Campbell River Project Water Use Plan

Upper Campbell, Lower Campbell, John Hart Reservoirs and Diversion Lakes Littoral versus Pelgaic Fish Production Assessment

Implementation Year 1

Reference: JHTMON-5

JHTMON-5: Stable Isotope Assessment

Study Period: 2014

Laich-Kwil-Tach Environmental Assessment Ltd. Partnership
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JHTMON-5: Stable Isotope Assessment

Year 1 Annual Monitoring Report

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EXECUTIVE SUMMARY

Water Use Plans (WUPs) were developed for all of BC Hydro's hydroelectric facilities through a consultative process and there is expected to be monitoring to address outstanding management questions in the years following the implementation of a WUP. As the Campbell River Water Use Plan process reached completion, a number of uncertainties remained with respect to the effects of BC Hydro operations on aquatic resources. The *Upper Campbell, Lower Campbell, John Hart Reservoirs and Diversion Lakes Littoral versus Pelagic Fish Production Assessment* (JTHMON-5) is part of wider monitoring of the Campbell River WUP. JTHMON-5 is designed to assess the extent to which fish production is driven by littoral vs. pelagic production and how this relates to BC Hydro operations.

The Campbell River WUP project area is complex and includes facilities and operations in the Campbell, Quinsam and Salmon watersheds. In addition to the mainstem rivers, there are three large reservoirs, nine diversion lakes influenced by water diverted from the Quinsam and Salmon rivers, and many tributaries and small lakes that are not directly affected by operations. During development of the Campbell River WUP, the Fish Technical Committee (FTC) hypothesized that fish production in Upper and Lower Campbell reservoirs was negatively impacted by large fluctuations in water level through its effect on littoral production. The FTC also hypothesized that short water residence time of the diversion lakes as a result of the BC Hydro diversion operations could negatively impact pelagic productivity.

The JTHMON-5 monitoring program aims to address the following two management questions:

1. To what extent do stabilized reservoir levels, as affected by BC hydro operations, benefit fish populations?
2. What is the relationship between residence time (as affected by diversion rate) and lake productivity?

The JHTMON-5 study is scheduled for 10 years with the first year as a pilot year to develop and confirm the stable isotope methodology. Substantial information regarding the structure and functioning of lake food webs can be gained by using stable isotopes to reconstruct the diets of lake biota. JHTMON-5 uses stable isotope analysis of nitrogen and carbon in fish tissues and their potential diet items to assess relative energy flows to fish from littoral vs. pelagic areas. Sampling was completed for Upper Campbell Reservoir, Gooseneck Lake, and Middle Quinsam Lake. Upper Campbell Reservoir was chosen because it experiences the greatest fluctuations in water levels. Gooseneck Lake and Middle Quinsam Lake were chosen because they are part of the Quinsam River diversion with Middle Quinsam experiencing greater water residence time (donor lake) and Gooseneck experiencing reduced water residence time (recipient lake).

The primary species of interest in JHTMON-5 are Cutthroat Trout (*Oncorhynchus clarkii*) and Rainbow Trout (*O. mykiss*). Sampling was geared toward understanding the diets and energy sources of these two fish species, which are the resident fish species of primary management concern in reservoirs and lakes of the Campbell River system. Gill netting and minnow trapping was completed

in August 2014 to obtain representative tissue samples from Cutthroat Trout, Rainbow Trout and their prey fish including Threespine Stickleback (*Gasterosteus aculeatus*), Sculpin spp. (*Cottus* spp.), and juvenile trout (*Oncorhynchus* spp.) from Upper Campbell, Gooseneck and Middle Quinsam lakes. Primary diet items for Cutthroat Trout and Rainbow Trout also include zooplankton (pelagic source), and benthic, stream and terrestrial invertebrates (littoral source). Invertebrate sampling occurred in June, July and August to obtain representative samples from the three lakes. Invertebrates were sorted in the lab and identified to Order, Family or Genus.

Invertebrate and fish samples were processed for nitrogen and carbon stable isotopes at the Stable Isotope in Nature Laboratory located within the Canadian Rivers Institute at the University of New Brunswick in Fredericton, New Brunswick. A total of 171 samples of invertebrates and fish were sent for analysis. The relative contributions of pelagic vs. littoral sources to Cutthroat Trout and Rainbow Trout diets were assessed through dual isotope ($\delta^{13}C$ and $\delta^{15}N$), four to seven-source Bayesian isotopic mixing models implemented in the program SIAR (Stable Isotope Analysis in R). SIAR takes isotope data from consumers (fish) and sources (diet items) along with estimates of diet - tissue isotopic fractionation, and fits Bayesian models that estimate source contributions to diet.

Catch-per-unit-effort (CPUE), fork length and age data were obtained from fish sampling on each lake. Average CPUE for Cutthroat Trout was 0.30 fish/net hour, 0.42 fish/net hour, and 2.42 fish/net hour for Upper Campbell Reservoir, Gooseneck Lake, and Middle Quinsam Lake, respectively. CPUE for Rainbow Trout on the Upper Campbell Reservoir was 0.81 fish/net hour. In Upper Campbell Reservoir, the fork length of Cutthroat Trout ranged from 127 mm to 459 mm, while Rainbow Trout ranged from 92 mm to 302 mm. The fork length of Cutthroat Trout captured in Gooseneck and Middle Quinsam lakes ranged from 132 mm to 286 mm and 132 mm to 329 mm, respectively. In Upper Campbell Reservoir, our subsample of Cutthroat Trout ranged in age from one to seven years, and Rainbow Trout ranged in age from one to six years. Cutthroat Trout sampled from Gooseneck Lake were four to five years, while Cutthroat Trout from Middle Quinsam Lake ranged in age from two to six years

Nitrogen and carbon stable isotope signatures of all fish and invertebrates were similar among all three lakes. Large Cutthroat and Rainbow trout had the highest $\delta^{15}N$ levels consistent with their top position within lake food webs, followed by smaller prey fish with intermediate trophic level positions. Zooplankton had the lowest $\delta^{13}C$ levels consistent with their pelagic habitat, while benthic, stream, and terrestrial invertebrates had higher $\delta^{13}C$ isotopic signatures, consistent with their terrestrial and benthic sources of carbon in diet. Among the small prey fish, Threespine Stickleback had the lowest $\delta^{13}C$ levels indicative of a pelagic dominated diet.

Nitrogen and carbon stable isotope signatures in bulk zooplankton varied by month of collection. Across all lakes, $\delta^{15}N$ signatures in zooplankton were significantly higher in August compared to June or July while $\delta^{13}C$ signatures were significantly higher in both July and August compared to June.

In Upper Campbell Reservoir, the total littoral contribution to Cutthroat Trout and Rainbow Trout diets was higher than from pelagic sources despite the large size of the reservoir and lake levels that are highly variable. Consistent with their role as a top predator, Cutthroat Trout (age >2+) diets in Upper Campbell Reservoir were dominated by prey fish species, in particular Sculpin, followed by juvenile trout and Threespine Stickleback (40%, 19%, and 18% diet contributions respectively). Zooplankton and benthic, stream and terrestrial invertebrates each made up less than 7% to Cutthroat Trout diet. In contrast, Rainbow Trout diets had a much higher prevalence of zooplankton (28%) and Threespine Stickleback (24%) and less Sculpin and juvenile trout (≤11%) in their diets. A total of 24% of the diet of Cutthroat Trout in Upper Campbell Reservoir is estimated to be derived from pelagic sources while 76% is estimated to be derived from littoral sources. In contrast, Rainbow Trout have an estimated pelagic contribution to diet of 45% and a littoral contribution to diet of 55%. The similarity in food webs between the three lakes and the dependence on littoral resources hint that Cutthroat Trout in Upper Campbell Reservoir may have a relatively fixed dependence on littoral production with limited ability to switch to a pelagic-dominated diet. Rainbow Trout appear to utilize more pelagic resources than Cutthroat Trout in Upper Campbell Reservoir. No Rainbow Trout were caught in the much smaller Gooseneck and Middle Quinsam lakes.

In Gooseneck and Middle Quinsam lakes, juvenile trout were the dominant source to Cutthroat Trout diet (35% and 34% respectively). Zooplankton contributed little to Cutthroat Trout diet in Middle Quinsam Lake (7%), but make up 21% of Cutthroat Trout diet in Gooseneck Lake. Littoral invertebrates from each group (benthic, stream, terrestrial) contributed from 3% to 16% of Cutthroat Trout diet across both lakes. In Gooseneck Lake, a total of 27% of the diet of Cutthroat Trout is estimated to be derived from pelagic sources while 73% is estimated derived from littoral sources. In Middle Quinsam Lake, at total of 18% of Cutthroat Trout diet is estimated to be derived from pelagic sources and 82% from littoral sources. The original prediction was that water residence time will be shorter in Gooseneck Lake (receiving lake) than Middle Quinsam Lake (donor lake), which could result in decreased zooplankton production. Our observations are opposite to the predictions made by the FTC; a greater pelagic source of production (ultimately from plankton) in Gooseneck Lake was observed in Cutthroat Trout diets compared to Middle Quinsam Lake. It is important to note that this contrast is only from two lakes.

Recommendations for the use of the stable isotope method and future years of the program include the following:

1. Stable isotope analysis of nitrogen and carbon has been used successfully in this pilot year to understand the diets of species or functional groups in lake food webs, and ultimately to provide estimates of total littoral and pelagic contributions to diets of adult Cutthroat Trout and Rainbow Trout. The stable isotope approach is recommended for future years of the program to address management questions posed in the TOR.

2. The Bayesian mixing model used to estimate diet contributions to fish in Upper Campbell Reservoir, Gooseneck Lake and Middle Quinsam Lake is scientifically sound. This approach is the current standard in scientific assessments to estimate target species' diets from multiple diet sources (e.g., Semmens *et al.* 2009). The Bayesian mixing model approach is also recommended for future years of the program.

3. The Bayesian mixing model may be sensitive to the diet-tissue fractionation estimate applied in the model for both isotopes. In this study, the diet-tissue fractionation values used in the models were 1.50 ± 1.16 for $\delta^{13}C$ and 2.79 ± 1.46 for $\delta^{15}N$. These values come from the literature and are average diet-tissue fractionation rates across several fish species and tissue types (Sweeting *et al.* 2007a, b). However, fractionation from fish diet to sampled tissue can vary depending on the fish species, tissue sampled (e.g., fin, muscle, whole fish) and the type of diet (invertebrate or fish prey). In future years, analyses should include more specific diet-tissue fractionation rates for each species and tissue type and sensitivity analyses of fractionation rates. For example, fin-specific or trout-specific diet-tissue fractionation rates could be used after a thorough literature review.

4. Zooplankton $\delta^{15}N$ and $\delta^{13}C$ both increased through the summer. We recommend that future sampling continue to occur across three time periods during the spring and summer so that the isotopic variation in zooplankton is adequately represented.

5. Upper Campbell Reservoir was sampled in the pilot year of JHTMON-5. In future years we recommend obtaining estimates of fish diets and sources of production in Lower Campbell Reservoir and John Hart Reservoir. This will allow for a more direct test of management question 1 because the three reservoirs have contrasting water level fluctuations associated with BC Hydro operations. Lower Campbell and John Hart reservoirs could be sampled in the same year or in different years (Year 2, Year 3).

6. The lake levels of the three reservoirs are monitored continuously by BC Hydro. We recommend that a metric for the depth of reservoir drawdown be developed to compare across the three reservoirs. BC Hydro also monitors the lake levels of Brewster Lake as part of JHTMON-10. We therefore recommend that Brewster Lake also be included in the set of diversion lakes to be sampled and that a metric for lake drawdown be developed for Brewster Lake to compare to the results generated in the reservoirs. This would increase the sample size for addressing hypotheses associated with management question 1; however, we note that the final sample size is still expected to be small (n=4).

7. Gooseneck and Middle Quinsam lakes were chosen because they have contrasting water diversion operations. Gooseneck Lake receives water from the Quinsam Diversion and is hypothesized to have lower lake water residence time and lower pelagic contribution to fish production than Middle Quinsam (the donor lake). This prediction is opposite to what was observed. Across the full program we recommend that as many diversion and control lakes be sampled as possible within the available budget, and that for each lake an estimate of

water residence time be developed based on lake volume and hydrology. For example, it is possible that Middle Quinsam Lake has a lower water residence time than Gooseneck Lake based on its unique morphology and hydrology. A modest number of lakes could be sampled over several years rather than in a single year. This would enable simple regression models relating water residence time in each lake to % littoral or % pelagic contributions to fish diets (Figure 31). Operations from water diversions could then be integrated into predictive models of how water inputs or extractions can change lake water residence time, lake productivity and food webs. This approach is consistent with the TOR, but represents a quantitative approach to answering the management questions rather than the qualitative approach described in the TOR.

8. Initial findings using stable isotopes show similar lake food webs across Upper Campbell Reservoir, Gooseneck Lake and Middle Quinsam Lake. These initial results hint that Upper Campbell Reservoir Cutthroat Trout may not be changing their diets to a pelagic-dominated source of production and, instead, maintain their dependence on littoral production. In contrast, Rainbow Trout have greater pelagic contribution to diet than Cutthroat Trout in Upper Campbell Reservoir. However, it is important to confirm these results from at least two more full years of data collection from all three reservoirs and three to four diversion lakes per year (including controls). The Terms of Reference for JHTMON-5 proposed that after the pilot year 1 full sampling take place in years 2, 5 and 10 of the program (BC Hydro 2013). We recommend that two full years of sampling occur in years 2 and 3 of the program in order to maintain continuity of staff and methods, rather than in years 2 and 5 as envisioned by the TOR. A third full year of sampling may not be necessary and should be evaluated at the end of Year 3.

9. Zooplankton sampling was conducted in triplicate in each sampling period on each lake. We recommend that all zooplankton samples be counted and weighed so an estimate of zooplankton production could be made for each lake. For example, the mass of zooplankton obtained could be divided by the volume of water pulled through the zooplankton net to derive an estimate of zooplankton biomass per m^3. This is important because zooplankton production could then be compared directly to estimates of lake water residence time.

10. It is possible that Cutthroat Trout and Rainbow Trout diet could shift among pelagic vs. littoral sources of production as they grow and age. For example, a negative relationship was observed between Rainbow Trout fork length and $\delta^{13}C$ in Upper Campbell Reservoir. In future years, if these relationships between $\delta^{13}C$ and size or age are observed then we recommend that analyses of Cutthroat Trout or Rainbow Trout diets be split by age or size classes. This could provide more specific information on the size and age classes of fish most affected by operational changes.

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1. INTRODUCTION

1.1. Background to Water Use Planning

Water use planning exemplifies sustainable work in practice at BC Hydro. The goal is to provide a balance between the competing uses of water that include fish and wildlife, recreation and power generation. Water Use Plans (WUPs) were developed for all of BC Hydro's hydroelectric facilities through a consultative process involving local stakeholders, government agencies and First Nations. The framework for water use planning requires that a WUP be reviewed on a periodic basis and there is expected to be monitoring to address outstanding management questions in the years following the implementation of a WUP.

As the Campbell River Water Use Plan (BC Hydro 2012) process reached completion, a number of uncertainties remained with respect to the effects of BC Hydro operations on aquatic resources. A key question throughout the WUP process was "what limits fish abundance?" For example, are fish abundance and biomass in lakes limited by pelagic or littoral sources of production? Answering this question is an important step to better understanding how human activities in a watershed affect fisheries, and to effectively manage water uses to protect and enhance aquatic resources. To address this uncertainty, monitoring programs were designed to assess whether fish benefits are being realized under the WUP operating regime and to evaluate whether limits to fish production could be improved by modifying operations in the future.

In lakes and reservoirs, fish production is assumed to be proportional to overall aquatic productivity, but there is considerable uncertainty over the extent to which fish production is driven by littoral vs. pelagic production and whether this is influenced by operations. BC Hydro affects lake littoral production through drawdowns, and pelagic production through alterations of water residence time (e.g., by manipulation of inflows and outflows). The *Upper Campbell, Lower Campbell, John Hart Reservoirs and Diversion Lakes Littoral versus Pelagic Fish Production Assessment* (JTHMON-5) is part of wider monitoring of the Campbell River WUP. JTHMON-5 is designed to assess the extent to which fish production is driven by littoral vs. pelagic production and how this relates to BC Hydro operations.

1.2. BC Hydro Infrastructure, Operations and the Monitoring Context

The Campbell River WUP project area is complex and includes facilities and operations in the Campbell, Quinsam and Salmon watersheds. In addition to the mainstem rivers, there are three large reservoirs, nine diversion lakes influenced by water diverted from the Quinsam and Salmon rivers, and many tributaries and small lakes that are not directly affected by operations (Map 1). Details of BC Hydro's Campbell River infrastructure and operations are provided in the Campbell River System WUP (BC Hydro 2012).

1.2.1. Reservoirs

Strathcona, Ladore and John Hart dams regulate reservoir water levels for Buttle/Upper Campbell, Lower Campbell, and John Hart reservoirs respectively. Buttle/Upper Campbell Reservoir varies the most in water levels, whereas John Hart Reservoir water levels vary the least. During development of the Campbell River WUP, the Fish Technical Committee (FTC) hypothesized that fish production in Upper and Lower Campbell reservoirs was negatively impacted by large fluctuations in water level through its effect on littoral production. Stable reservoir levels were assumed to have a positive influence on fish production. Evaluation of reservoir operations relied heavily on the Effective Littoral Zone (ELZ) Performance Measure (PM) with the assumption that increasing littoral development would lead to increases in fish productivity. This assumes a strong link between littoral and fish production. JHTMON-4 is designed to investigate the effect of operations on littoral primary production, and JHTMON-5 is designed to test the assumption that improvements in littoral production lead to corresponding increases in fish production. This information will then be used to directly evaluate the impact of the Campbell River WUP on reservoir fish production, help refine reservoir-related PMs and assess their relative importance for future WUP review processes. The understanding gained through the present monitoring program may also help guide the development of alternative management strategies for reservoir operations.

1.2.2. Diversion Lakes

The Quinsam and Salmon diversions divert water through several smaller lakes and into Lower Campbell Reservoir (Map 1). Among the diversion-affected lakes, there are lakes that receive water diverted from adjacent watersheds and thus have lower water residence time (e.g., Gooseneck, Fry and Gray lakes) and lakes that have water diverted away from them and thus have increased water residence time (e.g., Middle Quinsam, Lower Quinsam). During the WUP process, the FTC hypothesized that short water residence time as a result of the BC Hydro diversion operations could negatively impact pelagic productivity. Simple chemostat modelling exercises showed that high inflows flush pelagic organisms from the system. The loss in pelagic productivity from high inflows was thought to have a potential impact on fish production in these lakes. However, the hypothesis could not be tested during the WUP due to time and resource constraints. The FTC therefore assumed for decision-making purposes that there was limited impact, but strongly recommended that the test of this hypothesis be part of a monitoring program. Information collected in JHTMON-5 will be used to evaluate the effect of Campbell River WUP operations on diversion lake productivity, and help refine PMs for future WUP reviews.

1.3. Management Questions and Hypotheses

The JTHMON-5 monitoring program aims to address the following two management questions:

1) To what extent do stabilized reservoir levels, as affected by BC hydro operations, benefit fish populations?

2) What is the relationship between residence time (as affected by diversion rate) and lake productivity?

In addressing the questions, the monitoring program is designed to test the following three null hypotheses:

$H_0$1: The extent of littoral development in lakes, as governed by the magnitude and frequency of water level fluctuations, is not correlated with the ratio of littoral vs. pelagic energy flows to reservoir fish populations.

$H_0$2: The extent of pelagic production in lakes, as governed by the average water residence time, is not correlated with the ratio of littoral vs. pelagic energy flows to diversion lake fish populations.

$H_0$3: Standing crop of pelagic bacteria is not correlated with water residence time.

1.4. Scope of the JHTMON 5 Study

1.4.1. Overview

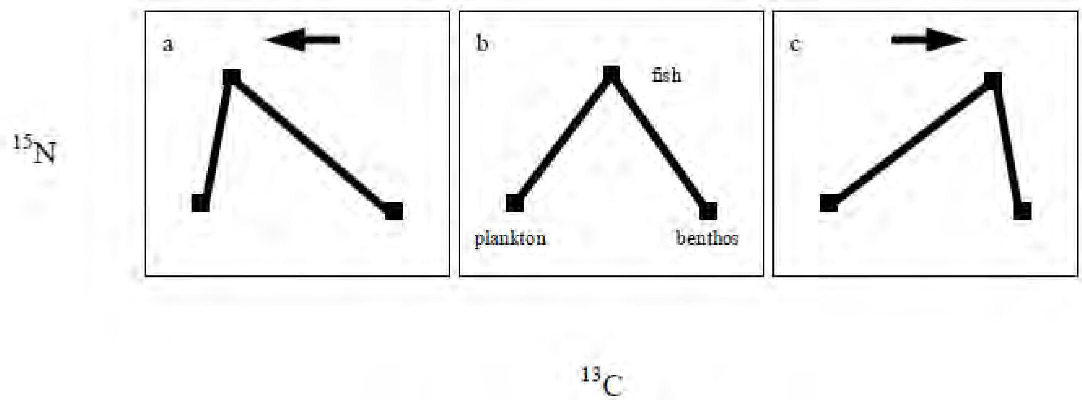
JHTMON-5 is scheduled for 10 years and has two components: stable isotope analysis of food webs in reservoirs and diversion lakes (used to address $H_0$1 and $H_0$2 above), and production estimates of pelagic bacteria in reservoirs and diversion lakes (used to address $H_0$3 above). Data from these two study components will be analyzed separately and together to assess linkages between benthic and pelagic production and the effect of BC Hydro operations on fish production in reservoirs and diversion lakes. This report presents data from Year 1, which is a pilot year to develop the stable isotope methods used to test $H_0$1 and $H_0$2 above. Under the current TOR, full sampling using stable isotope methods is scheduled for years 2, 5 and 10 of JHTMON-5 (BC Hydro 2013). Estimates of pelagic bacteria as an indicator of pelagic productivity will be addressed in years 7, 8, and 9 and thus will be discussed future years of the program.

1.4.2. Summary of the Main Method to Test Management Questions

Substantial information regarding the structure and functioning of lake food webs can be gained by using stable isotopes to reconstruct the diets of lake biota (Vander Zanden and Vadeboncoeur 2002, McIntyre *et al.* 2006). JHTMON-5 uses stable isotope analysis (SIA) of nitrogen and carbon of fish tissues and their potential diet items to assess relative energy flows to fish from littoral vs. pelagic areas. Nitrogen isotope ratios ($\delta^{15}N$) are commonly used to assess the trophic position of species in a food web (DeNiro and Epstein 1981, Peterson and Fry 1987), whereas carbon isotope ratios ($\delta^{13}C$) are commonly used to indicate the sources of primary production (DeNiro and Epstein 1978, Peterson and Fry 1987). The main premise is that the isotopic ratios in the tissues of consumers represent the isotopic ratios of their diet. In other words, you are what you eat. In lakes, fish that are high in the lake food web tend to have the highest $\delta^{15}N$ signatures. Further, carbon isotopes can be used to determine the relative contributions of littoral vs. pelagic sources of production because $\delta^{13}C$ signatures tend to be higher in littoral and benthic areas than pelagic areas.

Figure 1 represents a conceptual framework where energy flow through the aquatic food web (i.e., trophic level) is described by ^{15}N and energy source is described by ^{13}C. Figure 1b represents a natural system where fish receive quantities of energy from benthos and plankton at some natural system-specific ratio. When littoral production is negatively affected (relative to pelagic production), the peak of the triangle is shifted to the left, as fish obtain relatively more energy from plankton than benthos (Figure 1a). When pelagic production decreases (relative to littoral production) the peak is shifted to the right (Figure 1c) as energy production becomes increasingly dominated by benthos. The magnitude of the peak shifts will define the effect of the treatment impact.

Figure 1. Conceptual framework for the interpretation of stable isotope analysis (SIA) data where b) is the pre-treatment state, a) is dominance of a pelagic-derived energy in fish diet, and c) is dominance of benthos-derived energy in fish diet.



Using both $\delta^{15}N$ and $\delta^{13}C$ together allows for the development of stable isotope mixing models which can estimate the contributions of different prey sources to a consumers diet (Semmens *et al.* 2009, Parnell *et al.* 2010). The primary species of interest in JHTMON-5 are Cutthroat Trout (*Oncorhynchus clarkii*) and Rainbow Trout (*O. mykiss*). Sampling is geared toward understanding the diets and energy sources of these two fish species, which are the resident fish species of primary management concern in reservoirs and lakes of the Campbell River system. Primary diet items for Cutthroat Trout and Rainbow Trout include zooplankton (pelagic source), benthic invertebrates (littoral source), stream invertebrates that wash into littoral areas (allochthonous source), terrestrial invertebrates that fall into littoral areas (allochthonous source), and other fish including Threespine Stickleback (*Gasterosteus aculeatus*), Sculpin spp. (*Cottus* spp.), and juvenile trout (*Oncorhynchus* spp.). Thus the JHTMON-5 study was geared towards obtaining representative samples of Cutthroat Trout and Rainbow Trout and potential diet items from each reservoir and lake sampled. Stable isotope data can be obtained from tissue samples of individuals (e.g., fin clips, muscle samples), from whole organisms (e.g., whole insects), or from composite samples from multiple individuals (e.g., zooplankton samples).

1.4.3. Sampling in Pilot Season

Year 1 of JHTMON-5 was planned and implemented as a pilot year to confirm the stable isotope approach and to develop recommendations for full sampling beginning in Year 2. Sampling was completed for Upper Campbell Reservoir, Gooseneck Lake, and Middle Quinsam Lake (Map 2).

To what extent do stabilized reservoir water levels, as affected by BC Hydro operations, benefit fish populations? Upper Campbell Reservoir was chosen because it experiences the greatest fluctuations in water levels and because sampling for JHTMON-3 (*Upper and Lower Campbell Lake Fish Spawning Success Assessment*) could be used to support field collections of Cutthroat Trout and Rainbow Trout for JHTMON-5. Because sampling only occurred at one reservoir (Upper Campbell), contrasts of BC Hydro operations across reservoirs or through time are not possible with the pilot year data. It is hypothesized that less variation in reservoir water levels benefits littoral production and increases reservoir fish production.

What is the relationship between residence time (as affected by diversion rate) and lake productivity? Gooseneck Lake and Middle Quinsam Lake were chosen because they are part of the same diversion system (Quinsam River); Middle Quinsam Lake experiences greater residence time (donor lake) and Gooseneck Lake experiences reduced residence time (recipient lake). Based on this contrast in BC Hydro operations it is predicted that Gooseneck Lake will have a lower pelagic contribution to fish production and a greater reliance on littoral sources of production than Middle Quinsam Lake. This is because it is hypothesized that shorter water residence times decreases zooplankton production and thus the pelagic source to fish production.

The selection of Upper Campbell Reservoir, Gooseneck Lake and Middle Quinsam Lake support a preliminary examination of $H_0 1$ and $H_0 2$ with Year 1 data. At each lake, representative pelagic and littoral sampling sites were chosen to collect invertebrate prey sources (zooplankton, benthic invertebrates, stream invertebrates, and terrestrial invertebrates) and fish. The representative littoral sites were located near stream inflows at each lake.

In subsequent years sampling will occur in several reservoirs, and in several recipient and donor diversion lakes, and in several control lakes. The following lakes and reservoirs have been highlighted for potential study within the JHTMON-5 program:

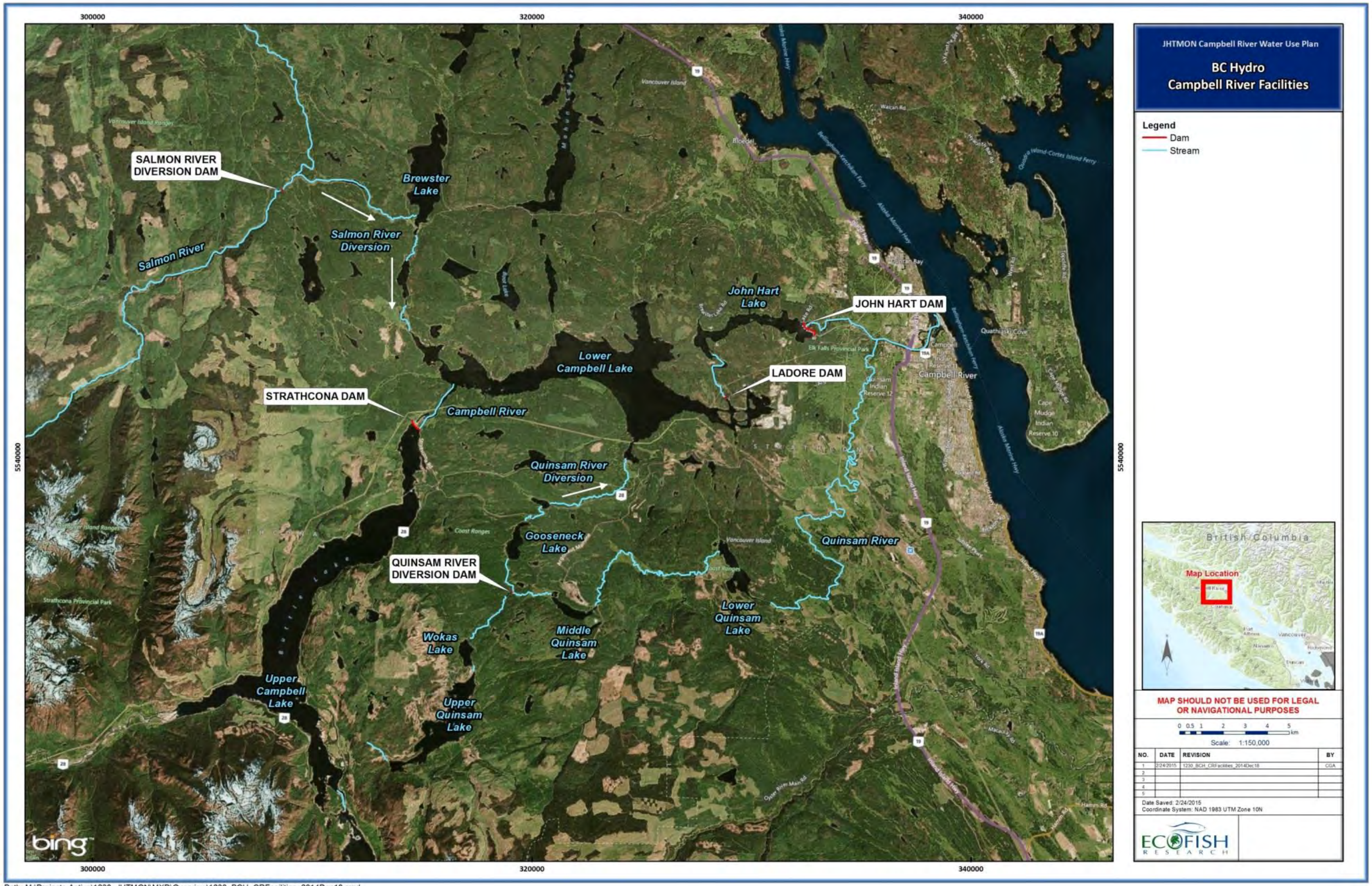
Reservoirs: Buttle/Upper Campbell, Lower Campbell, John Hart

Diversion Lakes: Brewster, Fry, Gooseneck, Gray, Lower Quinsam, McIvor, Middle Quinsam, Snakehead, Whymper

Crest, Upper Drum, and Lower Drum are decommissioned diversion lakes.

“Control” Lakes: Amor, Beavertail, Boot, Gentian, Gosling, Long, Merrill, Mohun, Paterson, Roberts, Upper Quinsam, Wokas

Map 1. Overview of BC Hydro Campbell River facilities.



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2. METHODS

2.1. Invertebrate Sampling

2.1.1. Zooplankton

2.1.1.1. Field

Zooplankton is the main source of pelagic production in lakes for upper-level consumers. In stable isotope studies of lakes it is important to use an appropriate isotopic baseline for zooplankton that is representative of the isotopic signatures experienced by the consumers. However, based on studies from other lakes and reservoirs on Vancouver Island, the nitrogen and carbon stable isotope signatures in zooplankton are known to vary seasonally (Matthews and Mazumder 2003, 2005). Therefore, zooplankton were sampled at three time periods (late June, late July and mid-August) to obtain a representative sample of zooplankton in each lake and to determine if this temporal sampling is necessary in subsequent years of the program.

Zooplankton sampling occurred at three sites in Upper Campbell Reservoir (UCR-LKZP01, UCR-LKZP02, UCR-LKZP03), one site at Gooseneck Lake (GOO-LKZP01) and one site at Middle Quinsam Lake (QUN-LKZP01) (Map 2, Map 3, Map 4, Table 1). These sites were marked with a GPS and revisited for sampling each time. The three zooplankton sites sampled on Upper Campbell Reservoir were situated in the northern arm of the reservoir close to the gill netting sampling locations. The zooplankton sampling sites in Gooseneck and Middle Quinsam lakes were approximately in the centre of the lakes, and they were both within the deepest areas located using a depth sounder.

Zooplankton were sampled using a tow net with a 30 cm diameter aperture and a mesh size of 80 μm (Figure 2). Sampling involved a single upwards vertical tow through the water column at approximately 1.5 m/s from a maximum of 20 m to surface (Table 1). The net was rinsed with deionized water prior to each tow. Care was taken to ensure the net did not touch the bed. Triplicate samples were collected during each sampling event (three vertical tows) and all samples were preserved in 95% ethanol (Figure 3).

Figure 2. Zooplankton net.

Figure 3. Zooplankton samples prior to adding ethanol. Note high density of captured specimens.

2.1.1.2. Lab

The first of the three zooplankton samples was used for identification, the second was transferred to a smaller vial and sent for stable isotope analysis, and the third was kept as a backup.

Zooplankton samples were identified primarily to Genus by Lech Dolecki of Ecofish Research Ltd. (Ecofish) and Casey Inrig of A-Tlegay Fisheries Society (A-Tlegay). Rose Bengal dye was added to the samples to aid in identification. Zooplankton were sorted and counted into the following groups: *Daphnia*, *Eubosmina*, *Diaptomus*, *Polyphemus*, *Leptodora*, Cyclopoida, and Nauplii. *Daphnia* are one of the most common Crustaceans in local lakes from the Order Cladocera. *Eubosmina*, *Polyphemus* and *Leptodora* are also common 'water fleas' within the Order Cladocera. *Diaptomus* is a Genus of copepods within the Order Calanoida. The Cyclopoida are another Order of copepods. Aquatic Crustaceans pass through several larval and immature stages when they often bear little resemblance to the adult. These immature Crustaceans were collectively labeled as Nauplii.

Zooplankton samples sent for stable isotope analysis were sent as composite zooplankton samples.

2.1.2. Benthic Invertebrates

2.1.2.1. Field

Samples of benthic invertebrates were collected from the littoral zone of each waterbody by inspecting a single composite sample of benthic sediments (Figure 4). Benthic invertebrate sampling occurred at two sites at Upper Campbell Reservoir (UCR-BIV01, UCR-BIV02), one site at Gooseneck Lake (GOO-BIV01) and one site at Middle Quinsam Lake (QUN-BIV02) (Map 2, Map 3, Map 4, Table 1). Samples were collected using a Ponar grab ('Petite' model) with an aperture of 152 mm × 152 mm. The Ponar grab was deployed five times in the littoral zone (within 10 m of the shore) at each waterbody, either by wading or from a boat (Upper Campbell Reservoir). All visible invertebrates were removed with forceps and placed in a clean sample jar for preservation with 95% ethanol.

Figure 4. Ponar grab sampling for benthic invertebrates.

2.1.2.2. Lab

Benthic invertebrates were sorted in the laboratory to Order, and, where possible, Family within Order, by Lech Dolecki of Ecofish and Casey Inrig of A-Tlegay. Benthic invertebrate samples sent for stable isotope analysis were split into four groups: 1) Odonata, 2) Pulmonata, 3) Unionida, and 4) all other taxa combined. This was done because these groups were predicted to have different isotope signatures. For example, Odonata are highly predaceous and thus were predicted to have higher isotope signatures than other benthic invertebrate taxa. Further, there were differences in body size and single large individuals can dominate aggregated samples across a range of other taxa.

2.1.3. Stream Invertebrates

2.1.3.1. Field

Stream invertebrates were sampled in one stream inflow to each of Upper Campbell Reservoir (UCR-SIV01), Gooseneck Lake (GOO-SIV01) and Middle Quinsam Lake (QUN-SIV01) (Map 2, Map 3, Map 4, Table 1). Duplicate samples were collected from sites located 10–30 m upstream of each water body. Kick sampling was used to collect stream invertebrates at the stream sites at Upper Campbell Reservoir and Middle Quinsam Lake. A single drift net (mesh size = 250 μm) was secured to the stream bed using rebar and the upstream substrate was agitated for three minutes using a wader boot (Figure 5). This was undertaken at a total of three sub–sites to collect a single composite sample of material that was thoroughly inspected. All visible invertebrates were removed with forceps and placed in a clean sample jar for preservation with 95% ethanol. Fine sediments (silt) at the stream site upstream of Gooseneck Lake prohibited the use of kick sampling, hence duplicate samples of stream invertebrates were collected by 'sweeping' a 10 m length of streamside aquatic vegetation for a three minute period using a drift net.

Figure 5. Drift net secured in the Quinsam River to sample benthic macroinvertebrates upstream of Middle Quinsam Lake (background).

2.1.3.2. Lab

Stream invertebrates were sorted in the laboratory to Order, and, where possible, Family within Order, by Lech Dolecki of Ecofish and Casey Inrig of A-Tlegay. Stream invertebrate samples sent for stable isotope analysis were split into three groups: 1) Odonata, 2) Pulmonata, and 3) all other taxa combined. This was done because these groups were predicted to have different isotopes signatures. For example, Odonata are highly predaceous and thus were predicted to have higher isotope signatures than other benthic invertebrate taxa. Further, there were differences in body size and single large individuals can dominate aggregated samples across a range of other taxa.

2.1.4. Terrestrial Invertebrates

2.1.4.1. Field

A single sample of terrestrial invertebrates was collected using a malaise trap placed at the shoreline of Upper Campbell Reservoir (UCR-TIV01), Gooseneck Lake (GOO-TIV01) and Middle Quinsam Lake (QUN-TIV02) (Map 2, Map 3, Map 4, Table 1). The trap consisted of a square–shaped tent (1.2 m long × 1.2 m wide × 2.1 m high) with openings at the side (Figure 6). Insects fly into the tent and climb upwards into a collecting jar. The trap was deployed for 2.5 to 4.5 hours at a single site on the shoreline of each lake. No chemical attractants or killing agents were used and samples were preserved using 95% ethanol.

Figure 6. Malaise trap deployed adjacent to the littoral site at Gooseneck Lake (left) and view of the sampling container at the end of the 2.5 hour deployment period.

2.1.4.2. Lab

Terrestrial invertebrates were sorted in the laboratory to Order, and, where possible, Family within Order, by Lech Dolecki of Ecofish and Casey Inrig of A-Tlegay. Terrestrial invertebrate samples sent for stable isotope analysis were not split by Order and rather sent as composite samples by lake across all species.

Table 1. Zooplankton, benthic invertebrate, stream invertebrate, and terrestrial invertebrate sampling site summary for the Upper Campbell, Middle Quinsam, and Gooseneck lakes, 2014.

Sampling Type	Waterbody	Site	Method	Date	UTM (NAD 83)			Replicates	Sample Start
					Zone	Easting	Northing		Depth (m)
Zooplankton	Gooseneck Lake	GOO-LKZP01	Plankton tow	25-Jun-14	10U	319337	5536221	6	13.0
				29-Jul-14	10U	319337	5536221	6	13.0
				19-Aug-14	10U	319337	5536221	6	13.0
	Middle Quinsam Lake	QUN-LKZP01	Plankton tow	25-Jun-14	10U	322169	5532796	6	10.0
				28-Jul-14	10U	322169	5532796	6	10.0
				19-Aug-14	10U	322169	5532796	6	10.0
	Upper Campbell Lake	UCR-LKZP01	Plankton tow	24-Jun-14	10U	308460	5530799	6	20.0
				27-Jul-14	10U	308460	5530799	6	20.0
		UCR-LKZP02	Plankton tow	24-Jun-14	10U	311771	5535849	6	20.0
				27-Jul-14	10U	311771	5535849	6	20.0
				20-Aug-14	10U	311771	5535849	6	20.0
		UCR-LKZP03	Plankton tow	24-Jun-14	10U	309887	5534278	6	20.0
				27-Jul-14	10U	309887	5534278	6	20.0
				20-Aug-14	10U	309887	5534278	6	20.0
Benthic Invertebrates	Gooseneck Lake	GOO-BIV01	Ponar grab	29-Jul-14	10U	318792	5535968	2	n/a
				19-Aug-14	10U	318792	5535968	2	n/a
	Middle Quinsam Lake	QUN-BIV02	Ponar grab	28-Jul-14	10U	322652	5533051	2	n/a
				19-Aug-14	10U	322652	5533051	3	n/a
	Upper Campbell Lake	UCR-BIV01	Ponar grab	27-Jul-14	10U	308517	5533680	1	n/a
		UCR-BIV02	Ponar grab	20-Aug-14	10U	310962	5525914	3	n/a
Stream Invertebrates	Gooseneck Lake	GOO-SIV01	Drift net	29-Jul-14	10U	318792	5535968	3	n/a
	Middle Quinsam Lake	QUN-SIV01	Drift net	28-Jul-14	10U	320848	5533816	3	n/a
	Upper Campbell Lake	UCR-SIV01	Drift net	27-Jul-14	10U	308517	5533680	3	n/a
Terrestrial Invertebrate	Gooseneck Lake	GOO-TIV01	Malaise trap	29-Jul-14	10U	318792	5535968	1	n/a
	Middle Quinsam Lake	QUN-TIV02	Malaise trap	28-Jul-14	10U	322652	5533051	1	n/a
	Upper Campbell Lake	UCR-TIV01	Malaise trap	27-Jul-14	10U	308517	5533680	1	n/a

"n/a" Indicates where data are not applicable.

2.2. Fish Sampling

2.2.1. Gill Netting

Gill netting was undertaken from August 20th to 26th 2014 to obtain representative fish samples from Upper Campbell Reservoir, Gooseneck Lake and Middle Quinsam Lake (Figure 7). Seven littoral sites and one pelagic site were sampled on Upper Campbell Reservoir, two littoral and two pelagic sites were sampled on Middle Quinsam Lake, and three littoral and three pelagic sites were sampled on Gooseneck Lake (Map 2, Map 3, Map 4, Table 2). Both floating and sinking gill nets were used to target various strata within the water column. At the littoral sites, nets were set perpendicular to shore with sinking nets set on the bed and floating nets set on the surface. At pelagic sites, nets were set perpendicular to depth contours with sinking nets set on the bed as well as suspended in the water column close to the thermocline. RISC standard gill nets were used; the nets consist of six panels, each 15.2 m long and of different mesh sizes, strung together in a "gang" to form a net 91.2 m long and 2.4 m deep. At sites (UCR-LKGN04 and UCR-LKGN07) a single 15.8 m long net was used in addition to the 91.2 m long nets. The mesh sizes were as follows: 25 mm, 76 mm, 51 mm, 89 mm, 38 mm, and 64 mm. This sequence of mesh sizes captures a range of size classes of fish.

When setting a net, the boat operator ensured the proper location and depth of the site using a GPS and depth sounder and positioned the net according to depth contours and wind conditions. The net was held in place with a net anchor at each end of the net. Nets were set overnight with soak times of 16–20 hours. Floating lights were attached to each net to mark their location overnight for boater safety. Individual fish processing is described in Section 2.2.3.

Table 2. Gill netting sampling site summary for Gooseneck, Middle Quinsam, and Upper Campbell lakes, 2014.

Waterbody	Site	Sampling Date	UTM			Location[1]	Turbidity	Water Temp. (°C)
			Zone	Easting	Northing			
Gooseneck Lake	GOO-LKGN01	20-Aug-2014	10u	319321	5536247	P	Clear	24
	GOO-LKGN02	20-Aug-2014	10u	319173	5536140	P	Clear	24
	GOO-LKGN03	20-Aug-2014	10u	319255	5536146	P	Clear	24
	GOO-LKGN04	20-Aug-2014	10u	318869	5536021	L	Clear	24
	GOO-LKGN05	20-Aug-2014	10u	318916	5535760	L	Clear	24
	GOO-LKGN06	20-Aug-2014	10u	318895	5535937	L	Clear	24
Middle Quinsam Lake	QUN-LKGN01	22-Aug-2014	10u	321997	5532814	P	Clear	24
	QUN-LKGN02	22-Aug-2014	10u	322080	5532804	P	Clear	24
	QUN-LKGN03	22-Aug-2014	10u	321200	5533276	L	Clear	24
	QUN-LKGN04	22-Aug-2014	10u	321323	5533388	L	Clear	24
Upper Campbell Lake	UCR-LKGN01	26-Aug-2014	10u	314096	5539930	L	Clear	-
	UCR-LKGN02	26-Aug-2014	10u	314629	5537246	L	Clear	-
	UCR-LKGN03	26-Aug-2014	10u	313301	5536669	P	Clear	-
	UCR-LKGN04	26-Aug-2014	10u	308638	5533904	L	Clear	-
	UCR-LKGN05	26-Aug-2014	10u	309356	5530967	L	Clear	-
	UCR-LKGN06	26-Aug-2014	10u	309419	5527967	L	Clear	-
	UCR-LKGN07	26-Aug-2014	10u	310848	5526008	L	Clear	-
	UCR-LKGN08	26-Aug-2014	10u	305645	5529532	L	Clear	-

"-" Dashes indicate where data are not available.

[1] P - pelagic zone and L - littoral zone.

Figure 7. Retrieving a RISC standard gill net from a pelagic site on Gooseneck Lake.

2.2.2. Minnow Trapping

Minnow trapping was used from August 20 to 26 2014 to obtain representative fish samples from littoral areas in Upper Campbell Reservoir, Gooseneck Lake and Middle Quinsam Lake (Table 3). On Upper Campbell Reservoir a total of three, Gee type, minnow traps were set at each of the seven gill netting littoral sites. With the inclusion of a second sampling event on UCR-LKMT08 on August

30, a total of 24 traps were deployed. Traps set within Upper Campbell Reservoir were targeted to be within the following depth ranges; 0-2 m, 3-6 m, and 7-10 m. For each of Gooseneck and Middle Quinsam lakes, 12 baited minnow traps were set overnight in the littoral zone. Traps were set at two different target depths; six traps were set at 2-3 m and six traps were set at 6-10 m. Minnow trapping effort was focused around locations of inlet streams.

Each trap was baited with a small amount fish roe placed in a film container perforated with holes, which allowed the scent to escape but prevented the attractant from being consumed. Traps were marked with a float, and UTM co–ordinates, depth, time, and mesh size of trap were recorded. Traps were fished overnight with soak times ranging from 16-20 hours. Captured fish were separated by site and trap number and then brought back to shore for processing. Individual fish processing is described in Section 2.2.3.

Table 3. Minnow trapping sampling site summary for Gooseneck, Middle Quinsam, and Upper Campbell lakes, 2014.

Waterbody	Site	Sampling Date	UTM			Water Temp. (^{o}C)
			Zone	Easting	Northing	
Gooseneck Lake	GOO-LKMT01	20-Aug-14	10u	318903	5535982	21
	GOO-LKMT02	20-Aug-14	10u	318856	5535974	21
Middle Quinsam Lake	QUN-LKMT01	22-Aug-14	10u	321331	5533391	24
	QUN-LKMT02	22-Aug-14	10u	321325	5533314	24
Upper Campbell Lake	UCR-LKMT01	28-Aug-14	10u	314096	5539930	-
	UCR-LKMT02	28-Aug-14	10u	314629	5537246	-
	UCR-LKMT04	26-Aug-14	10u	308638	5533904	-
	UCR-LKMT05	26-Aug-14	10u	309356	5530967	-
	UCR-LKMT06	27-Aug-14	10u	305645	5529532	-
	UCR-LKMT07	27-Aug-14	10u	310848	5526008	-
	UCR-LKMT08	26-Aug-14	10u	309419	5527967	-
	UCR-LKMT08	30-Aug-14	10u	309419	5527967	-

"-" Dashes indicate where data are not available.

2.2.3. Individual Fish Analysis

All fish captured by gill netting or minnow trapping were processed as soon as possible after capture. The majority of gill netted fish (>90%) did not survive and had already died by the time of net retrieval. Fish were picked out of the net as they were encountered and placed in a tote filled with water. Fork length was measured to nearest 1 mm and mass was measured to the nearest 0.1 g or 1 g for fish over 200 g. Photographs of all processed fish were taken. Some fish that were still alive were quickly measured for fork length and then released. Minnow trapped fish were all still alive upon capture. These fish were anaesthetized using ENO®, processed as above, allowed to recover in a tote filled with water and then released. Any mortality was noted.

Fin clip samples were collected for stable isotope analysis from all minnow trapped fish and up to 12 fish individuals per species from gill netting catch. Small fin clips were taken from the caudal fin of individuals and stored in small vials with 95% ethanol.

A total of 202 scale samples were collected: 37 Cutthroat Trout and 103 Rainbow Trout from Upper Campbell Reservoir, 18 Cutthroat Trout from Gooseneck Lake, and 44 Cutthroat Trout from Middle Quinsam Lake. Scale samples were taken from individuals across a range of sizes to ensure that a range of fish ages were captured and so that length-at-age relationships could be built for each species.

Scale samples were examined under a dissecting microscope to determine age at the Ecofish Campbell River laboratory. Representative scales were photographed and apparent annuli were noted using landmarks on a digital image (Figure 8). A subsample of scales was aged from the three lakes; Upper Campbell Lake (Cutthroat: n = 18, Rainbow: n = 15), Gooseneck Lake (Cutthroat: n = 10), and Middle Quinsam Lake (Cutthroat: n = 16). Fish age was determined by a QAQC methodology where by individual scales were initially aged by a junior staff (A-Tlegay and Ecofish) then ages were confirmed by a senior biologist (Ecofish).

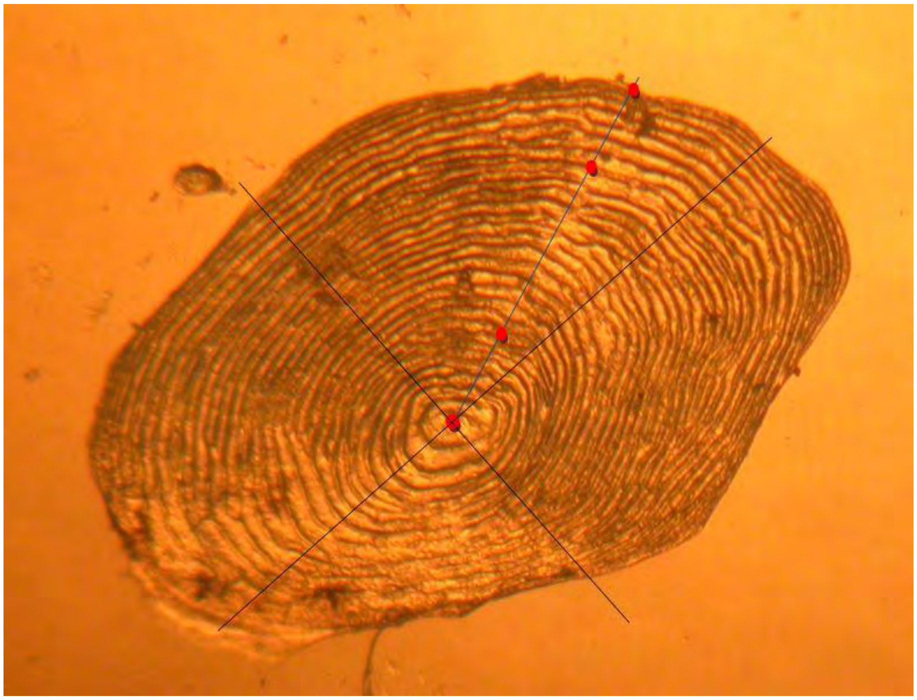
Further analysis consisted of defining age class structure and describing other characteristics of the fish populations such as the length-weight relationship, Fulton's condition factor (K), and length at age. Fulton's condition factor (K) was calculated for all captured fish as:

$$K = weight * length^{-3} * 100{,}000$$

DNA samples of Rainbow and Cutthroat Trout were also collected from a subsample of individuals and are currently stored at the Ecofish Laboratory in Campbell River.

Fish abundance data, including catch-per-unit-effort (CPUE), were analyzed for all fish species captured in Upper Campbell Reservoir, Gooseneck Lake and Middle Quinsam Lake to describe the fish community present in these systems. Data analysis was split by capture method (gill netting vs. minnow trapping).

Figure 8. An example scale aged as a 2+ fish with age annuli indicated with landmarks. The initial landmark and landmark on the outer edge are not counted in the fish age.



2.2.4. Stomach Contents

For comparison to isotope results, fish stomachs were extracted from 4 Cutthroat Trout and 6 Rainbow Trout from Upper Campbell Reservoir, 10 Cutthroat Trout from Gooseneck Lake, and 12 Cutthroat Trout from Middle Quinsam Lake. Fish stomachs were preserved in a 10% formalin solution. The stomachs were carefully cut open before placing them into the jar to ensure that the preservative was able to contact all of the stomach contents. Jars were sealed with tape and labeled with lake, species, date, and site #.

Stomach contents were examined under a microscope in a lab and were separated into the following categories by mass: % zooplankton, % littoral invertebrates (sum of any benthic, stream and terrestrial invertebrates), and % fish.

2.3. Stable Isotope Data

2.3.1. Stable Isotope Processing

Invertebrate and fish samples were processed for nitrogen and carbon stable isotopes at the Stable Isotope in Nature Laboratory (SINLAB) (http://www.unb.ca/research/institutes/cri/sinlab/) located within the Canadian Rivers Institute at the University of New Brunswick in Fredericton, New Brunswick. Dr. Brian Hayden, the Science Manager of SINLAB, was the primary contact.

A total of 171 samples of invertebrates and fish were sent for analysis (Table 4). Invertebrates were sent as whole individuals, while most fish were sent as fin clip samples. Threespine Stickleback was an important target fish species, although only a single individual was caught in all gill nets and minnow traps. During stomach content analysis nine small Stickleback were found in the gut of a single large Cutthroat Trout. These Stickleback were sent and processed for stable isotopes as whole individuals.

All samples were rinsed with distilled water, dried for 48 hours at 60°C and ground into a fine homogeneous powder using a pestle and mortar. Samples were then weighed into tin capsules and loaded into either a PN150 or Costech Zeroblank autosampler. Samples were converted to gases by combustion by a Carlo Erba NC2500 or Costech 4010 Elemental Analyzer (EA) and then analyzed for $\delta^{15}N$ and $\delta^{13}C$ using a Delta Plus or a Delta XP continuous flow isotope-ratio mass spectrometer (CF-IRMS) (ThermoFinnigan; Bremen, Germany) (see SINLAB website).

Isotopic signatures are expressed in delta notation (δ) as ratios relative to known isotopic standards of atmospheric N_2 and Vienna Pee Dee Belemnite (V-PDB) carbon. This is expressed in parts per thousand (‰) according to:

$$\delta^{15}N \text{ or } \delta^{13}C\ (‰) = (R_{sample}/R_{standard} - 1) * 1000$$

where R is the ratio of the heavy isotope (^{15}N or ^{13}C)/ light isotope (^{14}N or ^{12}C).

Eleven samples were run in duplicate to test repeatability of the stable isotope results. The mean difference in $\delta^{15}N$ between repeats was 0.16±0.18‰. The mean difference in $\delta^{13}C$ between repeats was 0.02±0.17‰.

Table 4. Invertebrate and fish samples sent for stable isotope processing at SINLAB.

Taxa	Upper Campbell	Gooseneck	Middle Quinsam	Total
Zooplankton	8	3	3	14
Benthic Invertebrates	4	4	5	13
Stream Invertebrates	2	3	2	7
Terrestrial Invertebrates	1	1	1	3
Threespine Stickleback	10	0	0	10
Sculpin spp.	6	6	4	16
Juvenile Trout	12	5	5	22
Dolly Varden	1	6	0	7
Rainbow Trout	18	0	1	19
Cutthroat Trout	20	20	20	60
Total	**82**	**48**	**41**	**171**

2.3.2. Assessing Fish Diet Using Mixing Models

The relative contributions of pelagic and littoral sources to Cutthroat Trout and Rainbow Trout diets were assessed through dual isotope (δ^{13}C and δ^{15}N), four to seven-source Bayesian isotopic mixing models implemented in the program SIAR (Stable Isotope Analysis in R; Parnell and Jackson 2011). SIAR takes isotope data from consumers (fish) and sources (diet items) along with estimates of diet -tissue isotopic fractionation, and fits Bayesian models based on Gaussian likelihoods with a Dirichlet prior mixture on the mean, which provide posterior distribution estimates of source contributions to diet (Parnell *et al.* 2010). The diet-tissue fractionation values used in the models were 1.50 ± 1.16 for δ^{13}C and 2.79 ± 1.46 for δ^{15}N. These are average diet-tissue fractionation rates across several fish species and tissue types (Sweeting *et al.* 2007a, b).

Two models were run for each of the three lakes. The first model estimated diet contributions to large Cutthroat Trout and Rainbow Trout (Age >2+, FL ≥ 190 mm). Seven potential diet sources (mean δ^{13}C and δ^{15}N ± SD) for large Cutthroat Trout and Rainbow Trout were included in this model: 1) zooplankton, 2) benthic invertebrates, 3) stream invertebrates, 4) terrestrial invertebrates, 5) juvenile trout (Age ≤ 2, FL ≤ 153), 6) Sculpin (FL ≤ 106 mm), and 7) Threespine Stickleback (FL ≤ 58 mm). The second model run for each lake estimated the diet contributions to the smaller prey fish (juvenile trout, Sculpins, and Threespine Stickleback). Four potential diet sources (mean δ^{13}C and δ^{15}N ± SD) were used to estimate the smaller prey fish diets: 1) zooplankton, 2) benthic invertebrates, 3) stream invertebrates, and 4) terrestrial invertebrates.

The two models were run to assess the total relative contributions of pelagic vs. littoral sources of production to large Cutthroat Trout and Rainbow Trout via direct and indirect pathways. The total littoral vs. pelagic contribution can be derived by summing the contributions of the invertebrate prey to Cutthroat Trout and Rainbow Trout diet in model one (direct pathway) with the relative contributions of invertebrate prey to the diets of small fish (model 2) that occur in the Cutthroat Trout and Rainbow Trout diet (indirect pathway). The direct pathway (model 1) is the contribution of zooplankton (pelagic) and summed contribution from benthic, stream, and terrestrial invertebrates (littoral) to Cutthroat Trout and Rainbow Trout diets. The indirect contribution (derived from model 1 and model 2) is the proportional contribution of pelagic and littoral sources to the small prey fish diets that is carried forward to the diets of large Cutthroat Trout and Rainbow Trout.

2.3.3. Correlations with Fish Size and Age

As fish become larger they tend to eat larger prey. It is also possible that Cutthroat Trout and Rainbow Trout shift among pelagic and littoral sources of production as they grow and age. Basic linear regression models were built for both Cutthroat Trout and Rainbow Trout to test the relationships between δ^{15}N and δ^{13}C stable isotope signatures and fish length or fish age. All analyses were conducted using the statistical program R (R Core Team 2014).

3. RESULTS

3.1. Invertebrate Sampling

3.1.1. Zooplankton

Daphnia, *Eubosmina*, *Diaptomus*, *Polyphemus*, *Leptodora*, Cyclopoida, and Nauplii were the zooplankton taxa identified in sampling from Upper Campbell, Gooseneck and Middle Quinsam lakes. Total catch and percent of catch by lake is presented in Table 5. *Daphnia* comprised the largest portion of zooplankton that was captured for all three lakes (33.6%, 53.3%, and 57.2%; Upper Campbell, Middle Quinsam, and Gooseneck lakes). *Polyphemus* was the second most abundant zooplankton taxa in Gooseneck (29.2%) and Middle Quinsam (26.9%) lakes, while in the Upper Campbell Reservoir *Eubosmina* (30.2%) was the second most abundant zooplankton taxa. The portion of captured zooplankton by month for the three lakes remained mostly consistent throughout the sampling period (Table 6). A decline in the proportion of *Eubosmina* was observed across June (18.6%), July (14.9%) and August (7.7%), coincident with a slight increase in the proportion of captured Nauplii across June (18.9%), July (20.4%) and August (25.3%).

3.1.2. Benthic Invertebrates

Benthic invertebrate sampling was completed at one site for each of Upper Campbell, Middle Quinsam, and Gooseneck lakes (Table 7). Sampling occurred on two occasions, once in July and again in August, 2014. The following Orders and Families were found to be present:

- Amphipoda – Gammaridae;
- Coleoptera – Chrysomelidae and Dytiscidae;
- Diptera – Chironomidae;
- Ephemeroptera – Ameletidae, Beatidae, and Leptophlebiidae;
- Hemiptera – Miridae and Veliidae;
- Odonata – Aeshnidae, Corduliidae, Lestidae, Petaluridae, and Protoneuridae;
- Gastropoda (Pulmonata);
- Trichoptera – Polycentropodidae and Leptoceridae;
- Bivalvia (Unionoida).

Total catch by lake is presented in Table 7. Distinct differences in taxonomic composition are observed in the presence/absence and relative abundance (percent catch) of Amphipods. This group was distinctly absent from the samples collected in the Upper Campbell Lake, but were the predominant group captured at Middle Quinsam (66.7%) and Gooseneck (70.2%) lakes.

3.1.3. Stream Invertebrates

Stream invertebrate sampling was completed at one site for each of the Upper Campbell, Middle Quinsam, and Gooseneck lakes (Table 8). Sampling occurred on one occasion in July and again in August, 2014. The following Orders and Families were found to be present:

- Amphipoda – Gammaridae;
- Coleoptera – Chrysomelidae and Dytiscidae;
- Diptera – Chironomidae, Pyschodidae, Simuliidae, and Tipulidae;
- Ephemeroptera – Ameletidae, Bactidae, Beatidae, Ephemerelidae, Heptageniidae, and Leptophlebiidae;
- Gastropoda (Pulmonata)
- Hemiptera – Mesoveliidae and Notonectidae;
- Hymenoptera – Ichneumonidae
- Lepidoptera – (specimens identified to order)
- Odonata – Aeshnidae, Gomphidae, Lestidae, and Protoneuridae,
- Oligochaeta – Lumbriculidae
- Plecoptera – Chloroperlidae and Perlodidae
- Trichoptera – Hydrosychidae, Philopotamidae, Polycentropodidae, and Rhyacophilidae.

Total catch by lake is presented in Table 8. The taxonomic makeup and relative abundances observed within the collected samples is highly variable between each lake system. Ephemeroptera, Odonata and Plecoptera were three of the most abundant Orders caught.

3.1.4. Terrestrial Invertebrates

Terrestrial invertebrate sampling was completed at one site for each of the Upper Campbell, Middle Quinsam, and Gooseneck lakes (Table 9). The following Orders and Families were found to be present:

- Diptera – Brachycera, Calliphoridae, Chironomidae, Conopidae, Dolichopodidae, Emplididae, Ephydridae, Lonchaeidae, Lonchopteridae, Micropezidae, Muscidae, Pelecorhynchidae, Sciaridae, Sphaerocidae, Syrphidae, Tabanidae, and Tachinidae;
- Ephemeroptera – (specimens identified to order)
- Hemiptera – Miridae;
- Homoptera – Cercorpoidea and Cicadellidae;
- Hymenoptera – Chalcidoidae, Ichencumonidae, and Proctotrupoidea.

Total catch by lake is presented in Table 9. Taxa collected are relatively consistent between lake systems and are dominated by the Diptera (Upper Campbell = 87.5%, Gooseneck = 93.0%, Middle Quinsam = 68.8%).

Table 5. Zooplankton catch results for Upper Campbell, Gooseneck, and Middle Quinsam lakes, 2014.

Waterbody	Site	Month	Date	No. of Replicates	Total Zooplankton Catch (#/Sampling Effort)						
					Daphnia	Eubosmina	Diaptomus	Cyclopoida	Polyphemus	Nauplii	Leptodora
Gooseneck Lake	GOO-LKZP01	June	25-Jun-2014	3	161	30	27	0	75	0	0
		July	29-Jul-2014	3	171	14	30	2	105	0	0
		August	19-Aug-2014	3	159	10	4	0	71	0	0
			Gooseneck Total	**9**	**491**	**54**	**61**	**2**	**251**	**0**	**0**
			Pecent of Catch	**-**	**57.2%**	**6.3%**	**7.1%**	**0.2%**	**29.2%**	**0.0%**	**0.0%**
Middle Quinsam Lake	QUN-LKZP01	June	25-Jun-2014	3	292	68	20	3	138	0	0
		July	28-Jul-2014	3	147	14	44	3	22	1	0
		August	19-Aug-2014	3	188	23	57	0	156	0	0
			Middle Quinsam Total	**9**	**627**	**105**	**121**	**6**	**316**	**1**	**0**
			Pecent of Catch	**-**	**53.3%**	**8.9%**	**10.3%**	**0.5%**	**26.9%**	**0.1%**	**0.0%**
Upper Campbell Lake	UCR-LKZP01	June	24-Jun-2014	3	122	68	42	6	69	0	0
		July	27-Jul-2014	3	77	62	11	0	29	0	0
	UCR-LKZP02	June	24-Jun-2014	3	48	100	9	5	71	0	0
		July	27-Jul-2014	3	75	71	18	1	98	0	0
		August	20-Aug-2014	3	77	36	9	3	49	0	0
	UCR-LKZP03	June	24-Jun-2014	3	67	127	23	2	47	0	0
		July	27-Jul-2014	3	86	85	35	10	83	0	0
		August	20-Aug-2014	3	97	33	18	0	60	0	0
			Upper Campbell Total	**24**	**649**	**582**	**165**	**27**	**506**	**0**	**0**
			Pecent of Catch	**-**	**33.6%**	**30.2%**	**8.6%**	**1.4%**	**26.2%**	**0.0%**	**0.0%**

Table 6. Zooplankton catch results summarized by month for the Upper Campbell, Gooseneck, and Middle Quinsam lakes, 2014.

Month	Waterbody	Total Zooplankton Catch (#/Sampling Effort)						
		Daphnia	Eubosmina	Diaptomus	Cyclopoida	Polyphemus	Nauplii	Leptodora
June	Gooseneck Lake	161	30	27	69	0	75	0
	Middle Quinsam Lake	292	68	20	230	3	138	0
	Upper Campbell Lake	237	295	74	192	13	187	0
	June Total	**690**	**393**	**121**	**491**	**16**	**400**	**0**
	Pecent of Catch	**32.7%**	**18.6%**	**5.7%**	**23.3%**	**0.8%**	**18.9%**	**0.0%**
July	Gooseneck Lake	171	14	30	98	2	105	0
	Middle Quinsam Lake	147	14	44	63	3	22	1
	Upper Campbell Lake	238	218	64	200	11	210	0
	July Total	**556**	**246**	**138**	**361**	**16**	**337**	**1**
	Pecent of Catch	**33.6%**	**14.9%**	**8.3%**	**21.8%**	**1.0%**	**20.4%**	**0.1%**
August	Gooseneck Lake	159	10	4	21	0	71	0
	Middle Quinsam Lake	188	23	57	60	0	156	0
	Upper Campbell Lake	174	69	27	196	3	109	0
	August Total	**521**	**102**	**88**	**277**	**3**	**336**	**0**
	Pecent of Catch	**39.3%**	**7.7%**	**6.6%**	**20.9%**	**0.2%**	**25.3%**	**0.0%**

Table 7. Benthic Invertebrate catch results for Upper Campbell, Gooseneck, and Middle Quinsam lakes, 2014.

Waterbody	Site	Month	Date	No. of Replicates	Total Benthic Invertebrate Catch (#/Sampling Effort)[1]								
					Amph.	Cole.	Dipt.	Ephe.	Pulm.	Hemi.	Odon.	Trich.	Unio.
Gooseneck Lake	GOO-LKIV01	July	29-Jul-14	3	32	2	3	0	0	2	2	2	0
		August	19-Aug-14	3	1	0	0	0	0	0	2	0	1
		Goosneck Total		**2**	**33**	**2**	**3**	**0**	**0**	**2**	**4**	**2**	**1**
		Pecent of Catch		**-**	**70.2%**	**4.3%**	**6.4%**	**0.0%**	**0.0%**	**4.3%**	**8.5%**	**4.3%**	**2.1%**
Middle Quinsam Lake	QUN-LKIV01	July	28-Jul-14	2	4	0	1	0	0	0	2	0	0
		August	19-Aug-14	2	14	0	1	3	0	0	1	0	1
		Middle Quinsam Total		**2**	**18**	**0**	**2**	**3**	**0**	**0**	**3**	**0**	**1**
		Pecent of Catch		**-**	**66.7%**	**0.0%**	**7.4%**	**11.1%**	**0.0%**	**0.0%**	**11.1%**	**0.0%**	**3.7%**
Upper Campbell Lake	UCR-LKIV01	July	27-Jul-14	1	0	0	1	3	0	0	0	0	0
		August	20-Aug-14	1	0	0	2	1	2	0	3	2	0
		Upper Campbell Total		**1**	**0**	**0**	**3**	**4**	**2**	**0**	**3**	**2**	**0**
		Pecent of Catch		**-**	**0.0%**	**0.0%**	**21.4%**	**28.6%**	**14.3%**	**0.0%**	**21.4%**	**14.3%**	**0.0%**

[1] Amph. - Amphipoda, Cole. - Coleoptera, Dipt. - Diptera, Ephe. - Ephemeroptera, Pulm. - Pulmonata, Hemi. - Hemiptera, Odon. - Odonata, Tric. - Trichoptera, Unio. - Unionoida

Table 8. Stream Invertebrate catch results for Upper Campbell, Gooseneck, and Middle Quinsam lakes, 2014.

Waterbody	Site	Month	Date	No. of Replicates	Total Invertebrate Catch (#/Sampling Effort)[1]											
					Amph.	Cole.	Dipt.	Ephe.	Gast.	Hemi.	Hyme.	Lepi.	Odon.	Olig.	Pleco.	Trich.
Gooseneck Lake	GOO-LKIV01	July	29-Jul-14	1	3	29	0	3	9	23	0	2	9	0	1	0
		Pecent of Catch		**-**	**3.8%**	**36.7%**	**0.0%**	**3.8%**	**11.4%**	**29.1%**	**0.0%**	**2.5%**	**11.4%**	**0.0%**	**1.3%**	**0.0%**
Middle Quinsam Lake	QUN-LKIV01	July	28-Jul-14	1	1	0	0	4	0	0	0	0	11	4	7	0
		Pecent of Catch		**-**	**3.7%**	**0.0%**	**0.0%**	**14.8%**	**0.0%**	**0.0%**	**0.0%**	**0.0%**	**40.7%**	**14.8%**	**25.9%**	**0.0%**
Upper Campbell Lake	UCR-LKIV01	July	27-Jul-14	3	0	1	5	27	0	0	1	0	0	2	18	7
		Pecent of Catch		**-**	**0.0%**	**1.6%**	**8.2%**	**44.3%**	**0.0%**	**0.0%**	**1.6%**	**0.0%**	**0.0%**	**3.3%**	**29.5%**	**11.5%**

[1] Amph. - Amphipoda, Cole. - Coleoptera, Dipt. - Diptera, Ephe. - Ephemeroptera, Gast. - Gastropoda, Hemi. - Hemiptera, Hyme. - Hymenoptera, Lepi. - Lepidoptera, Odon. - Odonata, Olig. - Oligochaeta, Plec. - Plecoptera, Tric. - Trichoptera

Table 9. Terrestrial Invertebrate catch results for Upper Campbell, Gooseneck, and Middle Quinsam lakes, 2014.

Waterbody	Site	Month	Date	No. of Replicates	Total Invertebrate Catch (#/Sampling Effort)				
					Diptera	Ephemeroptera	Hemiptera	Homoptera	Hymenoptera
Gooseneck Lake	GOO-LKIV01	July	29-Jul-14	9	53	0	2	0	2
		Pecent of Catch		**-**	**93.0%**	**0.0%**	**3.5%**	**0.0%**	**3.5%**
Middle Quinsam Lake	QUN-LKIV01	July	28-Jul-14	3	33	0	0	6	9
		Pecent of Catch		**-**	**68.8%**	**0.0%**	**0.0%**	**12.5%**	**18.8%**
Upper Campbell Lake	UCR-LKIV01	July	27-Jul-14	9	28	3	0	0	1
		Pecent of Catch		**-**	**87.5%**	**9.4%**	**0.0%**	**0.0%**	**3.1%**

3.2. Fish Sampling

3.2.1. Gill Netting

93 Cutthroat Trout, 259 Rainbow Trout, one Dolly Varden, two Prickly Sculpin (*Cottus asper*), and one Threespine Stickleback were captured in the Upper Campbell Lake. 50 Cutthroat Trout, nine Dolly Varden, and one Prickly Sculpin were captured in Gooseneck Lake. 184 Cutthroat Trout and one Coho Salmon were captured in Middle Quinsam Lake (Table 10).

Average catch-per-unit-effort (CPUE) for Cutthroat Trout was 0.30 fish/net hour (±0.29 SD), 0.42 fish/net hour (±0.56 SD), and 2.42 fish/net hour (±0.86 SD) for Upper Campbell Reservoir, Gooseneck Lake, and Middle Quinsam Lake, respectively (Table 10). CPUE for Rainbow Trout on the Upper Campbell Reservoir was 0.81 fish/net hour (±0.48 SD). Capture efficiencies of Cutthroat Trout, measured in CPUE, were similar between the Upper Campbell and Gooseneck lakes. The CPUE of Cutthroat Trout in Middle Quinsam was 5 times higher than in Gooseneck Lake and 8 times higher than in Upper Campbell Reservoir (Figure 9). CPUE for Coho Salmon, Prickly Sculpin, and Three-spine Stickleback are presented in Figure 10.

Table 10. Gill netting capture results from the Upper Campbell, Gooseneck, and Middle Quinsam lakes, 2014.

Waterbody	Site	Sampling Date	No. of Sets	Gill Netting Effort (hrs)	Gill Net Catch (# of fish)[1]						Gill Net CPUE (# of fish/net hr)[1]					
					CT	RB	DV	CO	CAS	TSB	CT	RB	DV	CO	CAS	TSB
Gooseneck Lake	GOO-LKGN01	20-Aug-2014	1	19.27	4	0	6	0	0	0	0.21	0.00	0.31	0.00	0.00	0.00
	GOO-LKGN02	20-Aug-2014	1	19.53	5	0	1	0	0	0	0.26	0.00	0.05	0.00	0.00	0.00
	GOO-LKGN03	20-Aug-2014	1	21.20	1	0	2	0	0	0	0.05	0.00	0.09	0.00	0.00	0.00
	GOO-LKGN04	20-Aug-2014	1	21.23	2	0	0	0	0	0	0.09	0.00	0.00	0.00	0.00	0.00
	GOO-LKGN05	20-Aug-2014	1	20.08	31	0	0	0	1	0	1.54	0.00	0.00	0.00	0.05	0.00
	GOO-LKGN06	20-Aug-2014	1	20.18	7	0	0	0	0	0	0.35	0.00	0.00	0.00	0.00	0.00
Gooseneck Total			**6**	**121.49**	**50**	**0**	**9**	**0**	**1**	**0**	**n/a**	**n/a**	**n/a**	**n/a**	**n/a**	**n/a**
Gooseneck Average			**1**	**20.25**	**8**	**0**	**2**	**0**	**0**	**0**	**0.42**	**0.00**	**0.08**	**0.00**	**0.01**	**0.00**
Gooseneck SD			**n/a**	**0.82**	**11**	**0**	**2**	**0**	**0**	**0**	**0.56**	**0.00**	**0.12**	**0.00**	**0.02**	**0.00**
Middle Quinsam Lake	QUN-LKGN01	22-Aug-2014	1	18.80	39	0	0	1	0	0	2.07	0.00	0.00	0.05	0.00	0.00
	QUN-LKGN02	22-Aug-2014	1	18.57	29	0	0	0	0	0	1.56	0.00	0.00	0.00	0.00	0.00
	QUN-LKGN03	22-Aug-2014	1	19.03	47	0	0	0	0	0	2.47	0.00	0.00	0.00	0.00	0.00
	QUN-LKGN04	22-Aug-2014	1	19.22	69	0	0	0	0	0	3.59	0.00	0.00	0.00	0.00	0.00
Middle Quinsam Total			**4**	**75.62**	**184**	**0**	**0**	**1**	**0**	**0**	**n/a**	**n/a**	**n/a**	**n/a**	**n/a**	**n/a**
Middle Quinsam Average			**1**	**18.91**	**46**	**0**	**0**	**0**	**0**	**0**	**2.42**	**0.00**	**0.00**	**0.01**	**0.00**	**0.00**
Middle Quinsam SD			**n/a**	**0.28**	**17**	**0**	**0**	**1**	**0**	**0**	**0.86**	**0.00**	**0.00**	**0.03**	**0.00**	**0.00**
Upper Campbell Lake	UCR-LKGN01	26-Aug-2014	2	32.76	26	17	1	0	0	0	0.79	0.52	0.03	0.00	0.00	0.00
	UCR-LKGN02	26-Aug-2014	2	32.91	1	36	0	0	0	0	0.03	1.09	0.00	0.00	0.00	0.00
	UCR-LKGN03	26-Aug-2014	4	40.97	2	53	0	0	0	0	0.05	1.29	0.00	0.00	0.00	0.00
	UCR-LKGN04	26-Aug-2014	3	51.64	24	38	0	0	0	0	0.46	0.74	0.00	0.00	0.00	0.00
	UCR-LKGN05	26-Aug-2014	2	34.83	0	0	0	0	0	0	0.00	0.00	0.00	0.00	0.00	0.00
	UCR-LKGN06	26-Aug-2014	2	31.10	13	31	0	0	1	0	0.42	1.00	0.00	0.00	0.03	0.00
	UCR-LKGN07	26-Aug-2014	3	47.72	6	67	0	0	1	1	0.13	1.40	0.00	0.00	0.02	0.02
	UCR-LKGN08	26-Aug-2014	4	42.40	21	17	0	0	0	0	0.50	0.40	0.00	0.00	0.00	0.00
Upper Campbell Total			**22**	**314.33**	**93**	**259**	**1**	**0**	**2**	**1**	**n/a**	**n/a**	**n/a**	**n/a**	**n/a**	**n/a**
Upper Campbell Average			**2.75**	**39.29**	**12**	**32**	**0**	**0**	**0**	**0**	**0.30**	**0.81**	**0.00**	**0.00**	**0.01**	**0.00**
Upper Campbell SD			**n/a**	**7.62**	**11**	**21**	**0**	**0**	**0**	**0**	**0.29**	**0.48**	**0.01**	**0.00**	**0.01**	**0.01**

[1] CT- Cutthroat Trout, RB - Rainbow Trout, DV - Dolly Varden, CO - Coho Salmon, CAS - Prickly Sculpin, TSB - Threespine Stickleback.

Figure 9. Catch-per-unit-effort (CPUE) during gill netting of captured Cutthroat Trout (CT), Rainbow Trout (RB), and Dolly Varden (DV) from the Upper Campbell, Middle Quinsam, and Gooseneck lakes, 2014.

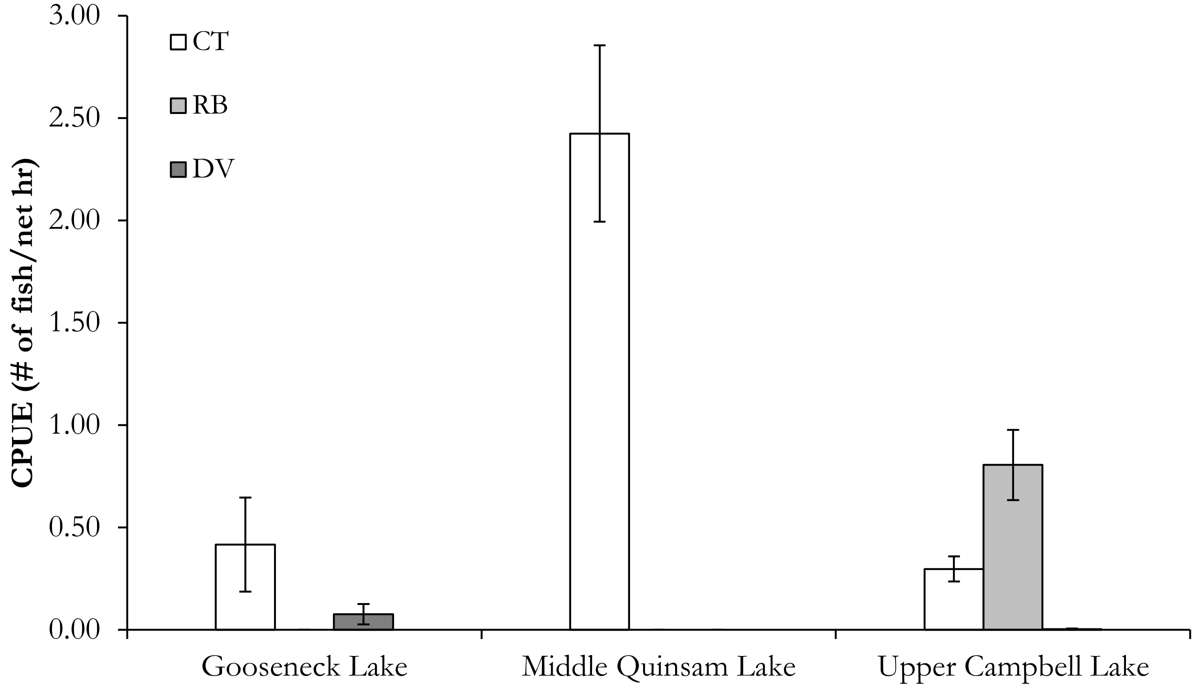
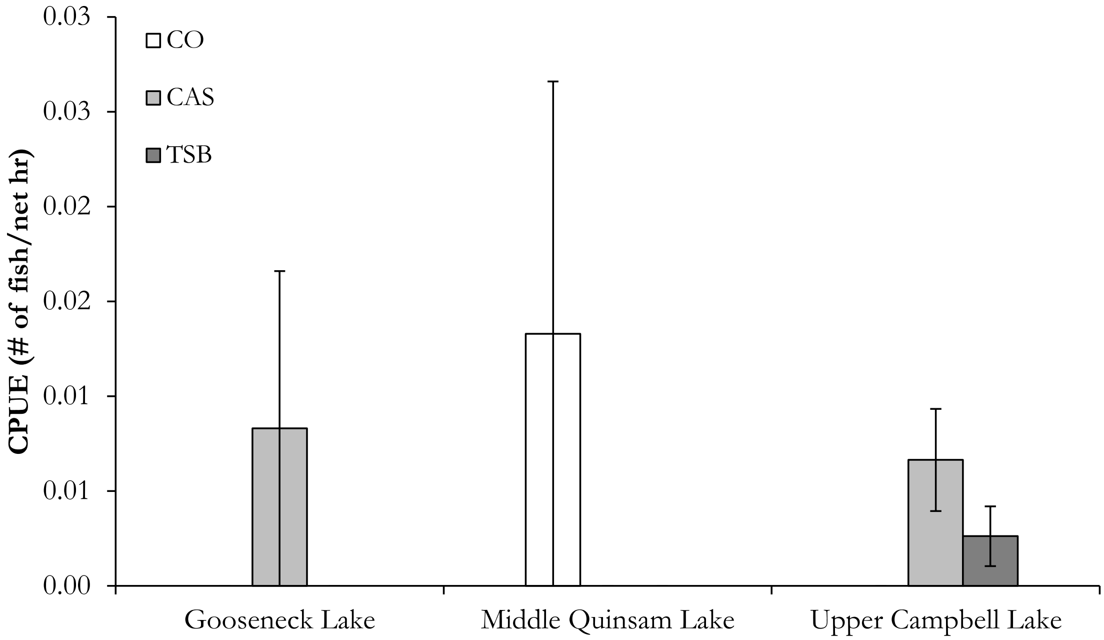


Figure 10. Catch-per-unit-effort (CPUE) during gill netting of captured Coho Salmon (CO), Prickly Sculpin (CAS), and Threespine Stickleback (TSB) from the Upper Campbell, Middle Quinsam, and Gooseneck lakes, 2014.



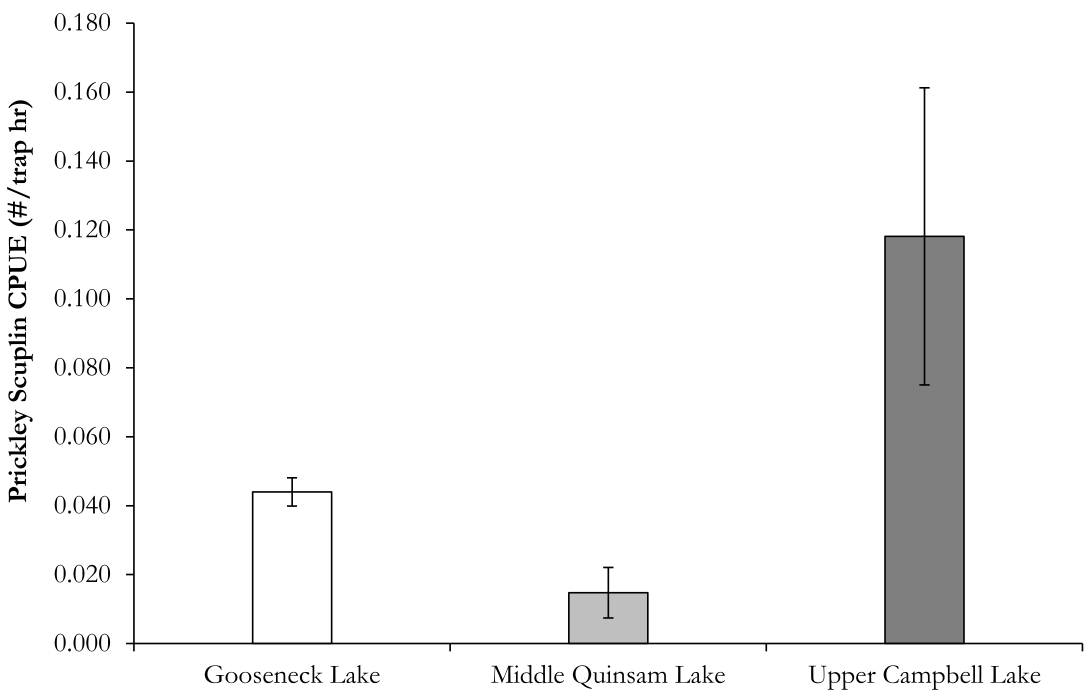
3.2.2. Minnow trapping

Prickly Sculpin was the only species captured using minnow trapping. A total of 32, 11, and 4 Prickly Sculpin were captured in Upper Campbell, Gooseneck, and Middle Quinsam lakes, respectively (Table 11). CPUE for Prickly Sculpin in Upper Campbell Lake was 0.12 fish/trap hour (±0.12 SD), Gooseneck Lake 0.04 fish/trap hour (±0.01 SD), and Middle Quinsam Lake 0.01 fish/ trap hour (±0.01 SD) (Table 11, Figure 11).

Table 11. Minnow trapping capture results from the Upper Campbell, Middle Quinsam, and Gooseneck lakes, 2014.

Waterbody	Site	Sampling Date	No. of Minnow Traps	Minnow Trapping Effort (hrs)	Minnow Trap Catch (# of CAS)	Minnow Trap CPUE (# of CAS/trap hr)
Gooseneck Lake	GOO-LKMT01	20-Aug-2014	6	125.3	5	0.04
	GOO-LKMT02	20-Aug-2014	6	124.7	6	0.05
	Gooseneck Total		**12**	**250.1**	**11**	**n/a**
	Gooseneck Average		**6**	**125.0**	**6**	**0.04**
	Gooseneck SD		**n/a**	**0.4**	**1**	**0.01**
Middle Quinsam Lake	QUN-LKMT01	22-Aug-2014	6	135.9	3	0.02
	QUN-LKMT02	22-Aug-2014	6	134.8	1	0.01
	Middle Quinsam Total		**12**	**270.6**	**4**	**n/a**
	Middle Quinsam Average		**6**	**135.3**	**2**	**0.01**
	Middle Quinsam SD		**n/a**	**0.8**	**1**	**0.01**
Upper Campbell Lake	UCR-LKMT01	28-Aug-2014	3	49.5	0	0.00
	UCR-LKMT02	28-Aug-2014	3	48.6	4	0.08
	UCR-LKMT04	26-Aug-2014	3	45.6	3	0.07
	UCR-LKMT05	26-Aug-2014	3	51.4	4	0.08
	UCR-LKMT06	27-Aug-2014	3	47.2	9	0.19
	UCR-LKMT07	27-Aug-2014	3	48.1	2	0.04
	UCR-LKMT08	26-Aug-2014	3	50.6	5	0.10
		30-Aug-2014	3	12.9	5	0.39
	Upper Campbell Total		**24**	**353.8**	**32**	**n/a**
	Upper Campbell Average		**3**	**44.2**	**4**	**0.12**
	Upper Campbell SD		**n/a**	**12.8**	**3**	**0.12**

Figure 11. Catch-per-unit-effort (CPUE) of Prickly Sculpin during minnow trapping from the Upper Campbell, Middle Quinsam, and Gooseneck lakes, 2014.



3.2.3. Individual Fish Analysis

Cutthroat Trout and Rainbow Trout captured in gill nets varied substantially in size. In Upper Campbell Reservoir, the fork length of Cutthroat Trout ranged from 127 mm to 459 mm, and Rainbow Trout ranged from 92 mm to 302 mm. The fork length of Cutthroat Trout captured in Gooseneck and Middle Quinsam lakes ranged from 132 mm to 286 mm and 132 mm to 329 mm, respectively. Length frequency histograms of Cutthroat Trout and Rainbow Trout captured in the Upper Campbell, Gooseneck, and Middle Quinsam lakes are presented in Figure 12, Figure 13, and Figure 14. The length-weight relationship for Cutthroat Trout and Rainbow Trout captured in the Upper Campbell, Gooseneck, and Middle Quinsam lakes are presented in Figure 15, Figure 16, and Figure 17.

In Upper Campbell Reservoir, our subsample of Cutthroat Trout ranged in age from one to seven years, and Rainbow Trout ranged in age from one to six years (Figure 18). Cutthroat Trout sampled from Gooseneck Lake were four to five years (Figure 19), while Cutthroat Trout from Middle Quinsam Lake ranged in age from two to six years (Figure 20). Length at age data from the scale analyses are presented for the Upper Campbell, Gooseneck, and Middle Quinsam lakes in Figure 18, Figure 19, and Figure 20, respectively.

Based on a review of the aging data, and length-frequency histogram, discrete fork length ranges were defined for each age class (Table 12). For example, in Upper Campbell Reservoir, 1+ Cutthroat Trout vary from 127 to 135 mm in length, while 7+ Cutthroat Trout are greater than 400 mm in length. These discrete fork length ranges allow all captured and measured fish to be assigned an age class based on fork length.

A summary of fish length, weight, and condition is presented for these age classes for the three lake systems in Table 13.

Figure 12. Length-frequency histogram of Cutthroat Trout and Rainbow Trout captured in the Upper Campbell Reservoir in August, 2014.

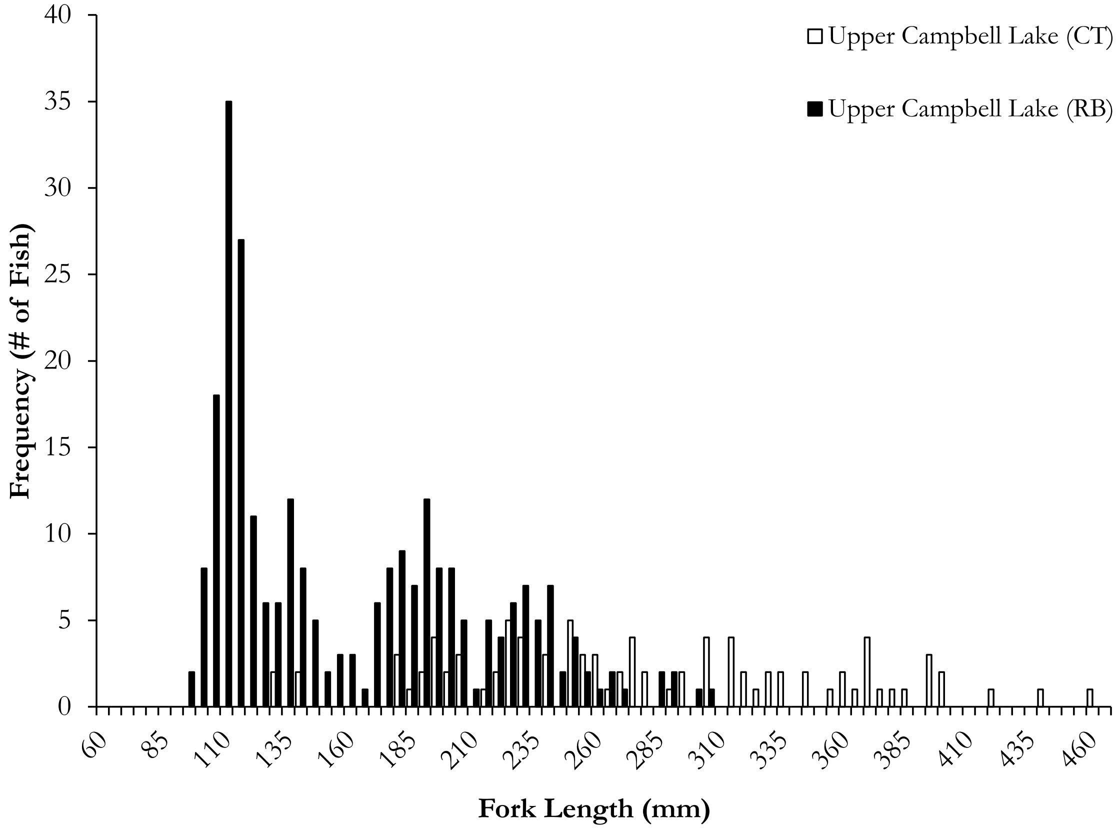


Figure 13. Length-frequency histogram of Cutthroat Trout captured in Gooseneck Lake in August, 2014.

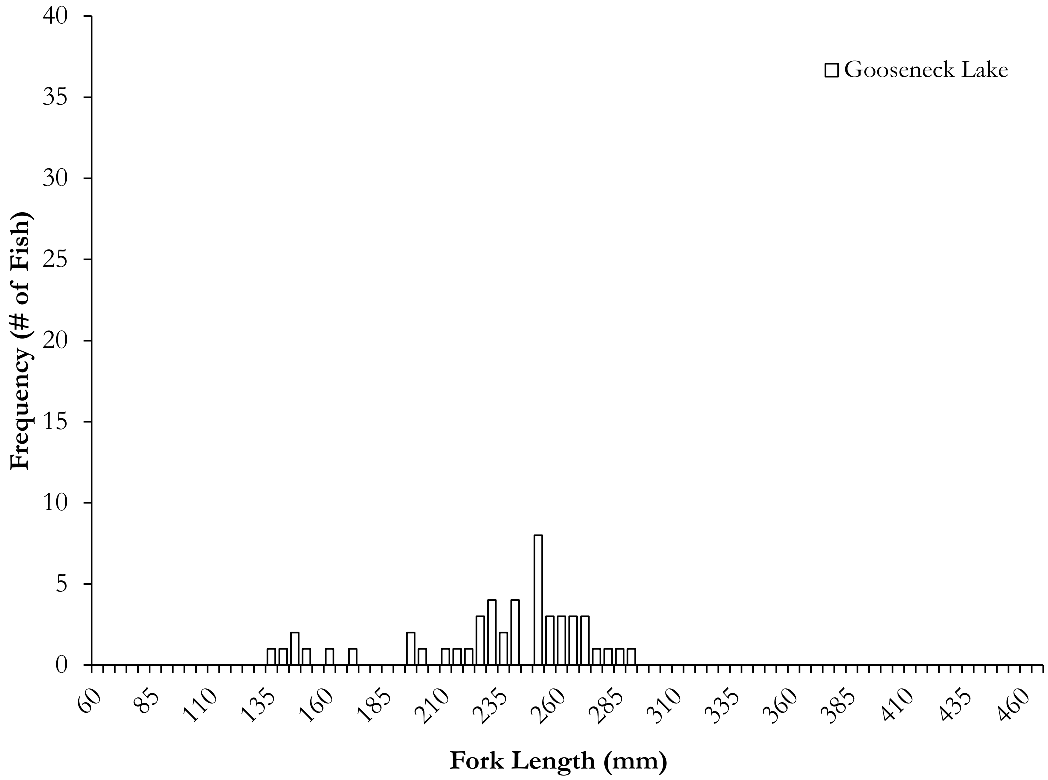


Figure 14. Length-frequency histogram of Cutthroat Trout captured in Middle Quinsam Lake in August, 2014.

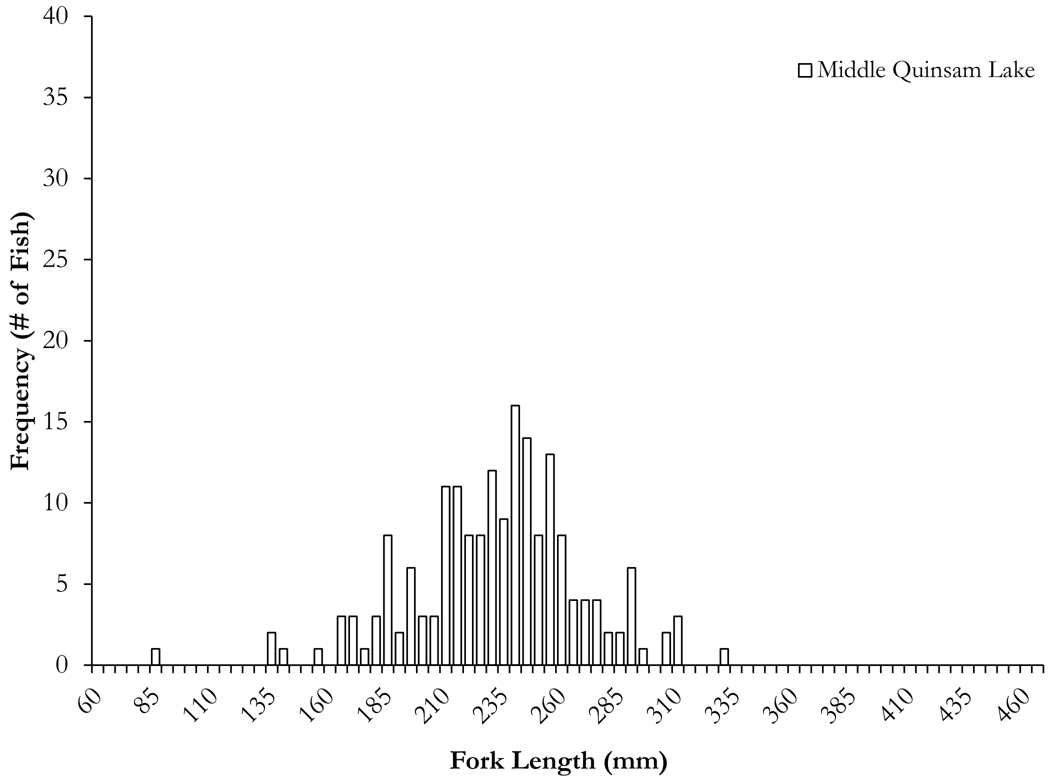


Figure 15. Length-weight regression for captured Cutthroat Trout and Rainbow Trout captured in the Upper Campbell Reservoir in August, 2014.

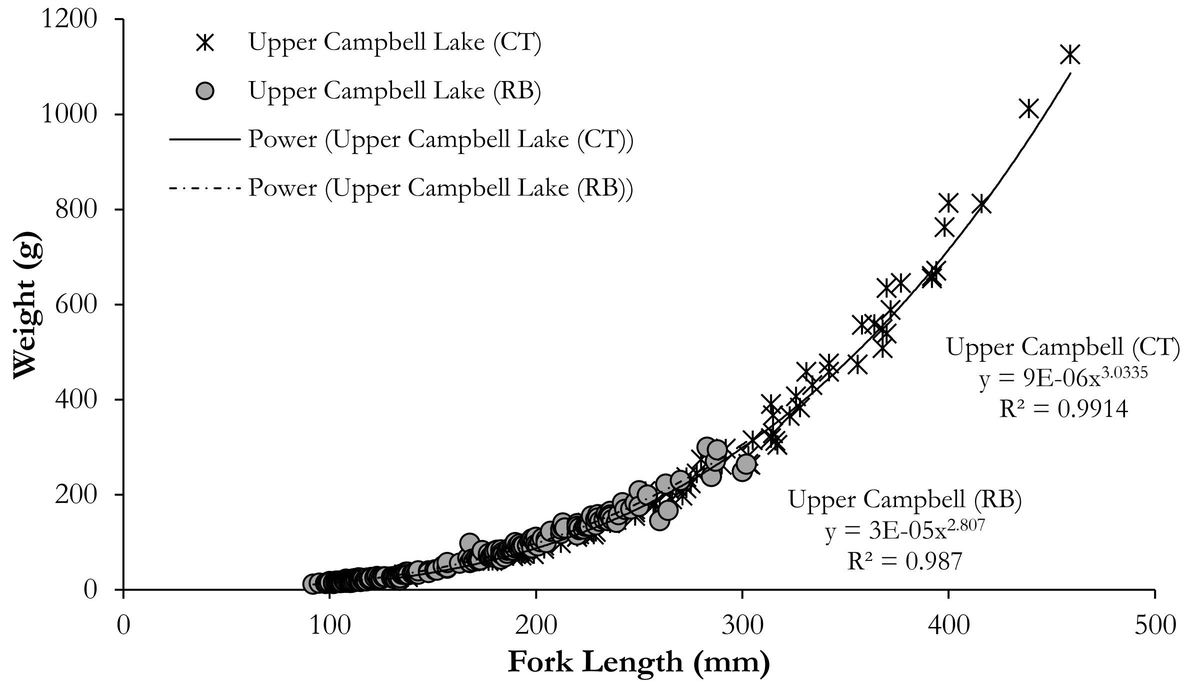


Figure 16. Length-weight regression for captured Cutthroat Trout captured in Gooseneck Lake in August, 2014.

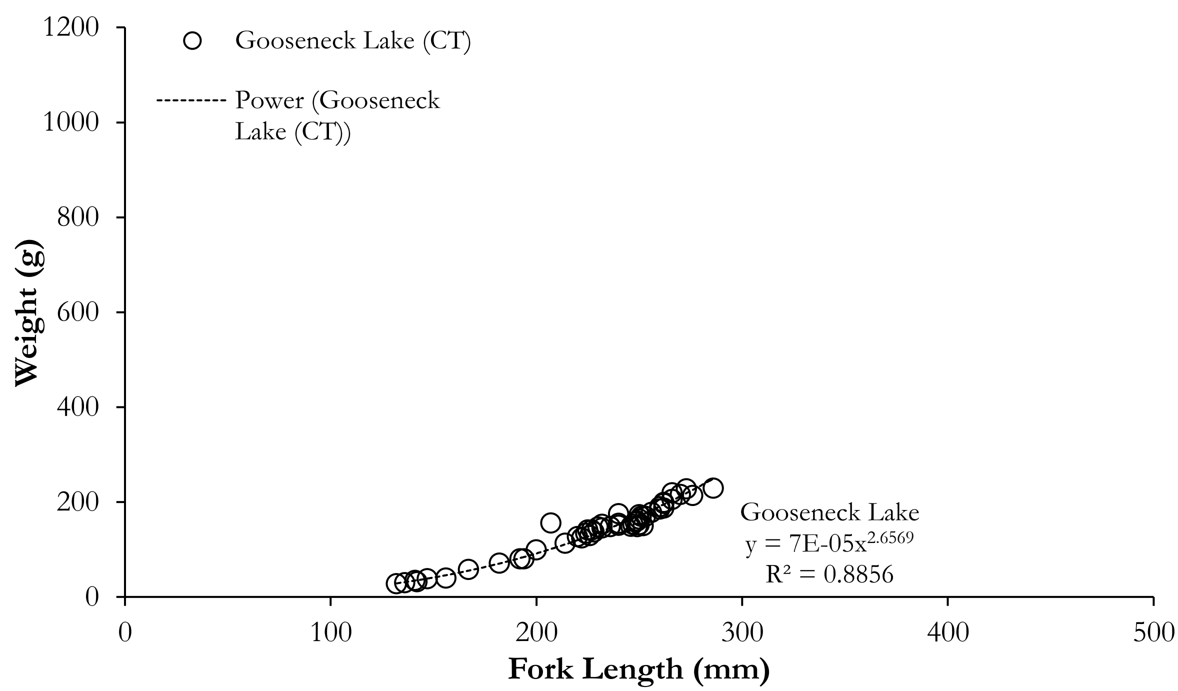


Figure 17. Length-weight regression for captured Cutthroat Trout captured in Middle Quinsam Lake in August, 2014.

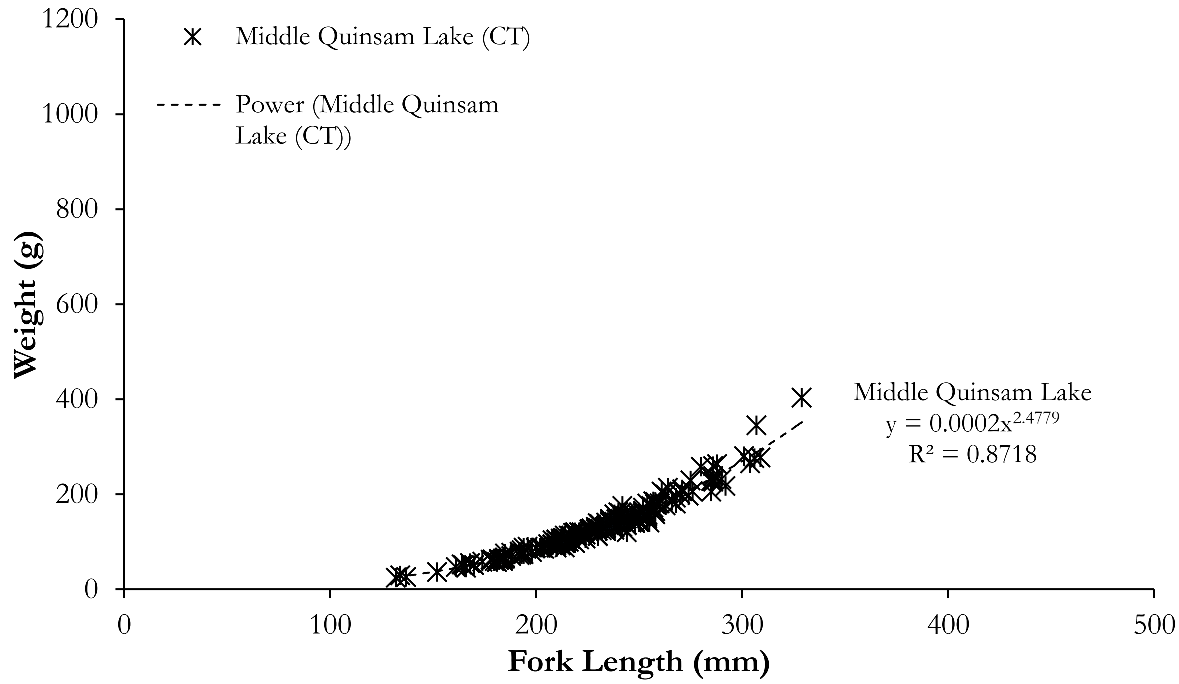


Figure 18. Length at age for Cutthroat Trout and Rainbow Trout in Upper Campbell Reservoir, 2014.

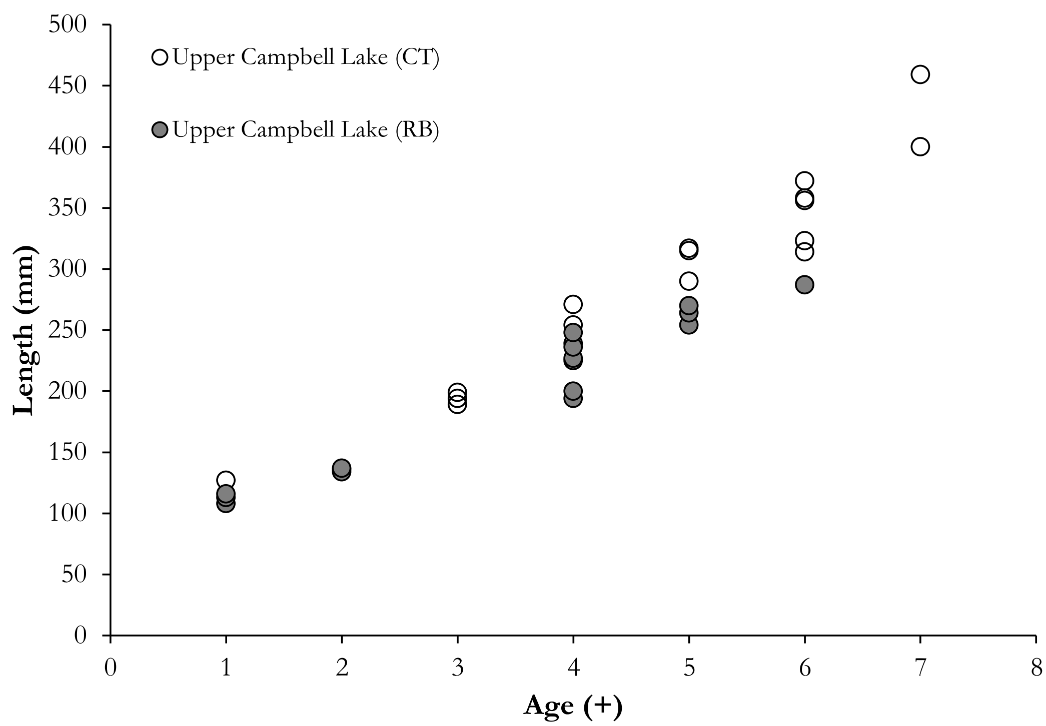


Figure 19. Length at age for Cutthroat Trout in Gooseneck Lake, 2014.

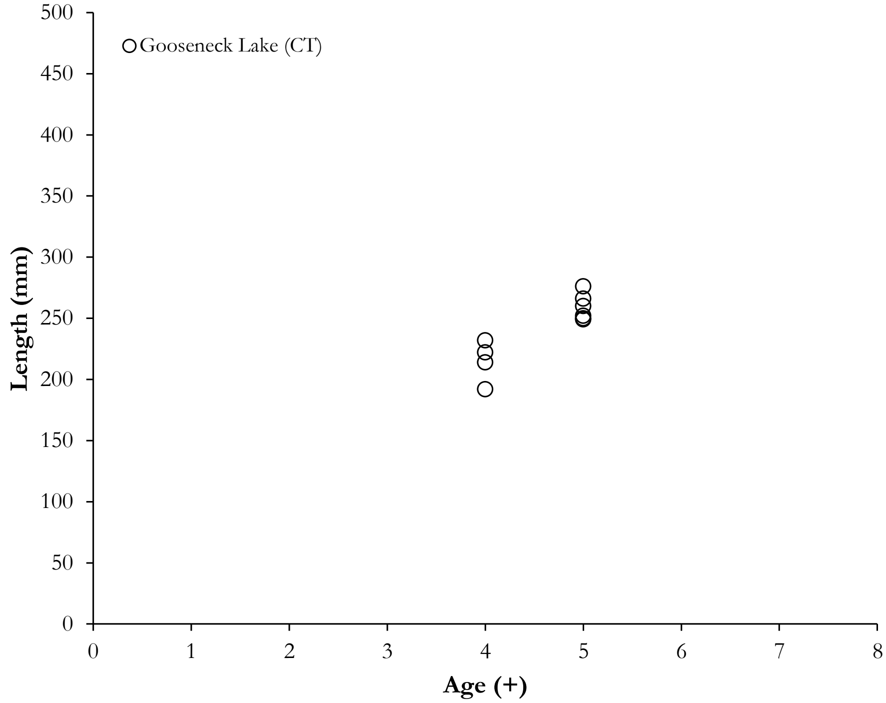


Figure 20. Length at age for Cutthroat Trout in Middle Quinsam Lake, 2014.

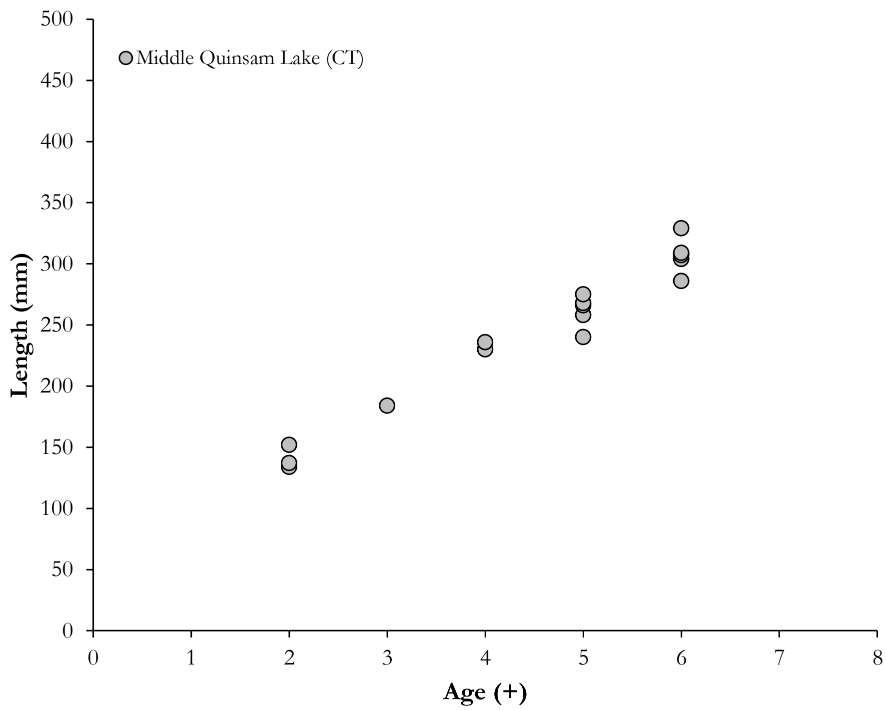


Table 12. Fork length ranges used to define age classes of Cutthroat Trout and Rainbow Trout in the Upper Campbell, Gooseneck, and Middle Quinsam lakes, 2014.

Age Class	Fork Length Range (mm)			
	Upper Campbell Lake (CT)	Upper Campbell Lake (RB)	Gooseneck Lake (CT)	Middle Quinsam Lake (CT)
Fry 0+	-	-	-	-
Parr (1+)	127 - 135	108 - 133	-	-
Parr (2+)	136 - 188	134 - 137	-	134 - 183
Adult (3+)	189 - 238	-	-	184 - 229
Adult (4+)	239 - 289	194 - 253	192 - 248	230 - 239
Adult (5+)	290 - 313	254 - 286	249 - 276	240 - 285
Adult (6+)	314 - 399	287+	-	286 - 329
Adult (7+)	400+	-	-	-

Table 13. Summary of fork length, weight, and condition for Cutthroat Trout and Rainbow Trout in the Upper Campbell, Gooseneck, and Middle Quinsam lakes, 2014.

Waterbody	Age Class	Fork Length (mm)				Weight (g)				Condition Factor (K)			
		n	Average	Min	Max	n	Average	Min	Max	n	Average	Min	Max
Gooseneck Lake (CT)	0+	0	n/a	n/a	n/a	0	n/a	n/a	n/a	0	n/a	n/a	n/a
	1+	1	132	132	132	1	28.0	28.0	28.0	1	1.2	1.2	1.2
	2+	7	153	136	182	7	43.4	30.0	71.0	6	1.2	1.1	1.2
	3+	0	n/a	n/a	n/a	0	n/a	n/a	n/a	0	n/a	n/a	n/a
	4+	16	219	192	236	16	128.4	80.0	156.0	16	1.2	1.1	1.8
	5+	25	255	240	276	25	177.8	148.0	228.0	25	1.1	0.9	1.3
	6+	1	286	286	286	1	229.0	229.0	229.0	1	1.0	1.0	1.0
	7+	0	n/a	n/a	n/a	0	n/a	n/a	n/a	0	n/a	n/a	n/a
	Combined	50	228	132	286	50	141.2	28.0	229.0	49	1.1	0.9	1.8
Middle Quinsam Lake (CT)	0+	1	132	132	132	1	24.0	24.0	24.0	1	1.0	1.0	1.0
	1+	16	167	134	182	16	50.9	26.0	64.0	16	1.1	1.0	1.2
	2+	8	185	184	188	8	67.3	59.0	77.0	7	1.1	0.9	1.2
	3+	82	219	192	239	82	112.3	72.0	158.0	82	1.1	0.9	1.2
	4+	64	254	240	285	64	167.5	120.0	258.0	64	1.0	0.8	1.2
	5+	13	298	286	329	13	270.2	217.0	403.0	13	1.0	0.9	1.2
	6+	184	231	132	329	184	134.9	24.0	403.0	183	1.0	0.8	1.2
	7+	0	n/a	n/a	n/a	0	n/a	n/a	n/a	0	n/a	n/a	n/a
	Combined	234	230	132	329	234	136.2	24.0	403.0	232	1.1	0.8	1.8
Upper Campbell Lake (CT)	0+	0	n/a	n/a	n/a	0	n/a	n/a	n/a	0	n/a	n/a	n/a
	1+	2	127	127	127	2	25	22	28	2	1	1	1
	2+	5	161	136	179	5	47	26	61	5	1	1	1
	3+	3	188	185	190	3	74	70	79	3	1	1	1
	4+	24	216	192	239	23	111	71	152	23	1	1	1
	5+	20	261	246	280	19	199	154	273	19	1	1	1
	6+	35	341	290	398	32	452	262	762	32	1	1	1
	7+	4	429	400	459	4	940	811	1125	4	1	1	1
	Combined	93	276	127	459	88	285	22	1125	88	1	1	1
Upper Campbell Lake (RB)	0+	38	103	92	107	34	16	12	20	34	1	1	2
	1+	81	116	108	133	69	21	15	28	69	1	1	2
	2+	55	159	134	183	54	53	20	98	53	1	1	2
	3+	16	188	184	191	16	85	69	99	16	1	1	1
	4+	53	215	192	239	53	124	88	165	53	1	1	1
	5+	16	256	240	285	15	196	145	300	15	1	1	1
	6+	4	294	287	302	4	269	249	294	4	1	1	1
	7+	0	n/a	n/a	n/a	0	n/a	n/a	n/a	0	n/a	n/a	n/a
	Combined	263	159	92	302	245	69	12	300	1	2	0	0

3.2.4. Stomach Contents

Stomach content results for Cutthroat Trout and Rainbow Trout sampled from Upper Campbell, Gooseneck and Middle Quinsam lakes are shown in Table 14. In Upper Campbell Reservoir, Cutthroat Trout stomachs (n = 4) contained Sculpin spp and Threespine Stickleback, whereas Rainbow Trout stomachs (n = 6) contained littoral invertebrates and zooplankton. In Gooseneck Lake, Cutthroat Trout stomachs (n = 10) contained more than 50% zooplankton, followed by littoral invertebrates. In Middle Quinsam Lake, Cutthroat Trout stomachs (n = 12) contained mostly littoral invertebrates.

Table 14. Stomach content results for Cutthroat Trout and Rainbow Trout sampled from Upper Campbell, Gooseneck and Middle Quinsam lakes, 2014.

Diet item	Upper Campbell Reservoir		Gooseneck Lake	Middle Quinsam Lake
	Cutthroat Trout	Rainbow Trout	Cutthroat Trout	Cutthroat Trout
Littoral invertebrates	1.2%	41.7%	35.6%	87.5%
Zooplankton	0.0%	58.3%	53.3%	4.2%
Fish	98.8%	0.0%	11.1%	8.3%

3.3. Stable Isotope Data

3.3.1. Summary of Stable Isotope Signatures by Taxa

Nitrogen and carbon stable isotope signatures of all fish and invertebrates were similar among all three lakes (Figure 21). Large Cutthroat Trout and Rainbow Trout had the highest $\delta^{15}N$ levels consistent with their top position within lake food webs, followed by smaller prey fish with intermediate trophic level positions (Figure 22). Littoral invertebrates and zooplankton had the lowest $\delta^{15}N$ signatures consistent with their lower relative food web positions. Zooplankton in particular had the lowest $\delta^{13}C$ levels consistent with their pelagic habitat, while benthic, stream, and terrestrial invertebrates had higher $\delta^{13}C$ isotopic signatures, consistent with their terrestrial and benthic sources of carbon in diet (Figure 23). Among the small prey fish, Threespine Stickleback had the lowest $\delta^{13}C$ levels indicative of a pelagic dominated diet, whereas juvenile trout and Sculpin spp. had $\delta^{13}C$ values that overlapped with the littoral invertebrates. Dolly Varden had high $\delta^{15}N$ levels consistent with a piscivorous diet but had the lowest $\delta^{13}C$ compared to large Cutthroat and Rainbow Trout. Rainbow Trout also had lower $\delta^{13}C$ values than Cutthroat Trout indicating that Rainbow Trout may have a higher pelagic contribution to diet than Cutthroat Trout.

Figure 21. Carbon – nitrogen stable isotope bi-plots (mean ± SD) of fish and invertebrates from Upper Campbell, Gooseneck, and Middle Quinsam lakes.

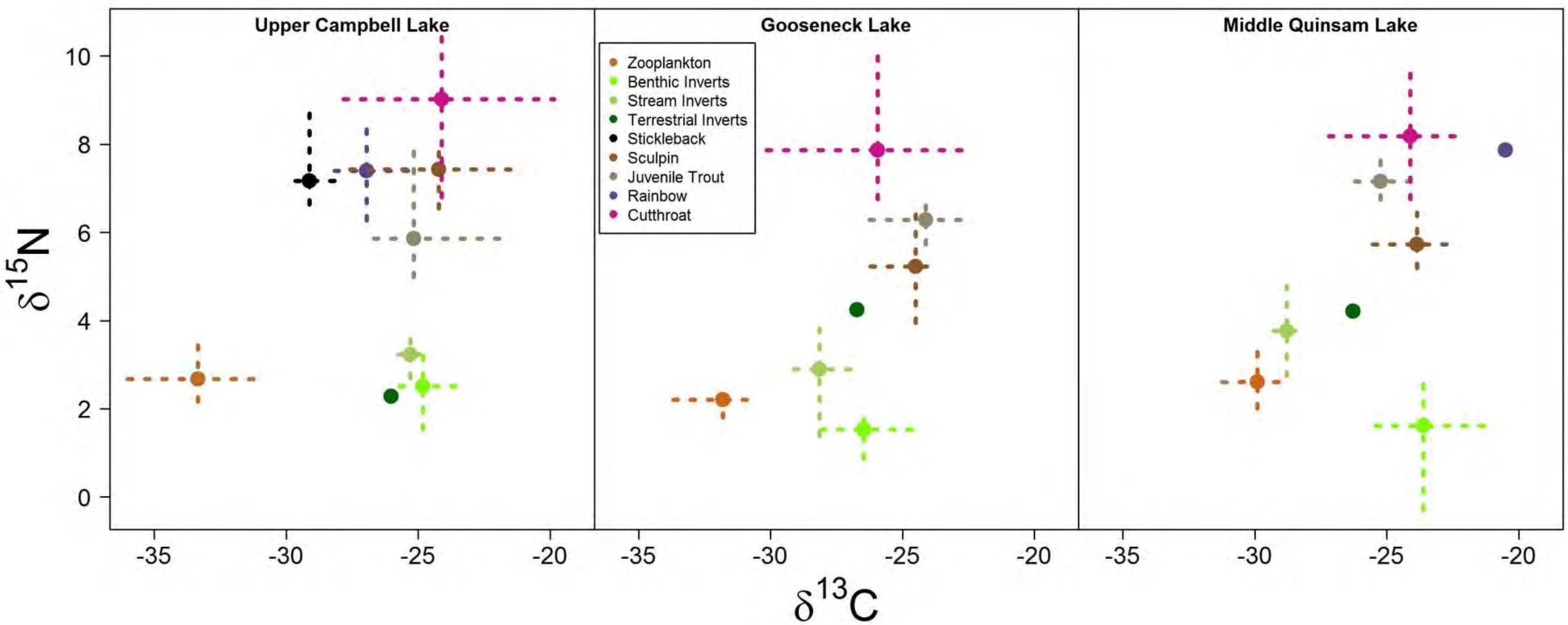


Figure 22. **Average $\delta^{15}N$ stable isotope signatures in all taxa sampled across all three lakes. ZOO = Zooplankton, BI = Benthic Invertebrates, SI = Stream Invertebrates, TI = Terrestrial Invertebrates, TSB = Threespine Stickleback, SC = Sculpin spp., JT = Juvenile Trout, DV = Dolly Varden, RB = Rainbow Trout > 190 mm, CT = Cutthroat Trout > 190 mm.**

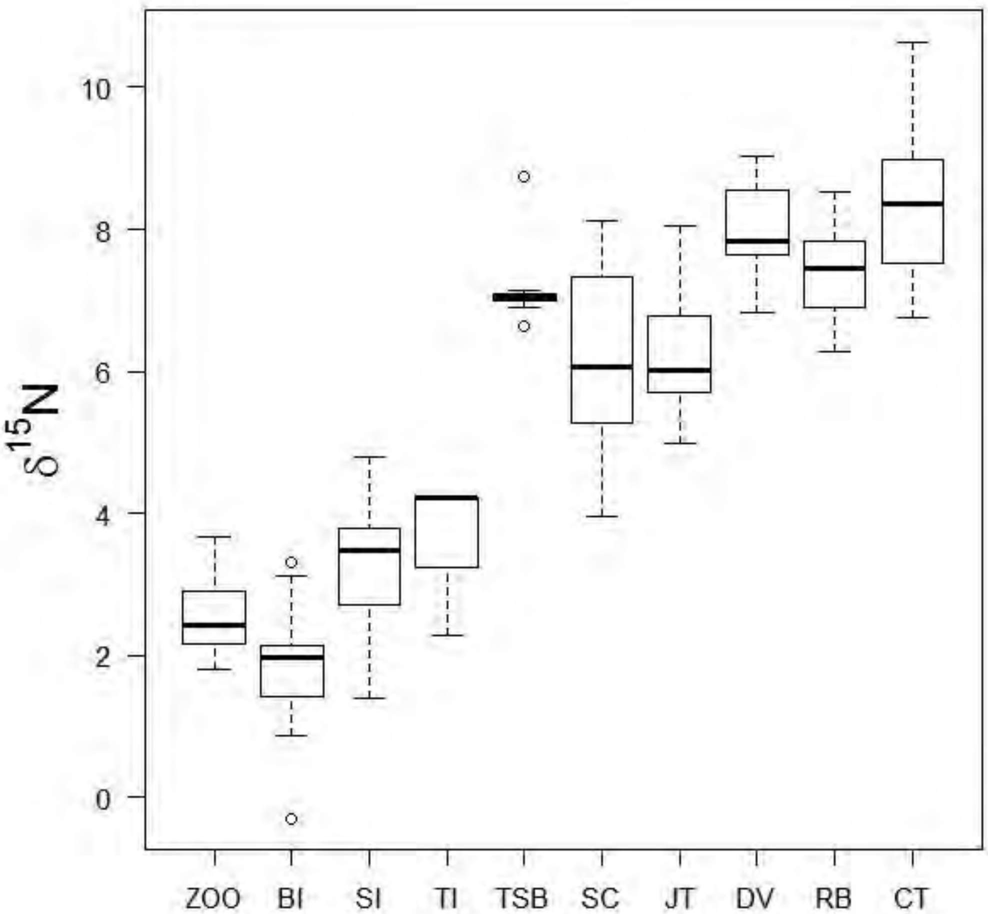
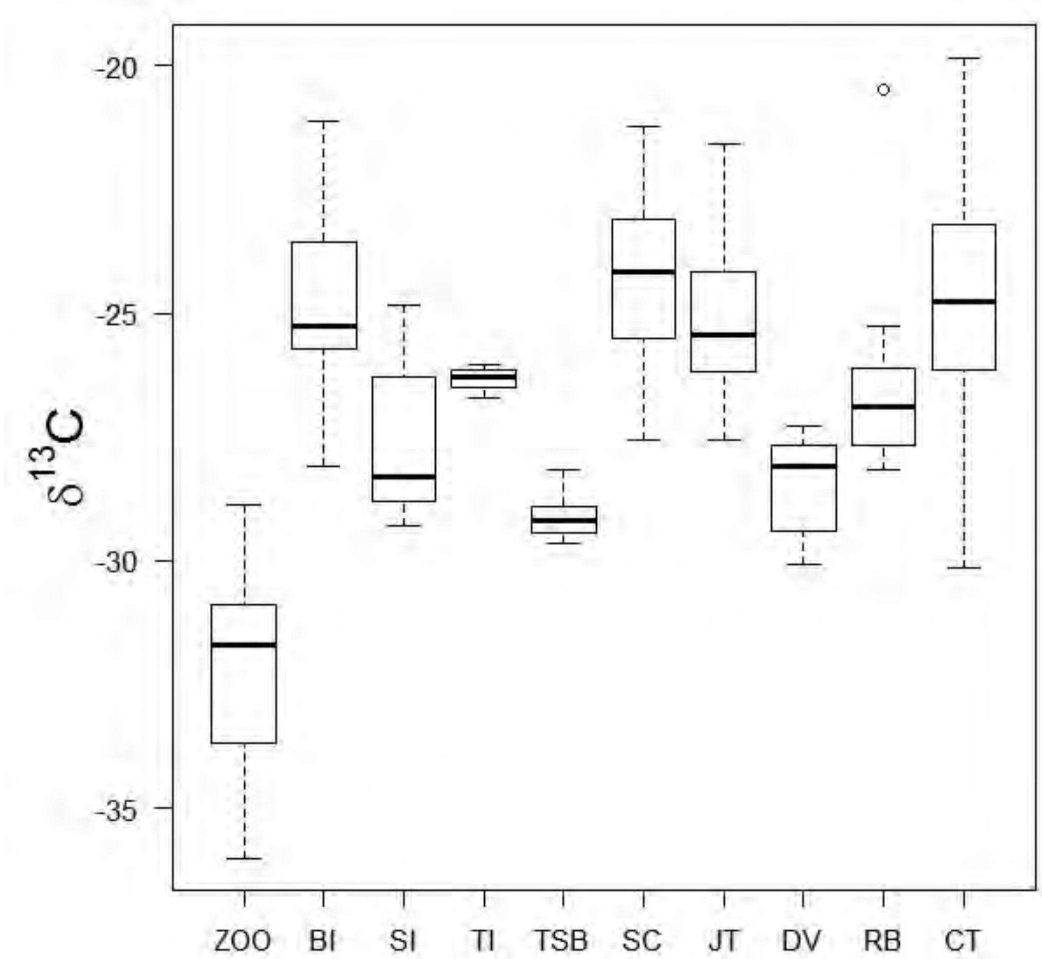


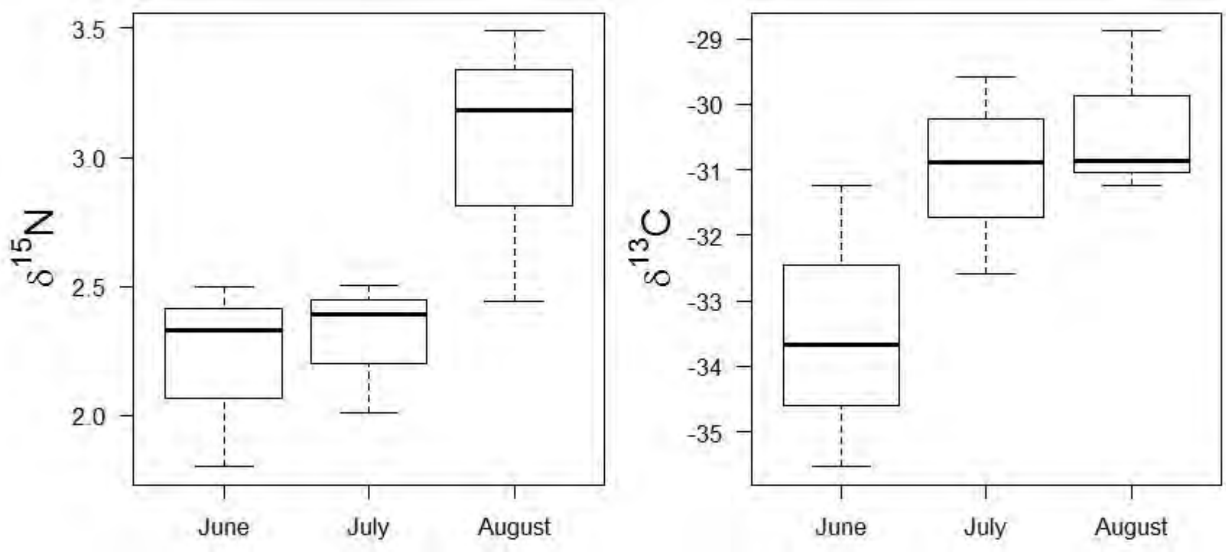
Figure 23. Average $\delta^{13}C$ stable isotope signatures in all taxa sampled across all three lakes. ZOO = Zooplankton, BI = Benthic Invertebrates, SI = Stream Invertebrates, TI = Terrestrial Invertebrates, TSB = Threespine Stickleback, SC = Sculpin spp., JT = Juvenile Trout, DV = Dolly Varden, RB = Rainbow Trout > 190 mm, CT = Cutthroat Trout > 190 mm.



3.3.2. Seasonal Variation in Zooplankton

Nitrogen and carbon stable isotope signatures in bulk zooplankton varied by month of collection. Across all lakes, $\delta^{15}N$ signatures in zooplankton were significantly higher in August compared to June or July (Figure 24, ANOVA: $F_{2,9} = 4.6$, $p = 0.043$). $\delta^{13}C$ signatures in zooplankton were significantly higher in both July and August compared to June (Figure 24, ANOVA: $F_{2,9} = 47.4$, $p < 0.0001$). $\delta^{15}N$ signatures in zooplankton did not differ by lake, whereas $\delta^{13}C$ signatures in zooplankton were significantly higher in Middle Quinsam Lake than in Gooseneck or Upper Campbell Lake (ANOVA: $F_{2,9} = 40.5$, $p < 0.0001$).

Figure 24. Monthly variation in the $\delta^{15}N$ and $\delta^{13}C$ stable isotope signatures in zooplankton across all three lakes.



3.3.3. Assessing Fish Diet Using Mixing Models

Mean estimates of diet contributions of pelagic and littoral sources to fish diets were fairly similar across the three lakes and are discussed for each lake in the sections below.

3.3.3.1. Upper Campbell Reservoir

In Upper Campbell Reservoir, Cutthroat Trout (age >2+) diets were dominated by prey fish species, in particular Sculpin, followed by juvenile trout and Threespine Stickleback (40%, 19%, and 18% diet contributions respectively) (Figure 25, Table 15). This is consistent with the biology of Cutthroat Trout as a top predator. Zooplankton and the three littoral invertebrate groups each made up less than 7% of Cutthroat Trout diet. In contrast, Rainbow Trout diets had a much higher prevalence of zooplankton (28%) and Threespine Stickleback (24%) and less Sculpin and juvenile trout (≤11%) in their diets.

These patterns in Cutthroat Trout and Rainbow Trout diet are similar to that observed in the stomach contents. Cutthroat Trout had a high percentage of fish (95%) in stomach contents, and Rainbow Trout had a high percentage of zooplankton (58%).

Invertebrate contributions to diets of Sculpin, juvenile trout and Threespine Stickleback differed by species (Figure 26, Table 15). Juvenile trout and Sculpin diets were dominated by littoral invertebrates (23-34% for each of the three littoral invertebrate groups at each lake), and Threespine Stickleback diets were dominated by zooplankton (60%). Based on these results for prey fish, only 15-18% of juvenile trout and Sculpin diets are pelagic, with the remainder of their diets made up of littoral invertebrate sources. In contrast, pelagic zooplankton makes up 60 % of Threespine Stickleback diets.

Figure 25. **Estimated proportions of invertebrate and vertebrate diet sources to Cutthroat Trout and Rainbow Trout in Upper Campbell Reservoir. Estimates are means with 5% and 95% quartile ranges of posterior probability distributions from carbon – nitrogen Bayesian mixing models based on isotopic signatures from these consumers and their potential diet sources.**

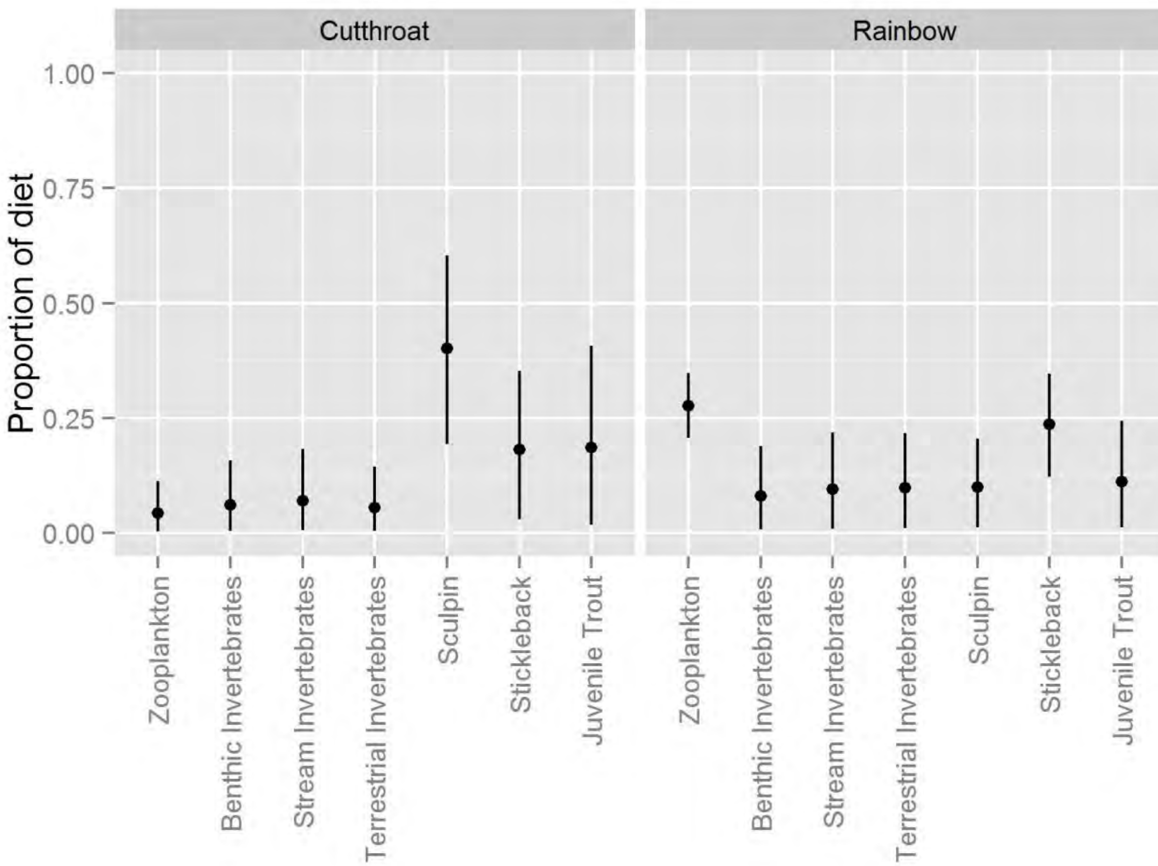


Figure 26. Estimated proportions of invertebrate diet sources to prey fish in Upper Campbell Reservoir. Estimates are calculated as means with 5% and 95% quartile ranges of posterior probability distributions from carbon – nitrogen Bayesian mixing models based on isotopic signatures from prey fish and their potential diet sources.

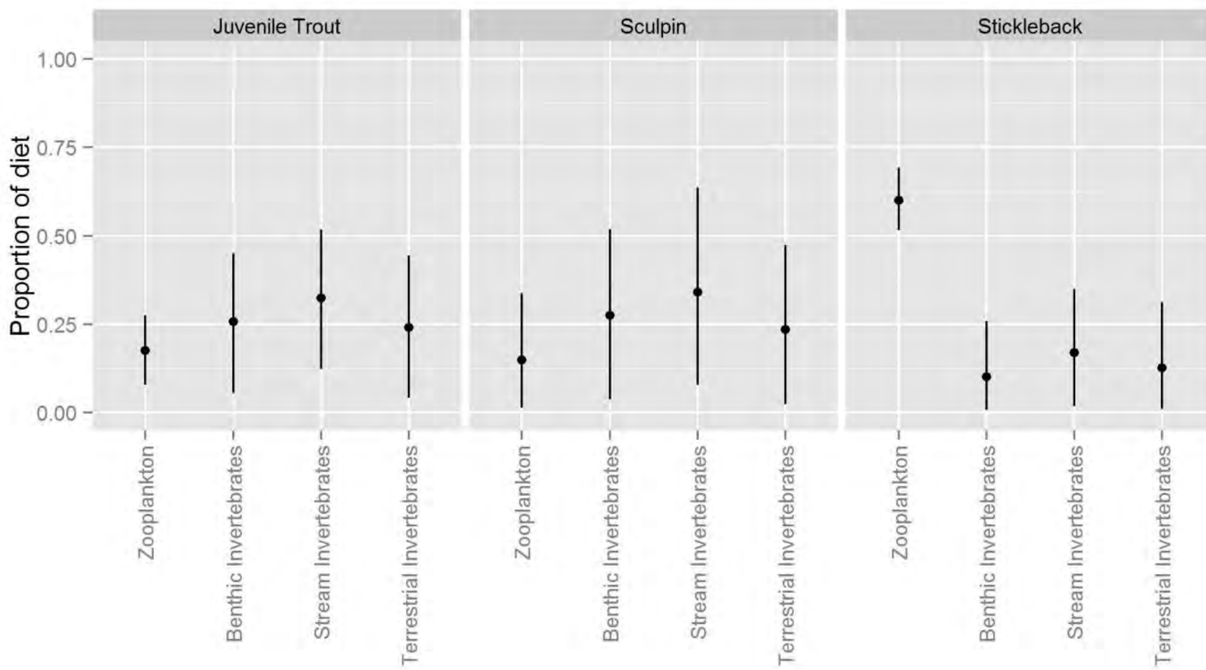


Table 15. Estimated diet contributions of A) pelagic and littoral invertebrates to Cutthroat Trout, Rainbow Trout and smaller prey fish species, and B) smaller prey fish species to Cutthroat Trout and Rainbow Trout in Upper Campbell, Gooseneck and Middle Quinsam lakes. Estimates are calculated as means with 5% and 95% quartile range of posterior distributions from carbon – nitrogen Bayesian mixing models based on isotopic signatures from these consumers and their potential diet sources.

A)

Waterbody	Consumer	Estimated Invertebrate Diet Contributions											
		Pelagic			Littoral								
		Zooplankton			Benthic Invertebrates			Stream Invertebrates			Terrestrial Invertebrates		
		Mean	Q 5%	Q 95%	Mean	Q 5%	Q 95%	Mean	Q 5%	Q 95%	Mean	Q 5%	Q 95%
Upper Campbell Lake	Cutthroat Trout	0.04	0.00	0.11	0.06	0.00	0.16	0.07	0.01	0.19	0.06	0.00	0.14
	Rainbow Trout	0.28	0.21	0.35	0.08	0.01	0.19	0.09	0.01	0.22	0.10	0.01	0.22
	Juvenile Trout	0.18	0.08	0.28	0.26	0.06	0.45	0.32	0.12	0.52	0.24	0.04	0.44
	Sculpin	0.15	0.01	0.34	0.27	0.04	0.52	0.34	0.07	0.64	0.24	0.02	0.48
	Stickleback	0.60	0.52	0.69	0.10	0.01	0.26	0.17	0.02	0.35	0.12	0.01	0.31
Gooseneck Lake	Cutthroat Trout	0.21	0.07	0.34	0.03	0.00	0.10	0.09	0.01	0.25	0.16	0.01	0.36
	Juvenile Trout	0.13	0.01	0.33	0.25	0.04	0.46	0.23	0.03	0.45	0.40	0.18	0.62
	Sculpin	0.09	0.01	0.27	0.42	0.20	0.65	0.20	0.02	0.42	0.30	0.08	0.50
Middle Quinsam Lake	Cutthroat Trout	0.08	0.01	0.18	0.06	0.01	0.15	0.10	0.01	0.23	0.16	0.02	0.33
	Juvenile Trout	0.17	0.02	0.36	0.21	0.04	0.38	0.26	0.04	0.47	0.36	0.10	0.63
	Sculpin	0.17	0.02	0.37	0.36	0.16	0.55	0.19	0.02	0.38	0.29	0.07	0.50

B)

Waterbody	Consumer	Estimated Vertebrate Diet Contributions								
		Threespine Stickleback			Sculpins			Juvenile Trout		
		Mean	Q 5%	Q 95%	Mean	Q 5%	Q 95%	Mean	Q 5%	Q 95%
Upper Campbell Lake	Cutthroat Trout	0.18	0.03	0.35	0.40	0.20	0.60	0.19	0.02	0.41
	Rainbow Trout	0.24	0.12	0.35	0.10	0.01	0.21	0.11	0.01	0.25
Gooseneck Lake	Cutthroat Trout	NA			0.15	0.01	0.34	0.35	0.17	0.53
Middle Quinsam Lake	Cutthroat Trout				0.26	0.08	0.43	0.34	0.20	0.49

3.3.3.2. Gooseneck Lake and Middle Quinsam Lake

Similar to Upper Campbell Reservoir, prey fish made up the majority of Cutthroat Trout (age >2+) diets in Gooseneck and Middle Quinsam lakes (Figure 27, Table 15). Juvenile trout in particular were the dominant source to Cutthroat Trout diet in both lakes (35% and 34% in Gooseneck Lake and Middle Quinsam Lake respectively). Zooplankton contributed little to Cutthroat Trout diet in Middle Quinsam Lake (7%), but make up 21% of Cutthroat Trout diet in Gooseneck Lake. Littoral invertebrates from each group (benthic, stream, terrestrial) contributed from 3% to 16% of the diet in Cutthroat Trout across both lakes.

These diet estimates for Cutthroat Trout are somewhat similar to the stomach content analysis results in that stomach contents also showed a higher proportion of zooplankton in Cutthroat Trout diet at Gooseneck Lake (53%) compared to Middle Quinsam Lake (4%).

Juvenile trout diets were dominated by terrestrial invertebrates (40% and 36% in Gooseneck and Middle Quinsam lakes respectively), followed by benthic and stream invertebrates (21-26%) (Figure 28, Table 15). Zooplankton made up the lowest proportion of juvenile trout diets in both lakes (13-17%). Sculpin diets were dominated by benthic invertebrates (36-42%), followed by terrestrial invertebrates (29-30%), stream invertebrates (19-20%) and zooplankton (9-17%).

Figure 27. Estimated proportions of invertebrate and vertebrate diet sources to Cutthroat Trout in Gooseneck Lake and Middle Quinsam Lake. Estimates are means with 5% and 95% quartile ranges of posterior probability distributions from carbon – nitrogen Bayesian mixing models based on isotopic signatures from these consumers and their potential diet sources.

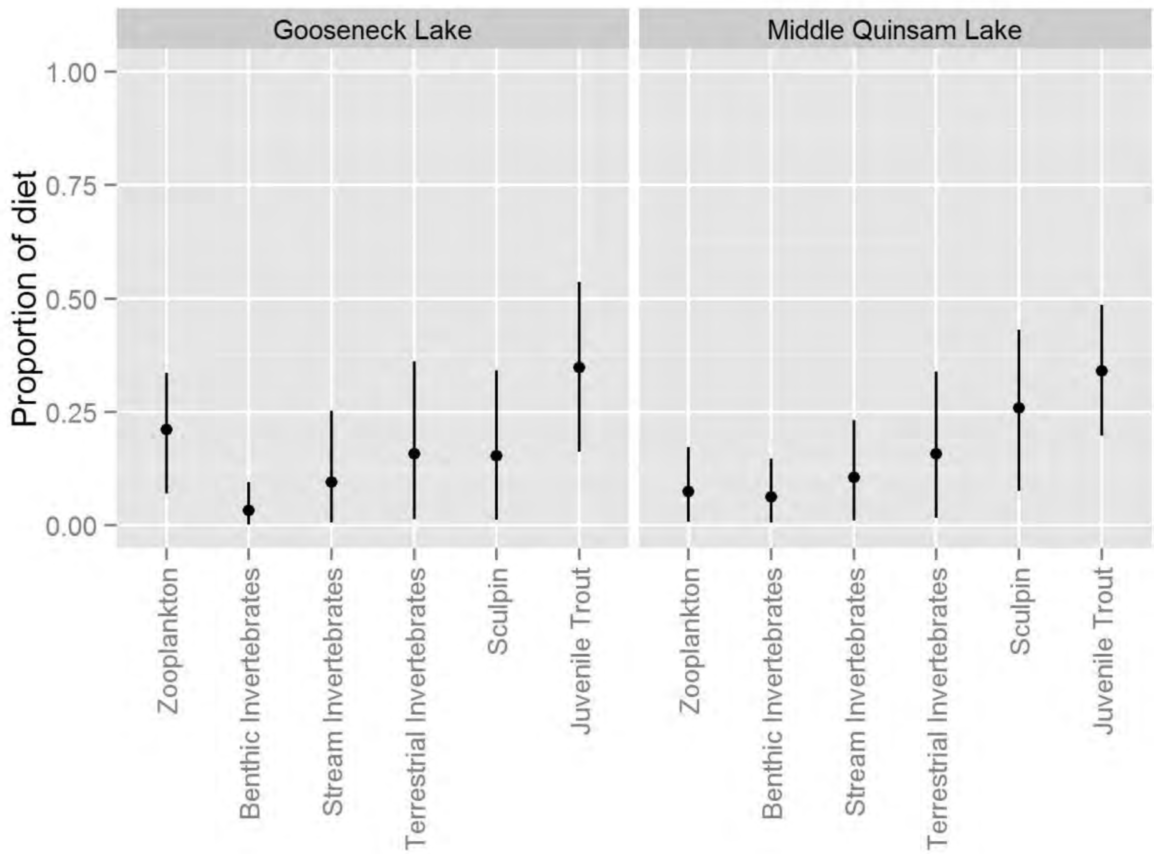
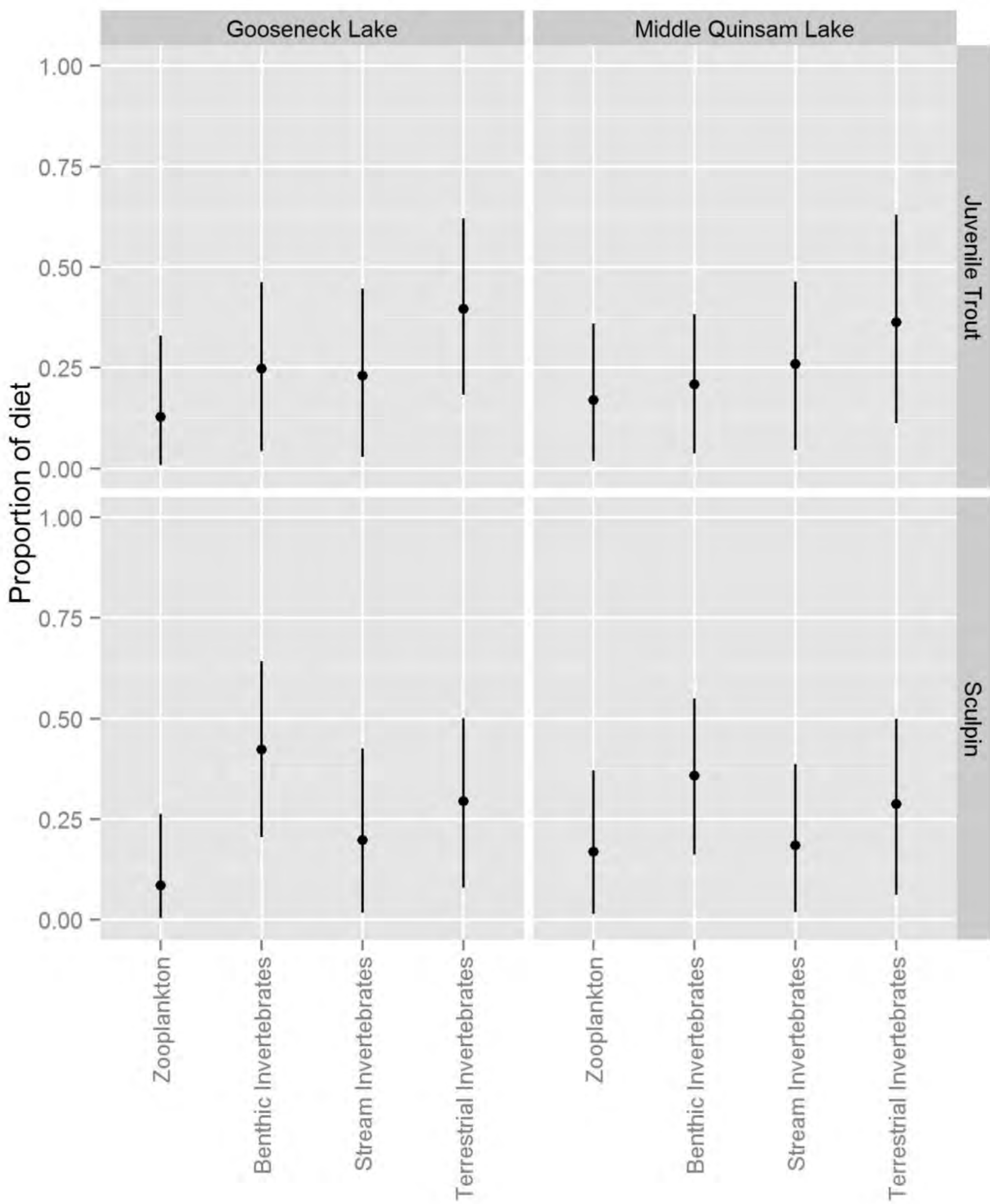


Figure 28. Estimated proportions of invertebrate diet sources to prey fish in Gooseneck Lake and Middle Quinsam Lake. Estimates are calculated as means with 5% and 95% quartile ranges of posterior probability distributions from carbon – nitrogen Bayesian mixing models based on isotopic signatures from prey fish and their potential diet sources.



3.3.4. Correlations with Fish Size and Age

Cutthroat Trout and Rainbow Trout $\delta^{15}N$ signatures are both highly positively correlated to fork length in Upper Campbell Reservoir (Figure 29, Cutthroat $F_{1,20} = 48.6$, Rainbow $F_{1,26} = 138.4$, both $p<0.0001$). This indicates that larger Cutthroat Trout and Rainbow Trout are more piscivorous and eat higher in the food web than smaller individuals. Cutthroat Trout $\delta^{13}C$ signatures are not related to fork length ($F_{1,20} = 0.3$, $p = 0.58$), while Rainbow Trout $\delta^{13}C$ signatures are negatively related to fork length ($F_{1,26} = 5.9$, $p = 0.022$). For Rainbow Trout in Upper Campbell Reservoir, this suggests that larger fish have more pelagic diets than Rainbow Trout juveniles.

Cutthroat Trout $\delta^{15}N$ signatures were also positively related to fork length in both Gooseneck Lake ($F_{1,18} = 4.3$, $p = 0.05$) and Middle Quinsam Lake ($F_{1,18} = 12.9$, $p = 0.002$) (Figure 30). Cutthroat Trout $\delta^{13}C$ signatures were not strongly related to fork length in Gooseneck Lake ($F_{1,18} = 1.1$, $p = 0.30$), but were weakly positively related to fork length in Middle Quinsam Lake ($F_{1,18} = 4.2$, $p = 0.06$). For Cutthroat Trout in Middle Quinsam Lake, this suggests that larger fish have more littoral diets than smaller individuals.

Across all three lakes, Cutthroat Trout and Rainbow Trout $\delta^{15}N$ signatures increased with increasing fish age ($F_{1,55} = 63.3$, $p < 0.0001$). In contrast, $\delta^{13}C$ signatures did not vary strongly with fish age ($F_{1,55} = 3.1$, $p = 0.08$).

Figure 29. $\delta^{15}N$ and $\delta^{13}C$ stable isotope signatures by fork length (mm) in Cutthroat Trout and Rainbow Trout from Upper Campbell Lake.

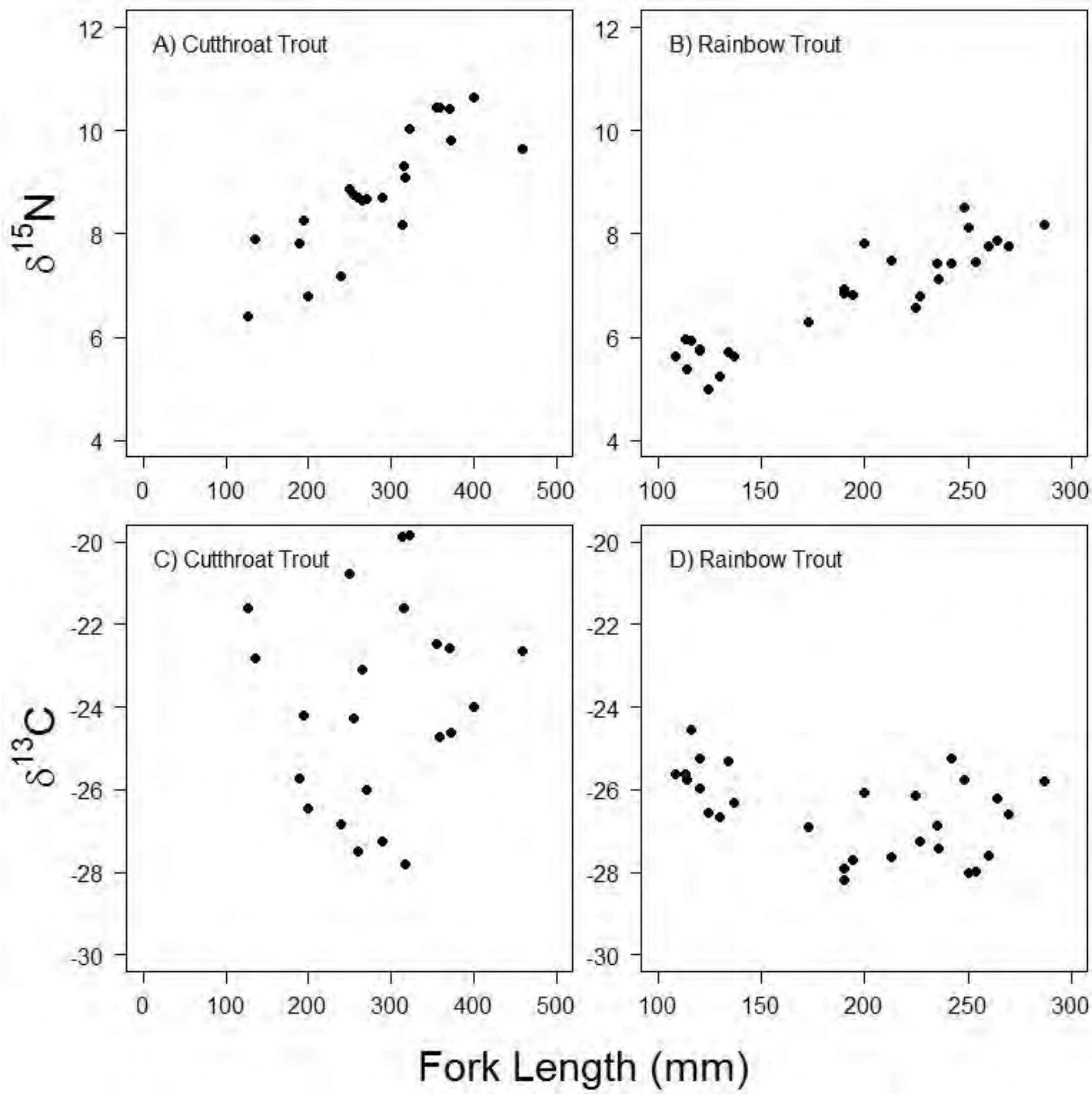
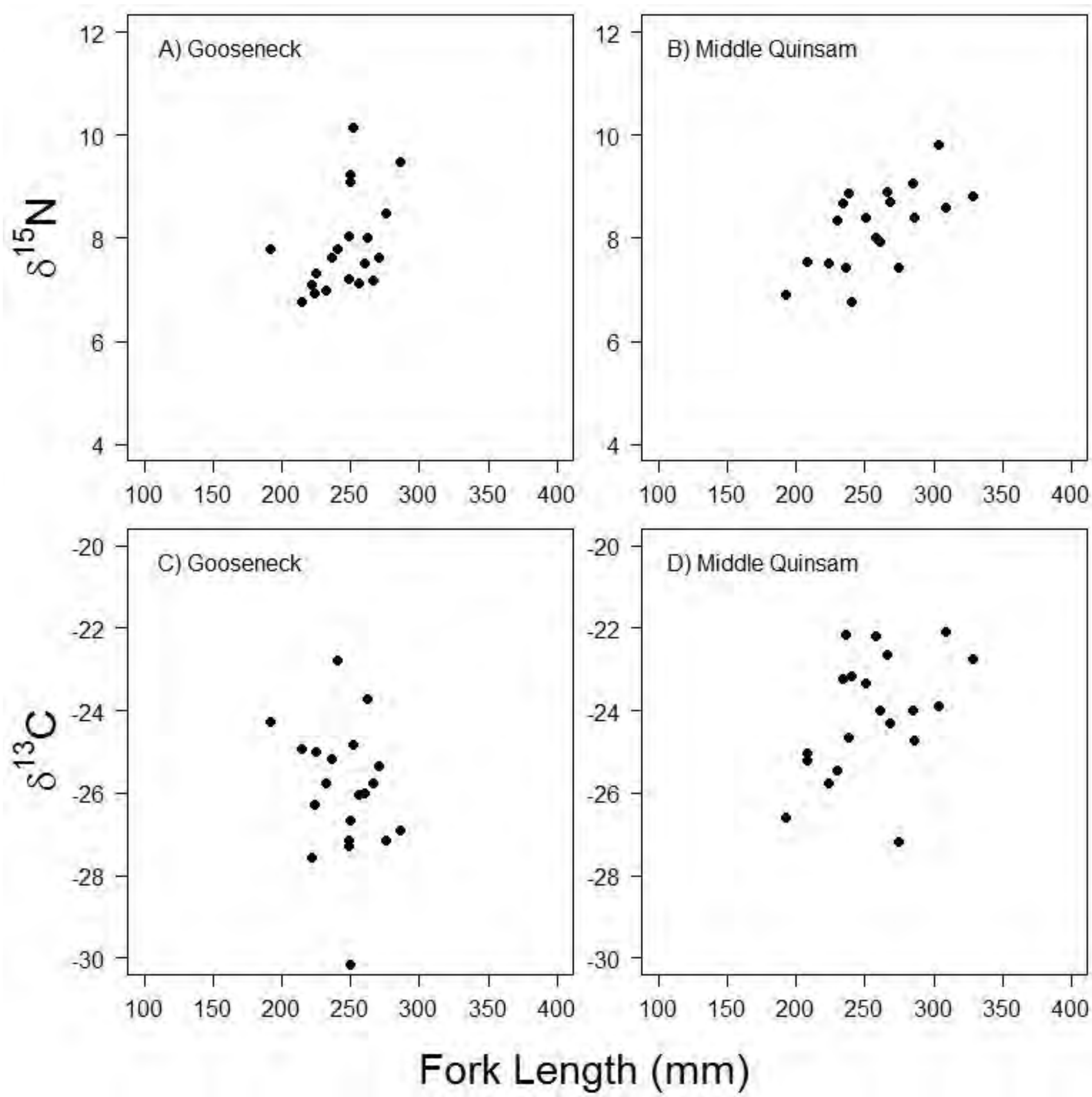


Figure 30. $\delta^{15}N$ and $\delta^{13}C$ stable isotope signatures by fork length (mm) in Cutthroat Trout from Gooseneck Lake and Middle Quinsam Lake.



3.4. Analysis of Management Questions

3.4.1. Reservoir Levels and Benefits to Fish Populations

The total littoral vs. pelagic contribution to Cutthroat Trout and Rainbow Trout diet for Upper Campbell Reservoir can be estimated by summing the contributions of the invertebrate prey to Cutthroat Trout and Rainbow Trout diet (direct pathway) with the relative contributions of invertebrate prey to the small fish in the Cutthroat Trout and Rainbow Trout diet (indirect pathway). Using this method, a total of 24% of the diet of Cutthroat Trout (age >2+) in Upper Campbell Reservoir is estimated derived from pelagic sources while 76% is estimated derived from littoral sources (Table 16). In contrast, Rainbow Trout have a pelagic contribution to diet of 45% and a littoral contribution to diet of 55%.

3.4.2. Water Residence Time and Lake Productivity

The total littoral vs. pelagic contribution to Cutthroat Trout diet for Gooseneck and Middle Quinsam lakes can be estimated by summing the contributions of the invertebrate prey to Cutthroat Trout diet (direct pathway) with the relative contributions of invertebrate prey to the small fish in Cutthroat Trout diet (indirect pathway). Using this method, a total of 27% of the diet of Cutthroat Trout (age >2+) is estimated derived from pelagic sources in Gooseneck Lake while 18% is estimated derived from pelagic sources in Middle Quinsam Lake (Table 16). Cutthroat Trout are estimated to have littoral contribution to diet of 73% in Gooseneck Lake and 82% in Middle Quinsam Lake.

Table 16. Total mean contributions of pelagic vs. littoral sources to Cutthroat Trout and Rainbow Trout diets in Upper Campbell Reservoir, Gooseneck Lake and Middle Quinsam Lake. Pelagic and littoral contributions are derived from direct (via invertebrates) and indirect (via prey fish) sources.

Waterbody	Consumer	Pelagic Contributions			Littoral Contributions		
		Direct	Indirect	**Total**	Direct	Indirect	**Total**
Upper Campbell Lake	Cutthroat Trout	0.04	0.20	**0.24**	0.19	0.57	**0.76**
	Rainbow Trout	0.28	0.18	**0.45**	0.27	0.27	**0.55**
Gooseneck Lake	Cutthroat Trout	0.21	0.06	**0.27**	0.29	0.45	**0.73**
Middle Quinsam Lake	Cutthroat Trout	0.08	0.10	**0.18**	0.32	0.50	**0.82**

4. CONCLUSIONS

4.1. Reservoir Levels and Benefits to Fish Populations

Total estimates of pelagic vs. littoral sources of production to Cutthroat Trout were similar between Upper Campbell Reservoir and the much smaller Gooseneck and Middle Quinsam lakes. Stable isotope data also indicate that the placement of each species within the lake food web is similar between the three lake systems despite large differences in waterbody size and operational influences. The total littoral contribution to Cutthroat Trout and Rainbow Trout diet is higher than the contribution from pelagic sources despite the large differences among waterbodies.

There is evidence that the pelagic contribution to Rainbow Trout diet is higher than the pelagic contribution to Cutthroat Trout diet in the Upper Campbell Reservoir. Rainbow Trout appear to be eating a higher proportion of zooplankton and a lower proportion of juvenile trout and Sculpin compared to the highly piscivorous Cutthroat Trout. The fish that Cutthroat Trout are eating (e.g., Sculpin, juvenile trout) are themselves highly dependent on littoral resources.

No comparisons were possible within this pilot year between the different reservoirs of the Campbell River project area. In future years it will be important to obtain estimates of fish diets and contrast sources of production in Upper Campbell, Lower Campbell and John Hart reservoirs. The similarity in dependence on littoral resources among Upper Campbell Reservoir, Gooseneck Lake and Middle Quinsam Lake hint that Cutthroat Trout in particular in Upper Campbell Reservoir may have a relatively fixed dependence on littoral production with limited ability to switch to a pelagic-dominated diet.

4.2. Water Residence Time and Lake Productivity

Pelagic sources of production to Cutthroat Trout were estimated to be slightly higher in Gooseneck Lake (27%) than in Middle Quinsam Lake (18%). Littoral contributions to Cutthroat Trout diet dominated in both lakes (73-82%), with juvenile trout, Sculpin and terrestrial invertebrates the most common littoral sources to Cutthroat Trout diets.

Gooseneck Lake receives water from the Quinsam River diversion whereas Middle Quinsam Lake has water diverted upstream of the lake. The original prediction was that water residence time will be shorter in Gooseneck Lake (receiving lake) than Middle Quinsam Lake (donor lake), which could result in decreased zooplankton production. Our observations are opposite to the predictions made by the FTC; a greater pelagic source of production (ultimately from plankton) in Gooseneck Lake was observed in Cutthroat Trout diets compared to Middle Quinsam Lake.

It is important to note here that absent from the current analysis and comparison is an actual measure of water residence time in Gooseneck or Middle Quinsam lakes. It is possible that Middle Quinsam Lake has a lower water residence time than Gooseneck Lake based on its lake volume and hydrology. In future years it is recommended that more diversion and control lakes be sampled and that for each lake an estimate for water residence time be developed. This would enable a true test of the effect of water residence time on lake productivity.

5. RECOMMENDATIONS

5.1. Methods

1. Stable isotope analysis of nitrogen and carbon has been used successfully in this pilot year to understand the diets of species or functional groups in lake food webs, and ultimately to provide estimates of total littoral and pelagic contributions to diets of adult Cutthroat Trout and Rainbow Trout. The stable isotope approach is recommended for future years of the program to address management questions posed in the TOR.
2. The Bayesian mixing model used to estimate diet contributions to fish in Upper Campbell Reservoir, Gooseneck Lake and Middle Quinsam Lake is scientifically sound. This approach is the current standard in scientific assessments to estimate target species' diets from multiple diet sources (e.g., Semmens *et al.* 2009). The Bayesian mixing model approach is also recommended for future years of the program.
3. The Bayesian mixing model may be sensitive to the diet-tissue fractionation estimate applied in the model for both isotopes. In this study, the diet-tissue fractionation values used in the

models were 1.50 ± 1.16 for $\delta^{13}C$ and 2.79 ± 1.46 for $\delta^{15}N$. These values come from the literature and are average diet-tissue fractionation rates across several fish species and tissue types (Sweeting *et al.* 2007a, b). However, fractionation from fish diet to sampled tissue can vary depending on the fish species, tissue sampled (e.g., fin, muscle, whole fish) and the type of diet (invertebrate or fish prey). In future years, analyses should include more specific diet-tissue fractionation rates for each species and tissue type and sensitivity analyses of fractionation rates. For example, fin-specific or trout-specific diet-tissue fractionation rates could be used after a thorough literature review.

4. Zooplankton $\delta^{15}N$ and $\delta^{13}C$ both increased through the summer. We recommend that future sampling continue to occur across three time periods during the spring and summer so that the isotopic variation in zooplankton is adequately represented.

5.2. Recommendations for Future Sampling

1. Upper Campbell Reservoir was sampled in the pilot year of JHTMON-5. In future years we recommend obtaining estimates of fish diets and sources of production in Lower Campbell Reservoir and John Hart Reservoir. This will allow for a more direct test of management question 1 because the three reservoirs have contrasting water level fluctuations associated with BC Hydro operations. Lower Campbell and John Hart reservoirs could be sampled in the same year or in different years (Year 2, Year 3).
2. The lake levels of the three reservoirs are monitored continuously by BC Hydro. We recommend that a metric for the depth of reservoir drawdown be developed to compare across the three reservoirs. BC Hydro also monitors the lake levels of Brewster Lake as part of JHTMON-10. We therefore recommend that Brewster Lake also be included in the set of diversion lakes to be sampled and that a metric for lake drawdown be developed for Brewster Lake to compare to the results generated in the reservoirs. This would increase the sample size for addressing hypotheses associated with management question 1; however, we note that the final sample size is still expected to be small (n=4).
3. Gooseneck and Middle Quinsam lakes were chosen because they have contrasting water diversion operations. Gooseneck Lake receives water from the Quinsam Diversion and is hypothesized to have lower lake water residence time and lower pelagic contribution to fish production than Middle Quinsam (the donor lake). This prediction is opposite to what was observed. Across the full program we recommend that as many diversion and control lakes be sampled as possible within the available budget, and that for each lake an estimate of water residence time be developed based on lake volume and hydrology. For example, it is possible that Middle Quinsam Lake has a lower water residence time than Gooseneck Lake based on its unique morphology and hydrology. A modest number of lakes could be sampled over several years rather than in a single year. This would enable simple regression models relating water residence time in each lake to % littoral or % pelagic contributions to fish diets (Figure 31). Operations from water diversions could then be integrated into

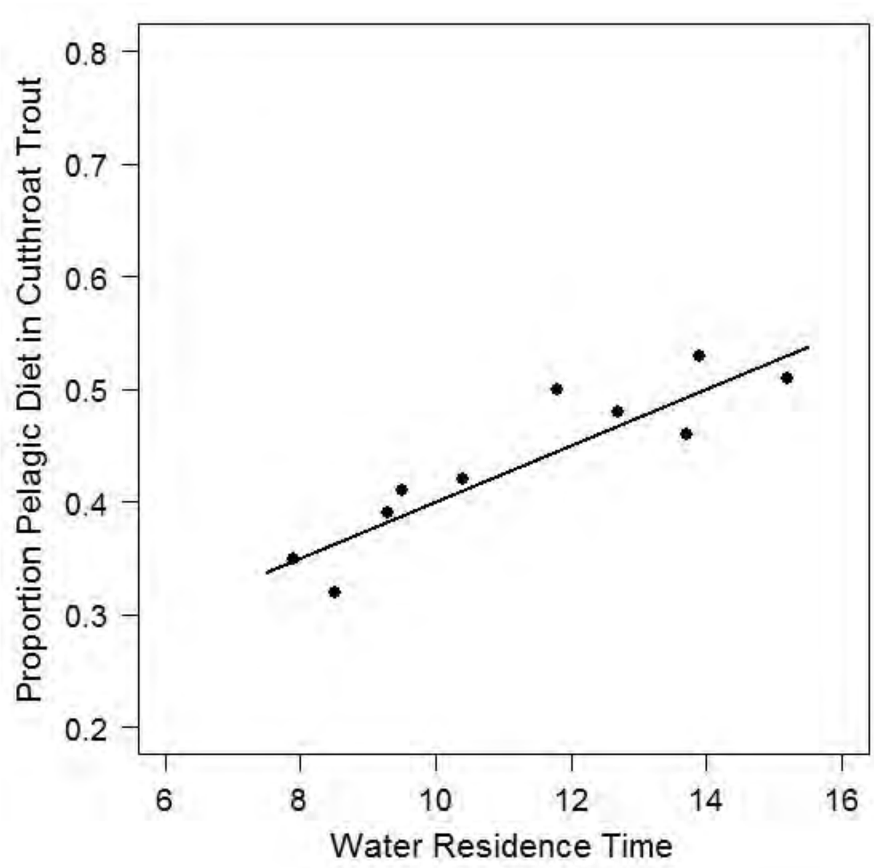
predictive models of how water inputs or extractions can change lake water residence time, lake productivity and food webs. This approach is consistent with the TOR, but represents a quantitative approach to answering the management questions rather than the qualitative approach described in the TOR.

4. Initial findings using stable isotopes show similar lake food webs across Upper Campbell Reservoir, Gooseneck Lake and Middle Quinsam Lake. These initial results hint that Upper Campbell Reservoir Cutthroat Trout may not be changing their diets to a pelagic-dominated source of production and, instead, maintain their dependence on littoral production. In contrast, Rainbow Trout have greater pelagic contribution to diet than Cutthroat Trout in Upper Campbell Reservoir. However, it is important to confirm these results from at least two more full years of data collection from all three reservoirs and three to four diversion lakes per year (including controls). The Terms of Reference for JHTMON-5 proposed that after the pilot year 1 full sampling take place in years 2, 5 and 10 of the program (BC Hydro 2013). We recommend that two full years of sampling occur in years 2 and 3 of the program in order to maintain continuity of staff and methods, rather than in years 2 and 5 as envisioned by the TOR. A third full year of sampling may not be necessary and should be evaluated at the end of Year 3.

5. Zooplankton sampling was conducted in triplicate in each sampling period on each lake. We recommend that all zooplankton samples be counted and weighed so an estimate of zooplankton production could be made for each lake. For example, the mass of zooplankton obtained could be divided by the volume of water pulled through the zooplankton net to derive an estimate of zooplankton biomass per m^3. This is important because zooplankton production could then be compared directly to estimates of lake water residence time.

6. It is possible that Cutthroat Trout and Rainbow Trout diet could shift among pelagic vs. littoral sources of production as they grow and age. For example, a negative relationship was observed between Rainbow Trout fork length and $\delta^{13}C$ in Upper Campbell Reservoir. In future years, if these relationships between $\delta^{13}C$ and size or age are observed then we recommend that analyses of Cutthroat Trout or Rainbow Trout diets be split by age or size classes. This could provide more specific information on the size and age classes of fish most affected by operational changes.

Figure 31. Hypothetical relationship between lake water residence time and pelagic productivity as indicated by the proportion of pelagic diet in Cutthroat Trout. Each point represents a different diversion or control lake with data accumulated over several years of the JHTMON-5 program. Similar plots could be developed for zooplankton density or Cutthroat Trout CPUE and lake water residence time.



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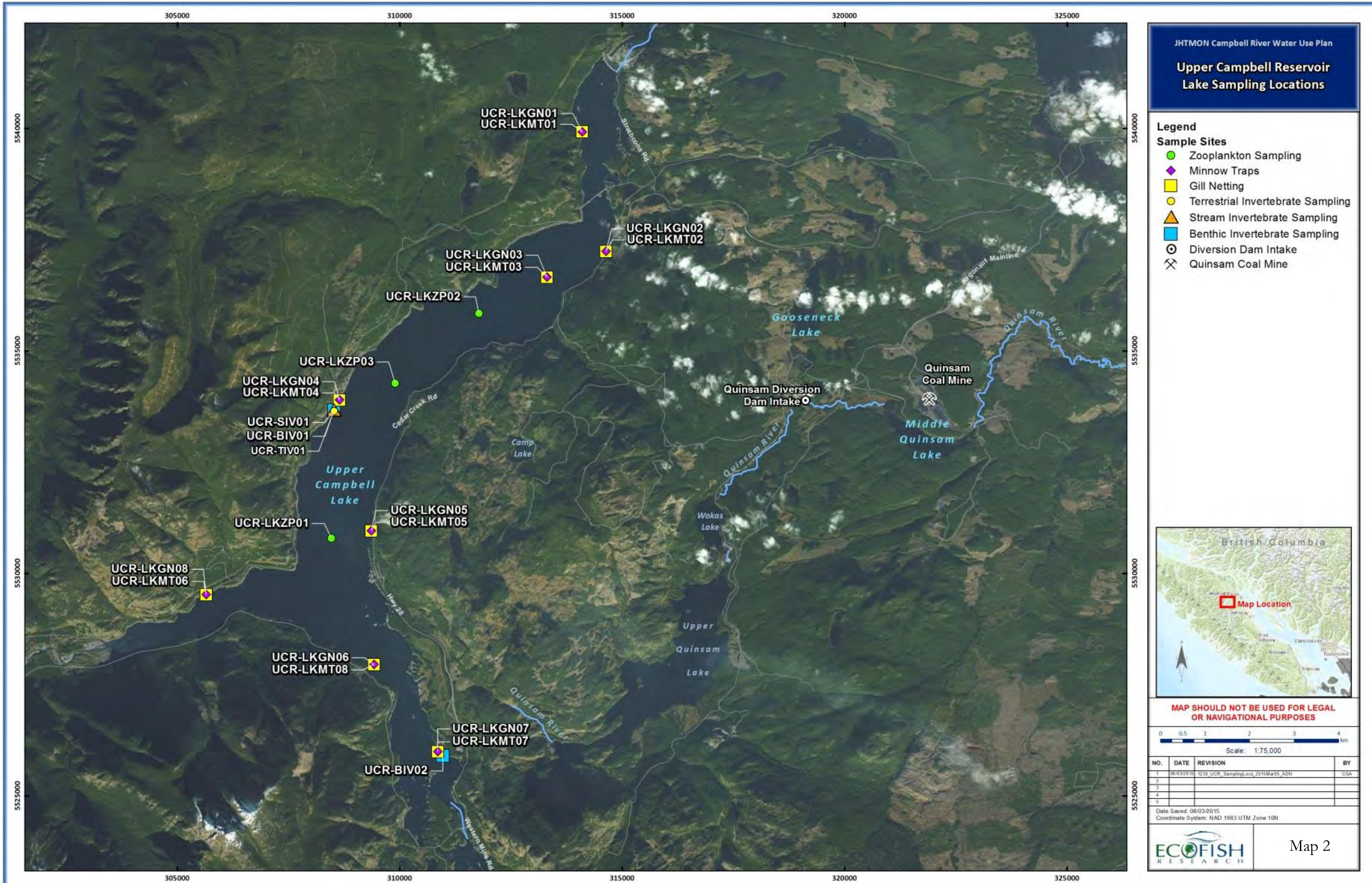
PROJECT MAPS



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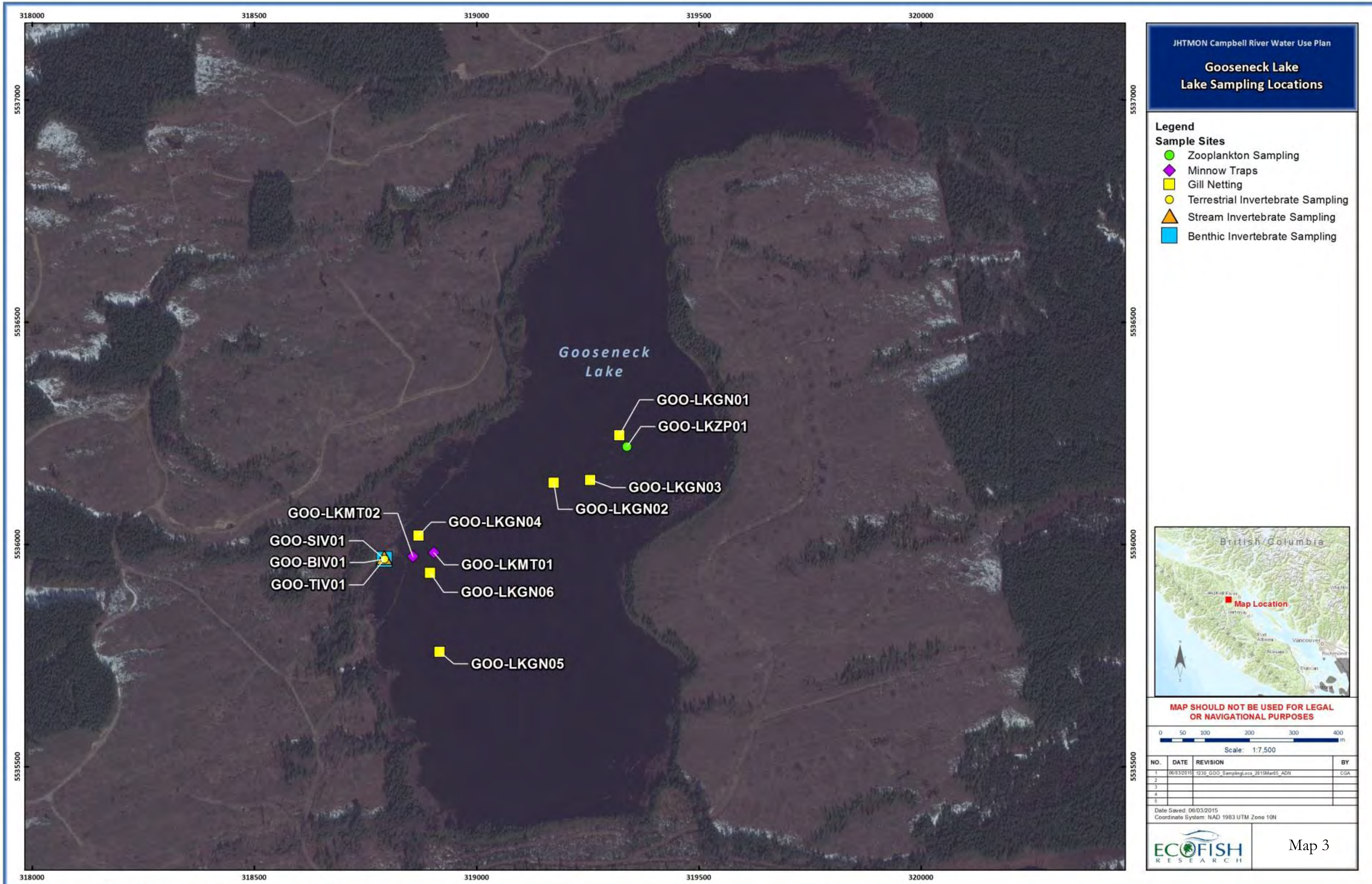

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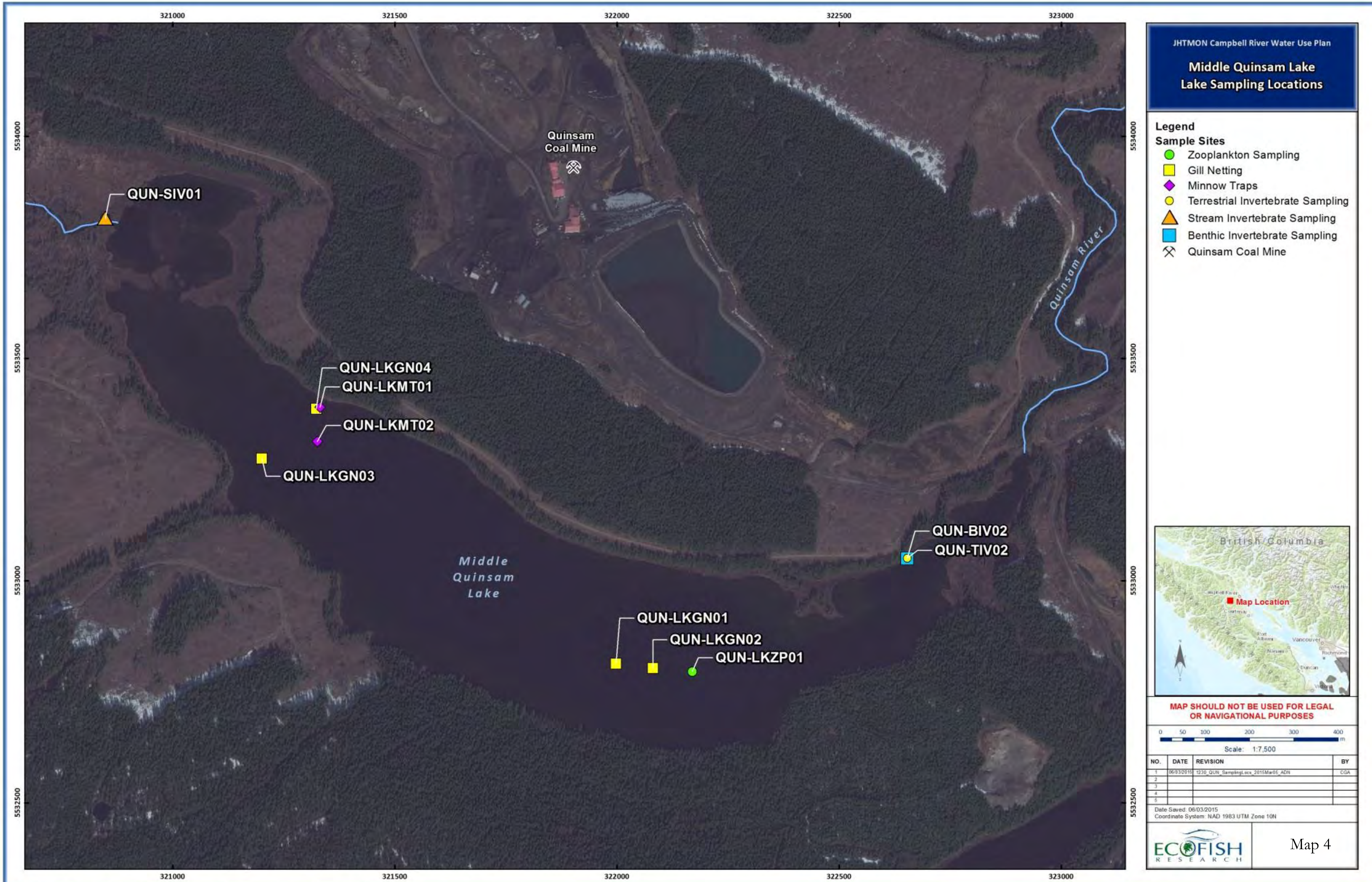

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