, and total phosphorous.

Chlorophyll-a and phytoplankton samples were collected by integrating three depths within the euphotic zone (approximated using 2x the Secchi depth). Chlorophyll-a samples were filtered through a 0.45 µm mixed cellulose filter (MCE), frozen, then submitted to ALS Environmental for laboratory analysis. Phytoplankton samples were preserved using Lugol's solution and submitted to Biolgica Environmental for taxonomic and biomass determination; edibility to zooplankton was not assessed. Zooplankton were collected via duplicate vertical hauls (from a depth of 2 m off bottom, up to a maximum of 30 m) using a 153 µm Wisconsin net with a 30 cm opening; samples were rinsed and then preserved with 10% sugared formalin and submitted to Biologica Environmental for taxonomic and biomass determination.

In situ water column profiles of temperature, turbidity, dissolved oxygen concentration, conductivity, fluorescence, and photosynthetically active radiation (PAR) were collected at all reservoir stations (C1 through C10) where the water depth was >10 m (Figure 2.4). *In situ* profiles were collected using a SeaBird SBE19Plus CTD (SeaBird Electronics, Bellevue WA) deployed on the sunny side of the boat following a 0.5-minute period in air and 1.5-minute period where the entire CTD was submerged just under the water's surface. Profiles were terminated at depths within 1 to 3 m of the reservoir bottom.

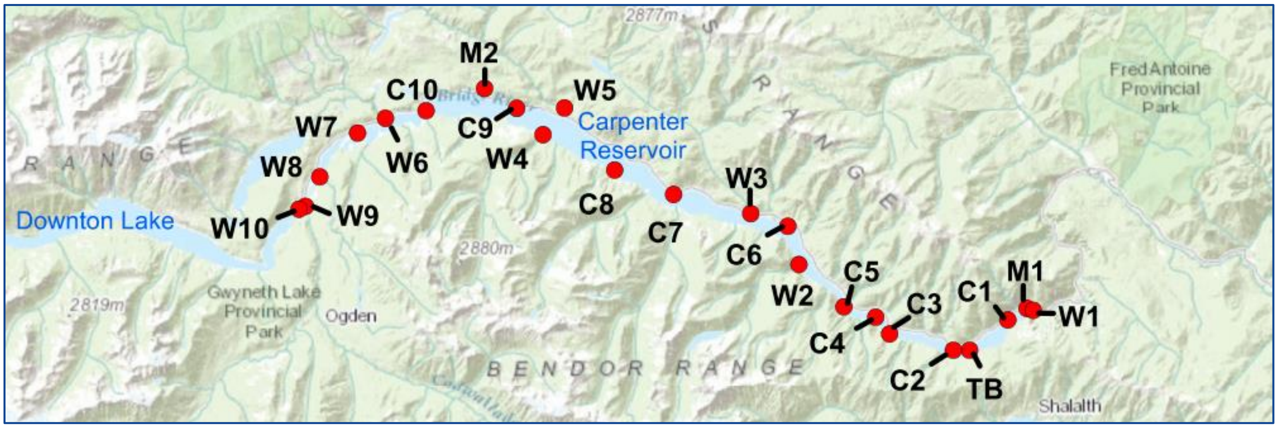


Figure 2.4 Carpenter Reservoir sampling stations (Figure 1 from Limnotek 2018). The prefix "W" represents tributary inflows, "M" represents meteorological stations, and "C" represents physical and chemical stations within the reservoir.

3. Results

3.1 Carpenter Reservoir Operating Parameters

3.1.1 Carpenter Reservoir Elevations

In 2021, Carpenter Reservoir elevation was characterized by a delayed moderate minimum elevation and high fall maximum elevation relative to previous years within BRGMON-4 (Figure 3.1). The reservoir reached a minimum elevation of 620.9 m on May 14, 2021, filled rapidly in May and June, then slowly reached a maximum elevation of 647.8 m on October 8, 2021 (Table 3.1). Reservoir elevation in 2021 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 between three operational regimes: the 10-year period prior to WUP implementation, the WUP/N2-2P regime (2011-2015), and the Modified Operations regime (2017-2021). There was no difference in average elevation in the first two weeks of April (Figure 3.3; ANOVA p-value = 0.553, DF = 2, F = 0.616) but there was a weakly significant difference between minimum elevation (ANOVA p-value = 0.028, DF = 2, F = 4.57). More importantly, there was less variation in elevation in the first two weeks of April, with elevation being low in all four years. There was also no difference in average elevation in August and September (Figure 3.4; ANOVA p-value = 0.109, DF = 2, F = 2.58) or maximum reservoir elevation (ANOVA p-value = 0.382, DF = 2, F = 1.03).

Overall, these comparisons highlight the substantial operational variation that is characteristic of Carpenter Reservoir. The most consistent findings were that minimum reservoir elevation (or elevation in the spring) has been low during Modified Operations relative to pre-WUP and N2-2P conditions. Although Carpenter Reservoir has historically experienced substantially lower minimum elevations (Figure 3.3), continued low minimum elevation are likely to have greater population-level effects relative to isolated low elevation events.

Table 3.1 Minimum and maximum elevations in Carpenter Reservoir from 2012 through 2021.

Year	Minimum Elevation	Minimum Elevation Date	Maximum Elevation	Maximum Elevation Date
2012	623.5	April 13	647.5	August 20
2013	622.5	April 12	648.5	October 10
2014	630.1	May 1	643.0	July 12
2015	630.8	March 21	648.8	October 29
2016	632.7	April 18	646.1	October 14
2017	615.2	May 5	644.7	September 26
2018	615.3	April 20	641.2	November 3
2019	616.2	May 5	645.1	August 20
2020	617.6	April 30	647.6	October 8
2021	620.9	May 14	647.8	October 8

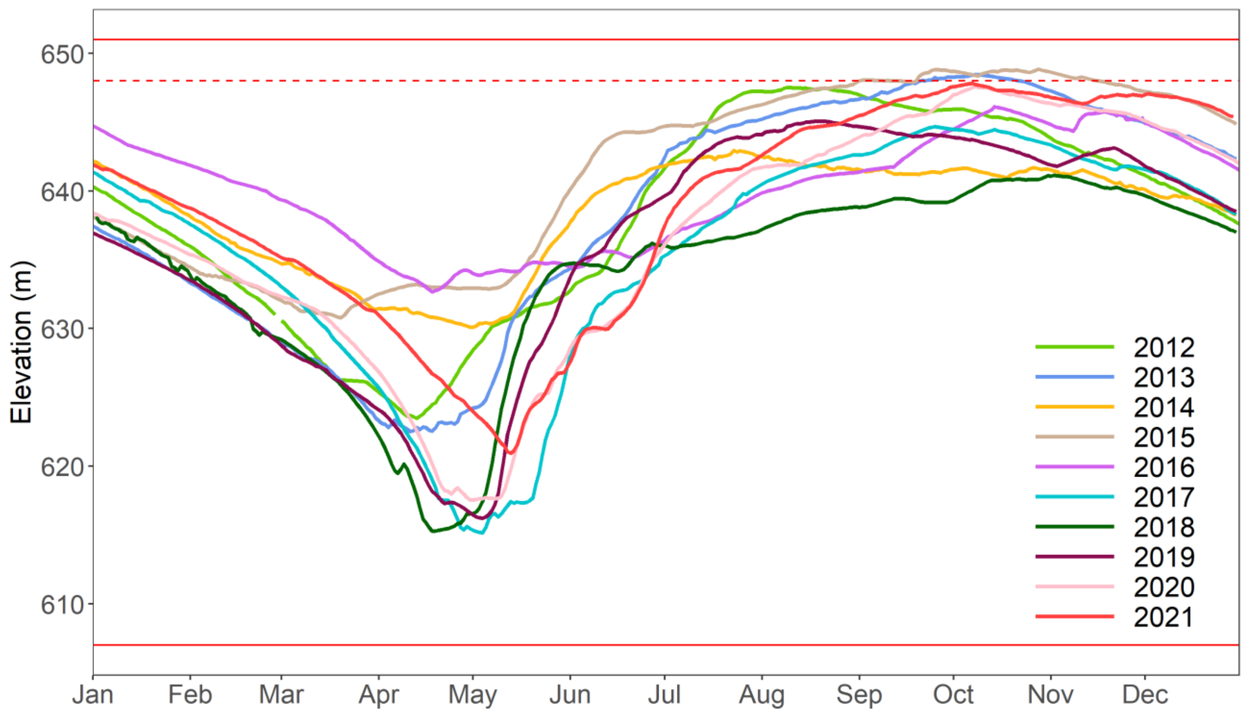


Figure 3.1 Carpenter Reservoir elevations (2012 to 2021). Solid horizontal red lines represent maximum and minimum operational targets of 606.55 m and 651.08 m, respectively, and dashed red line represents the soft operational maximum target of 648 m.

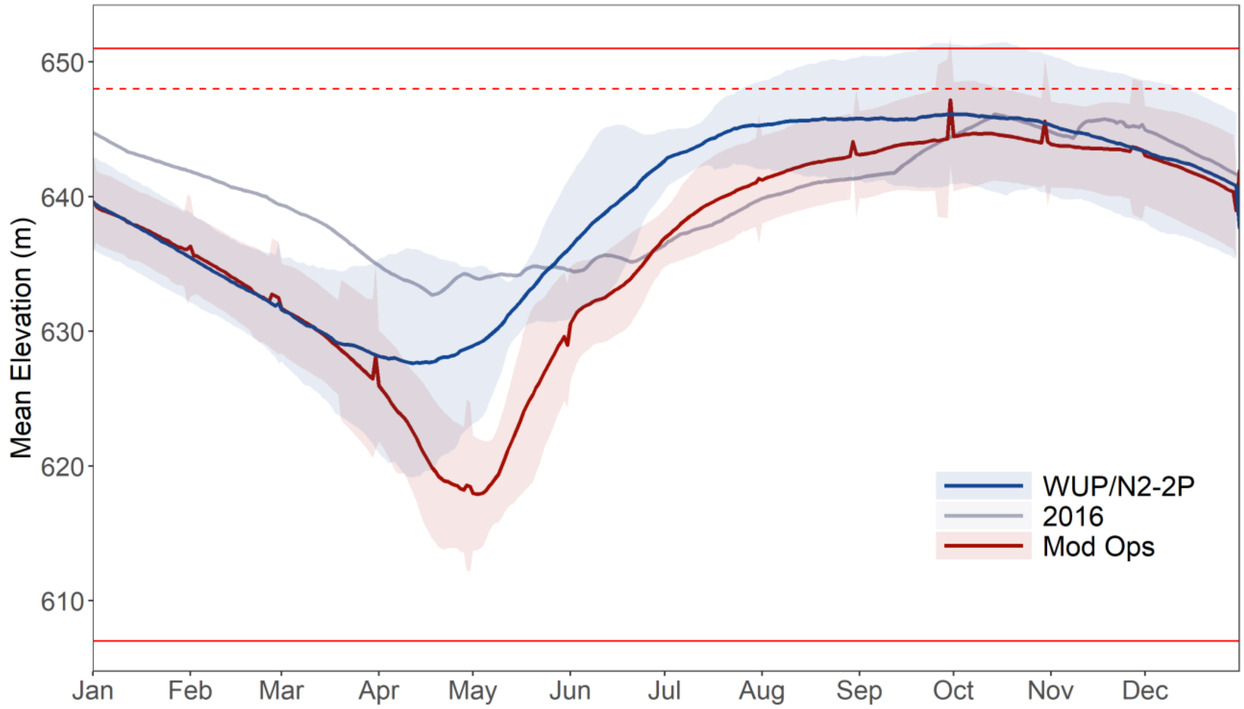


Figure 3.2 Average Carpenter Reservoir elevations from 2012 to 2021, separated into WUP/N2-2P (2012 to 2015), 2016, and Modified Operations (2017-2021) periods. Shading represents 95% confidence intervals. Solid red lines represent maximum and minimum operational targets of 606.55 m and 651.08 m, respectively, and dashed red line represents the soft operational maximum target of 648 m.

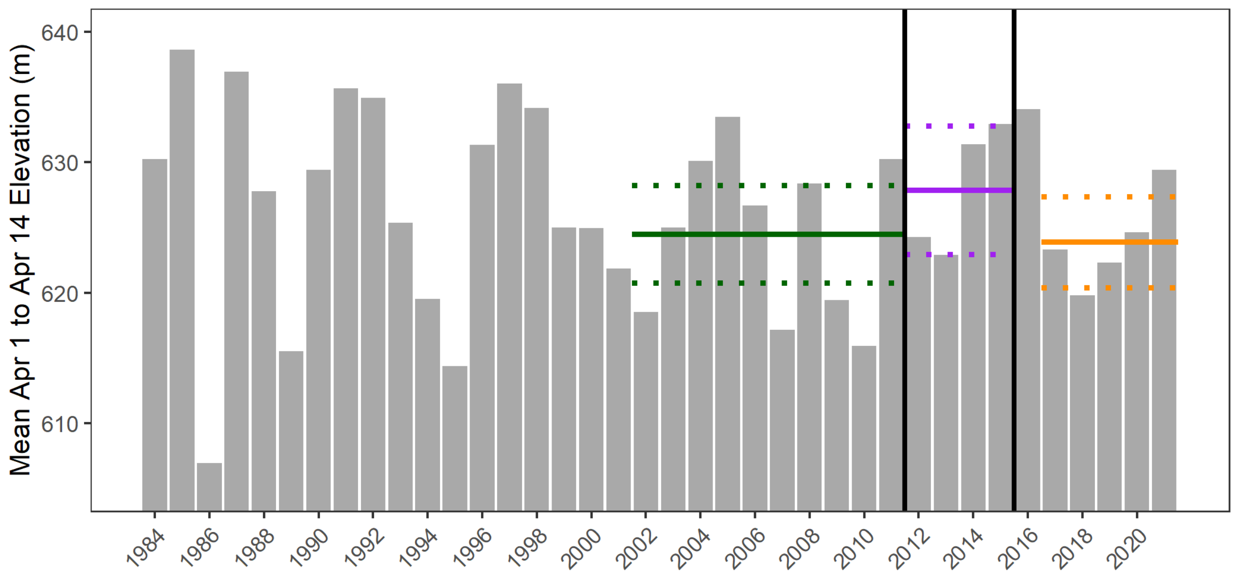


Figure 3.3 Historic average Carpenter Reservoir elevation from April 1 to April 14. Green lines show mean elevation (dashed lines represent 95% confidence intervals) from 2002 to 2011, purple lines show mean elevation from 2012 to 2015, and orange lines show mean elevation from 2017 to 2021 (2016 was not included in either N2-2P or Modified Operations because it was a transitional year).

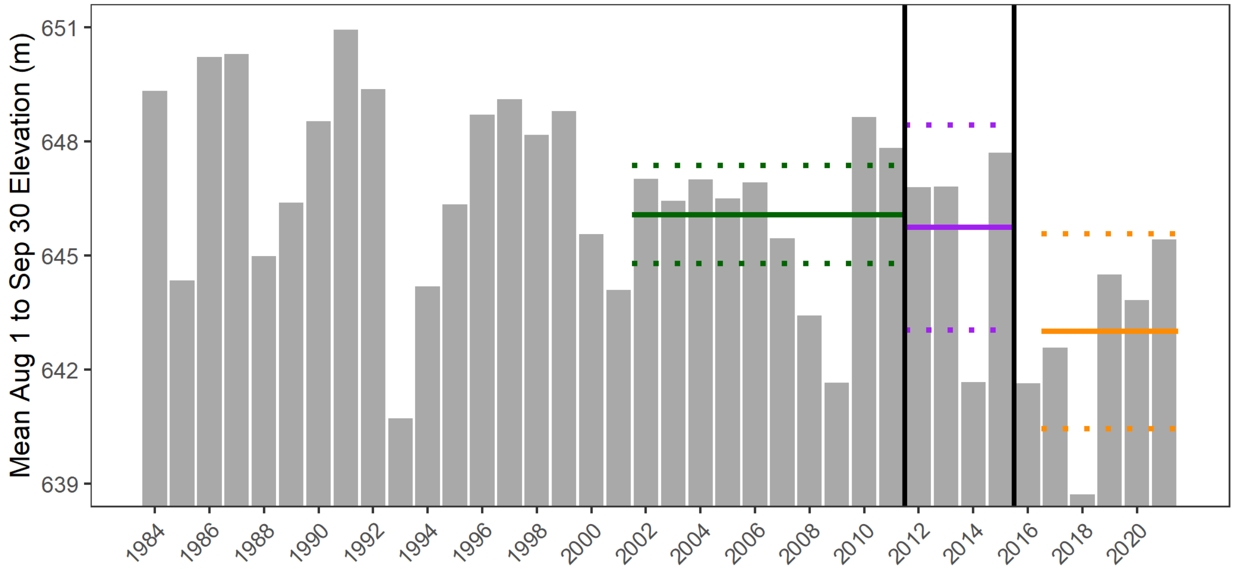


Figure 3.4 Historic average Carpenter Reservoir elevation from August 1 to September 30. Green lines show mean elevation (dashed lines represent 95% confidence intervals) from 2002 to 2011, purple lines show mean elevation from 2012 to 2015, and orange lines show mean elevation from 2017 to 2021 (2016 was not included in either N2-2P or Modified Operations because it was a transitional year).

3.1.2 Middle Bridge River Discharge

Instream discharge releases from Lajoie Dam in 2021 were relatively consistent with previous Modified Operation years (beginning in 2016; Figure 3.5). Discharge releases were consistently below 30 m^3/s from November through March (i.e., the combined kokanee and Mountain Whitefish incubation and hatching periods) with no substantial discharge reductions. Discharge releases were elevated from July through September and peaked in mid-September at ~100 m^3/s.

Qualitative comparisons among years suggest discharge releases from Lajoie Dam changed following the implementation of Modified Operations. Beginning in 2016, a relatively consistent pattern of increasing discharge releases occurred between May and October, resulting in substantially higher summer discharge releases relative to 2012 through 2015. In addition, winter discharges (i.e., November through April) appear to be more stable and lower (typically <30 m^3/s) relative to pre–Modified Operations. The consistent nature of winter discharges suggests a minimal risk of kokanee and Mountain Whitefish egg and alevin mortality because of Lajoie Dam operations.

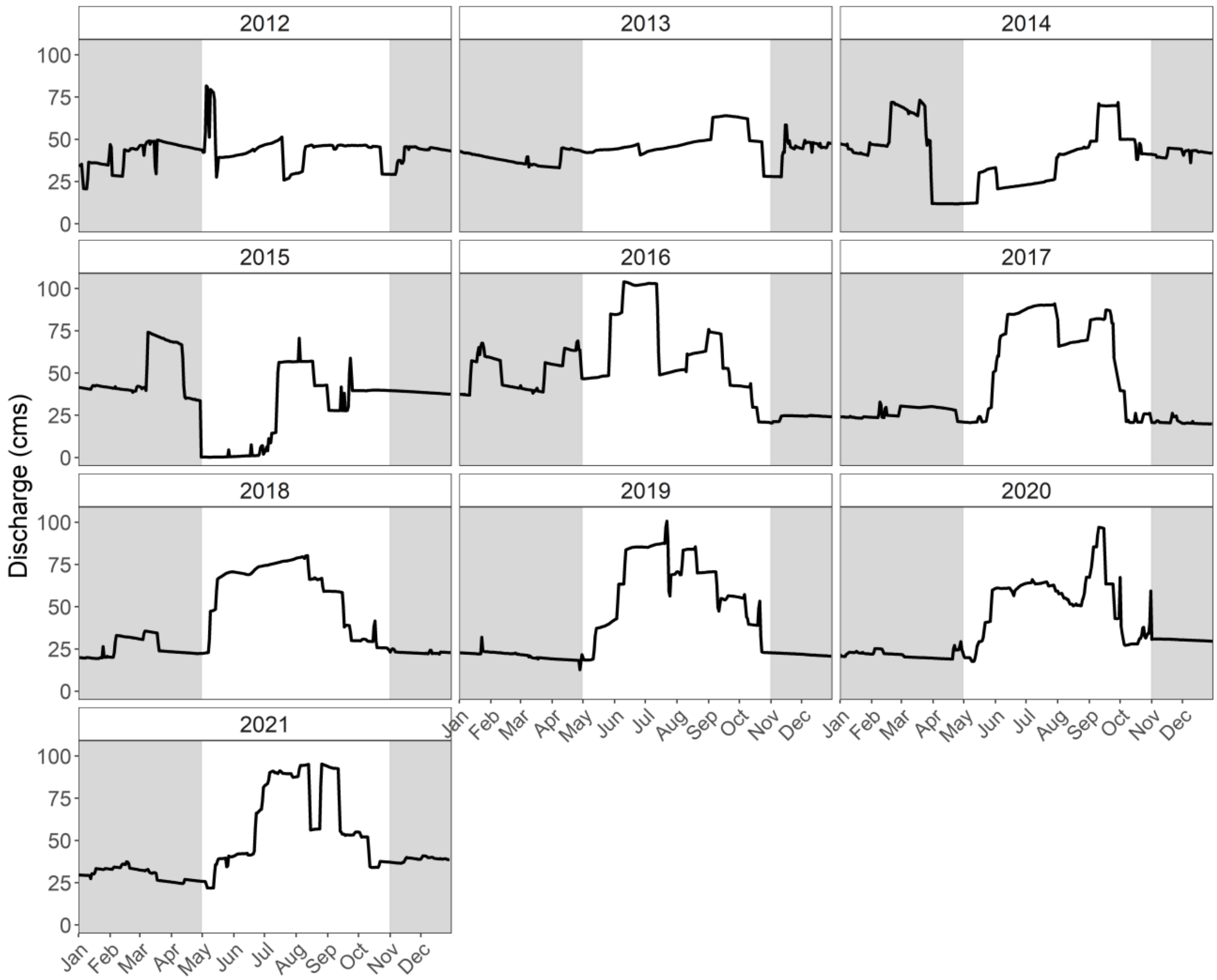


Figure 3.5 In-stream discharge releases from Lajoie Dam to the Middle Bridge River (2012 to 2021). Approximate egg incubation and hatching periods for kokanee (September through January) and Mountain Whitefish (November through March) are highlighted in grey.

3.2 Middle Bridge River Mountain Whitefish Spawning Assessment

A total of 18 Mountain Whitefish were angled from the Middle Bridge River at the Hurley and Goldbridge bridges between October 28 and December 9, 2020, the lowest total catch of all sampling years (2009, 2012, 2013, 2016, 2018; Figure 3.6). Due to low catches, we could not determine the peak spawn timing for Mountain Whitefish in 2020. Previous data indicate maximum catches typically occurred in the second or third week of November (e.g., Putt et al., 2017; Figure 3.7). To identify additional Mountain Whitefish spawning outside of the Middle Bridge River, visual surveys were performed in Macdonald Creek, Gun Creek, and Marshall Creek on November 18, 2020, but no evidence of spawning was observed.

Comparisons of Mountain Whitefish counts amongst survey years is a very uncertain method of assessing changes in population abundance. Catch-per-unit-effort (CPUE) would typically be the preferred method of comparison, but effort data were not available for years prior to 2016. In 2009, 2012, and 2013, field staff often capped catch data at 30 individuals; however, in 2016, 2018, and 2020, we sampled as many fish as possible within a 10-hour day (including travel time from Lillooet). Without effort data, we could not determine whether the total daily effort was similar between these two survey protocols. Furthermore, total catches were highly dependent on angler experience. From 2009 to 2013, the crew included highly experienced anglers. Since 2013, angler experience has decreased, with most recent crews consisting primarily of inexperienced anglers. However, even after accounting for variable effort and declining angler experience, data indicate that there are currently fewer Mountain Whitefish spawners holding at Middle Bridge River sampling sites relative to the early 2010s. Only 18 Mountain Whitefish were captured in 2020, and anglers did not observe the same degree of spawning evidence (e.g., bites, breaching) as in previous years.

Sex-specific fork length measurements suggest variability in fork lengths of Mountain Whitefish amongst sampling years, and low fork lengths for males in 2016 and 2018 relative to all other sampling years (Figure 3.8). We were unable to compare fork lengths statistically due to highly unequal sample sizes, but an increase in male fork lengths in 2020 suggest that the smaller fork lengths in 2016 and 2018 may not be a continued trend.

In 2016 and 2018, we determined the peak 50% hatch date for Mountain Whitefish in the Middle Bridge River using spawning dates and temperature data collected in the Middle Bridge River upstream of the Hurley River confluence (Figure 3.9). Temperature data for 2020-2021 was not available due to equipment failure. Based on an ATU requirement of 327, we predicted that peak

50% hatch likely occurs between January and March. Peak hatch dates were variable between the two years, as water temperatures were warmer in 2018 relative to 2016. Mountain Whitefish in British Columbia typically hatch in late March through early June (McPhail 2007). Because the Middle Bridge River is controlled by discharge releases from Lajoie Dam, its temperatures are warmer and more stable through the incubation period, resulting in an earlier estimated hatch date for Mountain Whitefish.

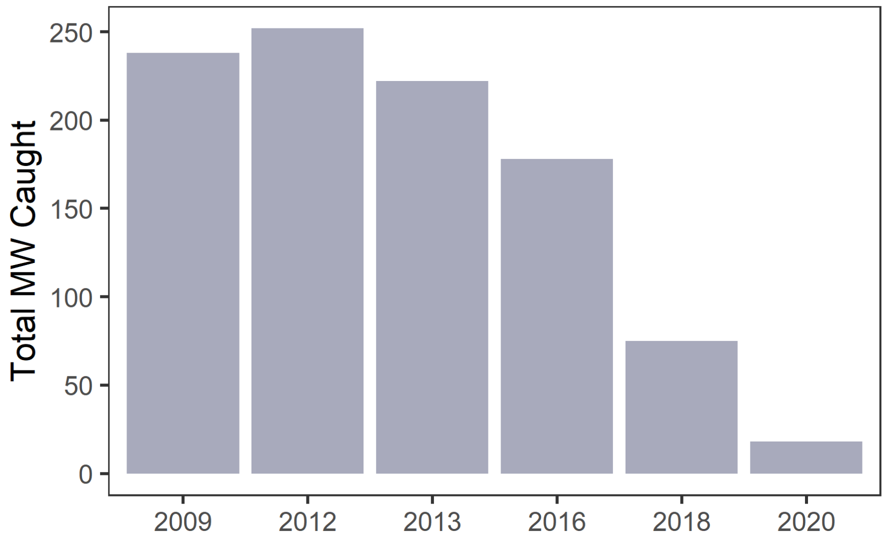


Figure 3.6 Counts of Mountain Whitefish captured during Middle Bridge River spawning assessments from 2009 to 2020. Counts are restricted to between October 25 and December 15 to account for variation in survey duration.

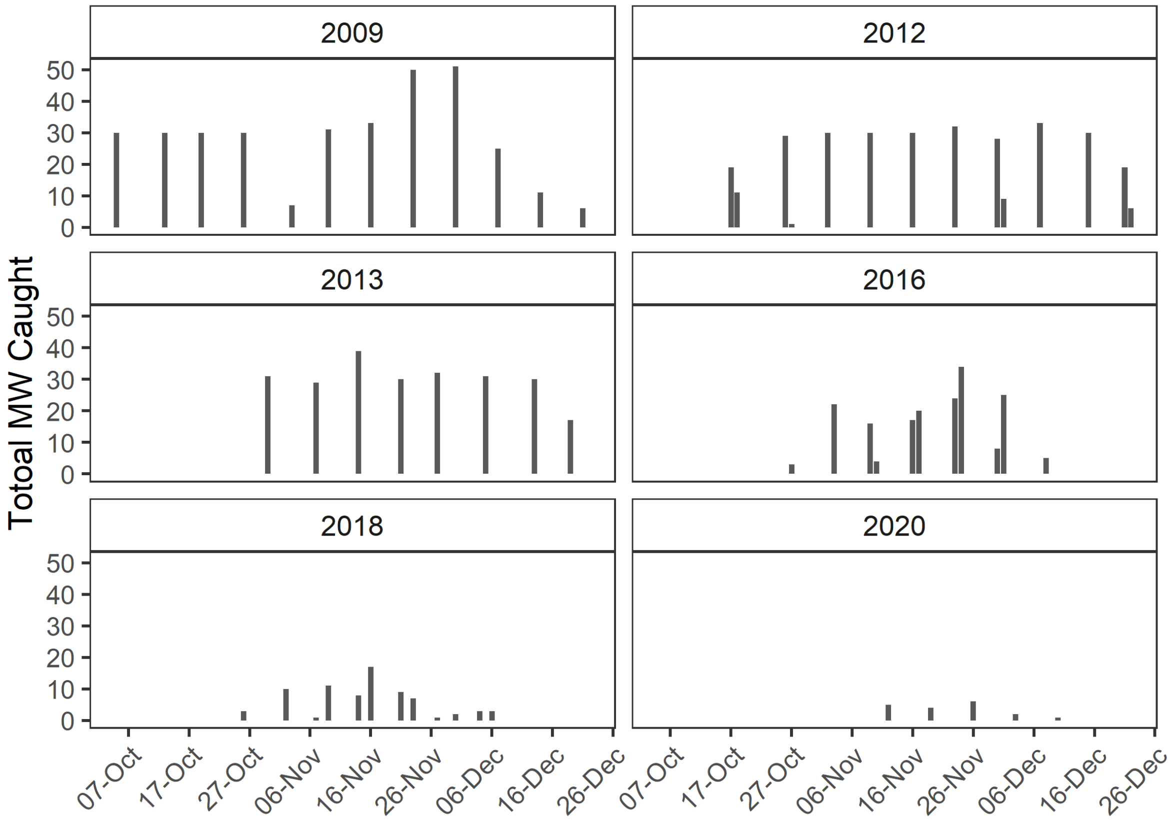


Figure 3.7 Catch distributions of Mountain Whitefish captured during Middle Bridge River spawning assessments from 2009 to 2020. In 2009, 2012, and 2013, a maximum of 30 fish were often sampled, and counts may have been higher given equal sampling effort to 2016 through 2020.

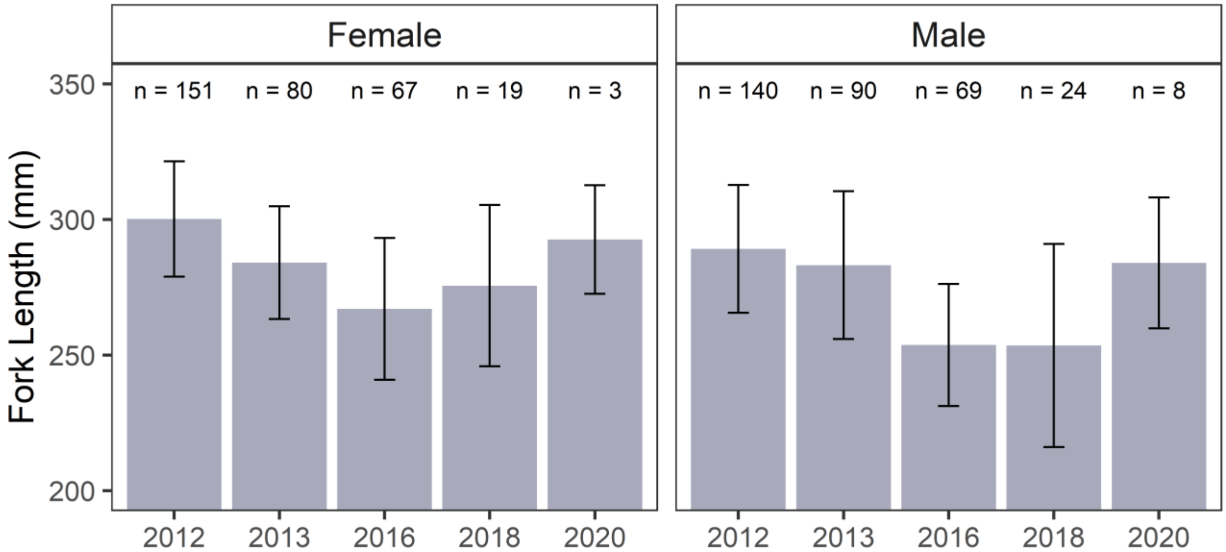


Figure 3.8 Fork lengths (with standard deviation) of mature male and female Mountain Whitefish captured during Middle Bridge River spawning assessments.

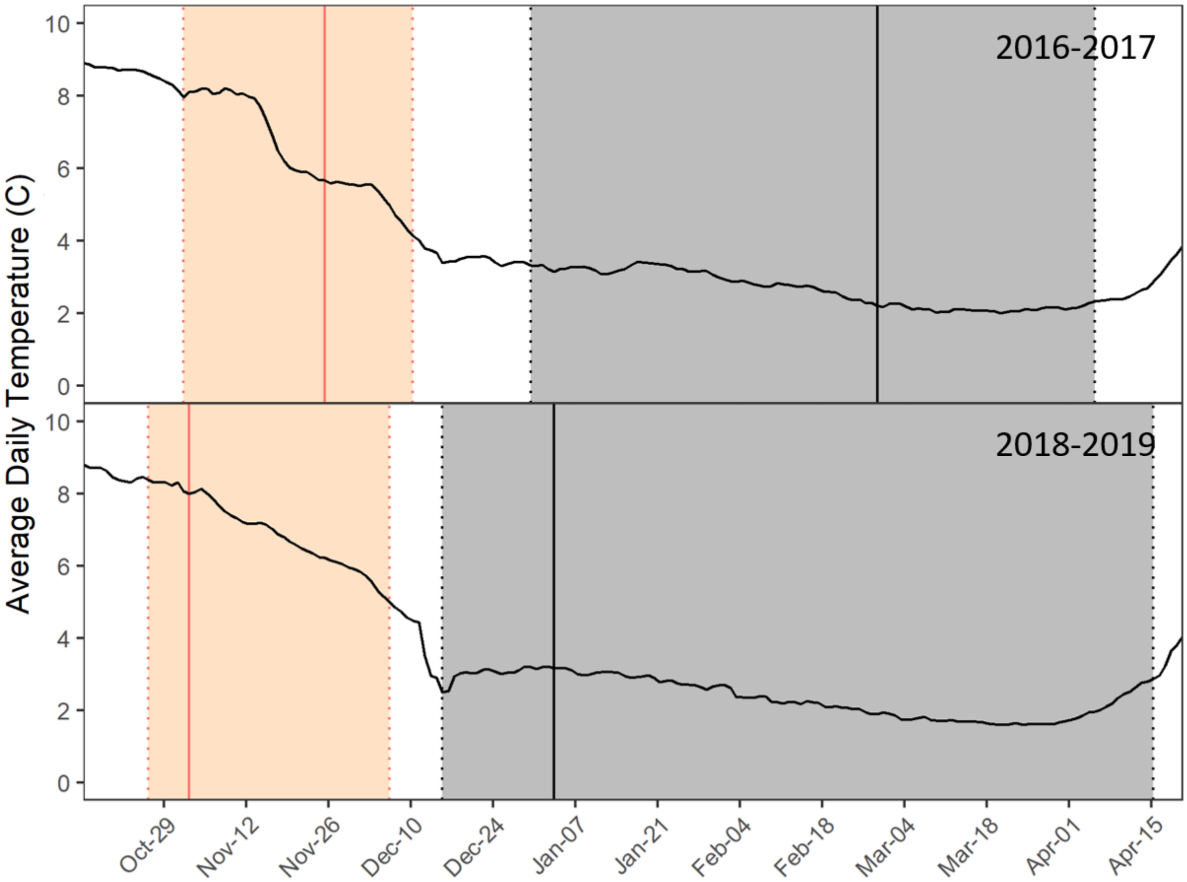


Figure 3.9 Mountain Whitefish spawning date range (red area) and 50% hatch date range (grey area) in the Middle Bridge River in winter 2016/2017 and 2018/2019 (ATU requirement of 327). Peak spawning and 50% hatch dates are shown as red and black lines, respectively.

3.3 Bull Trout Abundance Estimation

3.3.1 Mark-Recapture Field Program

The 2021 mark-recapture program took place in Carpenter Reservoir from June 14 to June 29 during reservoir filling (Table 3.2). Of the 104 Bull Trout captured via angling and boat electroshocking, 18 (17.3%) were recaptured from previous marking periods (Table 3.2). Relative effort for electroshocking remained similar amongst the five monitoring years, but angling effort was lower in 2021 due to an anomalous heat wave that caused challenging conditions and flooding within the watershed. In 2021, 65.1 hours were spent angling, and 4.8 hours were spent electroshocking. A total of 60 Bull Trout were captured during angling, while 47 were captured during electrofishing. CPUE was relatively consistent for each capture method across sampling years, with electrofishing CPUE consistently higher (yet more variable) than angling (Figure 3.10). During mark-recapture sampling, we also caught Mountain Whitefish (n = 376), Rainbow Trout (n = 160), and kokanee (n = 8), primarily during electroshocking. Rainbow Trout captures in 2021 were more than 2x higher than any previous year (160 in 2021 vs 68 in 2017), with Rainbow Trout being captured during both angling and tributary electrofishing. We did not quantitatively test for differences in electroshocking CPUE amongst years or locations due to the spatial and temporal variability of turbidity in Carpenter Reservoir.

All Bull Trout were sampled for length and weight, and we compared fork length and condition among years. The mean fork length of Bull Trout captured during the 2021 mark-recapture program was 402.6 mm (SD 77.6 mm; Table 3.3). Average fork length for Bull Trout captured during the mark-recapture program differed from 2015 to 2021 (ANOVA p-value <0.001, $F = 17.64$; Figure 3.11), and a Tukey's test indicated that mean fork lengths in 2018 through 2020 were statistically similar, and higher than in 2015 through 2017 ($\alpha = 0.05$). Fork lengths in 2021 were more variable, and were statistically similar to virtually all years of the mark recapture program (fork lengths were greater in 2021 relative to 2015).

Two subsets of Bull Trout fin rays were used to develop age length keys (ALKs) for Carpenter Reservoir: one subset primarily consisted of fin rays from 2015 and 2016, while the second sample was primarily from 2020 and 2021. Previous reports used ages from 2015 and 2016 to estimate Bull Trout ages for all other years; however, ageing results from 2020/2021 suggest Bull Trout age characteristics have changed since 2016. For this reason, we used two separate ALKs to estimate Bull Trout ages for the mark recapture period, and removed age estimates from 2017 through 2019, as it is not clear which ALK is most appropriate for these years. Age and fork length data suggest the age distribution of Bull Trout captured during the annual mark-recapture program is shifting towards younger Bull Trout (Figure 3.12). In 2015 and 2016, ~50% of Bull Trout captured during the mark recapture sampling had estimated ages greater than 5, while in 2020 and 2021 this percentage dropped to ~25% (Figure 3.12).

Table 3.2 Mark-recapture capture summary data for Carpenter Reservoir Bull Trout (2015 to 2020).

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
2019 (Jun 17 – July 5)	638.8 (637.6-639.9)	159	42	26.4
2020 (Jun 21 – July 10)	635.9 (633.0-638.1)	171	27	15.8
2021 (Jun 14 – Jun 29)	632.9 (630.2-637.0)	104	18	17.3

Table 3.3 Fork lengths (mm) of Bull Trout captured during mark-recapture sampling in Carpenter Reservoir (2015-2020).

Year	N	Mean	SD	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
2019	156	419.7	84.5	118	670
2020	170	419.8	69.5	242	720
2021	104	402.6	77.6	127	699

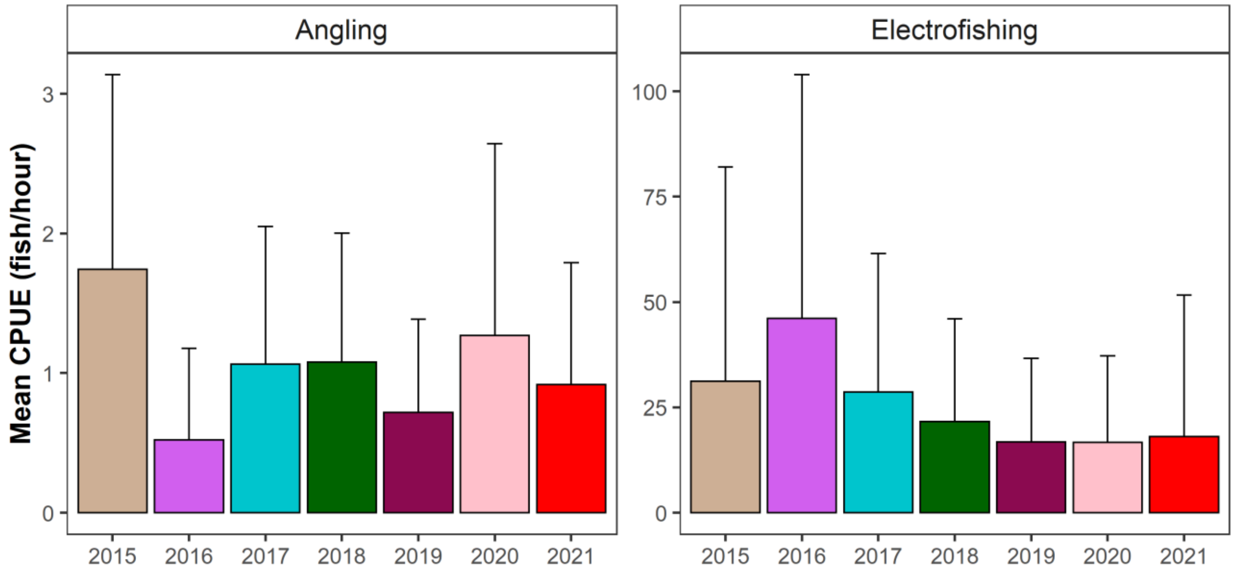


Figure 3.10 Gear-specific mean CPUE (fish/hour) with standard deviations for Bull Trout captured during the mark-recapture program. Y-axis is free to show variation in gear types.

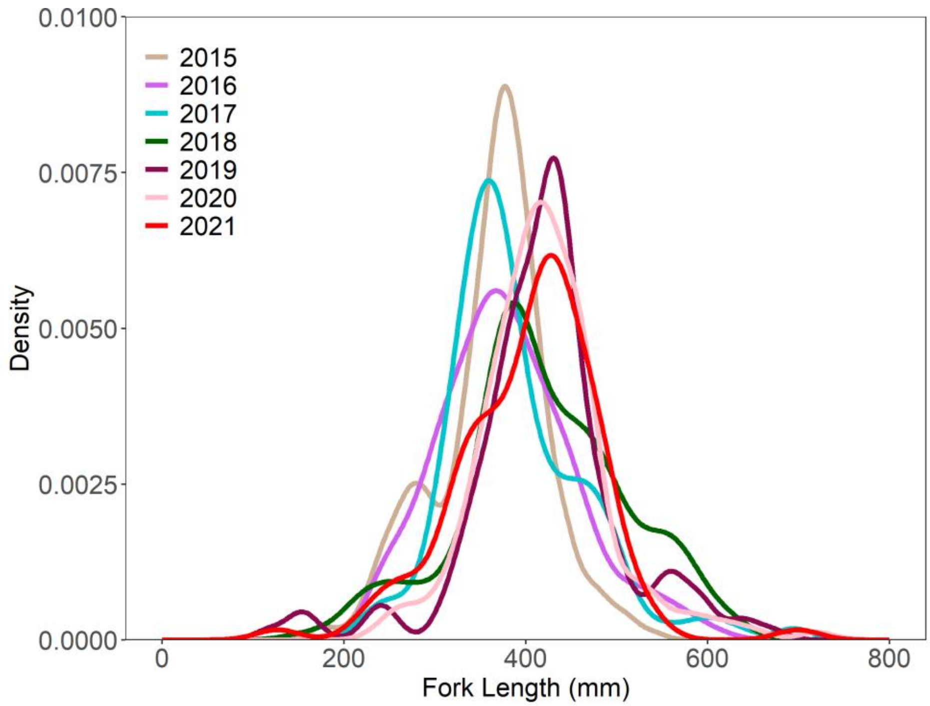


Figure 3.11 Probability density function (from kernel density estimation) of fork lengths for Bull Trout captured during the Carpenter Reservoir mark-recapture program.

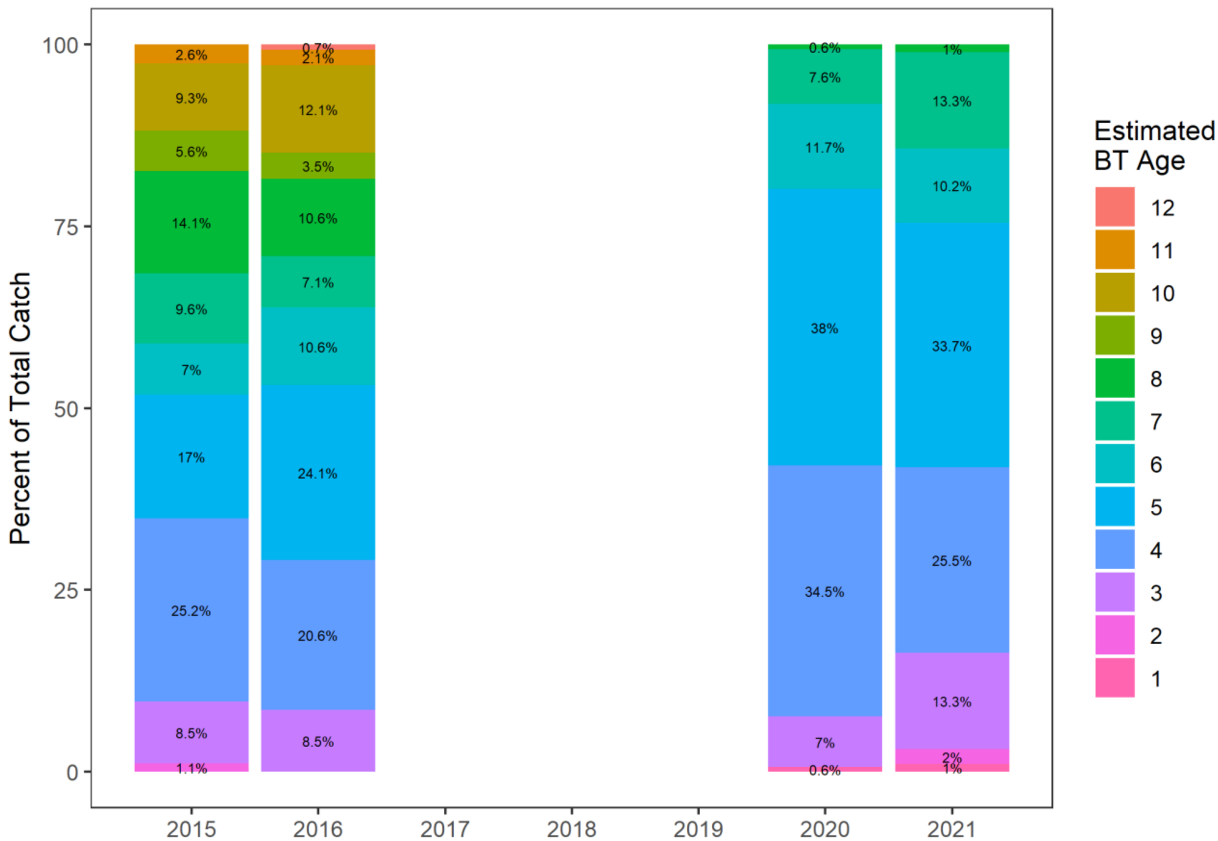


Figure 3.12 Bull Trout captures during annual mark-recapture sampling in Carpenter Reservoir separated into age classes estimated using Bull Trout Age Length Key (ALK).

3.3.2 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 2021 (abundance could not be calculated for 2015 because there was no value of capture probability for the first capture period). During model averaging, the fully time-varying model was dropped from the averaged results because survival in the final year was estimated as 1.0 (SE 0.0), indicating confounding between the survival and capture probabilities. The model-averaged CJS abundance of adult Bull Trout in Carpenter Reservoir was 2,779 individuals (95% CI: 1,1181-6,534) in 2016, 1,978 (95%CI: 1,549-2,526) in 2017, 844 (95% CI: 605-1,177) in 2018, 316 (95% CI: 175-569) in 2019, 450 in 2020 (95% CI: 269-754), and 445 in 2021 (95% CI: 265-747; Figure 3.13).

Parameter estimates and abundance estimates were relatively uncertain, as indicated by wide confidence intervals (Figure 3.13, Figure 3.14). The large uncertainty surrounding the 2016 abundance estimate is because of the large number of fish we tagged in the early mark-recapture years, followed by relatively low recapture rates in subsequent years. When 2015 data are removed from the analysis, estimated abundance remains virtually unchanged in subsequent years. Uncertainty in the mark-recapture estimates is expected given the broad nature of the program, the relatively low recapture rates in some years, and the varied reservoir conditions during sampling. Although there is uncertainty in the annual population of Bull Trout, preliminary evidence from the mark-recapture program suggests Bull Trout abundance in Carpenter Reservoir may have declined since Modified Operations (Figure 3.13).

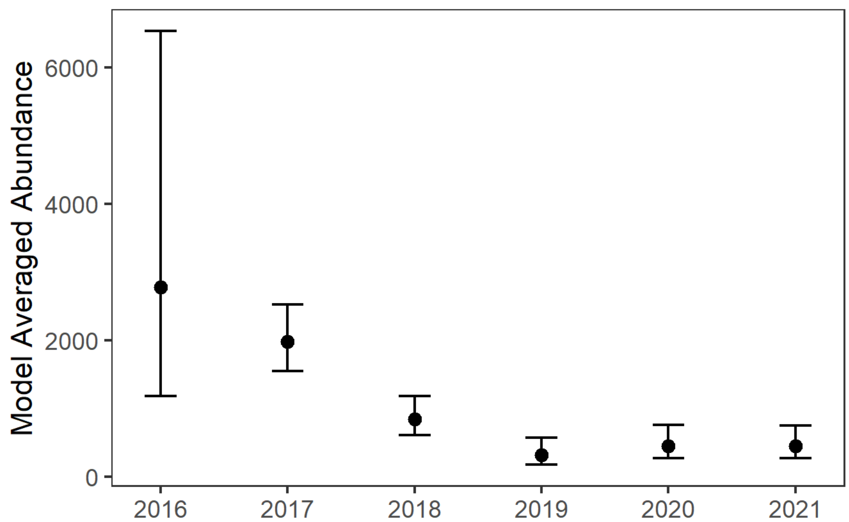


Figure 3.13 Bull Trout abundance in Carpenter Reservoir calculated using model-averaged capture probabilities from the open mark-recapture model.

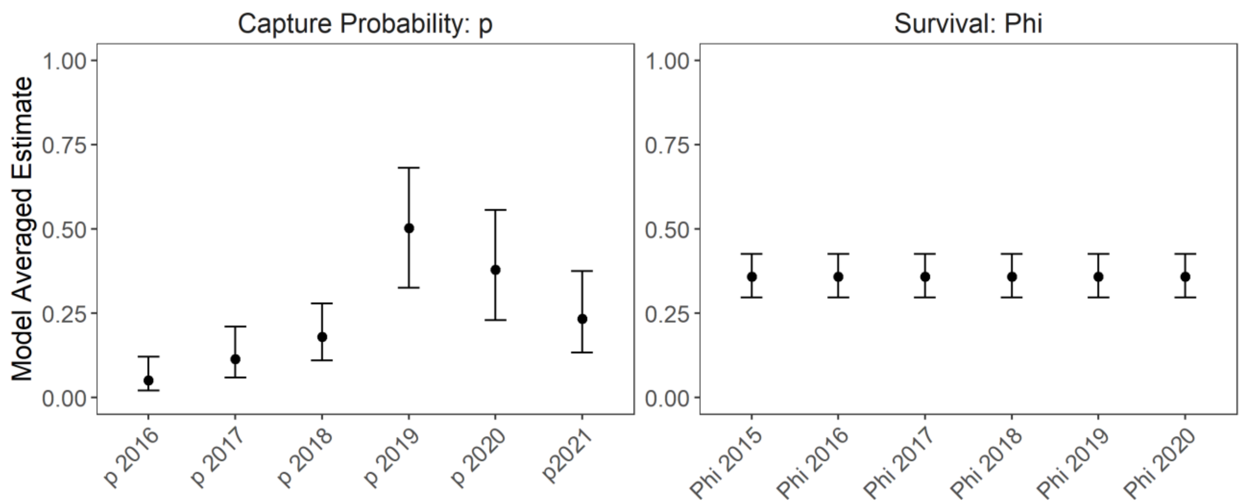


Figure 3.14 Model averaged capture and survival probabilities for the Carpenter Reservoir open mark-recapture model.

3.4 Bull Trout Movement Analysis

3.4.1 Acoustic Tagging and Movement Data

Approximately 20 Bull Trout were tagged annually from 2015 to 2021 with acoustic transmitters having an estimated battery life of two years. We aimed to tag Bull Trout with weights > 550 g to minimize tagging effects. Bull Trout tagged in 2021 were similarly sized relative to previous years, ranging from 410 mm to 522 mm.

We collected and downloaded the acoustic receivers in May 2021, and subsequently redeployed them to be downloaded in May 2022. There is a one-year lag between the acoustic data reported here and the other analyses described in this report (this report describes acoustic data up to May 14, 2020). A total of 35 tagged Bull Trout were detected by the acoustic receivers between May 1, 2020, and May 14, 2021. Detected tags were released in 2017 (n=1), 2018 (n=3), 2019 (n=11), and 2020 (n=20). The tags released in 2017 and 2018 were scheduled to deplete their battery early in the 2020 to 2021 monitoring period, after which their movement patterns are unknown.

Acoustic detection data showed that habitat used by Bull Trout varied spatially and temporally throughout the monitoring period (Figure 3.15). Despite this variation, tagged Bull Trout were detected consistently at the Terzaghi Dam Diversion, and C3 receivers throughout the monitoring period (Figure 3.15), suggesting Bull Trout use deep lacustrine habitat throughout the year.

Detection data also showed shifts in tagged Bull Trout as Carpenter Reservoir elevations slowly decreased from February to early May, then increased in June and July (Figure 3.1). Detections at Keary, Tommy, and Truax Creeks were low in the spring, when elevations were at a minimum, but increased substantially during the summer and fall. The data suggest Bull Trout may prefer these mid-reservoir habitats (Keary, Tommy, and Truax) when they are available in the summer. Then, in spring, as the amount and quality of habitat declines in Carpenter Reservoir (i.e., elevations decrease), Bull Trout likely move east towards the lacustrine portion of the reservoir.

We combined the Terzaghi Dam, Diversion, and C3 receivers into a single detection station representing the lacustrine portion of the reservoir and plotted detection histories for tags active in 2020 (i.e., tagged in 2020, or 2021; Figure 3.15 and Figure 3.16). Some Bull Trout were detected primarily on one or two receivers, while other Bull Trout moved throughout the system. These movement patterns suggest distinct behaviour types and spawning locations for Bull Trout in Carpenter Reservoir. We also summarized Bull Trout movements according to two elevation periods: low pool (April and May), and high pool (August through November). Based on receiver location alone (excluding movement in areas not monitored by receivers), Bull Trout moved an average of 10.3 km (SD 5.7 km) during low pool and 18.6 km (SD 9.6 km) during high pool. These values are similar, suggesting Bull Trout are relatively mobile, on average, when residing in the reservoir.

We further summarized the receiver detections for 2018 and 2019 into those from the Middle Bridge River, in Carpenter Reservoir east of Marshall Creek, and in Carpenter Reservoir west of Marshall Creek (splitting the reservoir approximately in half) to examine gross patterns in annual movement over the two years. One consistent finding was that detections at western receivers increase in June and July. This finding corroborates observations from the field, suggesting Bull Trout utilize western habitat as reservoir elevations rise sufficiently for these tributaries to discharge directly into the reservoir, rather than the drawdown zone/extended Middle Bridge River. Another consistent finding was that detection decrease on all receivers in the reservoir in August and September, during the Bull Trout spawning migration. Detections in the MBR display a corresponding increase in July through October, but vary among the three years.

Of the 35 fish detected, ten (29%) were detected by the Middle Bridge River receivers. Since 2015, the percentage of Bull Trout entering the Middle Bridge River in late summer has varied (2015 [55%], 2016 [28%], 2017 [40%], 2018 [12%], 2019 [19%]), and there has been weak evidence (due to high variability) of a decline in migrations into the Middle Bridge River.

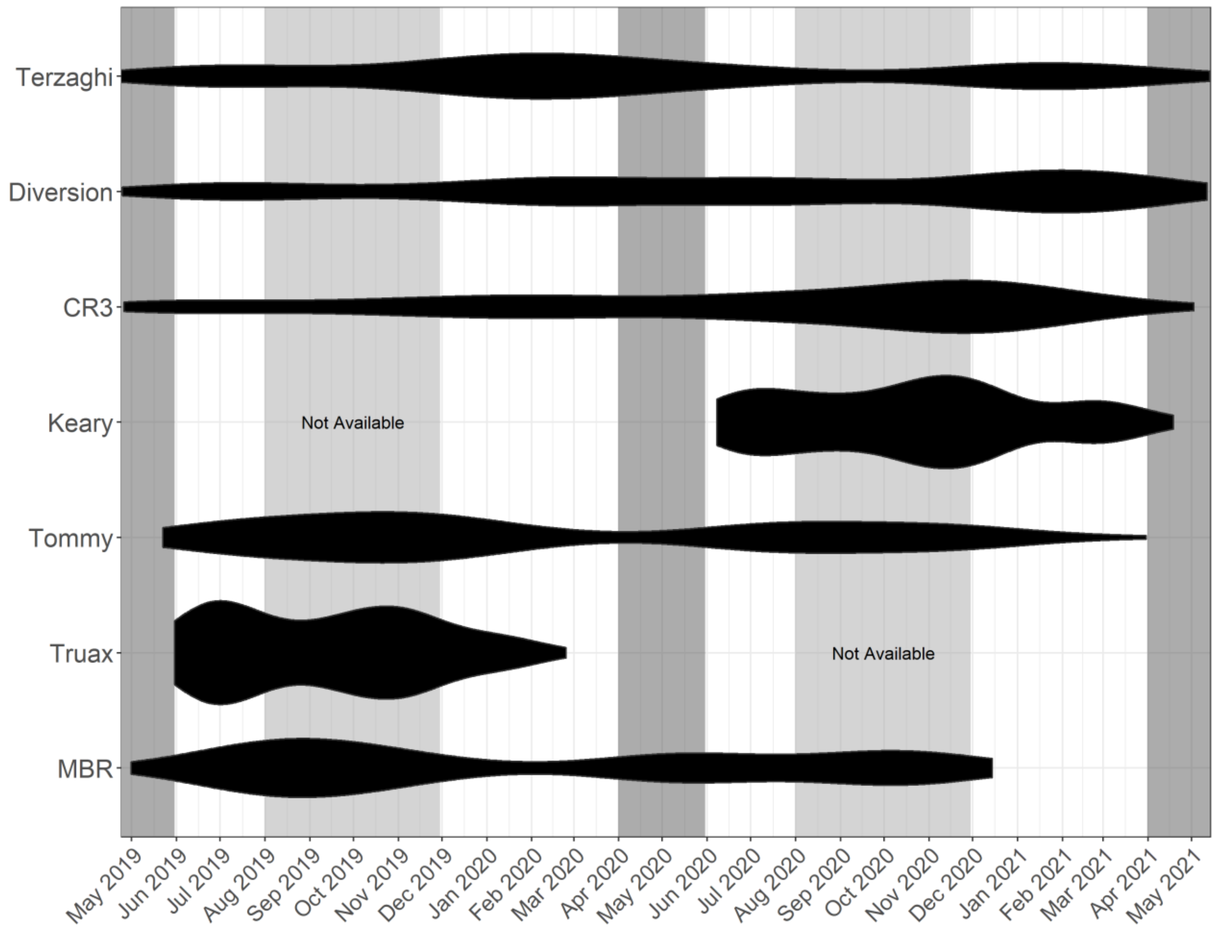


Figure 3.15 Presence of acoustic-tagged Bull Trout at seven receiver locations in Carpenter Reservoir and in the Middle Bridge River from April 2019 to May 2021. Light shaded areas represent approximate full pool conditions, while dark grey shaded areas represent approximate low pool conditions.

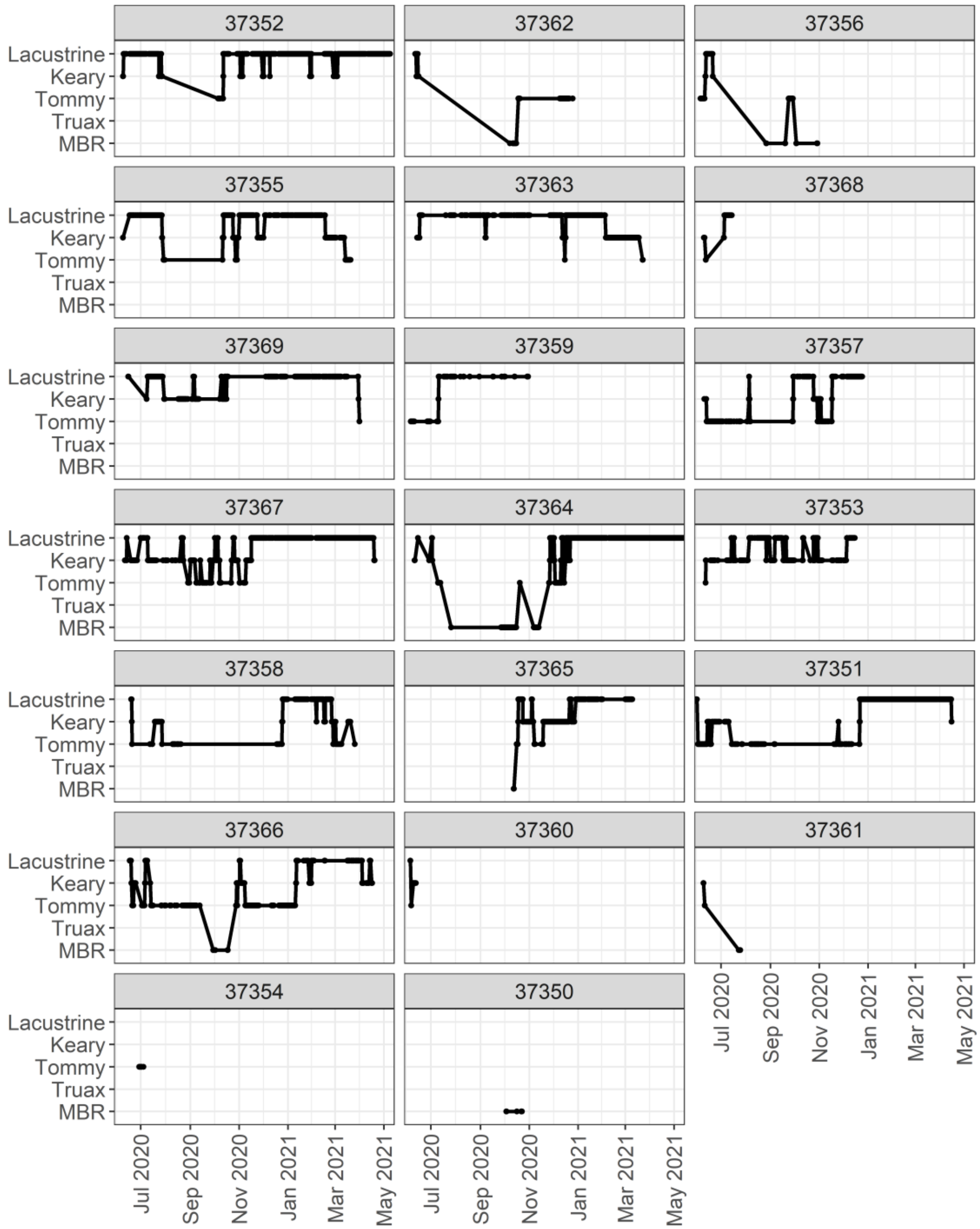


Figure 3.16 Movement summaries for acoustic Bull Trout tagged in May and June of 2020. Points show detections, while connecting lines represent presumed location.

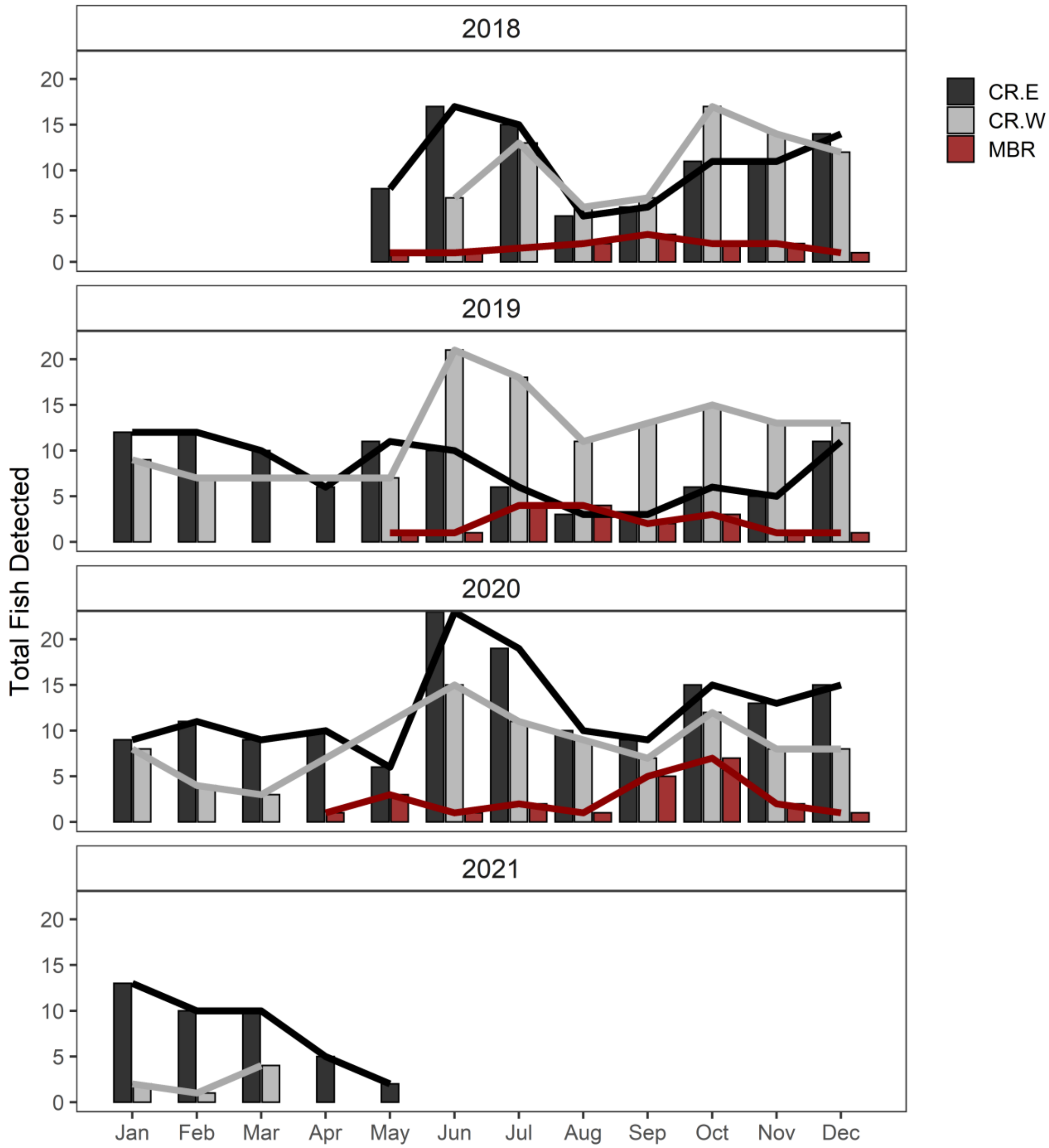


Figure 3.17 Summary of the number of fish detected monthly at acoustic receivers located in Carpenter Reservoir East (Terzaghi, Diversion, CR3, Keary), Carpenter Reservoir West (Tommy, Truax), and the Middle Bridge River.

3.4.2 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 2021. This recapture database was much larger than the mark-recapture database because it included captures and recaptures that occurred outside of the designated mark-recapture period. Of the 1,878 PIT tags deployed in Carpenter Reservoir Bull Trout since 2012, 399 were subsequently recaptured. It was difficult to draw conclusions from the PIT tag recapture database because the recapture rate was low, and the sampling period was typically restricted to June and July. Acoustic telemetry provides a much more complete movement history. Most Bull Trout recaptured in Carpenter Reservoir were only caught twice (i.e., their original capture occasion and one recapture; Figure 3.18). Also, most Bull Trout were recaptured relatively close to their original capture location (i.e., within 10 to 15 km; Figure 3.19).

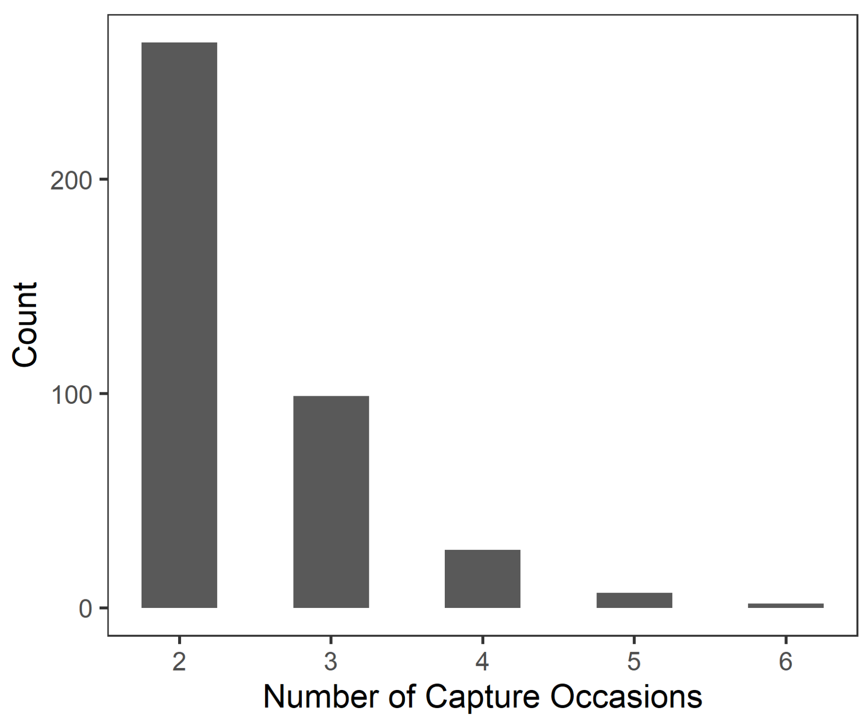


Figure 3.18 Number of capture occasions for Bull Trout tagged and subsequently recaptured in Carpenter Reservoir since 2012.

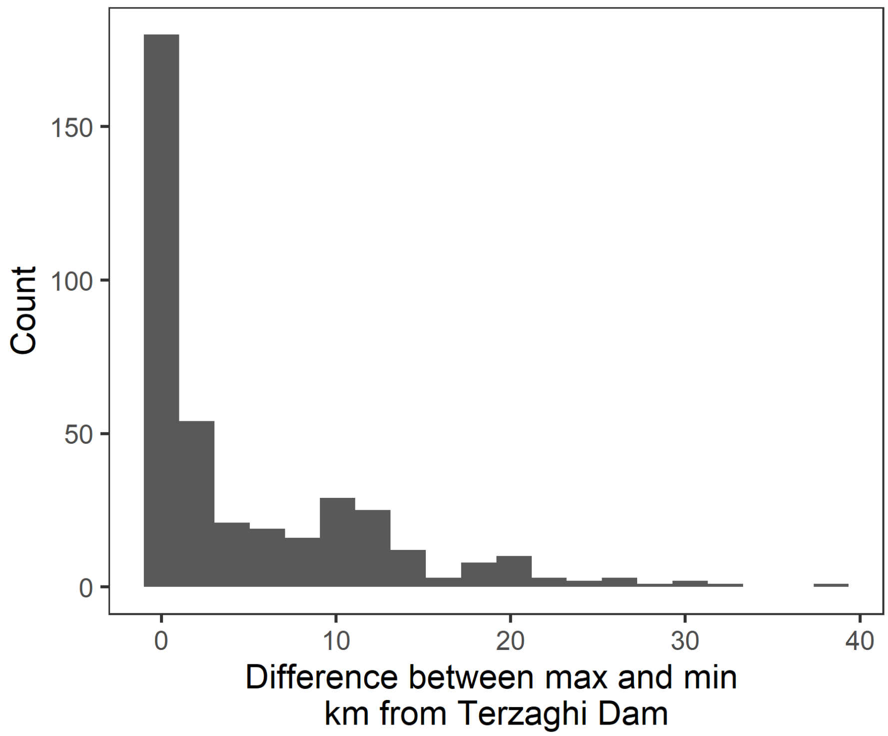


Figure 3.19 Summary of maximum km from Terzaghi Dam minus minimum km from Terzaghi of each Bull Trout recaptured in Carpenter Reservoir since 2012.

3.5 Analysis of Biological Data

Species-specific length, weight, and age data were collected to describe biological characteristics of fish species in the Carpenter Reservoir watershed (Table 3.4). Ages were determined for scales (kokanee, Rainbow Trout, Mountain Whitefish), fin rays (Bull Trout), and otoliths (accidental mortalities of all species; Table 3.5).

Table 3.4 Count of fish in Carpenter Reservoir sampled for biological characteristics (length, weight, and potential ageing structure) in 2013 through 2021 (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	344	3
2019	209	37	214	0
2020	235	60	223	1
2021	237	365	287	60
Total	1,795	698	1,524	144

Table 3.5 Ageing structures analyzed in 2014 through 2021 of BRGMON-4.

Species	Scales Aged	Otoliths Aged	Fin Rays Aged	Total Structures Aged
Bull Trout	18	10	142	170
Kokanee	56	0	0	56
Mountain Whitefish	234	31	0	265
Rainbow Trout	624	2	0	626

3.5.1 Bull Trout

Lengths and weights of Bull Trout captured in Carpenter Reservoir from 2013 to 2021 were highly correlated (adjusted R^2 = 0.94). Year and a year*length interaction were highly significant additions to the model (ANOVA p-values <0.001). 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. We also examined the length-to-weight relationship and condition factor of Bull Trout with lengths between 200 mm and 350 mm, or approximately age 3 to age 6. Length and weight were highly correlated for ages 3 through 6 (adjusted R^2 = 0.75) and the addition of year to the length-weight model was highly significant (ANOVA p-value <0.001, DF

= 8, F = 10.08); the interaction term was not significant, suggesting similar slopes among years but variable intercepts.

There was a significant difference between mean Fulton's condition factor in 2013 through 2021 for Bull Trout age 3 to 6 (ANOVA p-value = <0.001, DF = 8, F = 8.96), and a Tukey's HSD test indicated that although condition of age 3-6 Bull Trout was variable, condition in 2017 may have been lower relative to most years, while condition in 2019 and 2020 may have been high relative to other years (Figure 3.20). We also examined the change in condition of Bull Trout ages 7 and above captured in the reservoir each year (not shown). For Bull Trout ages 7 and above, annual condition was less variable, suggesting larger fish are undergoing reduced growth and are less affected by reservoir conditions.

A total of 170 Bull Trout were aged by IFR (otoliths and juvenile scales) and North South Consultants (fin rays; Table 3.5). Estimated Bull Trout ages ranged from 0 to 12 years. A Gompertz growth model was successfully fit to Bull Trout length and age data, which shows an asymptotic length of 517.02 mm (95% CI 478.36 – 567.70 mm) and fastest adult growth in ages 3 to 6 (Figure 3.21). We compared Bull Trout growth models between WUP (2013-2016) and Modified Operations (2017-2021; Figure 3.21), and found that growth rates may have increased in Carpenter Reservoir during Modified Operations (WUP asymptotic length: 531.82 mm, Mod Ops asymptotic length 659.28 mm), but Bull Trout older than age 7 were rarely caught during modified operations.

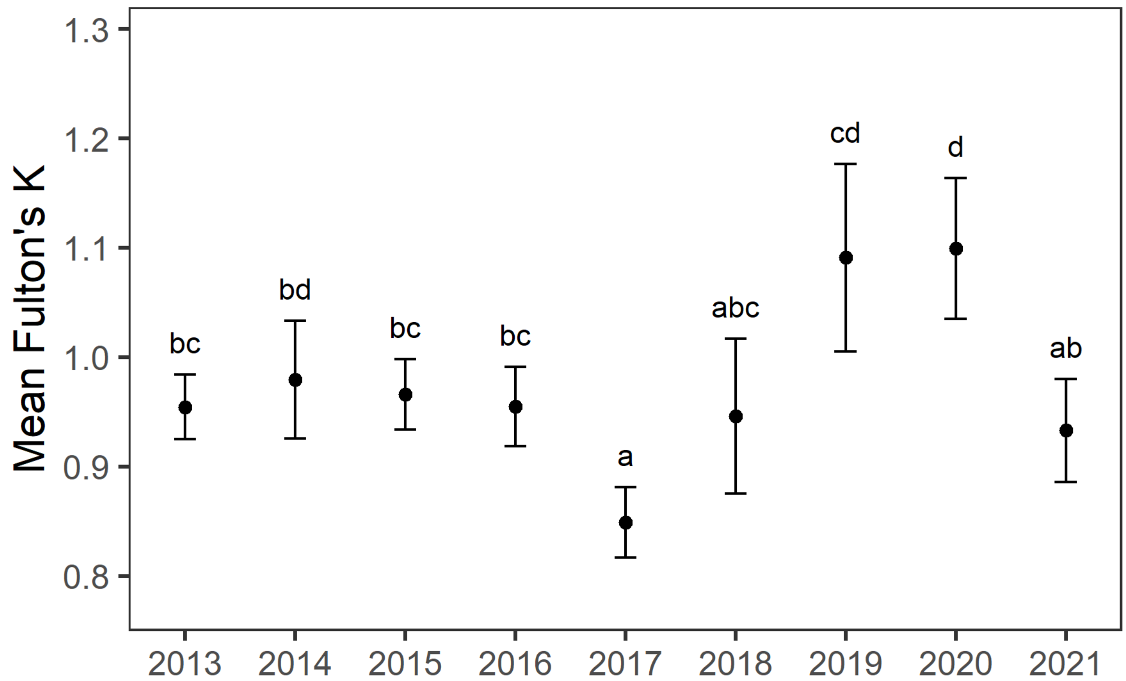


Figure 3.20 Mean annual condition factor (Fulton's K) and predicted 95% CI for Bull Trout in Carpenter Reservoir, approximately age 3 to 6. Means with the same significance letter are statistically equal.

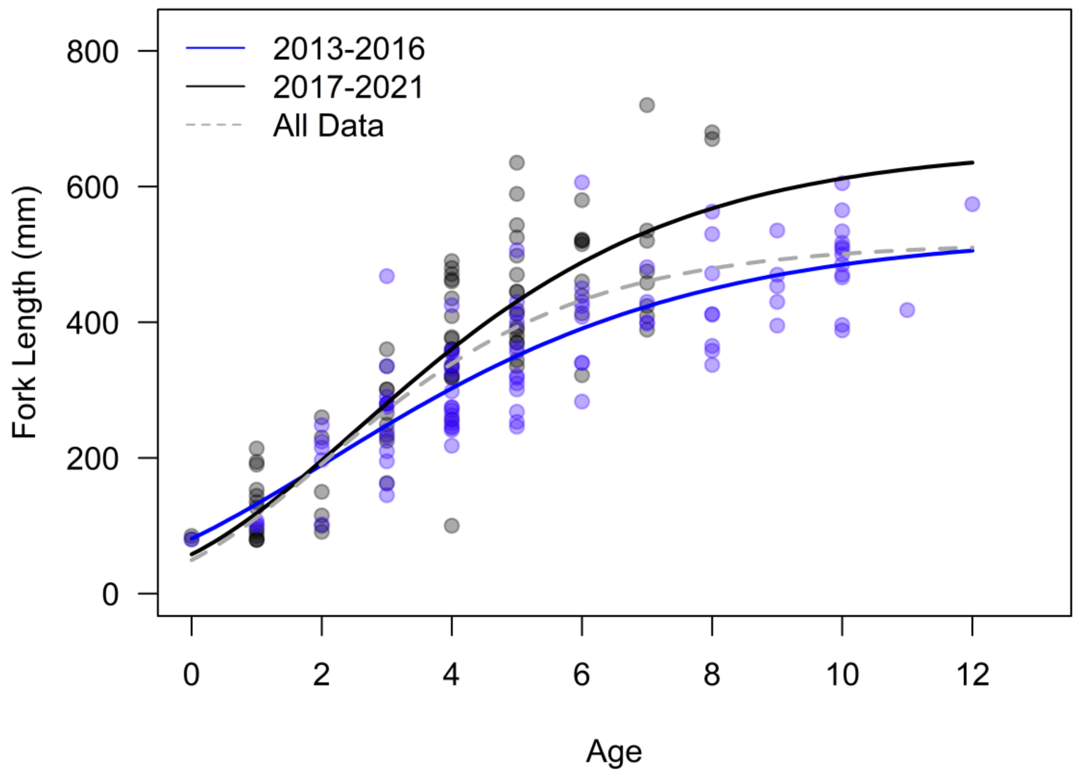


Figure 3.21 Gompertz growth model for Bull Trout fork length (mm) and observed ages for WUP (2013-2016) and Modified Operations (2017-2021) periods. Transparency shows point overlap.

3.5.2 Rainbow Trout

We separated Rainbow Trout into those captured in the reservoir, in the tributaries, and all data combined (Figure 3.22). Lengths and weights of Rainbow Trout only in Carpenter Reservoir in 2013 through 2021 were highly correlated (adjusted R^2 = 0.93), and the addition of year and year*length were both highly significant when compared to the intercept-only model (ANOVA p-values <0.001, DF = 8, F > 4). An ANOVA of annual condition for Rainbow Trout captured only in Carpenter Reservoir indicated significant differences in mean Fulton's condition factor (Figure 3.23; p-value <0.001, DF = 8, F = 7.49), and a Tukey's HSD indicated that although condition was variable, there appears to have been a slight decrease from 2016 to 2018, with somewhat higher condition in 2013 through 2015 and 2019 through 2021. For Rainbow Trout caught only in the tributaries (during electroshocking in 2016 through 2018 and 2021), year was not a significant addition to the length-weight relationship (ANOVA p-values >0.05, DF = 3, F < 6), and an ANOVA of mean condition factor was not significant (p-value = 0.41, DF = 3, F = 0.95).

Rainbow Trout were generally younger in the tributaries than in the reservoir, which may bias comparisons of condition factor. 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 = 80) and in the tributaries (n = 42) between 2016 – 2018 and 2021 (i.e., years during which tributary sampling occurred). Overall, Fulton's condition was greater for age-3 and age-4 Rainbow Trout in the tributaries compared to in the reservoir (2016 to 2018 and 2021 only; 2-way ANOVA p-value <2e-16, DF = 1, F = 96.10), and year was not a significant addition to the ANOVA (year coefficient p-value = 0.052, DF = 3, F = 2.65).

A total of 626 Rainbow Trout were aged by IFR (otoliths and scales; Table 3.5). Estimated Rainbow Trout ages range from 0 to 8 years. A Gompertz growth model was successfully fit to all Rainbow Trout length and age data, which shows an asymptotic length of 641.13 mm (95% CI 532.89 – 832.24 mm) (Figure 3.24). We compared Rainbow Trout growth models between WUP (2013-2016) and Modified Operations (2017-2021; Figure 3.24), and found that asymptotic lengths have decreased following Modified Operations; estimated asymptotic length was 796.05 during WUP and 428.99 during Modified Operations. However, there is high uncertainty in Rainbow Trout length modelling due to the variable temperature environments Rainbow Trout inhabit within the watershed (i.e., cool tributaries vs. warm reservoir) and the variable time periods juvenile Rainbow Trout spend in tributaries before moving into the reservoir.

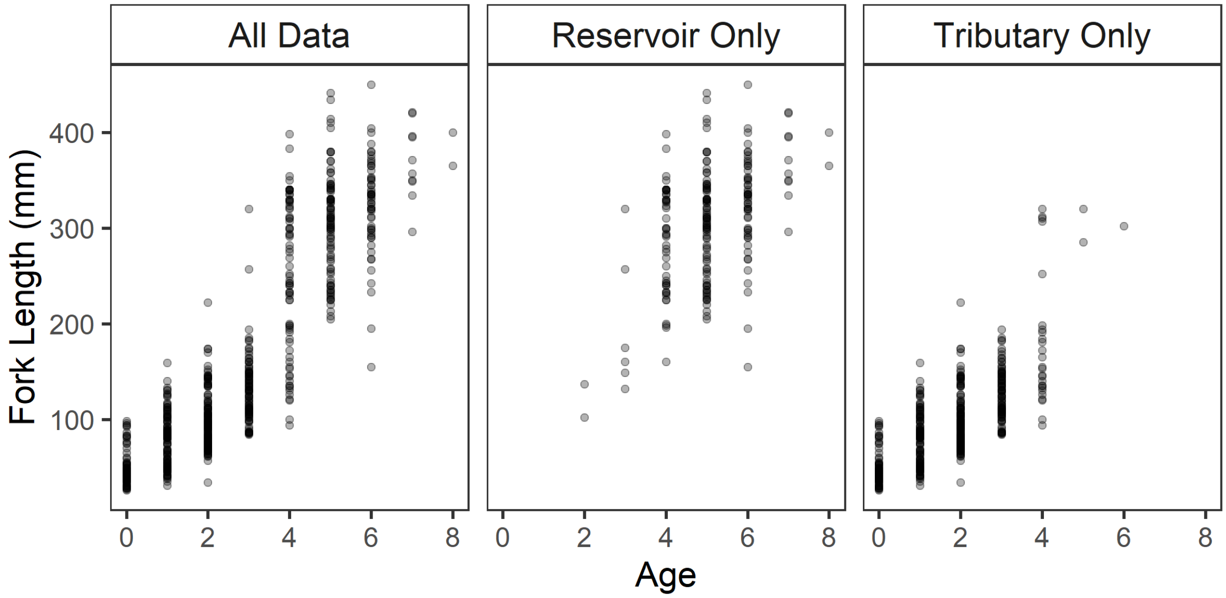


Figure 3.22 Rainbow Trout data groupings demonstrating the variation in age of capture in Carpenter Reservoir and its tributaries.

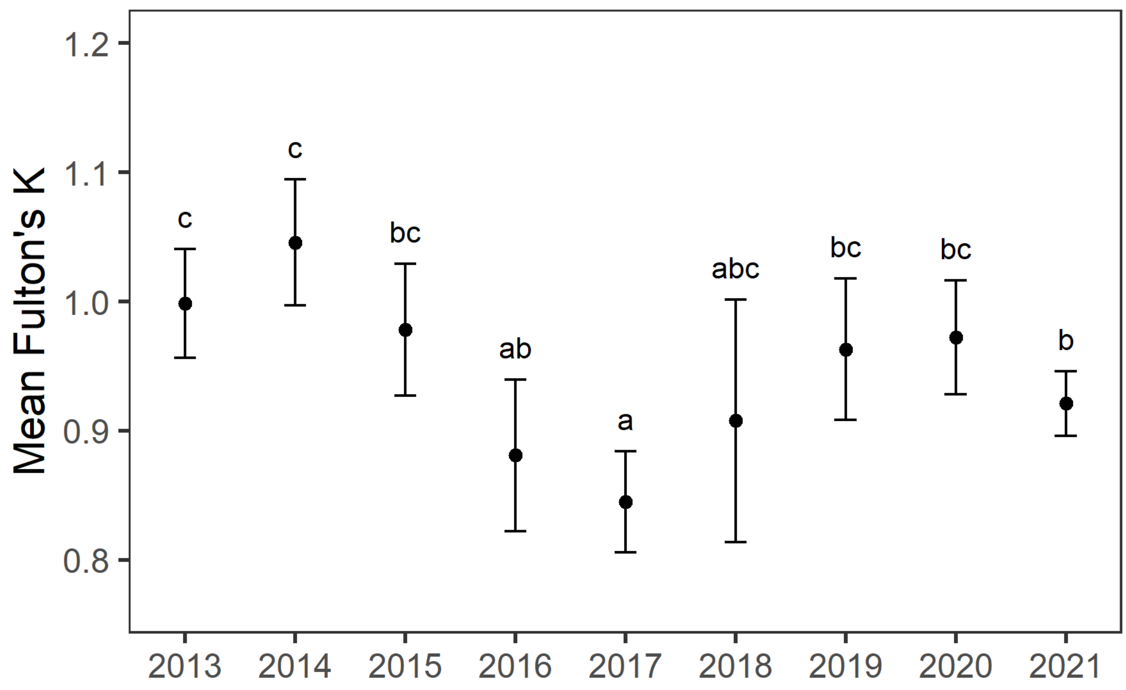


Figure 3.23 Mean annual condition factor (with predicted 95% CI) for Rainbow Trout (Carpenter Reservoir only). Means with the same significance letter are statistically equal.

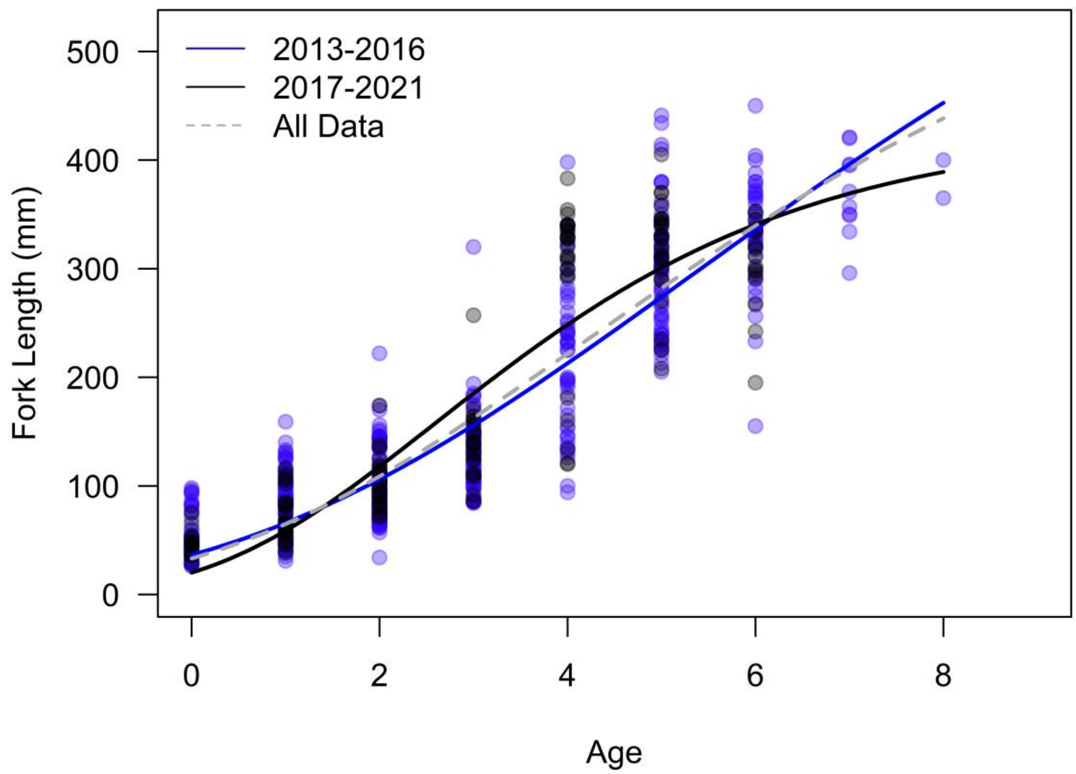


Figure 3.24 Gompertz growth model for Rainbow Trout fork length (mm) and observed ages for WUP (2013-2016) and Modified Operations (2017-2021) periods. Transparency shows point overlap.

3.5.3 Mountain Whitefish

Lengths and weights of Mountain Whitefish captured in Carpenter Reservoir in 2013 through 2020 were highly correlated (adjusted R^2 = 0.95), and the addition of year and year*length variables were significant when compared to the intercept-only model (ANOVA p-values <0.001, DF = 8, F > 8).

There was a significant difference in mean Fulton’s condition factor in 2013 through 2021 for Mountain Whitefish captured in Carpenter Reservoir (ANOVA p-value <0.001, DF = 8, F = 9.04).

A Tukey's HSD test showed that although there was substantial variation in Mountain Whitefish condition factor, there was weak evidence that condition was higher in 2018 relative to other years (Figure 3.25), consistent with the increased condition observed in 2018 for Rainbow Trout and Bull Trout (Figure 3.20 and Figure 3.23). We also compared Fulton's condition factor for Mountain Whitefish spawners captured in the Middle Bridge River (age-3 to age-5) during winter angling in 2013, 2016, and 2019 (not shown). There was no significant difference in condition of Mountain Whitefish captured in the Middle Bridge River (ANOVA p-value 0.053, DF = 3, F = 2.58), likely due to highly variable condition factor within years.

A total of 265 Mountain Whitefish were aged by IFR (otoliths and scales; Table 3.5). Estimated Mountain Whitefish ages ranged from 1 to 6 years. A Gompertz growth model was fit to Mountain Whitefish length and age data (Figure 3.26), and the asymptotic length of Mountain Whitefish was estimated to be 318.84 mm (95% CI 295.75 – 360.88 mm). We compared Mountain Whitefish growth models between WUP (2013-2016; asymptotic length 326.81 mm) and Modified Operations (2017-2021; asymptotic length 303.85 mm; Figure 3.26), but we did not see substantial evidence of unique growth characteristics between the two periods.

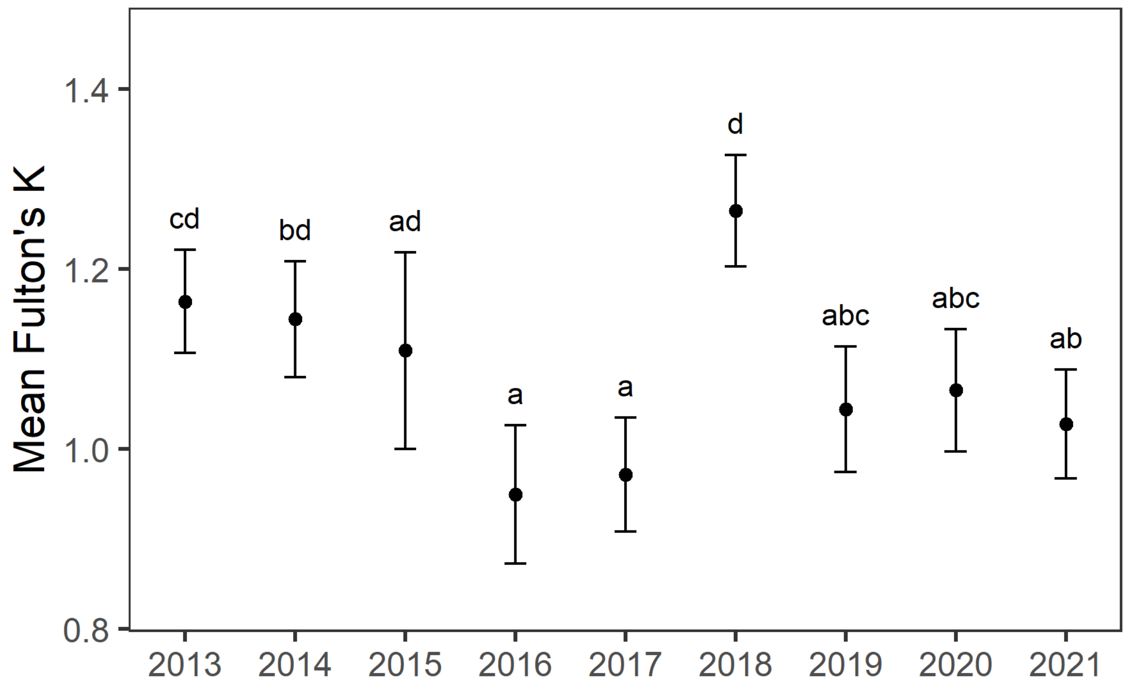


Figure 3.25 Mean annual condition factor (with predicted 95% CI) for Mountain Whitefish in Carpenter Reservoir and the Middle Bridge River (MBR). Means with the same significance letter are statistically equal.

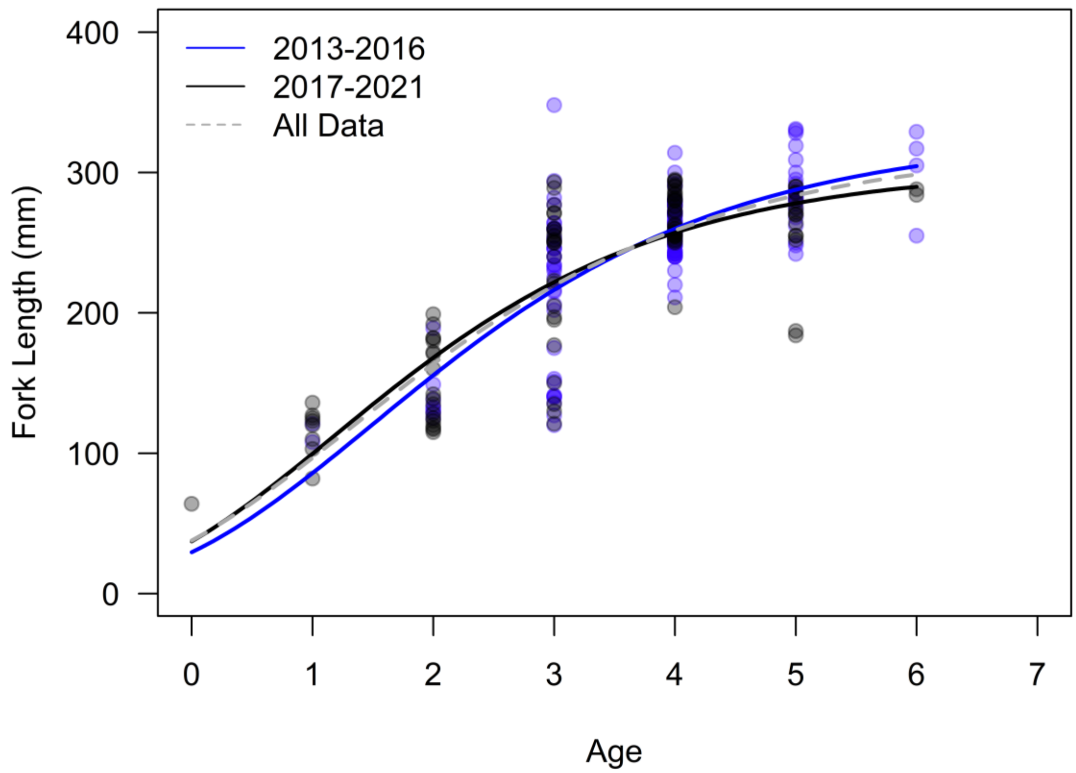


Figure 3.26 Gompertz growth model for Mountain Whitefish fork length (mm) and observed ages for WUP (2013-2016) and Modified Operations (2017-2021) periods. Transparency shows point overlap.

3.5.4 Kokanee

Lengths and weights of kokanee captured in Carpenter Reservoir in 2013 through 2021 were highly correlated (adjusted R^2 = 0.90), and the addition of a year variable to the length-weight model was significant when compared to the intercept-only model (ANOVA p-value <0.001, DF = 7, F = 20.82; the year*length interaction was not significant). An ANOVA of annual mean Fulton's condition factor was significant (p-value <0.001, DF = 7, F = 16.67), but no clear patterns emerged in condition factor among years (Figure 3.27).

A total of 56 kokanee were aged by IFR (scales; Table 3.5). Estimated kokanee ages ranged from 2 to 4 years. A growth model was not fit to kokanee length-at-age data due to the lack of juvenile age and length data.

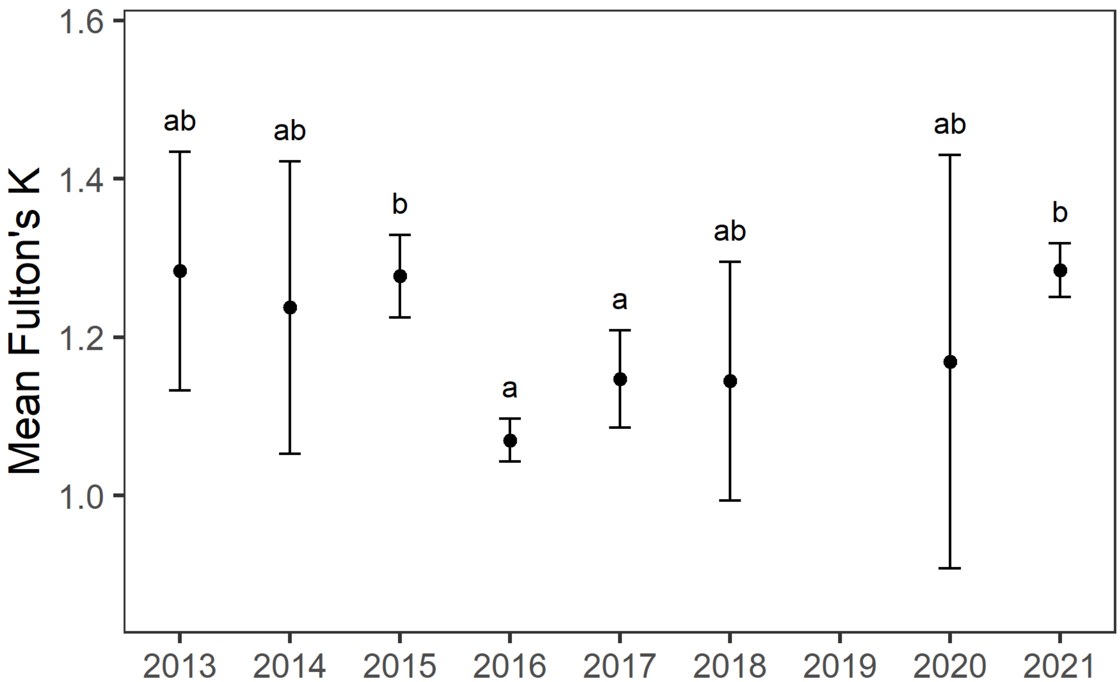


Figure 3.27 Mean annual condition factor (with predicted 95% CI) for kokanee in Carpenter Reservoir. Means with the same significance letter are statistically equal.

3.6 Tributary Surveys in the Carpenter Reservoir Watershed

3.6.1 Kokanee Spawner Assessments

Kokanee spawner assessments were completed annually in Carpenter Reservoir index tributaries from 2014 to 2021 (Figure 3.28). Categorical measures of water quality and discharge were assessed during each survey but did not appear to influence survey effectiveness. We also separated our surveys into areas within and above the inundation zone of the reservoir, but we have not observed evidence of spawning behaviour or redd digging in the inundation zone, suggesting the risk of redd inundation is very low.

We examined peak hatch dates for kokanee spawning tributaries (Middle Bridge River, Macdonald Creek, Truax Creek, and Marshall Creek) in years where kokanee spawners were observed, and temperature data were available throughout the incubation period (2015/2016 and 2017/2018). Estimated hatch dates for 2017/2018 are shown here. Kokanee spawners were observed in 2021, and hatch dates will be estimated for 2021/2022 once temperature loggers are recovered in the spring of 2022.

Peak hatch dates varied considerably amongst the tributaries evaluated due to the large ATU requirements for kokanee and temperature differences amongst the tributaries (Figure 3.29). Truax Creek is snowmelt-fed, Macdonald Creek and Marshall Creek are sourced from lakes (but Marshall Lake is substantially warmer), and the Middle Bridge River is controlled by Lajoie Dam. Macdonald Creek is marginally warmer and more stable than Truax Creek due to lake origin, resulting in earlier hatch dates and a prolonged hatching period; however, peak 50% hatch dates for both tributaries occurred in the spring (late April to early June). In contrast, the Middle Bridge River and Marshall Creek are substantially warmer, resulting in the 50% hatch date occurring in late November and late January, respectively. These temperature characteristics are consistent across years, suggesting kokanee emergence occurs earlier than in other spawning tributaries, with unknown effects to juvenile survival and growth.

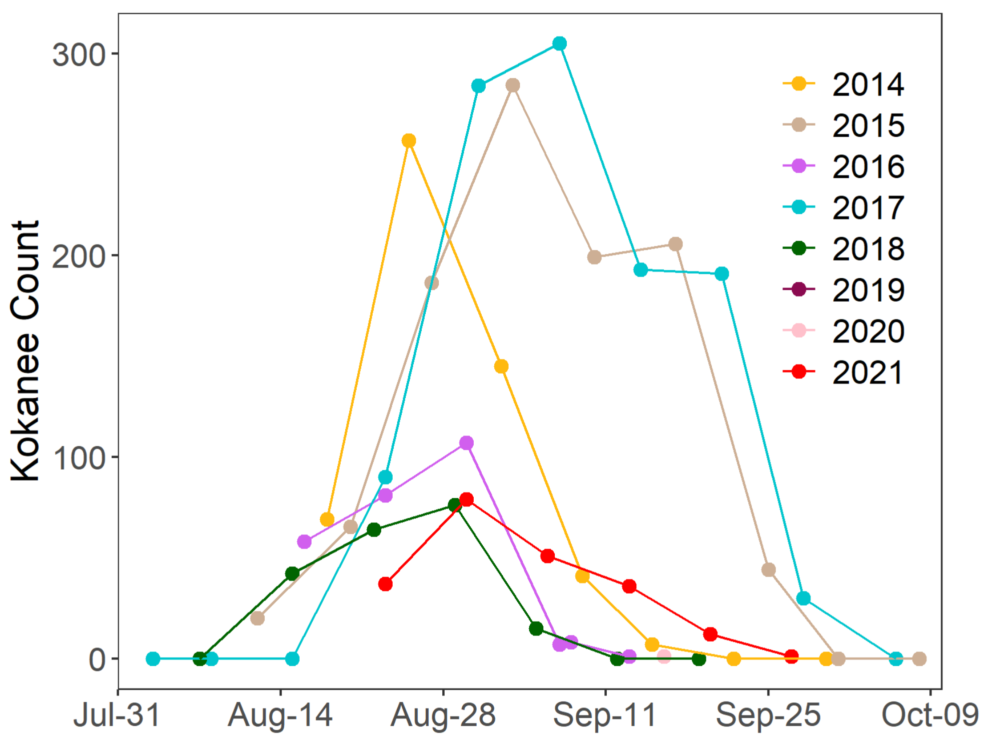


Figure 3.28 Counts of kokanee in Carpenter Reservoir tributaries (Truax, Girl, Macdonald, Sucker, and Marshall Creeks combined) in 2014 to 2021. No kokanee were observed in 2019, and only one kokanee was observed in 2020.

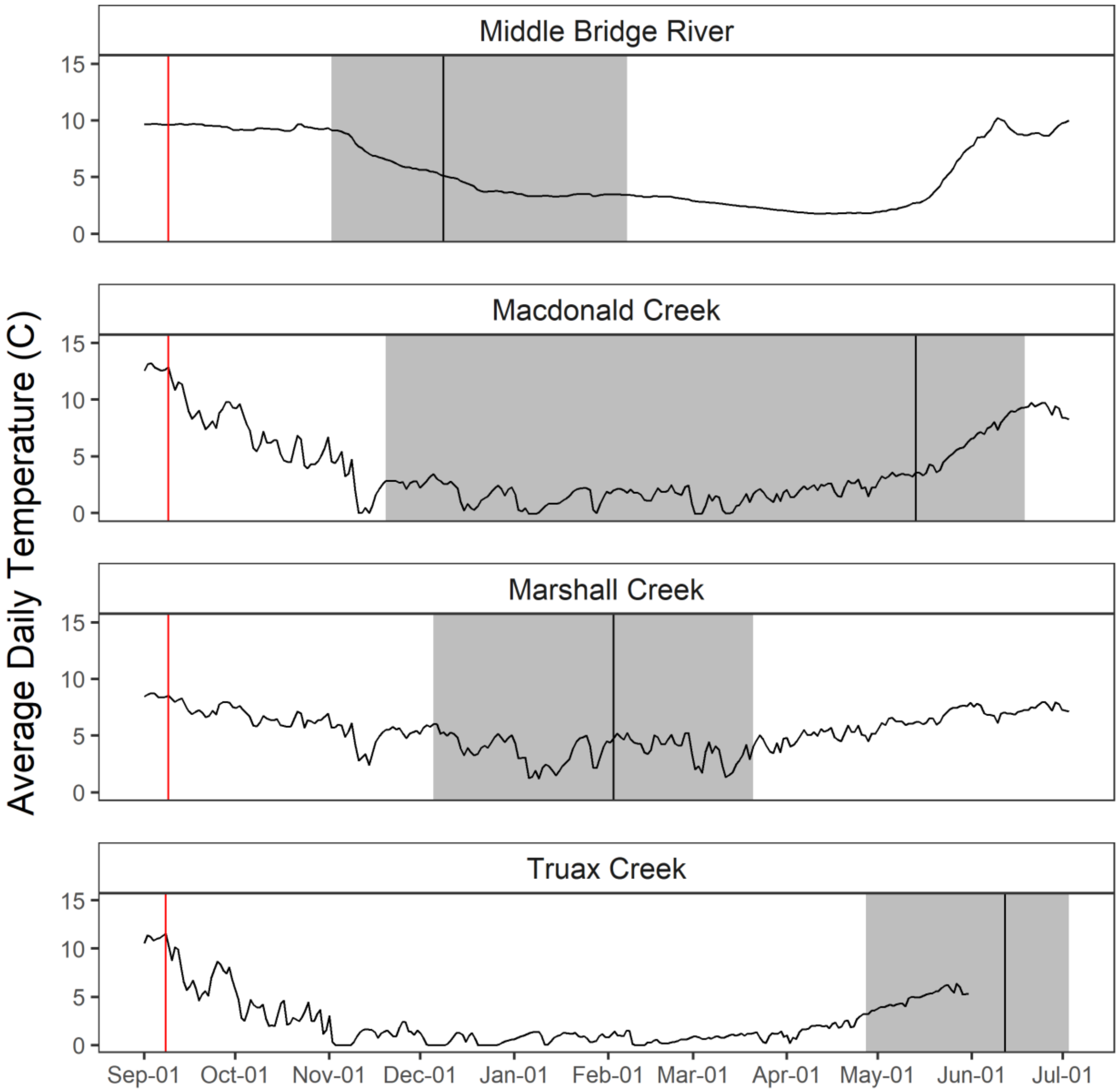


Figure 3.29 Estimated peak hatch dates (black line) and minimum and maximum estimated hatch dates (shaded area) for 2017-2018 corresponding to a peak spawning date for all tributaries of September 9, 2017 and an ATU requirement of 680 degrees.

3.6.2 Monthly Tributary Electroshocking

We cannot compare relative abundance from tributary electroshocking due to variable effort, crew experience/efficiency, and changing physical conditions. Overall, tributary catches were relatively low, in agreement with short stream lengths, cold water temperatures, and low productivity. The highest captures were of sculpin species and Rainbow Trout in Macdonald and Marshall Creeks, both of which have upstream lakes with resident Rainbow Trout populations. Age-0 Rainbow Trout were captured in all tributaries sampled (Marshall, Macdonald, Truax, and Gun Creeks) indicating successful Rainbow Trout spawning. Confirmed Age-0 Mountain Whitefish were captured in Gun and Macdonald Creeks and Age-0 Bull Trout were captured in Gun and Truax Creeks (length histograms in Appendix B). While the absence of juvenile captures does not preclude the possibility of successful spawning, the presence of juveniles within these tributaries provides some indication of preferred spawning locations and conditions for Carpenter Reservoir salmonids.

We used Gaussian general additive modelling (GAMs) to describe seasonal growth in Age-1 and Age-2 Rainbow Trout captured in all tributaries (Marshall, Macdonald, Truax, and Gun Creeks). All tributaries were combined because sampling was not consistent in each year due to access issues. The majority (86%) of Rainbow Trout used within the GAM were captured in Macdonald and Marshall Creeks, and we did not find that tributary was a significant predictor of seasonal growth for Age-1 Rainbow Trout in these two tributaries (ANOVA F = 0.751, p-value = 0.388).

GAMs fit separately to Age-1 and Age-2 Rainbow Trout successfully described Rainbow Trout seasonal growth patterns (Figure 3.30). Several potential outliers within Age-2 data reduced the ability of the GAM to accurately describe growth (i.e., modelled growth decreased slightly from April through June 2021); however, removing these points did not change the modelling conclusions.

We used ANOVAs to evaluate the significance of adding year to each of the models. Overall, we did not see strong evidence that Rainbow Trout growth differed among years, which was expected given that stream temperatures were similar among years (not shown), Modified Operations do not affect physical conditions within tributaries, and we observed considerable variation among growth characteristics within years. For Age-1 Rainbow Trout, there was weak evidence that year was an important predictor in the GAM (ANOVA F = 6.771, p-value = 0.0003), while for Age-2 Rainbow Trout, year was not a significant predictor (ANOVA F = 2.128, p-value 0.100).

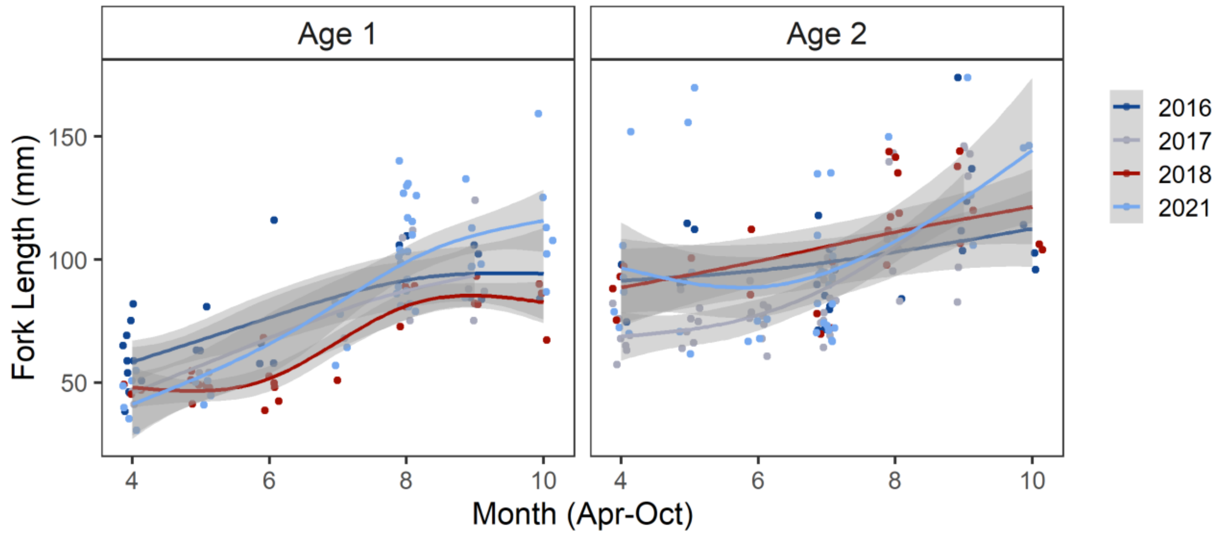


Figure 3.30 General additive models (GAMs) of Rainbow Trout seasonal growth in Carpenter Reservoir tributaries (Truax, Marshall, Macdonald, and Gun Creeks) in 2016, 2017, 2018, and 2021.

3.7 Targeted Kokanee Electroshocking

Kokanee were successfully captured on August 5, 2021 (n = 15) and August 10, 2021 (n = 37), further indicating kokanee are still present and spawning in Carpenter Reservoir. The majority (61%) of kokanee captures occurred at Keary Creek (n = 20, or 38%) and Truax Creek (n = 12, or 23%), but kokanee were also captured at the confluences of Bobb Creek, Jones Creek, Marshall Creek, Nosebag Creek, Tommy Creek, and Williams Creek.

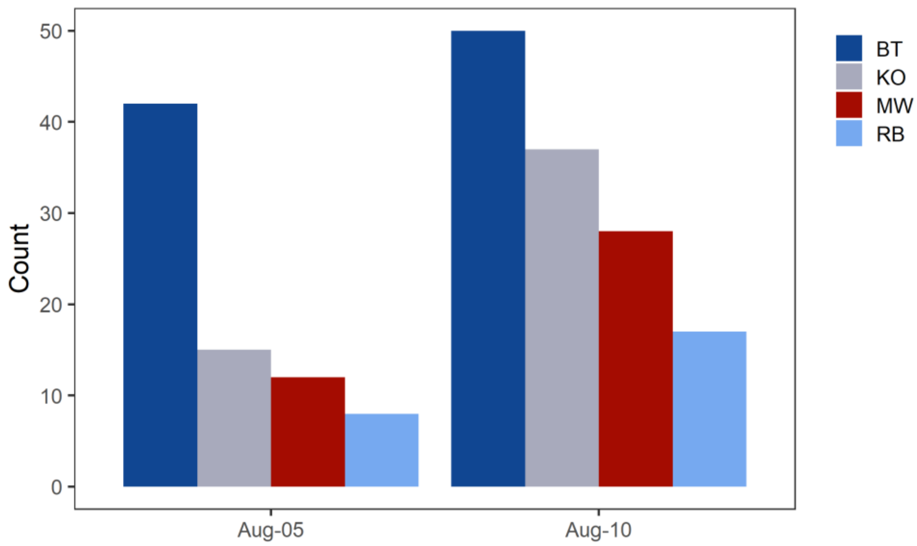


Figure 3.31 Counts of Bull Trout, kokanee, Mountain Whitefish, and Rainbow Trout captured during overnight electrofishing in Carpenter Reservoir on August 5 and August 10, 2021.

3.8 Monthly Limnological Sampling

Limnological sampling in 2021 was completed to describe physical conditions, nutrient availability, and zooplankton/phytoplankton biomass in Carpenter Reservoir under Modified Operations, and to verify predictions from CE-QUAL-W2 scenario modelling from BRGMON-10.

3.8.1 Physical Conditions

Water Temperature

Carpenter Reservoir surface water temperatures (whole lake averages, depth ≤ 2 m) were more variable throughout the year, cooler in the spring (May/Jun), and warmer in the summer in 2021 relative to 2015 and 2016. The maximum recorded water temperature in 2021 (measured in July) was over 2°C warmer than previous years and was the highest recorded during BRGMON-4 (22.7°C). Consistent with 2015 and 2016, thermocline depth (5 to 10 m) and strength of stratification increased from west to east with increasing reservoir depth and distance from the Middle Bridge River (Figure 3.32). Reservoir turnover began in September and complete mixing occurring by October (Figure 3.32).

Hypolimnetic water temperatures during the sampling period ranged from 7.0–15.1°C with maximum temperatures occurring in July through September. Hypolimnetic temperatures were generally warmer at the shallower west end of reservoir relative to the deeper east end. Average water temperatures in the hypolimnion (within 5 m of the bottom) were warmer in 2021 (mean = 11.6°C, SD = 1.7, min = 7.9, max = 15.1) compared to 2015 (mean = 10.9°C, SD = 1.6, min = 7.0, max = 14.8) but not 2016 (mean = 11.6°C, SD = 1.3, min = 8.0, max = 13.5).

Sediment, Turbidity and Light

Total suspended solids (TSS; the quantity of particulates suspended in water) from inflow tributaries and the Middle Bridge River were greater in 2021 than in 2015 and 2016. While all measured sources of inflow showed elevated TSS, increased levels were particularly pronounced in the Middle Bridge River, Gun Creek and Tyaughton Creek (Figure 3.33). Turbidity (optical water clarity and light scattering/absorption) from inflow sources was similar among years or slightly lower in 2021 depending on the tributary (Figure 3.33). Truax, Keary and Marshall Creeks had the lowest average annual turbidities (≤ 15 NTU) with maximums of < 30 NTU in May (except for May 2015 in Marshall Creek; Figure 3.34). The larger inflow tributaries, including the Upper Bridge River, Middle Bridge River, Hurley River and Gun Creek, had average annual turbidities of 12–66 NTU with maximums in the summer (July to September) between 35 and 110 NTU (Figure 3.34). Turbidity within Tyaughton Creek was highly variable among and within years (Figure 3.34).

In Carpenter Reservoir, 2021 TSS and turbidity were higher and corresponding Secchi and euphotic zone depths were lower, compared to 2015 and 2016 (Figure 3.35). Turbidity (from Seabird profiles) was highest in the western reservoir during the spring when elevation was low and the water column was fully mixed (max = 81 NTU), and in the hypolimnion during early summer (max = 84 NTU; Figure 3.36). As reservoir elevations increased and stratification occurred, cool dense inflows with high TSS loads plunged below the thermocline and surface sediment also settled downwards, resulting in higher turbidity in the hypolimnion relative to the epilimnion (see also BRGMON-10 [Limnotek 2018]). Turbidity in the epilimnion was very low (≤1 NTU) at the eastern monitoring stations (C1 to C3) in July and August 2021. After reservoir turnover, turbidity was relatively consistent throughout the reservoir. Similar turbidity patterns were observed in 2015 and 2016; however, maximum turbidities were lower (≤ 54 NTU) and the epilimnion was clearer over a greater proportion of the reservoir (i.e., ≤ 1 NTU from stations C1 to C7 in 2015 and to C6 in 2016) for a longer duration (i.e., from Jun to Sep in 2015 and Jul to Sep in 2016) relative to 2021 (data on file; Figure 3.37).

Inversely related to TSS and turbidity, Secchi and euphotic zone depths followed a similar seasonal pattern – increasing throughout the growing season then decreasing after fall mixing

(Figure 3.38). Peak water clarity occurred during the summer months (Jul to Sep) but varied among monitoring years. Annual mean Secchi depth was 4.2 m in 2015 (SD = 2.7), 3.1 m in 2016 (SD = 2.6), and 2.1 m in 2021 (SD = 2.3). Annual mean euphotic zone depth was 10.5 m in 2015 (SD = 4.5), 8.4 m in 2016 (SD = 3.7), and 6.1 m in 2021 (SD = 3.2).

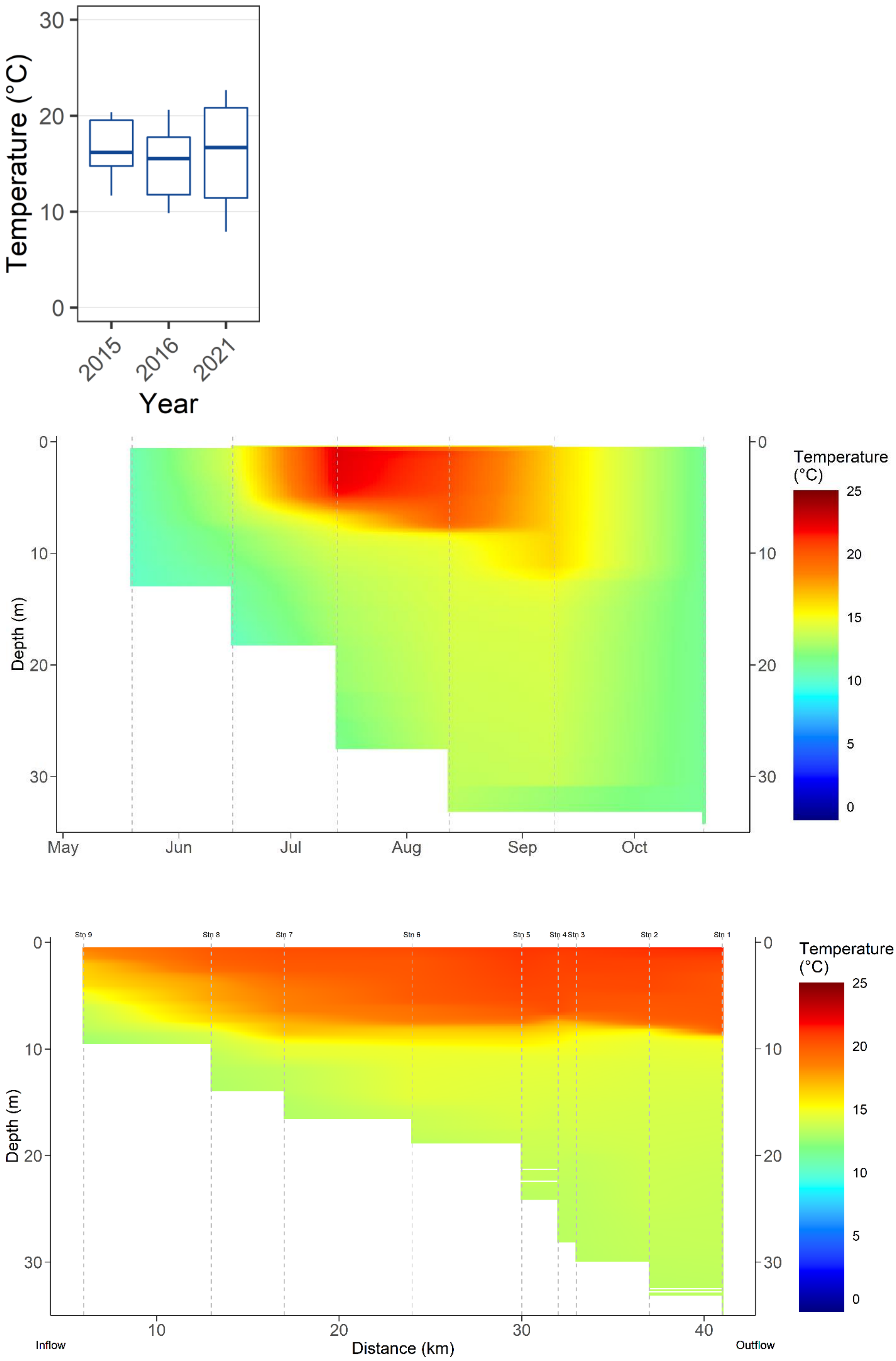


Figure 3.32 Top panel shows boxplot of annual surface water temperatures within Carpenter Reservoir (depths 0-2 m using data from stations C2 and C6 from May to October). Middle panel shows water temperature profiles taken at station C2 throughout the growing season of 2021 to illustrate seasonal water temperature patterns within Carpenter Reservoir. Bottom panel shows water temperature profiles at all monitoring stations in August 2021 to illustrate spatial water temperature patterns within Carpenter Reservoir when reservoir elevations and seasonal temperatures were near their maximums All water temperature data were from Seabird profiles.

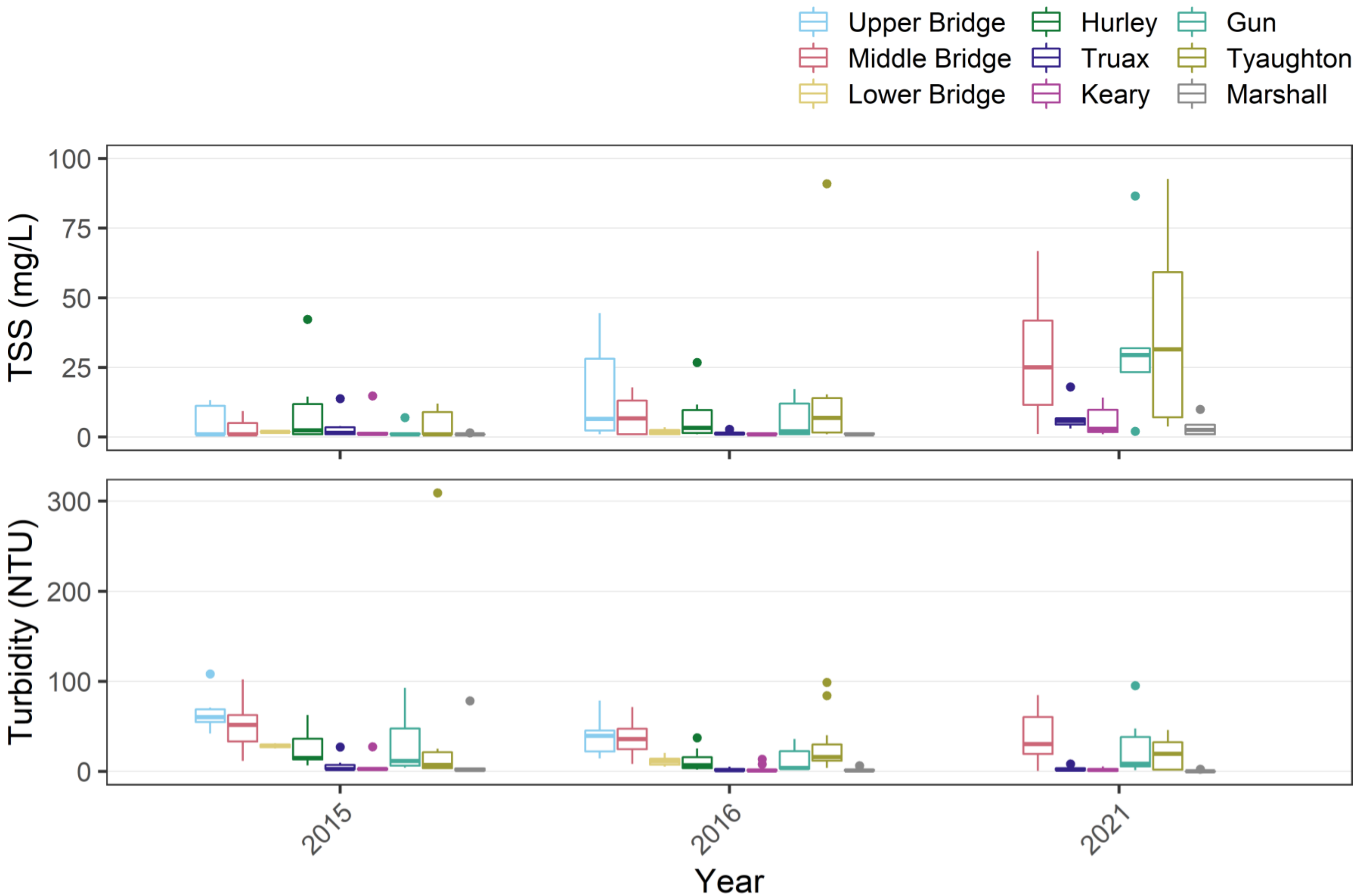


__Figure 3.33 Boxplots of annual total suspended solids (TSS) and turbidity within Carpenter Reservoir inflow tributaries as measured from ALS Environmental laboratory samples during the growing season. Values were standardized using data from May to October.__

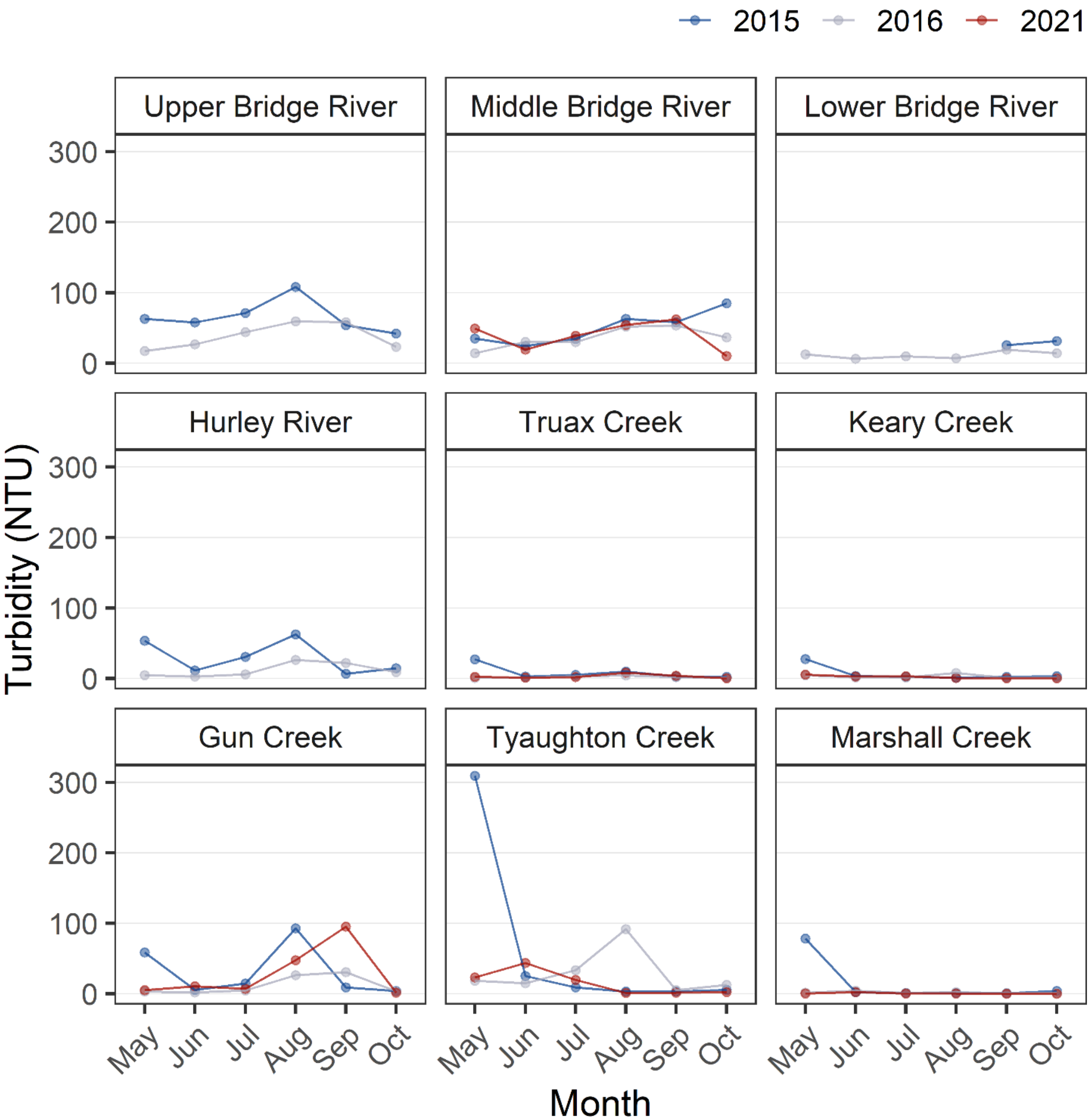


Figure 3.34 Monthly turbidity of tributary streams that act as sources of inflow to Carpenter Reservoir. Values were measured from ALS Environmental laboratory samples collected from surface water during the growing season.

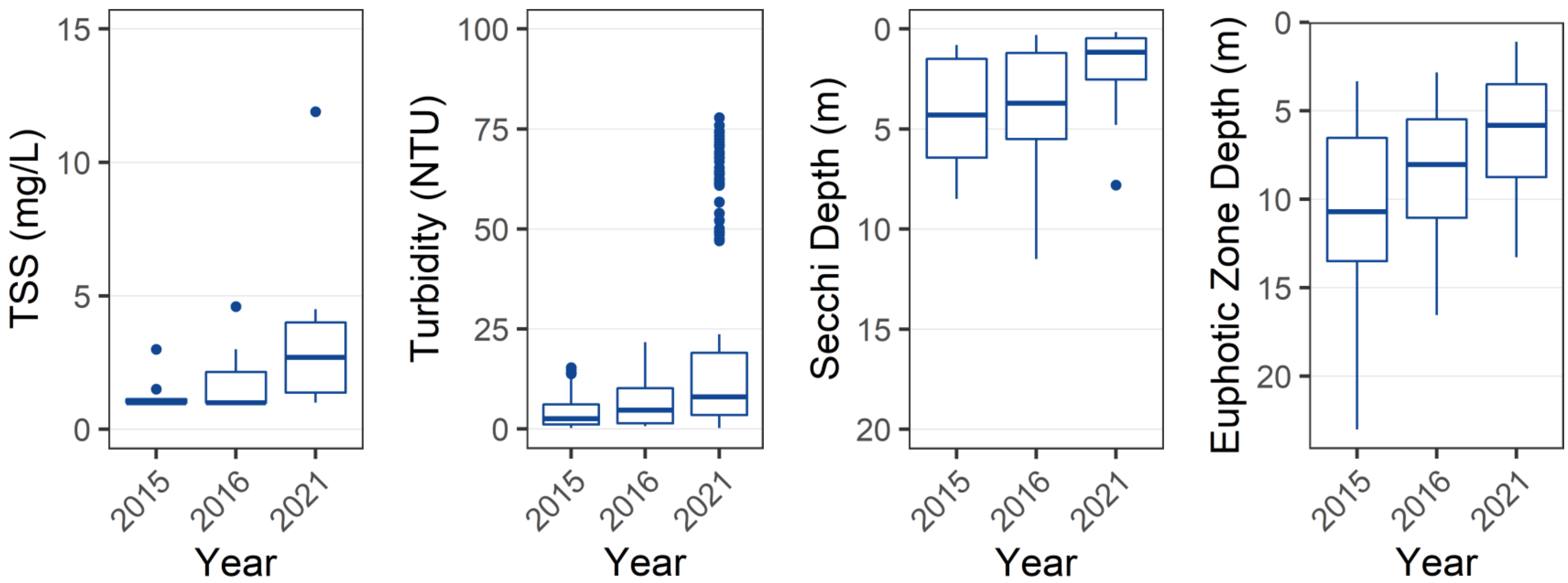


Figure 3.35 Boxplots of annual total suspended solids (TSS), turbidity, Secchi depths and euphotic zone depths (1% photosynthetically active radiation [PAR]) within Carpenter Reservoir. TSS was from ALS Environmental laboratory samples collected from the epilimnion. Turbidity was from Seabird measurements within the epilimnion at depths ≤ 2 m. Euphotic zone depths were calculated using Seabird PAR measurements. Values were standardized using data from stations C2 and C6 from May to October.

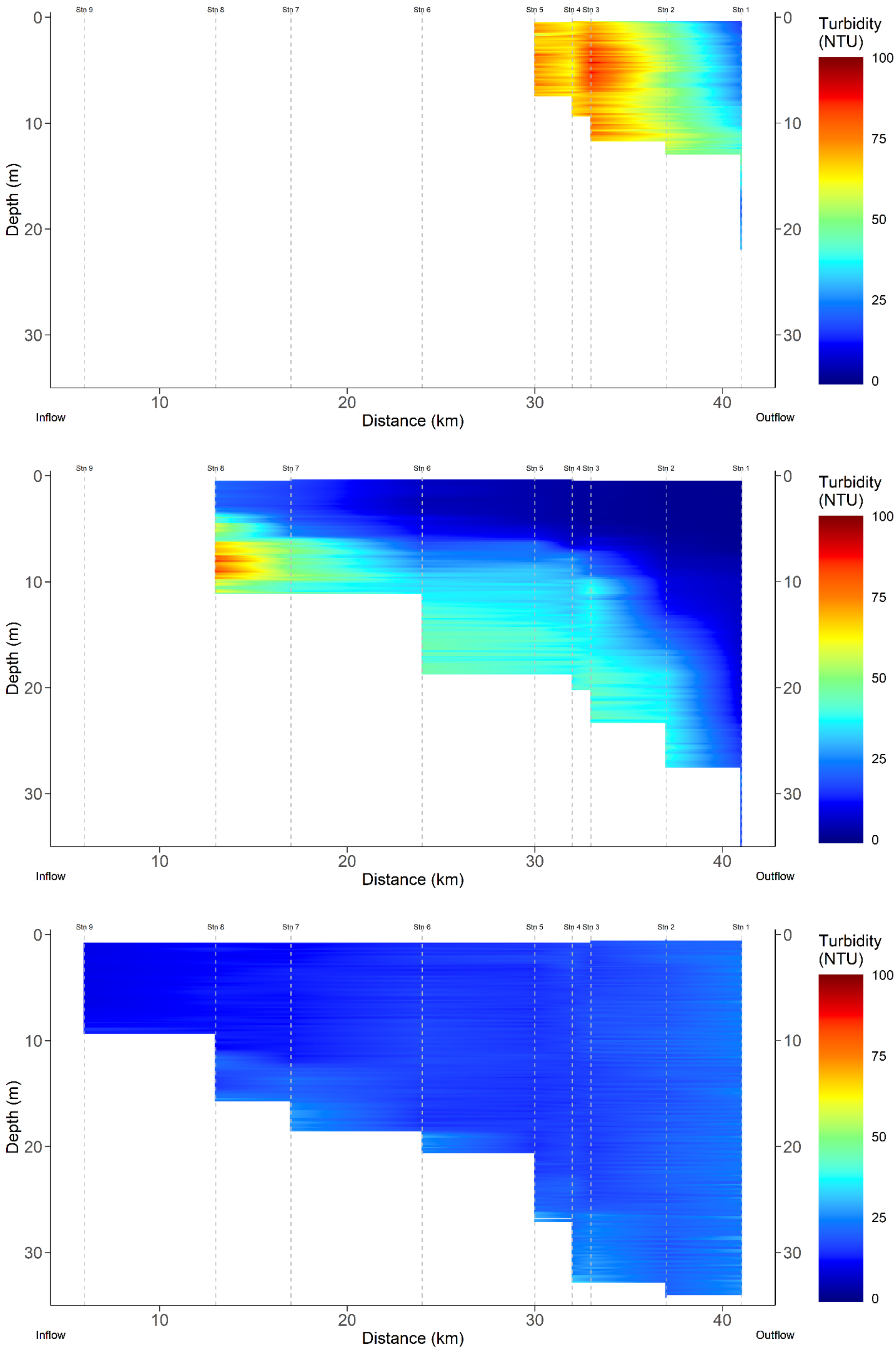


Figure 3.36 Turbidity as measured from Seabird profiles at all Carpenter Reservoir monitoring stations where water depths were ≥ 10 m. Panels are from May (top), July (middle) and October (bottom), 2021, to illustrate seasonal turbidity patterns within Carpenter Reservoir.

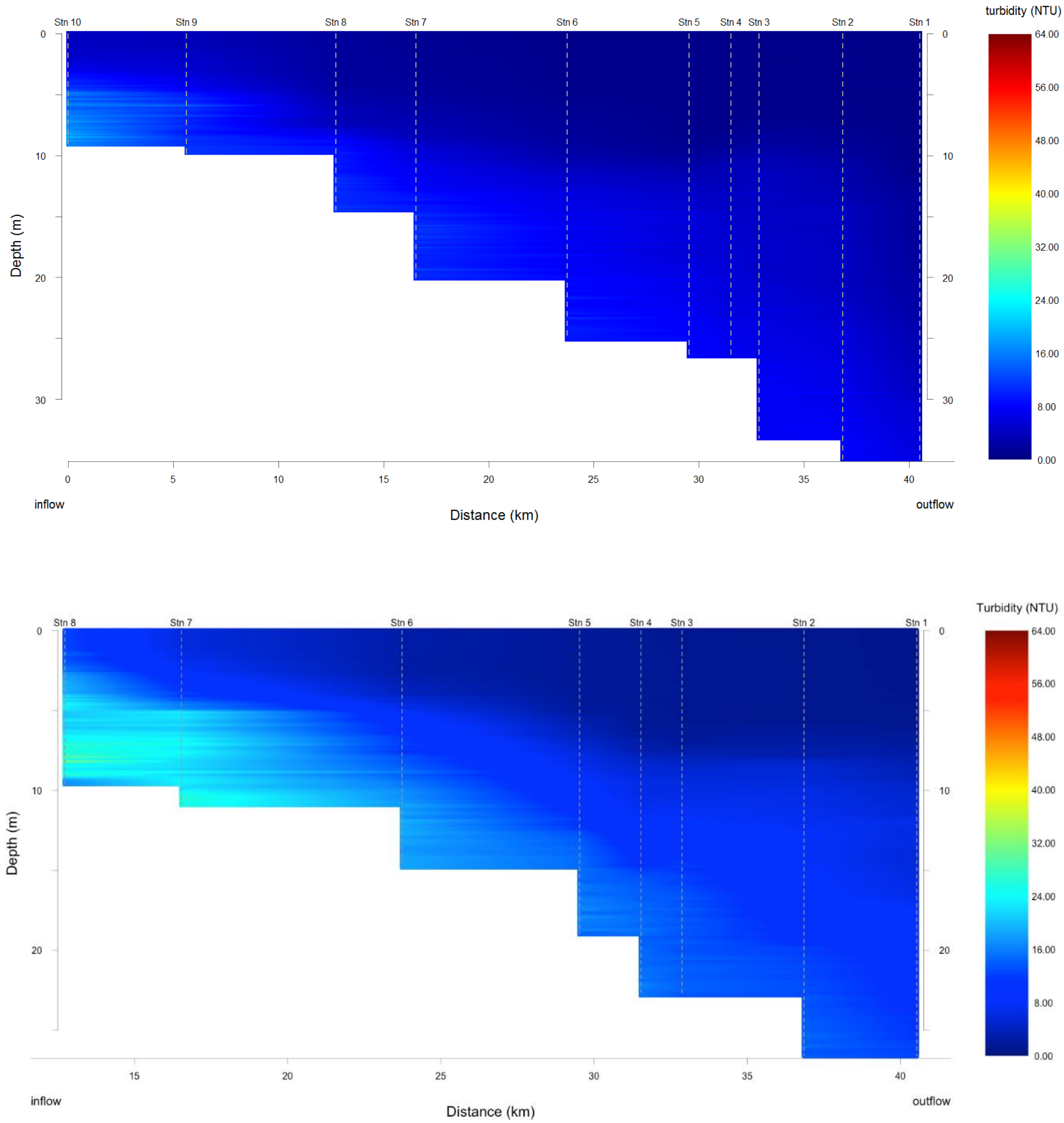


Figure 3.37 Turbidity as measured from Seabird profiles at all Carpenter Reservoir monitoring stations where water depths were ≥ 10 m. Panels are from July 2015 (top) and July 2016 (bottom) to illustrate differences in Carpenter Reservoir turbidity patterns between monitoring years.

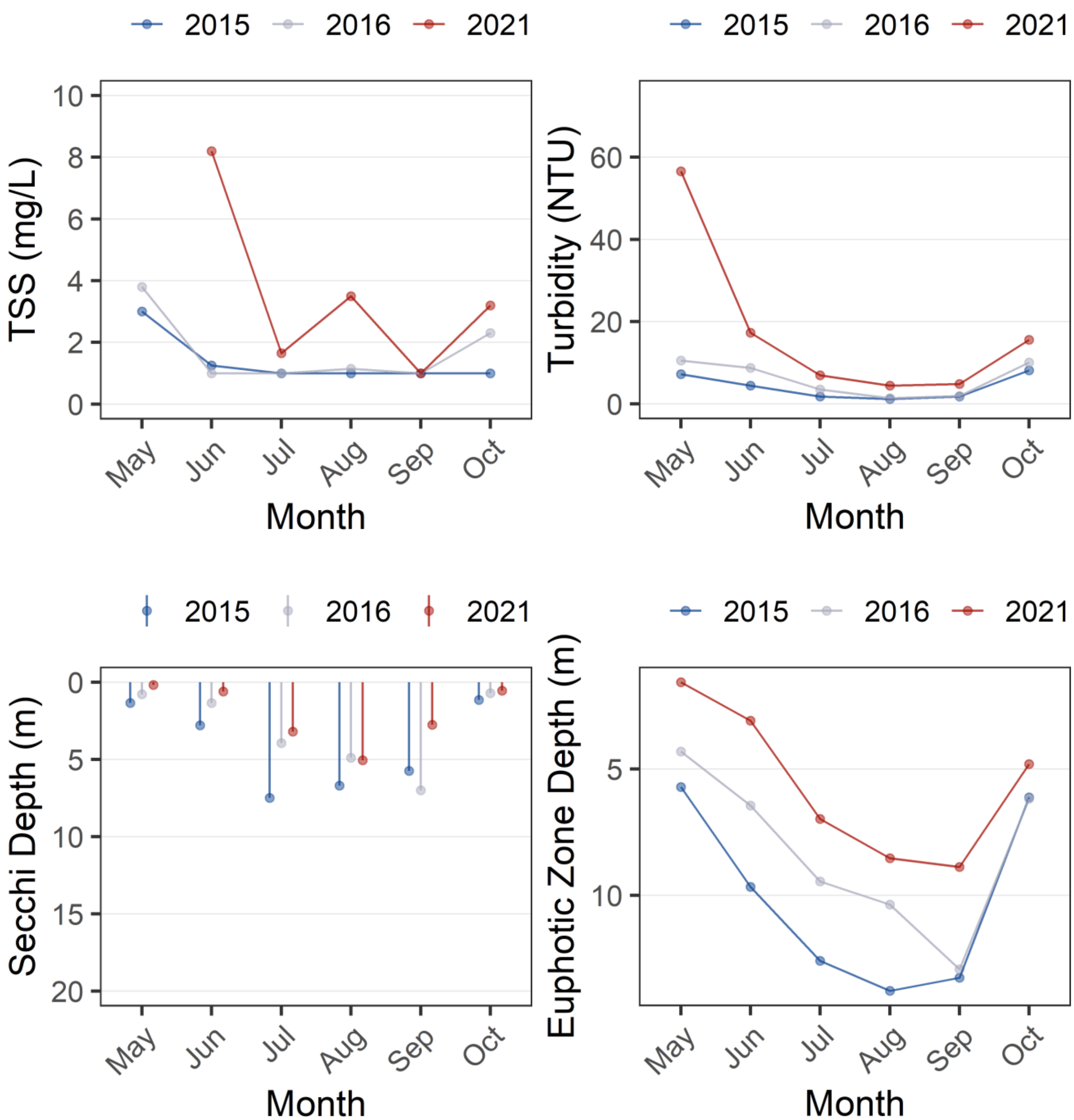


Figure 3.38 Mean monthly total suspended solids (TSS) as measured from ALS Environmental laboratory samples, turbidity as measured during Seabird profiles Secchi depth, and within surfaces waters of Carpenter Reservoir during the growing season. Mean monthly within Carpenter Reservoir during the growing season (standardized using stations C2 and C6 only). Mean monthly euphotic zone depth (1% photosynthetically active radiation) within Carpenter Reservoir as calculated from Seabird profile measurements collected during the growing season. All data were standardized using stations C2 and C6 only.

3.8.2 Chemistry and Nutrients

Carpenter Reservoir is slightly alkaline (Figure 3.39). Mean pH was 7.7–7.8 with values ranging from 7.5 to 8.0 during the 2015, 2016 and 2021 monitoring years; however, pH was determined in the laboratory and may be less reliable than field measurements. Carpenter Reservoir surface alkalinity was lower in 2016 (mean = 32.1 mg/L, SD = 4.6, min = 27.0, max = 41.2) and 2021 (mean = 33.4 mg/L, SD = 5.1, min = 27.5, max = 45.2) than in 2015 (mean = 36.8 mg/L, SD = 3.6, min = 30.3, max = 41.1) with a decreasing trend throughout the growing season in all years (Figure 3.40).

Overall, Carpenter Reservoir had low nitrogen (N) and phosphorus (P) concentrations, consistent with oligotrophic systems. In 2021, epilimnetic total nitrogen (TN; mean = 72.0 µg/L, SD = 51.3) and total phosphorus (TP; mean = 16.3 µg/L, SD = 20.3) were higher than 2015 (TN mean = 42.9 µg/L, SD = 12.3; TP mean = 3.7 µg/L, SD = 2.5) and 2016 (TN mean = 52.3 µg/L, SD = 26.1; TP mean = 5.7 µg/L, SD = 4.8). Bioavailable forms of N and P are dissolved inorganic nitrogen (nitrate NO_3-N and ammonia NH_4-N) and dissolved orthophosphate (PO_4-P), respectively. Nitrate and dissolved orthophosphate concentrations were greater in 2021 (NO_3-N mean = 19.3 µg/L, SD = 26.1; PO_4-P mean = 1.7 µg/L, SD = 0.6) than in 2015 (NO_3-N mean = 5.2 µg/L, SD = 0.7; PO_4-P mean = 1.0 µg/L, SD = 0.1) and 2016 (NO_3-N mean = 7.0 µg/L, SD = 5.1; PO_4-P mean = 1.0 µg/L, SD = 0.05). Ammonia concentrations were below the detection limits (5 µg/L) in all but one sample in 2015 and 2016, and all but two samples in 2021. Ammonia is the most readily available form of nitrogen, and ammonia concentrations are often low in the euphotic zone of unpolluted and well-oxygenated lakes (Wetzel 2001). Seasonally, all forms of N and P were most concentrated in the spring (May) and decreased over the growing season with a slight increase in October (Figure 3.41). Elevated nutrient concentrations in the reservoir in 2021 may be partially related to elevated inputs from tributaries, particularly in the spring (see Appendix C).

Due to consistently low concentrations of bioavailable N and P, we used the molar ratio of total nitrogen to total phosphorus (TN:TP) to assess epilimnetic suitability for phytoplankton growth. While optimal ratios vary among algal species, TN:TP < 20 is typically nitrogen limiting and TN:TP > 50 is typically phosphorus limiting (Guildford and Hecky 2000). In 2015 and 2016, epilimnetic TN:TP in Carpenter Reservoir was between 20 and 50 from May to September, indicating favorable conditions for phytoplankton (Figure 3.41). In 2021, TN:TP ratios indicated potential nitrogen limitation in May, June, September, and October (Figure 3.41).

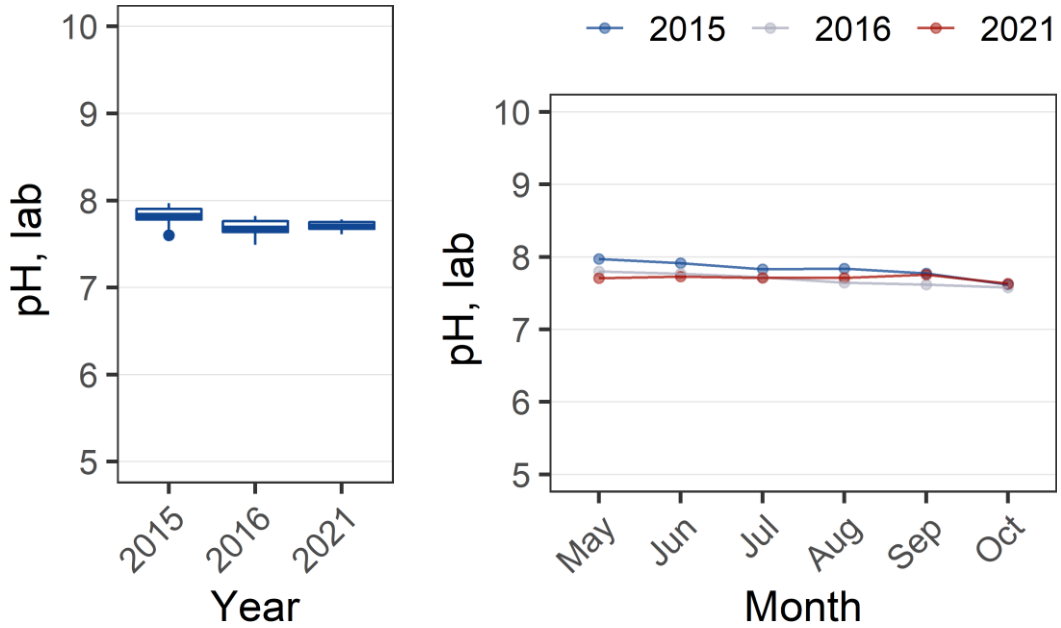


Figure 3.39 Boxplot of annual pH (left) and mean monthly pH (right) within surface waters of Carpenter Reservoir as determined from laboratory samples collected during the growing season (standardized using stations C2 and C6 only).

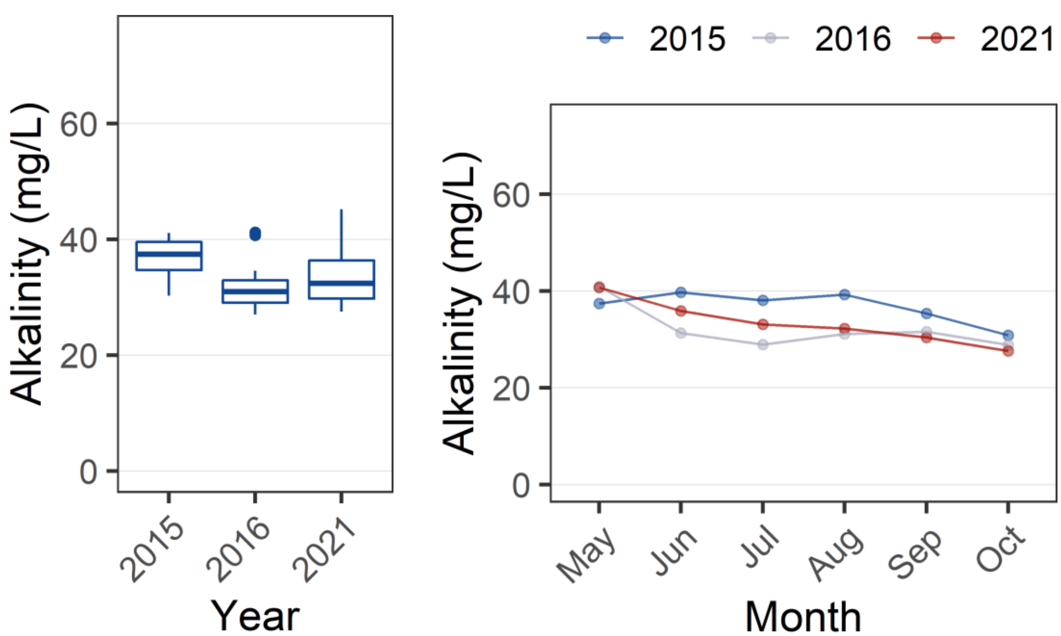


Figure 3.40 Boxplot of annual alkalinity (left) and mean monthly alkalinity (right) within surface waters of Carpenter Reservoir from samples collected during the growing season (standardized using stations C2 and C6 only).

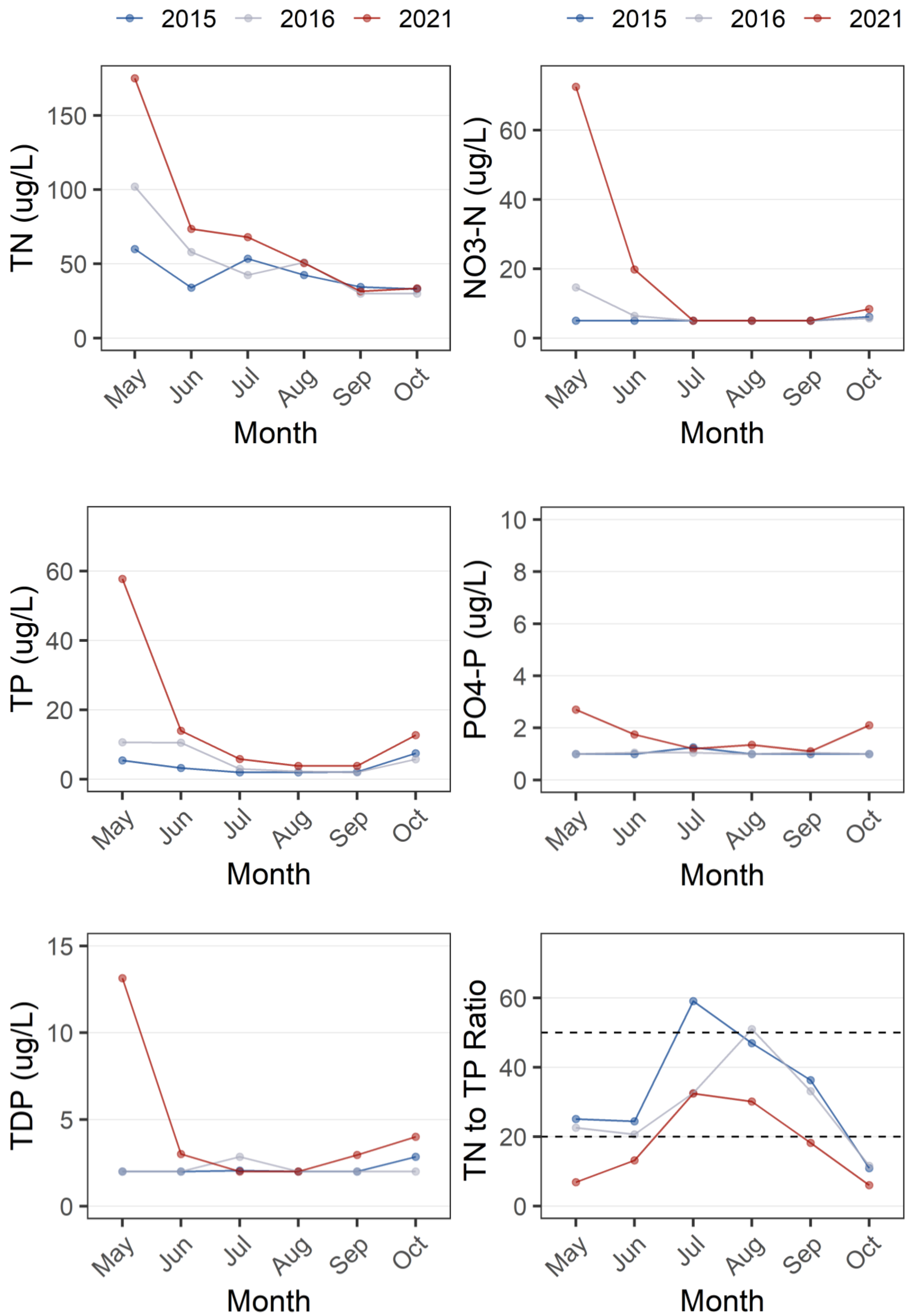


Figure 3.41 Mean monthly nitrogen (N) and phosphorus (P) concentrations measured in laboratory samples, as well as the molar ratio of total nitrogen (TN) to total phosphorus (TP) within surface waters of Carpenter Reservoir. Dissolved forms include nitrate (NO_3-N), total dissolved phosphorus (TDP) and dissolved orthophosphate (PO_4-P). Ammonia concentrations were almost always at or below detection limits (5 µg/L) and so are not shown. Values were standardized using data from stations C2 and C6 from May to October. The horizontal dashed lines at 20 and 50 in the lower right panel indicate the range of molar N:P values considered optimal for phytoplankton growth; below 20 will be nitrogen limited for many species and above 50 will be phosphorus limited.

3.8.3 Biological Production

Chlorophyll-a and Fluorescence

Chlorophyll-a samples collected in 2021 for laboratory analysis were filtered through a 0.45 µm MCE filter, while samples collected in 2015 and 2016 (BRGMON-10) were filtered through a 0.2 µm polycarbonate filter (to obtain size-fractionation of picoplankton, nanoplankton and microplankton), and a 0.75 µm glass fiber filter (for consistency with previous monitoring) (Limnotek 2016, 2018). While not directly comparable, we averaged the results of both filter sizes from 2015 and 2016 to facilitate an approximate comparison with 2021. Integrated samples from C6 suggested there was no evidence of differences among years (2015 mean = 1.08 µg/L, SD = 0.68, min = 0.52, max = 3.06; 2016 mean = 1.29 µg/L, SD = 0.61, min = 0.60, max = 2.55; 2021 mean = 1.02 µg/L, SD = 0.46, min = 0.34, max = 1.76). At station C2, the 2021 samples had a mean chlorophyll-a concentration of 2.22 µg/L (SD = 2.33) with values ranging from 0.57 to 6.90 µg/L; there were no applicable comparisons for C2 from earlier monitoring years. Seasonally, chlorophyll-a concentrations in 2015 and 2016 decreased from May to August then increased in September and October; samples from 2021 varied and did not follow a consistent pattern.

Chlorophyll-a was also measured *in situ* during Seabird profiles. *In situ* measurements are less accurate than laboratory analyses but provide a high-resolution indicator of chlorophyll-a throughout the full water column. In 2021, Seabird profiles indicated a decreasing gradient of chlorophyll-a concentrations from east to west (Figure 3.42), consistent with laboratory samples. Within the water column, maximum chlorophyll-a concentrations occurred in the epilimnion and near the thermocline where the water was clearest and warmest. Maximum concentrations occurred in June through August (Figure 3.42). Unfortunately, the Seabird fluorometer malfunctioned at station C2 during June 2021 when laboratory samples and profiles from other stations indicated concentrations peaked.

Phytoplankton

Of the three monitoring years, mean annual phytoplankton biovolume was lowest in 2021 (0.165 mm^3/L, SD = 0.223, min = 0.025, max = 0.887) and highest in 2016 (0.435 mm^3/L, SD = 0.245, min = 0.095, max = 1.096) with 2015 having an intermediate value (0.284 mm^3/L, SD = 0.148, min = 0.122, max = 0.604) (Figure 3.43). Conversely, species richness was lowest in 2016 (n = 32) and highest in 2021 (n = 46) with a total of 73 species detected overall (Appendix

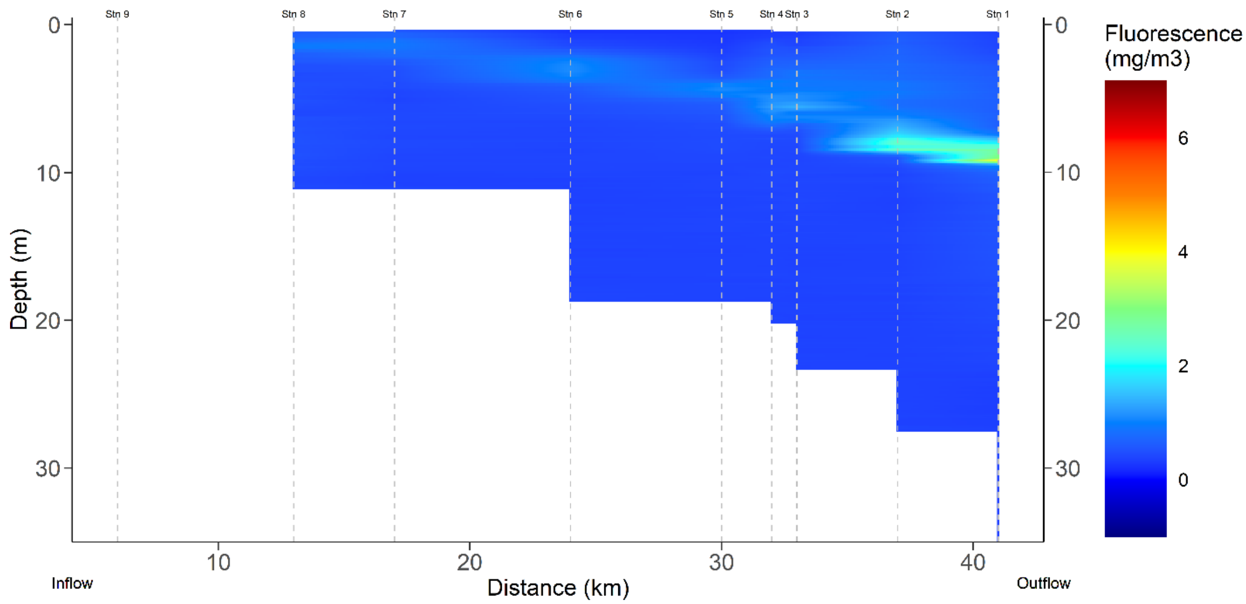
C). In all years, chrysomonads and cryptomonads (Cryptophyta, Katablepharidophyta, Ochrophyta, Haptophyta) and diatoms (Bacillariophyta) were the dominant taxonomic groups, while euglenoids (Euglenophycota) and blue-green algae (Cyanobacteria) were the least represented taxa (Figure 3.43). However, community composition varied among monitoring years. The dominant taxa in 2021 included *Cryptomonas* sp., *Asterionella formosa*, and *Diatoma* sp., while *Ochromonas* spp, *Uroglena americana*, *Fragilaria crotonensis*, and *Chrysochromulina* sp. were the dominant taxa in both 2015 and 2016. Blue-green algae, some of which are nitrogen fixers, were typically present in small volumes at the beginning or end of the growing season when the reservoir was in, or close to, a state of nitrogen limitation (Figure 3.44). Overall, phytoplankton biovolume was greatest in May or June of all years (Figure 3.44), slightly earlier than peak zooplankton biomass. Monthly phytoplankton biovolume does not reflect seasonal phytoplankton growth rates, but instead reflects a combination of factors (e.g., grazing, flushing, sinking) that provide a monthly snapshot of phytoplankton in the reservoir.

Trophic State

Trophic state is a general classification system of lakes and reservoirs by nutrient concentrations (i.e., nitrogen, phosphorus), chlorophyll concentration, and water transparency (e.g., Secchi depth) (Wetzel 2001). In glacial systems, such as Carpenter Reservoir, water transparency is not an appropriate trophic state classifier because it is affected more by inorganic suspended particles than by phytoplankton biomass, as in non-glacial systems. Therefore, we have not included Secchi depth as an indicator of trophic state. Our results indicate Carpenter Reservoir was ultra-oligotrophic or oligotrophic in all years (Table 3.6). Given the well-established relationship between nutrient loading and primary production, the productive potential in Carpenter Reservoir is relatively low. Moreover, since primary producers are the foundation of aquatic food webs, limited algal growth has consequences for higher organisms including zooplankton and fish.

Zooplankton

Mean zooplankton biomass was lower in 2016 (mean = 1032 mg dry weight/m^2, SD = 1182, min = 15, max = 5645) and 2021 (mean = 959 mg dry weight/m^2, SD = 1332, min = 2, max = 5645) compared to 2015 (mean = 1376 mg dry weight/m^2, SD = 1215, min = 33, max = 3960) (Figure 3.45). In 2016 and 2021, peak biomass occurred late in September, while in 2015, peak biomass occurred in July and remained high in August (Figure 3.46). In all years, *Daphnia* spp. comprised over 70% of the biomass with copepods (Copepoda Calanoida, Copepoda Cyclopoida) contributing most of the remaining biomass to the zooplankton community (Figure 3.45). The copepod portion of the community differed among monitoring years. In 2015, the calanoid copepod *Acanthodiaptomus denticornis* was dominant, whereas in 2016 and 2021, cyclopoid copepods *Diacyclops thomasi* and other unidentified cyclopoid species were dominant. Overall, eleven cladocerans (including *Daphnia* spp.), ten copepods, and six rotifers (Rotifera) have been identified among the zooplankton samples collected from Carpenter Reservoir (Appendix C).



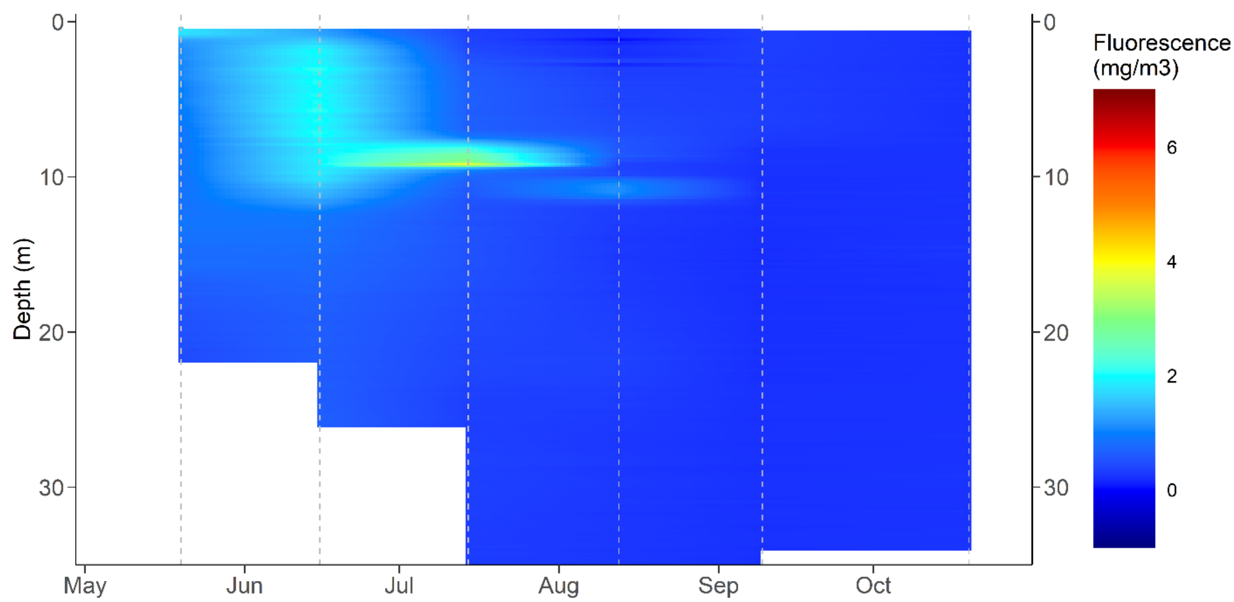


Figure 3.42 Complete Seabird profiles of fluorescence (mg/m^3 = 1 μg/L) taken at all stations in July 2021 near peak growing seaon (top) and at station C1 over the entire growing season (bottom) to illustrate patterns in fluorescence within Carpenter Reservoir. Unfortunately, due to equipment malfunction in June 2021, data from C2 (the core monitoring station) is uninfoimrative and therefore is not shown.

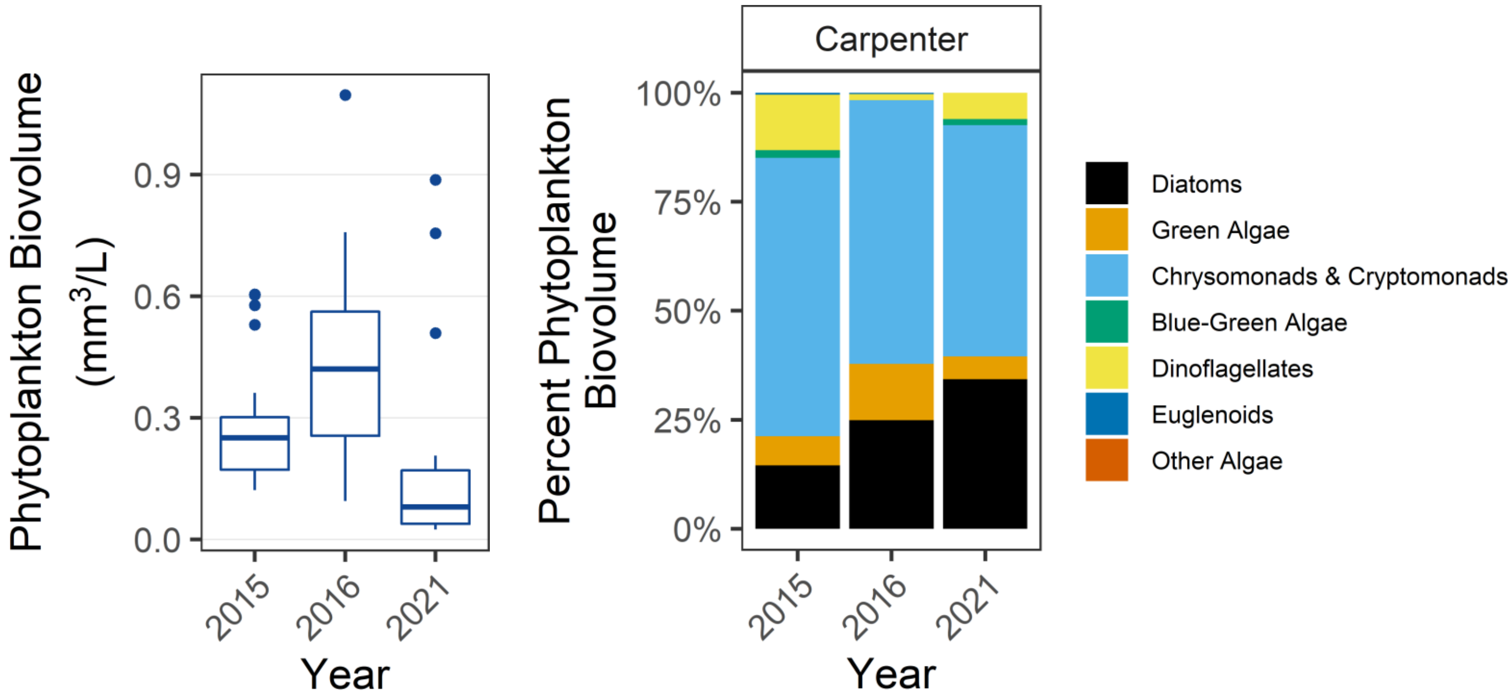


Figure 3.43 Boxplot of annual phytoplankon biovolume (left) and the percent composition of major taxonomic groups (right). Data are from integrated samples collected within the euphotic zone of Carpenter Reservoir at stations C2 and C6 from May to October.

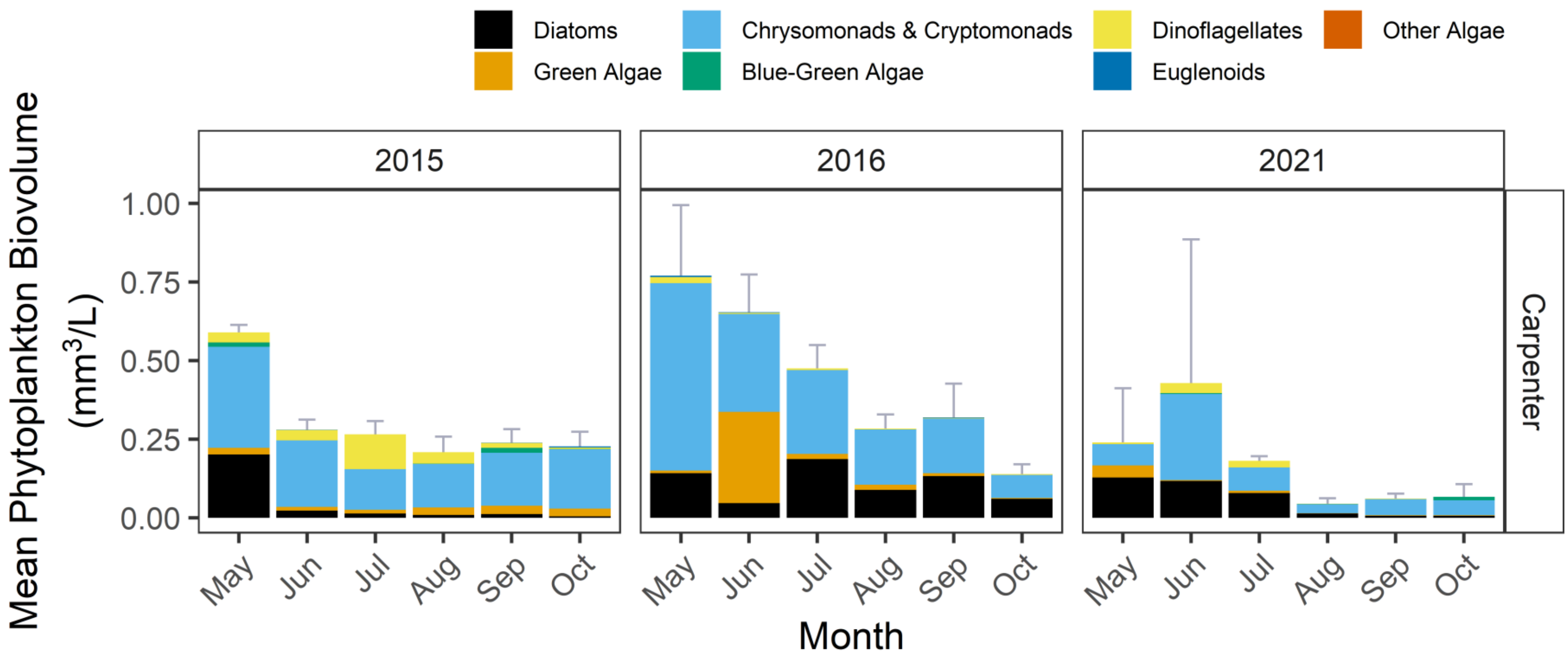


Figure 3.44 Mean monthly phytoplankton biovolume and community composition within the euphotic zone of Carpenter Reservoir (at stations C2 and C6) during the growing season. Error bars represent the standard deviation of total monthly biovolume.

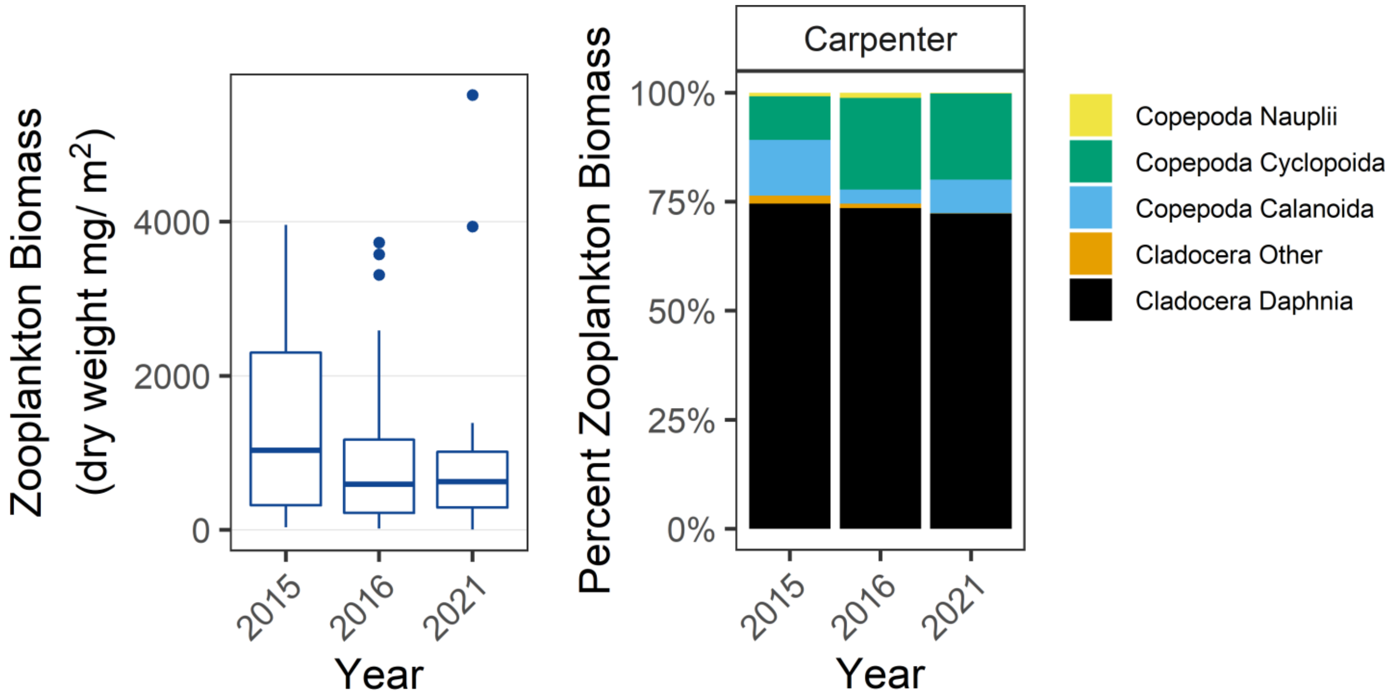


Figure 3.45 Boxplot of annual zooplantkon biomass (left) and the percent composition of major taxonomic groups (right). Data are from duplicate vertical hauls (from a depth of 2 m off bottom, up to a maximum of 30 m) collected within Carpenter Reservoir at stations C2 and C6 from May to October.

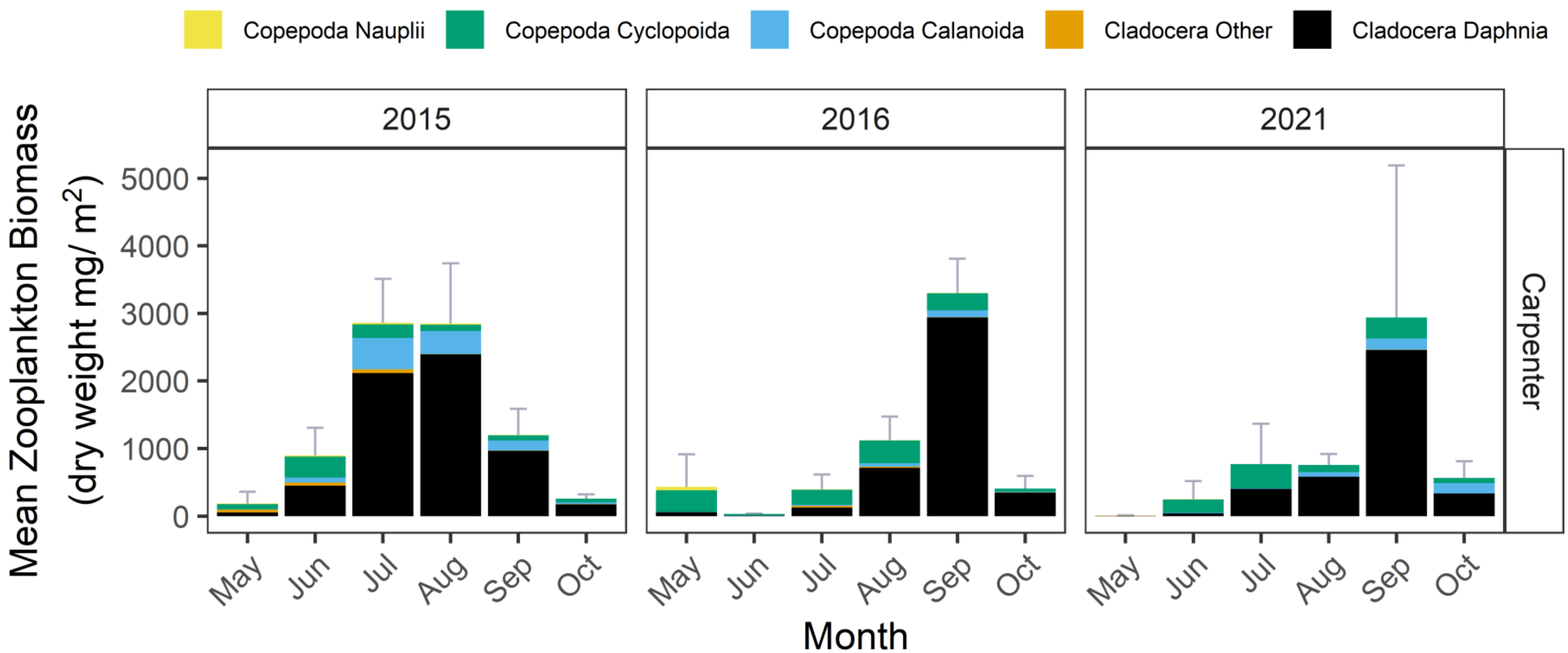


Figure 3.46 Mean monthly zooplankton biomass and community composition within Carpenter Reservoir (at stations C2 and C6) during the growing season. Error bars represent the standard deviation of total monthly biomass.

Table 3.6 Classification of trophic state of freshwater lakes and reservoirs using nutrient and chlorophyll-a concentrations (Wetzel 2001).

Parameter (based on mean annual values and range, µg/L)	Carpenter Reservoir**			Ultra-oligotrophic	Oligotrophic	Mesotrophic	Eutrophic	Hyper-eutrophic
	2015	2016	2021					
Total Phosphorus	3.7	5.7	16.3	NA	8.0	26.7	84.4	NA
	2.0–10.2	2.0–16.8	2.0–20.3	<1–5.0	3.0–17.7	10.9–95.6	16–386	750–1200
Total Nitrogen	43	52	72	NA	661	753	1875	NA
	30–62	30–105	30–184	<1–250	307–1630	361–1387	393–6100	NA
Chlorophyll-a of phytoplankton	1.1	1.3	1.0, 2.2*	NA	1.7	4.7	14.3	NA
	0.5–3.1	0.6–2.6	0.3–1.8, 0.6–6.9*	0.01–0.5	0.3–4.5	3–11	3–78	100–150
Chlorophyll-a maxima	3.1	2.6		NA	4.2	16.1	42.6	NA
			1.8–6.9*	NA	1.3–10.6	4.9–49.5	9.5–275	NA

* data from stations C2 and C6, chlorophyll values in 2015 and 2016 are from station C6 only, which data show has lower concentrations than C2

** based on values from May to October at stations C2 and C6 using epilimnetic samples only

4. Discussion

The primary objectives of BRGMON-4 are to assess the life history, biological characteristics, abundance, and composition of the fish community in Carpenter Reservoir and the Middle Bridge River, as well as to determine how reservoir operations affect fish populations. Monitoring in 2021 builds on data and understanding gained from 2012 to 2020 and helps direct future monitoring.

4.1 Carpenter Reservoir Operating Parameters

Operating parameters in Carpenter Reservoir were variable from 2012 to 2021, particularly minimum and maximum elevation. Since 2017, minimum elevations have been low relative to previous monitoring years due to Modified Operations in Downton Reservoir. Despite similar minimum elevations, rates of filling and the maximum elevations were variable, resulting in unique habitat conditions in these years (and all years of 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 reservoir elevation in early April predicts productivity during the growing season (Limnotek 2018). In years with low April elevation, growing season productivity is typically lower due to a more turbid surface layer becoming isolated during thermal stratification. Maximum summer elevation in July through October provides 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 (i.e., depth, length, and width) is lower, and second, the number of large, cool tributaries that discharge directly into the reservoir is reduced, thereby eliminating clear cool confluences with optimal Bull Trout habitat and foraging conditions. According to these indicators, growing season productivity was low to moderate in 2021 and habitat quantity at maximum pool was moderate relative to all other monitoring years. Implications of reservoir elevations are discussed below in the context of the monitor's five 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*, which are the dominant zooplankton taxa. Catch data from BRGMON-4 suggest the dominant fish species in Carpenter Reservoir are 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 therefore, are less constricted at low reservoir elevations.

Fish distribution varies in Carpenter Reservoir with season, habitat availability, reservoir elevation, and their interactions. At full pool in the summer (i.e., when Carpenter Reservoir most resembles a lake ecosystem), gillnetting and electroshocking results suggest 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 western areas (data on file from BRGMON-4; 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 (for both thermal refuge and foraging opportunities), 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 have been observed spawning in Carpenter Reservoir tributaries in August and September, and catch data suggest they remain in the eastern lacustrine habitat at all other times of the year. The volume of lacustrine habitat decreases at low pool in the spring, resulting in reduced habitat availability and increased competition because kokanee are not able to utilize more western riverine habitat (according to habitat preferences and BRGMON-4 catch data; McPhail 2007). Kokanee spawn when Carpenter Reservoir is nearing full pool; lower maximum reservoir elevations may make it more difficult to access western spawning tributaries because of the turbid nature of the Middle Bridge River inundation zone. Furthermore, low reservoir elevations increase the length of exposed areas in the drawdown zone within spawning tributaries that kokanee must migrate through to reach more covered spawning habitat, which could result in increased predation-related mortality. 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 catch data indicate they 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 the drawdowns result in a decrease in abundance or condition of prey species (i.e., juvenile Rainbow Trout, 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 ultra-oligotrophic to oligotrophic water body with relatively low productivity (results in this report; 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 small relative to nearby systems, 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 and Gompertz 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 during Modified Operations was 651 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. Similarly, the asymptotic length of Mountain Whitefish in Carpenter Reservoir and the Middle Bridge River during Modified Operations was estimated at 304 mm, while Mountain Whitefish in other systems are reported to have higher asymptotic lengths (Columbia River – 400 mm: Golder Associates Ltd., Okanagan Nation Alliance, and Poisson Consulting Ltd. 2016; Madison River Montana – 450 mm: Boyer et al. 2017). 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; however, there is minor evidence that Rainbow Trout growth may have declined due to Modified Operations.

4.2.2 Management Question 2

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

During the WUP alternative (N2-2P), the management of elevations in Carpenter Reservoir and Downton Reservoir were ranked lower than other priorities in the Bridge River system that had greater environmental and cultural significance. Constraints on minimum and maximum reservoir elevation remained at 606.6 m and 651.1 m, respectively (BC Hydro 2011), and the system was managed to maintain these parameters. N2-2P was followed from 2012 until 2015. In 2016, Modified Operations were implemented to address safety risks at Lajoie Dam. Although Modified Operations did not change the constraints on Carpenter Reservoir elevations, reservoir elevations were affected due to changes in constraints on Downton Reservoir elevations. 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 (including the change from N2-2P to Modified Operations part way through the study period) 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 isolate, 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 (e.g., shoreline electroshocking, gillnetting, spawning surveys, and hydroacoustic surveys; see Appendix A). 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 under BRGMON-4.

Results from the limnological monitoring and BRGMON-10 suggest reservoir elevation can affect fish habitat and food availability (Limnotek 2018), and when comparing reservoir parameters between operational regimes, we observed a weakly significant trend towards lower minimum elevations in the current Modified Operations regime relative to the pre-WUP and N2-2P regimes. This trend was driven by Modified Operations in 2016 through 2021, suggesting N2-2P may have had a neutral effect on fish populations; however, Modified Operations had a more pronounced negative affect.

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?

Quantitatively linking operating parameters to fish productivity in Carpenter Reservoir and the Middle Bridge River is difficult 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 are affected by reservoir elevation. Reservoir elevation affects fish in two ways: first, minimum elevation in the spring determines growing season productivity (i.e., food availability), and second, reservoir elevation affects the quality (e.g., suspended sediment, water temperature) and quantity of available habitat and the ease of access to preferred habitat.

Limnological monitoring indicated that reservoir operations are linked to physical and chemical conditions in the reservoir (temperature, sediment loading, water clarity, and nutrient concentrations), which subsequently affect productivity of lower trophic levels throughout the growing season. Minimum elevations have been lower under Modified Operations, including in 2021, resulting in elevated suspended sediment loads and turbidity, and reduced water clarity and euphotic zone volume. These observations are consistent with CEQUAL-W2 modelling completed during BGRMON-10, which predicted that low elevations and high turbidity in the spring would lead to delayed thermocline development and reduced euphotic zone depths over the growing season (Limnotek 2018). Even when summer elevations are high or average, low spring minimums can have negative effects on productivity throughout the growing season.

Total suspended sediment, turbidity, and light penetration in 2021 were consistent with predictions from BRGMON-10 CEQUAL-W2 modelling, but surface water temperatures and zooplankton biomass were higher in 2021 relative to model predictions. This was expected given that meteorological and inflow conditions in 2021 were not identical to inputs used for CEQUAL-W2 scenario modelling. CEQUAL-W2 modelling predicted that low spring elevations would result in low surface water temperature (primarily early in the growing season), but epilimnetic temperatures were elevated in Carpenter Reservoir in 2021 relative to modelled values. Ambient air temperatures in late June and early July were record-setting, with maximum daily temperatures reaching 46.8°C in Lillooet (data on file). Surface water temperatures in 2021 were likely driven by this extreme heat event, which was outside of meteorological conditions modelled under BGRMON-10. This surface water anomaly likely explains why zooplankton biomass in 2021 was higher than predicted by CEQUAL-W2 modelling, as higher water temperatures are associated with increased zooplankton biomass production (Limnotek 2018, Wetzel 2001, Shuter and Ing 1997, Schindler 1968).

Overall, growing season productivity in Carpenter Reservoir is relatively low (this study, Limnotek 2018), which typically corresponds to a smaller biomass of lacustrine invertebrates. A greater portion of the food web in Carpenter Reservoir is composed of invertebrate drift from the Middle Bridge River and reservoir tributaries (Limnotek 2018, Leslie 2003). Low food availability driven by a low biomass of lacustrine invertebrates may explain why primarily lacustrine species (e.g., kokanee, Redside Shiners, Rainbow Trout) are less resilient to extended periods of low reservoir elevation. Conversely, species that are more river-adapted, including Mountain Whitefish and Bull Trout, can survive in shallower riverine habitats while taking advantage of the food resources from the Middle Bridge River and large western tributaries. When reservoir elevations are high, all species benefit from higher habitat volume and increased food availability. For kokanee and Rainbow Trout, food availability during full pool is high due to warmer water temperatures and longer water residence times, resulting in increased zooplankton biomass. For Bull Trout and Mountain Whitefish, food availability is high due to easy access to large western reservoir tributaries, and for Bull Trout, better conditions for lacustrine prey species.

Summer elevations in Carpenter Reservoir have been variable, but lower mean summer elevations or a delay in maximum elevation in some Modified Operations years (e.g., 2016, 2017, and 2018) may have affected the condition, relative abundance, and distribution of Carpenter Reservoir Bull Trout. Bull Trout are adaptable to both reservoir and river conditions; however, Bull Trout are known to have strict thermal tolerances with optimal water temperatures in the range of 11-15°C and lethal temperatures of approximately 21°C or greater (Selong et al. 2001, McPhail 2007). Such thermal conditions were exceeded in the reservoir in 2021 with maximum surface water temperatures in the lethal range. Adfluvial Bull Trout populations generally seek refuge in cool tributaries as water temperatures increase in the summer (Kovach et al. 2017, Kang et al. 2017, Sawatzky 2016). A literature review found little information regarding the distribution of Bull Trout in lakes and reservoirs, but Bull Trout distribution data from Carpenter Reservoir suggest Bull Trout rely heavily on tributary confluences, possibly because the tributaries themselves are relatively small and steep (i.e., many are inaccessible to Bull Trout during all or part of the year), and because prey species congregate at the confluences to feed on invertebrate drift. When summer elevations are low or full pool is delayed, access to many large, cool tributaries (e.g., Truax Creek, Gun Creek, Tyaughton Creek) is restricted because they flow into the Middle Bridge

River (when elevations are high these tributaries flow into the reservoir itself). Tributaries that flow into the Middle Bridge River do not provide optimal habitat or forage conditions for Bull Trout or their prey species because they are difficult to access (i.e., fish must migrate further up the turbid Middle Bridge River to reach them), and high discharges in the Middle Bridge River inhibit the formation of a cool, clear pool at the confluence (ideal for thermal and turbidity refugia and visually-driven predation).

BRGMON-4 data provide some evidence that low or delayed mean summer elevations and low minimum spring elevations have resulted in population-level changes to Carpenter Reservoir Bull Trout. Not only does suspended sediment loading affect production and food availability, but it also has direct effects on fish. At the levels observed in Carpenter Reservoir, we would expect sublethal or behavioural effects on salmonids (which typically manifest when values range from tens to hundreds of mg/L, depending on exposure period, species, and life stage; DFO 2000, Bash et al. 2001) such as reduced foraging activity or ability, reduced growth, increased physiological stress, and reduced survival. Fulton's condition factor shows a general decline in condition of Bull Trout, Mountain Whitefish, and Rainbow Trout in 2016 and 2017, and a potential recovery of condition in 2018 through 2020. This trend is somewhat delayed in Bull Trout, suggesting condition may have been indirectly affected by decreased condition of prey species in the previous year. The cause of increased condition in 2018 through 2020 is unknown, but could be related to changes in age distributions, decreasing competition due to population declines, and higher summer elevations in 2019 and 2020. Although changes in body condition provide evidence of elevation-related population effects, condition factor may not fully reflect changes to fish health and overall body composition. Fulton's condition factor is effective at non-lethally and coarsely evaluating fish condition, but it may not reflect the complex changes to food webs that can occur with habitat alterations (Blackwell et al. 2000). There is also evidence that age distributions have shifted because of Modified Operations, such as most Bull Trout captured in the reservoir are now age 4 or 5, with almost no fish being caught over age 8. In contrast, captures during 2015 and 2016 were estimated to be 25% greater than age 8 (Figure 3.12). Overall, these lines of evidence suggest Bull Trout may grow faster in Carpenter Reservoir during lower elevation, low productivity conditions, but that the survival of large Bull Trout over age 7 has decreased considerably relative to higher elevation regimes.

The acoustic tagging program also suggests that low reservoir elevations restrict Bull Trout movements. We have seen preliminary evidence of a potential decline in the number of Bull Trout that migrate into the Middle Bridge River in late summer and an increase in the number of fish using the eastern reservoir habitat. Bull Trout may be spawning less frequently in the Middle Bridge River and instead spawning in Carpenter Reservoir tributaries (which have limited suitable spawning sites; Griffith 1999) or forgoing spawning in some years (skip-spawning). Skip-spawning can occur in Bull Trout populations when body condition decreases, fish densities increase, or productivity decreases (Caskenette et al. 2016), all of which may be occurring in Carpenter Reservoir as a result of Modified Operations in 2016 through 2021. Although these data are preliminary, increasing skip-spawning rates could lead to a decline in the Bull Trout population in future years.

Similar to Bull Trout, Rainbow Trout condition declined in Carpenter Reservoir in 2016 and 2017 and appeared to recover in 2019 and 2020. As with Bull Trout, declining Rainbow Trout condition may have been related to the decline in overall habitat volume in Carpenter Reservoir and a decrease in growing season productivity, particularly in 2017 and 2018, and recovery could be related to changes in age distributions, decreasing competition, and higher summer elevations in 2019 through 2021. These patterns are very similar to Rainbow Trout condition in Downton Reservoir, which also saw substantial elevation reductions beginning in 2015 (Sneep 2022). Similar to in Carpenter Reservoir, condition of Downton Reservoir Rainbow Trout declined during Modified Operations, particularly for age 1 to 3 individuals, but condition did not recover in Downton Reservoir in recent years as it has in Carpenter Reservoir. This discrepancy is likely related to different mechanisms acting on Rainbow Trout in the two habits. In Carpenter Reservoir, declining elevations likely decrease food availability and increase predation, whereas in Downton Reservoir, lower elevations increase competition for food and habitat (there is no lacustrine predation of Rainbow Trout in Downton Reservoir). The recovery of Rainbow Trout condition may be related to inter-species interactions, which are not present in Downton Reservoir, a Rainbow Trout monoculture, and the presence of stream-resident populations in Carpenter Reservoir tributaries, which are not directly affected by reservoir habitat conditions, and may supplement reservoir populations.

We also observed an increase in Rainbow Trout CPUE during the Bull Trout CMR program, relative to previous years of Modified Operations. The mechanisms behind this potential increase in Rainbow Trout abundance are uncertain but may be related to a depletion of several generations at the onset of Modified Operations, related to entrainment and competition. Rainbow Trout currently reaching age 4 or 5 may have been juveniles in 2016 and 2017, still utilizing tributary habitat, where they may have been buffered from the initial effects of low reservoir elevations.

For Mountain Whitefish, condition factor was more stable throughout BRGMON-4, but there is weak evidence of a decline in 2016 and 2017. Mountain Whitefish condition may have been more stable because whitefish are more adaptable to riverine habitats and therefore may be less affected by low reservoir elevations. Although BRGMON-4 does not estimate abundance of Rainbow Trout or Mountain Whitefish, relative capture rates of these species have been variable, potentially indicative of density-dependent processes. 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 and constricted movement patterns, both of which could potentially lead to declines in abundance.

The effect of reservoir operations on kokanee is more difficult to interpret. The primary index of kokanee abundance is annual spawner counts performed in August and September since 2014, which have been highly variable. Kokanee rely heavily on pelagic lacustrine habitat for most of their lifespan; they are also a planktivorous fish with preference for *Daphnia* prey. We would expect that years with low minimum and maximum reservoir elevation would reduce kokanee habitat (quality and quantity) 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). Low minimum reservoir elevations in 2017 through 2020 and entrainment of kokanee through the Terzaghi Dam in 2016 and 2017 may be negatively affecting kokanee abundance in Carpenter Reservoir (Putt et al. 2018). In 2018, kokanee spawner counts were very low, no kokanee spawners were observed in 2019, and one spawner was observed in 2020. In contrast, spawner counts were high in 2017, despite low spring elevations. The delayed effect of reservoir drawdown and entrainment on kokanee spawner abundance may have occurred because kokanee entrained in 2016 and 2017 likely reached sexual maturity in 2018, 2019, or 2020 (81% of kokanee entrained in 2016 were estimated to be age 1+ or 2+; McHugh et al. 2017).

In 2021, kokanee were once again observed in Carpenter Reservoir spawning tributaries, with spawner counts similar to those estimated in 2018. The recovery of spawner counts further indicate that several breeding groups may have been severely depleted by entrainment in 2016 and 2017, but that kokanee of younger age classes persisted and reached spawning maturity in 2021. This is consistent with previous population kokanee declines, particularly in the early 1990s, where researchers hypothesized that low elevation conditions caused kokanee to be extirpated from Carpenter Reservoir, only for them to recover in subsequent years, suggesting low elevations can cause age-structured collapses in the reservoir, but that younger age classes may be more robust to entrainment and reduced pelagic habitat availability.

Kokanee spawner surveys and observations of redds and paired kokanee suggest that kokanee rarely spawn within the drawdown zone of Carpenter Reservoir tributaries, suggesting a low risk of redd inundation. Qualitative habitat surveys support this finding, as habitat within the drawdown zone is generally highly braided, shallow, and has little to no riparian cover. 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 predation risk. These risks are exacerbated when reservoir elevations are low. Kokanee spawning 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 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. Furthermore, 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. Spawning Mountain Whitefish have been monitored in the Middle Bridge River via spawner angling surveys (Tisdale 2010, Putt et al. 2018), which indicate there has been a decline in spawners since 2009. The cause of this decline is unknown because Mountain Whitefish are not targeted by BRGMON-4 outside of the Middle Bridge River during adult spawning. The decline may be related to a shift in distribution, decreased juvenile survival, and/or changes in reservoir or river conditions.

Preliminary surveys of three Carpenter Reservoir tributaries (Macdonald Creek, Gun Creek, and Marshall Creek) did not identify evidence of Mountain Whitefish spawning outside of the Middle Bridge River, and habitat surveys in 2009 and 2012 suggested the current Middle Bridge River sampling sites are critical holding sites. Although this assessment is not comprehensive, we did not find evidence of a shift in Mountain Whitefish spawning distribution.

Spawn timing and hatch calculations suggest Mountain Whitefish spawn in the Middle Bridge River in mid- to late November and hatch in early February, and Kokanee spawn in the Middle Bridge River in September and hatch in early December. Middle Bridge River stage heights have been relatively stable through these periods throughout BRGMON-4 and there are generally few rampdowns at Lajoie Dam. Given this, Tisdale (2010) and BRGMON-4 both concluded that the direct risk to egg dewatering from Lajoie Dam operations is low for both Mountain Whitefish and kokanee.

Declining Mountain Whitefish spawner abundance may be related to changes in the Middle Bridge River hydrograph. Since the onset of Modified Operations in 2016, the Middle Bridge River hydrograph has become more consistent amongst years and is characterized by increased discharge from Lajoie Dam in June through October. These hydrograph changes may affect adult Mountain Whitefish feeding in the Middle Bridge River or migrating into the river to spawn, but this is uncertain given the lack of data for adult Mountain Whitefish in the river outside of the spawning period. Declining spawner abundance may also be related to changing conditions in Carpenter Reservoir because of Modified Operations. BRGMON-4 has identified negative effects of Modified Operations on Bull Trout, kokanee, and Rainbow Trout, but there are insufficient data to determine how reservoir operations affect Mountain Whitefish.

As a managed system, temperatures in the Middle Bridge River are warmer and more stable relative to typical glacially fed systems, which may impact fish in the river and in Carpenter Reservoir. Warmer and more stable winter temperatures may result in faster hatch dates, particularly for kokanee. Earlier emergence could expose alevin to different discharge velocities and food availability relative to those emerging later in the tributaries. Management of Lajoie Dam also affects turbidity and the amount of fine particulate matter in the Middle Bridge River. Regulated discharge regimes (with infrequent high discharge events) often result in armouring of substrates (i.e., interstitial spaces become filled with particulate), which can affect spawning success (Meibner et al. 2018; Sear 1993). We observed armoured and sandy substrate in many areas of the Middle Bridge River during Mountain Whitefish egg mat surveys in 2013 and 2016, but the degree of armouring and its effect on spawning success are uncertain.

Due to challenging sampling conditions in the Middle Bridge River, and the broad scope of BRGMON-4, we have limited data to determine how discharges in the Middle Bridge River affect fish in the river and reservoir. For kokanee, which spawn in the Middle Bridge River and in Carpenter Reservoir tributaries, declining spawner abundance (observed in Carpenter Reservoir tributaries) is likely related to decreased reservoir elevations, as kokanee rely heavily on pelagic lacustrine habitat during their adult life stage. In contrast, Mountain Whitefish are not dependent on lacustrine habitat, and the reason for declining spawner abundance in the Middle Bridge River is unclear.

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?

Preliminary evidence suggests that low elevations in the early spring and summer may result in decreased reservoir productivity and overall habitat volume, which may be detrimental to fish populations in Carpenter Reservoir. Increasing spring minimum elevations (to promote increased reservoir productivity) and summer maximum elevations (to increase overall habitat volume and access to large tributary inflows) may therefore improve habitat conditions and productivity of fish populations. Current data suggest Lajoie Dam operations are not likely to directly affect juvenile survival for Mountain Whitefish and kokanee, and stable discharge releases from November through April should be continued. The effect of the Middle Bridge River hydrograph on adult fish (both resident and of reservoir origin) is not examined during BRGMON-4, and therefore no refinements can be recommended.

Carpenter Reservoir is one of the main reservoirs for power generation in the Bridge-Seton system and balancing biological and management priorities may be difficult. Despite this, BRGMON-4 provides valuable insight into the effect of operations on fish in the reservoir and can be used to qualitatively predict the effect of changing operational regimes.

4.3 Conclusions and Recommendations

Data collected during BRGMON-4 suggest fish populations in Carpenter Reservoir and the Middle Bridge River are affected by operation of the Bridge River power system. The monitoring program appears to be on track to answering the management questions using a weight of evidence approach; however, not all species, life stages, and habitat areas can be comprehensively discussed. For example, it has not been feasible to monitor fish and fish habitat in the Middle Bridge River to a degree that allows for specific hydrograph recommendation that would benefit fish that spawn and rear in the river. Despite uncertainties, BRGMON-4 will provide valuable insight into fish communities in Carpenter Reservoir and the Middle Bridge River and help to answer each management question to the highest degree possible. Insights from BRGMON-4 can be used to develop future monitoring programs and recommend management changes to improve fish productivity.

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Appendix A

Table A.1 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) - Gillnetted 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 gillnet catches were obtained for Bull Trout and Rainbow Trout relative to other regional lakes but lower kokanee density relative to 1993 - Reservoir water residence time is low, likely resulting in 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 was from June 11 to July 23, 1999. - 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 2000 at a water surface elevation of 645 masl	- Analyzed 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 effects of an experimental drawdown of the Middle Bridge River on fish populations and habitat - Enumerated kokanee in the Middle Bridge River and reservoir tributaries	- Described Bull Trout movement (small sample size) - Monitored Middle Bridge River ramp-down in late July/early August - Increased stranding risk occurred but spawning effects were not quantified - No kokanee were observed in any streams	Chamberlain, M.W., O'Brien, D.S., Caverly, A., and A.R. Morris. 2001. 2000 Middle Bridge River Bull Trout (Salvelinus confluentus and Kokanee (Oncorhynchus nerka) Investigation. British Columbia Ministry of Environment, Lands and Parks, Fisheries 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 - 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 dependent 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 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 discharge 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 Exploratory Spawning Assessment October 4– December 21, 2009. Prepared for B.C. Hydro and Power Authority, Shalalth B.C. 40 p.

Appendix B

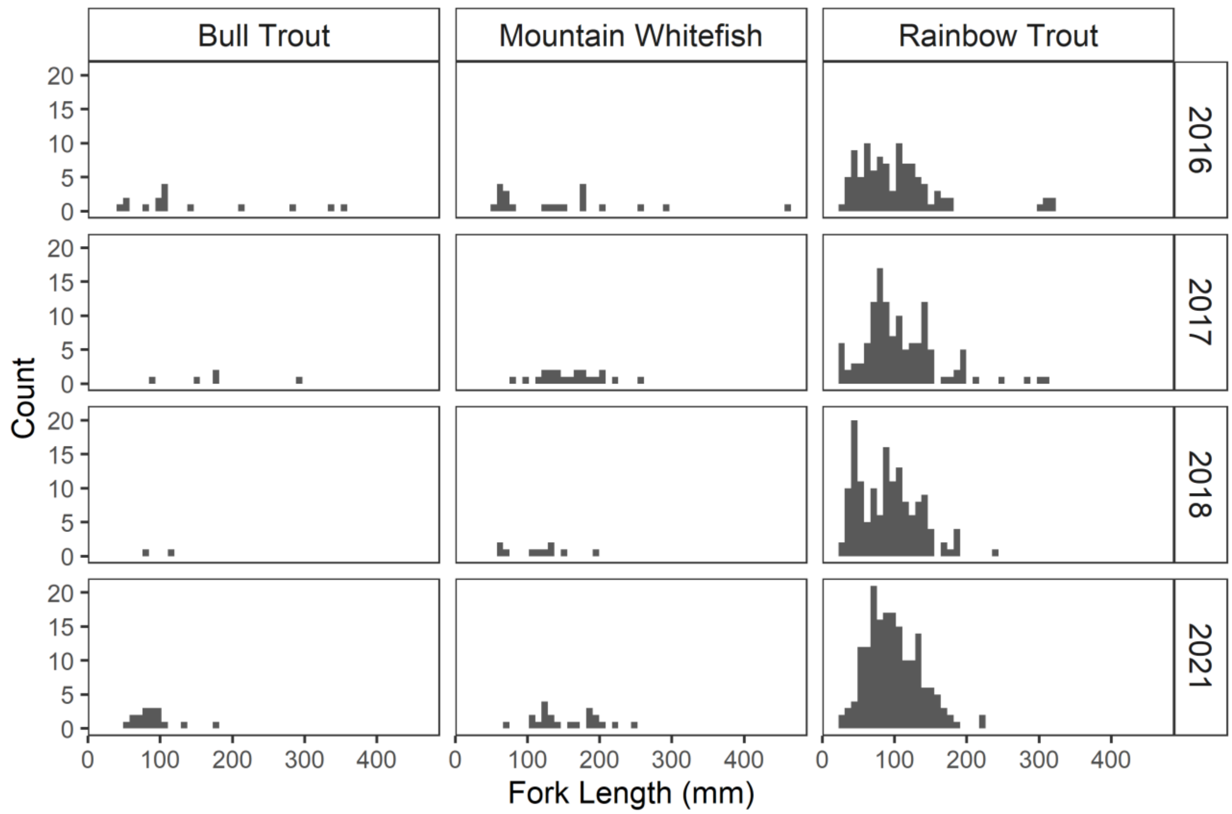

Figure B.1 Fork length histograms for all Bull Trout, Mountain Whitefish, and Rainbow Trout captured during tributary electroshocking in Marshall, Macdonald, Gun, and Truax Creeks from 2016 through 2018 and 2021.

Appendix C

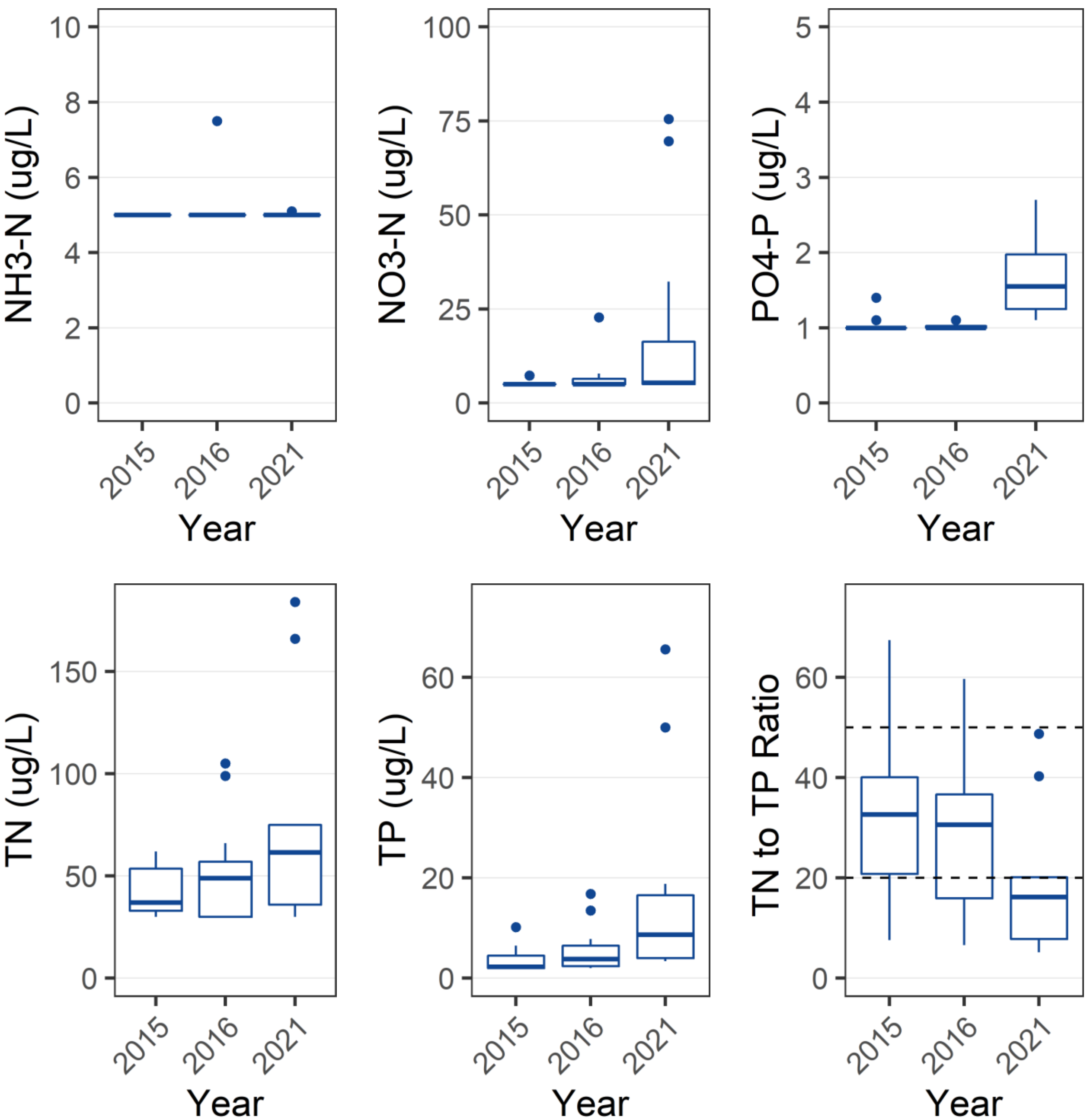

Figure C.1 Boxplots of annual nitrogen (N) and phosphorus (P) concentrations measured in laboratory samples, as well as the molar ratio of total nitrogen (TN) to total phosphorus (TP) within surface waters of Carpenter Reservoir. Bioavailable forms are shown in the top panels, including ammonia (NH_4-N), nitrate (NO_3-N), and dissolved orthophosphate (PO_4-P). Values were standardized using data from stations C2 and C6 from May to October. The horizontal dashed lines at 20 and 50

in the lower right panel indicate the range of molar N:P values considered optimal for phytoplankton growth; below 20 will be nitrogen limited for many species and above 50 will be phosphorus limited.

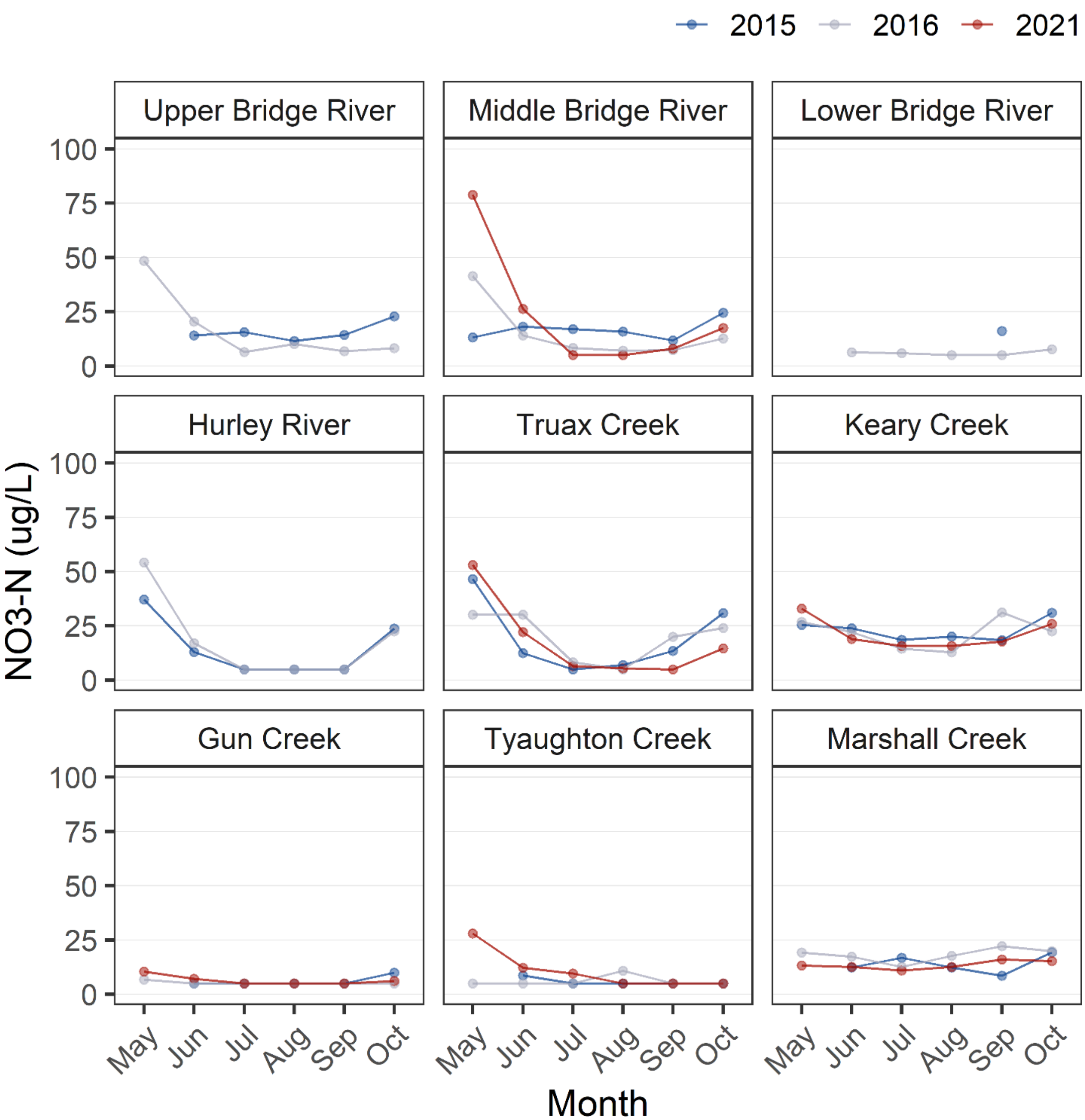

Figure C.2 Mean monthly nitrate (NO_3-N) concentrations measured from ALS laboratory samples within the surface waters of Bridge River tributaries, representing inflow sources to Carpenter Reservoir.

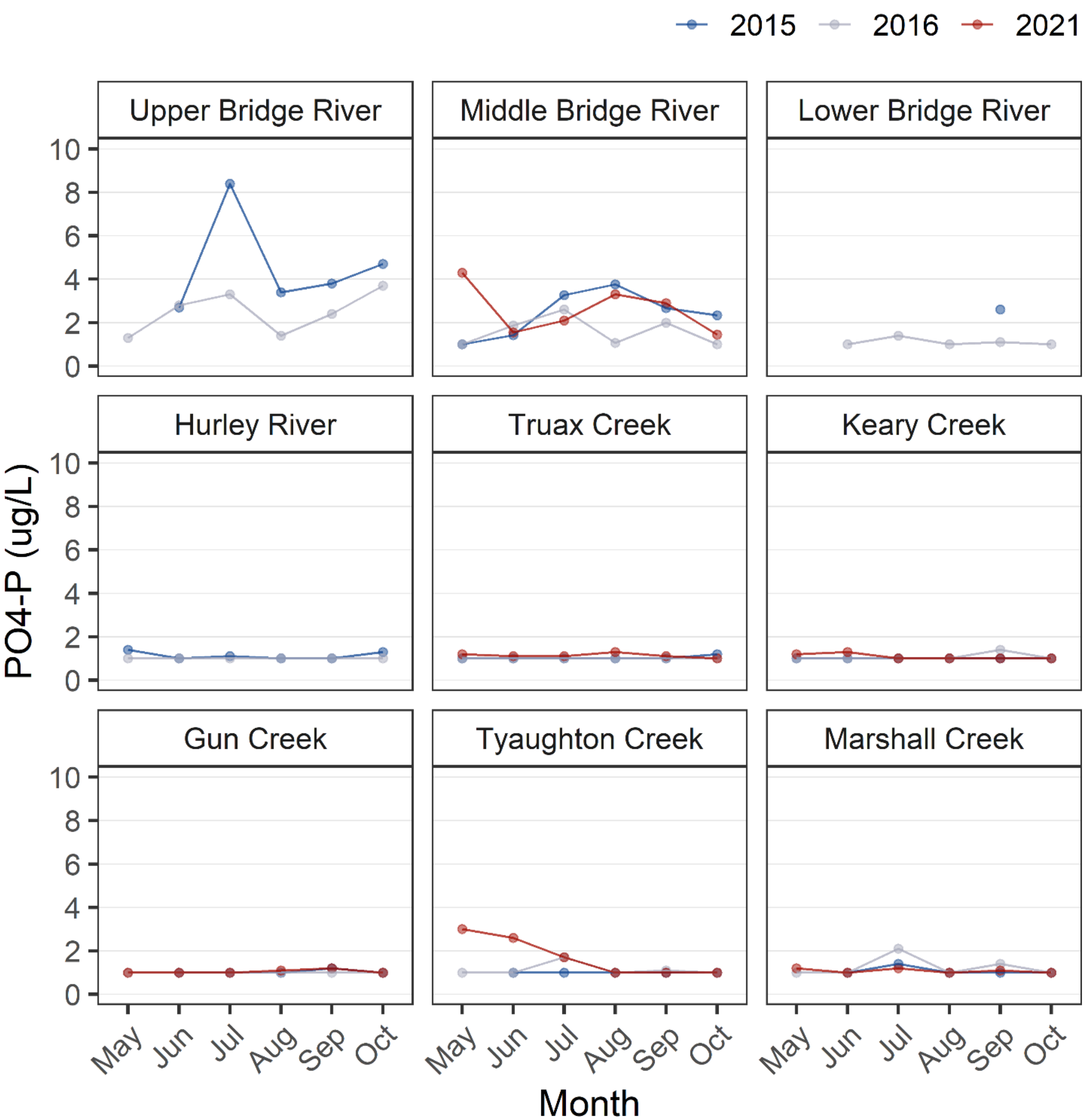

Figure C.3 Mean monthly dissolved orthophosphate (PO_4-P) concentrations measured from ALS laboratory samples within the surface waters of Bridge River tributaries, representing inflow sources to Carpenter Reservoir.

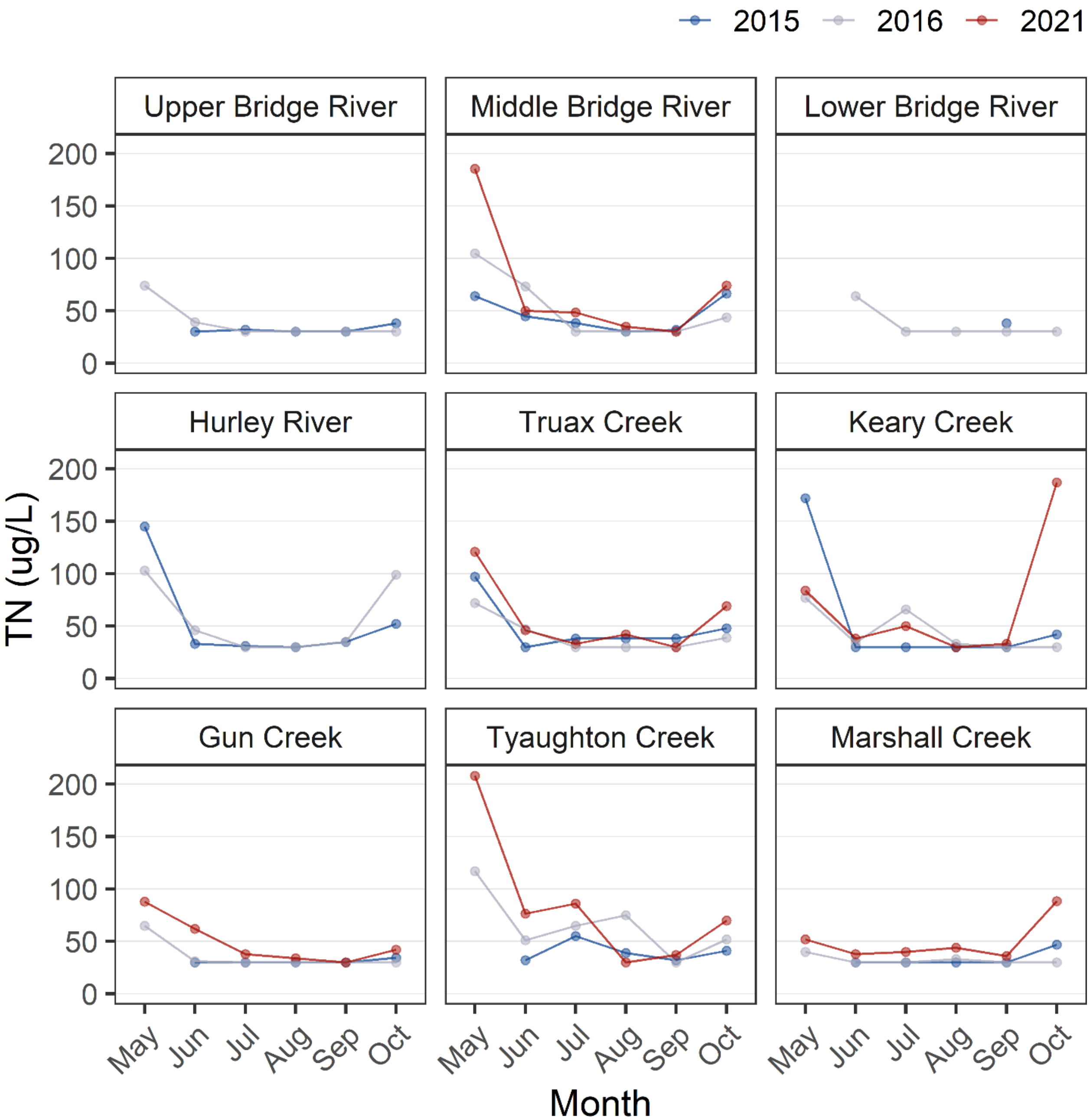

Figure C.4 Mean monthly total nitrogen (TN) concentrations measured from ALS laboratory samples within the surface waters of Bridge River tributaries, representing inflow sources to Carpenter Reservoir.

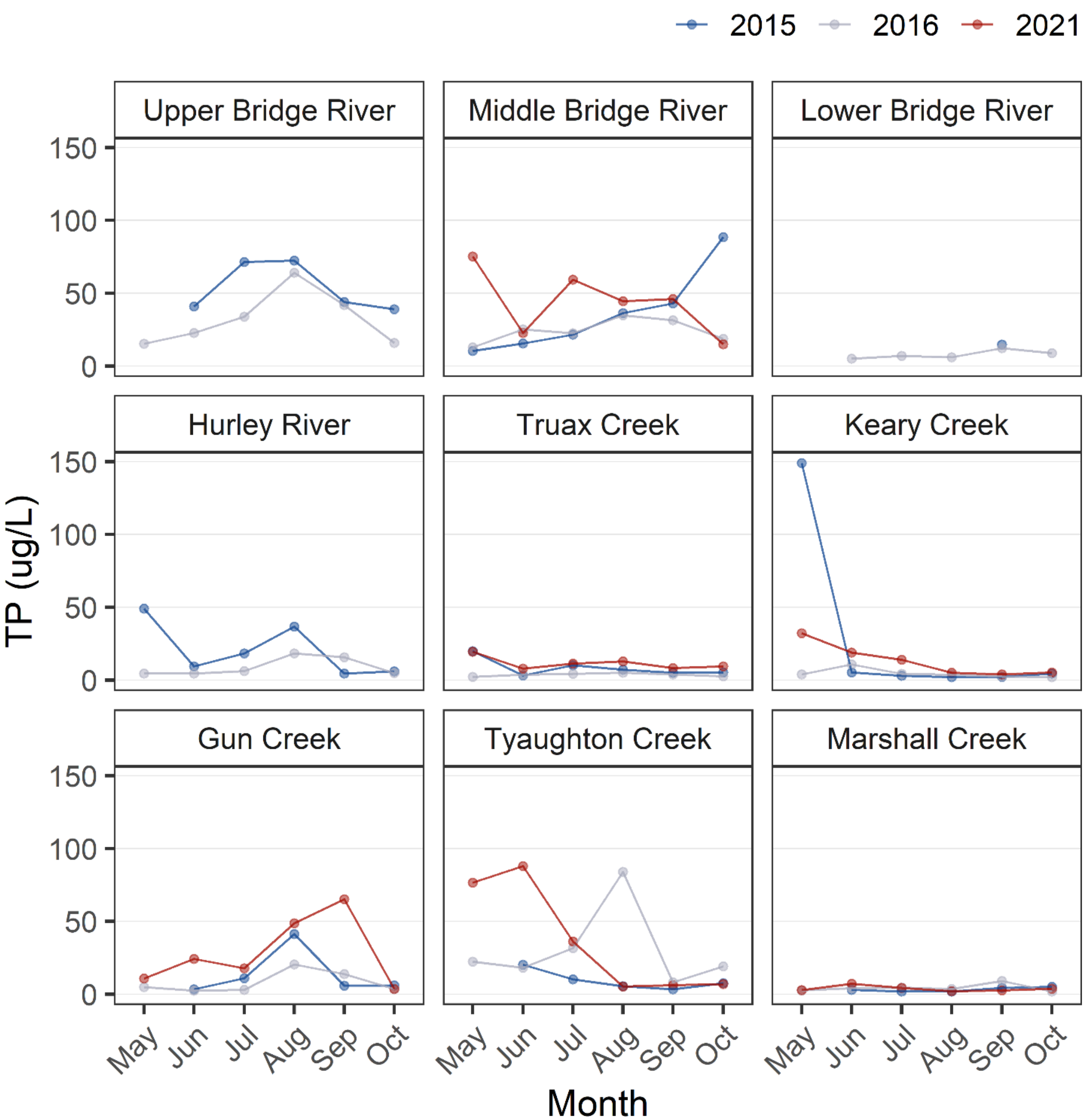

Figure C.5 Mean monthly total phosphorus (TP) concentrations measured from ALS laboratory samples within the surface waters of Bridge River tributaries, representing inflow sources to Carpenter Reservoir.

Appendix D

Table D.1 Presence and taxonomic classification of phytoplankton identified in Carpenter Reservoir during each limnological monitoring year

Group	*Taxon*	2015	2016	2021
Blue-Green Algae	*Anacystis* sp.	×	-	-
Blue-Green Algae	*Aphanizomenon* sp.	-	-	×
Blue-Green Algae	*Aphanothece* sp.	-	-	×
Blue-Green Algae	*Merismopedia punctata*	×	-	-
Blue-Green Algae	*Pseudanabaena* sp.	-	-	×
Chrysomonads & Cryptomonads	*Chilomonas* sp.	×	×	-
Chrysomonads & Cryptomonads	*Chlorobotris* sp.	×	-	-
Chrysomonads & Cryptomonads	*Chromulina minor*	×	×	-
Chrysomonads & Cryptomonads	*Chromulina* sp.	-	-	×
Chrysomonads & Cryptomonads	*Chromulina sphaeridia*	×	×	-
Chrysomonads & Cryptomonads	*Chrysochromulina* sp.	×	×	×
Chrysomonads & Cryptomonads	*Chrysophyte*	-	-	×
Chrysomonads & Cryptomonads	*Cryptomonas marssonii*	×	×	-
Chrysomonads & Cryptomonads	*Cryptomonas* sp.	-	-	×
Chrysomonads & Cryptomonads	*Dinobryon bavaricum*	×	-	-
Chrysomonads & Cryptomonads	*Dinobryon crenulatum*	-	-	×
Chrysomonads & Cryptomonads	*Dinobryon divergens*	×	×	×
Chrysomonads & Cryptomonads	*Dinobryon seratularia*	×	×	-
Chrysomonads & Cryptomonads	*Dinobryon* sp.	-	-	×
Chrysomonads & Cryptomonads	*Katablepharis ovalis*	-	-	×
Chrysomonads & Cryptomonads	*Kephyrion* sp.	×	×	-
Chrysomonads & Cryptomonads	*Mallomonas* sp.	-	-	×
Chrysomonads & Cryptomonads	*Ochromonas globosa*	×	×	-
Chrysomonads & Cryptomonads	*Ochromonas* sp.	×	×	-
Chrysomonads & Cryptomonads	*Plagioselmis nanoplanctica*	-	-	×
Chrysomonads & Cryptomonads	*Spiniferomonas* sp.	-	-	×

Group	*Taxon*	2015	2016	2021
Chrysomonads & Cryptomonads	*Stichogloea* sp.	-	-	×
Chrysomonads & Cryptomonads	*Uroglena americana*	×	×	-
Chrysomonads & Cryptomonads	*Uroglena* sp.	-	-	×
Diatoms	*Achnanthidium* sp.	-	-	×
Diatoms	*Asterionella formosa*	×	×	×
Diatoms	*Aulacoseira* sp.	×	×	-
Diatoms	*Cyclotella* sp.	×	×	×
Diatoms	*Cymbella* sp.	-	-	×
Diatoms	*Diatoma* sp.	-	-	×
Diatoms	*Discostella* sp.	×	×	×
Diatoms	*Fragilaria crotonensis*	×	×	×
Diatoms	*Fragilaria* sp.	-	-	×
Diatoms	*Gomphonema* sp.	-	-	×
Diatoms	*Gyrosigma* sp.	-	-	×
Diatoms	*Melosira* sp.	-	-	×
Diatoms	*Nitzschia* sp.	×	-	×
Diatoms	*Rhizosolenia* sp.	-	×	-
Diatoms	*Ulnaria ulna*	-	-	×
Diatoms	*Urosolenia* sp.	-	-	×
Dinoflagellates	*Ceratium hirundinella*	-	-	×
Dinoflagellates	*Ceratium* sp.	×	-	-
Dinoflagellates	*Gloeodinium* sp.	×	×	-
Dinoflagellates	*Gymnodinium* sp.	×	×	×
Dinoflagellates	*Peridinium* sp.	×	×	×
Euglenoids	*Euglena* sp.	×	×	-
Green Algae	*Ankistrodesmus falcatus*	×	×	-
Green Algae	*Ankyra* sp.	-	-	×
Green Algae	*Botryococcus* sp.	×	×	-
Green Algae	*Chlamydomonas* sp.	×	×	×
Green Algae	*Cosmarium depressum*	-	×	-
Green Algae	*Cosmarium ornatum*	×	×	-

Group	*Taxon*	2015	2016	2021
Green Algae	*Cosmarium* sp.	-	-	×
Green Algae	*Cosmarium subtumidum*	×	-	-
Green Algae	*Crucigenia quadrata*	-	×	-
Green Algae	*Elakatothrix gelatinosa*	×	×	×
Green Algae	*Elakatothrix* sp.	-	-	×
Green Algae	*Eudorina* sp.	-	-	×
Green Algae	*Lagerheimia* sp.	-	-	×
Green Algae	*Monoraphidium* sp.	-	-	×
Green Algae	*Mougeotia* sp.	-	-	×
Green Algae	*Nephrocytium* sp.	×	×	×
Green Algae	*Oocystis* sp.	×	×	×
Green Algae	*Scenedesmus arcuatus*	×	-	-
Green Algae	*Sphaerocystis* sp.	-	-	×
Green Algae	*Staurastrm planktonicum*	×	×	-
Green Algae	*Staurastrum pingue var. planctonicum*	-	-	×
Other Algae	*Bicosoeca ainikiae*	-	×	-

Table D.2 Presence and taxonomic classification of zooplankton identified in Carpenter Reservoir during each limnological monitoring year

Group	*Taxon*	2015	2016	2021
Cladocera Daphnia	*Daphnia mendotae* complex	×	×	×
Cladocera Daphnia	*Daphnia pulicaria*	×	×	×
Cladocera Daphnia	*Daphnia* sp.	×	-	-
Cladocera Other	*Alona* sp.	×	×	-
Cladocera Other	*Ceriodaphnia* sp.	×	×	-
Cladocera Other	*Chydorus sphaericus*	×	×	×
Cladocera Other	*Diaphanosoma brachyurum*	×	×	-
Cladocera Other	*Eubosmina longispina*	×	×	×
Cladocera Other	*Leptodora kindtii*	×	×	×
Cladocera Other	*Scapholeberis* sp.	×	×	×

Group	*Taxon*	2015	2016	2021
Cladocera Other	*Sida crystallina*	×	-	×
Copepoda Calanoida	*Acanthodiaptomus denticornis*	×	×	×
Copepoda Calanoida	*Calanoida* indet.	-	×	×
Copepoda Calanoida	*Diaptomidae* indet.	×	-	×
Copepoda Calanoida	*Epischura nevadensis*	×	×	-
Copepoda Cyclopoida	*Cyclopoida* indet.	-	-	×
Copepoda Cyclopoida	*Cyclops scutifer*	-	×	-
Copepoda Cyclopoida	*Diacyclops thomasi*	×	×	×
Copepoda Cyclopoida	*Eucyclops agilis*	×	-	-
Copepoda Cyclopoida	*Macrocyclops* sp.	-	-	×
Copepoda Cyclopoida	*Microcyclops rubellus*	-	-	×
Copepoda Nauplii	*Calanoida* indet.	-	-	×
Copepoda Nauplii	*Copepoda* indet.	×	×	-
Copepoda Nauplii	*Cyclopoida* indet.	-	-	×
Rotifera	*Ascomorpha* sp.	-	-	×
Rotifera	*Asplanchna* sp.	-	-	×
Rotifera	*Kellicottia* sp.	-	-	×
Rotifera	*Keratella* sp. 1	-	-	×
Rotifera	*Monostyla* sp.	-	-	×
Rotifera	*Polyarthra* sp.	-	-	×