BC Hydro

Bridge River Project Water Use Plan

Carpenter Reservoir and Middle Bridge River Fish Habitat and Population Monitoring

Implementation Year 3

Reference: BRGMON-4

Study Period: 2014-2015

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INSTREAM FISHERIES RESEARCH INC.

Bridge-Seton Water Use Plan

Implementation Year 3 (2014-2015):

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Executive Summary

The primary objective of this monitor is to collect data on fish and fish habitat in the reservoir and river to determine how the operation of BC Hydro facilities affects fish productivity. Monitoring in Year 3 included: a second year of Bull Trout radio tracking in the Carpenter Reservoir watershed, installation of acoustic telemetry gates in the reservoir and at the boundary of the reservoir and the Middle Bridge River, an open mark-recapture period for Bull Trout in the upper reservoir, visual surveys for spawning Rainbow Trout and kokanee, and a short survey of spawning habitat quality in visual survey stream sections.

Radio telemetry was continued in Year 3 to determine weekly positions of 30 radio-tagged Bull Trout tagged in Year 2 in the Carpenter Reservoir watershed. Of the 30 tagged fish, 22 were detected during monitoring in Years 2 and 3. A majority of detections occurred in the upper reservoir but no clear movement patterns were identified for the Bull Trout subsample. Radio telemetry is somewhat limited in Carpenter Reservoir due to its shallow depth range (i.e., <10 m) and a lack of year-round monitoring (i.e., manual tracking did not occur November through March). Two acoustic telemetry gates were installed in the reservoir in Year 3 (one at the Jones Creek confluence and one at the confluence of the Middle Bridge River), which will replace radio telemetry as a method of monitoring Bull Trout movement. Acoustic telemetry, which is effective at all depths in the reservoir, will help to identify overall Bull Trout movement patterns and verify assumptions of the open mark-recapture program.

The annual mark-recapture program took place in July of Year 3 in the upper portion of Carpenter Reservoir. Originally planned for the first two weeks of July, smoke from wildfires made working conditions challenging, and high water temperatures were stressful for fish processing. The program was postponed after one week of sampling and rescheduled for a second week at the end of July when conditions had improved. Because of the relatively short period between sampling events (2 weeks), we assumed the study area was closed and used the Chapman closed mark-recapture model to estimate adult Bull Trout abundance in the upper reservoir. The closed abundance estimate was 2,105 Bull Trout with a standard error of 653 fish.

Biological data (length, weight, and ageing structures) were collected for all species during the mark-recapture period. Scales and otoliths were aged for Bull Trout, Mountain Whitefish, kokanee, and Rainbow Trout, and von Bertalanffy growth models and age-length keys (ALKs) were developed for Rainbow Trout and Mountain Whitefish. The sample sizes of ageing structures for kokanee and Bull Trout were too small to model length-at age or develop ALKs. Length-weight relationships were examined for all species, and the significance of a year coefficient was used to determine whether size characteristics changed over Years 1 through 3. Year was a significant coefficient in the length-weight model for Bull Trout and Rainbow Trout. There was a significant difference in mean length of Bull Trout caught in Years 1 through 3 and between different capture

methods (angling, gill netting, and electrofishing). This suggests that characteristics of the sampling program (rather than biological or operational effects) may be responsible for the effect of year on the length-weight model. The significance of the year coefficient was very weak in the case of Rainbow Trout, and there were not enough data to draw conclusions on the effect of year or gear type on Rainbow Trout size characteristics.

Rainbow Trout visual surveys were not successful in Year 3, potentially due to low spawner numbers and/or poor survey conditions. Kokanee visual surveys produced spawner counts very similar to Year 2, although peak counts occurred ~1 week later in Year 3. Kokanee were observed in the drawdown zone of four tributaries; however, no spawning behaviour was observed and kokanee were likely migrating upstream into more suitable spawning habitat. Habitat surveys in Year 3 and historically suggest limited high quality spawning habitat in Carpenter Reservoir tributaries (particularly in the drawdown zone) and the drawdown zone is not likely critical spawning habitat for kokanee.

BRGMON-04 status of objectives, management questions, and hypotheses after Year 3 (2014-2015; see BRGMON-04 proposal for more details).

Study Objectives	Management Questions	Management Hypotheses	Year 3 (2014-2015) 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?	H1A: There is no measureable trend (negative or positive) in abundance or relative abundance of Bull Trout in Carpenter Reservoir after the implementation of WUP operations.	Performed one period of Bull Trout mark-recapture in July, but we will not be able to obtain an open model population estimate until a second mark-recapture period has been completed in July 2016. A closed estimate was obtained for Year 3 using two short periods of mark-recapture in July 2015.
		H1B: There is no measureable trend (negative or positive) in biological characteristics of fish in Carpenter Reservoir after the implementation of WUP operations.	Began to test for year and gear type effects on length-weight relationships in Carpenter Reservoir and began developing age-length keys. There is not enough data to perform time series analyses.
2: Provide information required to link the effects of reservoir operation on fish populations.	2: Will the selected alternative result in positive, negative, or neutral impact on abundance and diversity of fish populations?	H2: Implementation of the selected alternative following the WUP process had a negative impact on Bull Trout abundance or index of abundance compared with pre-WUP modelled abundance.	BRGMON-10 began collecting productivity data to model pre-WUP reservoir conditions (data are not yet available).
		H3: Implementation of the selected alternative following the WUP process had a negative impact on the area of preferred habitat for adult Mountain Whitefish.	Not yet directly addressed by BRGMON-04; however, CPUE is being recorded for Mountain Whitefish in the upper reservoir and may be used in the future to determine preferred areas. Gill net surveys will take place in four habitat types at high and low pool in Year 4 to further assess preferred habitat.
	3: Which are the key operating parameters that contribute to reduced or improved productivity of fish populations in Carpenter Reservoir and Middle Bridge River?	H4: There is no relationship between abundance or relative abundance of Bull Trout and reservoir productivity as predicted by the Carpenter Lake Reservoir Productivity Model (BRGMON-10).	Mark-recapture study and BRGMON-10 habitat monitoring began in Year 3.
		H5: Rainbow Trout spawning in the drawdown zone is negatively impacted by inundation in the late spring and summer in Carpenter Reservoir.	Performed a rough habitat assessment at low water elevation and counted Rainbow Trout in tributaries within and above full pool elevation during the spawning period.

	H6: Operation of Carpenter Reservoir at low elevations reduces adult Mountain Whitefish productivity through the dewatering of preferred habitat areas.	Not yet directly addressed by BRGMON-04; however, CPUE is being recorded for Mountain Whitefish in the upper reservoir and may be used in the future to determine preferred areas. Gill net surveys will take place in four habitat types at high and low pool in Year 4 to further assess preferred habitat.
4: Is there a relationship between specific characteristics of the in stream flow in Middle Bridge River that contribute to reduced or improved productivity of fish populations in Carpenter Reservoir and Middle Bridge River?	H7: Operation of Lajoie Generating Station restricts the amount of available effective spawning habitat for Mountain Whitefish in Middle Bridge River through egg dewatering.	Not yet directly addressed by BRGMON-04, but monitoring occurred in 2010 by Tisdale Environmental Consultants (TEC). TEC concluded that operations did not pose a significant risk to Mountain Whitefish egg survival in the Middle Bridge River. Middle Bridge River spawning habitat assessments will take place in Years 5, 7, and 9 following the methods of TEC.
	H8: Operation of Lajoie Generating Station restricts the amount of available effective spawning habitat for kokanee in Middle Bridge River through egg dewatering.	Not yet directly addressed by BRGMON-04. Middle Bridge River spawning habitat assessments will take place in Years 5, 7, and 9 following the methods of TEC.
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?	H9: Current management of Carpenter Reservoir and Lajoie Generating Station can be refined to improve productivity of fish populations in both areas.	Not yet directly addressed by BRGMON-04. Will be inferred based on the results of Hypotheses 1 through 8.

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1 Introduction

1.1 Background

The Bridge River power project, located in the Bridge River Valley of southwestern British Columbia (Figure 1-1), was initiated in the 1920s and completed in 1960 with the construction of Terzaghi Dam (BC Hydro 2014). Following its construction, the Bridge River generating system (consisting of three dams and four generating facilities) was the largest generator of power in British Columbia and today contributes 6-8% of BC Hydro's total generating capacity. Construction of the Bridge River power complex significantly altered flow of the Bridge River and resulted in substantial impacts to aquatic ecosystems throughout the valley. Following the construction of Terzaghi Dam, flow in the Bridge River ceased completely below the dam (except for periodic spill releases), and a four-kilometer section of channel remained dewatered before being fed by groundwater and tributary inflows further downstream. As a result of concerns from multiple user groups, an agreement was reached in 1998 and implemented in 2000 that resulted in an average of 3.0 m^3s^{-1} water release from Terzaghi Dam to the Lower Bridge River and continuous watering of the Lower Bridge River channel. The average annual discharge was increased to 6.0 m^3s^{-1} starting in May 2011.

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

Throughout the WUP process, uncertainties were identified that hindered the development of explicit fish population level performance measures for decision-making purposes. Qualitative performance measures were developed during the WUP process that aided in the development of the current operating strategy; however, a lack of quantitative data resulted in significant uncertainties. As a result, the WUP recommended comprehensive environmental monitoring in the Bridge River Valley to address uncertainties and to monitor impacts of the alternative operating strategy (BC Hydro 2011). These recommendations included monitoring of fish and fish habitat in Carpenter Reservoir and the Middle Bridge River, and led to the development of BRGMON-04 (BC Hydro 2015).

1.2 Previous Research in Carpenter Reservoir and the Middle Bridge River

Few historic data are available for Carpenter Reservoir and the Middle Bridge River; however, several preliminary investigations into fish populations and reservoir productivity have been completed. In 1995 and 1996 R.P. Griffith & Associates and Limnotek Research and Development Inc. performed an assessment of fish and fish habitat and limnological conditions in the reservoir (Griffith 1999). The fish and fish habitat assessment included a) the identification and assessment of stream spawning habitat using closed-site electroshocking, and b) fish index surveys via gill netting in the lower (pelagic) portion of the reservoir. Total counts of Rainbow Trout and Bull Trout were low in Carpenter Reservoir tributaries, and habitat investigations suggested limited stream-lengths accessible to fish (due to steep gradients and barriers to passage), limited spawning substrate in streams, and lack of cover in streams heavily affected by reservoir drawdown. Despite these habitat limitations, Griffith (1999) hypothesized that the large number of tributaries in the Carpenter Reservoir system could allow the reservoir to support large populations of Bull Trout, Rainbow Trout, and kokanee. Gill netting conducted in the vicinity of the Bridge 1 and Bridge 2 diversion tunnels (in the lower portion of the reservoir) yielded high numbers of both Rainbow Trout and Bull Trout, and low numbers of kokanee. Gill netting during high and low reservoir elevations suggested that Bull Trout and Rainbow Trout may be less reliant on pelagic habitat than kokanee, with the former able to occupy intermediate and upper portions of the reservoir during low pool conditions. Limnological surveys found low numbers of zooplankton and phytoplankton in Carpenter Reservoir, possibly due to a short water retention time in the reservoir. Griffith (1999) hypothesized that reservoir productivity, rather than spawning and recruitment, may limit fish production in Carpenter Reservoir and the Middle Bridge River.

A preliminary study into the impacts of hydro operations on Bull Trout and kokanee migrations, life histories, and critical life history stages was completed in 1999 and 2000 (Chamberlain et al. 2001). Two years of radio telemetry were performed on adult Bull Trout, and tributary spawner surveys were undertaken to determine relative spawning counts of kokanee in a number of Carpenter Reservoir tributaries. Radio telemetry indicated that Bull Trout generally migrate upstream into the top end of the reservoir as it fills in the spring and summer, and occupy the lower portion of the reservoir during the winter (Chamberlain et al. 2001). Stream surveys failed to identify spawning kokanee in any of the eleven streams surveyed, and only 2 kokanee carcasses were observed (both in Gun Creek). Also in 2000, a preliminary study of primary production resulted in the development of a light-based productivity model suggesting that Carpenter Reservoir productivity increases in an upstream direction (unpublished, referenced in Chamberlain et al. 2001).

Preliminary research into fish populations and productivity in Carpenter Reservoir highlighted uncertainties regarding the characteristics of the system and the effect of BC Hydro operations on fish productivity. The Carpenter Reservoir and Middle Bridge River Fish Habitat and Population Monitoring Program (BRGMON-04) was developed during the WUP process to address these uncertainties. This monitoring program will build on the information compiled during the WUP process to develop an understanding of Carpenter Reservoir and Middle Bridge River fish populations and determine whether BC Hydro operations affect fish productivity.

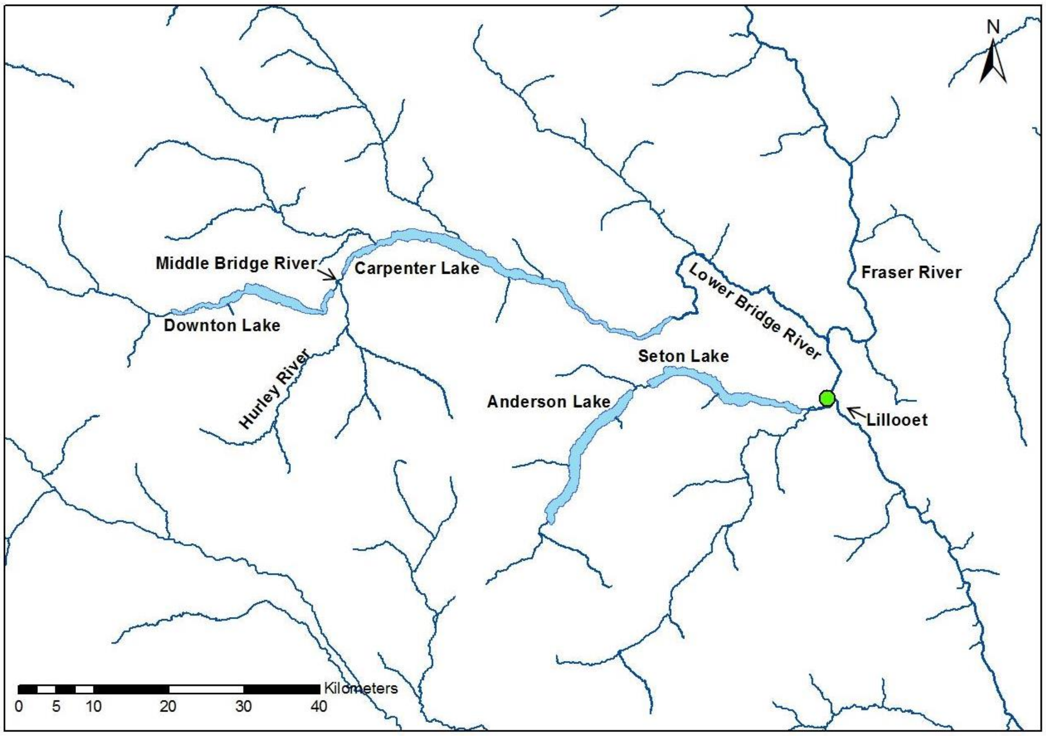

Figure 1-1 Bridge River system showing locations of BC Hydro reservoirs and dams.

1.3 Management Questions

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

1. What are the basic biological characteristics of parameters of fish populations in Carpenter Reservoir and its tributaries?
2. Will the selected alternative (N2-2P) operation result in positive, negative, or neutral impact on abundance and diversity of fish populations?
3. Which are the key operating parameters that contribute to reduced or improved productivity of fish populations in Carpenter Reservoir and Middle Bridge River?
4. Is there a relationship between specific characteristics of the in-stream flow in the Middle Bridge River that contribute 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 of these areas, or can existing constraints be relaxed?

[1] An amendment to the TOR was completed in 2015, during which the monitor hypotheses were modified. The management questions were not modified during the amendment.

1.4 Detailed Hypotheses

Management hypotheses (amended in March of 2015) are as follows:

H1: The Carpenter Reservoir fish community is dominated by Mountain Whitefish and Bull Trout.

- H1A: There is no measurable trend (negative or positive) in abundance or relative abundance of Bull Trout in Carpenter Reservoir after the implementation of WUP operations.
- H1B: There is no measureable trend (negative or positive) in biological characteristics (e.g., growth, size distribution, condition, and survival) of fish (Bull Trout and Mountain Whitefish) in Carpenter Reservoir after the implementation of WUP operation.

H2: Implementation of the selected alternative following the WUP process had a negative impact on Bull Trout abundance or index of abundance compared with pre-WUP modeled abundance.

H3: Implementation of the selected alternative following the WUP process had a negative impact on the area of preferred habitat for adult Mountain Whitefish.

H4: There is no relationship between abundance or relative abundance of Bull Trout and reservoir productivity as predicted by the Carpenter Lake Reservoir Productivity Model (MON10).

H5: Rainbow Trout spawning in the drawdown zone is negatively impacted by inundation in the late spring and summer in Carpenter Reservoir.

H6: Operation of Carpenter Reservoir at low elevations reduces adult Mountain Whitefish productivity through the dewatering of preferred habitat areas.

H7: Operation of Lajoie Generating Station restricts the amount of available effective spawning habitat for Mountain Whitefish in Middle Bridge River through egg dewatering.

H8: Operation of Lajoie Generating Station restricts the amount of available effective spawning habitat for Kokanee in Middle Bridge River through egg dewatering.

H9: Current management of Carpenter Reservoir and Lajoie Generating Station can be refined to improve productivity of fish populations in both areas.

1.5 Key Water Use Decision Affected

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

2 Monitoring Program Methods

2.1 Objectives and Scope

BRGMON-04 has two primary objectives, with the scope of monitoring being limited to fish populations in Carpenter Reservoir, Middle Bridge River, and fish-bearing tributaries of both systems.

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.
2. Provide information required to link the effects of reservoir operation on fish populations to:
   a. document impacts of the N2-2P alternative on existing reservoir fish populations, and
   b. allow more informed decision-making in the future regarding the operation of Carpenter Reservoir.

2.2 Monitoring Approach

The goal of this monitoring program is to collect a comprehensive long-term dataset of fish populations and habitat conditions (in Carpenter Reservoir and the Middle Bridge River) to resolve current gaps in data and scientific understanding. This information will identify any changes in population structure, and any changes over time will be used to develop and test hypotheses linking habitat conditions and population responses.

The first two years of BRGMON-04 monitoring (Year 1 completed by Tisdale Environmental Consultants [TEC] and Year 2 completed by InStream Fisheries Research Inc. [IFR]) highlighted deficiencies in some of the original hypotheses and methodological approaches outlined in the terms of reference. Carpenter Reservoir is a very large and remote reservoir, and there are significant logistical challenges to collecting comprehensive information for all species and life stages in both the reservoir and the Middle Bridge River. Techniques used in other large reservoirs and river systems (e.g., boat electrofishing, fly-over spawner surveys, hydroacoustic transects; Sebastian and Weir 2014, Zwart et al. 2013, Sebastian et al. 2003) proved to be challenging or not cost-effective in Carpenter Reservoir and the Middle Bridge River due to the large size of the system, remote access, high turbidities, and large reservoir fluctuations. An amended terms of reference was completed in March of 2015 (BC Hydro 2015) that included revised hypotheses and modifications to the original methodologies based on insights from the first two years of monitoring.

The revised TOR reflect a focused monitoring strategy in Carpenter Reservoir and the Middle Bridge River. Each management question will be answered either directly via a targeted monitoring program, or indirectly by compiling data and knowledge from multiple monitoring initiatives. The monitor focuses on species and life stages that are; a) abundant, ecologically important, and/or sensitive to habitat changes, and b) possible to assess using methods tested during BRGMON-04 pilot years. The monitoring program will be composed of both yearly surveys providing time series data (e.g., yearly abundance estimates), and one- or two-year programs that target specific hypotheses and potentially direct future activities to ensure that the management questions are addressed (e.g., determining primary spawning locations, examining species composition in the reservoir, etc). Although monitoring activities target specific species and life stages, ancillary data from non-target species collected during monitoring activities will be used to build a dataset of Carpenter Reservoir and Middle Bridge River fish communities. A synthesis of data collected and a review of the monitoring program will take place in Year 5. Adjustments to methodologies may occur during the review based on the assessment of the program to sufficiently answer the management questions in the last five years of the study.

3 Methods

3.1 Methods Overview

Table 3-1 provides an overview of the general approach and specific methods that were used in Year 3 to target specific management hypotheses outlined in the TOR (BC Hydro 2015). The report sections referenced in the table provide further details on the methods used. For detailed descriptions of methods identified in Table 3-1 that will be used in future monitoring years please refer to the Carpenter Reservoir and Middle Bridge River Fish Habitat and Population Monitoring Proposal Year 4; available from BC Hydro.

Table 3-1 Overview of the BRGMON-04 monitoring approach and methods implemented in Year 3 (report section in parentheses).

Management Question	Management Hypothesis	Monitoring Approach	Contributing Methods
What are the basic biological characteristics of fish populations in Carpenter Reservoir and its tributaries?	H1A: There is no measureable trend (negative or positive) in abundance or relative abundance of Bull Trout in Carpenter Reservoir after the implementation of WUP operations.	Determine yearly mark-recapture estimate of Bull Trout abundance and use time series regression to test whether abundance is stable, increasing, or decreasing over the monitoring period.	Bull Trout mark-recapture and Bull Trout movement analysis (3.2)
	H1B: There is no measureable trend (negative or positive) in biological characteristics of fish in Carpenter Reservoir after the implementation of WUP operations.	Use length, weight, distribution, and age data collected through gill net surveys and opportunistically during mark-recapture activities to create time series of growth and age distribution. Use linear regression to test whether these characteristics are stable, increasing, or decreasing over the monitoring period.	Bull Trout mark recapture (bycatch information; 3.2) Age, size, and growth analysis (3.3) Rainbow Trout and kokanee visual surveys (3.4)
Will the selected alternative (N2-2P) operation result in positive, negative, or neutral impact on abundance and diversity of fish populations?	H2: Implementation of the selected alternative following the WUP process had a negative impact on Bull Trout abundance or index of abundance compared with pre-WUP modelled abundance.	Estimate Bull Trout abundance for pre-WUP conditions using the model developed for H4 (abundance vs habitat characteristics modeled in BRGMON-10) and compare pre- and post-WUP abundances (e.g., time series analysis, ANOVA).	Bull Trout mark recapture (3.2) Habitat monitoring and productivity modeling (BRGMON-10 and -04; 3.5)
	H3: Implementation of the selected alternative following the WUP process had a negative impact on the area of preferred habitat for adult Mountain Whitefish.	Determine presence/absence and relative numbers of Mountain Whitefish in four different habitats in the reservoir affected by reservoir drawdown. Habitat requirements of Mountain Whitefish at various life stages can then be compared to preferred habitat availability at pre- and post-WUP reservoir elevations. This monitoring program is exploratory and will adapt based on the quality of data obtained and the ability of the data to answer the management questions.	No direct method in Year 3; Bull Trout mark recapture collects some data on Mountain Whitefish CPUE, distribution, etc.
Which are the key operating parameters that contribute to reduced or improved productivity of fish populations in Carpenter	H4: There is no relationship between abundance or relative abundance of Bull Trout and reservoir productivity as predicted by the Carpenter Lake Reservoir Productivity Model (BRGMON-10).	Use regression modeling to identify possible relationships between mark-recapture abundance of Bull Trout and habitat characteristics (i.e., algal productivity, PAR) obtained from BRGMON-10 productivity modeling.	Bull Trout mark recapture (3.2) Habitat monitoring and productivity modeling (BRGMON-10 and-04; 3.5)

Reservoir and Middle Bridge River?	H5: Rainbow trout spawning in the drawdown zone is negatively impacted by inundation in the late spring and summer in Carpenter Reservoir.	Perform monthly electroshocking surveys of juvenile fish in a subsample of Carpenter Reservoir tributaries. If both fry and par are observed in the tributaries it would suggest successful spawning, whereas if only par are observed there may be seeding of juveniles from upstream areas. Sampling plan will adapt based on the quality of data obtained and the ability of the data to answer the management questions.	Rainbow Trout visual surveys and basic assessment of spawning habitat quality (3.4)
	H6: Operation of Carpenter Reservoir at low elevations reduces adult Mountain Whitefish productivity through the dewatering of preferred habitat areas.	Determine presence/absence and relative numbers of Mountain Whitefish in four different habitats in the reservoir affected by reservoir drawdown. Habitat requirements of Mountain Whitefish at various life stages can then be compared to preferred habitat availability at different reservoir elevations. This monitoring program is exploratory and will adapt based on the quality of data obtained and the ability of the data to answer the management questions.	No targeted methods used in Year 3; Bull Trout mark recapture collects some data on Mountain Whitefish CPUE, distribution, etc.
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?	H7: Operation of Lajoie Generating Station restricts the amount of available effective spawning habitat for Mountain Whitefish in Middle Bridge River through egg dewatering.	Repeat Mountain Whitefish angling and egg screen deployment following the methods of Tisdale Environmental Consulting (2009; also repeated in 2013); add egg mats in high elevation areas at higher risk of dewatering; and compare relative spawn timing and peak egg counts to 2009 findings.	No targeted methods in Year 3
	H8: Operation of Lajoie Generating Station restricts the amount of available effective spawning habitat for kokanee in Middle Bridge River through egg dewatering.	Monitor high elevation areas in the Middle Bridge River identified in H7 and perform visual surveys for kokanee redds if the water level drops during incubation and exposes these areas.	No targeted methods in Year 3
Can refinements be made to the operation of Carpenter Reservoir and management of in-stream flow releases from Lajoie Generation Station into the Middle Bridge River to improve protection or enhance fish populations in both these areas or can existing constraints be relaxed?	H9: Current management of Carpenter Reservoir and Lajoie Generating Station can be refined to improve productivity of fish populations in both areas.	Use relationships developed in this monitor to explore the potential outcomes of alternative operating regimes. If no relationships are found, use weight of evidence and knowledge developed in the monitor to identify new potential hypotheses and links between operations and productivity.	No targeted methods in Year 3; all methods contribute to building data to answer this question.

3.2 Bull Trout Abundance Estimation and Movement Analysis

Bull Trout are the most abundant top predator in Carpenter Reservoir, and an open mark-recapture model is used to obtain annual population estimates for the reservoir. An open mark-recapture model allows for movement of fish in and out of the monitoring area via births, deaths, immigration and emigration, and can be used to obtain population estimates over longer time-periods. In an open mark-recapture program, fish are captured on several successive occasions (in this case years) and marked with a unique identifier (e.g., passive integrated transponder [PIT] tags). The sampling is repeated in subsequent years and both marked and unmarked animals are captured. Marked animals are recorded and released, and unmarked animals are tagged and released. Individual capture histories for each animal are combined to determine annual population abundance estimates, survival estimates, and recruitment.

The Carpenter Reservoir mark-recapture program has two main components: an intensive annual mark-recapture period in Carpenter Reservoir, and an acoustic telemetry study. The acoustic telemetry portion of the program is used to define the boundaries of the mark-recapture study area, verify mark-recapture model assumptions about Bull Trout movement during and between mark-recapture periods, and provides valuable habitat use and behavioral information on Carpenter Reservoir and Middle Bridge River Bull Trout.

Only the upper half of Carpenter Reservoir is included in the mark-recapture program (referred to as the upper reservoir). Bull Trout densities appear to be higher in the upper reservoir based on observations in Years 1 and 2, and focusing effort in this higher-density portion of the reservoir will result in higher catches and a more accurate estimate of Bull Trout abundance. Acoustically-tagged Bull Trout will be monitored during the mark-recapture period to determine the proportion of tagged fish present in the mark-recapture study area vs in the lower reservoir or Middle Bridge and Hurley rivers. These proportions will then be used in combination with the upper reservoir population abundance estimate to extrapolate a population estimate for the lower portion of Carpenter Reservoir.

3.2.1 Field Methods-Movement Analysis

Acoustic telemetry is used in the mark-recapture program to define the mark-recapture boundary, determine whether Bull Trout immigration and emigration are equal during the mark-recapture period, and gather timing information on Bull Trout movement between the upper and lower portions of the reservoir and the Middle Bridge River. Two telemetry gates (VR2W-69 kHz coded acoustic receivers; VEMCO, Bedford, Nova Scotia) were installed in the study area in June of 2015: one at the Jones Creek confluence (i.e., the gate will divide the reservoir into an upper reach and a lower reach) and one in the Middle Bridge River at the boundary of the reservoir and river (Figure 3-1). These gates bound the mark-recapture study area, which will be referred to as the upper reservoir. During the mark-recapture period, only Bull Trout caught within this boundary are considered part of the mark-recapture sample. Reservoir receivers were suspended in the water column and marked with floats that became submerged as pool elevation increased, while receivers in the Middle Bridge River were attached directly to bottom anchors (Figure 3-2). The gates are designed to detect and determine the direction of travel of tagged Bull Trout that move through the gate.

Range testing was performed in June of 2015 to determine the receiver spacing necessary to maintain an 80% minimum detection efficiency at all reservoir and river conditions. Range testing consists of deploying a unique range-test tag at known distances from fixed receivers and determining the percentage of transmissions successfully detected by each receiver. In the reservoir, six acoustic receivers were deployed 2 m off of the bottom and ~50 m apart (covering a total distance from a range-test tag of 550 m) and left to record for ~3 days. Detection probabilities dropped below 80% between a distance of 300 m and 350 m from the range-test tag (Figure 3-3), and 300 m was selected as a maximum detection distance for receivers in Carpenter Reservoir. The acoustic gate is located where the width of the reservoir is ~800 m at maximum pool, implying that a line of three receivers with a detection range of 300 m should detect 100% of Bull Trout moving past the gate.

Range testing was challenging in the river because it was not easy to deploy the receivers in the middle of the river or in water deeper than 1-2 m. Two range tests were performed in different river locations: the first location was in a wide, slow moving area where receivers could be deployed in ~2 m of water; and the second location was in a more constricted, fast moving area where receivers were located along the right bank in ~1 m of water. In the first range test, three receivers were deployed on the bottom of the river ~35 m apart and 2 m deep (covering a total distance from the test tag of 100 m). Detection probabilities were below 80% at all distances, but were above 60% at 35 m and 70 m from the range-test tag (Figure 3-3). In the second range test, two receivers were deployed very close to the right bank of the Middle Bridge River in 1 m of water. The receivers and the range-test tag were located on opposite banks (~60 m apart) to test whether receivers deployed in shallow, near-shore water would be able to detect Bull Trout migrating along the opposite bank of the river. Detection probabilities were very low for both receivers (<10%; Figure 3-3). Range testing demonstrated that a shoreline gate in this location will not be able to cover the full span of the river. For Year 4 we will add two additional receivers to the gate, reducing the distance between receivers to 35 m and bringing the detection probability closer to 80%.

A sample of 20 Bull Trout were angled in the mark-recapture study area and tagged with internal acoustic transmitters (V13 transmitters, VEMCO; estimated battery life two years). Tagging took place from June 10-12 at the confluence of three creeks (Gun Creek, Truax Creek, and Marshall Creek; see Figure 3-4) to distribute tags throughout the study area (i.e., the upper reservoir). Bull Trout were angled using roe as bait and held in swim tubes prior to surgery. Acoustic tags were surgically implanted using guidelines provided in Wagner et al (2011). Bull Trout were anaesthetized in dark coolers using clove oil (diluted to 10-parts ethanol and 1-part clove oil) until unable to maintain upright buoyancy (approximately 3-5 minutes). Surgeries were performed by an experienced biologist using sterile surgical techniques. Tags were implanted into the abdominal cavity using a small incision on the mid-ventral line, which was then closed using two monofilament sutures. Fish recovered in a dark cooler monitored for temperature and oxygen, and released when active and maintaining upright buoyancy (approximately 5-10 minutes).

The VR2W telemetry gate was recovered from the Middle Bridge River in December 2015 for downloading and battery replacement. Reservoir receivers will not be recovered until early April 2016, at which point the reservoir will have drafted sufficiently to access submerged floats. VR2Ws have an estimated battery life of 15 months (VEMCO), and one annual download and battery replacement should be sufficient. Receivers in the river are checked and downloaded more frequently in case of damage from flow/debris and/or vandalism.

Radio telemetry tags (Lotek Wireless, NTC-6-2, 9 mm x 30 mm) were surgically implanted into 30 Carpenter Reservoir Bull Trout in August of 2014 (Year 2) to assess Bull Trout behaviour and identify potential spawning locations in Carpenter Reservoir and its tributaries. Bull Trout were angled at two locations (Truax Creek and Gun Creek), anaesthetized using clove oil, surgically implanted with a gastric radio tag, and recovered and released at their tagging location (see methods in Wagner et al 2011). Weekly manual tracking (hand-held Lotek W31 radio receiver) occurred on foot and from a vehicle throughout the Carpenter Reservoir valley in Years 2 and 3. The time of detection, relative signal strength, and a GPS coordinate were recorded for each fish detection. To visualize the detections of radio-tagged Bull Trout in Carpenter Reservoir and the Middle Bridge River, the reservoir was split into six sections based on distance from Terzaghi Dam: 0-10 km, 10-20 km, 20-30 km, 30-40 km, 40-47 km, and 47+ km (i.e., the Middle Bridge River). Detections from Years 2 and 3 were plotted against time in the six sections to identify patterns in Bull Trout movement throughout the year and during spawn migration timing.

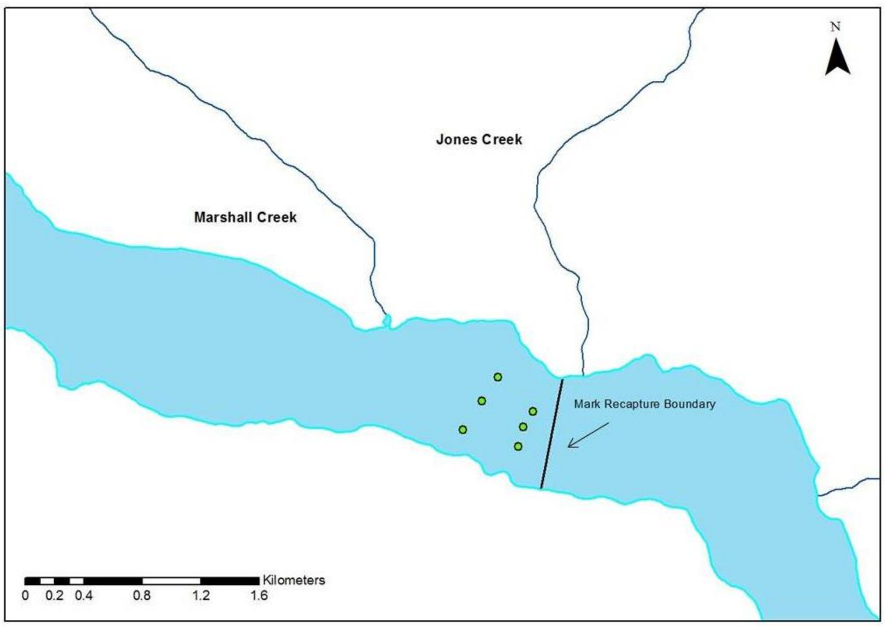

Figure 3-1 Map of Carpenter Reservoir showing the location of VR2W receivers (green circles) and the mark-recapture study barrier relative to Marshall and Jones Creeks.

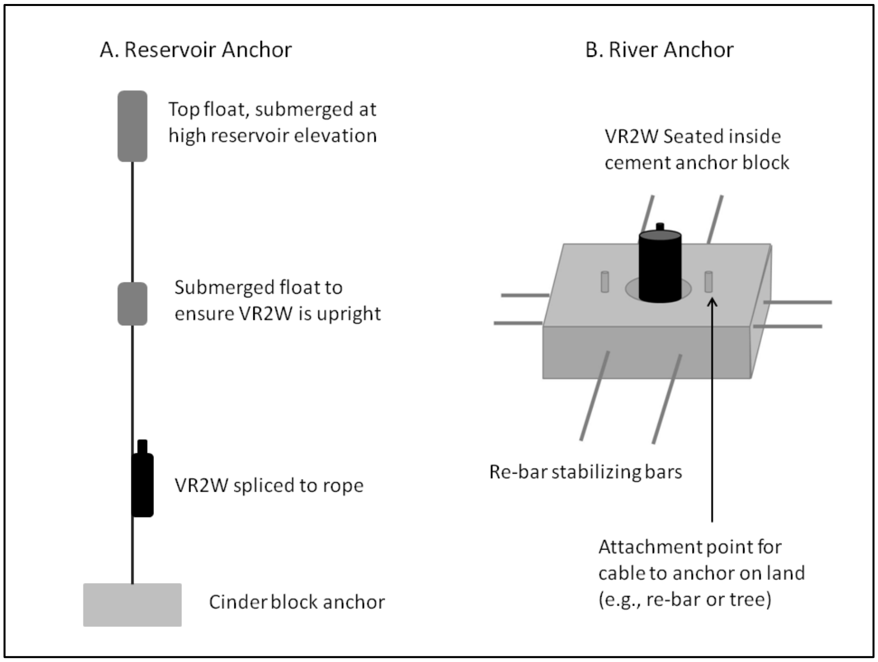

Figure 3-2 Anchor systems for VR2W acoustic transceivers in Carpenter Reservoir (A) and the Middle Bridge River (B)

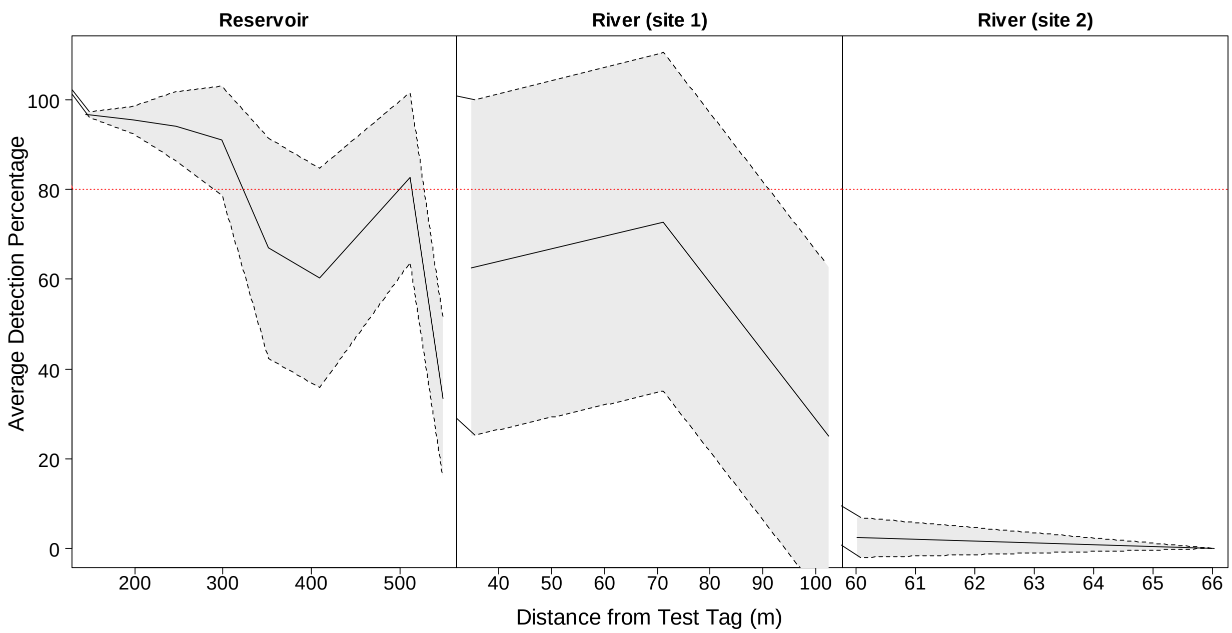

Figure 3-3. Average detection percentage at different distances from receiver to test tag of VR2Ws in Carpenter Reservoir and the Middle Bridge River in June 2015.

3.2.2 Analysis-Movement Analysis

The acoustic telemetry system in Carpenter Reservoir will not provide fine-scale movement data for Bull Trout in Carpenter Reservoir and the Middle Bridge River. Instead, acoustic detections at each gate will be used to determine the proportion of tagged Bull Trout present in each of the three regions of the study system: the lower Carpenter Reservoir, the upper Carpenter Reservoir (i.e., the mark-recapture study area), and the combined Middle Bridge and Hurley Rivers. Acoustic detections of Bull Trout will be examined and summarized in the statistical environment R (v. 3.2.2; R Development Core Team 2015). If a Bull Trout passes through both portions of a telemetry gate (either the reservoir gate or the Middle Bridge River gate) it is considered to have moved between regions. The gates are composed of two lines of receivers (Figure 3-1) so that the direction of travel can be determined when a Bull Trout encounters the gate. We will determine the date/time, gate name, and direction of travel for each encounter of a tagged Bull Trout and a telemetry gate to determine the proportional distribution of tagged Bull Trout in the three areas throughout the year.

A critical assumption of the open mark-recapture model is that all individuals have equal probabilities of capture, and any one-way immigration/emigration could violate this assumption. Acoustic data will be used to identify immigration and emigration and determine whether this assumption is valid in Carpenter Reservoir. These data will also be used to determine spawning migration timing and identify critical spawning habitat for Carpenter Reservoir Bull Trout within the tracking area. Distribution information will also be compared to reservoir elevations to gain insight into how reservoir operations (and changing habitat) affect the distribution and habitat use of Bull Trout in the reservoir and Middle Bridge River.

3.2.3 Field Methods-Mark Recapture

An intensive period of Bull Trout PIT tagging occurred between June 30 and July 31, 2015. The mark-recapture period was originally scheduled to take place as a 10 to 15 day consecutive period between June 30 and July 14; however, extremely high air and water temperatures were not ideal for fish capture/tagging, and thick smoke from nearby wildfires made for unsafe working conditions. Therefore, the planned mark-recapture study was cut short, and a second week of capture was performed at the end of July when conditions had improved. Ideally, the mark-recapture period should be constrained to a single period. Separating the capture period into two portions increases the risk of immigration and emigration from the area between capture periods. Acoustic data (when recovered in April 2016) will be used to determine whether immigration and/or emigration occurred between the two short mark-recapture periods.

A variety of capture techniques were used in Year 3 during the Bull Trout mark-recapture period to target all habitat types in the mark-recapture study area. This will allow the abundance estimate to be applied to the entire study area, rather than select habitats or size classes. In theory, each of the three capture methods used in this monitor target a slightly different size class and/or behavioral group of the adult Bull Trout population. A combination of angling at creek mouths (~9 days[2]), shoreline overnight electrofishing (2 days), and both shoreline and pelagic short-set gill netting (~6 days) was used during the mark-recapture period. All Bull Trout (regardless of capture method) were PIT tagged and released at their capture location, and lengths, weights, and aging structures (pelvic fin) were collected. General sampling conditions were recorded whenever possible for all capture methods (i.e., water temperature, water visibility, weather, sample duration, location coordinates), and method-specific characteristics were recorded for gill netting (i.e., net type, net depth, habitat type sampled, soak time) and electrofishing (i.e., site length, site depth, time spent electroshocking).

Biological data were obtained from by-catch species during mark-recapture sampling and will contribute to answering Hypothesis 1B regarding trends through time in biological characteristics of all Carpenter

[2] A day unit in this case represents one day of effort by one field crew. For example, if two crews were angling for a full day in separate locations, this would be considered two days of effort.

Reservoir fish species. By-catch of Rainbow Trout and kokanee were weighed and measured, and Rainbow Trout were also PIT tagged to obtain growth and habitat use data. Mountain Whitefish catches during electrofishing were very high at some sites, and a subsample of 30 individuals was weighed and measured at sites with Mountain Whitefish catches >30 individuals. Mountain Whitefish were not PIT tagged because of high tagging and handling mortality. Aging structures were collected from a subsample of all species in Years 1 through 3[3], and preliminary aging occurred following Year 3. In future years, all fish will be sampled for ageing structures (to be aged immediately or archived for future analysis). Scales will be collected from Mountain Whitefish, Rainbow Trout, and kokanee, pelvic fin rays will be collected from Bull Trout, and otoliths will be collected from all mortalities.

3.2.4 Analysis-Mark Recapture

BRGMON-04 will use the Jolly-Seber open population mark-recapture model to obtain a population estimate of Bull Trout in the upper portion of Carpenter Reservoir (detailed methods in BC Hydro 2015). The Jolly-Seber model estimates the population size at each sampling event and can also estimate survival and births between events (Pollock et al. 1990). A mark-recapture model requires at least two capture occasions, and therefore we could not use the Jolly-Seber model to estimate Bull Trout abundance for Year 3; however, a closed mark-recapture estimate (using the Chapman estimator) was produced using Year 3 mark-recapture data. Due to conditions described in Section 3.1.2.3, the mark recapture period in Year 3 was separated into two short sampling periods. These two periods happened within two weeks of each other, thus we assumed that the population was closed (this assumption will be verified once acoustic data are recovered) and used a simple closed mark-recapture model to obtain a rough abundance estimate. The Chapman estimator (i.e., the Lincoln-Petersen estimator adjusted to reduce bias: Seber 1982) was used to obtain a population estimate for Year 3 adult Bull Trout in the upper portion of Carpenter Reservoir using the equation:

$$\hat{N} = \frac{(n_1 + 1)(n_2 + 1)}{(m_2 + 1)} - 1 \qquad \text{Eq 1}$$

Where $\hat{N}$ is the predicted abundance, n_1 is the number of Bull Trout captured and marked in the first capture period, n_2 is the number of fish captured in the second capture period, and m_2 is the number of marked individuals captured during the second capture period. All mark-recapture analysis was performed in the statistical environment R using the FSA package (Ogle 2016, R Development Core Team 2015). The variance and standard error for the predicted abundance were calculated using:

$$Var(\hat{N}) = \frac{(n_1 + 1)(n_2 + 1)(n_1 - m_2)(n_2 - m_2)}{(m_2 + 1)^2(m_2 + 2)} \qquad \text{Eq 2}$$

$$SE(\hat{N}) = \sqrt{Var(\hat{N})} \qquad \text{Eq 3}$$

There are several possible distributions that can be used to calculate confidence intervals for closed mark-recapture estimates (Ogle 2016). Seber (2002), suggested that a binomial distribution be used if the proportion of recaptured fish in the second period (m_2) is >10%. If the recapture percentage is <10% a normal distribution should be used when $m_2 > 50$ and a Poisson distribution should be used when $m_2 < 50$.

[3] We did not collect ageing structures from all fish because our ability to age various structures had not been confirmed. Following discussion with BC Hydro and preliminary ageing analysis, ageing structures will be collected from all fish for the remainder of the monitoring program.

In this study, the recapture percentage was 9.1% and a Poisson distribution was used to calculate confidence intervals (Ogle 2016).

The Chapman estimator is characterized by four major assumptions:

1. The population is physically and demographically closed.
2. Marks are not lost or missed.
3. Marked fish return to the population and mix randomly with unmarked fish.
4. Each animal in the population has equal capture probability.

The population was not physically closed during the Carpenter Reservoir mark-recapture program (i.e., no physical boundaries prevented fish from entering or leaving the study area); however, we assumed closure by performing the recapture period within three weeks of the marking period. This timeline allowed for marked fish to recover and redistribute within the capture area, but was short enough that no major environmental changes occurred and we would expect Bull Trout to remain within the study area. This assumption will be verified using 2015 acoustic data by determining whether acoustically tagged fish immigrated or emigrated from the study area (see Section 3.2.2 for more details).

For this closed mark-recapture analysis we assumed that tag loss (i.e., Assumption 2) was negligible at 5% or less (Ombredane et al. 1998). The third and fourth assumptions were also met by using multiple capture methods (angling and gill netting) in roughly equal proportions for both the marking and recapture events. This allowed different size classes to be targeted. Electrofishing was used only during the recapture period; however, a Welch's t-test (for samples with non-equal variances) found no statistical difference between the length of Bull Trout captured by angling and by electrofishing during the mark-recapture period (p-value 0.41, df 34.8) and we assumed this does not introduce bias into the mark-recapture estimate.

3.3 Analysis of Biological Data Collected for All Reservoir Species

3.3.1 Laboratory Methods-Ageing Analysis

Ageing structures were collected opportunistically from Rainbow Trout, kokanee, Bull Trout, and Mountain Whitefish in Carpenter Reservoir. Scales were collected above the lateral line and immediately below the dorsal fin from Rainbow Trout, kokanee, and Mountain Whitefish. Scale samples were allowed to dry completely in coin envelopes before storage. Scales were mounted on glass slides and read under magnification by two independent analysts to determine growth annuli and assign fish age (Zymonas and McMahon 2009). Fin rays were sampled from Bull Trout (the first 2-3 rays from the left pectoral or pelvic fin), dried, and stored in labeled coin envelopes. A subset of fin rays collected from Carpenter Lake Bull Trout will be aged in Year 5 and ageing analysis will be included in the Year 5 synthesis report.

All methods of structure-ageing can be imprecise depending on analyst experience, fish species, fish age, and habitat characteristics of the system (Erhardt and Scarnecchia 2013). Otoliths, a calcified structure located in the brain cavity of the fish, are considered a more accurate ageing structure and can be used in conjunction with scales and fin clips to increase ageing accuracy. Otoliths were collected opportunistically from any mortalities (scales and/or fin clips were also taken), cleaned, and stored in glycerin. Mountain Whitefish scales can be particularly difficult to age, and a subsample of 30 otoliths were collected in Year

2 to compare estimated scale age and otolith age. Otoliths were examined under magnification by two independent analysts to identify growth annuli and estimate age (Zymonas and McMahon 2009).

3.3.2 Analysis - Size, Age, and Growth

Length, weight, and age data were analyzed for all fish species to describe the general characteristics of fish in the reservoir, and to explore how biological characteristics may be changing through time. An objective of BRGMON-04 is to determine whether reservoir operations are driving changes in biological characteristics and productivity in the reservoir and identifying whether biological characteristics are changing over time is the first step in this process. An iterative regression modelling process was used to explore whether size distributions changed between study years in Carpenter Reservoir for Bull Trout, Rainbow Trout, Mountain Whitefish, and kokanee. We first examined whether year influenced the length-weight relationship by assessing the significance of year as a model coefficient. If year was found to be significant, we then used ANOVA to determine whether mean length differed by year and by gear type. This length modelling helped to explain whether the effect of year on the length-weight relationship was related to effort and gear type, rather than biological or physical changes in the system. In future years (i.e., as sample sizes increase), gear will be evaluated as a coefficient in the length-weight regression model (along with other potential predictors).

Length and weight data can be characterized by a log-linear regression model (Ogle 2016), and the length-weight relationship is not likely to be affected by gear type or effort. A significant year affect suggests that factors outside of sampling effort may be affecting biological characteristics in Carpenter Reservoir. Length-weight relationships were modelled in the statistical environment R (R Development Core Team 2015) using a linear regression of log-transformed lengths (L) and weights (W):

$$W_i = \alpha L_i^{\beta} 10^{\epsilon_i} \qquad \text{Eq 4}$$

$$\log(W_i) = \log(\alpha) + \beta \log(L_i) + \epsilon_i \qquad \text{Eq 5}$$

Where α and β are intercept and slope parameters, and ε is the multiplicative model error. A year parameter was also added to the model and evaluated using ANOVA and AIC model selection to determine whether there is an interactive effect of length and year on body weight for Carpenter Reservoir fish. In cases where AIC values were almost identical, the model with the fewest parameters was considered to be the best fit model. All final models were examined using standard diagnostics to determine whether linear modelling assumptions had been met.

Table 3-2. Candidate linear models examining the effect of year and length on weight in Carpenter Reservoir, where ε is a normally distributed error term and α and β are the intercept and slope parameter, respectively.

Model 1	$\log(weight) = \alpha + \varepsilon$
Model 2	$\log(weight) = \alpha + \beta_1(\log(length)) + \varepsilon$
Model 3	$\log(weight) = \alpha + \beta_2(fYear) + \varepsilon$
Model 4	$\log(weight) = \alpha + \beta_1(\log(length)) + \beta_2 fYear + \varepsilon$
Model 5	$\log(weight) = \alpha + \beta_1(\log(length)) + \beta_2 fYear + \beta_3(\log(length) * fYear) + \varepsilon$

If year (or the interaction between year and length) was found to be a significant coefficient in the length-weight model, we then explored whether gear type may be driving this relationship. We compared mean lengths between years and between gear type using ANOVAs. We also used linear regression modelling to test for an interactive effect of year and gear type on fish length because relative effort and gear types may have changed between years. Five candidate models were evaluated using ANOVA and AIC model selection, with the best model being the model with the smallest AIC value (Table 3-3). The results of the length modelling helped to clarify the effect of year on the length-weight relationship by determining whether gear may be driving observed changes in length distributions.

Table 3-3. Candidate linear models examining the effect of year and gear factors on length in Carpenter Reservoir, where ε is a normally distributed error term and α and β are the intercept and slope parameter, respectively.

Model 1	$length = \alpha + \varepsilon$
Model 2	$length = \alpha + \beta_1 fYear + \varepsilon$
Model 3	$length = \alpha + \beta_2 fGear + \varepsilon$
Model 4	$length = \alpha + \beta_1 fYear + \beta_2 fGear + \varepsilon$
Model 5	$length = \alpha + \beta_1 fYear + \beta_2 fGear + \beta_3 (fGear * fYear) + \varepsilon$

Body condition was calculated for all fish with length and weight data using Fulton's Condition Factor (K; Anderson and Neumann 1996). Condition factors were calculated for all species over the entire study period and separated by year.

$$K = \frac{W * 10^N}{L^3} \qquad \text{Eq 6}$$

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).

Paired lengths and ages were used to fit a von Bertalanffy growth function (von Bertalanffy 1938) for Rainbow Trout, Mountain Whitefish and kokanee (there were not enough ages to fit the von Bertalanffy model to Bull Trout). For all species, a lack of younger and older fish may bias the von Bertalanffy parameter estimates and result in large confidence intervals at the upper and lower extremes of the function. In addition, the models currently contain data pooled for all years and do not account for year to year variation in growth parameters. In future years we will collect ageing structures from all fish in an effort to estimate von Bertalanffy growth parameters by year. The von Bertalanffy growth model is defined by the nonlinear model equation:

$$L_t = L_\infty\left[1 - \exp\left(-K(age - t_0)\right)\right] + \varepsilon \qquad \text{Eq 7}$$

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

Age data were used to develop age-length keys (ALKs) for Rainbow Trout and Mountain Whitefish in Carpenter Reservoir (there were not enough ages to create an ALK for Bull Trout or kokanee). The ALK is a probability matrix specific to a population, and displays the proportion of each length class that is contained within each age class. Lengths were divided into discrete intervals and the ALK calculated the frequency of all ages within each length interval (Guy and Brown 2007; Ogle 2016). The completed ALK was then used to estimate ages for all fish sampled for length (but not age) within the population. The proportions in the age-frequency table were used to determine the number of fish in each length class that should be assigned a particular age. Which fish from each size class was assigned a particularly age was randomly determined (see Isermann and Knight 2005 for more detail).

3.4 Reservoir Tributaries and Middle Bridge River Spawner Assessments

3.4.1 Field Methods - Tributary Visual Surveys

Tributary spawner surveys were performed during Rainbow Trout and kokanee spawning periods to document the abundance and distribution of fish spawning in Carpenter Reservoir tributaries and to determine the spawning intensity within and above the reservoir drawdown zone. Visual surveys were not performed for Bull Trout due to low spawner counts in previous years of this monitor. Counts for Rainbow Trout and kokanee occurred in Girl Creek, Gun Creek, Jones Creek, McDonald Creek, Marshall Creek, Sucker Creek, and Truax Creek (Figure 3-4), and the Middle Bridge River was assessed for kokanee spawners. Except for Gun Creek and the Middle Bridge River, all tributaries measured less than 5 m across, and crews were able to observe the entire wetted width from one bank. For Gun Creek, observers were only able to survey the East side of the creek due to time constraints. The Middle Bridge River is too turbid for a standard visual survey and spawner count; however, the presence of kokanee spawners was noted (but not counted) when spawners were rolling at the river surface.

During tributary surveys, two observers walked in a downstream direction on one streambank recording evidence of fish or redds. Survey lengths were constant each week, and match the stream sections surveyed in Year 2. Observers recorded the number of spawners, weather conditions (temperature and percent cloud cover), water clarity (good, moderate, or poor), discharge level (high, moderate, low, dry) and the presence of additional species in each tributary. Spawner counts were separated into those fish observed within the reservoir drawdown zone (potentially spawning in areas at risk of flooding) and fish observed above the drawdown zone/high water mark of the reservoir (unlikely to be affected by flooding). Surveys began prior to the estimated start of spawning and continued weekly until fish were no longer observed in monitored tributaries.

A simple overview fish habitat assessment was completed in June of Year 2 (FHAP; Johnston and Slaney 1996) in stream walk sections of Carpenter Reservoir tributaries (Marshall Creek, Truax Creek, McDonald Creek and Girl Creek). The assessment was performed at the lowest reservoir elevation possible to compare habitat quality within and above the drawdown zone. Habitat assessment procedures followed those described in Johnston and Slaney (1996). Hydraulic units were separated into riffles, glides, and pools in the two stream areas (above and within the drawdown zone). Physical measurements included unit length, bank full width, wetted width, bank full depth, averaged wetted depth, water velocity, woody debris numbers and sizes, barrier characteristics, and substrate characteristics. Habitat spawning quality was assessed in each surveyed section of the tributaries.

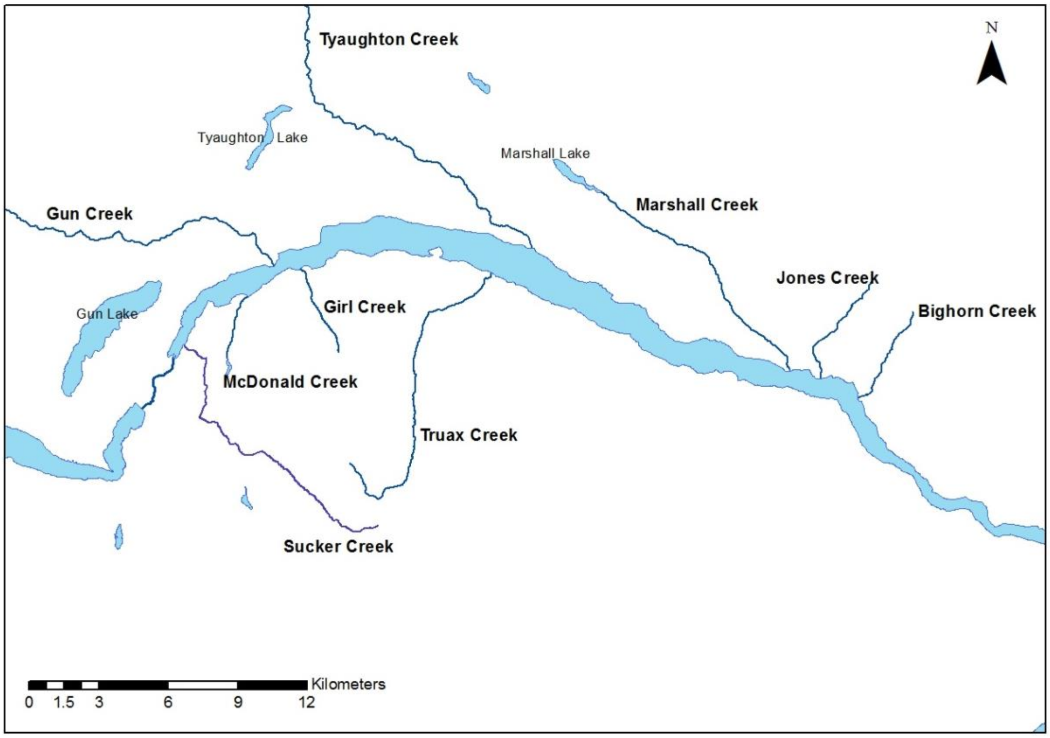

Figure 3-4 Locations of Carpenter Reservoir tributaries assessed for spawning activity.

3.4.2 Analysis - Tributary Visual Surveys

Spawner counts for Rainbow Trout and kokanee were analyzed to determine migration timing/duration and the peak date of spawning for all tributaries. Due to low spawner counts, particularly for Rainbow Trout, arrival and peak spawning dates were based on summed counts from all tributaries both above and within the drawdown zone. Observations of potential spawners within and above the drawdown zone were summarized and a ratio was calculated to determine the relative proportion of fish potentially spawning in the drawdown zone (where eggs and/or fry may be at risk of flooding or dewatering).

3.5 Habitat Monitoring and Productivity Modeling

Limnological surveys and physical habitat data were collected in Carpenter Reservoir and the Middle Bridge River during Year 3 as part of BRGMON-10 including:

1. Installation and maintenance of thermographs (HOBO TidbiT Water Temperature Data Logger) in key reservoir tributaries (Marshall Creek, Tyaughton Creek, Gun Creek, Middle Bridge River, Sucker Creek, McDonald Creek, Girl Creek, Truax Creek, Keary Creek, and the Hurley River);
2. Systematic monitoring of suspended sediment concentration from key tributaries (Marshall Creek, Tyaughton Creek, Gun Creek, Middle Bridge River, Truax Creek, and Keary Creek);
3. Local weather data collection at Terzaghi Dam including temperature, humidity, photosynthetically active radiation (PAR), and precipitation collection; and
4. Seasonal limnological surveys to document temperature/oxygen profiles and light penetration/water clarity.

These data are currently being collected and analyzed for BRGMON-10 (taking place in Years 3 and 4 of BRMON-04). BRGMON-10 will use CE-QUAL-W2, a USGS hydrodynamic and water quality simulation model, to model reservoir productivity under different operation scenarios (see SER 2014). CE-QUAL model outputs will be used as variables during BRGMON-04 regression modelling to link Bull Trout abundance and reservoir productivity. Potential variables from BRGMON-10 modelling include nutrient concentrations, periphyton biomass, phytoplankton biomass, chlorophyll concentration, and PAR levels. A majority of the habitat data and productivity modelling from BRGMON-10 will not be available for analysis in BRGMON-04 until Year 5. Thermograph data are being collected jointly by Limnotek and InStream, and stream temperature profiles are presented in this report.

4 Results

4.1 Bull Trout Abundance Estimation and Movement Analysis

4.1.1 Movement Analysis

Movement profiles for individual radio-tagged Bull Trout are shown in Figure 4-1 and Figure 4-2. Of the 30 fish tagged in the upper portion of Carpenter Reservoir, 22 were detected during both years of radio tracking. Seven fish were detected within the same 10 km reservoir block throughout the study period, suggesting that they were alive and present in the same block during tracking, or died following tagging and are no longer viable. Seven fish moved from their original tagging location downstream towards the Terzaghi dam, with three of these fish returning upstream. In contrast, six fish moved in an upstream direction (towards the Middle Bridge River), with four returning downstream and two only being detected in the upstream position.

In April of 2015, 20 Bull Trout were tagged with acoustic transmitter tags at the Marshall, Gun, and Truax Creek outflows. The mean fork length of tagged fish was 387.09 mm (sd 64.94 mm). Acoustic receivers were installed in the reservoir at a relatively low pool elevation and were submerged as elevation increased. Receivers will not be recovered until the reservoir elevation returns to the level during deployment. Acoustic data are therefore not available for analysis in this report; however, acoustic data will be available for the Year 4 report provided that the receivers functioned properly and are recoverable from the reservoir and river (i.e., were not damaged, lost, or vandalized).

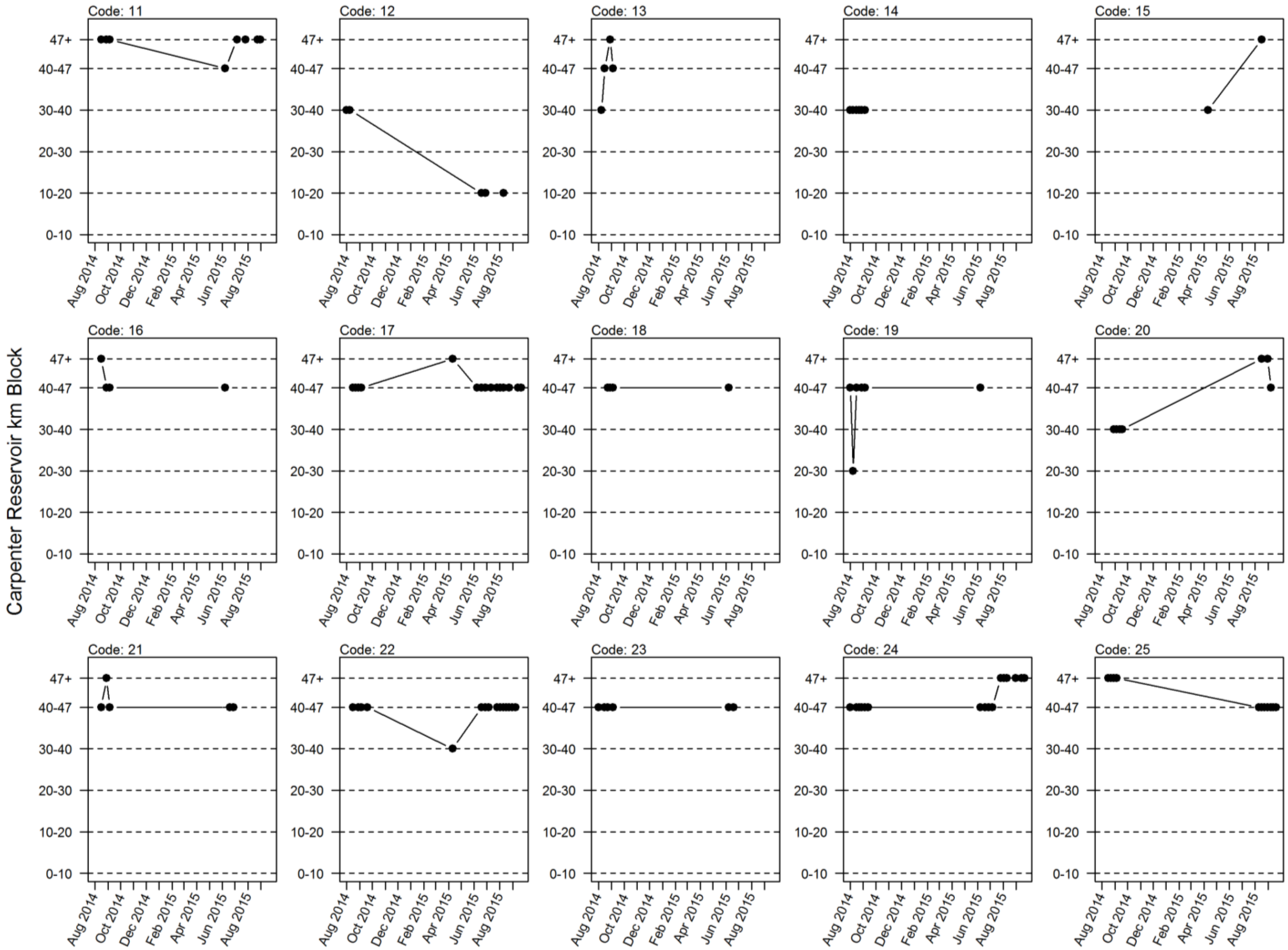

Figure 4-1. Movement profiles for radio-tagged Bull Trout (IDs 11 to 25) in Carpenter Reservoir and the Middle Bridge River from August 2014 to October 2015.

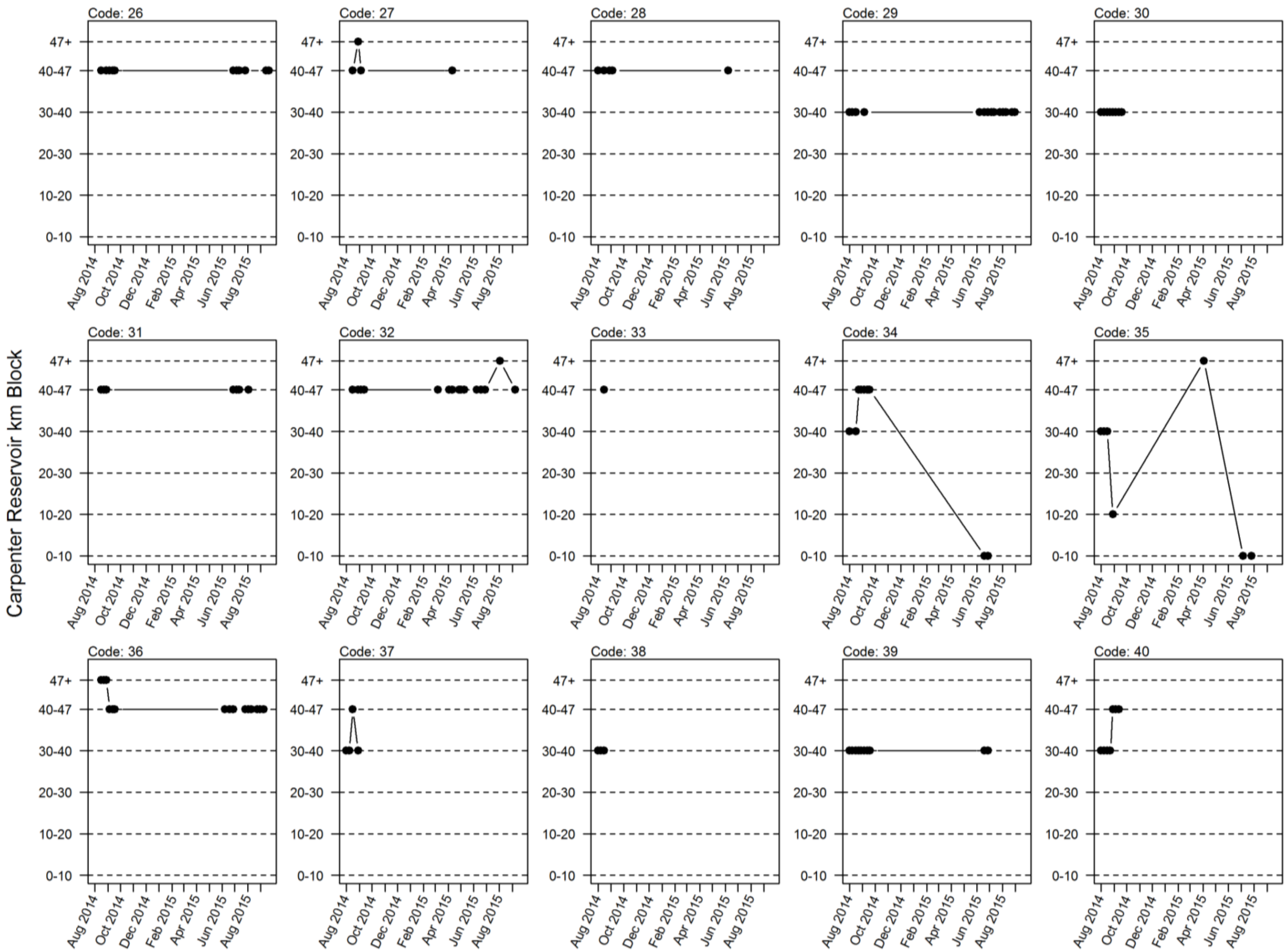

Figure 4-2. Movement profiles for radio-tagged Bull Trout (IDs 26 to 40) in Carpenter Reservoir and the Middle Bridge River from August 2014 to October 2015.

4.1.2 Mark-Recapture

During the mark-recapture period, a total of 215 Bull Trout were tagged during the initial marking period and 77 Bull Trout were captured during the recapture period. Of the Bull Trout captured during the recapture period, 7 were recaptures, resulting in a recapture rate of 9.1%. The Chapman modification of the closed Peterson estimate was used to obtain an estimate of adult Bull Trout abundance within the upper reservoir during the mark-recapture period (i.e., summer). The estimated abundance was 2,105 Bull Trout with a standard error of 653 Bull Trout (Table 4-1. Closed mark-recapture abundance estimate ($\hat{N}$), standard error, and 95% confidence interval for Bull Trout in the Carpenter Reservoir mark-recapture study area.).

Catch per unit effort (CPUE) was calculated for each species and gear type for all capture events occurring within the mark-recapture boundary during the mark-recapture period (i.e., July 1 to July 30; Table 4-2). Electrofishing CPUE was highest for all species because it was used primarily at high density creek mouths and targeted all species and behaviours. Although the Bull Trout CPUE for angling was low relative to electroshocking, angling received the highest relative effort and resulted in the greatest total catch of Bull Trout. Angling was also a successful capture method for Rainbow Trout, but no kokanee or Mountain Whitefish were captured angling. Gill netting was the least effective capture method for Bull Trout, and did not result in high catches of any species; however, gill netting was used to target deeper areas of the study area where fish were not expected to be present in high numbers.

Table 4-1. Closed mark-recapture abundance estimate ($\hat{N}$), standard error, and 95% confidence interval for Bull Trout in the Carpenter Reservoir mark-recapture study area.

Closed Mark-recapture Estimate (BT)	
$\hat{N}$	2,105
SE	652.6
95% CI	1,092; 4,416

Table 4-2 Catch per unit effort (CPUE) values (fish/hour) separated into angling (an), electrofishing (ef) and gill netting (gn) for Bull Trout (bt), Rainbow Trout (rb), Mountain Whitefish (mw), and kokanee (ko) during the Carpenter Reservoir mark-recapture study (July 2015).

Gear	Species	Total Effort (hours)	Count	CPUE (fish/hour)	
				Mean	St. Dev.
AN	BT	125.5	239	1.91	1.39
EF	BT	1.9	54	32.74	54.10
GN	BT	13.5	13	0.86	1.77
ALL	BT	140.9	306	6.26	24.03
AN	RB	125.5	12	0.10	0.22
EF	RB	1.9	8	5.24	10.98
GN	RB	13.5	2	0.17	1.18
ALL	RB	140.9	22	0.97	4.73
AN	KO	125.5	0	0.00	0.00
EF	KO	1.9	23	15.43	29.74
GN	KO	13.5	4	0.28	0.95
ALL	KO	140.9	27	2.64	12.84
AN	MW	125.5	0	0.00	0.00
EF	MW	1.9	331	191.35	233.90
GN	MW	13.5	6	0.40	1.92
ALL	MW	140.9	337	30.94	114.84

4.2 Analysis of Biological Data Collected for All Species

4.2.1 Ageing Analysis

Ages were determined for scales and otoliths collected during BRGMON-04 field activities in Years 2 and 3 (total numbers are presented in Table 4-3).

Otoliths were collected opportunistically from any mortalities that occurred during sampling, apart from a paired otolith/scale sample of 30 Mountain Whitefish that was taken in Year 2 to verifying scale ages in future years. The scales and otoliths from the paired sample were aged separately and compared using linear regression (Figure 4-3). The resulting model was moderately correlated with an R-squared of 0.52 and model diagnostics showed that linear model assumptions of independence, normality and homogeneity of variances were met. Ages from paired scales and otoliths should be identical, resulting in a 1:1 relationship. We used an ANOVA to test whether the linear model of scale ages versus otolith ages was significantly different from a 1:1 relationship. Two linear models were included in the ANOVA: the model of scale age vs otolith age, and a linear model of the data with a forced slope of 1 and an intercept of 0. The p-value of the ANOVA was 0.090 (residual df 28; F-statistic 2.63) and we failed to reject the null hypothesis that the full model (with estimated slope and intercept) did not explain more of the variation in the data than the model with the forced slope and intercept (i.e., the two models are not statistically different).

Table 4-3. Total number of aged structures collected in Years 2 and 3 of BRGMON-04.

Species	Scales Aged	Otoliths Aged
BT	0	9
KO	24	0
MW	30	31
RB	41	2

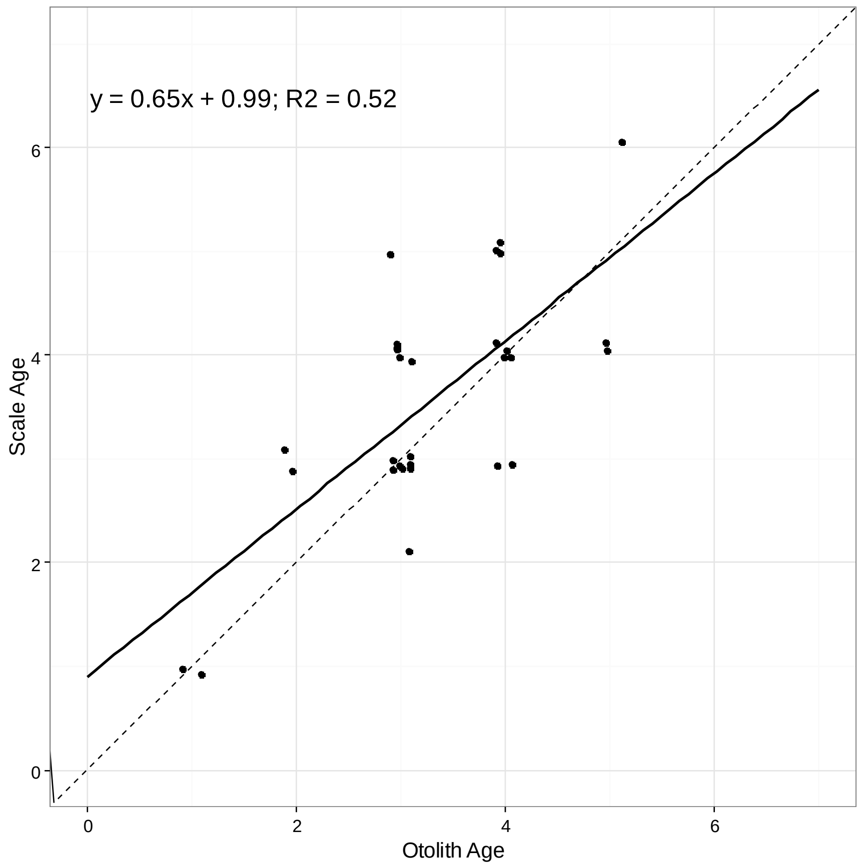

Figure 4-3. Linear model of Carpenter Reservoir Mountain Whitefish paired scale and otoliths ages. Ages are jittered to show overlap.

4.2.2 Length, Age, and Growth

Bull Trout

A total of 1,012 Bull Trout have been captured in Carpenter Reservoir over the three-year study period, 749 of which were PIT tagged (for potential future assessment of growth and distribution, Table 4-4). A strong log-linear relationship was identified between Bull Trout length and weight (R^2 0.91). Model diagnostics suggested minor heteroscedasticity of variances at larger Bull Trout lengths and weights; however, we did not consider it large enough to cause concern (the log transformation greatly reduced heteroscedasticity). We examined the effect of year on the length-weight relationship by evaluating the fit of five candidate models using ANOVA and AIC model selection (Table 3-2). The model including a year-length interaction term had the most support according to AIC (i.e., slopes varying by year, see Figure 4-5). All model coefficients were significant, and there was significant evidence of a year-length interaction effect on weight (the p-value of the interaction term was 9.7 E-4, df 2, residual df 837).

The year-length interaction identified during length-weight modelling may be an effect of changing methods and relative effort between years, rather than changing biological conditions. We used ANOVAs comparing mean lengths by year and gear type to test whether sampling characteristics were driving the effect of year on the length-weight relationship. There was a significant difference in mean length of Bull Trout between years (p-value 9.03 E-04, residual df 1,007) and between gear type (angling, electrofishing, and gill netting; p-value 8.2 E-7, residual df 925). We also examined the possibility of a year-gear interaction using multiple linear modeling and AIC model section. The best models were the model with both year and gear as model coefficients, as well as the model including a year-gear interaction term. The difference in AIC was very small (only a 0.03 % decrease in AIC value) and we therefore considered the model with the most support to be the simpler model without the interaction term. All model coefficients in the final model were significant with a 0.05 alpha level, suggesting that both year and gear type have a statistical effect on the mean fork length of Bull Trout sampled in Carpenter Reservoir in Years 1 through 3.

A total of 9 Bull Trout were aged using otoliths, but because of the small sample size we did not fit the von Bertalanffy length-age model or create an age-length key (ALK) for Bull Trout. Fin rays have been collected from a subsample of tagged Bull Trout (n=139), but are not planned to be analyzed until the 5-year review report.

Table 4-4. Characteristics of Bull Trout captured in Carpenter Reservoir in Years 1 through 3.

Year	Fish Count *	Mean Length (mm)	SD Length	Mean Weight (g)	SD Weight	Mean Condition Factor (K)	SD Condition Factor
1	432	363.85	72.34	469.86	244.10	0.92	0.15
2	210	384.75	59.74	505.06	234.47	0.89	0.15
3	368	369.56	62.24	471.69	217.28	0.91	0.21

* Counts represent fish for which lengths were recorded. Due to equipment issues, n may not be the same for mean length and mean weight, but the discrepancy is minor and not reported.

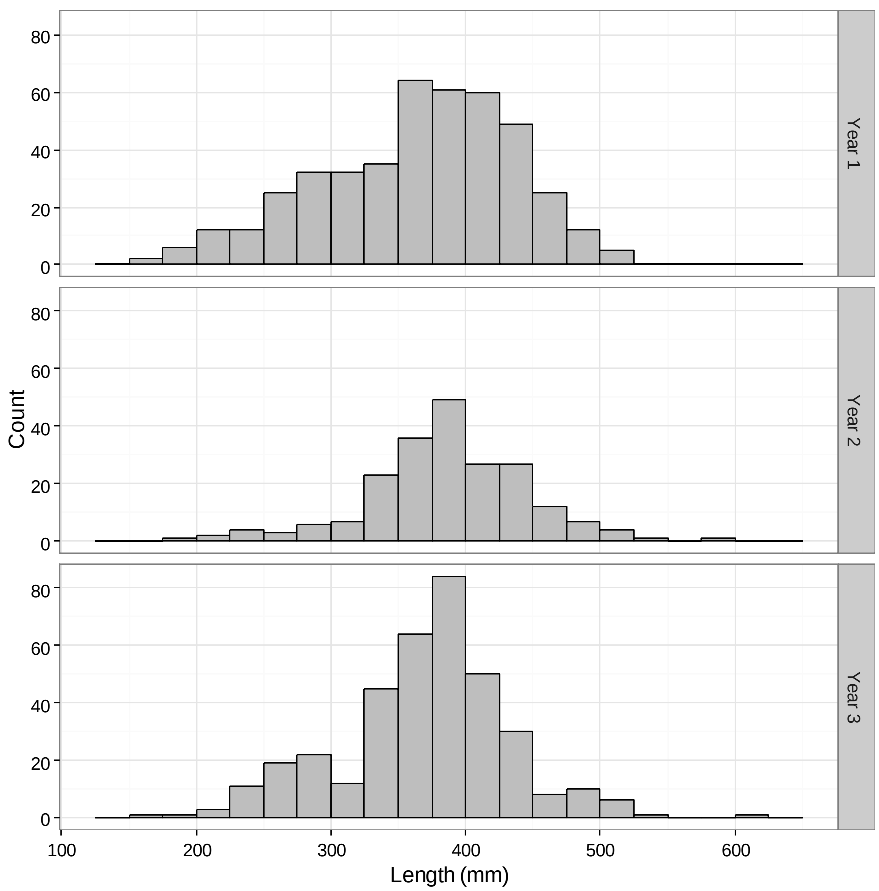

Figure 4-4. Length-frequencies of Carpenter Reservoir Bull Trout separated by study year.

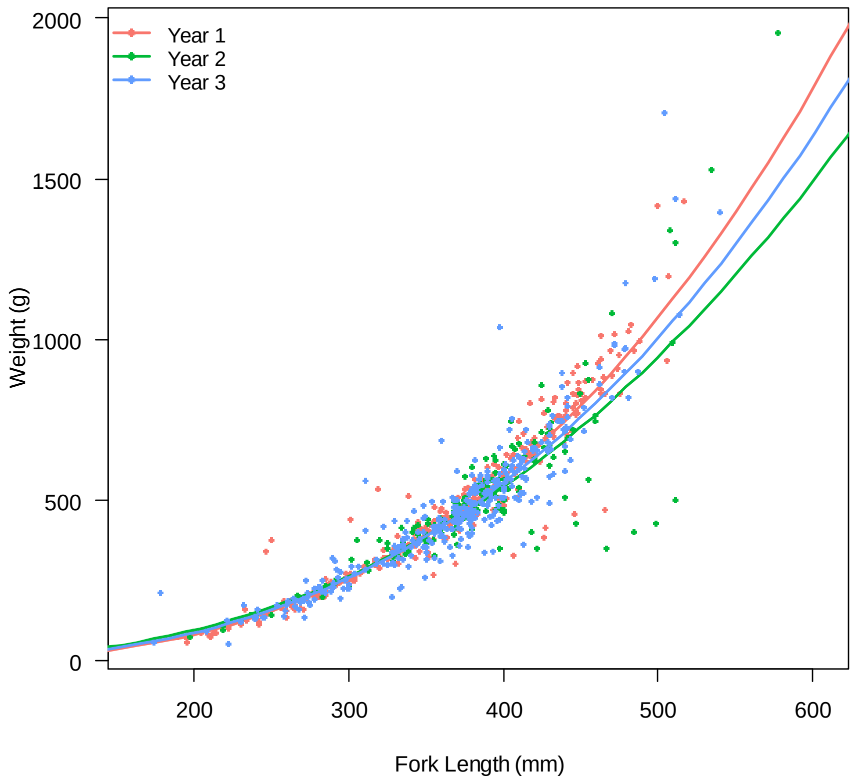

Figure 4-5. Length-weight relationships for Bull Trout in Carpenter Reservoir separated by year.

Rainbow Trout

A total of 202 Rainbow Trout have been captured in Carpenter Reservoir over the three-year study period, 181 of which were PIT tagged (for potential future assessment of growth and distribution, Figure 4-6). A strong log-linear relationship was modelled between Rainbow Trout length and weight (R^2 = 0.90). We examined the effect of year on the length-weight relationship by evaluating the fit of five candidate models using ANOVA and AIC model selection (Table 3-2). The model with the most support according to AIC was the model including a year-length interaction term (i.e., slopes vary by year, see Figure 4-7). According to an ANOVA of the best fit model, there was significant evidence of a year-length interaction effect on weight (p-value 2.1 E-04, df 2, residual df 149).

The year-length interaction identified during length-weight modelling may be an effect of changing methods and relative effort between years. An ANOVA of mean length grouped by year suggested no statistical effect of year on mean length (p-value 0.05, residual df 201), whereas an ANOVA of mean length grouped by gear type suggested a strong statistical effect of gear type on mean length (p-value 1.09 E-10, residual df 169). The gill net sample size for Rainbow Trout was very small in this analysis (only three fish), which likely explains the significance of gear type on length. A t-test comparing mean length of electrofished and angled Rainbow Trout in Carpenter Reservoir suggested only a weak statistical difference between mean length (p-value 0.04, df 144.9). We examined the effect of an interaction between year and gear type using ANOVA and AIC modelling and found the best model to be the model with only gear as a model coefficient (i.e., year was not included in the final model; ANOVA p-value for the gear coefficient was significant at 1.33 E-10, df 2, residual df 168). When gill netted Rainbow Trout were removed from the analysis, the gear coefficient became much less significant (p-value 0.04, df 1, residual df 166). The results of the regression modelling suggest that the length-weight relationship for Rainbow Trout may be statistically different by year, but it is not yet clear what is driving this difference.

A total of 41 Rainbow Trout (a combination of scales and otoliths) were aged (Table 4-6). The sample size of the aged sample is quite small and does not cover the full spectrum of size classes present in Figure 4-6; however, we were still able to fit the von Bertalanffy growth model to Rainbow Trout length-at-age data (Table 4-7). Bootstrapping was used to obtain 95% confidence intervals for the von Bertalanffy parameter estimates. The resulting confidence intervals were skewed for the $L_{\inf}$ and t_0 parameters, suggesting a weak model fit likely due to the small sample size (additional diagnostics on model residuals identified moderate heteroscedasticity of residuals). An increased sample size in future years should reduce the uncertainty in the Von Bertalanffy parameters for Carpenter Reservoir Rainbow Trout.

An age length key was created using the Rainbow Trout length and age data and used to estimate the total proportion of all fish in each age class as well as to assign ages to the unaged fish. Because the lengths sampled do not cover the full spectrum of rainbow trout ages we only estimated ages for fish that were within the length distribution of the aged fish. A length-frequency plot separated by age was created to display the estimated age-length distribution (Figure 4-9). As with the von Bertalanffy model for Rainbow Trout, the ALK and age predictions are limited by small sample size, but will be improved upon in future years of the monitor.

Table 4-5. Characteristics of Rainbow Trout captured in Carpenter Reservoir in Years 1 through 3.

Year	Fish Count *	Mean Length (mm)	SD Length	Mean Weight (g)	SD Weight	Mean Condition Factor (K)	SD Condition Factor
1	92	335.99	48.16	381.74	139.94	1.00	0.14
2	66	335.61	32.45	376.93	90.72	1.05	0.37
3	45	314.91	63.22	334.81	123.62	0.98	0.13

* Counts represent fish for which lengths were recorded. Due to equipment issues, n may not be the same for mean length and mean weight, but the discrepancy is minor and not reported.

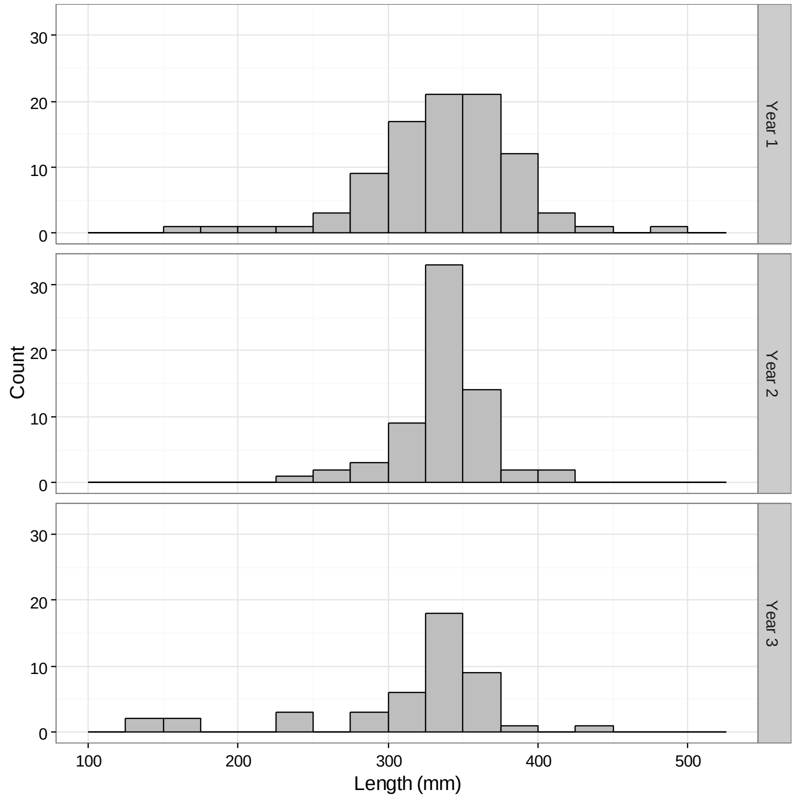

Figure 4-6. Length-frequencies of Carpenter Reservoir Rainbow Trout separated by study year.

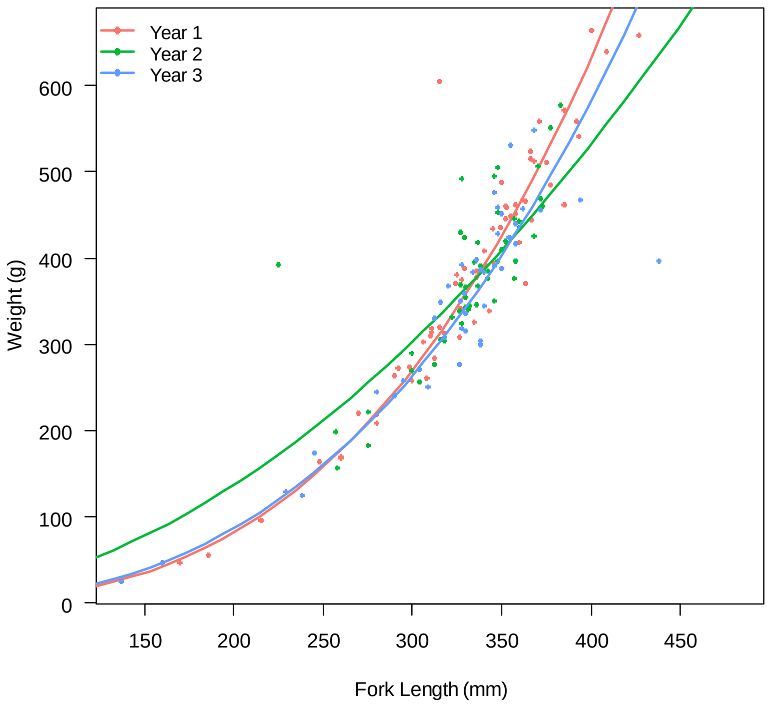

Figure 4-7. Length-weight relationships for Rainbow Trout in Carpenter Reservoir separated by year.

Table 4-6. Mean length and weight of estimated Rainbow Trout ages.

Estimated Age	N	Mean Length (mm)	SD Length	Mean Weight (g)	SD Weight
1	1	137.00	-	25.00	-
2	6	226.83	68.98	118.25	53.16
3	14	312.07	50.94	314.25	136.51
4	15	347.60	25.47	408.69	89.95
5	5	337.60	7.96	411.00	56.59

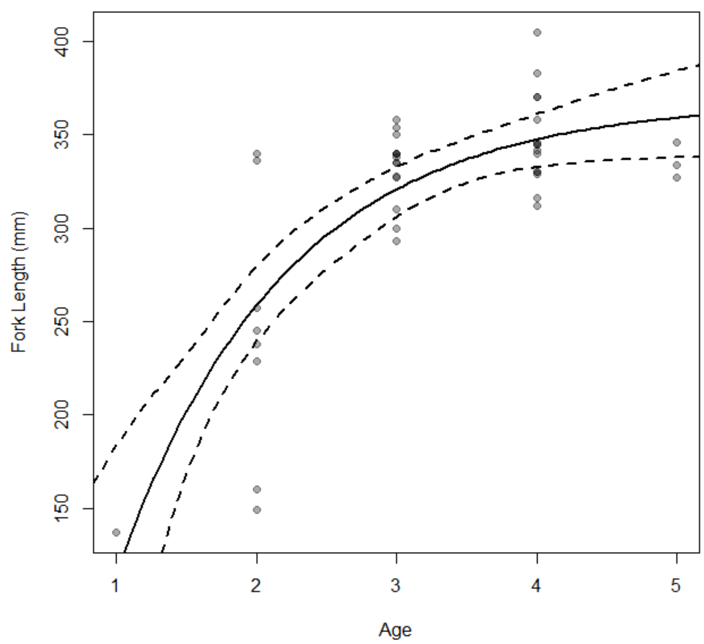

Figure 4-8. Von Bertalanffy growth model with 95% confidence intervals of Rainbow Trout length and age data. Shading shows overlap of data points.

Table 4-7. Von Bertalanffy parameter estimates and bootstrapped (n=1000) 95% confidence intervals for Carpenter Reservoir Rainbow Trout.

Parameter	Estimate	Bootstrap Lower CI	Bootstrap Upper CI
L_{inf}	367.73 mm	340.48	423.62
K	0.84	0.44	1.29
t_0	0.56	0.22	0.88

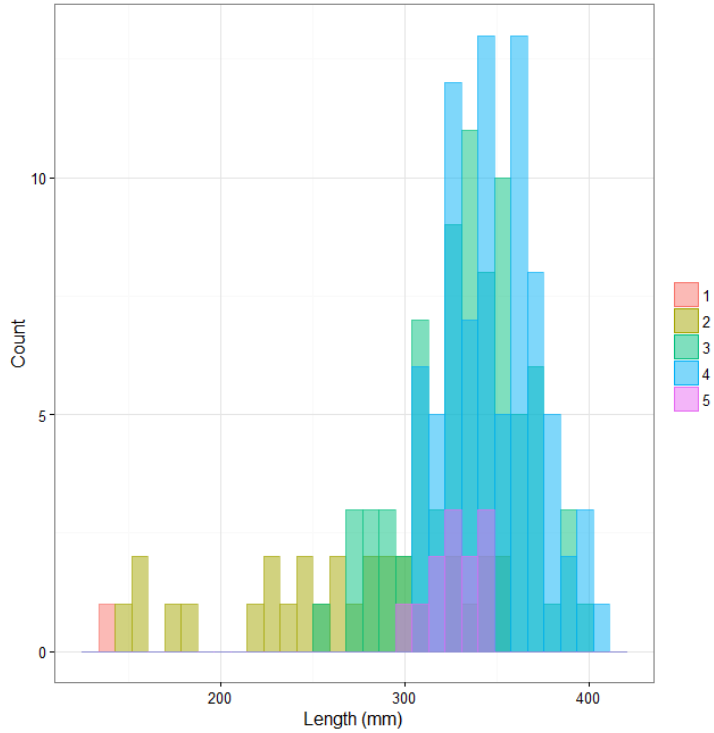

Figure 4-9. Length-frequency histogram for Rainbow Trout separated by age (observed and estimated combined). Transparency shows overlap.

Mountain Whitefish

A total of 646 Mountain Whitefish have been caught in Carpenter Reservoir in Years 1 through 3, and 212 have been PIT tagged (for potential future assessment of growth and distribution, Figure 4-10). A strong log-linear relationship was found between length and weight of Carpenter Reservoir Mountain Whitefish ($R^2 = 0.97$). We examined the effect of year on the length-weight relationship by evaluating the fit of five candidate models using ANOVA and AIC model selection (Table 3-3). The model with the most support according to AIC was the model with only length as a predictor of weight, suggesting that year does not explain any additional variation in weight of Mountain Whitefish in Carpenter Reservoir (Figure 4-11). To further support this conclusion, ANOVA analyses of mean length grouped by year and by gear type did not find any significant differences in weight between groups (year ANOVA p-value 0.69, df 2 residual df 643; gear ANOVA p-value 0.92, df 2, residual df 640).

A total of 31 Mountain Whitefish were aged using paired otolith and scale samples (Table 4-9). The von Bertalanffy growth model was fit to Mountain Whitefish length-at-age data (Table 4-10, Figure 4-12); however, as with Rainbow Trout, the small aged sample size resulted in heteroscedasticity at larger fork lengths and skewed bootstrapped confidence intervals for parameter estimates. A larger aged sample size in future years should reduce the uncertainty and bias in the von Bertalanffy growth parameters.

An age length key (ALK) was developed for Mountain Whitefish using length and age data and used to estimate the total proportion of all fish is each age class as well as to assign ages to unaged fish. Predictions were restricted to the length spectrum covered by the aged fish. A length-frequency plot separated by age was created to display the estimated age-length distribution. As with the von Bertalanffy model, the ALK is limited due to the small aged sample size but should become more accurate in future monitor years.

Table 4-8. Characteristics of Mountain Whitefish captured in Carpenter Reservoir in Years 1 through 3.

Year	Fish Count *	Mean Length (mm)	SD Length	Mean Weight (g)	SD Weight	Mean Condition Factor (K)	SD Condition Factor
1	311	224.25	70.17	156.93	103.35	1.16	0.23
2	249	228.53	67.43	160.75	103.57	1.14	0.26
3	86	229.29	46.23	146.30	76.39	1.11	0.15

* Counts represent fish for which lengths were recorded. Due to equipment issues, n may not be the same for mean length and mean weight, but the discrepancy is minor and not reported.

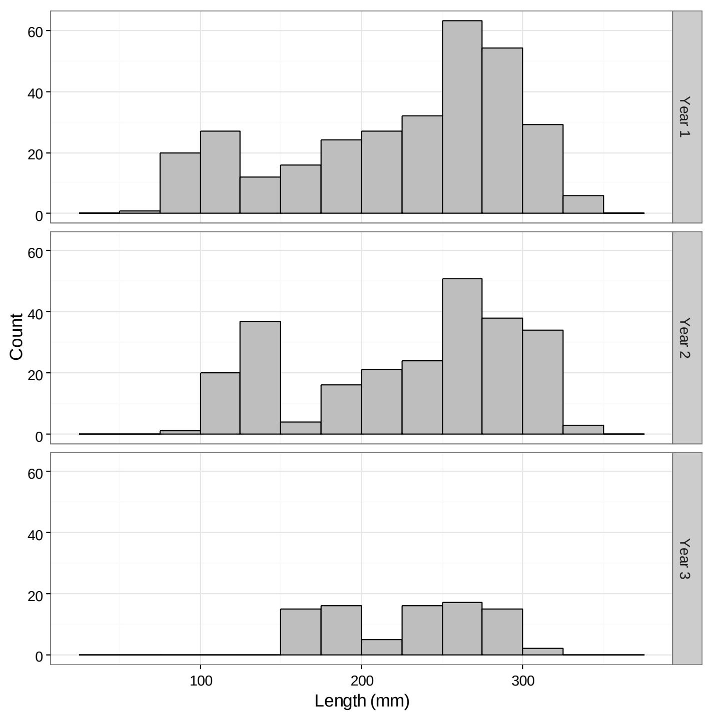

Figure 4-10. Length-frequencies of Carpenter Reservoir Mountain Whitefish separated by study year.

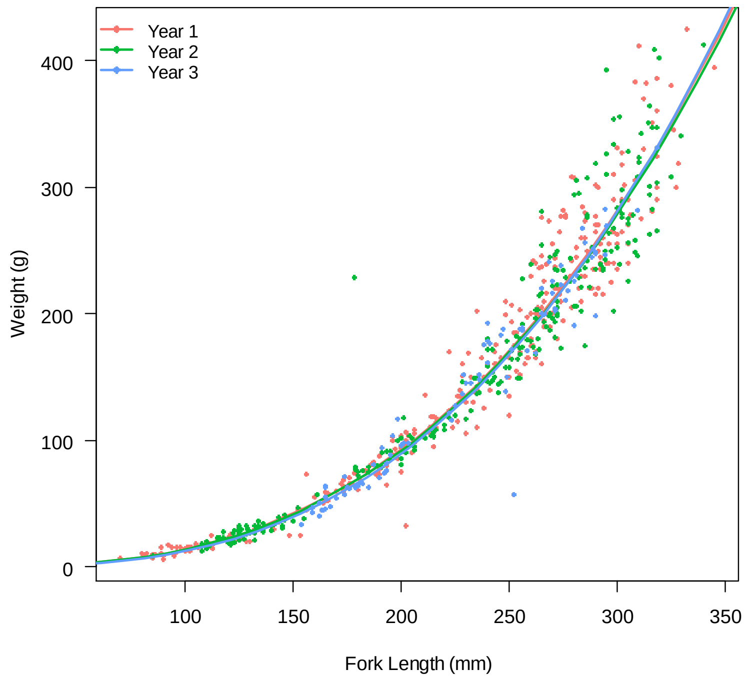

Figure 4-11. Length-weight relationships for Mountain Whitefish in Carpenter Reservoir separated by year.

Table 4-9. Mean length and weight of estimated Mountain Whitefish ages.

Estimated Age	N	Mean Length (mm)	SD Length	Mean Weight (g)	SD Weight
1	2	114.50	9.19	15.00	2.83
2	2	204.00	2.83	91.00	1.41
3	14	250.36	38.56	193.86	94.30
4	9	278.44	34.00	257.44	88.12
5	3	296.67	11.59	325.67	60.47
6	1	255.00	-	180.00	-

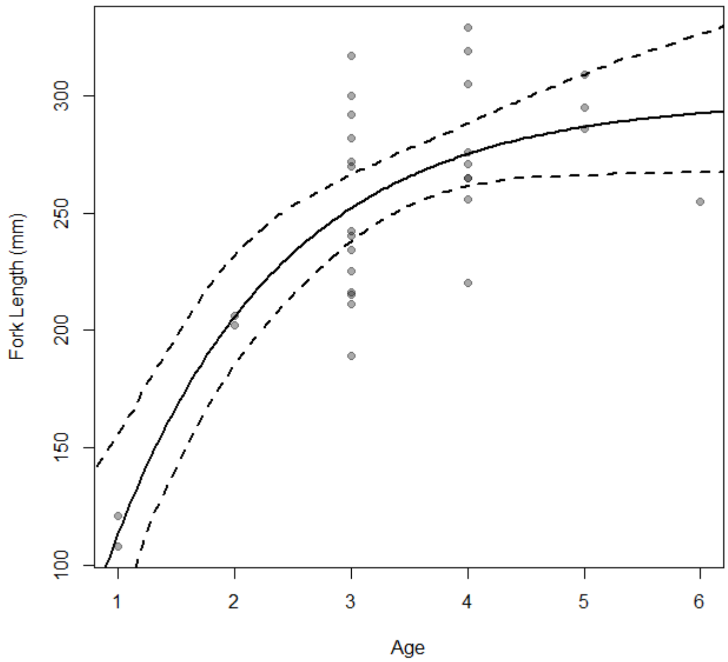

Figure 4-12. Von Bertalanffy growth model with 95% confidence intervals of Mountain Whitefish length and age data. Shading shows overlap of data points.

Table 4-10. Von Bertalanffy parameter estimates and bootstrapped (n=1,000) 95% confidence intervals for Carpenter Reservoir Mountain Whitefish.

Parameter	Estimate	Bootstrap Lower CI	Bootstrap Upper CI
Linf	298.06 mm	265.33	381.29
K	0.70	0.28	1.42
T0	0.31	-0.81	0.73

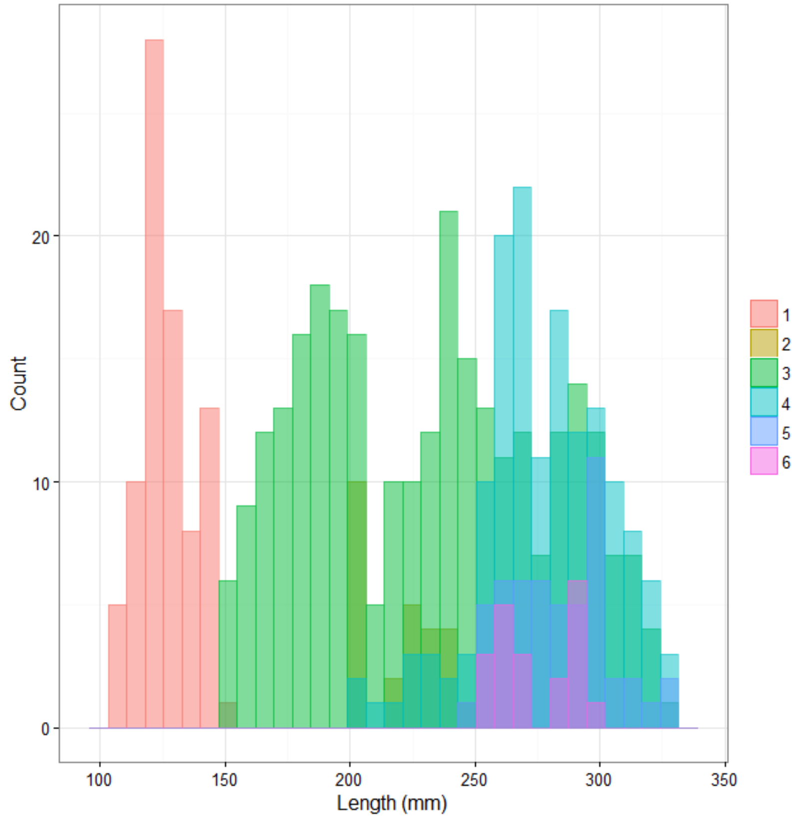

Figure 4-13. Length-frequency histogram for Mountain Whitefish separated by age (observed and estimated combined). Transparency shows overlap.

Kokanee

A total of 32 kokanee have been captured in Carpenter Reservoir in Years 1 through 3 (Table 4-11). A strong log-linear relationship was modelled between length and weight of Carpenter Reservoir kokanee (R^2 = 0.92). We examined the effect of year on the length-weight relationship by evaluating the fit of five candidate models using ANOVA and AIC model selection (Table 3-3). The model with the most support according to AIC was the model with only length as a predictor of weight, suggesting that year does not explain additional variation in weight of kokanee in Carpenter Reservoir. Although the slopes in Figure 4-15 appear to be different between years, the sample size is too small for the regression model to detect a significant year affect. To further support this conclusion, ANOVA analyses of mean length grouped by year and by gear type did not find any significant differences in weight between groups (year ANOVA p-value 0.17, df 2 residual df 29; gear ANOVA p-value 0.36, df 2, residual df 29).

A total of 23 kokanee (combination of scales and otoliths) were aged (Table 4-12). The aged sample size is small for Carpenter Reservoir kokanee and only three age categories were identified. For these reasons we did not fit the von Bertalanffy growth model or create an ALK for kokanee. Age structures will continue to be collected from kokanee and age modelling will be completed in a future monitor year.

Table 4-11. Characteristics of kokanee captured in Carpenter Reservoir in Years 1 through 3.

Year	Fish Count *	Mean Length (mm)	SD Length	Mean Weight (g)	SD Weight	Mean Condition Factor (K)	SD Condition Factor
1	3	341.00	27.62	524.67	182.26	1.28	0.14
2	2	294.00	22.63	316.50	65.76	1.24	0.03
3	27	315.30	27.48	398.28	97.72	1.28	0.11

* Counts represent fish for which lengths were recorded. Due to equipment issues, n may not be the same for mean length and mean weight, but the discrepancy is minor and not reported.

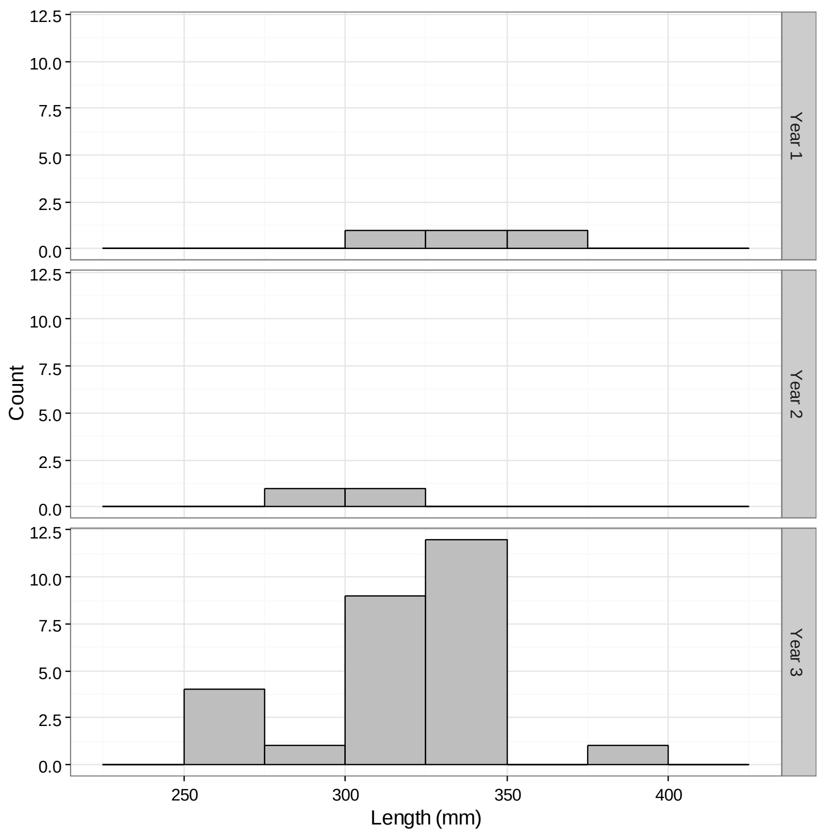

Figure 4-14. Length-frequencies of Carpenter Reservoir kokanee separated by study year.

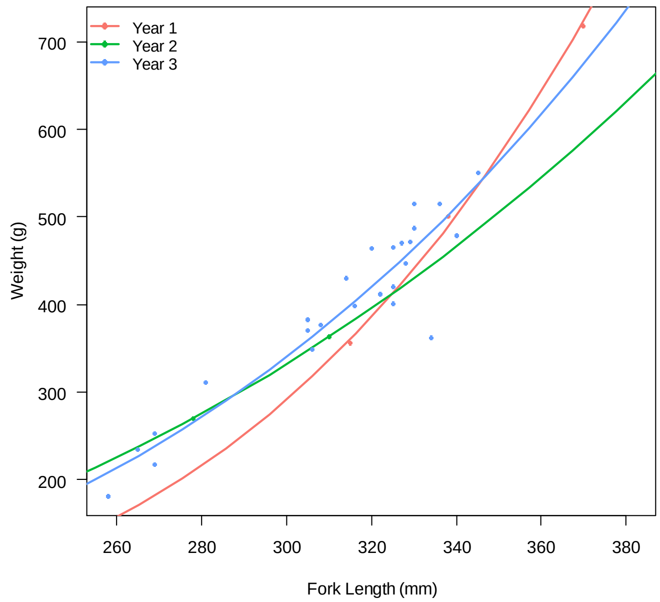

Figure 4-15. Length-weight relationships for kokanee in Carpenter Reservoir separated by year.

Table 4-12. Mean length and weight of estimated kokanee ages.

Estimated Age	N	Mean Length (mm)	SD Length	Mean Weight (g)	SD Weight
2	1	328.00	-	447.00	-
3	20	314.8	28.38	394.58	95.18
4	3	328.00	10.82	449.00	41.01

4.3 Tributary Visual Surveys

Weekly spawner surveys were performed in Carpenter Reservoir tributaries during spring and fall of Years 1 through 3. Surveys occurred during the Rainbow Trout (May-June) and kokanee (August-September) spawning periods (see Table 4-13 for spawning dates and peak counts). Spawner counts were summed across all tributaries to display spawn timing at the watershed level and to compare timing between years (only tributaries surveyed in all years were included in the annual sums; Figure 4-16). Kokanee peak spawning appears to have occurred approximately one week later in Year 3 relative to Year 2, and total spawner numbers were higher in Year 3. Kokanee counts by tributary (Figure 4-17) suggest that spawn timing is similar across all tributaries, and that McDonald and Sucker Creeks may be key kokanee spawning tributaries. Kokanee spawning also occurred in the Middle Bridge River (likely a key spawning area), but high turbidities prevented spawner enumerations. Rainbow Trout spawner counts were too low (only one fish was observed in Year 3) to draw comparisons between Years 2 and 3.

Rainbow Trout visual surveys were unsuccessful in Year 3 and the peak count in Year 2 was 14 fish. Low spawner counts are likely a result of low overall Rainbow Trout densities and poor survey conditions (i.e., high spring turbidities in potential spawning tributaries). Rainbow Trout visual surveys will not be continued in Year 4 and on because of low densities and unsuitable counting conditions.

In Year 3 we divided kokanee spawner counts into above and within the drawdown zone to evaluate the potential risks to spawning success of reservoir elevation changes. Kokanee were observed within the drawdown zone during visual surveys, and by the end of the spawning period the reservoir had filled to full pool levels (posing a potential risk to the survival of eggs that were deposited in the drawdown zone). In Girl Creek, 36.9% of kokanee observed over the spawning period were located within the drawdown zone[4], whereas in Truax Creek the percentage was 4.2%, 7.5% in McDonald Creek, and 3.7% in Sucker Creek (kokanee were not observed within the drawdown zone in Jones and Marshall Creeks). These percentages depict kokanee that were observed within the drawdown zone, but we cannot confirm that spawning occurred in this area. No spawning behaviour was observed and fish may have been holding or moving upstream when they were observed.

In the spring of Year 3 we performed an overview habitat survey comparing habitat above and within the drawdown zone in Marshall Creek, Truax Creek, McDonald Creek, and Girl Creek (roughly following Level 1 Fish Habitat Assessment Procedures of Johnston and Slaney 1996). Habitat in the drawdown zone of Carpenter Reservoir is not of high quality for spawning due to low cover, a lack of woody debris, and poor substrate conditions (mostly fine sediments).

Table 4-13. Dates of arrival, date last observed, and peak counts of Rainbow Trout and kokanee in Carpenter Reservoir tributaries.

Year	Species	First Date Observed	Last Date Observed	Date of Peak Count	Peak Count (all tribs combined)	Tributaries
Year 1	RB	Jun 11	Jun 11	Jun 11	4	Jones, Marshall
Year 1	KO	Sep 6	Sep 6	Sep 6	14	McDonald, Sucker
Year 2	RB	May 14	Jun 20	Jun 20	14	Marshall, Girl, McDonald, Truax
Year 2	KO	Aug 19	Sep 16	Aug 26	257	McDonald, Sucker, Girl, Truax, Marshall
Year 3	RB	Jun 12	Jun 12	Jun 12	2	Truax, Girl
Year 3	KO	Aug 13	Oct 2	Sep 11	345	Truax, Girl, McDonald, Sucker, Marshall, Jones

[4] This high percentage is somewhat misleading due to a large pool located in the Girl Creek drawdown zone that is used as a holding area by migrating kokanee (kokanee are easily enumerated in this pool but do not likely spawn there).

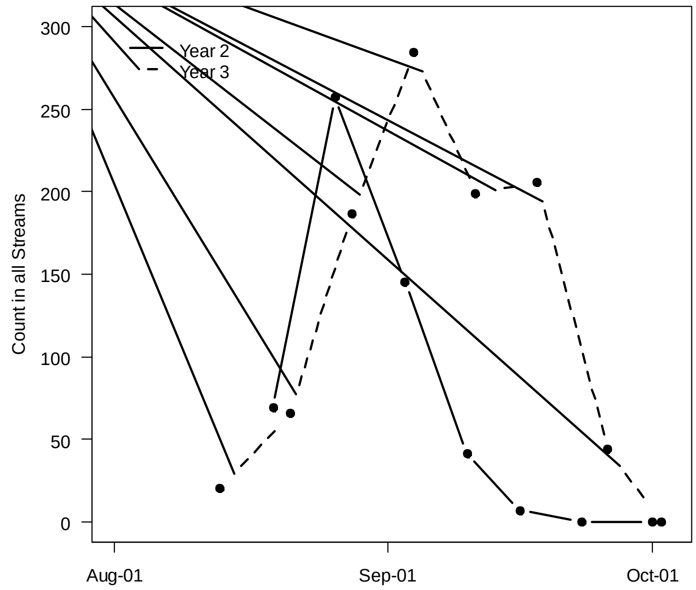

Figure 4-16. Counts of kokanee in Carpenter Reservoir tributaries (summed for Truax, Girl, McDonald, Sucker, and Marshall Creeks) in Years 2 and 3.

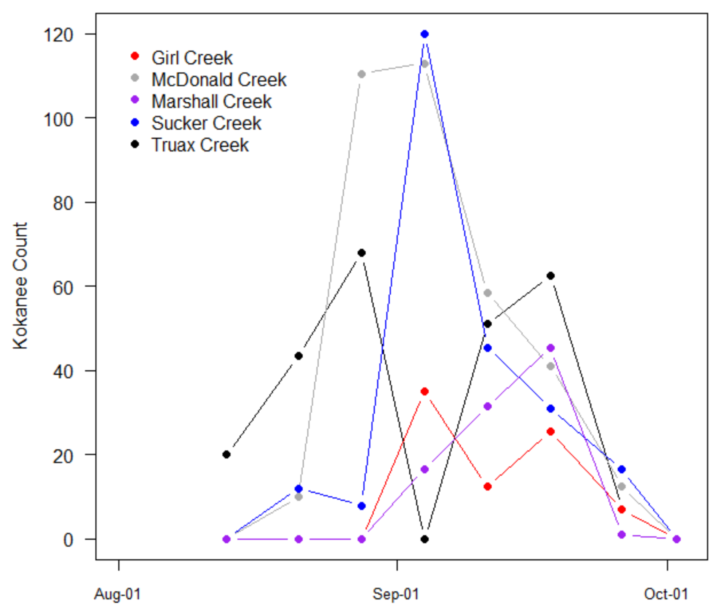

Figure 4-17. Kokanee visual survey counts for Year 3.

4.4 Habitat Monitoring

Thermographs (HOBO Tidbit temperature loggers) were installed in Marshall Creek, Gun Creek, Sucker Creek, McDonald Creek, Girl Creek, Truax Creek, the Hurley River, and the Middle Bridge River in September 2014. Additional thermographs were installed in Keary Creek, Tyaughton Creek, and the Middle Bridge River in the spring of 2015 as part of BRGMON-10. Average daily temperatures are displayed for a subset of these tributaries in Figure 4-18 along with daily reservoir elevations over the same time period. Many of the Carpenter Reservoir tributaries are influenced by glacier melt and maximum and minimum water temperatures differed by 10°C or more. Marshall Creek, one of the lake-fed tributaries, had a lower degree of temperature fluctuation (i.e., ~5°C over the monitored time period). In all tributaries, temperatures were lowest from November to March, and reached annual maximums in July and August. On average, Carpenter Reservoir reaches its maximum elevation in September and drafts at a slow, steady rate until the minimum level is reached in April. The reservoir filling period is quite short as the reservoir goes from low to high pool in approximately 1.5 months (May and June).

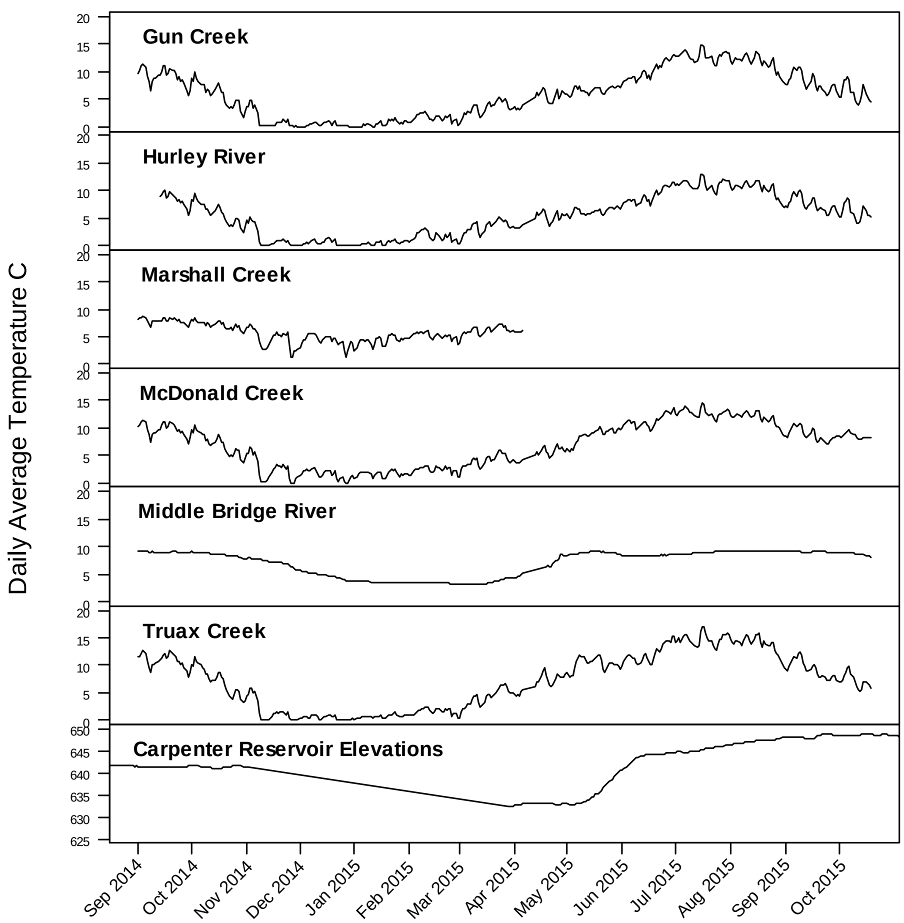

Figure 4-18. Carpenter Reservoir elevations and daily average temperatures from a sample of watershed tributaries and the Middle Bridge River from September 2014 to October 2015.

5 Discussion

5.1 BRGMON-04 Methods Consistency and Progression

The BRGMON-04 monitoring program has evolved in Years 1 through 3 to reflect the type and quality of data that can be collected from the reservoir and river, the scope of the management questions, and the logistical challenges involved in sampling a large, remote reservoir. Years 1 and 2 served primarily as pilot years, and the terms of reference were amended following Year 2 to refine the management hypotheses to focus on key species and habitat areas in the watershed (BC Hydro 2015). Year 3 represents the first year of monitoring following the amended TOR, and the results suggest the monitor is progressing towards a more consistent and effective sampling program. Methods will be added and refined in future years (as described in the project proposal) based on their ability to answer the management hypotheses. Carpenter Reservoir is large, complex, and has had limited previous monitoring. Refinements to the monitoring program will be an important step in ensuring that monitoring objectives are met.

5.2 Distribution and Biological Characteristics: Bull Trout

5.2.1 Bull Trout Distribution

Radio Tracking and relative CPUE (by location and method) from Years 2 and 3 indicate that Bull Trout were concentrated at tributary confluences in the upper portion of the reservoir during full pool conditions (i.e., July through October). A large portion of the radio-tagged Bull Trout were detected in the upper reservoir at or within 10 km of their tagging location for a majority of the full pool tracking period (Figure 4-1 and Figure 4-2). Although Bull Trout were detected throughout the reservoir, we were unable to identify clear and consistent linear movement within the reservoir or between the reservoir and river. This contrasts the results of Chamberlain et al (2001), where radio telemetry identified a general movement pattern of Bull Trout from Carpenter Reservoir into the Middle Bridge River in the spring (as reservoir elevation increased) and from the river into the reservoir in late fall/early winter (as reservoir elevation decreased). Chamberlain et al (2001) installed fixed radio telemetry receivers at the confluence of the Middle Bridge River and the reservoir and at the confluence of the Hurley River and Middle Bridge River, which monitored Bull Trout movement throughout the year. BRGMON-04 radio tracking was restricted to mobile tracking between April and October, which may explain why we did not detect similar general movement patterns.

The consistent movement of Bull Trout from reservoir habitats to river headwaters was also observed by Maret and Schultz (2013; using radio telemetry) in the Arrowrock Reservoir of southern Idaho. In Arrowrock Reservoir, Bull Trout moved from the headwater river into the reservoir in autumn and returned to the river in spring (Maret and Schultz, 2013). Although the Arrowrock Reservoir fish community is very similar to that of Carpenter Reservoir (including Bull Trout, Rainbow Trout, Mountain Whitefish, Kokanee, and Lake Whitefish), full pool and low pool occur at opposite times in the two reservoirs. Despite the different physical characteristics of the two reservoirs, the seasonal timing of Bull Trout movement between reservoir and river habitats was similar (Chamberlain et al 2001 and Maret and Schultz 2013). Similarities in movement timing suggest Bull Trout movement may be driven primarily by food availability and water temperature as opposed to physical habitat area as defined by changing reservoir elevations.

Radio telemetry in Carpenter Reservoir is limited by detection ranges and the amount and timing of radio tracking effort. Radio telemetry receivers are able to reliably detect radio tags at depths of ~10 m or less (Freud and Shepard 2002). All tributary inflow areas in Carpenter Reservoir and a majority of habitats in the Middle Bridge River are <10 m deep, and these areas are ideal Bull Trout habitat due to low water temperatures, high prey densities, and good cover. Bull Trout were frequently detected at tributary confluences, in shallow upper reservoir habitat, and in the Middle Bridge River; however, we cannot determine if Bull Trout were present in other areas due to the limited depth of detection. The BRGMON-04 radio telemetry program was restricted to April through November (i.e., when the reservoir was rising and at full pool), and migrations may have occurred outside of this period.

Due to the limitations of radio telemetry, BRGMON-04 will shift solely to acoustic telemetry in Year 4 as a means of tracking Bull Trout movement in Carpenter Reservoir and the Middle Bridge River. Acoustic telemetry gates were installed in the reservoir and at the confluence of the Middle Bridge River in June of Year 3, which will operate year-round and detect Bull Trout through the gate at any depth. Combined with radio telemetry results from Years 2 and 3, the acoustic gates will provide a more complete picture of Bull Trout movement throughout the reservoir and into and out of the Middle Bridge River.

5.2.2 Bull Trout Biological Characteristics

Preliminary analysis of Bull Trout size characteristics suggest Bull Trout length-weight relationships were statistically different between the three years of BRGMON-04. Mean lengths were statistically different between gear types, and changing sampling effort and gear type may be responsible for the yearly differences detected in the length-weight relationship. Future data will improve the models and larger sample sizes will allow the gear effect to be included as a model coefficient in a multiple regression model.

Fin rays were collected from Bull Trout throughout Years 1 through 3, and a small sample of otoliths (n=10) were collected in Year 2. Fin ray analysis is costly and requires a high degree of experience, and it is not practical to age all Bull Trout fin rays collected during BRGMON-04. Instead, a subsample of Bull Trout fin rays will be randomly selected to adequately represent all size classes of Carpenter Reservoir Bull Trout. The fin ray subsample will be aged for the Year 5 synthesis report and used to create a von Bertalanffy length-at-age model and derive an ALK for Bull Trout.

The closed mark-recapture estimate produced using Year 3 data is the first known estimate of abundance for Carpenter Reservoir Bull Trout. The abundance estimate is limited in both space (i.e., only the mark-recapture study area) and time (i.e., only July full pool conditions). In addition, at the time of this report acoustic telemetry data had not been recovered from the reservoir or Middle Bridge River, therefore we could not verify the assumption that the study area was closed. Due to these limitations, the abundance estimate should be interpreted cautiously; however, preliminary results suggest that the annual Bull Trout mark-recapture study will produce a reasonable annual estimate of Bull Trout abundance in Carpenter Reservoir.

5.3 Distribution and Biological Characteristics: Rainbow Trout, Mountain Whitefish, and Kokanee

5.3.1 Distributions

Although the Bull Trout mark-recapture program was designed to target Bull Trout in the upper reservoir, the variety of gear types used and habitats sampled provided valuable data on all species in the reservoir. Almost all catches for all species were concentrated at tributary confluences, suggesting that no fish were present in mid-lake areas or fish were present in mid-lake areas but were not vulnerable to gill netting (i.e., not moving). Mid-lake habitat in the upper reservoir is generally shallow (<20 m in most areas) and warm during the summer and we would not predict high catches in these areas. In contrast, tributary confluences are characterized by cooler waters and higher productivity, and represent ideal habitat for all species. We expected to encounter high catches of Mountain Whitefish as these fish have been found to concentrate along littoral fringes or at river-reservoir boundaries (Blackman 1992). Kokanee were holding at confluence areas during the late summer sampling in preparation for spawning migrations, and Bull Trout were most likely present to feed opportunistically on Redside Shiners, Mountain Whitefish, and kokanee. Rainbow trout catches were low throughout the mark-recapture period, likely because spawning occurs during the spring and Rainbow Trout were seeking thermal refugia in deeper areas of the lake.

Although we expected to find fish concentrated at tributary confluences during the mark-recapture program, the distributions may not be representative of distributions in other areas of the reservoir (particular the downstream portion) or during other time periods. The downstream portion of Carpenter Reservoir is deeper and is characterized by steeper banks (i.e., less littoral area). Although we did not sample downstream pelagic areas, we expect that fish were utilizing this deeper habitat during the mark-recapture period to avoid unsuitably high littoral temperatures. In addition, distributions from the mark-recapture period are not representative of low pool conditions (i.e., late May/early June) when temperatures are cooler and habitat areas are substantially reduced.

Gill netting during both full and low pool conditions in a variety of depths/habitat areas will be attempted in Year 4 to monitor fish distributions and relative CPUEs throughout the reservoir. Gill netting was previously performed in 1995 and 1996 by Griffith (1999) in the downstream portion of Carpenter Reservoir (close to the intake of BRG-1 and BRG-2). Overall CPUE was highest in October and lowest in July (netting also occurred in April and September). Bull Trout and Mountain Whitefish were the most frequently caught species, particularly in September during full pool conditions. Rainbow Trout CPUE was highest in September and April, and kokanee CPUE was highest in April. Limnological investigations by Griffith (1999) found low zooplankton and phytoplankton abundance in Carpenter Reservoir, possibly due to a short water retention time and the displacement of zooplankton through the water diversion tunnels. Food availability was hypothesized to limit fish production in the reservoir and food availability combined with water temperatures were thought to be the main factors driving distributions. Although the results from Griffith (1999) provide some insight into distributions and species composition in the reservoir, gill netting was restricted to one year and one habitat type. The proposed gill netting by BRGMON-04 will be repeated annually (depending on Year 4 success) in three different habitat types, resulting in a more systematic investigation into fish distributions in the reservoir.

5.3.2 Biological Characteristics

Biological data have been collected from all species in Years 1 through 3 of the BRGMON-04 monitoring program; however, length, weight, and age data are still somewhat limited over the full range of size/age classes. Biased parameter estimates in von Bertalanffy growth equations and clear overlaps in the age-separated histograms for Mountain Whitefish and Rainbow Trout (Figure 4-9 and Figure 4-13) demonstrate the need for a more diverse and comprehensive sample of ageing structures for all species in the reservoir. We will continue to collect age, length, and weight data for all fish captured in Carpenter Reservoir, which will build the database of biological data for Carpenter Reservoir fish.

The analysis of biological characteristics of fish in Carpenter reservoir suggested Rainbow Trout length-weight relationships were statistically different between the three years of BRGMON-04 (no statistical difference was found for kokanee or Mountain Whitefish). There was no statistical difference between mean lengths of Rainbow Trout caught electrofishing and angling. Although this could lead to the conclusion that biological characteristics are driving changes in the yearly length-weight ratio, the significance was small (p-value 0.05) and only two gear types were considered in the analysis. Further years of data collection will help to separate the effect on fish size of gear and sampling effort from biological characteristics of the reservoir.

5.4 Carpenter Reservoir Visual Surveys

Visual surveys have been somewhat unsuccessful in Carpenter Reservoir tributaries, particularly for Rainbow Trout and Bull Trout. Only one Bull Trout was observed over two years of visual surveys, and Rainbow Trout counts are too low to draw conclusions regarding spawning behaviour. Low spawner counts were also encountered by Griffith (1999) during visual surveys and open-site electroshocking throughout Carpenter Reservoir tributaries (electroshocking surveys were also characterized by low juvenile catches). Visual surveys are challenging in the Carpenter Reservoir watershed due to high flows and high turbidities during spawning periods. Observer efficiency has not been calculated for the watershed and efficiency may be low (i.e., spawners may be present that are not observed by surveyors); however, potentially low observer efficiency does not fully explain the low counts of Rainbow Trout and Bull Trout spawners in tributaries surveyed in this monitor and by Griffith (1999).

Low spawner counts of Bull Trout and Rainbow Trout in Carpenter Reservoir tributaries may be a result of low quantity and quality of spawning habitat in many of the tributaries in the watershed. Habitat surveys were completed within the drawdown zone and along the length of visual survey areas during Year 3 of BRGMON-04, and extensive habitat surveys throughout the watershed and tributary sub-watersheds were previously performed by Griffith (1999). Griffith (1999) found overall spawning habitat and rearing conditions in the watershed to be poor due to limited accessible stream lengths (from steep gradients and barriers) and limited spawning substrate. Habitat surveyed within the drawdown zone (as surveyed by BRGMON-04) was also found to be poor due to lack of cover, large amounts of fine sediments, and low quality spawning substrate. Poor quality and quantity of spawning habitat may explain the low spawner counts of Rainbow Trout and Bull Trout during visual surveys.

Catch data indicate that Carpenter Reservoir supports a healthy population of Bull Trout (and to a lesser extent Rainbow Trout); however, low spawner counts and poor quality spawning habitat suggest spawning occurs in areas of the watershed additional to those surveyed by this monitor and historically (Chamberlain et al 2001, Griffith 1999). For Bull Trout, spawning is likely occurring in the Middle Bridge and Hurley Rivers. Radio telemetry has detected substantial numbers of Bull Trout congregating in the upper portion of the reservoir, and individuals have been tracked as far as the confluence of the Middle Bridge and Hurley rivers during the fall (i.e., within the theoretical spawning period). The acoustic telemetry gate located in the Middle Bridge River will be used to verify this hypothesis by determining what portion of the tagged Bull Trout sample enters the Middle Bridge River prior to spawning, and at what time these fish return to the reservoir. For Rainbow Trout, there may be seeding (i.e., fall-down) of juveniles into Carpenter Reservoir from upstream watersheds. There are a number of Rainbow Trout monoculture lakes that drain into Carpenter Reservoir (MacDonald Lake, Marshall Lake, Gun Lake, and Tyaughton Lake), and juvenile Rainbow Trout may migrate from these systems into the reservoir. This hypothesis has been suggested by previous researchers based on poor quality spawning habitat in Carpenter Reservoir tributaries and the prevalence of Rainbow Trout monoculture lakes upstream of the reservoir (Chamberlain et al 2001, Griffith 1999). This possibility of Rainbow Trout fall-down from upstream lakes will be explored in Year 4 using a pilot growth sampling program to assess Rainbow Trout life stages present in Carpenter Reservoir tributaries with and without upstream Rainbow Trout sources (see BRGMON-04 proposal for detailed methods).

Tributary surveys were successful for kokanee, and spawner counts throughout Carpenter Reservoir tributaries were obtained in Years 2 and 3. Chamberlain et al (2001) and Griffith (1999) found almost no evidence of kokanee spawning in the watershed. Griffith (1999) captured small numbers of kokanee during gill netting in pelagic areas of the reservoir, only one juvenile kokanee was recorded in tributaries during closed-site electroshocking, and no adult spawners were observed. Substantial changes in kokanee population size might be an indication that kokanee undergo cycles of high and low abundance in Carpenter Reservoir, possibly as a result of reservoir operations.

Reservoir operations can negatively affect kokanee through flooding of spawning areas by rising reservoir elevations, or via extreme drawdown events that affect pelagic habitat quality and quantity. Habitat surveys in Year 3 found unsuitable kokanee spawning habitat within the drawdown zone of Carpenter Reservoir, and relatively few kokanee were observed within this area during visual surveys. Kokanee do not appear to be relying on drawdown areas for spawning, and thus operations are not likely to be negatively affecting spawning success. Extreme drawdown events are more likely to impact kokanee abundance due to increased predation, low food availability, and possible entrainment through BRG-1 and BRG-2. The extreme drawdowns in the early 1990s could have resulted in a population decline that was observed by Griffith (1999) during visual surveys and pelagic gill netting. Although reservoir operations may be negatively affecting kokanee production, it is important to note that kokanee are not native to the Carpenter Reservoir watershed. Approximately 1.1 million kokanee were introduced into the reservoir between 1970 and 1973 by the province of British Columbia (Chamberlain et al 2001).

6 Conclusions

The 3rd year of the Carpenter Reservoir and Middle Bridge River Fish Habitat and Population Monitoring program was completed in 2014/2015. A preliminary closed mark-recapture population estimate was obtained for Bull Trout in the upper portion of Carpenter Reservoir. Biological data were collected for all species, which built on data collected in previous years and allowed for size structure analysis and length-at-age modelling for some species. Although the sample size is still small for some species and age classes in the reservoir, future years of monitoring will reduce data gaps and result in a more complete analysis of size and age of Carpenter Reservoir fish. An acoustic telemetry program was initiated in the reservoir, and data will be downloaded from receivers in April 2016. The acoustic telemetry array will provide valuable movement data for Bull Trout and aid in verifying the assumptions of the open mark-recapture model. Catch rates and Year 3 results suggest that the open mark-recapture program will successfully produce an estimate of adult Bull Trout abundance in the upper portion of Carpenter Reservoir during full pool conditions.

Given the monitor objectives and the results from Years 1 through 3, we recommend the following monitoring for Year 4:

1. Perform pilot gill netting at both full pool and low pool elevations to enhance understanding of relative distributions and biological characteristics of fish species in Carpenter Reservoir.
2. Continue the Bull Trout mark-recapture program in Carpenter Reservoir, shifting the sampling into late June or early July to coincide with lower water temperatures.
3. Download and maintain acoustic telemetry gates in the reservoir and at the boundary of the reservoir and the Middle Bridge River to verify mark-recapture assumptions and characterize Bull Trout movement.
4. Continue tributary spawner assessments of kokanee in September and October.
5. Repeat Mountain Whitefish angling and egg screen deployment in the Middle Bridge River following the methods of TEC (Tisdale 2010), adding egg screens to high elevation areas at greater risk of dewatering.
6. Perform monthly electroshocking surveys of juvenile fish in a subsample of Carpenter Reservoir tributaries to assess juvenile abundance and the hypothesis of Rainbow Trout seeding from upstream lakes.

7 References

Anderson, R.O., R.M. Neumann. 1996. Length, weight, and associated structural indices. Pages 447-482 in B.R. Murphy and D.W. Willis, editors. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

BC Hydro. 2015. Bridge Seton Water Use Plan Monitoring Program No. BRGMON-04 Carpenter Reservoir and Middle Bridge River Fish Habitat and Population Monitoring. Bridge-Seton Water Use Plan Monitoring Program Terms of Reference Addendum 1. 10p.

BC Hydro. 2014. Bridge River Recreation Areas. Accessed online December 6, 2014: www.bcydro.com/community/recreation_areas/bridge_river.html.

BC Hydro. 2012. Bridge Seton Water Use Plan Monitoring Program No. BRGMON-04 Carpenter Reservoir and Middle Bridge River Fish Habitat and Population Monitoring. Bridge-Seton Water Use Plan Monitoring Program Terms of Reference. 10 p.

BC Hydro. 2011. Bridge River Power Development Water Use Plan. 79 p.

Blackman, B.G. 1992. Fisheries Resources of Williston Reservoir Twenty Years After Impoundment. B.C. Environment Fisheries Branch and B.C. Hydro Environmental Resources. 72 pp.

Chamberlain, M.W., O'Brien, D.S., Caverly, A., & Morris, A.R. 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.

Erhardt, J.M. and D.L. Scarnecchia. 2013. Precision and accuracy of age and growth estimates based on fin rays, scales, and mark-recapture information for migratory Bull Trout. *Northwest Science*. 87(4): 307-316

Franklin, A.B. 2002. Exploring ecological relationships in survival and estimating rates of population change using program MARK. Pages 350-356 in R. Fields, R.J. Warren, and H. Okarma, editors. *Integrating people and wildlife for a sustainable future: Proceedings of the Second International Wildlife Management Congress*. Godollo, Hungary.

Freud, J.G. & Shepard, B.B. 2002. Influence of depth on detection distance of low-frequency radio transmitters in the Ohio River: North American Journal of Fisheries Management, v. 22, p. 1301-1305.

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.

Guy, C.S. & M.L. Brown. 2007. Analysis and Interpretation of Freshwater Fisheries Data. Bethesda, Maryland, USA, American Fisheries Society.

Isermann D.A., and C.T. Knight. 2005. A computer program for age-length keys incorporating age assignment to individual fish. *North American Journal of Fisheries Management*. 25: 1153-1160.

Johnston, N.T. and Slaney P.A. 1996. Fish Habitat Assessment Procedures: Watershed Restoration Technical Circular No. 8. British Columbia Watershed Restoration Program: Ministry of Environment, Lands and Parks. 102 p.

Lebreton, J-D, Burnham, K.P., Clobert, J & D.R. Anderson. 1992. Modeling survival and testing biological hypotheses using marked animals: A unified approach with case studies.

Maret, T.R. & J.E. Schultz. Bull Trout (*Salveninus confluentus*) Movement in Relation to Water Temperature, Season, and Habitat Features in Arrowrock Reservoir, Idaho, 2012. Scientific Investigations Report 2013-5158 U.S. Department of the Interior and U.S. Geological Survey. 36 pp.

Ogle, D.H. 2016. Introductory Fisheries Analyses with R. Chapman & Hall/CRC The R Series. CRC Press. Kindle Edition; 99 pp.

Ombredane, D., Bagliniere, J., & Marchland, F. 1998. The effects of Passive Integrated Transponder tags on survival and growth of juvenile brown trout (*Salmo trutta* L.) and their use for studying movement in a small river. *Hydrobiologia*, 371, p 99-106.

Pollock, K.H., Nichols, J.D., Brownie, C. & Hines, J.E. 1990. Statistical inference for capture-recapture experiments. *Wildlife Monographs*, 107, p 1-97.

R Development Core Team. 2015. R: A language and environment for statistical computing. Vienna, Austria. http://www.R-project.org.

Sebastian, D. and T. Weir. 2014. CLBMON-2. Kinbasket and Revelstoke Reservoirs Kokanee Population Monitoring. Columbia River Project Water Use Plan. Submitted to BC Hydro November 2014.

Sebastian, D.C., Scholten, G.H. and P.E. Woodruff. 2003. Williston Reservoir fish assessment: Results of hydroacoustic, trawl and gill net surveys in August 2000. Peace/Williston Fish and Wildlife Compensation Program Report No. 274. 34pp plus appendices.

Seber, G.A.F. 1982. Estimation of animal abundance and related parameters. Charles Griffin, London. 654 p.

St'at'imc Eco-Resources Ltd. 2014. A Proposal: Carpenter Reservoir Productivity Model Validation and Refinement. Bridge-Seton Water Use Plan Study Number BRGMON-10. Submitted to BC Hydro Water License Requirements. Burnaby, BC. 62 p.

Tisdale, G.A.E. 2010. 2009 Middle Bridge River Rocky Mountain Whitefish (Prosopium williamsoni) Exploratory Spawning Assessment October 4, 2009 – December 21, 2009. Prepared for B.C. Hydro and Power Authority, Shalalth B.C. 40 p.

von Bertalanffy, L. 1938. A quantitate theory of organic growth. *Human Biology* 10:181-213.

Wagner, G.N., Cooke, S.J., Brown, R.S. and K.A. Deters. 2011. Surgical implantation techniques for electronic tags in fish. *Rev Fish Biol Fisheries*. 21:71-81.

Zwart, I., Andrusak, G. and H. McGregor. 2013. DDMMON-10 Duncan Reservoir Fish Habitat Use Monitoring. Duncan Dam Project Water Use Plan. Submitted to BC Hydro February 27, 2013.

Zymonas, N.D. and T.E. McMahon. 2009. Comparison of pelvic fin rays, scales and otoliths for estimating age and growth of bull trout, Salvelinus confluentus. *Fisheries Management and Ecology*. 16: 155-164.