Campbell River Project Water Use Plan

Upper and Lower Campbell Lake

Reference: JHTMON-3

JHTMON-3: Upper and Lower Campbell Lake Fish Spawning Success Assessment

Study Period: 2013 – 2023

Year 10 Program Summary Report

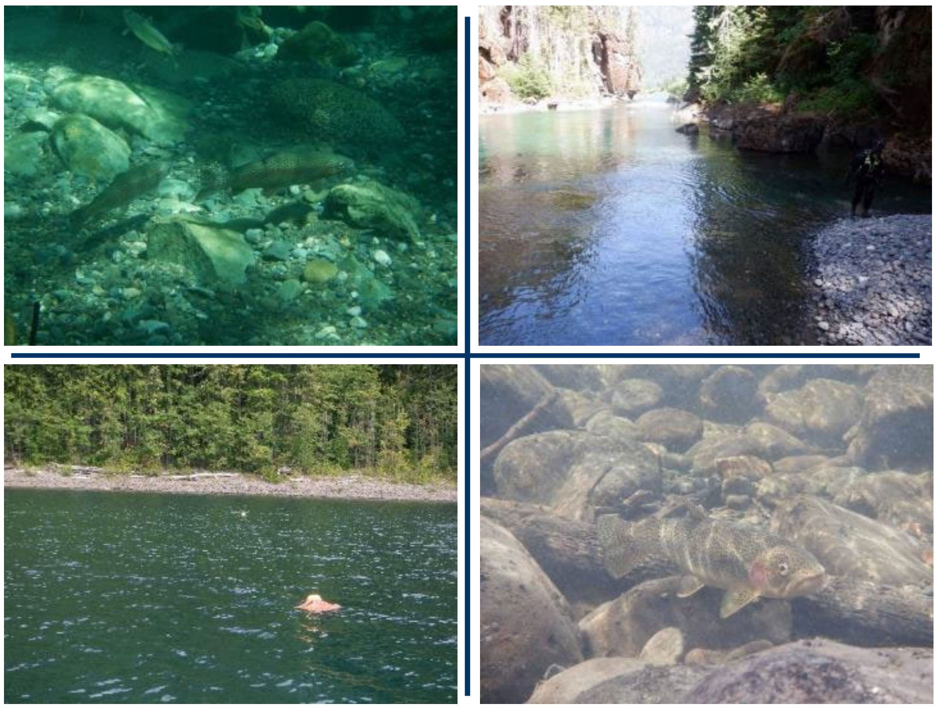
Laich-Kwil-Tach Environmental Assessment Ltd. Partnership

Ecofish Research Ltd.

July 11, 2025

JHTMON-3: Upper and Lower Campbell Lake Fish Spawning Success Assessment

Program Summary Report



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<u>Title Page Photographs</u>

Top left: Rainbow Trout observed during the Ralph River snorkel survey.

Top right: Looking downstream from snorkel start location on Wolf River.

Bottom left: Looking at UCR-LKGN08 net set location.

Bottom right: Cutthroat Trout observed during the Greenstone River snorkel survey.

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EXECUTIVE SUMMARY

The *Upper and Lower Campbell Lake Fish Spawning Success Assessment* (JHTMON-3) is one of the effectiveness monitoring studies within the Campbell River Water Use Plan (WUP). The WUP, implemented in 2012, replaced an **Interim Flow Management Strategy** (IFMS) that BC Hydro had implemented in October 1997. Both the IFMS and WUP aimed to balance power generation with fisheries and wildlife habitat, shoreline conditions, flood control, and recreation interests. Reservoir elevations under the WUP had a mean of 176.97 m and a median of 177.10 m. These values were similar to those observed during the IFMS period, which had a mean 177.312 m and a median of 177.364 m. The overall objective of JHTMON-3 is to test the assumption that recruitment of Rainbow Trout (*Oncorhynchus mykiss*), Cutthroat Trout (*Oncorhynchus clarkii*), and Dolly Varden (*Salvelinus malma*) in the Upper Campbell Reservoir (Upper Campbell Reservoir and Buttle Lake) and Lower Campbell Reservoir is limited by spawning habitat availability.

JHTMON-3 addresses the following three management questions:

1. Following implementation of the Campbell River WUP, does the population of Rainbow Trout, Cutthroat Trout and Dolly Varden in the Upper Reservoir and the Lower Reservoir increase as a result of the expected gains in functional spawning habitat?
2. Are the trout populations in the Upper Reservoir and the Lower Reservoir limited by the availability of functional spawning habitat?
3. Is the ESH performance measure a reliable measure of spawning habitat, and therefore useful in the present Monitor, as well as in future WUP investigations?

The management questions were addressed by integrating evidence from:

1. Experimental tests: Incubation experiments to determine whether egg incubation success was related to inundation,
2. Field data collection: gill net surveys, snorkel surveys of spawners in reservoir tributaries, spawning habitat assessments,
3. Desktop studies: Effective Spawning Habitat (ESH) modelling, and population dynamics model of Cutthroat Trout (Statistical catch-at-age modelling).

Field monitoring included gill net surveys, snorkel surveys of spawners in reservoir tributaries, and assessments of spawning habitat availability and use. Gill net surveys were conducted annually in August from 2014 to 2023 on the Upper Campbell Reservoir, with at least four sites sampled each year. Snorkel surveys during the same period targeted Cutthroat Trout spawning in the Lower Campbell Reservoir between February and April across three tributaries and Rainbow Trout spawning in June across six tributaries of the Upper Campbell Reservoir and Buttle Lake. Spawning habitat availability and use surveys were conducted in 2018 on the main reservoir tributaries. Experimental incubation tests were carried out on the Elk and Ralph rivers in 2018. These field and experimental data, along with information on reservoir levels, were synthesized into modelling of

Effective Spawning Habitat and Cutthroat Trout population dynamics to assess whether availability of spawning habitat limits the recruitment of target species.

For Management Question 1 (have trout populations increased following implementation of the Campbell River WUP, given the expected gains in functional spawning habitat?), estimates of ESH in the post-IFMS period show high inter-annual variability, with patterns after WUP implementation resembling those observed post-IFMS. The largest gains in functional spawning habitat occurred following the IFMS, whereas WUP implementation provided no notable improvements. For example, mean ESH for Cutthroat Trout in the Lower Campbell Reservoir went from 1,178 m^2d in the pre-IFMS period to 3,059 m^2d in the post-IFMS period to 3,869 m^2d in the WUP period. Further details on ESH values for the three salmonid species and both reservoirs are provided in Appendix A. Consequently, a population response from the WUP was unlikely and was not observed during monitoring.

For Management Question 2 (are trout populations limited by the availability of functional spawning habitat?), evidence from spawning habitat distribution, incubation experiments, and population modelling suggests that while functional spawning habitat may influence trout population abundances in the Upper and Lower Reservoirs, it is less influential than initially assumed in the WUP. Spawning habitat does not appear to be the primary driver of trout recruitment.

For Management Question 3 (is the ESH performance measure a reliable measure of spawning habitat?), while the ESH performance measure is grounded in sound concepts, some potential sources of bias and uncertainty remain unaddressed. These factors could influence the clarity of the relationship between Effective Spawning Habitat and recruitment, and as such, conclusions drawn from population modelling should be interpreted with caution. The realized effect of ESH on trout population dynamics appears to be lower than originally assumed during the WUP development, as most spawning has been observed to occur in stream habitats above the reservoir drawdown zone, where operations have no influence.

FINAL STATUS OF JHTMON-3

Objective	Management Question	Summary of Key Results
The aim of JHTMON-3 is to test the assumption that recruitment of salmonids (trout and char) in Upper and Lower Campbell reservoirs is limited by availability of ESH. The Monitor involves assessing the extent of spawning habitat both within and above the drawdown zone; evaluating overall habitat utilization and spawning success; and determining whether the area of ESH is sufficient to allow the salmonid populations to fully seed the reservoirs.	MQ-1: Following implementation of the Campbell River WUP, does the population of Rainbow Trout, Cutthroat Trout and Dolly Varden in Upper and Lower Campbell reservoirs increase as a result of the expected gains in functional spawning habitat?	Following the implementation of the IFMS in late 1997, increases in spawning habitat were realized. For example, mean ESH for Cutthroat Trout in the Lower Campbell Reservoir went from 1,178 m^2d in the pre-IFMS period to 3,059 m^2d in the post-IFMS period to 3,869 m^2d in the WUP period. Estimates of ESH in the post-IFMS a*nd WUP* periods are characterized by their high inter-annual variability. The greatest gains in functional spawning habitat were realized after the implementation of the IFMS, particularly for Cutthroat Trout and Rainbow Trout. Subsequent implementation of the WUP did not translate into notable gains in spawning habitat. Consequently, a population response from the WUP seems unlikely and this was not observed during the monitoring program.
	MQ-2: Are the trout populations in Upper and Lower Campbell reservoirs limited by the availability of ESH?	Evidence from the distribution of available spawning habitat, incubation experiments, and population modelling suggests that while functional spawning habitat may limit trout populations in the Upper and Lower Reservoirs, it is less impactful than initially assumed in the WUP. As a result, effective spawning habitat is not the primary driver of trout recruitment in these reservoirs.
	MQ-3 Is the ESH performance measure a reliable Measure of spawning habitat, and therefore useful in the Present Monitor, as well as in future WUP investigations?	The ESH PM is based on solid concepts, but unresolved sources of bias and uncertainty limit its effectiveness. In particular its utility for assessing the influence of operations is limited because most spawning occurs in stream habitats above the drawdown zone. Additionally, inundation of redds within the drawdown zone does notresult in immediate or complete mortality. As such, ESH is an incomplete performance measure for evaluation operational effects under the WUP.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF MAPS

LIST OF APPENDICES

LIST OF ABBREVIATIONS

ATU – Accumulated Thermal Unit

DO – Dissolved Oxygen

CPUE – Catch per Unit Effort

ESH – Effective Spawning Habitat

ESH PM – Effective Spawning Habitat Performance Measure

FHAP – Fish Habitat Assessment Procedure

GPS – Global Positioning System

IFMS – Interim Flow Management Strategy

K_r – Relative condition factor

LiDAR – Light Detection and Ranging

PM – Performance Measure

RPAS – Remotely Piloted Aircraft System

SD – Standard Deviation

TST– Total Station Theodolite

RISC – Resources Inventory Standards Committee

RWL – Reservoir Water Level

UAV – Unmanned Aerial Vehicle

WUP – Water Use Plan

GLOSSARY OF TERMS

Accumulated Thermal Unit – The cumulative sum of daily average water temperature

Alluvial Fan – A fan-shaped deposit of sediment formed where a river slows down and spreads out onto a flatter area, such as at a lake confluence

Catch per Unit Effort (CPUE) – The number of fish caught per gill net set-hour

Fry – An early salmonid life stage that has emerged from the gravel after the yolk sac has been absorbed

Effective Spawning Habitat – Habitat that maintains its quality sufficiently to allow successful spawning and incubation.

Effective Spawning Habitat (ESH) Performance Measure Model – A model that quantifies effective spawning habitat.

Parr – A juvenile salmonid developmental stage between the fry and adult life stages

Redd – The spawning bed of a female salmonid

Relative condition factor (K_r) – The ratio of observed weight of a fish at a given length to the expected weight (w) of a fish of the same length as calculated using a length-weight regression

Thalweg – The deepest and fastest-flowing part of a river channel

1. INTRODUCTION

The *Upper and Lower Campbell Lake Fish Spawning Success Assessment* (JHTMON-3) is an effectiveness monitoring study associated with the John Hart Water Use Plan (WUP) and is required by BC Hydro's provincial water licence. The WUP, implemented in 2012, replaced an Interim Flow Management Strategy (IFMS) that BC Hydro had implemented in October 1997. Both the IFMS and WUP aimed to balance power generation with fisheries and wildlife habitat, shoreline conditions, flood control, and recreation interests. Reservoir water level management under the WUP is similar to that described in the IFMS.

The JHTMON-3 study helps resource managers better understand the potential biological effects of BC Hydro operations by testing whether recruitment of salmonids (trout and char) in the Upper Campbell Reservoir (Upper Campbell Reservoir and Buttle Lake) and Lower Campbell Reservoir is limited by effective spawning habitat (ESH). JHTMON-3 provides: 1) an assessment of the extent of spawning habitat within and above the drawdown zone; 2) an evaluation of habitat utilization and spawning success; and 3) an assessment of whether the area of spawning habitat is sufficient to allow the salmonid populations to fully seed the reservoirs. The three species of primary interest for the study are Rainbow Trout (*Oncorhynchus mykiss*), Cutthroat Trout (*Oncorhynchus clarkii*), and Dolly Varden (*Salvelinus malma*).

This report provides an overview of the study area (Section 2), summarizes data collection over the 10-year study period (Section 3), and addresses the three Management Questions (Section 4) posed in the Terms of Reference for JHTMON-3. Detailed information about data collection methods and results is provided separately in appendices or annual monitoring reports listed in Table 1.

Table 1. Summary of Terms of Reference components and program years implemented.

Component	Time of Year	Program Year										Annual Report Citation(s)
		1	2	3	4	5	6	7	8	9	10	
		2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	
Effective Spawning Habitat	Species-specific spawning and incubation periods	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	Hatfield *et al.* 2015, 2016; Smyth and Hatfield 2017; Bayly *et al.* 2018; Buren *et al.* 2019, 2020, 2022; Kim *et al.* 2023a, 2023b; Appendix A
Population Index for Upper Campbell Reservoir	Late summer	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Snorkel Surveys of Spawners in Reservoirs	March, April, and June	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	
Spawning Habitat Availability	July and October				✓							Bayly *et al.* 2018
Spawning Habitat Use	Peak spawning periods in March, April, and June				✓	✓						Bayly *et al.* 2018; Buren *et al*. 2019
Incubation Experiments	June and July					✓						Buren *et al.* 2019
Statistical Catch-at-age Models	Late summer					✓					✓	Buren *et al.* 2019; Appendix B

2. STUDY AREA

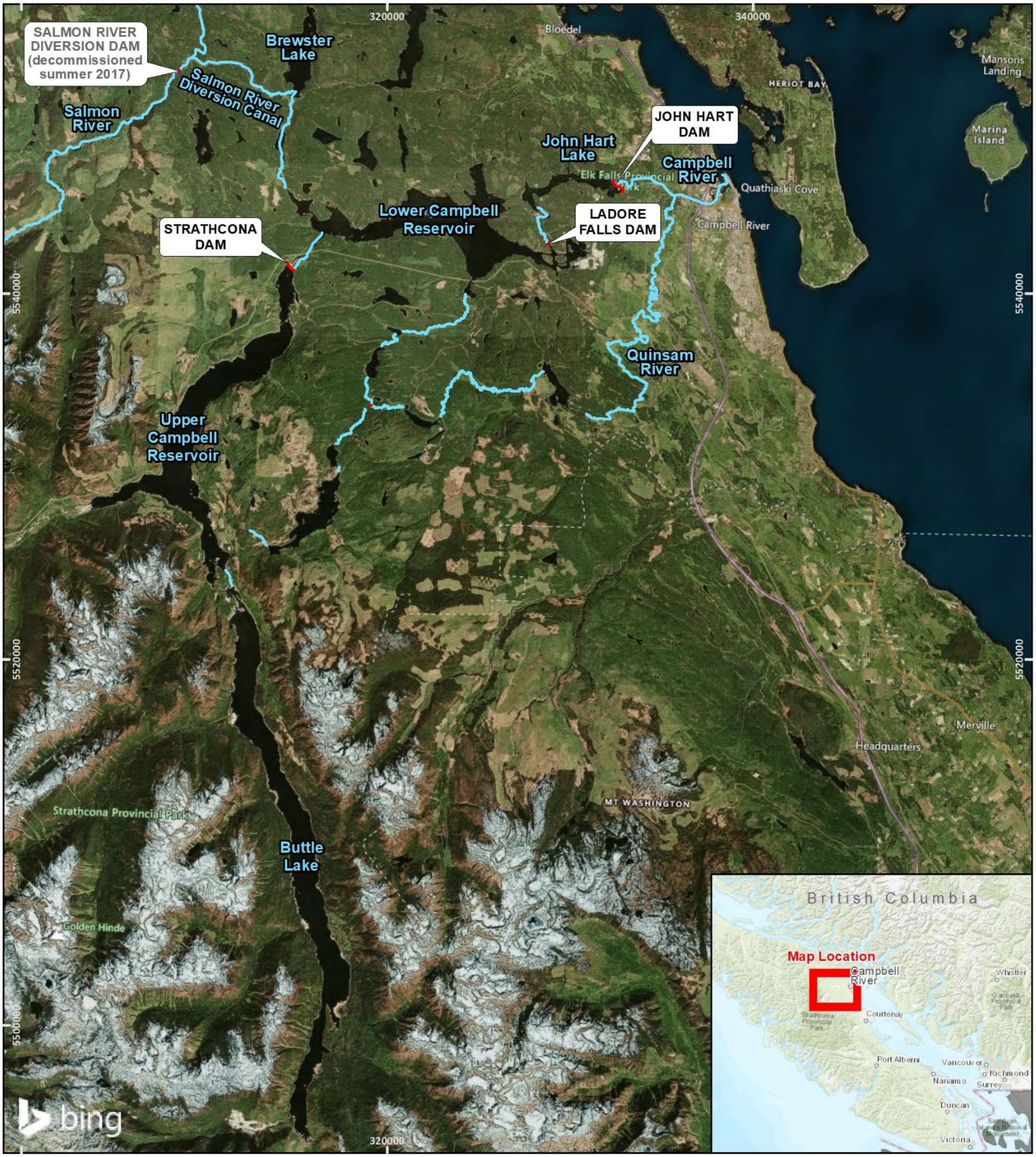
The Campbell River WUP project area is complex and includes facilities and operations in the Campbell and Quinsam watersheds. (Diversions into the Campbell system from the Heber and Salmon rivers were removed in 2012 and 2017, respectively). The Upper and Lower Campbell reservoirs are located due west of the City of Campbell River on the east coast of Vancouver Island, British Columbia (Map 1). Details of BC Hydro's Campbell River infrastructure and operations are provided in the Campbell River System WUP (BC Hydro 2012).

Buttle Lake and Upper Campbell Reservoir are effectively a single reservoir that is the largest in the Campbell River hydroelectric system. Tributaries to Upper Campbell Reservoir include the Elk River, Henshaw Creek, Phillips Creek, Ralph River, Thelwood Creek, and Wolf River. Upper Campbell Reservoir is impounded by Strathcona Dam, which was constructed between 1955 and 1958. The dam also provides primary flow regulation for the Ladore and John Hart dams, which are located downstream. Upper Campbell Reservoir's historical operational water elevation has been between 210.0 and 221.0 m. The licensed storage for operations in Buttle Lake and Upper Campbell Reservoir is 212.00 to 220.98 m and 192.00 to 220.98 m, respectively (BC Hydro 2012).

Lower Campbell Reservoir is impounded by Ladore Dam. Tributaries to Lower Campbell Reservoir include Fry Creek, Greenstone River, and Miller Creek. Ladore Dam was originally completed in 1949, and two generating units were added in 1957. The reservoir's historical operational water elevation has been between 174.0 and 178.3 m; the current water licence limits for operation are 163.65 to 178.30 m (BC Hydro 2012).

Upper Campbell Reservoir experiences annual water level fluctuations of about 4 to 10 m; Lower Campbell Reservoir varies about 1 to 3 m. The timing and magnitude of water level fluctuations differ among years depending on hydrological conditions. In general, the Upper Campbell Reservoir is drawn down in late winter and early spring and recharges during late spring and early summer. A second drawdown typically occurs in late summer and early fall, prior to recharge due to fall rains. The Lower Campbell Reservoir is usually drawn down from late spring to early summer, with recharge typically occurring in the fall due to rain; however, seasonal elevation changes are much less pronounced since the reservoir is operated within a narrower range of elevations. The much smaller John Hart Reservoir, located downstream of Lower Campbell Reservoir, is typically operated within a relatively stable water elevation range of 139.00 to 139.60 m (BC Hydro 2012).

Project Overview



Legend

Dam

MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

0 2 4 6 8 10 12 km

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ECOFISH RESEARCH

Map 1

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3. METHODS

3.1. Overview

To test whether recruitment of salmonids (trout and char) in the Upper Campbell Reservoir (Upper Campbell Reservoir and Buttle Lake) and Lower Campbell Reservoir is limited by spawning habitat availability (as estimated by the ESH metrics), desktop assessments and field studies were conducted. Desktop assessments used the ESH metrics developed by BC Hydro to estimate and track the amount of habitat available for spawning that also remains effective during incubation periods (Leake, pers. comm. 2015). Field studies included index snorkel surveys, detailed redd surveys, fish habitat surveys, an incubation study, and gill netting surveys. Desktop assessment and field components are described at a high level in the subsections below.

3.1.1. Effective Spawning Habitat (ESH)

The ESH model was created by BC Hydro and is used to estimate spawning habitat in tributary sections of drawdown zones affected by reservoir elevations. This model estimates "effective" spawning habitat, which is defined as suitable habitat during the spawning window that subsequently stays in flowing streamwater during the incubation period. Spawning habitat that is inundated by rising water levels is assumed to lead to mortality of eggs due to factors like insufficient oxygen or accumulation of by-products of metabolism. The model incorporates species-specific life histories and accumulated thermal units (ATU; i.e., cumulative sum of daily average water temperature) to determine incubation periods, while also tracking habitat availability based on reservoir levels. The model calculates spawning habitat and loss, including weighting of daily habitat areas by species-specific spawning intensities during the spawning season. Overall, the ESH model provides a comprehensive approach to evaluate spawning habitat dynamics in relation to reservoir elevation changes.

3.1.2. Population Index for Upper Campbell Reservoir

3.1.2.1. Gill Netting

Gill net surveys were used to produce a fish abundance index by species and age for each year of sampling. Sample sites were distributed across the Upper Campbell Reservoir, with bathymetric maps used to identify locations with suitable depth profiles. Site locations were selected in 2014 and the same locations were resampled in from 2015 to 2023 with some exceptions (e.g., fewer sites were sampled in years when catches were nearing the scientific collection permit catch limits). To maintain consistency, sites were sampled on similar dates each year in late summer. Both floating and sinking gill nets were used to target specific strata within the water column and were set overnight.

All fish captured during gill netting were identified to species, weighed, and measured to the nearest mm (fork length) in the field. Scales and otoliths were collected from a subset of Rainbow Trout and Cutthroat Trout to allow for age classes to be assigned to both species based on laboratory examination. Only one Dolly Varden was captured in each of 2014 and 2017, with none captured in any other monitoring year; therefore, age classes were not assigned for this species.

Catch per unit effort (CPUE) from gill netting, measured as fish caught per set-hour, was used as the metric of relative abundance in Upper Campbell Reservoir. CPUE was computed by individual net panel to estimate species relative abundance by 5 m depth intervals. Biological statistics computed for each species in the gill net catch include mean and standard deviation of length and weight, length-frequency and age distributions, length-weight regressions, and relative condition factor (K_r). CPUE and biological statistics calculated each year were used to assess for trends in the fish populations of Upper Campbell Reservoir.

3.1.3. Snorkel Surveys of Spawners in Reservoir Tributaries

Snorkel surveys were completed once each year in six tributaries of Buttle Lake and Upper Campbell Reservoir: Elk River (upper and lower reaches), Ralph River, Thelwood Creek, Wolf River, Phillips Creek, and Henshaw Creek. Snorkel surveys were also completed once annually in three tributaries of Lower Campbell Reservoir: Miller Creek, Fry Creek, and Greenstone River. Spring snorkel surveys were completed in tributaries of the Lower Campbell Reservoir in March and April to assess Cutthroat Trout spawning activity. Snorkel surveys of Upper Campbell Reservoir tributaries were completed in the late spring/early summer (June) to assess Rainbow Trout spawning. Snorkel surveys targeting the Dolly Varden spawning period (October to early December) were not undertaken and are outside the scope of this monitoring program; therefore, all observations of Dolly Varden are classified as incidental. The tributaries selected were based on their reported spawning value for Cutthroat Trout and Rainbow Trout and had been surveyed historically since the early 1990s.

On each survey date, individual stream sections were surveyed by two experienced technicians swimming in pairs. To allow for comparison between years, surveys followed standardized survey methods within each reach, consistent with historical data collected conducted by the Ministry of Forests, Lands, and Natural Resource Operations and the British Columbia Conservation Foundation (Pellett 2013). A fork length of 150 mm was designated as the boundary between juvenile and adult fish, based on the Provincial snorkel form template. The estimated fork length bins used each year were 0-80 mm for fry, 81-150 mm for parr, and adult bins of 151-250 mm, 251-350 mm, 351-450 mm, and 450+ mm.

3.1.4. Spawning Habitat Availability

Spawning habitat field surveys were carried out during a single year in 2017 (Year 4; Bayly *et al.* 2018). The delineation of drawdown zones for assessing spawning habitat required defining the upper and lower endpoint boundaries. Upper boundaries were defined by extracting the upper operational water levels of each reservoir from the LiDAR data collected by Terra Remote Sensing in 2017. Lower endpoints were defined when the main thalweg became undefined within the alluvial fan at the reservoir confluence.

Habitat surveys used both remotely piloted aircraft system (RPAS) and ground-based field inventory techniques to assess spawning habitat quantity and quality. High-resolution aerial imagery collected via RPAS was processed to calculate metrics such as linear distance, wetted area, and bankfull channel width providing insights into spawning habitat availability within and upstream of drawdown zones. Spawning potential was qualitatively assessed based on habitat characteristics observed in the imagery. Ground-based surveys focused on spawning gravel assessments in areas inaccessible to RPAS, providing data on gravel patch characteristics such as size, water depth, compaction, and embeddedness. Metrics were extended beyond RPAS survey extents using field ground survey data, allowing for evaluation of spawning habitat availability in areas with dense overhanging vegetation.

The study also evaluated habitat availability within drawdown zones during spawning periods, considering the impact of reservoir backwatering on spawning habitat. Reservoir elevation data were analyzed to estimate total available spawning habitat within drawdown zones during spawning periods. Overall, the combination of RPAS and ground-based surveys allowed insights into spawning habitat quantity and quality.

3.1.5. Spawning Habitat Use

Redd surveys were conducted in 2017 and 2018 to evaluate spawning habitat use within and upstream of drawdown zones of tributaries of the Upper and Lower Campbell reservoirs. In the Lower Campbell Reservoir, surveys targeted the peak spawning period for Cutthroat Trout, while surveys in the Upper Campbell Reservoir targeted the spawning period for Rainbow Trout. Surveys targeting Dolly Varden redds were not undertaken and are outside the scope of this monitoring program since they would need to be undertaken in the fall. These surveys involved visually enumerating and mapping redds by experienced field technicians, who walked and snorkeled the accessible length of each tributary. Redds could not be definitively attributed to a specific species based on visual observation alone; instead, survey timing was used to help infer which species likely constructed them. Detailed attributes of each redd, including location, depth, velocity, substrate, and cover were recorded.

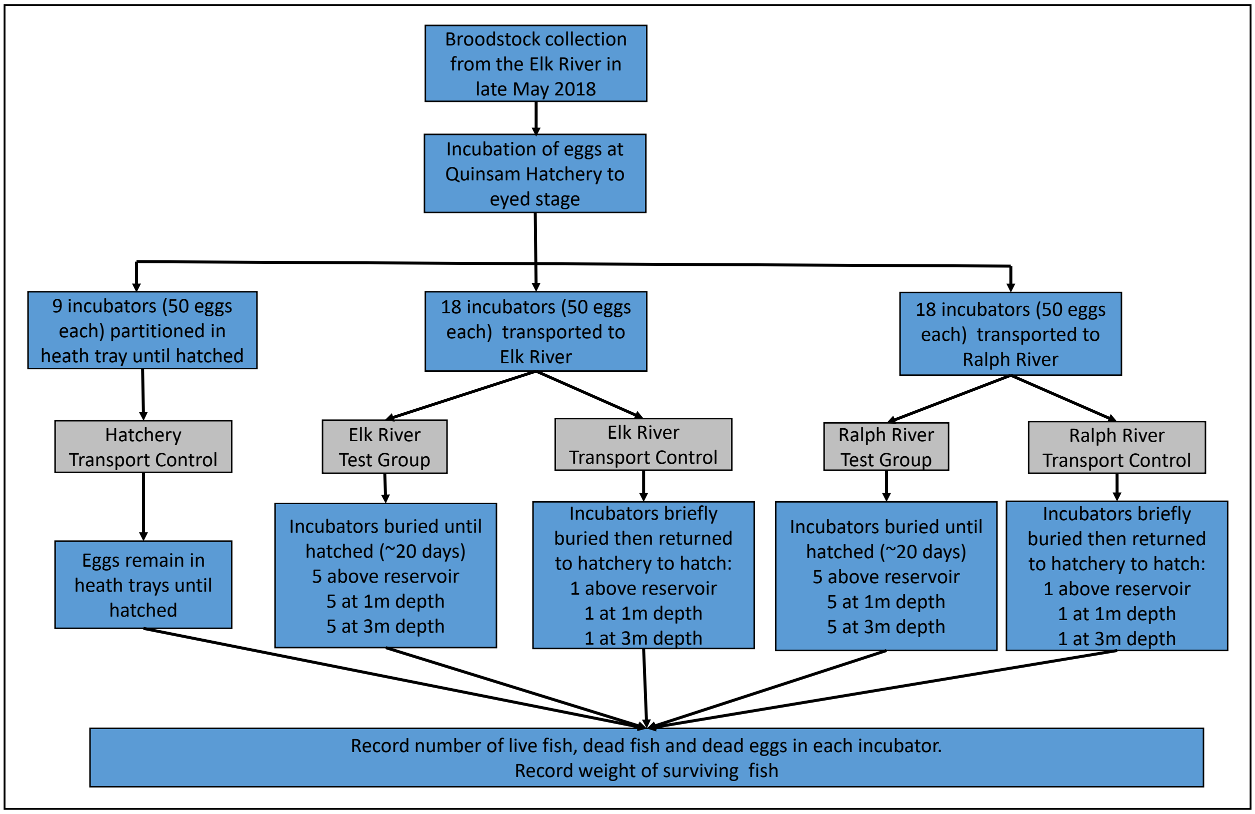
Redd locations were georeferenced using a Total Station Theodolite (TST) within the drawdown zones and high-accuracy GPS above the drawdown zones. The choice of equipment was influenced by the need for precise vertical accuracy, particularly within drawdown zones to calculate inundation periods accurately. Elevation of redds in drawdown zones were then compared with known reservoir levels to determine inundation or exposure thresholds. However, sources of error, such as difficulties in stabilizing survey rods in deep water and variations in reservoir elevation due to factors like internal waves and wind, could not be fully accounted for in the analysis.

3.1.6. Incubation Experiments

To test specific assumptions of the ESH performance measure, a study was conducted within the drawdown zone of two tributaries of the Upper Campbell Reservoir (Elk River and Ralph River) to determine whether egg incubation success was related to inundation (i.e., whether eggs were incubated in flowing water within the tributary above the reservoir level or in substrate below the reservoir level). Incubation tests were carried out in a single Rainbow Trout incubation season in June and July 2018. In each tributary, three sample sites were established across a gradient of inundation (above the drawdown zone, and at approximately 1 m and 3 m depths below reservoir water level at time of establishment). Substrate composition, groundwater levels, and water quality measurements were collected to assess habitat conditions. Rainbow Trout eggs were collected from wild broodstock in the Elk River. The study included hatchery-reared control groups for comparison to the treatment groups placed in the incubation sites.

The study involved two phases: the collection of broodstock and incubation of eggs to the eyed stage at the Quinsam River Hatchery, followed by the incubation test. This approach allowed for an examination of the impact of inundation on Rainbow Trout egg hatchability at several elevations in two tributaries. A flow chart of the incubation test study design and phases is depicted in Figure 1.

Figure 1. Summary of incubation test methods for the hatchery control, test groups, and transport controls.



3.1.7. Statistical Catch-at-age Models

Statistical catch-at-age models integrate biological information with fishery statistics, providing formal methods for estimating the abundance of existing cohorts (Hilborn and Walters 1992). This framework can incorporate multiple data sources while accounting for biological and environmental processes. It is particularly well-suited for integrating data on catch-at-age, gill netting effort, and effective spawning habitat for Cutthroat Trout in Upper Campbell Reservoir.

3.2. Datasets

Data used for the desktop assessments as well as field collected data are described at a high level in the subsections below.

3.2.1. Effective Spawning Habitat

BC Hydro provided information for reservoir-specific relationships of reservoir elevation and available habitat, water temperature in the Upper and Lower Campbell reservoirs, and species-specific life histories. Mean daily reservoir elevations for Strathcona Dam (Upper Campbell Reservoir) and Ladore Dam (Lower Campbell Reservoir) were provided for 1984 to 2023 and were used in ESH modelling (Appendix A).

For each day of the incubation period, an effective spawning elevation was derived from the daily average reservoir elevation. If this elevation exceeded the reservoir elevation on the day of spawning by 25 cm for two consecutive days, then a portion of habitat was assumed to be unsuitable for spawning and incubation. ESH area was determined from the effective spawning elevation and reservoir-specific relationships. To obtain overall ESH, the daily ESH area was weighted by species-specific intensity of spawning during the spawning season. Spawning intensities were assumed to be the same in all years and follow a normal distribution. Total annual ESH was calculated as the cumulative sum of the daily ESH during the spawning period. Similarly, total annual loss of effective habitat was calculated as the cumulative sum of the daily habitat loss during the spawning period.

3.2.2. Population Index for Upper Campbell Reservoir

1. Gill net survey data

Gill net surveys were conducted for a total of 10 years between 2014 and 2023. During this period, a total of eight sites were established, with the same sites sampled each year with some exceptions (e.g., fewer sites were sampled in years when catches approached the scientific collection permit catch limits). Sampling data were compiled into a single dataset used for analysis. The total sampling effort was 2,612 hours, averaging 261 hours per year, with an annual range of 170 to 448 hours. A total of 1,830 Rainbow Trout were captured, with yearly counts ranging from 103 to 286 and an average of 183 per year. Cutthroat Trout captures totaled 554, ranging from 22 to 148 annually, with an average of 55 per year.

2. Age structure data

A total of 395 Rainbow Trout and 240 Cutthroat Trout scale samples were aged, along with 72 Cutthroat Trout otoliths. Only one Dolly Varden was captured in each of 2014 and 2017, with none captured in any other monitoring year; therefore, age structures were not analyzed for this species.

3.2.3. Snorkel Surveys of Spawners in Reservoir Tributaries

1. Snorkel Survey Data

Between 2014 and 2023, 19 snorkel surveys were conducted in tributaries of the Upper Campbell Reservoir, 45 surveys in tributaries of Buttle Lake, and 28 surveys in tributaries of Lower Campbell Reservoir. The standard annual survey distance was 11.4 km in the Upper Campbell Reservoir tributaries, with the exception of 2014, when only 6 km were surveyed. In the Buttle Lake tributaries, 4.5 km were surveyed annually. For the Lower Campbell Reservoir tributaries, the typical survey distance was 4 km, except in 2014 and 2015, when 1.2 km and 2 km were surveyed, respectively. Yearly effort averaged 19.6 hours. A total of 64,346 Rainbow Trout and 1,073 Cutthroat Trout were observed over the course of the monitoring program, with yearly totals ranging from 3,287 to 10,970, and averaging 6,542. A total of 33,384 redds were observed over the course of the monitoring program (31,807 Rainbow Trout, 1,577 Cutthroat Trout), with yearly averages of 3,181 and 158, respectively.

3.2.4. Spawning Habitat Availability

1. LiDAR Data

Surveys were completed by Terra Remote Sensing at low reservoir levels in 2017 with average point spacing in the drawdown zones of approximately 0.5 m. These data were used to define the upper and lower extent of the drawdown zone on each waterbody.

2. RPAS Data

Surveys were conducted in 2017 using a DJI Phantom 3 Pro. Overlapping images collected with the RPAS were assembled into georeferenced orthomosaics using photogrammetric structure from motion techniques (Peterson *et al.* 2015). The final pixel resolution of the georeferenced orthomosaic layers ranged from 0.6 – 2.5 cm/pixel across the surveyed waterbodies. This imagery was used to assess fish habitat quantitatively and qualitatively in each tributary.

3. Ground-based Spawning Gravel Surveys

These surveys were undertaken in the upstream-most sections where RPAS data collection was restricted due to canopy cover or other visual obstructions. Total spawning habitat was estimated and classified according to Fish Habitat Assessment Procedure (FHAP) methods (Johnston and Slaney 1996) with minor modifications described in Buren *et al.* (2019).

4. Spawning habitat delineation from RPAS Imagery

Spatial habitat metrics were calculated manually from the RPAS orthomosaic including linear distance, wetted area, bankfull channel width, bankfull area, and spawning potential. Comparisons for each waterbody were made within the drawdown zone and upstream of the drawdown zone. All measurements and delineations were completed in QGIS (v. 2.18.14) (QGIS Development Team 2018) and ArcMap (v. 10.5) (ESRI 2016).

3.2.5. Spawning Habitat Use

In 2017 and 2018, 7,989 redds were identified and georeferenced in upstream reaches entering the Lower Campbell Reservoir, Upper Campbell Reservoir, and Buttle Lake and 1,854 redds were recorded in drawdown zones. Surveys covered a total of 24,638 m of linear distance upstream of the drawdown zone and 6,974 m within the drawdown zone.

3.2.6. Incubation Experiments

1. Egg Incubation Data
   a. Hatchery Controls: 450 eggs were distributed across nine incubation controls.
   b. Transport Controls: 300 eggs across six transport control groups, representing different treatment conditions in two tributaries.
   c. Field Treatments: 1,500 eggs distributed across 30 treatment replicates (15 per tributary).
2. Incubation Habitat and Seepage Conditions
   a. Substrate Composition: Data on substrate characteristics at each site.
   b. Water Temperature Profiles: Continuous temperature recordings at 2-minute intervals at depths of 0 cm (on the stream bed), 10 cm, 30 cm, and 50 cm within the substrate.
   c. Subsurface Water Quality: In-situ measurements of dissolved oxygen, specific conductivity, pH, and temperature within the substrate collected using piezometers.

3.2.7. Statistical Catch-at-age Models

The dataset consists of population index data for the Upper Reservoir, as described in Section 3.2.2 above.

4. MANAGEMENT QUESTIONS

Three management questions were posed in the Terms of Reference for JHTMON-3.

4.1. Management Question 1

Following implementation of the Campbell River WUP, does the population of Rainbow Trout, Cutthroat Trout and Dolly Varden in the Upper Reservoir and the Lower Reservoir increase as a result of the expected gains in functional spawning habitat?

4.1.1. Summary

The relative abundances of three salmonid species were monitored in the Upper Campbell Reservoir from 2014 to 2023. Six sampling locations were identified based on suitable depth profiles and were sampled each year using surface and bottom gill nets (Appendix A; Map 1). Sampling was conducted at approximately the same time each summer to target periods when Rainbow and Cutthroat Trout were expected to be present in the reservoir, rather than actively spawning in tributaries. This approach was intended to provide reasonable estimates of relative abundance of these species.

For Cutthroat Trout in Upper Campbell Reservoir, the mean relative abundance (as indexed by CPUE) decreased from 2014 (0.47 fish/hr) to 2018 (0.16 fish/hr), which is a ~66% decrease. From 2019 to 2022, CPUE was relatively stable around a mean of 0.13 fish/hr (Figure 2). There was a small increase in Cutthroat CPUE in 2023 to 0.22 fish/hr. The variation in CPUE results became more pronounced starting in 2020 and stayed high through 2023, meaning that the number of fish caught per hour varied more between sampling events.. Gill nets were not deployed at two sites in Years 7

(2020), 8 (2021), and 9 (2022) because cumulative catches were near or exceeded limits specified in the fish collection permits.

For Rainbow Trout in Upper Campbell Reservoir, mean relative abundance varied between years with no clear trend (Figure 3). The relative abundance of Rainbow Trout was relatively high for the first three years of monitoring (2014-2016) then from 2017 to 2019 the relative abundance was lowest in the time series (0.50 fish/hr). Subsequently, the relative abundance reached its highest value in 2020 (1.24 fish/hr), followed by declines until 2023 (0.87 fish/hr). Variability in the estimates of years 2020-2022 was higher than in the other years.

The ESH Performance Measure Model quantifies spawning habitat within the drawdown zone that is available to fish but not subsequently inundated by rising reservoir levels during the egg incubation. Because life histories and the timing of spawning and incubation vary among species, separate ESH models were run for Cutthroat Trout, Rainbow Trout and Dolly Varden. The ESH estimates for the three species were low for the period prior to the IFMS, particularly in the Upper Campbell Reservoir (Figure 4).

Functional spawning habitat increased following the implementation of the IFMS in late 1997, particularly for Cutthroat Trout and Rainbow Trout. Estimates of ESH in the post-IFMS period are characterized by high inter-annual variability. Implementation of the WUP did not result in notable gains in spawning habitat. Patterns in the data after the implementation of the WUP are similar to those observed during the post-IFMS period (Figure 4). ESH did not change markedly following implementation of the WUP, so no clear population response was apparent in the monitoring data. (Note that the relationship between spawning habitat and fish abundance is addressed further with respect to Management Question 2; see next section).

Figure 2. Cutthroat Trout catch per unit effort in the Upper Campbell Reservoir, from gill net surveys (2014-2023). Coloured dots represent CPUE recorded at the six sampling sites. Black dot represents annual mean CPUE, and the vertical lines represent ± SD.

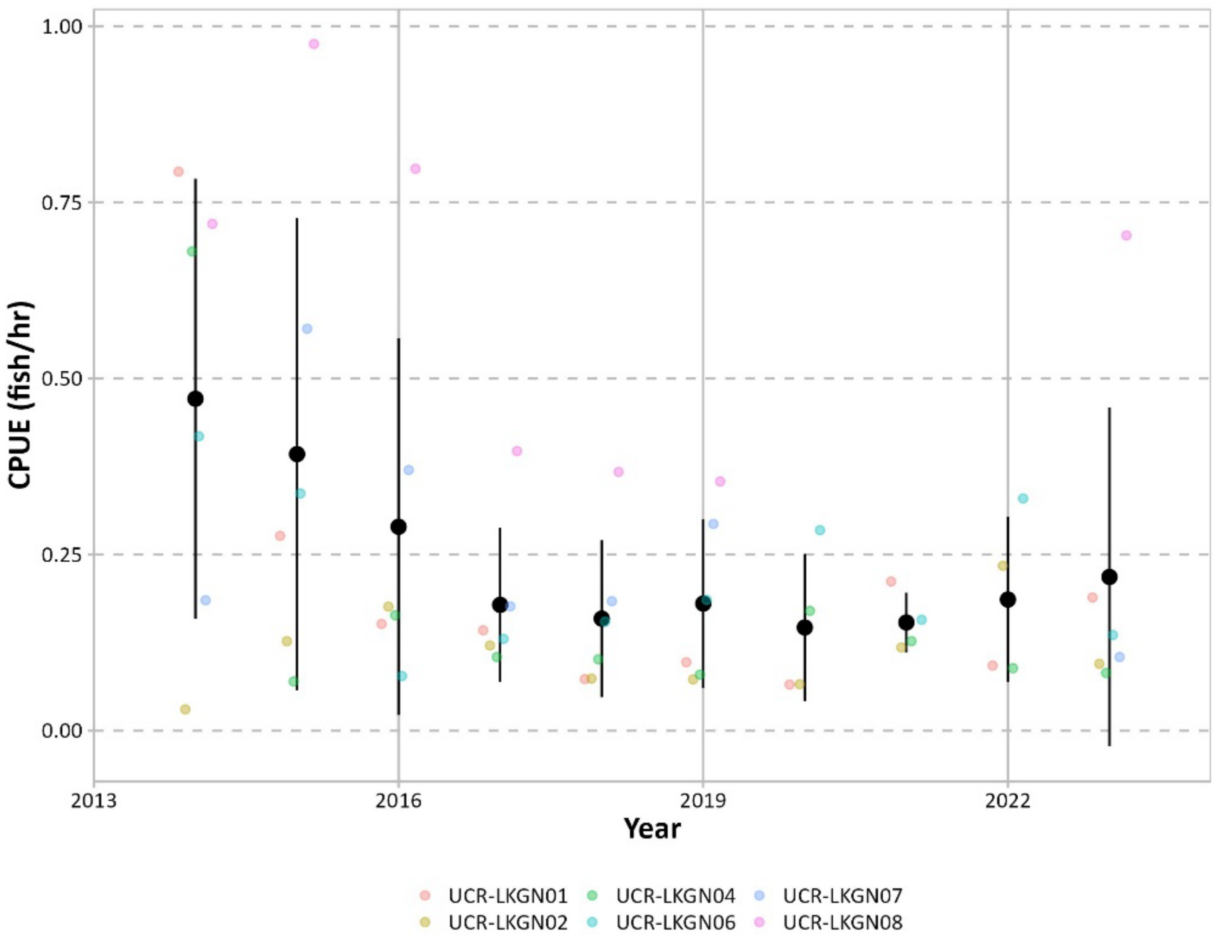


Figure 3. Rainbow Trout catch per unit effort in the Upper Campbell Reservoir, from gill net surveys (2014-2023). Coloured dots represent CPUE recorded at the six sampling sites. Black dot represents annual mean CPUE, and the vertical lines represent ± SD.

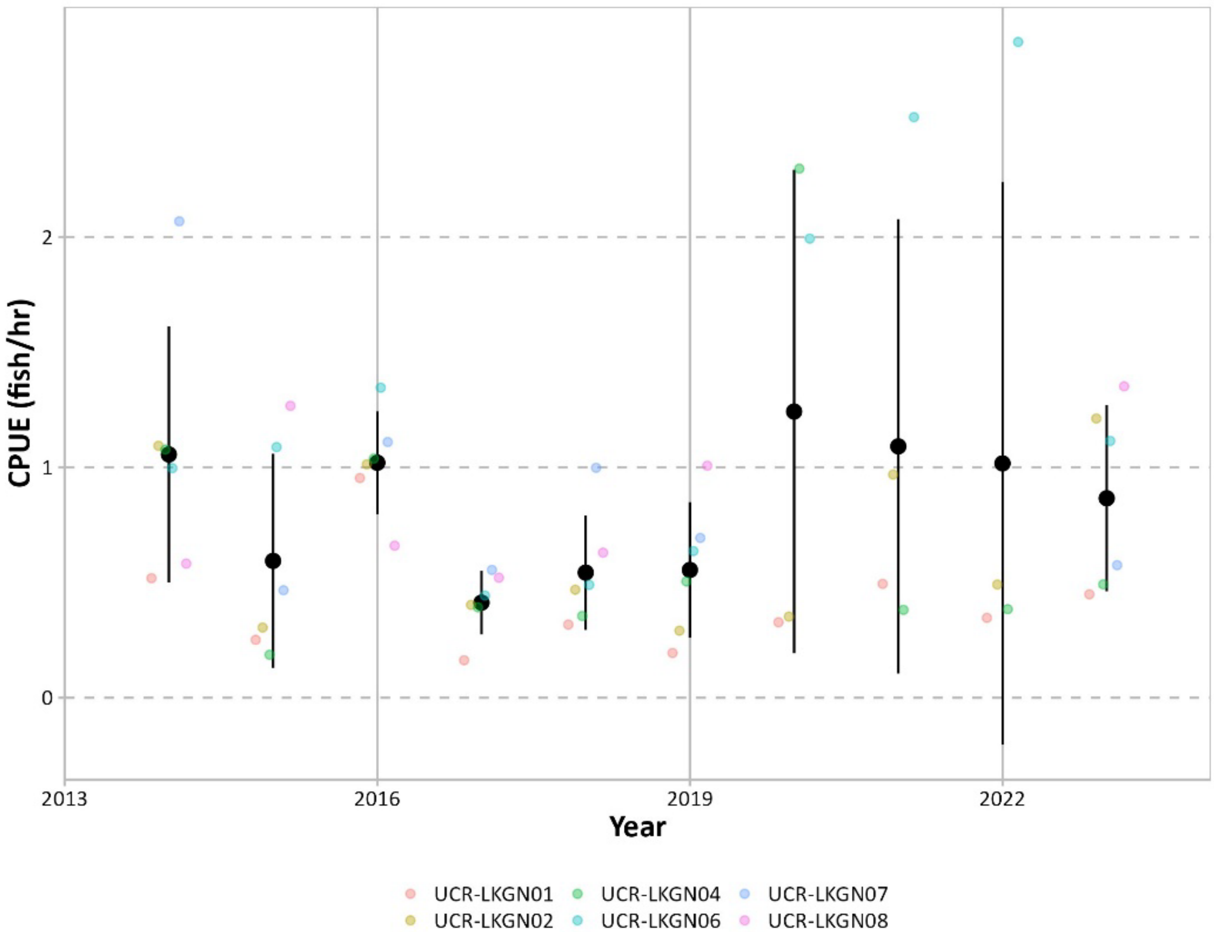
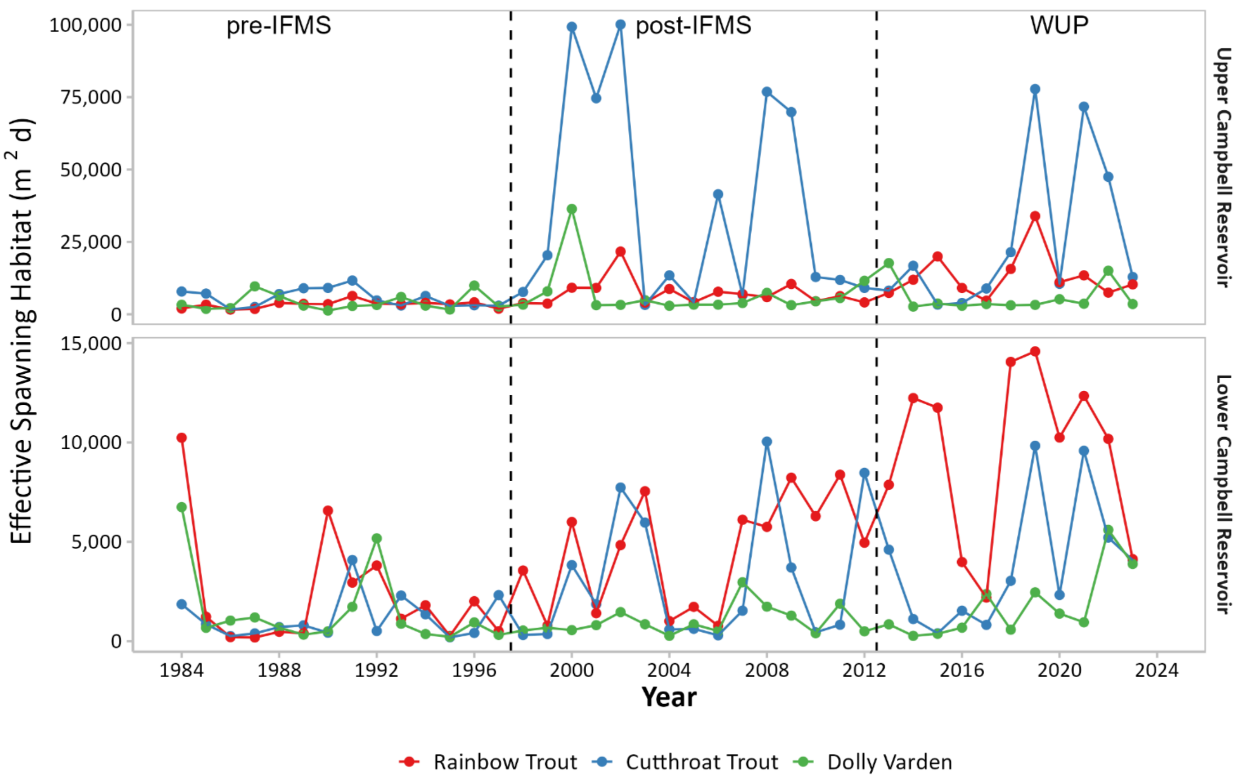


Figure 4. Effective spawning habitat estimates from 1984 to 2023 in the Upper Campbell Reservoir (top panel), and in the Lower Campbell Reservoir (bottom panel). Colours represent target species. Vertical lines denote dates of implementation of the IFMS (October 1997), and the WUP (November 2012).



4.2. Management Question 2

Are the trout populations in the Upper Reservoir and the Lower Reservoir limited by the availability of functional spawning habitat?

4.2.1. Summary

Spawning habitat surveys were carried out in 2017 using UAV imagery and ground-based assessments. Spawning habitat was considered the same across species to simplify the analysis and avoid assumptions about species specific spawn timing. This approach was considered reasonable given the similar body sizes of the target species. The focus was on identifying suitable substrate during the survey.

Spawning habitat was assessed in fish-accessible streams entering the Lower Campbell Reservoir, Upper Campbell Reservoir, and Buttle Lake. Approximately 80% of all accessible spawning habitat occurred upstream of the drawdown zones, and approximately 20% within it. However, this relative distribution differed within and among reservoir (Table 2).

In the Elk River and Lower Campbell Reservoir tributaries, upstream reaches had more available spawning habitat than drawdown zones. In contrast, Buttle Lake tributaries had more habitat within the drawdown zone. Despite this, the Elk River and its tributaries accounted for over 70% of the total accessible spawning habitat across Upper Campbell Reservoir and Buttle Lake.

Spawning habitat is determined in part by natural stream features unrelated to BC Hydro operations. Since most habitat lies upstream of the drawdown zones, the populations of the three salmonid species assessed are less likely to be affected by reservoir operation, suggesting recruitment is more influenced by upstream conditions.

To test assumptions of the ESH PM, incubation experiments were conducted in spring 2018. Survival and hatch rates differed among streams and depths, from almost no effect of inundation (close to 100% hatch and survival rates in Ralph River) to a substantial effect of inundation (0% hatch and survival rates at 3 m below reservoir water level in Elk River) (Figure 5). The results indicate that inundation effects differ by stream and depth.

A statistical catch-at-age model was developed to assess the influence of reservoir elevation on Cutthroat Trout dynamics in Upper Campbell Reservoir, where the largest drawdown occurs. This species was prioritized because it was expected to be most sensitive to changes in water levels during incubation, and results for this species could be extrapolated to other species. The model was first developed in 2019 using a limited dataset as part of the Year 5 summary report (Buren *et al.* 2019) and later updated in 2024 during finalization of the JHTMON-3 monitoring program (Appendix B).

Results in 2019 suggested a potential relationship between effective spawning habitat (ESH) and recruitment. However, the updated model using additional years of data showed a weaker relationship. For example, recruitment at age 2+ was negatively correlated with ESH (Figure 6), which is contrary to expectations if spawning habitat availability is limiting. This result suggests that other factors may be more influential than ESH in driving recruitment.

The model focused on Cutthroat Trout, similar analyses were not conducted for Rainbow Trout or Dolly Varden due to insufficient data on age structure and abundance trends. However, the lack of a strong ESH–recruitment relationship in Cutthroat Trout suggests that spawning habitat availability may not be a dominant driver of recruitment for other species either, particularly given less sensitivity due to later spawning and lower likelihood of inundation, , and the high proportion of spawning observed above the drawdown zone. Taken together, evidence from spawning habitat distribution, incubation experiments, and population modelling suggests that functional spawning habitat may influence trout abundance in the Upper and Lower reservoirs but is likely less influential than was assumed during preparation of the WUP. Monitoring data indicate that ESH is not a strong driver of trout recruitment in these reservoirs.

Table 2. Spawning habitat availability summaries for all tributaries within the Upper and Lower Campbell reservoirs and Buttle Lake.

Reservoir	Zone	Linear Distance (m)	Wetted Area (m^2)	Channel Width (m)	Bankfull Area (m^2)	Redd Count (n)[3]
Upper Campbell	Upstream	18,404	378,282	16.8	813,244	6,794
Upper Campbell	Drawdown	3,798	85,018	40.1	152,300	50
Buttle Lake	Upstream	1,226	16,084	20.9	22,297	453
Buttle Lake	Drawdown	2,134	65,424	49.3	106,831	1,605
Lower Campbell	Upstream	5,008	31,891	9.3	46,601	742
Lower Campbell	Drawdown	1,042	11,583	14.1	13,172	199
Total	**Upstream**	**24,638**	**426,257**	**15.7**	**882,142**	**7,989**
	Drawdown	**6,974**	**162,025**	**34.5**	**272,303**	**1,854**

[1] Direct measurements from UAV aerial imagery.

[2] Estimated channel widths, wetted area and spawning potential based on field surveys.

[3] Redd counts (2017+2018) considering total redds upstream across all tributaries

Figure 5. Hatch and survival rates, by river and treatment. Estimates are shown as mean ± 2SD. RWL: Reservoir Water Level.

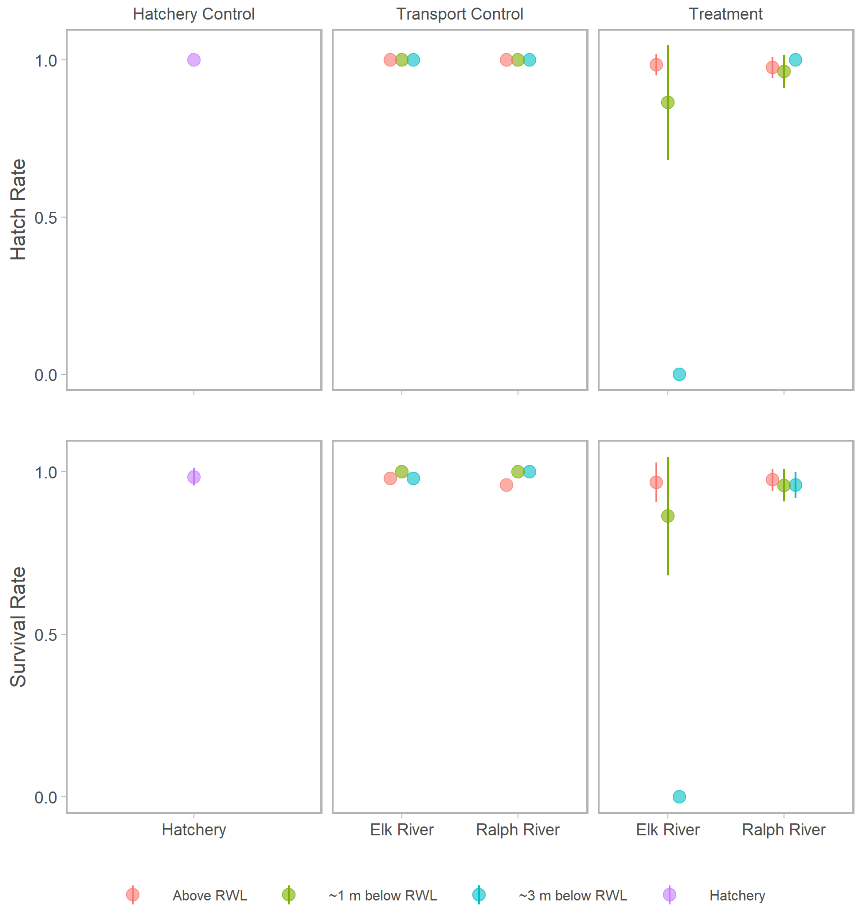
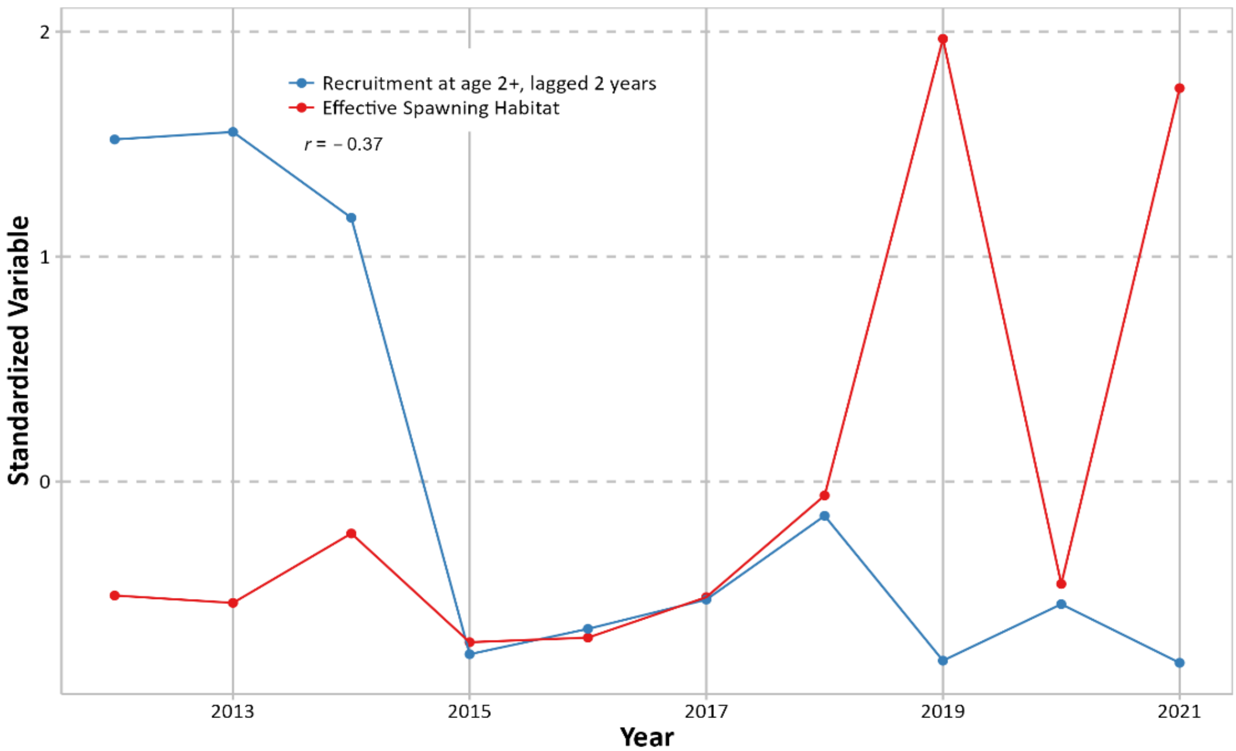


Figure 6. Estimated recruitment at age 2+ ($\hat{R}_y$) from the time-dependent model (blue), and Effective Spawning Habitat for Cutthroat Trout in the Upper Campbell Reservoir (red). To aid visualization, recruitment at age 2+ has been lagged by 2 years to match the year of effective spawning habitat (i.e., recruitment at age 2+ in year *y* is affected by ESH in year *y*-2).



4.3. Management Question 3

Is the ESH performance measure a reliable measure of spawning habitat, and therefore useful in the present Monitor, as well as in future WUP investigations?

4.3.1. Summary

The ESH performance measure was developed during the WUP to quantify effects of seasonal inundation within the drawdown zone on egg mortality of three salmonid species, and to support assessment of different potential operating regimes. The ESH performance measure rests on several key assumptions, which vary in their empirical support. The assumptions used in interpreting and estimating uncertainty are summarized in Table 3.

At the time, it was assumed that reservoir operations had a strong influence on the availability of suitable spawning habitat in Upper Campbell Reservoir, Buttle Lake, and Lower Campbell reservoir. Salmonids were believed to spawn primarily in the upper, accessible reaches of in-flowing tributaries. However, surveys indicated that substantial numbers also spawned near the confluence of some of these streams, particularly during periods of low reservoir elevation when the streams were flowing across alluvial fans.

As water levels rise in spring following spawning, redds may become inundated. This inundation was hypothesized to cause substantial mortality during embryonic development, potentially reducing fish abundance in the reservoir.

The amount of spawning habitat that remains viable after inundation is estimated using reservoir-specific relationships between reservoir level and available spawning habitat. ESH metrics are calculated by weighting available spawning habitat based on species-specific considerations.

The rationale and concepts incorporated into the ESH PM are, in our opinion, reasonable and supportable. However, based on data collected during the JHTMON-3 program, the actual influence of ESH on salmonid population abundances in the reservoirs appears to be lower than originally assumed. This poor relationship between ESH and recruitment is likely due to most spawning occurring above the drawdown zone and the finding that inundation of redds within the drawdown does not lead to instant and total mortality.

Table 3. Assumptions used in the ESH metrics and support, or uncertainty associated with the ESH PM assumptions.

Assumption	Specific Data Collected	General Comments on Validity
Rainbow and Cutthroat Trout spawn in the drawdown zones.	Information on spawning habitat use was integrated with availability data.	Overall, spawning habitat use surveys indicated that more than 80% of spawning occurs above the drawdown zone. In some tributaries, a considerable portion of spawning occurs within the drawdown zone, while in others, most occurs upstream.
Spawning habitats are no longer viable after reservoir inundation.	Incubation experiment to test egg survival under rising reservoir levels.	Results varied by stream and depth, showing minimal to substantial effects on egg survival. High mortality at 3 m below the reservoir level partially supports this assumption, though stream conditions suggest that the WUP assumptions overestimated inundation effects.
Life history timing and spawning intensity: **a.** Rainbow Trout spawning begins on May 15, ends on July 31. **b.** Rainbow Trout incubation lasts until August 15 or 600 ATU. **c.** Cutthroat Trout spawning begins on March 1, ends on April 30. **d.** Cutthroat Trout incubation lasts until July 15 or 550 ATU. **e.** Spawning intensities follow a normal distribution, with a species-specific mean equal to peak spawning day, and standard deviations equal to assumed spawning duration divided by six.	Timing and intensity assumptions were not tested in this study.	During development of the ESH performance measure, spawning and incubation timing were inferred from historical monitoring programs (e.g., snorkeling, gill netting), but no new data were collected to address these uncertainties. Hatchery-derived ATUs may not fully apply to natural settings, as interannual temperature variability and other environmental variables can influence actual hatch timing. Additionally, ATUs were calculated using generic temperature curves that assume constant conditions each year, which does not account for interannual variability and introduces potential bias. Similarly, spawning intensity and ESH weighting assume consistent distributions across years, though environmental fluctuations likely affect actual spawning dynamics. Further empirical data would be needed to refine these assumptions.
If the reservoir elevation exceeds the reservoir elevation on the assumed day of spawning by 25 cm for two consecutive days, then a portion of habitat was assumed to be lost.	No data were collected to test this assumption.	The concept of habitat loss due to inundation is conceptually reasonable; however, the study did not test the assumption that habitat is no longer functional when reservoir elevation exceeds the assumed spawning data by 25 cm for two consecutive days.

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APPENDICES