Campbell River Water Use Plan

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

JHTMON-5 – Upper Campbell, Lower Campbell, John Hart Reservoirs and Diversion Lakes Littoral versus Pelagic Fish Production Assessment
Monitoring Program Terms of Reference Revision 1

REVISION OVERVIEW

The purpose of JHTMON-5 is to test the assumption that improvements in littoral production lead to increases in fish productivity assess the extent to which fish production is driven by littoral vs. pelagic production and how this relates to BC Hydro operations. This study consists of two components. Component 1 included stable isotope analysis of food webs (completed in 2017), and Component 2 which involves production estimates of phototrophic bacteria. Component 2 methodology has been revised based on the results from Component 1 and is the focus of this Terms of Reference (TOR) Revision 1.

REVISION RATIONALE

Results from Component 1 indicated that BC Hydro operations might affect fish productivity; that increased water level fluctuations could result in declines of the importance of littoral food sources to Cutthroat Trout, with the opposite trend observed for Rainbow Trout.[1] It also demonstrated that terrestrial sources of carbon were important for maintaining fish productivity in the Campbell River reservoirs.

During the Water Use Plan (WUP) process, it was assumed that fish productivity was driven by carbon fixed within the lake by primary producers such as algae. Accordingly, a key management concern was ensuring that water management operations did not impair primary production by plants in the lakes and reservoirs because it was assumed that this was the driver of fish production. The Component 1 results show that this perceived link between fish production and primary production by aquatic plants is weaker than assumed when the WUP was developed.

While it is now apparent that carbon from the wider watershed is an important driver of fish production, there is a limited understanding of the forms of carbon transport processes, trophic transfers to fish, and carbon sources (riparian vs. upland). Component 2 was intended to address the remaining hypotheses about the effects of operations on fish production. This TOR Revision 1 is intended to modify the study design of Component 2 to address the following knowledge gaps:

1) What are the main forms and sources of terrestrial organic carbon that subsidize food webs in the study watercourses?

2) What are the relative contributions of carbon from the littoral (riparian) environment and carbon that originates from terrestrial sources?

[1] It is noted that conclusions are based on a small sample size.

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?

Table 1: Key changes to the JHTMON-5 TOR and rationale for their inclusion

Section	Change	Rationale
Overall	• Edits for clarity	
1.0 Monitoring Program Rationale	• No change	
2.0 Monitoring Goals and Objectives	• Focus on quantifying inputs from riparian areas to better understand how operations affect carbon sources contributing to fish biomass • Understand linkages between riparian productivity and drawdown zone variation	• These were the key remaining uncertainties identified in Component 1
Management Questions	• No change	
Hypotheses	• Do not implement study on pelagic bacteria ($H_0$3) • Additional hypotheses added	• Testing this hypothesis would only provide limited information about how residence time affects fish production; furthermore the use of pelagic bacteria to assess residence time is untested • Hypotheses added to better answer management questions
Key Water Use Decision Affected	• No change	
Methods	• Quantify riparian inputs variations in water bodies • Stable Isotope Analysis (SIA) • Fish sampling	• Assess contributions of terrestrial invertebrates to drawdown zone • Use SIA to quantify relative contributions of terrestrial vs. riparian carbon sources to fish • Fish sampling to assess how drawdown variations affect fish condition and abundance
Interpretation of Results	• Updated section	• To reflect results from additional analyses
Schedule	• No change	
Budget	• No change	

1.0 Monitoring Program Rationale

1.1 Background

In lakes and reservoirs, fish production is assumed to be proportional to overall aquatic productivity, but there is considerable uncertainty over the extent to which fish production is driven by littoral vs. pelagic production. BC Hydro affects littoral production through drawdowns, and pelagic production through alterations of water residence time (e.g., by manipulating inflows and outflows). This Monitoring Program is designed to assess the extent to which fish production is driven by littoral vs. pelagic production and how this relates to BC Hydro operations. The study has two main components, one concentrating on the reservoirs, and the other on the diversion lakes:

Component 1: Effect of water levels on energy flows to fish in reservoirs*.*

Evaluation of operating alternatives for the Campbell River reservoirs has concentrated on the effect of water levels, with the assumption that fish production is correlated with littoral productivity, an assumption that has not been tested. This hypothesis will be tested directly.

Component 2: Effect of water residence time on energy flows to fish in diversion lakes*.*

Given general relationships between residence time and productivity we expect there to be direct influences of diversion on biological productivity in diversion lakes, though the extent of this influence is unknown.

1.2 Management Questions

The Consultative Committee (CC), following the recommendations of the Fish Technical Committee, identified 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?

1.3 Management Hypotheses

The two Management Questions are addressed through the testing of eight Management Hypotheses:

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

This hypothesis was addressed through Component 1. 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.*

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

This hypothesis was addressed in Component 1. The original proposed method was to assess seasonal changes in pelagic bacteria standing crop (BC Hydro 2013). The method was subsequently dropped as bacteria could not be shown to be reliable indicators of productivity. Lake productivity was analyzed through zooplankton biomass and Cutthroat Trout and Rainbow Trout catch per-unit-effort (CPUE) as response variables. Cutthroat Trout fed 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 percent shoal habitat. This indicates that the null hypothesis $H_0$2 should be accepted for Rainbow Trout.

The remaining Management Hypotheses are:

$H_0$3: Terrestrial invertebrate fall is not correlated with distance from the riparian zone.

$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.

$H_0$5: Riparian sources of carbon do not make a biologically significant contribution to fish diets.

$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.

$H_0$7: Fish abundance is not correlated with drawdown magnitude.

$H_0$8: Changes to water residence time of lakes in the Quinsam River watershed do not have a biologically significant effect on trout population.

Table 2 below summarizes how the two management questions and their associated remaining hypotheses will be tested:

Table 2: Proposed null hypotheses and research methods to address the existing JHTMON-5 management questions

Management Question	Proposed Null Hypothesis	Proposed Research Method
1. To what extent do stabilized reservoir levels, as affected by BC Hydro operations, benefit fish populations?	$H_0$3 Terrestrial invertebrate fall is not correlated with distance from the riparian zone	Quantify how riparian inputs to waterbodies vary in space and time
	$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	Quantify how riparian inputs to waterbodies vary in space and time
	$H_0$5 Riparian sources of carbon do not make a biologically significant contribution to fish diets	Stable isotope analysis to quantify contribution of terrestrial carbon sources to fish
	$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	Stable isotope analysis to quantify contribution of terrestrial carbon sources to fish
	$H_0$7 Fish abundance is not correlated with drawdown magnitude	Sample fish abundance across waterbodies and over time to test how drawdown affects fish production
2. What is the relationship between residence time (as affected by diversion rate) and lake productivity?	$H_0$8 Changes to water residence time of lakes in the Quinsam River watershed doe not have a biologically significant effect on trout population	Develop lake-specific assessments of the potential effects of changing water residence time on trout production by quantifying how operations affect water residence time in each affected lake and evaluating lake food webs, fish population data, and the wider literature

1.4 Key Water Use Decision Affected

During development of the Campbell River WUP, evaluation of reservoir operations relied heavily on the Effective Littoral Zone (ELZ) Performance Measure (PM) with the assumption that increasing littoral development would lead to increases in fish productivity. This assumes a strong link between littoral and fish production. The results of this study will be used in conjunction with other monitoring work (e.g. Monitoring Programs 4 and 8, to assess how BC Hydro operations affect fish production in the reservoirs). 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. If deemed necessary, the understanding gained through the present monitoring program may also help guide the development of alternative strategies for reservoir operations.

Evaluation of diversions on lake productivity was examined indirectly during the Campbell River WUP by using simple chemostat models, and through expert judgment. Both sources indicated a likely effect of diversions on lake productivity, but the magnitude of effect needs to be assessed directly. The Fish Technical Committee (FTC) recommendations to implement operational changes with respect to diversion lakes were deferred due to insufficient data with the provision that the issue is considered for direct study during subsequent monitoring. Information collected by this study will be used to evaluate the Campbell River WUP and its impact of the diversion lakes, as well as help refine PMs for future WUP reviews.

2.0 Monitoring Program

2.1 Objective and Scope

The objective of this Monitoring Program is to address the Management Questions by collecting data necessary to test the impact hypotheses outlined in Section 1.3. The following aspects define the scope of the study:

1) The study area consists of selected study sites in Upper Campbell, Lower Campbell and John Hart Reservoirs, at least three diversion lakes, and two control lakes in the region.
2) The Monitoring Program consists of two components, a stable isotope analysis to map the food web dynamics leading to fish production, and a fish production component that investigates the decoupling of a lake's energy cycle due to operational changes in water residence times.
3) The Stable Isotope Analysis (SIA) component of the program was to be originally carried out in Years 2, 5 and 10 of the monitoring period. The monitoring study was preceded by a pilot study to assess sampling and analysis techniques, which was completed in Year 1 of the program. All study work must be completed and results available prior to the next WUP review period (10 years following WUP implementation).
4) Sampling will be carried out in a standardized manner and follow a specified schedule to ensure consistency among years in data quality and collection procedures. To minimize bias, all sampling and laboratory analyzes should be carried out by the same team of investigators.
5) Data reports will be prepared annually, including the results of the pilot work that summarizes the year's findings. All data will be archived according to BC Hydro protocols.
6) A final report will be prepared at the end of the program that summarizes results of the entire program, discusses inferences that can be drawn pertaining to the impacts of the WUP over time, and presents conclusions concerning the impact hypotheses and management questions in Sections 1.2 and 1.3.

2.2 Approach

Component 1 results were addressed in the Year 3 annual report (Hocking et al 2017). The approach, methods, interpretation of results and schedule below refer to efforts required for completion of Component 2 only.

2.3 Methods

2.3.1 Management Question 1

2.3.1.1 Quantify How Riparian Inputs to Waterbodies Vary

Component 1 showed that terrestrial carbon makes an important contribution to fish diets (via terrestrial insects) but there is uncertainty about how this source is affected by drawdown operations (Hocking *et al*. 2017). 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, the drawdown variation should reduce the inputs and rate of processing of organic material (leaf litter and woody debris) in the littoral zone, thereby reducing production of macroinvertebrates, which process this material and contribute to fish production.

To examine this, it is proposed to measure how riparian inputs (terrestrial insect fall and leaf litter) and macroinvertebrate biomass vary along environmental gradients along riparian vegetation communities in the drawdown zone.

Three waterbodies will be sampled: Upper Campbell Reservoir (largest drawdown), Lower Campbell Reservoir (moderate drawdown), and one control lake with no managed drawdown.

At first, sampling will be done during one pilot year, with the full suite of sampling undertaken over two subsequent years. Approximately five transects will be surveyed at each waterbody and extend perpendicular to the shoreline. Transect locations will be selected to provide a contrast in riparian vegetation characteristics (type and cover).

Transects will be established on the Upper Campbell Reservoir in the vicinity of JHTMON-3 gill net sampling sites (rationale discussed below). On each transect, approximately four areas will be sampled at fixed distances from the shoreline (e.g., 1 m, 4 m, 7 m, 12 m), where "shoreline" will be defined as the elevation of the zone of established riparian vegetation. Additional sites may be established on Upper Campbell Reservoir where the magnitude of drawdown is greatest.

At each site, the following data will be collected:

Terrestrial invertebrates: Terrestrial invertebrates inputs (e.g., in $g/m^2/day$) will be measured approximately three times through the growing season. Details of methods will be finalized based on the pilot study (cf. above) which will confirm details such as trap design, deployment duration, and how to minimize biological degradation of samples. The focus of this monitoring will be to quantify inputs of invertebrate biomass, although broad taxonomic analysis (e.g., to order) to provide information about the taxonomic composition of this potential food source for fish.

Macroinvertebrates: littoral benthic macroinvertebrates will be sampled using a grab sampler (e.g., Ponar grab). Samples will provide standardized measures of macroinvertebrate biomass (e.g., g/grab or g/m^3) that can be compared among sites. Broad taxonomic analysis (e.g., to order) will be completed on at least a sub-set of samples to provide information about the taxonomic composition of this potential food source for fish.

Terrestrial leaf fall: inputs of terrestrial organic material will be quantified by deploying traps (wire cages). This may include direct inputs from riparian vegetation that overhangs the site or material that is transported to each site by wind or advection. Material will then be collected once in late fall or early winter, weighed and dry mass calculated (based on measuring water content in a subsample). Results will be analyzed to quantify inputs of organic material and/or carbon (as g C/year).

Substrate type: substrate data will be collected once at each site. At a minimum, substrate type (e.g., silt, sand, bedrock) will be recorded. Laboratory analyses will quantify substrate characteristics (such as median particle size) of samples collected at some sites.

Substrate organic carbon content: the amount of organic carbon present on the bed at each site will be recorded. This will be undertaken by assigning qualitative classes (e.g., low, medium, high) and/or by taking quantitative measurements (e.g., with laboratory analysis to quantify g C/kg dry weight of sediment).

Riparian and littoral vegetation type and cover: if present, aquatic vegetation will be surveyed at each site to record its type and abundance. Details of riparian vegetation on the shoreline at each transect location will also be recorded. If possible, transect locations on Upper Campbell Reservoir, Lower Campbell Reservoir and Brewster Lake (if used as a control) will be aligned with vegetation transects established in JHTMON-10 to link the data to shoreline vegetation (Ballin *et al*. 2015; Krogh *et al*. 2019).

Water elevation will be recorded at each site during each sampling trip.

Fish data (described in Section 2.3.1.3) will also be collected at transect locations to link the information to fish production.

Data will be analyzed to investigate drivers of dependent variables that include: biomass of terrestrial invertebrate inputs, macroinvertebrate biomass, and inputs of terrestrial leaf litter. Key predictor variables will include distance from the shoreline, gradient, substrate characteristics, riparian vegetation cover, aquatic vegetation cover, waterbody, and sampling year. ANOVA or similar methods such as linear mixed effect models may be used in data analyses.

Results from methods outlined above will test the following null hypotheses; note that these differ from the previous TOR (BC Hydro 2013) and start with $H_0$3 as Component 1 addressed hypotheses defined as $H_0$1 and $H_0$2 (cf. Section 1.3; Hocking *et al*. 2017):

$H_0$3: Terrestrial invertebrate fall is not correlated with distance from the riparian zone

$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.

2.3.1.2 Stable Isotope Analysis to Quantify Contribution of Terrestrial Carbon Sources to Fish

Component 1 successfully used stable isotopes analysis of nitrogen and carbon to construct lentic food webs. Component 1 indicated that terrestrial carbon sources could be important for fish production in lakes and reservoirs in the

Campbell River watershed (Hocking *et al*. 2017). However, uncertainty remains about the sources of this carbon (e.g., upland vs. riparian vs. tributaries) and how it is processed in waterbodies. These uncertainties have an important bearing on whether reservoir management operations (drawdown variations) have the potential to affect fish production by modifying fluxes of carbon from terrestrial sources.

To examine this, the stable isotope analysis completed during Component 1 for the three waterbodies will be updated to include a gradient of drawdown magnitude (Section 2.3.1.1). This will involve collecting additional samples from a wider range of basal carbon sources that include multiple terrestrial sources. Examples include: riparian leaf litter, woody debris in tributaries, organic carbon from wetlands, littoral periphyton, and woody material from forest soils that were inundated during reservoir creation (collected using a sediment gravity corer). Bayesian mixing models developed during Component 1 for the three study waterbodies will be updated and improved using the additional data collected for these basal carbon sources, in addition to data collected for invertebrate tissues (Section 2.3.1.1) and fish tissues (Section 2.3.1.3) that will be collected as part of the other sampling activities.

Results will be used to test the following hypotheses:

$H_0$5: Riparian sources of carbon do not make a biologically significant contribution to fish diets.

$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.

2.3.1.3 Fish Abundance Sampling Across Waterbodies and Over Time to Test How Drawdown Affects Fish Production

If stabilized water levels benefit fish production (Management Question 1), then drawdown magnitude would be expected to have a negative effect on fish abundance. In theory, this could be investigated by comparing fish abundance among a large sample of waterbodies subjected to drawdown of varying magnitude. In the Campbell River watershed, only two reservoirs are actively drawn down and therefore the sample size for such analysis is small. Nonetheless, this analysis could provide insights as many of the waterbodies are similar and hence there is low variability in other factors that could confound the results (e.g., climate, harvest, food web structure, trophic status). Furthermore, there is an opportunity to use data collected as part of JHTMON-3, which involves collecting CPUE measurements using gill net sampling at six sites in Upper Campbell Reservoir during late summer (Bayly *et al*. 2018) over a 10-year period that is coincident with the JHTMON-5 study period.

Thus, there is an opportunity to analyze how the CPUE of JHTMON-5 priority species varies in relation to annual differences in drawdown operations at Upper Campbell Reservoir by analyzing fish abundance data collected as part of JHTMON-3. This analysis will therefore involve a time-for-space substitution; i.e., variability among years will be used to make inferences about potential differences among waterbodies subject to drawdown of different magnitude. The power of this analysis will be admittedly limited by the range of drawdown operations that at Upper Campbell Reservoir over the 10-year study period. This could limit the extent to which results can be used to answer Management Question 1. It is also acknowledged that this analysis is subject to process error, as it could only detect drawdown effects that occur within a single year, rather than effects that manifest over multiple years (e.g., desiccation of macrophyte beds and associated reduced littoral production that requires several years of stable water levels to remediate). However, these risks are at least partly offset by the potential that the results will provide useful insights with relatively low effort; additional sampling is not required and there will be opportunities to achieve efficiencies by combining analysis tasks with proposed analysis for JHTMON-3.

This task will involve two components. First, fish abundance sampling (CPUE measurements) will be conducted at Lower Campbell Reservoir and the control. Sampling will use methods consistent with those used for JHTMON-3 and will be conducted over two years to provide an estimate of annual variability. Effort assigned to this sampling is expected to 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. Sampling will occur at transect locations described in Section 2.3.1.1 to match data with the other datasets. These data will be combined with data collected during corresponding years at Upper Campbell Reservoir as part of JHTMON-3. Analyses will involve comparing differences in fish abundance 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 through regression methods.

Second, data collected as part of JHTMON-3 over 10 years will be compiled at the end of the monitor. Hydrologic metrics will then be developed and calculated using reservoir elevation data to quantify inter-annual variability in drawdown operations (e.g., annual drawdown range, minimum annual water elevation, and timing of drawdown relative to terrestrial invertebrate or leaf litter fallout). Opportunities will be examined to use results from JHTMON-10 (Krogh *et al*. 2019) to inform development of these metrics; e.g., to develop metrics to quantify the characteristics of the inundation of riparian vegetation. Models will be used to investigate whether annual variability in drawdown affects annual fish abundance. There should be an opportunity to use a population model already developed as part of JHTMON-3 (to examine effects due to variation in effective spawning habitat; Bayly *et al*. 2018) to support this analysis.

Together, the two lines of evidence described above will be evaluated to test hypothesis 7:

$H_0$7: Fish abundance is not correlated with drawdown magnitude.

2.3.2 Management Question 2

Component 1 provided important insights to Management Question 2 about relationships between water residence time and the percent pelagic contribution to trout diets, as well as relationships between water residence time and CPUE for the two trout species, based on a relatively low sampling effort of fish abundance (see above; Hocking *et al*. 2017). As part of Component 2, the uncertainties relating to Management Question 2 will be addressed by further analyzing data collected during Component 1, as well as relevant data collected as part of the tasks described in Section 2.3.1.

The uncertainties associated with Management Question 2 will be addressed by:

- Analysis of flow data collected in the Quinsam River watershed by the Water Survey of Canada. This will quantify how operation of the Quinsam River Diversion dam changes water residence time in Gooseneck Lake, Beavertail Lake, Middle Quinsam Lake, and Lower Quinsam Lake. Lower Quinsam Lake was not studied in Component 1 so additional work will be required to construct a water balance for that lake, which will be completed with existing data (bathymetric information from BC Hydro records and flow data obtained from the Water Survey of Canada). For each of lake, curves will be developed to estimate how water residence time of each lake varies in relation to diversion operations permitted under the WUP. This will provide a valuable tool to link changes in management operations to changes in fish habitat and will considerably extend hydrologic modelling undertaken in Component 1, which examined broader diversion scenarios (0%, 70% and 90% diversion).

- Statistical models developed during Component 1 to predict trout abundance (CPUE) as a function of changes to water residence time will be updated based on additional fish abundance data collected during Component 2 (Section 2.3.1.3). This will include using the updated CPUE data to inform uncertainties associated with CPUE estimates derived in Component 1 using relatively low effort sampling.

- Each of the four affected waterbodies will be considered to develop lake-specific assessments of the potential effects of changing water residence time on trout production. This will take into account lake-specific curves that relate diversion operations to changes in water residence time, statistical models developed to predict fish population parameters (e.g., CPUE and, potentially, condition) based on predictor variables that include water residence time, understanding of the food webs of each lake based on stable isotope analysis, and the wider literature on the relationship between water residence time and pelagic production (e.g., Campbell *et al*. 1998, Walz and Melker 1998, Obertegger *et al*. 2007).

These analyses will test the last hypothesis:

$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.

2.4 Interpretation of Results

Management Question 1 associated hypotheses:

$H_0$3: Terrestrial invertebrate fall is not correlated with distance from the riparian zone.

- Rejection of $H_0$3 will indicate that drawdown is expected to reduce inputs of terrestrial invertebrates (an important food source for fish) to the reservoirs. If $H_0$3 is rejected, the magnitude of the relationship will be analyzed in the context of the drawdown operations that occur and results of stable isotope analysis (regarding the importance of terrestrial invertebrates to fish diets; Section 2.3.1.2). This analysis will be used to make inferences about the biological significance of effects of drawdown operations in the Campbell River watershed on fish production due to reduced terrestrial invertebrate inputs.

$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.

- $H_0$4 involves several components; testing this hypothesis will inform whether inputs of organic material from the riparian zone control benthic macroinvertebrate biomass (a food source for fish). Furthermore, testing this hypothesis examines if and how drawdown affects organic material accumulation and benthic macroinvertebrate biomass. Results will be evaluated to infer whether drawdown is likely to affect the availability of benthic macroinvertebrates for fish to consume. For example, if benthic macroinvertebrate biomass abundance is strongly positively correlated with the availability of organic material in the substrate *and* both of these variables are negatively correlated with drawdown magnitude and distance from the riparian zone, then it may be concluded that drawdown reduces the availability of macroinvertebrates to support fish diets, as it constrains riparian inputs of organic material that are processed by macroinvertebrate guilds such as shredders.

- If adverse effects due to drawdown are identified when testing this hypothesis, then the biological significance of these effects will be evaluated by considering the effect size and results of stable isotope analysis (regarding the importance of benthic macroinvertebrates to fish diets). The terrestrial leaf fall data will be analyzed to provide another line of evidence to understand the potential importance of this carbon source and whether it is influenced by drawdown. For example, if benthic macroinvertebrate biomass abundance is strongly positively correlated with the availability of organic material in the substrate *and* the accumulation of terrestrial leaf fall is strongly negatively correlated with distance from the riparian zone, then this would provide further evidence that drawdown potentially affects fish production via this impact pathway.

$H_0$5: Riparian sources of carbon do not make a biologically significant contribution to fish diets.

- The stable isotope analysis will be used to improve our understanding of terrestrial carbon sources and processing relevant to fish production.

$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.

- The outcomes of testing these two hypotheses will be considered in the context of the outcomes of testing $H_0$3 and $H_0$4 above to make inferences about the potential for drawdown to affect fish production by reducing inputs of carbon from riparian sources.

$H_0$7: Fish abundance is not correlated with drawdown magnitude

- Rejection of this hypothesis will indicate that drawdown adversely affects fish production. The outcome will be considered in the context of the other applicable hypotheses (including $H_0$1, which was addressed in Component 1) to provide a final answer to Management Question 1.

Management Question 2 has one associated hypothesis:

$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.

- The rejection or acceptance of this hypothesis will be used to provide a final answer to Management Question 2.

2.5 Schedule

The schedule to complete Component 2 of JHTMON-5 is presented in Table 3. A pilot study will be conducted in 2019 to confirm methodological details, e.g., terrestrial invertebrate sampling and site locations. Two full field seasons will be completed in 2020 and 2021 and outstanding analysis in 2022. A final report will be submitted in early to mid-2023, during Year 10 of JHTMON-5.

Table 3: Proposed schedule to complete Component 2 of JHTMON-5

Component	Task	2019				2020				2021				2022				2023	
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2
First field season	Pilot study			■	■														
Second field season	Measure riparian inputs						■	■	■										
	Collect SIA samples						■	■	■										
	Fish sampling							■											
Third field season	Measure riparian inputs										■	■	■						
	Collect SIA samples										■	■	■						
	Fish sampling											■							
Analysis/reporting	Analysis				■	■			■	■				■	■	■	■	■	
	Submit annual report					■				■									
	Submit final report																		■

2.6 Budget

No changes to budget.

3.0 References

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