Campbell River Project Water Use Plan

Upper Campbell, Lower Campbell and John Hart Reservoirs and Diversion Lakes Littoral versus Pelagic Fish Production Assessment Component 2

Implementation Year 1

Reference: JHTMON-5

Year 1 Annual Monitoring Report

Study Period: April 1, 2020 to March 31, 2021

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

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JHTMON-5: Littoral versus Pelagic Fish Production Assessment Component 2

Year 1 Annual Monitoring Report




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Title Page Photographs: Top Left: Sampling site at Upper Campbell Reservoir (June 03, 2020); Top Right: Floating trap deployed at Lower Campbell Reservoir (June 02, 2020); Bottom Left: Adult caddisfly collected from Upper Quinsam Lake (June 11, 2020); Bottom Right: Malaise net and sticky trap deployed at Lower Campbell Reservoir (June 02, 2020).

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EXECUTIVE SUMMARY

Water Use Plans (WUPs) were developed for all of BC Hydro's hydroelectric facilities through a consultative process. As the Campbell River WUP process reached completion, several uncertainties remained regarding the effects of BC Hydro operations on aquatic resources. Monitoring programs were designed to assess whether environmental benefits are being realized under the WUP operating regime, and to evaluate whether operations could be further improved.

The *Upper Campbell, Lower Campbell, John Hart Reservoirs and Diversion Lakes Littoral versus Pelagic Fish Production Assessment* (JHTMON-5) is one such Campbell River WUP monitoring program. JHTMON-5 is designed to assess the extent to which fish production in reservoirs and diversion lakes is driven by littoral (near shore) versus pelagic (open water) production, and how this relates to BC Hydro operations. JHTMON-5 has two components: Component 1 included stable isotope analysis of food webs in reservoirs and diversion lakes and was completed in 2017, whereas Component 2 commenced in 2020. This Component 2 Year 1 report describes a pilot study comprising fieldwork in 2020 that informs two subsequent years of fieldwork. The study objective, management questions, hypotheses and status are summarized in Table i.

The Campbell River WUP project area includes the Strathcona-Ladore-John Hart series of three hydropower facilities on the Campbell River system, as well as the Quinsam River Diversion that can divert a portion of the flow in the Quinsam River to Lower Campbell Reservoir. In addition to the Campbell and Quinsam rivers, the watershed includes three large reservoirs, four diversion lakes influenced by water diverted from the Quinsam River, and many tributaries and small lakes that are not affected by operations. During development of the Campbell River WUP, a Fish Technical Committee (FTC) hypothesized that fish production in Upper and Lower Campbell reservoirs was negatively impacted by large fluctuations in water level that reduce littoral production. The FTC also hypothesized that reduced water residence time of the diversion lakes caused by BC Hydro diversion operations could negatively impact pelagic productivity by flushing plankton.

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

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

Component 1 of JHTMON-5 focused on both management questions, in addition to null hypotheses 1 and 2 (Table i). Notably, Component 1 showed that terrestrial (allochthonous) sources of carbon make a significant contribution to trout diets. This is contrary to the assumption made during the WUP development process when it was assumed that fish productivity was driven by carbon fixed within the lake by primary producers such as algae (autochthonous). Component 1 therefore showed that the link between fish production and primary production by aquatic plants in the Campbell River watershed is weaker than previously assumed. Based on the results of Component 1, the terms of

reference for Component 2 were revised to better focus on the outstanding uncertainties. Broadly, Component 2 involves three research methods:

1. Quantify how riparian inputs and benthic macroinvertebrates vary along shoreline transects;
2. Conduct stable isotope analysis to quantify contribution of terrestrial carbon sources to fish; and
3. Sample fish abundance across waterbodies and over time to test how drawdown affects fish production.

Year 1 JHTMON-5 Component 2 involved a pilot study that focused on the first research method listed above. Objectives of the Year 1 pilot study were to establish sampling sites and to trial invertebrate sampling methods. Fieldwork in Year 1 focused on Management Question 1 (effect of drawdown on fish populations) and included trialing four invertebrate sampling methods to better understand whether reservoir drawdown adversely affects fish production by increasing the distance between the shoreline and the riparian zone, which is a source of organic material and invertebrates (an important food source for resident salmonids). Malaise nets and sticky traps were used to sample terrestrial (aerial) invertebrates to collect data to test $H_0$3 (Table i). Ponar grabs and floating (emergence) traps were used to collect data to test $H_0$4 (Table i). Key factors considered during the pilot study were trap design, sampling effort (number of sites, deployment duration), the potential for sampling error due to methodological issues, managing biological degradation of samples, the need to minimize disturbance due to vandalism or wave action, and ensuring that sufficient sample volume/biomass is collected for analysis.

Three waterbodies were sampled in Year 1: Upper Campbell Reservoir (highest magnitude of drawdown), Lower Campbell Reservoir (intermediate magnitude of drawdown), and Upper Quinsam Lake (control waterbody with the lowest magnitude of drawdown). Year 1 results showed no clear relationship between terrestrial invertebrate abundance/biomass and drawdown magnitude of the waterbodies, although there was a clear decrease in terrestrial invertebrate abundance with increasing distance from the riparian zone at all waterbodies, based on sticky trap results. Somewhat unexpectedly, emergent invertebrate biomass was generally higher inside the drawdown zone compared to below the drawdown zone in Upper Campbell Reservoir and Upper Quinsam Lake, with this difference greatest at Upper Campbell Reservoir. Benthic invertebrate abundance and biomass was low for all waterbodies and there was no clear relationship between benthic invertebrate abundance/biomass and drawdown magnitude, although invertebrate species richness was highest in Upper Quinsam Lake (control lake) across all sampling methods.

Trials of the four sampling methods were encouraging. Sticky traps and floating traps were not used in Component 1 and both sampling methods provided high quality data to test the management hypotheses. A Malaise net was also successfully used to collect informative data, although the effort required was high relative to the amount of data collected. A Ponar grab was used to sample benthic invertebrate biomass, although it was challenging to use this method because substrate was generally coarse and sample processing was time consuming.

Results of the Year 1 pilot study were used to inform the study plan for the remainder of JHTMON-5 Component 2, which comprises two more years of fieldwork (2021 and 2022). Minor reallocation of sampling effort among field and laboratory tasks is recommended to improve the study design and better address the management questions.

Table i. Status of JHTMON-5 objective, management questions and hypotheses after completing Year 1 of Component 2.

Study Objectives	Management Questions	Management Hypotheses	Component 2 - Year 1 Status
Assess the extent to which trout production is driven by littoral versus pelagic production and evaluate how this relates to BC Hydro operations	1. To what extent do stabilized reservoir levels, as affected by BC Hydro operations, benefit fish populations?	$H_0$1: The extent of littoral development in lakes, as governed by the magnitude and frequency of water level fluctuations, is not correlated with the ratio of littoral versus pelagic energy flows to reservoir fish populations.	This hypothesis was addressed in the first component of JHTMON-5. In the three reservoirs, the contribution of littoral energy sources to Cutthroat Trout diets declined with increasing drawdown. This implies an effect from water management and supports rejection of the null hypothesis $H_0$1 for Cutthroat Trout. For Rainbow Trout, the opposite trend was observed with greater contribution of littoral energy sources in Upper and Lower Campbell reservoirs compared to John Hart Reservoir. This implies that the effects of water management through drawdown will be reduced for Rainbow Trout compared to Cutthroat Trout. These conclusions are qualitative in nature due to the fact that only three reservoirs could be compared and that other reservoir factors may influence energy contributions to fish populations. When both species are present, Cutthroat Trout and Rainbow Trout occupy distinct ecological niches in the lakes and reservoirs of the Campbell River system. Cutthroat Trout are more dependent on littoral habitats while Rainbow Trout are more dependent on pelagic habitats. Cutthroat Trout strongly out-compete Rainbow Trout in the shallower lakes with limited pelagic zones (e.g., Snakehead Lake). A caveat is that terrestrial invertebrates are an important food source for both

			species, meaning that impacts to riparian vegetation from drawdown may adversely affect both species. Across all waterbodies, the contribution of littoral energy sources to Cutthroat Trout diets declines with increasing shallow (<6 m) littoral volume relative to total lake volume. This result is counterintuitive but likely reflects a combination of niche expansion by Cutthroat Trout in smaller lakes without Rainbow Trout and increased productivity of smaller and shallower lakes that is driven by terrestrial carbon sources and results in higher zooplankton biomass (a pelagic food source). The relative volume of shallow littoral habitat was not related to the contribution of littoral energy sources to Rainbow Trout diet. Zooplankton (a pelagic food source) makes a high contribution to Rainbow Trout diets, although this contribution is reduced when other pelagic species (e.g., Kokanee) are present.
		$H_0$3: Terrestrial invertebrate fall is not correlated with distance from the riparian zone.	Year 1 of Component 2 was a pilot study and involved trialling sampling methods to test $H_0$3 and $H_0$4. Terrestrial (aerial) invertebrate biomass was sampled using Malaise nets and sticky traps, whereas emerging aerial invertebrates were sampled using floating traps. These methods provided suitable data to test this hypothesis in Year 3, following further data collection. Observations collected in Year 1 about the effectiveness of sampling methods have been used to refine the study plan for Years 2 and 3.
		$H_0$4: Organic material abundance and	Year 1 of Component 2 was a pilot study and involved trialling sampling methods to test $H_0$3 and $H_0$4. A Ponar grab was used

		macroinvertebrate biomass in the littoral zone are not correlated with the magnitude of drawdown or distance from the riparian zone.	to sample benthic macroinvertebrates, whereas novel floating traps were used to sample emerging invertebrates that have both benthic and aerial life stages. These methods provided suitable data to test this hypothesis in Year 3, following further data collection. Observations collected in Year 1 about the effectiveness of sampling methods have been used to refine the study plan for Years 2 and 3.
		$H_0$5: Riparian sources of carbon do not make a biologically significant contribution to fish diets.	This hypothesis is scheduled to be addressed in Years 2 and 3 of Component 2 of JHTMON-5. Analysis to test this hypothesis will use data collected using substrate analysis and stable isotope analysis.
		$H_0$6: Nitrogen and carbon isotopic signatures in littoral periphyton, benthic invertebrates and fish are not correlated with the magnitude of drawdown or distance from the riparian zone.	This hypothesis is scheduled to be addressed in Years 2 and 3 of Component 2 of JHTMON-5. Analysis to test this hypothesis will use data collected from stable isotope analysis.
		$H_0$7: Fish production is not correlated with drawdown magnitude.	This hypothesis is scheduled to be addressed in Years 2 and 3 of Component 2 of JHTMON-5. Analysis to test this hypothesis will use data collected from fish sampling collected at the three study waterbodies in 2021 and 2022, as well as analysis of gill net data collected over 10 years at Upper Campbell Reservoir as part of JHTMON-3.

	2. What is the relationship between residence time (as affected by diversion rate) and lake productivity?	$H_0$2: The extent of pelagic production in lakes, as governed by the average water residence time, is not correlated with the ratio of littoral versus pelagic energy flows to diversion lake fish populations.	This hypothesis was addressed in the first component of JHTMON-5. Across all waterbodies sampled, the pelagic energy flows to Cutthroat Trout increased with annual water residence time and with % shoal habitat in each waterbody. This suggests that Cutthroat Trout feed on zooplankton to a greater extent in shallow waterbodies with longer annual water residence times, which supports rejection of the null hypothesis $H_0$2 and implies an effect of water management through diversion. The contributions of pelagic energy sources to Rainbow Trout diets were not influenced by any of the lake variables tested, including annual or seasonal water residence time, lake volume or % shoal habitat. This indicates that the null hypothesis $H_0$2 should be retained for Rainbow Trout. An important caveat however is the reduced sample size in number of lakes where Rainbow Trout were sampled, which reduces the power to detect effects of water residence time. Lake productivity was also analyzed across all lakes and reservoirs sampled in JHTMON-5 using zooplankton biomass and Cutthroat Trout catch per-unit-effort (CPUE) and Rainbow Trout CPUE as response variables. Cutthroat Trout CPUE was positively predicted by annual water residence time and % shoal habitat, which suggests that water management through diversion may affect Cutthroat Trout abundance. For Rainbow Trout, only lake volume was an important predictor of CPUE, indicating that Rainbow Trout abundance decreases with decreasing lake size. Zooplankton biomass increased with

			% shoal habitat in each waterbody and not annual or seasonal water residence time, which may be driven by large terrestrial carbon inputs to zooplankton in smaller lakes. Scenarios of annual water residence time with water diversion were generated and simulated with the top statistical model predicting energy flows to Cutthroat Trout. Decreases in diversion post-WUP versus pre-WUP are predicted to have increased pelagic energy flows to Cutthroat Trout by a few percent. However, these pelagic energy flows may be influenced by terrestrial contributions to pelagic bacteria and ultimately incorporated into zooplankton production. The interaction between water residence time, trophic state and terrestrial contributions to pelagic productivity remains an uncertainty.
		$H_0 8$: Changes to water residence time of lakes in the Quinsam River watershed do not have a biologically significant effect on trout production.	This hypothesis is scheduled to be addressed in Years 2 and 3 of Component 2 of JHTMON-5. This hypothesis will be addressed by developing lake-specific assessments of the potential effect of changing water residence time on fish production. Assessments will be developed for the four lakes that are potentially affected by the Quinsam River Diversion.

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1. INTRODUCTION

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. WUPs are reviewed periodically and there may 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, several uncertainties remained about 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 littoral (near shore) or pelagic (open water) sources of production? Answering this key question is important to better understand how human activities in a watershed affect fisheries, and to effectively manage water uses to protect and enhance aquatic resources. To address this uncertainty, monitoring programs were designed to assess whether fish benefits are being realized under the WUP operating regime, and to evaluate whether limits to fish production could be improved by modifying operations in the future.

In lakes and reservoirs, fish production is assumed to be proportional to the overall productivity of lower trophic levels, but there is considerable uncertainty about the extent to which fish production is driven by littoral or pelagic production, and whether this is influenced by operations. BC Hydro affects reservoir littoral production through drawdown, and pelagic production through altering water residence time by manipulating inflows and outflows. The *Upper Campbell, Lower Campbell, John Hart Reservoirs and Diversion Lakes Littoral versus Pelagic Fish Production Assessment* (JHTMON-5) is part of wider monitoring of the Campbell River WUP. JHTMON-5 is designed to assess the extent to which fish production is driven by littoral versus pelagic production and how this relates to BC Hydro operations. JHTMON-5 has two components: Component 1 has been completed (Hocking *et al.* 2017) and Component 2 commenced in 2020.

This report presents outcomes from the first (pilot) year of JHTMON-5 Component 2, including recommendations regarding the design of the remaining two years of the study. This study builds on Component 1 of JHTMON-5, which has been completed (Hocking *et al.* 2017) and yielded important results that led to revisions to the terms of reference (TOR) for Component 2 (BC Hydro 2019). Further background to the scope and objectives of JHTMON-5 Component 2 is provided in Section 2 below.

2. BACKGROUND

2.1. BC Hydro Infrastructure, Operations, and the Monitoring Context

2.1.1. Infrastructure

The Campbell River WUP project area includes the Strathcona-Ladore-John Hart series of three hydropower facilities on the Campbell River system, as well as the Quinsam River Diversion that can divert a portion of the flow in the Quinsam River to Lower Campbell Reservoir (Map 1). In addition to the Campbell and Quinsam rivers, the watershed includes three large reservoirs, four diversion lakes influenced by water diverted from the Quinsam River, and many tributaries and small lakes that are not directly affected by operations (Map 1). Further details of BC Hydro's Campbell River infrastructure and operations are provided in the Campbell River System WUP (BC Hydro 2012).

2.1.2. Reservoirs

Strathcona, Ladore and John Hart dams regulate reservoir water levels for Upper Campbell, Lower Campbell, and John Hart reservoirs respectively (Map 1). The operating water level range is greatest for Upper Campbell Reservoir (connected to Buttle Lake) and lowest for John Hart Reservoir. Specifically, the historical ranges in daily average water surface elevation are 11.0 m in Upper Campbell Reservoir, 4.3 m in Lower Campbell reservoir, and 0.6 m for John Hart Reservoir (BC Hydro 2012). 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 that reduced littoral production, e.g., by causing desiccation of rooted macrophyte communities that grow near the shoreline. Stable reservoir levels were assumed to have a positive influence on fish production relative to fluctuating levels. Evaluation of reservoir operations during the WUP relied extensively on the Effective Littoral Zone (ELZ) Performance Measure (PM), with the assumption that increasing littoral development would lead to increases in fish productivity. This assumes a strong link between littoral and fish production. JHTMON-5 is designed to test the assumption that improvements in littoral production lead to corresponding increases in fish production. This information will then be used to directly evaluate the impact of the Campbell River WUP on reservoir fish production, help refine reservoir-related PMs and assess their relative importance for future WUP review processes. The understanding gained through the present monitoring program may also help guide the development of alternative management strategies for reservoir operations.

2.1.3. Diversion Lakes

The Quinsam Diversion diverts water through two lakes and into Lower Campbell Reservoir (Map 1). Among the diversion-affected lakes, there are two lakes that receive additional water diverted from the Upper Quinsam Lake watershed and thus have lower water residence time (Gooseneck and Snakehead lakes; "receiving lakes") and two lakes that have water diverted away from them and thus have increased water residence time (Middle Quinsam and Lower Quinsam lakes; "donor lakes"). During the WUP process, the FTC hypothesized that reductions to water residence time due to BC Hydro diversion operations could negatively impact pelagic productivity due to flushing pelagic organisms (plankton) from the system. This decline in pelagic productivity was hypothesized to potentially reduce fish production in these lakes. However, the hypothesis could not be tested during the WUP due to time and resource constraints. The FTC therefore assumed for decision-making purposes that there was limited impact, but recommended that this hypothesis be tested with a monitoring program.

Project Overview

Legend

- Dam
- Stream

MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

0 1 2 3 4 5 6 7 km

Scale: 1:180,000

NO.	DATE	REVISION	BY
1	2020-02-10	1230_BCH_CRFacilities_3603_20200210	CJA
2			
3			
4			
5			

Date Saved: 2020-02-10
Coordinate System: NAD 1983 UTM Zone 10N

ECOFISH RESEARCH

Map 1

Path: M:\Projects-Active\1230_JHTMON\MXD\Overview\1230_BCH_CRFacilities_3603_20200210.mxd

2.2. Scope of JHTMON-5

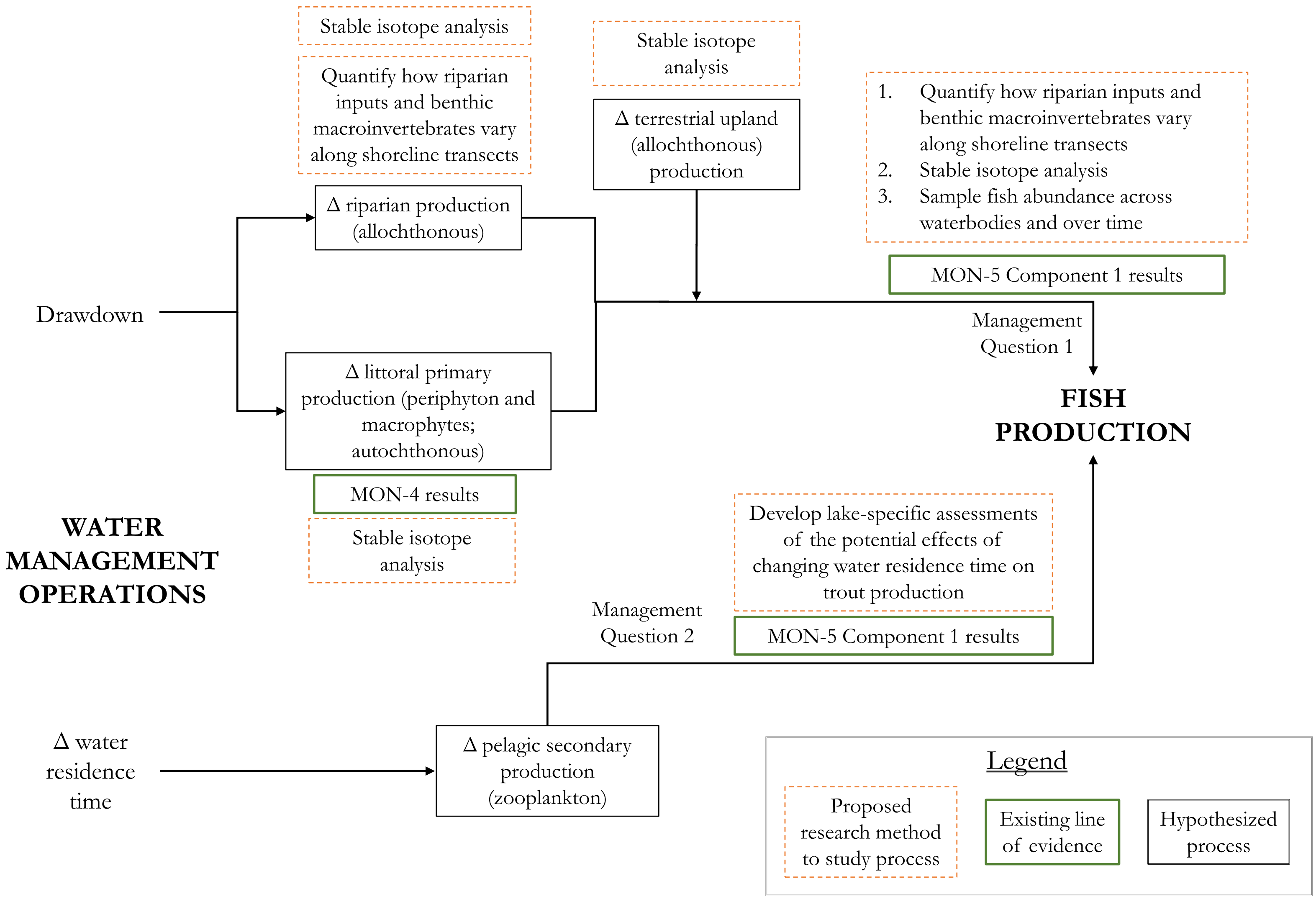
2.2.1. Overview

JHTMON-5 is scheduled for 10 years and has two components. Component 1 included stable isotope analysis of food webs in reservoirs and diversion lakes and has been completed (Hocking *et al.* 2017). Component 2 commenced in 2020 and is scheduled to be completed after three years of fieldwork (2020, 2021, 2022). The results from these two components will be evaluated to address the two management questions listed in Section 2.2.2 that relate to the potential effects of reservoir drawdown (Management Question 1) and water residence time (Management Question 2) on fish production.

Component 2 will address outstanding uncertainties with the two JHTMON-5 management questions that remained following Component 1 (Section 2.2.3). Component 1 made important contributions to addressing both management questions. Following Component 1, the JHTMON-5 TOR (BC Hydro 2019) was revised substantially by changing the scope of Component 2 to ensure it focuses on the outstanding uncertainties.

This annual report describes work undertaken in Year 1 of Component 2, which comprised a pilot study to collect initial results and trial sampling methods for use in Years 2 and 3 of Component 2. The results of this pilot study are used to develop a study plan for the remainder of JHTMON-5 Component 2, which will ultimately use a range of research methods to evaluate hypothesized effects that relate to both management questions (Figure 1).

Figure 1. Effect pathway diagram to show the linkages between water management operations and fish production that are relevant to JHTMON-5. The diagram shows the study methods and existing information that will be used to address the management questions.



2.2.2. Management Questions and Hypotheses

The JHTMON-5 monitoring program (Component 1 and Component 2) will address the following two management questions:

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

In addressing the questions, the monitoring program is designed to test the following null hypotheses (H_01 and H_02 were tested in Component 1; Hocking *et al.* 2017):

H_01: The extent of littoral development in lakes, as governed by the magnitude and frequency of water level fluctuations, is not correlated with the ratio of littoral versus pelagic energy flows to reservoir fish populations;

H_02: The extent of pelagic production in lakes, as governed by the average water residence time, is not correlated with the ratio of littoral versus pelagic energy flows to diversion lake fish populations;

H_03: Terrestrial invertebrate fall is not correlated with distance from the riparian zone;

H_04: Organic material abundance and macroinvertebrate biomass in the littoral zone are not correlated with the magnitude of drawdown or distance from the riparian zone;

H_05: Riparian sources of carbon do not make a biologically significant contribution to fish diets;

H_06: Nitrogen and carbon isotopic signatures in littoral periphyton, benthic invertebrates and fish are not correlated with the magnitude of drawdown or distance from the riparian zone;

H_07: Fish production is not correlated with drawdown magnitude; and

H_08: Changes to water residence time of lakes in the Quinsam River watershed do not have a biologically significant effect on trout production.

2.2.3. Uncertainties Remaining After JHTMON-5 Component 1

Component 1 of JHTMON-5 focused on Management Questions 1 and 2, in addition to null hypotheses 1 and 2 (Section 2.2.2). Notably, Component 1 showed that terrestrial (allochthonous) sources of carbon make a significant contribution to trout diets. This is contrary to the assumption made during the WUP development process, when it was assumed that fish productivity was driven by carbon fixed within lentic waterbodies by primary producers such as algae (autochthonous). Component 1 therefore shifted understanding of the food webs of the lakes and reservoirs in the Campbell River watershed, showing that the link between fish production and primary production by aquatic plants was weaker than previously assumed. These results led to revising the JHTMON-5 TOR to better focus on the outstanding uncertainties (BC Hydro 2019).

Key uncertainties that remain after Component 1 are listed below (Abell *et al*. 2018). Addressing these uncertainties will allow better understanding of how reservoir management affects fish production, thereby answering the management questions.

1. What are the main forms and sources of terrestrial (allochthonous) organic carbon that subsidize food webs in the study waterbodies?
2. What are the relative contributions to the study lakes of carbon fixed by aquatic plants (autochthonous) and carbon that originates from terrestrial sources?
3. How is carbon from terrestrial and aquatic sources processed in the study lakes to ultimately support fish production?
4. How do carbon forms, sources, fluxes and pathways vary among waterbodies? How do environmental factors and management operations affect this variation?

2.2.4. JHTMON-5 Component 2 Research Methods

To address outstanding uncertainties with the two JHTMON-5 management questions, Component 2 uses several research methods, in addition to lines of evidence based on the results of Component 1 and other WUP monitoring studies (Figure 1).

Uncertainties regarding Management Question 1 will be addressed by collecting data at Upper Campbell Reservoir, Lower Campbell Reservoir, and Upper Quinsam Lake (a control lake) using the following three research methods identified in the TOR (BC Hydro 2019).

1. Quantify how riparian inputs and benthic macroinvertebrates vary along shoreline transects;
2. Conduct stable isotope analysis to quantify contribution of terrestrial carbon sources to fish; and
3. Sample fish abundance across waterbodies and over time to test how drawdown affects fish production.

Uncertainties regarding Management Question 2 will be addressed by developing lake-specific assessments of the potential effect of changing water residence time on fish production. As required by the TOR (BC Hydro 2019), these assessments will focus on the four diversion lakes that are subject to water residence changes due to operation of the Quinsam River Diversion, namely Gooseneck Lake, Beavertail Lake, Middle Quinsam Lake, and Lower Quinsam Lake.

2.2.5. Scope of Year 1 of JHTMON-5 Component 2

Year 1 (2020) of JHTMON-5 Component 2 involved a pilot study to inform the remaining two years of the program. Objectives of the Year 1 pilot study were to establish sampling sites and to trial invertebrate sampling methods. Results of all invertebrate sampling and laboratory analysis are presented in this report, although conclusions have not been drawn here as the study is at an early stage.

Fieldwork in 2020 focused on Management Question 1 (regarding drawdown) and included trialing sampling approaches associated with the first research method listed in the TOR to "quantify how riparian inputs and benthic macroinvertebrates vary along shoreline transects" (BC Hydro 2019). Therefore, data collection was designed to understand whether reservoir drawdown adversely affects fish production by increasing the distance between the shoreline and the riparian zone, which is a source of invertebrates and organic material. Invertebrates are an important component of the diets of Cutthroat Trout, Rainbow Trout and Dolly Varden (McPhail 2007).

Four invertebrate sampling methods were trialed in Year 1. Key factors considered during the pilot study were trap design, sampling effort (number of sites, deployment duration), the potential for sampling error due to methodological challenges, managing biological degradation of samples, the need to minimize disturbance due to vandalism or wave action, and ensuring that sufficient sample volume/biomass is collected for analysis. The results of Year 1 have been used to refine the study plan for the remainder of the study.

3. METHODS

3.1. Experimental Design

Drawdown causes the wetted edge of a reservoir to retreat from the zone of established riparian vegetation, e.g., shrubs and trees. It is hypothesized that this reduces inputs of terrestrial invertebrates to the littoral zone. Furthermore, drawdown may reduce littoral primary production, as well as the inputs and rate of processing of organic material (leaf litter and woody debris) in the littoral zone, thereby reducing production of macroinvertebrates that consume this material and contribute to fish production. To examine these hypothesized effects of drawdown, Component 2 includes measuring how aquatic macroinvertebrate biomass varies along transects perpendicular to the shoreline, with samples collected at varying distances from the riparian zone, as well as from locations within and outside (below) the drawdown zone. Fieldwork in Year 1 focused on collecting data and trialling methods to test $H_0$3 and $H_0$4 (Section 2.2.2). $H_0$3 (*terrestrial invertebrate fall is not correlated with distance from the riparian zone*) is illustrated conceptually in Figure 2; the hypothetical outcomes are conceptually similar for retaining or rejecting $H_0$4 (*organic material abundance and macroinvertebrate biomass in the littoral zone are not correlated with the magnitude of drawdown or distance from the riparian zone*).

A key focus of Year 1 fieldwork was to trial invertebrate sampling methods to confirm the experimental design for Years 2 and 3. Aerial[1] (flying) invertebrates were sampled using Malaise nets and sticky traps. Malaise nets were used successfully in Component 1. Sticky traps have not been used previously in JHTMON-5, although they are used widely for pest monitoring (Anderson *et al.* 2013) and have been used by other researchers to study terrestrial subsidies to aquatic food webs (e.g., Francis *et al.* 2006). Invertebrate biomass measured using these sampling methods was assumed to provide a proxy for the potential for terrestrial invertebrates to fall onto the surface of the waterbodies and provide food for fish. These approaches were considered preferable to attempting to quantify terrestrial invertebrate inputs to the water surface more directly using buckets (Mason and MacDonald 1982) or plastic sheet traps (Cole *et al.* 1990) due to concerns about the potential for sampling issues associated with disturbance (e.g., by waves or vandalism), sample degradation, or difficulty with collecting sufficient biomass. Aquatic macroinvertebrates were sampled using a Ponar grab (benthic invertebrates) and floating (emergence) traps (emergent invertebrates). A Ponar grab was used in Component 1 but floating traps were not used. Floating traps were trialled primarily due to concerns about whether sufficient biomass could be collected using a grab sampler.

Three waterbodies were selected that provide a contrast in drawdown magnitude (Table 1): Upper Campbell Reservoir (largest drawdown), Lower Campbell Reservoir (moderate drawdown), and one control lake (Upper Quinsam Lake). Upper Quinsam Lake was selected as a control lake because this

[1] "Aerial" is technically precise as this is the phase that was sampled using the two methods. However, we use the term "terrestrial invertebrates" in the remainder of the report as this is the term that is used in the TOR (BC Hydro 2019) and in Component 1, although we recognize that many of the species sampled include aquatic life stages.

waterbody is the most similar to the two reservoirs (i.e., large and unproductive), with an annual water residence time (~200 days) intermediate between Upper Campbell Reservoir (~1 year) and Lower Campbell Reservoir (~1 month). It is recognized that water levels at Upper Quinsam Lake are managed via the Quinsam Storage Dam that impounds Wokas Lake, which is connected to Upper Quinsam Lake via a narrow channel; i.e., it is not a true control lake as water levels are managed. However, the annual water level range at Upper Quinsam Lake is lower than in the reservoirs (Table 1) and the magnitude of water level fluctuations is expected to be similar to that of unregulated lakes in the region.

3.2. Transect Establishment

Year 1 fieldwork was undertaken at all three waterbodies in June 2020, with the expectation that sampling would be undertaken in Year 2 and Year 3 twice per year at different water levels. Sampling was conducted at three areas (transects) per waterbody, with transects established perpendicular to the shoreline, starting at the riparian zone and extending into the lake. Transects were established based on the following general criteria:

- Transects were selected with riparian vegetation that is broadly characteristic of the riparian communities around each waterbody;
- Transects had different slopes so that the distance from riparian vegetation to the shoreline varied among transects;
- Transects were not clustered but were placed in the same general part of the reservoir at Upper Campbell Reservoir to avoid excessively long boat travel times on this large reservoir, although transects were in areas that are generally representative of habitats around the reservoir;
- Transects were in secluded locations to minimize risk of vandalism/theft of sampling equipment; and
- Transects were not established in areas with exposed bedrock or steep drop-offs to allow for sites to be revisited at different water levels to collect suitable samples from fixed distances from the shoreline.

At each transect, the position of established riparian vegetation was marked using a metal pin and/or flagging tape. The following data were recorded when establishing each transect:

- Waypoints (UTM coordinates) using a GPS;
- Photographs towards/away from water and along both directions parallel to the shoreline;
- The distance parallel to the ground from the riparian vegetation to the shoreline; and
- The average shoreline slope between the shoreline and the edge of the riparian vegetation using a clinometer.

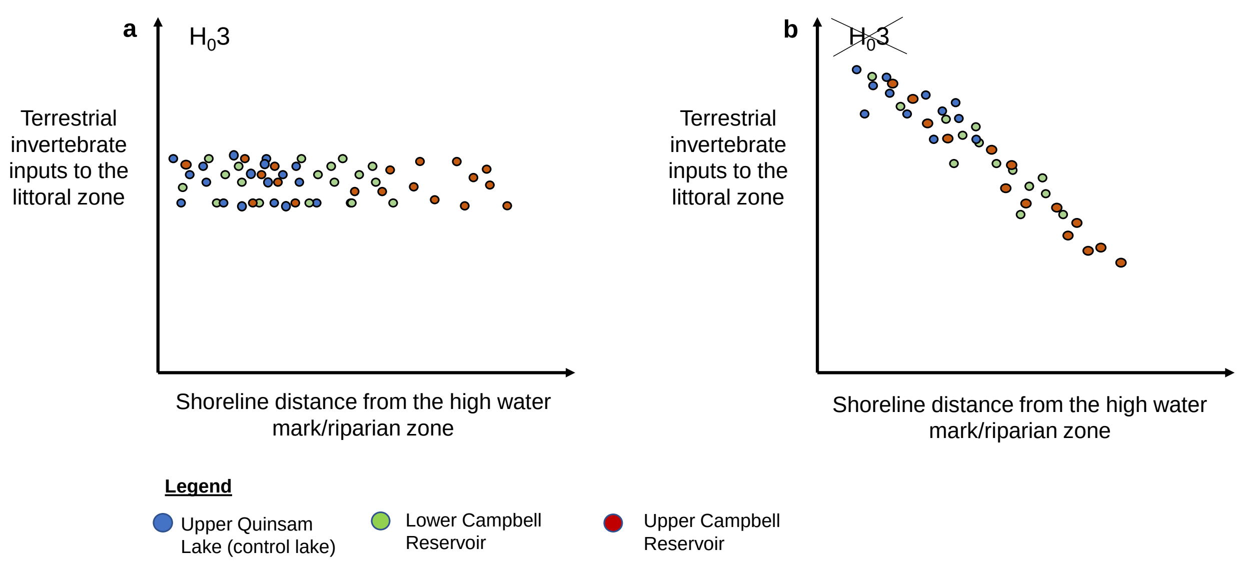
Table 1. Summary of water level regime in the three study waterbodies.

Waterbody	Drawdown range in Water Use Plan (BC Hydro 2012)	Observed range in water levels[2]
Upper Campbell Reservoir	8.5 m (El. 212.0–220.5 m)	~10 m since 2001. Rarely drops below El. 213.0 m. Level usually declines by ~2 m between June and September.
Lower Campbell Reservoir	4.3 m (El. 174.0–178.3 m)	Varies by 1.5–2 m in a typical year. Level usually declines by <1 m between June and September.
Upper Quinsam Lake	2.3 m[1]	~4.5 m since 1997 but it does not tend to vary by >2.5 m during most years. Level usually declines by ~1 m between June and September.

[1] Based on information provided by BC Hydro that is presented in Craig and Kehler (2009)

[2] Based on Water Survey of Canada data reviewed prior to fieldwork

Figure 2. Conceptual diagram of H_03 (a) H_03 accepted. (b) H_03 would be rejected if terrestrial invertebrate inputs to the littoral zone are negatively correlated with shoreline distance from the high-water mark/riparian zone (other relationships that would also result in rejection of H_03 are possible).



3.3. Field Methods

3.3.1. Terrestrial Invertebrates

Terrestrial invertebrates were sampled using a Malaise net, as used in Component 1, in the riparian zone at one transect of each waterbody during deployment and retrieval sampling dates (two samples per lake; Table 2). Sampling sites are shown on Map 2 to Map 4 (see 'TIV' sites). The Malaise net consisted of a square-shaped tent (1.2 m long × 1.2 m wide × 2.1 m high) with openings at the side (Figure 3). Insects fly into the trap and climb upwards into a collecting jar. The trap was deployed on both sampling dates for 4.0 to 5.5 hours at the site to collect a representative sample of terrestrial invertebrates that could potentially land on the waterbody and provide food for salmonids. The duration and time of day of sampling was standardized as much as possible across the three waterbodies to directly compare results among waterbodies. The same Malaise net was used to capture terrestrial invertebrates at each site. No chemical attractants or killing agents were used and samples were preserved using 95% ethanol.

Terrestrial invertebrates were also sampled using sticky traps at all three transects at each waterbody for a 6-day deployment period (Table 2). Sticky traps are made of a sticky card and are a simple and inexpensive way to catch flying insects (Anderson *et al.* 2013; Figure 4). Traps do not contain attractants; they passively sample invertebrates that fly into the traps and become adhered. Sticky traps were trialled as a secondary method to sample terrestrial invertebrates during the pilot year. A minimum of three sticky traps were deployed at each transect, with one sticky trap consistently deployed adjacent to the riparian vegetation (at the established marker; Section 3.2) and one sticky trap consistently deployed over the waterbody 1.0 m from the shoreline. Both these traps were attached to bamboo canes at a standard height (1.5 m) above the ground or water. At least one further trap was then deployed approximately 4–12 m from the shoreline. At transects where floating traps were deployed (see Section 3.3.2), sticky traps were attached to floating traps to sample at distances further from shoreline (maximum distance = 68 m). Effort was taken to standardize the height of the traps above the water at 1.5 m, although the height was lower (0.9–1.4 m) at traps positioned in deeper water or attached to floating traps. At transects where floating traps were not deployed, sticky traps were only deployed in shallower areas that could be accessed by wading. At each trap, the deployment time, trap height, water depth, and distance to the shoreline were recorded.

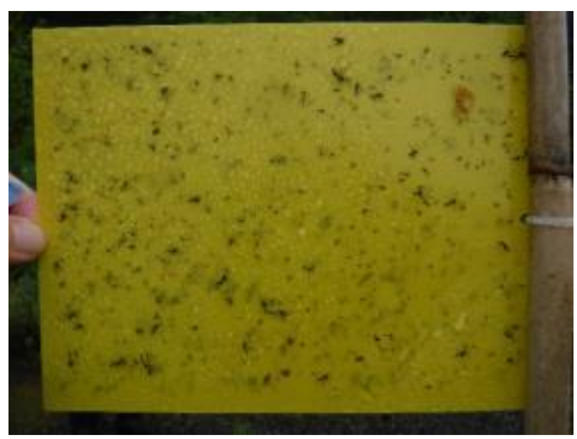
During retrieval, the abundance of terrestrial invertebrates on each sticky trap was tallied in the field. Insects were tallied based on size (length; mm) categories (bins). The following size bins were used: 0-5 mm, 5–10 mm, 10–15 mm. Invertebrate abundance was standardized by surface area of sticky trap (m^2) and by deployment duration (hours) to yield units of invertebrates/m^2/hour.

Table 2. Summary of Year 1 (2020) terrestrial invertebrate sampling sites.

Waterbody	Site ID	Deployment Date	Retrieval Date	Sampling Method	n	Distance to Riparian Zone (m)	UTM (NAD 83)		
							Zone	E (m)	N (m)
Upper Campbell Reservoir	UCR-TIV02	Jun-03	Jun-03	Malaise net	1	1.7	10U	309323	5527765
		Jun-10	Jun-10	Malaise net	1	2.5			
		Jun-03	Jun-10	Sticky traps	4	0, 3.6, 14.6, 64.6			
	UCR-TIV03	Jun-03	Jun-10	Sticky traps	3	0, 5.9, 9.1	10U	305609	5529535
	UCR-TIV04	Jun-03	Jun-10	Sticky traps	4	0, 6.8, 10, 13.8	10U	308567	5533702
Lower Campbell Reservoir	LCR-TIV03	Jun-02	Jun-02	Malaise net	1	2.96	10U	324321	5541298
		Jun-09	Jun-09	Malaise net	1	2.0			
		Jun-02	Jun-09	Sticky traps	4	0, 5.15, 10.15, 65.15			
	LCR-TIV04	Jun-02	Jun-09	Sticky traps	4	0, 4.55, 7.75, 11.55	10U	326235	5543193
	LCR-TIV05	Jun-02	Jun-09	Sticky traps	3	0, 9.8, 13	10U	323050	5545335
Upper Quinsam Lake	UPQ-TIV02	Jun-04	Jun-04	Malaise net	1	0.30	10U	316224	5527030
		Jun-11	Jun-11	Malaise net	1	0.25			
		Jun-04	Jun-11	Sticky traps	4	0, 2.3, 8.3, 69.3			
	UPQ-TIV03	Jun-04	Jun-11	Sticky traps	4	0, 1.35, 4.55, 9.15	10U	317031	5527684
	UPQ-TIV04	Jun-04	Jun-11	Sticky traps	3	0, 1.3, 4.5	10U	317347	5529996

Figure 3. Malaise net deployed at Upper Campbell Reservoir (UCR-TIV02) on June 03, 2020.

Figure 4. Left: sticky traps deployed at Lower Campbell Reservoir (LCR-TIV04) on June 02, 2020; right: sticky trap retrieved at Lower Campbell Reservoir (LCR-TIV04) on June 09, 2020.



3.3.2. Emergent Invertebrates

Emergent invertebrates are aquatic life stages of insects such as chironomids and mayflies that migrate vertically from the lakebed to the water surface as larvae. Emergent invertebrates were sampled at one transect in each waterbody (Figure 5) using floating traps, which seal off a portion of the water surface to capture invertebrates that emerge from the underlying water. It was assumed that floating traps predominantly sample emerging invertebrates that spend part of their life cycle in the benthos immediately under or close to the trap.

Emergent invertebrates were sampled using six floating traps per transect (Figure 6) deployed for six days (Table 3). Floating traps comprise sampling containers attached to an inverted funnel or bucket that permit capture of emergent invertebrates that have an aerial life stage. Floating traps (Figure 6) were fabricated for this study following the design in Cadmus *et al.* (2016). Polypropylene bottles were used as sampling containers and no chemical attractants or killing agents were used in the containers. Mesh fabric attached to PVC tubes was used to create a pyramid-shaped funnel, with foam tubes ("pool noodles") used to provide added flotation. Traps were anchored to the bed using a double anchor system. Sampling sites are shown on Map 2 to Map 4 (see 'EIV' sites).

Floating traps were deployed to achieve the following general criteria:

- Traps were deployed in two groups of three along each transect (Figure 5);
- For the two reservoirs, traps were deployed to ensure that one group of three traps was deployed within the drawdown zone and one group of traps was deployed outside (below) the drawdown zone, based on the reservoir surface elevations on the deployment date (Table 3) and the reservoir operating ranges prescribed in the WUP (Table 1);
- To the extent possible, the distances of the traps from the shoreline were standardized among waterbodies (Table 3); and
- Transects were selected that had similar gradients to seek to ensure that traps were deployed over similar depths of water at each waterbody, although priority was given to standardizing the distances to the shoreline (see above).

This sampling design was intended to provide replication within areas inside and outside (below) the drawdown zone at each waterbody. With future sampling at different locations and different water levels, this design will support analysis to examine whether emergent invertebrate biomass varies along a gradient of distances from the riparian zone, as well between locations inside and outside of the drawdown zone.

Following the 6-day deployment period, invertebrates were removed from the sampling containers and preserved in plastic invertebrate jars using 95% ethanol. A squeeze bottle containing ethanol was used to aid transfer of invertebrates to the jars. Invertebrates were enumerated in the laboratory (Section 3.4). Invertebrate biomass and abundance were standardized to comparable units ($/m^2/hour$) based on the sampling duration and the area enclosed by each floating trap ($0.33\ m^2$).

Figure 5. Schematic of the arrangement of floating traps at one transect in each waterbody.

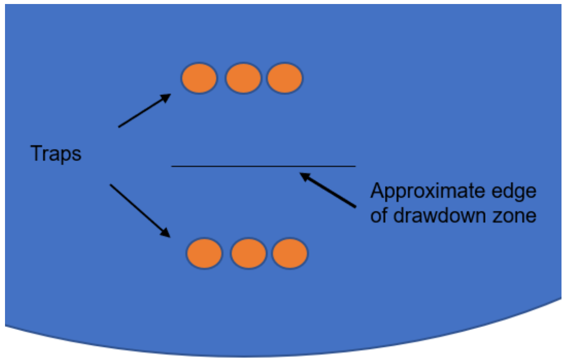


Figure 6. Left: floating trap deployed at Lower Campbell Reservoir (LCR-TIV03) on June 02, 2020; right: floating traps deployed inside and outside of drawdown zone at Upper Campbell Reservoir (UCR-TIV02) on June 03, 2020.

Table 3. Summary of Year 1 (2020) emergent invertebrate sampling sites.

Waterbody	Site ID	Deployment Date	Retrieval Date	UTM (NAD 83; Zone 10U E (m)	UTM (NAD 83; Zone 10U N (m)	Water Elevation on Deployment Date (masl)[1]	Trap #	Depth (m)	Distance to Shore (m)	Distance to Riparian Zone (m)
Lower Campbell Reservoir	LCR-EIV03	Jun-02	Jun-09	324376	5541328	176.10	1	1.00	6.0	10.0
							2	1.00	8.0	12.0
							3	1.00	13.0	17.0
							4	3.90	61.0	65.0
							5	3.70	69.0	73.0
							6	3.50	71.0	75.0
Upper Campbell Reservoir	UCR-EIV02	Jun-03	Jun-10	309337	5527825	217.70	1	2.70	12.0	14.6
							2	2.25	10.0	12.6
							3	2.08	11.0	13.6
							4	7.50	60.0	62.6
							5	7.10	60.0	62.6
							6	7.20	62.0	64.6
Upper Quinsam Lake	UPQ-EIV02	Jun-04	Jun-11	316196	5527107	364.60	1	0.95	7.0	7.0
							2	1.10	7.0	7.0
							3	1.25	13.0	13.0
							4	6.30	68.0	68.0
							5	6.45	71.0	71.0
							6	5.60	63.0	63.0

[1] Data for the reservoirs were provided by BC Hydro. Value for Upper Quinsam Lake is from WSC (2020) for the "Wokas Lake Near Campbell River" station.

3.3.3. Benthic Invertebrates

Benthic invertebrates were sampled using a Ponar grab, as undertaken in Component 1, at each of the three transects in each waterbody during the initial sampling date (Table 4). Sampling sites are shown on Map 2 to Map 4 (see 'BIV' sites). The Ponar grab was a 'Petite' model (Wildco, FL, USA) with an aperture of 152 mm × 152 mm. The Ponar grab was used to collect four sub-samples in the littoral zone at 6 m from the shoreline to collect a range of taxa that were representative of the potential macroinvertebrate prey available to salmonids in the littoral zone of each waterbody. The Ponar grab was deployed by wading. Sub-samples collected using the four Ponar grabs were emptied into a clean tray (Figure 7). Excess water was drained through a 500 μm screen. Large pieces of debris were rinsed thoroughly to remove any attached invertebrates and then discarded. Samples were preserved in the field in 95% ethanol. Substrate composition (% silt, % sand, % gravel) was recorded for each sample based on visual inspection.

Repeated sampling in future years at a range of water levels could provide measurements corresponding to a gradient of distance from the riparian zone, providing that the distance from the shoreline that is sampled (6 m) is kept constant.

Table 4. Summary of Year 1 (2020) benthic invertebrate sampling sites.

Waterbody	Site ID	Sampling Date	Sampling Method	UTM (NAD 83)		
				Zone	E (m)	N (m)
Upper Campbell Reservoir	UCR-BIV05	Jun-03	Ponar grab	10U	309323	5527765
	UCR-BIV06	Jun-03	Ponar grab	10U	305609	5529535
	UCR-BIV07	Jun-03	Ponar grab	10U	308567	5533702
Lower Campbell Reservoir	LCR-BIV03	Jun-02	Ponar grab	10U	324321	5541298
	LCR-BIV04	Jun-02	Ponar grab	10U	326235	5543193
	LCR-BIV05	Jun-02	Ponar grab	10U	323050	5545335
Upper Quinsam Lake	UPQ-BIV02	Jun-04	Ponar grab	10U	316224	5527030
	UPQ-BIV03	Jun-04	Ponar grab	10U	317031	5527684
	UPQ-BIV04	Jun-04	Ponar grab	10U	317347	5529996

Figure 7. Sample collected using a Ponar grab at Upper Quinsam Lake (UPQ-BIV04) on June 04, 2020.

3.4. Laboratory Methods

3.4.1. Taxonomic Identification

Invertebrate samples were identified to order, and, where possible, family. Invertebrate samples were enumerated by an Intermediate Aquatic Scientist with Canadian Aquatic Biomonitoring Network (CABIN) Project Manager certification, supported by an LKT technician.

Terrestrial and emergent invertebrates collected from Malaise nets and floating traps, respectively, were counted and identified to order. Due to laboratory time constraints in this pilot year, only one of the two Malaise net samples collected per waterbody was processed. Malaise net samples were prioritized for processing by selecting samples collected during days with the least-inclement weather conditions, as wind and rain can potentially confound capture rates of terrestrial invertebrates. Furthermore, all six floating trap samples were processed from each transect, except for two samples from LCR-EIV03 (Trap # 3 and #4). The omitted samples have been stored and can be processed during a future year if required. As described above in Section 3.3.1, the number of invertebrates collected on all sticky traps was recorded in the field.

Benthic invertebrate samples (Ponar) were 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). The microbenthos fraction was not processed for this study component but was preserved in 95% ethanol for future analysis, if required. The estimated abundance of organisms in the macrobenthos fraction for each sample was less than 200, thus that fraction was fully enumerated (if there were >200 animals estimated, the sample would have been sub-sampled). The organisms were identified to order/family.

To provide QA/QC, one of the nine samples was sorted twice to quantify precision. A target for acceptable sorting was 90% of the sample must be enumerated on the first sort. If efficiency was <90%, samples in the group to which the test applied was re-sorted. All benthic invertebrate samples were processed.

Abundance of terrestrial, emergent and benthic invertebrates were standardized by dividing invertebrate sample abundance by either area sampled (m^2) and/or deployment duration (hours) depending on the sampling method. This permits direct comparison of data among sites and, potentially, with other studies. The biomass of terrestrial and aquatic invertebrates was estimated based on length-weight regressions using methods described below in Section 3.4.2.

3.4.2. Invertebrate Biomass Determination

The biomasses of adult terrestrial, aquatic, and benthic invertebrates were estimated for each sample. Biomass (dry weight) of terrestrial and aquatic invertebrate taxa was determined using published relationships between body length and body mass for individual taxa (Hodar 1996, Sabo *et al.* 2002, Benke *et al.* 1999). Up to 25 random length measurements per taxon were taken per sample. This approach was chosen instead of methods that involve weighing or measuring displacement of bulk samples, as these techniques are susceptible to error due to the presence of other material (e.g., seston) in samples. Briefly, the approach involved calculating a mean length that was representative of each identified taxon. These lengths were then used to estimate the biomass of invertebrates in each sample using established biomass–length relationships. Finally, total invertebrate biomass in each sample was standardized to a standard sampling duration (e.g., mg/hour), or sampling duration and area (mg/m^2/hour), to account for variability in the sampling duration or area.

Body lengths of all taxa were measured using Vernier calipers to the nearest 0.01 mm. This method is less precise for measuring small invertebrates than using either an ocular micrometer or digital analysis software. However, accuracy and precision were deemed suitable for the study because the focus is on examining variability in biomass among the study waterbodies, which does not require highly accurate and precise measurements of the smallest taxa.

Taxon-specific mean body length (*L*) measurements were converted to dry biomass (*W*; mg) using relationships listed in Benke *et al.* (1999) for benthic invertebrates, and in Hodar (1996) and Sabo *et al.* (2002) for adult aquatic and terrestrial invertebrates.

W–L relationships followed the general power equation:

$$W = \alpha L^{\beta} \qquad (1)$$

where *W* is biomass (mg), L is mean body length (mm) and α and β are constants specific to each taxon. Relationships were converted to linear form by logarithmic transformation:

$$\ln W = \ln \alpha + \beta \cdot \overline{\ln L} \qquad (2)$$

where $\overline{\ln L}$ is calculated as the mean of the transformed length measurements in mm. Mean individual biomass for each taxon was then calculated following back transformation. Corrections were not made to reflect logarithmic transformation bias. The information necessary to estimate this (e.g., the residual mean square of the original regression) is not typically reported with published biomass–length relationships. McCauley (1984) estimates that failure to consider this source of bias may result in error of 2% to 11%, which was considered tolerable given that the objective was to primarily compare biomass estimates among waterbodies within the study, rather than with waterbodies elsewhere.

Estimates of the biomass of taxa in each sample were calculated as the product of total taxon abundance and taxon–specific mean biomass values (W). The sum of biomass for all taxa within a sample was calculated to determine the total sample biomass (mg). These estimates were then standardized by dividing the total biomass (mg) by either area sampled (m^2) and/or deployment duration (hours) depending on the sampling method.

4. RESULTS

4.1. Terrestrial Invertebrates

4.1.1. Malaise Nets

4.1.1.1. Abundance

The abundance of terrestrial invertebrates sampled from Malaise nets at all waterbodies is summarized in Table 5. As noted in Section 3.4.1, only one of the two Malaise net samples collected per waterbody was processed.

Terrestrial invertebrate abundance captured per net was highest at Upper Campbell Reservoir (22.56 individuals/hour), intermediate at Upper Quinsam Lake (9.25 individuals/hour) and lowest at Lower Campbell Reservoir (5.01 individuals/hour). Across all sites, the most abundant order was Diptera (true flies) (98%). The remaining four orders (Trichoptera [caddisflies], Lepidoptera [butterflies, moths], Hymenoptera [sawflies, wasps, bees, and ants], and Coleoptera (beetles)) that were enumerated each comprised ≤1% of all individuals that were sampled. An example of terrestrial invertebrates sampled from a Malaise net is shown in Figure 8.

Table 5. Terrestrial invertebrate abundance sampled from Malaise nets.

Waterbody	Site ID	Date	Deployment Duration (hh:mm)	Abundance (individuals/hour)				
				Diptera	Trichoptera	Lepidoptera	Hymenoptera	Coleoptera
Lower Campbell Reservoir	LCR-TIV03	2-Jun-20	5:35	4.84	0.18	0	0	0
Upper Campbell Reservoir	UCR-TIV02	3-Jun-20	4:43	22.05	0	0	0	0.21
Upper Quinsam Lake	UPQ-TIV02	11-Jun-20	4:00	8.75	0	0.25	0.25	0
Relative abundance (%; all samples combined)				**98**	**<1**	**<1**	**<1**	**<1**

Figure 8. Sub-sample of terrestrial invertebrates from a Malaise net at UPQ-TIV02 on June 11, 2020.

4.1.1.2. Biomass

A summary of data and relationships used to estimate the mean biomass of terrestrial invertebrate taxa sampled from Malaise nets for each waterbody is presented in Table 6.

Total invertebrate biomass captured per net was highest in Upper Campbell Reservoir (~26 mg/hour), intermediate in Upper Quinsam Lake (~14 mg/hour), and lowest in Lower Campbell Reservoir (~2 mg/hour) (Figure 9). In terms of biomass, Diptera was the dominant taxon at LCR-TIV03 and UCR-TIV02. At UPQ-TIV02, Hymenoptera was dominant, followed by Diptera, and then followed by Lepidoptera (Figure 10). There was no clear relationship between terrestrial invertebrate biomass capture per net (mg/hour) and waterbody drawdown regime (i.e., the highest and lowest values were recorded at the two reservoirs with intermediate biomass at the control lake).

Table 6. Summary of data and relationships used to estimate the mean biomass of terrestrial invertebrate taxa sampled from Malaise nets.

Sample			Taxon	# of individuals measured	Mean Length (mm)	Std. Dev. (mm)	Biomass (W) ~ Length (L) relationship	Estimated Mean Biomass (mg)	Reference
Waterbody	Site ID	Date							
Diptera									
Lower Campbell Reservoir	LCR-TIV03	2-Jun-20	Diptera	25	2.43	1.08	$\ln W = -3.22 + 2.26 \cdot \ln L$	6.62	Sabo *et al.* (2002)
Upper Campbell Reservoir	UCR-TIV02	3-Jun-20		25	4.51	1.23		112.68	
Upper Quinsam Lake	UPQ-TIV02	11-Jun-20		25	2.90	2.90		10.11	
Other taxa									
Lower Campbell Reservoir	LCR-TIV03	2-Jun-20	Trichoptera	1	2.88	-	$\ln W = -4.61 + 2.90 \cdot \ln L$	0.21	Sabo *et al.* (2002)
Upper Campbell Reservoir	UCR-TIV02	3-Jun-20	Coleoptera	1	7.18	-	$\ln W = -3.22 + 2.64 \cdot \ln L$	7.28	Sabo *et al.* (2002)
Upper Quinsam Lake	UPQ-TIV02	11-Jun-20	Lepidoptera	1	10.80	-	$\ln W = -4.42 + 2.69 \cdot \ln L$	7.23	Sabo *et al.* (2002)
Upper Quinsam Lake	UPQ-TIV02	11-Jun-20	Hymenoptera	1	15.48	-	$\ln W = -0.58 + 1.56 \cdot \ln L$	40.20	Sabo *et al.* (2002)

"-" indicates insufficient sample size to perform calculation

Figure 9. Terrestrial invertebrate biomass sampled in each Malaise net (mg/hour) plotted against distance from the riparian zone (m) at each waterbody.

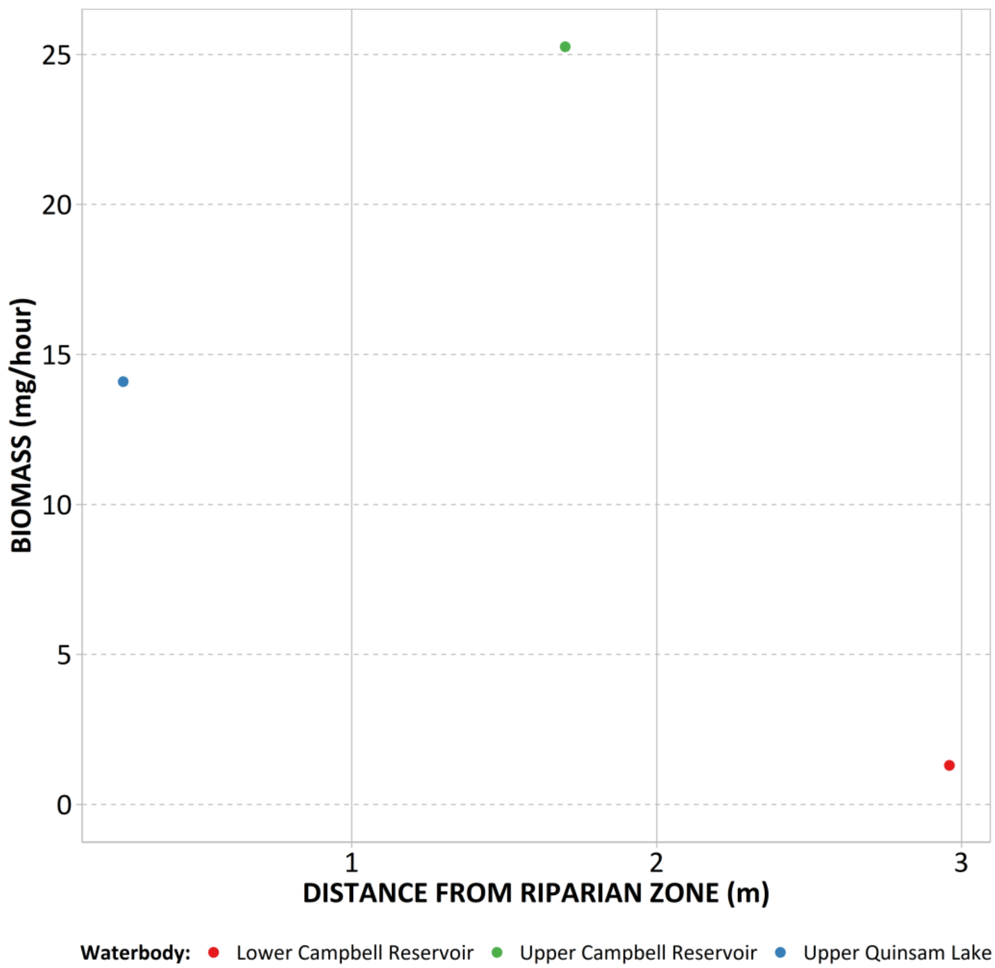
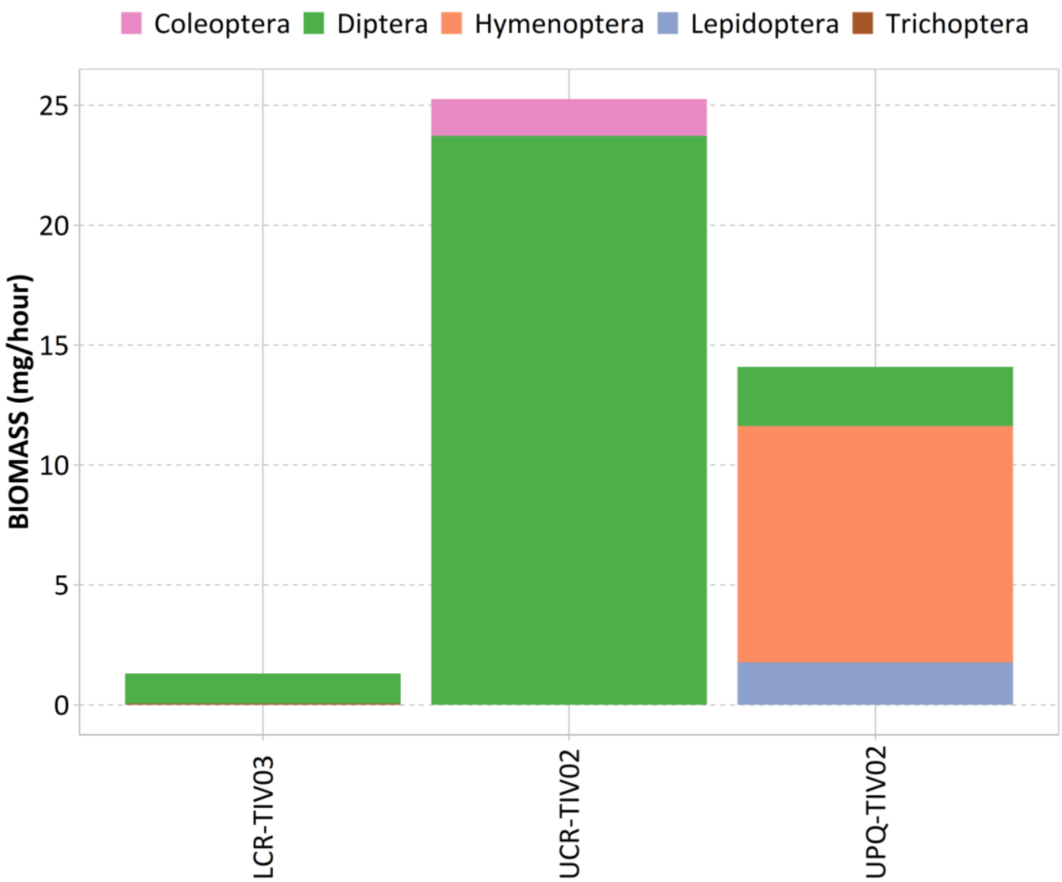


Figure 10. Relative contribution of taxa biomass sampled in each Malaise net (mg/hour) at each waterbody.



4.1.2. Sticky Traps

4.1.2.1. Abundance

Across all waterbodies, invertebrate abundance on sticky traps (invertebrates/m^2/hour) decreased with increasing distance from the riparian zone (Figure 11). Total invertebrate abundance was generally lowest in Upper Campbell Reservoir (Figure 12) and higher in Lower Campbell Reservoir (Figure 13) and Upper Quinsam Lake (Figure 14). The total abundance of invertebrates in the 10–15 mm category (largest bin) was highest in Upper Quinsam Lake, with invertebrates this large not recorded on most traps deployed at the reservoirs.

Figure 11. Sticky trap invertebrate abundance (invertebrates/m^2/hr) plotted against distance from the riparian zone (m) for all transects in each waterbody.

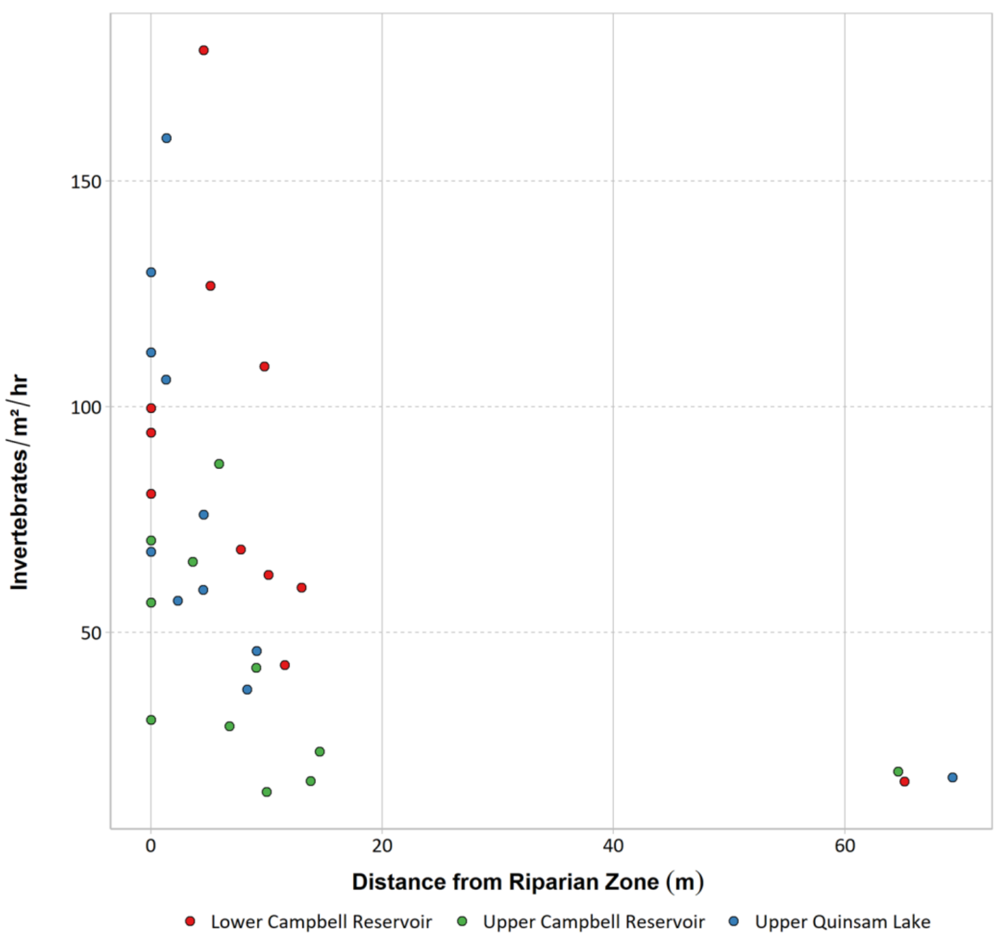


Figure 12. Sticky trap invertebrate abundance (invertebrates/m²/hr) plotted against distance from the riparian zone (m) for each transect on Upper Campbell Reservoir. The "All data" panel shows the total count of invertebrates on sticky traps. Invertebrates were also tallied based on length (mm) and grouped into the following size categories: 0–5 mm, 5–10 mm, 10–15 mm.

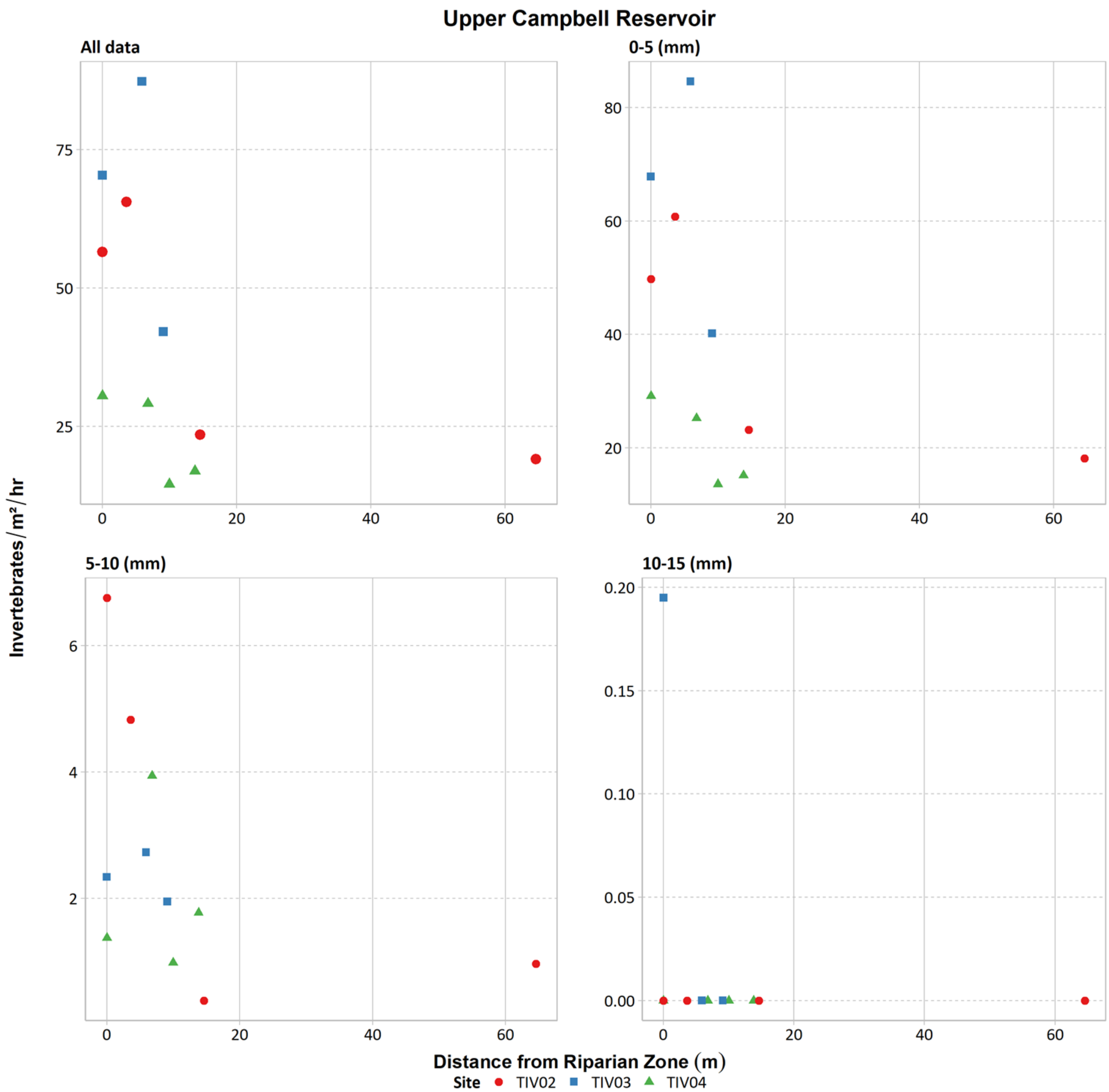


Figure 13. Sticky trap invertebrate abundance (invertebrates/m^2/hr) plotted against distance from the riparian zone (m) for each transect on Lower Campbell Reservoir. The “All data” plot shows the total count of invertebrates on sticky traps. Invertebrates were also tallied based on length (mm) and grouped into the following size categories: 0–5 mm, 5–10 mm, 10–15 mm.

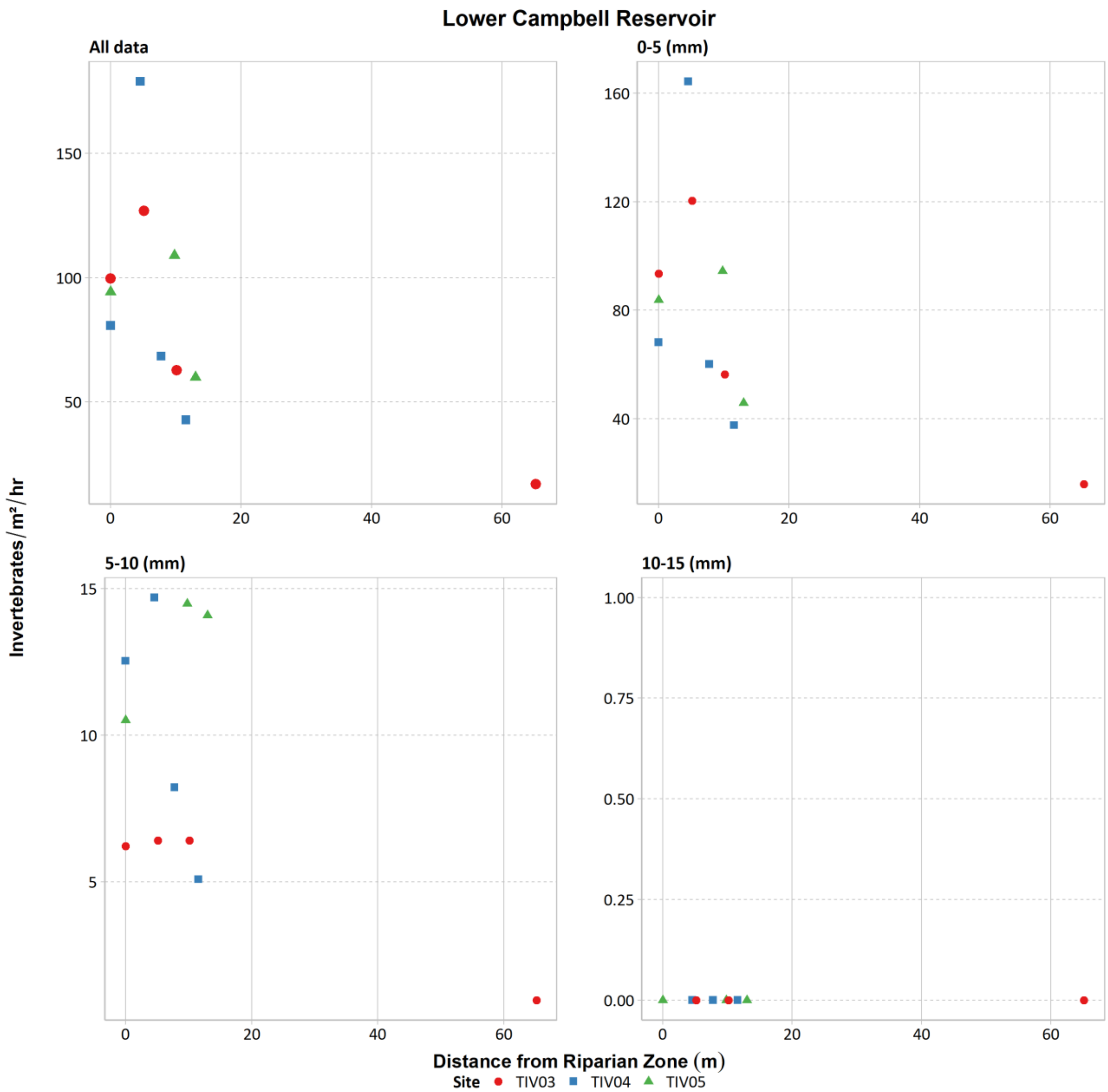
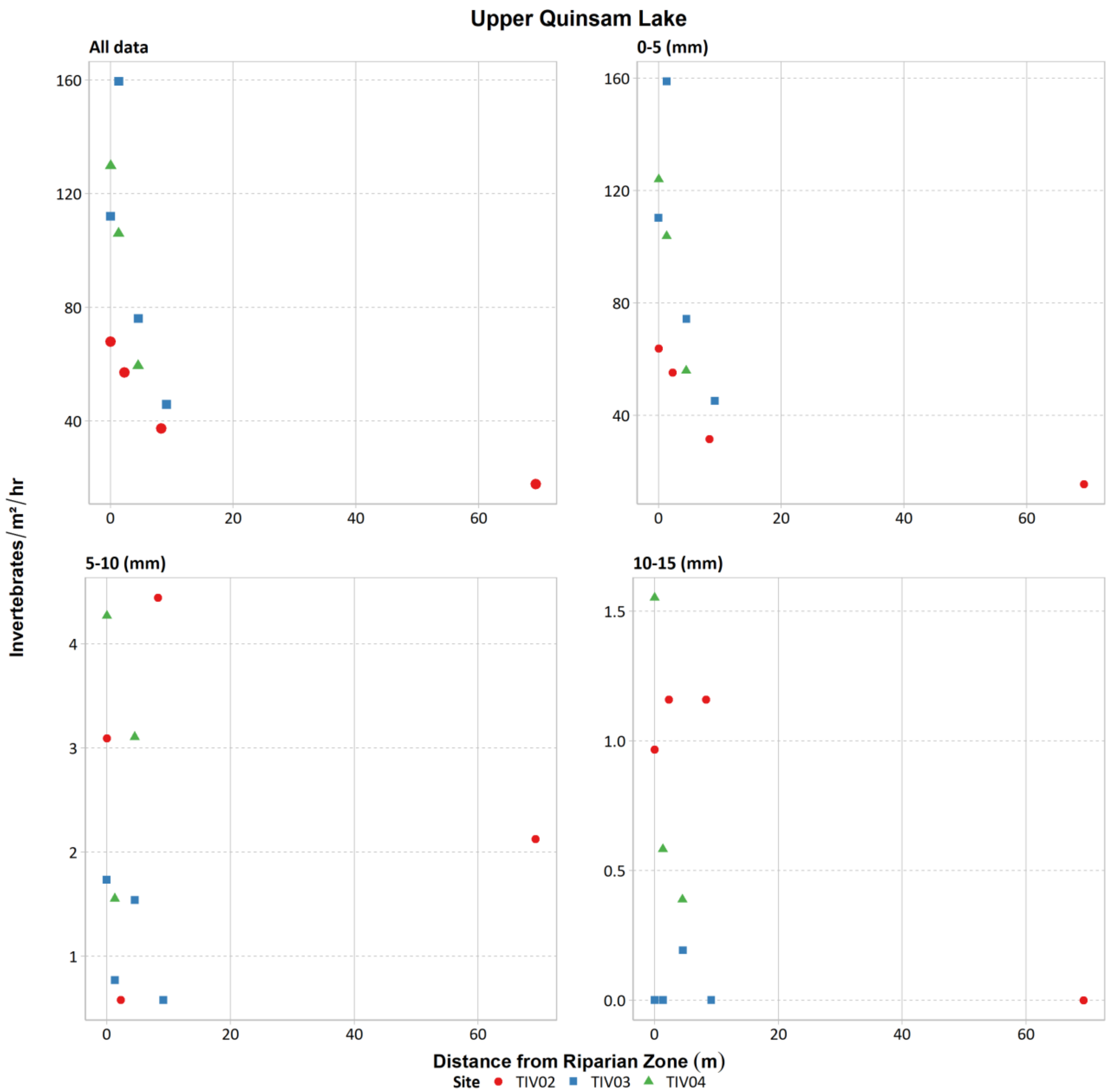


Figure 14. Sticky trap invertebrate abundance (invertebrates/m^2/hr) plotted against distance from the riparian zone (m) for each transect on Upper Quinsam Lake. The "All data" plot shows the total count of invertebrates on sticky traps. Invertebrates were also tallied based on length (mm) and grouped into the following size categories): 0–5 mm, 5–10 mm, 10–15 mm.



4.2. Emergent Invertebrates

4.2.1. Abundance

The abundances of emergent invertebrates sampled from floating traps at each waterbody is summarized in Table 7. As noted in Section 3.4.1, all six floating traps from each transect were processed, except for two samples from LCR-EIV03 (Trap #3 and #4).

Emergent invertebrate abundance (individuals/m^2/hour) ranged from 0.51 to 1.81 at LCR-EIV03, 1.22 to 3.26 at UCR-EIV02, and 0.57 to 0.97 at UPQ-EIV02. Across all sites, the most abundant order was Diptera (true flies) (97%); Trichoptera (caddisflies) comprised the second-most abundant order (3%). The remaining three orders (Neuroptera (lacewings, mantidflies, antlions), Coleoptera [beetles], and Ephemeroptera [mayflies]) that were enumerated each comprised ≤1% of all individuals that were sampled. An example of emergent invertebrates sampled from a floating trap is shown in Figure 15. Differences among sites are considered further in Section 4.2.2 below in relation to biomass.

Table 7. Emergent invertebrate abundance sampled from floating traps.

Waterbody	Site ID	Trap #	Inside/Outside Drawdown Zone	Collection Date	Deployment Duration (hours)	Abundance (individuals/m^2/hour)				
						Diptera	Trichoptera	Neuroptera	Coleoptera	Ephemeroptera
Lower Campbell Reservoir	LCR-EIV03	1	Inside	9-Jun-20	166	0.51	0	0	0	0
		2	Inside	9-Jun-20	166	1.08	0	0	0	0
		5	Outside	9-Jun-20	166	1.81	0	0	0	0
		6	Outside	9-Jun-20	166	1.24	0	0	0	0
Upper Campbell Reservoir	UCR-EIV02	1	Inside	10-Jun-20	168	3.26	0	0	0	0
		2	Inside	10-Jun-20	168	1.79	0	0	0	0
		3	Inside	10-Jun-20	168	2.53	0	0	0	0
		4	Outside	10-Jun-20	167	1.74	0	0	0	0
		5	Outside	10-Jun-20	167	1.22	0	0	0	0
		6	Outside	10-Jun-20	167	1.78	0	0	0	0
Upper Quinsam Lake	UPQ-EIV02	1	Inside	11-Jun-20	166	0.40	0.16	0	0	0
		2	Inside	11-Jun-20	166	0.71	0.09	0.02	0	0
		3	Inside	11-Jun-20	166	0.82	0.15	0	0	0
		4	Outside	11-Jun-20	167	0.82	0	0	0	0.02
		5	Outside	11-Jun-20	167	0.58	0.04	0	0.02	0
		6	Outside	11-Jun-20	166	0.66	0.24	0	0	0
Relative abundance (%; all samples combined)						**97**	**3**	**<1**	**<1**	**<1**

Figure 15. Emergent invertebrates sampled from a floating trap at UCR-TIV02 on June 10, 2020.

4.2.2. Biomass

A summary of data and relationships used to estimate the mean biomass of emergent invertebrate taxa sampled from floating traps for each waterbody is presented in Table 8.

Although no inferential statistical tests have been undertaken at this preliminary (pilot) stage, invertebrate biomass captured per trap (mg/m^2/hour) was consistently higher inside the drawdown zone compared to outside the drawdown zone in Upper Campbell Reservoir (Figure 16, Figure 17). Trends were weaker at the other two waterbodies, although a similar trend was apparent at Upper Quinsam Lake[2], with the opposite trend for Lower Campbell Reservoir.

Inside the drawdown zone, emergent invertebrate biomass was highest in Upper Campbell Reservoir and lowest in Lower Campbell Reservoir. Outside the drawdown zone, emergent invertebrate biomass was similar across samples and waterbodies, with the exception of one floating trap on Upper Quinsam Lake (Figure 16).

Diptera taxa made the only contribution to invertebrate biomass at Upper Campbell Reservoir and Lower Campbell Reservoir. At Upper Quinsam Lake, Trichoptera made the dominant contribution,

[2] There is no prescribed drawdown zone for Upper Quinsam Lake (control lake); however, inspection of historical water level data (WSC 2020) indicates that the nearshore floating traps (underlying water depth = 0.96–1.26 m) were positioned over benthic habitats that typically dewater every year in late summer, including each of the preceding five years.

with the second-greatest contribution to biomass made by Diptera (Figure 17). Invertebrate species richness was higher in Upper Quinsam Lake (five taxa identified) than Upper Campbell Reservoir and Lower Campbell Reservoir, where only one taxon was identified (Diptera). At Upper Quinsam Lake, species richness was higher outside the drawdown zone compared to inside the drawdown zone (Figure 17).

Table 8. Summary of data and relationships used to estimate the mean biomass of emergent invertebrate taxa sampled from floating traps.

Sample				Taxon	# of individuals measured	Mean Length (mm)	Std. Dev. (mm)	Biomass (W) ~ Length (L) relationship	Estimated Mean Biomass (mg)	Reference
Waterbody	Site ID	Trap #	Date							
Diptera										
Lower Campbell Reservoir	LCR-EIV03	1	9-Jun-20	Diptera	25	2.22	1.45	$\ln W = -3.22 + 2.26 \cdot \ln L$	4.08	Sabo *et al.* (2002)
		2	9-Jun-20		25	2.87	0.61		24.39	
		5	9-Jun-20		25	2.76	0.56		37.72	
		6	9-Jun-20		25	3.32	1.36		35.11	
Upper Campbell Reservoir	UCR-EIV02	1	10-Jun-20		25	3.29	0.68		102.13	
		2	10-Jun-20		25	3.68	0.37		74.39	
		3	10-Jun-20		25	3.71	0.84		102.65	
		4	10-Jun-20		25	2.88	0.89		38.92	
		5	10-Jun-20		25	2.71	0.54		24.55	
		6	10-Jun-20		25	2.48	0.56		28.80	
Upper Quinsam Lake	UPQ-EIV02	1	11-Jun-20		22	1.67	0.71		2.23	
		2	11-Jun-20		25	2.04	0.61		7.13	
		3	11-Jun-20		25	3.10	0.96		21.17	
		4	11-Jun-20		25	2.09	0.74		8.61	
		5	11-Jun-20		25	1.95	1.04		4.43	
		6	11-Jun-20		25	3.46	1.57		19.67	
Other taxa										
Upper Quinsam Lake	UPQ-EIV02	1	11-Jun-20	Trichoptera	9	8.29	0.56	$\ln W = -4.61 + 2.90 \cdot \ln L$	41.23	Sabo *et al.* (2002)
		2	11-Jun-20		5	8.95	1.30		28.10	
		3	11-Jun-20		8	10.62	2.61		70.43	
		5	11-Jun-20		2	10.09	3.56		14.85	
		6	11-Jun-20		13	8.43	1.03		61.62	
Upper Quinsam Lake	UPQ-EIV02	2	11-Jun-20	Neuroptera	1	5.43	-	$\ln W = -2.51 + 1.53 \cdot \ln L$	1.08	Hodar (1996)
Upper Quinsam Lake	UPQ-EIV02	5	11-Jun-20	Coleoptera	1	3.20	-	$\ln W = -3.22 + 2.64 \cdot \ln L$	0.86	Sabo *et al.* (2002)
Upper Quinsam Lake	UPQ-EIV02	4	11-Jun-20	Ephemeroptera	1	6.54	-	$\ln W = -4.27 + 2.49 \cdot \ln L$	1.50	Sabo *et al.* (2002)

"-" indicates insufficient sample size to perform calculation

Figure 16. **Emergent invertebrate biomass sampled in each floating trap (mg/m²/hour) plotted against distance from the riparian zone (m) at each waterbody. Sites inside and outside of the drawdown zone are distinguished.**

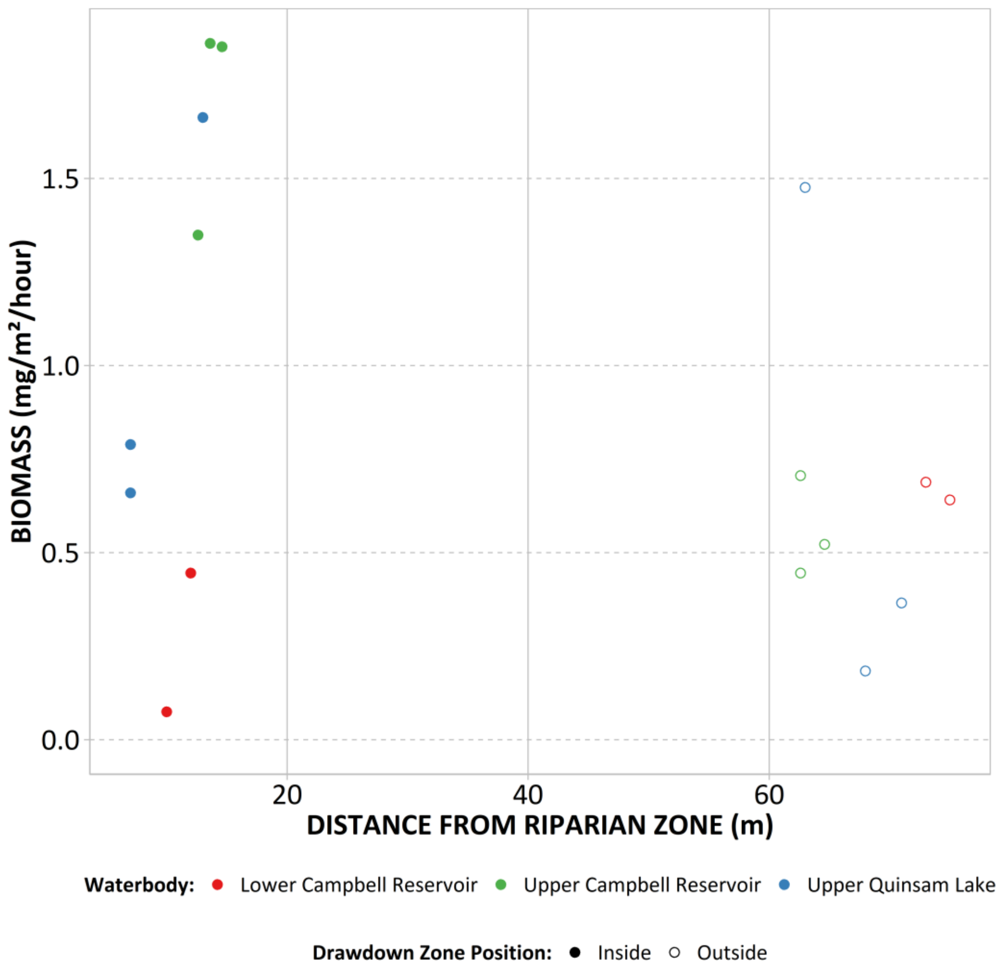
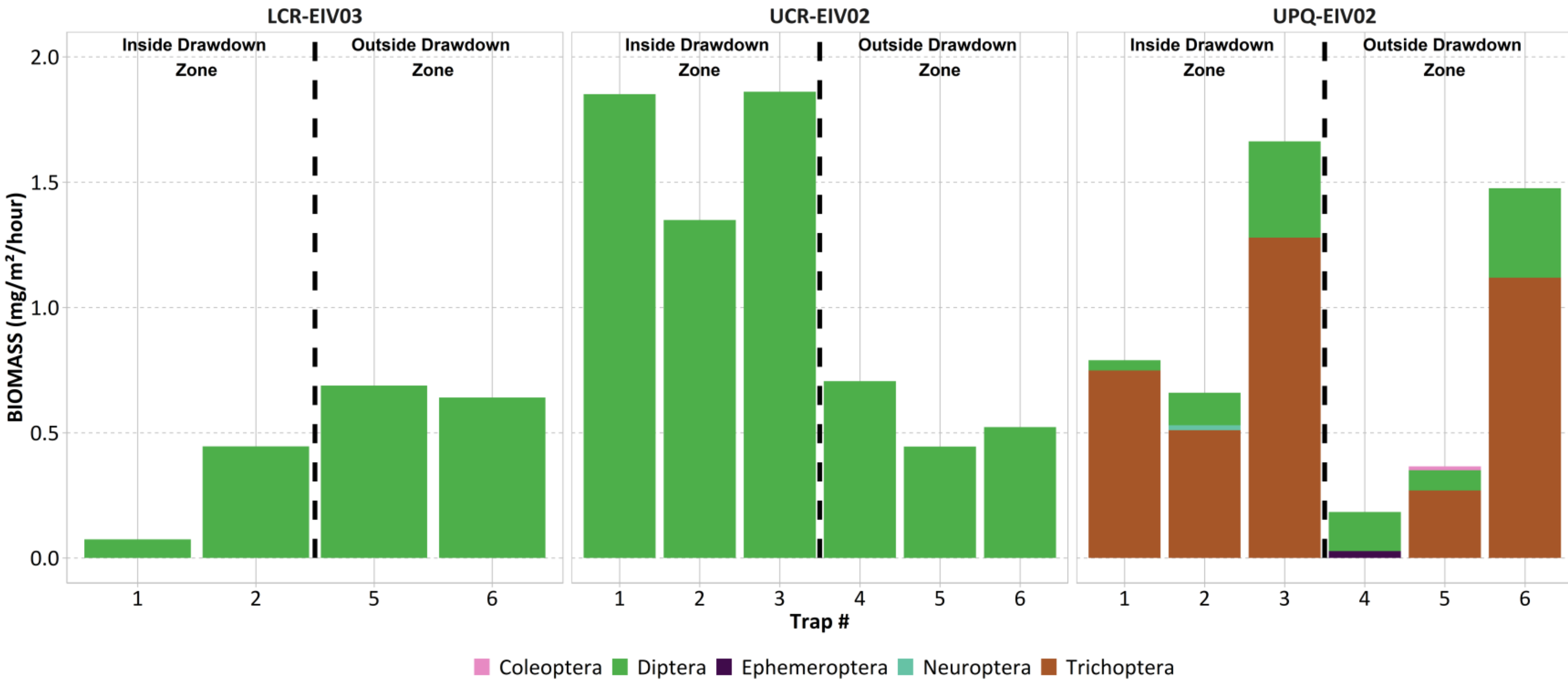


Figure 17. **Relative contribution of taxa biomass (mg/m²/hour) in floating traps at each waterbody. The vertical dashed line denotes floating traps located inside and outside (below) the drawdown zone. LCR, Lower Campbell Reservoir; UCR, Upper Campbell Reservoir; UPQ, Upper Quinsam Lake.**



4.3. Benthic Invertebrates

4.3.1. Abundance

Benthic invertebrate abundance (individuals/m^2) measured in the littoral zone sediments (6 m from shore) varied widely within waterbodies (Table 9). Benthic invertebrate abundance was highest at sites LCR-BIV03 and UPQ-BIV03, where densities of 736 individuals/m^2 were measured at each site. Benthic invertebrate abundance was lowest at site UCR-BIV06 (0 individuals/m^2), with similarly low values of 43 individuals/m^2 measured at individual sites in each of the other two waterbodies. Across all sites, the most abundant taxon was Chironomidae larvae (midges) (93%). The second-most abundant taxon was Diptera in their pupal life stage (6%), followed by one Amphipoda (1%) sampled at UPQ-BIV03.

Table 9. Benthic invertebrate abundance measured in the littoral zone, 6 m from shore.

Waterbody	Site ID	Date	Abundance (individuals/m^2)		
			Chironomidae (larvae)	Diptera (pupae)	Amphipoda
Lower Campbell Reservoir	LCR-BIV03	02-Jun-20	736	0	0
	LCR-BIV04	02-Jun-20	43	0	0
	LCR-BIV05	02-Jun-20	130	43	0
Upper Campbell Reservoir	UCR-BIV05	03-Jun-20	476	43	0
	UCR-BIV06	03-Jun-20	0	0	0
	UCR-BIV07	03-Jun-20	260	0	0
Upper Quinsam Lake	UPQ-BIV02	04-Jun-20	0	43	0
	UPQ-BIV03	04-Jun-20	649	43	43
	UPQ-BIV04	04-Jun-20	433	0	0
Relative abundance (%; all samples combined)			**93**	**6**	**1**

4.3.2. Biomass

A summary of data and relationships used to estimate the mean biomass of benthic invertebrate taxa sampled from Ponar grabs for each waterbody is presented in Table 10.

Total invertebrate biomass measured in the littoral zone was similar among waterbodies and ranged from approximately 0 mg/m^2 to 40 mg/m^2, with the exception of one sample in Lower Campbell Reservoir (~80 mg/m^2) (Figure 18). Chironomidae larvae (order: Diptera) made the dominant contribution to biomass at all waterbody transects except for LCR-BIV05 and UPQ-BIV02, where the dominant contribution to biomass was Diptera pupae (Figure 19). Benthic invertebrate species richness was highest in Upper Quinsam Lake, where three taxa were measured at one transect.

For context, benthic invertebrate biomass measured for waterbodies in this study (0 to 80 mg/m^2; Figure 18) was at the low end of the range for a global dataset of 51 lakes (0.5 to 23,700 mg/m^2) compiled by Plante and Downing (1989), which spanned a wide range of trophic states and biogeoclimatic zones, and had a median value of 170 mg/m^2. This low productivity likely reflects the low productivity of the JHTMON-5 waterbodies, as is typical of lentic ecosystems on Vancouver Island. Invertebrate biomass measured in Year 1 of this JHTMON-5 study was lower than mean biomass calculated from Ponar grab samples collected from Lower Campbell Reservoir and Upper Campbell Reservoir (~900 mg/m^2) during JHTMON-4 Year 2 sampling (Perrin *et al.* 2017).

Table 10. Summary of data and relationships used to estimate the mean biomass of benthic invertebrate taxa.

Sample			Taxon	# of Individuals Measured	Mean Length (mm)	Std. Dev. (mm)	Biomass (*W*) ~ Length (*L*) relationship	Estimated Mean Biomass (mg)	Reference
Waterbody	Site ID	Date							
Chironomidae (larvae)									
Lower Campbell Reservoir	LCR-BIV03	02-Jun-20	Chironomidae	17	4.88	0.95	$\ln W = -6.32 + 2.62 \cdot \ln L$	1.85	Benke *et al.* (1999)
Lower Campbell Reservoir	LCR-BIV04	02-Jun-20	(larvae)	1	2.38	-		0.02	
Lower Campbell Reservoir	LCR-BIV05	02-Jun-20		4	3.14	1.08		0.16	
Upper Campbell Reservoir	UCR-BIV05	03-Jun-20		12	4.36	1.28		0.90	
Upper Campbell Reservoir	UCR-BIV06	03-Jun-20		0	-	-		-	
Upper Campbell Reservoir	UCR-BIV07	03-Jun-20		6	2.95	1.65		0.13	
Upper Quinsam Lake	UPQ-BIV02	04-Jun-20		1	4.02	-		0.07	
Upper Quinsam Lake	UPQ-BIV03	04-Jun-20		16	3.12	0.86		0.53	
Upper Quinsam Lake	UPQ-BIV04	04-Jun-20		10	4.95	2.07		0.93	
Other taxa									
Upper Quinsam Lake	UPQ-BIV03	04-Jun-20	Amphipoda	1	3.78	-	$\ln W = -5.15 + 3.02 \cdot \ln L$	0.32	Benke *et al.* (1999)
Lower Campbell Reservoir	LCR-BIV05	02-Jun-20	Diptera (pupae)	1	4.50	-	$\ln W = -6.32 + 2.62 \cdot \ln L$	0.09	Benke *et al.* (1999)
Upper Campbell Reservoir	UCR-BIV05	03-Jun-20		1	4.02	-		0.07	
Upper Quinsam Lake	UPQ-BIV02	04-Jun-20		1	4.02	-		0.07	
Upper Quinsam Lake	UPQ-BIV03	04-Jun-20		1	3.98	-		0.07	

"-" indicates insufficient sample size to perform calculation

Figure 18. Benthic invertebrate biomass (mg/m²) measured in the littoral zone (6 m from shore) at each waterbody transect.

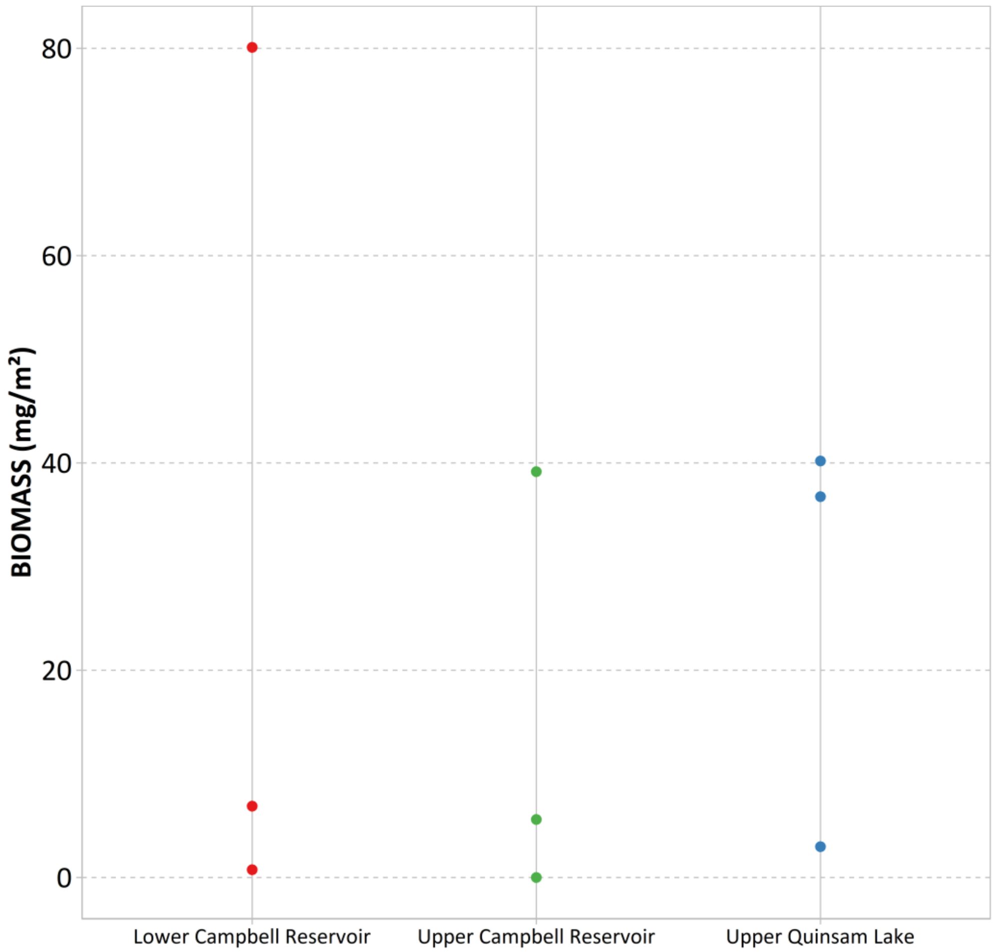
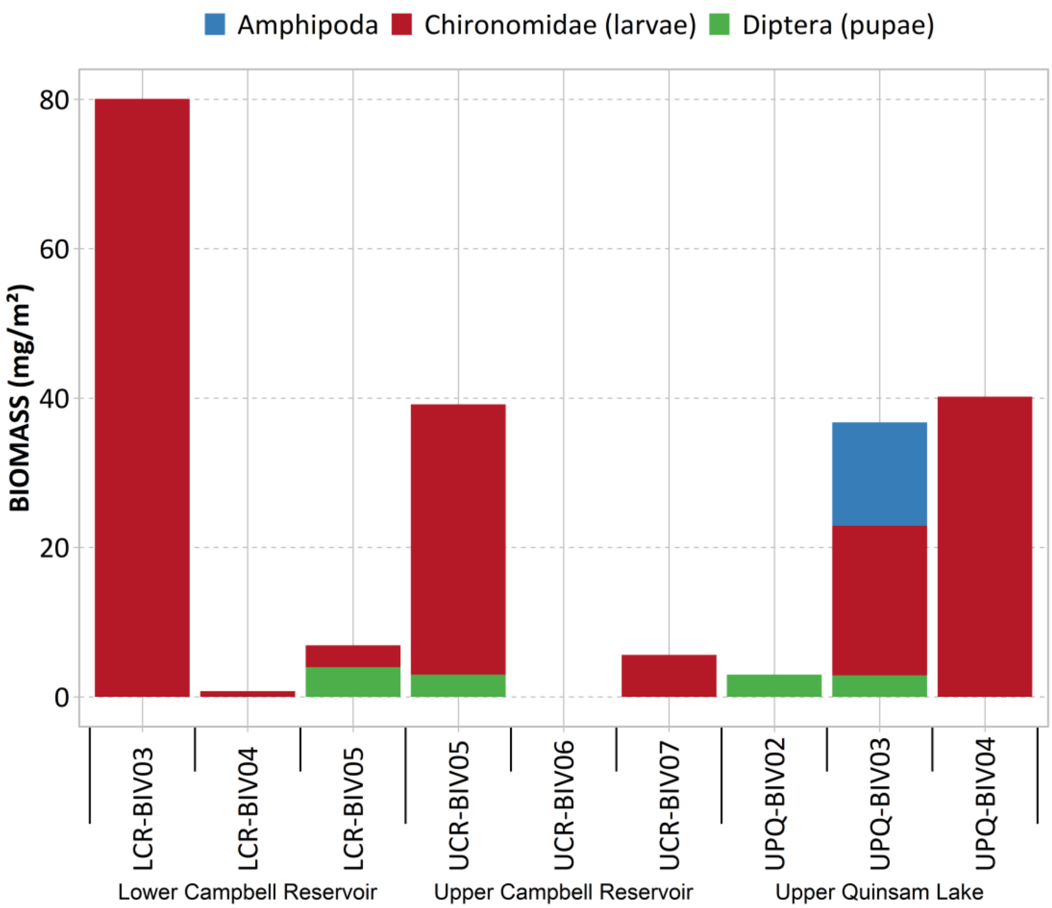


Figure 19. Biomass (mg/m²) of individual taxa in Ponar grabs at each waterbody transect.



5. DISCUSSION

5.1. Synthesis

Year 1 of JHTMON-5 Component 2 was a pilot study. Fieldwork was undertaken in 2020 to collect data relating to Management Question 1 (extent to which stabilized reservoir levels benefit fish populations) with focus on $H_0 3$ (correlation between terrestrial invertebrates and distance from riparian zone) and $H_0 4$ (correlation between invertebrate biomass and magnitude of drawdown zone or distance from riparian zone), which relate to understanding how the biomass of invertebrates (an important food source for resident salmonids) varies along a gradient of increasing distance from the riparian zone (Section 2.2.2; Figure 2). A focus of the pilot study was to establish monitoring sites and trial invertebrate sampling methods to inform the study plan for the remainder of JHTMON-5, when sampling effort will be greater and additional research methods will be used.

Analyses to address the management questions will be undertaken at the end of the study, although analysis undertaken in Year 1 has highlighted several initial results pertinent to Management Question 1 (effect of drawdown on fish populations). Year 1 results showed no clear relationship between terrestrial invertebrate abundance/biomass and drawdown magnitude of the three waterbodies. However, there was a clear decrease in terrestrial invertebrate abundance with increasing distance from the riparian zone at all waterbodies, based on sticky trap results (Figure 11). Emergent invertebrate biomass was generally higher inside the drawdown zone than outside the drawdown zone in Upper Campbell Reservoir and Upper Quinsam Lake, with this difference greatest at Upper Campbell Reservoir (Figure 16, Figure 17). This trend is contrary to the expectation that benthic invertebrate biomass would be higher below the drawdown zone where communities are not exposed to regular desiccation, e.g., as found at Sooke Lake Reservoir on Vancouver Island (Furey *et al.* 2006). Benthic invertebrate abundance and biomass was low for all waterbodies and there was no clear relationship between benthic invertebrate abundance/biomass and drawdown magnitude (Figure 18), although invertebrate species richness was highest in Upper Quinsam Lake (control lake) across all sampling methods.

A key objective of the pilot year was to trial invertebrate sampling methods to confirm methods and effort for the 2021 and 2022 field seasons. An evaluation of each invertebrate sampling method used in Year 1 is provided in the subsequent sections below. This evaluation includes the main advantages and disadvantages, trap efficiency, suitability to test the management questions/hypotheses, and recommendation for use in Years 2 and 3 field seasons. Invertebrate sampling methods are further summarized in Table 11. For the purpose of high-level evaluation only, the relative cost of each invertebrate sampling method was also assessed and presented in the summary table (Table 11) using qualitative categories of low ("$”), medium (“$$”), and high (“$$$”). The qualitative assessment of relative cost was based on both capital (equipment costs) and operational costs (e.g., field sampling logistics, sample processing time).

5.2. Evaluation of Invertebrate Sampling Methods

5.2.1. Malaise Nets

Malaise nets are recommended for sampling terrestrial invertebrates in Years 2 and 3.

In Year 1, a Malaise net was successful at capturing terrestrial invertebrates at all waterbodies; however, weather was variable among sampling days and this seemed to influence capture efficiency, with capture rates lower on wet and windy days. This does not necessarily invalidate use of this method, but supplementary sampling methods should be used to test $H_0$3 and this confounding effect of weather should be accounted for in the analysis, e.g., by not analyzing measurements from inclement days, or possibly by adding weather as a covariate to a mixed effects model if there is confidence that the data are adequate to characterize the confounding effect of this variable. In theory, multiple Malaise nets could be deployed simultaneously at each waterbody to standardize weather conditions, with traps potentially deployed for several days. However, the high cost of nets and logistical challenges with setting nets at multiple waterbodies simultaneously prohibit this approach. Consequently, shorter deployment times on waterbodies (i.e., less than a day) reduces the risk of vandalism. A single Malaise net was used in Year 1, although two additional nets have since been procured (delivery of these nets prior to the Year 1 fieldwork was delayed due to the COVID-19 pandemic). This will allow three sites to be sampled per waterbody in future years.

When placed at the shoreline, Malaise nets and sticky traps (see below) are expected to provide the best data to test $H_0$3 if they are deployed when water levels are low, e.g., in late summer or early fall. This is when the contrast in distance from the riparian zone will be greatest among the three waterbodies. Nonetheless, data collected when water levels are high in spring (as was the case for Year 1 sampling) are also useful if they can be compared with data collected at other periods when water levels are lower.

5.2.2. Sticky Traps

Sticky traps are recommended for sampling terrestrial invertebrates in Years 2 and 3.

Sticky traps efficiently captured terrestrial invertebrates at all waterbodies in Year 1. These traps are inexpensive and moderately efficient to process (several hours per waterbody), meaning that a high level of sampling effort is possible. The 6-day deployment duration seemed to provide a good compromise between the need to deploy traps for a sufficiently long period to sample an adequate number of invertebrates, and concerns about sampling error associated with multi-day deployment, e.g., due to sample degradation or increased risk of damage due to wind or waves. Furthermore, deployed sticky traps are relatively inconspicuous, compared to other methods, and this reduces their overall risk of vandalism. Unlike Malaise nets, it is straightforward to deploy multiple sticky traps near-simultaneously at multiple waterbodies, thereby partly standardizing for variability in weather that can affect capture rates (traps were deployed and retrieved on consecutive days so part of the deployment period overlapped at all sites). A drawback with sticky traps is the frequent poor condition of specimens when removed from the trap (Biological Survey of Canada 1994); therefore, Malaise nets are preferable for collecting samples for taxonomic identification and stable isotope analysis.

5.2.3. Ponar Grab

Ponar grabs are not recommended for sampling benthic invertebrates in Years 2 and 3.

In Year 1, it was challenging to sample benthic invertebrates using a Ponar grab due to poor sampler performance in coarse substrates that occur at many sites, particularly in Upper Campbell Reservoir. To an extent, the low abundance of individuals collected is expected to be an accurate reflection of the low density of benthic invertebrates in the study waterbodies. However, Ponar grab samples are time consuming to process, which limits the number of samples that can be collected, thereby limiting statistical power. Furthermore, each grab sample only encompasses a small area and therefore results are potentially prone to bias caused by heterogeneity in benthic invertebrate biomass because the time-consuming nature of sampling means it is not feasible to collect enough samples from randomly selected locations to accurately reflect environmental heterogeneity. Ponar grabs are most effective at sampling soft substrates, and they tend to collect only those taxa that are adapted to living in those habitats (Swift *et al.* 1996).

5.2.4. Floating Traps

Floating traps are recommended for sampling emergent invertebrates in Years 2 and 3.

Floating traps successfully sampled emergent invertebrates inside and outside the drawdown zone at all waterbodies in Year 1. Emergent life stages of semi-aquatic invertebrates such as mayflies and chironomids provide an important food source for resident salmonids (McPhail 2007) and therefore characterizing spatial variability in the biomass of these taxa is highly relevant to Management Question 1 (effect of drawdown on fish populations) and $H_0$4. Given the somewhat novel nature of these traps (Cadmus *et al.* 2016), demonstrating successful performance of the floating traps was an important outcome of Year 1. This method provides a suitable technique to test $H_0$4. Year 1 results highlighted that replication is important to adequately characterize emergent invertebrate biomass representative of different areas of the waterbodies, as indicated by the high variability among sites either inside or outside of the drawdown zone at waterbodies such as Upper Quinsam Lake (Figure 16). Increased floating trap sampling effort in future years is therefore desirable to maximize statistical power, although revisions to the current study plan would be required to provide time and budget to fabricate further traps, and complete additional laboratory analysis. Similarly, it would be useful to use floating traps to sample at more locations along a transect perpendicular from the shoreline to provide greater power to test $H_0$4.

Floating traps are expected to provide the most informative data when water levels are high in spring as this is when invertebrate emergence rates are expected to be highest (e.g., Davies 1984). This is also when the largest proportion of the littoral zone will be within the drawdown zone. Therefore, floating traps are only recommended during the spring sampling period in Years 2 and 3.

Table 11. Summary of advantages and disadvantages of invertebrate sampling methods used in Year 1 of JHTMON-5 Component 2.

Method	Advantages	Disadvantages	Relative Cost	Recommended for Use?
Malaise Nets	• Efficient at sampling terrestrial invertebrates at all waterbodies • Specimens collected are in good condition for taxonomic identification and stable isotope analysis • Time required for field deployment and sample collection is low to moderate	• Inclement weather can influence capture efficiency • Logistical challenges with setting nets at multiple waterbodies simultaneously • Risk of vandalism; however, short deployment time reduces risk • Malaise nets are expensive	$$	✓
Sticky Traps	• Efficient at sampling terrestrial invertebrates at all waterbodies • Sticky traps are inexpensive • Time required for field deployment and sample collection is low • Sticky traps can be effectively deployed for a long period of time • Multiple sticky traps can be deployed near-simultaneously at multiple waterbodies • Samples are moderately efficient to process	• Specimens collected are in poor condition for taxonomic identification and stable isotope analysis • Risk of vandalism; however, they are relatively inconspicuous which reduces risk	$	✓
Ponar Grabs	• Specimens collected are in good condition for taxonomic identification and stable isotope analysis • No risk of vandalism	• Poor sampler performance in coarse substrates that occurs at all waterbodies • Samples are time consuming (expensive) to process in the laboratory	$$$	✗
Floating Traps	• Efficient at sampling emergent invertebrates at all waterbodies • Specimens collected are in good condition for taxonomic identification and stable isotope analysis • Floating traps can be effectively deployed for a long period of time • Multiple floating traps can be deployed near-simultaneously at multiple waterbodies	• Time required to fabricate floating traps is high; however, materials are inexpensive • Risk of vandalism • Time required for field deployment and sample collection is high	$$	✓

6. STUDY PLAN

6.1. Overview

Results of the Year 1 pilot study were used to inform the study plan for the remainder of JHTMON-5 Component 2, which comprises two more years of fieldwork (2021 and 2022). The following three field trips are planned in each of 2021 and 2022:

1. Spring (May–June) invertebrate sampling;
2. Late summer (late August/early September) invertebrate sampling; and
3. Fish sampling (late August or September).

A single riparian leaf litter sampling fieldtrip in 2021 (only) in late fall/early winter was included in the study proposal (LKT and Ecofish 2019). The purpose of the sampling was: 1) to collect riparian leaf litter samples for stable isotope analysis, and; 2) estimate the inputs of riparian leaf litter to the littoral zone of each waterbody. However, we recommend that this trip is omitted, and resources are instead assigned to fabricate additional floating traps and process additional floating trap samples. Sufficient samples of riparian leaf litter for stable isotope analysis will still be collected during other sampling trips, and analysis of organic matter content collected from benthic sediment samples will be used to estimate organic material abundance in the littoral zone. This recommended change is described further below and is expected to improve our ability to address the management questions.

This section summarizes outstanding tasks in relation to the data requirements listed in the TOR (BC Hydro 2019). Proposed field and laboratory activities for the remainder of JHTMON-5 Component 2 are summarized in Table 12.

Table 12. Proposed scope of fieldwork in Year 2 and Year 3.

Activity	Timing	Tasks	Management Questions / Hypotheses
Spring invertebrate sampling	May–June	Deploy 6 floating traps at each of 3 transects per waterbody for a 6-day period (54 traps deployed in total). At each transect, deploy floating traps at distances of ~1 m, 10 m, 20 m, 30 m, 40 m, 60 m from shore.	M1; $H_0$4
		Attach sticky traps to each floating trap and in the riparian zone (7 traps per transect = 63 traps total)	M1; $H_0$3
		Record riparian and littoral vegetation characteristics	M1; $H_0$3, $H_0$4
		Collect benthic substrate samples for particle size and organic matter analysis at 5 distances of ~1 m, 10 m, 20 m, 40 m, 60 m from shore (~45 samples total). Complete only once.	M1; $H_0$4
		Collect samples of the following at each site for stable isotope analysis: 1) riparian leaf litter, 2) littoral periphyton, 3) small particulate organic material, 4) aquatic macrophytes, 5) benthic invertebrates	M1; $H_0$5, $H_0$6
Late summer invertebrate sampling	Late Aug–Sept	Deploy 3 malaise traps at each of 3 transects per waterbody (9 traps deployed in total) Deploy sticky traps (7 traps per transect = 63 traps total). Traps will be attached to floating traps as per the spring, although floating traps will not be sampled.	M1; $H_0$3
		Collect samples of the following at each site for stable isotope analysis: 1) riparian leaf litter, 2) littoral periphyton, 3) small particulate organic material, 4) aquatic macrophytes, 5) benthic invertebrates	M1; $H_0$5, $H_0$6
Fish sampling	Late Aug–Sept	Gill net sampling to determine CPUE at each waterbody	M1; $H_0$7

6.2. Invertebrate Sampling

Two invertebrate sampling trips will be completed in spring (May–June) and late summer (late August/early September) in 2021 and 2022. Trip timing is designed to sample a range of water level conditions. Sampling will be completed at the transects established in Year 1 (three per waterbody), and sampling duration will be consistent with Year 1. These data will be used to test $H_0 3$ and $H_0 4$ (Table 12).

The primary aim of the spring trip is to sample emergent invertebrates using floating traps to collect data to test $H_0 4$ (see Section 5.2.4 for rationale) We plan to deploy six floating traps per transect (18 traps per waterbody, 54 traps per trip), which is a substantial increase from the effort in Year 1 (six traps per waterbody, 18 traps per trip). To adequately sample at a range of distances from the riparian zone we plan to deploy floating traps at distances of ~1 m, 10 m, 20 m, 30 m, 40 m, 60 m from shore. Sticky traps will also be deployed to collect additional data to test $H_0 3$. Sticky traps will be attached to each floating trap, as well as in the riparian zone for a total of ~63 traps deployed (7 traps × 3 transects × 3 waterbodies).

The primary aim of the late summer trip is to sample terrestrial invertebrates using Malaise nets and sticky traps to test $H_0 3$ (see Section 5.2.1 for rationale). One Malaise net will be sampled at each transect to yield three samples per waterbody per trip (an increase from one sample per waterbody in Year 1). Sticky traps (n ~ 63) will be deployed using the same design as in the spring. Sticky traps will be attached to floating traps to provide a standardized sampling approach, although the floating traps will not be sampled.

Benthic macroinvertebrate biomass will not be sampled in 2021 and 2022 due to the challenges associated with using a Ponar grab (Section 5). Instead, sampling and processing time will be assigned to increasing the number of Malaise nets, floating traps, and sticky traps that are sampled.

6.3. Terrestrial Leaf Fall

The study proposal (LKT and Ecofish 2019) included a three-day riparian leaf litter sampling fieldtrip in 2021 (only) in late fall/early winter. The purpose of this trip was to collect riparian leaf litter samples for stable isotope analysis, and obtain coarse estimates of riparian leaf litter inputs to the riparian zone of each waterbody based on weighing samples of leaves collected within quadrats. However, we recommend that this trip be omitted and effort and resources are instead assigned to fabricating additional floating traps and processing additional floating trap samples in the Campbell River laboratory. We recommend this study plan change based on the results of the Year 1 pilot study that demonstrated that additional floating traps are needed to adequately address the associated management questions and hypotheses. This recommended change is not projected to change the number of days assigned to either LKT or Ecofish staff, and is projected to be budget neutral. Furthermore, sufficient samples of riparian leaf litter for stable isotope analysis will be collected during other sampling trips, and analysis of organic matter content in the benthic sediment samples will be used to test $H_0 4$.

6.4. Substrate Characteristics

Substrate characteristics (organic content and particle size) will be measured once per transect. Samples will be collected with a Ponar grab at approximately five distances (e.g., 1 m, 10 m, 20 m, 40 m, 60 m) along each transect during one of the spring invertebrate sampling trips (when water levels are typically high). Substrate characteristics are a key predictor variable of macroinvertebrate biomass that will be used in the analysis to test $H_0$4.

6.5. Riparian and Littoral Vegetation Type and Cover

Riparian and aquatic vegetation will be surveyed once at each transect to record vegetation type and abundance. This information will address Management Question 1 (effect of drawdown on fish populations) and test the associated hypotheses.

6.6. Fish

Gill net sampling will be undertaken at Lower Campbell Reservoir and Upper Quinsam Lake in late August or September during 2021 and 2022 as part of JHTMON-5. Sampling will also be undertaken at Upper Campbell Reservoir as part of the *Upper and Lower Campbell Lake Fish Spawning Success Assessment* (JHTMON-3), although the data collected at Upper Campbell Reservoir will be also used for JHTMON-5. Sampling will be undertaken using methods that are consistent with those used for JHTMON-3; i.e., deploying one surface and one bottom gill net overnight at approximately 5–6 locations in late summer (late August or early September). Effort assigned to this sampling will be higher than the effort undertaken in Component 1, when fish sampling was primarily undertaken to collect fish tissue samples and CPUE was estimated as a part of supplementary analysis task, generally using data collected using single gill nets at two sites. Analysis will involve comparing differences in fish productivity metrics across a gradient of drawdown magnitude using ANOVA or similar methods. The influence of other variables (e.g., distance of gill nets from established riparian zone) will also be examined using regression methods.

Furthermore, fish abundance data collected as part of JHTMON-3 and, potentially, preceding studies will be analyzed to examine relationships with hydrologic metrics that quantify inter-annual variability in drawdown operations, e.g., annual drawdown range, minimum annual water elevation, timing of drawdown relative to terrestrial invertebrate life stages or leaf fall. This analysis would therefore involve a time-for-space substitution, i.e., variability among years would be used to make inferences about potential differences among waterbodies subject to drawdown of different magnitude.

The results of the two groups of analyses described above will be used to test $H_0$7.

6.7. Stable Isotope Analysis (SIA)

Component 1 successfully used analysis of stable isotopes of nitrogen and carbon to construct lentic food webs (Hocking *et al.* 2017). Component 2 will build on the results from Component 1 to test H_05 and H_06. This will involve collecting additional samples from a wider range of basal carbon sources that include multiple terrestrial sources. Samples will be collected opportunistically during the scheduled field trips.

H_05 will be tested by quantifying the riparian contribution to carbon in fish tissues, based on the stable isotope signatures of riparian leaf litter and terrestrial invertebrates. This will involve using SIA mixing models to quantify the contributions of basal carbon sources (e.g., riparian leaf litter vs. aquatic macrophytes vs. algae) to invertebrate groups. Successfully testing this hypothesis is contingent on being able to distinguish the riparian basal carbon signature.

H_06 will be tested by examining how littoral periphyton and benthic invertebrate isotopic signatures vary among waterbodies and in relation to distance from the riparian zone. The nitrogen and carbon isotopic signatures will be compared among fish sampled from the three waterbodies with high, medium, and low drawdown magnitude.

The outcomes of testing these hypotheses will be considered in the context of the outcomes of testing H_03 and H_04 to make inferences about the potential for drawdown to affect fish production by reducing inputs of carbon from riparian sources.

6.8. Water Elevation and Water Residence Time

Water elevation data for the three waterbodies will be retrieved annually from the Water Survey of Canada and BC Hydro records.

Water residence time estimates will be generated and compiled for the four lakes that are affected by the Quinsam River Diversion, namely Gooseneck Lake, Beavertail Lake, Middle Quinsam Lake, and Lower Quinsam Lake. Water residence time was estimated for three of these lakes in Component 1 (Hocking *et al.* 2017), although we will re-evaluate the generality of these estimates to confirm if they need to be updated. Water balance modelling will be required to estimate water residence time for Lower Quinsam Lake, which was not studied in Component 1. This information will be used to develop curves to estimate how the water residence time of each lake varies in relation to diversion operations permitted under the WUP. Results of this analysis will inform analysis to address Management Question 2 (effect of water residence time on fish production) and test H_08.

REFERENCES

Abell, J., M. Hocking, T. Hatfield, I. Murphy and A. Cousins. Ecofish. 2018. Component 2 of JHTMON-5. Memorandum prepared for BC Hydro by Ecofish Research Ltd. 19 p

Anderson, J.T., L. Montalto, F. Zilli, M. Marchese. 2013. Chapter 5 Sampling and Processing Aquatic and Terrestrial Invertebrates in Wetlands in "Wetland Techniques: Volume 2: Organisms" Eds: J.T. Anderson and C.A. Davis. 54 p.

BC Hydro. 2012. Campbell River System Water Use Plan Revised for Acceptance by the Comptroller of Water Rights. November 21, 2012 v6. 46 p.

BC Hydro. 2019. Monitoring Program Terms of Reference: JHTMON-5 Upper Campbell, Lower Campbell, John Hart Reservoirs and Diversion Lakes Littoral versus Pelagic Fish Production Assessment. Revision 1 September 6, 2019. 16 p.

Benke, A.C., A.D. Huryn, L.A. Smock and J.B. Wallace. 1999. Length-mass relationships for freshwater macroinvertebrates in North America with particular reference to the southeastern United States. Journal of the North American Benthological Society, 18, 308-343.

Biological Survey of Canada. 1994. Terrestrial arthropod biodiversity: planning a study and recommended sampling techniques. Bulletin of the Entomological Society of Canada, Supplement 26: 1-33.

Cadmus, P., J. P. F. Pomeranz, and J. M. Kraus. 2016. Low-cost floating emergence net and bottle trap: comparison of two designs. Journal of Freshwater Ecology 31:653-658.

Cole, J.J., N.F. Caraco and G.E. Likens. 1990. Short range atmospheric transport: A significant source of phosphorus to an oligotrophic lake. Limnology and Oceanography 35:1230–1237.

Craig, J.D.C. and M. Kehler. 2009. Negative Storage Feasibility on Upper Quinsam and Wokas Lakes - Environmental Issues Associated with Maintaining Quinsam River Minimum Fisheries Flows. Report prepared for Ministry of Environment. 55 p.

Davies, I.J. 1984. Sampling Aquatic Insect Emergence. Chapter 6 in: Downing, J.A. and F.H. Rigler (eds.). *A manual on methods for the assessment of secondary production in fresh waters*. 2nd Edition. Blackwell Scientific Publications, Oxford, pp. 161-227.

Francis, T.B., D. E. Schindler, J.W. Moore. 2006. Aquatic insects play a minor role in dispersing salmon-derived nutrients into riparian forests in southwestern Alaska. Canadian Journal of Fisheries and Aquatic Sciences 63: 2543–2552.

Furey, P.C., R.N. Nordin and A. Mazumder. 2006. Littoral benthic macroinvertebrates under contrasting drawdown in a reservoir and a natural lake. Journal of the North American Benthological Society 25:19–31.

Hocking, M., J. Abell, N. Swain, N. Wright, and T. Hatfield. 2017. JHTMON5 – Littoral versus Pelagic Fish Production Assessment. Year 3 Annual Monitoring Report. Consultant's report prepared for BC Hydro by Laich-Kwil Tach Environmental Assessment Ltd. Partnership and Ecofish Research Ltd, October 23, 2017.

Hódar, J.A. 1996. The use of regression equations for estimation of arthropod biomass in ecological studies. Acta Oecologica 17(5), 421-433.

LKT and Ecofish (Laich-Kwil-Tach Environmental Assessment Ltd. Partnership and Ecofish Research Ltd.) 2019. JHTMON 5 Proposal: Upper Campbell, Lower Campbell, John Hart Reservoirs and Diversion Lakes Littoral Versus Pelagic Fish Production Assessment Component 2. 46 p.

Mason, C.F. and S.M. MacDonald. 1982. The input of terrestrial invertebrates from tree canopies to a stream. Freshwater Biology 12: 305–311.

McCauley, E. 1984. Chapter 7: The estimation of the abundance and biomass of zooplankton in samples. In: Downing, J.A. and Rigler, F.H. (eds.) A manual on methods for the assessment of secondary production in fresh waters. 2nd edition. IBP Handbook 17. Blackwell Scientific Publications.

McPhail, J.D. 2007. The Freshwater Fishes of British Columbia. The University of Alberta Press, Canada.

Perrin, C., J. Harding, M. Hocking, N. Swain, J. Abell, A. Marriner, and T. Hatfield. 2017. JHTMON4: Upper and Lower Campbell Reservoirs Littoral Productivity Assessment Year 2 Annual Monitoring Report. Consultant's report prepared for BC Hydro by Laich-Kwil-Tach Environmental Assessment Ltd. Partnership, Limnotek Research and Development Inc. and Ecofish Research Ltd., July 31, 2017.

Plante, C., and J.A. Downing. 1989. Production of freshwater invertebrate populations in lakes. Canadian Journal of Fisheries and Aquatic Sciences 46(9), 1489-1498.

Sabo, J.L., J.L. Bastow, and M.E. Power. 2002. Length–mass relationships for adult aquatic and terrestrial invertebrates in a California watershed. Journal of the North American Benthological Society, 21, 336-343.

Swift, M.C., T.J. Canfield, and T.W. La Point. 1996. Sampling benthic communities for sediment toxicity assessments using grab samplers and artificial substrates. Journal of Great Lakes Research, 22, 557-564.

WSC (Water Survey of Canada). 2020. Hydrometric data available online at: https://wateroffice.ec.gc.ca. Accessed June 2020.

PROJECT MAPS


JHTMON Campbell River Water Use Plan
Upper Campbell Reservoir
Lake Sampling Locations
Legend
Terrestrial and Benthic Invertebrate Sampling
Emergent Invertebrate Sampling
Diversion Dam Intake
Quinsam Coal Mine
UCR-TIV04
UCR-BIV07
UCR-TIV03
UCR-BIV06
UCR-EIV02
UCR-TIV02
UCR-BIV05
Upper Campbell Lake
Campbell River
Gooseneck Lake
Quinsam River
Quinsam Diversion Dam Intake
Quinsam Coal Mine
Middle Quinsam Lake
Camp Lake
Wokas Lake
Upper Quinsam Lake
Cedar Creek Rd
Argonaut Mainline
Hwy 28
Inset 1
Gold River Hwy
0 25 50 m
British Columbia
Map Location
MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES
Scale: 1:75,000
NO. DATE REVISION BY
Date Saved: 2020-11-24
Coordinate System: NAD 1983 UTM Zone 10N
ECOFISH RESEARCH
Map 2
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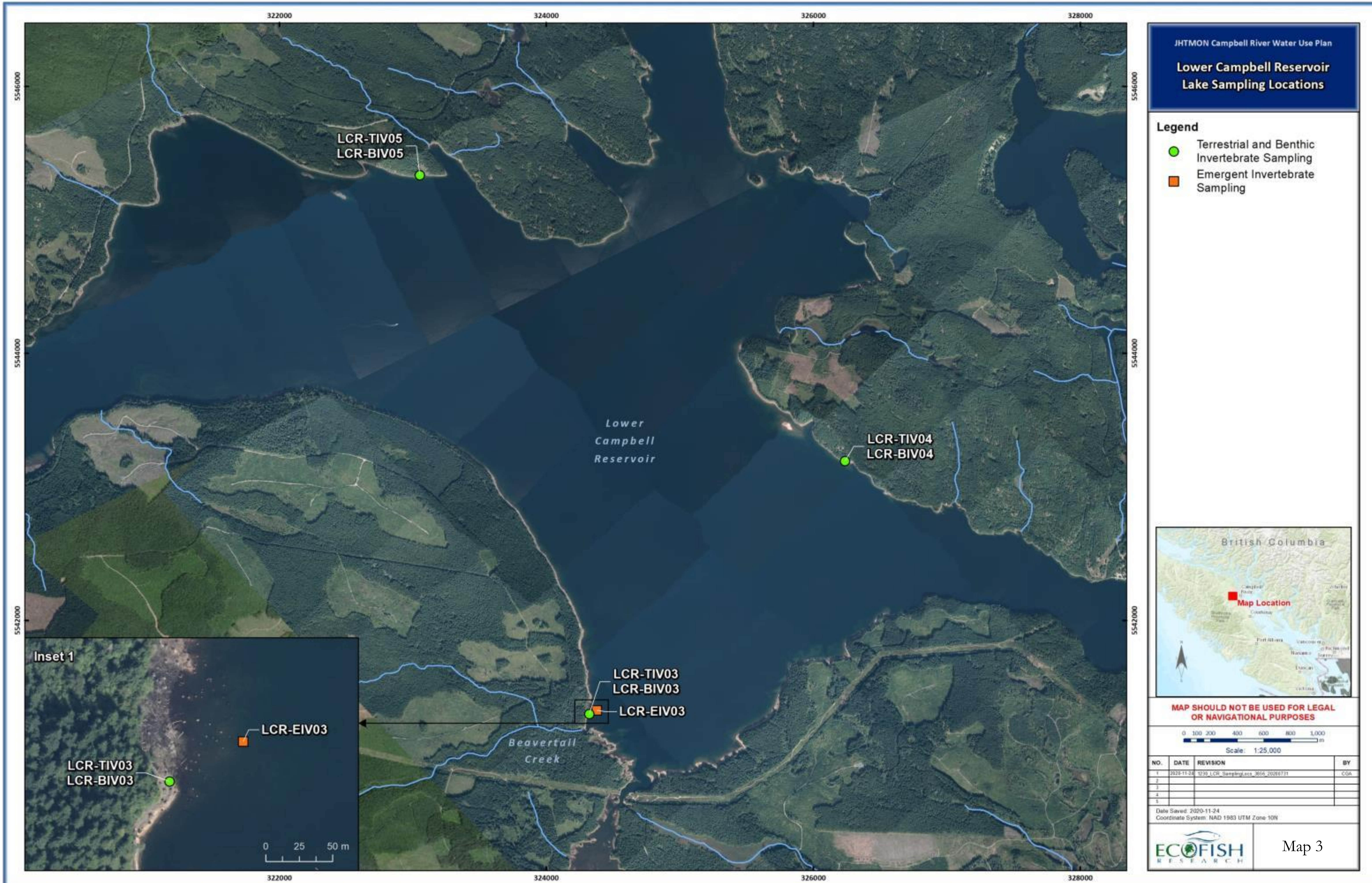

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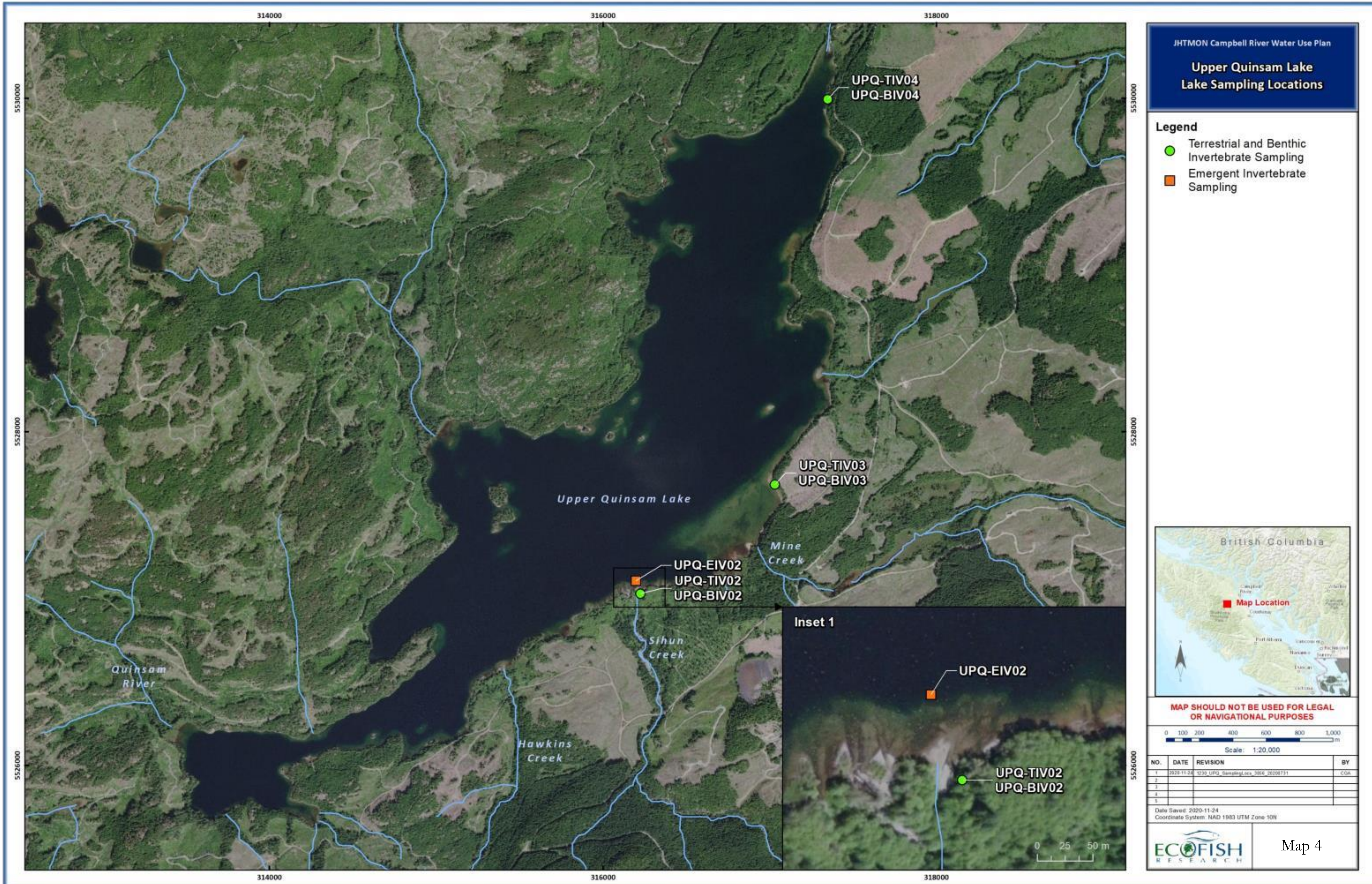

Map 4

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