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Campbell River Project Water Use Plan

JHTMON-4 Upper and Lower Campbell Reservoirs Littoral Productivity Assessment

Implementation Year 1

Reference: JHTMON-4

JHTMON-4 Year 1 Monitoring Report

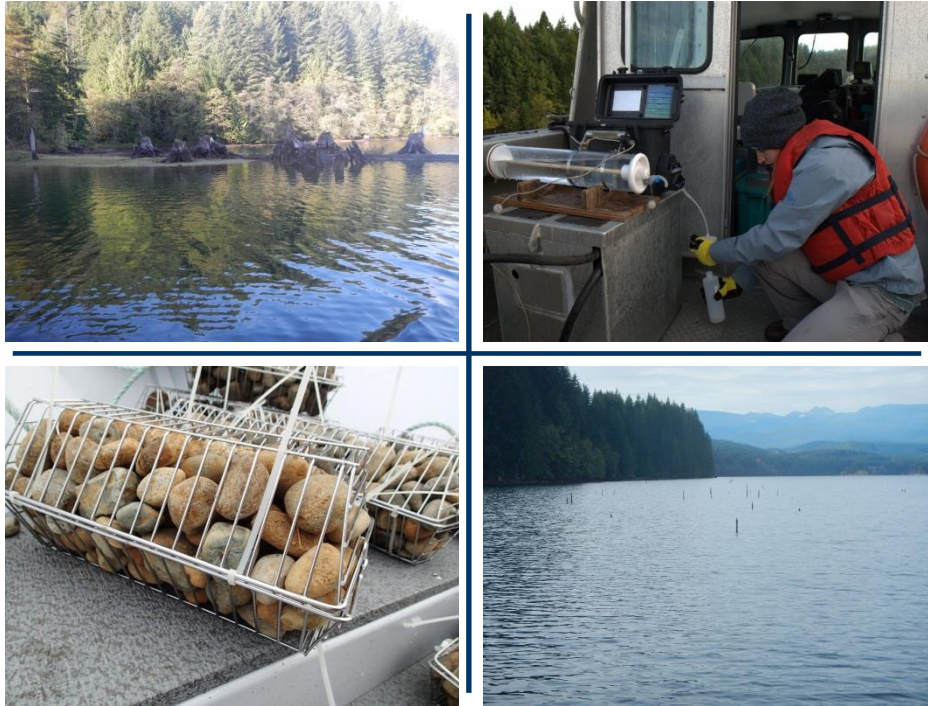
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**Laich-Kwil-Tach Environmental Assessment Ltd. Partnership
and Ecofish Research Ltd.**

July 15, 2016

JHTMON-4: Upper and Lower Campbell Reservoirs Littoral Productivity Assessment

Year 1 Annual Monitoring Report Draft V2



Prepared for:

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EXECUTIVE SUMMARY

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. As the Campbell River WUP (BC Hydro 2012) process reached completion, a number of uncertainties remained with respect to the effects of BC Hydro operations on aquatic resources. 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. The *Upper and Lower Campbell Littoral Productivity Assessment* (JHTMON-4) is part of a wider monitoring of the Campbell River WUP. JHTMON-4 is designed to assess the effect of variation in water surface elevation on biological production in the littoral zone of the Upper and Lower Campbell reservoirs, and how this relates to BC Hydro operations.

The Terms of Reference for JHTMON-4 focused on the Effective Littoral Zone (ELZ) Performance Measure (PM), with the assumption that increasing the primary productivity of the littoral zone would lead to increases in fish productivity. However, inherent uncertainties led to a first management question:

1. Does the ELZ performance measure adequately estimate the change in littoral productivity due to changes in reservoir operation, particularly in relation to changes implemented with the Campbell River WUP and potential future changes?

A second management question addressed ecological factors influencing ELZ:

2. To what extent does colonization rate, photosynthetically active radiation (PAR) penetration, growth rate and survival rate impact the utility and reliability of the ELZ performance measure for WUP decision-making purposes?

A third management question addressed changes to biological production in the littoral zone of the Upper and Lower Campbell reservoirs with application of water management rules under the WUP:

3. Following implementation of the Campbell River WUP, does littoral productivity increase as predicted by the ELZ performance measure?

Given ultimate interest in potential benefit to fish populations in the reservoirs from the WUP, a fourth management question asked:

4. How does littoral productivity translate into fish production in Campbell River reservoirs?

JHTMON-4 is scheduled for two years of field and lab work and a third year of analytical study. This report describes progress in the first year (2015-16) of work. Periphyton, benthic invertebrate, and fish sampling was completed in Lower Campbell Reservoir in Year 1, with sampling planned for Upper Campbell Reservoir in Year 2.

Summary of the Main Method to Test Management Questions

A challenge with ELZ as it was defined in the original TOR is it does not quantitatively consider environmental factors other than light that are known to modify periphyton accrual over water depths spanning a littoral zone. We therefore revised the ELZ to include three environmental attributes (photosynthetically active radiation (PAR), temperature, nutrient concentration) and we derived equations to express the relationship between periphyton accrual and those attributes. This change was discussed with representatives of BC Hydro and incorporated into a revised Terms of Reference (BC Hydro 2015).

ELZ was defined as the amount of periphyton biomass (B) accrued on an area of substrata in a littoral zone with modification by light, temperature, and nutrient concentrations over time and space. This performance measure is now called L as described in Equation 1. L is conceptually the same as ELZ but it is named differently because its calculation includes more variables than we understand were included in ELZ. Accrual of periphyton was measured as change in biomass over time on standardized submerged substrata, similar to the approach used by Bothwell (1989) and Perrin *et al.* (1987) to examine growth of stream periphyton.

The definition of L can be stated as follows:

Equation 1.

$$L_t = \sum_{i=1}^n A_{it} B_{it}$$

where;

L is accrued B that may be modified by habitat conditions and area of flooded littoral habitat at time t ,

A is area of stratum i within the littoral habitat having n strata at time t , and

B is biomass of accrued periphyton at time t in littoral depth stratum i ,

and

Equation 2.

$$B_{it} = \beta_0 + \beta_1 x_{1it} + \beta_2 x_{2it} + \beta_3 x_{3it} + \varepsilon$$

is a multiple regression model explaining B at time t in depth stratum i as a function of x independent variables where β_0 is the regression intercept, x_1 is PAR, x_2 is concentration of a nutrient that limits growth of periphyton, x_3 is water temperature, $\beta_{1...3}$ are regression coefficients, and ε is model error.

The combinations of equations 1 and 2 will be used to answer management questions 1 through 3. Management question 1 can be tested using Equation 1, which is sensitive to change in water surface

elevation. Management question 2 can be answered by entering values for independent habitat attributes (nutrient concentrations, temperature, PAR), to test different management scenarios. Management question 3 can be answered by testing sensitivity of periphyton biomass accrual in the littoral zone to different timing and magnitude of surface water elevation changes.

Management question 4 will be answered using multiple lines of evidence, including fish stomach contents and stable isotope analysis. Fish stomach data alone are not sufficient to determine sources of food for fish because they only relate to the time when samples were collected. JHTMON-4 uses stable isotope analysis of nitrogen and carbon of fish tissues and their potential diet items to assess relative energy flows to fish from the algal component of periphyton and from other basal nutrient sources in the littoral zone.

Digital Elevation Model

The extent of littoral area that can support periphyton biomass changes according to water surface elevation reflecting individual reservoir morphology. A digital elevation model (DEM) was developed following bathymetric surveys, and used to estimate littoral area vs. water surface elevation. The area of the littoral zone where periphytic algae grows is defined as substrata area within depth strata where PAR in the overlying water column is greater than 1% of that at the water surface (the standard measure of euphotic zone depth, Wetzel 2001).

Periphyton Accrual and Habitat Attributes

Periphyton accrual was measured following sequential weekly collection at four sampling stations on Lower Campbell Reservoir, during two eight-week sampling periods in 2015 (summer and fall). Peak biomass (PB) was the highest concentration of chl-*a* attained on a substrate over time of measurement. PAR, water temperature, and nutrient concentrations were measured during the same sampling periods. The combined and relative contributions of these habitat attributes to periphyton biomass accrual were calculated via the multiple regression model (Equation 2).

Periphyton can vary in its composition, and includes living algae but also bacteria, protozoa, fungi and non-living organic detritus. To account for this potential variability, periphyton was collected for stable isotope analysis from three sources: 1) Four acrylic plates that were submerged in the water column for two months, 2) Periphyton biomass from the mooring line, collected as a backup in case acrylic plate samples had insufficient biomass for sampling, and 3) Periphyton scraped from rocks in the wadable reservoir margins near three of the periphyton sampling stations. Periphyton from acrylic plates did not accrue sufficient biomass to obtain a sample. Backup samples of periphyton from the mooring lines were mainly comprised of living algal species and represented a portion of periphyton referred to hereafter as “periphytic algae”. The shoreline samples contained living algal biomass, detritus from reservoir and potentially terrestrial sources, and the assemblage of heterotrophic decomposer organisms associated with the substrate. These shoreline samples are referred to hereafter as “littoral periphyton”.

Performance Measure L

L (the performance measure defined as PB on substrate in the littoral zone and substituted for ELZ in the project terms of reference) demonstrated a lack of an effect of temperature and a small effect of nutrient concentration on PB. This result was a statistical outcome that does not mean that these attributes were not important in determining growth of periphyton. Indeed, these variables are known to be very important (Goldman and Carpenter 1974, Bothwell 1988, Bothwell 1989, Biggs 2000, Guildford and Hecky 2000). Instead, the ranges in values for these independent variables in summer and fall of 2015 were insufficient to isolate their effect. Water temperature over the depth of the littoral zone (top 20 m of the water column as defined using irradiance profiles) was 8.5 – 22°C during the period of measurement in summer and fall. That range did not affect periphytic algae accrual ($p=0.18$). Presence of a temperature effect might be expected at lower temperatures potentially occurring in winter. Ultra-oligotrophic conditions in Lower Campbell Reservoir curtailed algal growth rates, indicating that nutrient concentrations exert a strong control on algal growth. Incubation periods longer than the two months used in Year 1 are needed to achieve detection of true PB.

The equations developed in Year 1 of JHTMON-4 can be used to test the WUP hypothesis that the accepted management alternative will result in increased biological production in the littoral zone. Using existing findings, the equations show that if water surface elevations are lowered, biological production in the littoral zone derived from periphytic algae will be expected to decline by small amounts (about 5% over 3 m ranges of water surface elevations). The reverse would be expected if water surface elevations are maintained near the maximum elevation of 178 m. The water surface elevation in Lower Campbell Reservoir is not maintained at a constant level but instead fluctuates up and down. There is no clear statement in the WUP about whether this variability changed with rules imposed by the WUP, but equations can be used to test whether a given change in variance of water surface elevation can affect it. The WUP CC report p. 8-5 shows the selected Alternative (I) was expected to have a ‘neutral’ effect on the ELZ value in Lower Campbell Reservoir; however, this prediction would need to be validated with the observed water surface elevation time series.

Fish Stomach Contents Results

Fish stomach contents were used as a first step to examine links between periphyton production in the littoral zone and fish use of that habitat, thus addressing the fourth management question, “How does littoral productivity translate into fish production in Campbell Reservoirs?” The stomach contents data showed that the most common prey for Cutthroat Trout and Rainbow Trout were zooplankton and terrestrial taxa, with benthic insects that are common in littoral habitats making limited contribution to the diets of these fish species. Fish were a common diet item for Cutthroat Trout but not Rainbow Trout. These findings show a disconnection between biological production of food in littoral habitat where benthic insects are prevalent and food ingested by fish of management interest (Cutthroat Trout and Rainbow Trout). This preliminary evidence implies that

the littorally-derived periphyton production is not important for supporting resident fish species and that food production from riparian areas and pelagic habitat is more important.

Stable Isotope Analysis Results

Stable isotope data, which represents an integrated signature of fish diet over a growing season, showed similar results to stomach content analyses, in that littoral-derived algal production was not very important. Terrestrial primary production contributed 58% to Cutthroat Trout diets and 43% to Rainbow Trout diets, illustrating the importance of allochthonous nutrient sources in the ultra-oligotrophic Lower Campbell Reservoir. Riparian leaf litter (i.e., terrestrial vegetation) was consumed directly by littoral invertebrates and is the basal carbon source for terrestrial invertebrates, which were heavily consumed themselves by littoral prey fish (e.g., juvenile trout and Sculpin spp.), stickleback, and Cutthroat and Rainbow Trout.

Pelagic primary production was particularly important for Rainbow Trout: phytoplankton contributed 45% to Rainbow Trout diets and 16% to Cutthroat Trout diets, largely through consumption by zooplankton. When diet contributions are summed across trophic levels, the contribution of periphytic algae to Cutthroat Trout and Rainbow Trout is estimated to be only 7.9% and 3.7% respectively. We anticipate a similar result in Upper Campbell Reservoir, where pelagic contributions are higher than in Lower Campbell Reservoir (Hocking *et al.* 2016) and any decline in littoral productivity through declines in periphytic algal would have correspondingly less impact on fish production.

The current data thus suggest that, while algal accrual can be used to make predictions regarding the functioning of ELZ as described above, the littoral food web of Lower Campbell Reservoir is more complex than assumed under the ELZ model. The current ELZ approach would likely underestimate the effect of reservoir drawdown on impacts to fish because it does not consider the primary driver of littoral fish production, which is terrestrial-derived carbon via leaf litter and terrestrial invertebrates. Secondly, periphyton in littoral areas may not solely comprise periphytic algae and instead is likely an assemblage of algae, protozoa, bacteria, fungi and detrital material.

Two types of periphyton were analysed (periphytic algae and littoral), which were found to have distinct isotope signatures. The different signatures are likely due to several factors. Terrestrial allochthonous carbon sources contribute to littoral periphyton closer to shore and enrich the carbon signature. The presence of heterotrophs such as bacteria will enrich the carbon signature further. The algal portion of periphyton grown on the mooring line grew slowly under ultra-oligotrophic conditions with carbon derived from autochthonous production. More depleted $\delta^{13}\text{C}$ signatures are reported under slower growth rates in a variety of freshwater plants (MacLeod and Barton 1998). Overall, the isotope signatures of the two periphyton sources were only based on very few samples ($n = 3$ for each). Therefore, these results should be confirmed with another year of sampling in Upper Campbell Reservoir.

Considerations for Year 2

The following represents a summary of considerations for Year 2, based on Year 1 sampling of the JHTMON-4 program.

1. Periphyton accrual curves from 2015 showed that a time longer than 60 days is needed to reach peak biomass in the ultra-oligotrophic waters of the Campbell Reservoir system. Sampling is planned for Upper Campbell Reservoir in 2016. We plan to leave the periphyton moorings installed in Upper Campbell Reservoir for a 90-day sampling duration rather than the 60 days that was used in 2015. The two sampling periods that were defined in 2015 should be used in 2016. The time of sampling does not have to be the same in 2016 as it was in 2015. Indeed, changing the time would be advantageous to capture more variable habitat conditions in the regression modelling that is used to explain variance in periphyton peak biomass. This change will result in a six month duration of sampling in 2016 (2 periods of 90-day durations) rather than the four months (2 periods of 60-day durations) that was used in 2015. This consideration is based on JHTMON4 management questions that do not include objectives to quantitatively compare periphyton biomass between Upper and Lower Campbell Reservoirs.
2. The ELZ performance measure was based on measurement of algal biomass accruing over a period of time. A more robust measure of actual production is specific growth rate that can be calculated from accrual curves. To represent ELZ, it is desirable to include both peak biomass over an accrual period, as was done in this report, and specific growth rate at selected depths to determine if peak biomass is a reasonable indicator of specific growth rate.
3. Carbon isotope signatures showed that periphyton accrued on sampling apparatus in the water column may not be representative of littoral periphyton living near the shoreline. The conclusions based on stable isotope analysis are based on a small sample size of primary producers. Larger sample sizes of periphyton, SPOM, and leaf litter may be required to increase confidence in conclusions. We plan to increase sampling effort of periphyton in Year 2, including in different time periods throughout the growing season. These increases in sample size for isotope analysis can be incorporated into the existing Year 2 scope and budget.
4. The stable isotope component of JHTMON-4 was achieved through coordinated sampling between JHTMON-4 and JHTMON-5 in 2015. Fish, zooplankton and terrestrial invertebrate sampling are not scheduled to occur in Upper Campbell Reservoir in 2016 as a part of JHTMON-5, although it did occur in 2014. The stable isotope component of JHTMON-4 in Upper Campbell Reservoir in 2016 can be supported using existing data collected through JHTMON-5 in 2014.

MON-4 Status of Objectives, Management Questions and Hypotheses after Year 1.

Study Objectives	Management Questions	Management Hypotheses	Year 1 (fiscal year 2015) Status
The aim of JHTMON-4 is to test the assumption that reservoir drawdowns in Upper and Lower Campbell reservoirs decrease primary productivity in the littoral zone, and that this leads to a decrease in littoral fish production in the reservoirs. The Monitor involves: assessing the effect of variation in water surface elevation on primary production (periphyton) in the littoral zone; examining the link between littoral periphyton production and littoral fish production; determining the relative contribution of littoral vs. pelagic primary food sources to fish diets.	Does the Effective Littoral Zone (ELZ) performance measure adequately estimate the change in littoral productivity due to changes in reservoir operation, particularly in relation to changes implemented with the Campbell River WUP and potential future changes? To what extent does colonization rate, PAR penetration, growth rate and survival rate impact the utility and reliability of the ELZ performance measure for WUP decision-making purposes?	Upper and lower elevation boundaries of littoral zone periphyton production in Upper Campbell Lake Reservoir do not correlate with ELZ model predictions. There is no significant correlation between the modified ELZ model (which includes depth-integrated periphyton production estimates based on differential growth and survival information) and empirically measured values from the field.	Year 1 results were used to develop an ELZ model for Lower Campbell reservoir. After two years of data collection the model will be expanded to Upper Campbell reservoir and tested using operational water levels. Data were collected as planned, including periphyton accrual, water chemistry, temperature, and PAR. Stable isotope analysis was completed. The current study design is expected to answer the hypothesis, although some sampling refinements are required to determine periphyton peak biomass.
Implementation of the WUP in the Upper and Lower Campbell Reservoirs is predicted to increase productivity of Cutthroat Trout and Rainbow Trout by improving periphyton productivity in the littoral zone.	Following implementation of the Campbell River WUP, does littoral productivity increase as predicted by the ELZ performance measure?	Primary production in the littoral zone of Upper Campbell Lake reservoir does not increase following implementation of the Campbell River WUP.	The equations developed in Year 1 can be used to test this WUP hypothesis. Equations will be extended to Upper Campbell Reservoir in Year 2. The current study design is appropriate to address this hypothesis, with some refinements to sample peak periphyton biomass.
If stable isotope analysis results show littoral food source dominance in fish food then a supplemental analysis will be done using fish abundance data from JHTMON-3 to evaluate correlation between fish production and water level following WUP implementation.	How does littoral productivity translate into fish production in Campbell River reservoirs?	Following implementation of the Campbell River WUP abundance of adult trout is not correlated with littoral productivity during the cohort's first year.	The potential need for this supplemental analysis will be determined after Year 2 of data collection.

TABLE OF CONTENTS

EXECUTIVE SUMMARY	II
LIST OF FIGURES	XI
LIST OF TABLES	XIII
LIST OF MAPS.....	XIV
1. INTRODUCTION	1
1.1. BACKGROUND TO WATER USE PLANNING.....	1
1.2. BC HYDRO INFRASTRUCTURE, OPERATIONS AND THE MONITORING CONTEXT	2
1.2.1. <i>Reservoirs</i>	2
1.3. MANAGEMENT QUESTIONS AND HYPOTHESES	2
1.4. SCOPE OF THE JHTMON4 STUDY	6
1.4.1. <i>Overview</i>	6
1.4.2. <i>Summary of the Main Method to Test Management Questions</i>	6
1.4.3. <i>Stable Isotope Techniques</i>	10
2. METHODS.....	11
2.1. STUDY AREA	11
2.2. BATHYMETRIC SURVEY AND DIGITAL ELEVATION MODEL (DEM).....	13
2.2.1. <i>Field</i>	13
2.2.2. <i>Data Quality Assurance</i>	13
2.2.3. <i>Hydrological Field Conditions</i>	13
2.2.4. <i>Bathymetric Mapping</i>	14
2.3. PERIPHYTON BIOMASS ACCRUAL	14
2.4. PERIPHYTON HABITAT ATTRIBUTES	19
2.5. LINKING PERIPHYTON PERIPHYTONACCRUAL WITH HABITAT ATTRIBUTES	24
2.6. THE PERFORMANCE MEASURE CALLED <i>L</i>	25
2.7. FISH SAMPLING	25
2.7.1. <i>Gill Netting</i>	26
2.7.2. <i>Trap Netting</i>	26
2.7.3. <i>Minnow Trapping</i>	26
2.7.4. <i>Individual Fish Analysis</i>	27
2.7.5. <i>Stomach Content Analysis</i>	27
2.8. STABLE ISOTOPES	27
2.8.1. <i>Periphyton</i>	27
2.8.2. <i>Benthic Invertebrates</i>	29
2.8.3. <i>Primary Nutrient Sources</i>	31
2.8.4. <i>Stable Isotope Processing</i>	31

2.8.5. <i>Assessing Fish Diet Using Mixing Models</i>	33
3. RESULTS	34
3.1. HABITAT ATTRIBUTES	34
3.2. BATHYMETRIC SURVEY AND DIGITAL ELEVATION MAPPING	39
3.3. PERIPHYTON PERIPHYTONBIOMASS ACCRUAL	41
3.4. LINKING PERIPHYTON ACCRUAL WITH HABITAT ATTRIBUTES	44
3.5. THE PERFORMANCE MEASURE CALLED <i>L</i>	46
3.6. BENTHIC INVERTEBRATE COMPOSITION	47
3.7. FISH STOMACH CONTENTS	49
3.8. STABLE ISOTOPE MODELLING	50
3.8.1. <i>Summary of Stable Isotope Signatures by Taxa</i>	50
3.8.2. <i>Primary Nutrient Source Contributions to Reservoir Consumers</i>	51
4. DISCUSSION	57
4.1. ELZ PERFORMANCE MEASURE.....	57
4.2. FISH STOMACH CONTENTS	60
4.3. STABLE ISOTOPE MODELLING	60
5. CONSIDERATIONS FOR YEAR 2	61
REFERENCES	63
PROJECT MAPS	69

LIST OF FIGURES

Figure 1. Mean daily water surface elevation in Lower Campbell Reservoir, 2015. Horizontal line A shows the “peak summer season” preferred maximum water surface elevation as defined in the Water Use Plan and line B shows the preferred minimum elevation.	12
Figure 2. Image of Styrofoam balls clipped on to a mooring line. The balls provided substrata for colonization and growth of periphyticperiphytic algae.	17
Figure 3. Schematic image of rigging used to deploy a periphyton mooring.	18
Figure 4. Image of acrylic plates used to accrue periphyton for stable isotope analysis, and Styrofoam balls for examining periphyton accrual. Substrata were all attached to a standard mooring line prior to deployment in summer 2015.	29
Figure 5. Schematic of foodweb and trophic pathways by which littoral and benthic primary nutrient sources contribute to large trout diets in Lower Campbell Reservoir.	34
Figure 6. Temperature profiles at all four sampling stations on July 31 (top), September 25 (middle), and November 27 (bottom), 2015.....	36
Figure 7. Percent of surface PAR over the depth profile among periphyton sampling stations, 2015. The equation shows a logarithmic line of best fit (%SI is percent of PAR immediately under the water surface and depth is water depth). The r^2 is the correlation coefficient for the regression line.	38
Figure 8. Percent of surface PAR over the depth profile among periphyton sampling stations, 2015. The equation shows a logarithmic line of best fit (%SI is percent of PAR immediately under the water surface and depth is water depth). The r^2 is the correlation coefficient for the regression line.	39
Figure 9. Change in littoral (water depths <20 m) and pelagic (water depths >20 m) areas over the range of water surface elevations in 2015 in Lower Campbell Reservoir.....	40
Figure 10. Mean periphyton biomass (chlorophyll- <i>a</i> concentration) (\pm sd) over time of incubation of installed Styrofoam substrata at three depths in the euphotic zone of Lower Campbell Reservoir during summer. Values were calculated from four replicate stations.....	41
Figure 11. Mean periphyton periphytonbiomass (chlorophyll- <i>a</i> concentration) (\pm sd) over time of incubation of installed Styrofoam substrata at three depths in the euphotic zone of Lower Campbell Reservoir during fall. Values were calculated from 4 replicate stations.....	42
Figure 12. Mean algal biovolume by class in summer and fall in Lower Campbell Reservoir, 2015. Error bars are standard deviations of total biovolume among stations	43
Figure 13. Mean algal cell density by class in summer and fall in Lower Campbell Reservoir, 2015. Error bars are standard deviations of total cell counts measured for all depths.	44

- Figure 14. Sensitivity of PB to change in PAR and TN. Curves are simulations from Equation 4 in which the PAR curve (solid line) is the PB response to change in PAR when TN concentration was held constant (set at $0.1 \text{ mg}\cdot\text{L}^{-1}$) and the TN curve (dotted line) is the PB response to change in TN concentration when accumulated PAR is held at a constant high level (similar to that near the water surface ($800 \text{ mol}\cdot\text{m}^{-2}$)). Coordinate A shows that a 50% change in TN concentration produces a 10% change in PB from its lowest recorded value. Coordinate B shows that a 50% change in accumulated PAR from the lowest recorded value produces a 450% change in PB from its lowest recorded value.....46
- Figure 15. Percent change in littoral PB with a decline in water surface elevation.....47
- Figure 16. Density of benthic invertebrates in Lower Campbell Reservoir.....48
- Figure 17. Biomass of benthic invertebrates in Lower Campbell Reservoir.49
- Figure 18. Carbon – nitrogen stable isotope bi-plots (mean \pm SD) of basal nutrient sources, invertebrates, and fish from Lower Campbell Reservoir in 2015.....52
- Figure 19. Estimated proportions of basal nutrient diet sources to littoral invertebrates in Lower Campbell Reservoir. Estimates are calculated as means with 5% and 95% percentile ranges of posterior probability distributions from carbon – nitrogen Bayesian mixing models based on isotopic signatures from littoral invertebrates and their potential diet sources.53
- Figure 20. Estimated proportional contributions of invertebrate food sources to diets of littoral A) prey fish (juvenile trout and Sculpin spp) and B) Threespine Stickleback in Lower Campbell Reservoir. Estimates are calculated as means with 5% and 95% percentile ranges of posterior probability distributions from carbon – nitrogen Bayesian mixing models, based on isotopic signatures from prey fish and their potential diet sources.54
- Figure 21. Estimated proportional contributions of invertebrate and fish food sources to diets of A) Cutthroat Trout and B) Rainbow Trout in Lower Campbell Reservoir. Estimates are means with 5% and 95% percentile ranges of posterior probability distributions from carbon – nitrogen Bayesian mixing models, based on isotopic signatures from these consumers and their potential diet sources.....55

LIST OF TABLES

Table 1.	Operating alternatives and expected benefits in Upper and Lower Campbell Reservoirs Water Use Plans (BC Hydro 2012).	3
Table 2.	Lower Campbell Reservoir Water Surface elevations from October 20 – 24, 2015.....	14
Table 3.	Summary of chlorophyll <i>a</i> and PAR sampling in Lower Campbell Reservoir using periphyton sampling apparatus and LI-2050A light profile.	16
Table 4.	Methods and detection limits for laboratory nutrient analysis.....	21
Table 5.	Summary of water chemistry, benthic invertebrate, and stable isotope analysis sampling in water, and PAR sampling in air at the Lower Campbell Reservoir in 2015.....	22
Table 6.	Primary producers, invertebrate, and fish samples analysed for stable isotopes at SINLAB.	32
Table 7.	Mean concentrations or values of the various forms of N and P and other chemical analytes in surface and bottom waters among the four stations in Lower Campbell Reservoir in 2015.	37
Table 8.	Mean periphyton periphytonbiomass (PB) (\pm sd) by depth in the euphotic zone during the summer and fall, 2015.	42
Table 9.	Regression equation parameters from the analysis linking habitat attributes to PB.	45
Table 10.	Contents of fish stomachs, by fish species, captured during gill net sampling on Lower Campbell Reservoir on October 5, 2015.....	50
Table 11.	Proportional contributions of basal nutrient sources to Cutthroat Trout and Rainbow Trout in Lower Campbell Reservoir.....	56
Table 12.	Mean proportional contribution of intermediate consumers (zooplankton, littoral and terrestrial invertebrates, littoral prey fish and stickleback) and basal nutrient sources to Cutthroat Trout and Rainbow Trout diets in Lower Campbell Reservoir.....	56

LIST OF MAPS

Map 1.	Lakes and reservoirs in the Campbell River system (Hemmera 2010).	4
Map 2.	Lower Campbell Reservoir Lake Sampling Locations.	70
Map 3.	Bathymetry of lower Campbell Reservoir showing the demarcation between littoral (20 m water depth from the top water surface elevations of 177 m) and pelagic habitat (elevations <157 m).....	71

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. The Campbell River Water Use Plan Consultative Committee (CC) developed aquatic ecosystem objectives for the Campbell Lakes system that included efforts to maximize the abundance and diversity of fish populations while establishing flow controls for hydroelectric power generation, flood protection, water quality and supply, among other interests (BC Hydro 2012). Tradeoffs occurred in the water use planning, with some uncertainty among decisions to set water elevations in the Campbell system reservoirs, manage spills, and define flow releases from the Strathcona, Ladore and John Hart dams. The CC was constrained in making unequivocal decisions by lack of information about the effects of change in water elevations and flows on fish populations and biological production that support those populations.

To address uncertainties and better inform people tasked with water management decisions in future years, including the Laich-Kwil-Tach First Nation groups, 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. The *Upper and Lower Campbell Littoral Productivity Assessment* (JHTMON-4) is part of a wider monitoring of the Campbell River WUP. JHTMON-4 is designed to assess the effect of variation in water surface elevation on biological production in the littoral zone.

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. Within this project area there are mainstem rivers, 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 fluctuations in water level through its effect on littoral production. This hypothesis is supported by research elsewhere that has shown that large water level fluctuations can cause a decrease in littoral primary productivity (Furey *et al.* 2004), and that such fluctuations have a disproportionately negative effect on productivity in the littoral zone, compared with other habitats (Turner 2005). Stable reservoir levels were therefore assumed to have a positive influence on fish production.

Due to relatively large within-year water level fluctuations, the littoral zone of upper and lower Campbell reservoirs is spatially dynamic, moving up and down over substrata of the drawdown zone over the course of a year. These changes are less pronounced in Lower Campbell Reservoir, which is operated as a run-of-river system, unlike Upper Campbell, which is a storage reservoir. Evaluation of reservoir operations relied heavily on the Effective Littoral Zone (ELZ) Performance Measure (PM), with the assumption that increasing littoral productivity as predicted by the ELZ PM 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 help evaluate alternative management strategies for reservoir operations.

1.3. Management Questions and Hypotheses

The present study (called JHTMON-4) was designed to reduce uncertainty about the effect of variation in water surface elevation on biological production in the littoral zone of Upper and Lower Campbell reservoirs. The littoral zone refers to shallow water habitat where macrophyte and non-macrophyte primary production occurs, determined at least in part by the vertical extent of light penetration associated with water clarity and change in water surface elevation (Wetzel 2001). The

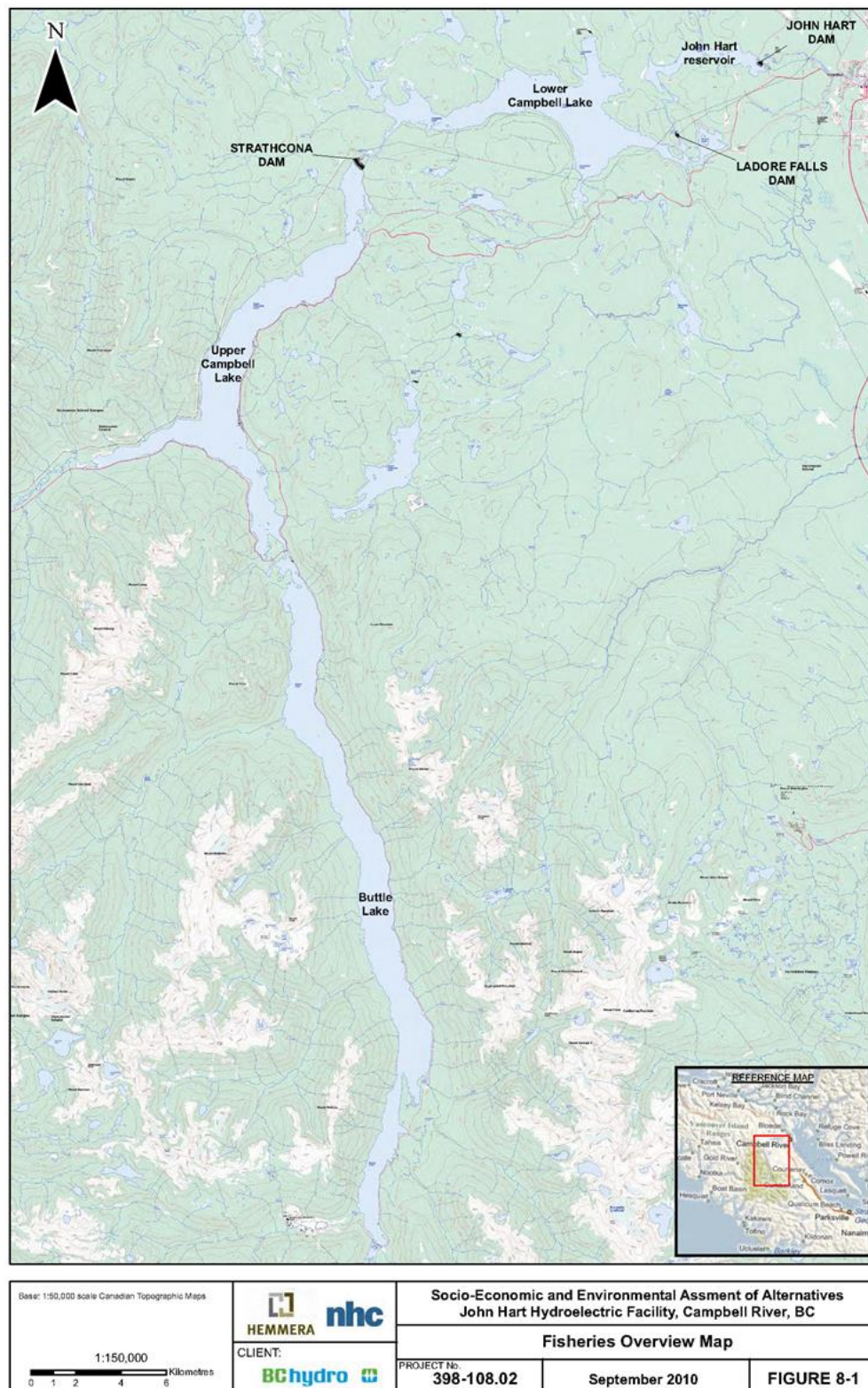
littoral zone is the shallow habitat of lake and reservoir shorelines extending to a water depth at which light is sufficient to support photosynthesis that produces biomass on substrata. The spatially dynamic littoral zones in reservoirs mean that potential effects of change in reservoir operation on littoral processes must be considered in terms of change relative to the entire area of benthic production where addition of benthic biomass from photosynthesis (P) exceeds loss from respiration (R) (i.e., $P/R > 1$).

The approved operating strategy for each reservoir in the WUP (BC Hydro 2012) is listed in Table 1. The intent was to maintain Lower Campbell Reservoir within a narrow range of 176.5 – 177.5 m and maintain Upper Campbell Reservoir within a range of 217.0 – 220.5 m, during the summer season. An additional objective for Upper Campbell was to maintain stable water surface elevations near 219 m where possible in the summer. These targets were expected to improve recreational opportunities and improve fish production within the littoral zone.

Table 1. Operating alternatives and expected benefits in Upper and Lower Campbell Reservoirs Water Use Plans (BC Hydro 2012).

Reservoir	Recommended operating alternative in the water use plan	Expected benefit
Lower Campbell Reservoir	Normal operating water surface elevation of 176.5 m (minimum) to 177.5 m (maximum) during the peak summer season of June 21 through September 10.	No change in erosion
		Improve access to the reservoir for recreation
		Increase fish productivity by improving littoral zone habitat and spawning conditions in tributary mouths.
Upper Campbell Reservoir	Normal operating water surface elevation of 217 m (minimum) to 220.5 m (maximum) during the peak summer season of June 21 through September 10.	Reduce erosion by reducing number of days when water surface elevation exceeds 220 m under normal operations
		Increase the number of days when the reservoir supports high quality recreation
	Maintain more stable peak season operations near a target water surface elevation of 219 m during the peak summer season of June 21 through September 10.	Improve access to the reservoir for recreation during shoulder seasons
		Improve aesthetics and terrestrial habitat when less variation in water surface elevation is combined with re-vegetation
		Increase fish productivity by improving littoral zone habitat and spawning conditions in tributary mouths.

Map 1. Lakes and reservoirs in the Campbell River system (Hemmera 2010).



The Terms of Reference (TOR) for JHTMON-4 described a term called the “effective littoral zone” (ELZ) that was a performance measure used during water use planning (BC Hydro 2012). ELZ was considered to be biomass of periphyton expressed as a function of rate of accrual of periphytic algae on substrata within a range of depths measured over a growing season in the littoral zone. The WUP used ELZ to assess change in productive potential of the littoral zone among scenarios of water level management but did so with much uncertainty because of unknown reliability of the ELZ measure. This uncertainty led to a first management question as follows:

1. Does the ELZ performance measure adequately estimate the change in littoral productivity due to changes in reservoir operation, particularly in relation to changes implemented with the Campbell River WUP and potential future changes?

A second management question asked about ecological factors influencing ELZ and was stated in the TOR as follows:

2. To what extent does colonization rate, PAR penetration, growth rate and survival rate impact the utility and reliability of the ELZ performance measure for WUP decision-making purposes?

PAR is photosynthetically active radiation that occurs within irradiance wavelengths of 400 – 700 nm (Wetzel 2001). Availability of PAR for photosynthesis in surface waters and lack of PAR in bottom waters is why lake and reservoir periphyton grows on shallow substrates but not at great depths. A general rule is that photosynthesis produces biomass where PAR occurs at intensities of more than 1% of irradiance found at the water surface (Wetzel 2001). PAR attenuation is affected by particles in water that contribute to turbidity. When turbidity is high, photosynthetic production occurs over a shallower depth than would occur if turbidity is lower.

A third management question asked about changes to biological production in the littoral zone of the Upper and Lower Campbell reservoirs with application of water management rules under the WUP as follows:

3. Following implementation of the Campbell River WUP, does littoral productivity increase as predicted by the ELZ performance measure?

Given ultimate interest in potential benefit to fish populations in the reservoirs from the WUP, a fourth management question asked:

4. How does littoral productivity translate into fish production in Campbell River reservoirs?

Each of these management questions will be addressed in this study over three years of study (two years of field and lab work and a third year of analysis). This report describes progress in the first year (2015-16) of work with the main objective of demonstrating the approach to answering the

management questions. This demonstration was completed with data collected from Lower Campbell Reservoir.

1.4. Scope of the JHTMON4 Study

1.4.1. Overview

The JHTMON-4 schedule consists of two years of field and lab work and a third year of analytical study. Year 1 of JHTMON-4 was designed as a pilot year to develop analytical procedures capable of answering the management questions. Sampling of periphyton, benthic invertebrates, and fish was completed in Lower Campbell Reservoir, with sampling planned for Upper Campbell Reservoir in Year 2. Bathymetric mapping was completed for the Lower Campbell Reservoir, and a digital elevation model (DEM) created.

1.4.2. Summary of the Main Method to Test Management Questions

A challenge with ELZ as it is defined in the TOR is it does not quantitatively consider environmental factors other than light that are known to modify periphyton accrual over water depths spanning a littoral zone. The second management question, in particular, suggests that physiological adaptation to habitat including algal colonization rate, growth rate, and survival upon desiccation determine ELZ. It also suggests that only one environmental factor (PAR) is important in determining ELZ. Physiological responses to environmental conditions (e.g., colonization and growth rate) are lumped in with an environmental condition (light) as predictor variables but the reality is that the two are correlated (physiological adaptation is a response to environmental condition) and thus cannot be used together as predictor variables. A resulting equation would be unstable because one independent variable depends on another. Algal biomass accrues according to environmental conditions of which light is a part and so we suggest that question 2 is really asking about what is the relative importance of several environmental factors that potentially determine growth and biomass of periphyton. Where PAR is sufficient to support photosynthesis (Krause-Jensen and Sand-Jensen 1998, Dodds *et al.* 1999, Wetzel 2001, Karlsson *et al.* 2009), production of algae may be limited by nutrient supply (Bothwell 1989, Biggs 2000, Guildford and Hecky 2000, Wetzel 2001) or temperature (Goldman and Carpenter 1974, Bothwell 1988) within available habitat that is influenced by reservoir filling and drawdown. The TOR included tasks to measure irradiance and temperature but did not suggest application of the data to the measurement of ELZ.

We revised the ELZ as defined in the TOR to include three environmental attributes (PAR, temperature, nutrient concentration) that can affect the accrual of periphyton biomass in a littoral zone and we derived equations to express the relationship between periphyton accrual and those attributes. That relationship can be linked to the area of the littoral zone and used to explore potential change in algal accrual with change in water surface elevation that can be affected by management actions. This change was discussed with representatives of BC Hydro and it was approved in spring and incorporated into the revised Terms of Reference (BC Hydro 2015.).

ELZ was defined as the amount of periphytic algal biomass (B) accrued on an area of substrata in a littoral zone with modification by light, temperature, and nutrient concentrations over time and space. This performance measure is called L as described in Equation 1 below. L is conceptually the same as ELZ but it is named differently because its calculation includes more variables having ecological relevance than we understand were conceived for ELZ. B is in units of $\mu\text{g chl-}a\cdot\text{cm}^{-2}$ where chl- a is chlorophyll- a , a primary plant pigment that is commonly used as a measure of biomass in algae (Wetzel 2001, Behrenfeld *et al.* 2005). Chlorophyll- a can be approximately converted to carbon (e.g., Riemann *et al.* 1989, Cloern *et al.* 1995, Behrenfeld *et al.* 2005, Li *et al.* 2010) to yield units of $\text{mg C}\cdot\text{m}^{-2}$ for carbon budgeting if needed later, or to support other WUP studies of Upper Campbell Reservoir. These measurements represent the amount of carbon fixed per unit area that corresponds to a set of defined environmental conditions found at some time. The area of the littoral zone where periphytic algae grows is defined as substrata area within depth strata where PAR in the overlying water column is greater than 1% of that at the water surface (the standard measure of euphotic zone depth, Wetzel 2001). Area of a littoral zone can therefore be modified by processes that change PAR attenuation.

The definition of L can be stated as follows:

Equation 3.

$$L_t = \sum_{i=1}^n A_{it} B_{it}$$

where;

L is accrued B that may be modified by habitat conditions and area of flooded littoral habitat at time t ,

A is area of stratum i within the littoral habitat having n strata at time t , and

B is biomass of accrued periphyton at time t in littoral depth stratum i ,

and

Equation 4.

$$B_{it} = \beta_0 + \beta_1 x_{1it} + \beta_2 x_{2it} + \beta_3 x_{3it} + \varepsilon$$

is a multiple regression model explaining B at time t in depth stratum i as a function of x independent variables where β_0 is the regression intercept, x_1 is PAR, x_2 is concentration of a nutrient that limits growth of periphyton, x_3 is water temperature, $\beta_{1...3}$ are regression coefficients, and ε is model error.

The combination of equations 1 and 2 will eventually be used to answer management questions 1 through 3. The WUP is designed to keep water surface elevation within agreed ranges. Equation 1 is

sensitive to change in water surface elevation. Input of littoral area that can support periphyton biomass changes according to water surface elevation. That equation can answer management question 1. The littoral area for any water surface elevation was defined using a DEM that was developed in 2015 by Ecofish Research Ltd. Also in 2015, periphyton biomasses and various habitat attributes were measured at replicate stations in the summer and fall in Lower Campbell Reservoir. Resulting data were used to develop the regression model in Equation 2 to predict periphyton biomass as a function of the three main habitat conditions: nutrient concentrations, temperature, and PAR. In 2015, all sampling was done in Lower Campbell Reservoir to coordinate activities between the present study and JHTMON-5 that was occurring at the same place and time. These two studies have elements that are closely linked, as will be explained below in relation to management question 4. Values for the independent habitat attributes can be entered into the model to show sensitivity of algal biomass to change in the habitat attributes (nutrient concentrations, temperature, PAR) and thus answer management question 2. Once finalized, the model can be used to test different management scenarios, as might be required during consideration of changes to reservoir operations. It can be used to test sensitivity of periphyton biomass accrual in the littoral zone to decisions on change to the timing and magnitude of change of different water surface elevations and thus answer management question 3. A change to water surface elevation at a given time of year changes littoral area and potentially physical and chemical attributes that drive periphyton accrual as shown in Equations 1 and 2.

Accrual of periphyton biomass must be measured under a wide range of PAR, nutrient concentrations, and temperature (independent variables) for an informative regression model to be developed that can be effectively used to tease apart the relative influence of each environmental factor. In 2015, this range of conditions was captured by completing measurements of periphyton biomass and habitat attributes in the fall (low temperature, low PAR) and summer (high temperature, high PAR). In addition, a gradient in nutrient concentrations was expected between the fall when mobile nutrients were likely flushed from forest soils and the summer, when there was expected to be lower flux of nutrients from the watershed to the reservoir. In each season, four sampling stations distributed throughout the reservoir were used to capture the variability of physical and chemical conditions that were needed for model development. At each station, periphyton biomass was measured on substrata at six depths covering potential ranges of PAR and temperature. Within a season, little to no variation in nutrient concentrations was expected between the surface and bottom of the littoral zone because water will be well mixed according to density gradients. This condition means that nutrient concentration may not be a good predictor of B within a given season. The influence of nutrient concentrations was hypothesized to be apparent based on comparison between data from summer and fall (mainly reflecting differences in nutrient mobility from forest soils).

A part of management question 2 that is not captured in equations 1 and 2, relates to the physiological adaptation of an algal mat to ambient conditions including cell colonization, growth,

and survival, all of which contribute to biomass accrual on substrata. Colonization can be defined as the time for algal cells to become established on a substratum (a linear process) before growth determines change in algal biomass (a logarithmic process) (Bothwell 1989). Algal survival in question 2 is related to senescence as substrata become exposed to air when water surface elevation declines during drawdown of a reservoir. For practical purposes, algae exposed to air will not survive and will decay from living algae to detrital matter.

Accrual of periphyton was measured as change in biomass over time on standardized submerged substrata, similar to the approach used by Bothwell (1989) and Perrin *et al.* (1987) to examine growth of stream periphyton. Colonization period was the linear part of the accrual curve before logarithmic growth was detected. That period showed the time required for a rudimentary community to become established on newly flooded substrata (e.g., after rising of water surface elevation over previously dewatered substrata in a reservoir). Growth was considered the logarithmic phase of biomass accrual, reaching a maximum or peak biomass (PB) over time as determined by ambient habitat conditions (PAR, temperature, nutrient concentrations). Measurements in 2015 allowed two months for colonization and growth to PB to be achieved; more than double the time reported for periphyton in running waters (Bothwell 1989, Perrin *et al.* 1987).

Question 4 will be answered using multiple lines of evidence. There are few studies showing direct links between littoral periphyton production and littoral fish production in lakes, the one by Hecky and Hesslein (1995) being particularly noteworthy, and none in reservoirs that we are aware of. In contrast, there is well known evidence of fish feeding on invertebrates of different origin (e.g., Mehner *et al.* 2005, Vadeboncoeur *et al.* 2002, Weidel *et al.* 2008) and of littoral invertebrates feeding on detrital matter of different aquatic and terrestrial origins (France 1995, Solomon *et al.* 2008). Part of the challenge in quantifying links between algae and fish is that valued fish species using littoral habitat are commonly opportunistic in their foraging behaviour, targeting invertebrates produced from many sources. This behaviour is particularly true in Rainbow Trout (*Oncorhynchus mykiss*) and Cutthroat Trout (*O. clarkii*) (Nilsson and Northcote 1981, Perrin *et al.* 2006), which are the two most abundant fish species in the Upper and Lower Campbell reservoirs (Hocking *et al.* 2015). Hence, there may be some disconnect between production of algae and benthic invertebrates within a littoral zone and fish using that habitat in Upper and Lower Campbell reservoirs. Juvenile trout in particular might be expected to use the littoral habitat but the carbon present in the assemblage of ingested food may not be fixed there and instead be derived from terrestrial sources. This food web structure is different from pelagic habitats, where growth of obligate planktivores like Sockeye Salmon juveniles, for example, can be predicted from rates of pelagic primary production (Shortreed *et al.* 2001). That pelagic food web is much simpler and easier to model than littoral habitats.

Some insight for answering question 4 was provided in this study by analysing fish stomach content data from fish sampled with gill nets in Lower Campbell Reservoir in 2015 as part of JHTMON-5. Lab work to enumerate stomach contents, by taxon, was part of the present JHTMON-4 project. Analysis of these data involved examining whether food ingested by fish was typical of food

produced in littoral benthos (e.g., benthic aquatic invertebrates), which would indicate that changes in production of littoral periphyton may influence availability of food for those fish. Conversely, if analysis showed that most food ingested by fish was not derived from littoral benthos (e.g., insects from the forest canopy), then changes in production of littoral periphyton may not strongly influence food availability for those fish.

Fish stomach data alone are not sufficient to unequivocally determine sources of food for fish because they only relate to the time when samples were collected and fish diets may vary. This problem can be resolved by collecting fish stomachs at several times and conditions, but that option was not available in this study because fish stomachs were only collected at a single time during JHTMON-5. A method was therefore needed that integrated the relative contributions of different food sources to fish diets over a wide temporal scale. Furthermore, stomach contents analysis does not necessarily provide clear information about the basal source of the carbon present in food sources. Fish may ingest littoral invertebrates that gain energy from living periphyton or from benthic detrital matter (e.g., small particulate organic matter (SPOM)) that is not related to periphyton production, or from a mixture of the two. They may feed on zooplankton (which predominantly derive energy from pelagic production) at some times and benthos at other times (Nilsson and Northcote 1981). Periphyton itself can also vary in composition, as it includes a living algal component, but also bacteria, fungi and non-living organic material (Schroeder *et al.* 2013). Even organic matter in different places of the littoral zone may come from different sources, including: terrestrial leaf litter, organic matter from the original forest floor that was flooded at the time of reservoir formation, macrophyte decay, or detritus from senesced periphyton. Analysis of sediment in John Hart Reservoir (immediately downstream of Lower Campbell Reservoir) found that the flooded forest floor remains intact and represents a large pool of labile organic matter (Perrin *et al.* 2012). Given the potentially different sources of food for fish, other lines of evidence were needed to examine links between periphyton and fish using littoral habitat.

Stable isotope techniques were applied to fill this void. Stable isotopes of nitrogen and carbon were measured in samples from fish, invertebrates (littoral invertebrates, terrestrial invertebrates, zooplankton), and basal nutrient sources in littoral areas, including small particulate organic matter (SPOM), terrestrial vegetation, periphytic algae, and littoral periphyton that includes non-algal material. All samples were collected from Lower Campbell Reservoir in 2015. Isotopic signatures were then used in mixing models to isolate the relative contribution of periphyton to fish diets in Lower Campbell Reservoir.

1.4.3. Stable Isotope Techniques

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-4 uses stable isotope analysis (SIA) of nitrogen and carbon of fish tissues and their potential diet items to quantify energy flow to fish from the algal component of periphyton, and from other basal nutrient sources in the littoral zone. Nitrogen isotope ratios ($\delta^{15}\text{N}$)

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 ($\delta^{13}\text{C}$) 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 $\delta^{15}\text{N}$ signatures. In contrast, fish that have higher $\delta^{13}\text{C}$ signatures tend to have a greater reliance on terrestrial sources of carbon than zooplankton.

Using both $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ together allows for the development of stable isotope mixing models, which can estimate the contributions of different prey sources to a consumer's diet (Semmens *et al.* 2009, Parnell *et al.* 2010). The primary species of interest in JHTMON-4 are Cutthroat Trout and Rainbow Trout. Sampling was designed to understand the relative contribution of periphyton to 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, benthic/littoral invertebrates, 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.). Periphytic algae is one of several primary nutrient sources for the littoral prey of Cutthroat Trout and Rainbow Trout. Thus, the JHTMON-4 study was designed to obtain representative samples of Cutthroat Trout and Rainbow Trout, their potential diet items and basal nutrient sources in littoral habitats. 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 (e.g., periphyton, zooplankton and SPOM samples).

2. METHODS

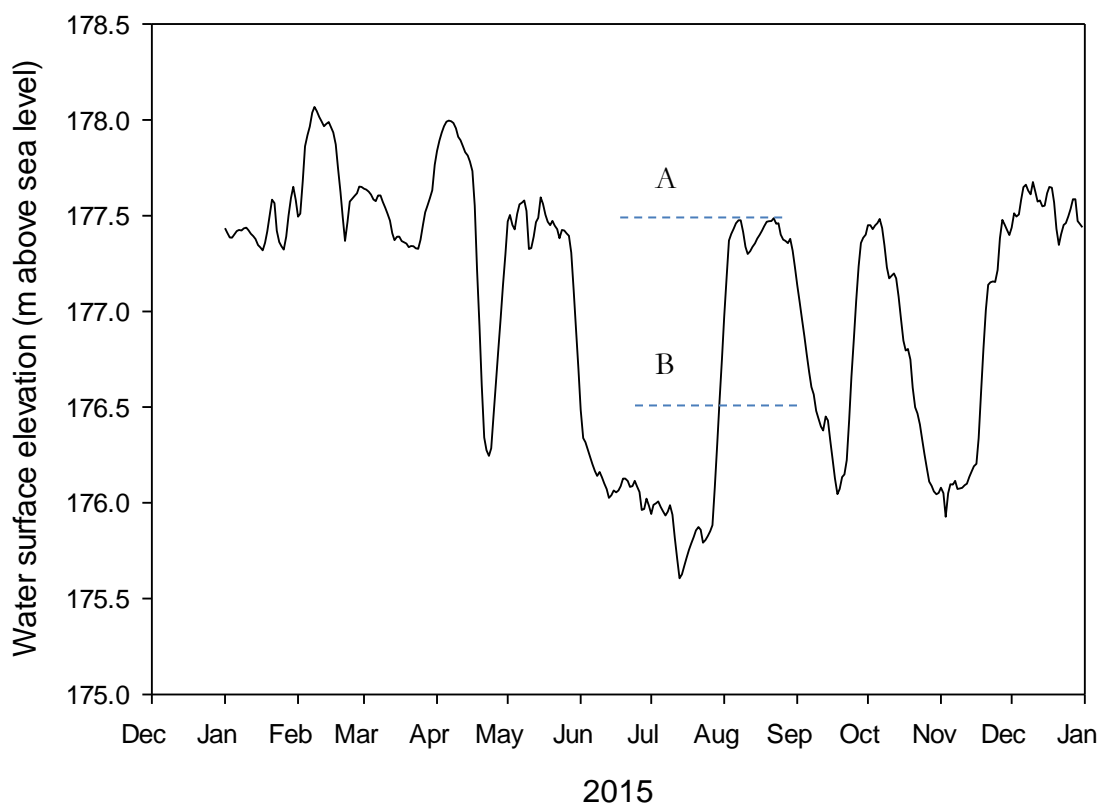
2.1. Study Area

The study reservoirs are within the Campbell River watershed, which originates in the Vancouver Island Mountain Range at elevations up to 1,900 m (Map 1). Headwaters flow north from Strathcona Park into Buttle Lake and then into Upper Campbell Lake that supplies most storage for the Campbell River hydroelectric generating system. From Upper Campbell Lake, water flows through the 65 MW Strathcona generating station into Lower Campbell Lake, where water flows through the 47 MW Ladore generating station and into John Hart Reservoir, which supplies water for the 126 MW John Hart generating station via three wood stave penstocks and surge towers. The John Hart water intake, penstocks, and power generating station are presently being replaced as part of upgrades to infrastructure in the Campbell power generating system.

Lower Campbell Reservoir is operated with little drawdown. It has a length of 15 km. It is <0.5 km wide near the inflow from Upper Campbell Reservoir, it broadens to 2 km wide in the central basin and narrows to small channels of 0.1 to 0.2 km at the east end where water is released to John Hart Reservoir. There is typically no regular seasonal drawdown, but the water surface

elevation can vary within seasons according to water and power production management within the whole Campbell system. In 2015, the elevation ranged over 2 m (177.6 – 175.6 m) during the biologically active period of May through October in 2015 and over 3 m for all of calendar 2015 (Figure 1). During the “peak summer season” defined in the WUP as June 21 to September 10, the water surface elevations were 175.6 – 177.5 m, which was about double the target range in the WUP (Table 1). The exceedance was 1m below the target low elevation of 176.5 m. At water elevation of 178.0 m (approximately full supply), the reservoir surface area is 26.4 km², total volume is 460.6 x 10⁶ m³, mean depth is 17.5 m, and maximum water depth is 71.3 m¹.

Figure 1. Mean daily water surface elevation in Lower Campbell Reservoir, 2015. Horizontal line A shows the “peak summer season” preferred maximum water surface elevation as defined in the Water Use Plan and line B shows the preferred minimum elevation.



¹ Morphometric data are from a DEM developed by Ecofish Research Ltd. 2015.

2.2. Bathymetric Survey and Digital Elevation Model (DEM)

2.2.1. Field

A digital elevation model (DEM) was developed and used to estimate littoral area vs. water surface elevation. Lake depth bathymetry surveys of the Lower Campbell Reservoir were completed from October 20 – 24, 2015 using a Lowrance LCX-27C depth sonar and GPS rover system. Bathymetric data collection was completed following standard data collection guidelines (OMNR 2004, Wilson and Richards 2006, MOE 2009). The depth sonar uses a single frequency transducer of 200 kHz to measure the distance from sensor to the lake bottom with a stated vertical accuracy of ± 0.10 m. The GPS system of the sonar unit has a horizontal accuracy of ± 3 m, depending on satellite coverage (Lowrance 2006), which will be about 3% of a 100 m spacing between two transects. The GPS system collected data in a proprietary coordinate system owned by Lowrance, the data were then converted to the WGS 1984 coordinate system following the standard methodology (MOE 2009).

The field data points collected during the field surveys are shown on Map 2. This study focused on the littoral zone, for the Lower Campbell Reservoir this was defined as the vertical zone from the water surface to 20 m depth based on irradiance profiles described in Section 3.1. Consequently, route planning focused effort in areas where depths were around 20 m and shallower. Typical transect spacing was approximately 50 m in the littoral zones (e.g., McIvor and Fry Lakes).

2.2.2. Data Quality Assurance

Manual spot soundings were taken at the beginning of each survey to verify the sounder and make sure the keel offset was correct. For bathymetric surveys, data quality may be compromised by a number of factors, including turbulence caused by excessive speed, and loss of signal in shallow water depths (< 2 m). Therefore, boat speed was maintained at < 15 km/hr while recording cross-lake transect measurements and < 5 km/hr while recording shoreline crawls and completing turns at the end of transects. The inner shoreline crawls were collected at depths as shallow as possible while maintaining continuous depth signals. Waves can cause the water surface elevation to fluctuate so surveys were not conducted if wave heights exceeded 0.5 m.

2.2.3. Hydrological Field Conditions

During the five days of field surveying the reservoir average daily water surface elevation varied 0.349 m from 176.332 m to 176.603 m (Table 2). Given the purpose of the DEM, this fluctuation was small enough that hourly data correction was deemed sufficient, and corrections using shorter interval data were not necessary.

Table 2. Lower Campbell Reservoir Water Surface elevations from October 20 – 24, 2015.

Date	Water Surface Elevation (m)
20-Oct-2015	176.603
21-Oct-2015	176.499
22-Oct-2015	176.466
23-Oct-2015	176.409
24-Oct-2015	176.332

2.2.4. Bathymetric Mapping

BC Hydro provided the following data for Lower Campbell Reservoir in 2015: daily water surface elevation (m), daily storage ($1 \times 10^6 \text{ m}^3$), daily flow released from Strathcona Dam (m^3/s), daily local inflow (m^3/s) and the daily flow released from Ladore Dam (m^3/s) (Nishi, pers. comm. 2016), and the average hourly reservoir elevations from October 20 – 24, 2015 (Walker, pers. comm. 2015). Additionally, BC Hydro previously provided (Kaulback, pers. comm. 2015) existing shoreline bathymetry data collected when water surface elevations were greater than those observed at the time of field study, but less than the 2015 annual maximum average daily water surface elevation.

Individual bathymetric data points (depths) collected in the field were converted into elevations by subtracting the depths from the hourly average elevation of Lower Campbell Reservoir observed at the corresponding time of survey. During the field survey, the maximum observed average daily water surface elevation was 176.6 m. This was less than the 2015 annual maximum average daily water surface elevation of 178.068 m observed on February 8, 2015. To generate bathymetric maps that reflect the maximum average daily water surface elevation observed in 2015 (178.068 m), existing bathymetric data were added to elevations from 176.6 m to 178.068 m. The two sources of data were used to generate the reservoir bathymetry with the ArcGIS commercial mapping software.

The Inverse Distance Weighted (IDW) method of interpolation was used to generate an elevation surface, with 5 m horizontal resolution, from the elevations data inputs. The surface area and volume calculations were completed using the ArcGIS Surface Volume tool with 0.1 m depth intervals. For this study, the littoral zone was classified as the top 20 m of the water column and the pelagic zone as the depths greater than 20 m below the water surface based on irradiance profiles described in Section 3.1.

2.3. Periphyton Biomass Accrual

On July 31, 2015 four sampling stations for measurement of periphyton accrual and habitat attributes were established on Lower Campbell Reservoir. They were called LCR-PERWQ1, LCR-PERWQ2, LCR-PERWQ3, and LCR-PERWQ4 (Map 2; Table 3). Map 2 shows five sampling stations but hardware at the one called LCR-PERWQ1 was vandalized within the first week after

installation on July 31, 2015 and was replaced with the one called LCR-PERWQ1A. The stations were widely distributed and placed where water depths were at least 20 m to allow unobstructed suspension of sampler mooring lines that extended to a depth of 18 m (Section 4.2). The 18 m sampler range covered the depth of the euphotic zone (depth where PAR is >1% of that at the water surface).

Increase in periphytic algal biomass on substrata over time is called algal accrual, which is a function of cell settlement during a colonisation phase, actual growth, and losses associated with senescence, invertebrate grazing, and sloughing. Peak biomass (PB) was the highest concentration of chl-*a* attained on a substrate over time of measurement. There can be differences in the amount of biomass accruing on different natural littoral substrata because of variation in surface texture. To avoid that surface effect, a standard artificial substratum for measurements of biomass accrual and PB was used. Styrofoam was selected, following its successful application by Bothwell (1989). Styrofoam balls were suspended on lines from surface floats at different water depths, thus removing the accrued periphyton from exposure to grazing by benthic invertebrates. This standardization was needed because of need to examine variability in algal accrual associated with PAR, temperature, and nutrient concentrations, and minimize variance associated with other factors.

Table 3. Summary of chlorophyll *a* and PAR sampling in Lower Campbell Reservoir using periphyton sampling apparatus and LI-2050A light profile.

Parameter	Site	Sampling Date	UTM		
			Zone	Easting	Northing
Chl- <i>a</i>	LCR-PERWQ1 [†]	7-Aug-15, 14-Aug-15, 22-Aug-15	10U	327193	5542199
PAR in water	LCR-PERWQ1A	28-Aug-15, 4-Sept-15, 11-Sept-15, 18-Sept-15, 25-Sept-15, 2-Oct-15, 9-Oct-15, 16-Oct-15, 23-Oct-15, 30-Oct-15, 6-Nov-15, 13-Nov-15, 20-Nov-15, 27-Nov-15	10U	323326	5543836
	LCR-PERWQ2	7-Aug-15, 14-Aug-15, 22-Aug-15, 28-Aug-15, 4-Sept-15, 11-Sept-15, 18-Sept-15, 25-Sept-15, 2-Oct-15, 9-Oct-15, 16-Oct-15, 23-Oct-15, 30-Oct-15, 6-Nov-15, 13-Nov-15, 20-Nov-15, 27-Nov-15	10U	326070	5545145
	LCR-PERWQ3	7-Aug-15, 14-Aug-15, 22-Aug-15, 28-Aug-15, 4-Sept-15, 11-Sept-15, 18-Sept-15, 25-Sept-15, 2-Oct-15, 9-Oct-15, 16-Oct-15, 23-Oct-15, 30-Oct-15, 6-Nov-15, 13-Nov-15, 20-Nov-15, 27-Nov-15	10U	324154	5544652
	LCR-PERWQ4	7-Aug-15, 14-Aug-15, 22-Aug-15, 28-Aug-15, 4-Sept-15, 11-Sept-15, 18-Sept-15, 25-Sept-15, 2-Oct-15, 9-Oct-15, 16-Oct-15, 23-Oct-15, 30-Oct-15, 6-Nov-15, 13-Nov-15, 20-Nov-15, 27-Nov-15	10U	327221	5542559

[†]Sampling apparatus at LCR-PERWQ1 was vandalized after the first week of incubation and the site was moved to LCR-PERWQ1A.

The Styrofoam balls measuring 2.5 cm in diameter were incubated at the four sampling stations in each of summer (July 31 through September 25) and fall (September 25 through November 20), 2015. A single ball was attached to a halibut setline clip using a cable tie that was threaded through the ball and around one end of the clip (Figure 2). To start each sampling series (summer and fall), 8 balls were clipped onto a vertical 5/16 inch nylon double braid mooring line at each of 1 m, 7 m, and 14 m depths, 1 other ball was clipped to the line at each of 4 m, 10 m, and 18 m depths, and another ball was clipped at the 1 m depth (28 balls on each line). The depth range of 18 m extended over the depth of the euphotic zone where PAR exceeded 1% of that immediately under the water

surface. This range of sampling depths provided a range of variation in PAR and temperature. The vertical line with Styrofoam balls was suspended from a float and held in position using a rigid mooring bar that was connected to a separate float, anchor line, and anchor as shown in Figure 3. By being suspended from a float on the water surface, the balls remained at a fixed depth regardless of change in water surface elevation. One mooring line (each configured as shown in Figure 3) was placed at each of the four sampling stations.

Figure 2. Image of Styrofoam balls clipped on to a mooring line. The balls provided substrata for colonization and growth of periphytic algae.

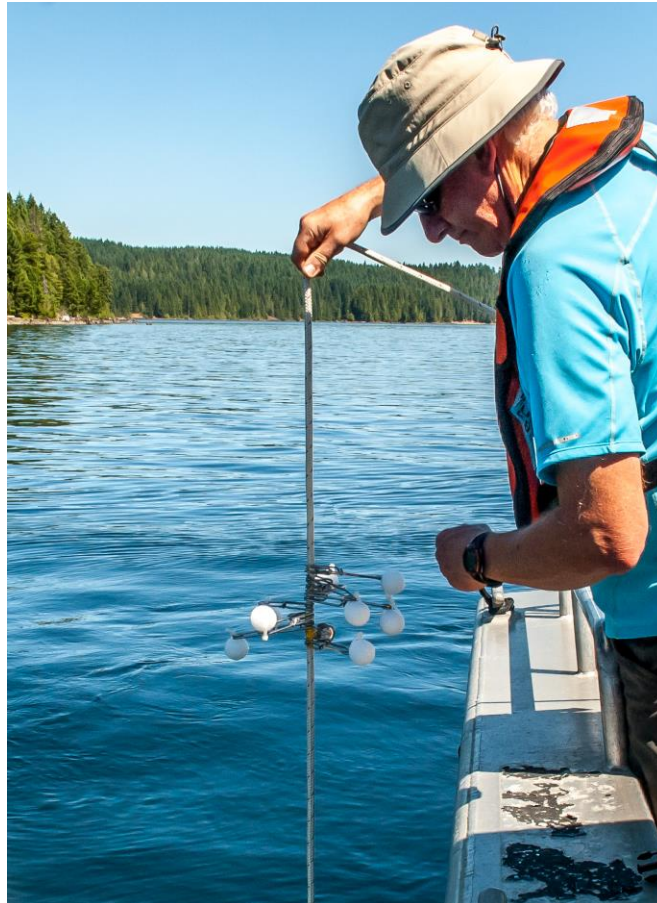
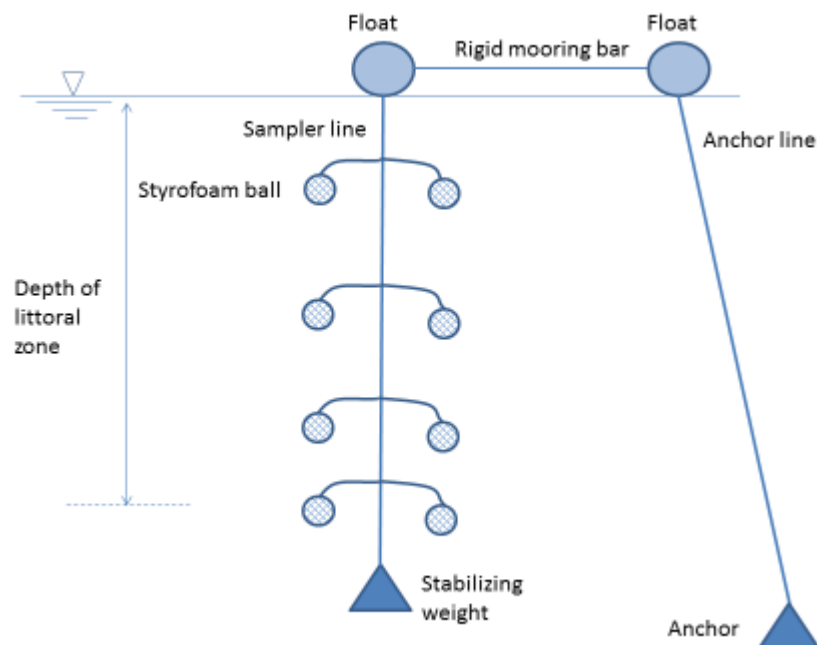


Figure 3. Schematic image of rigging used to deploy a periphyton mooring.



Periphyton accrual was measured following sequential collection of the Styrofoam balls over the duration of the summer and fall sampling periods. Samples were collected once per week during the two eight-week sampling periods (Table 3). Installation/removal of periphyton substrata (see Section 2.4) occurred on 31 July, 2015 (installation), 25 Sept, 2015 (removal and installation), and 27 Nov, 2015 (removal). At weekly intervals for eight weeks, one ball from each of the 1 m, 7 m, and 14 m depths was unclipped and each ball was placed into a separate plastic vial that was labelled with date, station, and position on the vertical line. These samples were used to measure change in biomass over time in relation to initial cell colonization, actual algal growth (logarithmic change in biomass after colonization), the duration to reach PB from the start of incubation, and the magnitude of PB. The vials were capped and packed on ice for delivery to Campbell River where the samples were stored at -15°C until shipment to the lab. On the final sampling date of each series, the final ball was removed from the 1 m, 7 m, and 14 m depths and the single ball at each of the 4 m, 10 m, and 18 m depths was removed and processed the same way for measurement of biomass at all six depths. Once all samples were collected for a sampling series (summer or fall), they were packed on dry ice and shipped frozen to the lab for analysis of chl-*a* concentration using extractions in acetone followed by analysis of chl-*a* concentration by fluorometry (EPA method 445²). Units of concentration were $\mu\text{g chl-}a \cdot \text{sample}^{-1}$. Values were corrected to areal units for analysis

² <http://monitoringprotocols.pbworks.com/f/EPA445.pdf>

($\mu\text{g chl-}a \cdot \text{cm}^{-2}$), where the sampling area was based on the surface area of the Styrofoam ball. Three replicate blanks that were not deployed at sampling sites were processed the same way to test for contamination: none was found. The extra ball that was attached at the 1 m depth on each line was also removed on the final sampling date of each series for enumeration of algal species composition. Each of those balls was placed in a vial with enough deionized water to cover the ball and preserved in Lugol's solution for later identification and enumeration of cells by species. In the lab, cells were removed from the Styrofoam using a fine spray of deionized water from a dental cleaning instrument inside the sample vial. Contents were dispensed into a Utermöhl chamber to settle over 24 hours. Cell counts were made at 500 \times magnification under an inverted microscope. Only cells containing cytoplasm were enumerated. A minimum of 100 cells of the most abundant species and a minimum of 300 cells in total were counted per sample. Biovolume, by species, was determined by multiplying cell counts by the volume of representative geometric shapes or combination of shapes that most closely approximated cell shape. Diversity metrics, including species richness (number of unique species per sample) and Simpson's Diversity Index were calculated from the cell counts.

Curves were produced from the biomass accrual measurements to present chl-*a* concentration as a function of time (days). Each of the four stations was considered an independent replicate for the calculation of mean chl-*a* concentration \pm standard deviation at each of the three depths at which weekly samples were collected (1 m, 7 m, and 14 m). PB was the highest chl-*a* concentration found on a substratum. A general linear model for analysis of covariance (ANCOVA) was used to test for homogeneity of slopes of the regression lines wherein the dependent variable was \log_{10} of 1+ chl-*a* concentration (a \log_{10} transformation was applied to produce a straight line that is required for ANCOVA and 1 was added to each value to avoid negative numbers), the independent covariate was days of incubation, and the independent variable was depth as follows:

Equation 5.

$$\log_{10}(1 + [\text{chla}]) = \text{Constant} + \text{Depth} + \text{Days} + (\text{Depth} * \text{Days})$$

If the interaction term ($\text{Depth} * \text{Days}$) was significant ($p < 0.05$), slopes of the regression lines were considered different because it indicated that algal biomass, measured as chl-*a* concentration, differed over time between the three depths (hence a difference in slope of the regression line).

2.4. Periphyton Habitat Attributes

PAR, temperature, and nutrient concentrations (predictor variables in Equation 2) were measured during the sampler incubations to correspond with the measurements of chlorophyll-*a* concentration (Table 5). Temperature was recorded in 30 minute intervals using a Tidbit temperature logger attached to each periphyton sampling position on each mooring line (six positions on each of the four mooring lines). PAR was measured weekly at 1 m intervals over a vertical profile from surface to the bottom of each sampler at each station using a LiCor LI250A irradiance meter equipped with a spherical quantum sensor (LiCor Inc. Lincoln, Nebraska). The instantaneous PAR data was correlated with PAR that was continuously logged at a base station (Onset pyranometer sensor and

microstation logger, Onset Computer Corporation, Bourne Massachusetts) located on the Strathcona Dam, allowing the continuous measurements to be corrected for attenuation in water to provide a continuous record of PAR at each position on the mooring line during incubation (see Section 2.3 for details).

Nutrient concentrations were measured in one water sample collected from the surface and one 2 m off bottom on July 31, 2015 (beginning of the summer periphyton sampling), September 25, 2015 (end of the summer periphyton sampling and start of the fall periphyton sampling), and November 27 (near the end of the fall periphyton sampling). Samples were collected in duplicate and field blanks were collected as part of QA procedures. Samples for determination of TN (total nitrogen), TP (total phosphorus) and ammonium ($\text{NH}_4\text{-N}$) were collected in an amber bottle and preserved with H_2SO_4 . Samples for determination of remaining nutrient fractions were not preserved with acid to avoid interference with analysis. All samples were stored on ice immediately following collection; samples were received by the laboratory either on the evening of the sampling date, or the following morning.

Samples were analyzed to determine concentrations of TN, TP, TDP (total dissolved phosphorus), nitrate ($\text{NO}_3\text{-N}$), ammonium and soluble reactive phosphorus (SRP). Water for TDP, nitrate, ammonium, and SRP determination was filtered in the field at the time of collection through Waterra 0.45 μm FHT-45 polyethersulphone filters³ using an Alexis peristaltic pump⁴. All samples were submitted within 24 hours to ALS Environmental in Burnaby for analysis using standard methods (APHA *et al.* 2014); laboratory analysis methods are presented in Table 4.

³ http://www.waterra.com/pages/Product_Line/filters/filters_2011.html

⁴ <http://pegasuspumpcompany.com/alexis-peristaltic-pumps>

Table 4. Methods and detection limits for laboratory nutrient analysis.

Variable	Method	Detection Limit ($\mu\text{g L}^{-1}$)
SRP	Colorimetry following field filtration (0.45 μm).	1.0
TDP	Colorimetry following field filtration (0.45 μm) and digestion by persulphate oxidation.	2.0
TP	Colorimetry following digestion by persulphate oxidation.	2.0
NO ₃ -N	Ion chromatography with conductivity and/or UV detection following field filtration (0.45 μm).	5.0
NH ₄ -N	Fluorescence following field filtration (0.45 μm).	5.0
TN	Colorimetry following digestion by persulphate oxidation.	30.0

Table 5. Summary of water chemistry, benthic invertebrate, and stable isotope analysis sampling in water, and PAR sampling in air at the Lower Campbell Reservoir in 2015.

Parameter	Site	Method	Sampling Date	UTM		
				Zone	Easting	Northing
Water chemistry	LCR-PERWQ1	Van Dorn	31-Jul-15	10U	327193	5542199
	LCR-PERWQ1A	grabs and YSI	25-Sept-15, 27-Nov-15	10U	323326	5543836
	LCR-PERWQ2	seabird	31-July-15, 25-Sept-15, 27-Nov-15	10U	326070	5545145
	LCR-PERWQ3		31-July-15, 25-Sept-15, 27-Nov-15	10U	324154	5544652
	LCR-PERWQ4		31-July-15, 25-Sept-15, 27-Nov-15	10U	327221	5542559
Benthic invertebrate abundance, biomass, and stable isotopes	LCR-LKIV01	Rock Baskets	25-Sep-15	10U	327212	5542144
	LCR-LKIV02		25-Sep-15	10U	326127	5545273
	LCR-LKIV03		25-Sep-15	10U	324185	5544832
	LCR-LKIV04		25-Sep-15	10U	327250	5542638
	LCR-PERWQ1A	Ponar grabs	13-Oct-15, 13-Nov-15	10U	323086	5543498
	LCR-PERWQ2		13-Oct-15, 13-Nov-15	10U	326134	5545255
	LCR-PERWQ3		13-Oct-15, 13-Nov-15	10U	324136	5544823
	LCR-PERWQ4		13-Oct-15, 13-Nov-15	10U	327243	5542624
Stable Isotope Analysis	LCR-PERWQ3	Rock scrapings	25-Sep-15	10U	324185	5544832
	LCR-PERWQ1	Leaf litter, and macrophyte biomass	02-Oct-15	10U	327212	5542144
	LCR-PERWQ2		02-Oct-15	10U	326127	5545273
	LCR-PERWQ3		02-Oct-15	10U	324185	5544832
	LCR-PERWQ4		02-Oct-15	10U	327250	5542638
	LCR-PERWQ1A	Mooring line scraping	02-Oct-15	10U	323326	5543836
	LCR-PERWQ2		02-Oct-15	10U	326070	5545145
	LCR-PERWQ3		03-Oct-15	10U	324154	5544652
	LCR-PERWQ4		04-Oct-15	10U	327221	5542559
	LCR-PERWQ1A	Scraping of 4 acrylic plates on periphyton mooring lines	25-Sept-15, 27-Nov-15	10U	323326	5543836
	LCR-PERWQ2		25-Sept-15, 27-Nov-15	10U	326070	5545145
	LCR-PERWQ3		25-Sept-15, 27-Nov-15	10U	324154	5544652
	LCR-PERWQ4		25-Sept-15, 27-Nov-15	10U	327221	5542559
	LCR-LKPAR	Land PAR station download	23-Oct-15, 30-Nov-15	10U	314729	5541619

¹ Collected at Strathcona Dam

The nutrient and form of nutrient to be used in Equation 2 was that shown from molar N:P ratios to potentially limit algal production. The molar ratio of bioavailable nitrogen: phosphorus in water can indicate whether nitrogen (N) or phosphorus (P) potentially limits algal production, given that N or P or combinations of N and P are growth-limiting nutrients in coastal lakes and reservoirs (Johnston *et al.* 1999, Perrin *et al.* 2006, Hyatt and Stockner 1985). The ratio was calculated from bioavailable forms of N, which includes dissolved inorganic nitrogen (called DIN and includes $\text{NH}_4\text{-N}$ plus $\text{NO}_3\text{-N}$) and P, which is best represented by SRP when it can be detected. If SRP was not detected using standard low level wet chemistry techniques ($\text{SRP} < 1 \mu\text{g}\cdot\text{L}^{-1}$), TDP was used. If TDP could not be detected ($\text{TDP} < 2 \mu\text{g}\cdot\text{L}^{-1}$), TP was used. If TP could not be detected ($\text{TP} < 2 \mu\text{g}\cdot\text{L}^{-1}$), extreme limitation of algal growth by phosphorus was assumed. Rhee (1978) showed that for a given species of algae, there is a sharp transition between P-limited and N-limited growth. The particular N:P ratio (using bioavailable forms of N and P) at which the transition between N and P-limitation occurs is species dependent, varying from as low as 7:1 for some diatoms (Rhee and Gotham 1980) to as high as 45:1 for some blue-green algae (Healey 1985). In aquatic ecosystems that support many algal species, the growth of most species will be N-limited at low supply ratios and P-limited at high supply ratios. Guildford and Hecky (2000) found that among lakes from wide ranging regions, N-deficient growth of microalgae occurs at molar nitrogen: phosphorus < 20 while P-deficient growth occurs at nitrogen: phosphorus > 50 . At intermediate ratios, either N or P can be deficient among the algal species within an assemblage. To determine the nutrient and form of nutrient to be used in the Equation 2, the molar N:P was calculated from results of the nutrient sampling described above. If the molar N:P for any site was > 50 , the concentration of SRP was used. If molar N:P for any site was < 20 , the concentration of DIN was used. If the molar N:P was between 20 and 50, the concentration of SRP and DIN was used in Equation 2, each nutrient being an independent predictor variable.

Other measurements were made for descriptive purposes. Profiles of turbidity, pH, conductivity, temperature, and dissolved oxygen were measured with a YSI Model 6920 Sonde (YSI Inc. Yellow Springs, Ohio) or Sea-Bird Electronics SBE19plusV2 CTD (Sea-Bird Electronics, Bellevue, Washington) on July 31, 2015 (beginning of the summer periphyton sampling), September 25, 2015 (end of the summer periphyton sampling and start of the fall periphyton sampling), and November 27 (near the end of the fall periphyton sampling). Each one of these instruments is generically called a CTD that measures conductivity, temperature, and depth among other parameters depending on types of installed sensors. The temperature data from these profiles were used to show characteristics of density stratification among stations on the three profiling dates (July 31, September 25, November 27). Time course change in water surface elevation, reservoir volume, inflow, and outflow, in daily time steps for each sampling series, was accessed from Power Records at BC Hydro.

2.5. Linking Periphyton PeriphytonAccrual with Habitat Attributes

A multiple regression model (Equation 2) was developed to examine links between peak biomass (PB) and the three habitat attributes (PAR, temperature, nutrient concentrations). The model was used to examine the following two things:

1. The *combined* contribution of the three habitat attributes (PAR, temperature, nutrient concentrations) to determining periphyton biomass accrual.
2. The relative contribution of each of the three habitat attributes (PAR, temperature, nutrient concentrations) to determining periphyton biomass accrual.

Regression yielded an equation (a model) that retained original units of measurement and allowed quantitative prediction of the dependent variable with estimated error. The dependent variable was chl-*a* concentration on the final sampling day of each series (day 57), which was expected to approximate the PB. The independent variables were PAR, temperature, and nutrient concentration. Temperature was based on the mean temperature over a sampling series as logged by the Tidbit logger at the same depth as the respective Styrofoam ball on a mooring line. Thus, the temperature data were specific to each mooring line and depth of periphyton sample. Nutrient concentrations were average concentrations in samples collected in the euphotic zone at the start and finish of each summer and fall sampling series (July 31 and September 25 for the summer series; September 25 and November 27 for the fall series). PAR was accumulated PAR ($\text{mol}\cdot\text{m}^{-2}$) specific to a given depth over the duration of a sampling series calculated as follows. The proportion of PAR in water at a specific depth relative to PAR measured in the air immediately above the water surface and also to PAR measured in water just below the surface was calculated for each of the weekly PAR profiles. A logarithmic model was fit to the data from each week (PAR attenuates logarithmically in water) resulting in 47 regression equations. Each equation was back transformed and used to predict the proportion of PAR in water relative to the PAR in air at each depth where a Styrofoam ball was located. These depth-specific predicted proportions of PAR in air were used as correction factors to calculate PAR at a specific sampler depth from the continuous record of PAR in air that was logged on the Strathcona Dam (see Section 2.3). Each weekly correction factor was employed for the period beginning on the day of one PAR profile and ending on the day before the next PAR profile. Those predicted PAR values were in units of $\mu\text{mol}\cdot\text{m}^{-2}\cdot\text{sec}^{-1}$. The predicted PAR values were multiplied by the number of seconds in each 15 min logging time interval (900 s). The sum of those 15-minute depth-corrected PAR values over each weekly calculation period resulted in units of $\text{mol}\cdot\text{m}^{-2}$ for the period of incubation of the periphyton samplers. This approach resulted in a single value of accumulated PAR to which each Styrofoam ball was exposed during the time of incubation.

The air PAR data from the Strathcona Dam were missing for two periods: July 31 to Aug 8, and Oct 23 to Oct 28. Accumulated PAR on August 9 was substituted for each day in the first period based on the assumption that PAR on August 9 was close to that on each day of the preceding week. In the case of the October 23 to 28 missing data, the data from October 22 and 23 were used to fill in

the missing values. For practical purposes, these substitutions were considered preferable to loss of corresponding observations of PB for solving Equation 2.

Regression analysis proceeded in the following steps. First, scatterplots were examined and Pearson correlation coefficients were calculated between pairs of the three independent variables to determine if any relationships existed between them and to determine whether or not the variables provided unique information. If any two of the independent variables were found to be statistically redundant, the variable with the most direct and explainable relationship to algal biomass was retained and the other variable was deleted. The selected independent variables (three or less) were tested for normality using the Shapiro-Wilk normality test ($\alpha=0.05$) and they were examined for both skewness and kurtosis of the sampling distribution. PAR was $\log_{10}(x+1)$ transformed to improve normality and reduce skew because it changes logarithmically with water depth. All variables were used in a complete regression analysis (no backward or forward selection). Goodness of fit of the model to the data was determined from the value of the multiple correlation coefficient (R^2) and the standard error of the estimate. The absolute value of standardized regression coefficients (subtracting the sample mean from a measured value and then dividing these new values by the standard deviation of the variable) indicated the relative importance of the predictor variables in determining change in algal biomass. Use of standardized regression coefficients removed bias due to different scales of measurement when comparing coefficients. Non-standardized coefficients were used in the regression equation used to predict PB to derive predictions based on the correct units of measurement of each independent variable.

2.6. The Performance Measure Called *L*

The performance measure, *L* (Equation 1) was calculated as iterative sums of products of periphyton biomass (Equation 2, described above in Section 4.5) and areas of submerged littoral strata. For demonstration purposes, Equation 1 was solved for the maximum operating level⁵ of 178.0 m, in addition to elevations of 177.0 m, 176.0 m, and 175.0 m, which covered the range of elevations recorded in 2015. For each elevation, values of the independent variables were changed within ranges that were measured in 2015 to show percent change in periphyton biomass extending throughout the littoral zone (depths extending from the surface to that corresponding with 1% of surface irradiance).

2.7. Fish Sampling

Fish sampling was undertaken to obtain representative stable isotope samples of the target fish species of Cutthroat Trout, Rainbow Trout and Dolly Varden and potential fish prey items including Threespine Stickleback, Sculpin spp., and juvenile trout. Several fishing methods were used to

⁵ Precisely, the maximum operating elevation defined in the WUP is 178.3 m (BC Hydro 2012). This was rounded to 178.0 m in this study.

maximize catch of these food web components, including: gill netting, minnow trapping and trap netting. Tissue and stomach samples for diet analysis were obtained

2.7.1. Gill Netting

Gill netting was undertaken on August 23 and October 4, 2015 in Lower Campbell Reservoir, at three littoral and three pelagic sites (Map 2). Sinking gill nets were used to target different depths within the water column. At the littoral sites, nets were set on the bed, perpendicular to shore. At pelagic sites, nets were set perpendicular to depth contours, with sinking nets suspended in the water column at a depth of 10 m below the surface, close to the assumed thermocline depth. 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. 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, although gill netting was primarily used to sample Cutthroat Trout and Rainbow Trout.

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 19–26 hours. Floating lights were attached to each net to mark their location overnight for boater safety.

2.7.2. Trap Netting

Trap netting was undertaken on October 4, 2015 in the Lower Campbell Reservoir at two sites: LCR-LKTN01 and LCR-LKTN02 (Map 2). Trap netting was primarily used to sample Threespine Stickleback. Traps were set overnight in littoral areas with a target soak time of 24 hours. Sites were selected for suitability for trap netting based on site depths and absence of underwater hazards. 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. Nets were set overnight with soak times of 19–29 hours.

2.7.3. Minnow Trapping

Minnow trapping was undertaken on June 25 and August 23, 2015 in the Lower Campbell Reservoir at three littoral and three pelagic sites (Map 2). Target species were Sculpin spp., juvenile trout and Threespine Stickleback. Traps were either deployed on the bed and secured to the shoreline or suspended at a range of depths (0.5–10 m beneath a buoy). Each trap was baited with a small amount of fish roe placed in a perforated photographic film container, 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 20–26 hours. Captured fish were separated by site and trap number and then brought back to shore for processing.

2.7.4. Individual Fish Analysis

All fish captured by gill netting, trap netting, or minnow trapping were processed as soon as possible after capture; 32 Cutthroat Trout and 70 Rainbow Trout were collected from Lower Campbell Reservoir. Sampling details, including target numbers of each species, are presented in the JHTMON-5 Year 2 annual report (Hocking *et al.* 2016).

2.7.5. Stomach Content Analysis

For comparison to isotope results, fish stomachs were extracted from 23 Cutthroat Trout, 61 Rainbow Trout, and 12 Sculpin from Lower Campbell Reservoir. At the time of capture, the body cavities were opened and each fish stomach was removed. The stomach was opened by longitudinal incision, the contents extracted, and placed in a 100 mL plastic sample bottle. Each sample was individually labelled and preserved with 60% denatured ethanol.

Stomach contents were identified to the lowest taxon that could be accurately identified and counted. Head counts were used for the enumeration of partly digested animals. Each identifiable fish retrieved from stomach contents was counted. Fish parts in advanced stages of digestion that could not be discriminated (e.g., muscle tissue) were counted together as a single fish. The data were compiled as counts per stomach for each fish species. The prey were grouped into eight categories: Ephemeroptera (mayflies), Plecoptera (stoneflies), Trichoptera (caddisflies), chironomids, other aquatic invertebrates, terrestrial invertebrates, zooplankton, and fish.

2.8. Stable Isotopes

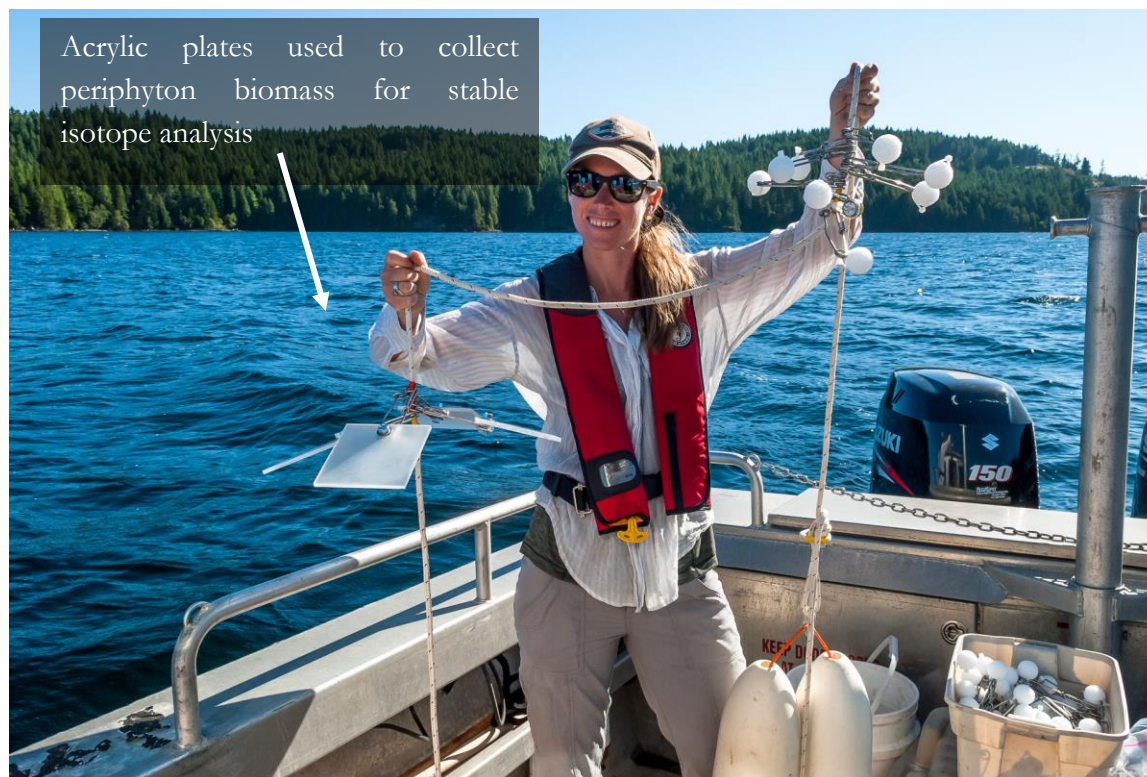
The stable isotope work for JHTMON-4, which was used to predict the periphyton contribution to fish diet, was undertaken through coordinated sampling between JHTMON-4 and JHTMON-5 (Map 2). Sampling for periphyton, benthic invertebrates and basal nutrient sources occurred in JHTMON-4 and is described further below. Sampling for Cutthroat Trout, Rainbow Trout and their diet items including zooplankton, terrestrial invertebrates, littoral invertebrates, and prey fish (Threespine Stickleback, Sculpin spp., and juvenile trout) were sampled as a part of JHTMON-5. Methods for their collection are summarized in Section 2.7, and can be viewed in detail in the JHTMON-5 Year 2 annual report (Hocking *et al.* 2016).

2.8.1. Periphyton

Periphyton communities have a varied composition, and include the living algal component, but also protozoa, bacteria, fungi and dead organic detritus. To account for this variable composition, periphyton was collected for stable isotope analysis from three sources. Four acrylic plates each measuring 10 cm x 10 cm were attached facing upwards onto each of the periphyton mooring lines that are described in Section 2.3 (Figure 4). The top surface of the plates was roughened using emery paper to favour colonization and growth of periphyton. The plates were attached to the mooring lines on the day of deployment of the periphyton Styrofoam balls and they were sampled following the 57 days of incubation in summer (Jul 31 – Sep 25) and the 56 days in fall (Sep 25 – Nov 20). Sampling dates and locations are described in Table 3 and Map 2. Sampling involved

removing the mooring line from the water, taking care not to disturb biomass on the plates. A clean razor blade was used to scrape and composite algal biomass from all plates into a plastic vial that was capped and labelled and placed on ice in a cooler for delivery to Campbell River. Unfortunately, this approach did not result in sufficient algal material for a stable isotope sample to be obtained from any of the four samples. The second source was periphyton biomass that accumulated on the nylon mooring line at each station. Again, a razor blade was used to scrape algal biomass from the line within the top 2 m from the water column following the 56 days of incubation in the fall (Sep 25 – Nov 20). Biomass was collected from each line, resulting in four samples for stable isotope analysis. This source of biomass was collected as a backup to the use of acrylic plates in case insufficient biomass was collected with the plates. Since this ended up being the case, these samples are the best available sample to describe the isotopic composition of periphyton, i.e., the algal component of periphyton communities that inhabit the littoral zone. The third source of periphyton was rock scrapings from the wadable reservoir margins near each of the periphyton sampling stations. Three samples were collected on Sept 25, 2015 at the shoreline near site LCR-PERWQ3. For each sample, 10 rocks were collected which were individually hand scrubbed in a bucket. Water was decanted and the remaining contents placed in one sample jar. These shoreline samples contained living algal biomass, detritus from reservoir and potentially terrestrial sources, and the assemblage of heterotrophic decomposer organisms associated with the substrata. These shoreline samples are referred to hereafter as “littoral periphyton”.

Figure 4. Image of acrylic plates used to accrue periphyton for stable isotope analysis, and Styrofoam balls for examining periphyton accrual. Substrata were all attached to a standard mooring line prior to deployment in summer 2015.



2.8.2. Benthic Invertebrates

Benthic invertebrates were collected from soft sediment and stony material in the littoral zone to optimize the diversity and biomass for SIA. Samples were collected from eight sites (Table 5, Map 2). A mini-Ponar sampler (Wildlife Supply Company, Yulee, Florida) was used to collect grabs from soft sediment and a basket sampling technique was used to collect invertebrates that graze on stony substrata. Invertebrate counts and biomass by taxon were measured for both types of sampler prior to stable isotope analysis.

One composite sample was collected by undertaking four or more casts with the mini-Ponar sampler along a transect that extended between the shore and each periphyton station. The sampler was deployed by hand from the boat. Jaws of the Ponar bucket collected material from an area of 0.023 m^2 to a substratum depth of 10 cm. Where hard substrate was encountered, the boat was moved and the cast was repeated until softer material was found that could be effectively grabbed. Hauling on a retrieval cable closed the sampler and returned it to the surface. Grab contents from each cast were washed into a plastic bin from which the contents were passed through a $250 \mu\text{m}$ mesh sieve to remove excess water and transferred to plastic sample containers. The samples were

preserved in 90% ethanol. The ethanol was thoroughly mixed and the containers were sealed for shipment to Limnotek in Vancouver for analysis of invertebrate density and biomass. All individuals picked from detrital material in those samples were sent to the Stable Isotopes in Nature Laboratory at the University of New Brunswick for SIA.

One composite invertebrate sample was collected at the end of the summer sampling period from three wire baskets that contained stones that were incubated for 60 days and installed shoreward of each periphyton sampling station (Map 2). Each basket was made of heavy gauge wire measuring 32 cm x 12 cm x 17 cm (planar area of 0.038 m²), similar to one described by Merritt *et al.* (1996). Each basket was filled with dry and clean stones with a size range of 2.5 to 3.5 cm that were collected from the beaches above the reservoir water surface elevation, near each sampling station. The baskets were locked closed with cable ties and placed in water depths of 2-4 m using 5/16 inch nylon double braid Samson line to tether the samplers to a tree on shore. The baskets were in the reservoir for 49 days (August 7 through September 25). This incubation time was considered adequate for development of a benthic invertebrate community, based on colonization times reported by Mackay (1992). At the end of the incubation period, the shore line for a given sampler was untied from shore, the boat was positioned over top of the sampler, and the sampler was lifted off bottom using the shore line. The sampler was slowly retrieved through the water column to a point where the basket was suspended just below the water surface alongside the boat. A 250 µm mesh Nitex scoop net was placed under the basket, the basket was unclipped from the shore line, lifted on board, and placed into a plastic bucket. The basket was opened in its bucket by clipping the closure ties. The basket and stones were brushed clean and removed. Sample contents in the bucket were passed back through the scoop net that had a 250 µm mesh to remove excess water and concentrate the sample in the cod end. The sample was washed from the cod end into one or more sample jars, preserved in 90% ethanol, and labelled for delivery to the laboratory in Vancouver. The three basket samples from a given station were composited to one sample for analysis in the lab, resulting in a total of four samples (one composite from each of the four stations).

In the laboratory, each benthic invertebrate sample (basket or Ponar) was washed through 1 mm and 250 µm mesh sieves to yield a macrobenthos fraction (>1 mm) and a microbenthos fraction (<1 mm and >250 µm). In this process, animals were picked from twigs, grasses, clumps of algae, and other debris and were returned to the 1 mm sieve. Microbenthos was passed through a large plankton splitter to produce 16 subsamples. Animals were enumerated from successive sub-samples until 200 animals were counted. If 200 animals were counted part way through the sorting of a sub-sample, that sub-sample was sorted in its entirety. If the estimated abundance of animals in the macrobenthos fraction was less than 200 animals, that fraction was enumerated in its entirety. If there were more than 200 animals, the subsample was partitioned in a level tray into four equal parts. Animals were enumerated from successive macrobenthos sub-samples until 200 animals were counted. Sub-sample counts were extrapolated to the total sample. The sample count was the sum of microbenthos and macrobenthos in the complete sample. The animals were identified to genus or

lowest reliable taxonomic level using keys from Edmondson (1959), Merritt and Cummins (1996), and Pennak (1978). One in 10 samples was sorted twice to test efficiency of the first sort. A target for acceptable sorting was that 90% of the sample must be enumerated on the first sort. If efficiency was <90%, samples in the group to which the test applied were re-sorted. Sorting efficiency was >90% on the first sort of all samples.

Biomass of benthos was determined using Zoobbiom Version 1.3 (Hopcroft 1991). The digitizing system included a dissecting microscope, drawing tube, digitizing SummaSketch III tablet with a cross-hair mouse equipped with a diode, and the digitizing program used to process the data. The software was customized for selected species and consequently specific measurements were required for each taxon. Biomass was determined from single measurements of individuals with straight-shaped bodies, whereas multiple measurements were made along a curve for organisms with bent bodies. The drawing tube transferred a point of light emitted by a diode on the mouse and made it appear on the image viewed through the microscope. When the images of the diode and the organism overlapped, the cursor button on the mouse was clicked. The coordinates from the digitizing tablet were converted to length by the program. Biomass of individuals was estimated from established length-to-weight regressions (Smock 1980, Benke *et al.* 1999). Up to 25 random length measurements per taxon were taken per sample, and the final biomass was expressed as mg per sample.

2.8.3. Primary Nutrient Sources

Littoral invertebrates and, ultimately, fish may derive some energy from periphyton, but may also derive energy from detritus, living plants and other terrestrial material. Samples of small particulate organic matter (SPOM), macrophytes and leaf litter were collected in the wadable shoreline areas near to the periphyton sampling stations (Table 5, Map 2) to account for these additional sources of primary nutrients to fish.

Fish also obtain energy derived from phytoplankton production in offshore areas that cycles to fish through the zooplankton. Zooplankton samples were collected in Lower Campbell Reservoir as a part of the sampling for JHTMON-5 in June, July and August of 2016. Further sampling and analytical methods can be viewed in the JHTMON-5 Year 2 report (Hocking *et al.* 2016).

2.8.4. Stable Isotope Processing

Littoral detritus, macrophytes, invertebrates, and fish samples were processed for nitrogen and carbon stable isotopes at the Stable Isotope in Nature Laboratory (SINLAB⁶) 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.

⁶ <http://www.unb.ca/research/institutes/cri/sinlab/>

A total of 109 samples of basal nutrient sources, zooplankton, invertebrates and fish were sent for analysis (Table 6). Basal nutrient sources (SPOM, leaf litter, and periphyton), zooplankton, littoral/benthic invertebrates and terrestrial invertebrates were sent as composite samples, while fish were sent as fin clip samples. Benthic invertebrates collected using the Ponar and basket sampling techniques overlapped highly in their $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ stable isotope signatures, and with the littoral invertebrates collected as a part of JHTMON-5. Therefore, these samples were lumped into a single group, which we have labelled as “littoral invertebrates” (Table 6).

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 Zerobank autosampler. Samples were converted to gases by combustion by a Carlo Erba NC2500 or Costech 4010 Elemental Analyzer (EA) and then analyzed for $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ 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:

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

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

Thirteen samples were run in duplicate to test repeatability of the stable isotope results. The absolute mean difference in $\delta^{15}\text{N}$ between repeats was $0.19 \pm 0.15\text{‰}$. The absolute mean difference in $\delta^{13}\text{C}$ between repeats was $0.22 \pm 0.16\text{‰}$.

Table 6. Primary producers, invertebrate, and fish samples analysed for stable isotopes at SINLAB.

Trophic Level	Taxa	Number of Samples
Primary Producers	Small particulate organic matter (SPOM)	4
	Leaf Litter	4
	Littoral periphyton	3
	Attached algae periphyton	3
Primary Consumers	Zooplankton	9
	Littoral invertebrates	11
Allochthonous Production	Terrestrial invertebrates	3
Secondary Consumers	Threespine Stickleback	10
	Sculpin spp.	11
	Juvenile Trout	6
Tertiary Consumers	Rainbow Trout	27
	Cutthroat Trout	29

2.8.5. Assessing Fish Diet Using Mixing Models

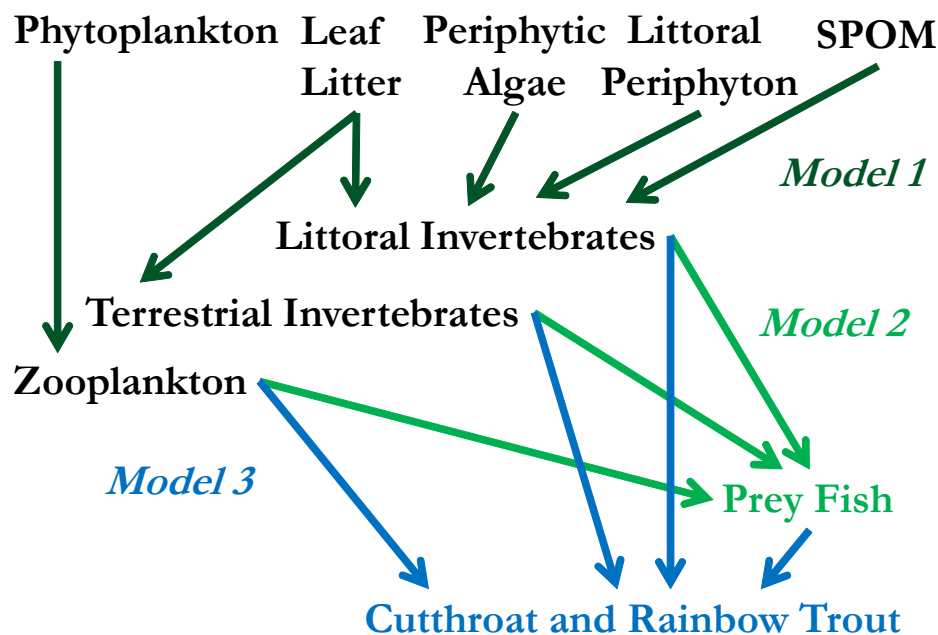
The relative contributions of pelagic and littoral primary production sources to Cutthroat Trout and Rainbow Trout diets were assessed through a series of dual isotope ($\delta^{13}\text{C}$ and $\delta^{15}\text{N}$), three to five-source Bayesian isotopic mixing models implemented in the program SIAR (Stable Isotope Analysis in R, Parnell and Jackson 2013). SIAR takes isotope data from consumers (littoral invertebrates and 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 0.40 ± 1.20 for $\delta^{13}\text{C}$ and 2.30 ± 1.60 for $\delta^{15}\text{N}$ for littoral invertebrate consumers and 1.50 ± 1.16 for $\delta^{13}\text{C}$ and 2.79 ± 1.46 for $\delta^{15}\text{N}$ for fish consumers. The former values are averaged diet-tissue fractionation rates for aquatic foodwebs (McCutchan *et al.* 2003), while the latter are average diet-tissue fractionation rates across several fish species and tissue types (Sweeting *et al.* 2007a, b).

A separate model was run for each of the three consumer groups within Lower Campbell Reservoir (Figure 5). The first model estimated diet contributions of the four primary nutrient sources (SPOM, leaf litter, littoral periphyton, and periphytic algae) to littoral invertebrates. The second model estimated diet contributions of three invertebrate diet sources (zooplankton, littoral invertebrates, and terrestrial invertebrates) to small bodied littoral prey fish (Threespine Stickleback, Sculpin spp., and juvenile trout). The third model estimated the diet contributions of potential diet items to large Cutthroat Trout and Rainbow Trout (age >2+, FL ≥ 159 mm). Five potential diet sources (mean $\delta^{13}\text{C}$ and $\delta^{15}\text{N} \pm \text{SD}$) for large Cutthroat Trout and Rainbow Trout were included in the third model: 1) zooplankton, 2) littoral invertebrates, 3) terrestrial invertebrates, 4) littoral prey fish (juvenile trout (age ≤ 2 , FL ≤ 143 mm) and Sculpin spp. (FL ≤ 170 mm)), and 5) Threespine Stickleback (FL ≤ 64 mm). The second model run for each lake estimated the diet contributions to the smaller prey fish (juvenile trout, Sculpin spp., and Threespine Stickleback). Four potential diet sources (mean $\delta^{13}\text{C}$ and $\delta^{15}\text{N} \pm \text{SD}$) were used to estimate the smaller prey fish diets: 1) zooplankton, 2) benthic invertebrates, 3) stream invertebrates, and 4) terrestrial invertebrates.

The three models were run to assess the total relative contributions of pelagic vs. littoral primary sources of production to large Cutthroat Trout and Rainbow Trout via indirect pathways. These total littoral vs. pelagic contributions can be derived through a series of steps: 1) multiplying the relative contributions of the four primary nutrient sources to littoral invertebrates in model one by the contributions of littoral invertebrates to prey fish in model two, 2) multiplying this indirect relative contribution of primary nutrient sources to prey fish diets through littoral invertebrates by the contribution of littoral prey fish to the diets of large Cutthroat and Rainbow Trout from model three, 3) multiplying the contribution of primary sources of production to littoral invertebrates by their contribution to large Cutthroat and Rainbow Trout, and then summing the indirect contributions of the primary nutrient sources to large Cutthroat and Rainbow Trout via littoral invertebrates and prey fish in steps 1 through 3. For simplicity, we assumed that zooplankton and

terrestrial invertebrates do not directly consume these littoral and pelagic primary nutrient sources, and therefore do not represent indirect pathways of these nutrient sources to fish diets.

Figure 5. Schematic of foodweb and trophic pathways by which littoral and benthic primary nutrient sources contribute to large trout diets in Lower Campbell Reservoir.



3. RESULTS

3.1. Habitat Attributes

Temperature profiles collected using the CTD showed typical two-layer stratification in summer followed by de-stratification in the fall, with all stations showing the same pattern (Figure 6). In July, surface temperatures approached 22°C, an epilimnion (surface mixed layer) was present in the top 10 m, a metalimnion (zone of rapid change in temperature separating surface and bottom mixed layers) was between 10 m and 20 m and a hypolimnion (bottom mixed layer) was found below 20 m. In September the epilimnion deepened to 18 m, a metalimnion was apparent at 18 – 20 m and weakly defined hypolimnion was again present below 20 m. An isothermal profile in November (8-9°C) showed that de-stratification had occurred between September and November profile collection dates.

The mean concentration of all forms of nitrogen and phosphorus were less than or close to method detection limits of 5 µg·N L⁻¹ for NH₄-N, 5 µg·N L⁻¹ for NO₃-N, 1 µg·L⁻¹ for SRP, and 2 µg·L⁻¹ for each of TDP and TP (Table 7). Phosphorus concentrations were less than the method detection limits in all samples. This was also the case for NO₃-N and NH₄-N at the surface in July and

September. $\text{NH}_4\text{-N}$ was not detected at the surface or bottom in the fall. $\text{NO}_3\text{-N}$ was detected at $\leq 40 \mu\text{g}\cdot\text{L}^{-1}$ near the bottom in summer and fall and it was $21 \mu\text{g}\cdot\text{L}^{-1}$ in surface water in the fall. Given that $\text{NH}_4\text{-N}$ can be readily oxidized to $\text{NO}_3\text{-N}$ via nitrification, the low $\text{NH}_4\text{-N}$ concentrations compared to $\text{NO}_3\text{-N}$ were expected. Detection of $\text{NO}_3\text{-N}$ in November indicates flushing from forest soils (nitrate is mobile in saturated soils) following a summer dry period (Verseveld *et al.* 2008) and mixing of the water column that occurred in November (Figure 6).

Absence of measurable phosphorus of any form means that molar N:P cannot be calculated and it indicates that algal growth in Lower Campbell Reservoir is strongly limited by availability of phosphorus. The unmeasurable and low concentrations of $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$ shows low availability of N, indicating that N was the secondary limiting nutrient or co-limiting algal growth. This finding is typical of lakes and reservoirs on northern Vancouver Island, which are generally ultra-oligotrophic (Stockner and MacIsaac 1996, Perrin and Harris 2006, Perrin *et al.* 2012, Suttle and Harrison 1988).

Figure 6. Temperature profiles at all four sampling stations on July 31 (top), September 25 (middle), and November 27 (bottom), 2015.

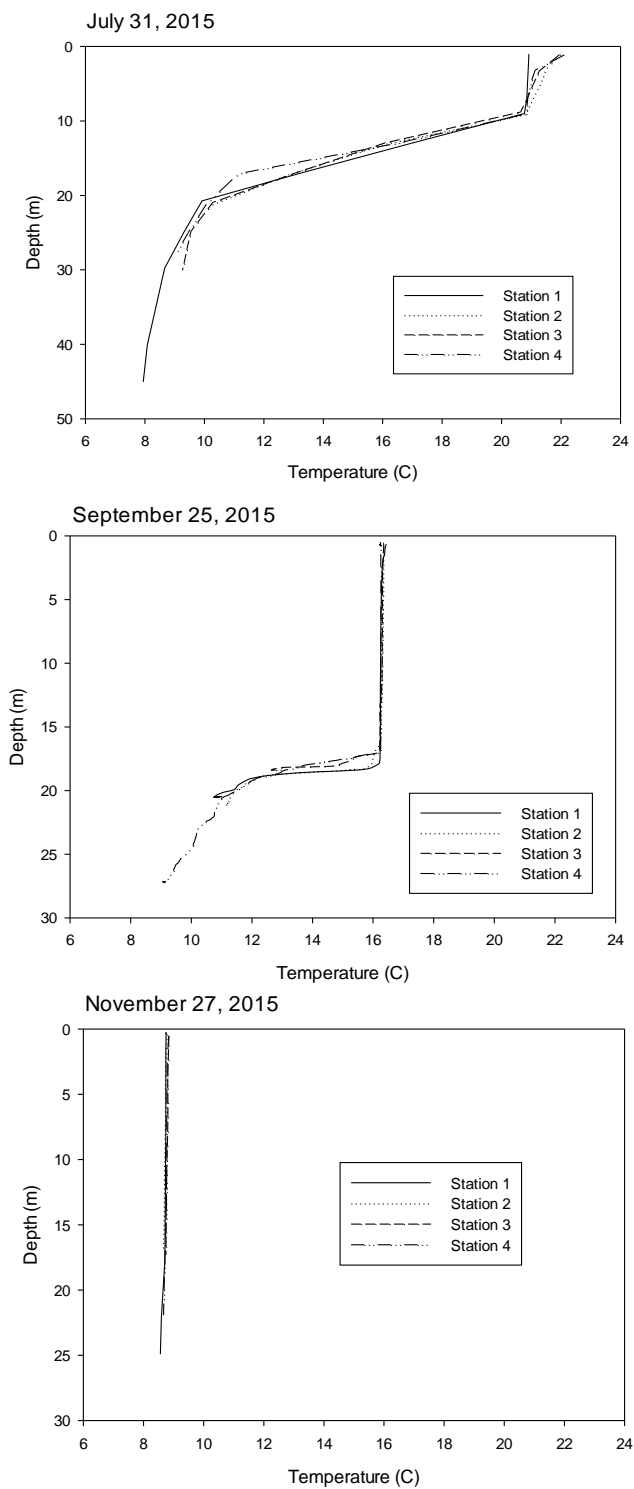


Table 7. Mean concentrations or values of the various forms of N and P and other chemical analytes in surface and bottom waters among the four stations in Lower Campbell Reservoir in 2015.

Date	Location	NH ₄ -N (µg·L ⁻¹)	NO ₃ -N (µg·L ⁻¹)	Total Nitrogen (µg·L ⁻¹)	Soluble Reactive Phosphorus (µg·L ⁻¹)	Total Dissolved Phosphorus (µg·L ⁻¹)	Total Phosphorus (µg·L ⁻¹)	pH	Turbidity (NTU)	Conductivity (µS·cm ⁻¹)	Dissolved oxygen (mg·L ⁻¹)
31-Jul-15	Surface	<5	<5	41	<1	<2	<2	7.6	0.48	48.8	9.1
	2 m from bottom	7.1	35	71	<1	<2	<2	7.5	0.65	48.8	10.8
25-Sep-15	Surface	<5	<5	Not measured	<1	<2	Not measured	7.6	0.36	43.5	8.9
	2 m from bottom	8	25.7	Not measured	<1	<2	Not measured	7.4	0.35	39.4	9.4
27-Nov-16	Surface	<5	20.6	76	<1	<2	<2	7.4	0.08	42	11
	2 m from bottom	<5	21.2	69	<1	<2	<2	7.4	0.08	42	10.6

Measurements of other chemical variables showed conditions typical of coastal lakes and reservoirs in BC. The pH was slightly alkaline, with no change with depth, indicating no effect of respiration in the sediments on the overlying water column (in richer reservoirs, pH can be relatively low near the sediments due to CO₂ release from decomposition in sediments). Low conductivity (39 – 49 µS·cm⁻¹) was consistent with the low nutrient concentrations. Turbidity was <0.5 NTU at all times and it was very low in November (0.08 NTU), which shows that few particles causing light scattering were present. The water column was well oxygenated (9 – 11 mg·L⁻¹) at all times, with no evidence of oxygen demand from sediments.

PAR profiles showed logarithmic attenuation of light through the water column during the summer (Figure 7) and fall (Figure 8) sampling periods. Using regression equations shown in each of Figure 7 for summer and Figure 8 for fall, the depth at which PAR was 1% of that at the surface was 22.3 m in the summer series and 19.5 m in the fall. These depths define the depth of the euphotic zone. For practical purposes it is rounded to 20 m.

Figure 7. Percent of surface PAR over the depth profile among periphyton sampling stations, 2015. The equation shows a logarithmic line of best fit (%SI is percent of PAR immediately under the water surface and depth is water depth). The r^2 is the correlation coefficient for the regression line.

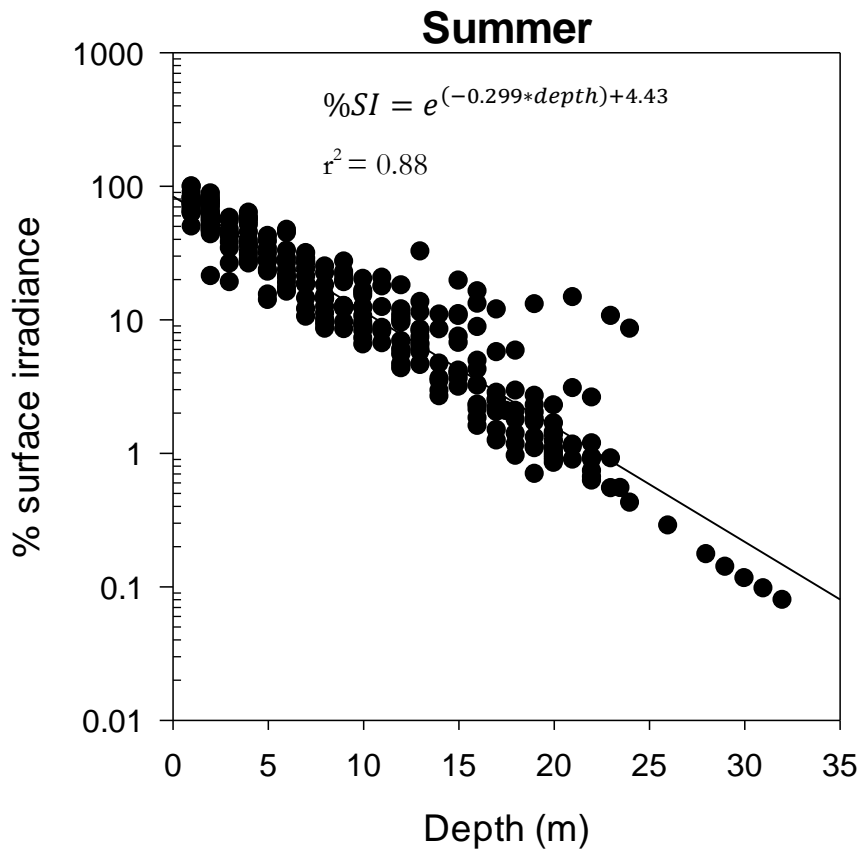
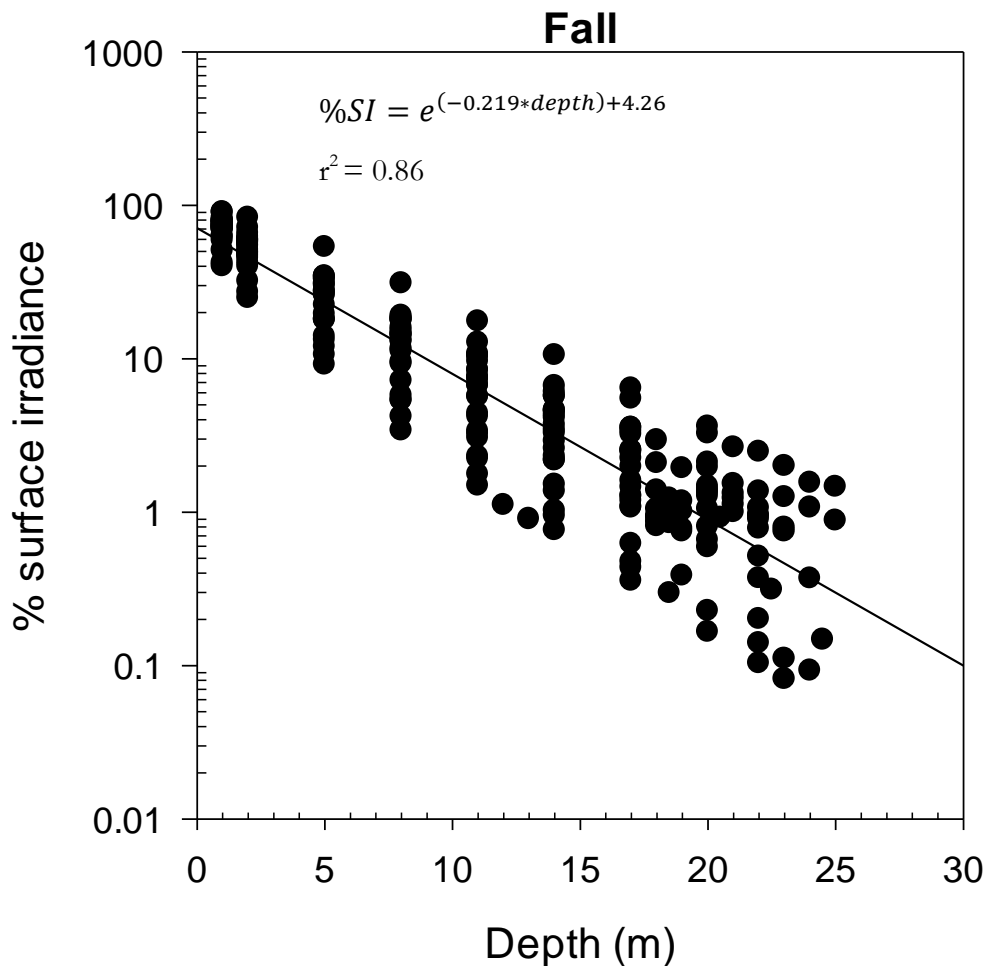


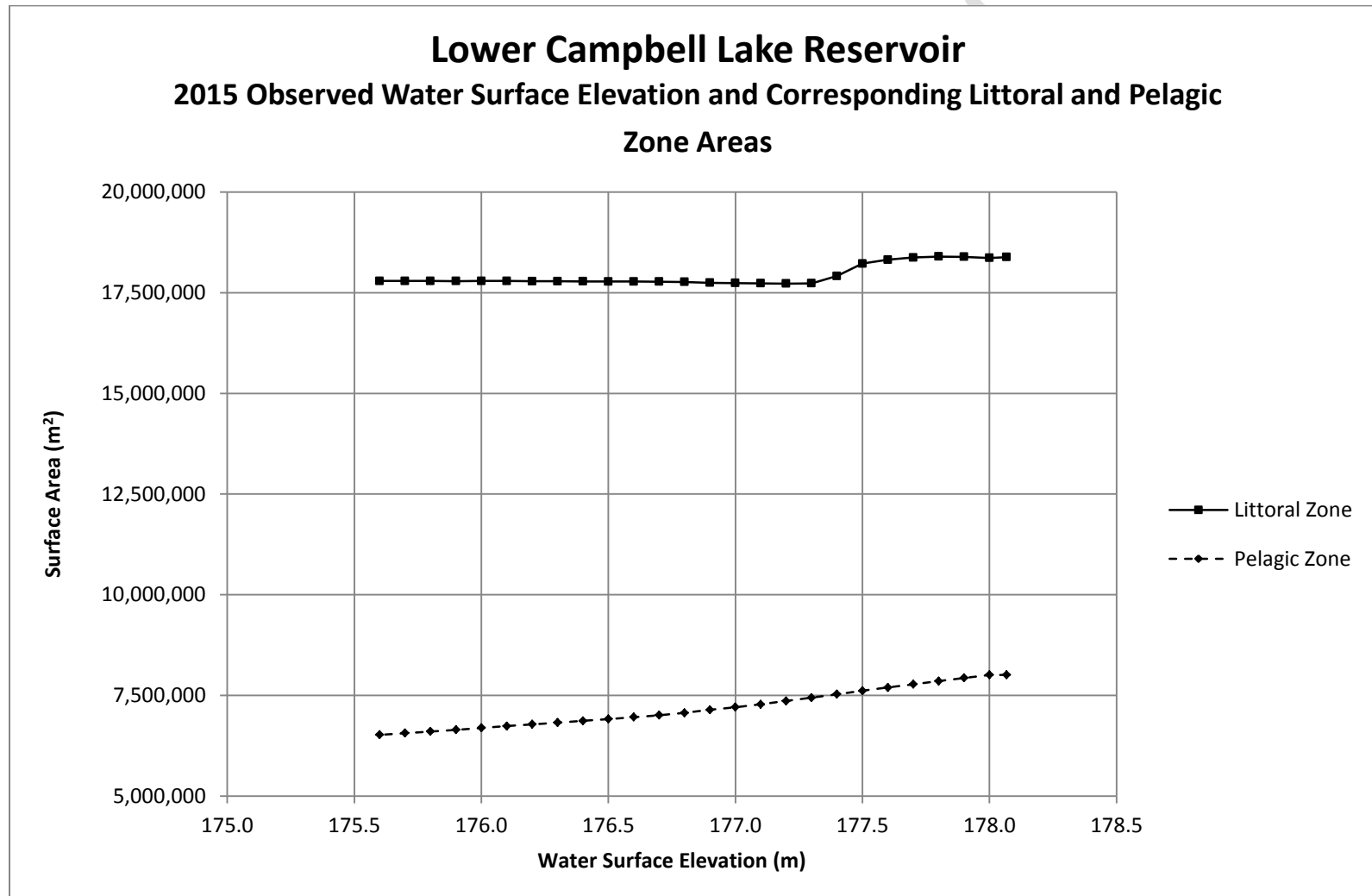
Figure 8. Percent of surface PAR over the depth profile among periphyton sampling stations, 2015. The equation shows a logarithmic line of best fit (%SI is percent of PAR immediately under the water surface and depth is water depth). The r^2 is the correlation coefficient for the regression line.



3.2. Bathymetric Survey and Digital Elevation Mapping

The maximum depth of the littoral zone was estimated as 20 m, based on the approximate depth at which 1% of PAR penetrates (Figure 7, Figure 8). Based on this, Figure 9 (produced using the DEM as explained in Section 2.2) shows the areal extent of littoral and pelagic zones in Lower Campbell Reservoir. Littoral areas are present throughout the west arm of the reservoir, all areas within a southern embayment and around all shorelines. Pelagic habitat is present in mid-basin areas and in central portions of a northern embayment. Littoral area (term A in Equation 1) is more than double pelagic area over the range of water surface elevations that were observed in 2015 (175 – 178 m, Figure 1, Map 3).

Figure 9. Change in littoral (water depths <20 m) and pelagic (water depths >20 m) areas over the range of water surface elevations in 2015 in Lower Campbell Reservoir.



3.3. Periphyton PeriphytonBiomass Accrual

Periphyton biomass, measured as chl-*a* concentration, grew exponentially at all depths in both seasons (Figure 10 and Figure 11). Maximum PB values were $0.38 \mu\text{g chl-}a \cdot \text{cm}^{-2}$ within the top 4 m and $0.02 \mu\text{g chl-}a \cdot \text{cm}^{-2}$ near the bottom of the euphotic zone at 18 m (Table 8). The slope of the accrual curves was significantly greater near the top of the littoral zone than near the bottom in summer ($p=0.002$) and fall ($p<0.001$) (ANCOVA significance test for interaction term), i.e., algae grew at a faster rate at the surface. There was no clear peak in biomass accrual, one exception being at 7 m depth in the fall. This accrual pattern shows that mat development did not exceed surficial capacity of the Styrofoam balls to retain algal biomass in the two-month incubation periods. For the periods of incubation, PB was significantly greater near the surface than near the bottom of the littoral zone in summer but not in fall (Table 8).

Figure 10. Mean periphyton biomass (chlorophyll-*a* concentration) (\pm sd) over time of incubation of installed Styrofoam substrata at three depths in the euphotic zone of Lower Campbell Reservoir during summer. Values were calculated from four replicate stations.

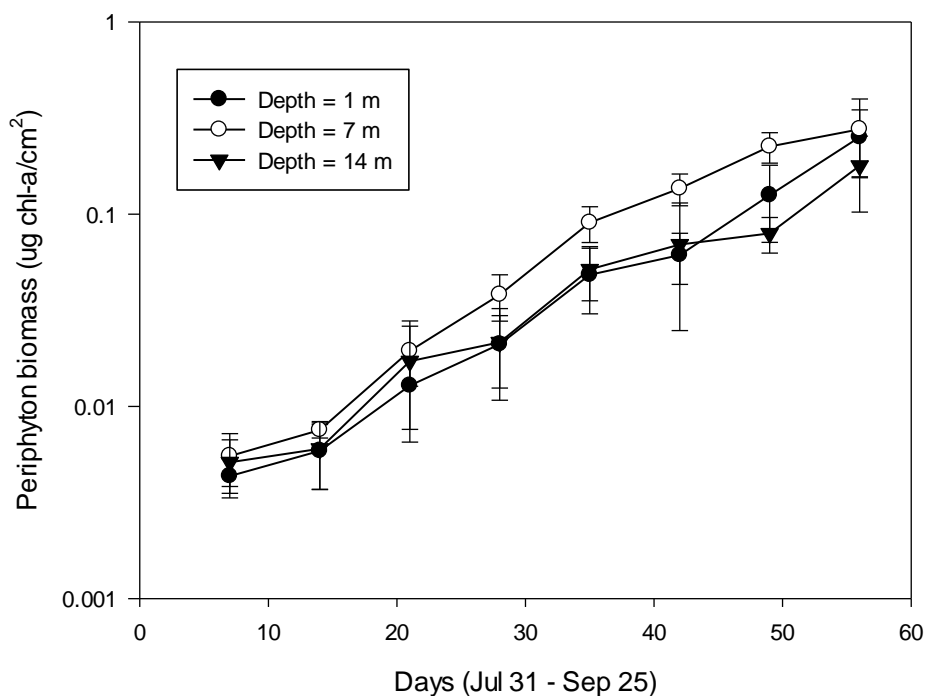


Figure 11. Mean periphyton periphytonbiomass (chlorophyll-*a* concentration) (\pm sd) over time of incubation of installed Styrofoam substrata at three depths in the euphotic zone of Lower Campbell Reservoir during fall. Values were calculated from 4 replicate stations.

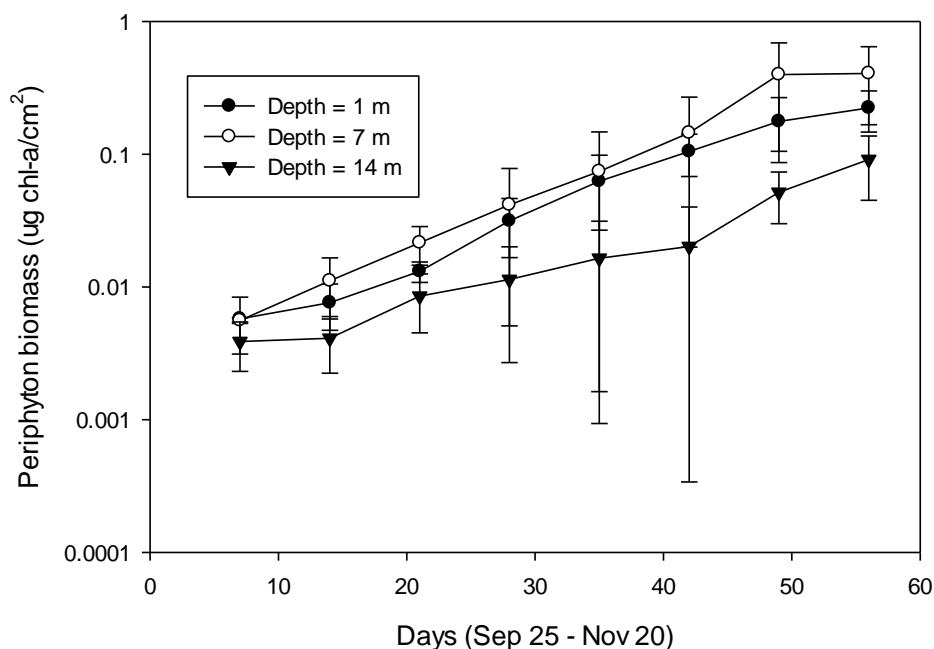


Table 8. Mean periphyton periphytonbiomass (PB) (\pm sd) by depth in the euphotic zone during the summer and fall, 2015.

Season	Mean periphyton biomass \pm sd by depth in the littoral zone ($\mu\text{g chl-a} \cdot \text{cm}^{-2}$)						Depth effect ANOVA (<i>p</i>)
	1m	4m	7m	10m	14m	18m	
Summer (Jul 31 – Sep 25)	0.25 \pm 0.1	0.36 \pm 0.1	0.28 \pm 0.12	0.23 \pm 0.11	0.18 \pm 0.08	0.02 \pm 0.002	0.003
Fall (Sep 25 – Nov 20)	0.18 \pm 0.1	0.38 \pm 0.29	0.31 \pm 0.27	0.19 \pm 0.18	0.07 \pm 0.06	0.02 \pm 0.02	0.08

The periphyton assemblage on the Styrofoam balls mainly comprised diatoms and green algae, with lower abundance of blue greens (Figure 12 and Figure 13). The diatoms and green algae comprised 97% of the community in summer and 94% in the fall. Mean summertime periphyton biovolume and cell density ($1,198 \mu\text{m}^3 \times 10^9 \cdot \text{m}^{-2}$ and $8,251 \times 10^6 \text{ cells} \cdot \text{m}^{-2}$ respectively) was double that of the fall ($574 \mu\text{m}^3 \times 10^9 \cdot \text{m}^{-2}$ and $3,508 \times 10^6 \text{ cells} \cdot \text{m}^{-2}$ respectively). Diatoms included *Tabellaria fenestrata*, *Achnanthes* sp., *Eunotia* sp., *Fragilaria* sp., *Nitzschia* sp., *Rhopalodia gibba*, *Gomphonema olivaceum*, and *Melosira* sp. *Spirogyra* sp. was the main chlorophyte. Trace biovolumes of blue greens (*Aphanizomenon* sp. and *Anabaena* sp.), Euglenoids, and Chryso-cryptophytes were found.

Figure 12. Mean algal biovolume by class in summer and fall in Lower Campbell Reservoir, 2015. Error bars are standard deviations of total biovolume among stations .

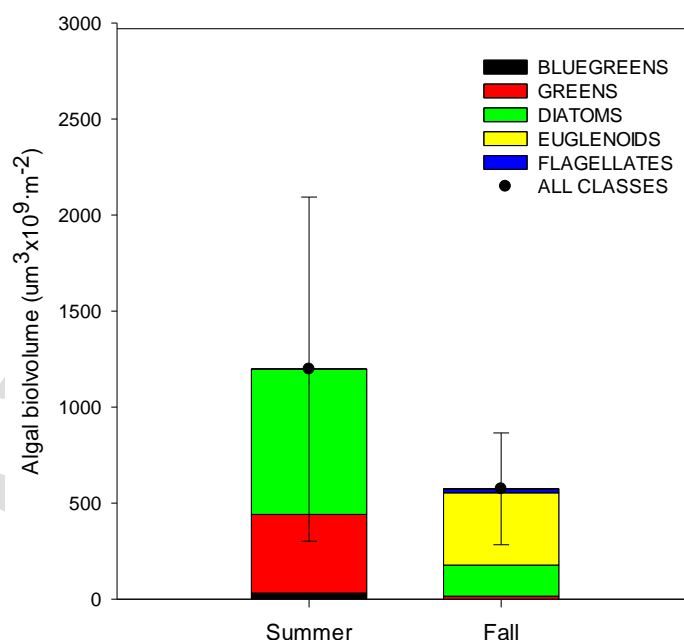
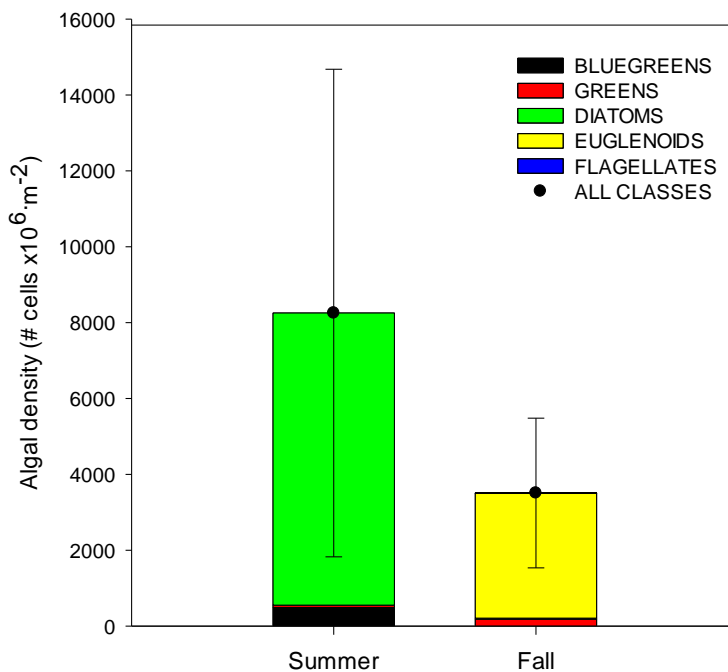


Figure 13. Mean algal cell density by class in summer and fall in Lower Campbell Reservoir, 2015. Error bars are standard deviations of total cell counts measured for all depths.



3.4. Linking Periphyton Accrual with Habitat Attributes

As explained in Section 2.5, three different habitat variables were used in a regression model to explain variation in PB. They were nutrient concentration, water temperature, and PAR. Although likely the primary limiting nutrient, it was not feasible to use any phosphorus form (TP or DRP) as an independent variable in the regression model because none of the phosphorus fractions could be detected and, therefore, there was no variance in the values. Concentrations of inorganic N forms (NH₄-N and NO₃-N) were also mostly below the method detection limit. NO₃-N was detectable in some samples but this was inconsistent. It was therefore necessary to use TN as a predictor variable, even though the likely occurrence of phosphorus as the primary limiting nutrient meant that TN was otherwise not likely to be the optimum predictor variable to represent the influence of nutrient concentrations in the model. This condition means that the use of TN concentration was likely to lead to underestimation of the relative importance of nutrients in controlling periphyton growth.

Overall, the regression was highly significant ($p < 0.001$) but the coefficient for the mean temperature term was not statistically significant ($p = 0.18$), meaning that it was not a significant variable for predicting algal biomass. As a result, mean temperature was removed and the regression was rerun. That regression model was highly significant ($p < 0.001$) and tolerance of the independent variables

was high (0.84 for each of TN and \log_{10} PAR), which confirmed little to no co-linearity of predictors and a computationally stable model (Table 9). \log_{10} PAR had a higher standardized coefficient than TN, meaning that \log_{10} PAR had greater influence on PB than TN. There was a lower standard error for \log_{10} PAR (0.011) than for TN (0.765), indicating that PAR was a more consistent predictor of PB compared to TN. Based on these criteria, \log_{10} PAR was identified as the most important predictor of PB. The overall regression correlation coefficient (r^2) was 0.53, showing that the regression model explained about half of the variance in PB: the other half was unexplained by the model.

Table 9. Regression equation parameters from the analysis linking habitat attributes to PB.

Effect	Coefficient	Standard Error	Standardized coefficient	Tolerance	p-Value
Constant	-0.139	0.033	0		<0.001
TN	1.244	0.765	0.44	0.84	<0.001
\log_{10} of PAR	0.076	0.011	0.8	0.84	<0.001

Using parameters in Table 9, the back transformed regression equation was as follows:

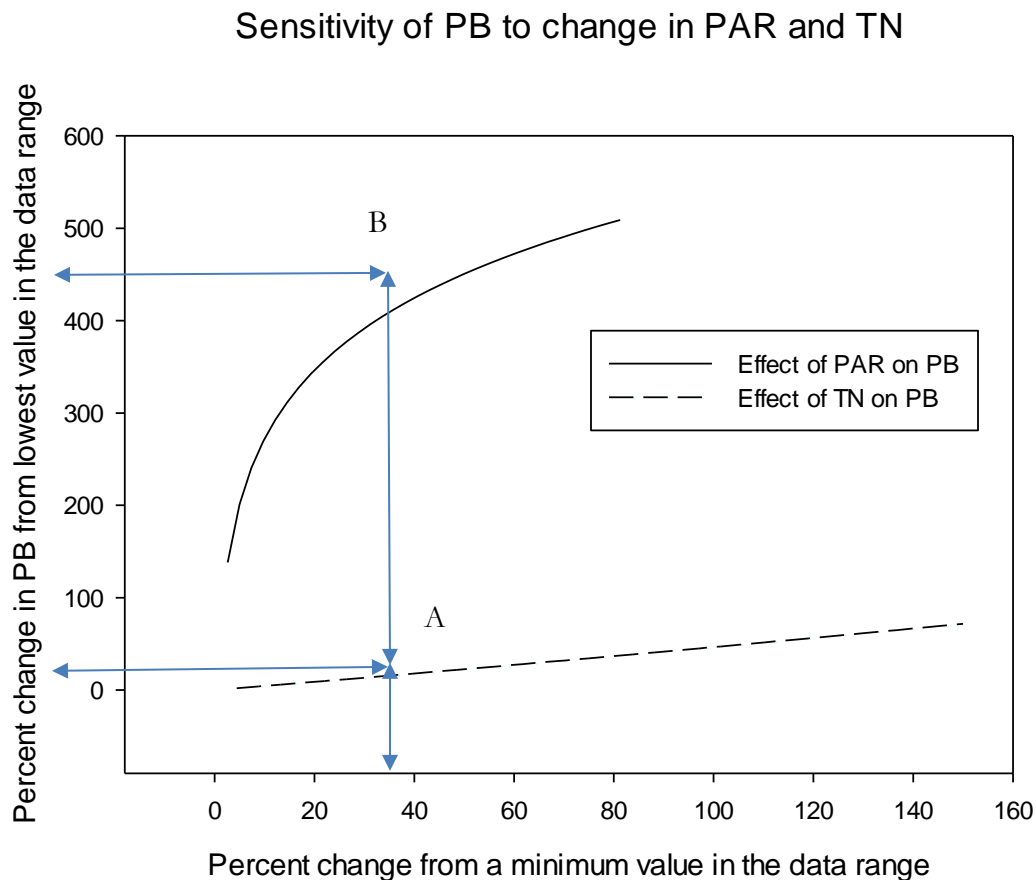
Equation 6

$$PB = (10^{-0.139}) * (10^{TN*1.244}) * (PAR^{0.076}) - 1$$

where: *PB* is peak biomass in units of $\mu\text{g chl-}a \cdot \text{cm}^{-2}$, *TN* is total nitrogen concentration in units of $\text{mg} \cdot \text{L}^{-1}$, and PAR is accumulated photosynthetically active radiation during the period of substrata incubation in units of $\text{mol} \cdot \text{m}^{-2}$.

Sensitivity of PB to change in PAR and TN was explored by running Equation 4 over a range of PAR values with TN held at a constant high level ($0.1 \text{ mg} \cdot \text{L}^{-1}$) and over a range of TN concentrations with accumulated PAR held at a constant high level (typical of near the water surface). Results in Figure 14 show a marked difference in sensitivity of PB to the two variables. When TN concentration is increased by 50% above the lowest concentration recorded in the data set, PB increases linearly by about 10% from its lowest level. In contrast when accumulated PAR is increased by the same 50% above a level at the bottom of the euphotic zone, PB increases logarithmically by about 450%.

Figure 14. Sensitivity of PB to change in PAR and TN. Curves are simulations from Equation 4 in which the PAR curve (solid line) is the PB response to change in PAR when TN concentration was held constant (set at $0.1 \text{ mg}\cdot\text{L}^{-1}$) and the TN curve (dotted line) is the PB response to change in TN concentration when accumulated PAR is held at a constant high level (similar to that near the water surface ($800 \text{ mol}\cdot\text{m}^{-2}$)). Coordinate A shows that a 50% change in TN concentration produces a 10% change in PB from its lowest recorded value. Coordinate B shows that a 50% change in accumulated PAR from the lowest recorded value produces a 450% change in PB from its lowest recorded value.

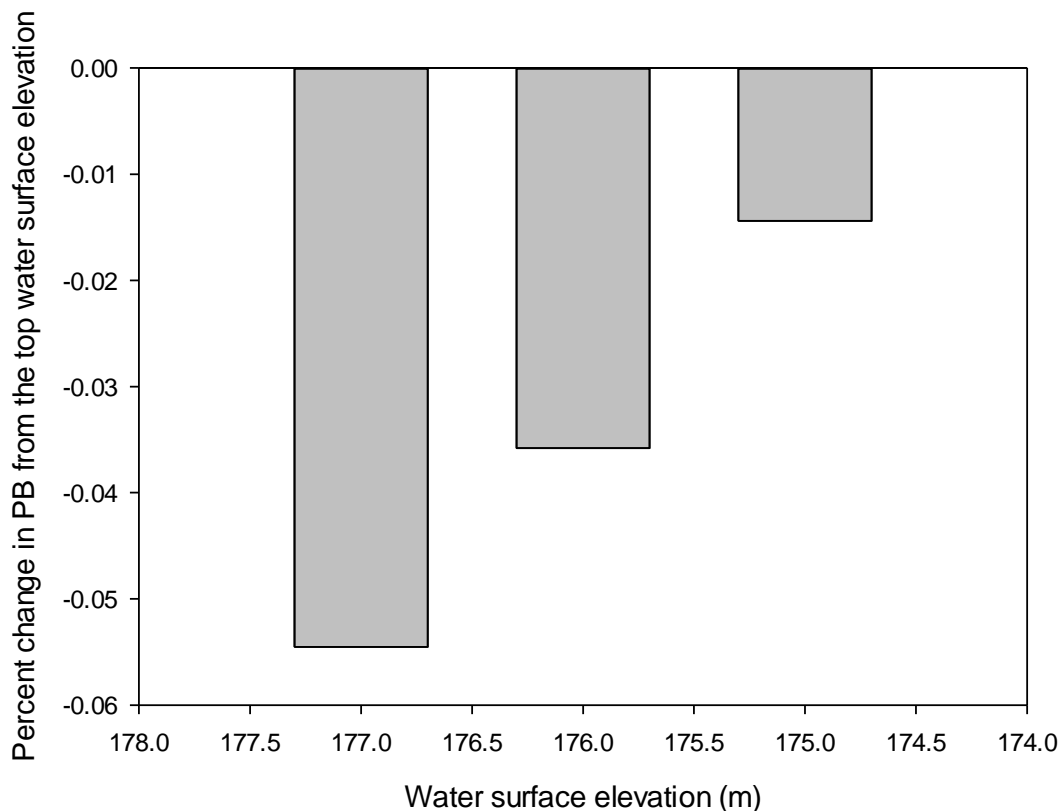


3.5. The Performance Measure Called ***L***

The performance measure called ***L*** was based on the application of Equations 1 and 2. It was calculated as the sum of products of areas of littoral strata and PB within each of those strata, wherein PB was determined from Equation 2 as a function of habitat attributes, namely depth-specific PAR and TN concentration. With a 1 m drop in water surface elevation, PB is predicted to decline by 5.5%. At a water surface elevation of 175 m, only a 1.5% decline in PB is predicted (Figure 15). The smaller decline in PB with drops in water surface elevation beyond 1 m (e.g., drop

from 178 m to 176 m and to 175 m) is due to little change in littoral area with those changes in water surface elevation and less PAR attenuation than occurs in the first 1 m change in elevation.

Figure 15. Percent change in littoral PB with a decline in water surface elevation.



3.6. Benthic Invertebrate Composition

Benthic invertebrates in the littoral zone of Campbell Lake Reservoir included the mayfly, caddisfly, and true fly orders of aquatic insects, oligochaetes, and an assemblage of mites, nematode worms, ribbon worms, Hydra, ostracods, gammarid amphipods, molluscs (gastropods and bivalves), crayfish and damselflies (Figure 16 and Figure 17). Densities of littoral benthos in Campbell Lake Reservoir were comparable between two methods, basket samplers ($23,645 \pm 13,144$ invertebrates·m⁻²) and a Ponar sampler ($25,732 \pm 15,782$ invertebrates·m⁻²) (Figure 16) although fewer aquatic invertebrate groups were captured using the basket samplers, including non-chironomid dipterans, which were not present in the basket samplers. However, regardless of sampling method, the community was mostly comprised of chironomids ($>17,000$ individuals·m⁻²) and oligochaetes (>1800 individuals·m⁻²). Mean biomass of littoral benthos in Campbell Lake Reservoir was greater in the basket samples ($1,956$ mg·m⁻²) compared to the Ponar samples (394 mg·m⁻²) mainly due to the presence of one large signal crayfish (*Pacifastacus leniusculus*) caught in a single basket sampler (Figure 17). Thelone crayfish comprised 97% of biomass in that sample and skewed the results presented in

Figure 17. However, the chironomids still represented a high proportion (15%) of the total biomass compared to the other invertebrate groups ($\leq 1\%$) excluding the other category which included the crayfish and accounted for 81% of the mean biomass in basket samples. In the Ponar samples, chironomids, mayflies, and oligochaetes accounted for 54%, 12% and 9% of the total littoral biomass respectively. Overall, the results show that regardless of sampler type, the littoral zone had higher abundance of chironomids and oligochaetes, and lower abundance of mayflies, caddisflies, non-chironomid true flies, and other aquatic invertebrates.

Figure 16. Density of benthic invertebrates in Lower Campbell Reservoir.

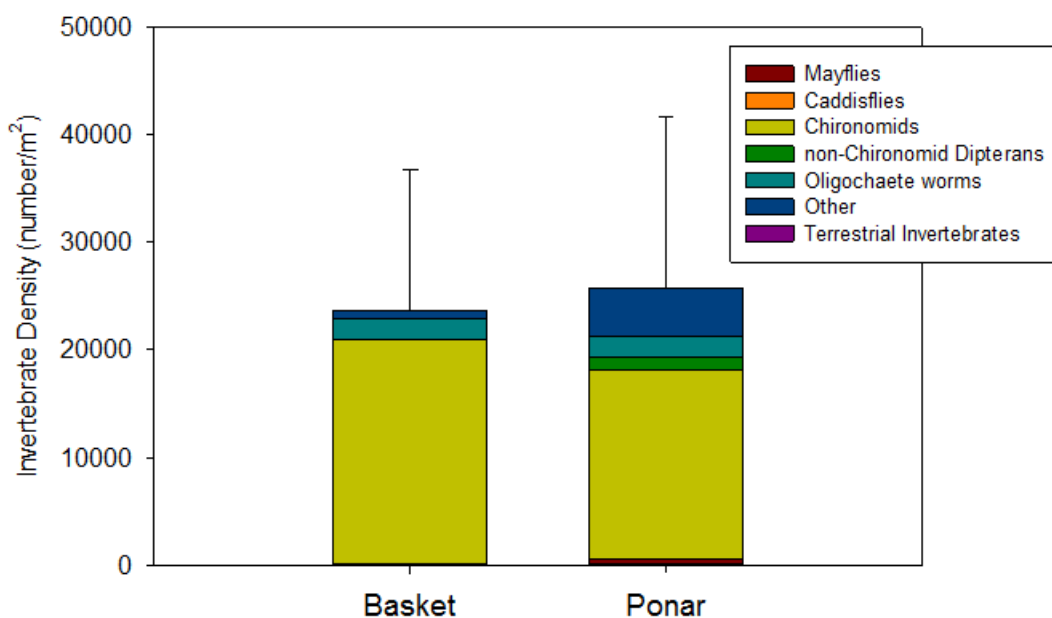
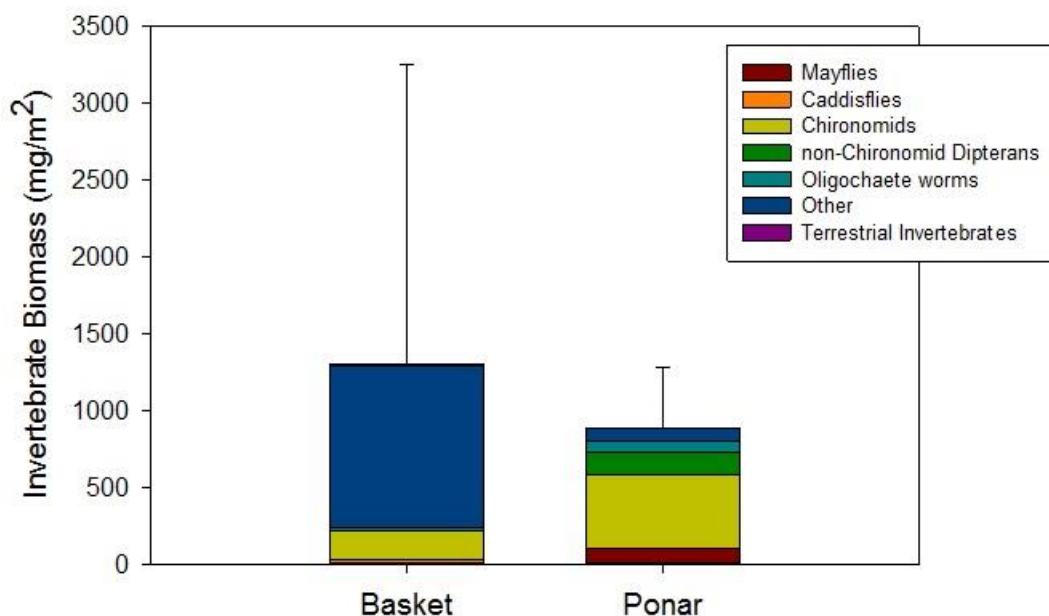


Figure 17. Biomass of benthic invertebrates in Lower Campbell Reservoir.

3.7. Fish Stomach Contents

Stomachs from fish collected in gill nets on October 5, 2015 contained an assortment of prey from aquatic and terrestrial habitats (Table 10). The cottids ingested aquatic taxa mainly including mayflies and chironomids that are common in littoral habitat, as well as individuals from terrestrial taxa and zooplankton. Coastrange Sculpin (*Cottus alenticus*) exclusively had terrestrial taxa in its stomach but only one fish was collected of this species, which is not representative of food preference by this species. In contrast, other cottids including Prickly Sculpin (*C. asper*) had an assortment of aquatic taxa in their stomachs including benthic insects and zooplankton. Rainbow Trout ingested zooplankton exclusively while Cutthroat Trout ingested a wider range of prey including other fish, zooplankton, and terrestrial taxa, with a minor component of benthic insects and other aquatic taxa.

Table 10. Contents of fish stomachs, by fish species, captured during gill net sampling on Lower Campbell Reservoir on October 5, 2015.

Metric		Average metric value by fish species				
		<i>Cottus aleuticus</i>	<i>Cottus asper</i>	<i>Cottus</i> sp.	<i>Oncorhynchus clarki</i> (Cutthroat trout)	<i>Oncorhynchus mykiss</i> (Rainbow trout)
Number of fish sampled		1	8	3	23	61
Mean fork length (mm)		170	102	146	297	243
Mean weight (g)		85	12	46	334	201
Average number of fishes per stomach		0	1	0.7	0.7	0
Average number of invertebrates per stomach		1	4.8	0.7	29.8	2678
Percent of total number of invertebrates among all samples	Mayflies	0.00%	9.30%	50.00%	1.50%	0.00%
	Stoneflies	0.00%	0.00%	0.00%	0.00%	0.00%
	Caddisflies	0.00%	7.00%	0.00%	0.10%	0.00%
	Chironomids	0.00%	23.30%	0.00%	0.70%	0.00%
	Other aquatic invertebrates ¹	0.00%	2.30%	0.00%	6.90%	0.00%
	Terrestrial ²	100.00%	2.30%	0.00%	37.10%	0.10%
	Zooplankton ³	0.00%	55.80%	50.00%	53.70%	99.90%

¹Mites, Coleoptera (beetles), non-chironomid dipterans, amphipods, and Hemipterans.

²Araneae (spiders), Coleoptera (winged beetles), Collembola (springtails), Diptera adults, Hemiptera adults (true bugs), Hymenoptera (bees, wasps, sawflies and ants), Odonata adults (damselflies and dragonflies), Psocodea (bark lice), and Blattodea (waterbugs).

³Cladocerans (*Daphnia* sp., *Bosmina/Eubosmina* sp., *Leptodora kindtii*, Chydoridae sp., *Simocephalus* sp., *Polyphemus* sp., and *Sida* sp.), copepods (*Cyclops* sp., and *Diaptomus* sp.), and Ostracods

3.8. Stable Isotope Modelling

3.8.1. Summary of Stable Isotope Signatures by Taxa

Nitrogen and carbon stable isotope signatures of all fish, invertebrates and primary nutrient sources were fairly distinct from one another, which provide evidence for species separation by energy source and trophic position within the Lower Campbell Reservoir food web (Figure 18). Cutthroat Trout had high $\delta^{15}\text{N}$ levels consistent with their top position within lake food webs. Rainbow Trout had lower $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values than Cutthroat Trout, indicating increased pelagic zooplankton contribution to diet. Smaller littoral prey fish generally had lower $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ than large Cutthroat Trout, but slightly higher signatures than Rainbow Trout, suggesting that higher proportions of their diets are made up of littoral and terrestrial invertebrates, whereas large bodied Rainbow Trout consume more zooplankton. Stickleback also had high $\delta^{15}\text{N}$ values but lower $\delta^{13}\text{C}$ relative to other fish species indicative of pelagic-dominated diet. Littoral invertebrates had the widest variation in stable isotope signatures, overlapping both zooplankton and terrestrial invertebrates in signatures of both $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ and overlapping $\delta^{13}\text{C}$ values with all four fish groups. On average, terrestrial

invertebrates had higher $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$ values than littoral invertebrates, indicative of their terrestrial habitat, while of all consumers, zooplankton had the lowest $\delta^{15}\text{N}$ signatures, consistent with lower relative food web position, and the lowest $\delta^{13}\text{C}$ signatures, consistent with preference for pelagic habitat.

Among primary nutrient sources, periphytic algae had the lowest $\delta^{13}\text{C}$ signatures in line with zooplankton, while littoral periphyton scraped off rocks had the highest $\delta^{13}\text{C}$ of all consumers and diet sources in the Lower Campbell food web. This result shows that the periphytic algae scraped from the mooring line rope derived most of its carbon from autochthonous production. In contrast, littoral periphyton scraped off of rocks likely consists of a high proportion of heterotrophic organisms, such as protozoa, bacteria and fungi, as well as terrestrial detrital material.

3.8.2. Primary Nutrient Source Contributions to Reservoir Consumers

Of the four primary nutrient sources examined in Lower Campbell Reservoir, leaf litter (i.e., carbon derived from terrestrial plants) and phytoplankton contributed the most to upper-level consumer diets (Table 11, Table 12). Periphyton of both types, including periphytic algae and littoral periphyton, contributed less than 10% each to the diet of Cutthroat Trout and less than 5% each to the diet of Rainbow Trout.

Consistent with their benthic association and feeding habits (e.g., Chironomids from Figure 16), the majority of the diet of littoral invertebrates was dominated by SPOM and littoral periphyton (approximately 30% each), while the algal component of periphyton and leaf litter contributed about 26% and 15% to littoral invertebrate diets respectively (Figure 19).

The diet of littoral prey fish was dominated by terrestrial invertebrates, while the diet of Threespine Stickleback was dominated by zooplankton (Figure 20). Terrestrial and littoral invertebrates made up the majority of littoral prey fish diets at roughly 64% and 26% respectively, while zooplankton made up only 10% of their diet. In contrast, zooplankton made up over 60% of Threespine Stickleback diets, while terrestrial and littoral invertebrates made up roughly 26% and 10% of their diets respectively. Given the high proportion of terrestrial invertebrates in prey fish diets, the most prevalent primary nutrient source in prey fish diets was leaf litter (68%). In contrast, periphytic algae, littoral periphyton, phytoplankton, and SPOM each contributed to less than 10% of littoral prey fish diets. Because stickleback diets were largely composed of zooplankton, phytoplankton contributed the most of all primary nutrient sources to stickleback diets (63%). Leaf litter had the next highest proportional contribution to stickleback diets (28%), due to the considerable proportion of terrestrial invertebrates in stickleback diets (26%). In contrast, periphytic algae, littoral periphyton, and SPOM comprised only about 3% of stickleback diets.

Consistent with stomach content analyses, Cutthroat Trout and Rainbow Trout diets were dominated by fish (58%) and zooplankton (35%), respectively (Figure 21). Among the basal nutrient sources, leaf litter contributed the most to large trout diets, including an estimated 58% to Cutthroat Trout and 43% to Rainbow Trout. Phytoplankton contributed the second highest proportion of basal nutrient sources to large Cutthroat Trout diets and the highest proportion of basal nutrient

sources to Rainbow Trout diets. In contrast, periphytic algae, littoral periphyton, and SPOM each contributed to less than 10% of basal nutrient sources in large trout diets.

Figure 18. Carbon – nitrogen stable isotope bi-plots (mean \pm SD) of basal nutrient sources, invertebrates, and fish from Lower Campbell Reservoir in 2015.

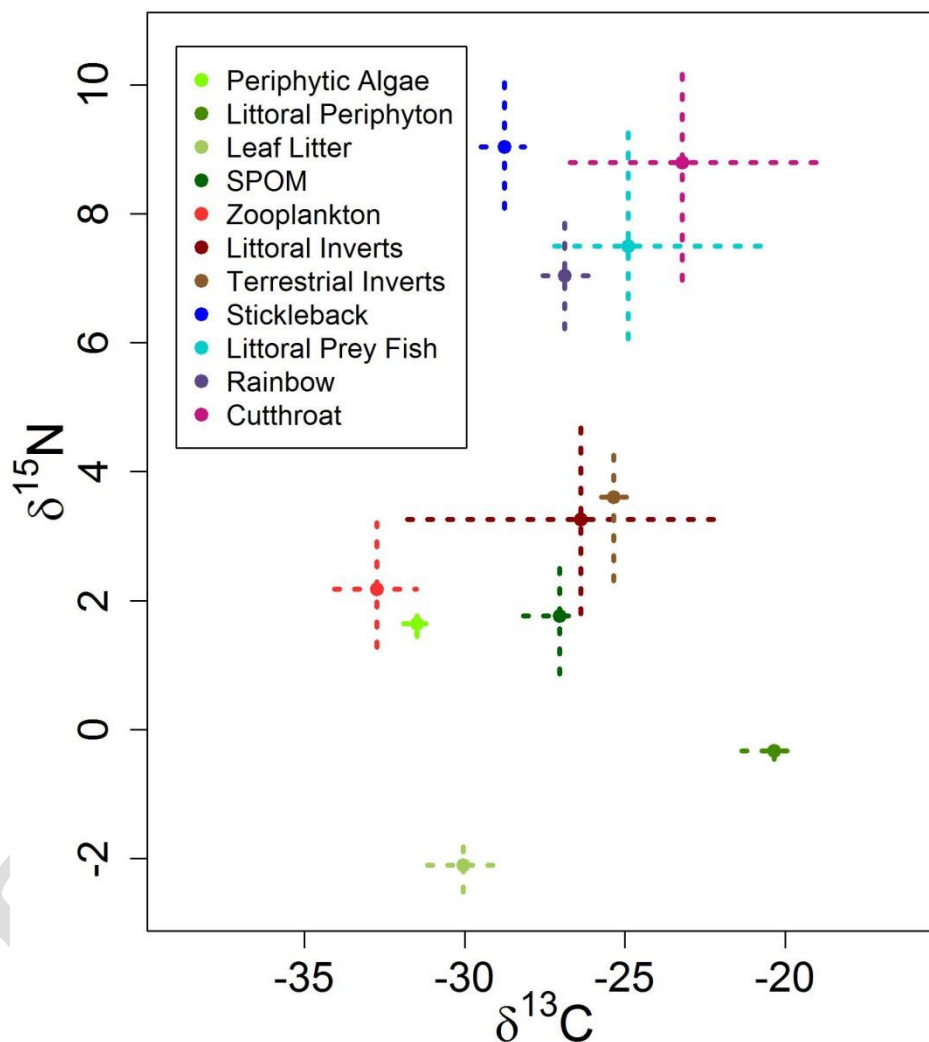


Figure 19. Estimated proportions of basal nutrient diet sources to littoral invertebrates in Lower Campbell Reservoir. Estimates are calculated as means with 5% and 95% percentile ranges of posterior probability distributions from carbon – nitrogen Bayesian mixing models based on isotopic signatures from littoral invertebrates and their potential diet sources.

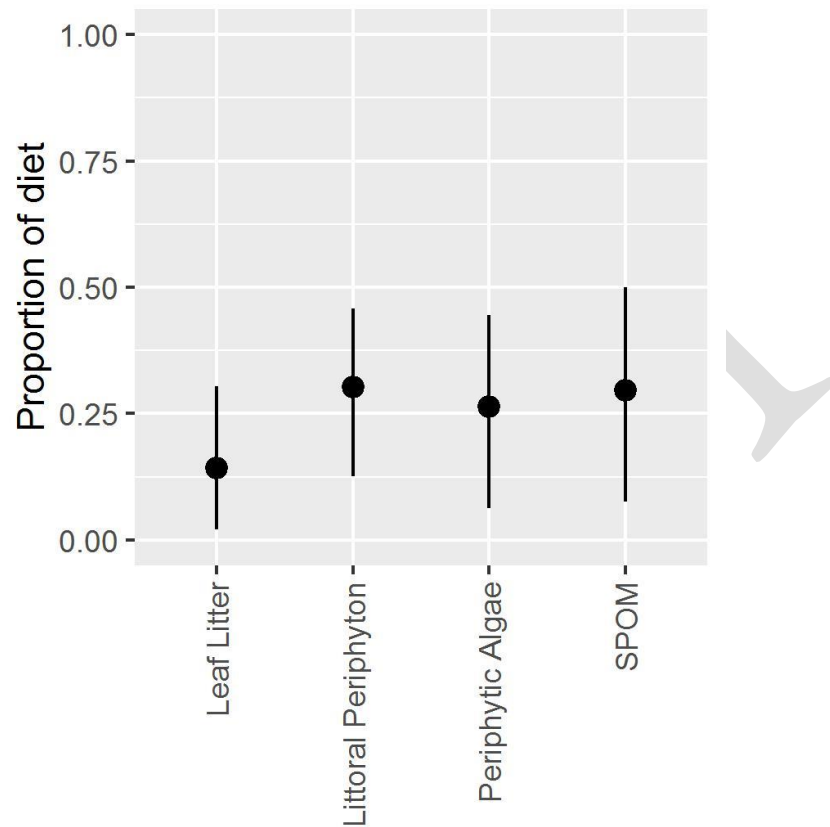


Figure 20. Estimated proportional contributions of invertebrate food sources to diets of littoral A) prey fish (juvenile trout and Sculpin spp) and B) Threespine Stickleback in Lower Campbell Reservoir. Estimates are calculated as means with 5% and 95% percentile ranges of posterior probability distributions from carbon – nitrogen Bayesian mixing models, based on isotopic signatures from prey fish and their potential diet sources.

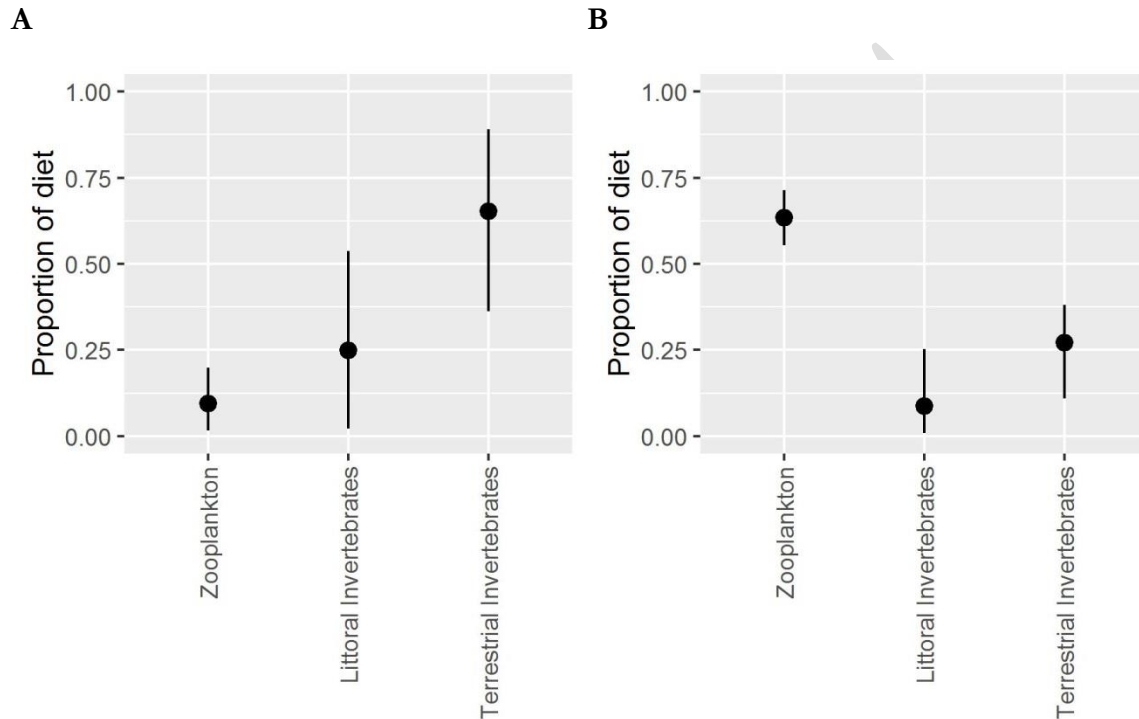


Figure 21. Estimated proportional contributions of invertebrate and fish food sources to diets of A) Cutthroat Trout and B) Rainbow Trout in Lower Campbell Reservoir. Estimates are means with 5% and 95% percentile ranges of posterior probability distributions from carbon – nitrogen Bayesian mixing models, based on isotopic signatures from these consumers and their potential diet sources.

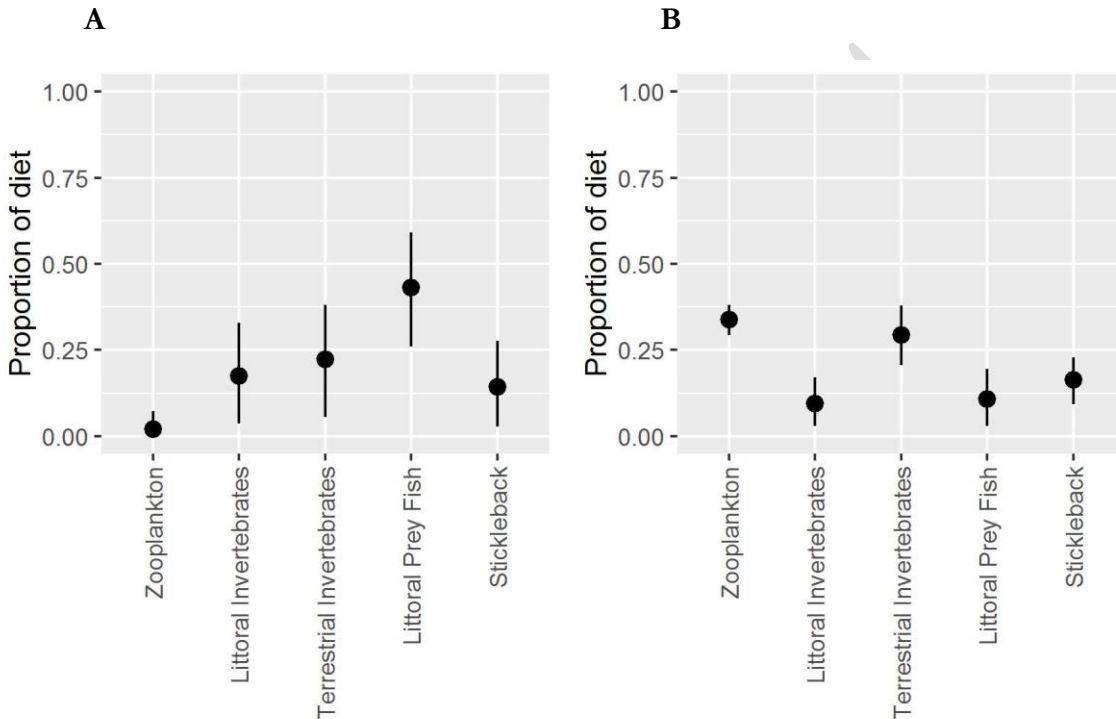


Table 11. Proportional contributions of basal nutrient sources to Cutthroat Trout and Rainbow Trout in Lower Campbell Reservoir.

Consumer	Source	Total primary nutrient sources in diet
Cutthroat Trout	Periphytic Algae	0.079
	Leaf Litter	0.579
	Littoral Periphyton	0.091
	SPOM	0.090
	Phytoplankton	0.161
Rainbow Trout	Periphytic Algae	0.037
	Leaf Litter	0.428
	Littoral Periphyton	0.043
	SPOM	0.042
	Phytoplankton	0.451

Table 12. Mean proportional contribution of intermediate consumers (zooplankton, littoral and terrestrial invertebrates, littoral prey fish and stickleback) and basal nutrient sources to Cutthroat Trout and Rainbow Trout diets in Lower Campbell Reservoir.

Consumer	Mean Estimated Diet Contributions						
	Intermediate Consumer	Primary Nutrient Source ¹					
		Periphytic Algae	Leaf Litter	Littoral Periphyton	SPOM	Phytoplankton	
Cutthroat Trout	Zooplankton	0.026	0.000	0.000	0.000	0.000	0.026
	Littoral Invertebrates	0.178	0.046	0.027	0.053	0.052	0.000
	Terrestrial Invertebrates	0.219	0.000	0.219	0.000	0.000	0.000
	Littoral Prey Fish	0.431	0.029	0.292	0.034	0.033	0.043
	Stickleback	0.146	0.004	0.041	0.005	0.004	0.092
	Total	1.000	0.079	0.579	0.091	0.090	0.161
Rainbow Trout	Zooplankton	0.337	0.000	0.000	0.000	0.000	0.337
	Littoral Invertebrates	0.097	0.025	0.015	0.029	0.029	0.000
	Terrestrial Invertebrates	0.294	0.000	0.294	0.000	0.000	0.000
	Littoral Prey Fish	0.109	0.007	0.074	0.008	0.008	0.011
	Stickleback	0.162	0.004	0.045	0.005	0.005	0.103
	Total	1.000	0.037	0.428	0.043	0.042	0.451

¹ Zooplankton and Terrestrial invertebrate diets assumed to be entirely composed of Phytoplankton and leaf litter respectively.

4. DISCUSSION

4.1. ELZ Performance Measure

Solving equations 1 and 2 provided answers to management questions 1 and 2 (Section 1) for Lower Campbell Reservoir. Equation 1 showed that L (the performance measure defined as PB on substrata in the littoral zone and substituted for ELZ in the project terms of reference) can be calculated as the sum of products of littoral area and PB within that area. Equation 1 was sensitive to variation in periphyton as determined by different habitat attributes, as defined by Equation 2, within depth strata of the littoral zone. The culmination of all calculations linking Equations 1 and 2 showed that a sustained decline of water surface elevation from 178 m to 177 m would be expected to result in a 5.5% decline in peak periphyton over the whole reservoir (Figure 15). Further sustained declines in water surface elevation to 175 m would be expected to result in less change. These changes were mainly due to variation in littoral area and PAR affecting substrata at different depths (Equation 2, Table 9, Figure 14). These findings show that L , which is conceptually similar to ELZ (see Section 2.0), estimates changes in periphyton accrual due to changes in reservoir water surface elevation and thus answers management question 1. That periphyton community was comprised mainly of diatoms and chlorophytes, which are typical along coastal lake shorelines. Habitat attributes that determine growth of periphyton were effectively measured and among them, PAR was found to be the strongest predictor, with nutrient concentration secondarily important in determining L . This finding of the relative importance of the habitat attributes answers part of management question 2.

Care is needed when interpreting Figure 15 that shows the amount of change in L with change in water surface elevation. While calculation of areas of littoral strata was done with little or no error using the DEM, error was present in equation 2 that predicted PB as a function of habitat attributes specific to water depths. Analysis of Equation 2 showed that about 50% of the variance in PB could be determined by depth-specific PAR, nutrient concentration, and temperature. Of these variables, temperature was not statistically important and nutrient concentration was about half as important as PAR. Half of the variance in PB could not be explained by the three predictor variables and was due to unmeasured variables and error. This unexplained variance is high given the control over PB measurement with exclusion of confounding factors. By suspending the samplers in the water column without contact with the reservoir bottom, invertebrate grazers would be expected to be excluded. None were found on the Styrofoam balls at the time of sampling, which supports this view, although grazing by very small substrata-associated zooplankton may have been a factor. Care was taken in sampling and handling the Styrofoam balls but this attention does not rule out error associated with sample processing. Other factors potentially affecting measurement of PB and the habitat attributes are unknown. A conclusion from these findings is that a decline in PB within the littoral zone with declining water surface elevation is expected to be 5.5% over a 1 m change in water surface elevation but the actual amount may be different in relation to unexplained variance in PB.

Absence of an effect of temperature and the small effect of nutrient concentration on PB was a statistical outcome that does not mean that these attributes were not important in determining growth of periphyton. Indeed, these variables are known to be very important (Goldman and Carpenter 1974, Bothwell 1988, Bothwell 1989, Biggs 2000, Guildford and Hecky 2000). The statistical outcome indicates that the data range found in summer and fall of 2015 was not enough to show an effect. Water temperature over the depth of the littoral zone (top 20 m of the water column) was 8.5 – 22°C during the period of measurement in summer and fall (Figure 6). That range did not affect periphyton accrual ($p=0.18$, Section 5.3). Presence of a temperature effect might be expected at lower temperatures potentially occurring in winter. Concentrations of the various forms of N and P were some of the lowest recorded for lakes in general and reflect the ultra-oligotrophic status of Lower Campbell Reservoir, which is typical of lakes and reservoirs on northern Vancouver Island (Suttle and Harrison 1988, Stockner and MacIsaac 1996, Perrin and Harris 2006) including John Hart Reservoir that is immediately downstream of Lower Campbell (Perrin *et al.* 2012). The lack of detection of any fraction of phosphorus indicates that phosphorus limited the growth and biomass of periphyton, consistent with the results of Bothwell (1989). The lack of $\text{NO}_3\text{-N}$ was unusual but not surprising. Given that $\text{NO}_3\text{-N}$ is a mobile anion in forest soils, this finding indicated very tight nitrogen cycling and reuse within the forested watershed of Lower Campbell Reservoir and Upper Campbell Reservoir, in addition to uptake by primary producers in the reservoirs. The use of TN was a substitute for using inorganic forms of N, which are highly bioavailable to periphyton. TN was mostly organic N, given the lack of $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$. Organic N can be labile but these compounds must first be mineralized by microbial decomposition. Hence, TN is not a direct measure of N available to algae: it is only an indicator of potentially available N, and will include N within living phytoplankton cells. These very low concentrations of N and P indicate that free N or P ions will be quickly sequestered by phytoplankton and periphyton, limiting the concentrations detected in water samples using wet chemistry techniques. In this respect, the variation in PB may have reflected small changes in the availability of inorganic N and P but nutrient concentrations were not a strong predictor because they could not be detected at a wide range of values. Thus, nutrients are expected to exert a strong control on algal growth in Lower Campbell Reservoir, although the issues discussed above meant that the study was unable to fully quantify the contribution of this factor.

Depth-specific PAR was a strong predictor of PB (Table 9) and PB was sensitive to change in PAR (Figure 14). At a depth of 18 m (the deepest of the periphyton samplers), PB was found in trace amounts, but it increased logarithmically with PAR and thus with declining water depth. Greatest changes in PB occurred with small changes in PAR at low PAR and smaller changes occurring at larger changes in PAR at high PAR. Over the depth range of surface to 14 m, the rates of biomass accrual were greater near the surface than at depth in summer but in the fall, this variance with depth was not found. The lack of distinct phases in those curves over the time of incubation was striking, i.e., an archetypal sigmoidal growth curve was not observed. Colonization (commonly a linear phase) was not distinguishable from a logarithmic growth-dominated phase and peaking was

not apparent. All curves showed a logarithmic pattern from start to finish, showing that logarithmic growth kinetics were most important in explaining biomass accrual throughout the incubation period. Lack of a plateau in the curves showed that a true PB was not achieved, even after the two month incubation period. This long period is consistent with the extremely low N and P concentrations that would have strongly curtailed the algal growth rates. The curves show that incubation periods longer than two months are needed to achieve detection of true PB. This finding answers another part of management question 2: “To what extent does colonization rate, growth rate, and survival rate impact the utility and reliability of ELZ” (which is called L in this report (see Section 2)). The answer is that the combination of colonization, growth, and survival are integrated in the accrual curves that ultimately show PB within a standardized measurement period. Given that PB, defined as the largest amount of biomass accrued on a substratum over a standard time period, was a function of logarithmic accrual that is consistent with patterns of algal growth (Bothwell 1989), a conclusion is that L is sensitive to the algal colonization, growth, and survival kinetics.

Equations 1 and 2 are set up to answer the third management question that states, “Following implementation of the Campbell River WUP, does littoral productivity increase as predicted by the ELZ performance measure?” In effect, equations 1 and 2 provide a framework to test whether the WUP affects the ELZ performance measure or, more correctly, the L term in equation 1. The equations can be used to test the hypothesis that was originally developed using ELZ during development of the WUP that the accepted management alternative will result in increased biological production in the littoral zone. Using existing findings, the equations show that if water surface elevations are lowered, biological production in the littoral zone derived from algae will be expected to decline by small amounts (about 5% over 3 m ranges of water surface elevations). The reverse would be expected if water surface elevations are maintained near the maximum elevation of 178 m. Figure 1 shows that the water surface elevation in Lower Campbell Reservoir is not maintained at a constant level but it fluctuates up and down. There is no clear confirmation in the WUP about whether this variability changed with rules imposed by the WUP but equations 1 and 2 can be used to test whether a given change in water levels can affect production in the littoral zone. Figure 10 and Figure 11 show that more than two months is required for PB to be achieved on submerged substrata, which means that any substrate that is continuously submerged will effectively contribute to algal production and the littoral food web. Any substrate that is continuously dewatered and submerged in cycles shorter than two months will make limited contribution to the littoral food web because it will be in a constant stage of recovery from dewatering and regrowth of the biofilm. L will be below what is already low biomass due to the ultra-oligotrophic state of Lower Campbell Reservoir. Any substrata that is dewatered for more extended periods of time will effectively be removed from productive potential in the littoral zone. This same approach along with using the DEM to quantify habitat area can be used to determine change in areas of productive and unproductive habitat for given variance in water surface elevation, once known or determined from ongoing monitoring.

4.2. Fish Stomach Contents

Fish stomach contents were used as a first step to examine links between algal production in the littoral zone and fish use of that habitat, thus addressing the fourth management question, “How does littoral productivity translate into fish production in Campbell Reservoirs?” The stomach content data showed that the most common prey for Cutthroat Trout and Rainbow Trout were zooplankton and terrestrial taxa, with benthic insects that are common in littoral habitats making almost no contribution to diets. Fish were also a common diet item for Cutthroat Trout but not Rainbow Trout. Other aquatic invertebrate taxa including Coleoptera (beetles), non-chironomid dipterans, amphipods, and hemipterans represented a small proportion of stomach contents. Cottids ingested a wider assortment of prey, potentially from wide ranging habitats. These findings show a disconnection between biological production of food assemblages in littoral habitat where benthic insects are prevalent, and food ingested by fish of management interest (Cutthroat Trout and Rainbow Trout). This preliminary evidence implies that the littoral-derived algal production is not important in supporting resident fish species and that food production from riparian areas and pelagic habitat is more important.

4.3. Stable Isotope Modelling

Stable isotope data, which represents an integrated signature of fish diet over a growing season, showed similar results to stomach content analyses in that littoral-derived algal production was not very important. Terrestrial primary production contributed 58% to Cutthroat Trout diets and 43% to Rainbow Trout diets, illustrating the importance of allochthonous nutrient sources in the ultra-oligotrophic Lower Campbell Reservoir. Riparian leaf litter (i.e., terrestrial vegetation) was consumed directly by littoral invertebrates and is the basal carbon source for terrestrial invertebrates, which were heavily consumed themselves by littoral prey fish (e.g., juvenile trout and Sculpin), stickleback, and Cutthroat and Rainbow Trout.

Pelagic primary production was particularly important for Rainbow Trout: phytoplankton contributed 45% to Rainbow Trout diets and 16% to Cutthroat Trout diets, largely through consumption by zooplankton. This finding confirms results of fish stomach analysis that demonstrated a large contribution of zooplankton to Rainbow Trout diets.

Littoral/benthic invertebrates eat mainly littoral periphyton and SPOM, with lesser amounts of periphytic algae and leaf litter. However, Cutthroat Trout eat fish, terrestrial invertebrates, littoral invertebrates, and zooplankton, in that order. Rainbow Trout eat zooplankton, terrestrial invertebrates, fish, and littoral invertebrates, in that order. In turn, littoral prey fish (e.g., juvenile trout) eat terrestrial invertebrates, littoral invertebrates, and then zooplankton. Stickleback eat zooplankton, terrestrial invertebrates, and littoral invertebrates, in that order. Therefore, when these diet contributions are summed across trophic levels, the contribution of periphytic algae to Cutthroat Trout and Rainbow Trout is estimated to be only 7.9% and 3.7% respectively. We anticipate a similar result in Upper Campbell Reservoir, where pelagic contributions are higher than

in Lower Campbell Reservoir (Hocking *et al.* 2016) and any decline in littoral productivity through declines in periphytic algal would have correspondingly less impact on fish production.

The current data thus suggest that, while algal accrual can be used to make predictions regarding the functioning of ELZ as described above, the littoral food web of Lower Campbell Reservoir is more complex than assumed under the ELZ model. The current ELZ approach would likely underestimate the effect of reservoir drawdown on impacts to fish because it does not consider the primary driver of littoral fish production, which is terrestrial-derived carbon via leaf litter and terrestrial invertebrates. Secondly, periphyton in littoral areas may not solely comprise periphytic algae and instead is likely an assemblage of algae, protozoa, bacteria, fungi and detrital material.

Two sources of periphyton were analysed (periphytic algae and littoral), which were found to have distinct isotope signatures. The periphyton living on stony hard substrates and macrophytes in the littoral zone of lakes is inhabited by an abundant and diverse algae and meiofauna assemblage (Schroeder *et al.* 2013), that can include dozens of living and dead algae and bacteria species. Depth-related factors such as light are important for structuring periphytic species assemblages (Schroeder *et al.* 2013), and the relative abundance of different algal taxa can explain up to 74% of periphyton $\delta^{13}\text{C}$ variability (Abe *et al.* 2013). The depleted $\delta^{13}\text{C}$ signature in the periphytic algae portion of periphyton in Lower Campbell Reservoir (-32‰) was most similar to that of planktonic algae reported in the literature (average -32‰). The more enriched carbon signature of littoral periphyton scraped off of rocks of Lower Campbell (-20‰) was more similar to that of lake benthic algae reported in the literature (average -26‰) (France 1995). The different signatures are likely due to several factors. Terrestrial allochthonous carbon sources contribute to littoral periphyton closer to shore and enrich the carbon signature. The presence of heterotrophs such as bacteria will enrich the carbon signature further. The algal portion of periphyton grown on the mooring line grew slowly under ultra-oligotrophic conditions with carbon derived from autochthonous production. More depleted $\delta^{13}\text{C}$ signatures are reported under slower growth rates in a variety of freshwater plants (MacLeod and Barton 1998). Overall, the isotope signatures of the two periphyton sources were only based on very few samples ($n = 3$ for each). Therefore, these results should be confirmed with another year of sampling in Upper Campbell Reservoir.

5. CONSIDERATIONS FOR YEAR 2

The following represents a summary of considerations for Year 2, based on Year 1 sampling of the JHTMON-4 program.

5. Periphyton accrual curves from 2015 showed that a time longer than 60 days is needed to reach peak biomass in the ultra-oligotrophic waters of the Campbell Reservoir system. Sampling is planned for Upper Campbell Reservoir in 2016. We plan to leave the periphyton moorings installed in Upper Campbell Reservoir for a 90-day sampling duration rather than the 60 days that was used in 2015. The two sampling periods that were defined in 2015 should be used in 2016. The time of sampling does not have to be the same in 2016 as it was in 2015. Indeed, changing the time would be advantageous to capture more variable habitat conditions in the

regression modelling that is used to explain variance in periphyton peak biomass. This change will result in a six month duration of sampling in 2016 (2 periods of 90-day durations) rather than the four months (2 periods of 60-day durations) that was used in 2015. This consideration is based on JHTMON4 management questions that do not include objectives to quantitatively compare periphyton biomass between Upper and Lower Campbell Reservoirs.

6. The ELZ performance measure was based on measurement of algal biomass accruing over a period of time. A more robust measure of actual production is specific growth rate that can be calculated from accrual curves. To represent ELZ, it is desirable to include both peak biomass over an accrual period, as was done in this report, and specific growth rate at selected depths to determine if peak biomass is a reasonable indicator of specific growth rate.
7. Carbon isotope signatures showed that periphyton accrued on sampling apparatus in the water column may not be representative of littoral periphyton living near the shoreline. The conclusions based on stable isotope analysis are based on a small sample size of primary producers. Larger sample sizes of periphyton, SPOM, and leaf litter may be required to increase confidence in conclusions. We plan to increase sampling effort of periphyton in Year 2, including in different time periods throughout the growing season. These increases in sample size for isotope analysis can be incorporated into the existing Year 2 scope and budget.
8. The stable isotope component of JHTMON-4 was achieved through coordinated sampling between JHTMON-4 and JHTMON-5 in 2015. Fish, zooplankton and terrestrial invertebrate sampling are not scheduled to occur in Upper Campbell Reservoir in 2016 as a part of JHTMON-5, although it did occur in 2014. The stable isotope component of JHTMON-4 in Upper Campbell Reservoir in 2016 can be supported using existing data collected through JHTMON-5 in 2014.

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PROJECT MAPS

DRAFT



JHTMON Campbell River Water Use Plan

**Lower Campbell Reservoir
Lake Sampling Locations**

- Legend**
- Sample Sites**
- PAR Sensor
 - JHTMON-5 Zooplankton Sampling
 - ◆ Periphyton Sampling
 - ▲ Benthic Invertebrate Sampling
 - ▲ JHTMON-5 Littoral Invertebrate Sampling
 - ▲ JHTMON-5 Terrestrial Invertebrate Sampling
 - JHTMON-5 Fish Sampling



MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

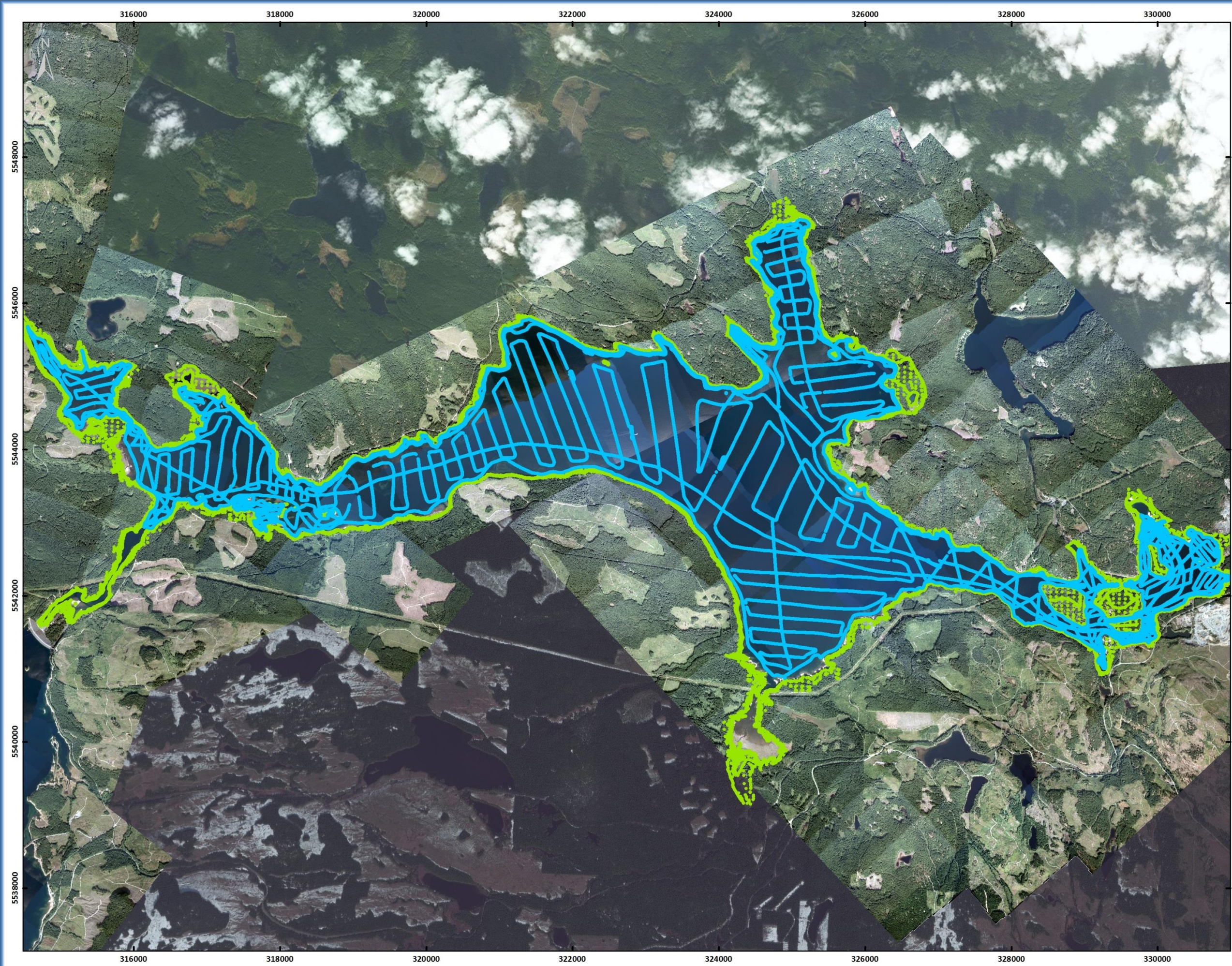
0 250 500 1,000 1,500 2,000 2,500 m

Scale: 1:45,000

NO.	DATE	REVISION	BY
1	19/04/2016	1230_MON4_LCR_SamplingLocs_2016Feb02	CGA
2			
3			
4			
5			

Date Saved: 19/04/2016
Coordinate System: NAD 1983 UTM Zone 10N

Map 2



JHTMON CAMPBELL RIVER WATER USE PLAN

Lower Campbell Lake Bathymetry

- Legend**
- Field Data Point
 - Terrestrial Data Point



MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

0 0.25 0.5 1 1.5 2 2.5 km

Scale: 1:50,000

NO.	DATE	REVISION	BY
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2			
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4			
5			

Date Saved: 01/04/2016
Coordinate System: NAD 1983 UTM Zone 10N

Map 3