Bridge River Project Water Use Plan

Lower Bridge River Adult Salmon and Steelhead Enumeration

Implementation Year 11

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Data Report (Year 11)

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Lower Bridge River Adult Salmon and Steelhead Enumeration, 2022

BRGMON-3, Year 11

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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 2022 (Year 11) 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 2022 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, 2021-2022). This year is the first that extends beyond the original timeline of the 10-year WUP monitoring program. 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.

While escapement estimates in 2022 for Coho (n = 936) and Chinook Salmon (n = 531), were still low in a historical context, they were both the highest they have been since 2016 and 2014, respectively. Steelhead Trout abundance (n = 38) was consistent with the mean since 2015 (43 ± 19). Chinook Salmon have been depressed since 2005 (as indicated by historic visual survey estimates) and Coho Salmon abundances have been variable since 1997 but have remained at depressed levels since 2013.

Escapement estimates in 2022 were confounded by the operation of a broodstock fence for Chinook Salmon broodstock collection. The fence, which has operated since 2018 in Reach 3, prevents 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 Coho redd surveys to assess the quality and quantity of spawning habitat and how it may be affected by the instream flow regime. Water depth and velocity were not able to be collected at Chinook redds due to a ramp down occurring before the survey, however substrate composition was still characterized. 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 until this year as 30 Chinook and 25 Coho redds were observed. 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 2022, 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 – 2022), and the majority of spawning habitat is in Reach 2. A separate evaluation of substrate size observed a significant decrease in substrates size between 2018 and 2021, although still within species preference ranges. Substrate size increased in all reaches in 2022 compared to the previous year, suggesting that smaller substrate may have been mobilized.

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 following MOD flow events to ensure that spawning habitat quality and quantity in the LBR has not been affected.

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). Prior to 2021, Chinook Salmon had not been observed spawning in Reach 2 during the monitoring period. This new trend may also be a result of the broodstock fence preventing access to preferred spawning grounds. 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 modified operations status of objectives, management questions, and hypothesis after Year 11

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 2022, counter estimates were 38 Steelhead Trout, 531 Chinook Salmon and 936 Coho Salmon. 2022 had the largest abundance estimate for Coho since 2016 and Chinook since 2014. • 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 H1,3. • Chinook Salmon have begun spawning in Reach 4 more frequently starting in 2018. • Since 2018, Chinook Salmon distribution has been affected by the broodstock fence, which confounds our ability to address H1,3 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 $H_{2.2}$ 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.	$H_{3.1}$ • 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, 2021, and 2022). 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, 2021, and 2022). 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.	$H_{4.1}$ • 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 3 and 4. • Coho Salmon continue to spawn in both Reach 3 and 4. • Support for $H_{4.1}$ for Coho Salmon, however Chinook Salmon distribution has been affected by the broodstock fence which confounds our ability to address $H_{4.1}$ completely.

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1. Introduction

1.1 Background

The Bridge River provides an 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.

In 2018, the St’at’imc Nation, together with BC Hydro, developed a conservation hatchery program for Chinook salmon. This was done in response to the operational effects of Terzaghi dam and the consequent high flow events in 2016, 2017 and 2018. The program included the installation of a broodstock fence and trap box directly upstream of the electronic counters (26 rkm). The collection of Chinook Salmon brood in the LBR intends to increase the egg-to-fry survival in a hatchery. The target number for egg collection has varied annually, and in 2022 was approximately 75,000 eggs. Since 2019 the LBR Chinook hatchery program has been operated out of N’Quatqua (D’Arcy), due to the desire to build community-led salmon enhancement capacities. The Big Bar landslide and fish fence operational difficulties due to pink salmon migration resulted in low numbers of ripe female Chinook Salmon until 2022, which was the first year a holding tank was implemented on site. The total numbers of Chinook eggs brought to the hatchery in 2022 resulted in ~74,000 fry, of which 52,000 were released in fall 2023 as fed fry and 22,000 were released in spring 2024 as smolts. Continuous efforts for brood collection in future years will focus on Chinook and Coho Salmon as mitigation efforts are required for these species through the “High Flow Settlement Agreement”. Since 2018, catch data from fence operation have been used in tandem with electronic fish counters data to calculate a Chinook Salmon abundance estimate in the LBR.

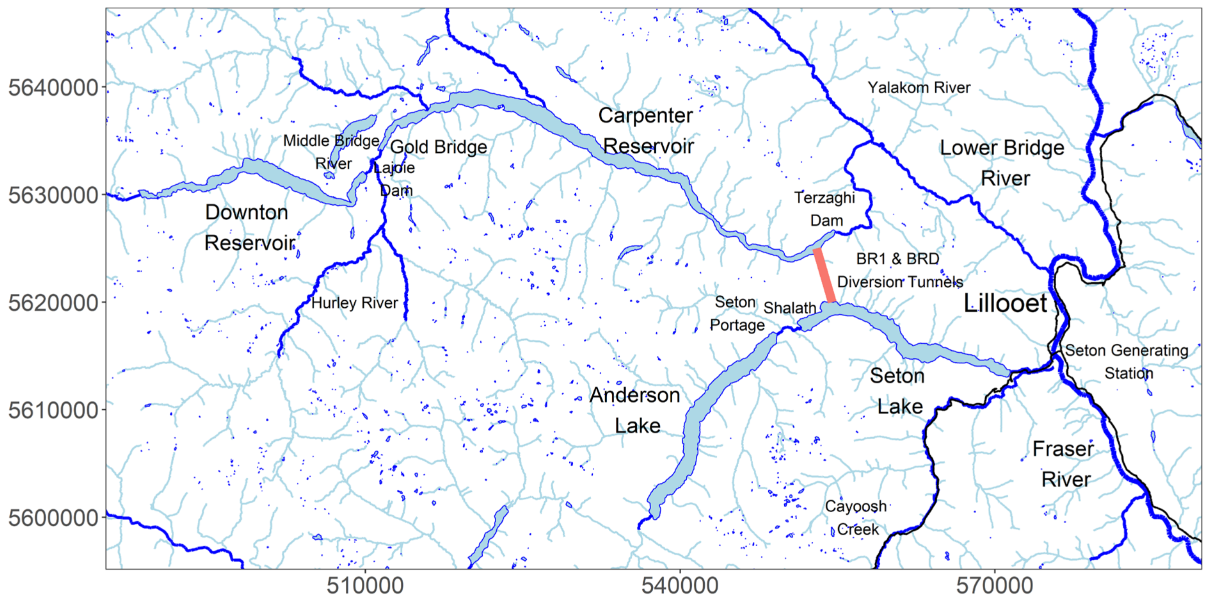

Figure 1. Bridge and Seton Watersheds showing Terzaghi Dam and diversion tunnels to Bridge River Generating Stations 1 and 2.

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. A second revision was made to the TOR in 2022 that extended the program beyond the original monitoring timeline of 10 years and supported the Interim Flow Decision (IFD). The IFD was introduced to manage potential flow changes stemming from seismic upgrades in the Bridge River-Seton system. Under Revision 2, BRGMON-3 management questions and methods remained the same for 2022. However, program methods will be reevaluated following the 2022 report.

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 provide adult population estimates for 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 2022, 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	2022 Period	Prior Years of Data
Adult Salmonid Abundance (electronic methods)	Combination of resistivity counter and multi-beam sonar	Steelhead Trout	Mar 21 to May 31	2014*, 2015*, 2017-2022
		Chinook Salmon	Aug 10 to Aug 18	2014*, 2015*, 2016-2022
		Coho Salmon	Sept 29 to Nov 30	2013-2015*, 2016, 2018-2022
Adult Salmonid Abundance (visual methods)	Area under the curve estimates calculated from visual counts	Steelhead Trout	NA	2014
		Chinook Salmon	Aug 3 to Oct 12	2011-2022
		Coho Salmon	Oct 5 to Dec 7	2011-2022
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	Feb 26 to Jun 5	2011-2022
		Chinook Salmon	Aug 12 to Oct 7	2012-2022
		Coho Salmon	Oct 11 to Dec 7	2014-2022
Spawning Habitat Selection	Depth, velocity, and substrate surveys at observed redds following spawning	Steelhead Trout	NA	NA
		Chinook Salmon	Sep 28 and Oct 28	2014-2022
		Coho Salmon	Nov 13, 15, 23 and 24	2018-2022
Scale Age Analysis	Ageing based on scale samples of individuals that spawned in the LBR	Steelhead Trout	Feb 26 to Apr 7	2014-2022
		Chinook Salmon	Aug 12 to Aug 29	2013-2022
		Coho Salmon	Oct 11 to Nov 4	2011-2022
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 19 to Sep 27	2017-2019, 2021-2022***
		Coho Salmon	Oct 17 to Nov 4	2019, 2021-2022

* Resistivity counter only; ** Fence count data from 1993-1996; *** 2017 and 2018 in Reach 3 and 4, 2019, 2021, and 2022 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 slightly upstream of the Reach 2/3 break. In 2022, discharge from Terzaghi Dam exceeded 20 m3s-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, 2021 and 2022.

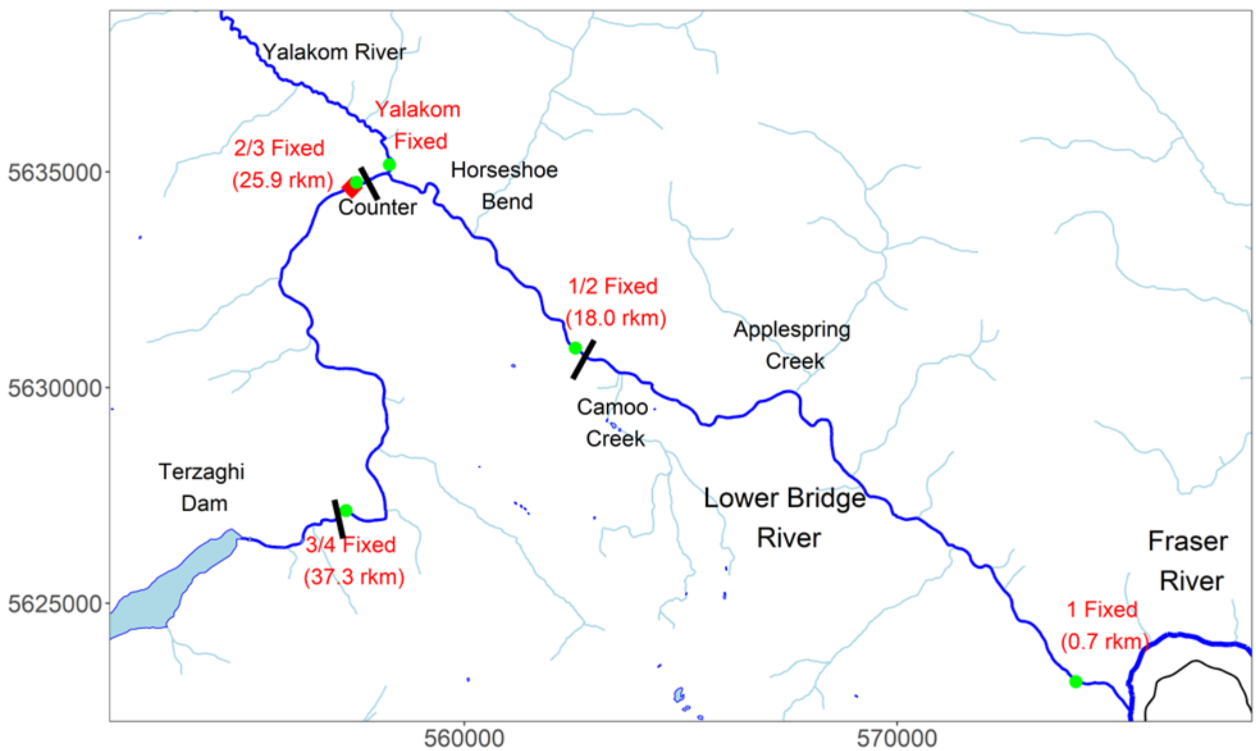

Figure 2. BRGMON-3 Lower Bridge River study area including fixed radio telemetry stations (green circles), counter location (red diamond) and reach breaks (black lines).

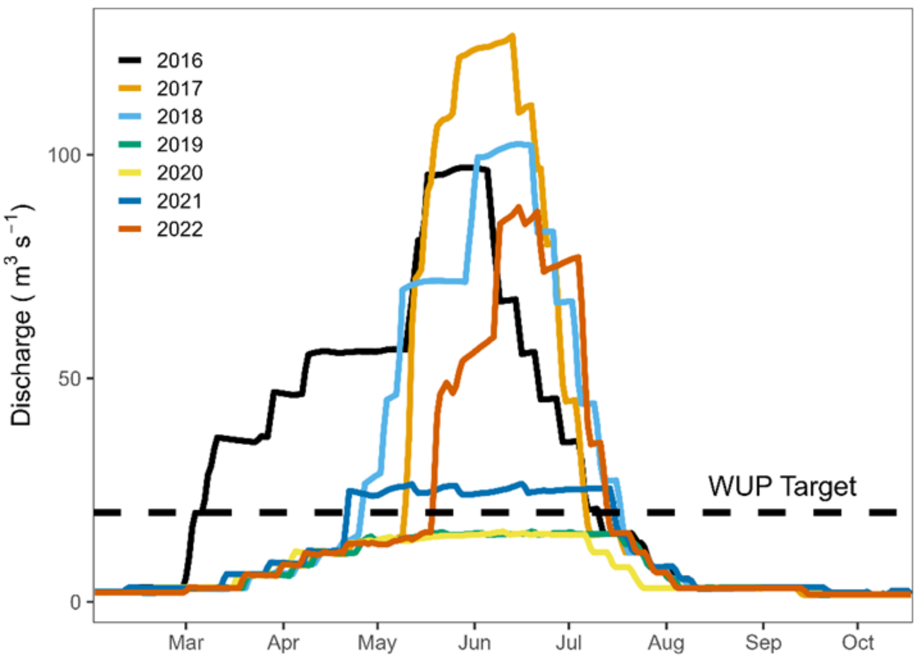

Figure 3. Discharge from Terzaghi Dam into the Lower Bridge River from 2011 to 2022.

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 flows less than 1.5m^{3}s^{-1}, 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).

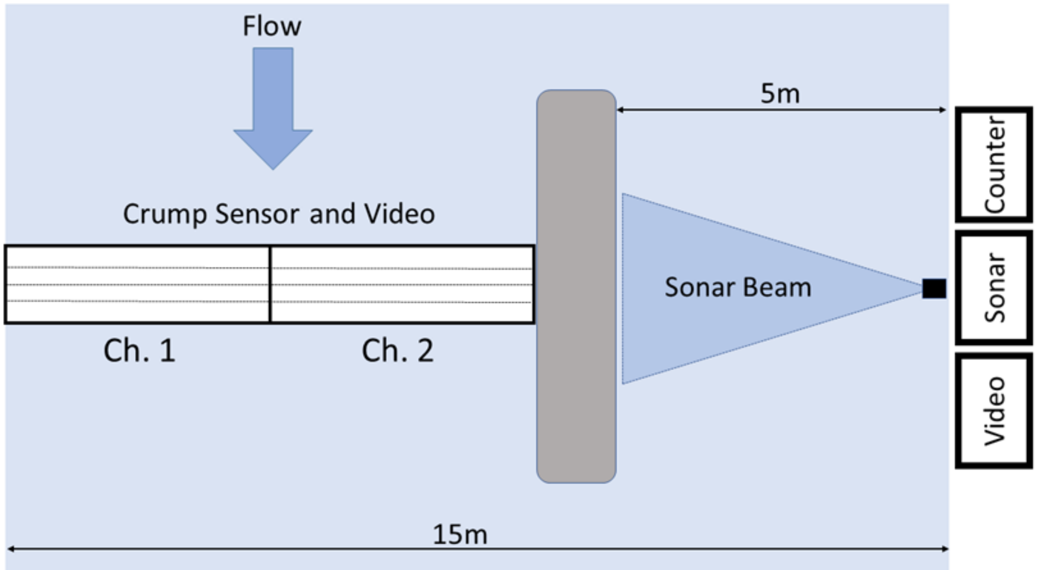

Figure 4. Configuration of the resistivity counter crump sensor, video validation system, multibeam sonar, and power system.

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 2022 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	Aug 10 to Aug 18**	Sonar
Coho Salmon	Oct 5 to Dec 1	Sept 29 to Dec 1	Sonar

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

**Enumeration was compiled from broodstock fence data between August 19 and September 28.

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 four-step validation process including (1) review of graphical traces for each counter record to determine TP, FP and FN created by the counter algorithm, (2) targeted video validation to identify TP and FP produced by the counter, (3) random video validation to identify FN by the counter, and (4) calculation of counter accuracy using the number of TP, FP and FN. Review of the graphical traces is a form of pseudo-validation of the counter algorithm and all mis-classified events were corrected. 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. To validate the data, 10-minute segments of video data are randomly selected to be reviewed. Before 2022, counter accuracy was calculated using a binominal method derived from a confusion matrix model. An alternative estimation method utilizing multinomial accuracy was developed by IFR in 2021 (Putt et al. 2021). This new multinomial method increases the calculation's applicability to different operational and biological circumstances (where FP rates may be higher than FN rates). Moreover, the multinomial method does not require the user to make assumptions about the TN error. This reduces the associated uncertainties around the calculated errors.

In the original accuracy method used prior to 2022, the number TP, FP, and expanded FN were summarized by direction (up and down), species, and counter channel. These values were used to calculate channel- and direction-specific counter accuracy (A) in the original binominal method (Equation 1).

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

The new multinominal method continues to use the same TP, FP and FN counter error estimates to calculate counter accuracies. Accuracy was calculated by assuming that all TP, FP, and FN observations were multinomially distributed random variables (Equation 2):

(2) $$\hat{V} \sim mult(N, \theta)$$

Where $\hat{V}$ is a vector of the total number of TPs, FPs, and FNs ($\hat{V}TP$, $\hat{V}FP$, $\hat{V}FN$), θ is a vector of estimated probabilities of being in each of the three states (θ_TP, θ_FP, θ_FN), and N is the total number of observations from the counter-validation comparison (TP+FP+FN). Counter accuracy is defined as, θTP, or as the proportion of fish passing the counter that are correctly recorded by the counter algorithm. Given that the θ values must sum to 1.0, accuracy can also be expressed as Equation 3:

(3) $$A = \theta_{TP} = 1 - \theta_{FP} - \theta_{FN}$$

To ensure data accuracy and consistency, IFR validated the accuracy method by re-analyzing data using multiple counter data sets. The accuracy estimates remained unchanged in each analysis. IFR is continuing to develop the multinomial uncertainty method to include circumstances where targeted and random validation is completed.

Counter accuracy[1] was calculated by assuming that all TP, FP, and FN observations were multinomially distributed random variables:

(2.1)

$$V \sim \boldsymbol{mult}(\boldsymbol{N}, \boldsymbol{\theta})$$

Where V is a vector of the total number of TPs, FPs, and FNs (V_{TP}, V_{FP}, V_{FN}), θ is a vector of estimated probabilities of being in each of the three states (θ_{TP}, θ_{FP}, θ_{FN}), and N is the total number of observations from the counter-validation comparison ($TP + FP + FN$). Counter accuracy is defined as, θTP, or as the proportion of fish passing the counter that are correctly recorded by the counter algorithm.

Length Measurements and Species Determination

A length measurement was taken from each fish observed during video validation to aid with species determination and to develop a length vs PSS relationship. The total length (tip of nose to end of tail) of a fish measured on the video was determined using the ratio of the on-screen pad length (known to be 30 cm) and on-screen fish length:

(4)

$$FL_T = \frac{FL_m}{PL_m} \; x \; PL_T$$

where FL_T is the total fish length, FL_m is the fish length as measured on the video screen, PL_m is the distance between electrodes at the point where the fish crossed as measured on the video screen, and PL_S is the true distance between the upper to middle or lower to middle electrodes on the counter pad (30 cm).

During video validation, fish were identified to species based on length (BRGMON-3 tagging data) and body shape (e.g., narrow and small-bodied for resident species). The species and fish length results were plotted against PSS values to develop a cut-off value that could be used to determine species during periods when video data was not present. These species cut-offs were visually determined where the least overlap between species occurs based on PSS value. Because of differing detection efficiencies, channel 1 and 2 were analyzed separately as well as to calculate separate counter accuracies that were applied to time periods where no video was recorded.

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. Therefore, a subset of fish lengths are manually measured using the sonar's proprietary software (ARISFish, Sound Metrics Corporation, Bellevue, Washington, USA). 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 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).

2.2.4 Steelhead Trout Enumeration

Sonar and resistivity counters were used to collect data on Steelhead Trout migration, from March 21st to May 31st, which covers their entire expected migratory period (April 1st to June 1st). Therefore, an estimate of upstream-migrating steelhead spawner abundance based solely on counter data is expected to be accurate.

Fourteen randomly selected 10-minute segments of video data per day were reviewed to validate Steelhead Trout (April 1 to May 30). Approximately 105 hours Steelhead Trout migration was validated in 2022. For sonar data, a size cut-off of 600 mm was determined by length-frequency distributions based on catch data to date.

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).

2.2.5 Chinook Salmon Enumeration

The resistivity counter was damaged during a period of high flows and it was not able to be repaired until after flows has subsided. As a result, Chinook Salmon were enumerated using only the sonar counter from August 10 to 18. A channel spanning fence was installed on August 19 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 19 to provide an overall abundance estimate.

2.2.6 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 September 28. In the days immediately following the removal of the broodstock fence, there was considerable up and down movement 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 (Chinook, Coho and Sockeye) 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 14 (White et al. 2021), so this date was used to begin the enumeration. This date was cross-referenced with streamwalk and telemetry data. A kelting date of November 1st was assigned for the removal of all downs.

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 Reaches 1, 2 and 3 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 fitted 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 23 to December 7 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 nine 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 whitewater 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.

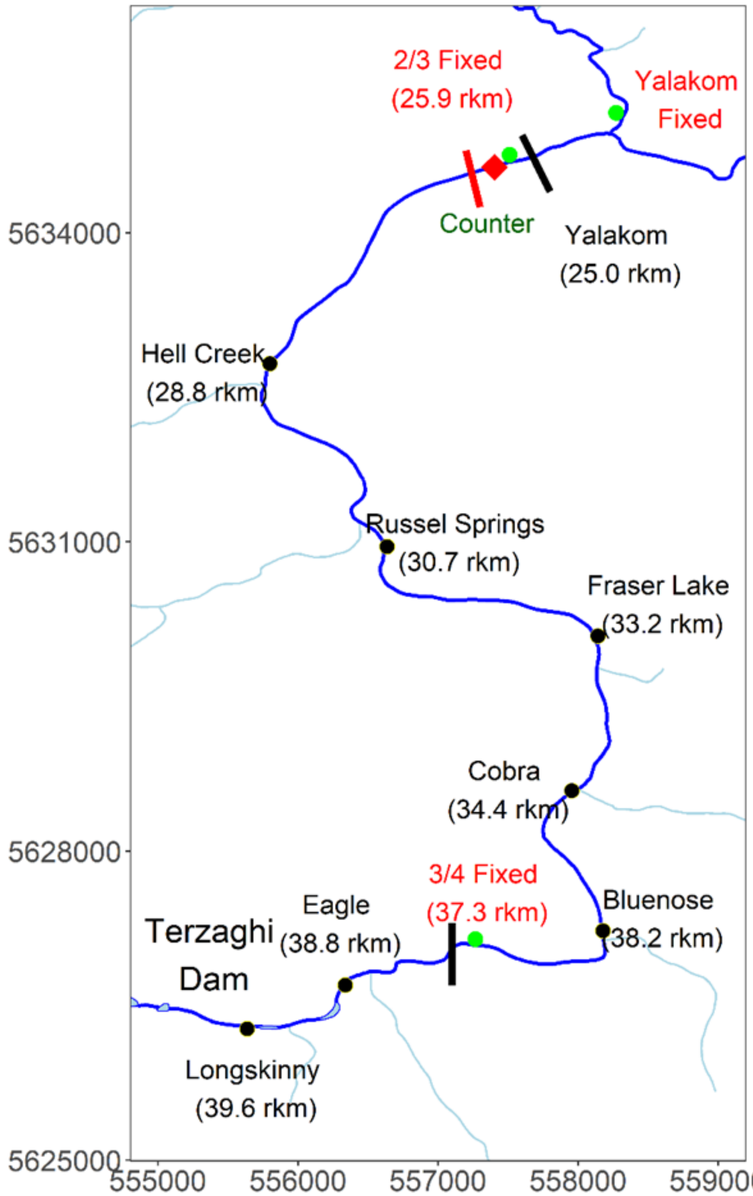

Figure 5. Visual survey boundaries (black circles), fixed telemetry stations (green circles), counter location (red diamond), reach breaks (black lines) and broodstock fence location (red line) in Reach 3 and 4 of the Lower Bridge River.

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 19. 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, 2016-2018, and 2022 (Table 3; Appendix 2). Due to small sample size, mean OE and SL were used for Coho in 2022. 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 0.021 for Coho Salmon, while SL standard error was 0.65 for Chinook Salmon and 1.22 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	0.5	10.5	0.209	20
2012	**0.58**	**10**	**0.25**	**16**
2013	**0.28**	**11**	**0.27**	**19**
2014	**0.28**	**12**	0.209	20
2015	0.5	10.5	0.209	20
2016	**0.86**	**9**	**0.17**	**22**
2017	0.5	10.5	**0.19**	**23**
2018	0.5	10.5	**0.20**	**18**
2019	0.5	10.5	0.209	20
2020	0.5	10.5	0.209	20
2021	0.5	10.5	0.209	20
2022	0.5	10.5	**0.167**	20

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.

To evaluate potential changes in Chinook Salmon spawning habitat and to evaluate effects of the year's high flows (discharge 3 m^3s^{-1}), habitat surveys were conducted in Reach 2-4 between September 19 and September 27, 2022. Observations of Coho Salmon from radio telemetry, visual counts and redd surveys indicate similar habitat use in the LBR. Habitat surveys were conducted between October 17 and November 4, 2022, 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 1m x 1m 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.

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).

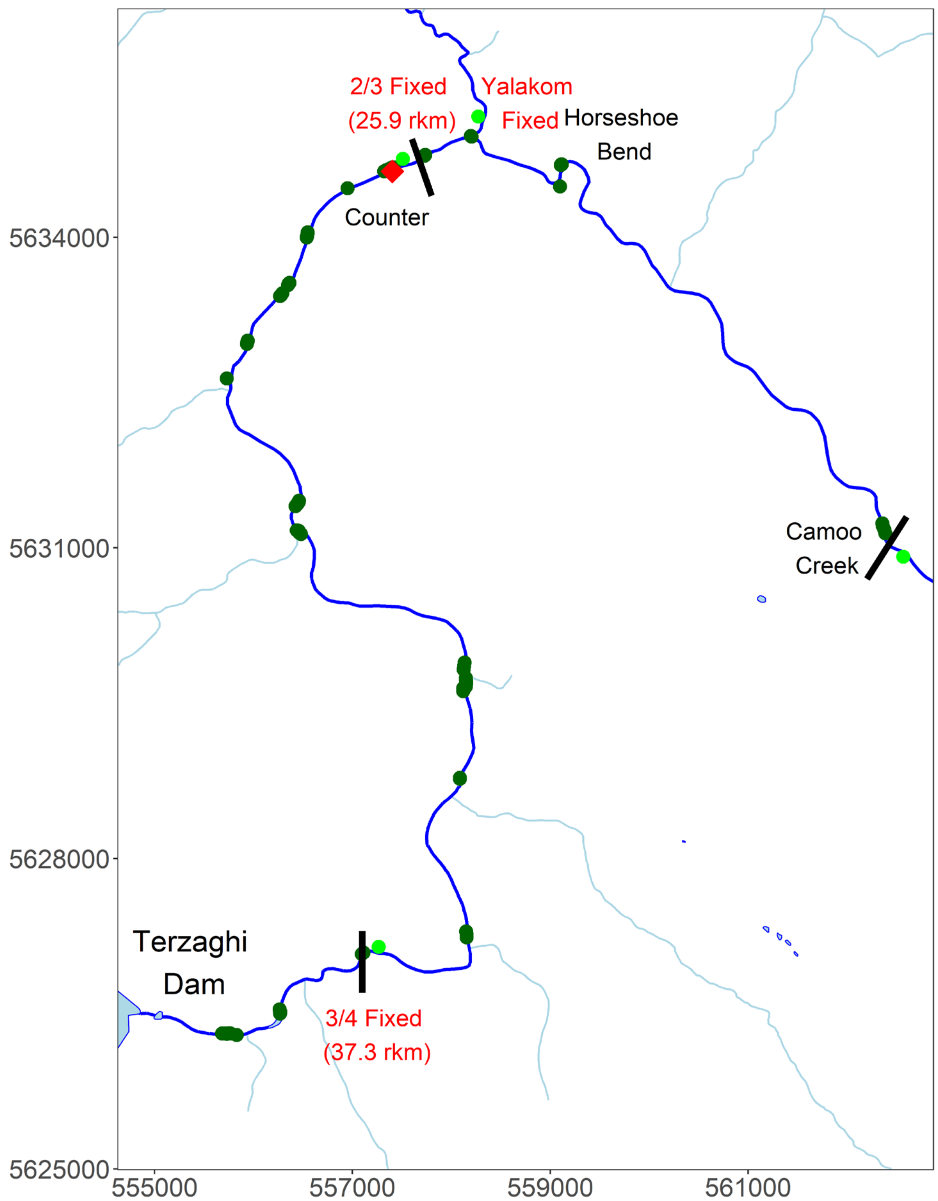

Figure 6. Habitat units (dark green) where transects were performed to assess Chinook and Coho Salmon spawning habitat. Fixed radio stations (green circles) and reach breaks (black lines).

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 Coho redd during redd surveys performed in Reach 2, 3, and 4. Due to a ramp down occurring prior to surveying, only substrate characteristics were able to be measured at Chinook redds. 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 (2nd 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 and Coho Salmon spawning preferences stated in the literature. Redds were identified as either Chinook or Coho based on characteristics outlined by Gallagher and Gallagher (2005) and by field technicians' firsthand observations while conducting streamwalks. Technicians directly observed the fish constructing the redds, allowing for accurate species identification. Similar redd characteristics among years would suggest spawning site selection is consistent and that habitat availability is not limiting Chinook and Coho 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 2021-2022) 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^3s^{-1}. A second, fixed factor one-way ANOVA compared 2019, 2021, 2022 WUA for Coho Salmon at 1.5 m^3s^{-1}.

Substrate Size

Substrate size was measured at transects in Reach 3 and 4 following high flows (2017-2019, and 2021-2022) and since 2018 in Reach 1 and 2. In 2021 and 2022, 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 2021-2022) 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:

$$\text{Substrate size} \sim \text{Year} * \text{Reach} + (1|\text{site/transect})$$

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 ageing 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 reabsorbed 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 2022, Steelhead Trout were enumerated using both the resistivity counter and the ARIS sonar. The migration period was monitored between March 21 to May 31, as forecasted high flows above operating threshold (15 m^3s^{-1}) necessitated the removal of all electronic enumeration equipment. This occurred after the Steelhead Trout upstream migration period and potentially only impacts the number of kelts estimated. 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). After accounting for counter accuracy, the net upstream movement of Steelhead Trout recorded by the resistivity counter was 5 and the sonar recorded 33, for an abundance of 38 individuals (Figure 7). This is within the range of abundances recorded since 2016 (mean 43 ± 19; Table 4).

Electronic Counter Data

Validation occurred for 105 hours of video data. The counter had a channel 1 accuracy of 100% for up and down movements and a channel 2 accuracy of 50% and 100% for up and down movements, respectively. 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 between 75 to 127 (PSS range of Steelhead Trout verified on video) were considered Steelhead Trout.

The sonar recorded 864 fish tracks (602 ups and 262 downs), and all were manually measured using ARISfish. 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 2022 and has been shown to minimize the amount of overlap between Steelhead Trout and other species. Of the 864 recorded fish tracks, 69 were larger than 600mm (51 ups and 18 downs), producing a Steelhead Trout estimate of 33 for the sonar.

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

Year	Abundance	Method	Comments
2020	62	Resistivity Counter and Multibeam Sonar	Complete Estimate: Fraser River rockslide may confound escapement
2021	49	Resistivity Counter and Multibeam Sonar	Counting equipment removed early due to forecasted high flows
2022	38	Resistivity Counter and Multibeam Sonar	Complete Estimate

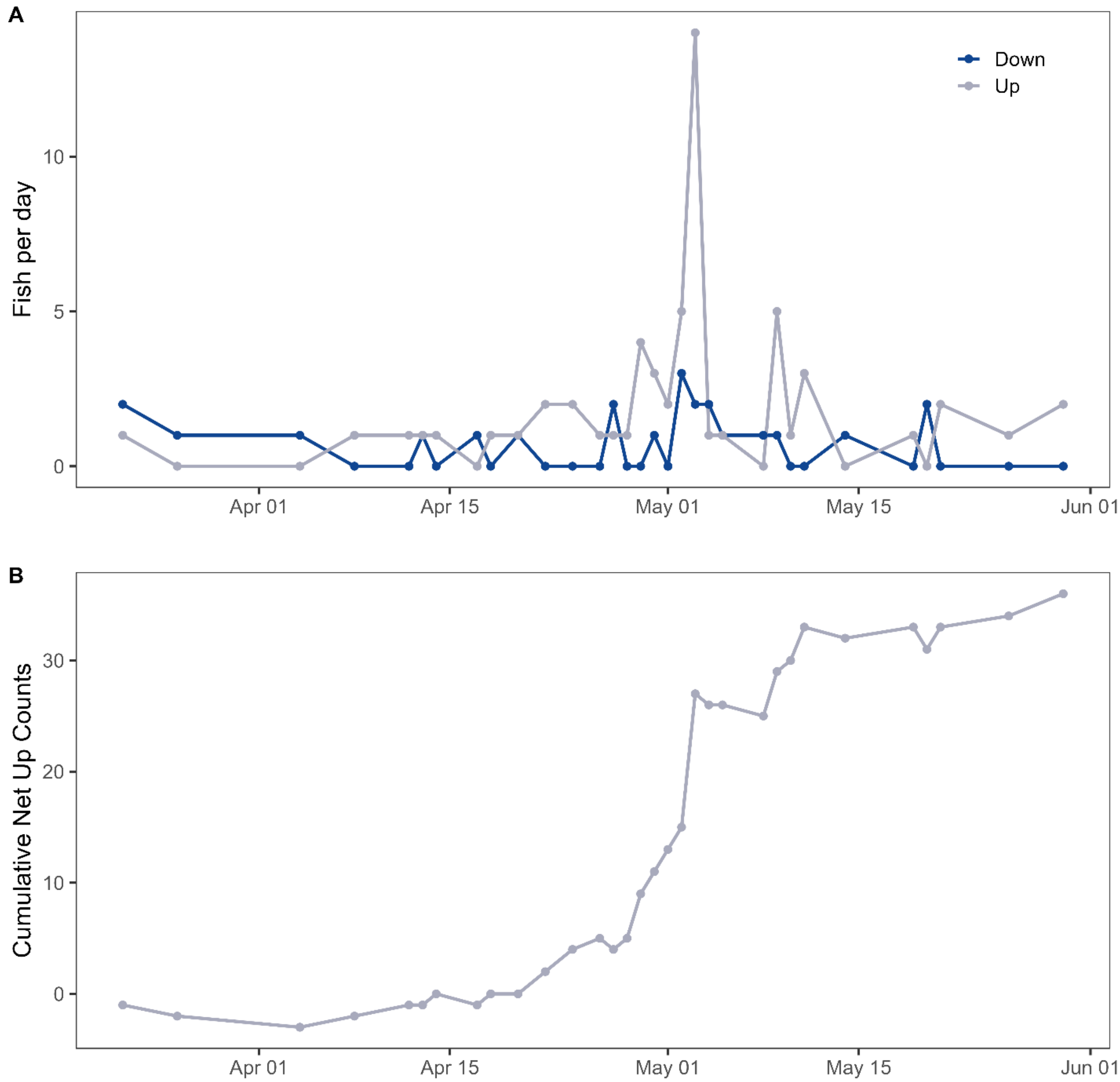

Figure 7. (A) Combined multibeam sonar and resistivity counter daily upstream (blue) and downstream (grey) counts and (B) cumulative net upstream counts for Steelhead Trout in the Lower Bridge River in 2022.

3.1.2 Chinook Salmon (Multibeam Sonar)

In 2022, Chinook Salmon were enumerated using ARIS sonar between August 10 and 18, after which counts from the broodstock collection fence were used. The resistivity counter was not used in 2022 as it was damaged during a period of high flows and could not be repaired until flows decreased. The net upstream abundance of Chinook Salmon recorded by the ARIS sonar was 446, which was added to the fence count of 85, for a total estimate of 531.

The sonar recorded 945 fish tracks (693 upstream movements and 252 downstream movements) and all individuals were measured manually using ARISfish. 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 sonar was 446. After August 19, 85 Chinook Salmon were enumerated at the broodstock fence. The resulting estimate is 531 Chinook Salmon (Figure 8). It is difficult to compare Chinook Salmon escapement from 2022 to previous years due to the fence operation and the effects of the Fraser River rockslide, which resulted in increased straying. Additionally, there was a large Sockeye Salmon return in 2022, which may confound the data and potentially leading to an overestimation of the Chinook escapement. However, none of the 134 Sockeye sampled at the broodstock fence exceeded the established size cut-off. Despite these uncertainties, Chinook Salmon abundance is higher than it's been in recent years, with escapement estimates between 2018 and 2021 being the lowest since monitoring began in 2014 (Table 5).

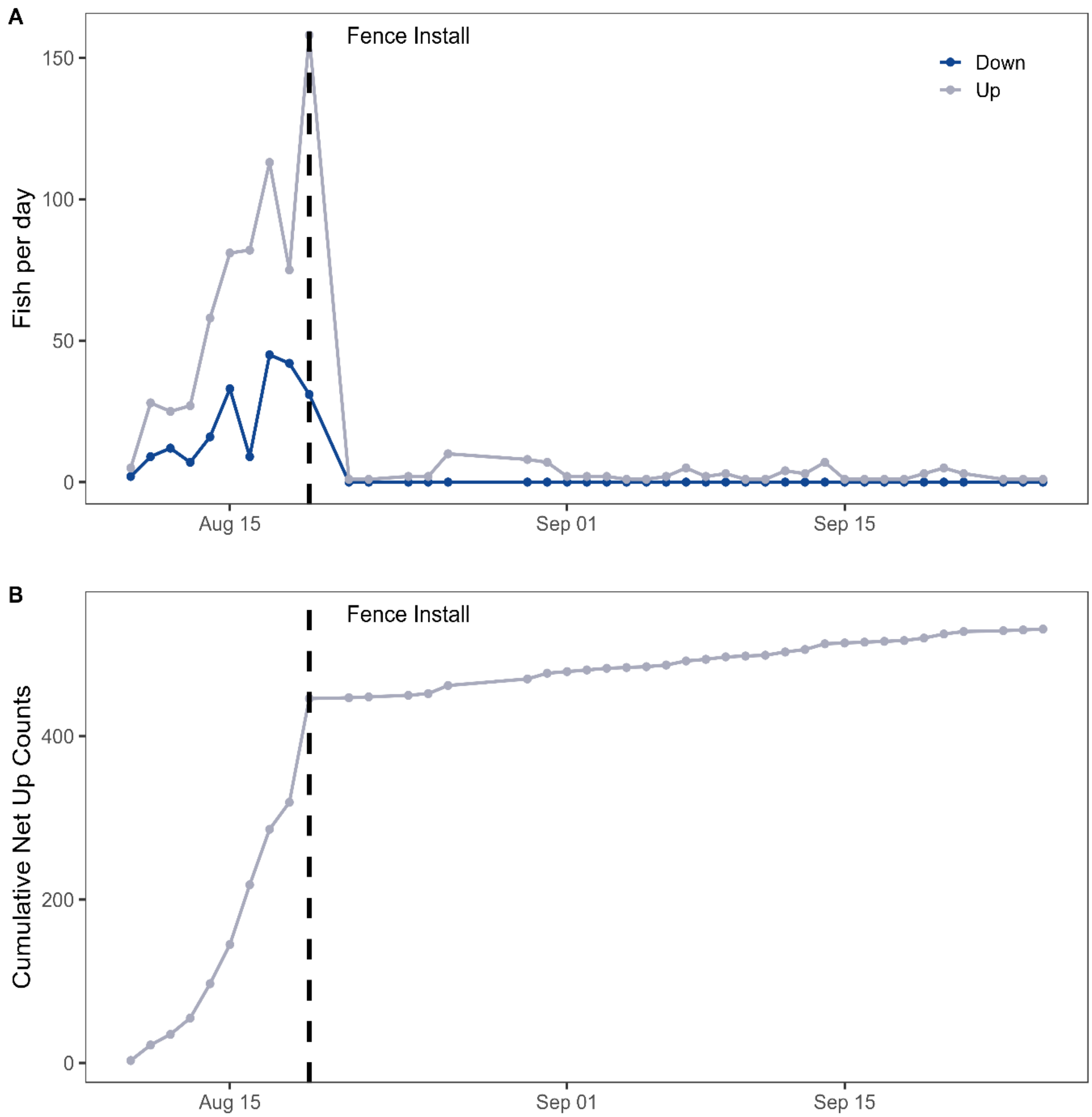

Figure 8. (A) Combined multibeam sonar and broodstock daily upstream (grey) and downstream (blue) counts and (B) cumulative net upstream counts for Chinook Salmon in the Lower Bridge River. The broodstock fence was installed on August 19th, after which all up counts were recorded from the fish fence.

Table 5. 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 confounded estimates in recent years because of 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
2022	531	Multibeam Sonar, and fence captures	Partial Estimate – broodstock fence limited estimates (pre-August 19)

3.1.3 Coho Salmon (Multibeam Sonar)

In 2022, Coho Salmon were enumerated solely using the Echoview sonar, which was operational between September 29 and November 30, 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. The sonar was operational between September 29 and November 30. After applying the length model to improve species classification, the net upstream abundance of Coho Salmon recorded by the sonar between October 14 and November 30 was 936 (Figure 9). This value is high compared to the average abundance since 2015 (597 SD 265; Table 7).

The sonar recorded 5,480 fish tracks (2896 upstream movements and 2583 downstream movements). There was an equipment malfunction prior to November 4, which affected the quality of the sonar image and made manual length measurements difficult. Thus, the dataset was split into two parts for analysis – before November 4 (3871 fish tracks), Echoview-derived lengths were used whereas after (1609 fish tracks), ARISfish measurements were used to develop a relationship between Echoview-derived and manually measured fish lengths. Of the 1609 fish tracks after November 4, 465 were measured manually (28.5% of events). The predicted length model for up fish used Echoview lengths (R^2 = 0.84, p < 0.001; Appendix 3). The predicted length model for down fish used only Echoview lengths, target length mean, and number of targets (R^2 = 0.86, p < 0.001; 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 after October 14th and downs before December 14th were used to enumerate Coho Salmon. This decision was made due to the overlap in migration timing between Chinook Salmon and Coho Salmon, with October 15th historically marking the occurrence of the Coho Salmon migration passing the counter site.

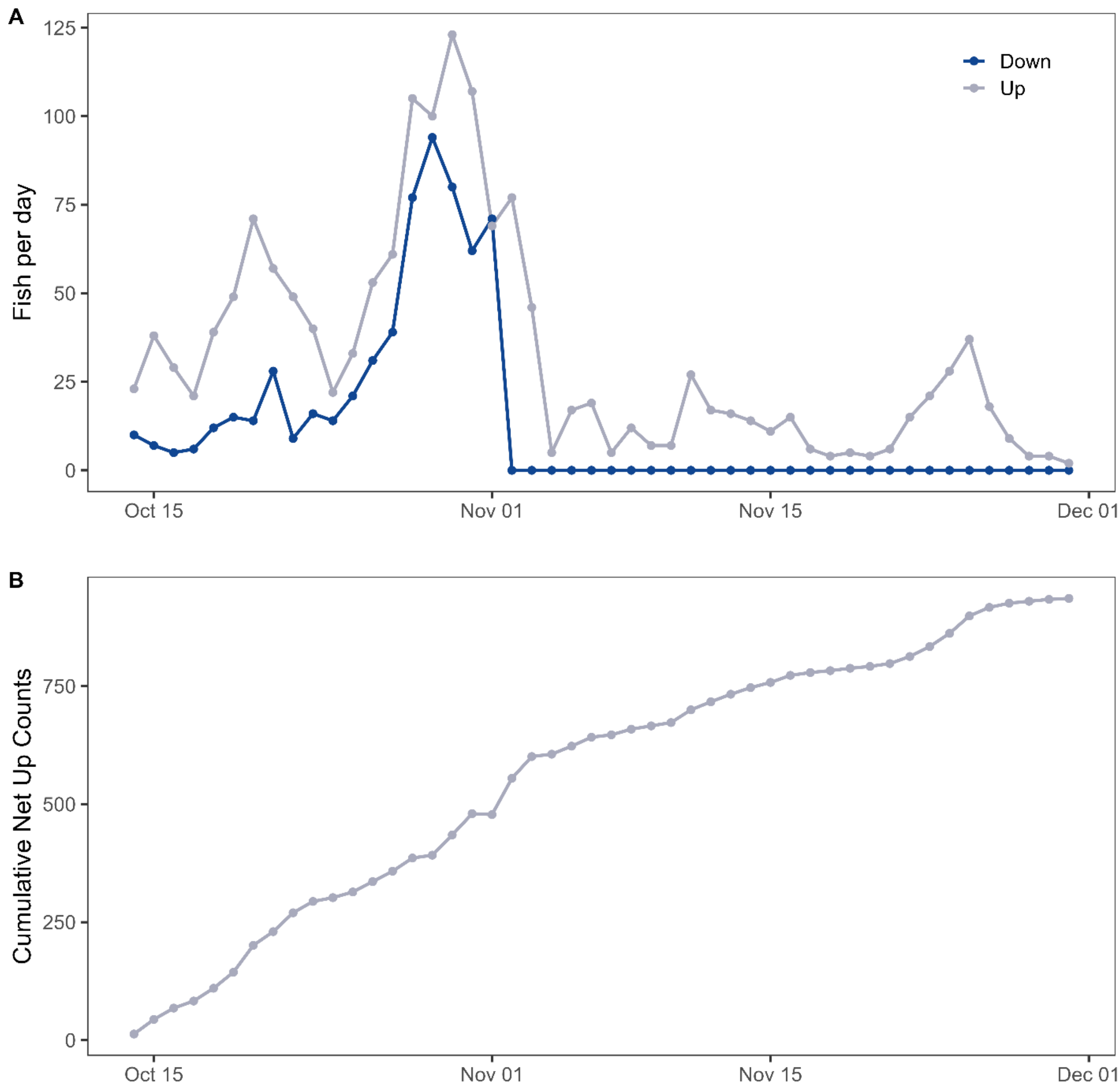

Figure 9. (A) Sonar derived daily upstream (grey) and downstream (blue) counts and (B) cumulative net upstream counts for Coho Salmon in the Lower Bridge River in 2022.

Table 6. 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
2022	936	Multibeam Sonar	Complete estimate

3.2 Spawning Distribution (Radio Telemetry)

Radio telemetry was used to assess migration timing, spawner residence time, and spawner distribution. 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 50% at Station 1 (Reach 1), 100% at Station 2 (Camoo), and 33% at Station 3 (Counter).

Seven female Steelhead Trout were tagged at the Seton-Fraser confluence from February 26 to April 7, 2022 (Appendix 4). Of these fish, 6 individuals were detected by either fixed receivers or mobile tracking following tagging. Telemetry detections indicated that Steelhead Trout entered the LBR throughout April and spawned from late-April through mid-May. Spawning locations were determined for four Steelhead Trout, one spawned in Reach 3 (25.0 – 25.5 rkm), and three in Reach 4 (39.6 - 38.8; Figure 10). Steelhead continue to utilize Reach 3 and 4 to spawn, as in previous years (Figure 11). Both fish with unknown spawning locations were detected by a PIT array in the fishway at Seton Dam.

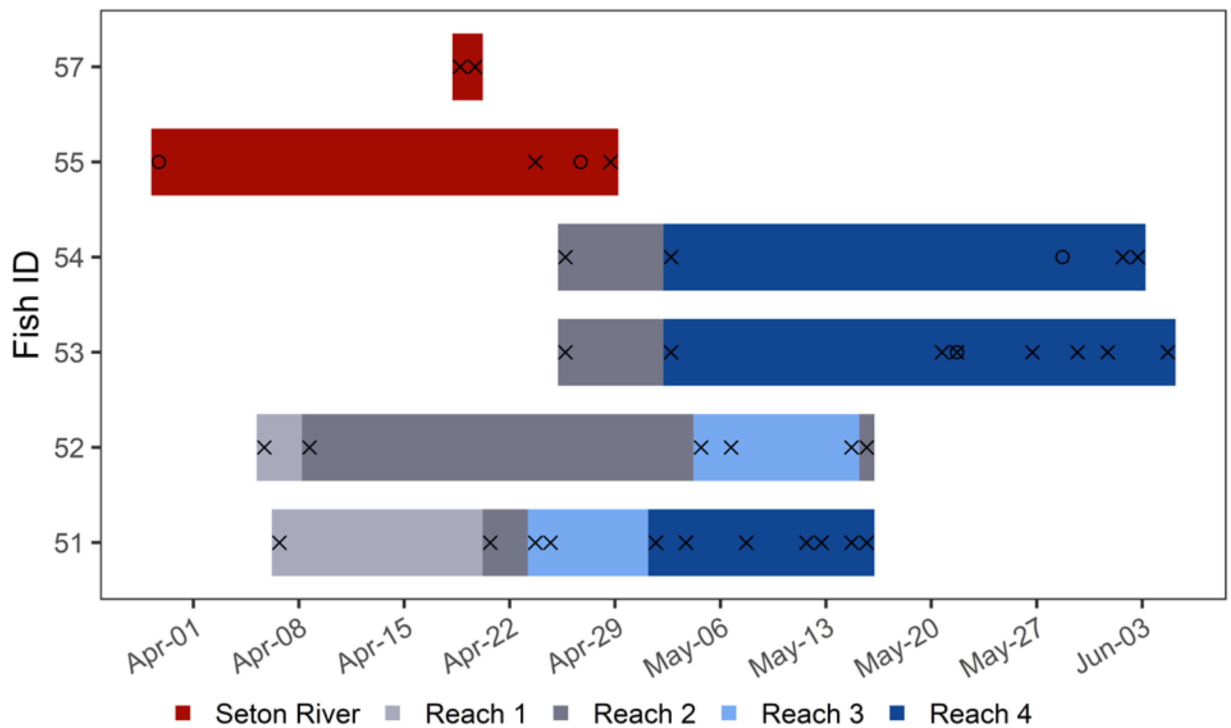

Figure 10. Time series of radio-tagged Steelhead Trout in the Seton and Lower Bridge River in 2022. o denotes mobile tracking detections, × denotes fixed receiver detections.

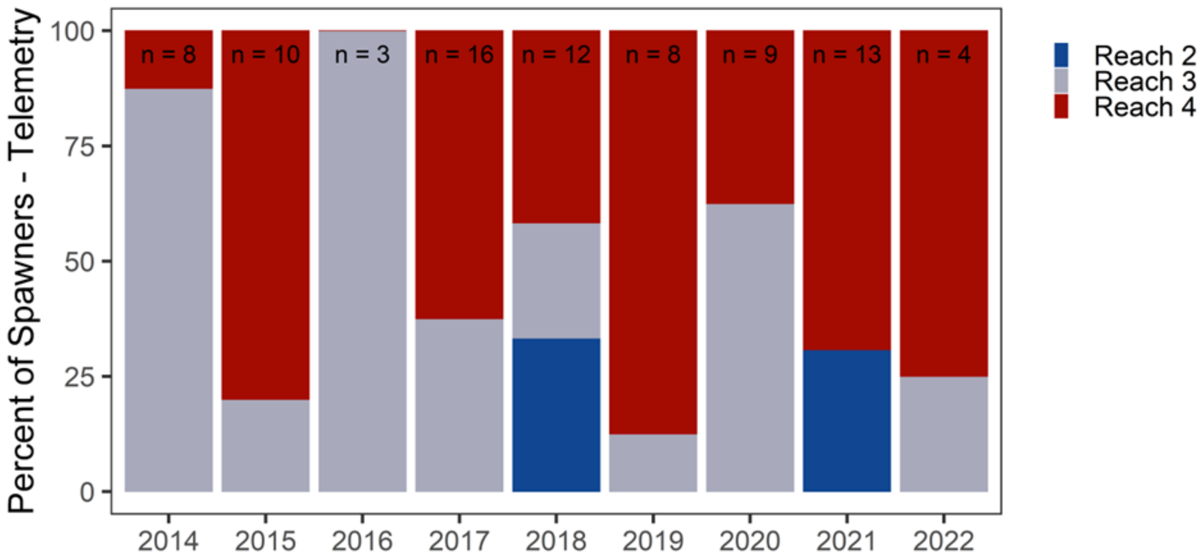

Figure 11. Relative proportion of estimated spawning locations in Reach 2, 3 and 4, for Steelhead Trout based on radio telemetry, including sample size.

3.2.2 Chinook Salmon

In 2022, a total of 30 Chinook Salmon were radio-tagged, consisting of 16 females and 14 males. Chinook were tagged between August 12 and August 29 and this was the most tags deployed since the study began. Most of the fish (25 individuals) were tagged at the Yalakom-Bridge confluence (25.0 rkm), one was tagged at Hippie Pool (25.3 rkm) and the remaining four were tagged at Horseshoe Bend (22 rkm; Appendix 4). Out of the 30 Chinook, four were not detected again after the initial tagging and five successfully passed the broodstock fence, which was installed on August 19 (Figure 12). Among those five Chinook, four were estimated to have spawned in Reach 3, while one was likely to have spawned in Reach 4 (Figure 13). Reach 3 is the preferred spawning location for Chinook Salmon; however, since the broodstock fence has been active since 2018, more Chinook have begun spawning downstream. Detection efficiency, residence time and migration rate could not be estimated for Chinook Salmon in 2022 due to little movement from capture location and recycling of fish downstream of the fence. Figure 14 illustrates repeated migration attempts made by two Chinook Salmon downstream of the broodstock fence, where fish repeatedly attempted to swim past the fence and then circulated downstream to the counter. This recycling behaviour was observed in the majority of tagged Chinook.

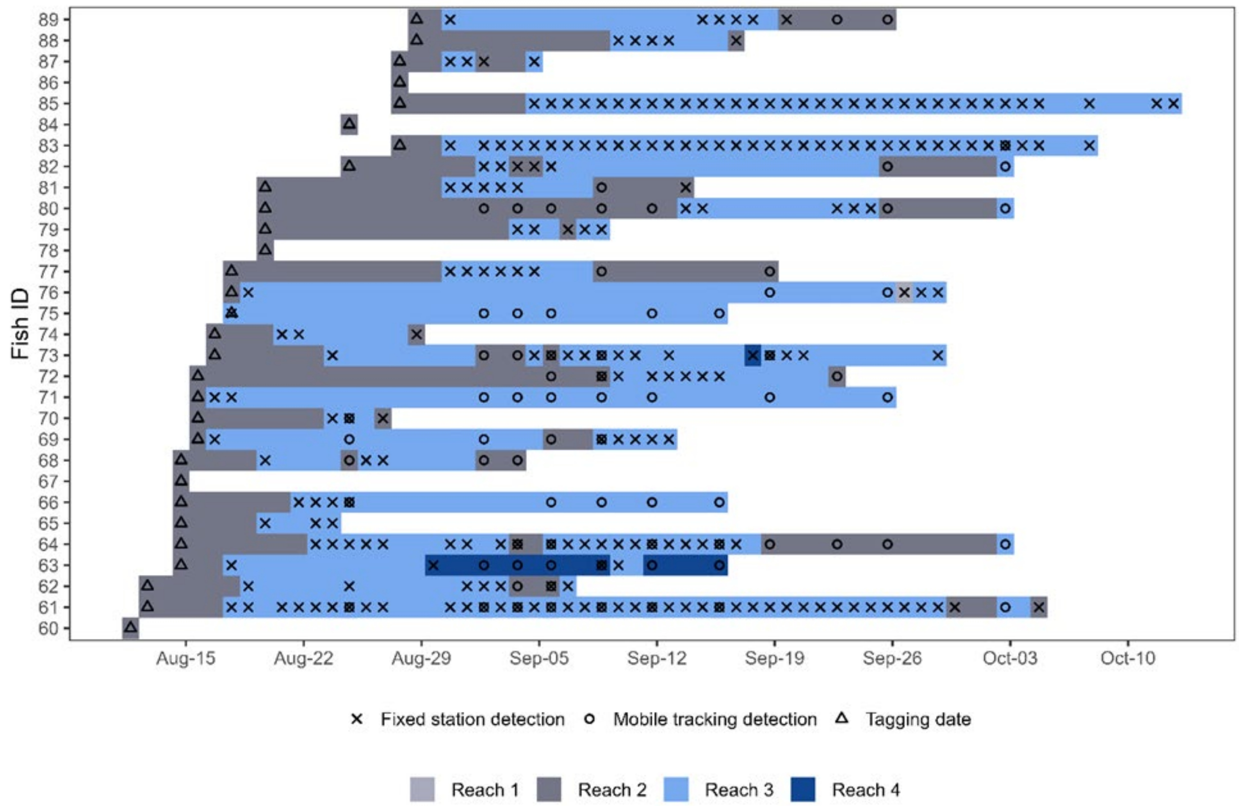

Figure 12. Time series of radio-tagged Chinook Salmon in the Lower Bridge River in 2022.

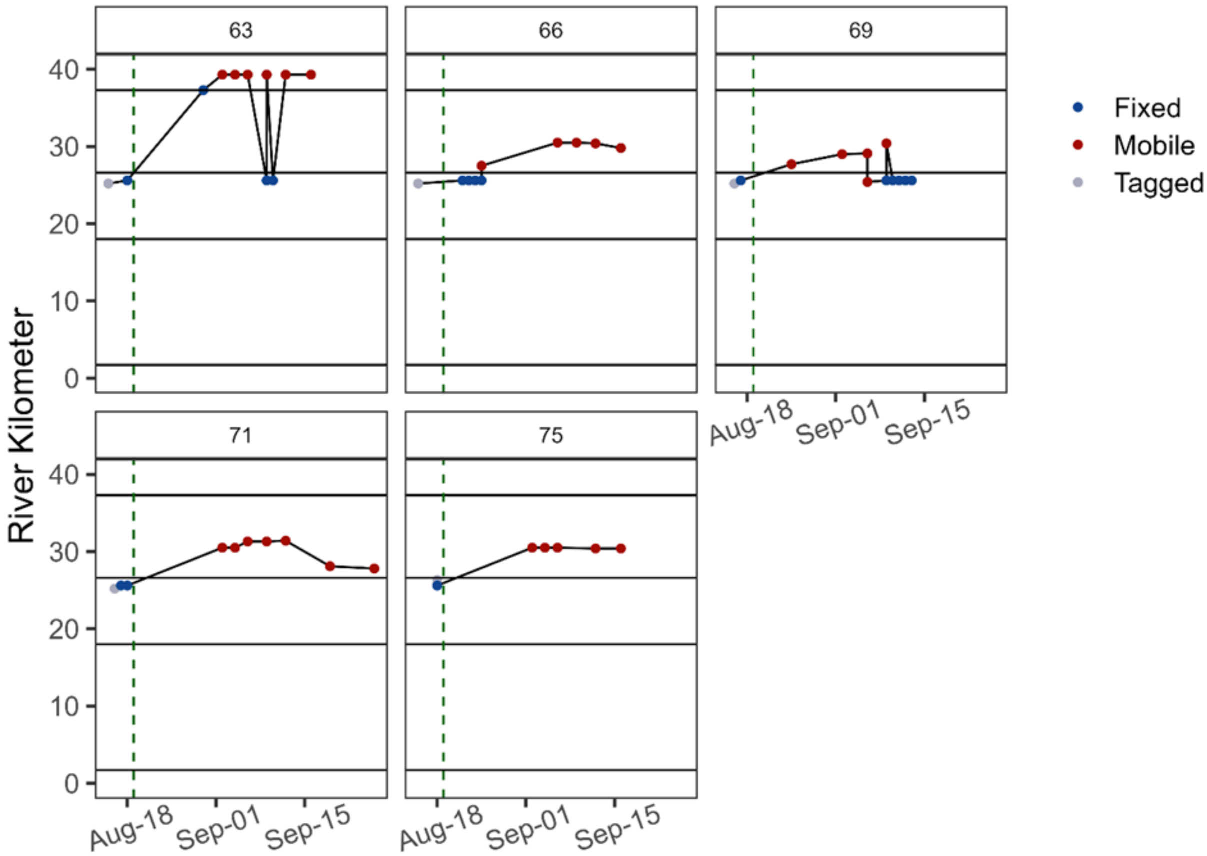

Figure 13. Detection histories of the five radio-tagged Chinook Salmon in the Lower Bridge River that made it past the broodstock fence in 2022. The vertical green line indicates when the broodstock fence was installed (August 19).

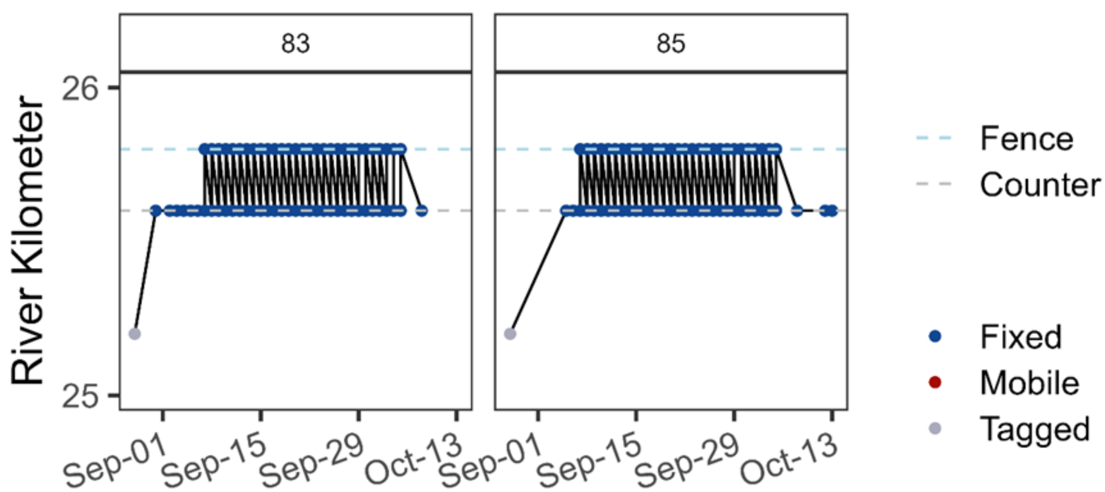

Figure 14. Detection histories of two radio-tagged Chinook Salmon in the Lower Bridge River in 2022, highlighting the effect of the broodstock fence on upstream migration.

3.2.3 Coho Salmon

Only 10 Coho Salmon, six males and four females, were tagged between October 11 and November 4, 2022. Coho were tagged at Eagle Canyon (n = 3, 2 rkm), Camoo FSR (n = 4; 18.0 rkm), Horseshoe Bend (n = 1; 22 rkm), and Hippie Pool (n = 2; 25.3 rkm; Appendix 4). Half of the radio tags were not detected again after deployment, and another was only detected once in Reach 1 (Figure 15). As such these tags were not considered when spawning reach was being assigned. Suspected spawning sites for the remaining four Coho were in Reach 4 (n = 1), Reach 3 (n = 1) and at the Reach 2-3 break (n = 2; Figure 16). Residence time was not able to be determined due to the small sample size. Detection efficiency could not be calculated as little movement occurred after tagging.

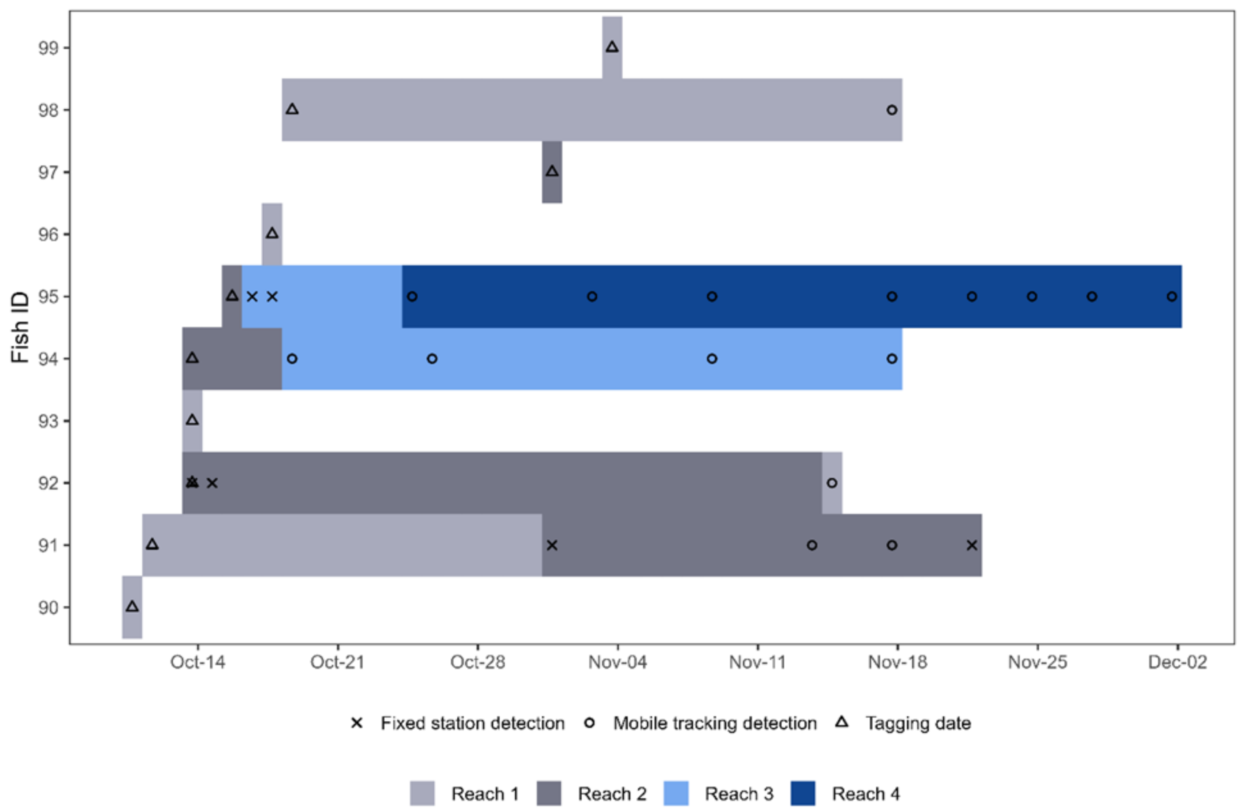

Figure 15. Time series of radio-tagged Coho Salmon in the Lower Bridge River in 2022.

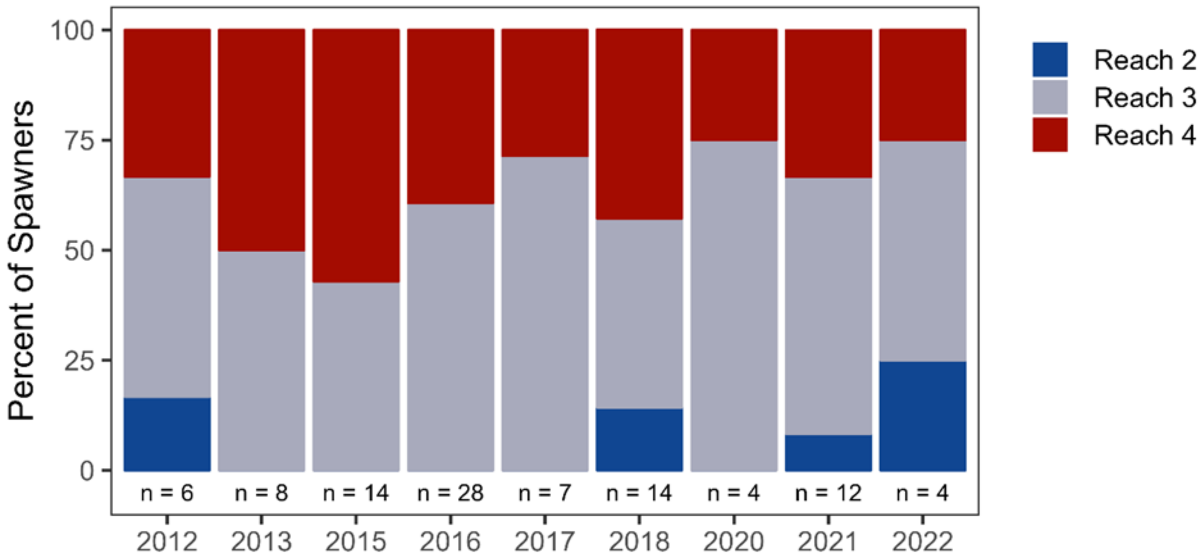

Figure 16. Relative proportion of estimated spawning locations in Reach 2, 3 and 4, for Coho Salmon based on radio telemetry.

3.3 Migration Timing

Migration timing was assessed across all years of the monitoring project, using both counter and radio telemetry data, when available. The objective was to determine whether changes in migration timing have occurred in response to alterations in the instream flow regime in the LBR (Table 7).

Table 7. Radio telemetry and counter estimates, when available, were used to derive migration timing curves for Steelhead, Chinook, and Coho in the LBR. Years where data were not collected are denoted by NA. Counter estimates are summarized as either having been included (i.e., "Yes") or excluded due to a disruption in data collection (i.e., "No"). The number of fish tagged for radio telemetry is summarized and years with fewer than 3 tagged individuals were excluded from the analysis.

	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	Yes
2014	8	Yes	17	Yes	15*	Yes
2015	10	Yes	14	Yes	14*	Yes
2016	2	No**	14	Yes	30	Yes

2017	16	Yes	2	Y	8	No***
2018	8	Yes	2	No****	12	Yes
2019	8	Yes	1	No****	0	Yes
2020	7	Yes	0	No****	4	Yes
2021	13	Yes	3	No****	5	Yes
2022	7	Yes	30	No****	10	Yes

* 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 2022, while counter data were available for 2014, 2015, and 2017 through 2022. 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). Migrating spawners were exposed to high flows from 2016 to 2018, 2021, and 2022. With exception of 2021, in which reach entry was early, MOD years do not appear to affect the timing of Steelhead reach entry (Figure 17).

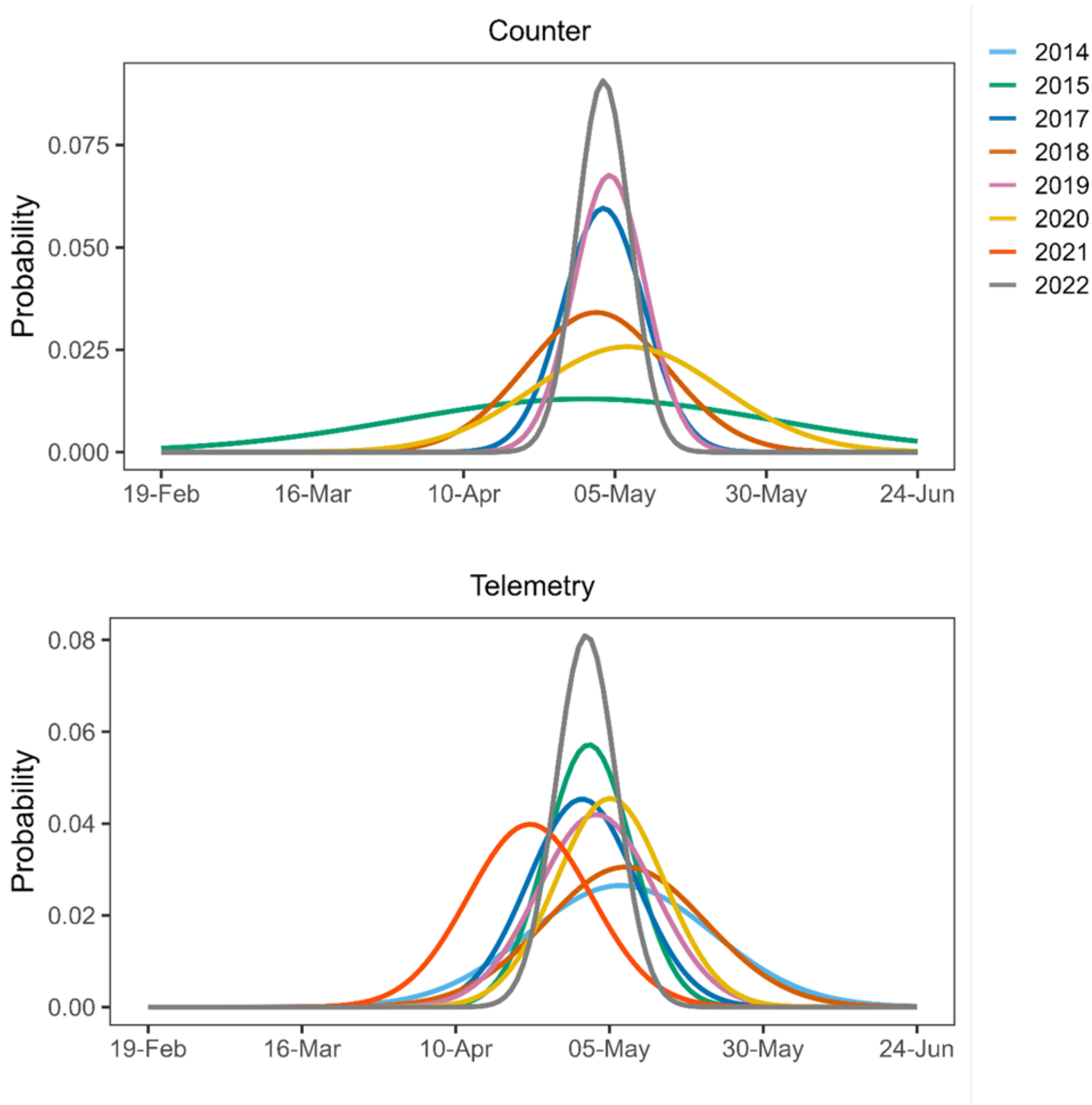

Figure 17. Normal distributions of Steelhead Trout migration timing from electronic counters (top) and Reach 3 telemetry data (bottom) from 2014-2022. Years with low sample size (n<5) or incomplete estimates were removed.

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 and the installation of the broodstock fence has prevented proper assessment since 2018. 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 18). 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 confounded due to the presence of the broodstock fence.

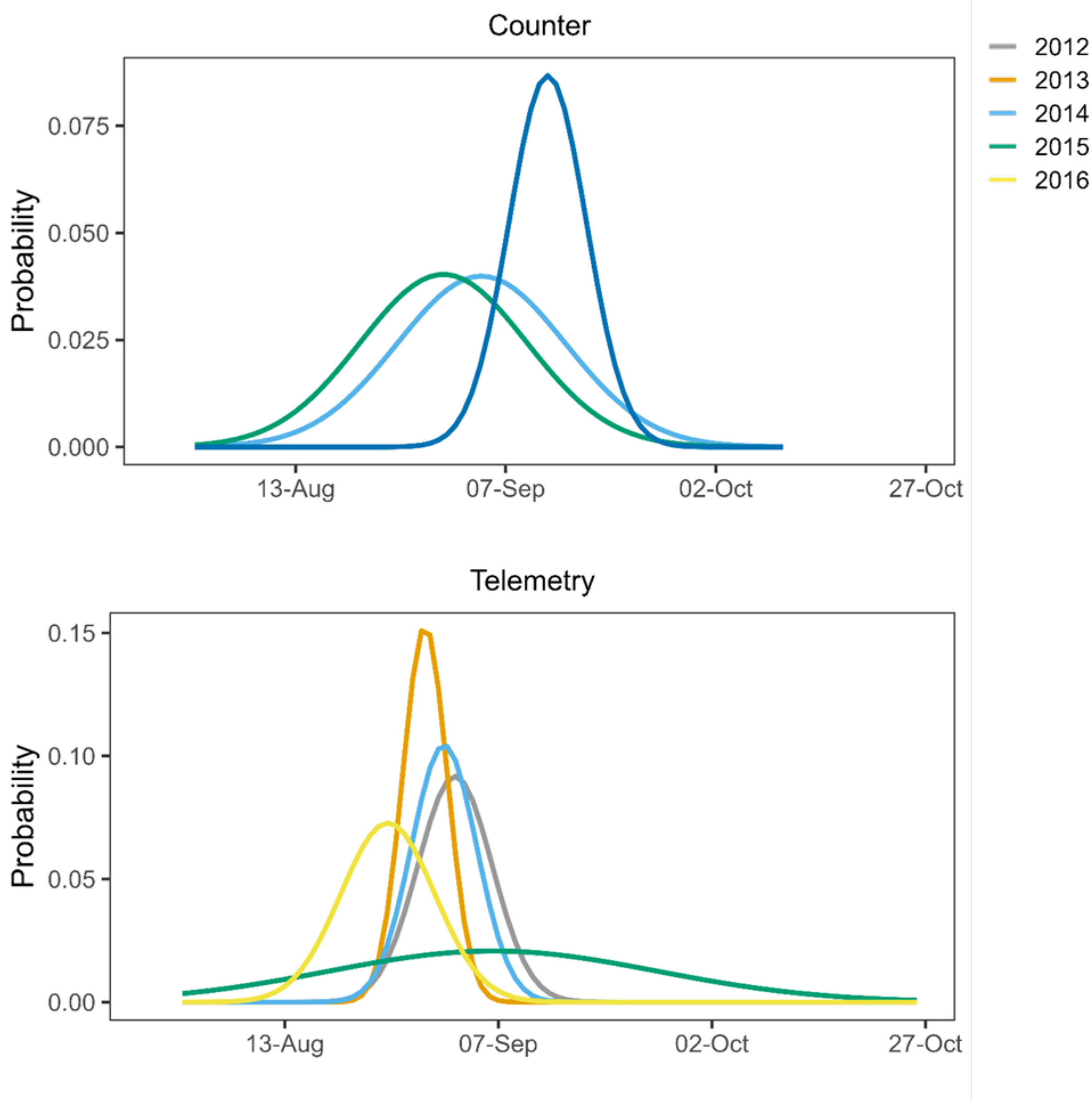

Figure 18. Normal distribution of Chinook Salmon peak migration timing from electronic counters (top) and Reach 3 telemetry data (bottom), which are located at the same place along the river, from 2012-2017. Years with low sample size (n ≤ 3) or incomplete estimates were removed.

3.3.3 Coho Salmon

For Coho Salmon, telemetry data were available from 2012 - 2018 and 2020 - 2022 (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 not interrupted by the broodstock fence, which was removed on September 28. Based on historic migration data and current streamwalk and telemetry data, October 13 was used as the start date for the estimate. 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 19). Like Chinook Salmon, Coho Salmon migrate in October and November and are subjected to a consistent flow regime (1.5 m^3s^{-1}).

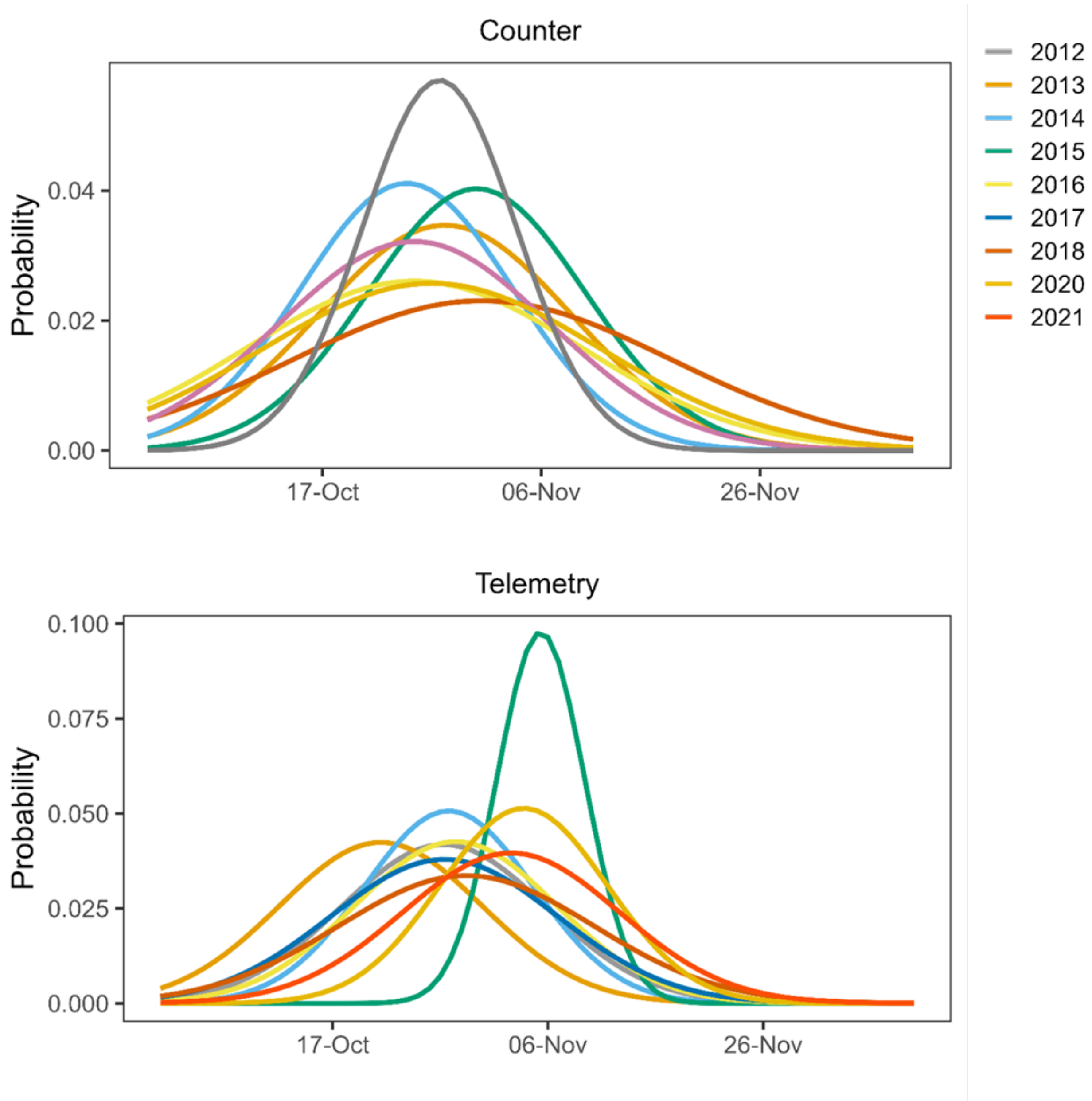

Figure 19. Normal distribution of Coho Salmon peak migration timing from electronic counters (top) and Reach 3 telemetry data (bottom) from 2012-2021. Years with low sample size (n ≤ 3) or incomplete estimates were removed.

3.4 Visual Counts and AUC Population Estimates

3.4.1 Chinook Salmon

Visual surveys of Chinook Salmon began on August 3 and the first Chinook were observed on August 24 (n = 13), no chinook were seen after October 12. Our surveys only assessed fish that were able to pass the broodstock fence prior to installation on August 19. 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.

As in previous years with the broodstock fence operating, OE could not be calculated, as few tagged individuals migrated past the fence. Spawner distribution was primarily assessed from individuals that passed the fence site prior to its' installation and individuals that were passed by the fence. A peak of 69 Chinook Salmon were observed on September 14. During peak count in 2022, the largest percentage of spawners observed above the broodstock fence were located between Fraser Lake and Cobra in Reach 3 (n = 24; rkm 33.2 to 34.4), followed by Longskinny to Terzaghi Dam (n = 26; rkm 39.6 to 40.0). Visual survey data collected in 2018 - 2022 suggest an increase in the use of Reach 4 for Chinook Salmon to spawn (Figure 20). Chinook observed between the Yalakom River and the broodstock fence were excluded in Figure 20. As such, these counts may not accurately represent spawner distribution in the absence of the fence. Should fence operation continue in its current form, evaluating the effects of the instream flow regime on spawner distribution will be challenging.

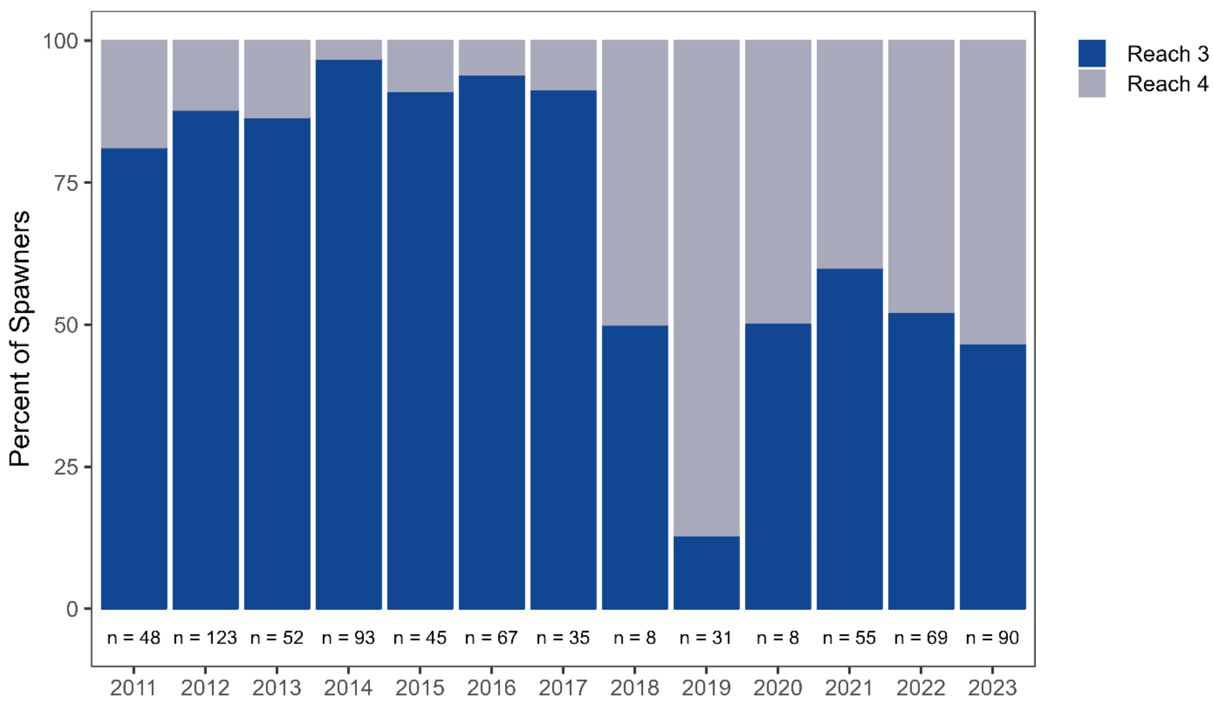

Figure 20. Proportion of Chinook Salmon spawners observed during peak visual survey in Reach 3 and 4 of the LBR.

AUC Abundance Estimate

The 2022 AUC abundance of Chinook Salmon between the broodstock fence and Terzaghi Dam was 225 (95CI 122 – 414; Appendix 7). After August 19, 85 Chinook Salmon were enumerated at the broodstock fence, resulting in a coarse Chinook Salmon spawner escapement of 310.

AUC estimates were compared with abundance estimated by electronic counters and the AUC estimate was much lower (Figure 21). While streamwalk counts downstream of the fence were not included in the estimate, they were still conducted.

Average values were used for SL and OE (10.5 days and 0.5 for SL and OE, respectively). 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 22). 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).

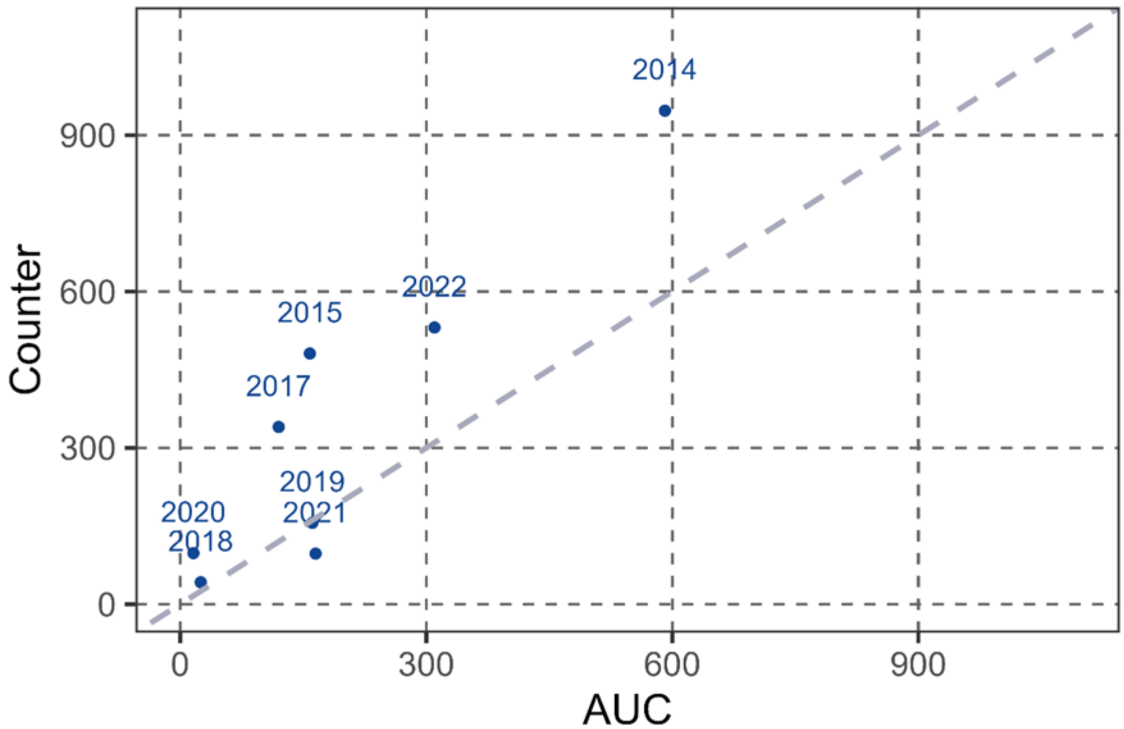

Figure 21. Comparison of Chinook Salmon AUC visual survey estimates, and estimates derived from counting technology. The 2016 point was removed from this figure as the counter estimate did not reflect the entire migration period. Dashed line represents a ratio of 1:1.

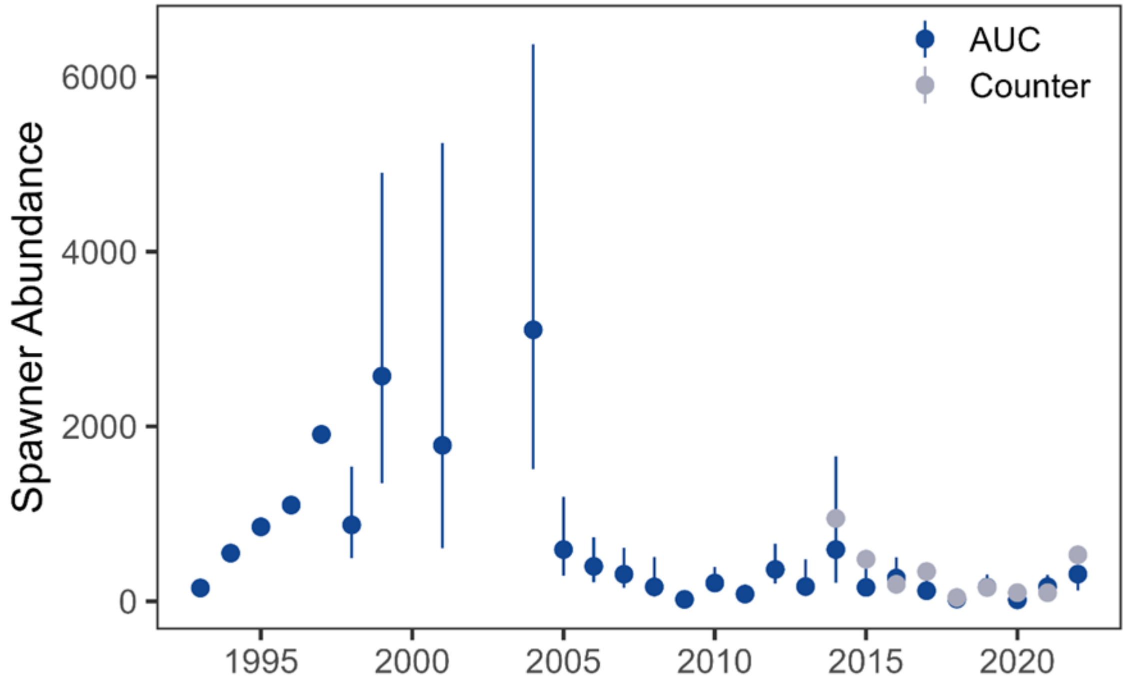

Figure 22. AUC and fence estimates for Chinook Salmon from 1993 to 2022 and electronic counter estimates from 2014 to present in the LBR. Vertical lines represent 95% confidence limits around visual estimates.

3.4.2 Coho Salmon

Visual counts of Coho Salmon were conducted from October 5 to December 7. The first Coho Salmon was observed on October 18 and a peak count of 148 fish was recorded on November 14. Water clarity during the Coho Salmon migration period remained good (mean Secchi depth = 1.4 m ± 0.63). In 2022, the highest percentage of spawners observed during peak counts was observed from Plunge Pool to Longskinny (n = 386, rkm 39.6 to 40.0) and 79% 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 23).

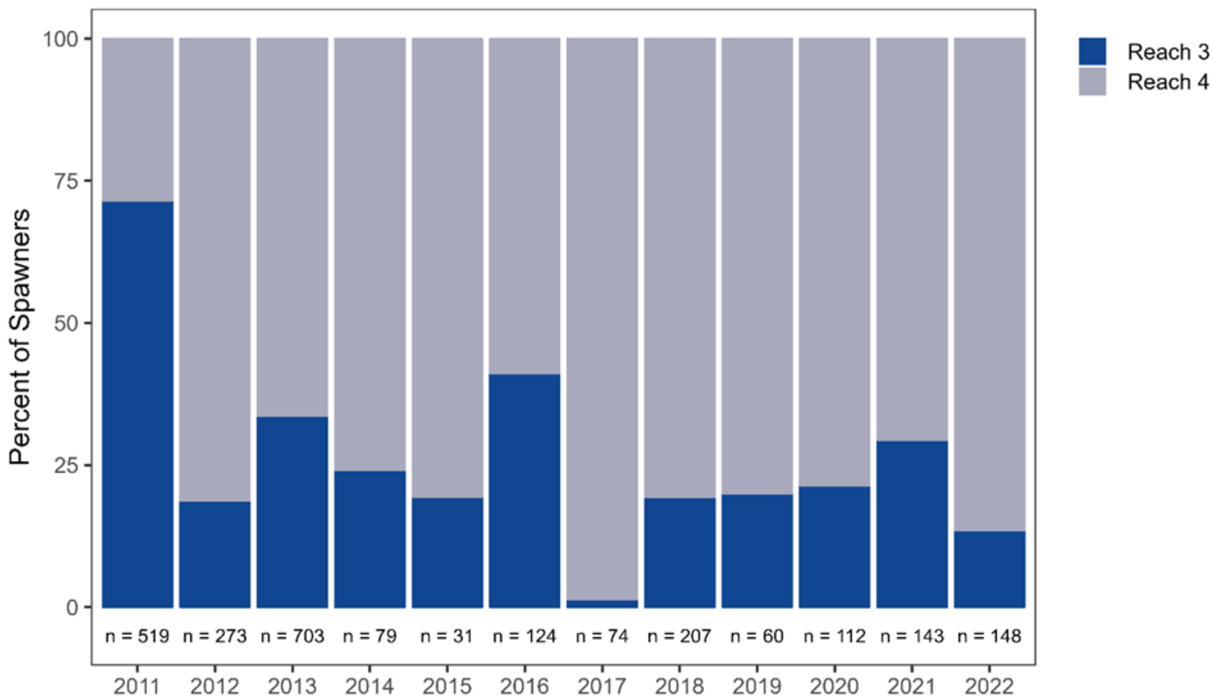

Figure 23. Proportion of Coho Salmon spawners observed during peak visual survey in Reach 3 and 4 of the LBR.

AUC Abundance Estimate

Estimated AUC abundance of Coho Salmon in 2022 between the Yalakom River and Terzaghi Dam was 836 (95% CI: 655 – 1,065; Appendix 7), the second highest abundance calculated since counter infrastructure was installed (1,298 in 2018). Observer efficiency was 0.167 and SL could not be calculated. This OE was added to previous years observations to calculate a historic average over the study period (SL = 19.7 days and OE = 0.208) and used for model parameters. The historic average was used for 2022.

AUC estimates were compared with abundance estimated by electronic counters (Figure 24). In 2019, 2020, and 2022 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 24). 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 25).

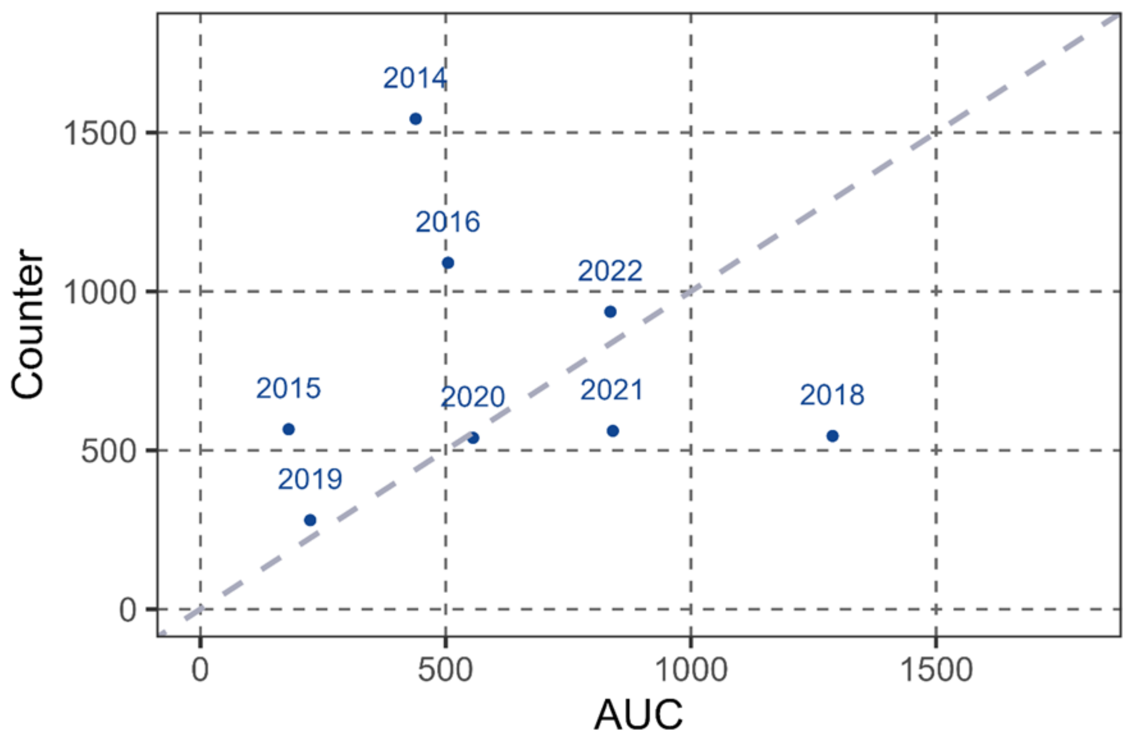

Figure 24. Comparison of Coho Salmon AUC visual survey estimates, and estimates derived from counting technology. No electronic data was available for 2017. Dashed line represents a ratio of 1:1.

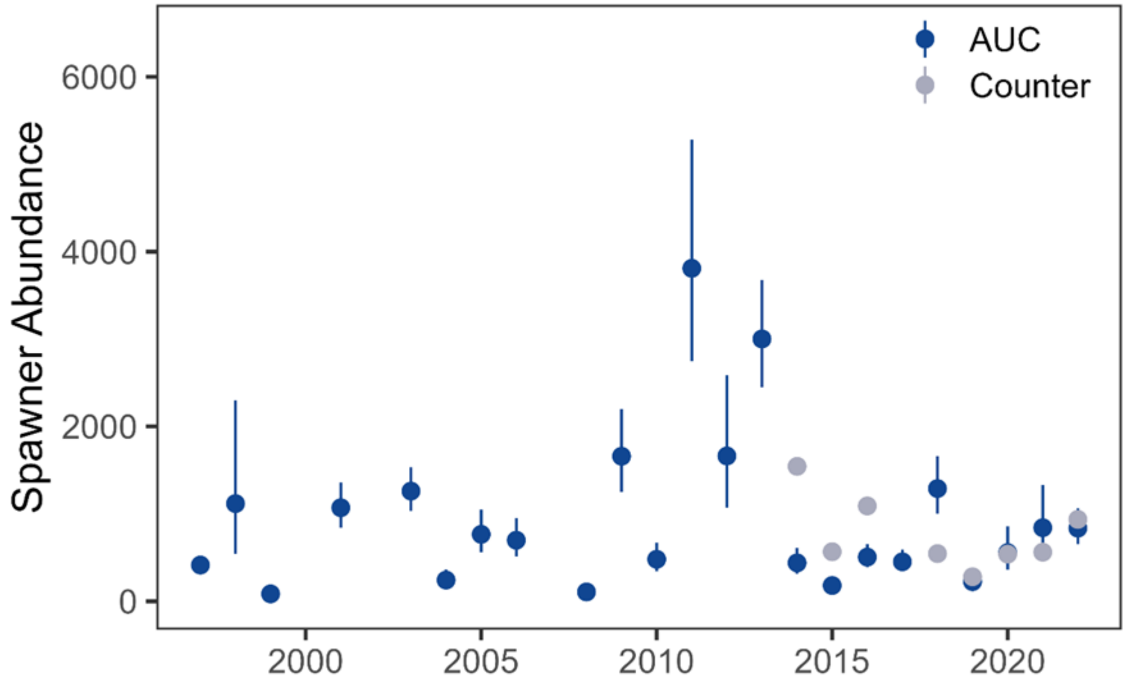

Figure 25. AUC estimates for Coho Salmon from 1997 to 2022 and electronic counter estimates from 2014 to present in the LBR. Vertical lines represent 95% confidence limits around visual estimates.

3.5 Spawning Habitat

3.5.1 Weighted Usable Area for Chinook and Coho Salmon

In 2022, 21 habitat units and 82 transects were surveyed at both 3 and 1.5 m^3s^{-1}. 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 6,712 m^2 of suitable Chinook Salmon spawning habitat was calculated for all habitat units in 2022, with the majority located in Reach 3 (44%; Figure 26; Appendix 8). The largest quantities of spawning habitat at a site level were located specifically above the Camoo FSR bridge (Reach 2; 2080 m^2), Horseshoe Bend (Reach 2; 786 m^2), Longskinny (Reach 4; 509 m^2), Fraser Lake (Reach 3; 523 m^2), and Unit 1 (Reach 3; 342 m^2). There were no statistical differences in WUA for Chinook Salmon among years (ANOVA: $F_{4, 112}$ = 1.69, p = 0.16).

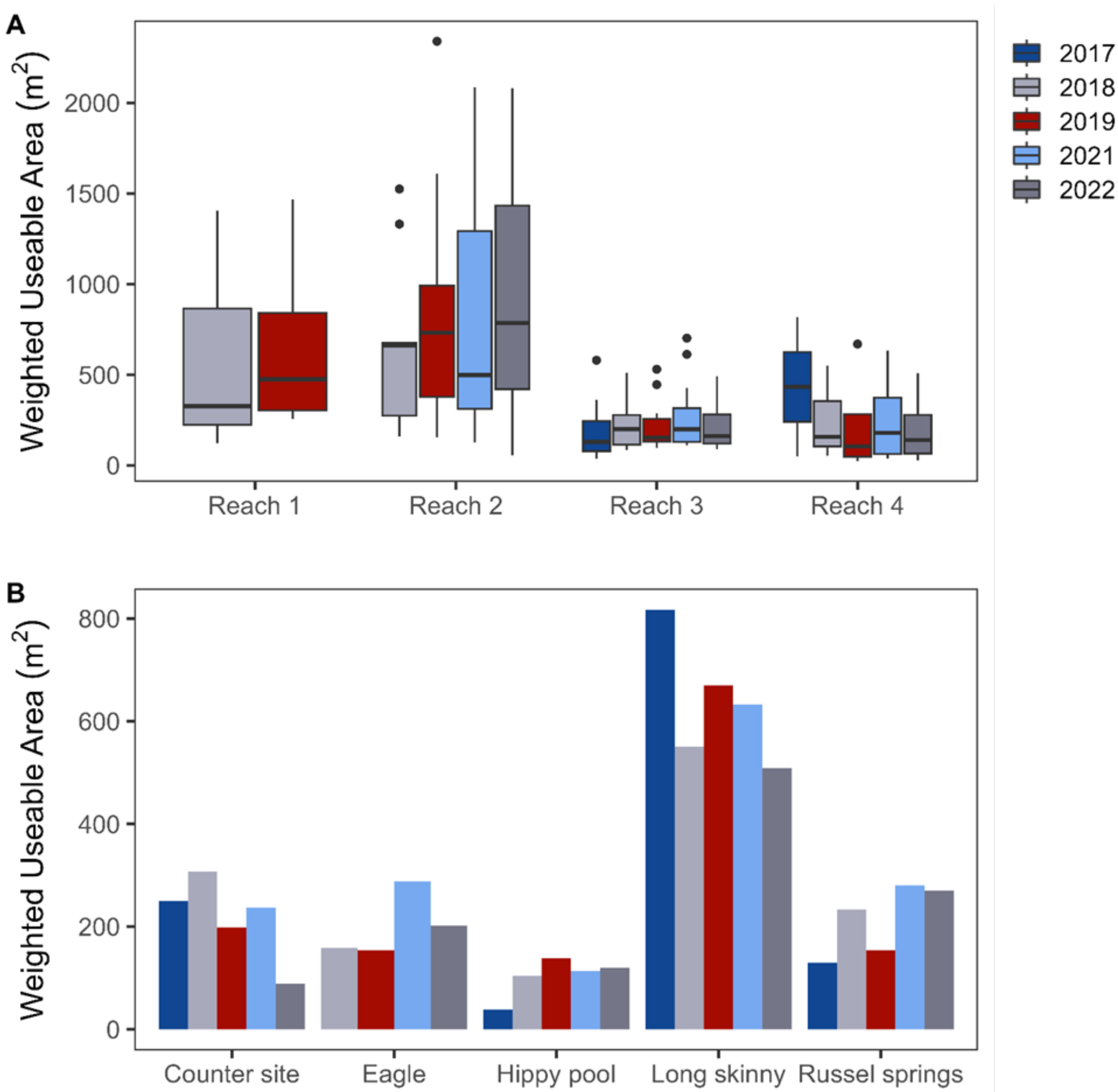

Figure 26. Weighted Usable Area of Chinook Salmon spawning habitat, separated by A) reach and B) important spawning locations surveyed following the high flows in 2017-2019 and 2021-2022.

Coho Salmon Spawning Habitat

A total of 8,912 m^2 of suitable Coho Salmon spawning habitat was calculated for all habitat units in 2022, with the majority located in Reach 2 (47%; Figure 27; Appendix 8). The largest quantities of spawning habitat were located specifically above the Camoo FSR bridge (Reach 2; 3,807 m^2), Fraser Lake (Reach 3; 719 m^2), Longskinny (Reach 3; 599 m^2), and Unit 1 (Reach 3; 541 m^2).

There were no statistical differences in WUA for Coho Salmon among years (ANOVA: $F_{2, 52}$ = 1.84, p = 0.17).

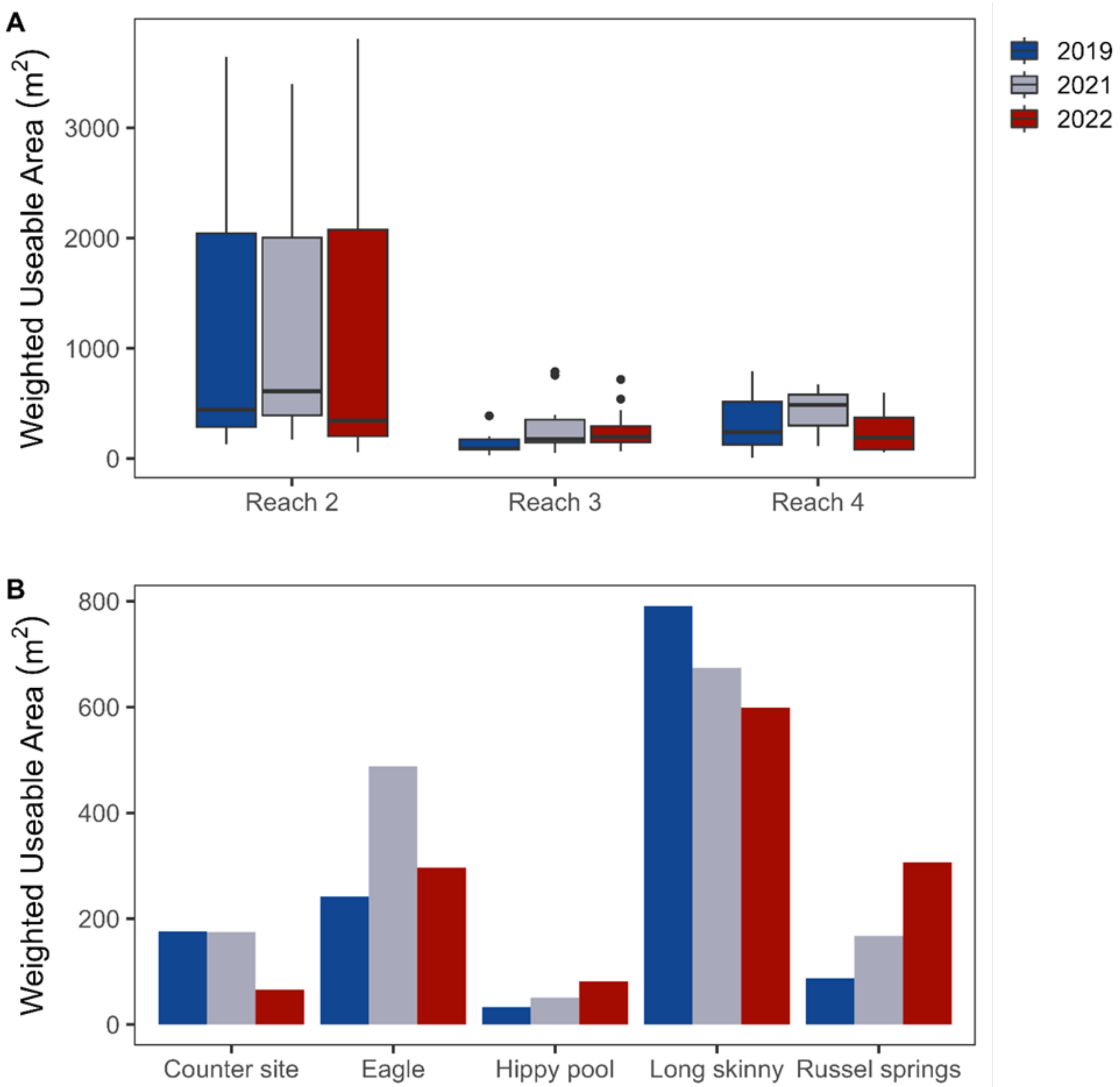

Figure 27. Weighted Usable Area of Coho Salmon spawning habitat, separated by A) reach and B) important spawning locations surveyed following the high flows in 2019, 2021, and 2022.

3.5.2 Substrate Analysis

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 66.3%

of the variation in the distribution of substrate (Figure 28). The amount of variation that the random effect accounts for, means that the remainder (33.7%) 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. 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.

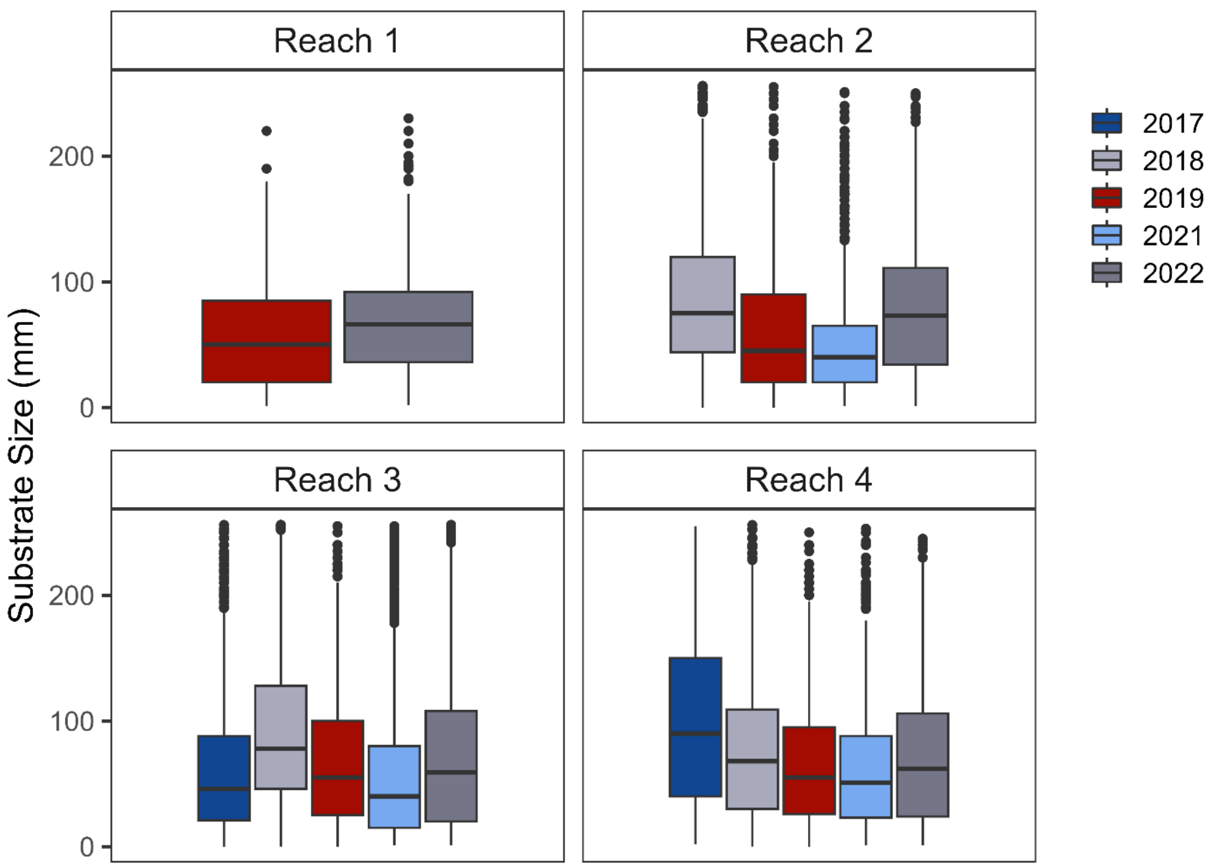

Figure 28. Substrate size (mm) measured at HSI transects in the Lower Bridge River. Solid lines denote the annual median substrate size and boxes represent the interquartile range (IQR). Lines represent the range excluding outliers, which are shown as points. Substrate larger than 256mm were removed from analysis.

3.5.3 Redd Surveys

Chinook Salmon

A total of 30 Chinook Salmon redds were observed in 2022. There were 23 in Reach 3, and seven in Reach 4 (Figure 29; Appendix 10). For the first time since 2014, glides were not the only habitat redds were observed in as a subset of redds (n = 10; 33%) were observed in riffle habitat. 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 were not able to be collected in 2022, due to the flow regime being changed before the redd surveys were completed. In previous years redd locations have remained similar and within ranges considered suitable for spawning Chinook Salmon (Ptolemy 1994; Figure 30). Substrate sizes observed at redd locations were smaller than the overall mean calculated from transect data (36.8 mm ± 18.8 at redds compared to 72.5 mm ± 58.4 at transects) and on the lower end of the range considered suitable for spawning Chinook Salmon (25-150 mm; Groves and Chandler 1999).

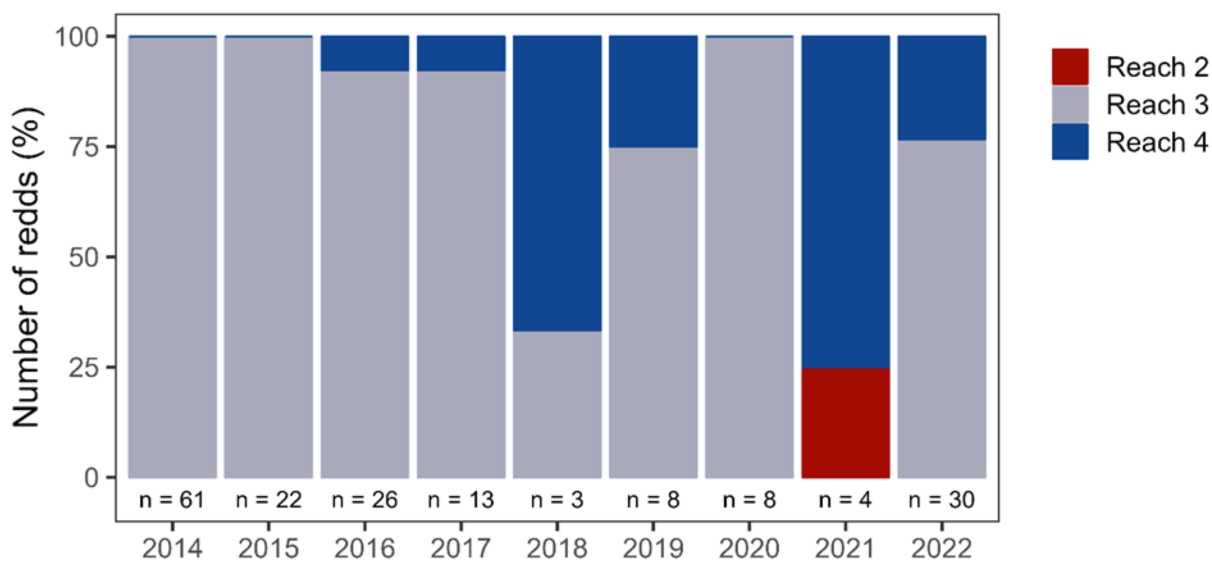

Figure 29. Proportion of Chinook Salmon redds observed in Reach 3 and 4 of the LBR.

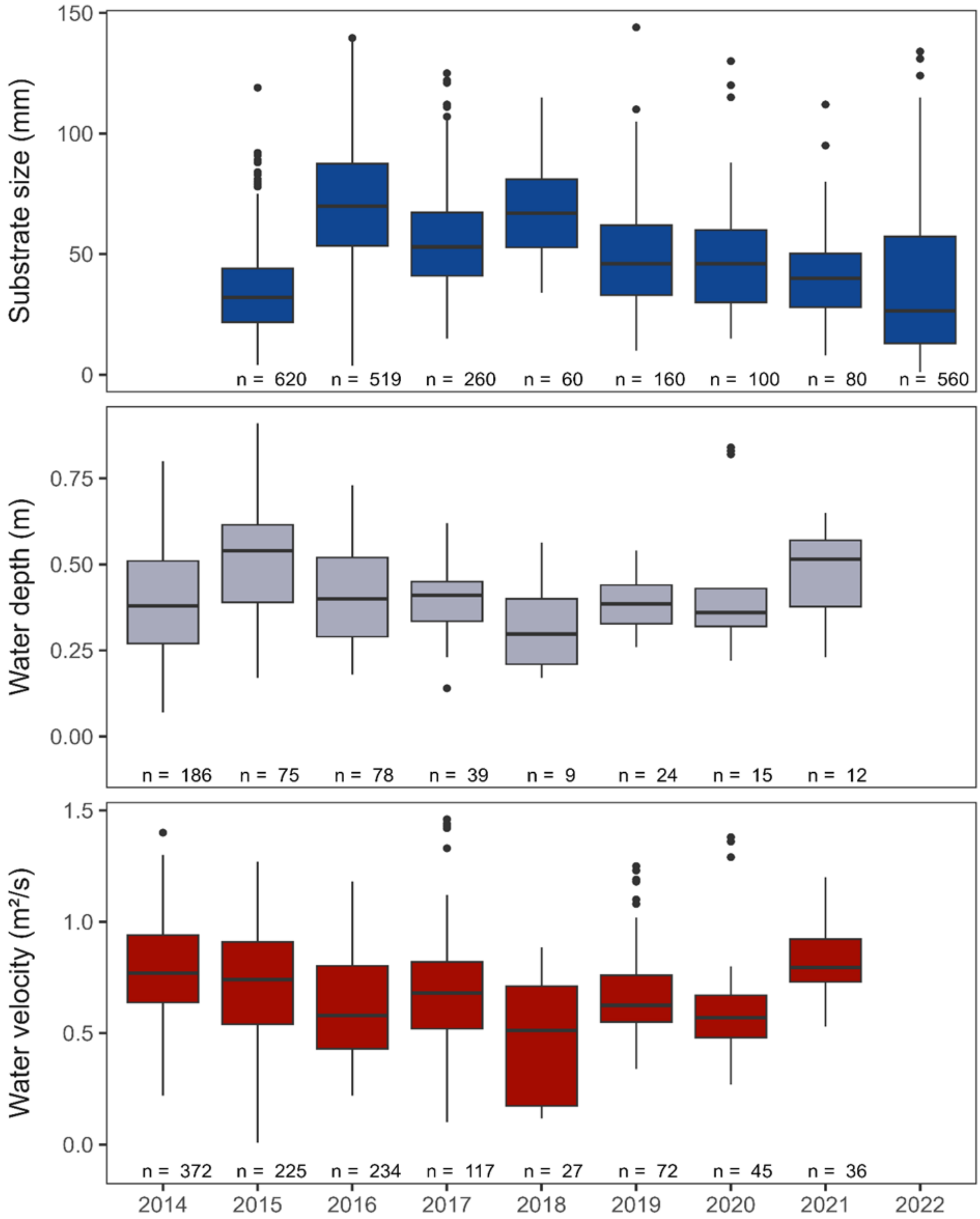

Figure 30. Water velocities (ms-1), depths (m) and substrate size (axis length; mm) measured at Chinook Salmon redds in the LBR. Solid lines denote the annual median water depth, boxes represent the interquartile range (IQR). Lines represent the range excluding outliers, which are shown as points. Substrate surveys were not conducted in 2014 and water velocity and depth could not be collected in 2022.

Coho Salmon

In 2022, 25 Coho Salmon redds were observed, 23 in Reach 4, and 2 in Reach 3 (Figure 31; Appendix 10). Of the 25 redds, 15 were in glide habitat, which is consistent with observations since 2018, while 10 redds were in riffle habitat. Water depths, velocities, and substrate sizes at redd locations were variable between years and were consistent with ranges considered suitable for spawning Coho Salmon – greater than 0.18 m deep and between 0.3 – 0.91 ms^{-1} for water depth and velocity, respectively and between 13 – 102 mm for substrate (Levy and Staney 1993, Reisner and Bjornn 1979; Figure 32). Smaller substrate sizes were observed at redd locations than the overall mean calculated from transect data (33 mm ± 19.2 at redds compared to 72.5 mm ± 58.4 at transects). Data on the distribution of Coho redds is limited to only five years of data following the MOD flows; however, from 2018 to 2021 (Appendix 10).

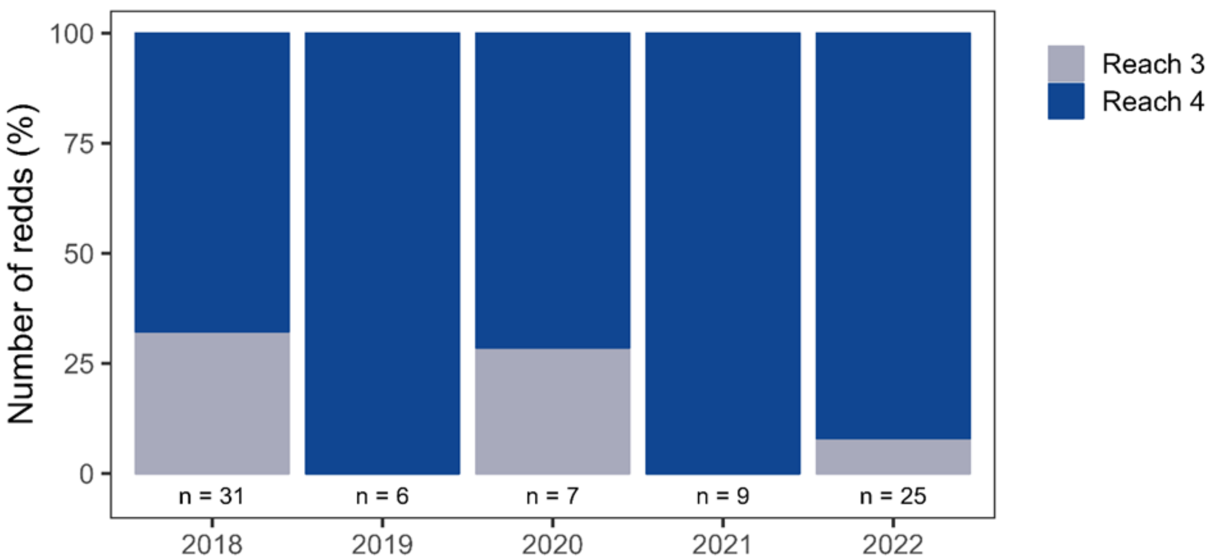

Figure 31. Proportion of Coho Salmon redds observed in Reach 3 and 4 of the LBR.

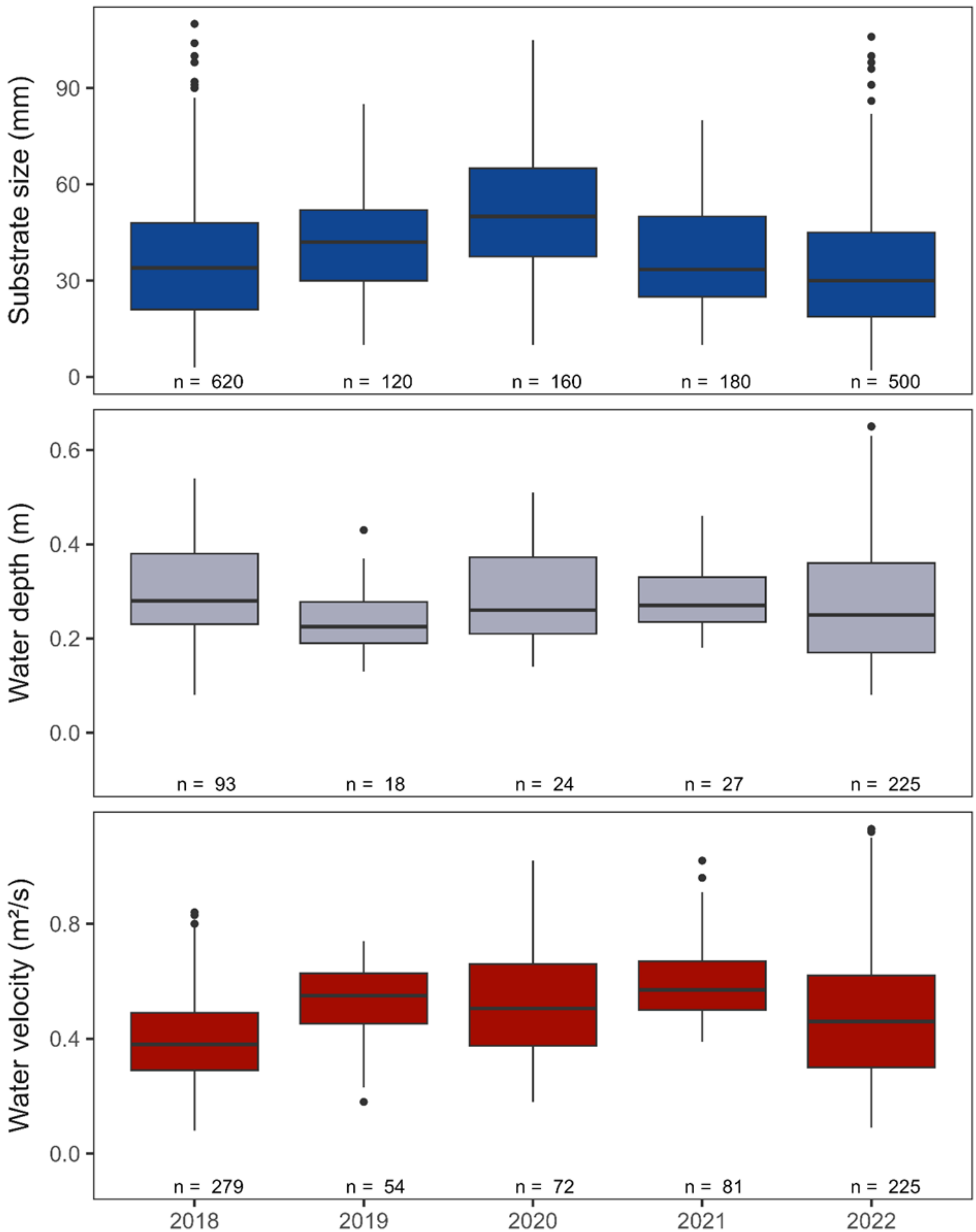

Figure 32. Water velocities (ms-1), depths (m) and substrate (mm) measured at Coho Salmon redds in the Lower Bridge River. Solid lines denote the annual median water depth, boxes represent the interquartile range (IQR). Lines represent the range excluding outlier, which are shown as points.

3.6 Ageing of Adult Salmon and Steelhead Trout

3.6.1 Steelhead Trout

In 2022 only four scales were aged from Steelhead Trout, which were assumed to have spawned in the LBR in 2022. Since 2014, 74 Steelhead Trout scales have been aged. Age 4 (2.2) fish were the dominant age class for 2022 (n = 3). Since 2020, age 4 (2.2) has been the most dominant age class of sampled Steelhead. This is a shift from previous years where age 5 and 6 were the most common for sampled Steelhead. Importantly however, very few Steelhead have been sampled each year, which limits our ability to draw conclusions on trends. 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 33; Appendix 11). In 2022, both age cohorts (2.2 and 2.3) would have experienced high flows as juveniles.

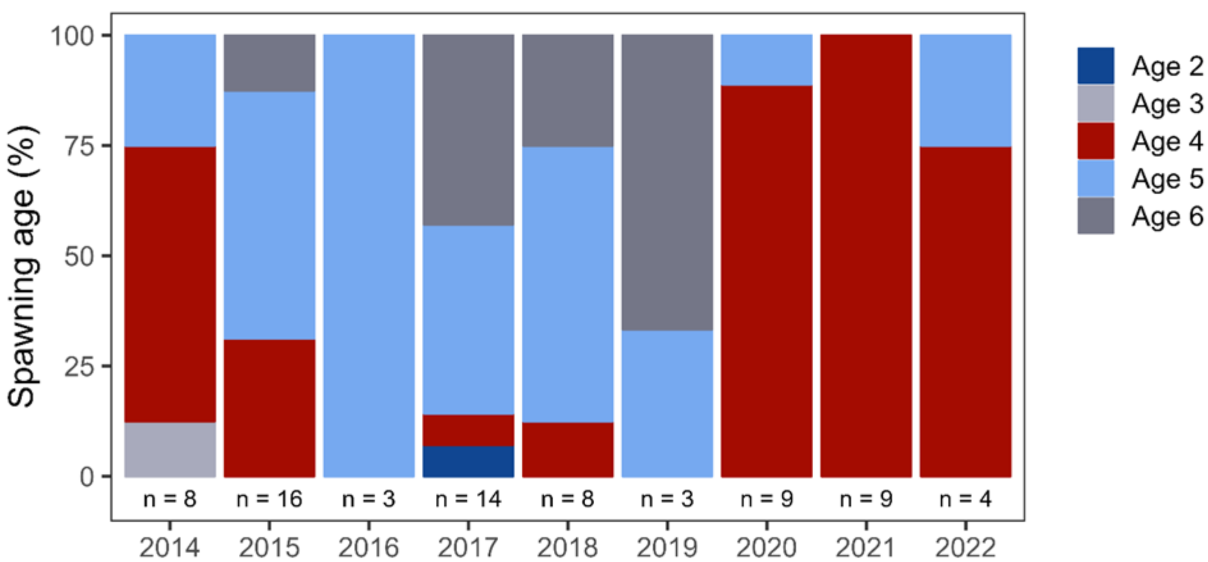

Figure 33. Relative proportion of Steelhead total age classes by year from 2013 to 2022.

3.6.2 Chinook Salmon

In 2022, 26 Chinook Salmon scales were assessed; 24 were age 4 (1.3) and two were age 3 (1.2). Since 2013, 83 Chinook Salmon scales have been aged and most Chinook have been age 4 with a few age 3 (1.2) individuals (Figure 34; Appendix 11). The one exception is the scale sample from 2021, which could have potentially been a stray from another river system. All scales, except in 2021, display a yearling (stream-type) life history, with juveniles spending one winter in freshwater. Age 4 (1.3) Chinook Salmon returning in 2022 would have experienced MOD flows in the LBR the spring they emerged (2018), but would not have experienced MOD flows as smolts the following year.

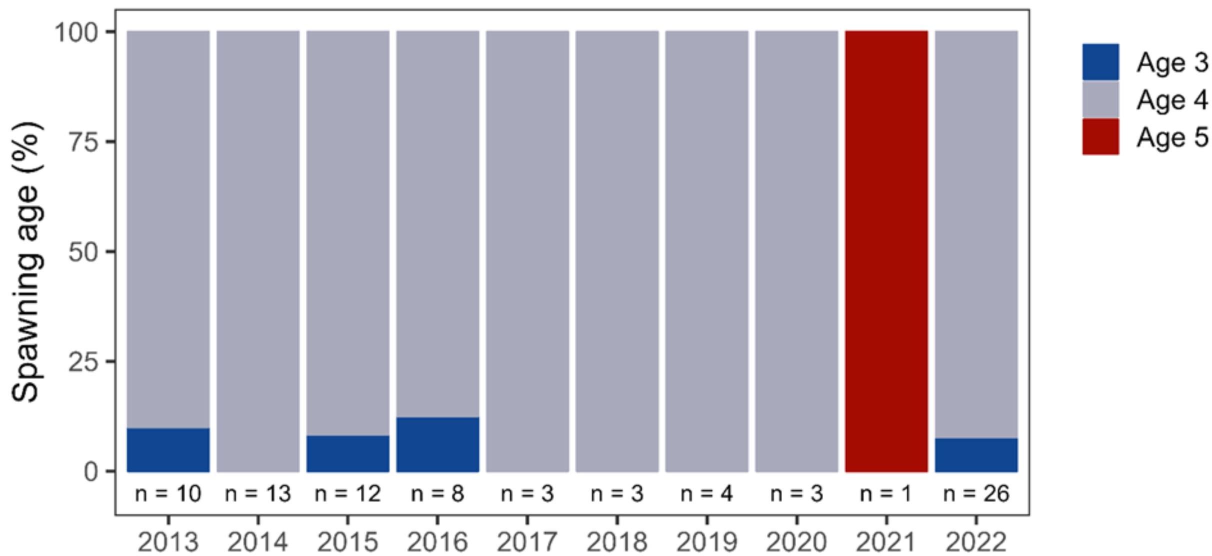

Figure 34. Relative proportion of Chinook Salmon total age classes by year from 2013 to 2022.

3.6.3 Coho Salmon

All nine scales from Coho Salmon in 2022 were aged as two-year-old (1.1). Since 2011, 181 Coho Salmon scales have been aged. LBR Coho Salmon returned most frequently at age 2 (1.1) followed by age 3 (2.1; Figure 35; Appendix 11). All scales displayed similar juvenile life histories, with juveniles spending 1-2 years in freshwater before out-migrating as smolts. All age 2 (1.1) Coho Salmon returning in 2022 would have experienced high flows in the LBR as smolts.

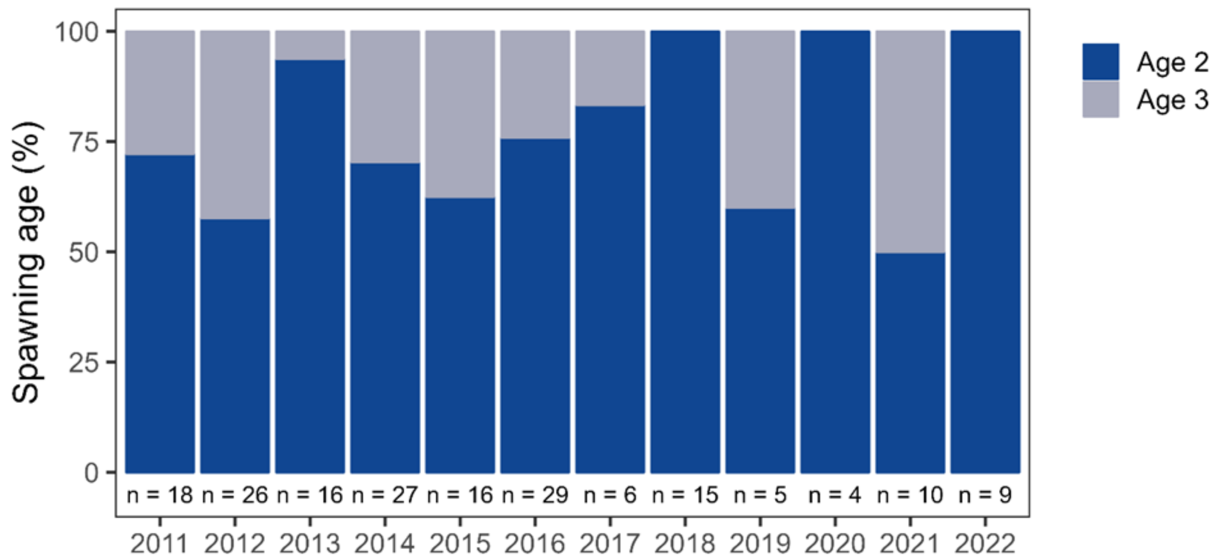

Figure 35. Relative proportion of Coho Salmon age classes by year from 2011 to 2022.

4. Discussion

BRGMON-3 monitors adult salmon and Steelhead Trout abundance and habitat quantity and quality. Adult salmonid population estimates from this monitoring program are used to inform BRGMON-1, which evaluates the effects of LBR flow regime on salmonid productivity. The BRGMON-3 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 2022 builds upon data from 2012 to 2022 and will be used to answer 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, 2021, and 2022 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 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 BRGMON-3 (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). In 2022, the complete estimate of Steelhead Trout abundance was 38, which is the third lowest estimate since monitoring began and it was also one of the only years, in which a full estimate was obtained (2018, n = 14, incomplete estimate; 2017, n = 26, incomplete estimate). The Steelhead abundance estimate in 2022 was less than the overall monitor mean (67 ± 66). The Chinook Salmon electronic counter abundance in 2022 was 531 (monitor mean = 321 ± 276), which is more than five times the abundance estimates in 2021 (n = 97) and 2020 (n = 98) and the highest since 2014 (n = 947). Similarly, Coho Salmon electronic counter abundance in 2022 (n = 936) was larger than in recent years (2021 = 561, 2020 = 539) and the mean recorded over the monitor (757 ± 380).

Due to migration timing, Steelhead Trout are the only adult salmonid that have the potential to experience MOD flows in the LBR. However, depending on the year, eggs and juveniles of all salmonids may be exposed and negatively affected to high flows in the lower Bridge River (Gendaszek et al. 2018).

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, increased straying due to the Fraser River rockslide, high flow events during Steelhead migration, poor visibility during streamwalks, and for Chinook specifically, the installation of the broodstock fence) and uncertain conditions affecting salmonids outside of the LBR (e.g., ocean conditions, rising 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 modelling 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 that the two techniques are rarely congruent. Chinook AUC estimates have often been lower than the counter estimate. The 2022 Chinook Salmon counter estimate (n = 531) was larger than the AUC estimate (n = 310). Comparisons for Coho Salmon have also been variable, with the 2022 AUC estimate (n = 836) being low compared to the counter estimate (n = 931). 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. Chinook estimates are complicated further by the broodstock fence, which has operated since 2018.

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 six years for Coho Salmon, and average values were used in all other years and for historic reconstruction.

Migration Timing

Peak migration timing has been relatively consistent across 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 and 2021. In 2021, Steelhead also arrived at their spawning grounds (Reach 3) earlier than in all other years. 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 14 (per historical migration timing data and current telemetry and streamwalk data), as the broodstock fence and multiple overlapping species spawning made distinguishing species challenging during early October.

Scale Ageing

Ageing analyses show that age 4 (1.3) Chinook and age 2 (1.1) Coho Salmon spawners returning to the LBR in 2022 would have experienced high flows as parr and juveniles, respectively. Steelhead Trout have a more diverse life history, and BRGMON-3 ageing has identified six different life history types. In 2022, Age 4 (n = 3) and 5 (n = 1) Steelhead would have experienced high flows as juveniles. 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.

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. In non-Pink years, such as 2022, 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. In 2022, more Chinook Salmon were tagged (n = 30) and a larger number of redds were observed (n = 30) compared to recent years. 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, 2021, and 2022, but this trend was not observed in 2020. Chinook Salmon redds were observed in Reach 2 in 2021, which is the first time since monitoring began. The broodstock collection program in 2018 to 2022 disrupted the natural migration of Chinook Salmon above the counter site and may have altered spawning site selection. Angling success for Coho Salmon has decreased in 2019-2022; however, telemetry data, redd surveys, and visual surveys all suggest preference towards Reach 4.

Increased spawning in Reach 4, as observed in 2018, 2019, 2021, and 2022 for Chinook Salmon, may affect juvenile survival due to variations in thermal regime (Geist et al. 2006). Water released from Terzaghi Dam is warmer than water 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 because their peak spawning occurs in early November. As a result, water temperatures are generally colder leading to fewer accumulated thermal units (ATUs), even in the typically warmer upper reaches. Consequently, even if Coho emerge early, emergence still occurs late enough in the year that sufficient food and resources are available (Ramos-Espinoza et al., 2018).

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 groundwater 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, such as: the quantity and location of riparian cover, water quality, competition, and climate change.

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 – 2022 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 and 2021-2022), overall mean particle size decreased in the LBR between 2018 and 2021 and increased in 2022 (White et al. 2021). 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 in 2022 was the highest since the first year of the survey (2014 for Chinook and 2018 for Coho). Meaningful comparison amongst recent years has been limited by small sample size.

HSI surveys indicate that the overall quantity of Coho and Chinook Salmon spawning habitat has been consistent from 2017-2019, and 2021-2022 (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, which may be related to high flows (White et al. 2021). It should be noted that the effects of only three high flow events 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. 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.

4.3 Additional Considerations

The Fraser River rockslide (2019) and a broodstock fence installed for Chinook Salmon broodstock collection (2018 - 2022) require further discussion given their potential to affect the behaviour 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. DNA samples from 2022 have not yet been analyzed, however results from the government of BC's Big Bar operation suggest that fish passage has been restored (Government of BC Ministry of Environment and Climate Change Strategy 2023). As such, we are unsure whether straying remains an issue. Straying affects our ability to compare abundance over time, as abundance estimates may 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. 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 19 and October 4, which impaired Chinook Salmon migration into 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 monitoring program. 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. As part of the 2022 Terms of Reference Amendment, BC Hydro requested to be provided with recommendations as to which research activities should continue and in what capacity moving forward with BRGMON-3. These recommendations are provided in Table 8.

Table 8 A summary of the recommendations for BRGMON-3 activities moving forward with the monitor in future years.

Activity	Recommendation	Rational
Sonar Counter	Discontinuing the use of the sonar and replace it with a resistivity counter, including the replacement of the crump lost during the first modified flow year with a concrete crump. This would require a one-time up-front cost to replace the section of aluminum crump weir with a concrete crump, which is more robust against high flows.	This would reduce analysis and operation costs. The other advantage of resistivity is that species composition can more accurately be determined, which is especially important during periods of co-migration (i.e., Pink, Sockeye and Chinook).
Resistivity Counter	Continue to operate the resistivity counter for species enumeration. See above for recommendation.	See above for rationale.
Chinook & Coho Radio Telemetry	Discontinue radio telemetry and replace it with an HDX PIT system with antenna at Counter (Reach 3) and at the Reach 3-4 break.	By changing to this method, we will continue to assess the spawner distribution between Reach 3 and 4 that is potentially shifting for Chinook. PIT system will cost less for tags and we can apply more PIT tags on Chinook through the broodstock collection program thus increasing our confidence in distribution data between Reach 3 and 4. In addition to distribution, radio telemetry was used to collect data for Observer efficiency and Residence Time to increase confidence in streamwalk counts, but we have determined that AUC estimates will never achieve the accuracy of electronic counters. In addition, the intent of back casting OE and RT data on historic counts prior to WUP monitoring has proved unreliable due to different methods utilized and environmental and stream conditions during the pre-2011 stream walk work.
Chinook & Coho Streamwalks	Reduce frequency of streamwalks.	Electronic Counter provides a more accurate estimate of run timing and abundance, and HDX PIT will provide distribution data to determine if distribution is shifting between Reach 3 and 4. Streamwalks will continue to provide detailed in reach distribution.

Activity	Recommendation	Rational
Chinook and Coho Redd Survey	Reduce the number of redds surveyed for detailed habitat measurements but continue to count and map redd locations for distribution.	Redd characteristics have been consistent over the course of the monitor and so detailed habitat surveys can be decreased. However, enumerating redds and determining their distribution remain priorities as counts inform BRGMON-1 and redd locations have not been consistent between years.
IFIM Surveys in Reach 1-4	Continue IFIM work in years when modified operations occur to monitor potential shifts in habitat and substrate changes.	We have not determined the effects of high flow on habitat and substrate and as such these surveys should continue.
Steelhead Telemetry	Continue to radio tag Steelhead adults and begin to apply HDX PIT tags as well.	HDX PIT may lose its accuracy at higher flows experienced during the kelt migration. Radio tagging should continue in conjunction with PIT tagging to establish whether it is effective at high flows.
Scale Analysis	Continue to take scale samples opportunistically through tagging and broodstock efforts, expand budget to age additional samples from broodstock program.	Expanding the scale analysis to include broodstock will allow us to develop a strong age-length relationship for Chinook. Scale ageing could be reduced once that was developed.

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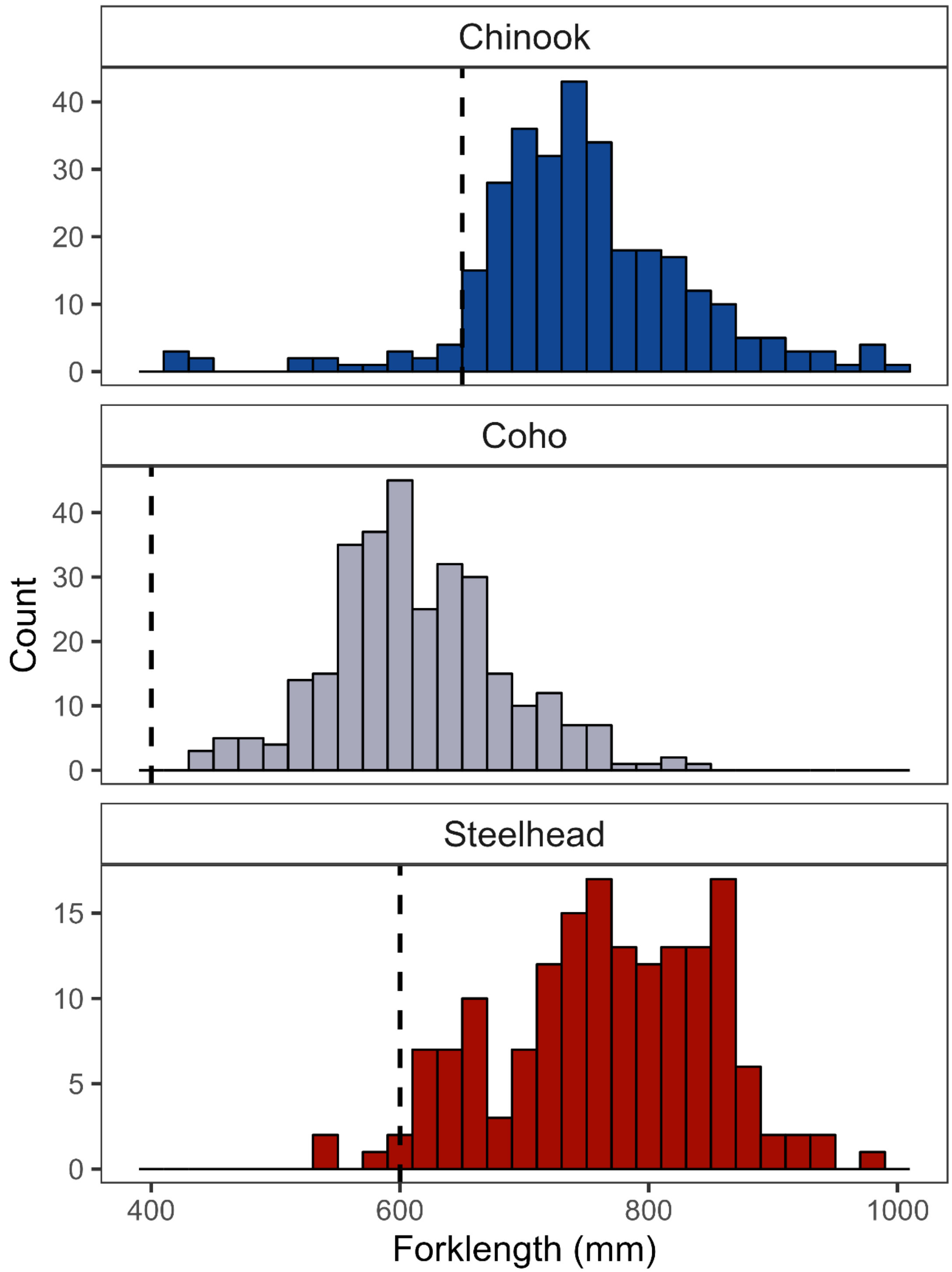
Appendix 1: Length-frequency Distribution

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

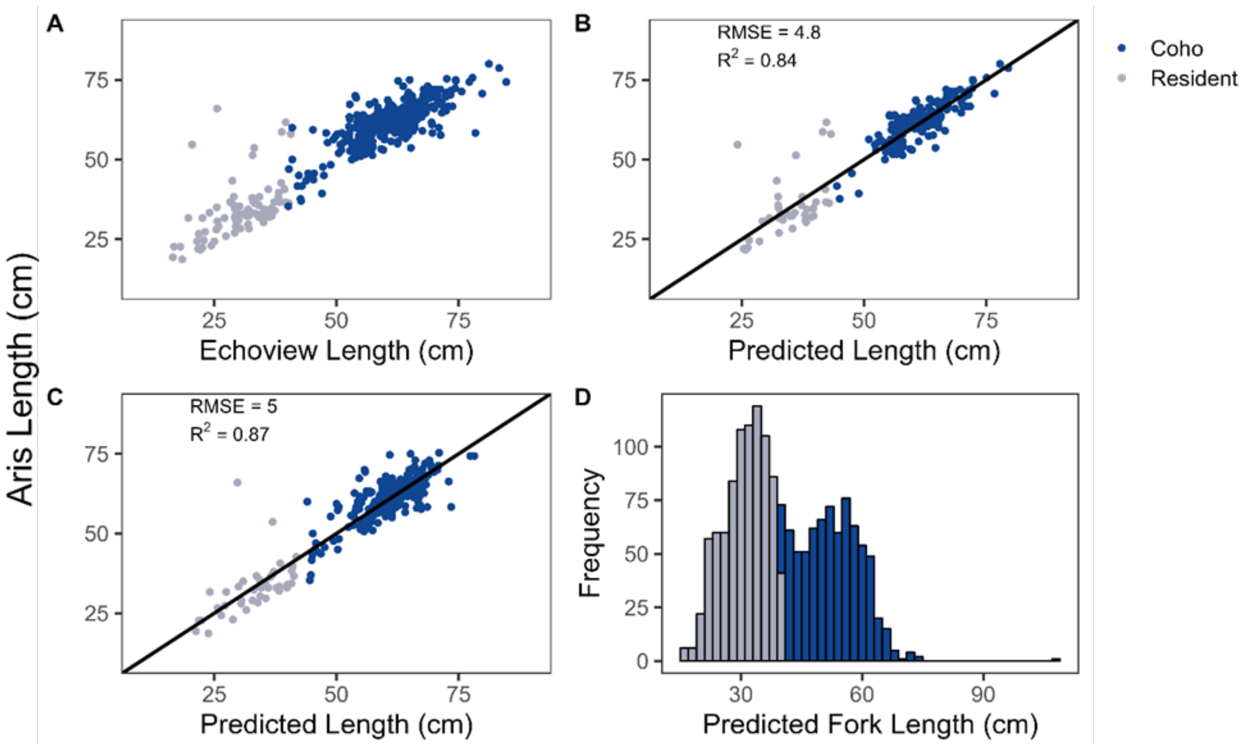
Chinook Salmon AUC abundance estimates with standard error (SE) and upper and lower confidence intervals (CI) for the Lower Bridge River from 1993-2022. Abundance results are calculated considering estimates of observer efficiency (OE) and residences times (survey life; SL).

Year	OE	OE SE	SL	SL SE	Escapement	Escapement SE	Method	Lower 95CI	Upper 95CI
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	1909	1238	visual survey	535	6803
1998	0.5	0.139	10.5	0.65	873	254	visual survey	494	1542
1999	0.5	0.139	10.5	0.65	2576	847	visual survey	1352	4905
2001	0.5	0.139	10.5	0.65	1784	981	visual survey	607	5243
2004	0.5	0.139	10.5	0.65	3106	1139	visual survey	1513	6374
2005	0.5	0.139	10.5	0.65	591	213	visual survey	291	1195
2006	0.5	0.139	10.5	0.65	399	124	visual survey	217	732
2007	0.5	0.139	10.5	0.65	309	108	visual survey	155	612
2008	0.5	0.139	10.5	0.65	164	94	visual survey	53	506
2009	0.5	0.139	10.5	0.65	21	7	visual survey	10	40
2010	0.5	0.139	10.5	0.65	208	67	visual survey	110	391
2011	0.5	0.139	10.5	0.65	82	33	visual survey	37	178
2012	0.58	0.139	10	0.65	363	110	visual survey	200	657
2013	0.28	0.139	11	0.65	168	90	visual survey	58	478
2014	0.28	0.139	12	0.65	591	311	visual survey	210	1656
2015	0.5	0.139	10.5	0.65	158	68	visual survey	67	369
2016	0.5	0.139	10.5	0.65	265	87	visual survey	139	503
2017	0.5	0.139	10.5	0.65	120	42	visual survey	60	239
2018	0.5	0.139	10.5	0.65	25	7	visual survey	13	43
2019	0.5	0.139	10.5	0.65	161	53	visual survey	84	307
2020	0.5	0.139	10.5	0.65	16	8	visual survey	6	41
2021	0.5	0.139	10.5	0.65	165	50	visual survey	90	299
2022	0.5	0.139	10.5	0.65	225	70	visual survey	122	414

Coho Salmon AUC abundance estimates with standard error (SE) and upper and lower confidence intervals (CI) for the Lower Bridge River from 1993-2022. Abundance results are calculated considering estimates of observer efficiency (OE) and residences time (survey life; SL).

Year	OE	OE SE	SL	SL SE	Escapement	Escapement SE	Method	Lower 95CI	Upper 95CI
1997	0.208	0.017	19.6	1.29	415	47	visual survey	331	519
1998	0.208	0.017	19.6	1.29	1121	415	visual survey	542	2316
1999	0.208	0.017	19.6	1.29	84	NA	visual survey	NA	NA
2001	0.208	0.017	19.6	1.29	1074	137	visual survey	836	1377
2003	0.208	0.017	19.6	1.29	1265	136	visual survey	1024	1561
2004	0.208	0.017	19.6	1.29	242	52	visual survey	159	369
2005	0.208	0.017	19.6	1.29	768	127	visual survey	555	1061
2006	0.208	0.017	19.6	1.29	701	113	visual survey	510	962
2008	0.208	0.017	19.6	1.29	106	17	visual survey	78	143
2009	0.208	0.017	19.6	1.29	1664	248	visual survey	1243	2228
2010	0.208	0.017	19.6	1.29	482	84	visual survey	342	676
2011	0.208	0.017	19.6	1.29	3822	654	visual survey	2733	5345
2012	0.25	0.017	16	1.29	1662	383	visual survey	1058	2609
2013	0.27	0.017	19	1.29	3001	331	visual survey	2416	3726
2014	0.208	0.017	19.6	1.29	440	76	visual survey	314	617
2015	0.208	0.017	19.6	1.29	180	23	visual survey	140	231
2016	0.208	0.017	19.6	1.29	507	70	visual survey	386	664
2017	0.19	0.017	23	1.29	451	63	visual survey	342	593
2018	0.208	0.017	19.6	1.29	1294	173	visual survey	995	1681
2019	0.208	0.017	19.6	1.29	225	36	visual survey	163	308
2020	0.208	0.017	19.6	1.29	558	125	visual survey	359	865
2021	0.208	0.017	19.6	1.29	844	200	visual survey	530	1342
2022	0.208	0.017	19.6	1.29	839	109	visual survey	650	1080

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 and blue correspond to resident fish and 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*
0.617		0.850		0.843	3	0
0.585	0.007	0.853		0.843	4	1.603
0.617		0.850	0	0.843	4	2.077
0.584	0.008	0.854	-0.005	0.843	5	3.629

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*
0.708	0.037	0.813	-0.030	0.868	5	0
0.679	0.030	0.816		0.866	4	1.195
0.754		0.818		0.861	3	8.895
0.768		0.817	-0.009	0.861	4	10.627

Appendix 4: Radio Tagging

Tagging information and spawning distribution of radio-tagged Steelhead Trout in the Lower Bridge River in 2022, including calculated residence time in specific reaches. All fish were tagged at the Seton-Fraser confluence.

Tag Number	Sex	Fork Length (mm)	Tagging Date	Entry Date to LBR	End Date	Assumed Spawning Reach	Reach 2 Residence	Reach 3 Residence
51	F	655	26-Feb	7-Apr	N/A	4	3	8
52	F	800	27-Feb	6-Apr	N/A	2	37	N/A
53	F	990	19-Mar	26-Apr*	N/A	4	7**	N/A
54	F	643	23-Mar	26-Apr*	N/A	4	7**	N/A
55	F	670	27-Mar	N/A	N/A	N/A	N/A	N/A
56	F	575	01-Apr	N/A	N/A	N/A	N/A	N/A
57	F	635	07-Apr	N/A	N/A	N/A	N/A	N/A

***Individual missed at Reach 1 station.**

***Individual missed at Reach 3 station, there was 7 days between detections at Reach 2 and 4.**

Tagging information and spawning distribution of radio-tagged Chinook Salmon in the Lower Bridge River in 2022, including capture location and residence time in Reach 3 and 4.

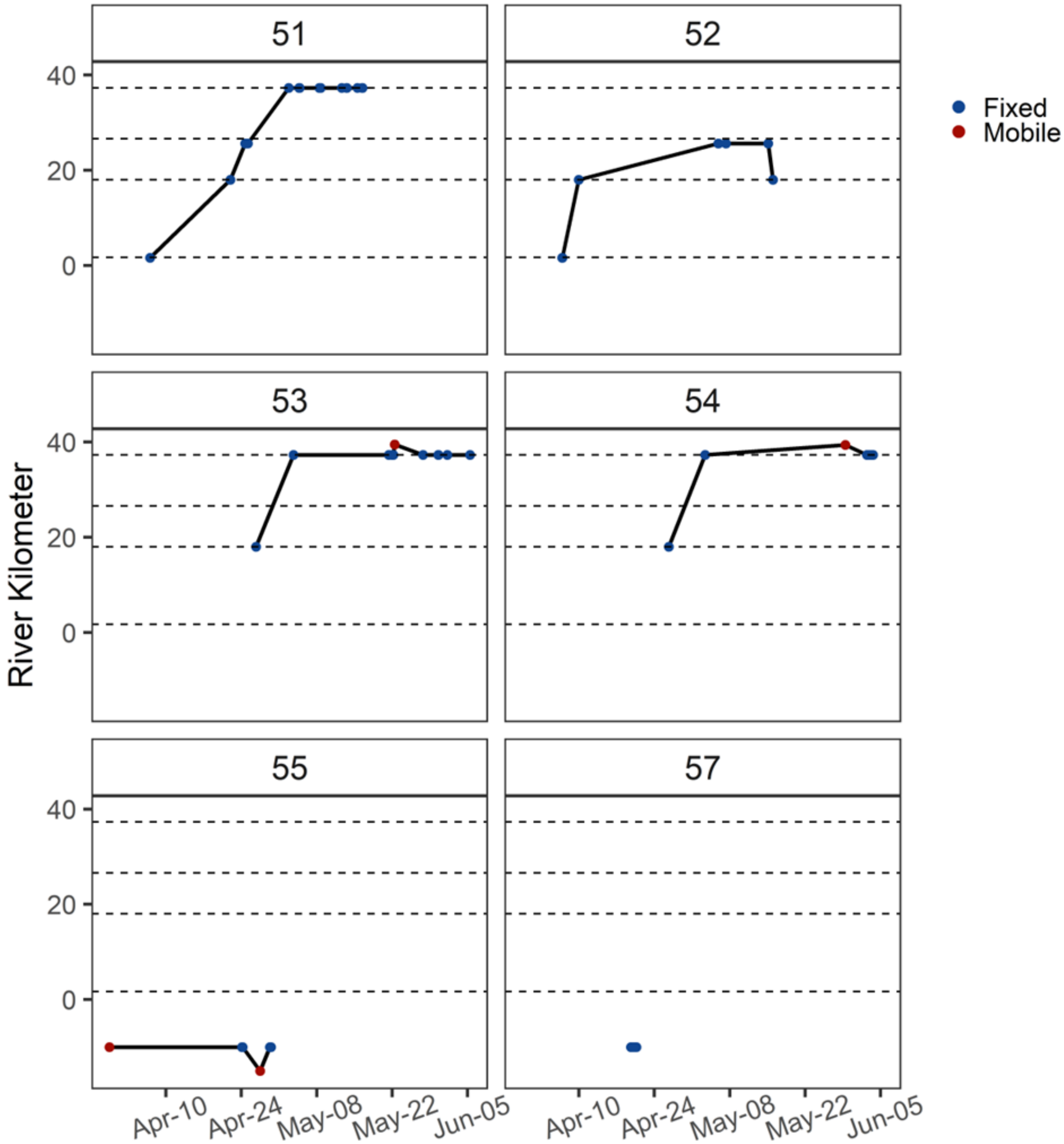
Code	Sex	Fork Length (mm)	Date	Tagging Location	End Date	Assumed Spawning Reach	Assumed Spawning Section	Reach 3 and 4 Residence Time (Days)
60	F	820	12-Aug	Yalakom	N/A	N/A	N/A	N/A
61	F	903	13-Aug	Yalakom Con	19-Sept	2	Below fence	N/A
62	F	595	13-Aug	Yalakom Con	N/A	2	N/A	N/A
63	M	775	15-Aug	Yalakom Con	19-Sept	4	Long skinny	35
64	F	757	15-Aug	Yalakom Con	7-Oct	2	Below fence	N/A
65	M	757	15-Aug	Yalakom Con	N/A	2	Below fence	N/A
66	F	725	15-Aug	Yalakom Con	N/A	3	Below Russel	N/A
67	M	712	15-Aug	Yalakom Con	N/A	N/A	N/A	N/A

Code	Sex	Fork Length (mm)	Date	Tagging Location	End Date	Assumed Spawning Reach	Assumed Spawning Section	Reach 3 and 4 Residence Time (Days)
68	F	777	15-Aug	Yalakom Con	N/A	2	Below fence	N/A
69	M	835	16-Aug	Yalakom Con	N/A	3	Hell Creek	N/A
70	F	710	16-Aug	Yalakom Con	N/A	2	Below fence	N/A
71	M	825	16-Aug	Yalakom Con	3-Oct	3	Yankee Creek	48
72	F	819	16-Aug	Yalakom Con	19-Sept	2	Below fence	N/A
73	M	790	17-Aug	Yalakom	N/A	2	Below fence	N/A
74	F	812	17-Aug	Yalakom	N/A	2	Below fence	N/A
75	F	820	18-Aug	Hippie pool	N/A	3	Below Russel	N/A
76	M	834	18-Aug	Yalakom	N/A	3	Long skinny	N/A
77	F	725	18-Aug	Yalakom Con	23-Sept	2	Below fence	N/A
78	F	765	20-Aug	Horseshoe	N/A	N/A	N/A	N/A
79	M	738	20-Aug	Horseshoe	23-Sept	2	Below fence	N/A
80	F	812	20-Aug	Horseshoe	7-Oct	2	Below fence	N/A
81	M	662	20-Aug	Horseshoe	N/A	2	Below fence	N/A
82	M	727	25-Aug	Yalakom Con	23-Sept	2	Below fence	N/A
84	M	874	25-Aug	Yalakom Con	N/A	N/A	N/A	N/A
85	F	747	28-Aug	Yalakom Con	N/A	2	Below fence	N/A
83	M	720	28-Aug	Yalakom Con	N/A	2	Below fence	N/A
86	M	680	28-Aug	Yalakom Con	N/A	2	Below fence	N/A
87	M	990	28-Aug	Yalakom Con	N/A	2	Below fence	N/A
88	F	756	29-Aug	Yalakom Con	N/A	2	Below fence	N/A
89	F	769	29-Aug	Yalakom Con	N/A	2	Below fence	N/A

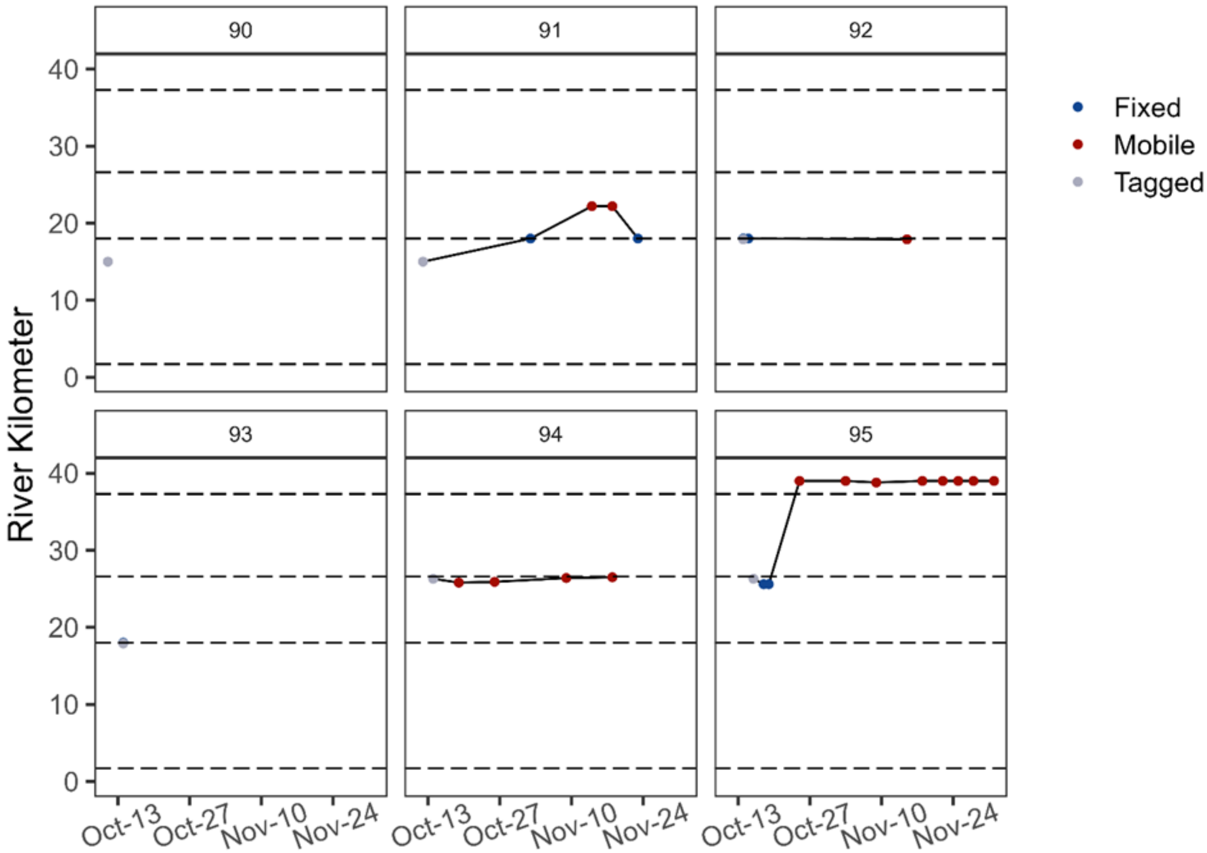
Tagging information and spawning distribution of radio-tagged Coho Salmon in the Lower Bridge River in 2021, including capture and estimated spawning location and residence time in Reach 3.

Code	Sex	Fork Length (mm)	Date	Tagging Location	End Date	Assumed Spawning Reach	Assumed Spawning Section	Reach 3 and 4 Residence Time (days)
90	M	605	11-Oct	Eagle Canyon	N/A	N/A	N/A	N/A
91	M	715	12-Oct	Eagle Canyon	22-Nov	3	Horseshoe Bend	41
92	M	563	14-Oct	Camoo	18-Nov	2	Camoo	N/A
93	M	648	14-Oct	Camoo	15-Nov	N/A	N/A	N/A
94	M	762	14-Oct	Hippie pool	25-Oct	2	Hippie Pool - Counter	N/A
95	F	568	16-Oct	Hippie pool	14-Nov	4	Eagle	28
96	F	578	18-Oct	Camoo	15-Nov	N/A	N/A	N/A
98	M	765	19-Oct	Eagle Canyon	N/A	N/A	N/A	N/A
97	F	558	01-Nov	Horseshoe	N/A	N/A	N/A	N/A
99	F	465	04-Nov	Camoo	N/A	N/A	N/A	N/A

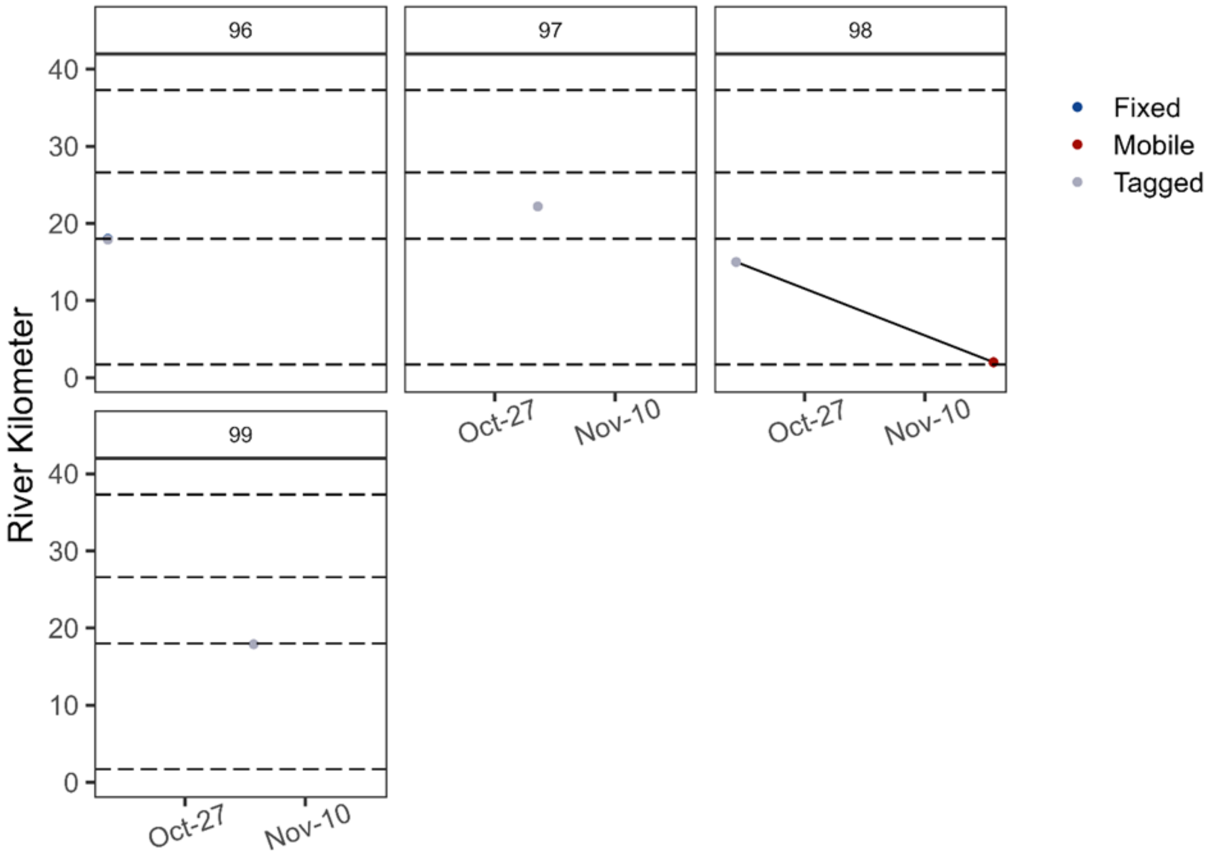
Appendix 5: Radio Telemetry Traces



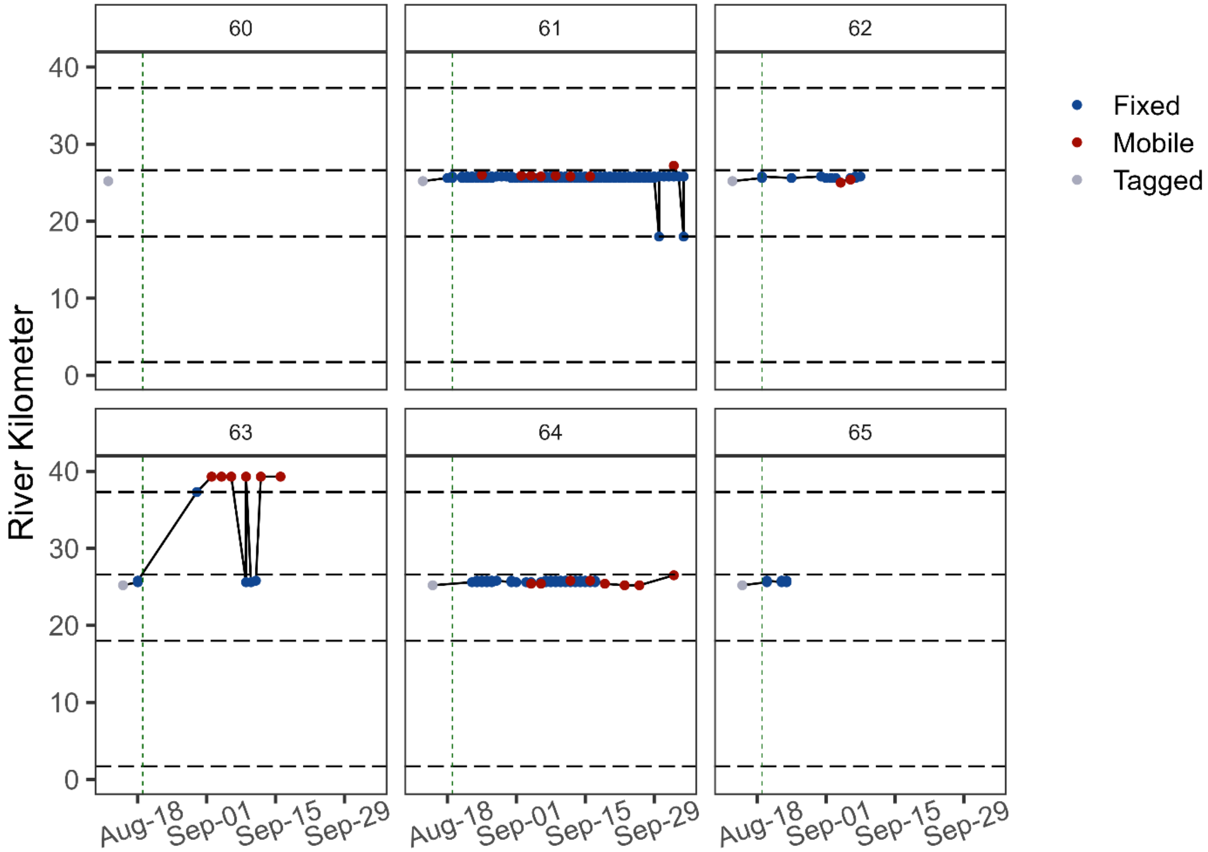
Detection histories of all radio tagged adult Steelhead Trout in the Lower Bridge River in 2022. Numbers at the top of each fish trace correspond to the Fish ID. Black lines connect the data collected from fixed (blue) and mobile (red) telemetry. Dashed lines indicate boundaries between different reaches. Observations below 0 river kms are sites located in the Seton River.



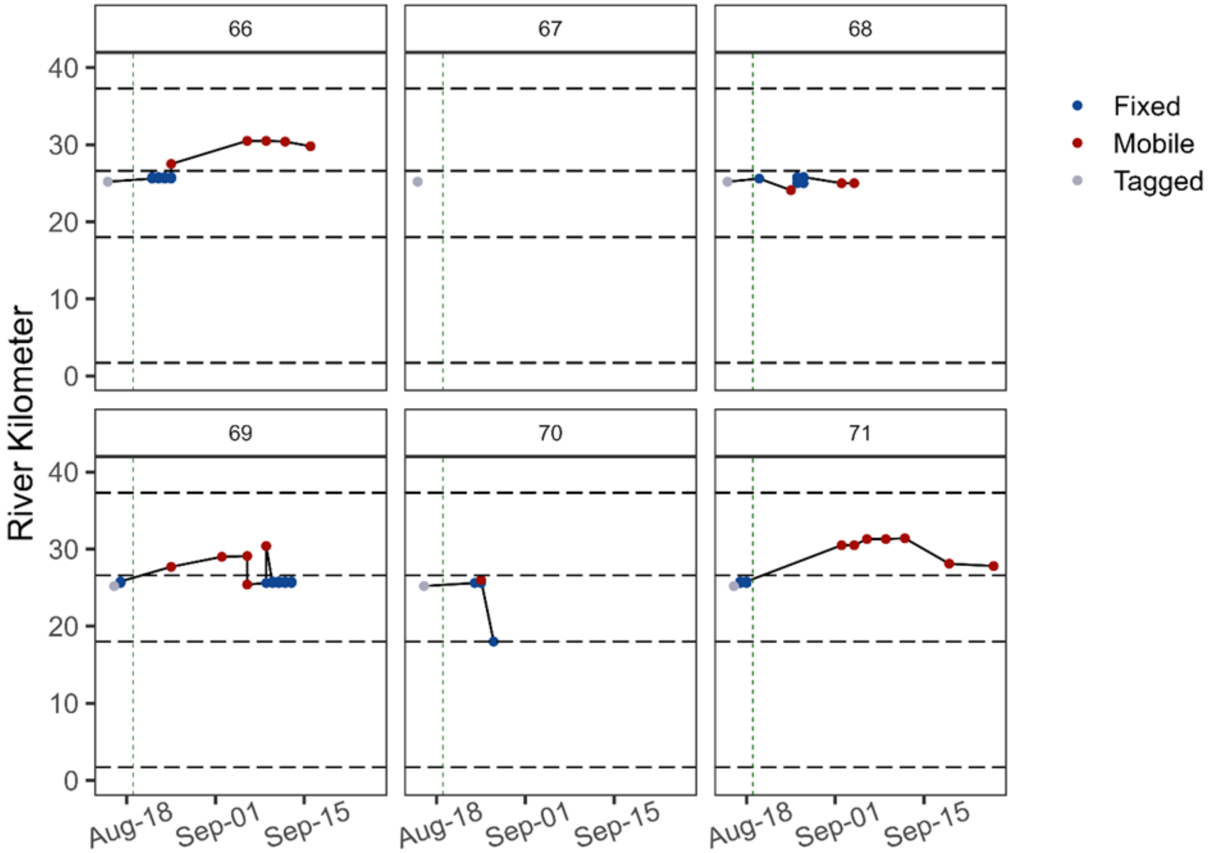
Detection histories of all radio tagged adult Coho Salmon in the Lower Bridge River in 2022. Numbers at the top of each fish trace correspond to the Fish ID. Black lines connect the data collected from fixed (blue) and mobile (red) telemetry. Dashed lines indicate boundaries between different reaches.



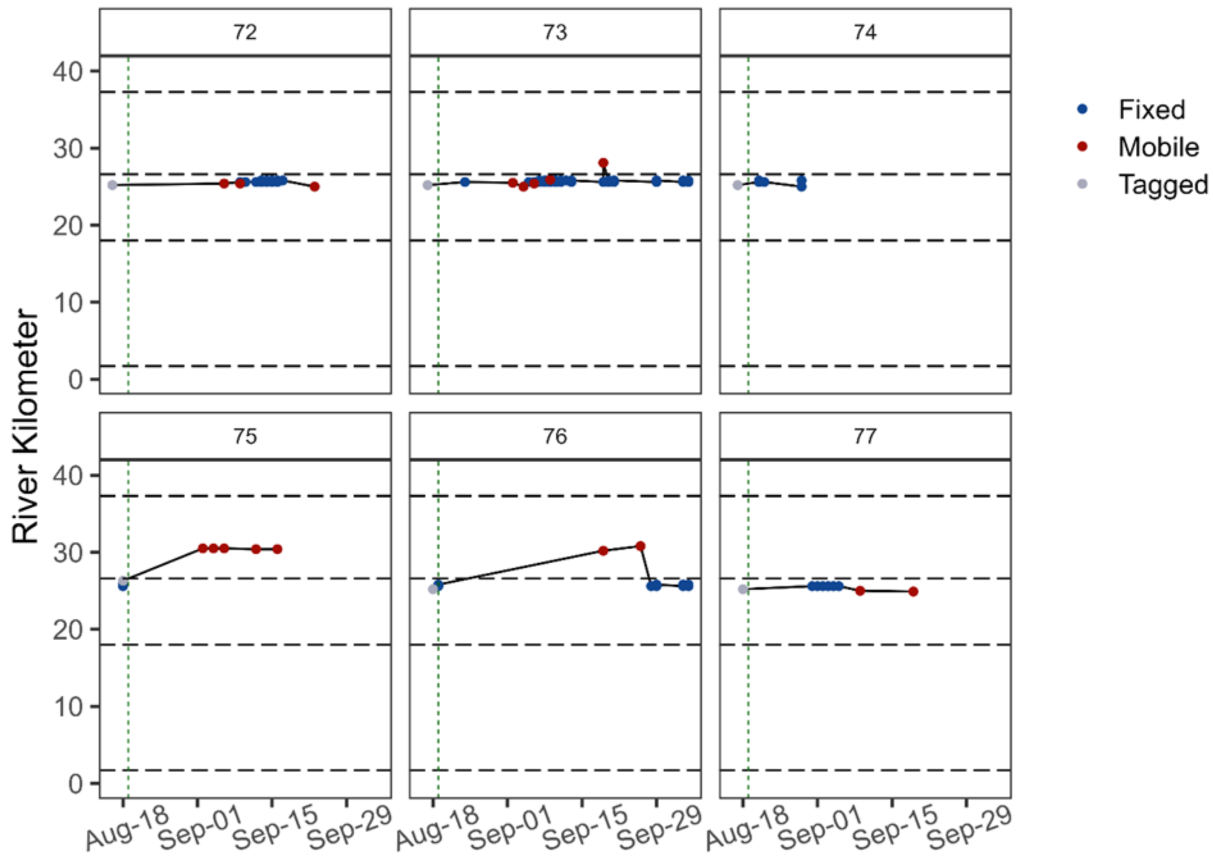
Cont'd: Detection histories of all radio tagged adult Coho Salmon in the Lower Bridge River in 2022.Numbers at the top of each fish trace correspond to the Fish ID. Black lines connect the data collected from fixed (blue) and mobile (red) telemetry. Dashed lines indicate boundaries between different reaches.



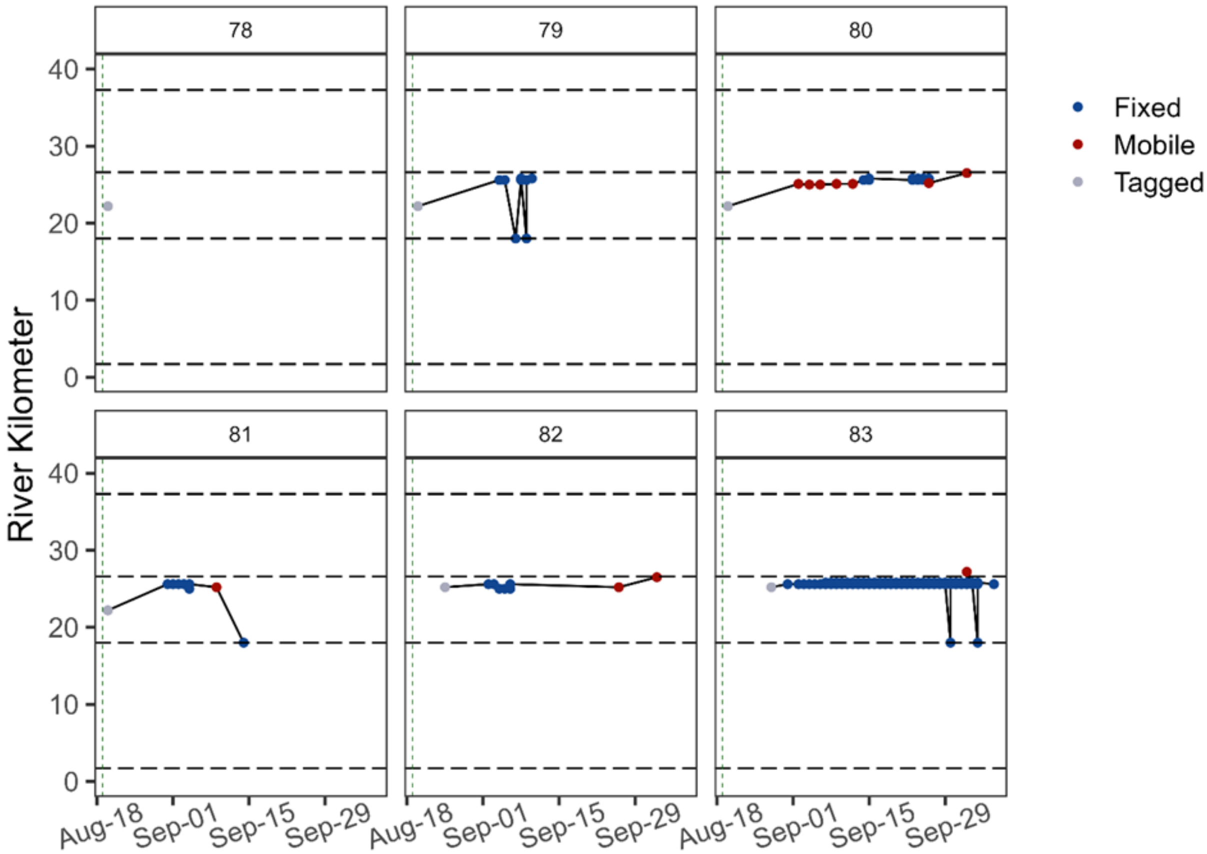
Detection histories of all radio tagged adult Chinook Salmon in the Lower Bridge River in 2022. Numbers at the top of each fish trace correspond to the Fish ID. Black lines connect the data collected from fixed (blue) and mobile (red) telemetry. Dashed lines indicate boundaries between different reaches. The vertical green line indicates the day the broodstock fence was installed.



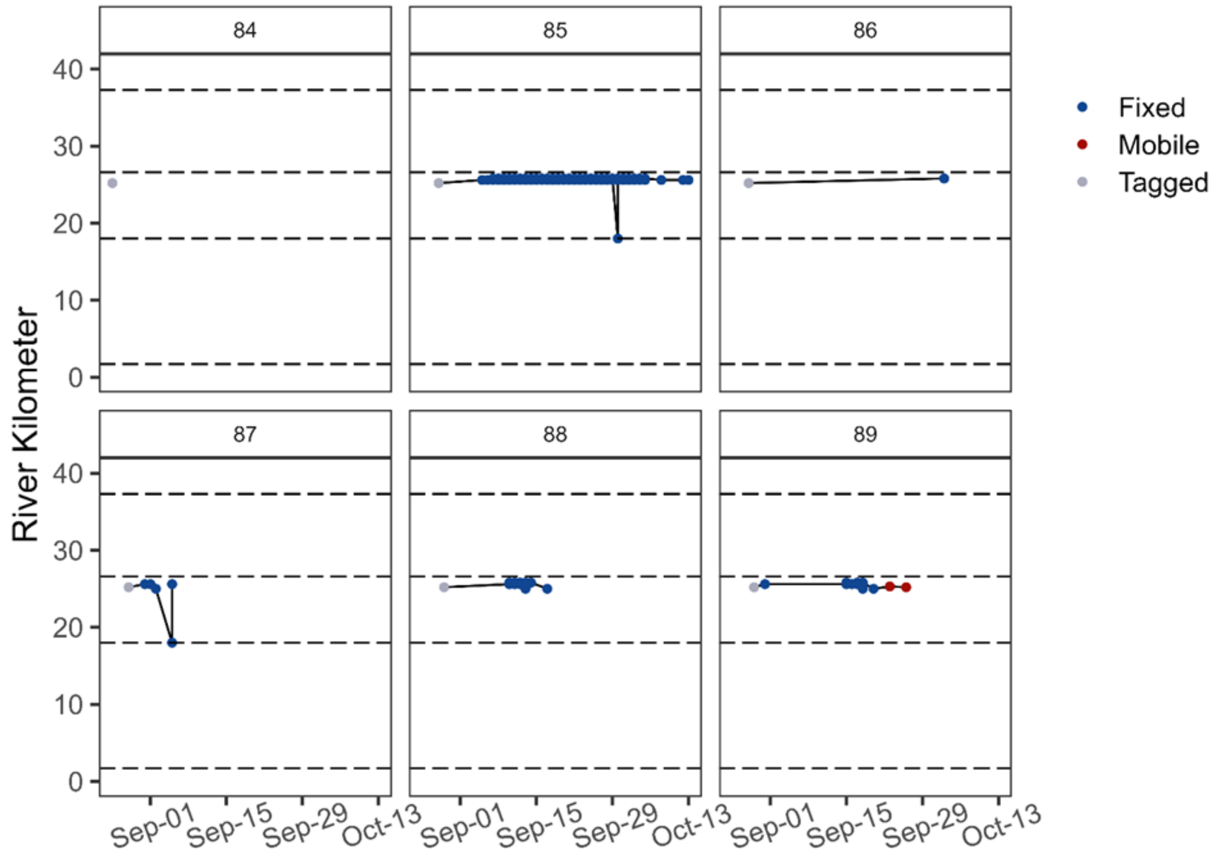
Cont'd: Detection histories of all radio tagged adult Chinook Salmon in the Lower Bridge River in 2022. Numbers at the top of each fish trace correspond to the Fish ID. Black lines connect the data collected from fixed (blue) and mobile (red) telemetry. Dashed lines indicate boundaries between different reaches. The vertical green line indicates the day the broodstock fence was installed.



Cont'd: Detection histories of all radio tagged adult Chinook Salmon in the Lower Bridge River in 2022. Numbers at the top of each fish trace correspond to the Fish ID. Black lines connect the data collected from fixed (blue) and mobile (red) telemetry. Dashed lines indicate boundaries between different reaches. The vertical green line indicates the day the broodstock fence was installed.



Cont'd: Detection histories of all radio tagged adult Chinook Salmon in the Lower Bridge River in 2022. Numbers at the top of each fish trace correspond to the Fish ID. Black lines connect the data collected from fixed (blue) and mobile (red) telemetry. Dashed lines indicate boundaries between different reaches. The vertical green line indicates the day the broodstock fence was installed.



Cont'd: Detection histories of all radio tagged adult Chinook Salmon in the Lower Bridge River in 2022. Numbers at the top of each fish trace correspond to the Fish ID. Black lines connect the data collected from fixed (blue) and mobile (red) telemetry. Dashed lines indicate boundaries between different reaches. The vertical green line indicates the day the broodstock fence was installed.

Appendix 6: Visual Survey Count

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
17-Aug	0	N/A	0	0	0	0	0	0	0	0	0	**0**
24-Aug	0.2	N/A	0	0	0	0	1	0	0	0	12	**13**
31-Aug	0	N/A	0	0	0	0	6	0	4	0	33	**43**
07-Sep	0	N/A	15	0	0	0	18	0	3	0	41	**77**
14-Sep	0.9	N/A	26	7	0	1	25	0	5	5	74	**143**
21-Sep	0	1.75m	9	13	0	1	15	0	3	0	71	**112**
28-Sep	1	1.25m	0	3	0	0	3	0	0	0	18	**24**
05-Oct	0	N/A	2	2	0	0	0	0	0	0	0	**4**
12-Oct	0.5	.20m	0	2	0	0	0	0	0	0	0	**2**
19-Oct	0.3	N/A	0	0	0	0	0	0	0	0	0	**0**

Chinook Salmon visual survey data by visual survey section in 2022.

Streamwalk			Year										
Section	**Description**	**River KM**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**Total**
1	Terzaghi Dam to Longskinny	40.0 to 39.6	11	6	8	20	9	1	31	4	25	52	**167**
2	Longskinny to Eagle	39.6 to 38.8	4	5	5	6	1	6	34	0	0	27	**88**
3	Eagle to Bluenose	38.8 to 38.2	1	0	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	2	**95**
5	Cobra to Fraser Lake	34.4 to 33.2	17	56	6	64	32	7	13	6	0	68	**269**
6	Fraser Lake to Russel Springs	33.2 to 30.7	7	14	6	14	10	5	6	0	0	0	**62**
7	Russel Springs to Hell Creek	30.7 to 28.8	17	5	8	43	21	0	1	1	17	15	**128**
8	Hell Creek to Yalakom	28.8 to 25.5	61	197	79	55	10	0	31	87	15	5	**540**
		Total	**138**	**299**	**118**	**202**	**87**	**19**	**116**	**98**	**104**	**169**	**1350**

Compiled observations of spawning distribution of Chinook Salmon across streamwalk sections in Reach 3 and 4 of the LBR from all visual surveys (2013-2022).

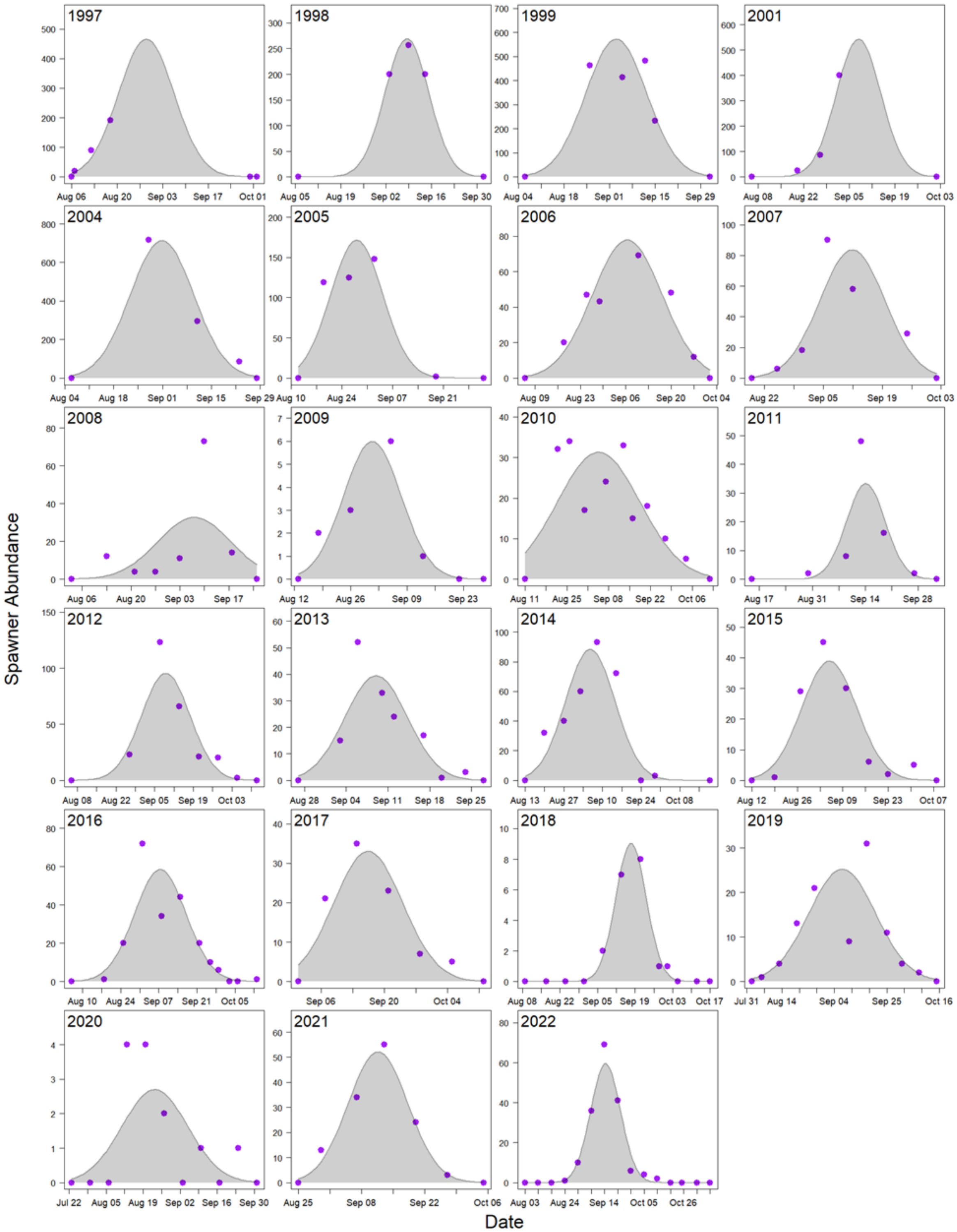
Date	Cloud Cover (%)	Water Clarity (m)	Plunge Pool to Longskinny	Longskinny to Eagle	Eagle to Bluenose	Bluenose to Cobra	Cobra to Fraser Lake	Fraser Lake to Russel Spring	Russel Spring to Hell Creek	Hell Creek to Counter	Counter to Yalakom	Live Count
05-Oct	0	N/A	0	0	0	0	0	0	0	0	0	**0**
12-Oct	0.5	.20m	0	0	0	0	0	0	0	0	0	**0**
19-Oct	0.3	N/A	0	0	0	0	0	0	0	0	0	**0**
25-Oct	0.9	N/A	8	0	0	0	9	4	0	0	0	**21**
02-Nov	0.05	N/A	37	27	0	0	5	0	0	0	0	**69**
09-Nov	0.95	1.2m	55	21	0	0	5	0	0	0	0	**81**
14-Nov	0.95	1.2m	82	46	0	0	20	0	0	0	0	**148**
19-Nov	0.9	1.2m	36	41	0	0	13	0	0	0	0	**90**
21-Nov	1	1.2m	60	23	0	0	34	0	0	3	4	**124**
25-Nov	1	2m	46	30	0	0	29	0	0	0	0	**105**
28-Nov	0.05	2m	28	24	0	0	20	0	0	0	0	**72**
02-Dec	1	1.2m	15	6	0	0	6	0	0	0	0	**27**
07-Dec	0.95	2.5m	14	4	0	0	4	0	0	0	0	**22**

Coho Salmon visual survey data by visual survey section in 2022.

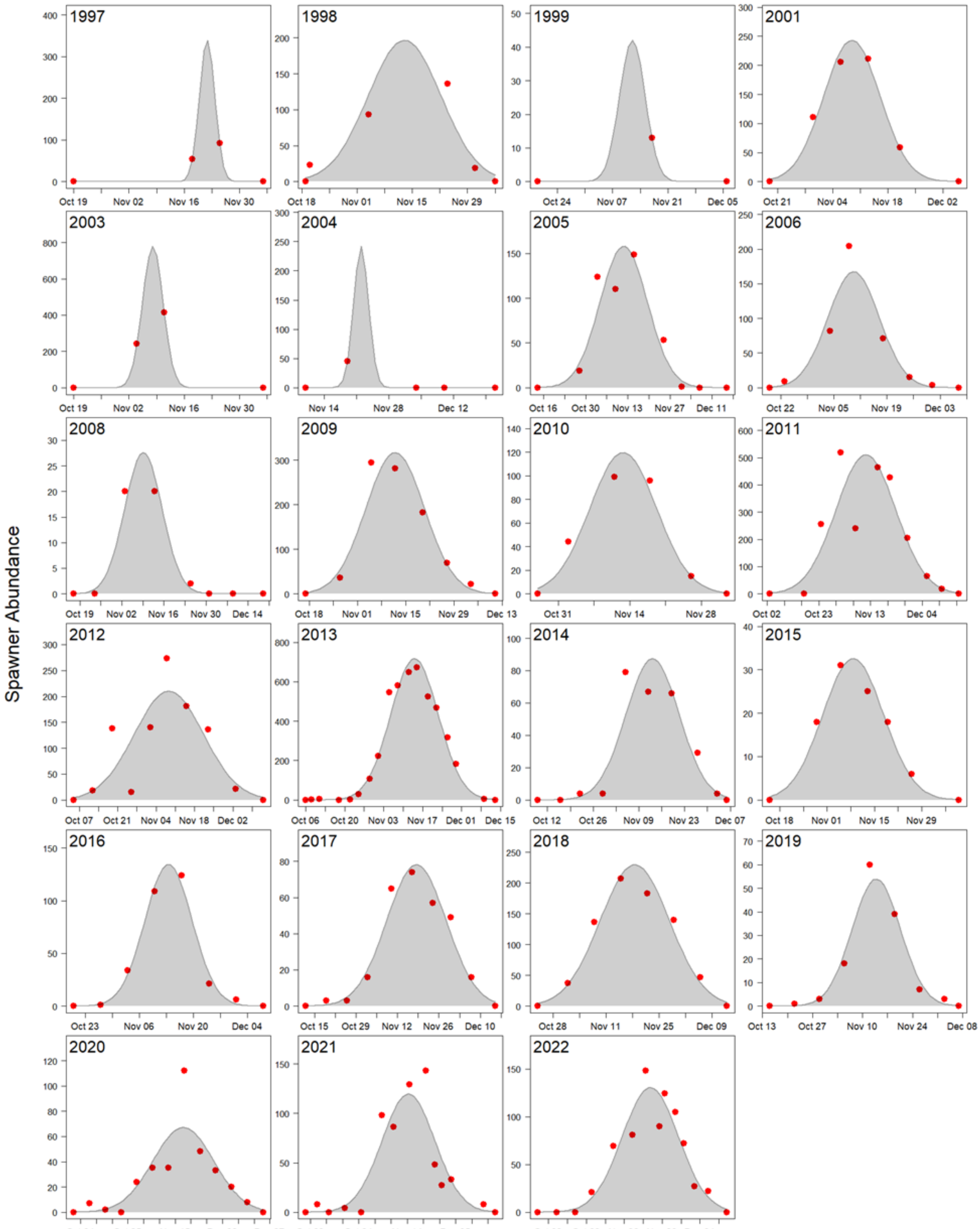
Streamwalk			Year											
Section	**Description**	**River KM**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**Total**
1	Terzaghi Dam to Longskinny	40.0 to 39.6	324	1715	104	61	139	189	348	35	152	284	381	**3732**
2	Longskinny to Eagle	39.6 to 38.8	92	1186	73	7	66	83	212	71	93	163	222	**2268**
3	Eagle to Bluenose	38.8 to 38.2	223	70	6	4	0	0	16	0	22	30	0	**371**
8574	Bluenose to Cobra	38.2 to 34.4	64	745	23	15	0	0	8	0	1	1	0	**857**
9805	Cobra to Fraser Lake	34.4 to 33.2	151	352	24	10	72	5	102	1	37	81	145	**980**
2226	Fraser Lake to Russel Springs	33.2 to 30.7	26	127	2	0	4	3	11	13	13	19	4	**222**
7	Russel Springs to Hell Creek	30.7 to 28.8	23	33	0	1	8	3	21	3	5	0	0	**97**
8	Hell Creek to Yalakom	28.8 to 25.5	19	177	21	0	6	0	32	8	1	6	3	**273**
		Total	**922**	**4405**	**253**	**98**	**295**	**283**	**750**	**131**	**324**	**584**	**755**	**8800**

Compiled observations of spawning distribution of Coho Salmon across streamwalk sections in Reach 3 and 4 of the LBR from all visual surveys (2013-2022).

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 – 2022). Scope changes in 2021 reduced HSI surveys in Reach 1 and 2.

Weighted Useable Area (m^2)						
Site	**Reach**	**2017**	**2018**	**2019**	**2021**	**2022**
Apple Springs Unit1	1	NA	1404.45	1467.68	NA	NA
Apple Springs Unit2	1	NA	122.69	631.88	NA	NA
Apple Springs Unit3	1	NA	327.11	319.51	NA	NA
Bridge River Office	1	NA	NA	257.8	NA	NA
Antoine Creek	2	NA	190.79	261.74	NA	NA
Below Antoine Creek	2	NA	1525.16	1609.91	NA	NA
Camoo FSR	2	NA	1331.4	2339.81	2086.61	2079.83
Horseshoe Bend	2	NA	671.85	673.88	498.47	786.21
wpt37	2	NA	677.13	992.74	NA	NA
wpt38	2	NA	661.11	732.15	NA	NA
wpt41	2	NA	274.63	378.57	NA	NA
wpt44	2	NA	563.75	855.78	NA	NA
Yalakom Confluence	2	NA	158.76	154.4	126.96	56.68
Cobra	3	67.46	141.74	120.02	125.96	126.91
Counter Site	3	249.84	307.19	198.32	236.97	88.93
Fraser Lake	3	580.4	512.03	530.4	702.53	491.47
Hell Creek	3	112.85	104.98	132.28	141.23	122.77
Hippy Pool	3	38.59	104.05	138.39	113.63	120.06
KM 30.2 Pool	3	244.48	288.44	288.23	312.22	276.56
KWL Site	3	NA	84.1	NA	NA	NA
Lower Spawning Platform	3	196.49	185.24	228.46	317.8	283.59
Michael Moon Creek	3	NA	268.05	NA	150.51	134.3
Mid Spawning Channel	3	78.78	200.1	139.33	162.25	189.99
Russel Springs	3	129.97	233.7	153.72	280.38	270.37
Unit 1	3	362.55	395.17	445.84	612.76	342.07
Unit 2	3	226.62	218.31	256.98	426.41	325.81
Unit 3	3	105.24	125.44	120.02	116.44	107.71
Unit 4	4	48.81	52.92	56.8	109.97	79.51
Upper Spawning Channel	4	57.98	96.45	96.59	38.92	91.13
Below Longskinny	4	NA	NA	24.39	288.08	27.73
Eagle	4	NA	158.57	154.1	632.63	201.82
Long Skinny	4	817.64	550.85	669.72	71.6	508.94

Summary of the Coho Salmon spawning habitat available in Reach 1 to 4 from HSI surveys in 2019, 2021, and 2022.

Weighted Useable Area (m²)				
Site	**Reach**	**2019**	**2021**	**2022**
Camoo FSR	2	3645.52	3396.19	3807.49
Horseshoe Bend	2	444.05	612.68	346.18
Yalakom Confluence	2	132.82	171.89	60.42
Cobra	3	84.15	118.54	134.14
Counter Site	3	175.83	175.08	65.88
Fraser Lake	3	204.23	789.8	719.23
Hell Creek	3	90.54	127.1	158.84
Hippy Pool	3	32.95	50.92	81.27
KM 30.2 Pool	3	172.15	397.29	441.01
Lower Spawning Platform	3	88.85	169.71	214.9
Michael Moon Creek	3	NA	NA	265.7
Mid Spawning Channel	3	71.44	145.96	181.78
Russel Springs	3	87.25	167.84	306.99
Unit 1	3	389.18	757.35	540.83
Unit 2	3	118.78	354.45	218.77
Unit 3	3	202.05	249.18	179.56
Unit 4	4	9.89	NA	57.82
Upper Spawning Channel	4	62.36	340.72	145.13
Below Longskinny	4	NA	113.96	90.12
Eagle	4	241.82	487.97	296.74
Long Skinny	4	791.6	674.7	598.89

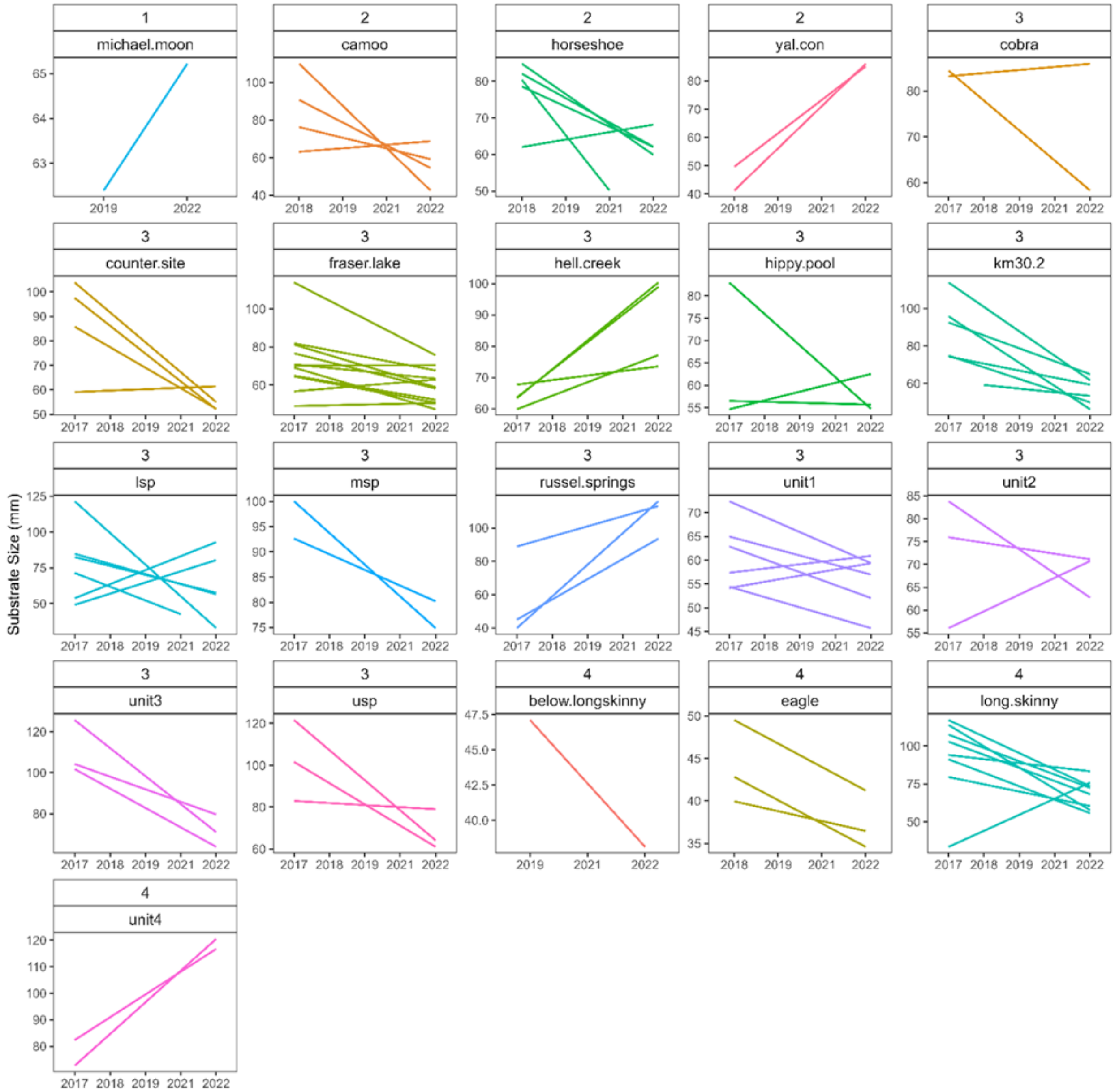
Appendix 9: Substrate Analysis

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

Year Comparison	Difference	Lower	Upper	P - value
2018-2017	1.35043	1.181171	1.51969	0
2019-2017	0.072809	-0.09501	0.240631	0.76
2021-2017	-0.66066	-0.82833	-0.49299	0
2022-2017	0.267763	0.100078	0.435449	0.0001
2019-2018	-1.27762	-1.43082	-1.12443	0
2021-2018	-2.01109	-2.16412	-1.85806	0
2022-2018	-1.08267	-1.23571	-0.92962	0
2021-2019	-0.73347	-0.88491	-0.58203	0

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

Groups	Name	Variance	Std. Deviation
Transect:Site	Intercept	0.2596	0.5096
Site	Intercept	0.489	0.6993
Residual		11.3189	3.3644



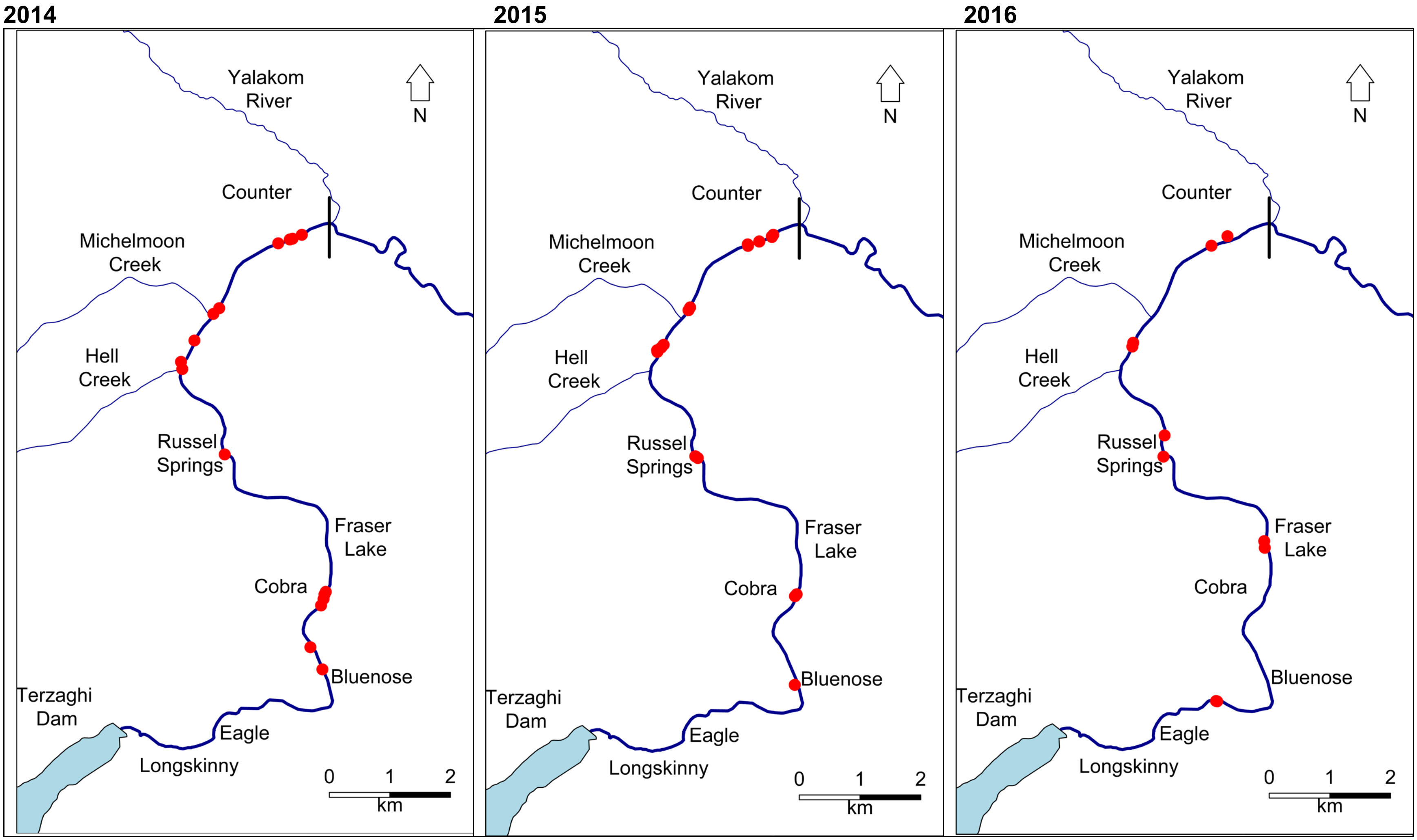
Mean substrate size from 100-pebble count for each transect (line), by year at all habitat units evaluated in Reach 2, 3, and 4, 2017 to 2022.

Appendix 10: Redd Distribution

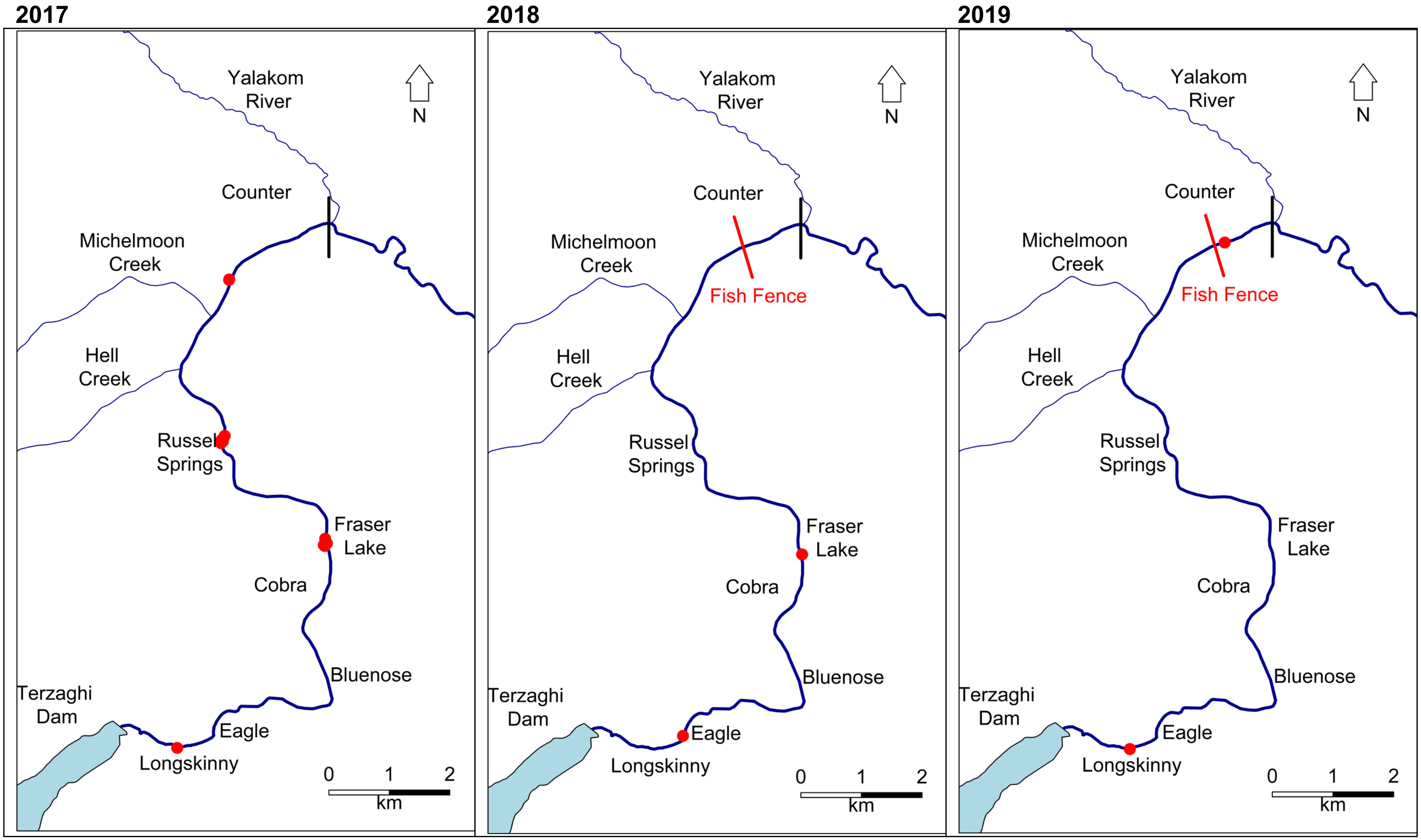
Chinook Salmon redd distribution across streamwalk sections in Reach 3 and 4 of the LBR (2014-2022).

Streamwalk			Year									
Section	**Description**	**River KM**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**Total**
1	Terzaghi Dam to Longskinny	40.0 to 39.6	0	0	0	1	0	1	0	2	2	**6**
2	Longskinny to Eagle	39.6 to 38.8	0	0	0	0	2	1	0	1	3	**7**
3	Eagle to Bluenose	38.8 to 38.2	4	1	2	0	0	0	0	0	2	**9**
4	Bluenose to Cobra	38.2 to 34.4	10	2	0	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	9	**24**
6	Fraser Lake to Russel Springs	33.2 to 30.7	7	3	5	4	0	0	2	0	0	**21**
7	Russel Springs to Hell Creek	30.7 to 28.8	25	6	4	2	0	0	0	0	0	**37**
8	Hell Creek to Yalakom	28.8 to 25.5	15	10	7	0	0	6	3	0	14	**55**
		Total	**61**	**22**	**26**	**13**	**3**	**8**	**5**	**4***	**30**	**171**

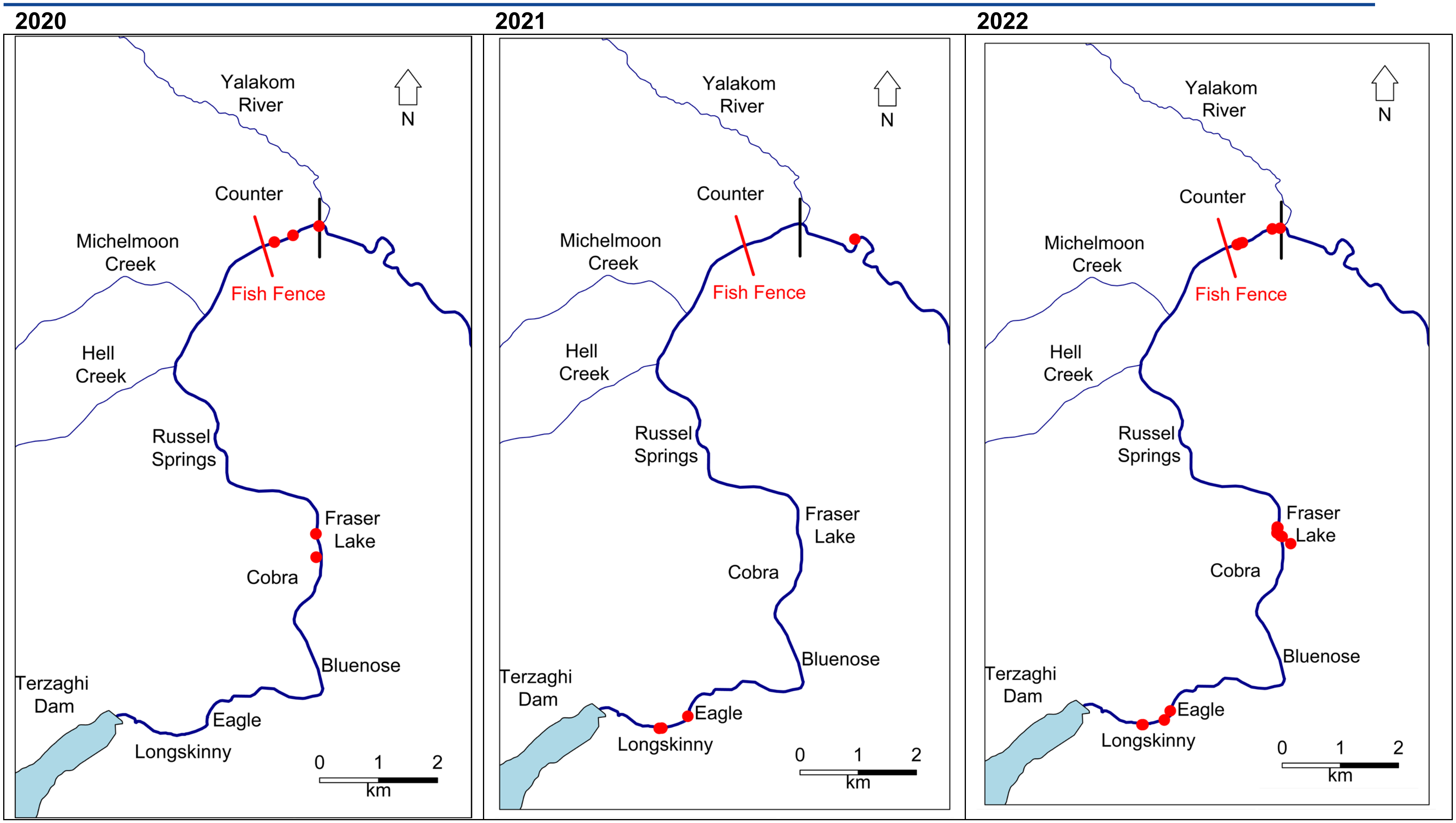
*One redd was located in Horseshoe Bend



Location of Chinook Salmon redds in the Lower Bridge River in 2014 - 2022. Black lines indicate the boundary between reaches.



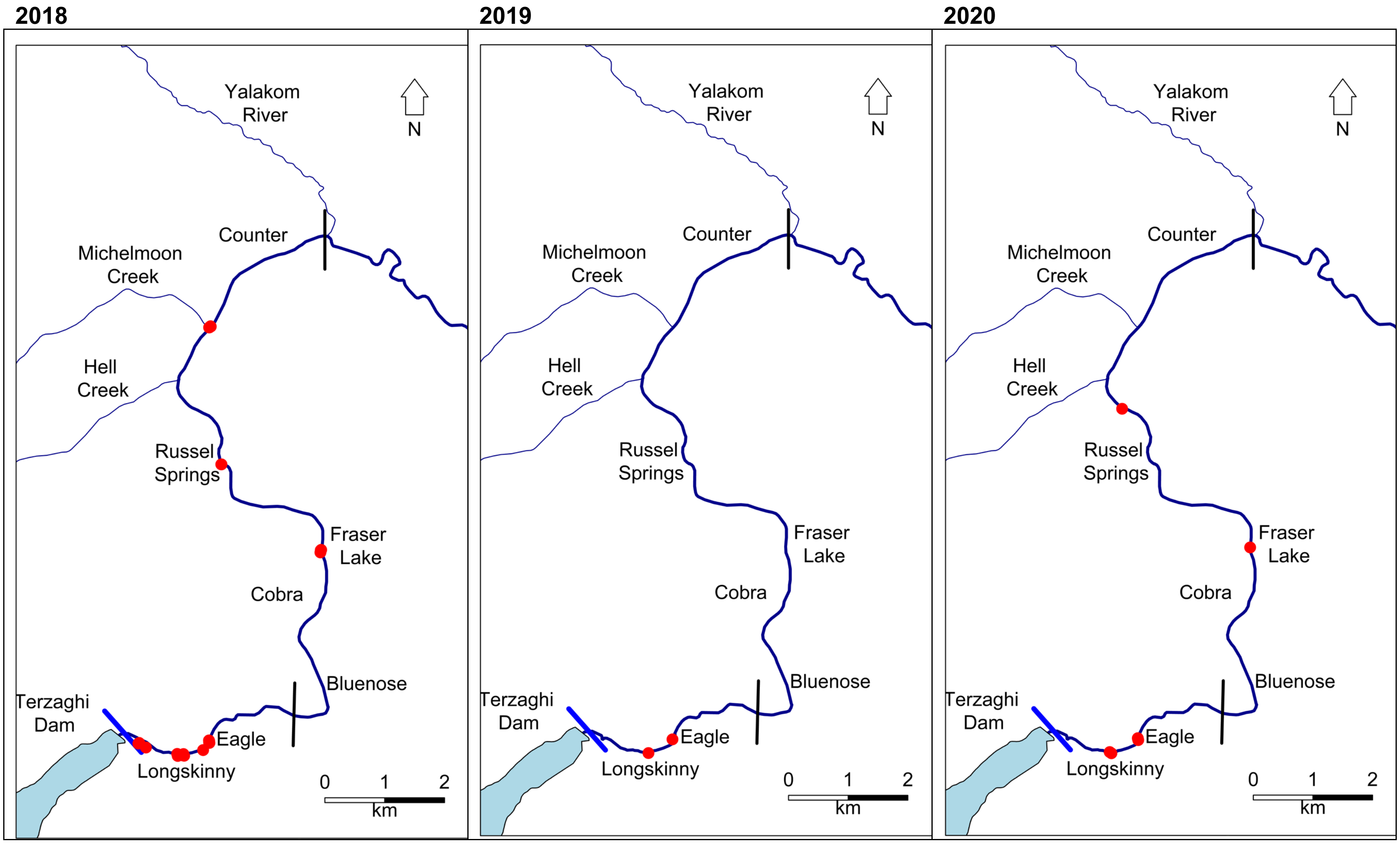
Con't: Location of Chinook Salmon redds in the Lower Bridge River in 2014 - 2022. Black lines indicate the boundary between reaches.



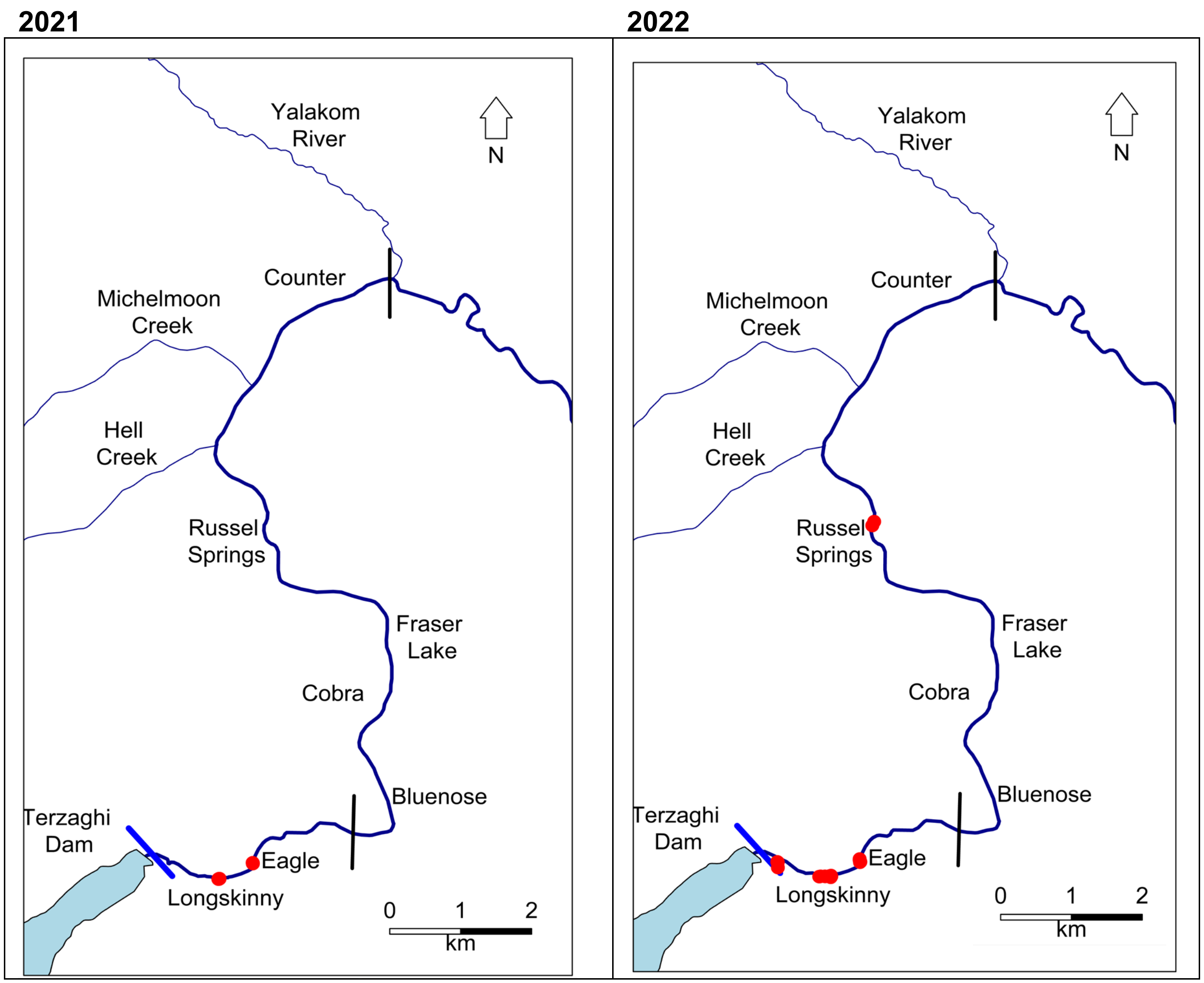
Con't: Location of Chinook Salmon redds in the Lower Bridge River in 2014-2022. Black lines indicate the boundary between reaches.

Coho Salmon redd distribution across streamwalk sections in Reach 3 and 4 of the LBR (2018-2022).

Streamwalk			Year					
Section	**Description**	**River KM**	**2018**	**2019**	**2020**	**2021**	**2022**	**Total**
1	Terzaghi Dam to Longskinny	40.0 to 39.6	15	6	2	6	16	**45**
2	Longskinny to Eagle	39.6 to 38.8	6	2	3	3	7	**21**
3	Eagle to Bluenose	38.8 to 38.2	0	0	0	0	0	**0**
4	Bluenose to Cobra	38.2 to 34.4	0	0	0	0	0	**0**
5	Cobra to Fraser Lake	34.4 to 33.2	4	0	0	0	0	**4**
6	Fraser Lake to Russel Springs	33.2 to 30.7	2	0	2	0	0	**4**
7	Russel Springs to Hell Creek	30.7 to 28.8	4	0	0	0	2	**6**
8	Hell Creek to Yalakom	28.8 to 25.5	0	0	0	0	0	**0**
		Total	**31**	**8**	**7**	**9**	**25**	**80**



Location of Coho Salmon redds in the Lower Bridge River in 2018 - 2022. Black lines indicate the boundary between reaches.



Con't: Location of Coho Salmon redds in the Lower Bridge River in 2018-2022. Black lines indicate the boundary between reaches.

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.

Species	Age (Koo 1962)	Total Age	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	Total
Chinook	1.2	3	0	0	1	0	1	1	0	0	0	0	0	2	**5**
	1.3	4	0	0	9	13	11	7	3	3	4	3	0	24	**77**
	2.3	5	0	0	0	0	0	0	0	0	0	0	1*	0	**1**
Coho	1.1	2	13	15	15	19	10	22	12	17	3	4	5	9	**144**
	1.2	3	0	0	0	1	0	0	0	0	0	0	0	0	**1**
	2.1	3	5	11	1	8	6	7	4	0	2	0	5	0	**49**
Steelhead	1.1	2	0	0	0	0	0	0	1	0	0	0	0	0	**1**
	2.1	3	0	0	0	1	0	0	0	0	0	0	0	0	**1**
	2.2	4	0	0	0	3	4	0	1	2	0	8	9	0	**27**
	2.3	5	0	0	0	0	1	1	5	7	1	0	0	0	**15**
	3.1	4	0	0	0	2	1	0	0	0	0	0	0	0	**3**
	3.2	5	0	0	0	2	8	2	3	2	2	1	0	0	**20**
	3.3	6	0	0	0	0	2	0	7	5	6	0	0	0	**20**
		Total	**18**	**26**	**26**	**49**	**44**	**40**	**36**	**36**	**18**	**16**	**20**	**35**	**363**

***Likely a Chinook Salmon from another river system**