BC Hydro

Bridge River Project Water Use Plan

Lower Bridge River Adult Salmon and Steelhead Enumeration

Implementation Year 8

Reference: BRGMON-03

Study Period: March 2019 – December 2019

Carson White, Daniel Ramos-Espinoza, Michael Chung, Katrina Cook, Stephanie Lingard, Annika Putt and Gillian Pool

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Bridge-Seton Water Use Plan

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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 2019 (Year 8 of 10) consisted of:

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

In 2018, revisions to the BRGMON-3 Terms of Reference added four management questions which address two separate operational regimes: Water Use Planning (WUP; 2011-2015) and Modified Operations (MOD; 2016-2019). Despite this delineation, all data collected since 2011 help to describe the effect of flow regime on adult salmonids in the lower Bridge River, and therefore all relevant data are used to answer each question to the highest degree possible.

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

Escapement estimates in 2019 suggest a continued trend of low abundance in the LBR (Steelhead Trout 52, Chinook Salmon 156, and Coho Salmon 280). Estimated Coho Salmon escapement in 2019 was the

lowest estimate since 2014, while Steelhead Trout escapement was similar to 2015 through 2018 (14 to 59) but substantially lower than the maximum escapement estimated in 2014 (238). Although the Chinook Salmon escapement in 2019 was higher than the 2018 partial estimate of 42, 2018 and 2019 represent the lowest Chinook Salmon escapement estimates since 2014.

The 2019 escapement estimates were potentially confounded by a rockslide on the Fraser River and operation of a fish fence for Chinook Salmon broodstock collection. The Fraser River rockslide may have led to higher escapement for all species due to increased straying of adults from other systems into the LBR. We could not separate the effects of the rockslide from flow regime, making it difficult to determine how MOD operations affected adult abundance in 2019. Also, the fish fence operated in 2018 and 2019 prevented complete Chinook Salmon escapement estimates, further inhibiting our ability to determine how flow regime affects adult Chinook Salmon in the LBR.

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. Lower Bridge River 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 peak migration timing has remained relatively consistent 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. There is preliminary evidence that Chinook Salmon spawning has increased in Reach 4 and decreased in Reach 3, but this interpretation is uncertain due to low sample sizes. The distribution of available spawning habitat can also be used to inform spawner distribution. We began HSI surveys in 2018 to describe available Chinook and Coho Salmon spawning habitat throughout the LBR, and these data will be used to inform potential changes in 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?

Habitat Suitability Index (HSI) surveys completed in reaches 1 through 4 suggest that the 2019 Weighted Usable Area (WUA) of Chinook and Coho Salmon spawning habitat was 13,978 m^2 (31.0% of the area sampled) and 13,128 m^2 (29.1% of the area sampled), respectively. Reach-specific WUA (both total area and % of area surveyed) suggests reaches 1 and 2 currently contain the largest amount of suitable spawning habitat for both species. HSI surveys were completed from 2017 through 2019 for Chinook Salmon and in 2019 for Coho Salmon, and therefore cannot be used to assess changes in spawning habitat quantity during the WUP period (2011-2016). We compared Chinook Salmon spawning habitat quantity between 2017 and 2018/2019 to determine whether habitat quantity changed following high flows in the spring and summer of 2018. We did not find a significant difference in spawning habitat quantity, suggesting high flows in 2018 did not substantially affect overall habitat quantity in the LBR (see details in MQ3).

Redd surveys can be used to assess habitat quality (depth, velocity, and substrate characteristics) at confirmed spawning locations, and have been completed in the LBR for Chinook Salmon since 2014 and Coho Salmon since 2018. Since the beginning of high flows in 2016 it has been difficult to obtain an appropriate sample size of redds. For Chinook Salmon, depth and velocity have been consistent amongst years and flow regimes, while substrate size has varied but has remained within preferred ranges. Preliminary evidence suggests instream flow affects Chinook Salmon critical spawning habitat through substrate redistribution; however, high quality spawning habitat did not limit Chinook Salmon spawning success during either WUP flows or MOD flows. Coho Salmon redd data were not compared due to low sample sizes in both 2018 and 2019 – comparisons will be made following additional data collection.

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?

We compared WUA for Chinook Salmon in 2017 to WUA in 2018 and 2019 to determine whether high flows in the spring and summer of 2018 resulted in changes in spawning habitat quantity (only reaches 3 and 4 could be compared because Reach 1 and 2 data were not collected in 2017). We found no significant change in WUA related to the 2018 high flows. Also, we did not find a significant difference between WUA in 2018 and 2019, which was expected given that high flow conditions did not occur between the two surveys. The consistency in WUA between 2018 and 2019 suggest HSI surveys are a robust method of assessing spawning habitat quantity in the LBR. BRMON-3 will continue to quantify spawning habitat in all reaches for both Chinook and Coho Salmon to inform changes in habitat quantity resulting from instream flow regime.

Detailed analyses of substrate data collected during HSI surveys suggests that overall substrate size decreased in Reaches 2 through 4 of the LBR following high flows in the spring and summer of 2018. Habitats transect data suggest that despite changes in substrate size and distribution, spawning habitat is not limited for Chinook Salmon or Coho Salmon in the LBR, which is consistent with redd survey data (MQ2). Continued monitoring is required to determine whether substrate redistribution is due to MOD flows, and whether this potential trend will lead to significant changes in spawning habitat quality and quantity in the LBR.

MQ4: Have flow releases from Terzaghi Dam under the modified flow regime affected the distribution of adult 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 between the two flow regimes, while Chinook Salmon spawning may have shifted somewhat from Reach 3 to Reach 4 following the implementation of high flows. Increased spawning in Reach 4 could lead to early juvenile emergence, which could have implications for development and survival. Evaluating the effect of high flows on Chinook Salmon spawning distribution may be confounded by operation of a fish fence used to collect broodstock (operated in 2018 and 2019) because adults are collected at the fence and do not distribute and spawn naturally. Further monitoring is required to verify the extent to which Reach 4 continues to be utilized for spawning; however, operation of the fish fence severely limits our ability to answer MQ4.

Several challenges have limited the ability of BRGMON-3 to provide data and insight for assessing 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), modified high flows, challenging visual conditions, a Chinook Salmon broodstock collection fence, and the Fraser River rockslide; however, monitoring remains on track to answering the management questions. We recommend the continued use of radio telemetry to calculate Chinook and Coho Salmon OE and SL and improve AUC abundance estimates, and moving the fish fence greater than 250m upstream reduce the effect on the monitoring equipment and provide a more confident abundance estimate.

BRGMON-3 Status of Objectives, Management Questions and Hypotheses after Year 8

Study Objectives	Management Questions	Management Hypotheses	Year 8 (Fiscal Year 2019) Status
Evaluate effects of Terzaghi Dam operations on the spawning habitat and distribution of Steelhead Trout, and Chinook and Coho Salmon, and generate spawner abundances under alternative test flow regimes.	What is the annual abundance, timing, and distribution of adult salmon and Steelhead Trout 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 Trout 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 Trout 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 Trout in the Lower Bridge River.	• Estimated 2019 spawner escapement was 156 for Chinook Salmon (considered a minimum as broodstock collection limited this estimate to pre-fence installation), 52 for Steelhead Trout, and 280 for Coho Salmon. • Coho Salmon escapement in 2019 was the lowest recorded since 2014. • Steelhead Trout escapement in 2019 was similar to 2015 through 2018, but substantially lower than maximum escapement recorded in 2014 (238). • Chinook Salmon escapement in 2019 was higher than the partial estimate from 2018 (42), but 2018 and 2019 were the lowest escapement estimates since 2014. • Preliminary evidence suggests migration timing of all species has not changed across monitoring years. • The distribution of Steelhead Trout and Coho Salmon spawners has not changed under the instream flow regime; however, Reach 4 is more frequently being used by Chinook Salmon since 2016.

Study Objectives	Management Questions	Management Hypotheses	Year 8 (Fiscal Year 2019) 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.	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.	• HSI surveys were completed for Chinook Salmon in Reaches 3 and 4 in 2017 and Reaches 1 through 4 in 2018 and 2019. HSI surveys were completed for Coho Salmon in Reaches 1 through 4 in 2019. • In 2019, the WUA of spawning habitat was 13,978 m^2 for Chinook Salmon and 13,128 m^2 for Coho Salmon, and the largest amount of spawning habitat for both species was found in Reaches 1 and 2. • WUA cannot be compared between WUP years, but preliminary analyses suggest the quantity of available spawning habitat did not change following high flows in the spring and summer of 2018 (see MQ3). • Chinook Salmon redd surveys were completed since 2014, while Coho Salmon redd surveys were completed since 2018. No Steelhead Trout redd surveys are conducted due to high flows and low visibility at the time of spawning. • Chinook Salmon redd depth and velocity have remained similar amongst years and flow regimes, while substrate has been variable but has consistently remained within Chinook Salmon preferred ranges. • We did not compare redd characteristics for Coho Salmon between 2018 and 2019 due to low sample sizes. • Combined results from HSI surveys and redd surveys suggest spawning habitat is not limiting for Chinook Salmon and Coho Salmon in the LBR.

BRGMON-3 Modified Operations Management Questions and Hypotheses after Year 8

Study Objectives	Management Questions	Management Hypotheses	Year 8 (Fiscal Year 2019) 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.	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.	• No Steelhead Trout redd surveys are conducted due to high flows and low visibility at the time of spawning. • There was no statistical difference between WUA of Chinook Salmon spawning habitat in Reaches 3 and 4 of the LBR between 2017 and 2018/2019, suggesting high flows in the spring and summer of 2018 did not substantially affect spawning habitat in the LBR. • Detailed analyses of substrate data collected during HSI surveys suggest that substrate size may be decreasing throughout Reaches 2, 3 and 4. The decrease in substrate size does not appear to have affected the spawning habitat selected for by Chinook. • 2019 was the first year of monitoring at Coho discharges, comparisons will be made in the future with additional high flow events.
	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.	• Steelhead Trout continue to spawn in both Reach 3 and 4. • Low abundances of Chinook Salmon since the high flow regime began (2016) have limited evaluations, but there appears to be a shift in preference in spawning locations to Reach 4. • Increased spawning in Reach 4 may lead to early emergence of Chinook Salmon juveniles (due to warmer temperatures in Reach 4 relative to Reaches 1 through 3), which could affect juvenile survival. • Coho Salmon continue to spawn in both Reach 3 and 4.

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Acknowledgements

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1.0 Introduction

1.1 Background

The Bridge River provides important habitat for Pacific salmon and Steelhead Trout (*Oncorhynchus* spp.) and is an important cultural and sustaining resource for the St'át'imc Nation. As part of the Bridge-Seton power system, the Lower Bridge River (LBR) is impounded by Terzaghi Dam and is controlled by BC Hydro through the operation of Carpenter Reservoir and Bridge River Generating Stations 1 and 2 (BRGS). From 1960 to 2000, Bridge River flows were diverted through the BRGS to the Seton River catchment for power production at the Seton Generating Station (SGS; Figure 1), and the upper 4 kms of the Bridge River below Terzaghi Dam remained almost continuously dewatered (groundwater and small tributaries contributed ~ 1 m^3s^{-1} averaged across the year; Longe and Higgins 2002).

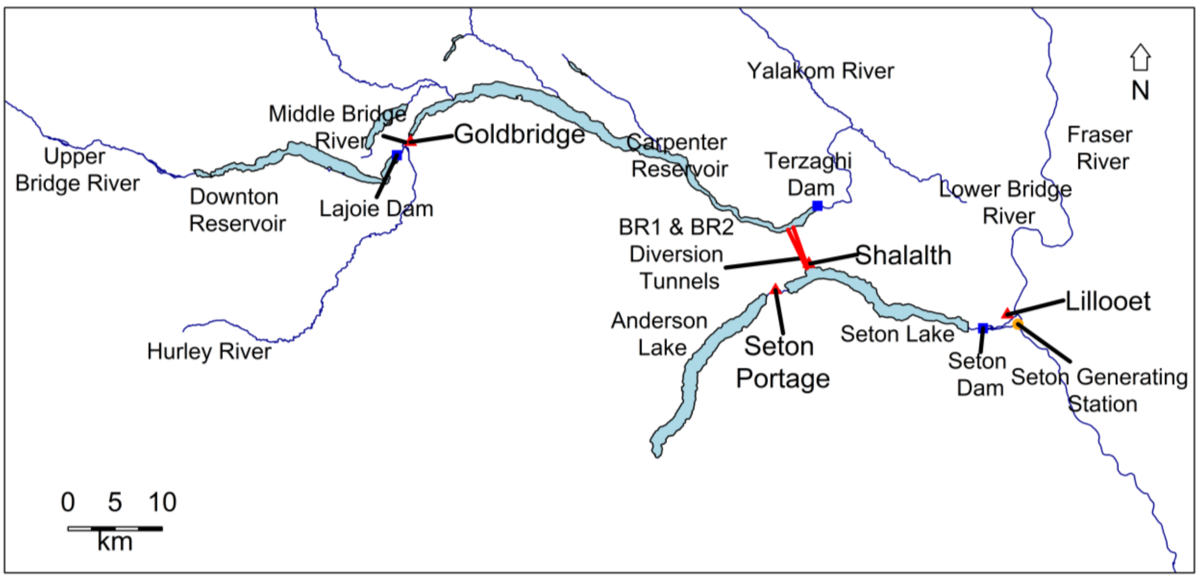

Figure 1: Bridge and Seton Watersheds showing Terzaghi Dam and diversion tunnels to Bridge River Generating Stations 1 and 2.

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 amongst 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 Water Use Plan (WUP) for the Bridge River hydroelectric complex was approved in 2011. The WUP proposed a 12-year flow release program to evaluate three alternative flow regimes (1 m^3s^{-1}, 3 m^3s^{-1}, 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. This modified high flow regime (MOD) resulted in LBR discharge surpassing the previous 15 m^3s^{-1} maximum during the high flow period from March to August (Figure 2). Modified high flows occurred in 2016 through 2018, but in 2019 flows did not surpass 20 m^3s^{-1}. 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 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 2017 following high flows in 2016.

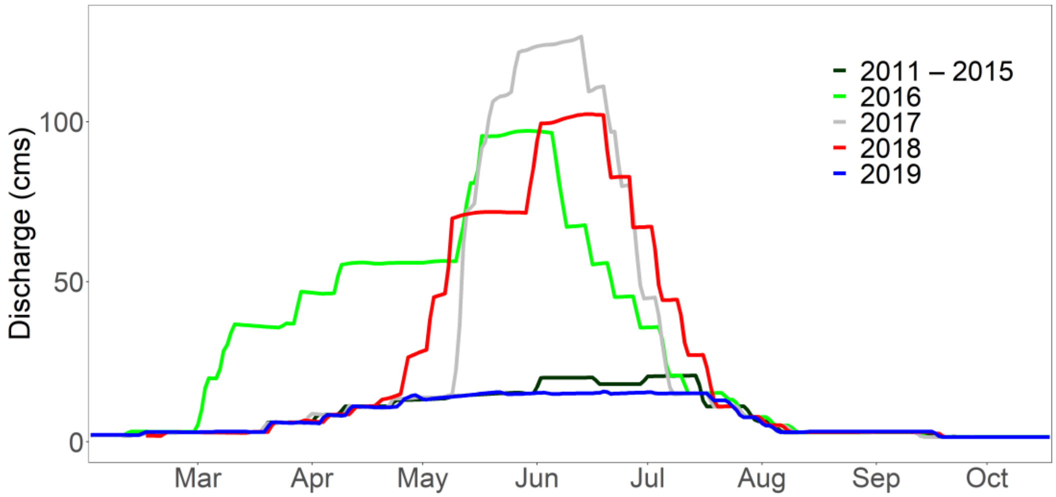

Figure 2: Discharge from Terzaghi Dam into the Lower Bridge River from 2011 to 2019. 2011 to 2015 are shown with one color to highlight their similarity (minor discharge variations occurred).

In 2018 and 2019, a broodstock program was implemented in the LBR to enhance Chinook Salmon populations and a fish fence and trap box were installed directly upstream of the electronic counters (26 rkm). The fence operation caused fish to cycle up and down over the counter site, and the counter could not be used to enumerate Chinook Salmon while the fence was operational. In addition, in 2019, a landslide occurred near the Big Bar ferry crossing on the Fraser River (~100 km north of Lillooet), which impeded the upstream migration of Fraser River salmon and Steelhead Trout. The LBR is one of the largest tributaries of the Fraser River downstream of the obstruction, and in the months following the slide, an increased number of salmon were observed entering the LBR. Spawner abundance, distribution, and migration timing were evaluated in 2019 as in previous years, but some individuals may not be of LBR origin.

1.2 Management Questions and Objectives

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

WUP Management Questions:

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

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

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

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

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

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

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

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

Modified Operations Management Questions:

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

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

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

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

The primary objective of BRGMON-3 is to inform BRGMON-1 juvenile stock recruitment models, which will be used to determine the response of salmonid productivity to instream flow regimes in the LBR. BRGMON-3 also addresses uncertainties surrounding the effects of flow regime on spawning timing, distribution, and spawning habitat quality and quantity. Monitoring objectives are met using a combination of adult enumeration (Steelhead Trout (*Oncorhynchus mykiss*), Chinook Salmon (*O. tshawytsch*), and Coho Salmon (*O. kisutch*)), visual surveys, radio telemetry, and spawning habitat assessments. BRGMON-3 was originally restricted to Reaches 3 and 4; however, the TOR modification in 2018 expanded the study area to include Reach 1 and 2. This report focuses on the data collected in 2019, 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	2019 Period	Prior Years of Data
Adult Salmonid Abundance (electronic methods)	Combination of resistivity counter and multi-beam sonar	Steelhead Trout	Mar 21 to Jun 6	2014*, 2015*, 2017, 2018
		Chinook Salmon	Aug 1 to Sep 30	2014*, 2015*, 2016, 2017, 2018
		Coho Salmon	Oct 1 to Dec 6	2013*, 2014*, 2015*, 2016, 2018
Adult Salmonid Abundance (visual methods)	Area under the curve estimates calculated from visual counts	Steelhead Trout	Apr 22 to Jun 23	2014
		Chinook Salmon	Aug 1 to Sep 30	2011-2018
		Coho Salmon	Oct 1 to Dec 3	2011-2018
Compilation of Historic Visual Counts	Compiling historic visual surveys (helicopter and streamwalk) data provided by DFO	Steelhead Trout	NA	NA
		Chinook Salmon	Aug 1 to Sep 30	1997-1999, 2001, 2004-2010 (fence count data 1993-1996)
		Coho Salmon	Oct 1 to Dec 3	1997-1999, 2001, 2003-2006, 2008-2010
Radio Telemetry	Angling, tagging, and tracking of Steelhead Trout and Chinook and Coho Salmon	Steelhead Trout	Mar 7 to Jun 11	2011-2018
		Chinook Salmon	Aug 17 to Sep 30	2012-2018
		Coho Salmon	Oct 1 to Dec 5	2014-2018
Spawning Habitat Selection	Surveys at observed Chinook and Coho Salmon redds following spawning	Steelhead Trout	NA	NA
		Chinook Salmon	Aug 29	2014-2018
		Coho Salmon	Nov 27 and Dec 11	NA
Scale Age Analysis	Ageing based on scale samples of individuals that spawned in the LBR	Steelhead Trout	Jan 1 to Feb 15	2014-2018
		Chinook Salmon	Jan 1 to Feb 15	2013-2018
		Coho Salmon	Jan 1 to Feb 15	2011-2018
High Flow Monitoring	Habitat suitability index based on instream measurements of depth, velocity, and substrate at previous spawning locations	Steelhead Trout	NA	NA
		Chinook Salmon	Aug 27 to Sep 30	2017-2018
		Coho Salmon	Oct 7 to 16	NA

*Resistivity counter only

2.0 Methods

2.1 Site Description

The LBR extends from the Terzaghi Dam 40 km downstream to its confluence with the Fraser River (Figure 1). The river is separated into four study reaches from downstream to upstream (Figure 3): 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 ~300 m upstream of the Yalakom River at the Reach 2/3 break.

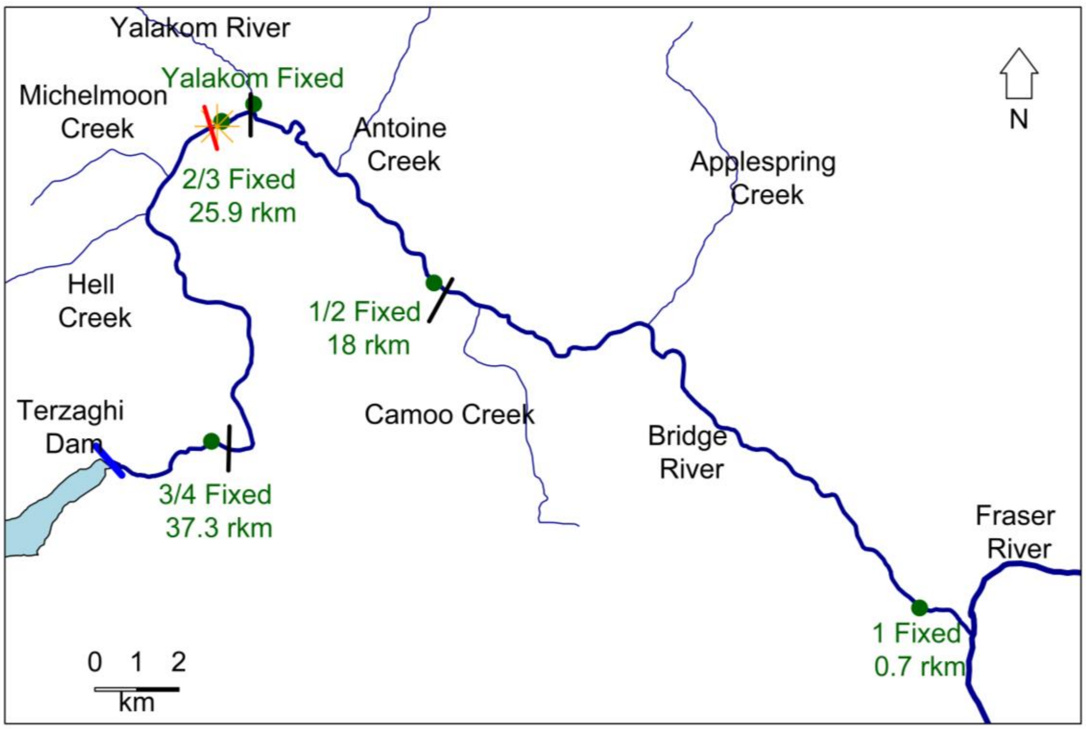

Figure 3: BRGMON-3 Lower Bridge River study area including reach breaks (black lines), fixed telemetry stations (green circles), counter location (orange star), and fish fence location during Chinook Salmon migration (red line).

2.2 Electronic Counter Spawner Enumeration

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

Table 2: Lower Bridge River migration timing and counter operational dates for Steelhead Trout, Chinook Salmon, and Coho Salmon.

Species	Estimated Migration Timing	Operational Dates	Technology Used
Steelhead Trout	Apr 1 to Jun 1	Mar 21 to Jun 6	Combined resistivity and sonar
Chinook Salmon	Aug10 to Sep 30	Aug 1 to Sep 30	Combined resistivity and sonar
Coho Salmon	Oct 1 to Dec 1	Oct 1 to Dec 6	Sonar

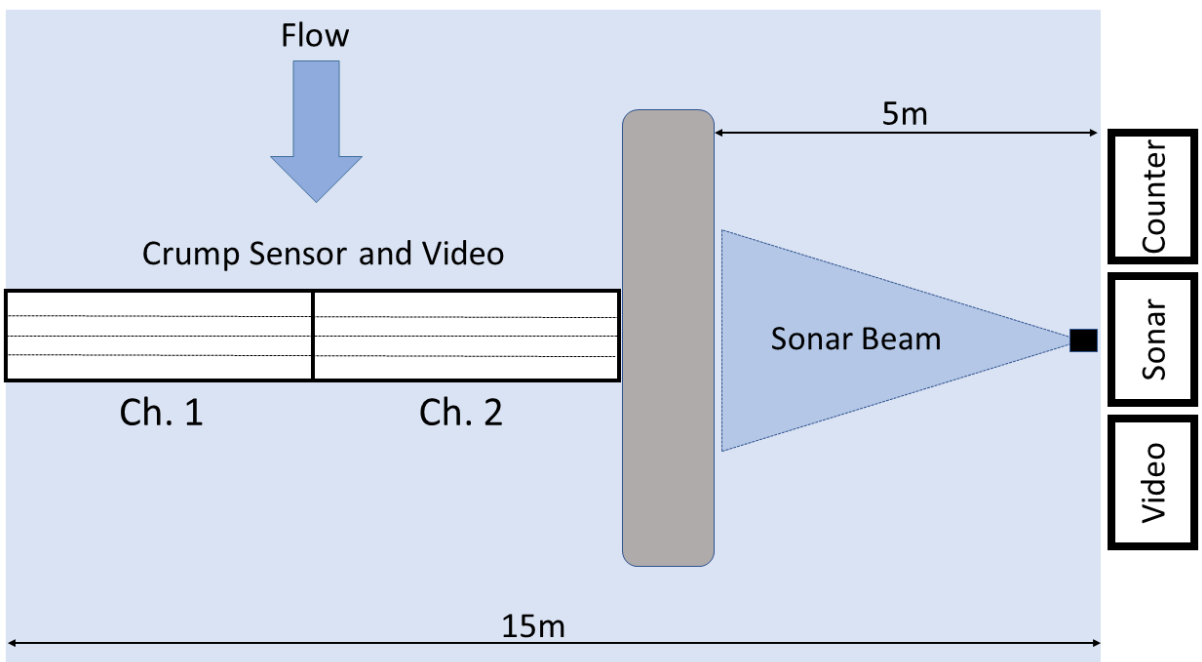

Figure 4: Configuration of the resistivity counter crump sensor, video validation system, multibeam sonar, and power system in the LBR, 2019.

2.2.1 Resistivity Counter Abundance Estimates

Resistivity counters measure the resistance between two paired 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 up, down, or 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, adult salmon, Rainbow Trout, and other resident species (e.g., 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 digital video recorder (DVR4575, Swann®). White LED lights (3-watt, 300 Lumen) were installed alongside the cameras to improve the quality of night footage.

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

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

The frequency of the above states was determined using a two-step validation process including targeted validation to identify FP and TP, and random validation to identify FN. During targeted validation, all counter records were matched to video data (plus one minute before and after) to determine the number of TPs and FPs. During random validation, a subset of randomly selected video segments were reviewed to determine a FN rate that could be applied to the full migration window. Validation date ranges were selected considering peak migration timings in 2014 (Melville et al. 2015) and 2015 (Burnett et al. 2016). Ten randomly selected 20-minute segments of video data per day were reviewed to validate both the Steelhead Trout (April 1 to May 26) and Chinook Salmon (August 1 to September 29[1]) migrations. Approximately 14% of the Steelhead Trout migration and 5% of the Chinook Salmon migration were validated in 2019.

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

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

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

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

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

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

Equation 2 must be adjusted if the counter records kelting movements – the downstream movement of fish following spawning (Steelhead Trout only). When the counter records kelting, a kelting date must be identified after which downs are considered kelts and are not subtracted from the net abundance.

The use of accuracy in Equation 2 allows abundance to be estimated even in the event of missing data or changes in river conditions (minimal in 2019). Although days with missing data are not included in the

[1] Although data were validated up to August 29, the dataset was later truncated to include only enumeration prior to the installation of the broodstock collection fence on August 20.

validation process, accuracy calculated from outside these days can be used to obtain a full estimate of abundance.

2.2.2 Multibeam Sonar Abundance Estimates

An ARIS Explorer 1800 (Sound Metrics Corporation, Bellevue, Washington, USA) was 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. The ARIS sonar malfunctioned on November 13, 2019 and a BlueView P900 sonar was installed on November 15 (41 hours of the Coho Salmon migration were not monitored). The BlueView was operated throughout the remainder of the Coho Salmon migration period and removed December 3.

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

Echoview produces estimates of fish length; however, these may be inaccurate due to the nature of the site and flow dynamics. A subset of fish lengths (Steelhead Trout 29%; pre-August 20 Chinook Salmon 11%; Coho Salmon 24%) were 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 (m), number of targets, and time in beam 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). A final net abundance was then estimated by subtracting downs from ups of the target species.

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 distribution, and visual survey observer efficiency (OE). 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 estimates of residence time in Reach 3 and 4. External identification tags (Peterson discs) were also applied to Chinook and Coho Salmon to estimate OE during visual surveys (no visual surveys occurred for Steelhead Trout). Estimates of residence time and OE were needed to estimate abundance through area-under-the-curve (AUC) methods (see Section 2.5). 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 (Figure 2). Angling for Steelhead Trout at the Bridge-Fraser confluence was not possible as in previous years due to gravel infilling, and Steelhead Trout angling occurred ~8 rkm downstream at the Seton-Fraser confluence. For Chinook Salmon, operation of the fish fence restricted angling to Reach 1. Coho Salmon capture locations were also changed in 2019 due to gravel infilling at the Yalakom-Bridge confluence, and Coho Salmon were instead angled near the Bridge-Fraser confluence, at the Camoo FSR bridge, and downstream of the Yalakom river.

2.3.2 Fixed and Mobile Receivers

All reach boundaries had fixed radio receivers to assess entry and exit into corresponding reaches (Stations 1-4), and an additional receiver was located on the Yalakom River ~100 m upstream of its confluence with the LBR to observe spawning outside of the LBR (Station 5; Figure 3). Two additional stations were installed in the Seton River mainstem and Cayoosh-Seton River confluence during the Steelhead Trout migration period to monitor movement into these areas. Each 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, and twice weekly during peak spawning for increased spatial and temporal resolution. The full lengths of Reach 3 and 4 were surveyed, but access issues resulted in Reach 1 being monitored at the LBR-Fraser confluence, and Reach 2 being monitored at Antoine Creek and Horseshoe Bend.

2.3.3 Radio Telemetry Analysis

Fixed and mobile 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 date of first detection on an upstream receiver minus the date of last detection on a downstream receiver). Residence times within Reach 2, 3, and 4 were calculated for each tagged fish based on the time spent above each reach boundary prior to assumed spawning. Detection efficiency of telemetry stations in the LBR was determined as the ratio of fish detected at an upstream receiver that were previously detected on a downstream receiver (no efficiency could be calculated for the most upstream Reach 3/4 receiver).

2.4 Migration Timing

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

For counter data, peak migration timing was established for each species by fitting a normal distribution to the peak up count recorded by the counter and the calculated standard deviation. For telemetry data, migration timing distributions were developed by determining when tagged fish moved upstream through the 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. For Steelhead Trout, which are primarily captured at the Seton-Fraser confluence, dates of entry into the LBR (Station 1) were also determined. Only species and year combinations with five or more individuals observed at a specific receiver were included in the calculations. A normal distribution was then fit to the annual mean date and standard deviation of entry into each Reach. For Coho Salmon, radio telemetry data were not available for 2014 or 2015 and PIT telemetry data was used to develop migration timing distributions for those years. The counter data was used to corroborate telemetry date of entry into Reach 3 and Reach 1 data (Steelhead Trout only) was used to evaluate entry into the LBR.

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 Area Under the Curve (AUC) method (visual surveys are not performed for Steelhead Trout due to low visibility). Visual survey data were also used to evaluate spawning distribution and timing because of insufficient radio telemetry sample sizes in many years.

Visual surveys occurred from August 2 to December 3 to monitor Chinook and Coho Salmon. During each survey, two observers walked downstream along the rivers edge and recorded fish count, species, location, water clarity (Secchi disk), and cloud cover. Visual surveys were performed in Reaches 2 through 4 but historically focused on Reach 3 and 4, which were subdivided into eight visual survey sections from Terzaghi Dam to the Yalakom River, with boundaries 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 (25.5 rkm; Figure 5). Surveys in Reach 2 occurred at $<3.5\ m^3s^1$ from the upstream end of Horseshoe bend to Camoo FSR bridge (24.5-18 rkm). When LBR discharge was $>3.5\ m^3s^1$, spot counts in Reach 2 occurred at Horseshoe bend and Camoo FSR bridge. Spot counts were also conducted at the LBR confluence with the Fraser River throughout Chinook and Coho Salmon migration.

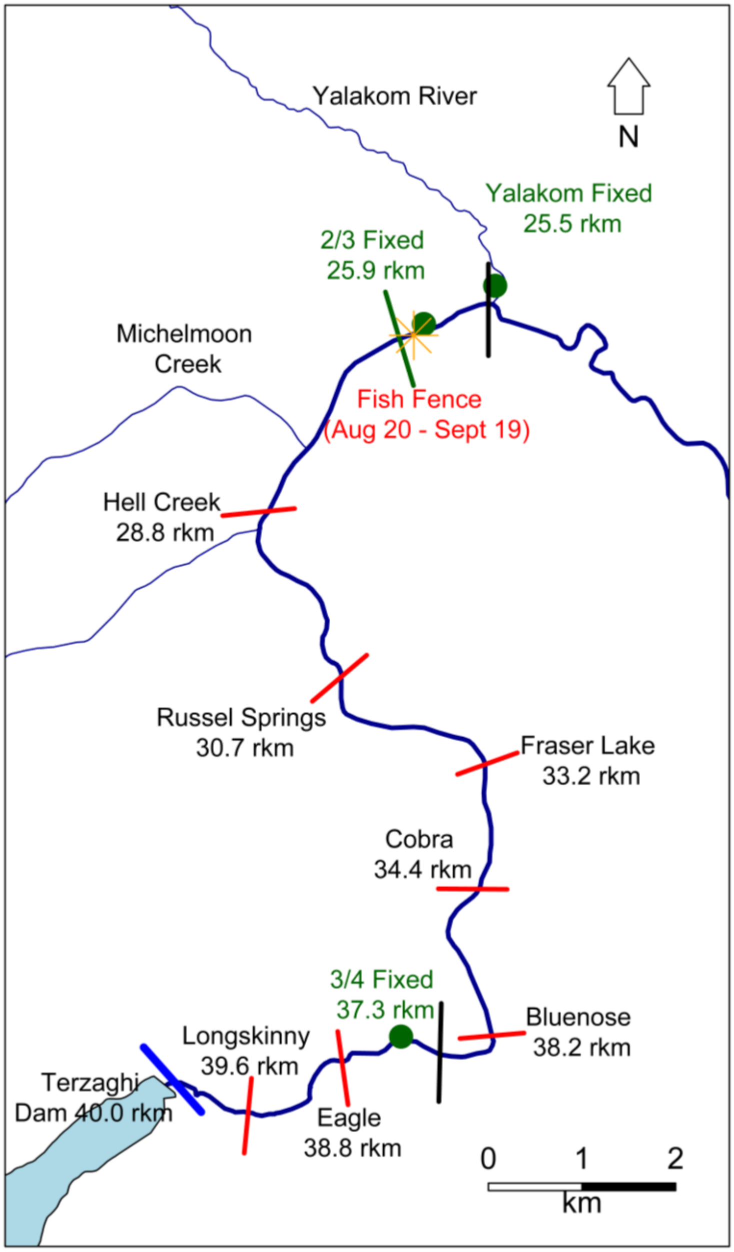

Figure 5: Visual survey boundaries (red lines), reach boundaries (black lines), fixed receiver locations (green circles), counter location (orange star) and fish fence location (green line) in Reach 3 and 4 of the Lower Bridge River.

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

(3)

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

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 3 becomes $\sqrt{2\pi\tau_s}$ and the equation can be expressed as

(4)

$$F_g = a\sqrt{2\pi\tau_s}$$

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.

(5)

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

$\hat{E}$ is estimated using maximum likelihood (ML), where $\hat{a}$ and $\hat{\tau}$ are the ML estimates of *a* and τ_s in Equation 4 ($\hat{C}_t = \hat{a}\sqrt{2\pi\hat{\tau}_s}$).

Equation 5 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

(6)

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

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 Observer Efficiency and Survey Life

OE and SL parameters are difficult to estimate in the LBR due to high levels of glacial turbidity, low visibility, and low number of tagged individuals. 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 radio tagged fish known to be in the survey area. PIT telemetry was also used for Coho Salmon during 2014 and 2015, after which high flows made PIT unsuitable. Individual SL was the time from entry into Reach 3 until assumed mortality (i.e., the radio tag switched to 13 s burst rate) or downstream migration (kelting) was observed. The average SL was then calculated and used in the AUC model.

The availability of OE and SL data has been inconsistent during BRGMON-3 modelling, particularly due to years with small sample sizes. Year-specific OE were available for Chinook salmon for 2012, 2013, 2014, and 2016, but average values of 0.50 (OE) and 10.5 days (SL) were used in all other years (Table 3; Appendix 1). For Coho Salmon, year-specific values were available for 2012, 2013, 2016, 2017, and 2018, while average values of 0.22 (OE) 20 days (SL) were used in all other years (Table 3; Appendix 1). Standard errors are the same for all years (i.e., standard error of all year-specific values). OE standard error was 0.139 for Chinook Salmon and 0.019 for Coho Salmon, while SL standard error was 0.65 for Chinook Salmon and 1.29 for Coho Salmon.

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

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

2.5.4 AUC Reconstructions of Historic Count Data

A historic time series of AUC estimates using past count data obtained from the DFO was constructed and average OE and SL values described above (Table 3). Helicopter count data were available for Chinook and Coho Salmon from 1997 to 2004, and visual survey data were available from 2005 to 2010 (not all years were available for both species – see Appendix 1). 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 fish 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 severely limited by a lack of 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 1). Historic estimates will continue to be updated as more OE and SL data are collected; however, reconstructed AUC estimates should be considered highly uncertain given the lack of OE and SL data and the change in instream conditions since the 1990s.

2.5.5 OE and SL Sensitivity Analysis

A sensitivity analysis was conducted to examine the effect of uncertainty in OE and SL on AUC abundance. The accuracy of AUC estimates is dependent on SL and OE (English et al. 1992, Perrin and Irvine 1990, Korman et al. 2002), which are highly uncertain in the LBR. We evaluated the effect on abundance estimates of varying both OE and SL by three standard deviations from their mean value (as calculated using BRGMON-3 data). The SL range was extended to encompass averages for Coho and Chinook Salmon found in Perrin and Irvine (1990;

Table 4). SL resolution was 1 day, while OE was tested at intervals of 1% and 2% for Coho and Chinook Salmon, respectively.

Table 4: SL and OE ranges tested during a sensitivity analysis evaluating the effects of SL and OE on AUC abundance.

Species	Parameter	Observed Range	Mean ± SD	± 3*SD of Mean	Lit Value	Tested Range
Coho Salmon	SL	16 – 23	19.56 ± 1.14	16.13, 23.0	11.4	11 - 23
	OE	0.19 - 0.27	0.22 ± 0.015	0.17, 0.27	NA	0.17 -0.27
Chinook Salmon	SL	12-Oct	10.58 ± 0.37	9.46, 11.69	12.1	9 – 12
	OE	0.28 - 0.58	0.47 ± 0.084	0.22, 0.72	NA	0.22 -0.72

2.6 Spawning Habitat

Spawning habitat was monitored using redd surveys (2014 through 2019 for Chinook Salmon and 2018 and 2019 for Coho Salmon). In 2017, an Instream Flow Incremental Methodology (IFIM) was initiated to assess Chinook Salmon spawning habitat in Reaches 3 and 4, whereby cross-sectional transects spanning the full width of the river were sampled and habitat suitability index (HSI) curves were applied to determine weighted usable area (WUA). HSI surveys were expanded in 2018 and 2019 to include Reaches 1 and 2, and to determine WUA for both Chinook and Coho Salmon. These two methods are complementary as redd surveys evaluate spawning habitat selected by active spawners, while HSI curves assess spawning habitat quantity throughout the LBR and help to determine whether spawning habitat is limiting.

2.6.1 Instream Flow Incremental Methodology (IFIM)

Weighted Usable Area (WUA)

WUA for Chinook and Coho Salmon was estimated using HSI curves from the Instream Flow Incremental Methodology (IFIM; Doerksen 1991). Within this framework, cross-sectional transects spanning the full river channel were conducted to obtain habitat data for input into HSI curves for Chinook and Coho Salmon. There are no reliable HSI curves specific to the LBR[2], and general DELPHI-derived curves developed for Chinook and Coho Salmon were used (Ptolemy 1994). Redd data collected from the LBR may be used in the future to develop system-specific curves.

Cross-sectional habitat assessments were conducted at spawning locations in Reach 1 through 4. Spawning locations in Reach 3 and 4 were selected based on direct observations of spawners during radio telemetry and visual surveys in previous years, while sites in Reaches 1 and 2 were selected based on theoretical habitat preferences. Chinook Salmon habitat surveys were performed when LBR discharge was 3 m^3s^{-1} (August 27 to September 30, 2019). Coho Salmon spawning habitat surveys occurred in the same locations when LBR discharge was 1.5 m^3s^{-1} (October 7 to October 16, 2019).

Spawning locations were divided into habitat units (e.g., pool, riffle, run; Johnston and Slaney 1996) and multiple transects were performed within each unit. The number of transects per habitat unit was dependent on the heterogeneity of the unit (depth, velocity, and substrate composition), and sites with considerable heterogeneity required more transects. Depth, velocity (triplicate values at 60% of the total depth; Swoffer Instruments, Model 2100), and substrate composition were measured at every meter on the transects. Substrate composition was recorded using two methods. First, a visual assessment of a 100 cm x 100 cm quadrat and recorded the percentage of fines, small gravel, large gravel, small cobble, large cobble, boulder, and bedrock. Second, geometric mean particle size was

[2] BC Hydro provided LBR-specific HSI curves; however, background data were not available, and these curves were deemed unreliable and not usable for BRGMON-3 analyses.

measured (i.e., the geometric mean of the longest length axis of each particle, also called a pebble count). The first assessment method was used during HSI analyses, while particle size data were used during an additional quantitative analysis of substrate size.

Depth, velocity, and substrate classifications were used within HSI curves to estimate the amount of suitable spawning habitat at different discharges (Ptolmey et al. 1994). The three parameters were given an HSI score ranging from 0 (unsuitable) to 1 (optimal habitat suitability). The amount of suitable habitat in each transect was the product of the three HSI scores plus the wetted width of the transect. Habitat suitability was extrapolated throughout the area between transects to calculate species-specific percent WUA, and total WUA.

Cross-channel transects could not always be completed due to unsafe wading conditions in the middle of the channel. When only one shoreline could be assessed, transect data was mirrored to approximate the second shoreline. Although Chinook Salmon can spawn in deep habitat that is unsafe to wade, these areas are rare in the LBR and the lack of mid-channel data should not substantially bias the HSI model.

Total WUA for Chinook Salmon were compared amongst years (2017-2019) for Reach 3 and 4 using a fixed factor one-way analysis of variance (ANOVA; Reach 1 and 2 were not surveyed in 2017) to evaluate changes to available spawning habitat amongst years. In particular, the analysis focused on comparing 2017 to 2018/2019 to evaluate the effects of high flows in the spring and summer of 2018 on habitat quantity in the LBR. A second fixed factor one-way ANOVA compared only 2018 and 2019 WUA across all reaches. High flows did not occur between the 2018 and 2019 HSI surveys and we did not expect to see a change in spawning habitat quantity as described by WUA. Instead, this comparison was intended to assess the consistency and robustness of the IFIM methodology for detecting changes in habitat quantity in the event of future changes to instream flow conditions. No comparisons were made for Coho Salmon WUA as 2019 was the first year the IFIM methodology was applied to Coho Salmon.

Substrate Analysis
Substrate characteristics obtained from habitat transect data (i.e., 100 measurements of substrate size per transect) were further analysed to quantitatively assess changes in substrate size among years. Substrate size was measured at transects in Reach 3 and 4 annually since 2017, and in 2018 and 2019 in Reach 1 and 2; only transects with ≥ two years were retained in analyses. To achieve a normal distribution, values were square root transformed and outliers, defined as values above or below 1.5 times the interquartile range (IQR), were removed.

A linear mixed effect model (LME) with random effects of transect and site was used to assess changes in substrate size across years. The interactive effects of year and reach on substrate size were included; however, because the temporal distribution of sampling differed among reaches (i.e., Reach 1 and 2 in two years, Reach 3 and 4 in three years), the interaction had to be assessed according to the time course of data available. One model was therefore fit to Reach 1 and 2 data, and another to Reach 3 and 4 data. 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:

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

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

2.6.2 Redd Surveys

Chinook Salmon redd surveys occurred annually since 2014, and Coho Salmon redd surveys took place in 2018 and 2019. Redd surveys were performed in Reaches 3 and 4, where depth, velocity, substrate characteristics, and redd dimensions were measured at each redd. Depth and triplicate measures of velocity (at 60% of the total depth; Swoffer Instruments, Model 2100) were taken 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 to determine the geometric mean particle size of preferred spawning substrate.

Annual values of depth, velocity, and mean particle size were assessed to confirm that Chinook Salmon spawning preferences were consistently within ranges stated in the literature. Similar redd characteristics amongst years would suggest spawning site selection is consistent and that habitat availability is not limiting Chinook Salmon spawning in the LBR. A detailed quantitative analysis was not performed because some years (particularly 2018 and 2019) had small redd sample sizes, and because the visual comparison did not suggest differences amongst years. Redd data were also combined with results from the IFIM to determine whether there is evidence that spawning habitat availability has changed since 2014. Redd data may also be used in future to develop HSI curves specific to the LBR, which would better inform changes in habitat availability due to alterations in flow regime.

Redd surveys were also used to compare distributions of confirmed spawning from 2014 through 2019 for Chinook Salmon, and 2018 vs. 2019 for Coho Salmon. This assessment is combined with visual surveys of migrating adults to inform whether flow regime has affected spawner distributions.

Eight temperature loggers (4 each for Chinook and Coho Salmon; HOBO Water Temperature Pro v2; Onset Computer Corporation, Massachusetts, USA) were attached to rebar at 60% of the total redd depth to monitor accumulated thermal units (ATU) over the incubation period. Data loggers were not buried into the adjacent substrate as in previous years because groundwater was not found to influence subsurface temperature (Ramos-Espinoza et al. 2018). Loggers were deployed on September 29, 2019 for Chinook Salmon and December 12, 2019 for Coho Salmon and will be removed in late March 2020 (to be reported upon in the synthesis report of BRGMON-3).

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 during visual surveys. Only age data of individuals known to have spawned in the LBR were included (some radio- and PIT-tagged individuals migrated further up the Fraser River). It has been difficult to collect scales from Chinook Salmon, as abundances returning to the LBR have been low and scales have typically been resorbed by the time Chinook Salmon are captured.

Ageing followed methods outlined in Ward and Slaney (1988), where two people independently determined age ignorant of fish size and time of capture. Age was expressed as two numbers separated by a decimal (Koo 1962), where the first number is the number of years or winters spent in freshwater and the second number is the number of years or winters spent in the ocean. These two numbers summed together is the total age of the fish (ignoring larval stage). For example, a 1.2 represents a 3-year-old fish that spent 1 year (or 1 winter) in freshwater and 2 years (or 2 winters) in the ocean before spawning in their fourth year.

3.0 Results

3.1 Electronic Counter Spawner Enumeration

3.1.1 Steelhead Trout (Resistivity and Multibeam Sonar)

In 2019, Steelhead Trout were enumerated using both the resistivity counter and the ARIS sonar. The resistivity counter operated from March 21 to May 27 and after accounting for accuracy, the net upstream abundance of Steelhead Trout recorded by the resistivity counter was 34. Validation occurred for 66.3 hours (4.9% of the total record) of video data (20 hours targeted and 46.3 hours random) with upstream and downstream accuracies of 87% and 90%, respectively (Table 5). Species was identified during validation and there was a positive relationship between standard length and PSS. A PSS of 80 was visually determined to distinguish Steelhead Trout from resident species; however, in 2019 all fish were identified to species during validation and the length-PSS relationship was not required.

Table 5: Resistivity counter accuracy during the 2019 Steelhead Trout migration in the Lower Bridge River.

Direction	True Positive	False Positive	False Negative	Accuracy
Up	52	7	1	87%
Down	18	1	1	90%

The sonar operated from March 28 to June 7 and the net upstream abundance of Steelhead Trout recorded by the sonar was 18. Echoview lengths were positively correlated to ARISFish lengths (Appendix 2) and the relationship was not affected by direction (a single model was used to evaluate both directions). Two models had virtually equal AIC support due to their small difference in AIC (i.e., 0.10), and therefore the simpler model was selected as the best fit model. The final model included only Echoview lengths, which explained a large portion of the variance in ARISFish lengths ($R^2 = 0.91$, $p < 0.05$; AICc rankings and model coefficients in Appendix 2). A fork length cut-off of 600 mm to distinguish between Steelhead Trout (>600 mm) and other resident species (<600 mm). This cut-off was developed using LBR fork length data from 2014 to 2019 because it minimizes the overlap between Steelhead Trout and smaller resident species (Appendix 2). There were two radio tagged individuals that exhibited kelting behavior prior to the removal of counting equipment (mid May) and were subtracted from the estimate. The total abundance of Steelhead Trout was 50, combining abundance monitored by the resistivity counter (34), sonar (18) and kelts (-2; Figure 6). This continues the trend of low returns of Steelhead Trout to the LBR since 2014 (Table 6).

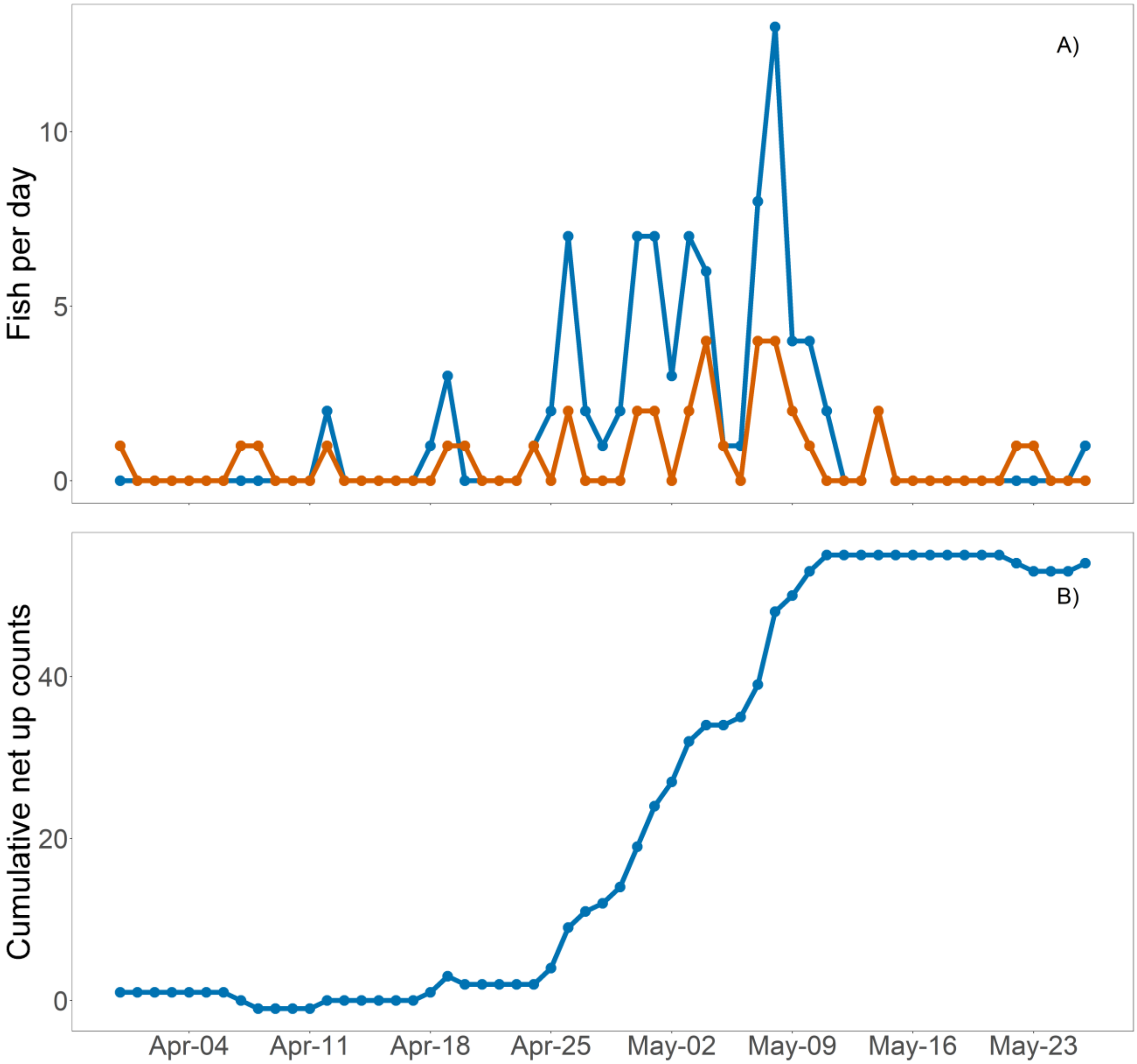

Figure 6: (A) combined multibeam sonar and resistivity counter daily up (blue) and down (orange) counts and cumulative net up (B) counts for Steelhead Trout in the Lower Bridge River in 2019.

Table 6: 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

3.1.2 Chinook Salmon (Resistivity and Multibeam Sonar)

In 2019, Chinook Salmon were enumerated using both the resistivity counter and the ARIS sonar.

The resistivity counter operated from August 1 to August 20 and after accounting for accuracy, the net upstream abundance of Chinook Salmon recorded by the resistivity counter was 40. Validation occurred for 123.5 hours of video data (8.4% of total video recorded; 10.5 hours targeted and 113 hours random). The counter had upstream and downstream accuracies of 100% for Chinook Salmon on all channels (Table 7). A river-spanning fish fence was installed on August 20 upstream of the counter site for broodstock collection. The fish fence caused substantial noise and up and down cycling of Chinook Salmon and other species at the counter site and rendered subsequent counter data unusable. In addition, the fence resulted in increased use of the crump weir by Chinook Salmon relative to previous years, in which virtually all Chinook Salmon movements occurred on river left (monitored by the sonar). Peak migration of Chinook Salmon past the counter site typically occurs in the first week of September, and therefore it is assumed that more than 50% of the migration may have been impaired from the installation of the fish fence. Here, Chinook Salmon abundance is presented up to August 20.

Table 7: Resistivity counter accuracy during the 2019 Chinook Salmon migration in the Lower Bridge River.

Direction	True Positive	False Positive	False Negative	Accuracy
Up	49	0	0	100%
Down	9	0	0	100%

The sonar operated from August 1 to August 20 and the net upstream abundance of Steelhead Trout recorded by the sonar was 54. Lengths estimated by Echoview were positively related to the ARISFish lengths (Appendix 2). The most parsimonious model for up movements included Echoview lengths and number of targets (R^2 = 0.97, $p < 0.05$; Appendix 2), while the most parsimonious model for down movements included only Echoview lengths (R^2 = 0.98, $p < 0.05$; Appendix 2). 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 2019 and has been shown to minimize the amount of overlap between Chinook Salmon and other species (Appendix 2).

The partial abundance of Chinook Salmon measured by the electronic counters was therefor 94 (40 [resistivity counter] + 54 [sonar]; Figure 7). After August 20, 62 Chinook Salmon were enumerated at the fish fence, resulting in a coarse Chinook Salmon spawner escapement of 156. It is difficult to compare Chinook Salmon escapement from 2019 to previous years (Table 8) due to the fence operation, which resulted in an incomplete estimate, and the effects of the Fraser River rockslide, which resulted in increased prevalence of Chinook Salmon from other watersheds straying into the LBR. Despite these uncertainties, Chinook Salmon abundance in the LBR is low, and escapement estimates in 2018 and 2019 were the lowest since monitoring onset in 2014.

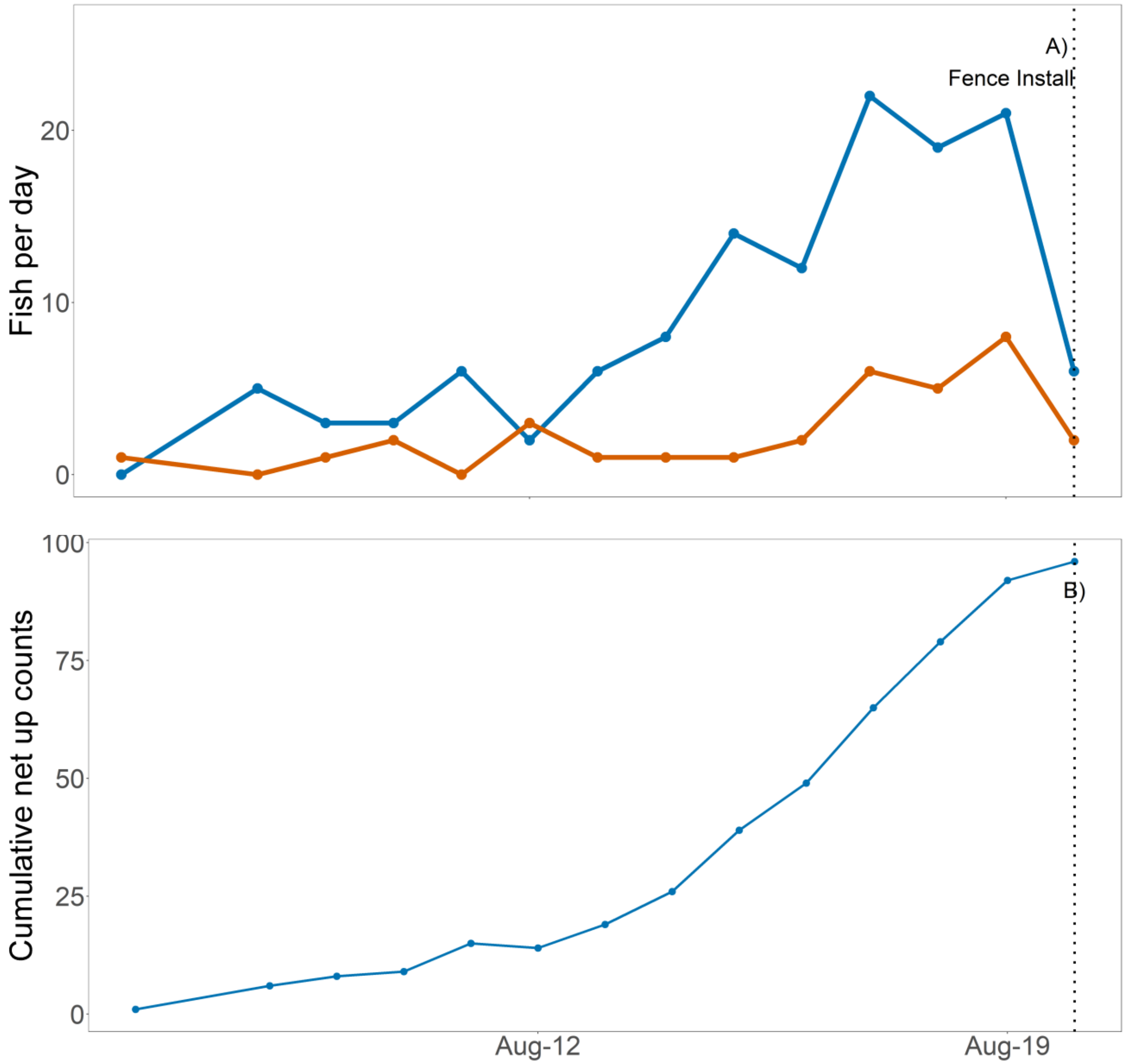

Figure 7: (A) combined multibeam sonar and resistivity counter daily up (blue) and down (orange) counts and cumulative net up (B) counts for Steelhead Trout in the Lower Bridge River up to August 20, after which a fish fence was installed upstream and enumeration could no longer occur.

Table 8: Summary of Chinook Salmon electronic counter data used in abundance estimates.

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 and Multibeam Sonar	Partial Estimate - fish fence for broodstock collection limited estimate (pre-August 29)
2019	156	Resistivity Counter and Multibeam Sonar	Partial Estimate – pre-August 20 estimate from sonar and resistivity counter, plus 62 fish captured at the fish fence

3.1.3 Coho Salmon (Multibeam Sonar)

Coho Salmon were enumerated solely using the ARIS sonar, as LBR discharge was too low (1.5 $m^3 s^{-1}$) during the Coho Salmon migration to allow for passage over the resistivity counter. The sonar operated from October 8 to December 6 and the net upstream abundance of Coho Salmon recorded by the sonar was 280 (Figure 8). Echoview lengths were positively correlated to the ARISFish lengths (Appendix 2). The most parsimonious model for up movements included Echoview lengths, number of targets, and target range mean (R^2 = 0.85, p < 0.01**;** Appendix 2), while the most parsimonious model for down movements included Echoview lengths, number of targets, and time in beam (R^2 = 0.96, p < 0.01; Appendix 2). These models were used to predict length for all sonar traces, and a fork length cut-off of 400 mm was then used to differentiate Coho Salmon (>400 mm) from all other species (<400 mm). This cut-off was developed using fork length data collected in the LBR during angling from 2014 to 2019, and minimizes the overlap between large-bodied Coho Salmon and smaller resident species.

This is the lowest abundance calculated for Coho Salmon over this monitor and shows a continued trend of declining abundance for this species (Table 9). As with other species, the Fraser River rockslide may have resulted in a high percentage of stray fish from other rivers and may not reflect the true abundance of LBR origin Coho Salmon. In fact, the true abundance of LBR-origin fish may be lower than reported here.

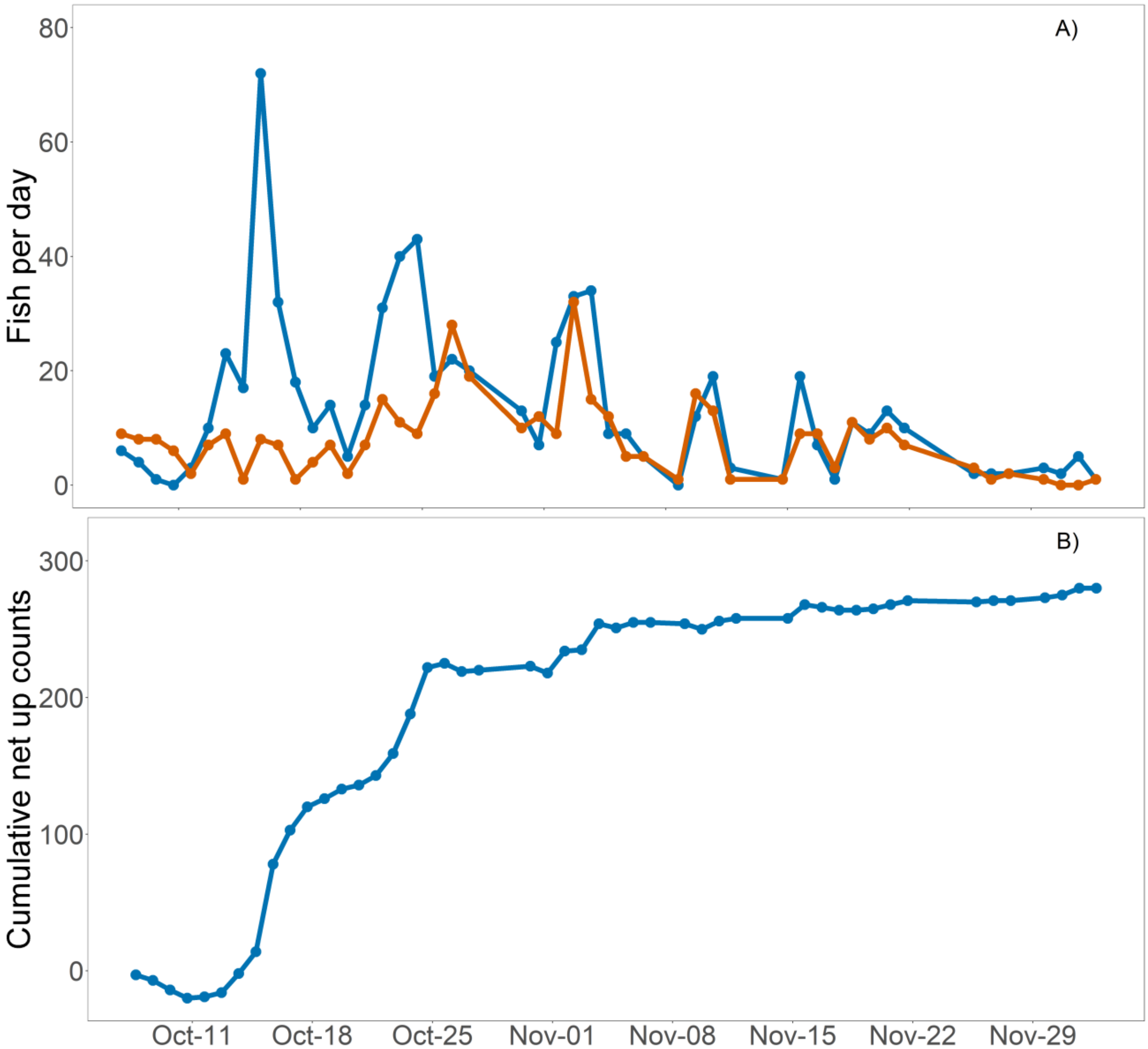

Figure 8: (A) sonar derived daily up (blue) and down (orange) counts and cumulative net up (B) counts for Coho Salmon in the Lower Bridge River in 2019.

Table 9: 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	Resistivity Counter and Multibeam Sonar	Complete Estimate - testing of new multibeam sonar following infrastructure damage
2017	NA	Resistivity Counter and Multibeam Sonar	Post season data loss
2018	545	Resistivity Counter and Multibeam Sonar	Complete Estimate
2019	280	Resistivity Counter and Multibeam Sonar	Complete Estimate: Fraser River rockslide may confound escapement

3.2 Spawning Distribution (Radio Telemetry)

Radio telemetry was used to assess spawning distributions for Steelhead Trout. For Chinook Salmon and Coho Salmon, radio telemetry sample sizes were insufficient to fully assess spawning distributions (driven by low tag deployment or few tagged individuals entering the LBR), and visual survey data were also used to inform spawner distributions when answering the BRGMON-3 management questions (see Sections 3.4.3 and 3.5). Detection efficiency was high at all fixed receiver stations during the Steelhead Trout migration (82% at Station 1 and 100% at Stations 2 and 3). Detection efficiency could not be calculated for Chinook or Coho Salmon due to limited post-tagging migration into the LBR.

3.2.1 Steelhead Trout

Twenty-five Steelhead Trout (6 males, 19 females) were tagged at the Seton-Fraser confluence from March 7 to April 25, 2019 (Appendix 3). Of these fish, 22 individuals were detected by either fixed receivers or mobile tracking following tagging. Telemetry detections indicated that Steelhead Trout entered the LBR in mid-April and spawned from mid-April through early June. Spawning locations were determined for eight Steelhead Trout, one of which spawned in Reach 3 (between the Yalakom confluence and Hell Creek; Figure 5), and seven of which spawned in Reach 4 (Figure 9; Appendix 3). In Reach 4, one fish spawned between Longskinny and Terzaghi Dam, four fish spawned between Eagle and Longskinny, and two fish spawned between Cobra and Bluenose (Figure 5). Of the 14 fish with unknown spawning locations, three were detected only near the confluence of the Bridge and Fraser Rivers (Station 1; 1.6 rkm), and ten were detected within the Seton River or near the confluence of the

Seton and Fraser Rivers. Two tags that were detected at the Seton-Fraser confluence and the LBR-Fraser confluence were recovered at the Fraser River rockslide site by the DFO (i.e., Big Bar).

Confirmed spawning locations have been variable since 2014, and no trends in spawning location can be identified to date (Figure 10; Appendix 4). In 2019, two Steelhead Trout were detected at fixed stations in the Seton River and three were detected in the Seton River before migrating into the LBR. Kelting behaviour was observed for six Steelhead Trout, which migrated out of the Bridge River system by mid-May. The mean residence time in 2019 was 26.5 days ±11.6 above Reach 2 and 24.4 days ±11.9 above Reach 3 (Appendix 3). Steelhead Trout that showed directed upstream migrations in the LBR had a mean migration rate of 5.1 km day^{-1} ±3.4 (Appendix 3).

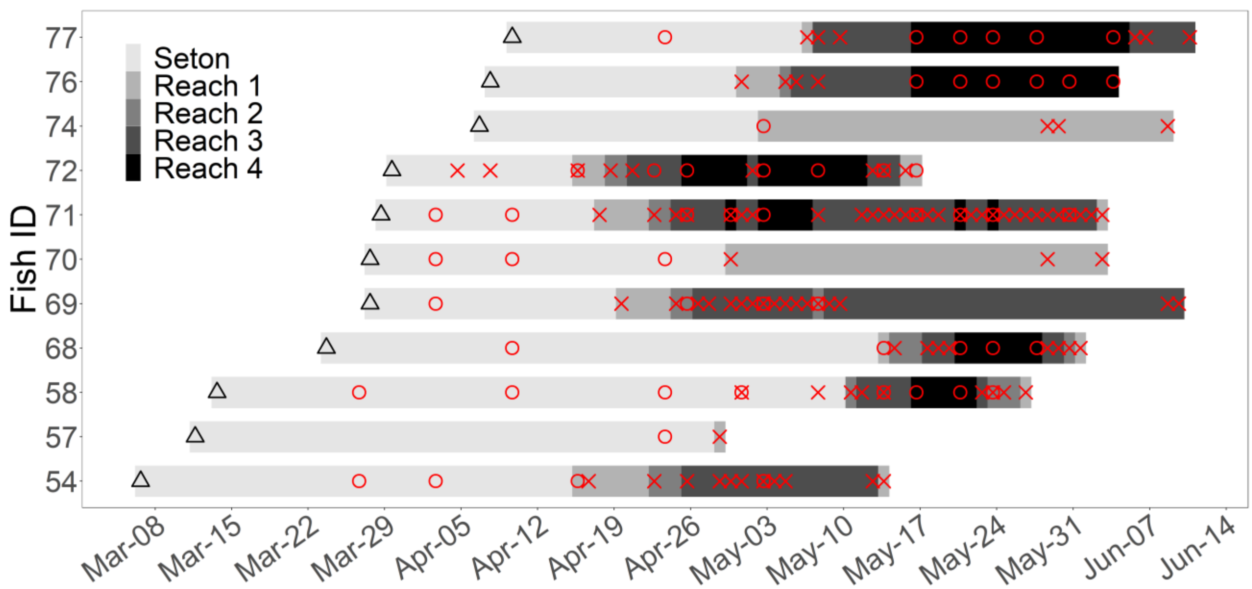

Figure 9: Time series of radio-tagged Steelhead Trout in the Seton and Lower Bridge River in 2019. Triangles denote tagging date, o denotes mobile tracking detections, × denotes fixed receiver detections and ■ denotes dates of both mobile and fixed detections.

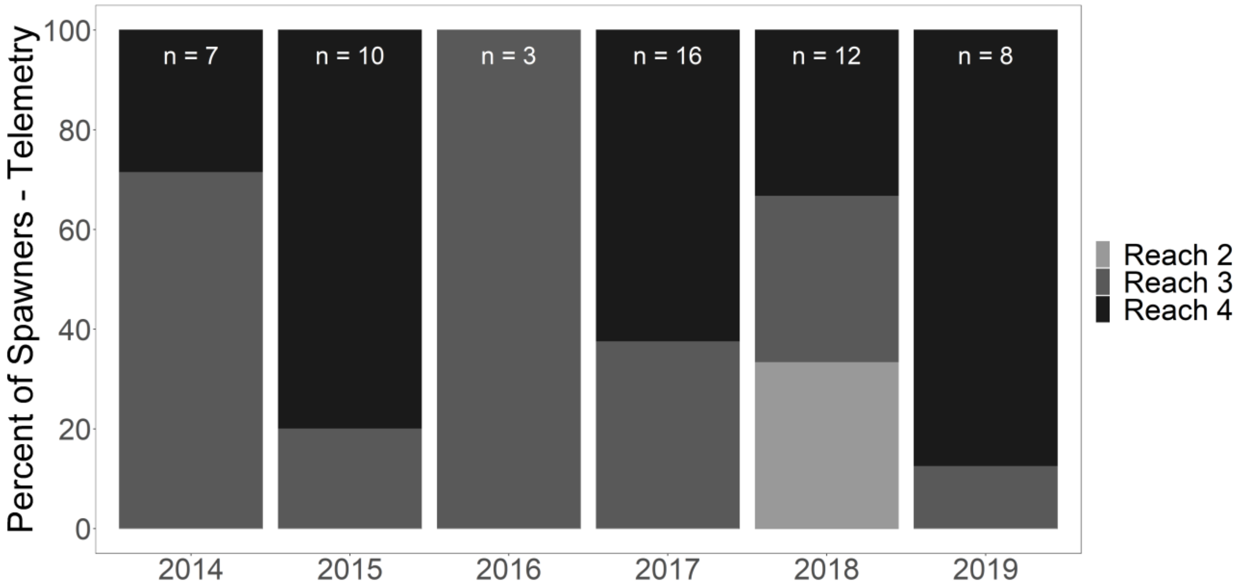

Figure 10: Relative proportion of estimated spawning locations in Reach 2, 3 and 4, for Steelhead Trout based on radio telemetry.

3.2.2 Chinook Salmon

Five female Chinook Salmon were tagged in 2019; four tags were applied at the Bridge-Fraser confluence, and one tag was applied at the fish fence in Reach 3 (Appendix 3). One fish that was released above the fish fence was detected for a prolonged period at the Reach 2/3 telemetry station, where it was presumed to have spawned (Figure 11; Appendix 3). Spawning locations could not be determined for the remaining four tags. One individual entered Reach 2, but later fell back and exited the LBR (Figure 11; Appendix 5). The remaining three fish were not detected within the LBR but were detected 1.5 rkm downstream of the Bridge Fraser confluence by DFO-managed telemetry stations. Residence time and migration speed could not be estimated for Chinook Salmon in 2019 due to low sample size.

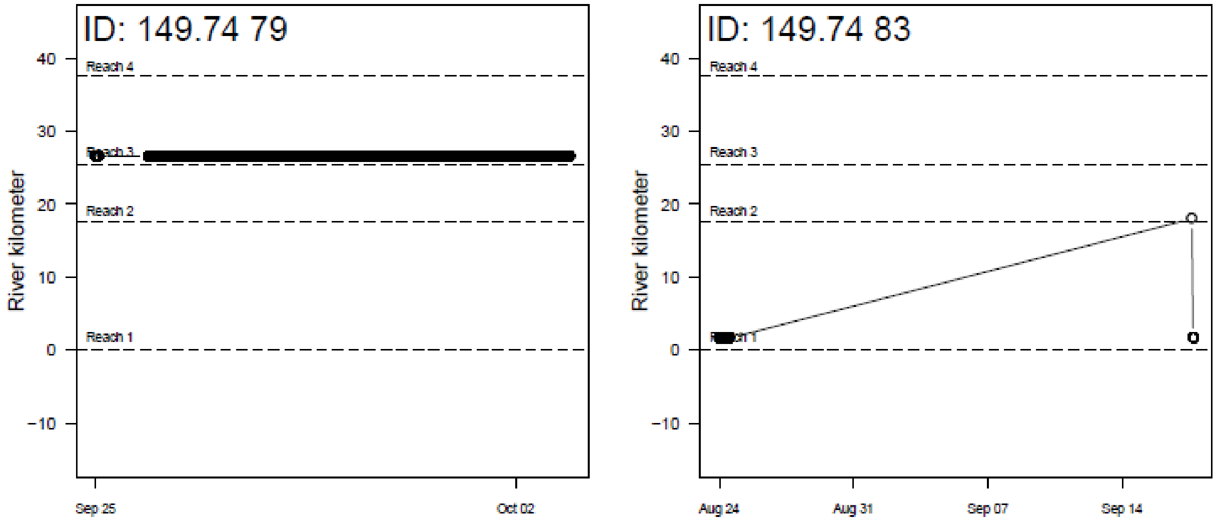

Figure 11: Detection histories of radio-tagged Chinook Salmon in the Lower Bridge River in 2019.

3.2.3 Coho Salmon

Twenty-one Coho Salmon (14 males and 7 females) were tagged between September 30 and November 2 at the Bridge River – Fraser River confluence (n = 14), LBR bridge (n = 4), and Hippy Pool (n = 3; Figure 5, Appendix 3). 2019 represents the lowest return of radio-tagged Coho Salmon above the Yalakom Confluence (rkm 25.5) since 2011, despite a relatively high number of tagged individuals. Detection histories indicate that one individual likely spawned in Reach 3 between the Yalakom confluence and Hell Creek (Figure 12; Appendix 5), and once individual likely spawned in Reach 2 near the Camoo fixed station site. Eleven individuals were detected in the LBR, but their spawning location could not be confirmed because they were only detected at the lower receiver, proximate to the confluence of the Bridge and Fraser Rivers. Six individuals were detected in the Fraser River 1.5 km downstream of the Bridge-Fraser confluence by DFO-managed telemetry stations. Low number of radio tagged individuals detected upstream of Reach 3 corroborate low Coho Salmon escapement estimated by electronic counting equipment in 2019.

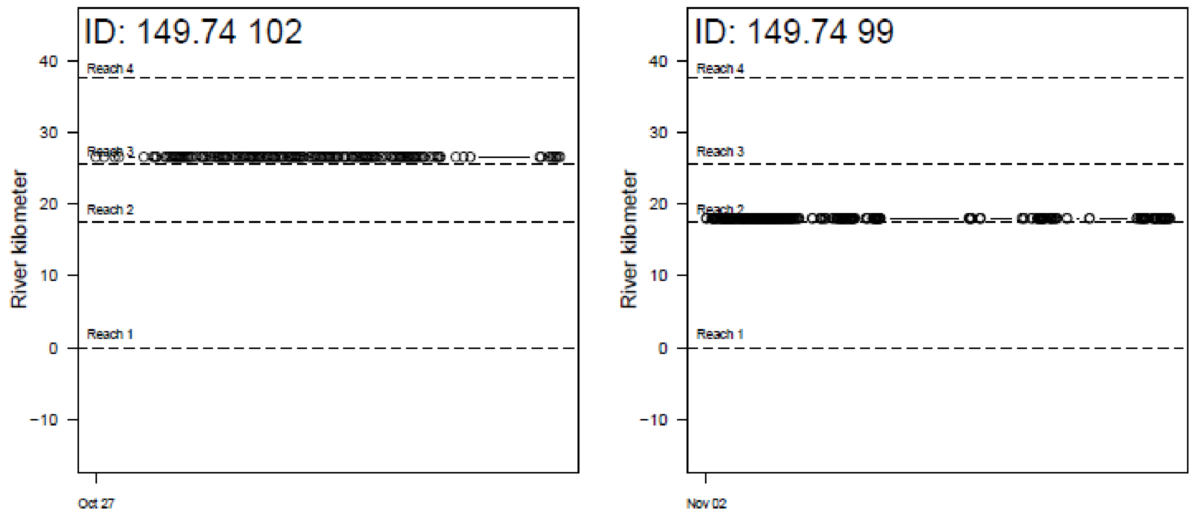

Figure 12: Detection histories of radio-tagged Coho Salmon in the Lower Bridge River in 2019.

3.3 Migration Timing

3.3.1 Steelhead Trout

Steelhead Trout migration timing was assessed amongst years and between counter data and radio telemetry data to determine whether changes in migration timing have occurred in response to changes to instream flow regime in the LBR. Telemetry data were available for 2014 through 2019, while counter data were available for 2014 to 2015 and 2017 through 2019 (high flows in 2016 damaged the electronic counter infrastructure; Table 10). Migration timing distributions were relatively consistent amongst years, indicating Steelhead Trout typically spawn in the first or second week of May (Table 11). Migrating spawners were exposed to high flows in 2016 through 2018, but no trends in migration timing were observed in either resistivity counter or telemetry data (Figure 13). Visual assessments of timing distributions were also assessed for entry into Reach 1. Entry into Reach 1 was relatively consistent apart from 2017, when peak entry into the LBR occurred approximately one month earlier than any other year (n = 9; Figure 14).

Table 10: Data used to derive migration timing curves for Steelhead Trout and Chinook and Coho Salmon in the LBR. Years where a method was not available are denoted by NA. Radio telemetry data with <5 individuals were not included in the analysis.

	Steelhead Trout		Chinook Salmon		Coho Salmon	
Year	Radio Telemetry Sample Size	Counter Estimate Included	Radio Telemetry Sample Size	Counter Estimate Included	Radio Telemetry Sample Size	Counter Estimate Included
2012	NA	NA	15	NA	25	NA
2013	NA	NA	26	NA	19	Y
2014	8	Y	17	Y	15*	Y
2015	10	Y	14	Y	14*	Y
2016	2	N (high flow damage)	14	Y	30	Y
2017	16	Y	2	Y	8	N (post season data loss)
2018	8	Y	2	N (fish fence)	12	Y
2019	8	Y	1	N (fish fence)	0	Y

* PIT Tags

Table 11: Values of electronic counter and telemetry dates (Reach 3) that were used to calculate normal distribution functions for migration timing analyses.

	Counter				Telemetry			
	min	max	mean	std (days)	min	max	mean	std (days)
2014	NA	NA	NA	NA	04-17	05-21	05-05	14.2
2015	04-09	06-04	04-25	30.7	04-18	05-12	05-01	7.0
2016	NA	NA	NA	NA	NA	NA	NA	NA
2017*	04-22	05-08	05-03	6.7	04-14	05-20	04-30	8.8
2018*	03-22	05-08	04-29	11.7	04-20	05-31	05-07	13.1
2019	04-22	05-14	05-03	5.9	04-21	05-18	05-02	9.5

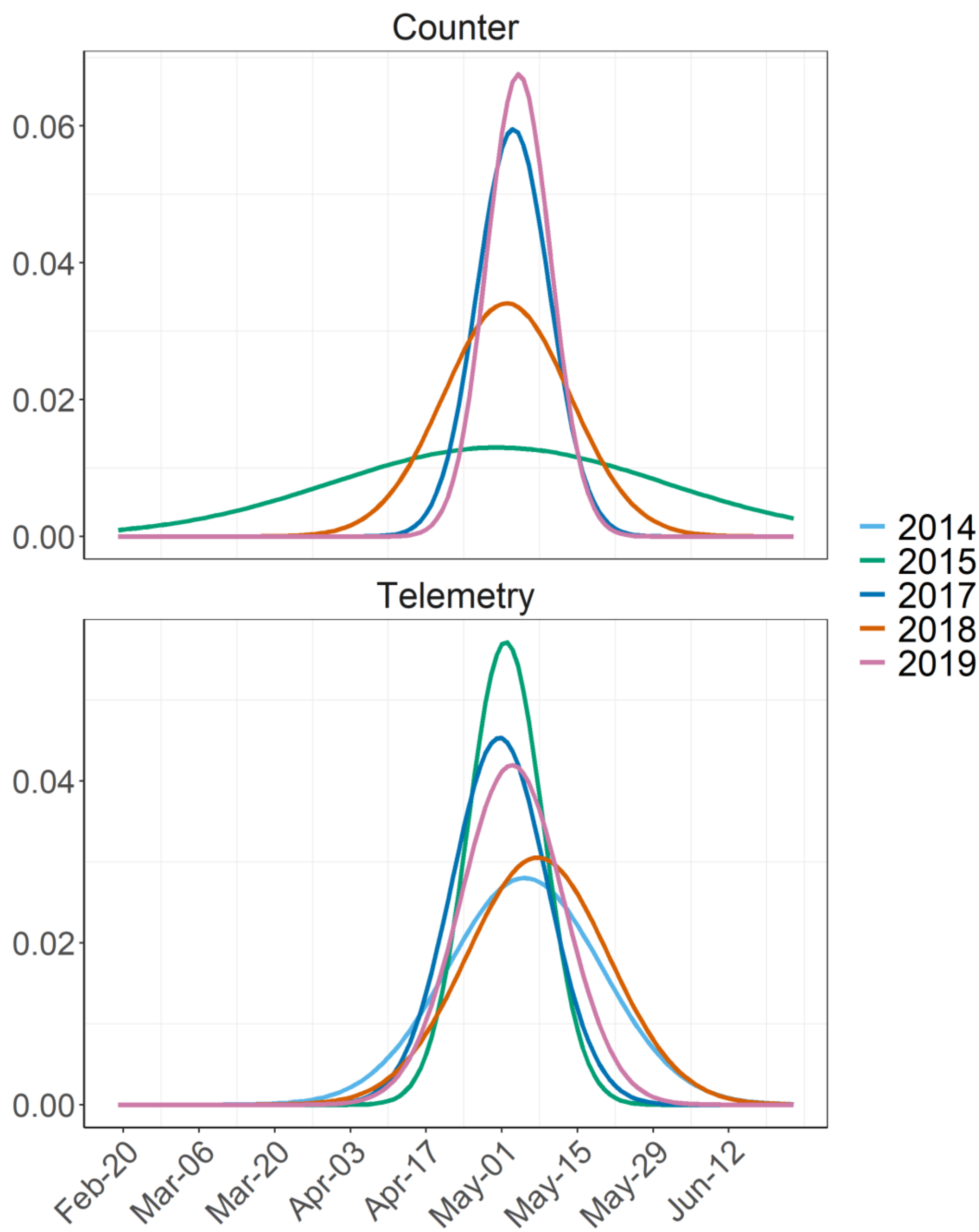

Figure 13: Normal distribution of Steelhead Trout peak migration timing from electronic counters (top) and telemetry data (bottom) from 2014-2019. Years with low sample size (n<5) or incomplete estimates were removed.

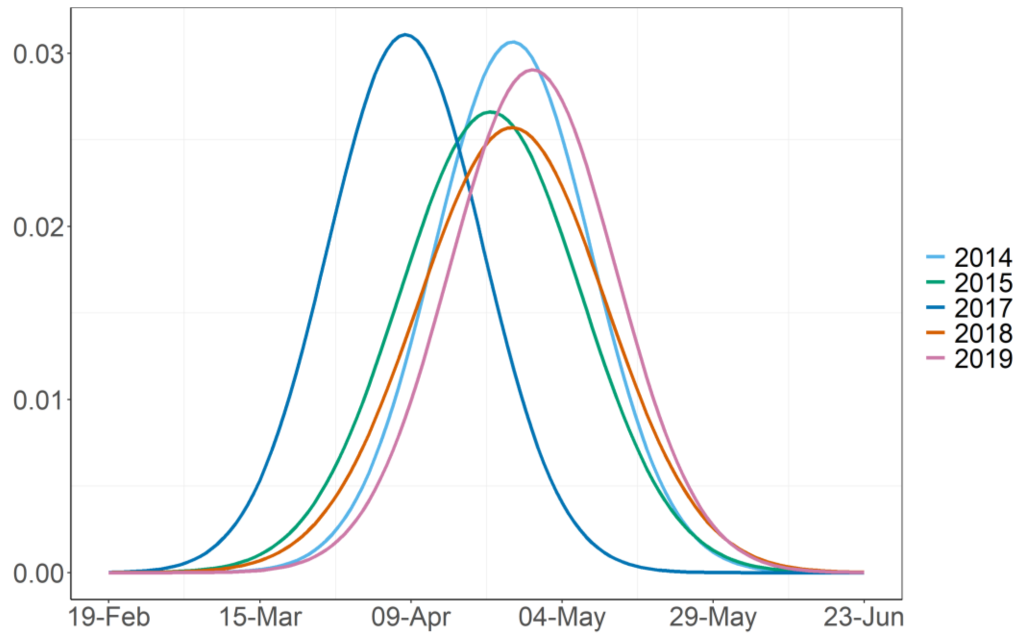

Figure 14: Normal distributions of Steelhead Trout entry into Reach 1 derived from telemetry from telemetry data from 2014 to 2018. Data with low sample sizes (n<5) were removed.

3.3.2 Chinook Salmon

To assess Chinook Salmon migration timing, telemetry data were available from 2012 to 2016, while counter data were available for 2014 through 2017 (Table 10). Decreased angling success prevented the use of telemetry data between 2017 and 2019, while the fish fence installed in 2018 and 2019 prevented the use of electronic counter data. Migration timing distributions were relatively consistent amongst 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, which is expected given that Chinook Salmon migrate in August and September and are subjected to a consistent flow regime.

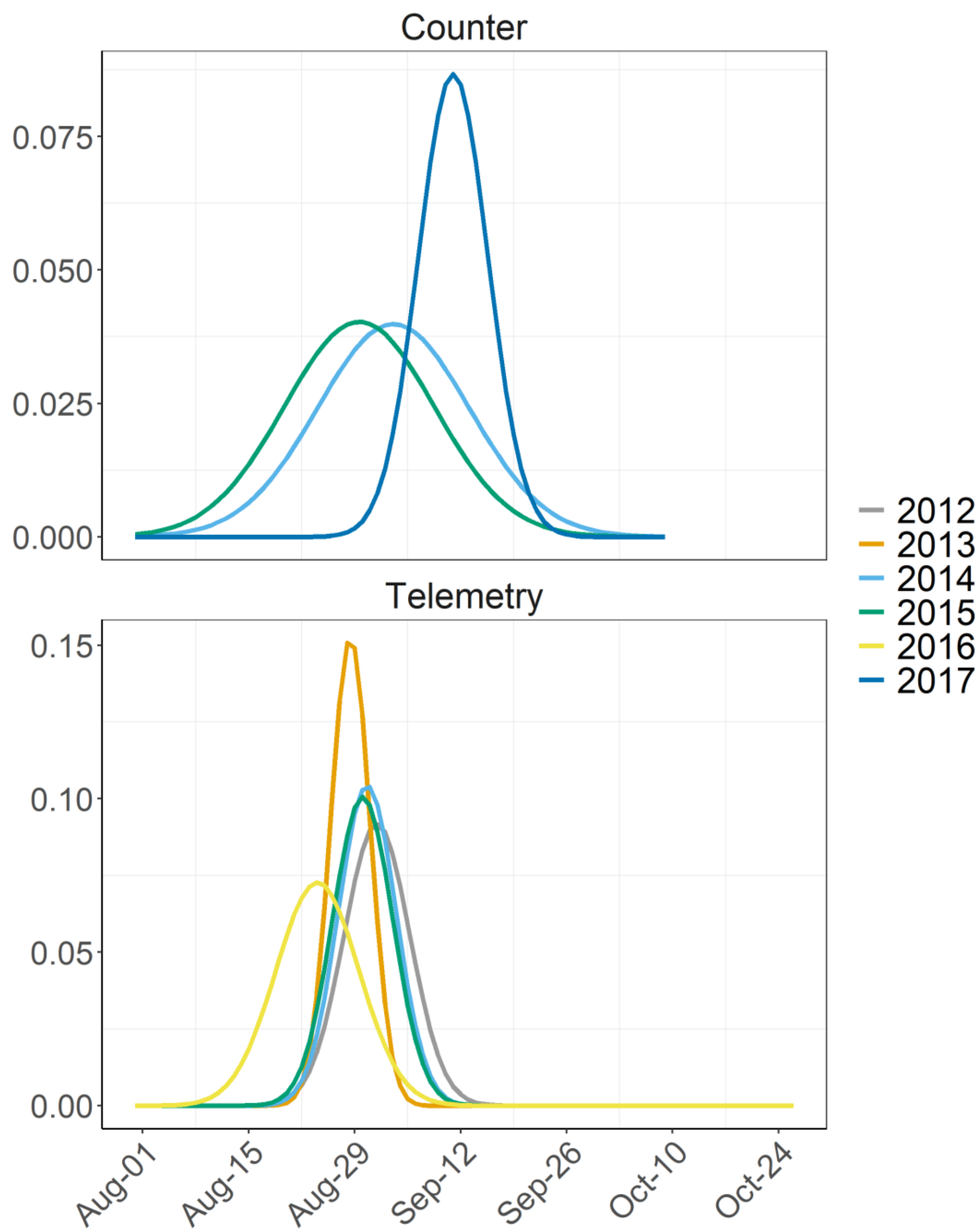

Figure 15: Normal distribution of Chinook Salmon peak migration timing from electronic counters (top) and telemetry data (bottom) from 2012-2017. Years with low sample size (n<5) or incomplete estimates were removed.

3.3.3 Coho Salmon

For Coho Salmon, telemetry data were available for 2012 to 2018 (2014 and 2015 used PIT telemetry) and electronic counter data were available in all years since 2013, except 2017 (post-season data loss;

Table 10). Migration timing distributions were relatively consistent amongst years and between the counter and telemetry data and indicate Coho Salmon typically spawn in the last week of October (Figure 16). The lack of trends in migration timing is expected given that Coho Salmon migrate in October and November and have therefore not been exposed to MOD flows.

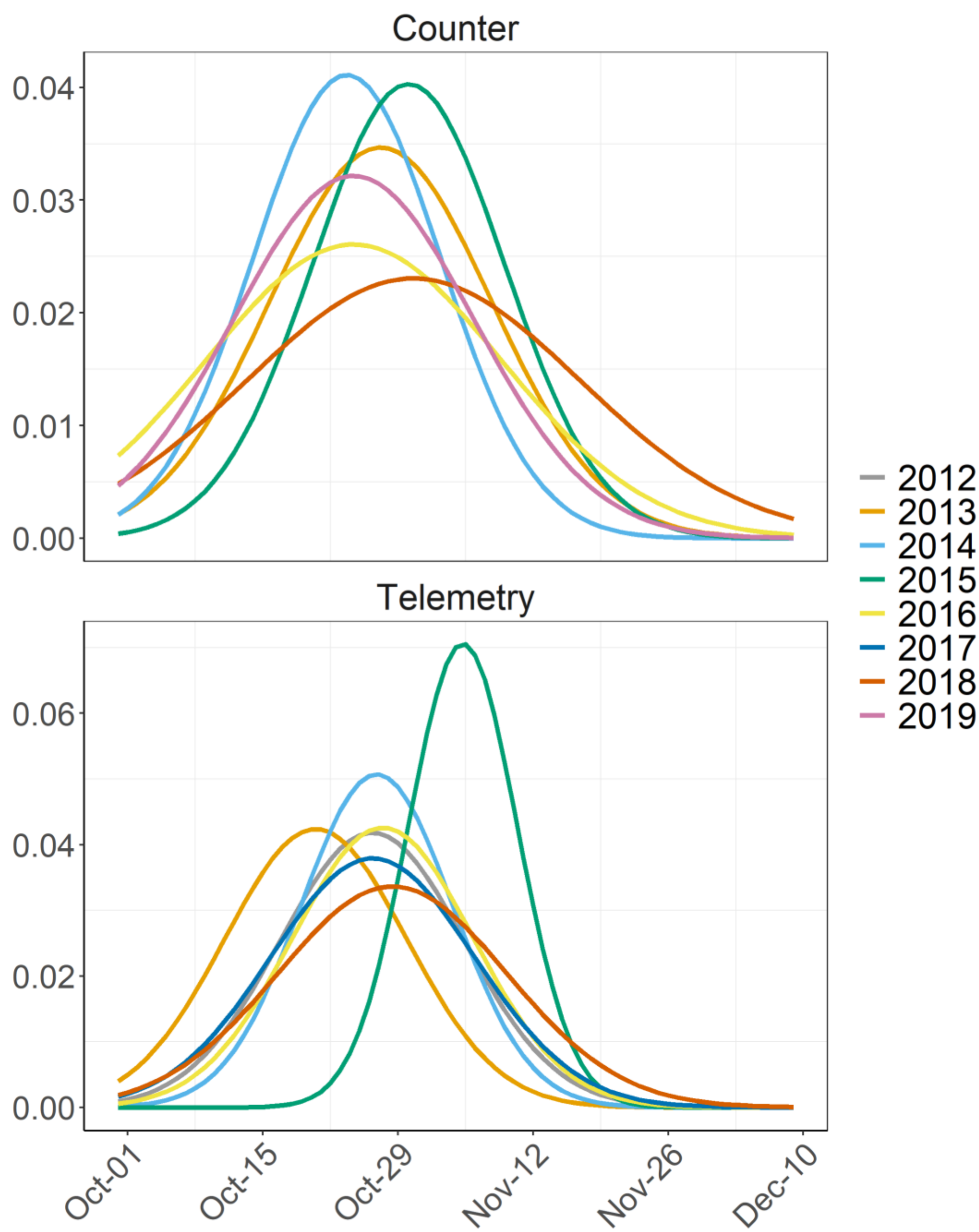

Figure 16: Normal distribution of Coho Salmon peak migration timing from electronic counters (top) and telemetry data (bottom) from 2012-2019. Years with low sample size (n<5) or incomplete estimates were removed.

3.4 Visual Counts and AUC Population Estimates

3.4.2 Chinook Salmon

Visual surveys of Chinook Salmon began on August 2, 2019 and continued until October 15, 2019, when no fish were observed. A channel-spanning fish fence was installed downstream of the visual survey study area on August 20, and therefore our surveys only assessed fish that were able to pass the fence site before this date, or fish that were released upstream by fence crews. Visual counts and AUC estimates are therefore incomplete and may represent <50% of the true AUC (peak count is typically after August 20).

As in previous years, water visibility was relatively low throughout the survey period (mean = 0.7 m ± 0.5 m; Appendix 6), suggesting a consistently low OE. Chinook Salmon were first observed on August 6, and a peak count of 31 fish occurred on September 17. In 2019, the largest cumulative percentage of spawners was observed in Reach 4 from Terzaghi Dam to Eagle (rkm 40.0 to 38.8 rkm; Figure 17). Chinook Salmon were observed in Reach 2, despite not being observed there in 2018; however, spawning behaviour was not confirmed. Visual survey data from 2019 build upon visual surveys beginning in 2012 and suggest a potential trend of increased spawning in Reach 4 and decreased spawning in Reach 3 (Figure 17).

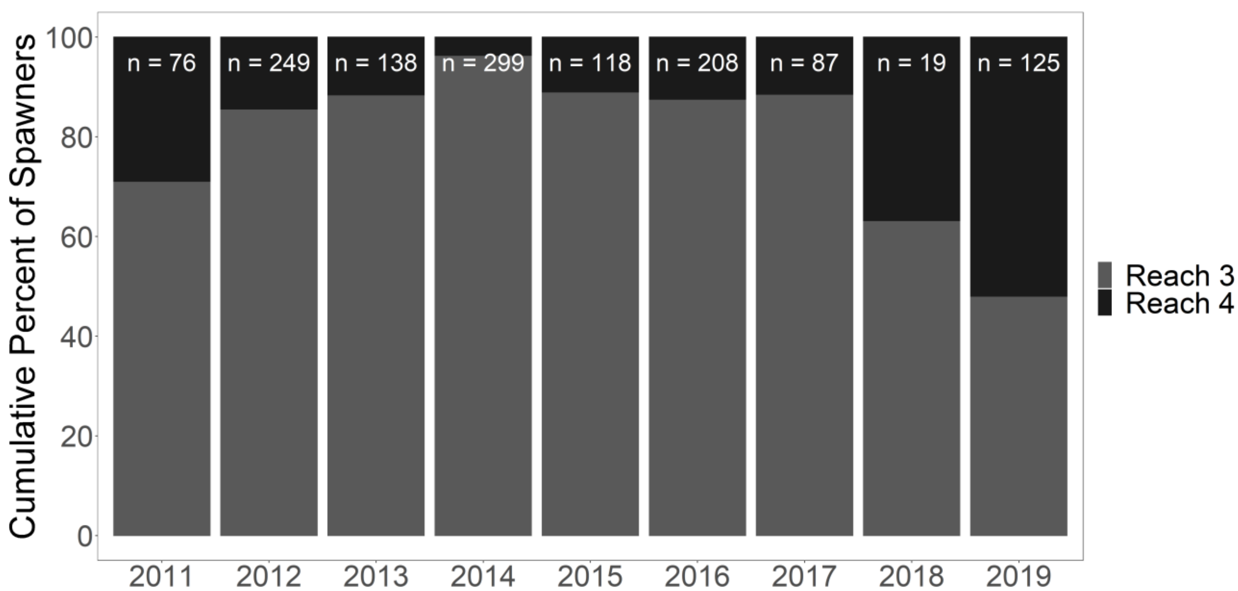

Figure 17: Cumulative proportion of Chinook Salmon spawners observed during visual surveys in Reach 3 and 4 of the LBR.

AUC Abundance Estimate

The 2019 AUC abundance of Chinook Salmon between the fish fence and Terzaghi Dam was 161 (95% CI: 84-310; Appendix 7: Historical AUC Estimates). There was insufficient radio tag and visual tag data to estimate OE and SL for 2019, and therefore average values were used (10.5 days and 0.5 for SL and OE, respectively). AUC estimates were compared with abundance estimated by electronic counters (Figure 18). Preliminary comparisons suggest counter estimates are generally higher than AUC estimates (i.e., AUC underestimates the true abundance) and that the two methods may be positively correlated but do not follow a 1:1 relationship.

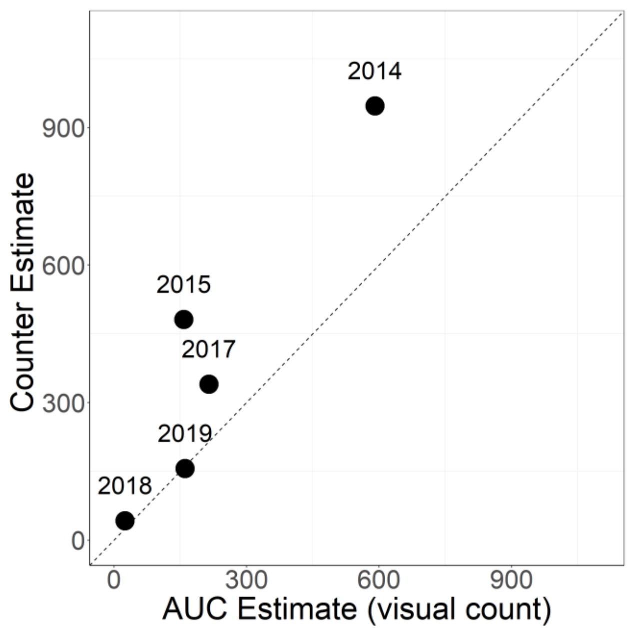

Figure 18: Comparison of Chinook Salmon AUC visual survey estimates, and estimates derived from counting technology. The 2016 point was removed from this figure as this was a sonar trial period and the estimate does not reflect the entire migration period. Dashed line represents a ratio of 1:1.

Average values of OE and SL and historic count data obtained from the 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 fish fence. 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 19). 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.

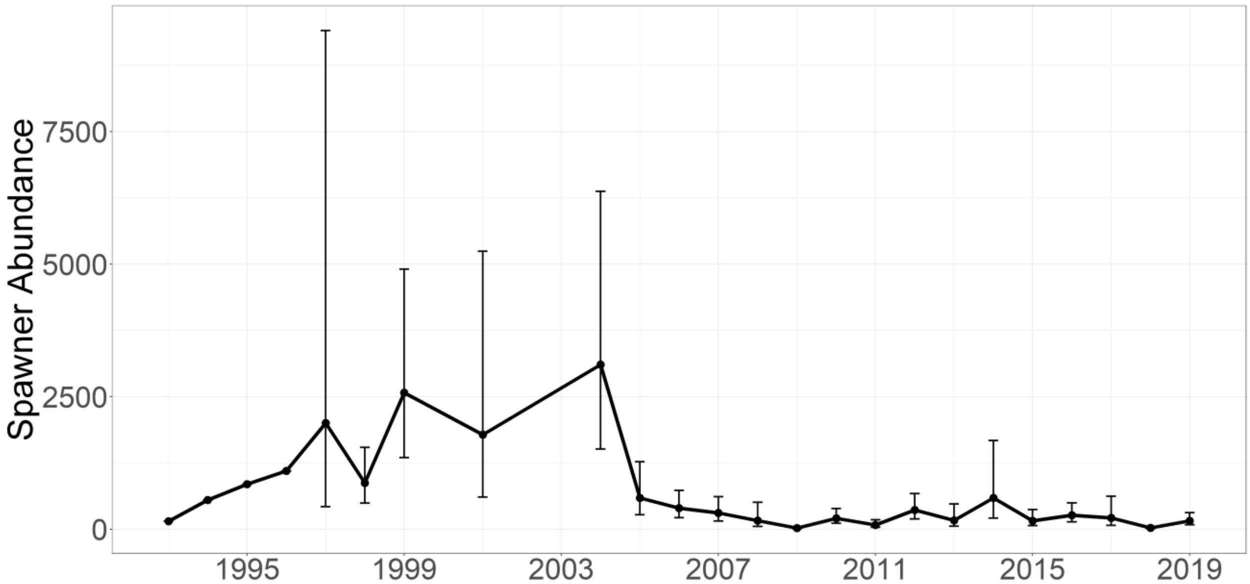

Figure 19: AUC and fence estimates for Chinook Salmon in the Lower Bridge River from 1993 to 2019. Vertical lines represent 95% confidence limits around estimates.

3.4.3 Coho Salmon

Visual counts of Coho Salmon were conducted from October 11 to December 3, at which point no fish were observed. Water clarity during October was like the Chinook Salmon migration period (mean = 0.5 m ± 0.3); however, visibility improved in November (mean = 1.1 m ± 0.25). The first Coho Salmon was observed on October 22 and a peak count of 60 fish was recorded on November 12.

In 2019, the highest cumulative percentage of spawners (80%) was observed from Plunge Pool to Eagle in Reach 4 (rkm 38.8 to 40.0; Appendix 6). A single Coho Salmon was observed during Reach 2 surveys, but no spawning behaviour was observed. The distribution of spawners has been relatively consistent from 2012 to 2019 with a higher proportion (>70%) of individuals spawning in Reach 4 (Figure 20).

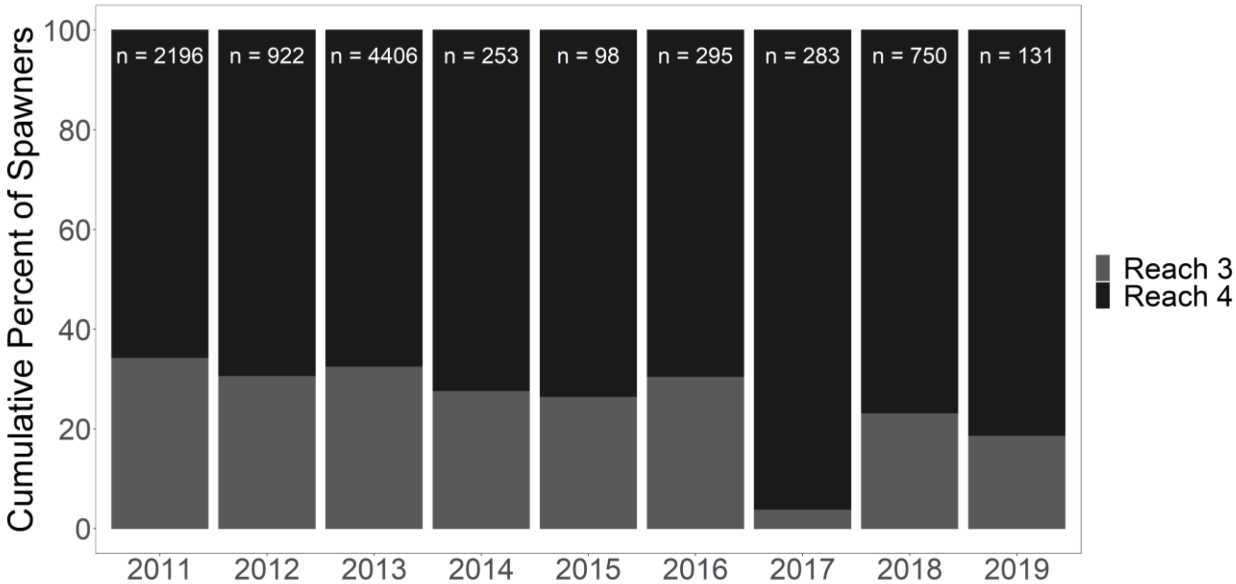

Figure 20: Cumulative proportion of Coho Salmon spawners observed during visual surveys in Reach 3 and 4 of the LBR.

AUC Abundance Estimate

Estimated AUC abundance of Coho Salmon in 2019 between the Yalakom River and Terzaghi Dam was 214 (95% CI: 152-301; Appendix 7), the lowest abundance since 2015 (174). There was insufficient radio tag and visual tag data to estimate OE and SL for 2019, and therefore average values were used (19.6 days and 0.2 for SL and OE, respectively). AUC estimates were compared with abundance estimated by electronic counters (Figure 21). Except for 2018, counter estimates have been consistently higher than AUC estimates. Additional years of comparable data will help to determine whether 2018 is an outlier and should be removed from the comparison.

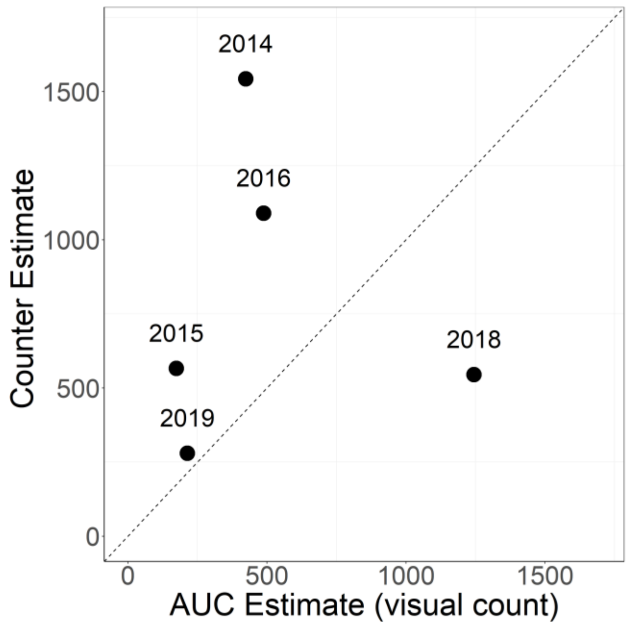

Figure 21: Comparison of Coho Salmon AUC visual survey estimates, and estimates derived from counting technology. The 2017 point is removed from this figure as no electronic data is available for this year. Dashed line represents a ratio of 1:1.

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 22).

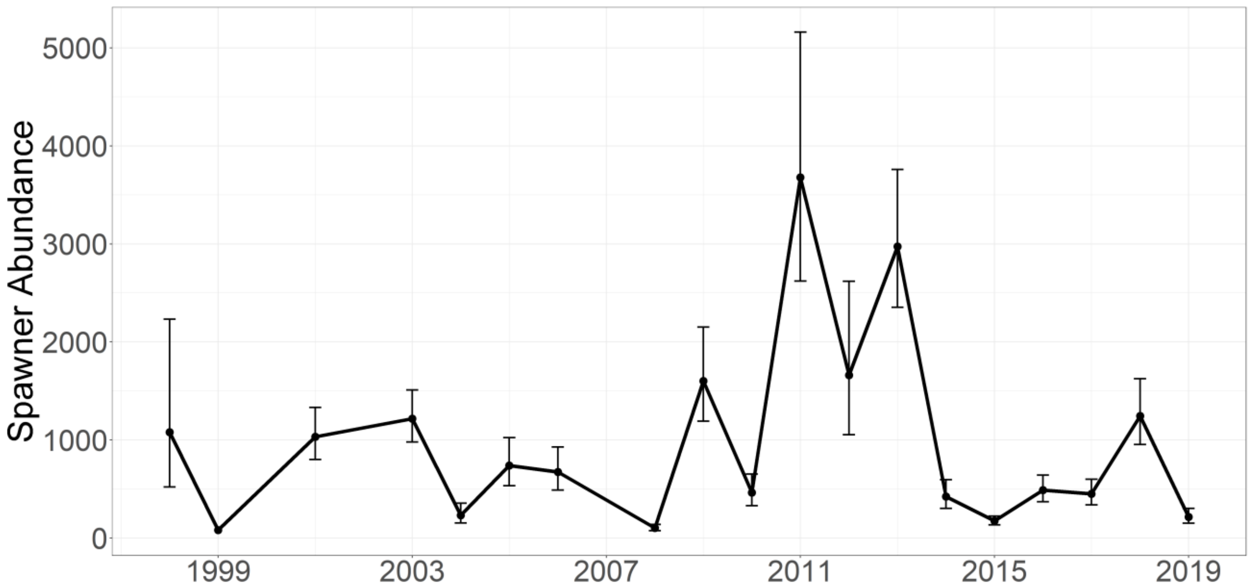

Figure 22: AUC estimates for Coho Salmon in the Lower Bridge River from 1997 to 2018. Vertical lines represent 95% confidence limits around estimate.

3.4.4 OE and SL Sensitivity Analysis

AUC estimates for both species were sensitive to input parameters, indicating that uncertainty in OE and SL compromise the accuracy and precision of both BRGMON-3 AUC estimates and historic reconstructions. The ranges of OE and SL included in the analysis reflect the standard deviations of parameter values calculated during BRGMON-3, and larger ranges therefore indicate greater uncertainty in the parameter and species being examined.

Both Chinook Salmon and Coho Salmon AUC abundance were sensitive to OE values; however, a larger range of OE values was tested for Chinook Salmon. With SL constant at 19.6 days, increasing OE from 0.17 to 0.27 resulted in a 60% decrease in estimated Coho Salmon abundance. For Chinook Salmon, with SL constant at 10.5, increasing OE from 0.22 to 0.72 resulted in a 250% decrease in estimated abundance. Coho Salmon abundance was sensitive to SL values: with OE equal to 0.22, increasing SL from 11 to 23 resulted in a 95% decrease in estimated abundance. For Chinook Salmon, because SL has been relatively consistent across years, a relatively small range of values was tested (9.5 to 11.5), which did not have a substantial effect on estimated abundance (15% decrease).

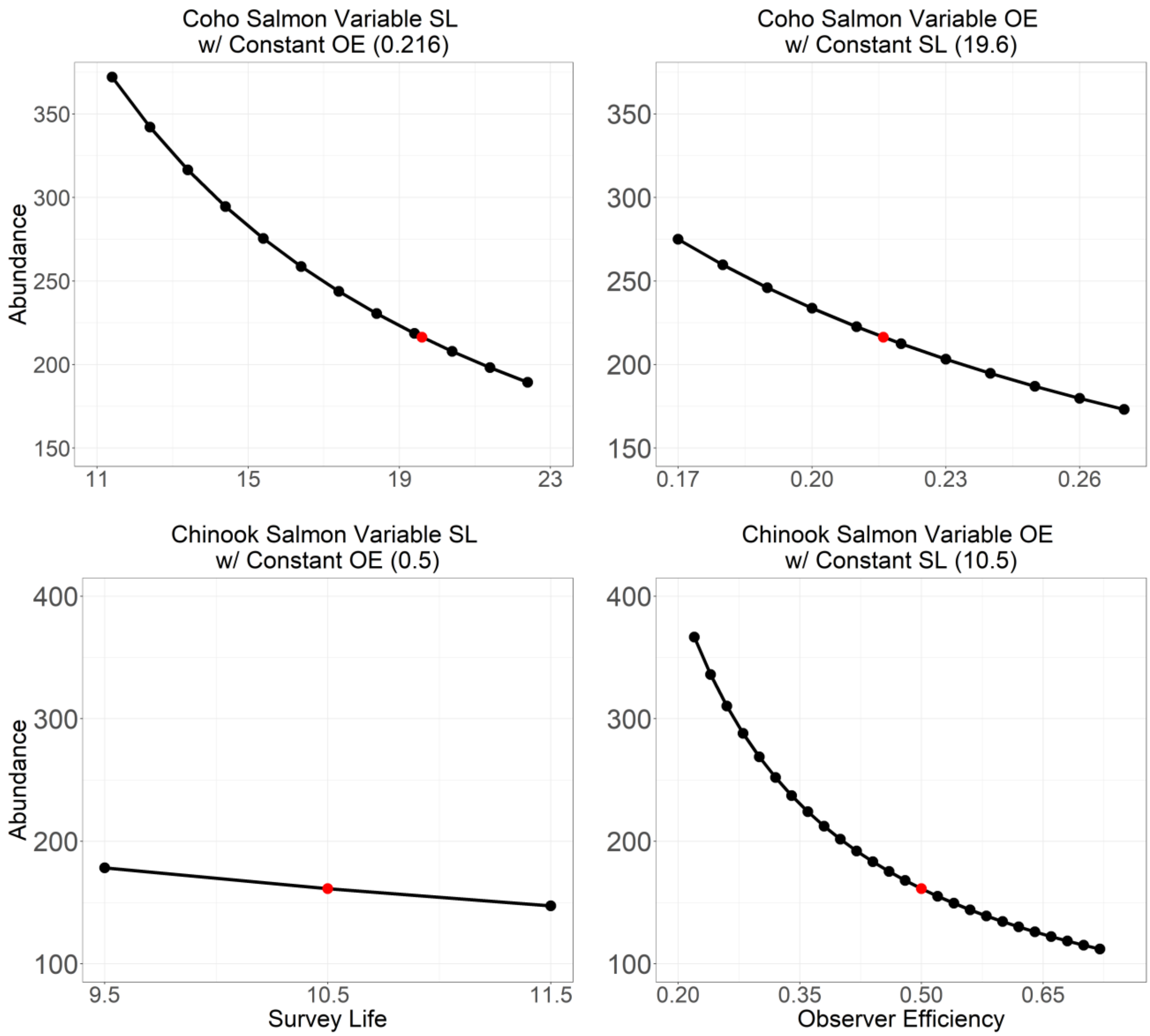

Figure 23: Sensitivity analysis testing the effects of SL and OE on abundance estimates for Coho and Chinook Salmon. Constant values (as indicated in plot titles and represented by red points) used during the analysis are those used to estimate AUC abundance in 2019.

3.5 Spawning Habitat

3.5.1 Instream Flow Incremental Methodology (IFIM)

Chinook Salmon WUA

In 2019, 112 habitat transects were monitored between August 27 and September 30, in 29 habitat units that covered 44,959.4 m^2 the LBR (Table 12; Figure 31; Appendix 8).

Table 12: Number of transects, total area sampled, and estimated Weighted Usable Area (WUA) for Chinook Salmon and Coho Salmon spawning habitat assessments in the LBR in 2019.

Reach	Habitat Units Sampled	Number of Transects	Area Surveyed (m^2)	Chinook Salmon WUA (m^2)	Chinook Salmon WUA %	Coho Salmon WUA (m^2)	Coho Salmon WUA %
1	3	14	5964.5	2676.9	44.9	1993.1	33.4
2	9	28	17890.0	7999.0	44.7	8517.2	47.6
3	13	55	15949.8	2422.0	15.2	1574.7	9.9
4	4	15	5336.5	880.6	16.5	1043.3	19.6
Total	**29**	**112**	**45140.8**	**13978.4**	**-**	**13128.3**	**-**

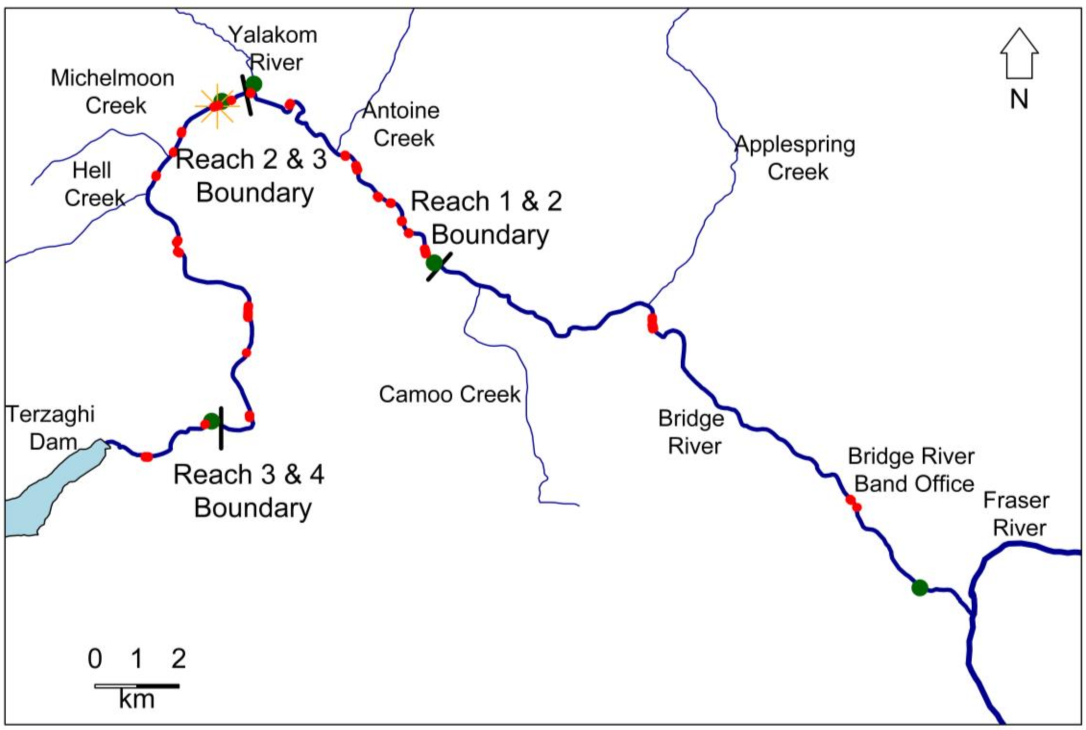

Figure 24: Habitat units (red) where transects were performed to assess Chinook and Coho Salmon spawning habitat. Green points are radio telemetry locations and black lines indicate the boundary between study Reaches.

Transect data were applied to established HSI curves for Chinook Salmon (Ptolemy 1994) and the total WUA in all sampled habitats was 13,978 m^2 (Table 11). The largest amounts of WUA and the highest percent WUA of the total area surveyed were found in Reach 1 and Reach 2 (Figure 32). Specifically, WUA was concentrated above the Camoo FSR bridge (16.2%) and below Antoine Creek (11.2%) in Reach

2 (Appendix 8). Redd surveys indicate that Chinook Salmon redds are <2.0 m^2 in area (Ramos-Espinoza et al. 2018), and therefore spawning habitat is not limiting Chinook Salmon production in the LBR. There was no statistical difference in the mean Chinook Salmon WUA in Reach 3 and 4 amongst 2017 through 2019 (Figure 25; ANOVA: $F_{2, 46} = 0.48$, $p = 0.62$). This suggests that high flows in the spring and summer of 2018 did not significantly affect the quantity of spawning habitat available in Reaches 3 and 4 of the LBR. This finding is corroborated by redd survey data, which indicate depths, velocities, and substrate characteristics at confirmed spawning locations are currently within preferred ranges and are not limiting spawning in the LBR (see Section 3.5.2).

WUA data are available for all reaches in 2018 and 2019, and a comparison between these two years found no significant difference in the mean amount of WUA (ANOVA: $F_{1, 58} = 0.10$, $p = 0.75$). The lack of difference in habitat quantity between the two years is expected given that no high flows occurred between the two surveys, and suggest that HSI surveys are a robust method that can be used to assess changes habitat quantity in the LBR.

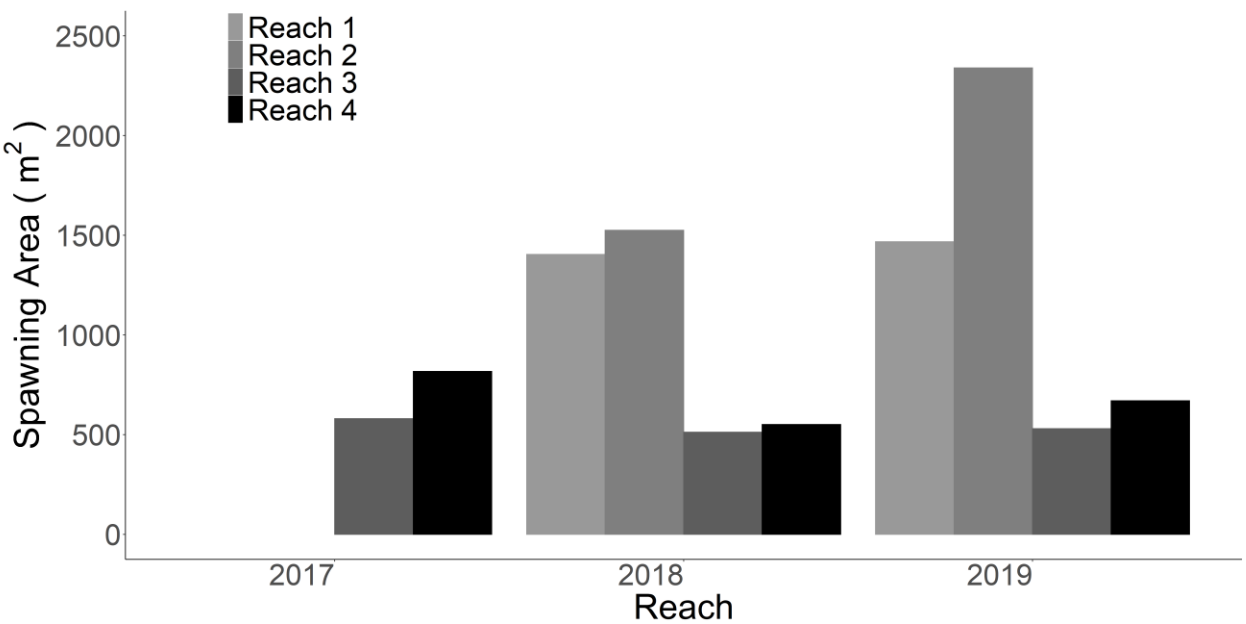

Figure 25: Weighted usable Chinook Salmon spawning area, separated by year following the high flows in 2017, 2018, 2019.

Coho Salmon WUA

This was the first year that WUA was calculated for Coho Salmon. IFIM surveys took place between October 7 to 16, while discharge was at 1.5 m^3s^{-1}. The total WUA for Coho Salmon in Reaches 1 through 4 was 13,128 m^2, with the majority located in Reaches 2 and 3 (Table 11). The largest quantities of WUA in Reach 2 were at Camoo FSR bridge (27.8%) and below Antoine Creek (10.4%) and at Apple Springs in Reach 1 (9.5%).

Substrate Analysis

A detailed quantitative analysis of substrate suggested that substrate size decreased in the LBR following high flows in 2018. Both the Reach 1/2 and the Reach 3/4 lme models that evaluated changes to substrate size with reach and year found significant effects of year, and the year-by-reach interaction, but not reach itself (Table 13). That is, substrate size did not vary between Reach 1 and 2 or between Reach 3 and 4 (no main effect of Reach in either model), but did change across years (significant main effect of year); the magnitude of change also differed between Reaches (significant interaction). Random effects accounted for ~5% of variation in both models, and with few exceptions, results were consistent among individual transects.

Table 13: Model terms from two linear mixed effects models evaluating changes in substrate size with reach, year, and their interaction. Models were conducted separately for Reach 1/2 and Reach 3/4 given the differences in years surveyed.

	Reach 1 and 2 Model			Reach 3 and 4 Model		
Term	Estimate	SE	p-value	Estimate	SE	p-value
Intercept	8.19	0.40	NA	11.70	0.22	NA
Year	-0.049	0.17	< 0.0001	-3.08	0.073	< 0.0001
Reach	0.76	0.47	0.46	-0.98	0.51	0.12
Year:Reach	-2.18	0.20	< 0.0001	0.27	0.18	< 0.0001

Post hoc comparisons of year – the only main fixed-effect factors with significance in the overall model – indicate that substrate size has significantly decreased across years, except for in Reach 1 (Table 14). In Reach 1 there has been no change in substrate size. In Reach 3 and 4, a larger decrease occurred from 2017 to 2018, while the decrease from 2018 to 2019 was small and only weakly significant. These results are expected given there were no high flow periods between the 2018 and 2019 surveys (Figure 26; Appendix 9).

Table 14: A linear mixed-effects model evaluating effects of year and reach on substrate size was followed up by post hoc comparisons using least-squares means. Resulting term estimates, standard errors (SE), and p-values are shown for sequential year comparisons. The main effect of Reach was not significant.

Years Compared		Reach	Estimate	SE	p-value
2018	2019	1	0.0487	0.173	0.99
2018	2019	2	2.23	0.106	< 0.0001
2017	2018	3	2.39	0.0731	< 0.0001
2018	2019	3	1.37	0.072	< 0.0001
2017	2018	4	2.53	0.166	< 0.0001
2018	2019	4	0.556	0.149	0.002

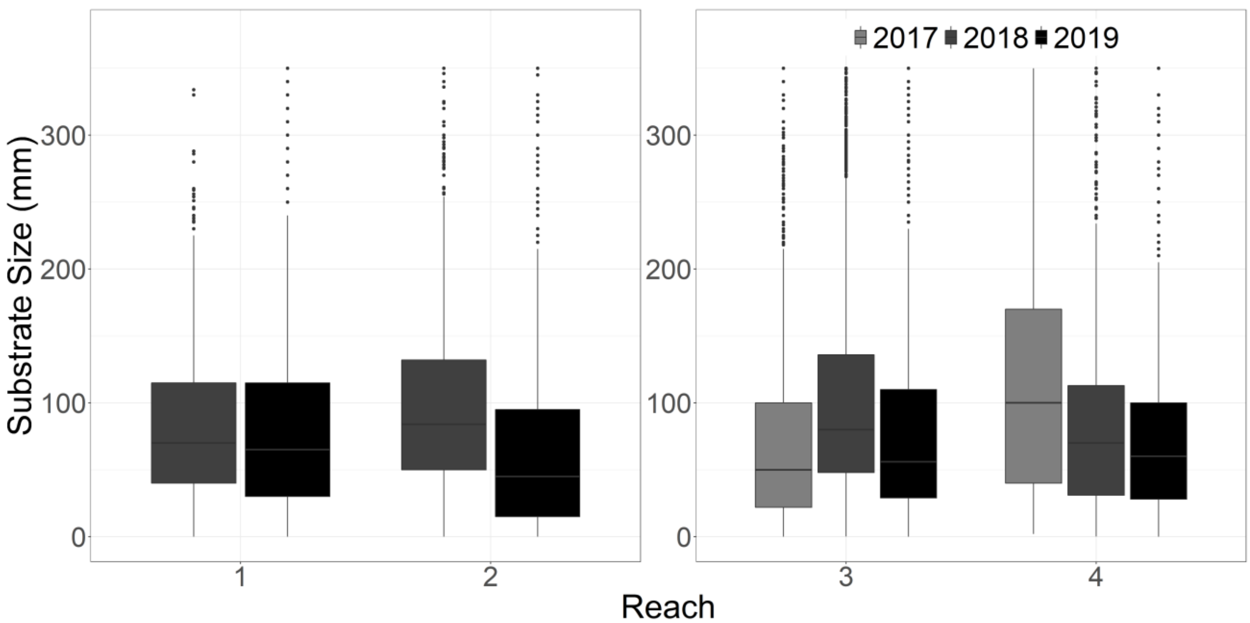

Figure 26: Substrate size (mm) measured at HSI transects in the Lower Bridge River from 2018 to 2019 in Reach 1 and 2 and 2017-2019 in Reach 3 and 4. Solid lines denote the annual median substrate size and boxes represent the interquartile range (IQR). Measurements greater than 350 mm were removed from the figure for clarity.

3.5.2 Redd Surveys

Chinook Salmon

In 2019, 6 Chinook Salmon redds were observed in Reach 3 and 2 redds were observed in Reach 4. All redds were in run habitat, consistent with observations from 2014 to 2018. Depths and water velocities at redd locations were similar between years and were consistent with average preferences of 35 cm and 0.5 ms^{-1} stated in McPhail and McPhail (2007; Figure 27). Substrate size was variable, but within species preferences of 25-150mm stated in Groves and Chandler 1999).

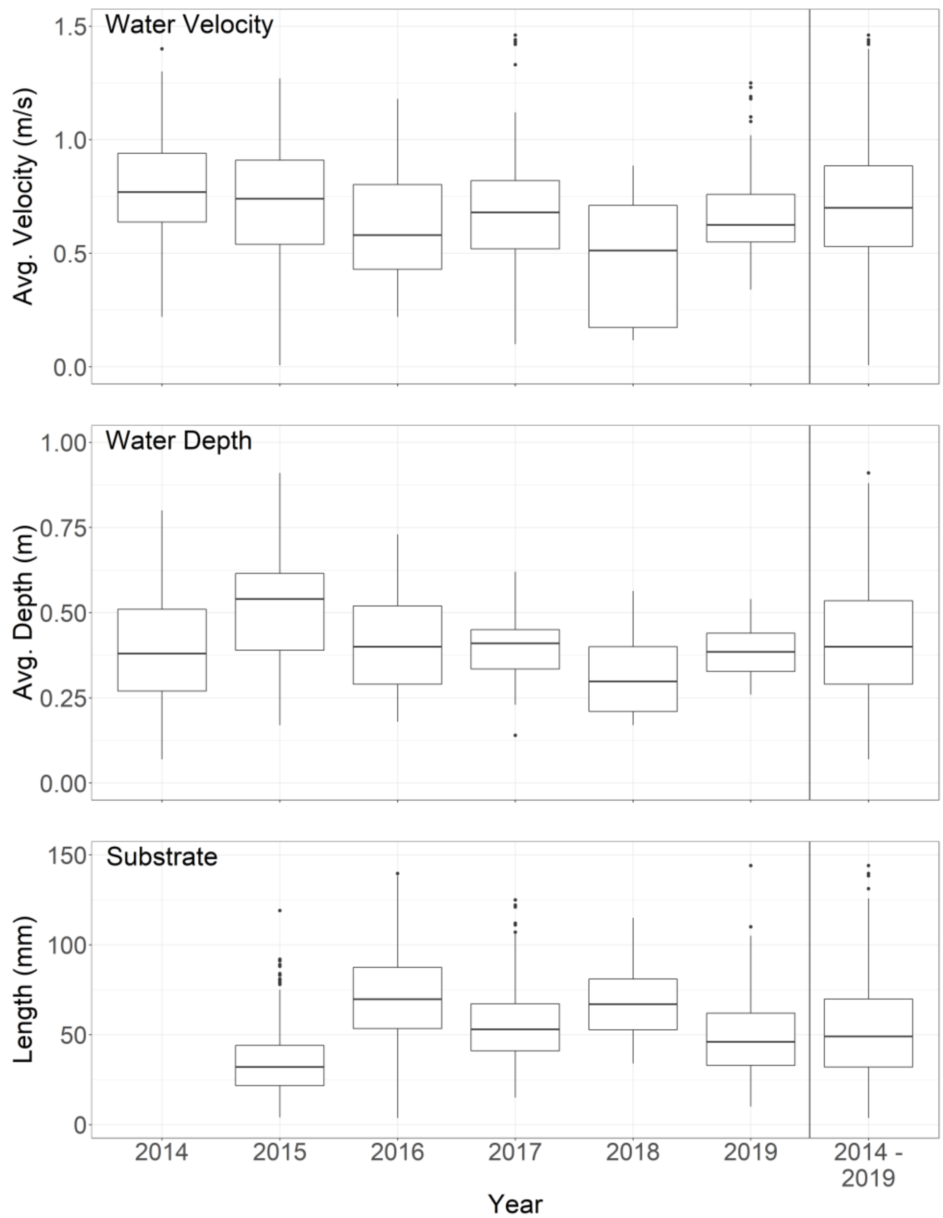

Figure 27: Water velocities (ms^{-1}), depths (m) and substrate (mm) measured at Chinook Salmon redds in the Lower Bridge River from 2014 to 2019 and for all data combined. Solid lines denote the annual median water depth, boxes represent the interquartile range (IQR). Lines represent the range excluding outliers, which are shown as points. Substrate surveys were not conducted in 2014.

Redd distributions was evaluated to inform the effect of flow regime on spawner distributions; however, the fish fence installed upstream of the counter site on August 20, 2019 severely restricts our ability to assess redd distributions in Reaches 3 and 4. Of the eight redds surveyed in 2019, one was in Longskinny (rkm 39.6), one was in Eagle (rkm 38.8) and the remaining were between the counter site and fish fence (rkm 26; Figure 28). No redds were observed during Reach 2 visual surveys or Reach 1 spot counts. In 2014 and 2015, prior to the implementation of the MOD flow regime, Chinook Salmon redds were only observed in Reach 3 (Figure 29). Since 2016, redds have been observed in Reach 4 in all years (Figure 28, Appendix 10), indicating that Chinook Salmon spawner distributions may have been affected by MOD high flows.

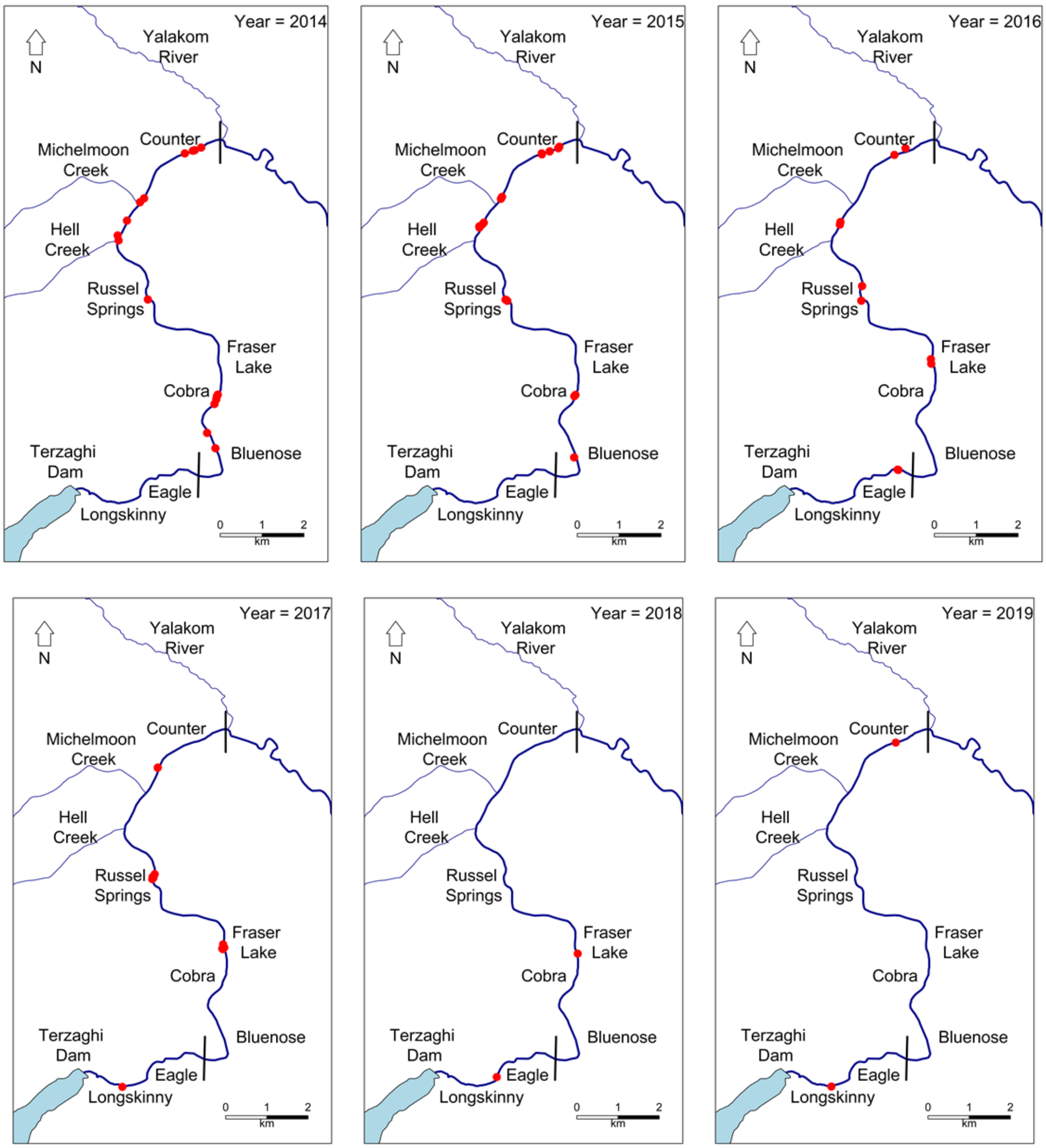

Figure 28: Location of Chinook Salmon redds in the Lower Bridge River in 2014 - 2019. Black lines indicate the boundary between reaches.

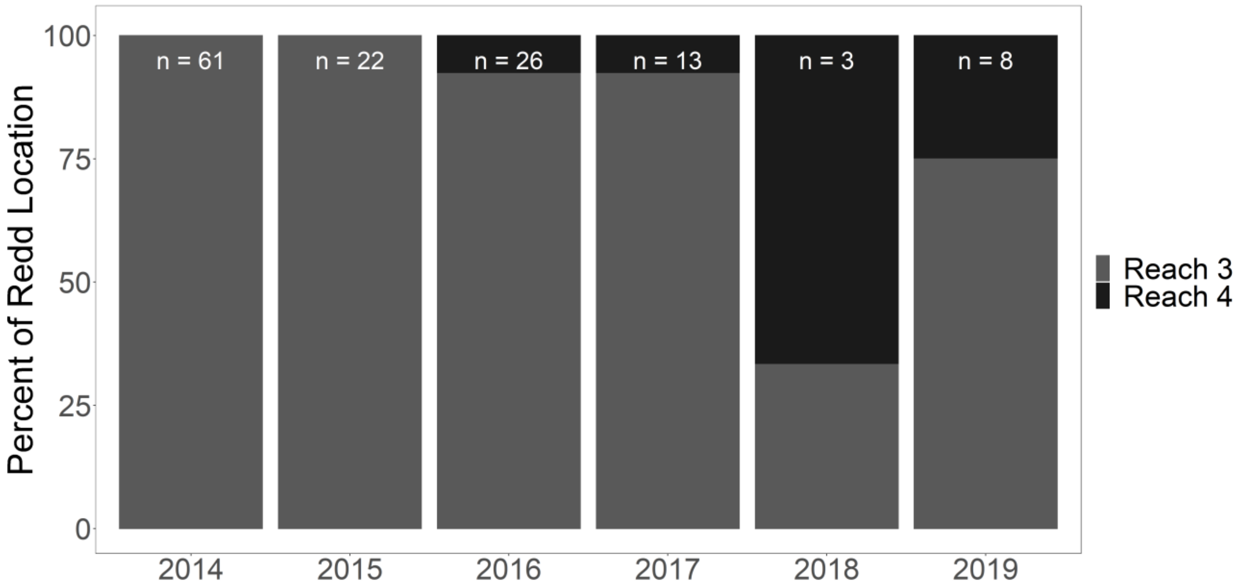

Figure 29: Proportion of Chinook Salmon redds observed in Reach 3 and 4 of the LBR.

Coho Salmon

Coho Salmon redds were observed in Reach 4 (n = 6). All redds were in run habitat, consistent with observations from 2018. Redds sampled in 2019 had average water depths of 0.24 m ± 0.07, velocities of 0.53 m s^{-1} ± 0.12 and a geometric mean particle size of 38 mm ± 1.8. These mean values are within preferred values of depths >18 cm, velocities of 0.3-0.91 ms^{-1} (Levy and Slaney 1993) and substrate between 13-102mm (Reisner and Bjornn 1979). No comparison between 2018 and 2019 redd characteristics was made due to the limited sample size, but this comparison may be made with additional years of data.

All six Coho Salmon redds were observed in Reach 4, either in Longskinny (n = 4; rkm 39.6) or at the outflow of Eagle pool (n = 2; rkm 38.8), whereas in 2018 68% of redds were in Reach 4 (21/31). No redds were observed during Reach 2 visual surveys or Reach 1 spot counts. Inferring changes in redd distributions is limited to only two years of data and small sample size within years; however, from 2018 to 2019 there appears to be a shift in redd distribution from Reach 3 to Reach 4 (Appendix 9).

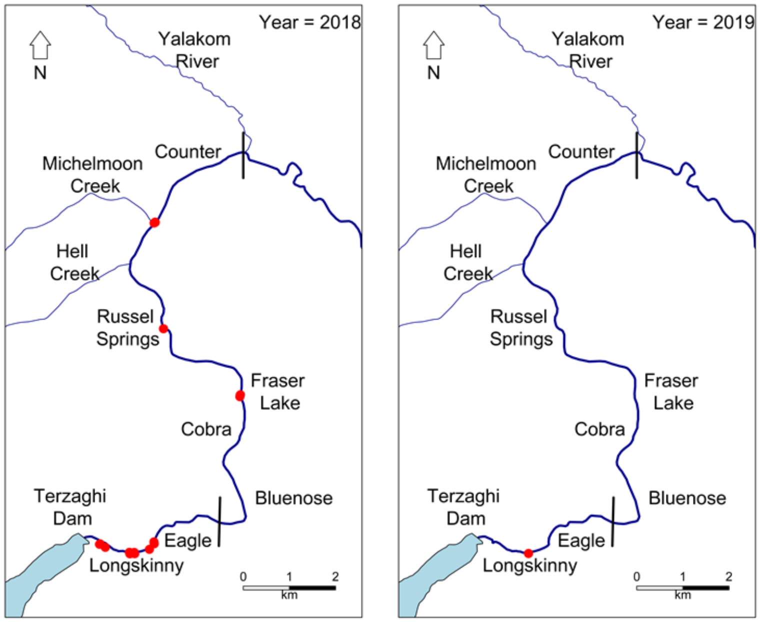

Figure 30: Location of Coho Salmon redds in the Lower Bridge River in 2018 and 2019. Black lines indicate the boundary between reaches 2 and 3 and reaches 3 and 4.

3.6 Ageing of Adult Salmon and Steelhead Trout

3.6.1 Steelhead Trout

Three scales from Steelhead Trout assumed to have spawned in the LBR in 2019 were aged (unable to obtain readable scales from five of the eight fish that entered the LBR). Since 2014, 49 Steelhead Trout scales have been aged. The dominant age classes of fish with confirmed spawning in the LBR were age 5 (i.e., 2.3, 3.2), followed by age 6 (3.3), and age 4 (2.2, 3.1; Figure 31; Appendix 10). Scale ages suggest the proportion of spawners residing in saltwater for 2+ years has increased since 2014. Also, scales collected in 2019 did not show evidence of repeat spawning, which has been observed during scale analysis in previous years.

The ages of all Steelhead Trout captured and aged in 2018 and 2019 were examined to determine whether these fish were exposed to high flows as juveniles. Fish that smolted in 2016 were not considered to have been exposed to high flows as they likely migrated prior to high flows. Very few of the adults aged in 2018 or 2019 were exposed to high flows. Only two individuals captured in 2019 were exposed to high flows in 2016 when they were two years of age, all other adult returns did not experience a high flow event (Table 15). Scale sample sizes are small, but there may be evidence that brood years exposed to high flows have lower adult returns. This hypothesis is preliminary and will be further investigated with additional years of ageing data.

Table 15: Steelhead Trout ages collected from tagged individuals in 2018 and 2019, indicating brood and smolt year, exposure to high flows, and sample size.

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

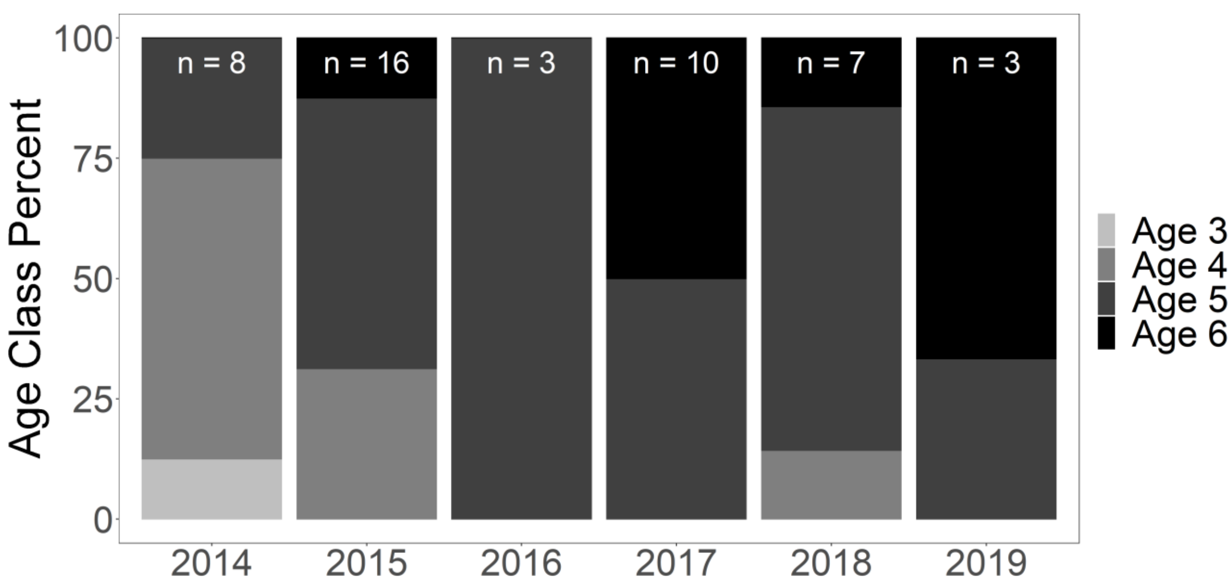

Figure 31: Relative proportion of Steelhead Trout total age classes by year from 2014 to 2019.

3.6.2 Chinook Salmon

Four Chinook Salmon scales were aged in 2019, all of which were assessed as age 1.3. All Chinook Salmon returning at age 1.3 in 2019 would have experienced high flows in the LBR as juveniles in the spring of 2016. Since 2014, 54 Chinook Salmon scales have been aged. All scales displayed a yearling (stream-type) life history, with juveniles spending one winter in freshwater. The majority of scales have been age 4, relative to age 3 (1.2, Figure 32; Appendix 11).

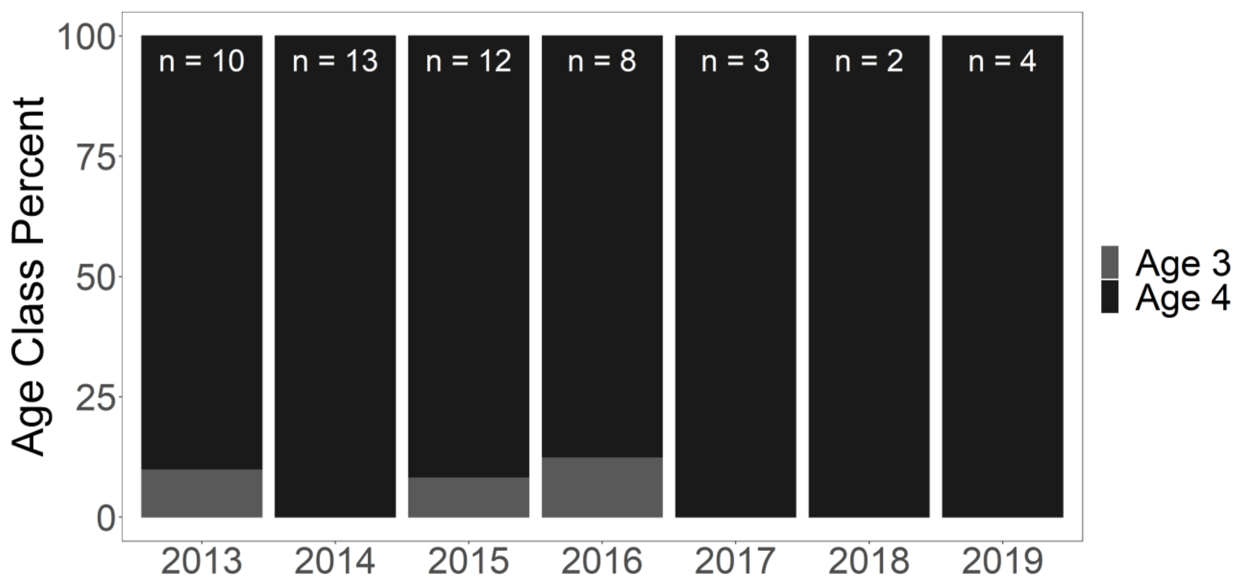

Figure 32: Relative proportion of Chinook Salmon total age classes by year from 2013 to 2019.

3.6.3 Coho Salmon

Three Coho Salmon scales were aged in 2019 that were collected during visual surveys in Reach 3 and 4. Only two individuals were assumed to have spawned in the LBR via radio telemetry; however, these scales were not readable. Since 2011, 158 Coho Salmon scales have been aged. LBR Coho Salmon returned most frequently at age 2 (1.1) followed by age 3 (2.1; Figure 33). Coho Salmon returning at either age 1.1 or 2.1 in 2019 would have experienced high flows in the LBR as juveniles in the spring of 2017 and 2016 and 2017, respectively. All scales displayed similar juvenile life histories, with juveniles spending 1-2 years in freshwater before out-migrating as smolts. One scale collected in 2014 was assessed as age 1.2, indicating it spent one winter in freshwater and two in saltwater (not shown in Figure 33; Appendix 11).

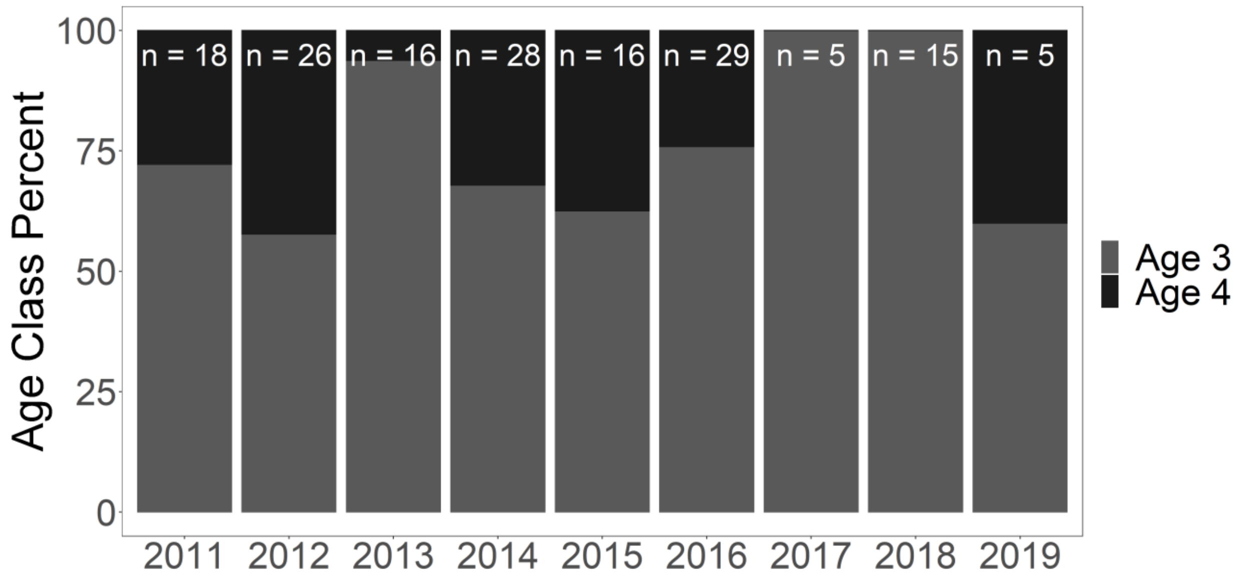

Figure 33: Relative proportion of Coho Salmon age classes by year from 2011 to 2019.

4.0 Discussion

BRGMON-3 monitors adult abundance and habitat quantity and quality and supports BRGMON-1, which evaluates the effects of LBR flow regime on salmonid productivity. The monitor also evaluates the effects of instream flow and MOD flows on adult salmonid abundance, migration timing, spawner distribution, and quantity and quality of spawning habitat in the LBR. Beginning in 2019 and first reported upon here, BRGMON-3 now addresses four management questions: two management questions related to WUP flows, and two related to MOD flows. Monitoring in 2019 builds upon data from 2012 to 2018 and will be used to answer the management questions and inform future monitoring.

4.1 Terzaghi Dam Operating Parameters

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

MOD discharges have involved several flow variances, but all exceeded 50 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 migrations, 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. For example, during MOD years 2016 through 2018, LBR discharge on May 15 was >50 m^3s^{-1} but was <20 m^3s^{-1} during WUP years and in 2019.

4.2 BRGMON-3 Management Questions

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

Abundance

Steelhead Trout abundance has declined over the course of this monitor (2014-2019), while Chinook Salmon and Coho Salmon abundance has been declining in the LBR since before the implementation of BRGMON-3 (1993-2013; unpublished DFO data). Steelhead Trout abundance in 2019 was 50, which is the highest since 2015 (59); however, almost five times lower than the first year of counter operation in 2014 (238). Chinook Salmon abundance in 2019 was 156, which is the second lowest observed over the monitor and four times less than the highest estimate in 2014 (947). Coho Salmon abundance in 2019 was 280, which is the lowest observed over this monitor and two times less than the next highest abundance in 2018 (545).

Flow variances are only experienced by Steelhead Trout adults, as flows are consistent for Chinook and Coho Salmon migration periods. Eggs and juveniles exposed to high flows may be affected; however, abundance declines observed in adults 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, the effect of a fish fence installed for broodstock collection, increased straying due to the Fraser River rockslide) and uncertain conditions affecting salmonids outside of the LBR (e.g., ocean temperatures, fishing pressures, disease, etc.). Also, 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, and effects of flow regime on adult 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 we have found no clear link between spawner escapement and LBR flow.

Adult abundance is estimated using two methods: electronic counter equipment and AUC modeling using visual survey data (Chinook and Coho Salmon only). An objective 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. Initial comparisons between counter and AUC estimates suggest no relationship between the two methods. AUC estimates are highly uncertain in the LBR due to low counts, poor visual conditions, and uncertainty in OE and SL. 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. We will continue to compare abundance estimated from electric counter and visual surveys as this comparison is valuable for understanding the utility and limitations of both current and historic AUC estimates.

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

Migration Timing

Peak migration timing has been relatively consistent amongst monitoring years despite inconsistent counting methods and sample size limitations, suggesting there is no clear relationship between instream flow and migration timing in the LBR. The Steelhead Trout migration may be most vulnerable to MOD flows as Steelhead enter the LBR during the increasing limb of the spring hydrograph. Despite experiencing variable discharge conditions throughout BRGMON-3, peak migration and entry into Reach 1 has remained relatively consistent for Steelhead Trout.

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. Early Chinook Salmon migrants present in the LBR in the beginning of August may be exposed to higher discharges as the LBR hydrograph descends from its peak in early August to 3.0 m^3s^{-1} by mid-August. Although Chinook Salmon were observed in the LBR in early August of 2019, peak migration is typically later in August or in early September when the hydrograph is stable at WUP target flows. Early migrants in 2019 could potentially be strays from other rivers, as high levels of straying were observed during the broodstock collection program. However, Coho Salmon migration timing remained consistent in 2019 even with potential stray fish included. Ageing analyses suggest instream flow regime may affect age distributions of returning Steelhead Trout spawners in the LBR, but not for Chinook or Coho Salmon. Steelhead Trout have a more diverse life history, and BRGMON-3 ageing has identified six different life history types. Adult Steelhead Trout cohorts exposed to high flows as juveniles have been relatively absent from scale analyses in 2018 and 2019 (8%). In the LBR, the most common age classes of Steelhead Trout spawners are ages 5 and 6, and age 5/6 spawners returning in 2020 and 2021 will represent the first cohorts of these ages exposed to high flows as juveniles. Low returns of age classes 5 and 6 in 2020 and 2021 could indicate that high flows negatively affected juvenile Steelhead Trout survival in the LBR. 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 (1 freshwater and 3 saltwater winters) and Coho Salmon typically return to spawn at 1.1 or 2.1, and we have not observed a substantial change in age class data since the onset of high flows, although the sample sizes for these two species have been low (<5) for the past two years.

Spawner Distribution

Our discussion on spawner distribution is combined with a 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 that there is no clear relationship between instream flow and distribution of spawning salmon and Steelhead Trout in the LBR. Competition for spawning habitat is likely low for all species given low spawner abundances in the LBR, and habitat surveys indicated that spawning habitat is not limiting.

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 for the first time in 2018. Despite limited success angling Chinook Salmon from 2017 to 2019, telemetry data, redd surveys, and visual surveys all suggest Chinook Salmon prefer to spawn in Reach 3 but are increasingly spawning in Reach 4 following MOD flows.

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) and the upper sections of Reach 3 were deemed unsuitable for spawning given larger substrate size (Lister and Beniston 1995). Lister and Beniston 1995, mention that flow stability and groundwater influence could produce favorable conditions for spawning salmon, despite the limitation is suitable substrate. 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 may have increased spawning habitats in Reaches 3 and 4, which could partially explain the shift in spawning distributions between the 1990s and today. Spawner distributions may also have been impacted by factors outside of the flow regime. The broodstock collection program in 2018 and 2019 disrupted the natural migration of Chinook Salmon above the counter site and may have altered spawning site selection. In addition, the Fraser rockslide in 2019 resulted in an increased prevalence of stray fish in the LBR, and these individuals may have different spawning preferences (Keefer and Caudill 2014).

Increased spawning in Reach 4 may affect survivorship of juveniles due to variations in thermal regime (Geist et al. 2006). Releases from Terzaghi Dam are warmer than observed further downstream in the LBR and an upstream shift in spawning could accelerate gamete development and lead to early emergence. ATU calculations (accumulated thermal units) 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. The potential shift of Chinook Salmon spawning preference from Reach 3 to Reach 4 should continue to be monitored.

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?

IFIM monitoring in 2017 through 2019 and redd surveys since 2014 suggest that access to abundant high-quality spawning habitat is not currently limited in the LBR. IFIM monitoring assesses 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, overall mean particle size decreased in the LBR following high flow events in 2018. Despite this overall decrease, substrate size at confirmed redd locations has remained consistent since 2014, suggesting access to preferred spawning habitat is not a limiting factor for Chinook Salmon productivity in the LBR. Spawner distributions also indicate sufficient spawning habitat is available, as spawners are not observed in Reaches 1 and 2 despite both reaches having abundant preferred spawning habitat.

Chinook Salmon redd surveys completed since 2014 suggest habitat selected by Chinook Salmon spawners has remained consistent and within preferred ranges regardless of instream flow regime; however, the number of observed redds surveyed each year has decreased despite consistent effort. Depth, velocity, and substrate composition at confirmed spawning locations have remained relatively consistent and within preferred ranges, which is expected given that spawners select areas according to species-specific preferences and are unlikely to construct redds outside of these ranges. Chinook Salmon have been utilizing Reach 4 more frequently in 2018 and 2019 and should this trend of decreasing substrate size continue, available spawning habitat may become limited. However, low returns to the LBR and the fish fence restricting movement into Reach 3 and 4, should not result in limited spawning habitat.

HSI surveys indicate that the overall quantity of high-quality Chinook Salmon spawning habitat has been consistent from 2017 through 2019, but the distribution of this habitat has shifted, potentially due to changes in substrate composition. Substrate monitoring indicates a decrease in substrate size in Reaches 2 through 4, which may be partially related to high flows in 2016 through 2018. It should be noted that the effects of only one high flow event were monitored by these HSI surveys. Two high flow events occurred prior to HSI monitoring, either of which may have had a stronger effect on substrate composition by immediately flushing highly mobile particles downstream. In addition, substrate measurement can be biased (Olsen et al. 2005; Daniels and McCusker 2010), and different technicians have been involved in substrate measurements during both redd surveys and transect data collection. If substrate changes were flow related, we would expect the mobilization of smaller substrate to scour upstream habitats and infill downstream habitats, which has not been observed. Continued substrate monitoring is required to determine whether substrate size is affected by the MOD flow regime and whether this affects preferred habitat availability for spawners in the LBR.

We found no significant change in WUA between 2018 and 2019 (no high flow events occurred between these surveys) suggesting that our survey method is resilient to changing technicians and measurement errors. HSI surveys therefore show promise as a means of monitor spawning habitat quantity in the LBR; however, the HSI curves used here were developed for the full British Columbia range and may not be representative of the LBR (Ptolemy 1998). If data continue to be collected at confirmed redd locations, LBR-specific HSI curves could be developed. Custom HSI curves would more accurately evaluate whether changes spawner distributions are a function of habitat availability.

4.3 Additional Considerations

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

A fish fence was operated for Chinook Salmon broodstock collection between August 20 and September 16, 2019, which impaired Chinook Salmon migration into preferred spawning habitat in Reaches 3 and 4. Many individuals spawned immediately downstream of the fence, which affected comparisons of spawner distribution amongst monitoring years. Increased recycling (up and down movements) of Chinook Salmon was observed over both the crump weir and through the sonar channel (White et al. 2019), which caused additional stress to migrants and may have affected spawning success. In addition to affecting fish behavior, the fence 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 fish 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 sample sizes, BRGMON-3 is collecting valuable data that will be used to address the specific management questions outlined for the monitor. To date, although there have been shifts in adult salmonid spawner abundance, distribution, and habitat characteristics, there is no clear evidence that these changes are directly related to instream flow regimes. Additional data collection will further inform this conclusion. Particularly, visual OE and SL data are required to improve current and historic AUC abundance estimates, for Chinook and Coho, and have not been calculated in recent years due to low tag deployment and few tags moving into Reach 3 and 4. Additional years of abundance and habitat data will help to determine whether the MOD flow regime (projected to continue through 2028) will affect the spawning success of adult salmonids in the LBR.

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

Recommendations for 2019 BRGMON-3 data collection include:

- Delay Terzaghi flow release above WUP target discharge until early June to allow for more accurate Steelhead Trout enumeration.
- Continued use of radio telemetry to improve estimates of Steelhead Trout spawning locations and inform Chinook and Coho Salmon OE and SL for AUC abundance estimates. OE may also be improved by comparing the full counter estimate to the number of adults observed upstream of the fence during visual surveys. This would provide a second metric of OE that could be compared to or combined with the visual survey OE.
- Continued redd surveys combined with habitat (IFIM) surveys following high flow events to compare species preferred habitat with available habitat in the LBR.
- Modify visual survey surveys to subdivide sections in Reach 3 and 4 to increase the level of detail for evaluating changes in spawner distribution.
- If a fish fence is to be installed during the Chinook Salmon migration period, we recommend that it be moved greater than 250m upstream to minimize recycling over the counter while still allowing for an accurate abundance estimate.

5.0 References

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Appendix 1: AUC metrics

Chinook Salmon AUC abundance estimates with standard error (SE) and upper and lower confidence intervals (CI) for the Lower Bridge River from 1993-2019. Abundance results are calculated considering estimates of observer efficiency (OE) and residences times (survey life; SL). OE and SL measures are bold face where calculations were based on observations, the remaining values are the calculated average of these measures.

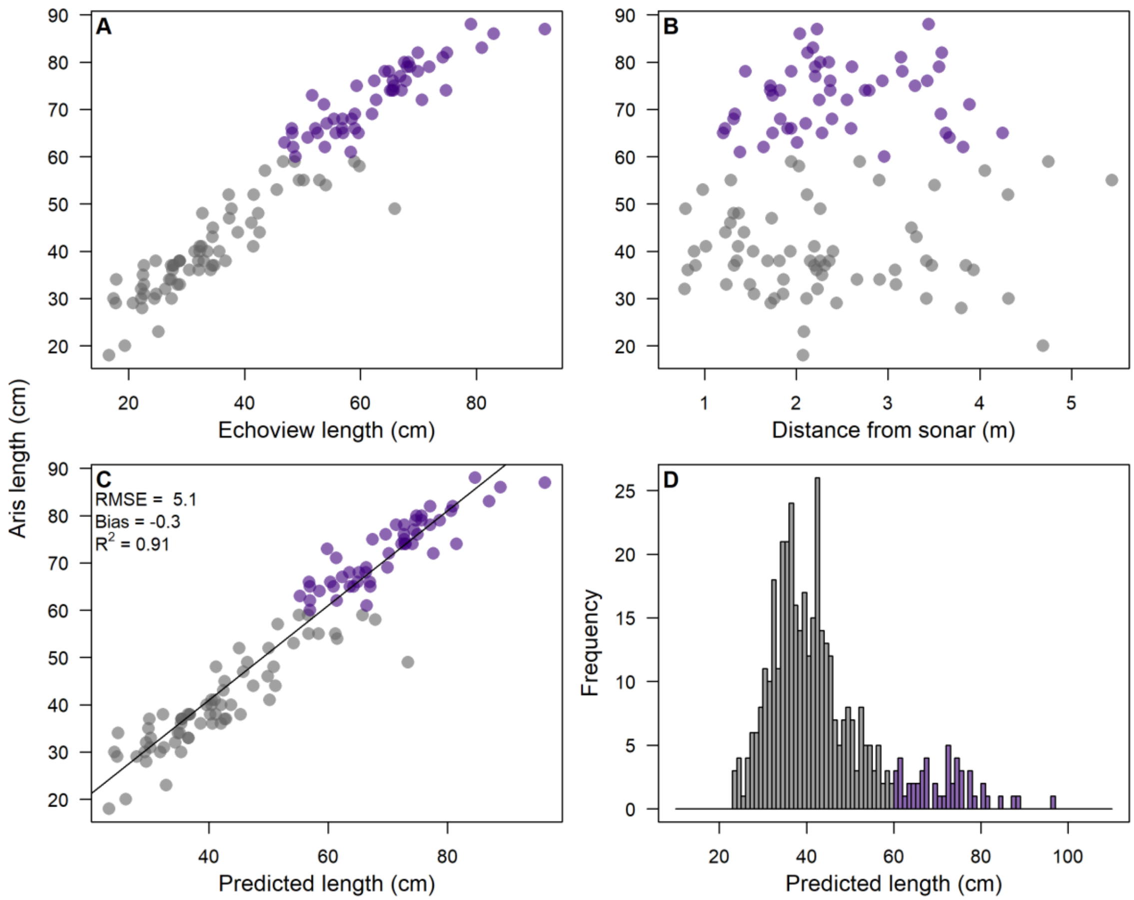
year	oe	oe.se	sl	sl.se	escapement	escapement.se	method	lower95CI	upper95CI
1993	NA	NA	NA	NA	151	0	fence count	151	151
1994	NA	NA	NA	NA	550	0	fence count	550	550
1995	NA	NA	NA	NA	851	0	fence count	851	851
1996	NA	NA	NA	NA	1100	0	fence count	1100	1100
1997	0.50	0.14	10.50	0.65	2005	1581	visual survey	427	9406
1998	0.50	0.14	10.50	0.65	873	254	visual survey	494	1543
1999	0.50	0.14	10.50	0.65	2576	847	visual survey	1352	4906
2001	0.50	0.14	10.50	0.65	1784	981	visual survey	607	5244
2004	0.50	0.14	10.50	0.65	3106	1139	visual survey	1514	6374
2005	0.50	0.14	10.50	0.65	591	232	visual survey	274	1274
2006	0.50	0.14	10.50	0.65	399	124	visual survey	217	733
2007	0.50	0.14	10.50	0.65	309	108	visual survey	156	613
2008	0.50	0.14	10.50	0.65	164	94	visual survey	53	507
2009	0.50	0.14	10.50	0.65	21	7	visual survey	10	41
2010	0.50	0.14	10.50	0.65	208	67	visual survey	110	392
2011	0.50	0.14	10.50	0.65	82	33	visual survey	38	179
2012	**0.58**	0.14	**10.00**	0.65	364	114	visual survey	196	674
2013	**0.28**	0.14	**11.00**	0.65	168	90	visual survey	59	479
2014	**0.28**	0.14	**12.00**	0.65	591	314	visual survey	209	1673
2015	0.50	0.14	10.50	0.65	158	68	visual survey	68	370
2016	0.50	0.14	10.50	0.65	265	85	visual survey	141	497
2017	**0.28**	0.14	**10.50**	0.65	215	116	visual survey	74	621
2018	0.50	0.14	10.50	0.65	25	7	visual survey	14	44
2019	0.50	0.14	10.50	0.65	161	54	visual survey	84	310

Coho Salmon AUC abundance estimates with standard error (SE) and upper and lower confidence intervals (CI) for the Lower Bridge River from 1993-2019. Abundance results are calculated considering estimates of observer efficiency (OE) and residences times (survey life; SL). OE and SL measures are bold face where calculations were based on observations, the remaining values are the calculated average of these measures.

year	oe	oe.se	sl	sl.se	escapement	escapement.se	method	lower95CI	upper95CI
1997	0.22	0.02	19.60	1.29	619	1419	visual survey	7	55245
1998	0.22	0.02	19.60	1.29	1079	400	visual survey	522	2232
1999	0.22	0.02	19.60	1.29	81	NA	visual survey	NA	NA
2001	0.22	0.02	19.60	1.29	1033	134	visual survey	801	1331
2003	0.22	0.02	19.60	1.29	1217	134	visual survey	981	1510
2004	0.22	0.02	19.60	1.29	233	50	visual survey	153	356
2005	0.22	0.02	19.60	1.29	739	123	visual survey	533	1025
2006	0.22	0.02	19.60	1.29	674	110	visual survey	489	929
2008	0.22	0.02	19.60	1.29	102	16	visual survey	75	139
2009	0.22	0.02	19.60	1.29	1601	242	visual survey	1191	2152
2010	0.22	0.02	19.60	1.29	463	81	visual survey	329	653
2011	0.22	0.02	19.60	1.29	3678	636	visual survey	2621	5161
2012	**0.25**	0.02	**16.00**	1.29	1662	386	visual survey	1055	2619
2013	**0.27**	0.02	**19.00**	1.29	2974	355	visual survey	2353	3759
2014	0.22	0.02	19.60	1.29	424	74	visual survey	301	596
2015	0.22	0.02	19.60	1.29	174	23	visual survey	135	224
2016	0.22	0.02	19.60	1.29	488	69	visual survey	370	642
2017	**0.19**	0.02	**23.00**	1.29	451	65	visual survey	339	599
2018	0.22	0.02	19.60	1.29	1245	169	visual survey	954	1624
2019	0.22	0.02	19.60	1.29	214	37	visual survey	152	301

Appendix 2: Sonar Length Modelling and Linear Model Coefficients

Steelhead Trout

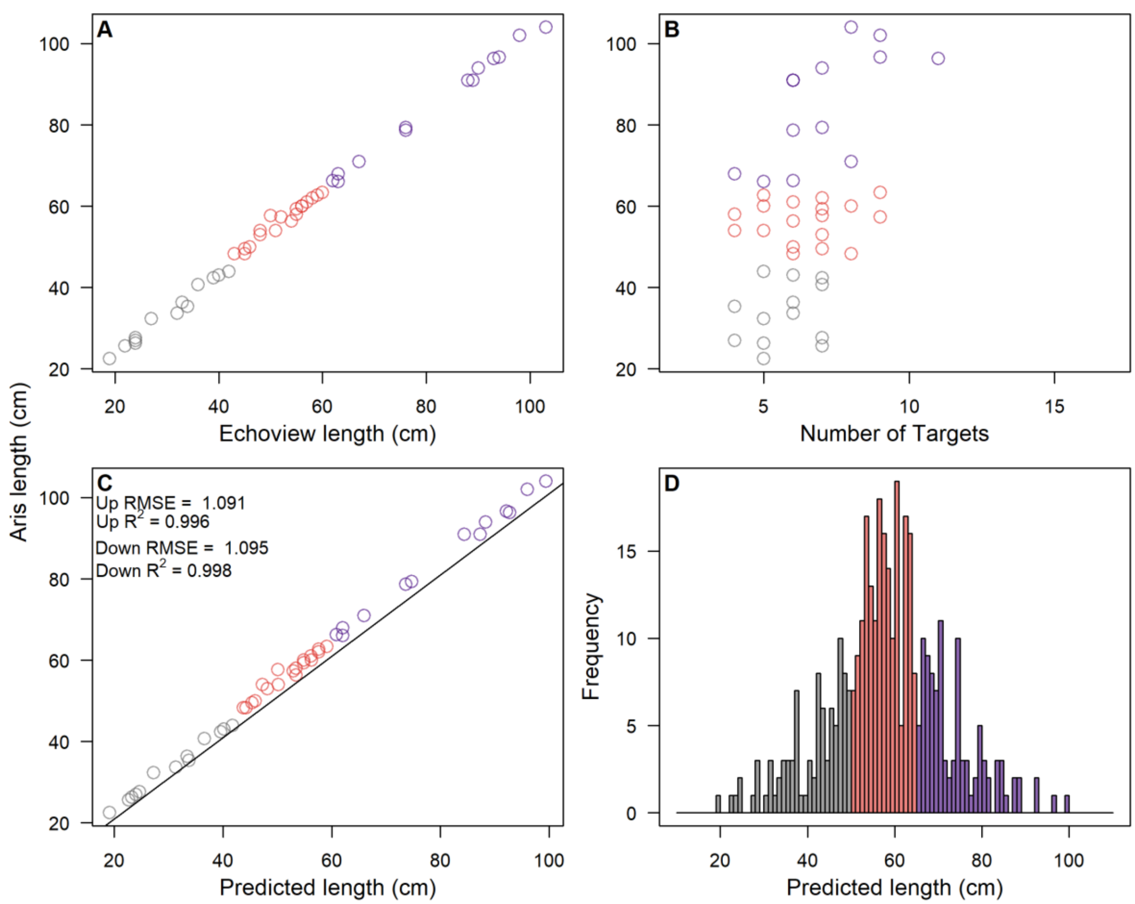


Manually measured fish length in ARISFish software in relation to (A) Echoview generated length and (B) distance from sonar. (C) Observed ARISfish lengths in relation to predicted lengths from a linear model that included Echoview length. Black line indicates unity (1:1). (D) Histogram of the predicted lengths of fish counted by Echoview. Purple and grey correspond to Steelhead Trout and resident fish species, respectively. Dots are fish observed using Echoview.

Model output and AICc for predicting ARIS lengths from Echoview target length, number of targets, target mean range, and time in beam. Predicted lengths were used to distinguish Steelhead Trout and enumerate abundance.

Intercept	log Target Length Mean	Number of Targets	Target Range Mean	Time in Beam	R^2	df	ΔAIC
0.770	0.844	-0.013	-	0.111	0.915	5	0.00
0.808	0.832	-	-	-	0.912	3	0.10
0.772	0.833	-	-	0.045	0.913	4	0.78
0.816	0.834	-	-0.005	-	0.912	4	1.98
0.774	0.845	-0.012	-0.004	0.111	0.915	6	2.06

Chinook Salmon



Manually measured fish length in ARISFish software in relation to (A) Echoview generated length and (B) distance from sonar. (C) Observed ARISfish lengths in relation to predicted lengths from a linear model that included Echoview length. Black line indicates unity (1:1). (D) Histogram of the predicted lengths of fish counted by Echoview. Points are fish observed using Echoview. Purple, orange, and grey correspond to Chinook and Sockeye Salmon and resident fish species, respectively.

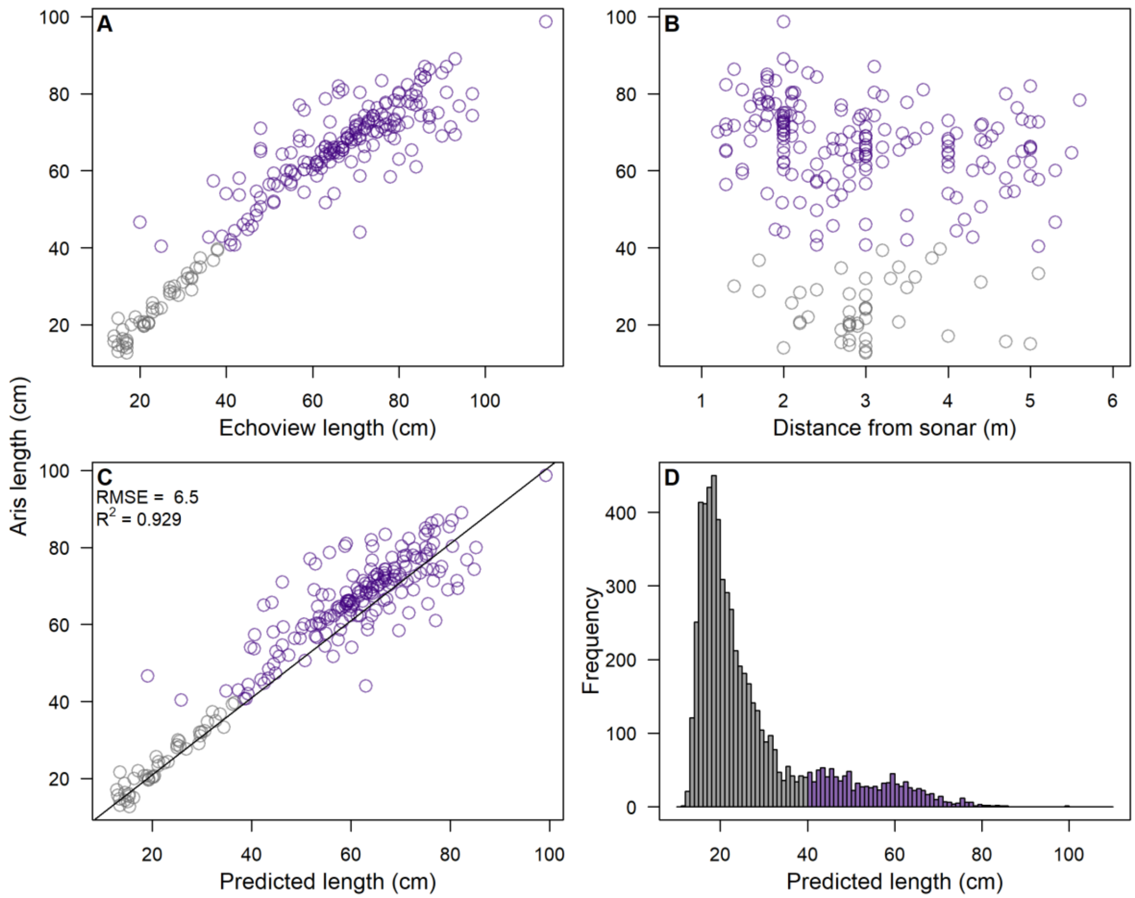
Model output and AICc for predicting upstream ARIS lengths from Echoview target length, number of targets, target mean range, and time in beam. Predicted lengths were used to distinguish Chinook Salmon and enumerate abundance.

Intercept	log Target Length Mean	Number of Targets	Target Range Mean	Time in Beam	R^2	df	ΔAIC
0.394	0.905	0.008	-	-	0.996	4	0.00
0.406	0.908	-	-	0.052	0.996	4	1.47
0.389	0.905	0.008	0.002	-	0.966	5	2.60
0.396	0.905	0.007	-	0.010	0.966	5	2.79
0.399	0.908	-	0.002	0.054	0.996	5	3.84

Model output and AICc for predicting downstream ARIS lengths from Echoview target length, number of targets, target mean range, and time in beam. Predicted lengths were used to distinguish Chinook Salmon and enumerate abundance.

Intercept	log Target Length Mean	Number of Targets	Target Range Mean	Time in Beam	R^2	df	ΔAIC
0.225	0.959	-	-	-	0.998	3	0.00
0.211	0.972	-0.006	-	-	0.998	4	1.53
0.218	0.966	-	-	-0.033	0.998	4	2.45
0.242	0.958	-	-0.003	-	0.998	4	4.00
0.211	0.972	-0.006	-	0.005	0.998	5	7.09

Coho Salmon



Manually measured fish length in ARISFish software in relation to (A) Echoview generated length and (B) distance from sonar. (C) Observed ARISfish lengths in relation to predicted lengths from a linear model that included Echoview length. Black line indicates unity (1:1). (D) Histogram of the predicted lengths of fish counted by Echoview. Purple and grey correspond to Coho Salmon and resident fish species, respectively. Dots are fish observed using Echoview.

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

Intercept	log Target Length Mean	Number of Targets	Target Range Mean	Time in Beam	R^2	df	ΔAIC
0.804	0.789	0.001	0.024	-	0.852	5	0.00
0.926	0.762	0.001	0.022	-0.007	0.855	6	0.32
0.873	0.774	-	0.025	-	0.849	4	0.57
0.824	0.785	-	0.025	0.002	0.849	5	2.41
1.091	0.737	0.002	-	-0.008	0.848	5	2.93

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

Intercept	log Target Length Mean	Number of Targets	Target Range Mean	Time in Beam	R^2	df	ΔAIC
0.123	0.960	0.003	-	-0.004	0.961	5	0.00
0.044	0.979	0.002	-	-	0.960	4	1.71
0.107	0.961	0.003	0.004	0.003	0.961	6	1.90
0.024	0.979	0.002	0.007	-	0.960	5	3.18
0.132	0.963	-	-	-	0.956	3	14.43

Appendix 3: Radio Tagging

Tagging information and spawning distribution of radio-tagged Steelhead Trout in the Lower Bridge River in 2019, including calculated migration rates and residence time in specific reaches. All fish were tagged at the Seton-Fraser confluence.

Tag NO.	Sex	Fork Length (mm)	Tagging Date	Entry Date to LBR	End Date	Assumed Spawning Reach	Assumed Spawning Section	Migration Rate (km day^{-1})	Reach 2 Residence Time (days)	Reach 3 Residence Time (days)
54	F	725	2019-03-07	2019-04-16	2019-05-14	Reach 4	Bluenose to Cobra	3.0	20.2	17
55	F	843	2019-03-07	NA	2019-04-24	NA	NA	NA	NA	NA
56	F	682	2019-03-11	NA	2019-05-29	NA	NA	NA	NA	NA
57	F	735	2019-03-12	2019-04-29	2019-04-29	NA	NA	NA	NA	NA
58	F	740	2019-03-14	2019-05-11	2019-05-27	Reach 4	Longskinny to Eagle	6.2	13.8	12.2
59	F	776	2019-03-15	NA	NA	NA	NA	NA	NA	NA
60	F	797	2019-03-15	NA	NA	NA	NA	NA	NA	NA
61	F	725	2019-03-17	NA	2019-04-24	NA	NA	NA	NA	NA
62	F	842	2019-03-18	NA	2019-04-24	NA	NA	NA	NA	NA
63	F	758	2019-03-18	NA	2019-05-28	NA	NA	NA	NA	NA
64	F	764	2019-03-19	NA	2019-05-10	NA	NA	NA	NA	NA
65	M	927	2019-03-20	NA	NA	NA	NA	NA	NA	NA
66	F	825	2019-03-22	NA	2019-04-03	NA	NA	NA	NA	NA
67	M	932	2019-03-23	NA	2019-04-24	NA	NA	NA	NA	NA
68	F	800	2019-03-24	2019-05-14	2019-06-01	Reach 4	Longskinny to Eagle	4.6	15.4	12.5
69	M	632	2019-03-28	2019-04-20	2019-06-10	Reach 3	Counter to Yalakom	3.5	46.1	43.9
70	F	842	2019-03-28	2019-04-30	2019-06-03	NA	NA	NA	NA	NA
71	M	628	2019-03-29	2019-04-18	2019-06-03	Reach 4	Bluenose to Cobra	3.1	40	38
72	F	865	2019-03-30	2019-04-16	2019-05-17	Reach 4	Plunge Pool to Longskinny	2.3	25.8	23
73	F	872	2019-04-01	NA	2019-05-16	NA	NA	NA	NA	NA
74	F	743	2019-04-07	2019-05-29	2019-06-09	NA	NA	NA	NA	NA
75	F	748	2019-04-08	NA	2019-05-27	NA	NA	NA	NA	NA
76	M	844	2019-04-08	2019-05-01	2019-06-04	Reach 4	Longskinny to Eagle	5.4	30.2	28.7
77	M	839	2019-04-10	2019-05-07	2019-06-11	Reach 4	Longskinny to Eagle	12.8	33.9	33.5
78	F	777	2019-04-25	NA	2019-05-11	NA	NA	NA	NA	NA
							Mean	5.1	26.5	24.4
							Minimum	2.3	13.8	12.2
							Maximum	12.8	46.1	43.9

Tagging information of radio-tagged Chinook Salmon in the Lower Bridge River in 2018 and inferred spawning location. Fish were tagged at the Yalakom Confluence (rkm 25.5)

Tag no.	Sex	Tagging Location	Tagging Date	End Date	Assumed Spawning Location	
					Reach	Section
79	F	Counter Site	2019-08-23	2019-10-03	Reach 3	Hell Creek to Counter
80	F	Bridge Confluence	2019-08-24	2019-08-25	NA	NA
81	F	Bridge Confluence	2019-08-24	2019-08-24	NA	NA
82	F	Bridge Confluence	2019-08-24	2019-08-24	NA	NA
83	F	Bridge Confluence	2019-08-24	2019-09-18	NA	NA

Tagging information of radio-tagged Coho Salmon in the Lower Bridge River, with inferred spawning location and calculated migration rates and residence time.

Tag no.	Sex	Tagging location	Tagging Date	End Date	Assumed Spawning Location	
					Reach	Section
84	F	Bridge Confluence	2019-09-30	NA	NA	NA
85	F	Bridge Confluence	2019-10-02	2019-10-02	NA	NA
86	M	Bridge Confluence	2019-10-02	2019-10-15	NA	NA
87	M	Bridge Confluence	2019-10-02	2019-10-15	NA	NA
88	F	Bridge Confluence	2019-10-02	2019-10-23	NA	NA
89	M	Bridge Confluence	2019-10-03	2019-10-04	NA	NA
90	M	Bridge Confluence	2019-10-03	2019-10-04	NA	NA
91	M	Bridge Confluence	2019-10-13	2019-10-15	NA	NA
92	M	Bridge Confluence	2019-10-10	2019-10-16	NA	NA
93	M	Bridge Confluence	2019-10-11	2019-10-15	NA	NA
94	M	Bridge Confluence	2019-10-13	NA	NA	NA
95	F	Bridge Confluence	2019-10-13	NA	NA	NA
96	F	Bridge Confluence	2019-10-16	NA	NA	NA
97	M	Bridge Confluence	2019-10-16	2019-10-17	NA	NA
98	F	Above LBR Bridge	2019-10-16	2019-10-23	NA	NA
99	F	Above LBR Bridge	2019-10-16	2019-11-03	Reach 2	NA
100	M	Above LBR Bridge	2019-10-19	2019-10-23	NA	NA
101	M	Above LBR Bridge	2019-10-20	2019-11-10	NA	NA
102	M	Hippie Pool	2019-10-27	2019-10-27	Reach 3	Hell Creek to Yalakom
103	F	Hippie Pool	2019-10-30	NA	NA	NA
104	M	Hippie Pool	2019-10-30	NA	NA	NA
105	M	Camoo Bridge	2019-11-02	NA	NA	NA

Note: Yalakom River to Hell Creek (25.5 to 28.8 rkm), Hell Creek to Russel Springs (28.8 to 30.7 rkm), Russel Springs to Fish Fence (30.7 to 33.2 rkm), Fish Fence to Cobra (33.2 to 34.4 rkm), Cobra to Bluenose (34.4 to 38.2 rkm), Bluenose to Eagle (38.2 to 38.8 rkm), Longskinny to Plunge Pool (39.3 to 40.0 rkm)

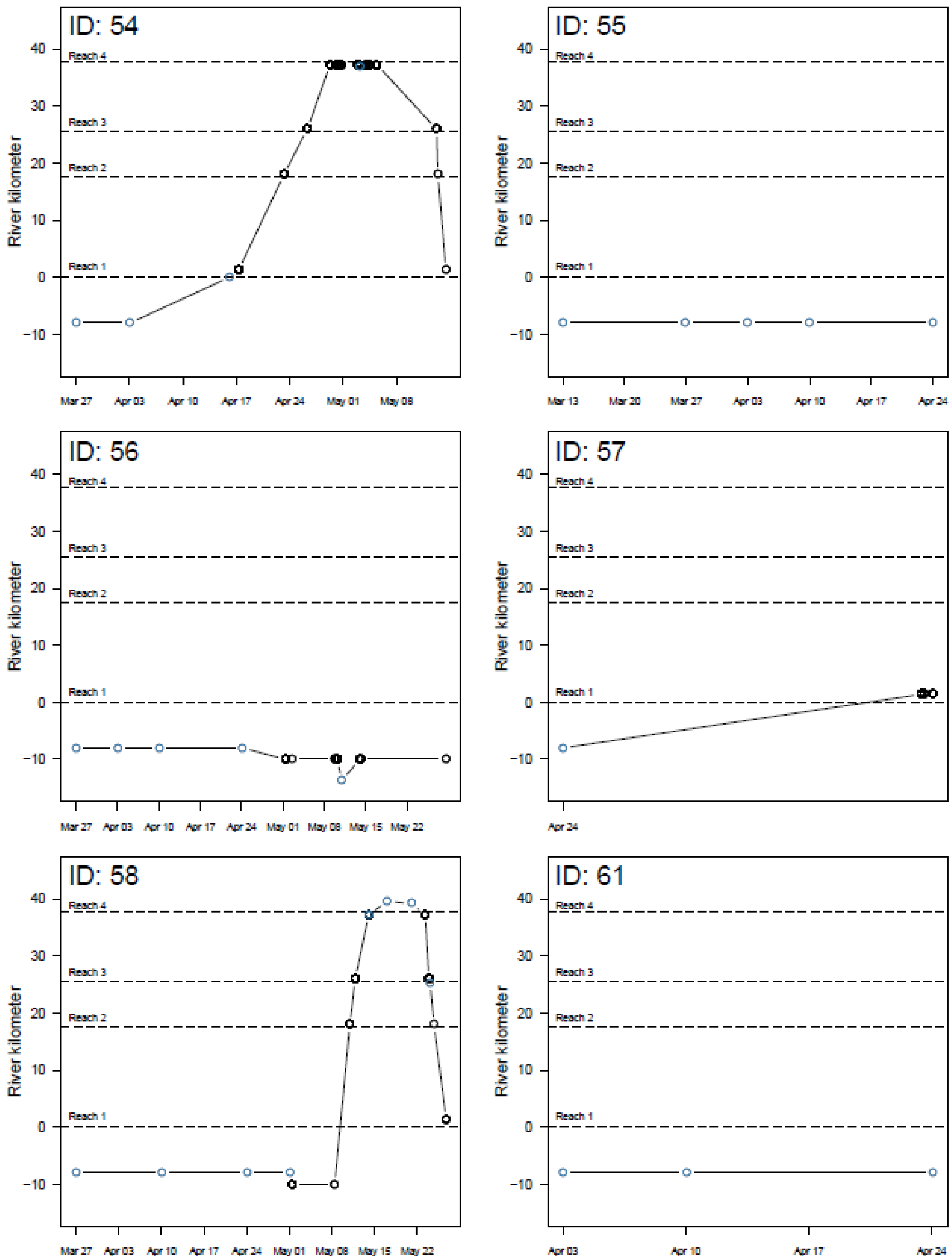
Appendix 4: Steelhead Spawning Distribution

Steelhead Trout spawning distribution across streamwalk sections in Reach 3 and 4 of the LBR inferred from radio telemetry (2014-2019).

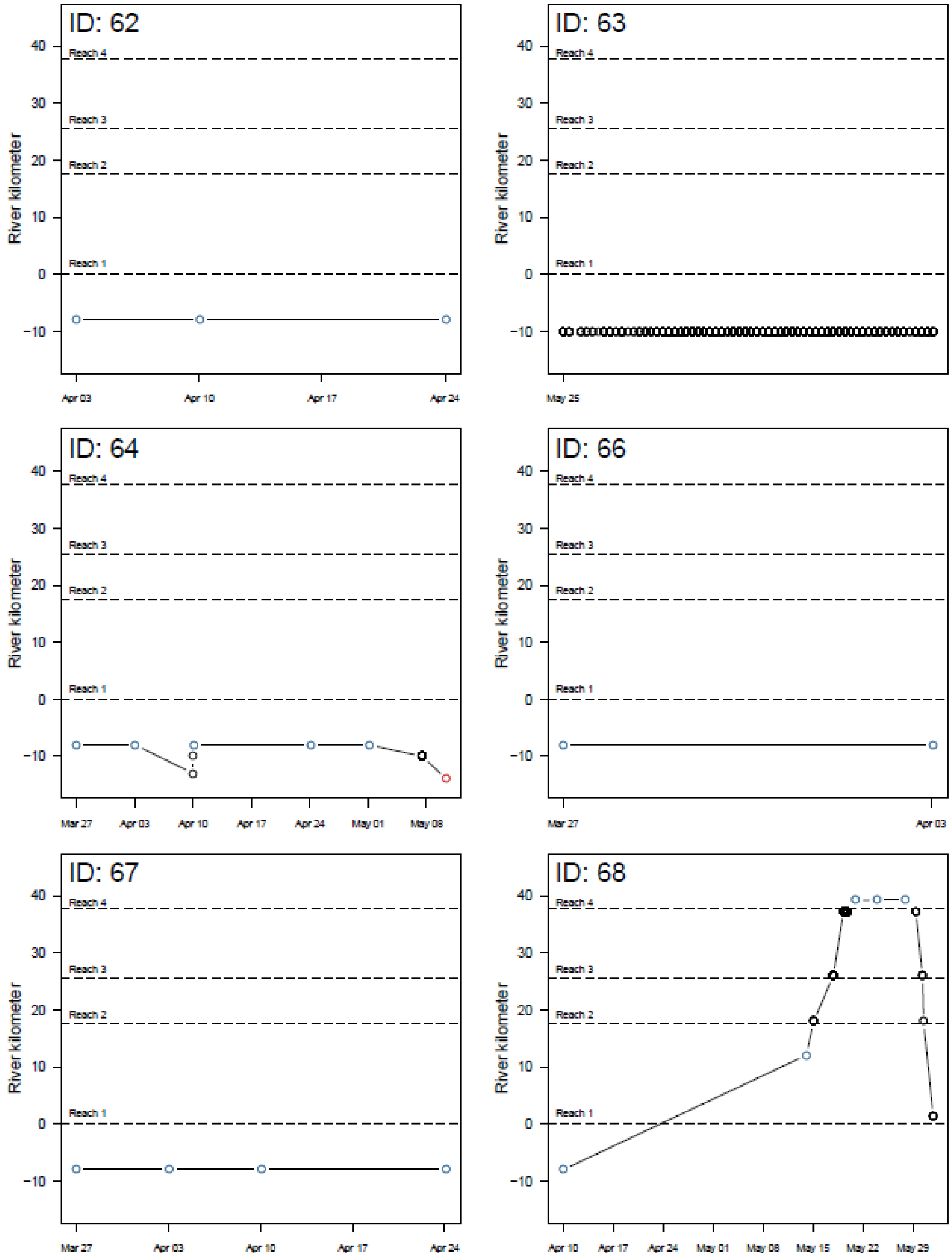
	Streamwalk		Year						
Section	Description	RiverKM	2014	2015	2016	2017	2018	2019	Total
1	Terzaghi Dam to Longskinny	40.0 to 39.6	1	1	0	1	1	1	5
2	Longskinny to Eagle	39.6 to 38.8	0	7	0	4	0	4	15
3	Eagle to Bluenose	38.8 to 38.2	1	0	0	2	1	0	4
4	Bluenose to Cobra	38.2 to 34.4	4	0	0	4	3	2	13
5	Cobra to Fraser Lake	34.4 to 33.2	0	0	0	0	0	0	0
6	Fraser Lake to Russel Springs	33.2 to 30.7	0	0	2	1	1	0	4
7	Russel Springs to Hell Creek	30.7 to 28.8	0	0	0	0	0	0	0
8	Hell Creek to Yalakom	28.8 to 25.5	2	2	0	1	1	1	7
		Total	8	10	2	13	7	8	48

Appendix 5: Graphical Fish Traces

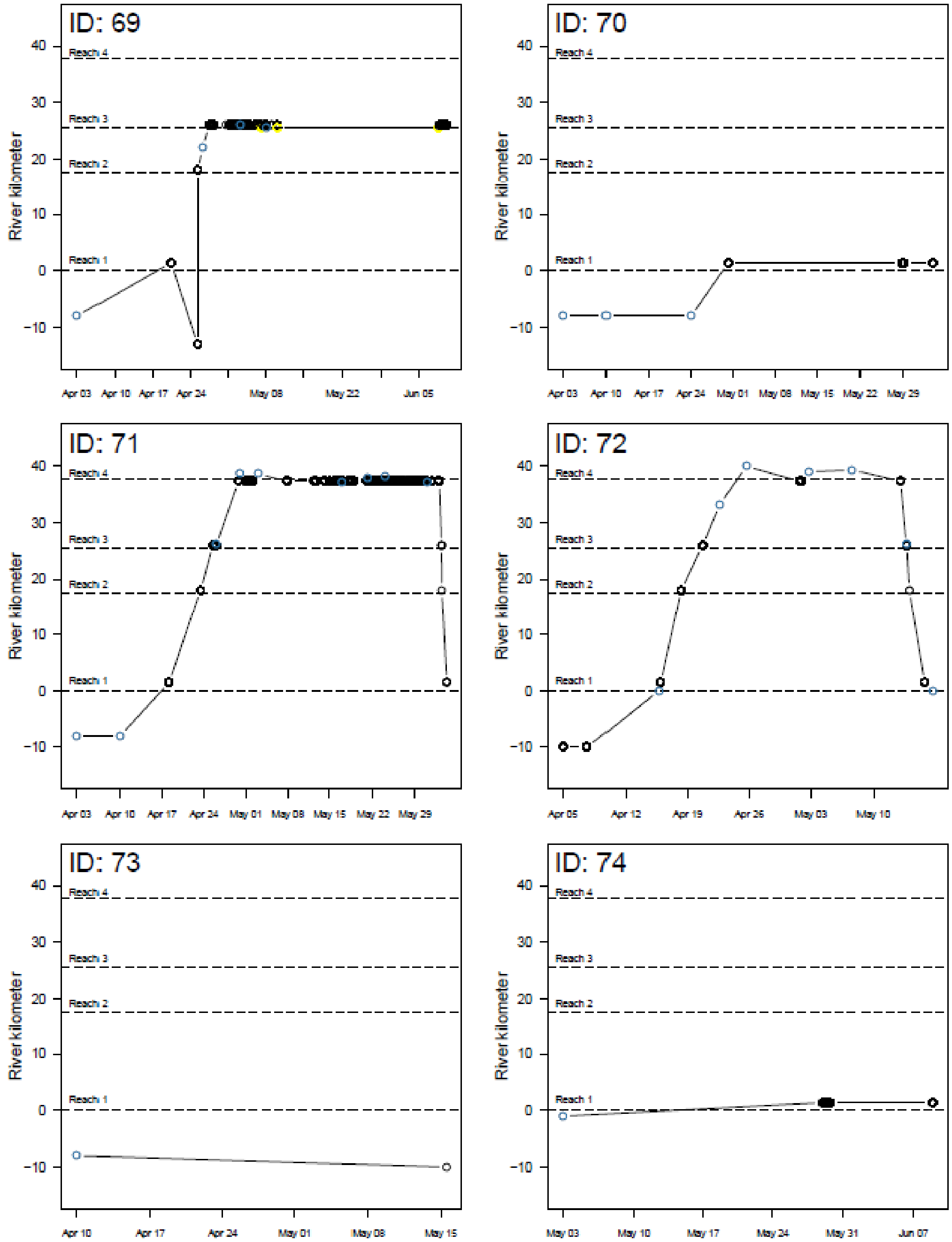
Steelhead Trout



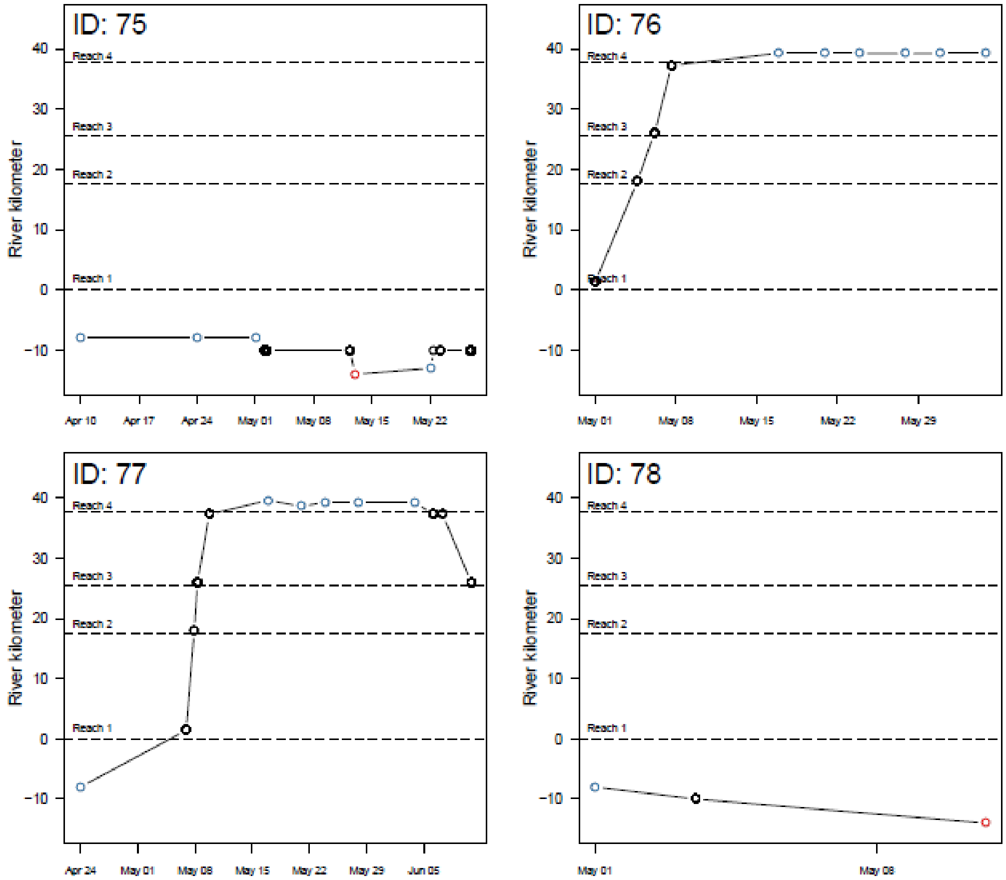
Detection histories of all radio tagged adult Steelhead Trout in the Lower Bridge River in 2019. Black lines connect the data collected from fixed (black) and mobile (blue) telemetry. Dashed lines indicate boundaries between different reaches. Observations below 0 river kms are sites located in the Seton River.



(Cont'd) Detection histories of all radio tagged adult Steelhead Trout in the Lower Bridge River in 2019. Black lines connect the data collected from fixed (black) and mobile (blue) telemetry. Dashed lines indicate boundaries between different reaches. Observations below 0 river kms are sites located in the Seton River.

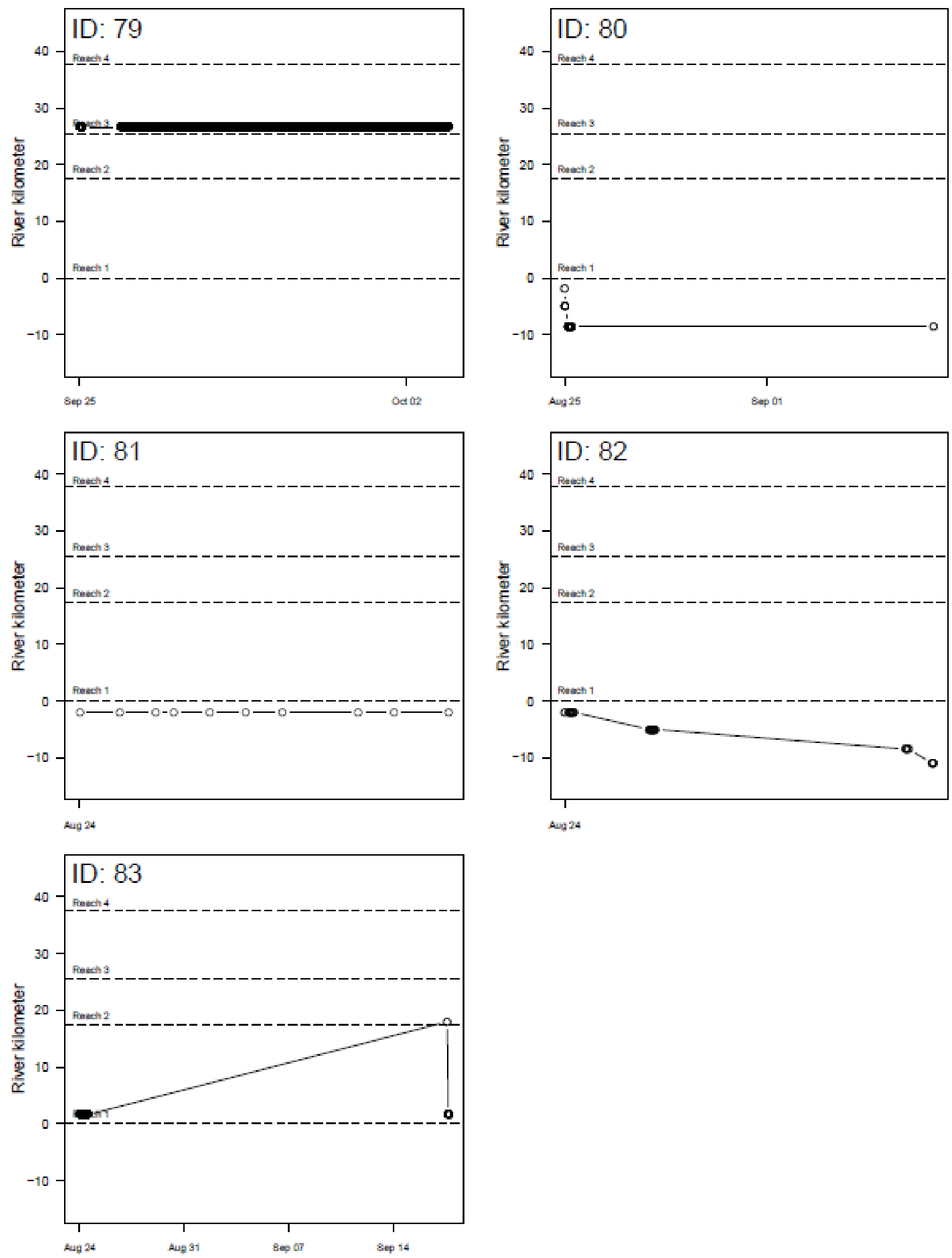


(Cont'd) Detection histories of all radio tagged adult Steelhead Trout in the Lower Bridge River in 2019. Black lines connect the data collected from fixed (black) and mobile (blue) telemetry. Dashed lines indicate boundaries between different reaches. Observations below 0 river kms are sites located in the Seton River.



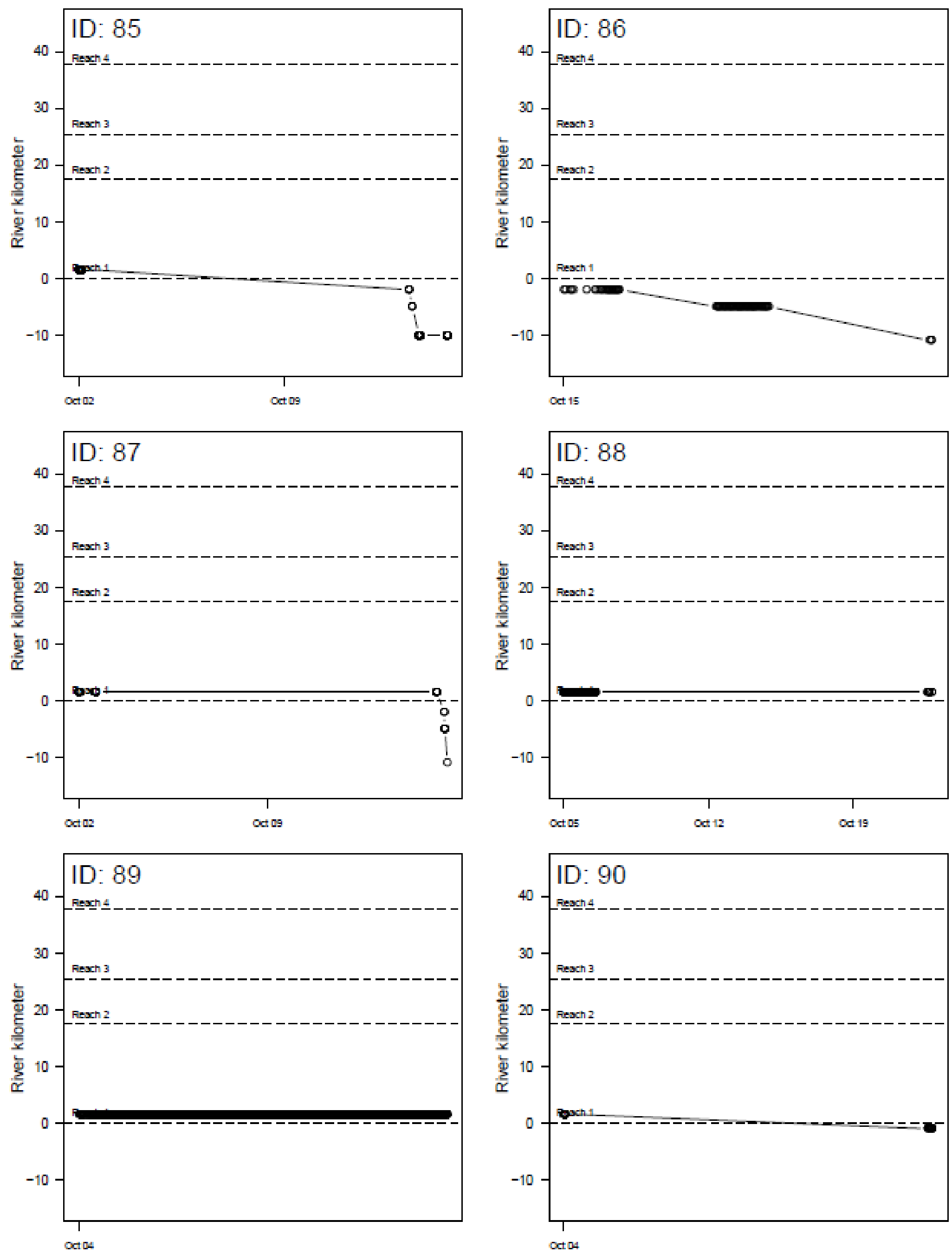
(Cont'd) Detection histories of all radio tagged adult Steelhead Trout in the Lower Bridge River in 2019. Black lines connect the data collected from fixed (black) and mobile (blue) telemetry. Dashed lines indicate boundaries between different reaches. Observations below 0 river kms are sites located in the Seton River.

Chinook Salmon

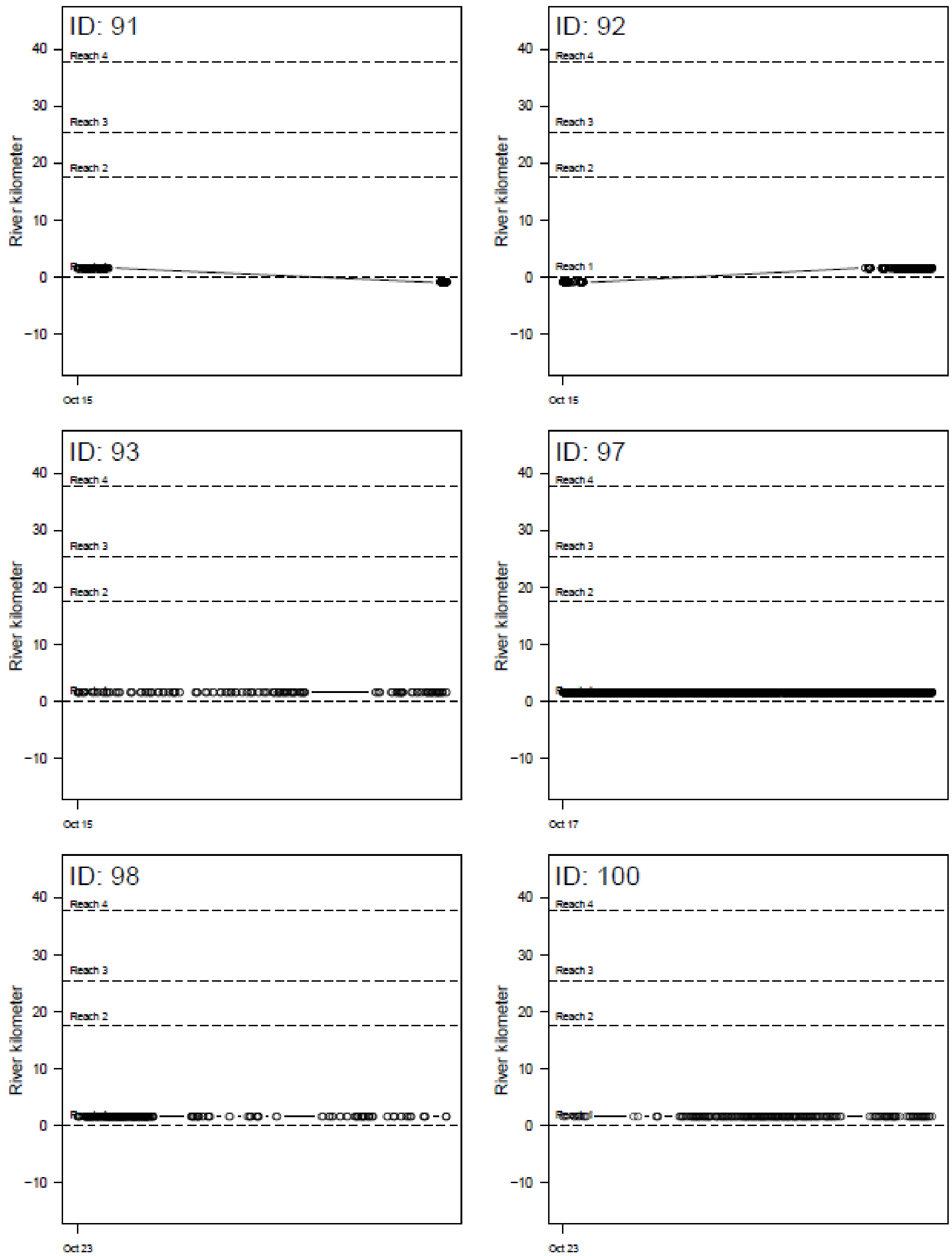


Detection histories of all radio tagged adult Chinook Salmon in the Lower Bridge River in 2019. Black lines connect the release information (red) with data collected from fixed (black) and mobile (blue) telemetry. Dashed lines indicate boundaries between different reaches. Observations below 0 river kms are sites located in the Fraser River below the LBR.

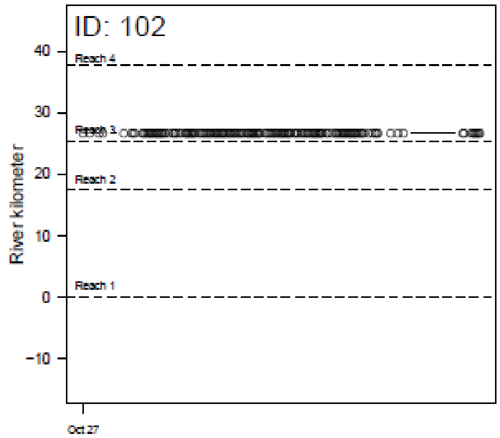
Coho Salmon



Detection histories of all radio tagged adult Coho Salmon in the Lower Bridge River in 2019. Black lines connect the release information (red) with data collected from fixed (black) and mobile (blue) telemetry. Dashed lines indicate boundaries between different reaches. Discharge in the Lower Bridge River was 1.5 $m^3 s^{-1}$ throughout the migration and spawning period. Observations below 0 river kms are sites located in the Fraser River below the LBR.



(Cont'd). Detection histories of all radio tagged adult Coho Salmon in the Lower Bridge River in 2018. Black lines connect the release information (red) with data collected from fixed (black) and mobile (blue) telemetry. Dashed lines indicate boundaries between different reaches. Discharge in the Lower Bridge River was 1.5 $m^3 s^{-1}$ throughout the migration and spawning period. Observations below 0 river kms are sites located in the Fraser River below the LBR.



(Cont'd). Detection histories of radio tagged adult Coho Salmon in the Lower Bridge River in 2018. Black lines connect the release information (red) with data collected from fixed (black) and mobile (blue) telemetry. Dashed lines indicate boundaries between different reaches. Discharge in the Lower Bridge River was 1.5 $m^3 s^{-1}$ throughout the migration and spawning period. Observations below 0 river kms are sites located in the Fraser River below the LBR.

Appendix 6: Visual Survey Counts

Chinook Salmon visual survey data by visual survey section in 2019.

Date	Observers	% Cloud Cover	Water Visibility (m)	Plunge Pool to Longskinny	Plunge Pool to Longskinny (tagged)	Longskinny to Eagle	Longskinny to Eagle (tagged)	Eagle to Bluenose	Eagle to Bluenose (tagged)	Bluenose to Cobra	Bluenose to Cobra (tagged)	Mortalities
08-02-2019	CB, RJ	100	0.7	0	0	0	0	0	0	0	0	0
08-06-2019	RL, VD	10	NA	0	0	0	0	0	0	0	0	0
08-07-2019	RJ, CB	0	NA	0	0	0	0	0	0	0	0	0
08-13-2019	WP, AA	99	NA	0	0	0	0	0	0	0	0	0
08-14-2019	CB, RJ	20	NA	0	0	0	0	0	0	0	0	0
08-20-2019	CB, WP	0	NA	4	0	6	0	0	0	0	0	0
08-27-2019	WP, MA	20	NA	10	0	5	0	0	0	0	0	0
09-10-2019	CB, VD	0	NA	0	0	0	0	0	0	0	0	3
09-17-2019	CB, DJ	100	1.75	13	0	14	0	0	0	0	0	0
09-25-2019	BP, CW	95	0.5	1	0	6	0	0	0	0	0	12
10-01-2019	CB, WP	95	0.8	1	0	3	0	0	0	0	0	0
10-08-2019	CB, WP	60	0.3	2	0	0	0	0	0	0	0	0
10-15-2019	CB, MA	95	0.3	0	0	0	0	0	0	0	0	0

Date	Cobra to Fish Fence	Cobra to Fish Fence (tagged)	Fish Fence (excluding FF) to Russel	Fish Fence (excluding FF) to Russel (tagged)	Russel to Hell	Russel to Hell (tagged)	Hell to Counter	Hell to Counter (tagged)	Counter to Yalakom	Counter to Yalakom (tagged)	Total	Above Fence Total
08-02-2019	0	0	0	0	0	0	0	0	0	0	0	0
08-06-2019	0	0	0	0	1	0	0	0	0	0	0	1
08-07-2019	0	0	0	0	0	0	0	0	0	0	0	0
08-13-2019	2	0	2	0	0	0	0	0	0	0	0	4
08-14-2019	0	0	0	0	0	0	0	0	2	0	0	0
08-20-2019	3	0	0	0	0	0	0	0	2	0	10	13
08-27-2019	5	0	0	0	0	0	1	0	18	0	15	21
09-10-2019	0	0	0	0	9	0	0	0	6	0	3	9
09-17-2019	3	0	0	0	0	0	1	0	3	0	27	31
09-25-2019	0	0	4	0	0	0	0	0	0	0	19	11
10-01-2019	0	0	0	0	0	0	0	0	0	0	4	4
10-08-2019	0	0	0	0	0	0	0	0	0	0	2	2
10-15-2019	0	0	0	0	0	0	0	0	0	0	0	0

Compiled observations of spawning distribution of Chinook Salmon across streamwalk sections in Reach 3 and 4 of the LBR from all visual surveys (2013-2019).

Section	Streamwalk Description	RiverKM	Year 2013	2014	2015	2016	2017	2018	2019	Total
1	Terzaghi Dam to Longskinny	40.0 to 39.6	11	6	8	20	9	1	31	86
2	Longskinny to Eagle	39.6 to 38.8	4	5	5	6	1	6	34	61
3	Eagle to Bluenose	38.8 to 38.2	1	0	0	0	0	0	0	1
4	Bluenose to Cobra	38.2 to 34.4	20	16	6	0	4	0	0	46
5	Cobra to Fraser Lake	34.4 to 33.2	17	56	6	64	32	7	13	195
6	Fraser Lake to Russel Springs	33.2 to 30.7	7	14	6	14	10	5	6	62
7	Russel Springs to Hell Creek	30.7 to 28.8	17	5	8	43	21	0	1	95
8	Hell Creek to Yalakom	28.8 to 25.5	61	197	79	55	10	0	31	433
		Total	138	299	118	202	87	19	116	979

Coho Salmon visual survey data by visual survey section in 2019.

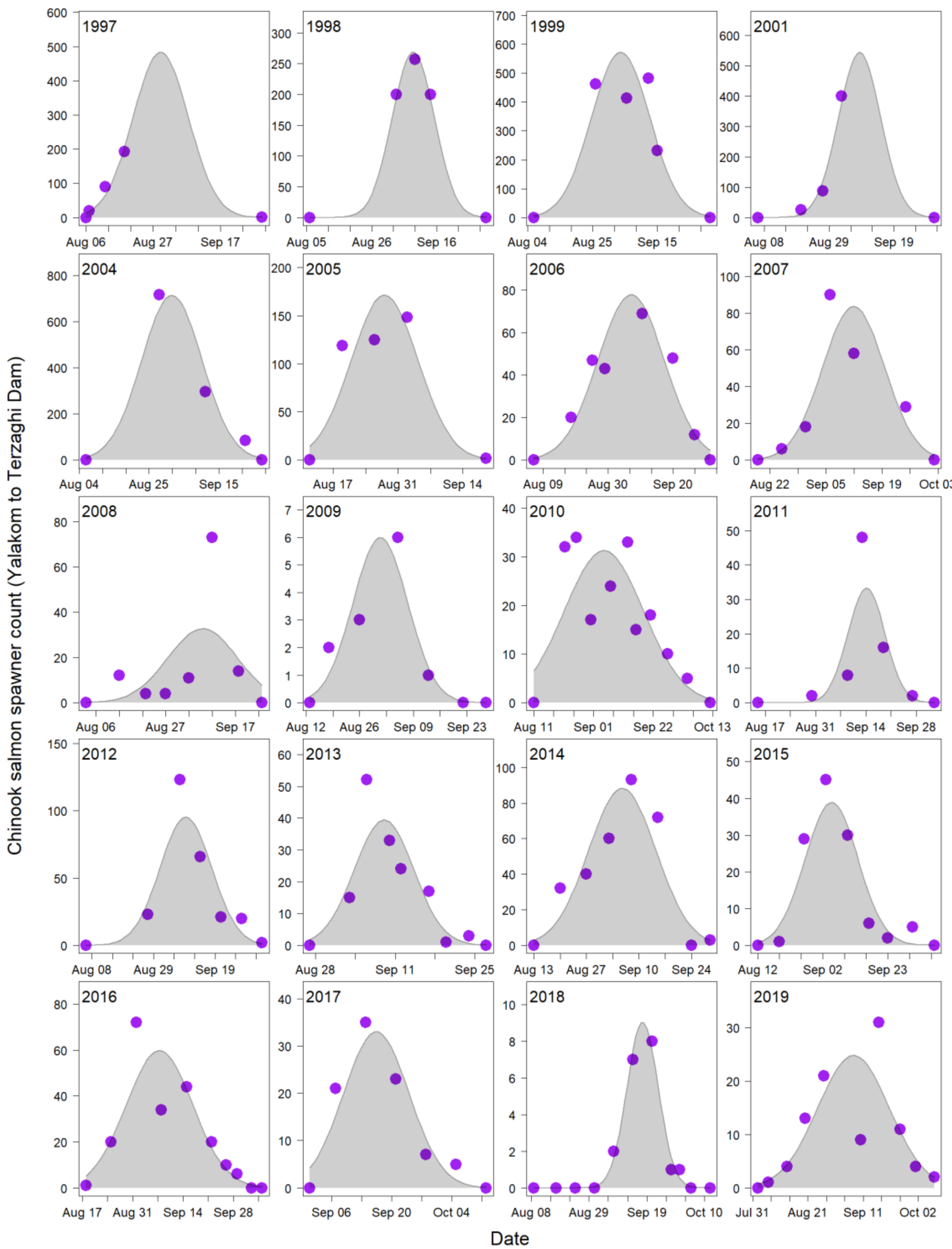
Date	Observers	% Cloud Cover	Water Visibility (m)	Plunge Pool to Longskinny	Plunge Pool to Longskinny (tagged)	Longskinny to Eagle	Longskinny to Eagle (tagged)	Eagle to Bluenose	Eagle to Bluenose (tagged)	Bluenose to Cobra	Bluenose to Cobra (tagged)	Morts
10-01-2019	CB, MA	50	0.8	0	0	0	0	0	0	0	0	0
10-08-2019	CB, WP	60	0.3	0	0	0	0	0	0	0	0	0
10-11-2019	CB, WP	95	NA	0	0	0	0	0	0	0	0	0
10-15-2019	CB, MA	95	0.3	0	0	0	0	0	0	0	0	0
10-22-2019	CB, MA	0	0.3	1	0	0	0	0	0	0	0	0
10-29-2019	CB, KA	0	1.0	1.5	0	1	0	0	0	0	0	0
11-05-2019	CB, DM	95	1.5	3	0	15	0	0	0	0	0	0
11-12-2019	CB, WP	100	1.0	11	0	37	0	0	0	0	0	0
11-19-2019	CB, WP	n/a	1.0	11	1	16	0	0	0	0	0	0
11-26-2019	CB, MA	40	1.0	4	0	2	0	0	0	0	0	0
12-03-2019	CB, WP	65	1.0	3	0	0	0	0	0	0	0	0

Date	Cobra to Fish Fence	Cobra to Fish Fence (tagged)	Fish Fence (excluding FF) to Russel	Fish Fence (excluding FF) to Russel (tagged)	Russel to Hell	Russel to Hell (tagged)	Hell to Counter	Hell to Counter (tagged)	Counter to Yalakom	Counter to Yalakom (tagged)	Total	Tagged Fish Total
10-01-2019	0	0	0	0	0	0	0	0	0	0	0	0
10-08-2019	0	0	0	0	0	0	0	0	0	0	0	0
10-11-2019	0	0	0	0	0	0	0	0	0	0	0	0
10-15-2019	0	0	0	0	0	0	0	0	0	0	0	0
10-22-2019	0	0	0	0	0	0	0	0	0	0	0	0
10-29-2019	0	0	0	0	1	0	0	0	0	0	1	0
11-05-2019	0	0	0	0	0	0	0	0	0	0	0	0
11-12-2019	0	0	6	0	2	0	1	0	3	0	12	0
11-19-2019	0	0	7	0	0	0	1	0	3	0	11	1
11-26-2019	1	0	0	0	0	0	0	0	0	0	1	0
12-03-2019	0	0	0	0	0	0	0	0	0	0	0	0

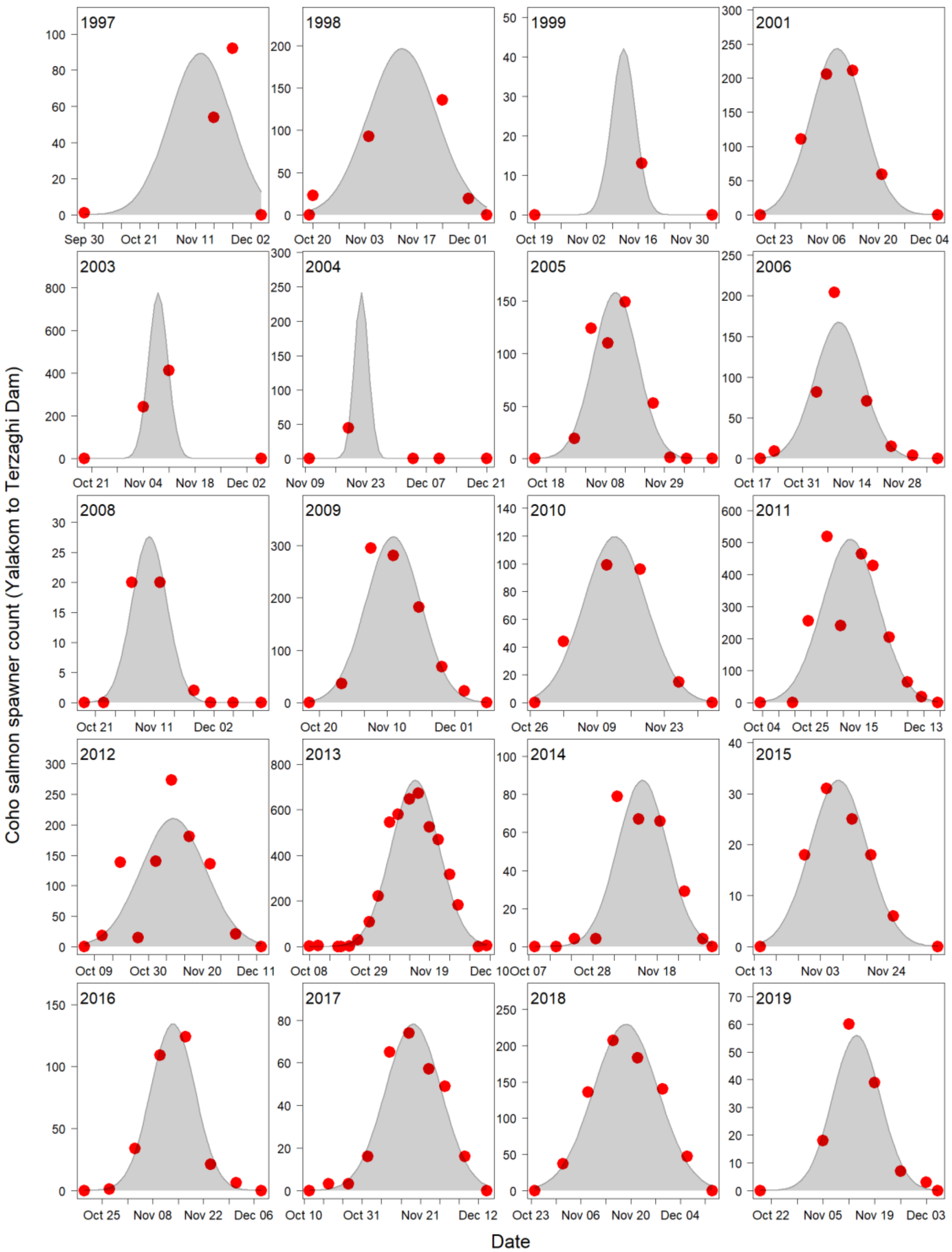
Compiled observations of spawning distribution of Coho Salmon across streamwalk sections in Reach 3 and 4 of the LBR from all visual surveys (2013-2019).

	Streamwalk		Year								
Section	Description	RiverKM	2012	2013	2014	2015	2016	2017	2018	2019	Total
1	Terzaghi Dam to Longskinny	40.0 to 39.6	324	1715	104	61	139	189	348	34.5	2914.5
2	Longskinny to Eagle	39.6 to 38.8	92	1186	73	7	66	83	212	71	1790
3	Eagle to Bluenose	38.8 to 38.2	223	70	6	4	0	0	16	0	319
4	Bluenose to Cobra	38.2 to 34.4	64	745	23	15	0	0	8	0	855
5	Cobra to Fraser Lake	34.4 to 33.2	151	352	24	10	72	5	102	1	717
6	Fraser Lake to Russel Springs	33.2 to 30.7	26	127	2	0	4	3	11	13	186
7	Russel Springs to Hell Creek	30.7 to 28.8	23	33	0	1	8	3	21	2.5	91.5
8	Hell Creek to Yalakom	28.8 to 25.5	19	177	21	0	6	0	32	8	263
		Total	922	4405	253	98	295	283	750	130	7136

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 2019. 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 2019. 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).

		Spawning Habitat (m^2)		
Site	Reach	2017	2018	2019
Apple Springs Unit1	1	NA	1404.45	1467.68
Apple Springs Unit2	1	NA	122.69	631.88
Apple Springs Unit3	1	NA	327.11	319.51
Bridge River Office	1	NA	NA	257.80
Antoine Creek	2	NA	190.79	261.74
Below Antoine Creek	2	NA	1525.16	1609.91
Camoo FSR	2	NA	1331.40	2339.81
Horseshoe Bend	2	NA	671.85	673.88
wpt37	2	NA	677.13	992.74
wpt38	2	NA	661.11	732.15
wpt41	2	NA	274.63	378.57
wpt44	2	NA	563.75	855.78
Yalakom Confluence	2	NA	158.76	154.40
Cobra	3	67.46	141.74	120.02
Counter Site	3	249.84	307.19	198.32
Fraser Lake	3	580.40	512.03	530.40
Hell Creek	3	112.85	104.98	132.28
Hippy Pool	3	38.59	104.05	138.39
KM 30.2 Pool	3	244.48	288.44	288.23
KWL Site	3	NA	84.10	NA
Lower Spawning Platform	3	196.49	185.24	228.46
Michael Moon Creek	3	NA	268.05	NA
Mid Spawning Channel	3	78.78	200.10	139.33
Russel Springs	3	129.97	233.70	153.72
Unit 1	3	362.55	395.17	445.84
Unit 2	3	226.62	218.31	256.98
Unit 3	3	105.24	125.44	120.02
Unit 4	4	48.81	52.92	56.80
Upper Spawning Channel	4	57.98	96.45	96.59
Below Longskinny	4	NA	NA	24.39
Eagle	4	NA	158.57	154.10
Long Skinny	4	817.64	550.85	669.72

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

Site	Reach	Spawning Habitat (m^2)
Apple Springs Unit1	1	1252.73
Apple Springs Unit2	1	446.85
Apple Springs Unit3	1	99.5
Bridge River Office	1	193.98
Antoine Creek	2	181.31
Below Antoine Creek	2	1359.01
Camoo FSR	2	3645.52
Horseshoe Bend	2	679
wpt37	2	674.75
wpt38	2	638.41
wpt41	2	361.66
wpt44	2	844.76
Yalakom Confluence	2	132.82
Cobra	3	84.15
Counter Site	3	175.83
Fraser Lake	3	204.23
Hell Creek	3	90.54
Lower Spawning Platform	3	88.85
Mid Spawning Channel	3	71.44
Russel Springs	3	87.25
Unit 1	3	389.18
Unit 2	3	118.78
Unit 3	3	202.05
Unit 4	4	9.89
Upper Spawning Channel	4	62.36
Eagle	4	241.82
Long Skinny	4	791.6

Appendix 9: Redd Distribution

Chinook Salmon redd distribution across streamwalk sections in Reach 3 and 4 of the LBR (2014-2019).

Section	Streamwalk Description	RiverKM	Year 2014	2015	2016	2017	2018	2019	Total
1	Terzaghi Dam to Longskinny	40.0 to 39.6	0	0	0	1	0	1	2
2	Longskinny to Eagle	39.6 to 38.8	0	0	0	0	2	1	3
3	Eagle to Bluenose	38.8 to 38.2	4	1	2	0	0	0	7
4	Bluenose to Cobra	38.2 to 34.4	10	2	0	0	0	0	12
5	Cobra to Fraser Lake	34.4 to 33.2	0	0	8	6	1	0	15
6	Fraser Lake to Russel Springs	33.2 to 30.7	7	3	5	4	0	0	19
7	Russel Springs to Hell Creek	30.7 to 28.8	25	6	4	2	0	0	37
8	Hell Creek to Yalakom	28.8 to 25.5	15	10	7	0	0	6	38
		Total	61	22	26	13	3	8	133

Coho Salmon redd distribution across streamwalk sections in Reach 3 and 4 of the LBR (2018-2019).

Section	Streamwalk Description	RiverKM	Year 2018	2019	Total
1	Terzaghi Dam to Longskinny	40.0 to 39.6	15	6	21
2	Longskinny to Eagle	39.6 to 38.8	6	2	8
3	Eagle to Bluenose	38.8 to 38.2	0	0	0
4	Bluenose to Cobra	38.2 to 34.4	0	0	0
5	Cobra to Fraser Lake	34.4 to 33.2	4	0	4
6	Fraser Lake to Russel Springs	33.2 to 30.7	2	0	2
7	Russel Springs to Hell Creek	30.7 to 28.8	4	0	4
8	Hell Creek to Yalakom	28.8 to 25.5	0	0	0
		Total	31	8	39

Appendix 10: Scale Analysis

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

Species	Age (Koo 1962)	Total Age	2011	2012	2013	2014	2015	2016	2017	2018	2019	Total
Chinook	1.2	3	-	-	1	0	1	1	0	0	0	3
	1.3	4	-	-	9	13	11	7	3	3	4	50
Coho	1.1	2	13	15	15	19	10	22	12	17	3	126
	1.2	3	0	0	0	1	0	0	0	0	0	1
	2.1	3	5	11	1	8	6	7	4	0	2	44
Steelhead	1.1	2	-	-	-	0	0	0	1	0	0	1
	2.1	3	-	-	-	1	0	0	0	0	0	1
	2.2	4	-	-	-	3	4	0	1	2	0	10
	2.3	5	-	-	-	0	1	1	5	7	1	15
	3.1	4	-	-	-	2	1	0	0	0	0	3
	3.2	5	-	-	-	2	8	2	3	2	2	19
	3.3	6	-	-	-	0	2	0	7	5	6	20
		Total	18	26	26	49	44	40	36	36	18	293