Bridge River Project Water Use Plan

Lower Bridge River Adult Salmon and Steelhead Enumeration

Implementation Year 10

Reference: BRGMON-3

Study Period: March 2021 – December 2021

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Executive Summary

The Lower Bridge River Adult Salmon and Steelhead Enumeration program (BRGMON-3) monitors adult salmonids in the Lower Bridge River (LBR) to support evaluation of the effects of flow releases from Terzaghi Dam on salmon productivity. Monitoring in 2021 (Year 10 of 10) consisted of:

1. Electronic enumeration of Steelhead Trout, Chinook Salmon, and Coho Salmon.
2. Radio telemetry to inform species-specific spawning location, migration rates, migration timing, and residence times.
3. Visual surveys to enumerate Chinook and Coho Salmon using Area Under the Curve (AUC) analyses.
4. Redd surveys to determine Chinook and Coho Salmon spawning distributions and record habitat quality at confirmed spawning locations.
5. Habitat Suitability Index (HSI) surveys to quantify effects of high flows in 2021 on the availability of spawning habitat for Chinook and Coho Salmon.
6. Ageing analyses to evaluate life history characteristics and high flow exposure.

Management questions were first defined in 2018 and revised in 2019. The management questions address two operational regimes: Water Use Planning (WUP; 2011-2015, 2019-2020) and Modified Operations (MOD; 2016-2018, and 2021). The WUP proposed an instream flow regime of three alternative base flows for evaluation (1, 3, and 6 m^3s^{-1}), with maximum flows not exceeding 20 m^3s^{-1}. These flows were exceeded in MOD years. Despite this delineation, data collected since 2011 describe how each year's flow regime affected adult salmonids in the LBR, and therefore all relevant data are used to answer each question.

WUP Management Questions:

MQ1: What is the annual abundance, timing, and distribution of adult salmon and steelhead spawning in the LBR and are these aspects of spawning affected by the instream flow regime?

We determined annual abundance in the LBR using electronic counter data for Steelhead Trout, Chinook and Coho Salmon and AUC analyses of visual survey data for Chinook and Coho Salmon. Migration timing was assessed using peak count dates from electronic counters and movement data from radio telemetry. Radio telemetry, visual surveys, and redd surveys were used to inform spawner distribution.

Escapement estimates in 2021 suggested a continued trend of low abundance in the LBR (Steelhead Trout 68, Chinook Salmon 97, Coho Salmon 561). Steelhead Trout abundance was consistent with the mean since 2015 (mean 71 SD 19). Chinook Salmon have been depressed since 2005 (as indicated by historic visual survey estimates), and the 2021 estimate was the second lowest escapement during BRGMON-3 (the 2018 estimate was 42). Coho Salmon abundances have been variable since 1997 but have remained at depressed levels since 2013.

Escapement estimates in 2021 were confounded the operation of a broodstock fence for Chinook Salmon broodstock collection, and wildfires near Lillooet that resulted in road closures and prevented counter operation. The Fraser River rockslide could still be causing inflated escapement estimates for all species due to increased straying of adults from other systems into the LBR. The effects of the rockslide cannot be distinguished from flow changes, making it difficult to determine how operations affected adult abundance in 2021. Additionally, the Chinook Salmon broodstock collection fence, operated from 2018 through 2021 in Reach 3, prevented complete Chinook Salmon escapement estimates, further inhibiting our ability to determine the effects of flow regime on LBR adult Chinook Salmon.

It is difficult to evaluate the effects of flow regime on adult abundance because anadromous salmonids spend a significant portion of their life cycle outside of the LBR. LBR flows are consistently at WUP targets during the Chinook and Coho Salmon enumeration periods (regardless of flow regime), and any effects of flow regime would likely have been incurred during the juvenile rearing stage. The effect of flow on fish abundance is more comprehensively assessed by BRGMON-1 using productivity metrics that incorporate both adult and juvenile abundance (i.e., egg-to-fry or adult-to-fry survival). BRGMON-3 is limited to evaluating the direct effects of flow regime on adult Steelhead Trout, Chinook Salmon, and Coho Salmon when they are present in the LBR during spawning migrations, and thus far we have found no clear link between spawner escapement and LBR flow.

Preliminary analyses of migration timing for Steelhead Trout and Chinook and Coho Salmon indicate consistency since 2011, suggesting migration timing is not strongly affected by instream flow regime. Spawning distributions for all species have remained similar over the course of BRGMON-3. Chinook Salmon spawning has increased in Reach 4 since 2018; however, the broodstock collection fence likely affected spawner distribution.

MQ2: What is the quality and quantity of spawning habitat in the LBR and how is spawning habitat affected by the instream flow regime?

Physical instream habitat characteristics (water depth, velocity, and substrate) were measured during redd surveys to assess the quality and quantity of spawning habitat and how it may be affected by the instream flow regime. Redd surveys at confirmed spawning locations have been completed in the LBR for Chinook Salmon since 2014 and for Coho Salmon since 2018. Despite consistent effort, redd sample sizes have been low since the beginning of high flows in 2016. For Chinook Salmon, water depth and velocity at redd locations have been consistent among years and flow regimes. While substrate size at redd locations has varied, it has remained within ranges recommended to be suitable for spawning. Preliminary evidence suggests instream flow regime may affect critical Chinook Salmon spawning habitat through substrate redistribution; however, high quality spawning habitat is not limiting in the LBR. Coho Salmon spawning habitat has observed variability among all assessed variables, but measurements are still within ranges recommended to be suitable for spawning.

MOD Management Questions:

MQ3: Have flow releases from Terzaghi Dam under the modified flow regime affected the quality and quantity of spawning habitat available in the LBR? If so, what are the potential effects on fish and what mitigation options are available?

Effects of flow releases during the modified regime were assessed using Habitat Suitability Index (HSI) surveys. HSI surveys take measurements of depth, velocity, and substrate along a transect across the river channel and are assigned a suitability value (0-1) based on species-specific habitat suitability curves. From this, Weighted Usable Area (WUA) is calculated by multiplying the surveyed area habitat size by the combined suitability value for that area to quantify available spawning habitat. In 2021, HSI surveys were reduced to Reach 3 and 4 and important spawning locations in Reach 2 (Camoo. Horseshoe Bend, and Yalakom River confluence). Total WUA has not significantly changed between years (2017, 2018, 2019, and 2021), and the majority of spawning habitat is in Reach 2. A separate evaluation of substrate size observed a significant decrease in substrates size between years, although still within species preference ranges.

Habitat transect data complement redd survey data and suggest that despite some changes in redd substrate size and spatial distribution, spawning habitat is not limited for Chinook or Coho Salmon in the LBR. Continued monitoring is required to determine whether substrate redistribution is due to MOD flow regimes, and whether this potential trend will lead to significant changes in spawning habitat quality and quantity in the LBR.

MQ4: Have flow releases from Terzaghi Dam under the modified flow regime affected the distribution of adult salmon and steelhead spawning in the LBR? If so, what are the potential effects on spawning success and what mitigation options are available?

Radio telemetry, visual surveys, and redd surveys were used to evaluate critical spawning habitat under both the WUP and MOD flow regimes. Spawner distributions of Steelhead Trout and Coho Salmon have remained consistent in Reach 3 and 4 between the two flow regimes, while Chinook Salmon showed increased preference for Reach 4 (relative to Reach 3) in 2018, 2019 and 2021. This trend was not observed in 2020, likely due to the broodstock fence that prevented migration into the upper sections of the LBR (Reach 3 and 4). Evaluating the effect of high flows on Chinook Salmon spawning distribution will continue to be confounded by the operation of the broodstock fence, as adults are collected at the fence and do not distribute and spawn as naturally as they normally would.

Several challenges have limited the ability of BRGMON-3 to assess the effects of flow regime on adult salmonid abundance, spawning timing, distribution, and critical spawning habitat in the LBR. Data collection and interpretation have been complicated by low adult salmon abundance (and therefore sample sizes), MOD flows, challenging visual conditions, a Chinook Salmon broodstock collection fence, and the Fraser River rockslide; however, monitoring remains on track to answer the management questions.

BRGMON-3 status of objectives, management questions, and hypothesis after Year 10.

Study Objectives	Management Questions	Management Hypotheses	Year 10 (Fiscal Year 2021) Status
Evaluate effects of Terzaghi Dam operations on the spawning habitat and distribution of Steelhead Trout, Chinook and Coho Salmon, and generate spawner abundances under alternative test flow regimes.	MQ1: What is the annual abundance, timing, and distribution of Steelhead Trout, Chinook and Coho Salmon spawning in the Lower Bridge River and are these aspects of spawning affected by the instream flow regime?	$H_{1.1}$: There is no relationship between the instream flow regime and the abundance of Steelhead Trout, Chinook and Coho Salmon spawning in the Lower Bridge River. $H_{1.2}$: There is no relationship between the instream flow regime and the timing of Steelhead Trout, Chinook and Coho Salmon spawning in the Lower Bridge River. $H_{1.3}$: There is no relationship between the instream flow regime and the distribution of Steelhead Trout, Chinook and Coho Salmon spawning in the Lower Bridge River.	$H_{1,1}$ • Electronic counters and visual surveys were used to enumerate Steelhead Trout, Chinook, and Coho Salmon. • In 2021, counter estimates were 68 Steelhead Trout, 97 Chinook Salmon and 561 Coho Salmon, continuing a decline in abundance for all species since the monitor began. • Cannot support or reject $H_{1,1}$. Effects of flow regime on anadromous species are difficult to evaluate given a significant portion of life history is outside of the LBR. Effects of the instream flow regime on abundance is more accurately evaluated by BRGMON-1. $H_{1,2}$ • Electronic counters and radio telemetry were used to evaluate migration timing. • Preliminary evidence suggests migration timing of all species has not changed across monitoring years. • Support for $H_{1,2}$. $H_{1,3}$ • Radio telemetry and visual surveys were used to evaluate spawner distribution. • The distribution of Steelhead Trout and Coho Salmon spawners has not changed between instream flow regimes, supporting $H_{1,3}$. • Chinook Salmon spawned more frequently in Reach 4 relative to Reach 3 in 2018, 2019, and 2021. Since 2018, Chinook Salmon distribution has been affected by the broodstock fence which confounds our ability to address $H_{1,3}$ completely.

Study Objectives	Management Questions	Management Hypotheses	Year 10 (Fiscal Year 2021) Status
Evaluate effects of Terzaghi Dam operations on the spawning habitat and distribution of Steelhead Trout, Chinook and Coho Salmon, and generate spawner abundances under alternative test flow regimes.	MQ2: What is the quality and quantity of spawning habitat in the Lower Bridge River and how is spawning habitat affected by the instream flow regime?	$H_{2.1}$: The instream flow regime does not affect spawning habitat quality in the Lower Bridge River. $H_{2.2}$: The instream flow regime does not affect spawning habitat quantity in the Lower Bridge River.	• $H_{2.1}$ and $H_{2.2}$ were both evaluated by surveys of Chinook and Coho Salmon redds since 2014 and 2018, respectively. No Steelhead Trout redd surveys were conducted due to high flows and low visibility at the time of spawning. • Chinook and Coho Salmon redd depth and velocity have remained similar among years and flow regimes, while substrate size has been variable but within ranges suitable for spawning. • Support for $H_{2.1}$ and $H_{2.2}$ for Chinook and Coho Salmon. Data not available for Steelhead Trout.

BRGMON-3 modified operations status of objectives, management questions, and hypothesis after Year 10.

Study Objectives	Management Questions	Management Hypotheses	Year 10 (Fiscal Year 2021) Status
Evaluate effects of the modified flow regime on the spawning habitat and distribution of Steelhead Trout, Chinook and Coho Salmon, and generate spawner abundances under alternative test flow regimes.	MQ3: Have flow releases from Terzaghi Dam under the modified flow regime affected the quality and quantity of spawning habitat available in the Lower Bridge River? If so, what are the potential effects on fish and what mitigation options are available?	$H_{3.1}$: Quality and quantity of spawning habitat in the Lower Bridge River has not been changed as a result of the modified flow regime.	• HSI surveys were used to evaluate habitat quality and quantity following high flows. • There was no statistical difference between WUA for Chinook Salmon spawning habitat in Reach 2, 3, and 4 of the LBR (2017, 2018, 2019, and 2021). High flows do not substantially affect spawning habitat in the LBR. • There was no statistical difference between WUA for Coho Salmon spawning habitat in Reach 2, 3, and 4 of the LBR (2019, and 2021). High flows do not substantially affect spawning habitat in the LBR. • Support for $H_{3.1}$ for Chinook and Coho Salmon
	MQ4: Have flow releases from Terzaghi Dam under the modified flow regime affected the distribution of adult spawning in the Lower Bridge River? If so, what are the potential effects	$H_{4.1}$: Distribution of adult spawning in the Lower Bridge River has not been changed as a result of the modified flow regime.	• Radio telemetry, visual and redd surveys were used to evaluate spawner distribution following high flows. • Steelhead Trout continue to spawn in both Reach 3 and 4. • Few Chinook Salmon redds have been observed since the onset of MOD (2016), but Chinook Salmon appear to spawn in both Reach 3 and 4. • Coho Salmon continue to spawn in both Reach 3 and 4. • Support for $H_{4.1}$.

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1. Introduction

1.1 Background

The Bridge River provides important habitat for Pacific salmon and Steelhead Trout (*Oncorhynchus* spp.) and is an important cultural and sustaining resource for the St'át'imc Nation. As part of the Bridge-Seton power system, the Lower Bridge River (LBR) is impounded by Terzaghi Dam and is controlled by BC Hydro through the operation of Carpenter Reservoir and Bridge River Generating Stations 1 and 2 (BRGS). From 1960 to 2000, Bridge River flows were diverted through the BRGS to the Seton River catchment for power production at the Seton Generating Station (SGS; Figure 1), and the upper 4 kms of the Bridge River below Terzaghi Dam remained almost continuously dewatered (groundwater and small tributaries contributed ~1 m^3s^{-1} averaged across the year; Longe and Higgins 2002).The lack of a continuous flow release from Terzaghi Dam was a long-standing concern for the St'át'imc Nation, federal and provincial regulatory agencies, and the public. In 1998, an agreement was reached among BC Hydro, Fisheries and Oceans Canada (DFO), and the BC Provincial Ministry of Environment stipulating that an instream flow test release and companion monitoring studies be implemented to determine the effect of flow releases on the LBR aquatic ecosystem. This agreement (called the interim flow order, IFO) resulted in water being released from Terzaghi Dam beginning on August 1, 2000, with an annual water budget of 3.0 m^3s^{-1} based on a semi-naturalized hydrograph from 2 to 5 m^3s^{-1}.

The IFO continued until the Bridge River Water Use Plan (WUP) was approved in 2011. The WUP proposed a 12-year flow release program to evaluate three alternative flow regimes (1, 3, and 6 m^3s^{-1}), intended to inform a long-term flow release strategy for the LBR. The WUP recommended monitoring the effects of flow on spawner abundance, habitat, and distribution, which resulted in the Adult Salmon and Steelhead Enumeration Program (BRGMON-3; Bridge-Seton WUP Monitoring Terms of Reference 2012). BRGMON-3 uses a combination of electronic fish counters, radio telemetry, visual surveys, and spawning habitat assessments to evaluate the impact of flow on adult spawning in the LBR. The monitor builds on previous monitoring conducted by the DFO and provides critical data to BRGMON-1, Lower Bridge River Aquatic Monitoring.

In 2016, safety concerns at the Lajoie Dam, upstream of the LBR, and critical infrastructure upgrades at the BRGS resulted in the need to increase LBR flow releases above the WUP specifications. The potential for high flows will continue until 2028 when modifications to Lajoie

Dam and repairs at the BRGS are expected to be complete. The high flow releases in 2016 caused extensive damage to resistivity counter sensors, video validation equipment, and passive integrated transponder (PIT) telemetry gear, and therefore no resistivity counter data were collected in 2016. A combination of sonar and resistivity counter technologies were installed in 2017 (Burnett et al. 2017) and have been used since. High flow releases can also increase substrate mobilization and affect spawning and rearing habitat, and comprehensive spawning habitat surveys were implemented as part of BRGMON-3 in spring of 2018 following high flows in 2017.

A broodstock program was implemented in 2018 to enhance the Chinook Salmon population in the LBR. The program included the installation of a broodstock fence and trap box directly upstream of the electronic counters (26 rkm). Catch data from fence operation were used in place of electronic fish counters to calculate a Chinook Salmon abundance estimate in the LBR.

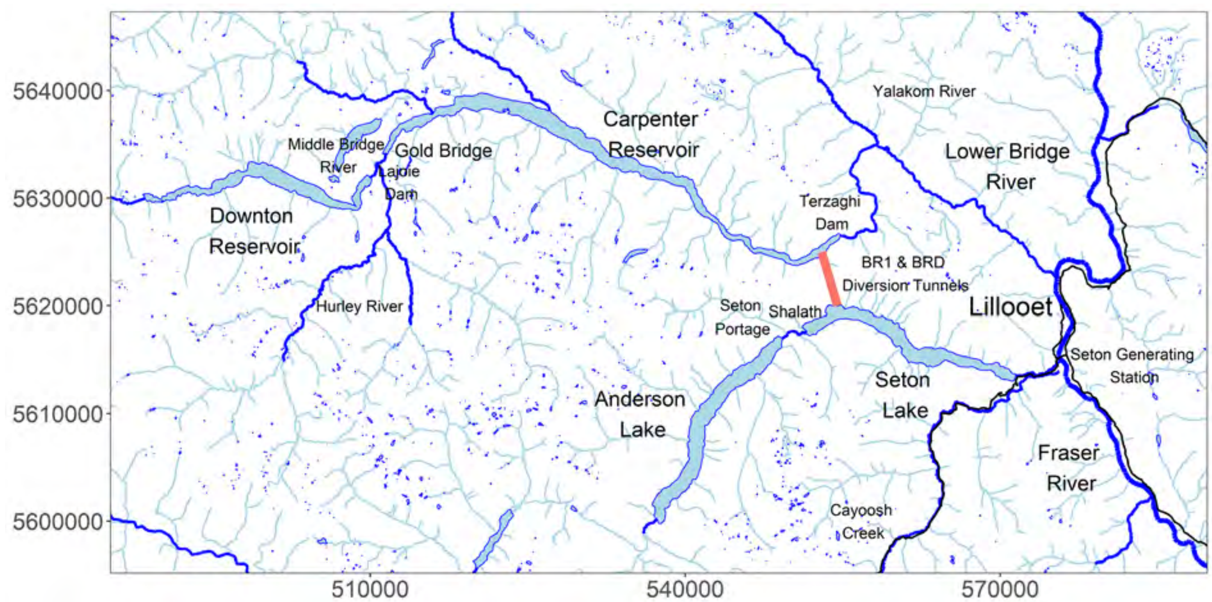

Figure 1: Bridge and Seton Watersheds showing Terzaghi Dam and diversion tunnels to Bridge River Generating Stations 1 and 2.

1.2 Management Questions and Objectives

Specific management questions were not listed in the original BRGMON-3 terms of reference (2012 TOR; BC Hydro 2012) as the monitor was designed to aid the interpretation of BRGMON-1 results. The TOR were amended in 2018 (BC Hydro 2018) to include two management questions and associated hypotheses that are now addressed by BRGMON-3.

WUP Management Questions:

1. What is the annual abundance, timing, and distribution of adult salmon and steelhead spawning in the Lower Bridge River and are these aspects of spawning affected by the instream flow regime?

   $H_{1.1}$ There is no relationship between the instream flow regime and the abundance of spawning salmon and steelhead in the Lower Bridge River.

   $H_{1.2}$ There is no relationship between the instream flow regime and the timing of spawning salmon and steelhead in the Lower Bridge River.

   $H_{1.3}$ There is no relationship between the instream flow regime and the distribution of spawning salmon and steelhead in the Lower Bridge River.

2. What is the quality and quantity of spawning habitat in the Lower Bridge River and how is spawning habitat affected by the instream flow regime?

   $H_{2.1}$ The instream flow regime does not affect spawning habitat quality in the Lower Bridge River.

   $H_{2.2}$ The instream flow regime does not change spawning habitat quantity or distribution in the Lower Bridge River.

In addition to the above management questions, two additional management questions were added to the BRGMON-3 Scope of Services in 2019 in response to modified high flow operations (MOD).

MOD Management Questions:

3. Have flow releases from Terzaghi Dam under the modified flow regime affected the quality and quantity of spawning habitat available in the Lower Bridge River? If so, what are the potential effects on fish and what mitigation options are available?

   $H_{3.1}$ Quality and quantity of spawning habitat in the Lower Bridge River has not been changed as a result of the modified flow regime.

4. Have flow releases from Terzaghi Dam under the modified flow regime affected the distribution of adult spawning in the Lower Bridge River? If so, what are the potential effects on spawning success and what mitigation options are available?

$H_{4.1}$ Distribution of adult spawning in the Lower Bridge River has not been changed as a result of the modified flow regime.

The primary objective of BRGMON-3 is to inform BRGMON-1 juvenile stock recruitment models, which will be used to determine the response of salmonid productivity to instream flow regimes in the LBR. BRGMON-3 also addresses uncertainties surrounding the effects of flow regime on spawning timing, distribution, and spawning habitat quality and quantity. Monitoring objectives are met using a combination of adult enumeration (Steelhead Trout *Oncorhynchus mykiss*, Chinook Salmon *O. tshawytsch*, and Coho Salmon *O. kisutch*), visual surveys, radio telemetry, and spawning habitat assessments. BRGMON-3 was originally restricted to the LBR between the Yalakom River and Terzaghi Dam; however, the TOR modification in 2018 expanded the study area to include the entire LBR. This report focuses on the data collected in 2021, and comparisons with previous years are included where relevant and available (Table 1).

Table 1: Summary of data collected during BRGMON-3 monitoring.

Task	Components	Species	2021 Period	Prior Years of Data
Adult Salmonid Abundance (electronic methods)	Combination of resistivity counter and multi-beam sonar	Steelhead Trout	Mar 19 to May 4	2014*, 2015*, 2017-2020
		Chinook Salmon	August 5 to Aug 25	2014*, 2015*, 2016-2020
		Coho Salmon	Oct 5 to Dec 13	2013-2015*, 2016, 2018-2020
Adult Salmonid Abundance (visual methods)	Area under the curve estimates calculated from visual counts	Steelhead Trout	NA	2014
		Chinook Salmon	Aug 25 to Sep 30	2011-2020
		Coho Salmon	Oct 1 to Dec 13	2011-2020
Compilation of Historic Visual Counts	Compiling historic visual surveys (helicopter and streamwalk) data provided by DFO	Steelhead Trout	NA	NA
		Chinook Salmon	NA	1997-1999, 2001, 2004-2010**
		Coho Salmon	NA	1997-1999, 2001, 2003-2006, 2008-2010
Radio Telemetry	Angling, tagging, and tracking movements	Steelhead Trout	Mar 15 to Jun 17	2011-2020
		Chinook Salmon	Aug 24 to Sep 30	2012-2020
		Coho Salmon	Oct 1 to Dec 14	2014-2020
Spawning Habitat Selection	Depth, velocity, and substrate surveys at observed redds following spawning	Steelhead Trout	NA	NA
		Chinook Salmon	Sep 24 and 29	2014-2020
		Coho Salmon	Dec 14	2018-2020
Scale Age Analysis	Ageing based on scale samples of individuals that spawned in the LBR	Steelhead Trout	Jan 1 to Feb 15	2014-2020
		Chinook Salmon	Jan 1 to Feb 15	2013-2020
		Coho Salmon	Jan 1 to Feb 15	2011-2020
High Flow Monitoring	Habitat suitability index based on instream measurements of depth, velocity, and substrate at previous known spawning locations	Steelhead Trout	NA	NA
		Chinook Salmon	Sep 14 to Sep 28	2017-2019***
		Coho Salmon	Oct 21 to Nov 2	2019

*Resistivity counter only; ** Fence count data from 1993-1996; *** 2017 and 2018 in Reach 3 and 4, 2019 and 2021 in Reach 2-4.

2. Methods

2.1 Site Description

The LBR extends from the Terzaghi Dam 40 km downstream to its confluence with the Fraser River (Figure 2). The river is separated into four study reaches from downstream to upstream (Figure 2): Reach 1 extends from the Bridge-Fraser confluence to Camoo FSR Bridge (rkm 0-18); Reach 2 continues to the Yalakom-Bridge confluence (rkm 18-25.5); Reach 3 continues to 37.3 rkm (rkm 25.5-37.3); Reach 4 continues to Terzaghi Dam (rkm 37.3-40). Electronic counter infrastructure is located ~500 m upstream of the Yalakom River at the Reach 2/3 break. In 2021, discharge from Terzaghi Dam exceeded 20 m^3s^{-1} (WUP target) during the high flow period from May to August (Figure 3). WUP flows occurred in 2019 and 2020, and MOD flows occurred in 2016 through 2018, and 2021.

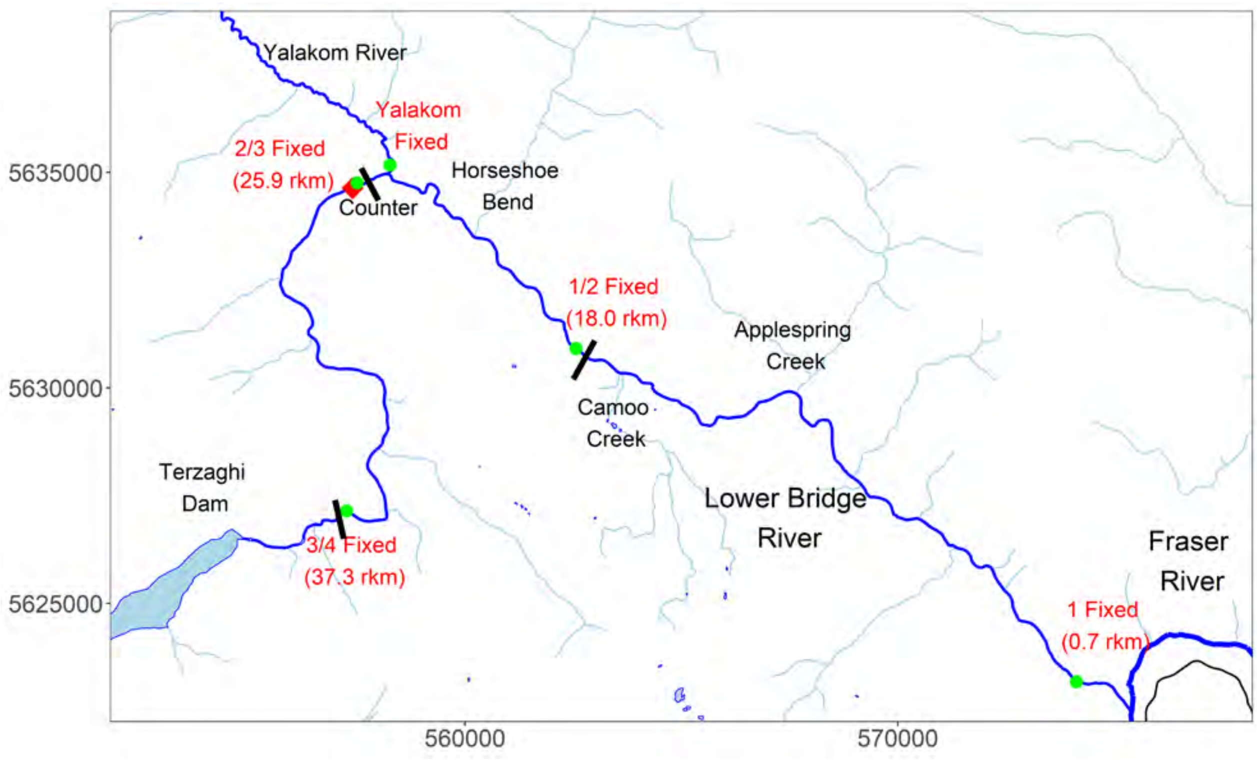

Figure 2: BRGMON-3 Lower Bridge River study area including fixed radio telemetry stations (green circles), counter location (red diamond) and reach breaks (black lines).

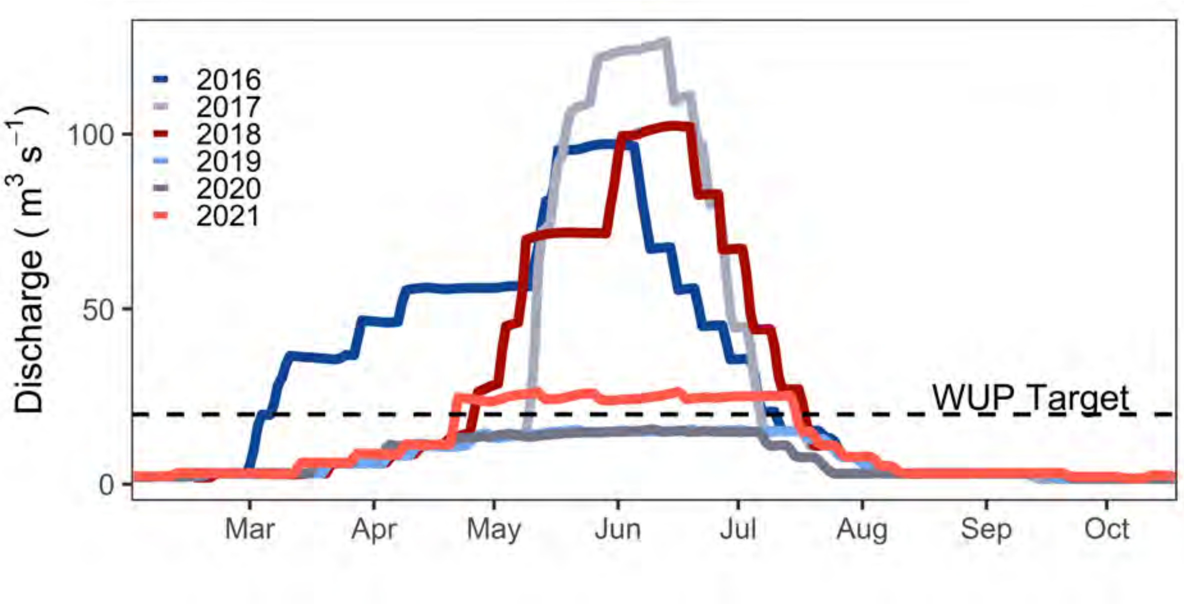

Figure *3*: **Discharge from Terzaghi Dam into the Lower Bridge River from 2011 to 2021.**

2.2 Electronic Counter Spawner Enumeration

BRGMON-3 uses electronic counters to produce annual estimates of Steelhead Trout, Chinook Salmon, and Coho Salmon abundance. Since the onset of high flow releases in 2016, a two-channel crump-weir resistivity counter operates on river right and an ARIS sonar operates on river left (Figure 4). Passage over the crump weir may not be possible at low flows, resulting in enumeration solely occurring via the sonar counter. The minimum water level for passage over the crump weir varies with fish size and migration timing, leading to species-specific enumeration methods (Table 2).

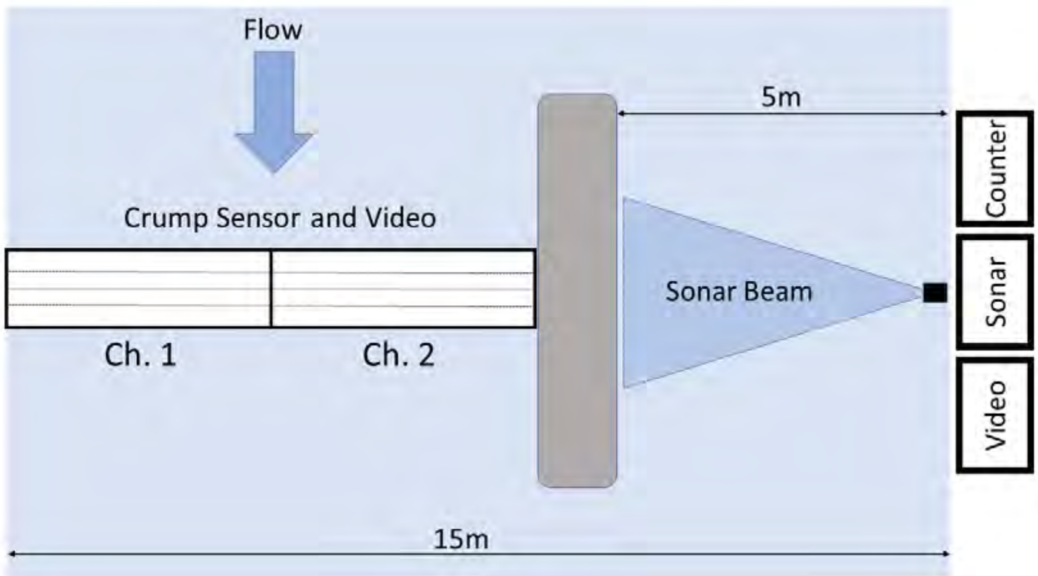

Figure 4: Configuration of the resistivity counter crump sensor, video validation system, multibeam sonar, and power system.

Table 2: Migration timing and electronic counter type and operational dates for Steelhead Trout, Chinook Salmon, and Coho Salmon in the Lower Bridge River during the 2021 monitoring season.

Species	Estimated Migration Timing	Operational Dates	Technology Used
Steelhead Trout	Apr 1 to Jun 1	Mar 19 to May 4*	Combined resistivity and sonar
Chinook Salmon	Aug 10 to Sep 30	August 5 to Aug 25**	Combined resistivity and sonar
Coho Salmon	Oct 5 to Dec 1	Oct 5 to Dec 13	Sonar

*Operational period was reduced due to discharges exceeding counting equipment thresholds.

**Enumeration was compiled from broodstock fence data between August 25 and October 4. Wildfires along the LBR interrupted data collection during the month of August.

2.2.1 Resistivity Counter Abundance Estimates

Resistivity counters measure the resistance between two pairs of electrodes (lower-middle and middle-upper) as a function of water conductivity. Fish are more conductive than water, and when a fish swims over the electrodes the counter records a change in resistance. An internal algorithm then classifies each record as an upstream movement, downstream movement, or an event by interpreting the characteristics of a sinusoidal curve created by the counter (i.e., a graphical 'trace'). The counter also records the peak signal size (PSS), corresponding to the peak of the sinusoidal curve. If a record does not follow a typical fish trace but its PSS is above a pre-defined threshold, it is classified as an event. Events can be due to a fish not completely passing over all three electrodes, other objects or animals that cause a change in resistance, or from electrical noise. PSS is related to mass and can be used as a proxy for fish size or species, when size differs among species that spawn at similar times (McCubbing and Ignace 2000).

PSS cut-offs were developed for the LBR counter to differentiate Steelhead Trout and adult salmon from resident species (e.g., Rainbow Trout, Bull Trout, Mountain Whitefish). PSS frequency distributions were visually examined to identify troughs that indicated the descending limb of small-bodied residents and the ascending limb of larger salmon or Steelhead Trout. The point where the least overlap occurred was used as the PSS cut-off.

Counter Validation and Accuracy

Resistivity counters are subject to measurement error and must be validated to determine counter performance and estimate abundance. Continuous video data were collected for validation using four infrared cameras situated over the crump weir and connected to a video recorder (Geovision). White LED lights (3-watt, 300 Lumen) were installed alongside the cameras to improve the quality of night footage.

To determine counter accuracy, paired video validation and counter data were classified into three states:

1. True Positive (TP): The counter recorded a movement, and a fish was observed during validation.
2. False Positive (FP): The counter recorded a movement, but no fish were observed during validation.
3. False Negative (FN): The counter did not record a movement, but a fish was observed during validation.

The frequency of the above states was determined using a two-step validation process including targeted validation to identify FP and TP, and random validation to identify FN. During targeted validation, all counter records were matched to video data (plus one minute before and after) to determine the number of TPs and FPs. During random validation, a subset of randomly selected video segments was reviewed to determine a FN rate that could be applied to the full migration window. Validation date ranges were selected based on range of peak migration timings observed throughout the monitoring period 2014-2020 (White et al. 2020). Twenty randomly selected 10-minute segments of video data per day were reviewed to validate Steelhead Trout (March 23 to April 29). Wildfires that resulted in the temporary closure of highway 40, allowed for limited video collection during the Chinook Salmon migration (August 5 to 25). 12 hours of video were watched between August 12 and 13.

Counter accuracy was calculated for upstream and downstream movements using the rates of *TP*, *FP*, and *FN* determined during validation:

(1)
$$A = \frac{TP}{TP + FP + FN}$$

where *A* is the accuracy, *TP* is the number of true positives from targeted validation, *FP* is the number of false positives from targeted validation, and *FN* is the estimated number of false negatives derived from random validation (i.e., the number of false negatives in the randomly validated subset multiplied by the total migration period).

Abundance Estimates

Species-specific net up counts (spawner abundance) were calculated using the equation:

(2)
$$E = \sum_{t=1}^{n} \left(\frac{U_t}{A_{up}} - \frac{D_t}{A_{down}} \right)$$

where E is the estimated abundance, U_t is the daily number of upstream fish detections for day t, D_t is the daily number of downstream detections for day t, A_{up} is upstream counter accuracy, A_{down} is the downstream counter accuracy, and n is the final date of the upstream migration. Although overlapping migrations can make it difficult to determine the start and end date for each species, migration timing was defined using data from radio telemetry, stream-walks, video observations, and a previous telemetry study by Webb et al. (2000).

The use of accuracy in Equation 2 allows abundance to be estimated even in the event of missing data or changes in river conditions. Although days with missing data are not included in the validation process, accuracy calculated from outside these days can be used to obtain a full estimate of abundance.

2.2.2 Multibeam Sonar Abundance Estimates

An ARIS Explorer 1800 (Sound Metrics Corporation, Bellevue, Washington, USA) was mounted to an aluminum bracket and positioned at half of the water depth and oriented horizontally across the channel. A tilt angle of 28° upstream was introduced in 2019 to increase the area covered by the sonar beam and increase the number and accuracy of length measurements.

Echoview post-processing software (Version 8; Echoview Software Pty Ltd., Hobart, Australia) was used to enumerate fish migrating through the sonar beam (ARIS). Sonar data were imported into Echoview as a virtual echogram (objects are plotted in relation to beam angle and distance to the sonar head), background noise was reduced, and Echoview highlighted sections of sonar data that contained fish-like movements. These movements were then verified by an experienced analyst to determine the number of true fish movements.

Echoview produces estimates of fish length; however, these may be inaccurate due to the nature of the site and flow dynamics. A subset of fish lengths pre-August 25 Chinook Salmon 16%; Coho Salmon 14%) were manually measured using the sonar's proprietary software (ARISFish, Sound Metrics Corporation, Bellevue, Washington, USA). All Steelhead Trout were measured in 2021. Direction-specific linear models of ARISFish lengths vs lengths estimated by Echoview were used to predict the lengths of all other fish. Echoview length, distance from the sonar head, and number of targets were included as potential covariates in the linear models and AICc model selection (corrected for small sample sizes) was used to determine the most parsimonious models.

Predicted lengths were used to differentiate Steelhead Trout and adult salmon from smaller resident fish species. A species-specific size cut-off was applied to predicted lengths to estimate the number of each species crossing upstream and downstream through the sonar beam. Size cut-offs were determined by length-frequency distributions based on previous years catch data for both the Seton River (Sockeye Salmon; BRGMON-14) and LBR (Steelhead Trout, Chinook, and Coho Salmon; BRGMON-3 and broodstock program; Appendix 1). A final net abundance was then estimated by subtracting downstream movements from upstream movements of the target species.

2.2.3 Steelhead Trout Enumeration

Electronic counter data was collected up until May 4, when both the sonar and resistivity counters were removed because of discharges exceeding operational threshold.

Therefore, an estimate of upstream-migrating steelhead spawner abundance based solely on counter data is expected to be biased low. To estimate the up-stream migrating abundance after May 4, an arrival model was used to make predictions of daily abundance after May 4. Daily abundance (Nt) from the onset to completion of the run is predicted by assuming that the run is normally distributed over time and scaled by an overall abundance parameter (N). The counter is located within the spatial distribution of spawning. Therefore, to predict the daily abundance migrating upstream past the counter, another scale parameter is introduced according to the estimated proportion of radio tagged steelhead that migrated upstream of the counter (12/14 in 2021, denoted at the parameter pUp). The abundance passing the counter on any given day is therefore predicted by:

(3) $$Nt = N * pUp * normdist(day, md, sd, false)$$

To estimate the number of upstream detections by the counter, a scale parameter for detection efficiency (counter accuracy) is introduced as follows:

(4) $$Ct = q * Nt$$

where q is the detection efficiency assumed to be 1. Resistivity counter accuracy is > 90% and sonar are assumed to be 1.

All error is assumed to be in the form of observation error, so

(5) $$Ct = q * Nt + et$$

where et is assumed to be Poisson distributed.

Therefore, the likelihood of the daily number of upstream migrating Steelhead detected by the counter, given the parameters pUp, md and sd is the product of the likelihoods computed across days.

In addition to the likelihood of the counter detection data, an additional likelihood component is used to support the md parameter by using the radio tagging data. The likelihood of the day of passage of a radio tagged Steelhead given md is computed assuming observation error in md is normally distributed. The likelihood for all radio tagged Steelhead data is the product of likelihoods across all radio tagged fish that migrated upstream past the counter.

The total likelihood is therefore the product of:

1. the likelihood of the daily number of upstream migrating Steelhead detected by the counter,
2. the likelihood of the day of passage of radio tagged Steelhead.

A maximum likelihood estimate of N is the hypothesis of N that maximizes the total likelihood by searching over parameters pUp, md, sd, and a nuissance parameter for the obseration error model of md (due to the assumption that observation error is normally distributed).

Therefore, an estimate of total abundance (N) for the Bridge watershed for the time period up to May 4 is the sum of upstream detections/pUp/qUp and an estimate of N for the period after May 4 is the sum of Nt/pUp after that date.

2.2.4 Chinook Salmon Enumeration

Both the resistivity and sonar counter were deployed from August 5 to 25 to enumerate Chinook Salmon. As a result of a wildfire near the LBR, highway 40 was closed to non-essential traffic so sonar and resistivity data were intermittent during its operational period. A channel spanning fence was installed on August 25 for the Chinook Salmon broodstock program. After this date, the broodstock fence alone was used for Chinook Salmon enumeration and counts were added to electronic counter data up to August 25 to provide an overall abundance estimate.

2.2.5 Coho Salmon Enumeration

During the beginning of the Coho Salmon migration period (October 1), it is possible to have Chinook, Sockeye, Pink, and Coho Salmon in the LBR at the same time. Adding to the challenge was the Chinook Salmon broodstock fence operated until October 4. In the days immediately following the removal of the broodstock fence, there was considerable up and down movements past the sonar, likely a result of a pulse of activity once the impediment was removed and natural migration was restored. It was difficult to differentiate between species during the days immediately following fence removal, so migration timing data from past years were used to infer the start of Coho Salmon migration. Historical migration timing indicates that Coho Salmon begin migrating past the counter October 15 (White et al. 2021), so this date was used to begin the enumeration.

2.2.6 Kelting or Downstream Movement

The downstream movement of adult salmonids following spawning can be a result of kelting, (in Steelhead Trout) where individuals migrate out of the LBR and return to the ocean, or moribund or dead individuals that move past the counter as they yield to the flow. To calculate an accurate abundance estimate, a date must be identified after which down counts because of kelting or moribund/dead individuals are not subtracted from the net abundance. The onset of the kelt out-migration for Steelhead Trout typically begins after mid-May and moribund/dead Coho Salmon begins after the first week of November. To estimate this date for abundance estimation purposes, counts from fish recycling (moving up and down over the counter sensor pads) and downstream moving fish due to kelting need be distinguished. One difference between recycling down counts and kelting down counts is that recycling does not produce a temporal pattern of down detections, while kelt detections produce a temporal pattern resembling a normal distribution. In other river systems where resistivity counters are deployed (e.g., Deadman and Bonaparte Rivers, BC), a date is calculated from a normal distribution of down counts after a river-specific kelt date (based on historic counter data) has been set. The date after which 5% of down counts occurs on the ascending limb of the modelled normal distribution (Braun et al. 2017).

2.3 Radio Telemetry

2.3.1 Fish Capture, Tagging and Sampling

Radio telemetry was used to assess migration timing, spawner residence time (survey life, SL), spawner distributions, and visual survey observer efficiency (OE). SL and OE are key components of estimating abundance through area-under-the-curve (AUC) methods (see Section 2.5). Fish were captured by angling and gastrically implanted with a TX-PSC-I-1200-M radio tag (45 × 16 × 16 mm; Sigma Eight Inc., Ontario, Canada). Tag burst rate varied depending on whether the fish was active (presumed alive; 5 second burst rate) or inactive (presumed dead; 13 second burst rate), thus informing SL. External identification tags (Peterson discs) were applied to Chinook and Coho Salmon to estimate OE during visual surveys (no visual surveys occurred for Steelhead Trout). Fork length (mm) and sex were recorded during tagging, and scale samples were obtained for ageing analysis (see Section 2.7).

Tagging effort was distributed throughout each species' migration period: February through April for Steelhead Trout, August through September for Chinook Salmon, and October through

November for Coho Salmon). Angling occurred ~8 rkm downstream of the Seton-Fraser confluence for Steelhead Trout and in Reach 1 and 2 of the LBR or Chinook and Coho Salmon.

2.3.2 Radio Tag Tracking

All reach boundaries had fixed radio receiver stations (herein, ‘fixed stations’) to assess entry and exit into corresponding reaches (Stations 1-4; Figure 2). Additional fixed stations were located on the Yalakom River ~100 m upstream of its confluence with the LBR (Station 5; Figure 2), ~3.5 rkm upstream of the LBR-Fraser confluence and, during the Steelhead Trout migration period, in the Seton River downstream of the lower spawning channel. Each fixed station consisted of an Orion receiver (Sigma Eight Inc., Ontario, Canada) connected to a single 6-element Yagi antenna oriented perpendicular to flow. Fixed stations were operated from March to June for Steelhead Trout, August to October for Chinook Salmon, and October to December for Coho Salmon.

Mobile tracking (by foot and by vehicle) was conducted weekly during each species’ spawning period using a hand-held SRX 400 receiver (Lotek Wireless, Ontario, Canada), and twice weekly during peak spawning for increased spatial and temporal resolution. The full lengths of Reach 3 and 4 were surveyed. Given access issues, Reach 1 was monitored at the LBR-Fraser confluence and Reach 2 at Camoo FSR, Antoine Creek and Horseshoe Bend (Figure 2).

2.3.3 Radio Telemetry Analyses

All detection data were collated and filtered to remove noise and erroneous data. Migration rate (in km day^{-1}) was calculated between reach boundaries by dividing the known kilometers between reaches by the number of days a fish took to move from one reach boundary to the next (i.e., the difference between first detection at an upstream reach and last detection at a downstream reach). Survey Life (SL) or residence time in Reach 2 and 3 was calculated for each tagged fish based on the time spent above each reach boundary prior to assumed spawning. Detection efficiency of fixed stations was determined as the ratio of fish detected upstream previously detected downstream (efficiency could not be calculated for the most upstream Reach 3/4 fixed station).

2.4 Migration Timing

Species-specific peak migration timing (a proxy for peak spawn timing) was assessed for all years using count data from resistivity and sonar counters, and detection data from fixed stations. Normal distribution models of migration timing were developed for both counter data and telemetry data, and visually compared among years and data types.

For counter data, peak migration timing was established for each species by fitting a normal distribution to the peak up count and the standard deviation recorded by the counter, assumed to represent peak migration. For telemetry data, migration timing distributions were developed by determining when tagged fish moved upstream through study reaches. Telemetry data were collated for all available years and the date of entry into Reach 3 (i.e., past the counter site) was calculated for each tagged fish. Only species and year combinations with five or more individuals observed at a given fixed station were included. A normal distribution was then fit to the annual mean date and standard deviation of entry into Reach 3. For Steelhead Trout, which are primarily captured at the Seton-Fraser confluence, dates of entry into the LBR (Station 1) were also determined. For Coho Salmon in 2014 and 2015, PIT telemetry was used instead of radio telemetry to calculate date of entry above the counter site, which was used to develop migration timing distributions for those years (Burnett et al. 2016).

2.5 Visual Counts and AUC Population Estimates

2.5.1 Visual Counts

Visual surveys of Chinook and Coho Salmon were conducted in the LBR and used to estimate abundance using an AUC method (visual surveys are not performed for Steelhead Trout due to low visibility). Visual survey data were also used to corroborate spawning distribution and migration timing of radio telemetry data.

Visual surveys occurred weekly from August 25 to December 13 for Chinook and Coho Salmon. During each survey, two observers walked downstream along the river's edge and recorded fish count, species, location, water clarity (Secchi disk), and cloud cover. Visual surveys have been performed in Reaches 2 through 4 since 2018. Visual surveys historically focused on Reach 3 and 4, which were subdivided into eight visual survey (or 'streamwalk') sections from Terzaghi Dam to the Yalakom River. Visual surveys (or 'streamwalk' surveys) were conducted by walking entire lengths of sections or driving to specific locations where the LBR is accessible and has habitat conducive to visually identifying fish (i.e. not white water sections). Survey section boundaries are at Longskinny (39.6 rkm), Eagle (38.8 rkm), Bluenose (38.2 rkm), Cobra (34.4 rkm), Fraser Lake (33.2 rkm), Russel Springs (30.7 rkm), Hell Creek (28.8 rkm), and Yalakom (25.0 rkm; Figure 5). Surveys in Reach 2 consisted of point counts from the upstream end of

Horseshoe bend and Camoo FSR bridge (24.0 and 18 rkm). No visual surveys were conducted in Reach 1 due to lack of access.

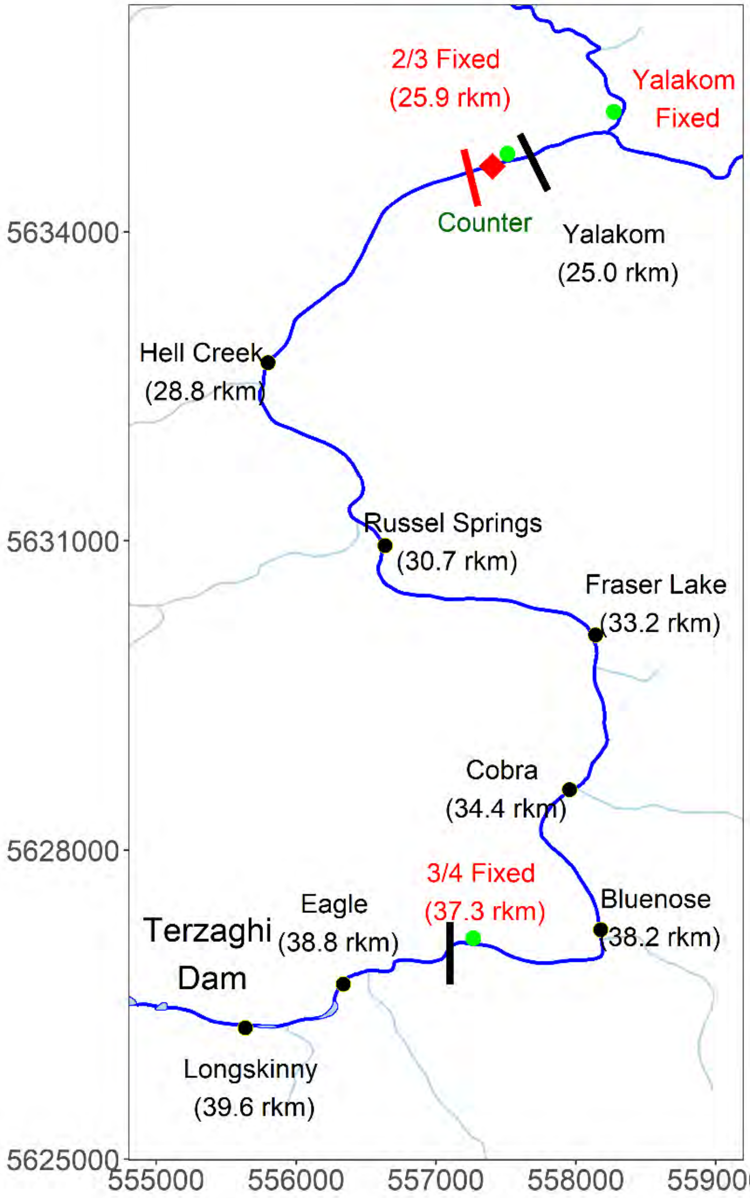

Figure 5: Visual survey boundaries (black circles), fixed telemetry stations (green circles), counter location (red diamond), reach breaks (black lines) and broodstock fence location (red line) in Reach 3 and 4 of the Lower Bridge River.

2.5.2 AUC Abundance Estimates

To estimate abundance, count data were modelled using a quasi-Poisson distribution with spawn-timing described by a normal distribution, and parameter estimates evaluated using maximum likelihood estimation (see details in Millar et al. 2012).

The number of observed spawners at time t (C_t) is

(6)
$$C_t = a\ exp\left[-\frac{(t-m_s)^2}{2\tau_s^2}\right]$$

where a is the maximum height of the spawner count curve, m_s is the date of peak spawning, and τ_s^2 is the standard deviation of the arrival timing curve. Because the normal density function integrates to unity, the exponent term in Equation 7 becomes $\sqrt{2\pi\tau_s}$ and the equation can be expressed as

(7)
$$F_g = a\sqrt{2\pi\tau_s}$$

where F is the number of observed fish. The final abundance ($\hat{E}$) is then estimated (using maximum likelihood) by applying observer efficiency OE (v) and residence time (also called survey life; SL; l) to the expected number of observed spawners

(8)
$$\hat{E} = \frac{\hat{F}_G}{l * v}$$

$\hat{E}$ is estimated using maximum likelihood (ML), where $\hat{a}$ and $\hat{\tau}$ are the ML estimates of a and τ_s in Equation 7 $\hat{C}_t = \hat{a}\sqrt{2\pi\hat{\tau}_s}$).

Equation 8 can be re-expressed as a linear model, allowing the estimation to be performed as a log-linear equation with an over-dispersion correction factor. The correction accounts for instances where the variance of the spawner count exceeds the expected value. The expected number of observed fish $\hat{F}_G$can be estimated by

(9)
$$\hat{F}_G = \sqrt{\frac{\pi}{-\hat{\beta}_2}}exp\left(\beta_0 - \frac{\hat{\beta}_1^2}{4\hat{\beta}_2}\right)$$

where β_0, β_1, β_2) are the regression coefficients of the log-linear model. Uncertainty in OE and SL are incorporated into the estimated abundance using the covariance matrix of the modeled parameters β_0, β_1, β_2 via the delta method (described in Millar et al. 2012).

2.5.3 Chinook Salmon Visual Enumeration

As with electronic counter estimates, Chinook Salmon abundance estimates were limited to fish that migrated past the counter site prior to broodstock fence installation on August 25. Streamwalk section 8 (Hell Creek to Yalakom; rkm 25.0 to 28.8) was subdivided into upstream and downstream of the broodstock fence. Only fish that were counted upstream of the fence were included in the AUC estimate and broodstock collection data were added to this estimate for comparisons to electronic counter data.

2.5.4 Observer Efficiency and Survey Life

OE and SL parameters are difficult to estimate in the LBR due to low number of tagged individuals and low underwater visibility caused by the highly turbid glacial runoff. Species-specific OE and SL have been collected since 2011 using a combination of radio telemetry, PIT telemetry, and visual surveys, but are highly uncertain. To estimate OE, the percentage of visually marked individuals (i.e., Peterson disc tags) observed during visual surveys was compared to the number of fish known to be in the survey area via telemetry. PIT telemetry was used for Coho Salmon during 2014 and 2015 to calculate SL, after which high flows made PIT telemetry unsuitable (Burnett et al. 2016). Individual SL was calculated as the time between Reach 3 entry and assumed mortality (i.e., the radio tag switched to 13 second burst rate) or downstream migration (kelting) was observed (for Steelhead). Most spawning occurs in Reach 3 and 4 of the LBR; date of entry into Reach 3 is used to differentiate migration from spawning behavior. The average SL was then calculated and used in the AUC model.

Availability of OE and SL data have been inconsistent, mostly due to low sample size in many years. Where year-specific OE and SL could not be obtained, averages among year-specific values were used. OE and SL were available for Chinook Salmon in 2012, 2013, 2014, and 2016 and for Coho Salmon in 2012, 2013, and 2016-2018 (Table 3; Appendix 2). Standard errors were the same for all years (i.e., standard error of all year-specific values). OE standard error was 0.139 for Chinook Salmon and 0.019 for Coho Salmon, while SL standard error was 0.65 for Chinook Salmon and 1.29 for Coho Salmon.

Table 3: Observer efficiency (OE) and survey life (SL) used during AUC abundance estimation for Chinook and Coho Salmon. Calculated values are bold, while all other values represent the average of calculated values.

	Chinook		Coho	
year	OE	SL	OE	SL
1997-2011	0.50	10.5	0.22	19.6
2012	**0.58**	**10.0**	**0.25**	**16.0**
2013	**0.28**	**11.0**	**0.27**	**19.0**
2014	**0.28**	**12.0**	0.22	19.6
2015	0.50	10.5	0.22	19.6
2016	**0.86**	**9.0**	**0.17**	**22.0**
2017	0.50	10.5	**0.19**	**23.0**
2018	0.50	10.5	**0.20**	**18.0**
2019	0.50	10.5	0.22	19.6
2020	0.50	10.5	0.22	19.6
2021	0.50	10.5	0.22	19.6

2.5.5 AUC Reconstructions of Historic Count Data

A historic time series of AUC estimates using past count data obtained from the DFO was constructed for Coho and Chinook Salmon using the average OE and SL values. Helicopter count data were available from 1997 to 2004, and visual survey data were available from 2005 to 2010 (not all years were available for both species – see Appendix 2). Zero counts were not collected during all historic surveys (necessary for AUC modelling with low sample sizes) and zeros were added on August 8 and October 2 for Chinook Salmon and October 19 and December 6 for Coho Salmon, where necessary. A broodstock fence located in Fraser Lake (rkm 33.2) was also used to enumerate Chinook Salmon between 1993 to 1996. The fence data are assumed to be a complete population estimate, and the reconstructed AUC estimates help to complete the historic record from 1993 onwards.

Reconstructed AUC estimates are limited by a lack of accurate OE and SL data. For both Chinook and Coho Salmon, means and standard errors of OE and SL from years with OE and SL data were used during historic reconstructions (Appendix 2). Historic estimates will continue to be updated as more OE and SL data are collected; however, reconstructed AUC estimates should be considered highly uncertain and interpreted with caution given the lack of OE and SL data and the change in instream conditions since the 1990s.

2.6 Spawning Habitat

2.6.1 Habitat Surveys

Historical radio telemetry, visual survey, and redd evaluation data were used to identify important spawning locations where reach-wide, cross-sectional habitat assessments were completed. Spawning locations were divided into habitat units as defined in Johnston and Slaney (1996) and cross-sectional transect sites were identified within each individual unit (87 transects in 21 distinct habitat units; Figure 6). The number of transects established within each habitat unit was dependent on the heterogeneity of the unit (visual estimates of depth, velocity, and substrate), with more similar habitat requiring fewer transects to accurately model habitat conditions. Each transect was located equidistant from the upstream and downstream end of the unit and represented an area of stream bed halfway to the neighboring points along the transect and to the boundaries of the next upstream and downstream transect (Mosley 1985). All transect sites were geo-referenced using a hand-held GPS receiver (accurate to ±10 m) and marked with a 5/8” diameter rebar pin placed above bankfull width.

Habitat surveys were conducted in Reach 2-4 between September 14 and September 28, 2021, to evaluate potential changes in Chinook Salmon spawning habitat and to evaluate effects of the year’s high flows (discharge 3 m^3s^{-1}). Observations of Coho Salmon from radio telemetry, visual counts and redd surveys, indicate similar habitat use in the LBR.Surveys were also conducted between October 21 and November 2, 2021, at the same transects to evaluate spawning habitat for Coho Salmon (discharge 1.5 m^3s^{-1}). Water depth and velocity were measured every meter along each cross-sectional transect with a current velocity meter (Swoffer Instruments, Model 2100). Water velocity was measured at 60% of the total depth (mean column velocity-V60) and three successive five second averages were recorded to calculate an overall average velocity at each location along the transect. Two methods of substrate data were collected along each transect. A visual assessment of substrate within a 1 m x 1 m visual quadrat at each point along the transect was conducted whereby the dominant substrate type was classified into seven categories: fines, small gravel, large gravel, small cobble, large cobble, boulder, and bedrock. Additionally, the intermittent axis (2nd largest length) of 100 pieces of substrate randomly selected along each transect was calculated.

Due to high levels of turbidity in the LBR in Fall 2021, visual substrate estimates were conducted in Winter 2022 (March 29 and 30) prior to flows exceeding 3 m^3s^{-1}.

Water depth, velocity, and qualifications of dominant substrate type for each point on each transect were integrated into Habitat Suitability Index (HSI) models, which provide objective criteria regarding habitat suitability for a given species and life stage (Raleigh et al. 1986).

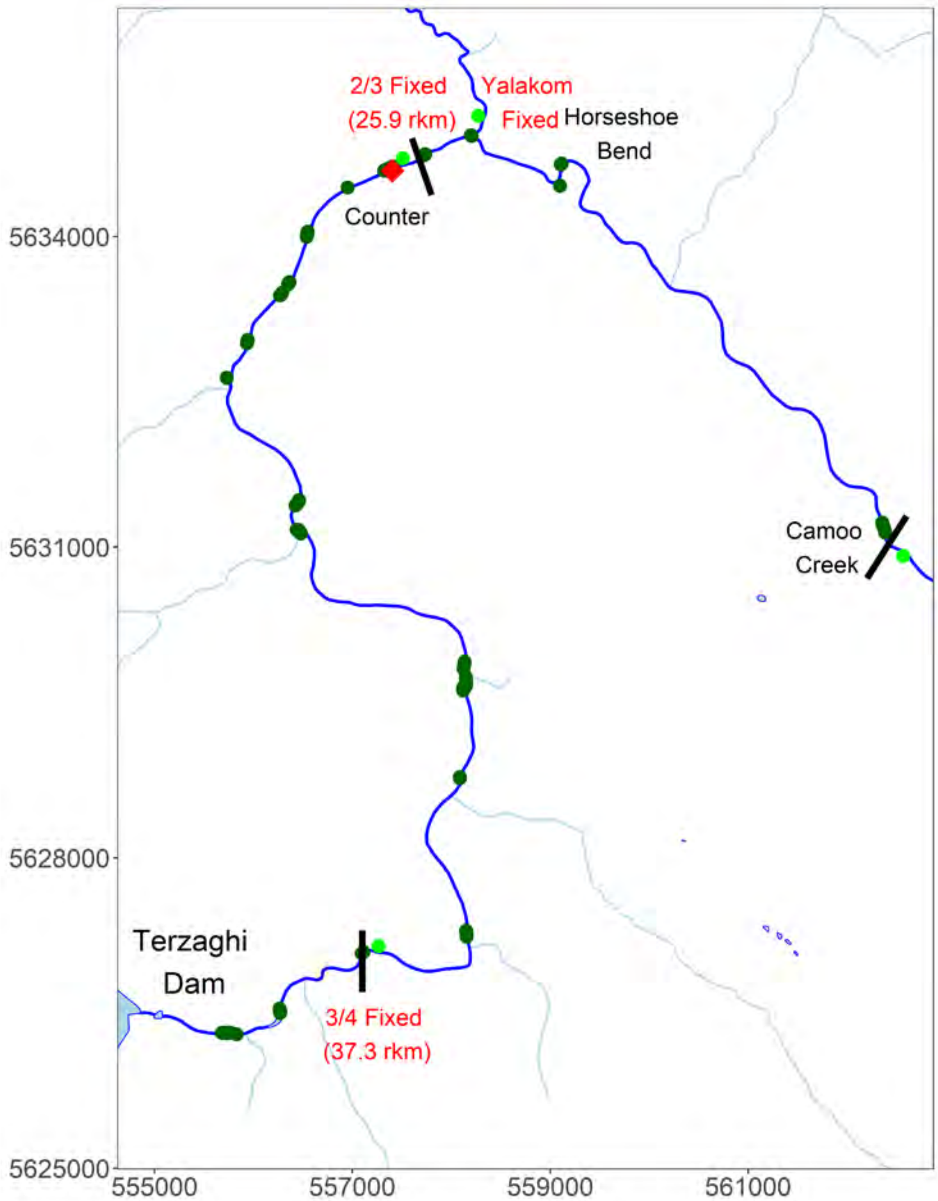

Figure 6: Habitat units (dark green) where transects were performed to assess Chinook and Coho Salmon spawning habitat. Fixed radio stations (green circles) and reach breaks (black lines).

2.6.2 Habitat Suitability Index

Habitat data were analyzed using a model based on HSI scores developed by Ptolmey et al (1994). The Ministry of Environment provided species- and life stage-specific HSI scores for water depth, velocity, and substrate size class. This model estimates a relative index of habitat suitability for different species and life stages at a given discharge. Each habitat parameter (e.g., water depth, velocity, and substrate) is weighted by species- and life stage-specific HSI score ranging from 0 (least suitable) to 1 (most suitable). The amount of suitable habitat is quantified as the product of the three weighted HSI scores (depth, velocity, and substrate) and the wetted width of the transect. Weighted Useable Area (WUA) was calculated by multiplying each meter width along the transect by the length between transects or to the end of the habitat unit. In circumstances where whole channel cross-sections could not be completed, transects were evaluated from each shoreline until wading became unsafe. This is not a concern when using the HSI model to determine the distribution of spawning salmon in the LBR, as areas where velocities are too fast or too deep for safe data collection tend to be unsuitable spawning habitat (i.e., HSI score = 0).

2.6.3 Redd Surveys

Water depth, velocity, substrate characteristics, and dimensions were measured at each redd during redd surveys performed in Reach 2, 3, and 4. Depth and triplicate measures of velocity were taken using a flow meter (at 60% of the total depth; Swoffer Instruments, Model 2100) at the leading edge, adjacent to, and the tailspill of each redd (i.e., substrate mobilized by spawners during redd construction). The tailspill represents the substrate selected by spawners, and 20 pieces of substrate were randomly selected from the tailspill for measurement. The intermittent axis (2^{nd} largest length) was measured to determine the geometric mean particle size of preferred spawning substrate.

Measures of water depth, velocity, and substrate size at redd locations were compared to Chinook Salmon spawning preferences stated in the literature. Similar redd characteristics among years would suggest spawning site selection is consistent and that habitat availability is not limiting Chinook Salmon spawning in the LBR. A detailed quantitative analysis was not performed because in some years (particularly 2018 to 2021) few redds were sampled, and visual comparisons did not suggest observations outside of species preferences. Redd data were also compared with results from the HSI model to determine whether there is evidence that spawning habitat availability has changed since 2014. Redd data could be used in future to develop HSI scores specific to the LBR.

Redd surveys were also used to compare distributions of confirmed spawning since 2014 and 2018 for Chinook and Coho Salmon, respectively. This assessment is combined with visual surveys of migrating adults to inform whether flow regime has affected spawner distributions.

2.6.4 Analysis of Habitat Data

Weighted Usable Area

Total WUA for Chinook Salmon were compared across years (2017-2019, and 2021) using a fixed factor one-way analysis of variance (ANOVA; Reach 1 and 2 not surveyed in 2017) to evaluate changes to available spawning habitat at 3 $m^{-3}s^{-1}$. A second, fixed factor one-way ANOVA compared 2019 and 2021 WUA for Coho Salmon at 1.5 $m^{-3}s^{-1}$.

Substrate Size

Substrate size was measured at transects in Reach 3 and 4 following high flows (2017-2019, and 2021) and since 2018 in Reach 1 and 2. In 2021, only transects located in Reach 3 and 4 and important spawning locations in Reach 2 (Camoo, Horseshoe Bend, and Yalakom) were surveyed. Only transects surveys two or more years were retained in analyses. Boulders (>256mm) were removed from analysis, as these are less likely to be mobilized by high flows, are not utilized by spawning salmon, and result in a non-normal distribution. In addition, all values were square root transformed to improve test assumptions. Removing boulders removed 7.6% of the total sample size and reduced the sample mean from 105.1mm ± 185.4 to 70.41mm ± 185.4 (small cobble; mean of the outliers = 537.1mm ± 186.0).

Substrate sizes were compared across years (2017-2019, and 2021) using a fixed factor one-way analysis of variance (ANOVA; Reach 1 and 2 not surveyed in 2017). A significant ANOVA test was followed by a Tukey post-hoc test to identify where year differences occurred. The most suitable statistical model to assess changes in substrate size across years is a linear mixed effect model (LME) that can accommodate repeated collection of the response variable (i.e., substrate size) at fixed time points. LME models can include random effects (i.e., grouping factors) that need to be controlled for. Random effects (e.g., transect and site) are needed because although there isn't interest in their effect on the response variable, they likely influence resulting patterns in the data. That is, the random effects in this case account for inherent differences among transect and sites. We are interested in the interactive effects of year and reach on substrate size. Final LME models with a response of substrate size included fixed effects of year, reach, and their interaction, and a random group intercept of transect nested within site and a constant random slope:

Substrate size ~ Year * Reach + (1|site/transect)

The 'lme4' package was used to analyze data. Model diagnostics were assessed by observing Q-Q plots of standardized residuals. Post hoc comparisons of fixed-effect factors were evaluated using least-squares means adjusted to account for variation explained by transect and site.

2.7 Ageing of Adult Salmon and Steelhead Trout

Scales were collected from Steelhead Trout and Chinook and Coho Salmon during angling and opportunistic sampling of moribund/dead fish during visual surveys. Scale aging identifies the amount of time that an individual spends in fresh and salt water and can potentially signify changes in quality of the respective environments. Age classes exposed to high flows as juveniles will be monitored to observe potential changes to freshwater life history. Only age data of individuals known to have spawned in the LBR were included (e.g., excluding those radio- and PIT-tagged individuals migrated further up the Fraser River). It has been difficult to collect scales from Chinook Salmon, as abundances returning to the LBR have been low and scales have typically been resorbed by the time Chinook Salmon are captured.

Ageing followed methods outlined in Ward and Slaney (1988), where two people independently determined age ignorant of fish size and time of capture. Age was expressed as two numbers separated by a decimal (Koo 1962), where the first number is the number of years or winters spent in freshwater and the second number is the number of years or winters spent in the ocean. These two numbers summed together is the total age of the fish (ignoring larval stage). For example, a 1.2 represents an age 3 fish.

3. Results

3.1 Electronic Counter Spawner Enumeration

3.1.1 Steelhead Trout (Resistivity and Multibeam Sonar)

In 2021, Steelhead Trout were enumerated using both the resistivity counter and the ARIS sonar, until May 4. The maximum likelihood arrival timing model used a normal distribution to estimate the number of Steelhead Trout that migrated past the counter between May 5 and June 15. The net upstream abundance of Steelhead Trout recorded by the resistivity counter and sonar was 57, and the abundance model was 11, for a counter abundance estimate of 68. This is within the range of abundances recorded since 2016 (mean 43 ± 19; *Table 4*).

Electronic Counter Data

Validation occurred for 113 randomly selected hours of video data. The resistivity counter had a Channel 1 accuracy of 93% and 100% for up and down movements, respectively, and a Channel 2 accuracy of 100% in both directions (*Table 5*). All Steelhead Trout were assigned as such from the visually reviewed video clips, except for counter records that did not have matching video records. In such instances, counter records with a PSS of 127 (largest possible PSS) were considered Steelhead Trout on Channel 2. On Channel 1, a species ratio generated from video validated data was used to differentiate between Steelhead Trout and resident species for records where no video was available.

Maximum Likelihood Model

The maximum likelihood model was estimated using both electronic counter data (March 20 – May 4) and radio telemetry data (April 8 – May 14)(Figure 7). The calculated total abundance estimate (75 steelhead), mean arrival date (April 26), arrival date standard deviation (9.1 days) and proportion of tagged fish past the counter (12/14 tagged fish = 0.86), were used. Counts were rounded to the nearest whole number and added to the electronic counter data. The model was used to estimate abundance from May 5 to June 15 and calculated an additional 11 Steelhead Trout migrated after counter equipment removal.

Validation occurred for 113 hours of video data. The counter had a channel 1 accuracy of 93% and 100% for up and down movements, respectively, and a channel 2 accuracy of 100% in both directions (Table 5). All Steelhead Trout were assigned as such from the visually reviewed video clips, with the exception to counter records that did not have matching video records. In such instances, counter records with a PSS of 127 (largest possible PSS) were considered Steelhead Trout on channel 2. On channel 1, a species ratio generated from video validated data was used to differentiate between Steelhead Trout and resident species for records where no video was available.

The sonar recorded 357 fish tracks (284 upstream movements and 73 downstream movements) and all fish were measured, so no predictive linear fork length model was required. A fork length cut-off of 600 mm was used to distinguish between Steelhead Trout (>600 mm) and resident species (<600 mm). This cut off was developed using LBR fork length data collected during angling from 2014 to 2021 and has been shown to minimize the amount of overlap between Steelhead Trout and other species (Appendix 1).

The Steelhead Trout abundance estimate measured by the electronic counters from March 20 to May 4, was 57 (sonar = 27, counter = 30). The modelled data was added to the electronic counter data for a Steelhead Trout estimate of 68 (Figure *8*). No kelt date was used in the abundance estimates, because counter equipment was removed prior to kelt dates observed in previous years (White et al. 2019).

Table 4: Summary of Steelhead Trout electronic counter data used in abundance estimates.

Year	Abundance	Method	Comments
2014	238	Resistivity Counter	Complete Estimate
2015	59	Resistivity Counter	Complete Estimate
2016	NA	Resistivity Counter	High flows prevented the operation of the resistivity counter
2017	26	Resistivity Counter and Multibeam Sonar	Counting equipment removed early due to forecasted high flows
2018	14	Resistivity Counter and Multibeam Sonar	Counting equipment removed early due to forecasted high flows
2019	50	Resistivity Counter and Multibeam Sonar	Complete Estimate: Fraser River rockslide may confound escapement
2020	62	Resistivity Counter and Multibeam Sonar	Complete Estimate: Fraser River rockslide may confound escapement
2021	68*	Resistivity Counter and Multibeam Sonar	Counting equipment removed early due to forecasted high flows

*Estimate based on modelled between May 4 to June 1

Table 5: Resistivity counter accuracies by channel and direction for 2021 Steelhead Trout.

Channel	Direction	True Positive	False Positive	False Negative	Accuracy
1	Up	13	1	0	93%
1	Down	0	0	0	100%
2	Up	8	0	0	100%
2	Down	0	0	0	100%

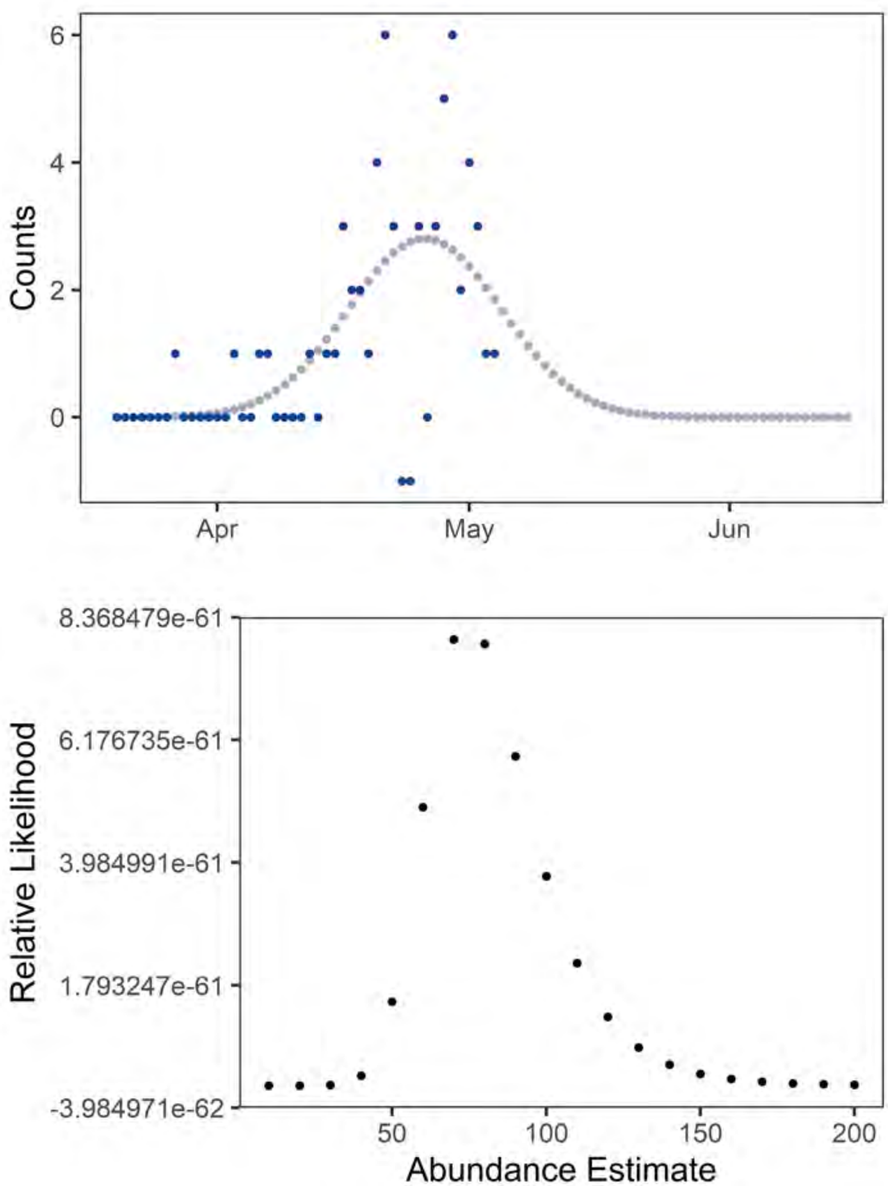

Figure 7: A) Counter observed counts (blue) and modelled counts (grey) plotted between March 20 and June 15. B) Maximum Likelihood estimated from the likelihood of daily number of upstream migrating Steelhead detected by the counter and likelihood of the day of passage of radio tagged Steelhead.

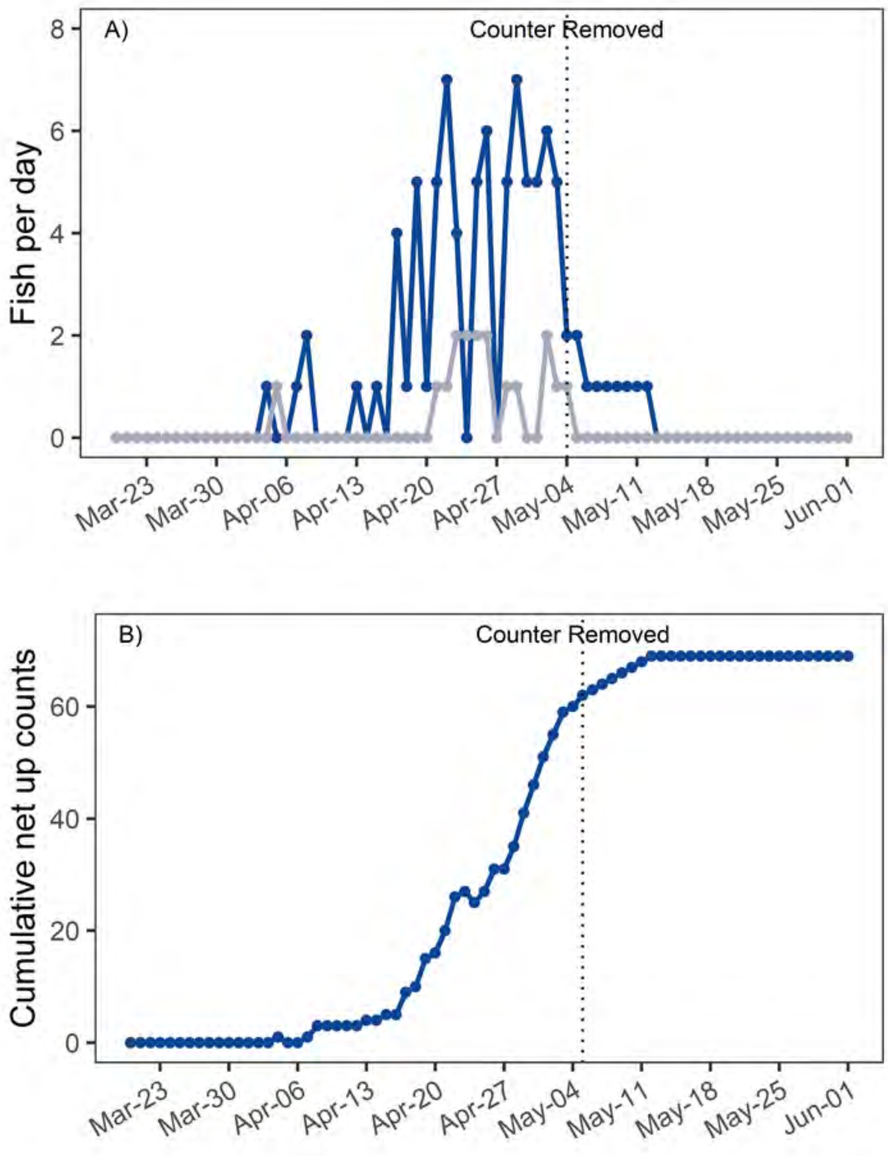

Figure 8: (A) Combined multibeam sonar and resistivity counter daily upstream (blue) and downstream (grey) counts and (B) cumulative net upstream counts for Steelhead Trout in the Lower Bridge River in 2021. Counter equipment was removed May 4 (dotted line) and daily counts following this date were modelled.

3.1.2 Chinook Salmon (Resistivity and Multibeam Sonar)

In 2021, Chinook Salmon were enumerated using the resistivity counter and the ARIS sonar between August 5 and 25, after which counts from the broodstock collection fence were used. Debris on the resistivity counter sensor was not able to be removed until discharge was reduced to 3.0 m^3s^{-1} and the fence was installed. A wildfire and resulting road closures interrupted the collection of both sonar and video data as batteries could not be changed.

Video was collected for August 12 and 13, and video from 22:00 to 6:00 was viewed continuously and observed one Chinook Salmon migrating upstream on August 12. The net upstream abundance of Chinook Salmon recorded by the resistivity counter was 1 and the sonar recorded 33, for a counter abundance estimate of 34. This should be interpreted as a minimum estimate due to outages and equipment malfunctions.

The sonar recorded 535 fish tracks (369 upstream movements and 166 downstream movements) and 83 individuals (15.5% of events) were measured using ARISfish to develop the relationship between Echoview-derived and manually measured fish lengths. The predicted length model for up fish was biased low (-0.5) and used both log Echoview lengths and distance from sonar (R^2 = 0.88, p < 0.05; Appendix 3). The predicted length model for down fish was biased low (-0.8) and used only log Echoview lengths (R^2 = 0.72, p < 0.05; Appendix 3). A fork length cut-off of 650 mm was used to distinguish between Chinook Salmon (>650 mm) and other salmon and resident species (<650 mm). This cut off was developed using LBR fork length data collected during angling from 2014 to 2021 and has been shown to minimize the amount of overlap between Chinook Salmon and other species (Appendix 1).

The partial abundance of Chinook Salmon measured by the electronic counters was 34 (1 [resistivity counter] and 33 [sonar]; Figure 9). After August 25, 63 Chinook Salmon were enumerated at the broodstock fence. The resulting estimate is 97 Chinook Salmon. It is difficult to compare Chinook Salmon escapement from 2021 to previous years due to the fence operation and the effects of the Fraser River rockslide, which resulted in increased straying. Despite these uncertainties, Chinook Salmon abundance in the LBR is low, and escapement estimates between 2018 and 2021 were the lowest since monitoring began in 2014 (Table 6).

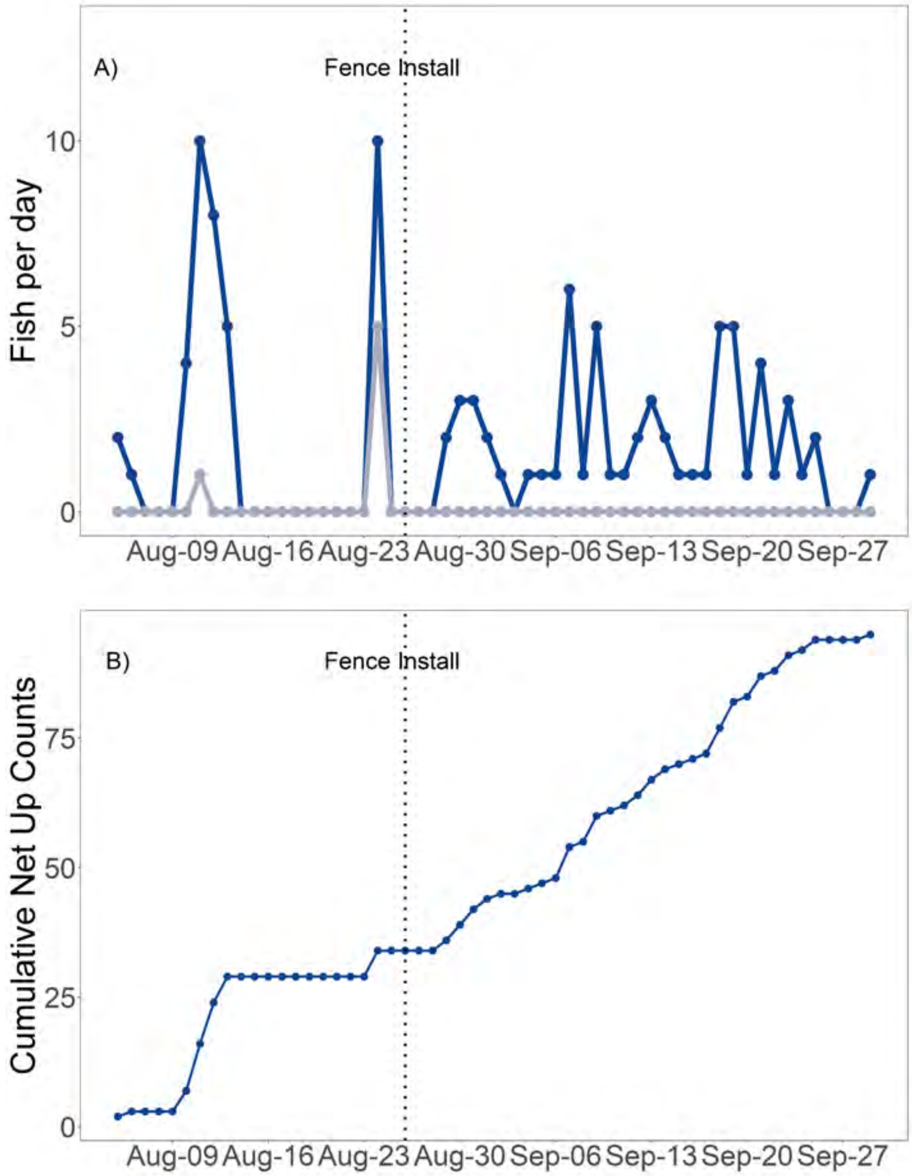

Figure 9: (A) Combined multibeam sonar and resistivity counter and broodstock daily upstream (blue) and downstream (grey) counts and (B) cumulative net upstream counts for Chinook Salmon in the Lower Bridge River. The broodstock fence was installed on August 25th, after which all up counts were recorded from the fish trap.

Table 6: Estimated abundance of Chinook Salmon in the Lower Bridge River since 2014 and a summary data used to achieve estimates. A river-spanning broodstock fence for broodstock collection upstream of the counter site has interfered with counting and the Fraser River rockslide may confound estimates in recent years because we expect increased straying.

Year	Abundance	Method	Comments
2014	947	Resistivity Counter	Complete Estimate
2015	481	Resistivity Counter	Complete Estimate
2016	193	Resistivity Counter and Multibeam Sonar	Partial Estimate - testing of new multibeam sonar following infrastructure damage
2017	340	Resistivity Counter and Multibeam Sonar	Complete Estimate
2018	42	Resistivity Counter, Multibeam Sonar, and fence captures	Partial Estimate - broodstock fence limited estimate (pre-August 29)
2019	156	Resistivity Counter, Multibeam Sonar, and fence captures	Partial Estimate – broodstock fence limited estimate (pre-August 20), affected by Fraser River rockslide
2020	98	Resistivity Counter, Multibeam Sonar, and fence captures	Partial Estimate – broodstock fence limited estimates (pre-August 10), affected by Fraser River rockslide
2021	97	Resistivity Counter, Multibeam Sonar, and fence captures	Partial Estimate – broodstock fence limited estimates (pre-August 25), affected by wildfire

3.1.3 Coho Salmon (Multibeam Sonar)

In 2021, Coho Salmon were enumerated solely using the Echoview sonar, as instream flows in the LBR were too low during the Coho Salmon migration (1.5 m^3s^{-1}) to allow for passage over the resistivity counter. After applying the length model to improve species classification, the net upstream abundance of Coho Salmon recorded by the sonar between October 15 and December 12 was 561 (Figure *10*). This value is comparable to the average abundance since 2015 (597 SD 265; Table 7).

The sonar recorded 11,104 fish tracks (5130 upstream movements and 5974 downstream movements) between September 29th and December 14th and 1577 individuals (14.2% of events) were measured using ARISfish to develop the relationship between Echoview-derived and manually measured fish lengths. The predicted length model for up fish used Echoview lengths, number of targets, and target range mean (R^2 = 0.96, p < 0.01; Appendix 3). The predicted length model for down fish was biased low (-0.1) and used only Echoview lengths (R^2 = 0.94, p < 0.01; Appendix 3). A fork length cut-off of 400 mm was used to distinguish between Coho Salmon (>400 mm) and resident species (<400 mm). This cut off was developed using LBR fork length data collected during angling from 2014 to 2021 and has been shown to minimize the amount of overlap between Coho Salmon and other species (Appendix 1). Only sonar data between October 15th and December 14th were used to enumerate Coho Salmon as there was overlap in the migration timing of Pink and Chinook Salmon and October 15th is historically when the Coho Salmon migration passed the counter site occurs.

The 2021 estimate is comparable to 2015, 2018 and 2020, and almost double the 2019 estimate (280; Figure 9; Table 8). As with other species, the Fraser River rockslide may have resulted in a high percentage of stray fish and/or their offspring from other rivers and may not reflect the true abundance of LBR origin Coho Salmon.

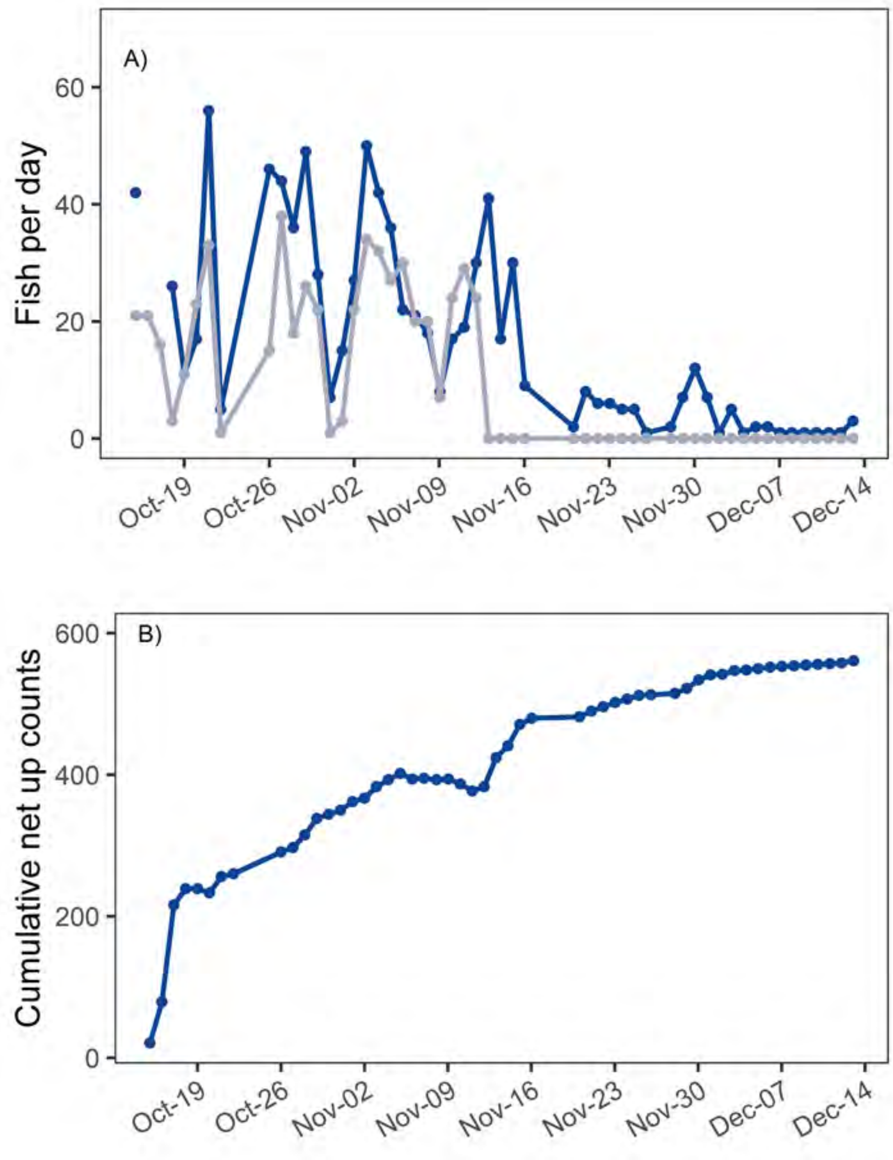

Figure 10: (A) Sonar derived daily upstream (blue) and downstream (grey) counts and (B) cumulative net upstream counts for Coho Salmon in the Lower Bridge River in 2021.

Table 7: Summary of Coho Salmon electronic counter data used in abundance estimates.

Year	Abundance	Method	Comments
2014	1543	Resistivity Counter	Complete estimate
2015	566	Resistivity Counter	Complete estimate
2016	1090	Multibeam Sonar	Complete estimate - testing of new multibeam sonar following infrastructure damage
2017	NA	Multibeam Sonar	Partial estimate - Post season data loss
2018	545	Multibeam Sonar	Complete estimate
2019	280	Multibeam Sonar	Complete estimate, affected by Fraser River rockslide
2020	539	Multibeam Sonar	Complete estimate, affected by Fraser River rockslide
2021	561	Multibeam Sonar	Complete estimate,

3.2 Spawning Distribution (Radio Telemetry)

Radio telemetry was used to assess spawning distributions for Steelhead Trout. Sample sizes of radio-tagged Chinook and Coho Salmon were low (driven by low tag deployment, and few tagged individuals entering the LBR), so visual survey data were also used to inform spawner distributions (see Sections 3.4.3 and 3.5).

3.2.1 Steelhead Trout

Radio telemetry was used to assess spawning distributions for Steelhead Trout. Detection efficiency was high at all fixed receiver stations during the Steelhead Trout migration (100% at Station 1, 100% at Station 2, and 67% at Station 3).

Twenty-three Steelhead Trout (8 males, 15 females) were tagged at the Seton-Fraser confluence from February 24 to April 9, 2021 (Appendix 4). Of these fish, 16 individuals were detected by either fixed receivers or mobile tracking following tagging (Appendix 5). Telemetry detections indicated that Steelhead Trout entered the LBR throughout April and spawned from late-April through mid-May. Spawning locations were determined for thirteen Steelhead Trout, one likely spawned in Reach 2, three in Reach 3 (counter site to Yalakom), nine in Reach 4 (longskinny to eagle), and two potentially in the Yalakom River or in Reach 2 (Figure 11). Steelhead continue to utilize Reach 3 and 4 to spawn, as in previous years (Figure 12). Of the three fish with unknown spawning locations; one was detected only near the confluence of the Seton and Fraser Rivers by mobile tracking, and two were detected within the Seton River. Kelting behaviour was observed for six Steelhead Trout, which migrated out of the Bridge River system in mid to late May (Appendix 5). Four tags (181, 183, 193, and 201) which exhibited kelting behavior from the LBR were detected at a DFO operated telemetry station at Hells Gate (~120 rkm downstream of Lillooet).

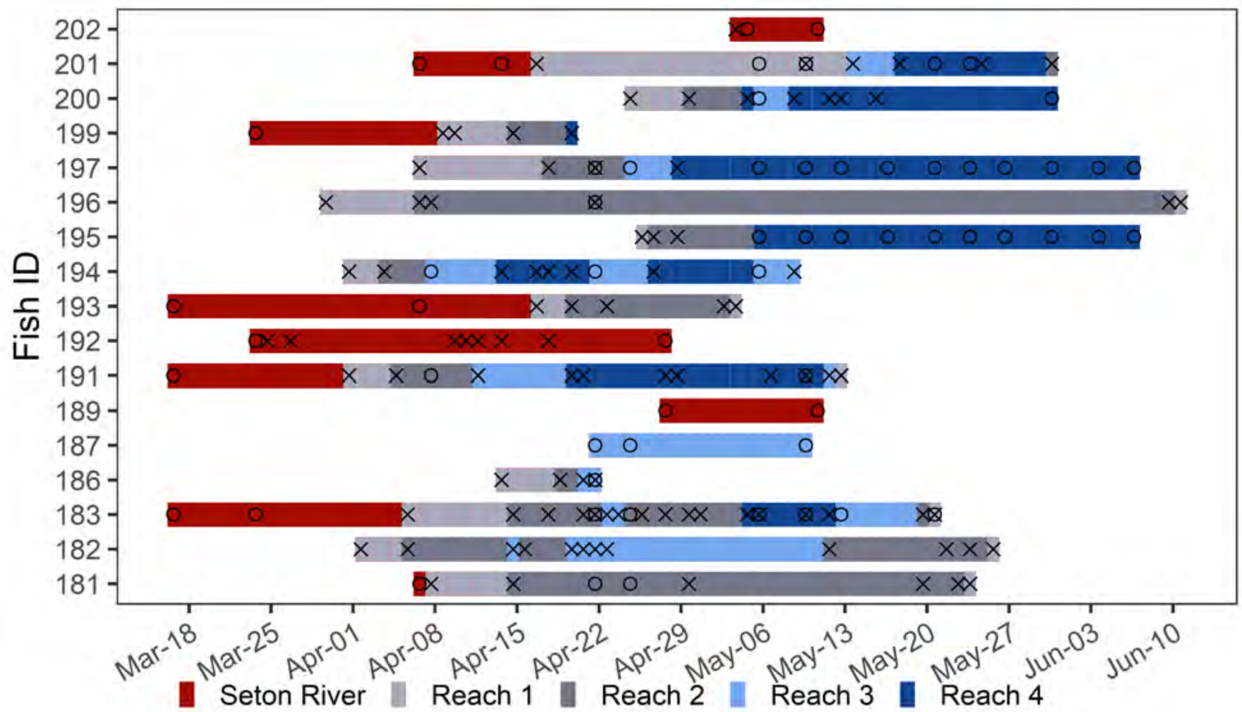

Figure 11: Time series of radio-tagged Steelhead Trout in the Seton and Lower Bridge River in 2021. o denotes mobile tracking detections, × denotes fixed receiver detections.

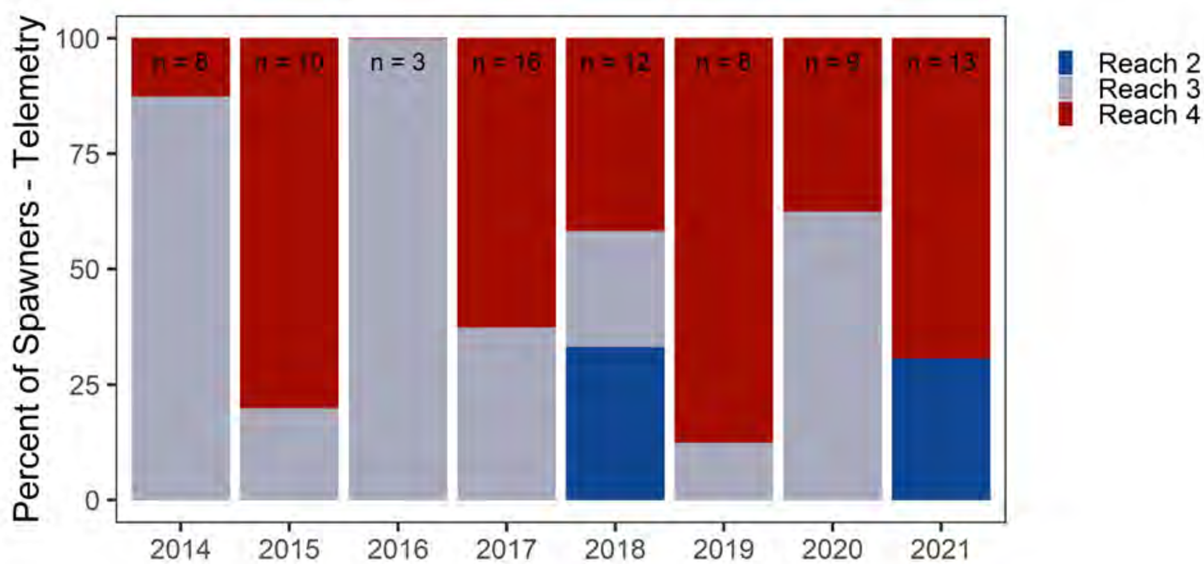

Figure 12: Relative proportion of estimated spawning locations in Reach 2, 3 and 4, for Steelhead Trout based on radio telemetry.

3.2.2 Chinook Salmon

Three Chinook Salmon (2 female and 1 male) were tagged in 2021, all from the Yalakom-Bridge confluence (25.0 rkm; Appendix 4). Of the three fish tagged, one fish was estimated to have spawned between the broodstock fence and the lower spawning platform (25.6 – 25.7 rkm), and the other two fish were estimated to have spawned between the Yalakom-Bridge confluence and Hippie Pool (25.0 – 25.3 rkm; Figure 13). Fish ID 12 was detected briefly at the Yalakom River fixed station. Reach 3 is the preferred spawning location for Chinook Salmon; however, the broodstock fence operated between 2018 and 2021 resulted in individuals being forced to spawn downstream (Figure 14). Residence time and migration rate could not be estimated for Chinook Salmon in 2021 due to little movement from capture location.

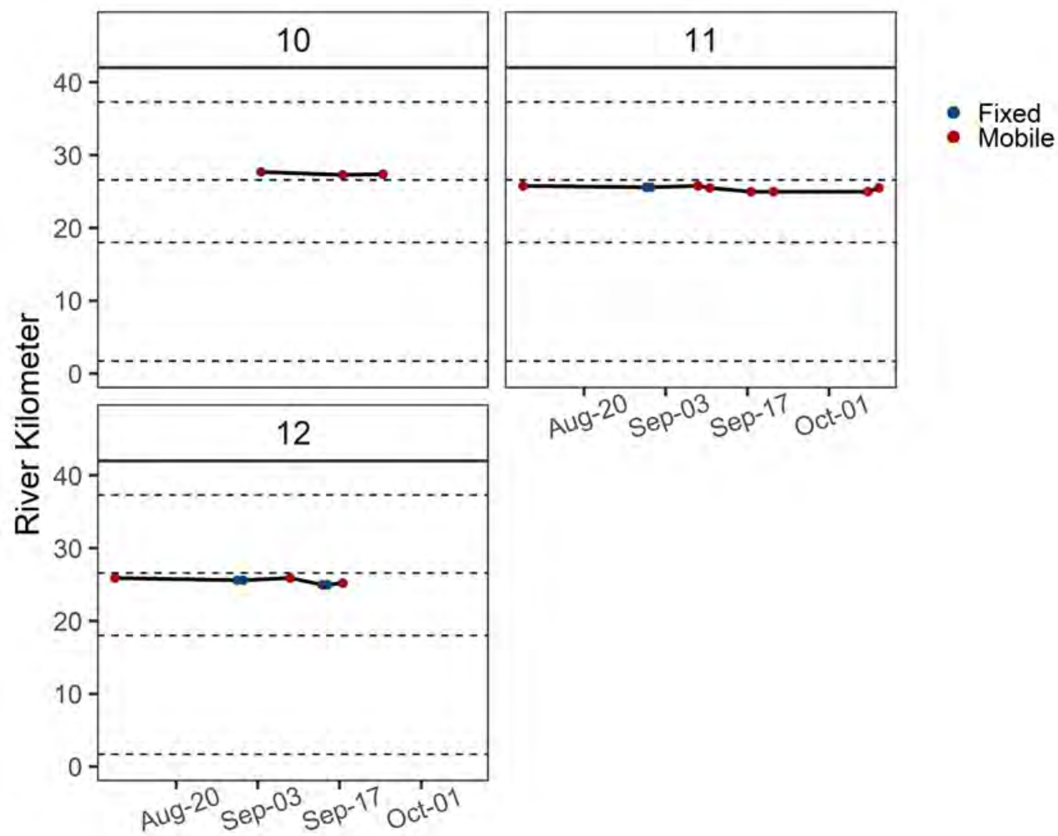

Figure 13: Detection histories of radio-tagged Chinook Salmon in the Lower Bridge River in 2021. The number above plots refers to the fish ID.

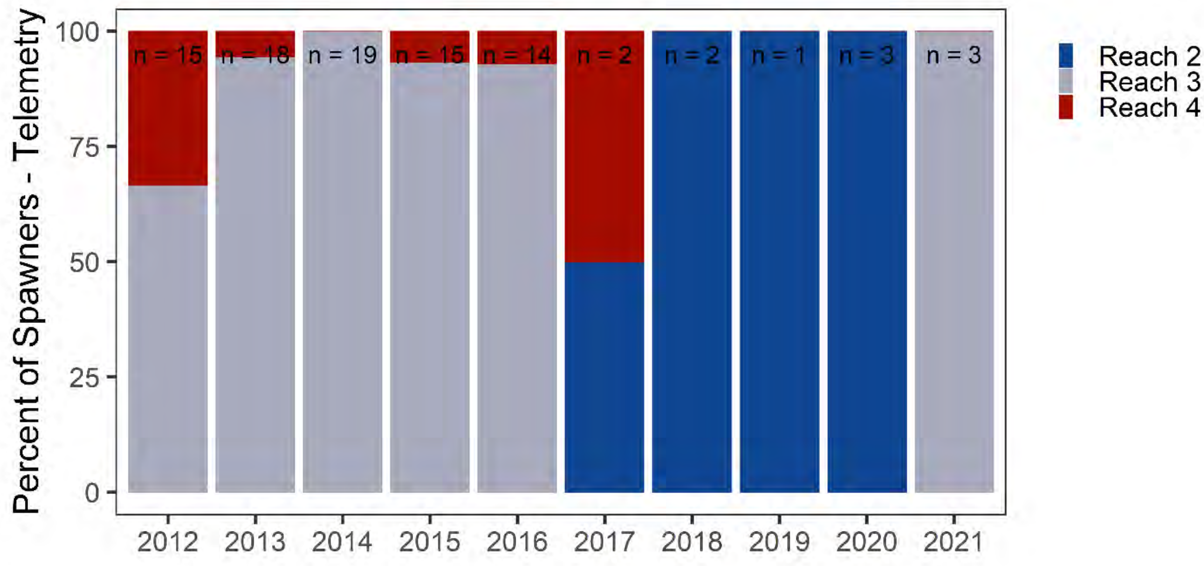

Figure 14: Relative proportion of estimated spawning locations in Reach 2, 3 and 4, for Chinook Salmon based on radio telemetry.

3.2.3 Coho Salmon

Twenty-eight Coho Salmon (18 males and 10 females) were tagged in 2021 between September 28 and November 4 at the Bridge-Fraser River confluence (n = 15; 0.5 rkm), Yalakom-Bridge River confluence (n = 7; 25.0 rkm), Hippie Pool (n = 5; 25.3 rkm), and Camoo FSR (n = 1; 18.0 rkm; Appendix 4). Thirteen were detected by either fixed or mobile telemetry receivers and twelve fish were suspected to spawn above the Reach 1 and 2 boundaries (18.0 rkm; Figure 15). One fish spawned between Terzaghi Dam and Longskinny, one between Longskinny and Eagle, two between Bluenose and Cobra, two between Fraser Lake and Russel Springs, five between the Counter and Yalakom River and one at Camoo FSR. The other four fish were detected at the Reach 1 or briefly by either fixed or mobile telemetry. The remaining fish had unknown fates. Coho Salmon continue to spawn throughout Reach 2 through 4, with Reach 3 used most (Figure 16). Residence time was 22.0 ± 14 days above Reach 3 (Appendix 4).

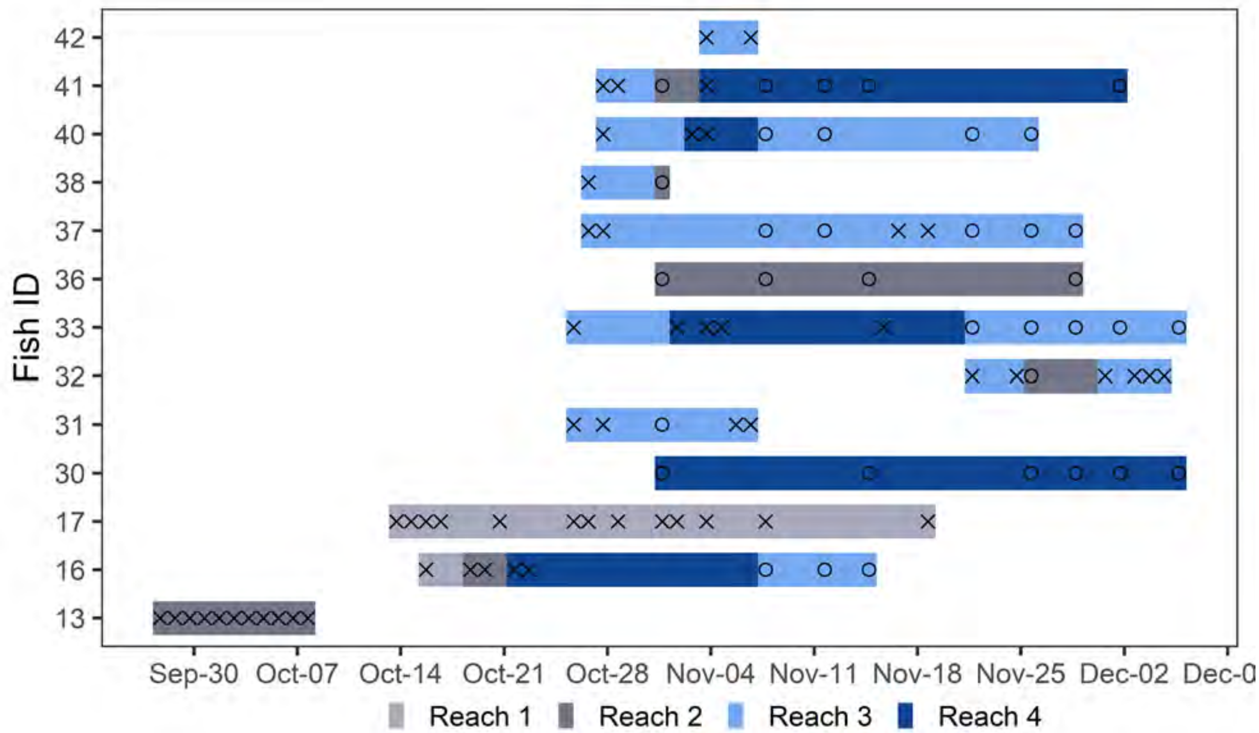

Figure 15: Time series of radio-tagged Coho Salmon in the Lower Bridge River in 2021. o denotes fixed receiver detections, and × denotes mobile detections.

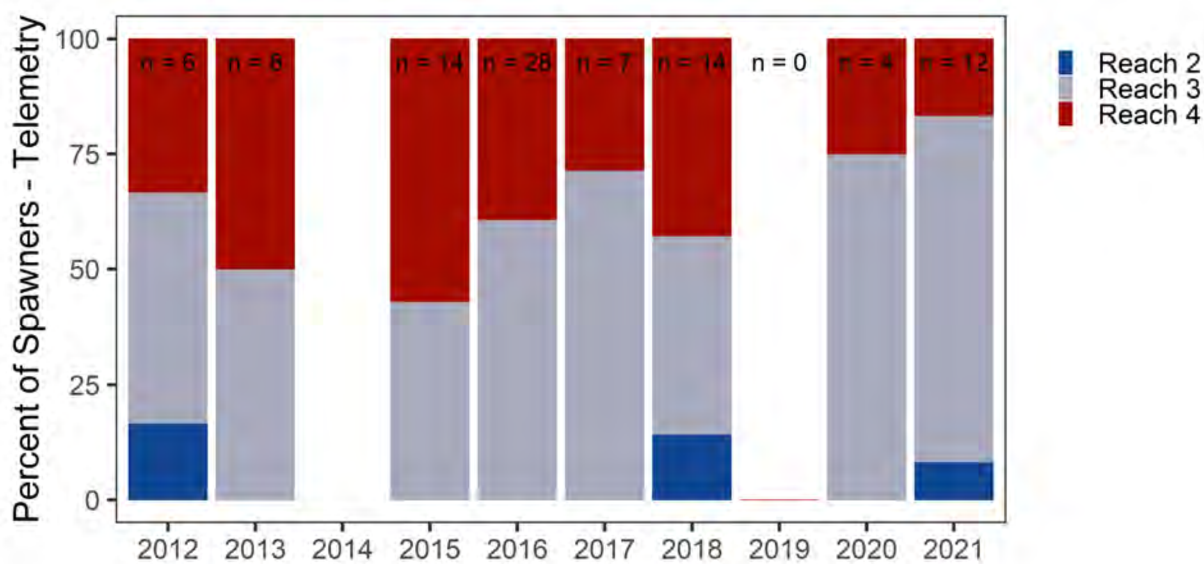

Figure 16: Relative proportion of estimated spawning locations in Reach 2, 3 and 4, for Coho Salmon based on radio telemetry. Note: PIT telemetry was used in 2014, so specific spawning reach could not be determined.

3.3 Migration Timing

Migration timing was assessed among years and between counter data and radio telemetry data, where available, to determine whether changes in migration timing have occurred in response to changes to instream flow regime in the LBR (Table 8).

Table 8: Radio telemetry and counter estimates, where available, were used to derive migration timing curves for Steelhead Trout and Chinook and Coho Salmon in the LBR. Years where a method was not available are denoted by NA. Radio telemetry data with <5 individuals were not included in the analysis. Confounded counter estimates (as specified) were not used.

	Steelhead Trout		Chinook Salmon		Coho Salmon	
Year	Radio Telemetry n	Counter Estimate	Radio Telemetry n	Counter Estimate	Radio Telemetry n	Counter Estimate
2012	NA	NA	15	NA	25	NA
2013	NA	NA	26	NA	19	Y
2014	8	Y	17	Y	15*	Y
2015	10	Y	14	Y	14*	Y
2016	2	N**	14	Y	30	Y
2017	16	Y	2	Y	8	N***
2018	8	Y	2	N****	12	Y
2019	8	Y	1	N****	0	Y
2020	7	Y	0	N****	4	Y
2021	13	Y	3	N****	5	Y

* PIT telemetry was used instead of radio telemetry.
** Counter infrastructure was damaged by high flows
*** Sonar data loss
**** Broodstock fence

3.3.1 Steelhead Trout

Steelhead Trout telemetry data were available for 2014 through 2021, while counter data were available for 2014, 2015, and 2017 through 2021 (Table 9). Distributions of migration past the counter site were relatively consistent among years and between data types, indicating Steelhead Trout typically spawn in the first or second week of May (Figure 17: Normal distributions of Steelhead Trout migration timing from electronic counters (top) and Reach 3 telemetry data (bottom) from 2014-2021. Years with low sample size (n<5) or incomplete estimates were removed.). Entry date into the LBR has occurred earlier than average in 2017, 2020, and 2021 (Figure 18: Normal distributions of Steelhead Trout entry into Reach 1 derived from telemetry from 2014 to 2021. Years with low sample sizes (n<5) were removed.); however, the migration past the counter site has remained consistent. Migrating spawners were exposed to high flows from 2016 to 2018 and 2021, but these years do not appear to differ from others (Table 9; Figure 17).

Table 9: Minimum, maximum, and mean dates of entry into Reach 3 by Steelhead Trout recorded by electronic counters and radio telemetry.

Counter				Radio Telemetry		
	min	max	mean	min	max	mean
2014	NA	NA	NA	17-Apr	21-May	05-May
2015	09-Apr	04-Jun	25-Apr	18-Apr	12-May	01-May
2016	NA	NA	NA	NA	NA	NA
2017*	22-Apr	08-May	03-May	14-Apr	20-May	30-Apr
2018*	22-Mar	08-May	29-Apr	20-Apr	31-May	07-May
2019	22-Apr	14-May	03-May	21-Apr	18-May	02-May
2020	02-Apr	08-Jun	04-May	21-Apr	14-May	05-May
2021	04-Apr	12-May	28-Apr	08-Apr	29-Apr	19-Apr

*electronic counters were removed mid-May due to forecasted high flows above operating threshold.

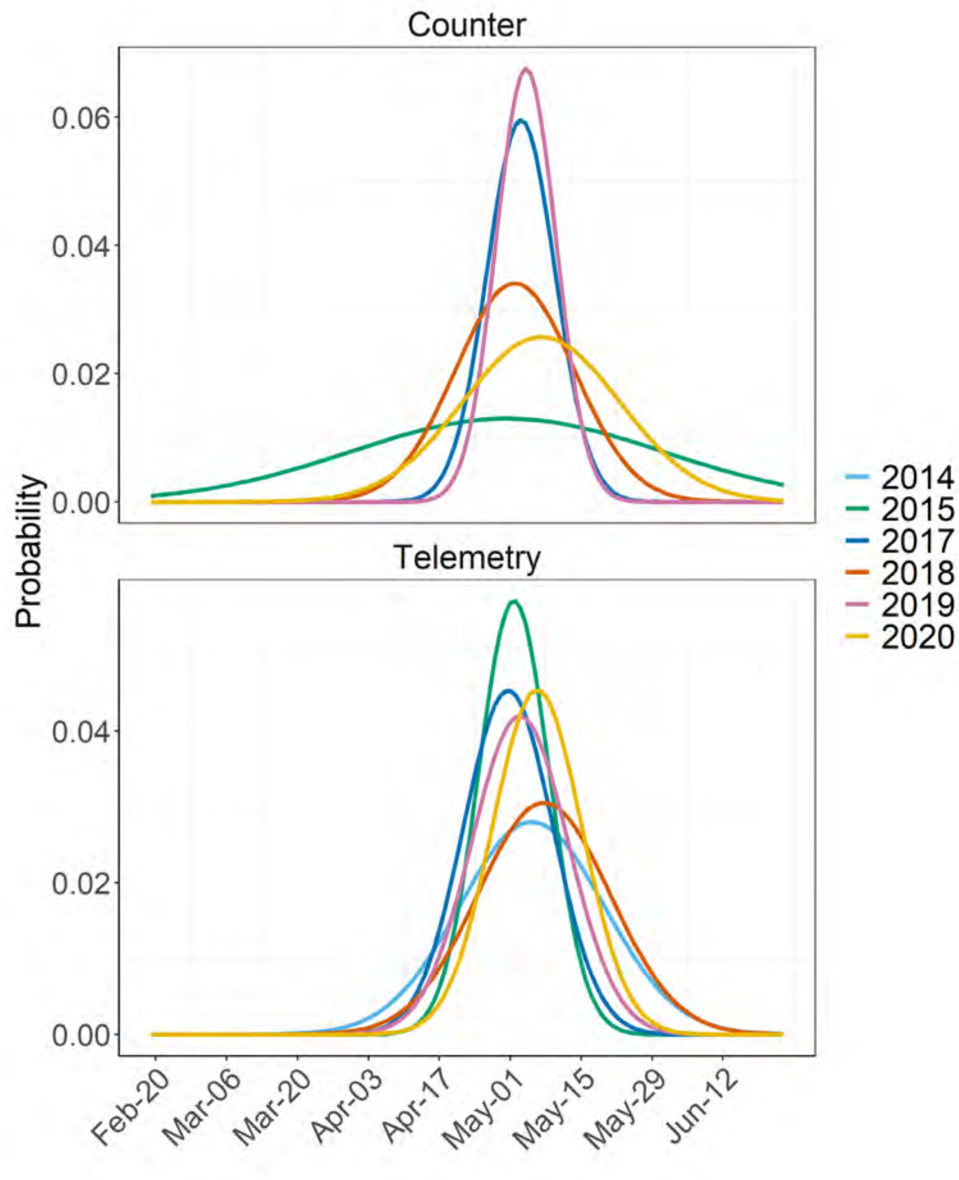

Figure 17: Normal distributions of Steelhead Trout migration timing from electronic counters (top) and Reach 3 telemetry data (bottom) from 2014-2021. Years with low sample size (n<5) or incomplete estimates were removed.

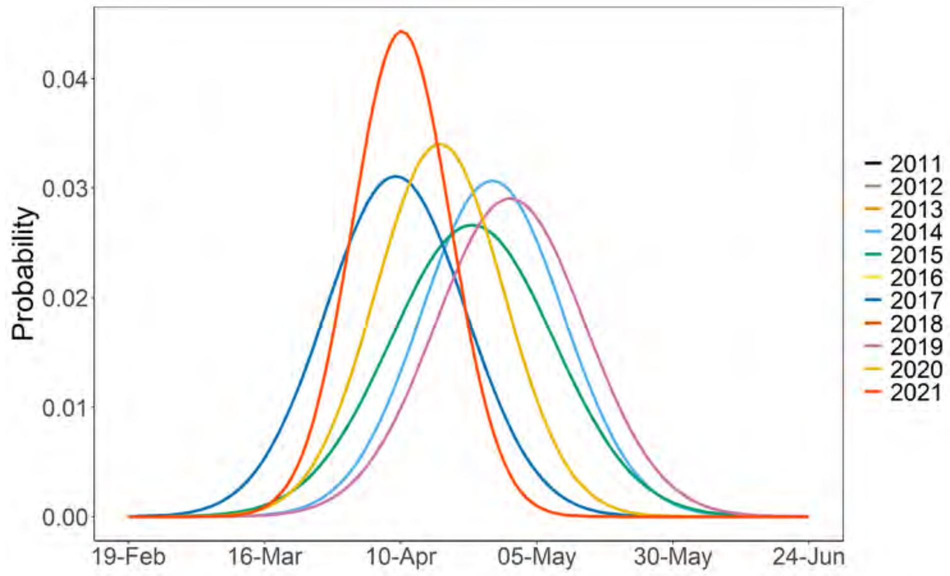

Figure 18: Normal distributions of Steelhead Trout entry into Reach 1 derived from telemetry from 2014 to 2021. Years with low sample sizes (n<5) were removed.

3.3.2 Chinook Salmon

To assess Chinook Salmon migration timing, telemetry data were available from 2012 to 2016, and counter data from 2014 to 2015 and 2017. Limited angling success since 2017 has prevented the use of telemetry data and counter data is not available from 2018 because of installation of the broodstock fence. Migration timing distributions were relatively consistent among years and between the counter and telemetry data and indicate Chinook Salmon typically spawn in the last week of August or beginning of September. There does not appear to be evidence that migration timings have shifted during BRGMON-3, outside of 2017 where peak migration occurred in the second week of September (Figure 19). Chinook Salmon migrate in August and September and are subjected to a consistent flow regime (3 m^3s^{-1}). Assessing migration timing in Chinook Salmon will continue to be limited, provided the broodstock fence remains in its current location.

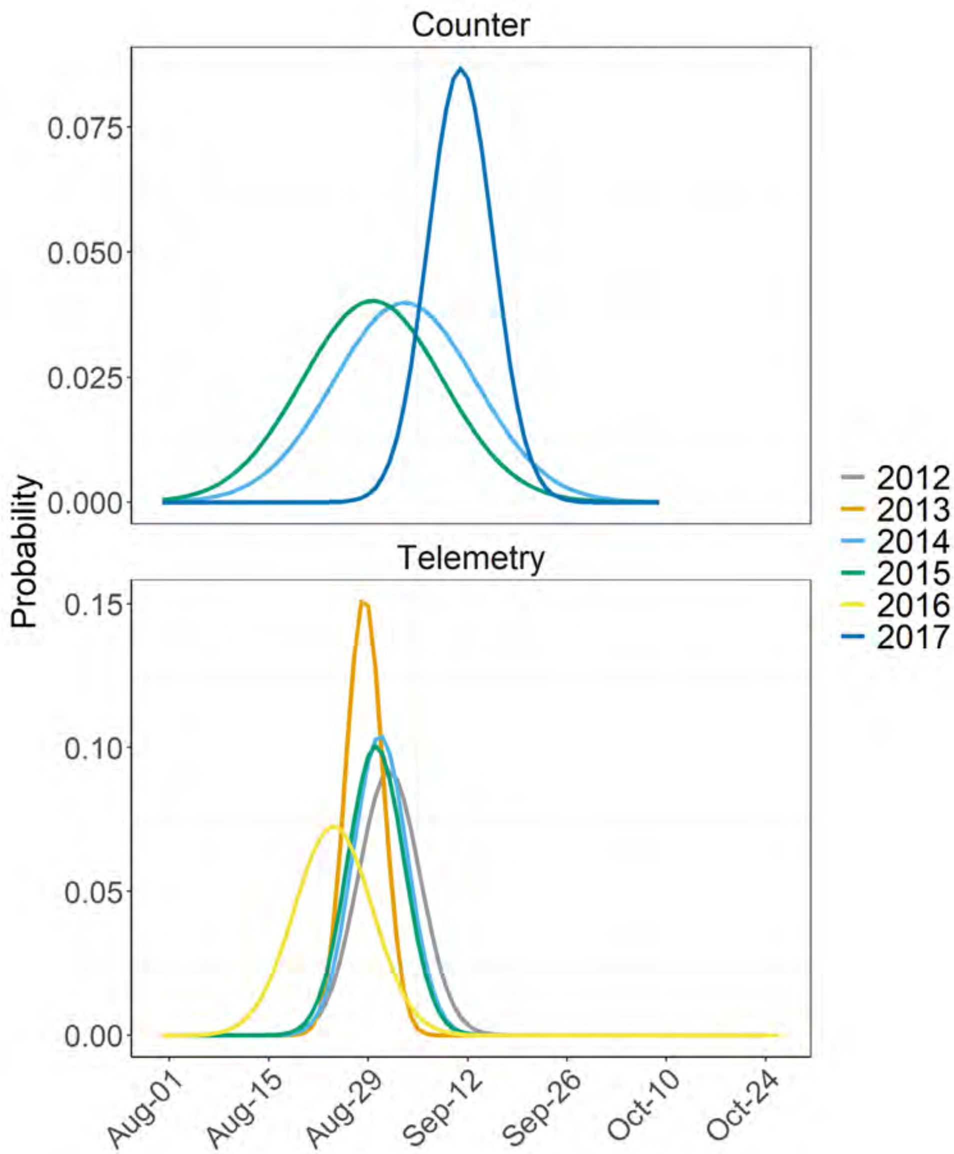

Figure 19: Normal distribution of Chinook Salmon peak migration timing from electronic counters (top) and Reach 3 telemetry data (bottom) from 2012-2017. Years with low sample size (n<5) or incomplete estimates were removed.

3.3.3 Coho Salmon

For Coho Salmon, telemetry data were available from 2012 to 2018, 2020, and 2021 (2014 and 2015 used PIT telemetry), and electronic counter data were available in all years since 2013, except 2017 and 2021. The historical start of the Coho Salmon monitoring period (October 1) was interrupted by the broodstock fence, operated until October 4. The restricted migration past the counter site caused an increase in both up and downstream movement past the counter site following its removal. The migration timing analysis to date indicate that October 15 is the beginning of the Coho Salmon migration data past the counter and was therefore used as the start date for the estimate. Because of the delayed start date, a normal distribution function could not be fit to the data and was omitted from 2021 analysis. Migration timing distributions have been relatively consistent among years and between the counter and telemetry data and indicate Coho Salmon typically spawn in the last week of October (Figure 20). Like Chinook Salmon, Coho Salmon migrate in October and November and are subjected to a consistent flow regime (1.5 m^3s^{-1}).

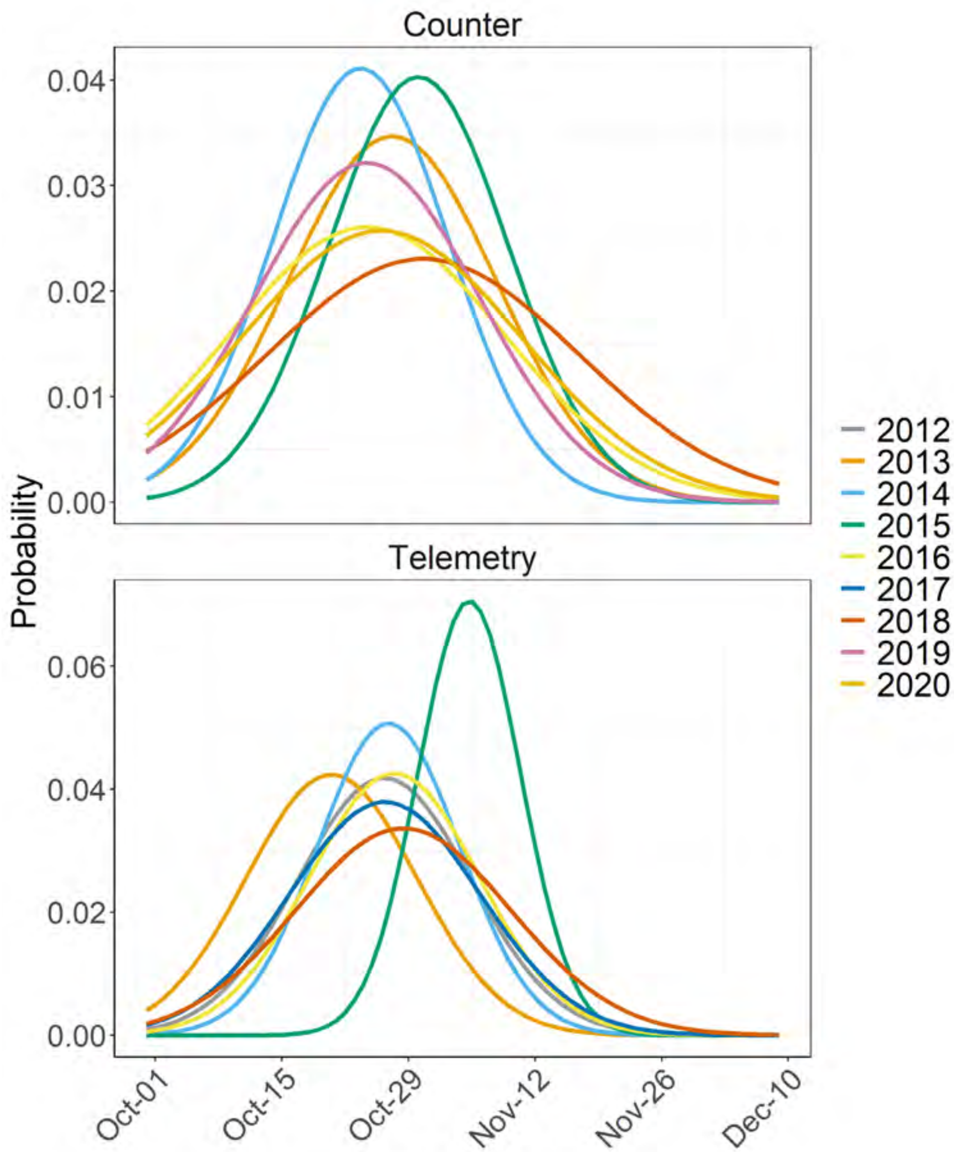

Figure 20: Normal distribution of Coho Salmon peak migration timing from electronic counters (top) and Reach 3 telemetry data (bottom) from 2012-2021. Years with low sample size (n<5) or incomplete estimates were removed.

3.4 Visual Counts and AUC Population Estimates

3.4.1 Chinook Salmon

Visual surveys of Chinook Salmon began on August 25, and continued until October 5, when no fish were observed. Our surveys only assessed fish that were able to pass the broodstock fence prior to installation on August 25. Chinook Salmon captured by the broodstock fence will be added to the AUC estimate based on fish above the fence for comparison with the electronic counter estimate.

Water visibility was poor throughout the Chinook Salmon migration period in 2021, where Secchi disc measurements were 0.18 m ± 0.03 (August 30 to September 27; Appendix 6). This low water visibility would suggest a decreased OE value; however, as in previous years with the broodstock fence operating, OE could not be calculated, as no tagged individuals migrated past the fence. Chinook Salmon were first observed on August 30 (n = 13), and a peak count of 63 fish occurred on September 13. In 2021, the largest percentage of spawners observed above the broodstock fence were located between Fraser Lake and Cobra in Reach 3 (n = 20; rkm 33.2 to 34.4), followed by Longskinny to Terzaghi Dam, during peak count (n = 16; rkm 39.6 to 40.0). Visual survey data collected in 2018, 2019 and 2021 suggested an increase in the use of Reach 4 for Chinook Salmon to spawn (Figure 21). Should fence operation continue in its current form, evaluating the effects of the instream flow regime on spawner distribution will be challenging.

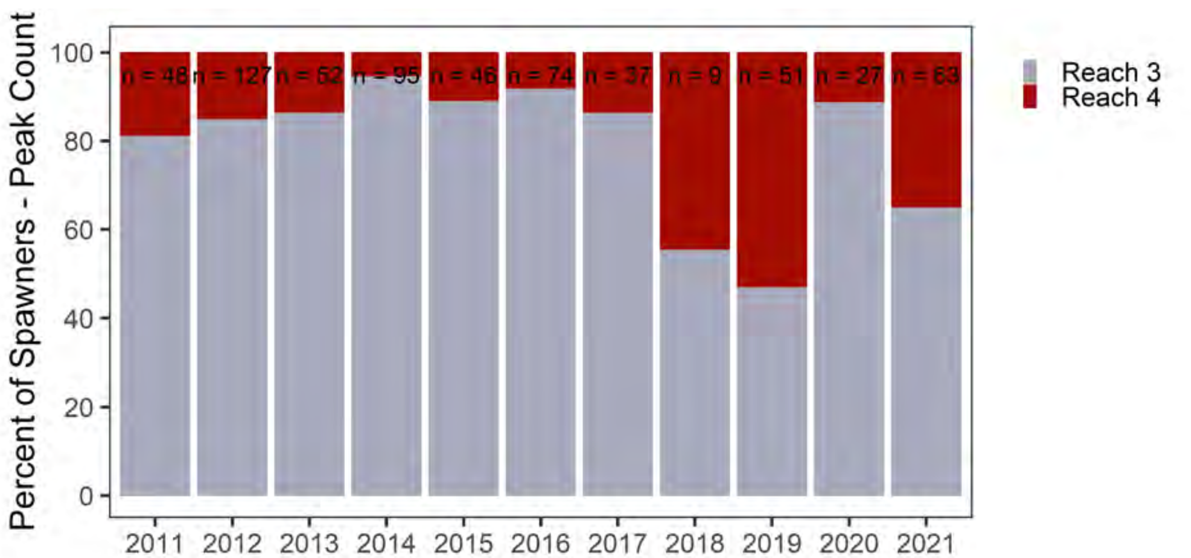

Figure 21: Proportion of Chinook Salmon spawners observed during peak visual survey in Reach 3 and 4 of the LBR.

AUC Abundance Estimate

The 2021 AUC abundance of Chinook Salmon between the broodstock fence and Terzaghi Dam was 187 (95CI 98 – 360; Appendix 7). After August 25, 63 Chinook Sal mon were enumerated at the broodstock fence and 25 were released upstream of the fence, resulting in a coarse Chinook Salmon spawner escapement of 225. There was insufficient radio tag and visual tag data to estimate OE and SL for 2021 and, therefore, average values were used (10.5 days and 0.5 for SL and OE, respectively). AUC estimates were compared with abundance estimated by electronic counters (Figure 22). Abundance estimates between 2018 and 2020 follow a 1:1 relationship; however, in 2021, the electronic counter estimate (97) was lower than the AUC estimate. The counter estimate should be considered a minimum estimate as counter issues and road closures due to wildfire risks prevented the continuous operation of equipment.

Average values of OE and SL and historic count data obtained from DFO were used to reconstruct Chinook Salmon population abundance since 1997. The time series was extended to 1993 using consensus fish counts obtained from a channel-spanning broodstock fence (33.2 rkm). The reconstructed time-series is highly uncertain given the variation in methods, the low number of visual counts in some years, and the uncertainty in OE and SL; however, the reconstructed time series provides a very basic understanding of how Chinook Salmon abundance has changed in the LBR since the 1990s (Figure 23). In particular, the time series indicates that abundance decreased in the mid-2000s and has not since recovered. It is important to note that fence counts from 1993 to 1996 were low relative to AUC estimates from the 2000s. This is likely because prior to 1999, no water was released from Terzaghi Dam and a large percentage of preferred spawning habitat may have been located downstream of the counting fence. The broodstock fence was also located at Fraser Lake (33.2 rkm), whereas streamwalk counts were recorded from Terzaghi Dam to the Yalakom-Bridge confluence (25.0 – 40.0 rkm).

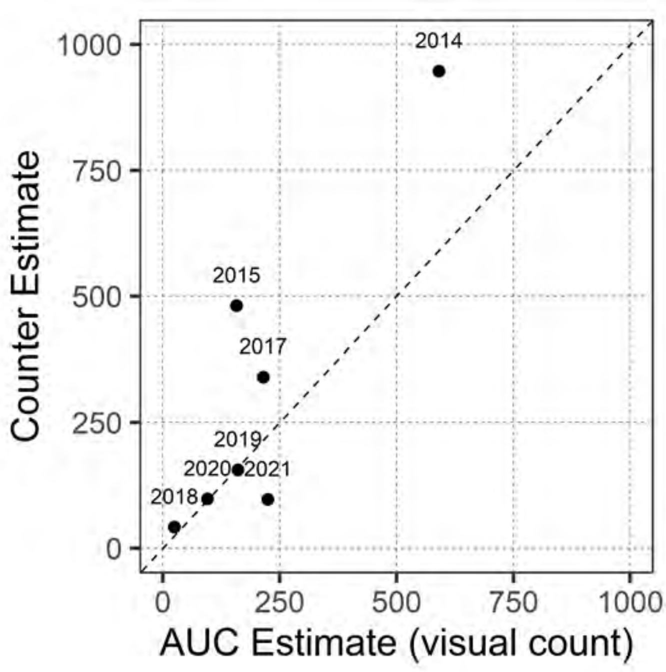

Figure 22: Comparison of Chinook Salmon AUC visual survey estimates, and estimates derived from counting technology. The 2016 point was removed from this figure as the counter estimate did not reflect the entire migration period. Dashed line represents a ratio of 1:1.

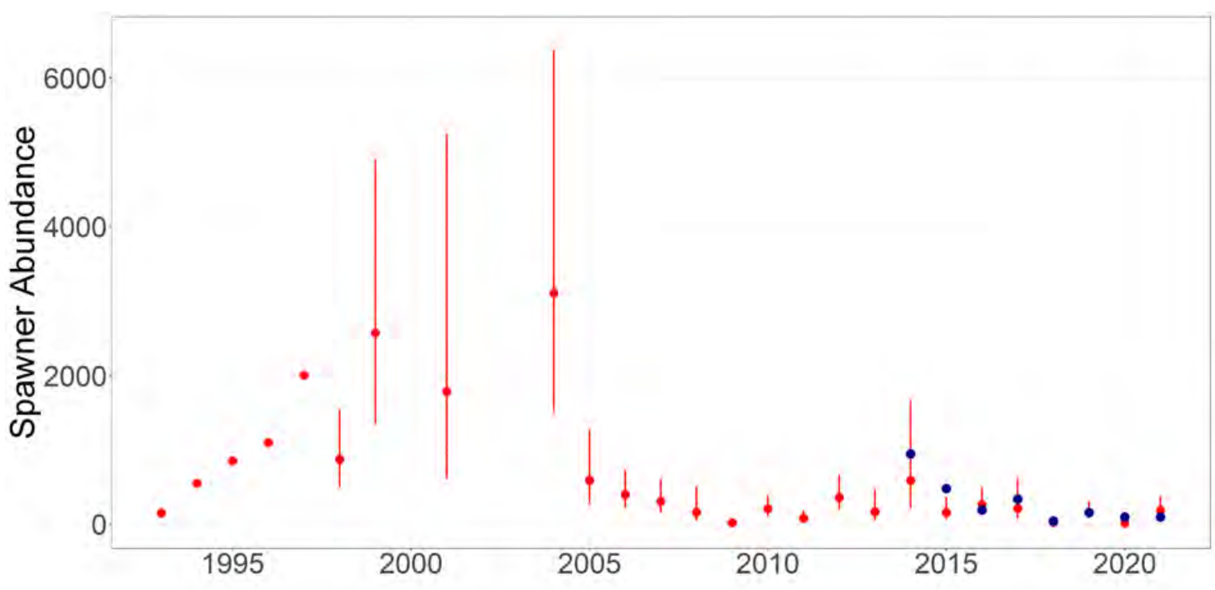

Figure 23: AUC and fence estimates for Chinook Salmon from 1993 to 2021 (red points) and electronic counter estimates from 2014 to present (blue points) in the LBR. Vertical lines represent 95% confidence limits around visual estimates.

3.4.2 Coho Salmon

Visual counts of Coho Salmon were conducted from September 27 to December 17. The first Coho Salmon was observed on October 6 and a peak count of 143 fish was recorded on November 22. Water clarity during the Coho Salmon migration period remained poor (mean Secchi depth = 0.53 m ± 0.20). In 2021, the highest percentage of spawners observed during peak counts was observed from Plunge Pool to Longskinny 4 (51%; rkm 39.6 to 40.0) and 71% of total spawners were observed in Reach 4 (rkm 37.3 to 40.0; Appendix 6). There has been an increase in preference towards Reach 4 among spawners since 2011 (Figure 24).

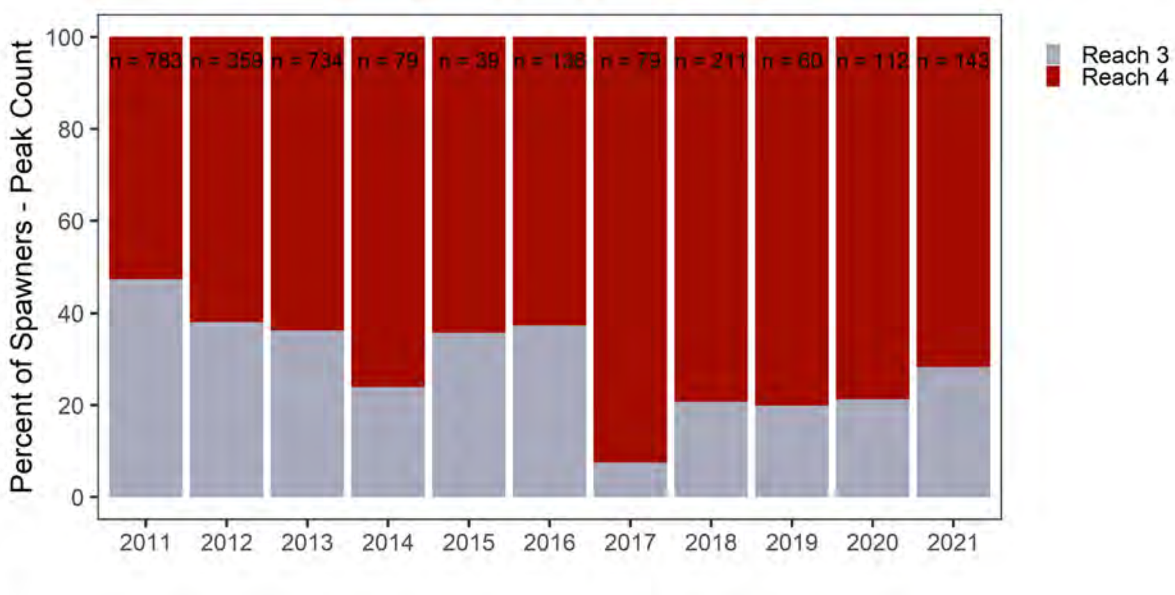

Figure 24: Proportion of Coho Salmon spawners observed during peak visual survey in Reach 3 and 4 of the LBR.

AUC Abundance Estimate

Estimated AUC abundance of Coho Salmon in 2021 between the Yalakom River and Terzaghi Dam was 781 (95% CI: 491-1241; Appendix 7), the second highest abundance calculated since counter infrastructure was installed (1,198 in 2018). There was insufficient radio tag and visual tag data to estimate OE and SL for 2021, and therefore average values were used (20.0 days and 0.22 for SL and OE, respectively).

AUC estimates were compared with abundance estimated by electronic counters (Figure 25). In 2019 and 2020, counter and AUC estimates were comparable. The counter estimates were higher in 2014 through 2016, and the 2018 and 2021 counter estimates were lower than AUC

(Figure 25). Average values of OE and SL and historic count data obtained from the DFO were used to reconstruct Coho Salmon population abundance since 1997. The reconstructed time-series is highly uncertain given the variation in methods, low number of visual surveys in some years, and the uncertainty in OE and SL. Estimated abundance ranged from 78 fish in 1999 to a 3,539 in 2011 (Figure 26).

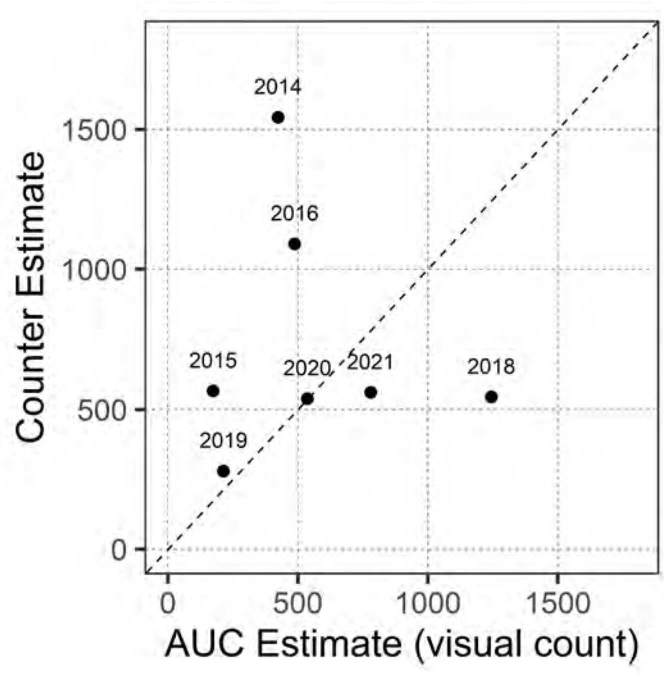

Figure 25: Comparison of Coho Salmon AUC visual survey estimates, and estimates derived from counting technology. No electronic data were available for 2017. Dashed line represents a ratio of 1:1.

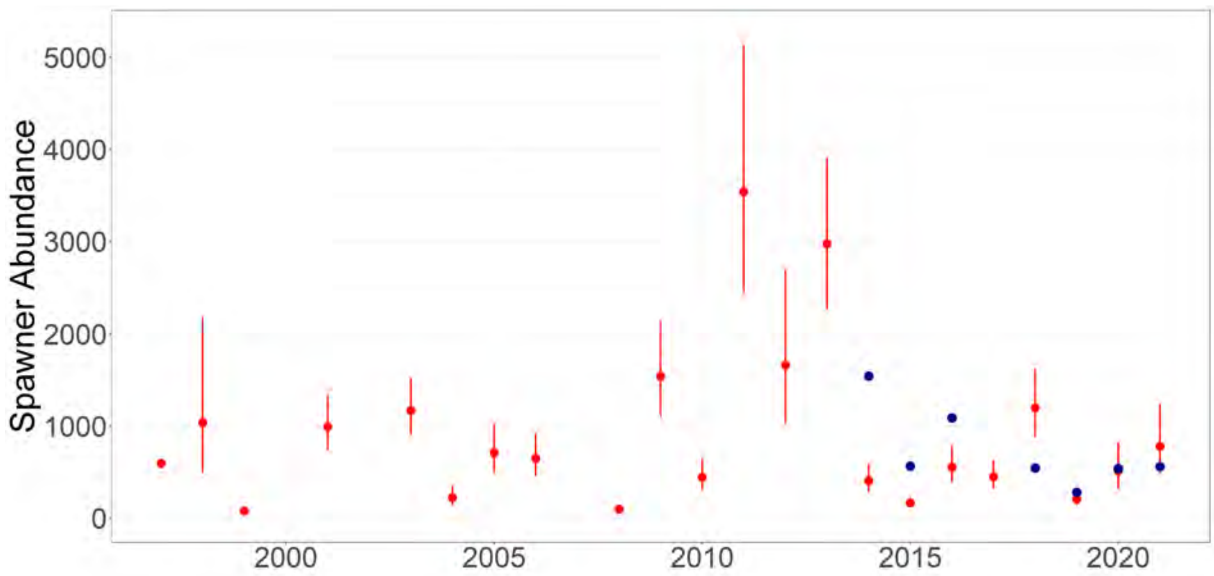

Figure 26: AUC estimates for Coho Salmon from 1997 to 2021 (red points) and electronic counter estimates from 2014 to present (blue points) in the LBR. Vertical lines represent 95% confidence limits around visual estimates.

3.5 Spawning Habitat

3.5.1 Weighted Usable Area for Chinook and Coho Salmon

In 2021, 21 habitat units and 87 transects were surveyed at both 3 and 1.5 m^3s^{-1}, that covered 44,959.4 m^2 of instream habitat. Only three habitat units were surveyed in Reach 2 (Camoo, Horseshoe Bend and the Yalakom-Bridge confluence) from the original nine habitat areas surveyed in 2019. These habitat units were selected based on visual/telemetry observations of Chinook and Coho Salmon.

Chinook Salmon Spawning Habitat

A total of 7,552 m^2 of suitable Chinook Salmon spawning habitat was calculated for all habitat units in 2021, with the majority located in Reach 2 (55%; Figure *27*; Appendix 8). The largest quantities of spawning habitat were located specifically above the Camoo FSR bridge (Reach 2; 2087 m^2), Unit 1 (Reach 3; 613 m^2), Fraser Lake (Reach 3; 703 m^2), and Longskinny (Reach 4; 633 m^2). There were no statistical differences in WUA for Chinook Salmon among years (ANOVA: $F_{3, 70} = 0.83$, $p = 0.48$).

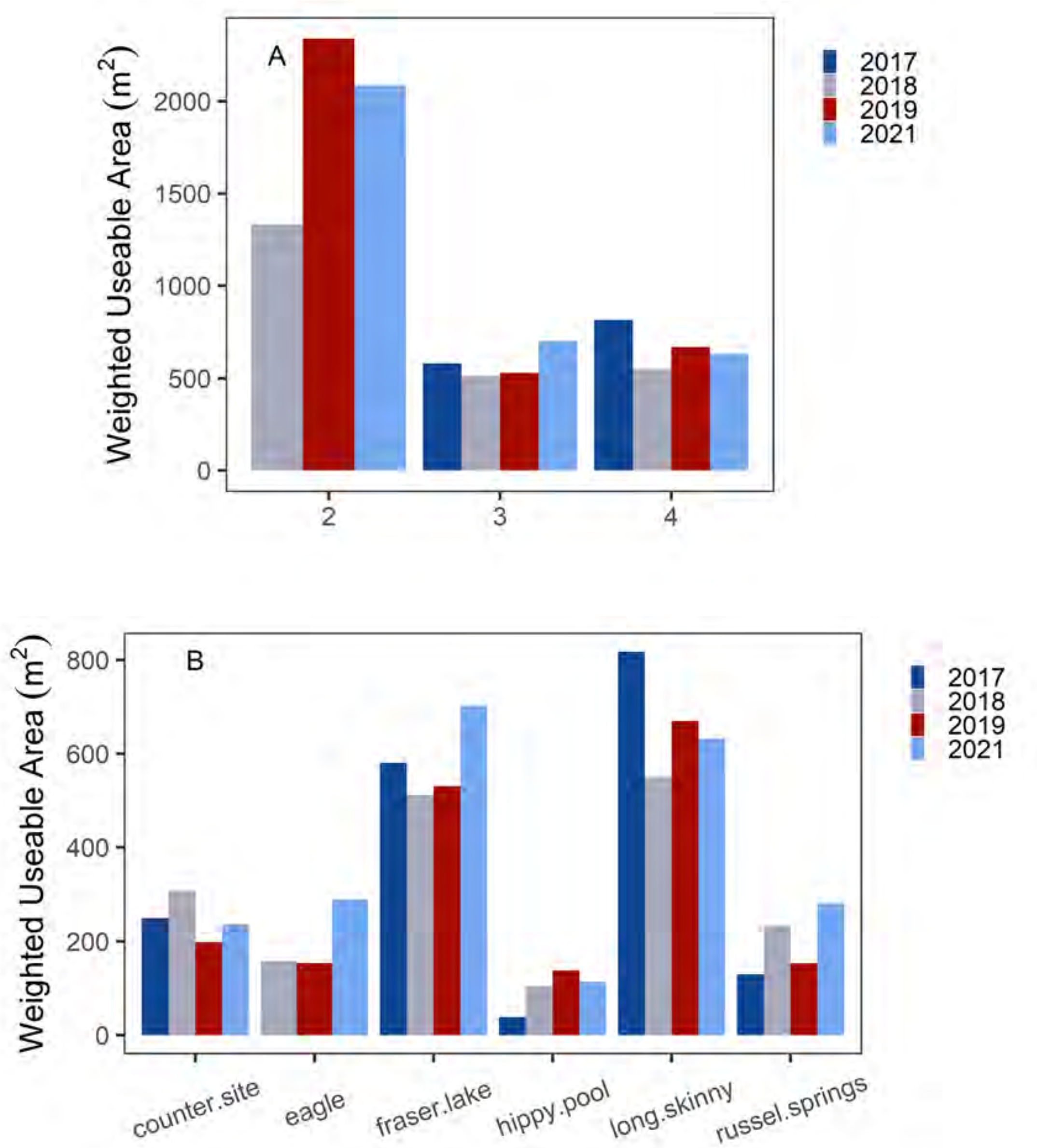

Figure 27: Weighted Usable Area of Chinook Salmon spawning habitat, separated by A) reach and B) important spawning locations surveyed following the high flows in 2017-2019 and 2021.

Coho Salmon Spawning Habitat

A total of 9,301 m^2 of suitable Coho Salmon spawning habitat was calculated for all habitat units in 2021, with the majority located in Reach 2 (45%; Figure *28*; Appendix 8). The largest quantities of spawning habitat were located specifically above the Camoo FSR bridge (Reach 2; 3,396 m^2), Fraser Lake (Reach 3; 790 m^2), Unit 1 (Reach 3; 757 m^2), and Longskinny (Reach 3; 675 m^2). There were no statistical differences in WUA for Coho Salmon among years (ANOVA: $F_{1, 36} = 3.32$, $p = 0.08$).

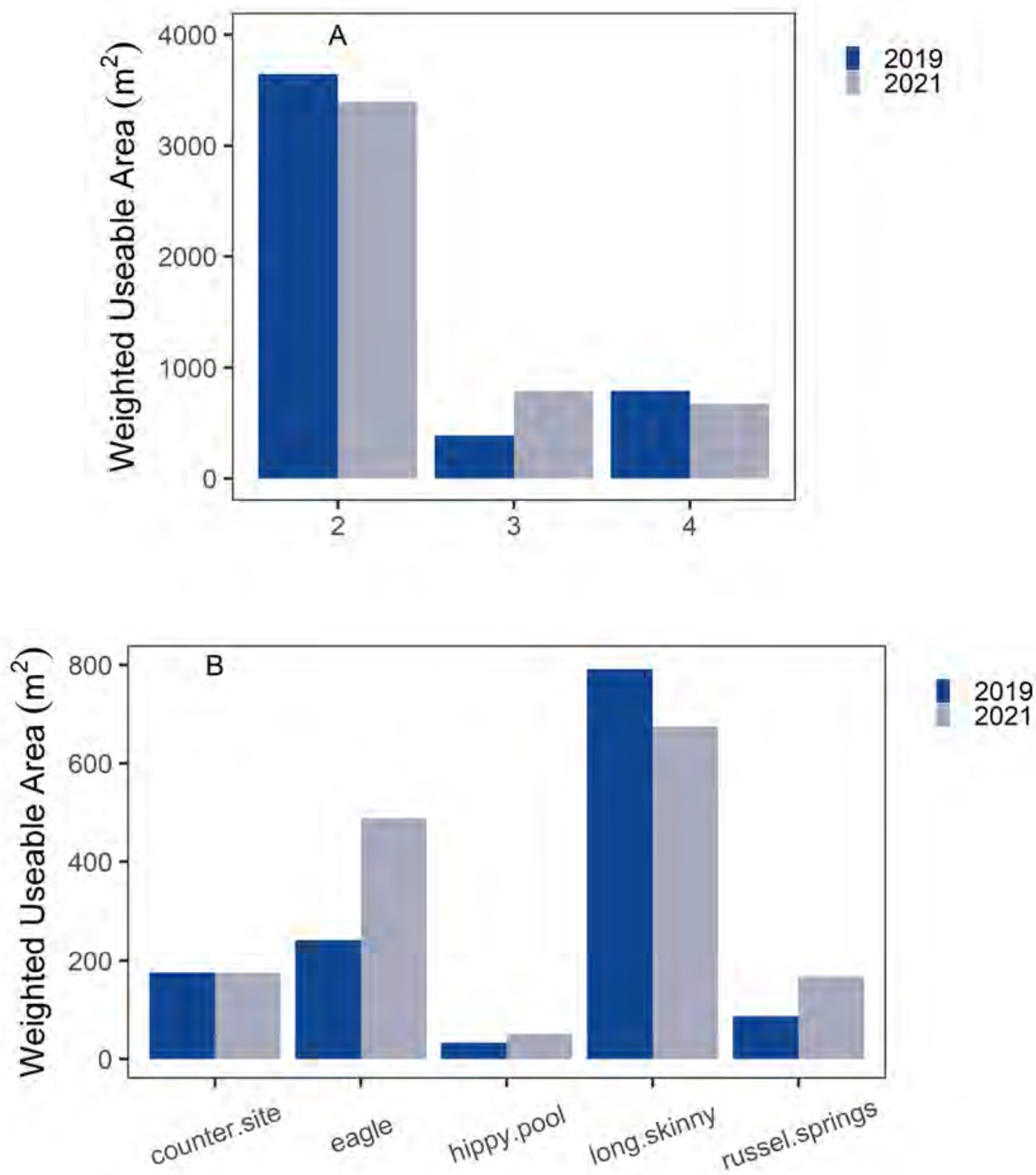

Figure 28: Weighted Usable Area of Coho Salmon spawning habitat, separated by A) reach and B) important spawning locations surveyed following the high flows in 2019 and 2021.

3.5.2 Substrate Analysis

The ANOVA model found a significant effect of year on substrate size ($F_{3,\ 28,069} = 458.3$, $p < 0.001$). A Tukey post-hoc analysis found a significant difference between all year comparisons, except for 2017-2019 (Appendix 9). Substrate size has declined at transect locations across all reaches from 2018 (Figure *29*).

The most parsimonious LME model included year and transect nested in site as the random effect (Substrate size ~ Year + (1 | Site/Transect); Appendix 9). The LME found a significant negative effect of year (fixed factor), and that random effect of transect nested in site accounted for 62.1% of the variation in the distribution of substrate. The amount of variation that the random effect accounts for, means that the remainder (37.9%) is the amount that the variation in substrate size can be explained by (i.e., site and site nested in transect account for most of the variation in the distribution of substrate). The site and transect variables account for more variation in substrate size than the year variable. Evaluating the random model effects indicate that common spawning locations for Chinook and Coho Salmon (below Longskinny, Eagle, Fraser Lake, Counter Site and Hippy Pool) have substrate sizes that are less than the Reach 3 and 4 average (70.8 mm, small cobble; Appendix 9).

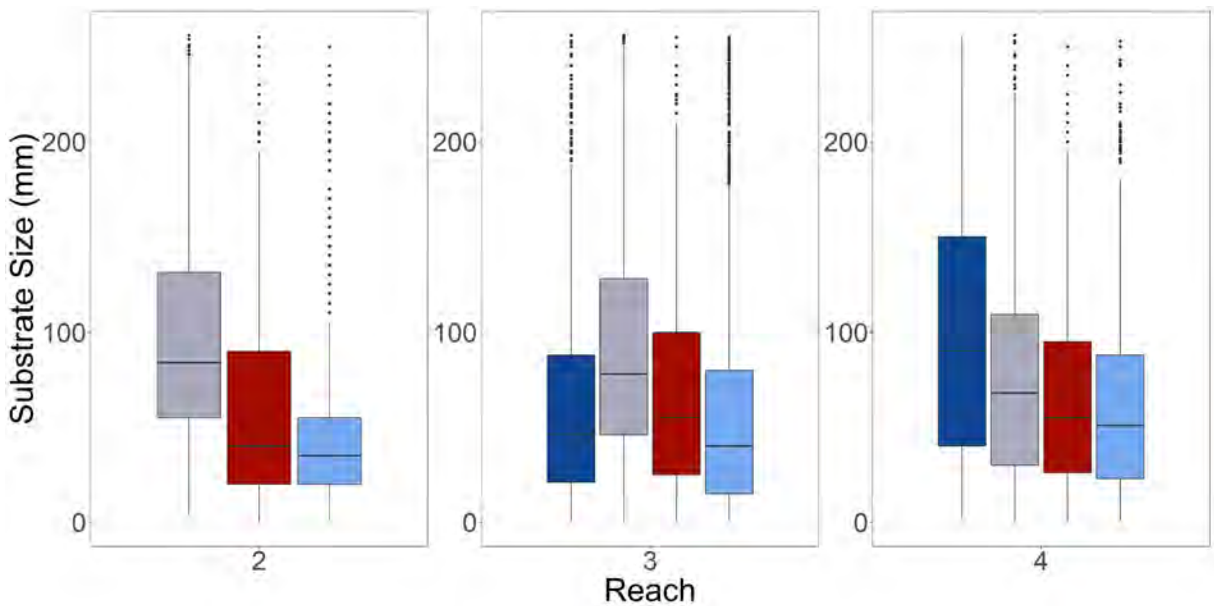

Figure 29: Substrate size (mm) measured at HSI transects in the Lower Bridge River from 2018 (grey), 2019 (red), and 2021 (light blue) in Reach 2 and 2017 (dark blue) to 2019, and 2021 in Reach 3 and 4. Solid lines denote the annual median substrate size and boxes represent the interquartile range (IQR). Lines represent the range excluding outliers, which are shown as points. Substrate >256mm was removed from analysis and figure.

3.5.3 Redd Surveys

Chinook Salmon

In 2021, a total of four Chinook Salmon redds were observed: one in Reach 2 (Horseshoe Bend; 24.0 rkm) and three in Reach 4 (n = 2; Longskinny 39.3 rkm and n = 1; Eagle, 38.8 rkm; Figure *30*; Appendix 10). All redds were in glide habitat, consistent with observations since 2014. Installation of the broodstock fence limited movement to historical spawning locations and the redds surveyed above the fence were early migrants that passed the counter site prior to fence operation. Water depths and velocities at redd locations were similar between years and within ranges considered suitable for spawning Chinook Salmon (Ptolemy 1994; Figure *31*). Substrate sizes observed at redd locations were smaller than the overall mean calculated from transect data (51.7 mm ± 25.8 at redds compared to 70.5 mm ± 57.9 at transects) and on the lower end of the range considered suitable for spawning Chinook Salmon (25-150 mm; Groves and Chandler 1999). Pebble count data from transect surveys observed that preferred spawning locations (Below Longskinny, Eagle, Fraser Lake, and Counter Site) all had mean substrate sizes less than the reach wide average, which is consistent with substrate data collected at redd locations.

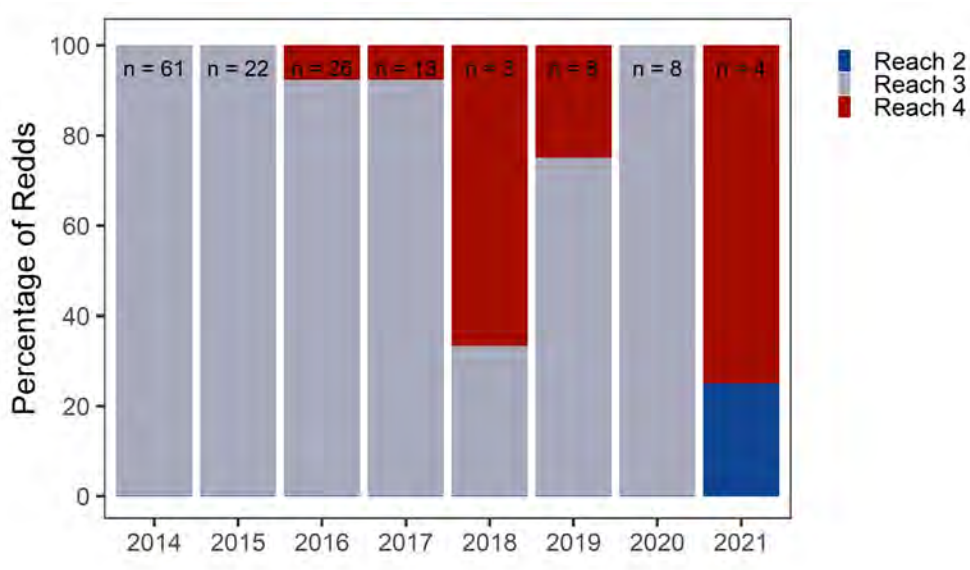

Figure 30: Proportion of Chinook Salmon redds observed in Reach 3 and 4 of the LBR.

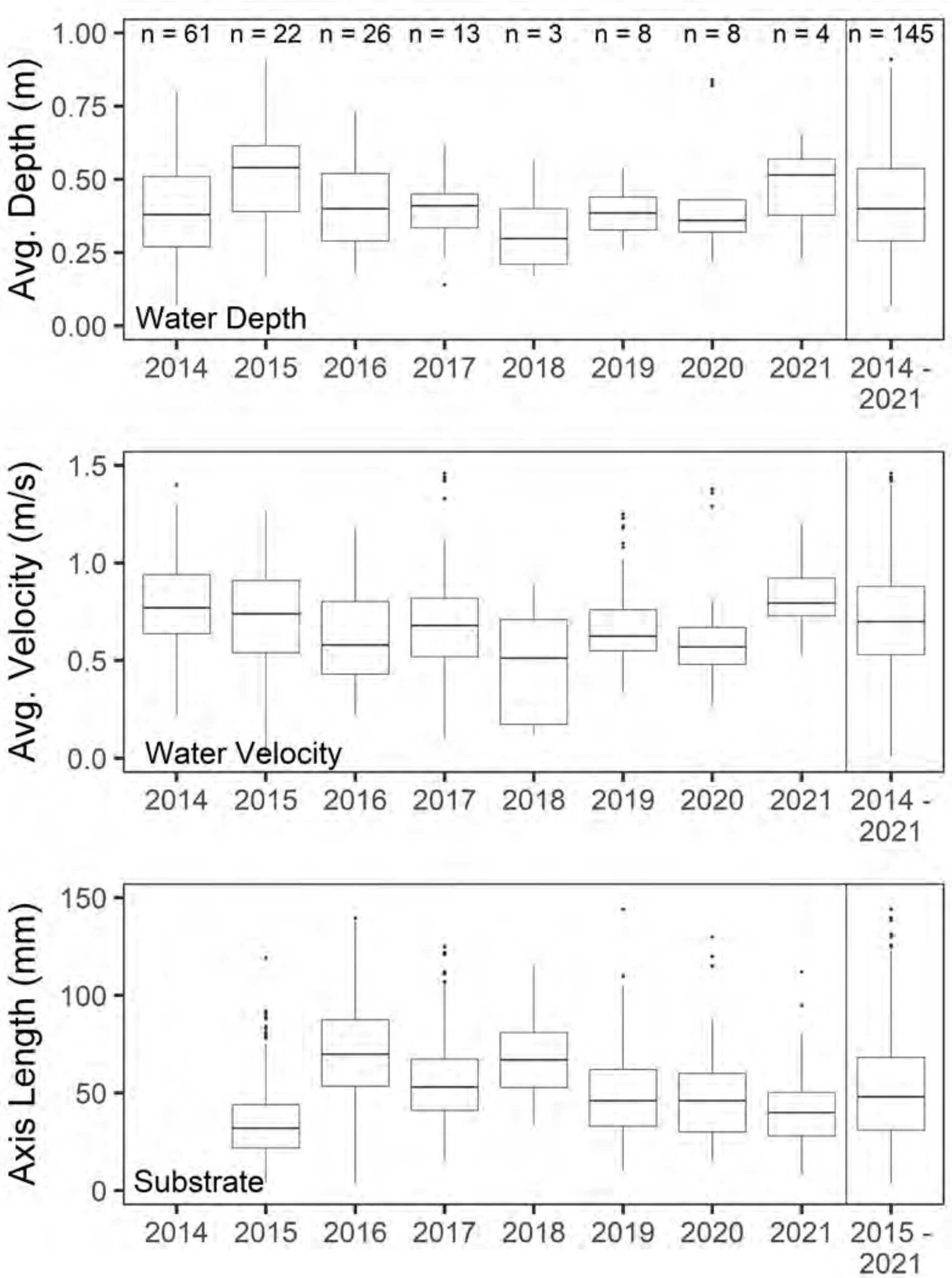

Figure 31: Water velocities (ms^{-1}), depths (m) and substrate size (axis length; mm) measured at Chinook Salmon redds in the Lower Bridge River from 2014 to 2021 and for all data combined. Solid lines denote the annual median water depth, boxes represent the interquartile range (IQR). Lines represent the range excluding outliers, which are shown as points. Substrate surveys were not conducted in 2014.

Coho Salmon

In 2021, nine Coho Salmon redds were observed in Reach 4 (Longskinny; n=6, Eagle; n=3; Figure *32*; Appendix 10). All redds were in glide habitat, consistent with observations since

2018. Water depths, velocities, and substrate sizes at redd locations were variable between years and were consistent with ranges considered suitable for spawning Coho Salmon (>0.18 m and 0.3–0.91 ms^{-1} for water depth and velocity, respectively [Levy and Staney 1993]; 13-102 mm for substrate [Reisner and Bjornn 1979]; Figure *33*). No redds were observed during Reach 3 visual surveys or Reach 2 and 1 spot counts. Inferring changes in redd distributions is limited to only four years of data following the MOD flows; however, from 2018 to 2021, there appears to be a preference to spawn in Reach 4 (Appendix 10).

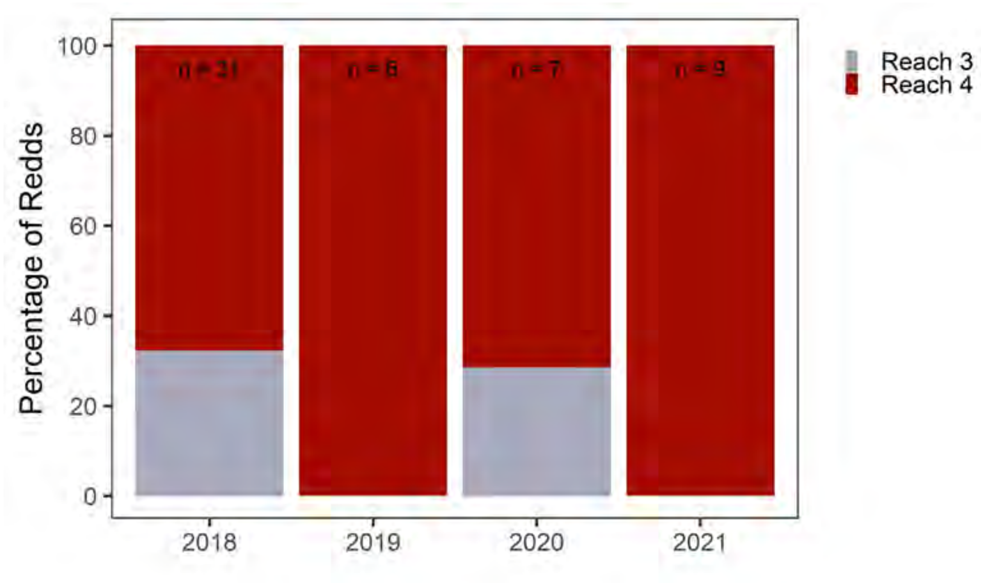

Figure 32: Proportion of Coho Salmon redds observed in Reach 3 and 4 of the LBR.

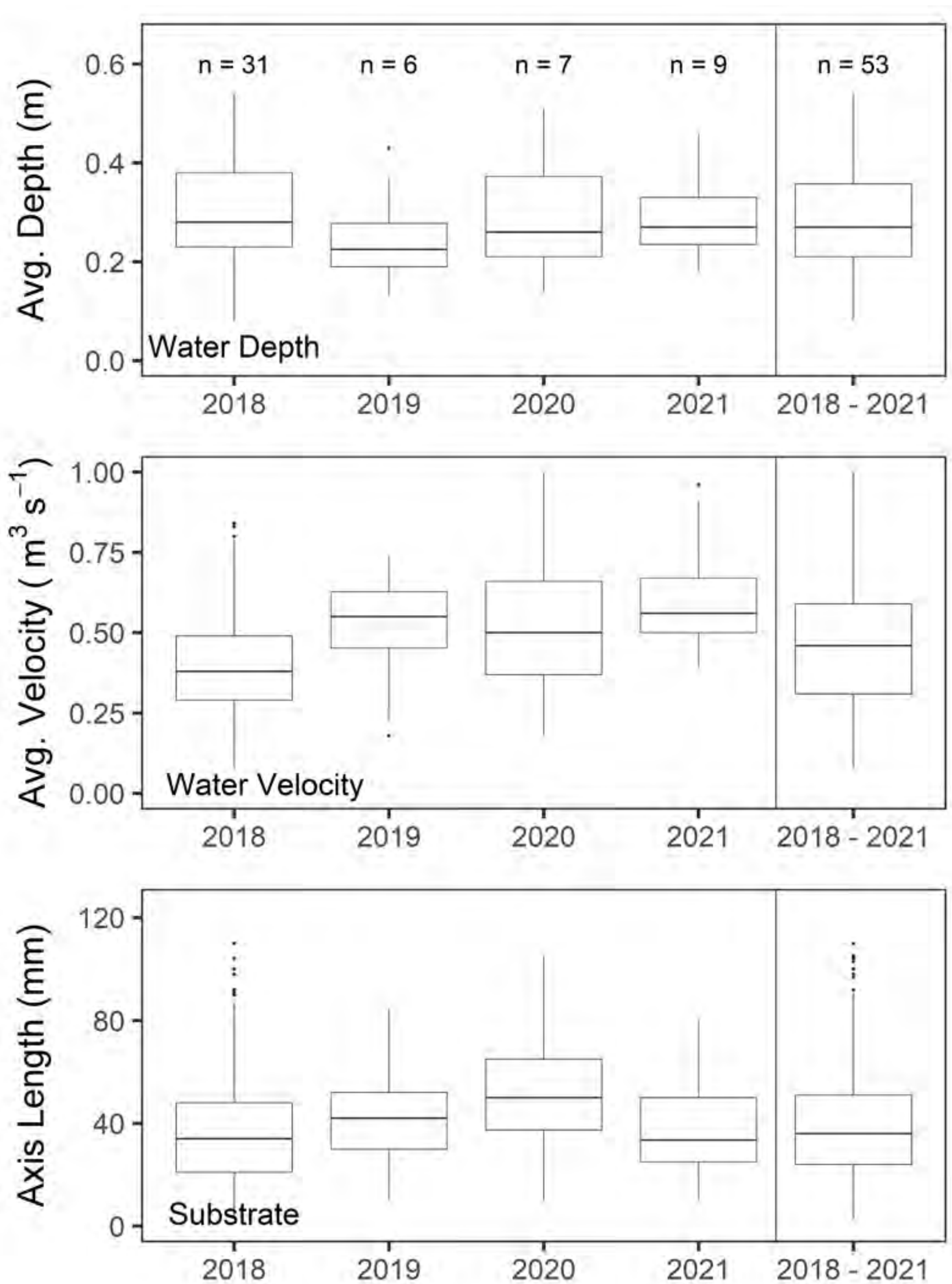

Figure 33: Water velocities (ms^{-1}), depths (m) and substrate (mm) measured at Coho Salmon redds in the Lower Bridge River from 2018 to 2021 and for all data combined. Solid lines denote the annual median water depth, boxes represent the interquartile range (IQR). Lines represent the range excluding outliers, which are shown as points.

3.6 Ageing of Adult Salmon and Steelhead Trout

3.6.1 Steelhead Trout

Nine scales were aged from Steelhead Trout assumed to have spawned in the LBR in 2021. Since 2014, 67 Steelhead Trout scales have been aged. Age 4 (2.2) fish were the dominant age class for 2021 and 2021, which is a shift from previous years (except 2014) where age 5 and 6 fish were the dominant age class. Overall, the dominant age classes of fish with confirmed spawning in the LBR were age 4 (2.2, 3.1), followed by age 5 (2.3, 3.2), and age 6 (3.3; Figure *34*; Appendix 10). Scale ages suggest the proportion of spawners residing in saltwater for 2+ years has increased since 2014 (Appendix 11). Also, scales collected in 2021 did not show evidence of repeat spawning, which has been observed during scale analysis in previous years.

The ages of all Steelhead Trout captured and aged between 2018 and 2021 were examined to determine whether these fish were exposed to high flows as juveniles. Fish that smolted in 2016 were not considered to have been exposed to high flows as they likely migrated prior. In 2021, the dominant age class was 2.2, with all juveniles experiencing high flows in both freshwater years (Table 10).

Table 10: Steelhead Trout ages collected from tagged individuals from 2018 to 2021, indicating brood and smolt year, exposure to high flows, and sample size.

Year	Age	Brood Year	Smolt Year	High Flow Year(s)	Sample Size
2018	2.1	2015	2017	2016	0
	2.2	2014	2016	NA	2
	2.3	2013	2015	NA	7
	3.1	2014	2017	2016, 2017	0
	3.2	2013	2016	NA	2
	3.3	2012	2015	NA	5
2019	2.1	2016	2018	2017	0
	2.2	2015	2017	2016	0
	2.3	2014	2016	NA	1
	3.1	2015	2018	2016, 2017	0
	3.2	2014	2017	2016	2
	3.3	2013	2016	NA	6
2020	2.1	2017	2019	2018	0
	2.2	2016	2018	2016, 2017	8
	2.3	2015	2017	2017	0
	3.1	2016	2019	2017, 2018	0
	3.2	2015	2018	2017, 2018	1
	3.3	2014	2017	2017	0
2021	2.1	2018	2020	NA	0
	2.2	2017	2019	2017, 2018	9
	2.3	2016	2018	2018	0
	3.1	2017	2020	2018	0
	3.2	2016	2019	2018	0
	3.3	2015	2018	2018	0

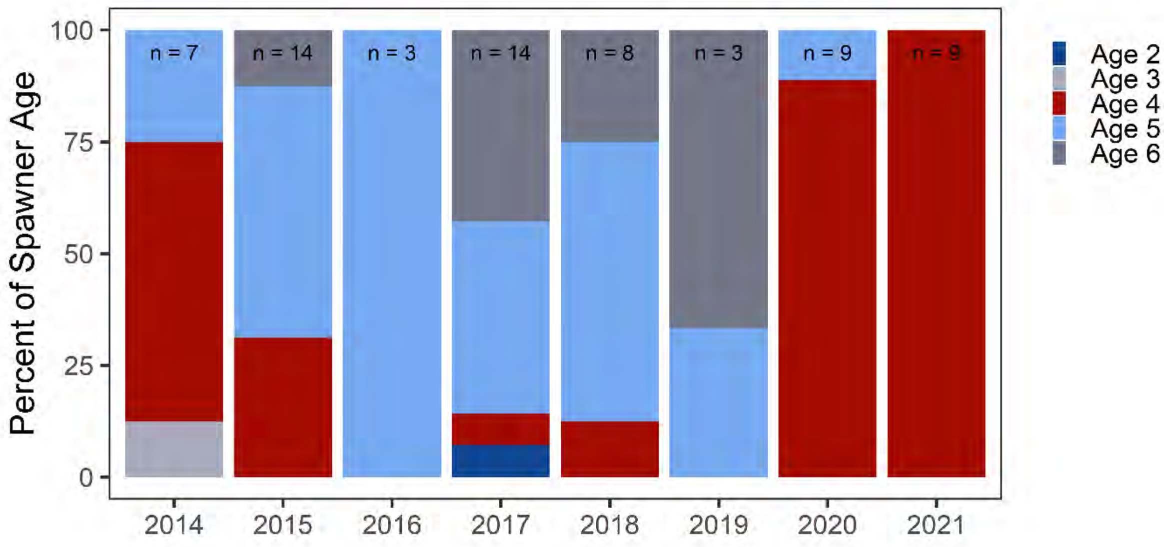

Figure 34: Relative proportion of Steelhead Trout total age classes by year from 2014 to 2021.

3.6.2 Chinook Salmon

Only one Chinook Salmon scale aged in 2021 was assessed as age 2.3 and would have experienced high flows in the LBR as juveniles in the spring of 2018. Since 2014, 59 Chinook Salmon scales have been aged. Since 2013, most Chinook have been age 4 with a few age 3 (1.2) individuals (Figure *35*; Appendix 10). All scales prior to 2021, displayed a yearling (stream-type) life history, with juveniles spending one winter in freshwater. The 2021 fish is unlike all other scales aged over the course of BRGMON3 and could potentially be a stray from another river system.

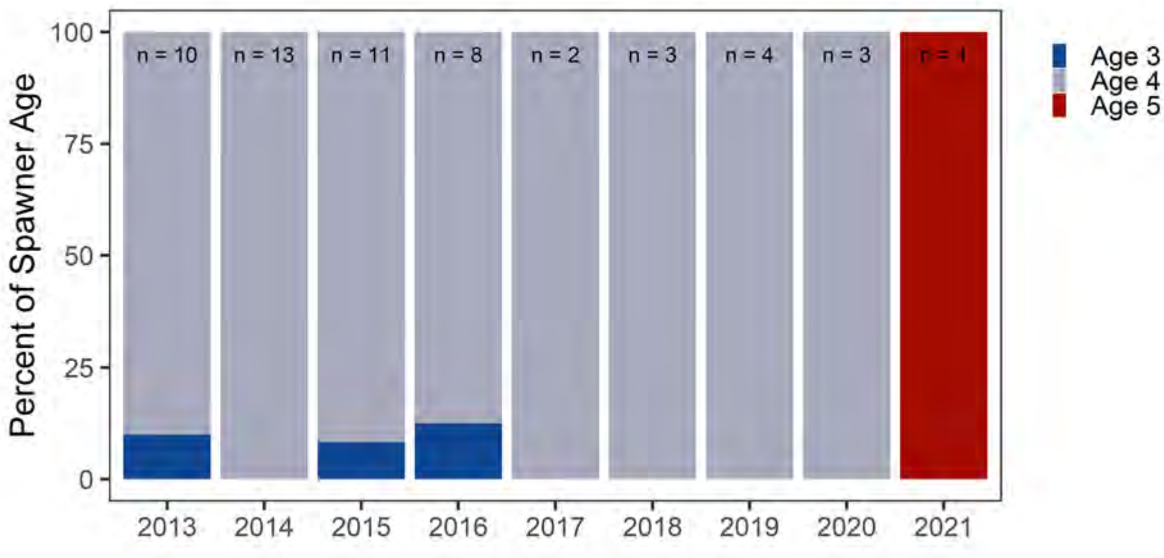

Figure 35: Relative proportion of Chinook Salmon total age classes by year from 2013 to 2021.

3.6.3 Coho Salmon

Ten scales from Coho Salmon assumed to have spawned in the LBR in 2021 were aged as either 1.1 or 2.1 (n = 5 and 5, respectively). Since 2011, 172 Coho Salmon scales have been aged. LBR Coho Salmon returned most frequently at age 2 (1.1) followed by age 3 (2.1; Figure *36*). All scales displayed similar juvenile life histories, with juveniles spending 1-2 years in freshwater before out-migrating as smolts. Coho Salmon returning in 2021 would have not experienced high flows in the LBR as juveniles.

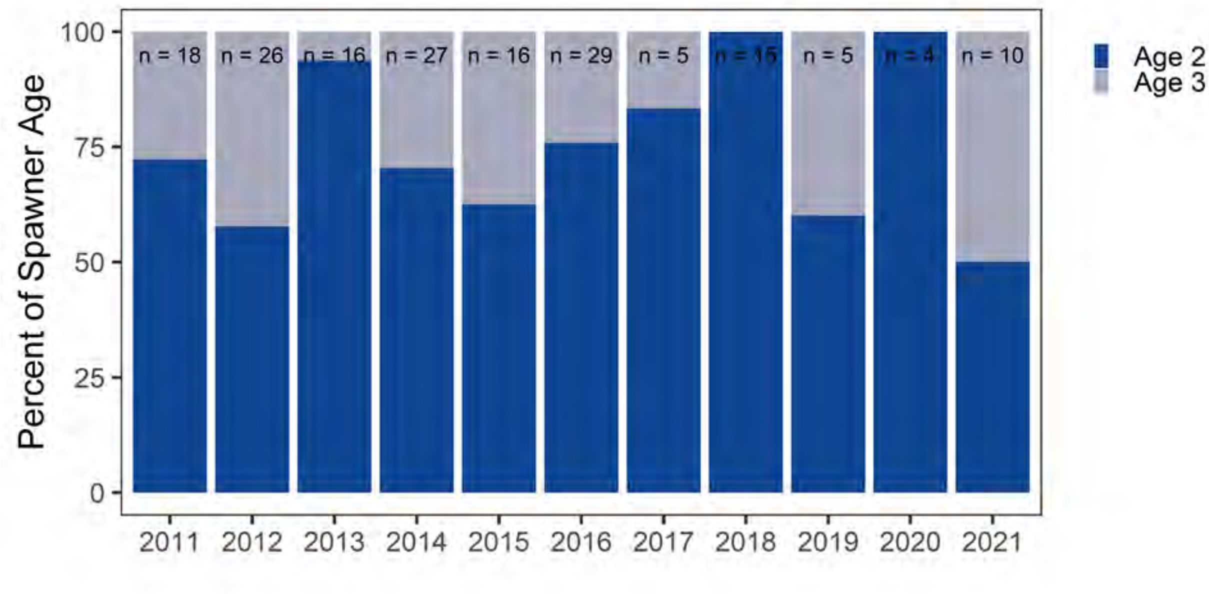

Figure 36: Relative proportion of Coho Salmon age classes by year from 2011 to 2021.

4. Discussion

BRGMON-3 monitors adult salmon and Steelhead Trout abundance and habitat quantity and quality. The results support BRGMON-1, which evaluates the effects of LBR flow regime on salmonid productivity. The monitor also evaluates the effects of WUP and MOD flows on adult salmonid abundance, migration timing, spawner distribution, and quantity and quality of spawning habitat in the LBR. As of 2019, BRGMON-3 addresses four management questions: two related to WUP flows, and two related to MOD flows. Monitoring in 2021 builds upon data from 2012 to 2020 and will be used to answer the management questions and inform future monitoring.

4.1 Terzaghi Dam Operating Parameters

The LBR flows outlined during the WUP process and stipulated in the original BRGMON-3 TOR were 3 m^3s^{-1} from August 2000 to April 2011, and 6 m^3s^{-1} from May 1, 2011, to April 15, 2015. Flows in 2016 through 2018 and in 2021 exceeded the 20 m^3s^{-1} WUP operating parameters and fall under the MOD flow regime. In 2019 and 2020, flows remained below 20 m^3s^{-1}, and are, therefore, not technically MOD operation years. The MOD regime was implemented due to limited storage potential at La Joie Dam, an issue that likely will not be resolved until 2028 when modifications to address dam safety risks are expected to be complete.

MOD discharges have involved several flow variances, but all exceeded the 20 m^3s^{-1} by early May and returned to WUP targeted flows prior to the beginning of Chinook Salmon migration period in mid-August. Adult Chinook and Coho Salmon experience a consistent flow regime of 3.0 and 1.5 m^3s^{-1} for their respective spawning periods, while Steelhead Trout experience an ascending hydrograph during peak spawn timing (mid-May) and are likely the adult species most impacted by the MOD flow regime when they are present in the LBR for spawning.

4.2 BRGMON-3 Management Questions

What is the annual abundance, timing, and distribution of adult salmon and steelhead spawning in the Lower Bridge River and are these aspects of spawning affected by the instream flow regime?

Abundance

Steelhead Trout abundance has declined over the course of this monitor (2014-2021; no previous abundance estimates available), while Chinook Salmon and Coho Salmon abundances have been declining in the LBR since before the implementation of BRGMON-3 (1993-2013). Although Steelhead Trout abundance in 2021 was 62, which is slightly higher than the 2019 estimate of 50, it is still considerably lower than the first year of counter operation in 2014 (238). Chinook Salmon abundance in 2021 was 97, the second lowest observed over the monitor (2018 = 42). Coho Salmon abundance in 2021 was 561, which is less than the mean recorded over the monitor (740 ± 429).

Steelhead Trout are the only adult salmonid to experience MOD flows in the LBR. Eggs and juveniles exposed to high flows may be negatively affected by high flows (Gendaszek et al. 2018); however, declines in adult abundance may also be a function of factors external to the LBR. It is difficult to determine the cause of declining abundance given challenges in monitoring (e.g., changes in counting methodology, installation of the broodstock fence for Chinook Salmon broodstock collection, increased straying due to the Fraser River rockslide) and uncertain conditions affecting salmonids outside of the LBR (e.g., ocean conditions, raising water temperatures, fishing pressures, disease, etc.). It is challenging to evaluate the effects of flow regime on adult abundance because anadromous salmonids spend a significant portion of their life cycle outside of the LBR.

LBR flows are consistently at WUP target values while Chinook and Coho Salmon adults are in the river for spawning; therefore, effects of flow regime on abundance are more likely to be expressed in juveniles when flow variances are experienced. The effects of flow on fish abundance are more comprehensively addressed by BRGMON-1 using productivity, which incorporates both adult and juvenile abundance (i.e., egg-to-fry or adult-to-fry survival). BRGMON-3 is limited to evaluating the direct effects of flow regime on adult Steelhead Trout, Chinook Salmon, and Coho Salmon when they are present in the LBR during spawning migrations, and thus far there is no clear link between spawner escapement and LBR flow.

Adult abundance is estimated using two methods: electronic counters and AUC modeling using visual survey data (Chinook and Coho Salmon only). An interest of BRGMON-3 is to compare electronic counter and visual survey AUC abundance estimates to determine whether AUC estimates are biased, and if so, to back-calculate estimates of historical visual counts to produce more precise historic estimates. Current comparisons between counter and AUC estimates suggest similar results for Chinook Salmon when abundances are low (<160), and in most other years AUC estimates have been biased low. The 2021 Chinook Salmon estimate was lower than the AUC estimate; however, there was intermittent operation due to local fires and resulting road closures. Comparisons for Coho Salmon are variable, with 2019-2021 estimates following a 1:1 relationship, 2014-2016 having the counter estimate above the AUC, and the inverse relationship for 2018. AUC estimates are highly uncertain in the LBR due to low counts, poor visual conditions, uncertainty in OE and SL, and, in some years, poor model fit. In addition, LBR discharge and turbidity have varied considerably from the 1990s to today (with unknown OE and SL) and extrapolating a relationship between counter and AUC estimates is therefore not feasible. Despite uncertainties, we will continue to compare abundance estimated from electric counter and visual surveys as results are valuable for understanding the utility and limitations of both current and historic AUC estimates.

Accurate year-specific OE and SL are important for reliable AUC analyses (Grant et al. 2007, Muhlfeld et al. 2006). OE can vary with observer experience and survey conditions, while SL varies with discharge and water temperature, all of which can change annually and throughout the monitoring period (Gallagher and Gallagher 2005). A sensitivity analysis of data collected to 2019 suggested AUC abundance is sensitive to both OE and SL, indicating that average values used for both current AUC estimates and historic reconstructions may result in unreliable abundance estimates (White et al. 2021). Year-specific OE and SL could only be calculated for four years for Chinook Salmon and five years for Coho Salmon, and average values were used in all other years and for historic reconstruction. Improving SL and OE estimates is challenging given low spawner abundances, but additional OE metrics could be included to better inform OE under ranging environmental conditions (e.g., water clarity). For example, counter estimates could be compared to the number of individuals observed upstream of the counter during visual surveys to obtain a second measure of OE for each year.

Migration Timing

Peak migration timing has been relatively consistent among monitoring years, suggesting no relationship between instream flow and migration timing in the LBR. Steelhead Trout are most vulnerable to MOD flows with entry into the LBR occurring during the ascending limb of the spring hydrograph. Despite experiencing variable discharge conditions throughout BRGMON-3, peak migration and entry into Reach 3 has remained relatively consistent for Steelhead Trout. Since modified operations have occurred (Spring 2016), Steelhead entry into the LBR has occurred earlier than average in 2017, 2020, and 2021; however, the earlier entry date has not affected arrival on spawning grounds (Reach 3). Chinook and Coho Salmon typically migrate when LBR flows are at stable WUP targets (3.0 and 1.5 m^3s^{-1}, respectively) and are therefore unlikely to be significantly impacted by changes to spring flow regimes. The potential exception are early Chinook Salmon migrants present in the LBR during late July or early August that may be exposed to higher discharges. However, peak migration is typically late August or early September when the hydrograph is stable at WUP target flows. Coho Salmon electronic counter enumeration began on October 15 (per historical migration timing data), as the broodstock fence and multiple overlapping species spawning made distinguishing species challenging during early October. As a result, the normal distribution function did not fit the daily count data well, so 2021 Coho Salmon migration timing counter data were omitted from comparison.

Ageing analyses show Steelhead Trout, Chinook, and Coho Salmon spawners returning to the LBR in 2021 all experienced high flows as juveniles. Steelhead Trout have a more diverse life history, and BRGMON-3 ageing has identified six different life history types. Few adult Steelhead Trout cohorts aged in 2018 and 2019 were exposed to high flows as juveniles (8%). In 2020 and 2021 the most common age was 2.2 (89% and 100%, respectively), all of which would have been exposed to high flows in 2017. There is evidence from BRGMON-1 that high flows led to a reduction in juvenile salmon abundance; abundance declined by 77% relative to the 1 m^3s^{-1} flow trial, and 75% relative to and 3 m^3s^{-1} flow trial (Sneep et al. 2018). Most Chinook Salmon return to spawn at 1.3 years and Coho Salmon at 1.1 or 2.1, and we have not observed a substantial change in age class data since the onset of high flows, although the sample sizes for these two species have been low (<5) for the past three years.

Spawner Distribution

Our discussion on spawner distribution is incorporated with the second management question evaluating the effects of the MOD flow regime on spawner distributions in the LBR.

Have flow releases from Terzaghi Dam under the modified flow regime affected the distribution of adult spawning in the Lower Bridge River? If so, what are the potential effects on spawning success and what mitigation options are available?

Spawner distribution was evaluated using a combination of radio telemetry and redd and visual surveys. Preliminary data indicate no direct relationship between instream flow and distributions of spawning Steelhead Trout and salmon in the LBR. Competition for spawning habitat is likely low for all species given low spawner abundances and abundant spawning habitat. Spawning for all species typically occurs in Reach 3 and 4 of the LBR. Steelhead Trout consistently spawn at surveyed habitats in Reach 3 and 4 and were observed spawning in Reach 2 in 2018 and 2021. Despite limited success angling Chinook Salmon from 2017 to 2021, telemetry data, redd surveys, and visual surveys all suggest Chinook Salmon prefer to spawn in Reach 3. Increased spawning in Reach 4 was observed among Chinook Salmon in 2018, 2019, and 2021, but this trend was not observed in 2020. The broodstock collection program in 2018 to 2021 disrupted the natural migration of Chinook Salmon above the counter site and may have altered spawning site selection. Angling success for Coho Salmon has also decreased in 2019-2021; however, telemetry data, redd surveys, and visual surveys all suggest preference towards Reach 4. A consideration for all species is that the Fraser rockslide in 2019 resulted in an increased prevalence of stray fish in the LBR, and these individuals may have different spawning preferences (Keefer and Caudill 2014).

Increased spawning in Reach 4, as observed in 2018, 2019, and 2021, for Chinook Salmon, may affect juvenile survival due to variations in thermal regime (Geist et al. 2006). Releases from Terzaghi Dam are warmer than observed further downstream in the LBR and an upstream shift in spawning could accelerate gamete development and lead to early emergence. Accumulated thermal unit calculations for Chinook Salmon indicate that warmer water temperatures could lead to 50% hatch in January in Reach 4, as opposed to March in Reach 3 (Ramos-Espinoza et al., 2018). This difference in emergence timing could have implications for survival as juveniles may emerge sooner, be exposed to cooler conditions post-emergence, and have less immediate access to abundant food resources. Coho Salmon are likely less affected by early emergence as peak spawning occurs in early November.

In 1993, Chinook Salmon were primarily observed spawning between the upstream end of Horseshoe Bend in Reach 2 and Hell Creek in Reach 3 (23.7-29 rkm) The upper sections of Reach 3 were deemed unsuitable for spawning given larger substrate size (Lister and Beniston 1995). Lister and Beniston (1995) state that flow stability and groun dwater influence in the upper portion of Reach 3 could produce favorable conditions for spawning salmon, despite no previous use. Historic data and current observations suggest Chinook Salmon spawner distributions have shifted upstream considerably since the 1990s. It is difficult to determine whether these changes are related to the instream flow regime, but prior to 1990 there were no flow releases from Terzaghi Dam and LBR flows slowly increased downstream of the dam due to tributary inflows. With the onset of discharge directly from Terzaghi Dam, gravel mobilization and increased available spawning area in Reach 3 and 4, could contribute to the shift in spawning distributions between the 1990s and today. However, spawner distributions may also have been impacted by factors outside of the flow regime.

What is the quality and quantity of spawning habitat in the Lower Bridge River and how is spawning habitat affected by the instream flow regime?

AND

Have flow releases from Terzaghi Dam under the modified flow regime affected the quality and quantity of spawning habitat available in the Lower Bridge River? If so, what are the potential effects on fish and what mitigation options are available?

Habitat surveys in 2017 – 2019, and 2021 and redd surveys since 2014 suggest that access to abundant high-quality spawning habitat is not currently limited in the LBR. Habitat surveys assess the overall quantity and quality of habitat in the LBR, while redd surveys describe habitat characteristics in confirmed spawning locations. According to substrate data collected during HSI surveys (2017-2019, 2021), overall mean particle size decreased in the LBR following high flow events in 2018 (White et al. 2021). Despite this overall decrease, substrate size at confirmed redd locations has remained consistent, suggesting access to preferred spawning habitat is not a limiting factor for Chinook of Coho Salmon productivity in the LBR. Spawner distributions also indicate sufficient spawning habitat is available, as spawners are not observed in Reach 1 and 2 despite both reaches having abundant spawning habitat.

Water depth, velocity, and substrate size at confirmed spawning locations have remained relatively consistent and within ranges considered suitable for spawning, which is expected given that spawners are unlikely to construct redds outside of these ranges. The number of

Chinook and Coho Salmon redds surveyed since 2018 has decreased, limiting meaningful comparison among recent years.

HSI surveys indicate that the overall quantity of Chinook Salmon spawning habitat has been consistent from 2017-2019, and 2021 (no surveys in 2020), but the distribution of this habitat within reaches and habitat units has shifted. Habitat changes are potentially due to changes in substrate composition. Substrate size decreased in Reach 2, 3, and 4, which may be related to high flows (White et al. 2021). It should be noted that the effects of only one high flow event were monitored by these HSI surveys. Two high flow events occurred prior to HSI monitoring, which may have had a stronger effect on substrate composition by immediately flushing highly mobile particles downstream. In addition, substrate measurement can be biased (Olsen et al. 2005; Daniels and McCusker 2010), and different technicians have been involved in substrate measurements during both redd surveys and transect data collection. If substrate changes were flow related, we would expect the mobilization of smaller substrate from upstream habitats to infill downstream habitats, which has not been observed. Continued substrate monitoring is required to determine whether substrate size is affected by the MOD flow regime and how this may impact spawning habitat availability in the LBR.

We found no significant change in WUA between 2018 and 2019 (no high flow events occurred between these surveys) suggesting that our survey method is resilient to changing technicians and measurement errors. HSI surveys therefore show promise as a means of monitor spawning habitat quantity in the LBR; however, the HSI scores used here are generalized for all of British Columbia and may not be representative of LBR salmonids (Ptolemy 1994). If data continue to be collected at confirmed redd locations, LBR-specific HSI scores could be developed which would more accurately evaluate whether changes spawner distributions are a function of habitat availability.

4.3 Additional Considerations

The Fraser River rockslide (2019) and a broodstock fence installed for Chinook Salmon broodstock collection (2018 - 2021) require further discussion given their potential to affect the behavior and abundance of adult salmonids. DNA analyses from the Chinook Salmon broodstock program indicated that a high proportion of stray Chinook Salmon were present in the LBR in 2019 - 2021, which was likely also the case for Steelhead Trout and Coho Salmon. Straying affects our ability to compare abundance over time, as abundance estimates in 2019 - 2021 include both stray fish and those of LBR origin. Migration timing, distribution of spawners, and redd surveys were also affected given that different Fraser River populations have specific run timing and spawning habitat preferences. Increased straying may provide both short- and long-term benefits to LBR salmonid populations by increasing abundance and genetic diversity (Keefer and Caudill 2014). The long-term effects of the Fraser River rockslide are unknown, and additional years of monitoring data will help to inform effects to behaviour and abundance.

A broodstock fence was operated for Chinook Salmon broodstock collection between August 25 and October 4, which impaired Chinook Salmon migration into preferred spawning habitat in Reach 3 and 4. Many individuals spawned immediately downstream of the fence, biasing comparisons of spawner distribution among monitoring years. The fence also prevented a complete Chinook Salmon abundance estimate for both electronic counters and visual counts. Enumerating Chinook Salmon and monitoring spawner distributions will be challenging if the broodstock fence continues to be operated immediately upstream of counter infrastructure, and continued fence operation will severely inhibit our ability to answer the BRGMON-3 management questions.

4.4 Summary and Recommendations

The results of BRGMON-3 inform BRGMON-1 analyses and provide insight into how instream flows in the LBR affect adult abundance, migration timing, spawner distribution, and spawning habitat quality and quantity. Despite changing methodologies, difficult survey conditions, and low abundances in recent years, BRGMON-3 is collecting valuable data that will be used to address the specific management questions outlined for the monitor. To date, although there have been shifts in adult salmonid spawner abundance, distribution, and habitat characteristics, there is no clear evidence that these changes are directly related to instream flow regimes. Additional data collection will further inform this conclusion. Particularly, visual OE and SL data are required to improve current and historic AUC abundance estimates and have not been calculated in recent years due to low tag deployment and few tags moving into Reach 3 and 4. Additional years of abundance and habitat data will help to determine whether the flow regime will affect the spawning success of adult salmonids in the LBR.

Of particular concern is the effect of the broodstock fence used to collect Chinook Salmon broodstock on the abundance, distribution, and timing of LBR Chinook Salmon and the effect of the Fraser River rockslide on rates of straying of all species into the LBR. The effect of these events on the ability of BRGMON-3 to collect informative data should be considered alongside their direct effects to migration and spawning success.

Recommendations for 2022 BRGMON-3 data collection include:

- Delay Terzaghi flow release above WUP target discharge until early June to allow for a complete Steelhead Trout enumeration.
- Continue redd surveys and habitat surveys following high flow events to compare habitat use to habitat availability in the LBR.
- If a broodstock fence is to be installed during the Chinook Salmon migration period, we recommend that it be removed by the end of September to allow for more accurate enumeration and migration timing analysis.

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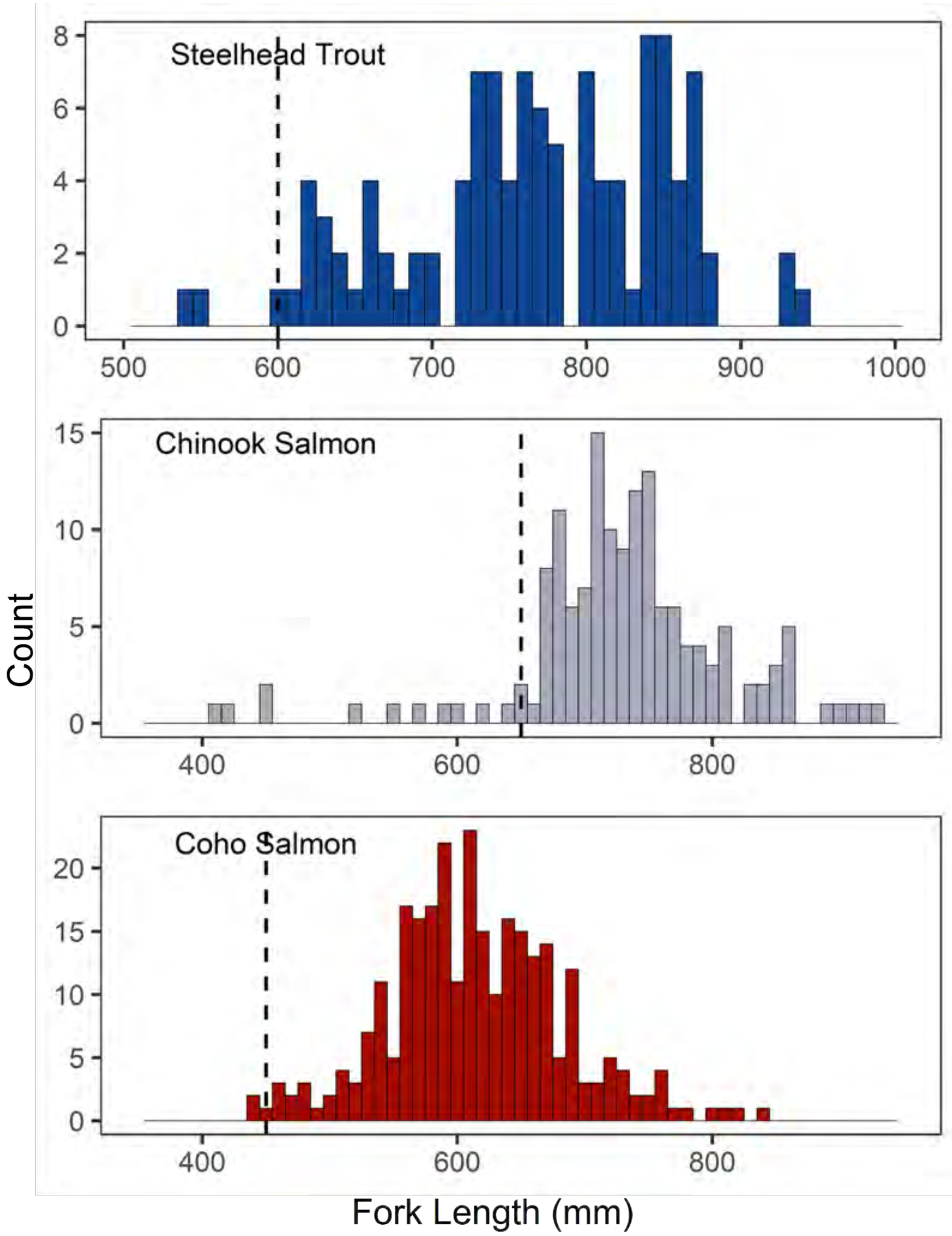
Appendix 1: Length-frequency Distribution

Steelhead Trout, and Chinook and Coho Salmon fork lengths (mm) collected from BRGMON-3, BRGMON-14 and broodstock collection. Dashed line represents the fork length cut off used in sonar species assignment.



Appendix 2: AUC Metrics

Chinook Salmon AUC abundance estimates with standard error (SE) and upper and lower confidence intervals (CI) for the Lower Bridge River from 1993-2021. Abundance results are calculated considering estimates of observer efficiency (OE) and residences times (survey life; SL). OE and SL measures are bold face where calculations were based on observations, the remaining values are the calculated average of these measures.

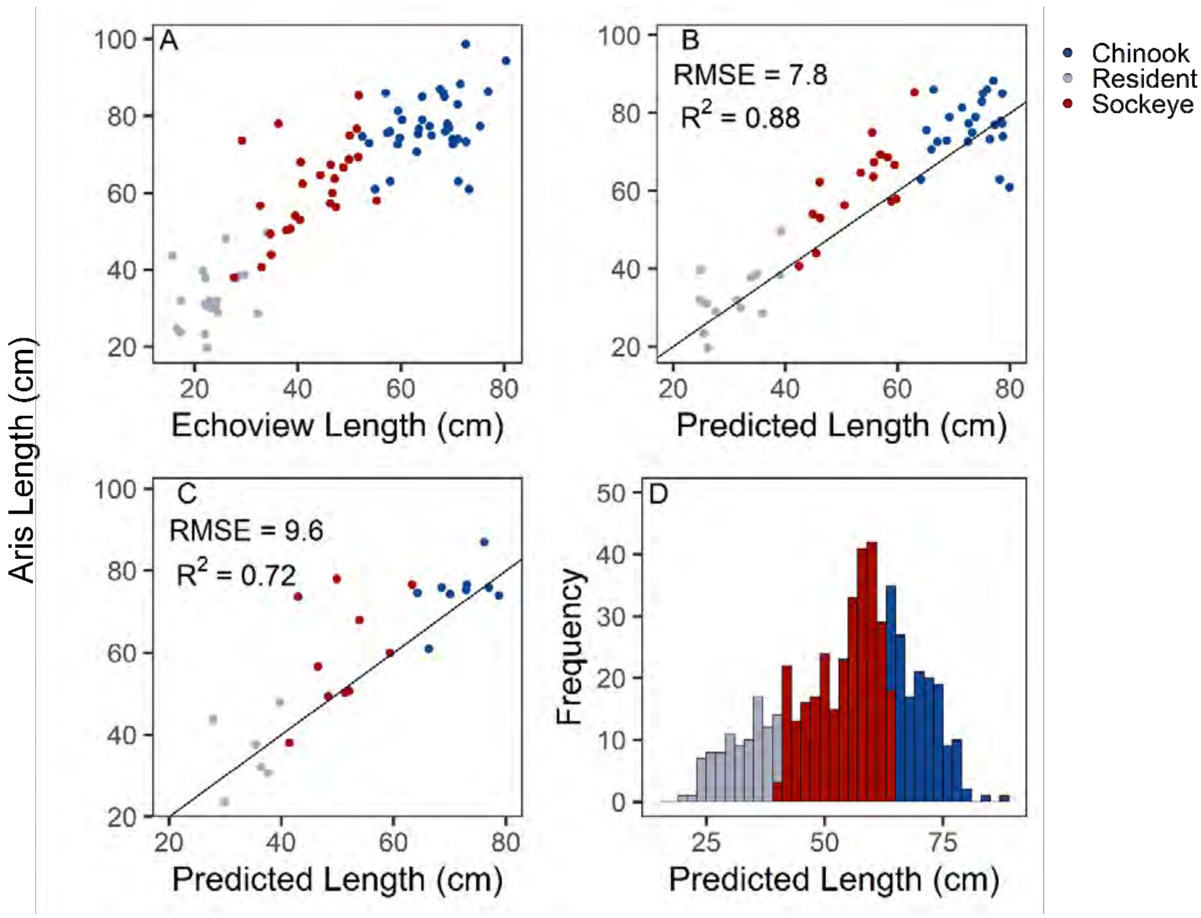
Year	OE	OE.SE	SL	SL.SE	Escapement	Escapement.se	Method	Lower95CI	Upper95CI
1993	NA	NA	NA	NA	151	0	fence count	151	151
1994	NA	NA	NA	NA	550	0	fence count	550	550
1995	NA	NA	NA	NA	851	0	fence count	851	851
1996	NA	NA	NA	NA	1100	0	fence count	1100	1100
1997	0.5	0.139	10.5	0.65	2005	1581	visual survey	427	9406
1998	0.5	0.139	10.5	0.65	873	254	visual survey	494	1543
1999	0.5	0.139	10.5	0.65	2576	847	visual survey	1352	4906
2001	0.5	0.139	10.5	0.65	1784	981	visual survey	607	5244
2004	0.5	0.139	10.5	0.65	3106	1139	visual survey	1514	6374
2005	0.5	0.139	10.5	0.65	591	232	visual survey	274	1274
2006	0.5	0.139	10.5	0.65	399	124	visual survey	217	733
2007	0.5	0.139	10.5	0.65	309	108	visual survey	156	613
2008	0.5	0.139	10.5	0.65	164	94	visual survey	53	507
2009	0.5	0.139	10.5	0.65	21	7	visual survey	10	41
2010	0.5	0.139	10.5	0.65	208	67	visual survey	110	392
2011	0.5	0.139	10.5	0.65	82	33	visual survey	38	179
2012	**0.58**	0.139	**10**	0.65	364	114	visual survey	196	674
2013	**0.28**	0.139	**11**	0.65	168	90	visual survey	59	479
2014	**0.28**	0.139	**12**	0.65	591	314	visual survey	209	1673
2015	0.5	0.139	10.5	0.65	158	68	visual survey	68	370
2016	**0.28**	0.139	**10.5**	0.65	473	247	visual survey	170	1317
2017	0.5	0.139	10.5	0.65	120	42	visual survey	61	239
2018	0.5	0.139	10.5	0.65	25	7	visual survey	14	44
2019	0.5	0.139	10.5	0.65	161	54	visual survey	84	310
2020	0.5	0.139	10.5	0.65	16	8	visual survey	6	41
2021	0.5	0.139	10.5	0.65	184	56	visual survey	101	334

Coho Salmon AUC abundance estimates with standard error (SE) and upper and lower confidence intervals (CI) for the Lower Bridge River from 1993-2021. Abundance results are calculated considering estimates of observer efficiency (OE) and residences times (survey life; SL). OE and SL measures are bold face where calculations were based on observations, the remaining values are the calculated average of these measures.

year	oe	oe.se	sl	sl.se	escapement	escapement.se	method	lower95CI	upper95CI
1997	0.216	0.019	19.6	1.29	619	1419	visual survey	6.940512	55245.03
1998	0.216	0.019	19.6	1.29	1079	400	visual survey	521.5082	2232.028
1999	0.216	0.019	19.6	1.29	81	NA	visual survey	NA	NA
2001	0.216	0.019	19.6	1.29	1033	134	visual survey	801.4703	1331.385
2003	0.216	0.019	19.6	1.29	1217	134	visual survey	980.5683	1510.181
2004	0.216	0.019	19.6	1.29	233	50	visual survey	152.892	356.0635
2005	0.216	0.019	19.6	1.29	739	123	visual survey	532.7264	1025.037
2006	0.216	0.019	19.6	1.29	674	110	visual survey	489.3859	929.0487
2008	0.216	0.019	19.6	1.29	102	16	visual survey	74.98446	138.9845
2009	0.216	0.019	19.6	1.29	1601	242	visual survey	1191.47	2152.115
2010	0.216	0.019	19.6	1.29	463	81	visual survey	328.8576	653.1707
2011	0.216	0.019	19.6	1.29	3678	636	visual survey	2620.984	5160.678
2012	**0.25**	0.019	**16**	1.29	1662	386	visual survey	1054.822	2618.98
2013	**0.27**	0.019	**19**	1.29	2974	355	visual survey	2353.094	3759.042
2014	0.216	0.019	19.6	1.29	424	74	visual survey	301.152	595.7595
2015	0.216	0.019	19.6	1.29	174	23	visual survey	134.5335	224.1282
2016	**0.216**	0.019	**19.6**	1.29	488	69	visual survey	370.3827	642.3499
2017	**0.19**	0.019	**23**	1.29	451	65	visual survey	339.2249	599.3597
2018	0.216	0.019	19.6	1.29	1245	169	visual survey	953.8967	1624.493
2019	0.216	0.019	19.6	1.29	216	35	visual survey	156.9518	298.351
2020	0.216	0.019	19.6	1.29	537	121	visual survey	344.9745	834.9001

Appendix 3: Sonar Length Modelling and Linear Model Coefficients

Manually measured fish length in ARISFish software in relation to (A) Echoview generated length and (B) ARISfish lengths in relation to predicted lengths from a linear UP model (C) ARISfish lengths in relation to predicted lengths from a linear DOWN model. Black line indicates unity (1:1). (D) Histogram of the predicted lengths of fish counted by Echoview. Grey, red and blue correspond to resident fish and Sockeye and Chinook Salmon, respectively.



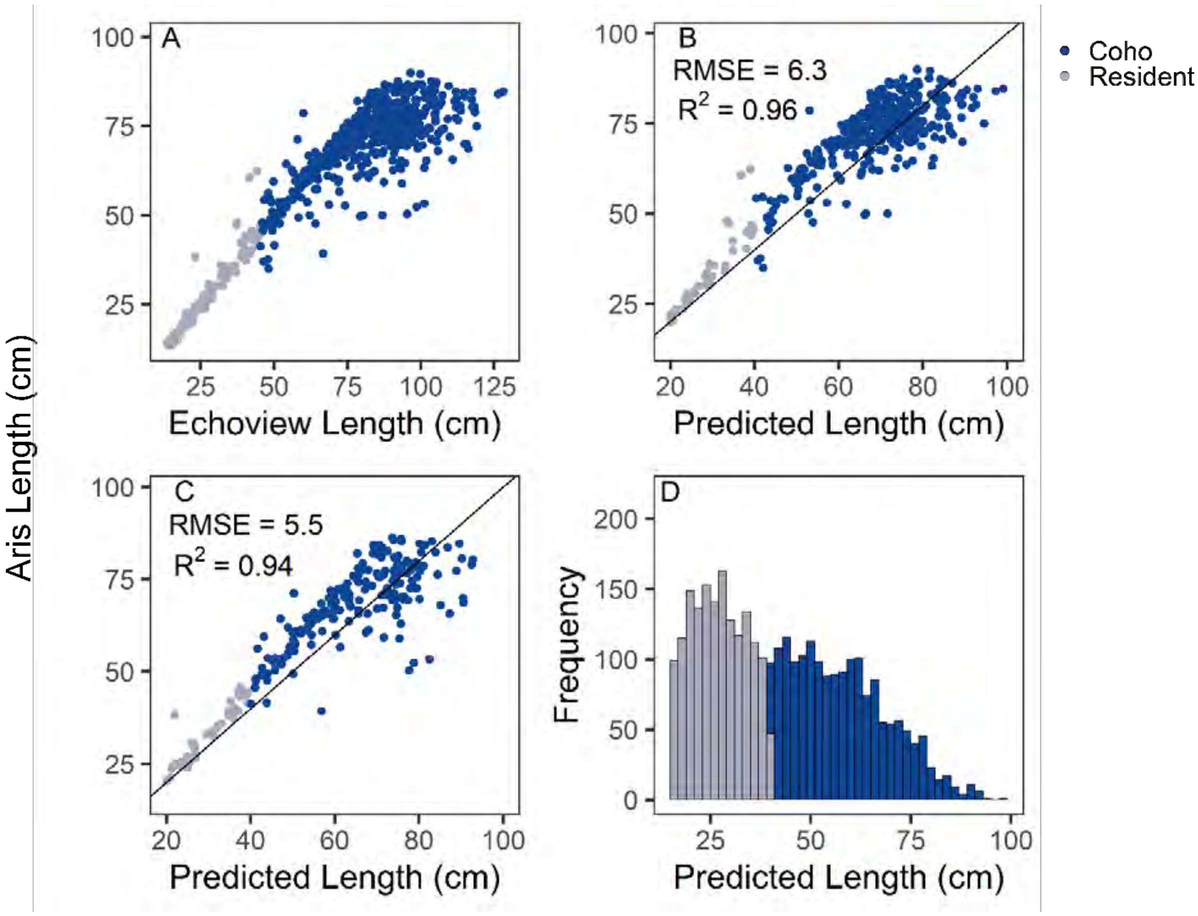
Model output and AICc for predicting ARIS lengths of “up” fish from Echoview target length, number of targets, and target mean range. Predicted lengths were used to distinguish Chinook Salmon and enumerate abundance.

Intercept	log Number of Targets	log Target Length Mean	log Target Range Mean	R^2	df	ΔAIC
0.902		0.860	-0.118	0.875	4	0.000
0.849	-0.070	0.898		0.875	4	0.070
0.909	-0.044	0.884	-0.076	0.879	5	0.760
0.754		0.862		0.862	3	3.470

Model output and AICc for predicting ARIS lengths of “down” fish from Echoview target length, number of targets, and target mean range. Predicted lengths were used to distinguish Chinook Salmon and enumerate abundance.

Intercept	log Number of Targets	log Target Length Mean	log Target Range Mean	R^2	df	ΔAIC
1.642		0.654		0.719	3	0.000
1.702		0.622	0.056	0.722	4	2.560
1.623	-0.007	0.664		0.719	4	2.800
1.643	-0.032	0.656	0.088	0.724	5	5.450

Manually measured fish length in ARISFish software in relation to (A) Echoview generated length and (B) ARISfish lengths in relation to predicted lengths from a linear UP model (C) ARISfish lengths in relation to predicted lengths from a linear DOWN model. Black line indicates unity (1:1). (D) Histogram of the predicted lengths of fish counted by Echoview. Grey, and blue correspond to resident fish Coho Salmon, respectively.



Model output and AICc for predicting ARIS lengths of "up" fish from Echoview target length, number of targets, and target mean range. Predicted lengths were used to distinguish Coho Salmon and enumerate abundance.

Intercept	log Number of Targets	log Target Length Mean	log Target Range Mean	R^2	df	ΔAIC
0.5524	0.0107	0.8484	-0.0371	0.9563	5	0
0.5776		0.8472	-0.0288	0.9561	4	1.51
0.5041		0.8573		0.9557	3	7.36
0.4904	0.0031	0.8585		0.9557	4	9.02

Model output and AICc for predicting ARIS lengths of "down" fish from Echoview target length, number of targets, and target mean range. Predicted lengths were used to distinguish Coho Salmon and enumerate abundance.

Intercept	log Number of Targets	log Target Length Mean	log Target Range Mean	R^2	df	ΔAIC
0.6102		0.8424	-0.0323	0.9399	4	0
0.599	0.0097	0.8411	-0.0399	0.9401	5	0
0.5427		0.85		0.939	3	9.06
0.5489	-0.0022	0.8499		0.9391	4	10.94

Appendix 4: Radio Tagging

Tagging information and spawning distribution of radio-tagged Steelhead Trout in the Lower Bridge River in 2021, including calculated residence time in specific reaches. All fish were tagged at the Seton-Fraser confluence.

Fish ID	Sex	Fork Length	Tagging Date	Entry Date to LBR	End Date	Assumed Spawning Reach	Assumed Spawning Section	Reach 2 Residence Time (days)	Reach 3 Residence Time (days)	Kelt Date Past the Counter
180	F	880	2021-02-24	NA	NA	NA	NA	NA	NA	NA
181	F	730	2021-02-24	2021-04-08	2021-05-24	2*	NA	38	NA	2021-05-20
182	M	945	2021-02-24	2021-04-02	2021-05-26	2*	NA	48	NA	2021-05-22
183	F	780	2021-02-26	2021-04-06	2021-05-21	4	2	35	2	2021-04-24
184	F	730	2021-02-27	2021-04-14	2021-04-22	NA	NA	3	1	NA
185	F	850	2021-02-27	NA	NA	NA	NA	NA	NA	NA
186	M	850	2021-03-01	2021-04-14	2021-04-22	4	2	3	1	NA
187	F	840	2021-03-03	NA	NA	NA	NA	NA	NA	NA
188	M	850	2021-03-06	NA	NA	NA	NA	NA	NA	NA
189	F	765	2021-03-11	NA	NA	NA	NA	NA	NA	NA
190	F	860	2021-03-11	NA	NA	NA	NA	NA	NA	NA
191	F	885	2021-03-12	2021-04-01	2021-05-13	4	2	37	30	2021-05-12
192	M	809	2021-03-13	NA	NA	NA	NA	NA	NA	NA
193	F	740	2021-03-15	2021-04-17	2021-05-04	2/3	NA	13	NA	NA
194	M	865	2021-03-17	2021-04-01	2021-05-09	4	2	35	31	NA
195	F	845	2021-03-18	2021-04-26	2021-06-07	4	2	41	39	NA
196	M	875	2021-03-18	2021-03-30	2021-06-11	2	NA	64	NA	NA
197	F	730	2021-03-19	2021-04-07	2021-06-07	4	2	50	46	NA
198	F	705	2021-03-21	NA	NA	NA	NA	NA	NA	NA
199	M	845	2021-03-22	2021-04-09	2021-04-20	4	2	5	NA	NA
200	M	820	2021-04-02	2021-04-25	2021-05-31	4	2	31	NA	NA
201	F	855	2021-04-02	2021-04-17	2021-05-31	4	2	21	NA	NA
202	F	NA	2021-04-09	NA	NA	NA	NA	NA	NA	NA
							Mean	**30**	**21**	**2021-05-12**
							Std	**19**	**20**	**13**

*unconfirmed spawning location, individual potentially migrated into the Yalakom River

Tagging information and spawning distribution of radio-tagged Chinook Salmon in the Lower Bridge River in 2021, including capture location and residence time in Reach 3.

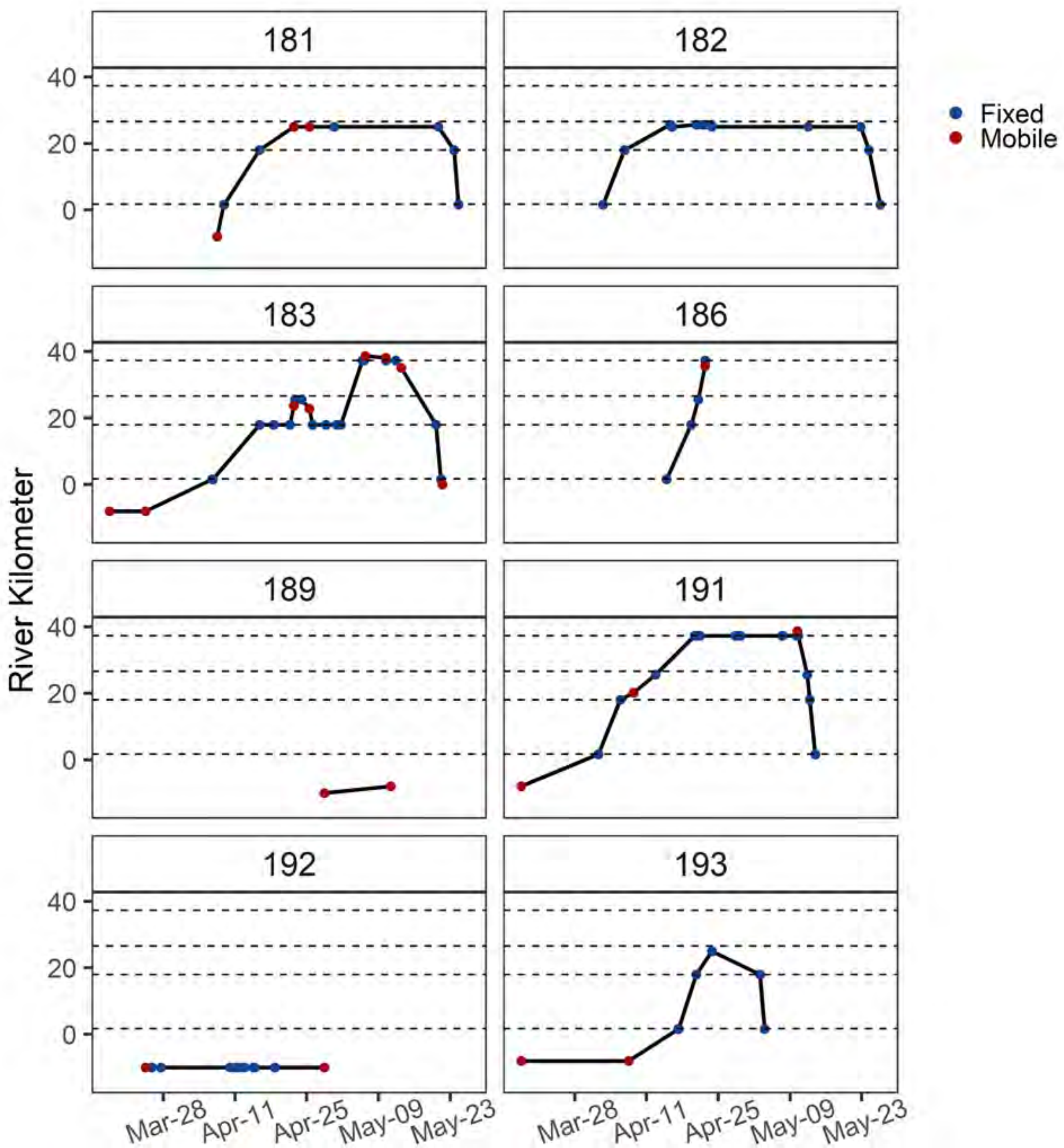
Fish ID	Sex	Fork Length	Tagging Date	Tagging Location	End Date	Assumed Spawning Reach	Assumed Spawning Section	Reach 3 Residence Time (days)
10	F	740	08-10	Yalakom Pool	09-24	3	Hell Creek - Counter	21
11	F	706	08-10	Yalakom Pool	10-09	3	Counter - Yalakom	40
12	M	918	08-10	Yalakom Pool	09-17	3	Counter - Yalakom	3
							Mean	**21**
							Std	**19**

Tagging information and spawning distribution of radio-tagged Coho Salmon in the Lower Bridge River in 2021, including capture and estimated spawning location and residence time in Reach 3.

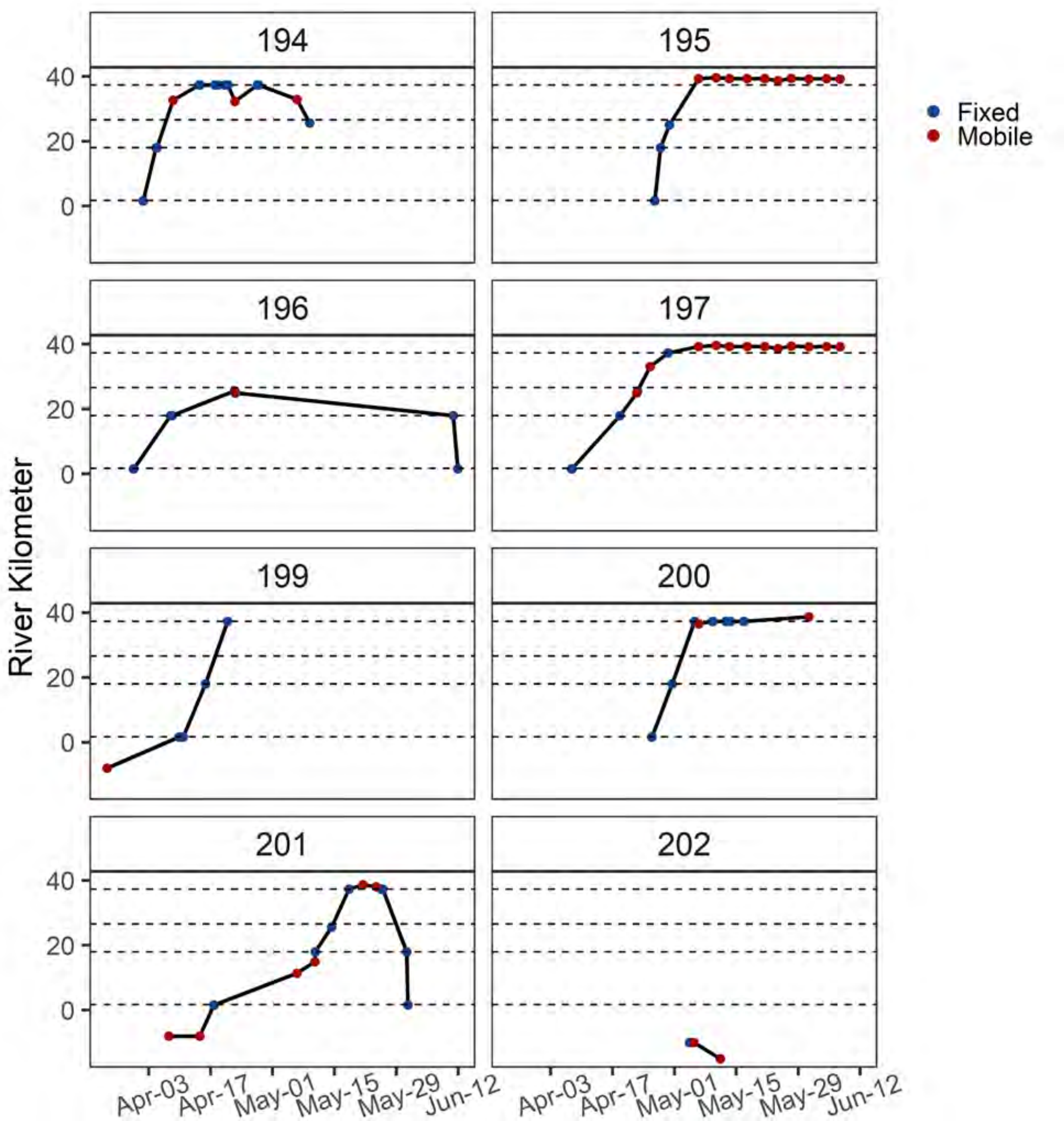
Fish ID	Sex	Fork Length	Tagging Date	Tagging Location	End Date	Assumed Spawning Reach	Assumed Spawning Section	Reach 3 Residence Time (days)
13	M	670	09-28	Camoo Bridge	10-08	2	Camoo FSR	NA
14	F	600	10-09	Bridge Confluence	NA	NA	NA	NA
15	M	505	10-09	Bridge Confluence	NA	NA	NA	NA
16	M	525	10-12	Bridge Confluence	11-15	3	Fraser Lake - Russel Springs	24
17	F	540	10-12	Bridge Confluence	10-14	NA	NA	NA
18	M	530	10-14	Bridge Confluence	NA	NA	NA	NA
19	F	630	10-14	Bridge Confluence	NA	NA	NA	NA
20	F	610	10-14	Bridge Confluence	NA	NA	NA	NA
21	M	610	10-14	Bridge Confluence	NA	NA	NA	NA
22	M	570	10-14	Bridge Confluence	NA	NA	NA	NA
23	F	515	10-15	Above LBR Bridge	NA	NA	NA	NA
24	M	670	10-15	Above LBR Bridge	NA	NA	NA	NA
25	M	445	10-15	Above LBR Bridge	NA	NA	NA	NA
26	M	540	10-16	Bridge Confluence	NA	NA	NA	NA
27	F	450	10-17	Bridge Confluence	NA	NA	NA	NA
30	M	675	10-22	Yalakom Pool	12-06	4	Longskinny - Eagle	NA
31	M	695	10-22	Yalakom Pool	11-07	3	Counter - Yalakom	10
32	M	638	10-26	Yalakom Pool	12-05	3	Counter - Yalakom	10
33	F	668	10-26	Yalakom Pool	12-06	3	Bluenose - Cobra	41
34	M	717	10-26	Yalakom Pool	NA	NA	NA	NA
35	M	565	10-26	Yalakom Pool	NA	NA	NA	NA
36	F	573	10-26	Yalakom Pool	11-29	3	Counter - Yalakom	28
37	F	554	10-27	Hippie Pool	11-29	3	Fraser Lake - Russel Springs	33
38	M	557	10-27	Hippie Pool	11-01	3	Counter - Yalakom	5
39	F	555	10-27	Bridge Confluence	NA	NA	NA	NA
40	M	650	10-28	Hippie Pool	11-26	3	Bluenose - Cobra	29
41	M	600	10-28	Hippie Pool	12-02	4	Plunge Pool - Longskinny	35
42	M	650	11-04	Hippie Pool	11-07	3	Counter - Yalakom	3
							Mean	**22**
							Std	**14**

Appendix 5: Radio Telemetry Traces

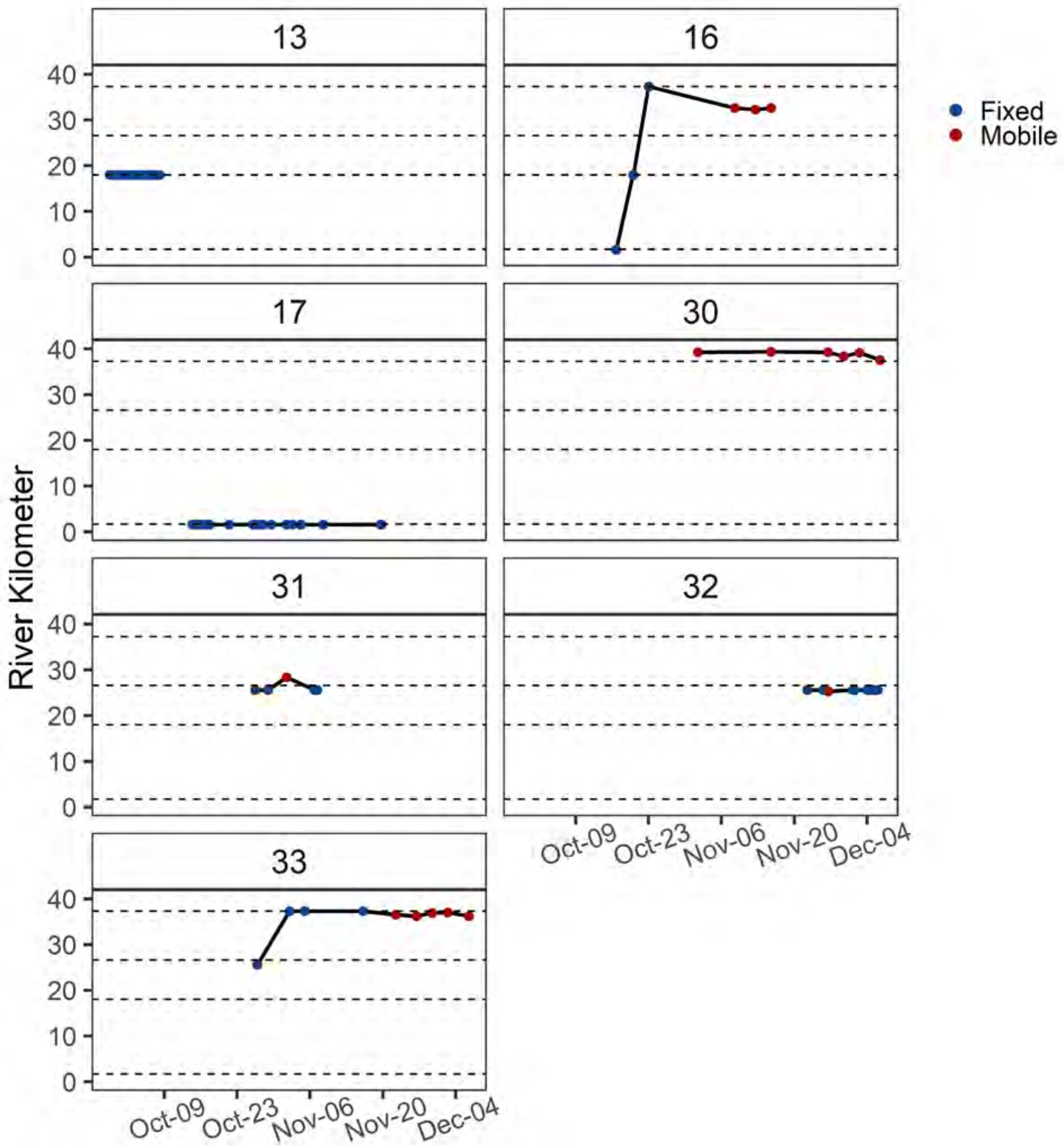
Detection histories of all radio tagged adult Steelhead Trout in the Lower Bridge River in 2021. Numbers at the top of each fish traces corresponds to the Fish ID. Black lines connect the data collected from fixed (blue) and mobile (red) telemetry. Dashed lines indicate boundaries between different reaches. Observations below 0 river kms are sites located in the Seton River.



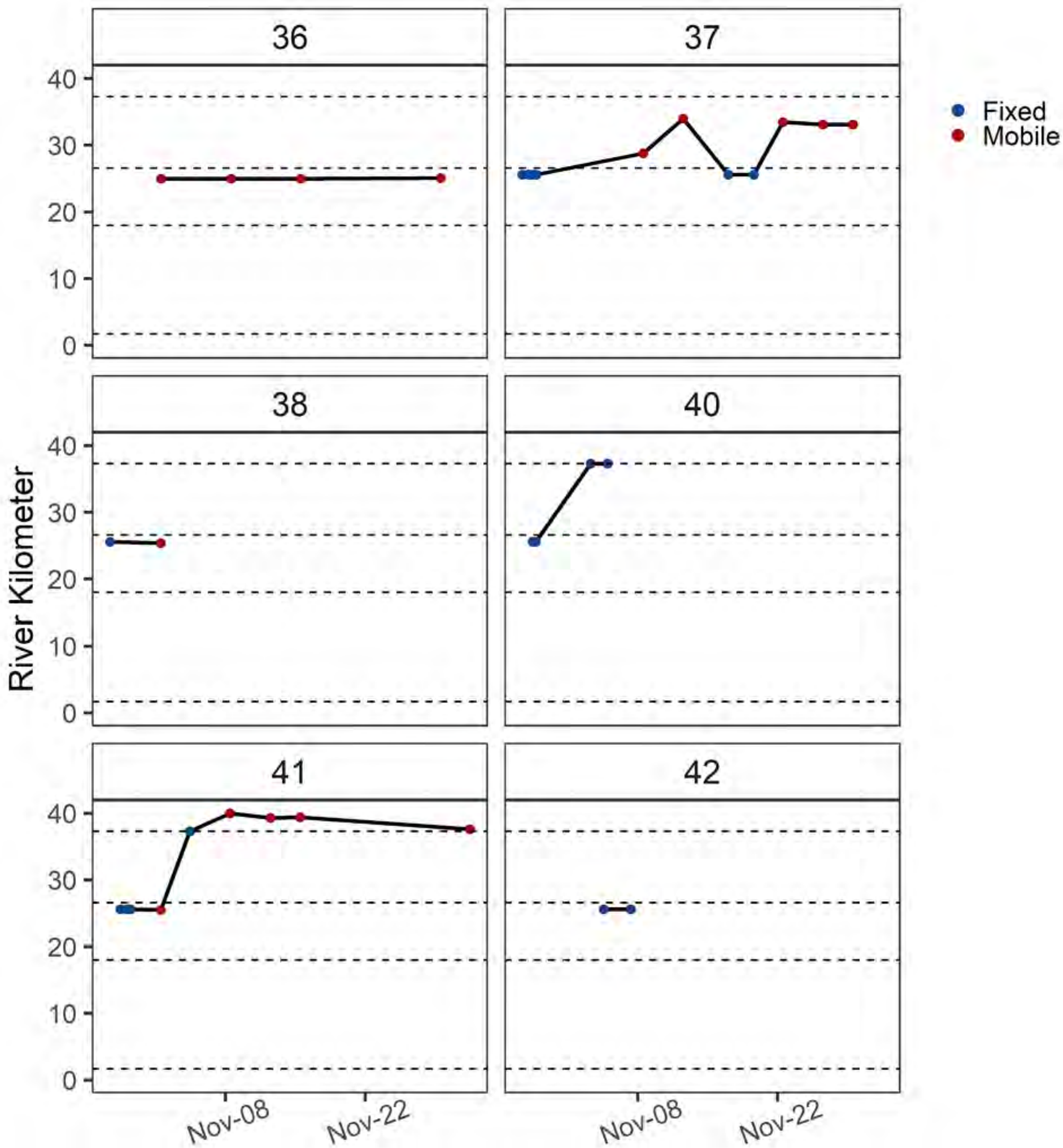
Con't: Detection histories of all radio tagged adult Steelhead Trout in the Lower Bridge River in 2021. Numbers at the top of each fish traces corresponds to the Fish ID. Black lines connect the data collected from fixed (blue) and mobile (red) telemetry. Dashed lines indicate boundaries between different reaches. Observations below 0 river kms are sites located in the Seton River.



Detection histories of all radio tagged adult Coho Salmon in the Lower Bridge River in 2021. Numbers at the top of each fish traces corresponds to the Fish ID. Black lines connect the data collected from fixed (blue) and mobile (red) telemetry. Dashed lines indicate boundaries between different reaches.



Con't: Detection histories of all radio tagged adult Coho Salmon in the Lower Bridge River in 2021. Numbers at the top of each fish traces corresponds to the Fish ID. Black lines connect the data collected from fixed (blue) and mobile (red) telemetry. Dashed lines indicate boundaries between different reaches.



Appendix 6: Visual Survey Count

Chinook Salmon visual survey data by visual survey section in 2021.

Date	Cloud Cover (%)	Water Clarity (m)	Plunge Pool to Longskinny	Longskinny to Eagle	Eagle to Bluenose	Bluenose to Cobra	Cobra to Fraser Lake	Fraser Lake to Russel Spring	Russel Spring to Hell Creek	Hell Creek to Counter	Counter to Yalakom	Live Count
08-25	0	NA	0	0	0	0	0	0	0	0	0	**0**
08-30	100	0.22	0	2	0	0	11	0	0	0	0	**13**
09-07	80	NA	15	6	0	0	9	0	0	4	2	**36**
09-13	100	0.16	16	6	0	0	20	0	0	13	8	**63**
09-20	50	0.16	11	6	0	0	7	0	0	0	5	**29**
09-27	100	0.18	0	3	0	0	0	0	0	0	0	**3**
10-05	100	0.25	0	2	0	0	0	0	0	0	0	**2**
10-11	50	0.48	0	0	0	0	0	0	0	0	0	**0**

Compiled observations of spawning distribution of Chinook Salmon across streamwalk sections in Reach 3 and 4 of the LBR from all visual surveys (2013-2021).

Streamwalk			Year									
Section	Description	River KM	2013	2014	2015	2016	2017	2018	2019	2020	2021	Total
1	Terzaghi Dam to Longskinny	40.0 to 39.6	11	6	8	20	9	1	31	4	25	90
2	Longskinny to Eagle	39.6 to 38.8	4	5	5	6	1	6	34	0	0	61
3	Eagle to Bluenose	38.8 to 38.2	1	0	0	0	0	0	0	0	0	1
4	Bluenose to Cobra	38.2 to 34.4	20	16	6	0	4	0	0	0	47	46
5	Cobra to Fraser Lake	34.4 to 33.2	17	56	6	64	32	7	13	6	0	201
6	Fraser Lake to Russel Springs	33.2 to 30.7	7	14	6	14	10	5	6	0	0	62
7	Russel Springs to Hell Creek	30.7 to 28.8	17	5	8	43	21	0	1	1	17	96
8	Hell Creek to Yalakom	28.8 to 25.5	61	197	79	55	10	0	31	87	15	520
		Total	**138**	**299**	**118**	**202**	**87**	**19**	**116**	**98**	**146**	**1077**

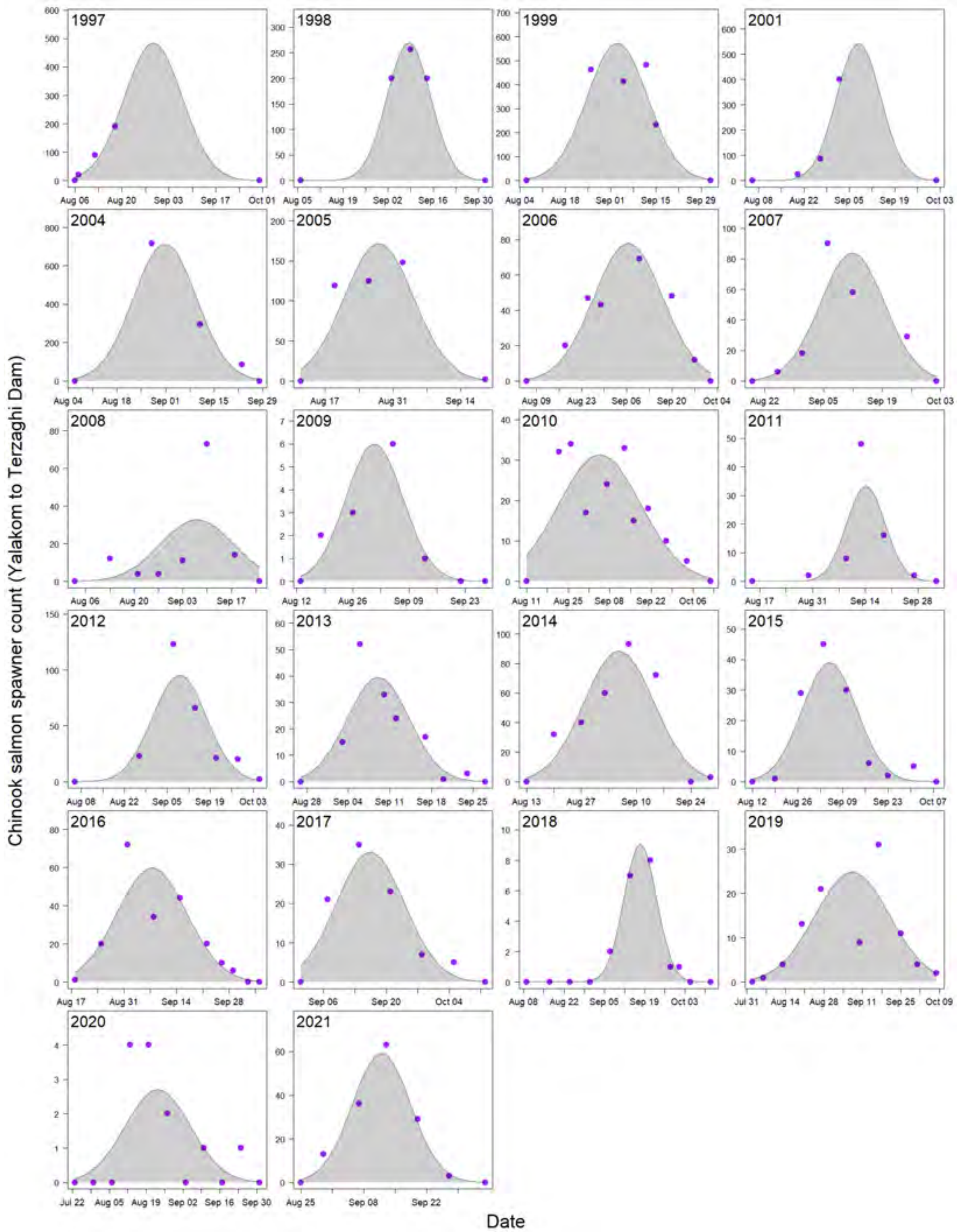
Coho Salmon visual survey data by visual survey section in 2021.

Date	Cloud Cover (%)	Water Clarity (m)	Plunge Pool to Longskinny	Longskinny to Eagle	Eagle to Bluenose	Bluenose to Cobra	Cobra to Fraser Lake	Fraser Lake to Russel Spring	Russel Spring to Hell Creek	Hell Creek to Counter	Counter to Yalakom	Live Count
09-27	100	0.18	0	0	0	0	0	0	0	0	0	0
10-06	100	0.60	0	6	2	0	0	0	0	0	0	8
10-11	50	0.48	0	0	0	0	0	0	0	0	0	0
10-18	70	0.50	0	0	0	0	4	0	0	0	0	4
10-25	50	0.40	0	0	0	0	0	0	0	0	0	0
11-03	100	0.50	70	15	0	0	5	5	0	1	2	98
11-08	90	0.70	46	37	0	0	2	1	0	0	0	86
11-15	100	0.40	59	47	0	0	18	5	0	0	0	129
11-22	100	0.50	73	28	0	0	38	1	0	0	3	143
11-26	100	0.90	23	4	5	1	8	7	0	0	0	48
11-29	20	NA	7	8	6	0	6	0	0	0	0	27
12-03	80	0.45	0	16	17	0	0	0	0	0	0	33
12-17	100	0.70	6	2	0	0	0	0	0	0	0	8
12-22	NA	NA	0	0	0	0	0	0	0	0	0	0

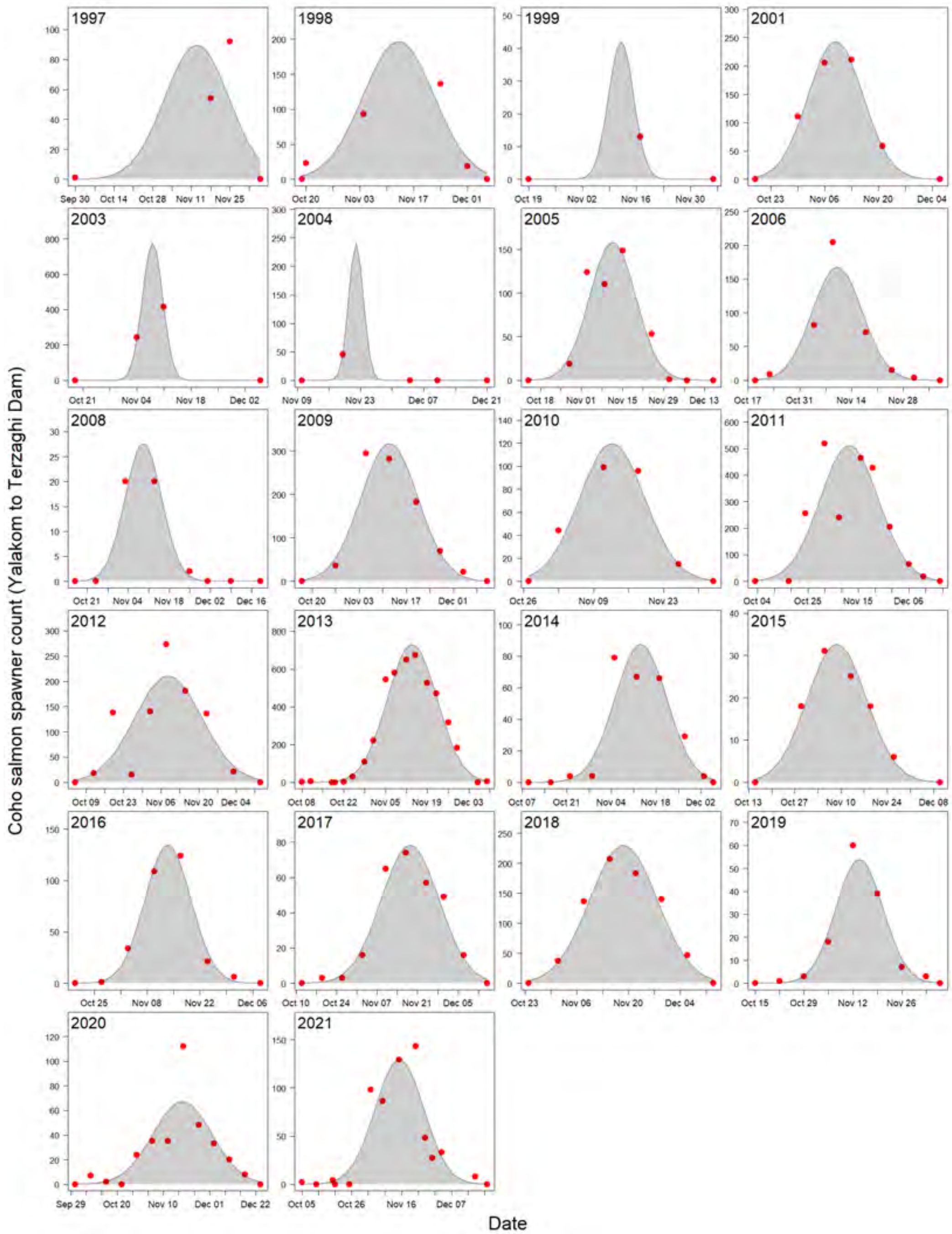
Compiled observations of spawning distribution of Coho Salmon across streamwalk sections in Reach 3 and 4 of the LBR from all visual surveys (2013-2021).

Streamwalk			Year										
Section	**Description**	**River km**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**Total**
1	Terzaghi Dam to Longskinny	40.0 to 39.6	324	1715	104	61	139	189	348	35	152	284	3351
2	Longskinny to Eagle	39.6 to 38.8	92	1186	73	7	66	83	212	71	93	163	2046
3	Eagle to Bluenose	38.8 to 38.2	223	70	6	4	0	0	16	0	22	30	371
4	Bluenose to Cobra	38.2 to 34.4	64	745	23	15	0	0	8	0	1	1	857
5	Cobra to Fraser Lake	34.4 to 33.2	151	352	24	10	72	5	102	1	37	81	835
6	Fraser Lake to Russel Springs	33.2 to 30.7	26	127	2	0	4	3	11	13	13	19	218
7	Russel Springs to Hell Creek	30.7 to 28.8	23	33	0	1	8	3	21	3	5	0	97
8	Hell Creek to Yalakom	28.8 to 25.5	19	177	21	0	6	0	32	8	1	6	270
		Total	**922**	**4405**	**253**	**98**	**295**	**283**	**750**	**130**	**324**	**584**	**8044**

Appendix 7: Historical AUC Estimates



Chinook Salmon adult spawner counts (purple points) to the modelled arrival timing (grey shaded area) in the Lower Bridge River from 1997 to 2021. Note that there are different date ranges between years.



Coho Salmon adult spawner counts (red points) to the modelled arrival timing (grey shaded area) in the Lower Bridge River from 1997 to 2021. Note that there are different date ranges between years.

Appendix 8: Habitat Suitability Index

Summary of the Chinook Salmon spawning habitat available in Reach 1 to 4 from HSI surveys (2017 – 2019, 2021).

Weighted Useable Area (m^2)					
Site	Reach	2017	2018	2019	2021
Apple Springs Unit1	1	NA	1404.45	1467.68	NA
Apple Springs Unit2	1	NA	122.69	631.88	NA
Apple Springs Unit3	1	NA	327.11	319.51	NA
Bridge River Office	1	NA	NA	257.8	NA
Antoine Creek	2	NA	190.79	261.74	NA
Below Antoine Creek	2	NA	1525.16	1609.91	NA
Camoo FSR	2	NA	1331.4	2339.81	2086.61
Horseshoe Bend	2	NA	671.85	673.88	498.47
wpt37	2	NA	677.13	992.74	NA
wpt38	2	NA	661.11	732.15	NA
wpt41	2	NA	274.63	378.57	NA
wpt44	2	NA	563.75	855.78	NA
Yalakom Confluence	2	NA	158.76	154.4	126.96
Cobra	3	67.46	141.74	120.02	125.96
Counter Site	3	249.84	307.19	198.32	236.97
Fraser Lake	3	580.4	512.03	530.4	702.53
Hell Creek	3	112.85	104.98	132.28	141.23
Hippy Pool	3	38.59	104.05	138.39	113.63
KM 30.2 Pool	3	244.48	288.44	288.23	312.22
KWL Site	3	NA	84.1	NA	NA
Lower Spawning Platform	3	196.49	185.24	228.46	317.8
Michael Moon Creek	3	NA	268.05	NA	150.51
Mid Spawning Channel	3	78.78	200.1	139.33	162.25
Russel Springs	3	129.97	233.7	153.72	280.38
Unit 1	3	362.55	395.17	445.84	612.76
Unit 2	3	226.62	218.31	256.98	426.41
Unit 3	3	105.24	125.44	120.02	116.44
Unit 4	4	48.81	52.92	56.8	109.97
Upper Spawning Channel	4	57.98	96.45	96.59	38.92
Below Longskinny	4	NA	NA	24.39	288.08
Eagle	4	NA	158.57	154.1	632.63
Long Skinny	4	817.64	550.85	669.72	71.6

Summary of the Coho Salmon spawning habitat available in Reach 1 to 4 from HSI surveys in 2019, 2021.

Weighted Useable Area (m^2)			
Site	Reach	2019	2021
Apple Springs Unit1	1	1252.73	NA
Apple Springs Unit2	1	446.85	NA
Apple Springs Unit3	1	99.5	NA
Bridge River Office	1	193.98	NA
Antoine Creek	2	181.31	NA
Below Antoine Creek	2	1359.01	NA
Camoo FSR	2	3645.52	3396.19
Horseshoe Bend	2	679	612.68
wpt37	2	674.75	NA
wpt38	2	638.41	NA
wpt41	2	361.66	NA
wpt44	2	844.76	NA
Yalakom Confluence	2	132.82	171.89
Cobra	3	84.15	118.54
Counter Site	3	175.83	175.08
Fraser Lake	3	204.23	789.8
Hell Creek	3	90.54	127.1
Lower Spawning Platform	3	88.85	169.71
Mid Spawning Channel	3	71.44	145.96
Russel Springs	3	87.25	167.84
Unit 1	3	389.18	757.35
Unit 2	3	118.78	354.45
Unit 3	3	202.05	249.18
Upper Spawning Channel	4	62.36	340.72
Eagle	4	241.82	487.97
Long Skinny	4	791.6	674.7

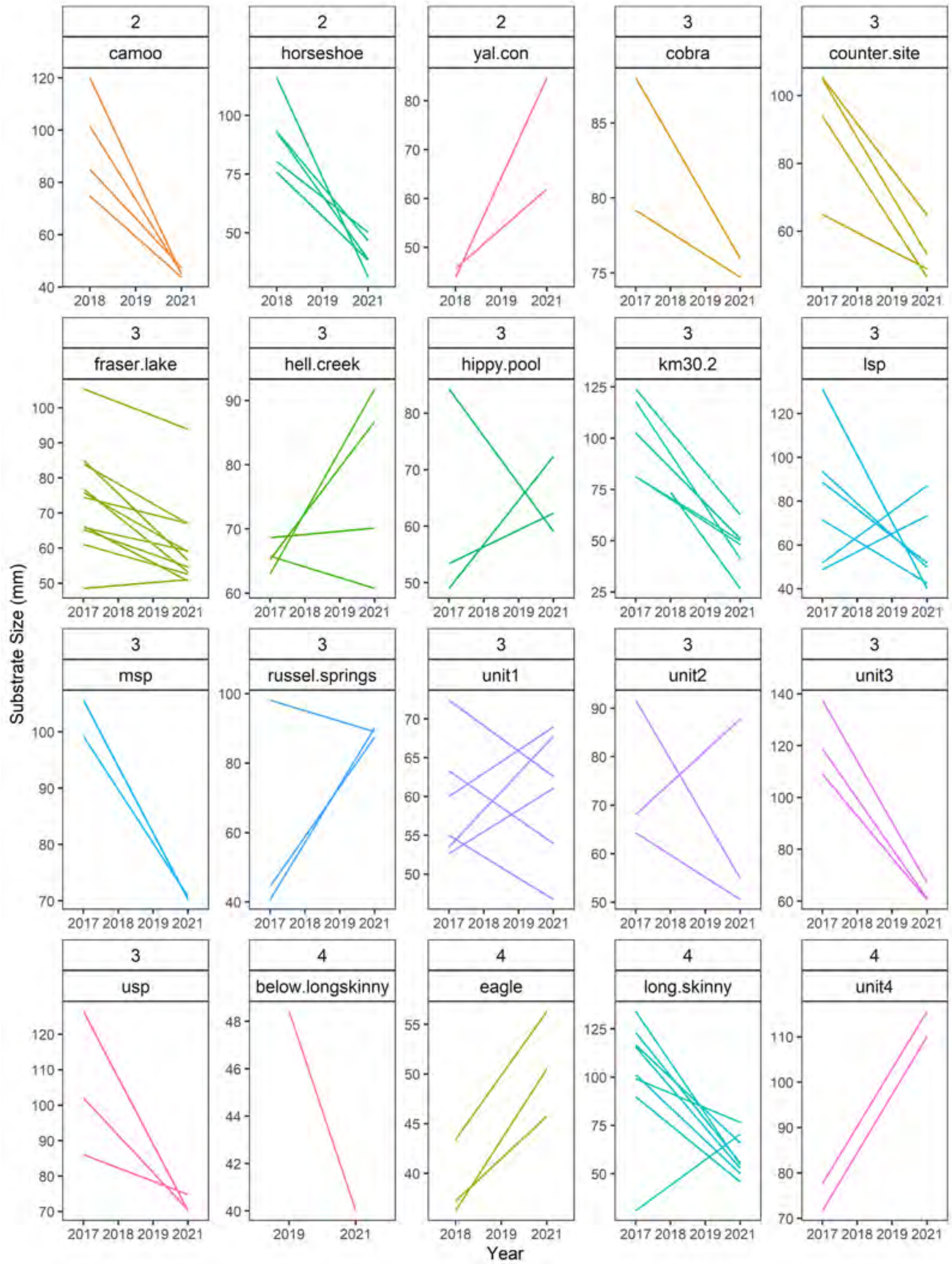
Appendix 9: Substrate Analysis

Tukey post-hoc comparison of substrate size between years from all transects.

Year Comparison	Difference	Lower	Upper	p - value
2017-2018	1.3504	1.1936	1.5073	0.0000
2017-2019	0.0772	-0.0787	0.2332	0.5805
2017-2021	-0.6607	-0.8161	-0.5053	0.0000
2018-2019	-1.2732	-1.4156	-1.1308	0.0000
2018-2021	-2.0111	-2.1529	-1.8693	0.0000
2019-2021	-0.7379	-0.8787	-0.5971	0.0000

Random effects output from best fit LME model (Substrate size ~ Year + (1 | Site/Transect))

Groups	Name	Variance	Std. Deviation
Transect:Site	Intercept	0.3567	0.5973
Site	Intercept	0.3678	0.6064
Residual		10.951	3.3092



Mean substrate size from 100-pebble count for each transect (line), by year at all habitat units evaluated in Reach 2, 3, and 4, up to 2021.

Appendix 10: Redd Distribution

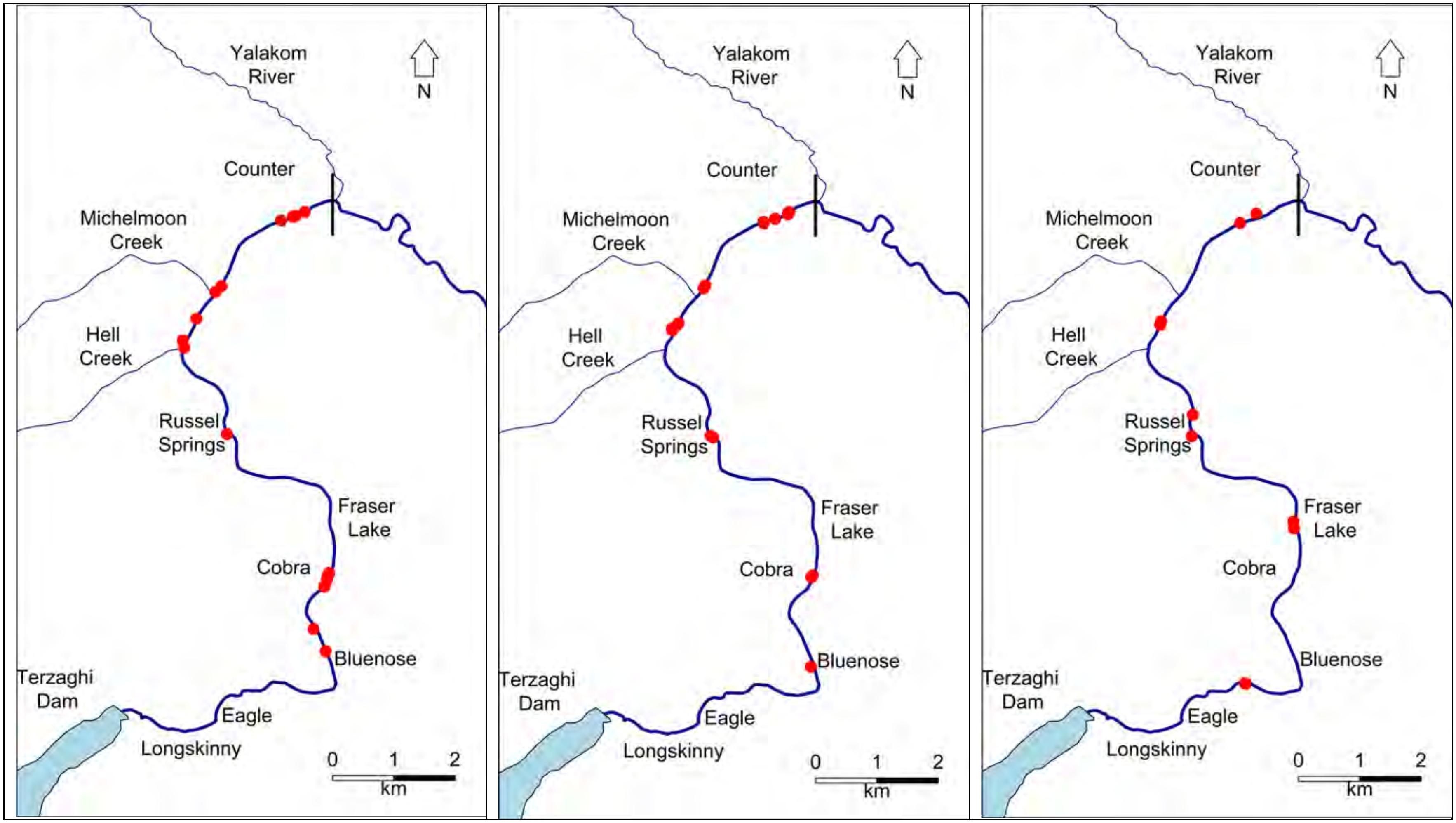
Chinook Salmon redd distribution across streamwalk sections in Reach 3 and 4 of the LBR (2014-2021).

Streamwalk			**Year**								
Section	Description	RiverKM	2014	2015	2016	2017	2018	2019	2020	2021	Total
1	Terzaghi Dam to Longskinny	40.0 to 39.6	0	0	0	1	0	1	0	2	4
2	Longskinny to Eagle	39.6 to 38.8	0	0	0	0	2	1	0	1	4
3	Eagle to Bluenose	38.8 to 38.2	4	1	2	0	0	0	0	0	7
4	Bluenose to Cobra	38.2 to 34.4	10	2	0	0	0	0	0	0	12
5	Cobra to Fraser Lake	34.4 to 33.2	0	0	8	6	1	0	0	0	15
6	Fraser Lake to Russel Springs	33.2 to 30.7	7	3	5	4	0	0	2	0	19
7	Russel Springs to Hell Creek	30.7 to 28.8	25	6	4	2	0	0	0	0	37
8	Hell Creek to Yalakom	28.8 to 25.5	15	10	7	0	0	6	3	0	38
		Total	**61**	**22**	**26**	**13**	**3**	**8**	**5**	**4***	**137**

*One redd was located in Horseshoe Bend

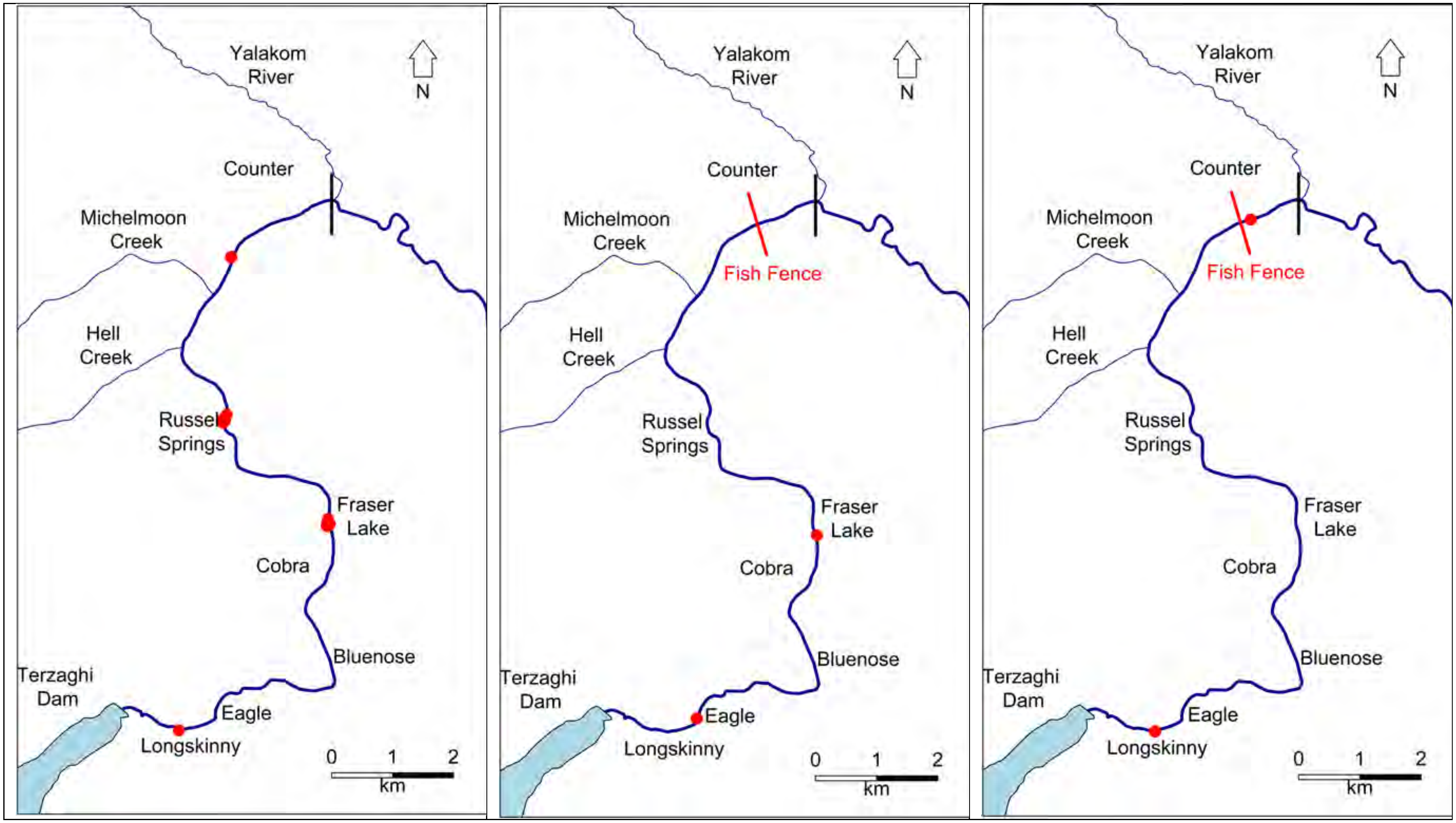
Location of Chinook Salmon redds in the Lower Bridge River in 2014 - 2021. Black lines indicate the boundary between reaches.

2014 **2015** **2016**



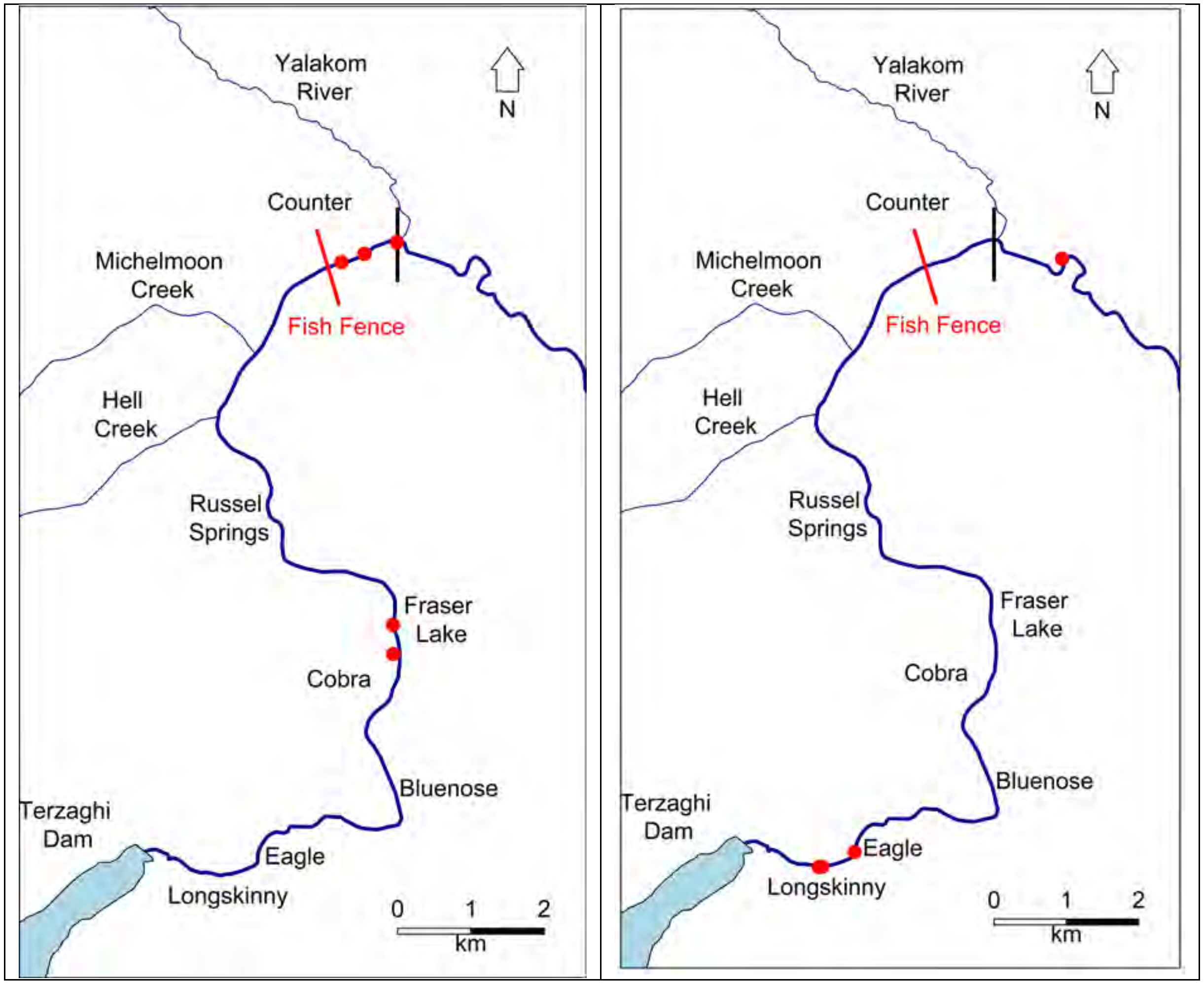
Con't: Location of Chinook Salmon redds in the Lower Bridge River in 2014 - 2021. Black lines indicate the boundary between reaches.

2017 **2018** **2019**



Con't: Location of Chinook Salmon redds in the Lower Bridge River in 2014-2021. Black lines indicate the boundary between reaches.

2020 **2021**

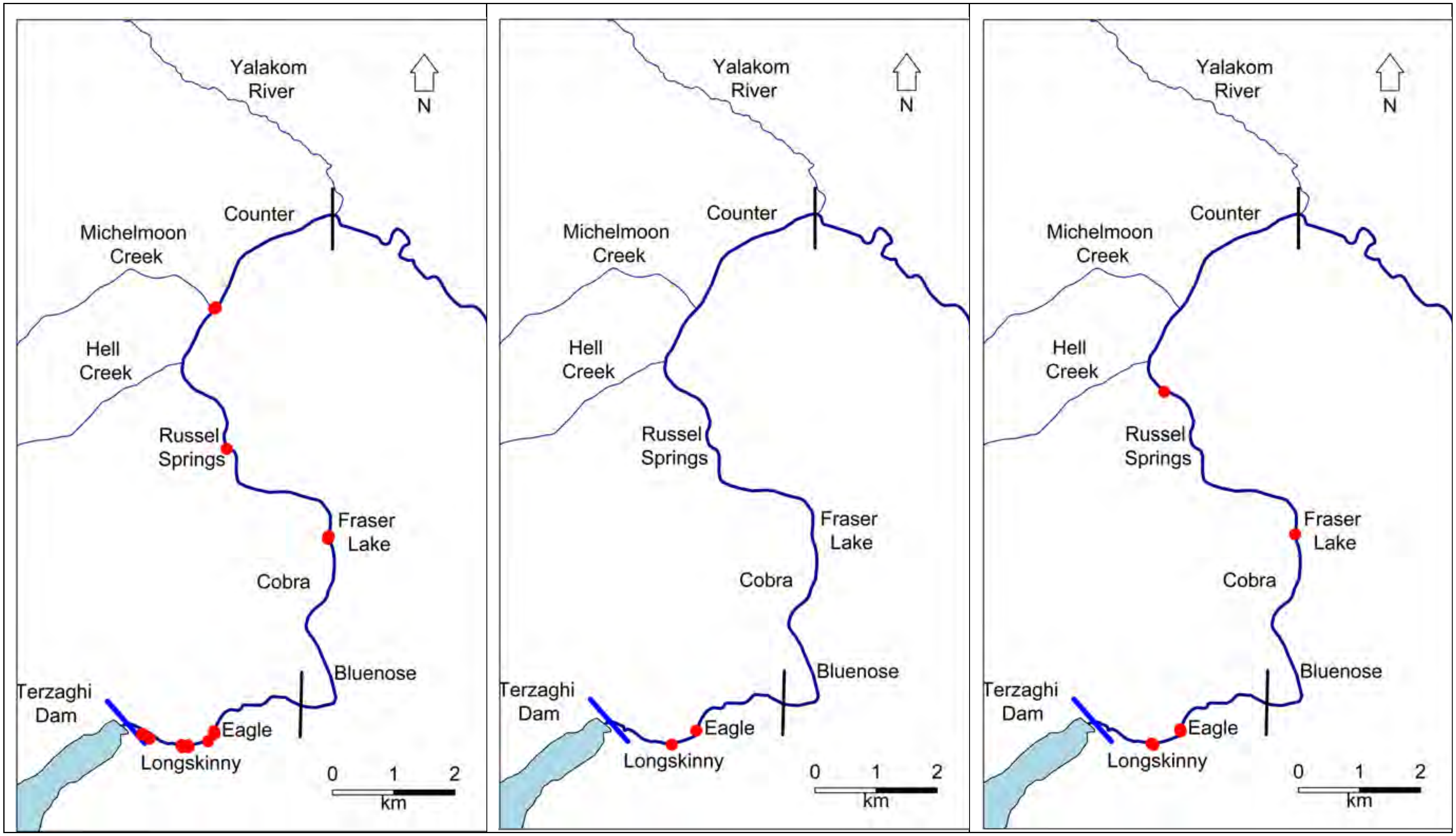


Coho Salmon redd distribution across streamwalk sections in Reach 3 and 4 of the LBR (2018-2021).

Streamwalk			Year				
Section	Description	RiverKM	2018	2019	2020	2021	Total
1	Terzaghi Dam to Longskinny	40.0 to 39.6	15	6	2	6	27
2	Longskinny to Eagle	39.6 to 38.8	6	2	3	3	11
3	Eagle to Bluenose	38.8 to 38.2	0	0	0	0	0
4	Bluenose to Cobra	38.2 to 34.4	0	0	0	0	0
5	Cobra to Fraser Lake	34.4 to 33.2	4	0	0	0	4
6	Fraser Lake to Russel Springs	33.2 to 30.7	2	0	2	0	2
7	Russel Springs to Hell Creek	30.7 to 28.8	4	0	0	0	4
8	Hell Creek to Yalakom	28.8 to 25.5	0	0	0	0	0
		Total	**31**	**8**	**7**	**9**	**48**

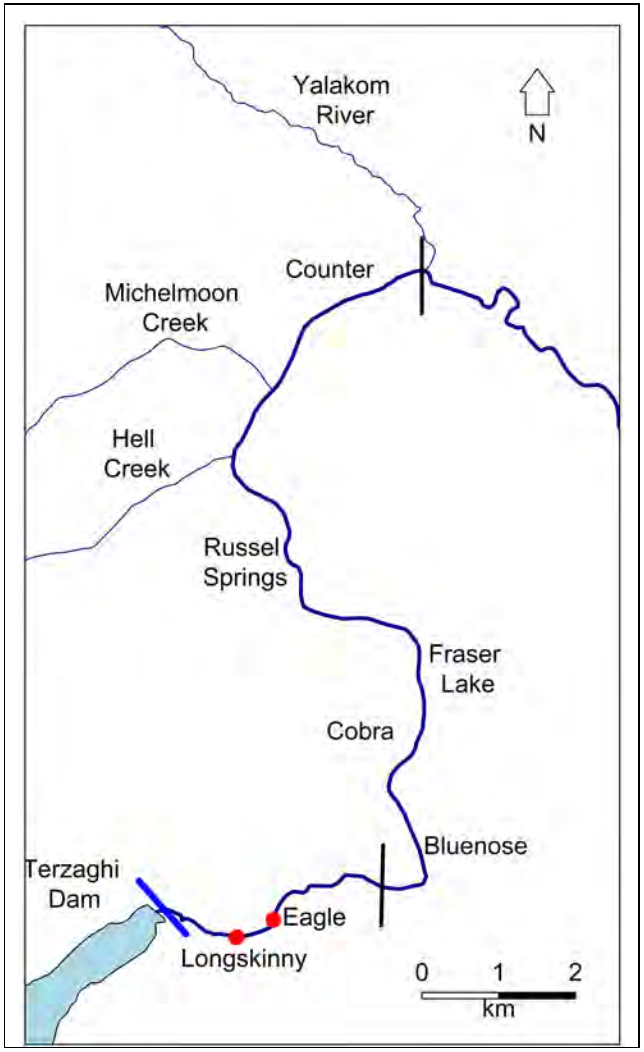
Location of Coho Salmon redds in the Lower Bridge River in 2018 - 2021. Black lines indicate the boundary between reaches.

2018 **2019** **2020**



Con't: Location of Coho Salmon redds in the Lower Bridge River in 2018-2021. Black lines indicate the boundary between reaches.

2021



Appendix 11: Scale Analysis

Summary of age analysis conducted during BRGMON-3. Age is shown using two methods: 1. Koo 1962 method, where freshwater age is separated from marine age by a decimal, and 2. the total age resulting from the summation of both freshwater and marine ages. Years where there were no sampled fish, readable scales, or fish not of LBR origin are indicated with (-).

Species	Age (Koo 1962)	Total Age	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	Total
Chinook	1.2	3	-	-	1	0	1	1	0	0	0	0	0	3
	1.3	4	-	-	9	13	11	7	3	3	4	3	0	53
	2.3	5	-	-	0	0	0	0	0	0	0	0	1*	1
Coho	1.1	2	13	15	15	19	10	22	12	17	3	4	5	135
	1.2	3	0	0	0	1	0	0	0	0	0	0	0	1
	2.1	3	5	11	1	8	6	7	4	0	2	0	5	49
Steelhead	1.1	2	-	-	-	0	0	0	1	0	0	0	0	1
	2.1	3	-	-	-	1	0	0	0	0	0	0	0	1
	2.2	4	-	-	-	3	4	0	1	2	0	8	9	27
	2.3	5	-	-	-	0	1	1	5	7	1	0	0	15
	3.1	4	-	-	-	2	1	0	0	0	0	0	0	3
	3.2	5	-	-	-	2	8	2	3	2	2	1	0	20
	3.3	6	-	-	-	0	2	0	7	5	6	0	0	20
		Total	18	26	26	49	44	40	36	36	18	16	20	309

*Likely a Chinook Salmon from another river system