Bridge River Project Water Use Plan

Lower Bridge River Adult Salmon and Steelhead Enumeration

Implementation Year 6

Reference: BRGMON-3

Study Period: April 1 2017 to December 31 2017

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December 31, 2017

Bridge-Seton Water Use Plan

Implementation Year 6 (2017):

Lower Bridge River Adult Salmon and Steelhead Enumeration

Reference: BRGMON-03

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Lower Bridge River Adult Salmon and Steelhead Enumeration, 2017

Multibeam sonar and resistivity counters in the Lower Bridge River in 2017

Executive Summary

The Lower Bridge River Adult Salmon and Steelhead Enumeration program (BRGMON-3) enumerates adult salmonid returns, data that supports evaluation of the effects of different flow releases from Terzaghi Dam on salmon productivity in the Lower Bridge River (LBR). BRGMON-3 aims to develop new, and refine historic, approaches for estimating adult abundance and egg deposition. Adult escapement data from BRGMON-3 will be used with juvenile salmonid abundance collected from the Lower Bridge River Aquatic monitor (BRGMON-1) to develop stock recruitment models which will evaluate the effects of dam flow releases on juvenile salmonids independently from other factors such as marine survival and adult exploitation.

In 2017, the operations of the Bridge River hydroelectric complex were modified due to dam safety risks at La Joie Dam and repairs at the Bridge River Generating Stations in Shalalth. High flow releases from Terzaghi Dam were used to manage the excess water stored in Carpenter Reservoir, resulting in a hydrograph that ramped up on May 23, 2017, peaked at 127 $m^3 s^{-1}$ from June 10 to June 27, and ramped down to 5.1 cms by August 17. Terzaghi Dam discharges returned to the target WUP hydrograph prior to the historic run timing of Chinook and Coho salmon (August to December). Steelhead spawn from April to early June and the high flows may have affected Steelhead spawning.

Data from visual streamwalk surveys in 2017 were used to generate area-under-the-curve (AUC) abundance estimates of Chinook and Coho Salmon in the LBR. Observer efficiency and residence time estimates were generated using radio telemetry mark-recapture. We radio tagged, 3 Chinook Salmon and 20 Coho Salmon in 2017. Using AUC methods, a total spawner abundance estimate of 120 Chinook and 451 Coho Salmon were derived for the area upstream of the confluence with the Yalakom River (Reaches 3 and 4). The 2017 estimates are within the range of returns seen in since 1997. Historic visual count data were compiled and AUC estimates were calculated for Chinook and Coho Salmon in the area upstream of the Yalakom River. AUC estimates from 1993 to 2016 ranged from 21(2009) to 3,106 (2004) Chinook Salmon, and from 79 (1999) to 3,539 (2011) Coho Salmon from 1997 to 2016. Chinook returns severely declined after 2004 and have remained at these depressed levels since. Coho returns were high between 2011 and 2013 (ranged from 1,700 to 3,500) but declined after 2013. The 2017 Coho estimate is within the lower range of levels observed between 1997 – 2010 (78 – 1541 individuals).

We radio tagged 21 Steelhead Trout, but no visual counts were conducted due to the limited visibility in the river. No historical visual count data were available for Steelhead Trout prior to 2014, but through data collected using radio and PIT telemetry the majority Steelhead have been observed to spawn in Reaches 3 and 4 of the Lower Bridge River.

In 2017, we used a multibeam sonar and resistivity counter to enumerate Steelhead Trout, Chinook and Coho Salmon. We assessed the first five weeks (March 29 to May 8) of the 9-week-long Steelhead Trout spawning period (Late March to Early June). We estimated that 26 Steelhead Trout spawned upstream of the counter site from March 29 to May 08, 2017. The counters were removed early due to increasing Terzaghi Dam releases and the steelhead estimate should be considered a minimum number. Two methods of counting (resistivity and multibeam sonar) were also used to estimate Chinook Salmon abundance during the spawning period of August 15 to October 1. Due to post-season data loss, Chinook abundance could only be assessed from August 15 to September 20. In total, 340 Chinook Salmon were estimated to have spawned upstream of the counter site and is ~3x higher than the AUC estimate of spawners above the counter site. Only the sonar counter was used to estimate coho salmon abundance during the spawning period of ~ October 1 to December 7. Due to post-season data loss, Coho Salmon abundance could only be assessed from November 12 to December 7 and the estimate could not be compared to the AUC estimate. During this period, a total of 66 Coho Salmon were estimated to have spawned upstream of the counter site. We will continue to collect electronic counter data with the end goal of comparing AUC- and counter-derived (resistivity and sonar) estimates of abundance during the final synthesis process for BRGMON-3.

We sampled 13 Chinook Salmon redds for a fourth straight year to characterize the preferred spawning habitat characteristics (water depth, velocity and substrate characteristics) and determine the distribution of redds throughout Reaches 3 and 4 of the LBR. We found that Chinook Salmon sought out the same water depths and velocities in 2017 as in 2014-2016 . Consistent with the findings from 2016, the first year of spawning following high discharges, we found a significant increase in the geometric mean (D_{50}) of the substrate sampled in the tailspill of the redds relative to pre-high discharge years. Substrate measured in 2017, however, is still within the preferred spawning substrate size range of Chinook Salmon. We note that this increase is likely associated with the downstream mobilization of smaller sized substrate during high flow releases from Terzaghi Dam in 2016 and 2017. The locations of redds throughout Reaches 3 and 4 are also consistent with findings from 2016, but how the redds are distributed (proportions) in these areas has changed. Chinook salmon continue to use some past key spawning locations (Russel Springs, Fraser Lake) with increased spawning density at some of these sites (Fraser Lake). However, in 2017 spawning did not occur at some sites that were previously used by spawning Chinook (Hippy pool, counter site, Cobra, Hell Creek). Coho salmon redds could not be located for assessment during the spawning period due to low water visibility.

Surface and sub-surface temperature loggers were placed adjacent to ten Chinook salmon redds to monitor accumulated thermal units over the incubation period (late September 2016 to late February 2017) and assess for potential ground water effects. We did not observe any differences between surface and sub-surface water temperatures indicating no groundwater effect at any of the redds throughout Reach 3 and 4. However, a strong gradient of temperature was observed with temperatures decreasing with distance from the dam Fifty percent of emergence ATUs were reached in January at sites near the Terzaghi Dam but this threshold was not reached in the mid to lower sections of Reach 3 by the end of the study period (late February). Consequently, there may be a selection bias for fish to spawn in Reach 3 *versus* Reach 4 because hatching and emerging early likely has significant survival consequences (i.e., limited food, cold water conditions) for juvenile Chinook Salmon in the LBR.

BRGMON-3 Status of Objectives, Management Questions and Hypotheses after Year 6

Study Objectives	Management Questions	Management Hypotheses	Year 6 (Fiscal Year 2017) Status
Evaluate effects of Terzaghi Dam operations on the spawning habitat and distribution of Steelhead Trout, and Chinook and Coho Salmon, and to generate spawner abundances under the alternative test flow regimes.	How informative is the use of juvenile salmonid standing crop biomass as an indicator of flow impact?	1) Adult spawner abundance is not the limiting factor in the production of juvenile salmonids in the Lower Bridge River.	Historic streamwalk data has generated a time series of Chinook and Coho Salmon spawner abundance, however confidence in the accuracy of these estimates is limited due to varying methods and visibility. Abundance estimates are useful for providing a trend in LBR spawner abundance relative to other Fraser River salmon stocks over the course of the monitoring period. Differences among populations may be attributable to flow trial effects. Continued monitoring is required to adequately evaluate Hypothesis 1. Two complete years (2014, 2015) of resistivity counter data for all species have been collected. High flow releases from Terzaghi Dam in 2016 damaged the resistivity counter and in 2017 counter data were partially lost. Future abundance estimates will be generated using a combination of counter technologies (resistivity and multibeam sonar) and will provide accurate and consistent estimates to compare to historical streamwalk datasets (AUC-derived estimates). Such data will allow for a rigorous assessment of Hypothesis 1.
		2) Quantity and quality of spawning habitat in the Lower Bridge River is sufficient to provide adequate area for the current escapement of salmonids.	Data on spawning habitat used by Chinook Salmon (but not for steelhead or coho due to conditions during their spawning period) has been collected for four years. Data will be combined with habitat data collected by BRGMON-1 (water depth, velocity and substrate) to evaluate the total area available to spawners. Spawner distribution for all species has been identified through telemetry, and continued effort will reveal whether managed flows in the LBR impact spawner distribution. Data will answer

		Hypothesis 2 when data collection and analysis is complete. Locating and surveying Steelhead Trout and Coho Salmon redds has not been possible due to poor visibility.

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Glossary of Terms

AUC	Area-Under-The-Curve
ATU	Accumulated Thermal Units
BRGS	Bridge River Generating Stations
BRS CC	Bridge-Seton Consultative Committee
BRS FTC	Bridge-Seton Fisheries Technical Committee
DFO	Department of Fisheries and Oceans Canada
IFO	Interim Flow Order
IFR	InStream Fisheries Research
LBR	Lower Bridge River
ML	Maximum Likelihood
OE	Observer Efficiency
PIT	Passive Integrated Transponder
PSS	Peak Signal Size
SER	St'át'imc Eco-Resources Ltd.
WUP	Water Use Plan

Acknowledgements

St'át'imc Eco-Resources Ltd. (SER) fisheries technicians provided essential field service throughout the duration of this monitoring program. SER administrators Bonnie Adolph, Gilda Davis and Jude Manahan provided logistical and administrative support for this project. Richard Bailey from the Department of Fisheries and Oceans (DFO) Canada provided historical abundance data.

1.0 Introduction

1.1 Background

The Bridge River hydroelectric complex is a power producing tributary of the middle Fraser River. It provides important habitat for salmon (*Onchorhynchus* spp.) and Steelhead Trout (*O. mykiss*) and has historic and current significance for the St'át'imc Nation. River discharge is affected by BC Hydro through the operation of Carpenter Reservoir and Bridge River Generating Stations 1 and 2 (BRGS). The Bridge River was originally impounded in 1948 through the construction of the Mission Dam approximately 40 km upstream of the confluence with the Fraser River. In 1960, Mission Dam was raised to its present configuration (~ 60 m high, ~ 366 m long earth fill structure) and renamed as Terzaghi Dam in 1965. From 1960 to 2000, with the exception of periodic spill releases during high inflow years, flows were exclusively diverted through the BRGS to the adjacent Seton River catchment for power production at the Seton Generating Station (Figure 1). A 4-km section of the Bridge River channel immediately downstream of Terzaghi Dam remained continuously dewatered; groundwater and small tributaries contributed flow in the dewatered reach (~ 1 $m^3 s^{-1}$ averaged across the year; Longe and Higgins 2002).

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 general public. During the late 1980s, BC Hydro, Fisheries and Oceans Canada, and the BC Provincial Ministry of Environment engaged in discussions over appropriate flow releases from the dam. In 1998, an agreement was reached for a continuous flow release from Carpenter Reservoir, via a low-level flow control structure, to provide fish habitat downstream of the dam. The agreement included the provision of a 3.0 $m^3 s^{-1}$ interim annual water budget for instream flow releases based on a semi-naturalized hydrograph ranging from 2 $m^3 s^{-1}$ to 5 $m^3 s^{-1}$. The Deputy Comptroller of Water Rights for British Columbia issued an Order under Section 39 of the *Water Act* to allow initiation of the interim flow releases from Carpenter Reservoir into the Lower Bridge River (LBR), and the continual release of water into the LBR began on August 1, 2000.

A condition of the Interim Flow Order (IFO) was the continuation of environmental monitoring studies in response to concerns regarding environmental impacts of the introduction of water from Carpenter Reservoir and the need to develop a better understanding of the influence of reservoir releases on the recovery of the LBR aquatic ecosystem. The Aquatic Ecosystem Monitoring Program was implemented (continuing as BRGMON-1, Bridge-Seton WUP Monitoring Terms of Reference 2012), which collected data on baseline conditions before the continuous release began and monitored ecosystem responses to the flow trials (e.g. Sneep and Hall 2011).

The IFO continued until the Water Use Plan (WUP) for the Bridge River hydroelectric complex was approved by the St'át'imc Nation and regulatory agencies, and authorized by the Comptroller of Water Rights for the Province of British Columbia. The Bridge-Seton Consultative Committee (BRS CC) submitted a draft WUP to the Comptroller in

September 2003. Subsequent recommendations by the St'át'imc Nation were adopted in 2009 and 2010, and a final WUP was submitted to the Comptroller of Water Rights on March 17, 2011.

A 12-year test flow release program was proposed under the draft WUP in 1998 that tested three alternative flow release regimes (referred to as: 1 $m^3 s^{-1}$/y, 3 $m^3 s^{-1}$/y, 6 $m^3 s^{-1}$/y treatments) that differed in the total magnitude of the annual water budgets, but not the shape of the hydrograph. The flow treatment was subsequently revised, and was set to 3 $m^3 s^{-1}$/y from August 2000 to April 2011, and 6 $m^3 s^{-1}$/y from May 1, 2011 to April 15, 2015. The intention of the flow trial was to establish a long-term flow release strategy for the LBR. The BRS CC recommended detailed monitoring of ecosystem responses to instream flow. In response, the BRS Fisheries Technical Committee (BRS FTC) developed a monitoring program aimed at evaluating the physical habitat, aquatic productivity, and fish responses to instream flows.

The BRS FTC expressed uncertainty about the availability and importance of spawning habitat for anadromous species, and how this may affect interpretation of the juvenile salmonid response monitored under BRGMON-1. Coincident time series data of adult salmon abundance and juvenile standing crop estimates during the flow trials were identified to determine whether any differences could be interpreted as the effects of flow rather than the influence of spawner density on juvenile recruitment. Accordingly, the BRS CC recommended a monitoring program to evaluate the effects of the flow regime on spawning habitat and distribution to enumerate spawning abundances under the alternative test flow regimes (Adult Salmon and Steelhead Enumeration Program BRGMON-3, Bridge-Seton WUP Monitoring Terms of Reference 2012).

Abundance and distribution of spawning salmonids has been assessed previously by DFO in the LBR. A secondary objective of BRGMON-3 is to build on previous studies by developing survey methods and analytical techniques that produce rigorous, quantitative estimates of LBR salmon and steelhead abundance and distribution to assist in evaluating the usefulness of historical archived data.

In 2016, BC Hydro implemented modifications to La Joie Dam operations to address dam safety risks associated with the integrity of the upstream shotcrete dam face when reservoir levels exceed El. 734 m. Specifically, the modification involved lowering the maximum normal reservoir level to El. 734 m as an interim measure to mitigate potential seismic risk associated with the integrity of the dam face. In late 2015, an assessment of flow management options identified the need for further modifications of planned operations, including the LBR hydrograph, to be able to pass higher flows down the LBR due to: (1) the loss of storage capacity at Downton Reservoir, and (2) additional capacity limitations associated with de-rated generator units in 2015 at the BRGS in Shalalth.

Modified operations have involved several flow variances in the LBR, including a peak hydrograph of 97 $m^3 s^{-1}$ in 2016 and 127 $m^3 s^{-1}$ in 2017 (Figure 2). We highlight that the fish counter located upstream of the Yalakom River was designed to withstand a peak flow of 20 $m^3 s^{-1}$, and thus damage to the site was expected. High flow releases in 2016 caused extensive damage to previously deployed fish counter equipment, including the resistivity counter sensors (on river left), video validation equipment and PIT telemetry gear. Due to the high-water levels and extent of damage, the resistivity counter could not be used to enumerate Steelhead Trout, and Chinook and Coho Salmon in 2016. Instead, IFR tested alternative methods of enumeration which included a combination of sonar and resistivity counter technologies which was determined to be an effective method for future study years in which high flows are anticipated (Burnett et al 2017) .

Management Questions

Specific management questions were not listed in the terms of reference for this monitor. Instead the works from this monitoring program would aide in the interpretations of the results of the Aquatic Ecosystems Monitoring Program (BRGMON-01). Specifically, the objectives of the monitor are to provide information to aide in addressing the questions:

1) How informative is the use of juvenile salmonid standing crop biomass as the primary indicator of impact of flow?

This monitoring program will also aim to address uncertainty about spawning habitat in the Lower Bridge River.

2) What is the quality and quantity of spawning habitat in the Lower Bridge River?

BRGMON-3 addresses these management questions via two hypotheses:

H_1: Adult spawner abundance is not the limiting factor in the production of juvenile salmonids in the Lower Bridge River.

H_2: Spawning habitat quantity and quality in the Lower Bridge River is sufficient to provide adequate area for the current abundance of salmonids.

H_1 relates to the interpretation of the results from BRGMON-1. BRGMON-3 aims to collect the data needed to support evaluations of whether there are sufficient numbers of adults to produce progeny that would fully seed available rearing habitat.

H_2 attempts to fill data gaps identified during WUP development. The BRS WUP process identified significant uncertainty regarding the quality and quantity of spawning habitat in the LBR. Implementation of this monitoring program is intended to improve the utility of the juvenile standing crop data by examining relationships with egg deposition and the amount of spawning habitat available for adult abundance.

1.2 Key Water Use Decisions Affected

Results from BRGMON-3 will inform the development of the long-term flow regime for the LBR. BRGMON-3 provides the data needed to build spawner recruit relationships, support BRGMON-1 in the interpretation of the response of the aquatic ecosystem to the varied flow treatments (0 $m^3 s^{-1}/y$, 3 $m^3 s^{-1}/y$, and 6 $m^3 s^{-1}/y$), and improve our understanding of the influence of instream flow on salmon spawning and rearing habitat quantity and quality in the LBR. In 2017, however, we monitored spawner abundance and distribution in relation to a new high flow treatment (19 $m^3 s^{-1}/y$). We note that there is potential for a high flow treatment in the LBR that will persist for approximately 10 years until La Joie Dam and the BRGS are repaired. The high flow treatment may be having effects on juvenile abundance (Coldstream Ecology 2017) and will likely be reflected in adult abundance even after the repairs are completed and the flow treatment is returned to a more conservative level. Results presented herein pertain to the high flow treatment and not to the original WUP flow treatments outlined above but will still support the development of a long-term flow regime for the LBR.

2.0 Methods

2.1 Objectives and Scope

The objective of the test flow program is to determine the relationship between the magnitude of flow releases from Terzaghi Dam and the relative productivity of the LBR aquatic and riparian ecosystem by observing changes in juvenile salmonid productivity responses to test flows. BRGMON-3 specific objectives include documenting the abundance of adult salmonids to:

1. Ensure changes in standing crop are associated with flow changes and not confounded by variation in spawner abundances.
2. Understand the effects of flow releases on salmon and Steelhead Trout spawning habitat.

BRGMON-3 monitors abundance and distribution of spawning salmonids in the LBR, with a particular focus on stream-rearing species (Steelhead Trout, and Chinook and Coho Salmon). BRGMON-1 aims to understand the impacts of changes in Terzaghi Dam discharge by measuring juvenile population responses (i.e., egg-to-fry survival, smolts produced per spawner, fry-parr standing crop). Estimating egg-to-fry survival and smolts produced per spawner requires accurate estimates of spawner abundance; this is the main focus of BRGMON-3. Salmonid abundance is not a direct indicator of habitat condition, and changes in spawner abundance will not be used as a response to flow impacts.

2.2 Monitoring Approach

BRGMON-3 focuses on the stock assessment of adult Steelhead Trout, Chinook Salmon (*O. tshawytscha*) and Coho Salmon (*O. kisutch*), as these are the only anadromous salmonids that rear for an extended period in the LBR.

Following the BRGMON-3 terms of reference (Adult Salmon and Steelhead Enumeration Program BRGMON-3, BC Hydro 2012), supplemental surveys are conducted (when possible) to estimate the spawning abundance of Sockeye (*O. nerka*) and Pink Salmon (*O. gorbuscha*) when present.

In October 2013, the construction of a fish counter near the downstream end of Reach 3 was completed, where a five-channel (Channel 1 on river left and Channel 5 on river right) Logie 2100C (Aquantic, Scotland, UK) electronic resistivity counter enumerated Steelhead Trout, and Chinook and Coho Salmon abundance upstream of the counter site (Figure 3). Resistivity counters can provide accurate estimates of spawner abundance within 10% of the true abundance (e.g., Deadman River; McCubbing and Bison 2009).

Since 2001, visual counts of salmonids in the LBR have occurred annually using methods developed and implemented through BC Hydro monitoring in the Bridge River and prior to 2000 using several methods, including stream-side visual counts. The BRGMON-3 survey area extends from Terzaghi Dam to the Yalakom River – Bridge River confluence, cover all of Reach 3 and 4 (Figures 4 and 5; Table 1).

Prior to 2013, historic fish counts are available from BRGMON-3 and DFO visual surveys, helicopter surveys, and fence counts. Abundance estimates for these counts (except fence counts) are calculated through area-under-the-curve (AUC) estimation (Hilborn et al. 1999, Millar et al. 2012) using observer efficiencies and residence times (also termed 'survey life') determined by radio telemetry and visual surveys conducted since 2011. Two PIT arrays – one at the counter site and one at the Reach 3-4 break – were installed in the LBR in October 2015 to estimate observer efficiency and residence time in 2016 and future study years. Similar to the resistivity counter site, the high flow releases in 2016 caused extensive damage to the PIT antennas. Consequently, IFR and BC Hydro agreed to reinstate the use of radio telemetry in 2016 and 2017 to assess spawner distribution and migration behaviour. Counter estimates will be compared in the future to aid in back-calculating historic estimates of abundance from AUC alone (Troffe et al. 2008).

IFR has conducted an assessment of Chinook Salmon spawner habitat quantity and quality from 2014 to 2017. Redd habitat surveys characterize the preferred spawning habitat of Chinook Salmon and monitor any changes to habitat characteristics (water depth, velocity, spawning substrate) that might occur due to managed flow releases.

2.2.1 Fish Capture, Tagging and Sampling

Fish capture by angling was completed by teams of two to three SER fisheries technicians. Previous quality angling sites above the Yalakom confluence have been in filled by gravel, reducing the amount of accessible fishable waters, limiting the effectiveness of fish capture. Tag application and effort was distributed throughout each species migration periods: February o April for Steelhead Trout, August to September for Chinook Salmon, and

October to November for Coho Salmon (Figure 2). Effort was also made to evenly distribute tags between males and females as migration behaviour and run timing can differ by sex (Korman et al. 2010, Troffe et al. 2010).

Steelhead Trout were captured and tagged at the Seton-Fraser confluence with a gastrically implanted TX-PSC-I-1200-M radio tag (45 × 16 × 16 mm; Sigma Eight Inc., Ontario, Canada). SER fisheries technicians did not angle for Steelhead Trout at the Bridge-Fraser confluence (as in previous study years) due to changes in the instream river conditions. The sections of the river previously used had been filled in by gravel and created poor angling conditions. releases. In 2017, effort was made to capture Chinook Salmon in lower reaches (Reaches 1 and 2) of the LBR. Despite extensive effort, we were unsuccessful at capturing Chinook Salmon at these locations; thus, fish were captured via angling and tagged immediately downstream of the counter site at the Bridge-Yalakom confluence. Coho Salmon were captured and tagged throughout the LBR in Reaches 1, 2 and 3.

Chinook and Coho Salmon were tagged with a gastrically implanted TX-PSC-I-1200-M radio tag that alters the burst rate depending on whether the fish is active (i.e., presumed alive; 5 s burst rate) or inactive (i.e., presumed dead; 13 s burst rate). Telemetry data from the mortality radio tags helped generate accurate estimates of residence time in Reaches 3 and 4 in 2017. External visual identification (i.e., spaghetti) tags were applied to Chinook and Coho Salmon in 2017 to generate an estimate of observer efficiency. Estimates of residence time and observer efficiency are needed for use in estimating abundance through AUC methods (see Section 2.3.1).

Fork length (mm) and sex were recorded during tagging, and scale samples were obtained from Steelhead Trout, and Chinook and Coho Salmon for ageing purposes. Following capture, fish were held in a submersible holding tube for a minimum of 30 minutes prior to release to ensure survival and tag retention.

2.2.2 Radio Telemetry

Fixed radio telemetry stations were installed at three locations along the LBR (Figure 4). Stations consisted of SRX_400 receivers (Lotek Wireless Inc., Ontario, Canada) connected to a single 6-element Yagi antenna oriented perpendicular to flow. Fixed stations were installed prior to tagging and operated during the Steelhead Trout (March to June), Chinook Salmon (August to October) and Coho Salmon (October to December) migrations. Data from fixed stations were used to corroborate fish location identified during mobile tracking, determine entry and exit timing of tagged fish into each reach, and to collect information on migration and spawning behaviour in the LBR. Detection efficiency of the fixed stations were high and are presented in Table 2.

Mobile tracking was conducted weekly in Reaches 3 and 4 using a hand-held SRX_400 receiver, and was conducted twice a week during peak spawning to increase the temporal and spatial resolution of telemetry data. Tracking was carried out from March 16 to May 29 for Steelhead Trout, August 25 to September 21 for Chinook Salmon and October 6 to December 7 for Coho Salmon. Radio tracking was conducted by vehicle and on foot independently of the technicians who conducted the visual count to avoid observer bias (i.e., searching for tags known to be in the area). We present the migration rates (in km day^{-1}) of radio-tagged fish to account for the different release sites and thus variable distances from release to the spawning reach.

2.2.3 Ageing of Adult Salmon and Steelhead

Burnett et al. (2017) synthesized the age data collected under the BRGMON-3 monitoring program from 2011 to 2016. Age data from 2017 (n = 16 for Steelhead Trout, n = 1 for Chinook Salmon, n = 7 for Coho Salmon) will be reported with the scales collected in 2018 to produce a complete dataset of age data for fish prior to the high flow releases (2016 and beyond) in the LBR.

2.2.4 Visual Counts

Visual surveys followed methods used in previous years, where two observers walked in a downstream direction on the riverbank, counted fish and recorded species and location. Viewing conditions, cloud cover, and lateral water visibility were also recorded (Sneep and Hall 2011). Visual counts occurred weekly for Chinook, Sockeye, Pink and Coho Salmon in Reaches 3 and 4 (Figure 5). Surveys started on August 18 and continued until December 8 when spawning ceased based on streamwalk and telemetry data. Surveys for Steelhead Trout were deemed ineffective in Year 1 (2011) of BRGMON-3 due to high turbidity and flows in the LBR; thus, visual surveys were not completed for Steelhead Trout in 2017.

2.2.5 Chinook Salmon Habitat Evaluation

We undertook a detailed investigation of Chinook Salmon redds in Reaches 3 and 4 of the LBR. Water depth, velocity, dominant substrate characteristics and redd dimensions were measured at each redd. Specifically, water depth was measured at three locations around the redd (leading edge, tailspill and adjacent), and velocities were measured adjacent to the redd and at the tailspill (Reibe et al. 2014). Measurements adjacent to the redd were assumed to be representative of habitat prior to the digging of redds, and thus can be interpreted as the preferable spawning habitat for Chinook Salmon. Water velocity was taken at 60% of the total depth (mean column velocity-V60) where depth was less than one meter. A Swoffer (Model 2100) current velocity meter was used to measure velocities and the top set wading rod of the Swoffer was used to measure depth to the nearest centimeter. We calculated the geometric mean (D_{50}) of 20 pieces of substrate located in the tailspill of each Chinook Salmon redd to characterize the substrate that Chinook Salmon sought out during redd digging. Note that the geometric mean is commonly used to reduce the influence of extreme substrate sizes on the mean (e.g., sand and large boulders).

Ten temperature loggers (HOBO Water Temperature Pro v2; Onset Computer Corporation, Massachusetts, USA) were buried adjacent to sampled Chinook Salmon redds in Reaches 3 and 4 to monitor accumulated thermal units (ATU) over the incubation period. Loggers were deployed on September 24, 2016 and were removed February 22, 2017 prior to a ramp up to 3 m^3s^{-1} on March 1, 2017. It should be noted that the ATU data presented only represents the time from when the loggers were deployed and not the true (full) incubation period that is experienced by all eggs, which could potentially begin as early as late August. Loggers were attached to rebar and buried at a representative depth for deposited Chinook Salmon eggs (30 cm below streambed; DeVries 1997). An additional temperature logger (HOBO TidbiT v2 Water Temperature Data Logger UTBI-001) was placed on each length of rebar at 60% of the total depth to examine if Chinook Salmon eggs experience groundwater effects during incubation. Loggers were accurate to ± 0.2 ºC. Following the findings of Geist et al. (2006), we considered the required ATUs to reach 50% emergence for Chinook Salmon to be 931 ATUs (95% confidence intervals: 906-955 ATUs). Where 50% emergence represents the number of ATUs at which 50% of the fish would have emerged from the gravel. Steelhead Trout and Coho Salmon redds have not been sampled in this monitoring program due to poor visibility (high turbidity and/or flows) prohibiting the location of redds.

2.3 Analysis Methods

2.3.1 Area Under the Curve Estimates of Spawner Abundance

In 2017, as in previous years, an AUC analysis (Hilborn et al. 1999, Millar et al. 2012) was used to estimate abundance for Chinook and Coho Salmon using visual count data combined with observer efficiency and residence time (or survey life) estimates obtained from radio telemetry. Abundance of Chinook and Coho Salmon in 2017 were modelled using a quasi-Poisson distribution with normally distributed arrival timing (described in Millar et al. 2012).

With abundance modelled as a quasi-Poisson distribution with normally distributed arrival timing (Millar et al. 2012), the number of observed spawners at time t (C_t) is

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

where a is the maximum height of the spawner curve, m_s is the time of peak spawners, 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 1 becomes $\sqrt{2\pi\tau_s}$ and Equation 1 can be simplified to

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

A final estimate of abundance ($\hat{E}$) is obtained by applying observer efficiency (v) and survey life (l) to the estimated number of observed spawners

(3)
$$\hat{E} = \frac{\hat{F}_G}{l * v}$$

$\hat{E}$ in Equation 3 is estimated using maximum likelihood (ML), where $\hat{a}$ and $\hat{\tau}$ are the ML estimates of a and τ_s in Equation 2 ($\hat{C}_t = \hat{a}\sqrt{2\pi\hat{\tau}_s}$).

The AUC estimation in Equation 1 can be re-expressed as a linear model, allowing the estimation to be performed as a simple log-linear equation with an over-dispersion correction factor. Correction for over-dispersion accounts for instances where the variance of the observations exceeds the expected value. The log-linear model is computationally simple and can be completed using standard generalized linear modelling.

The estimated number of fish-days ($\hat{F}_G$) can be estimated following

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

where $\beta_0,\ \beta_1,\ \beta_2$ are the regression coefficients of the log-linear model. Uncertainty in observer efficiency and survey life are incorporated into the estimated spawner abundance using the covariance matrix of the modeled parameters ($\beta_0,\ \beta_1,\ \beta_2$) via the delta method (described in Millar et al. 2012).

Chinook Salmon

In 2012 and 2013, observer efficiency for Chinook Salmon was calculated as the number of externally-tagged fish observed in each visual survey divided by the total number of tagged fish present as indicated by radio telemetry. Deceased fish were not included in calculations of observer efficiency as only live counts are used in AUC estimates. Chinook Salmon were not spaghetti tagged in 2014 or 2015, and thus observer efficiency could not be estimated. In 2017, we used the mean observer efficiency (0.50) and residence time (10.5 days) across study years for use in AUC estimation (Tables 3 and 4) due to low sample sizes (n = 3 fish tagged) and high variance among streamwalk surveys.

Historical Chinook Salmon count data between the confluence of the Yalakom River and the Terzaghi Dam (Reaches 3 and 4) were obtained from DFO. From 1993 to 1996, a counting fence was used to determine the number of fish present between the Yalakom River and Terzaghi Dam. Visual data from 1997 to 2010 were used to reconstruct AUC estimates of spawner abundance following the methods outlined above. Visual count data prior to 2000 were recorded from paper copies of spawner survey datasheets by IFR staff. Data from more recent years (post-2000) were retrieved from the DFO Stock Assessment database. Prior to 1993, the data did not have sufficient detail to calculate estimates, and three years (2000, 2002-2003) were missing from the dataset; therefore, no estimate is available for these years. Historical count data were often missing zero counts at the beginning and end of surveys, which can result in inaccurate estimates or no estimate. Zeroes were added to the count dataset to improve the accuracy and temporal coverage of estimates. A zero count was added on August 8 for all years that did not start with a zero count. A zero count was added on October 2 for all years that did not end with a zero count. We chose these dates based on other years of count data that had zero count surveys at the beginning and end of the survey.

Generating accurate and precise historic AUC estimates is challenging due to inconsistencies in historic methods, a lack of historic observer efficiency data, and only a short time series of AUC-derived abundance estimates for resistivity counter comparisons. No historical data exist for observer efficiency or residence time. Mean and standard error of observer efficiencies and residence times from 2012-2014 and 2016 were used in the historical AUC modelling of both helicopter and streamwalk counts (Tables 3 and 4). Historical estimates will continue to be updated as more observer efficiency and residence time data is collected.

Coho Salmon

In 2012 and 2013, observer efficiency and residence time for Coho Salmon were calculated using the same methods outlined above for Chinook Salmon. In 2017, we used the observer efficiency (0.23) and residence time (19 days) calculated from fish tagged in 2017 for use in AUC estimation (Tables 3 and 5).

Historical AUC estimates of Coho Salmon abundance from 1997 to 2010 were calculated using the same methods described for Chinook Salmon. Data prior to 1997 was of insufficient detail to produce estimates and the years 2000, 2002 and 2007 were missing from DFO's historical records.

Mean and standard error of observer efficiencies and residence times from 2012, 2013, 2016 and 2017 were used in the historical AUC modelling of Coho Salmon abundance (Tables 3 and 5).

2.3.2 Resistivity Counter Abundance Estimate

IFR modified the resistivity Crump weir sensor on river right in February 2017 from a one-channel to a two-channel sensor to increase counter accuracy (Figure 3). Water levels are high enough during the Steelhead Trout migration period to permit passage over the Crump weir sensor. Consequently, we partially estimated the abundance of Steelhead Trout in 2017 using the resistivity counter on river right. The Crump weir sensor was also used during the Chinook Salmon migration period, but in a different manner. During the Chinook Salmon migration period, flows in the LBR are decreasing and water levels over the crump weir sensor are low (2 cm depth). We suspect that Pink Salmon can use the crump weir sensor to move upstream, but water levels may be too low for Chinook Salmon to use (due to their body size). The crump weir sensor was operated to verify this assumption and enumerate any Chinook Salmon migrating over the shallow sensor. The resistivity counter validation process is described in detail in Section 2.3.2.1.

The Logie 2100C resistivity counter (Thurso, Caithness, Scotland) operates in conjunction with up to four electrode sensors (e.g., Crump weir sensors) that span the channel width to detect the upstream and downstream movement of fish over the sensors. Briefly, the counter measures the resistance between two pairs of electrodes: one pair consists of the downstream electrode and the center electrode, and the other pair consists of the upstream electrode and the center electrode. The resistance that is measured is a function of water conductivity. There is a change in resistance when a fish swims over the electrodes (the fish is more conductive than the water it displaces); this change is recorded by the counter. A fish moving over the sensor pad creates a change in resistance which is then interpreted by the counter algorithm to determine if it is consistent with that of a fish and the direction is recorded along with a date and time stamp. The counter algorithm can classify each counter record as one of the following: (1) up, (2) down, or (3) event. If the change in resistance is determined to not follow a typical trace (by algorithm) but the values reach some predefined threshold value, the record is classified as an event instead of an up or down count. Events can be due to a fish interacting with the electrodes but not completely passing over the three electrodes, other objects or animals that cause a change in resistance, or from electrical noise. For each record (ups, downs or events), the counter also records the peak signal size (PSS) that corresponds to the peak of a sinusoidal curve that is created when a fish passes over the sensor pad (Figure 6). PSS is related to mass and can thus be used as a proxy for fish size (McCubbing et al. 2000) or species if there is a clear difference in size among species.

2.3.2.1 Resistivity Counter Validation

Counter data were validated to determine true positives, true negatives and error rates, including false positives and false negatives, and calculate the counter accuracy. True positives were defined as any up or down counts that corresponded to a fish passing over the sensor in the recorded direction; these can be verified from graphical traces and/or video footage. False positives were defined as any up or down count where no fish was observed on the video footage. False negatives were defined as any time a fish passed upstream or downstream over the counter sensor, as determined by video, but the counter did not record anything.

We used a four-stage validation approach that included: (1) review of graphical traces (Figure 6) for each counter record to determine false positives and false negatives created by the counter algorithm, (2) targeted video validation to identify false positives produced by the counter, (3) random video validation to identify false negatives by the counter, and (4) calculation of counter accuracy using the number of true positives, false positives and false negatives. Each individual stage is described below.

The resistivity counter can be programmed to record and display the individual graphical traces or changes in resistance observed (Figure 6). Review of the graphical traces is a form of pseudo-validation of the counter algorithm, which determines if the change in resistance detected by the sensor pad is due to a fish moving upstream, downstream or actively moving near or on the sensor pad but not resulting in a passage event. After review of all the counter records, records that were misclassified by the counter algorithm were corrected. If completed by an experienced analyst, this is a cost-effective approach to correct many of the algorithm's false positive and false negative counts (Braun et al. 2016).

During targeted validation, all corrected records were matched with the video to verify the presence of fish. All video records were viewed one minute before to one minute after the counter record which estimates the false positive and false negative error rates. Because targeted validation focuses on fish that have been detected by the counter, it does not provide a random assessment of false negative errors. To do this, we also reviewed a subset of randomly selected video segments and recorded all false negatives, which we term 'random validation'. We reviewed 22, randomly selected 10-minute segments of video data per day from April 14 to May 8. We selected these date ranges based on peak migration timing of Steelhead Trout in 2014 (Melville et al. 2015) and 2015 (Burnett et al. 2016). Video data were collected using four Swann infrared cameras connected to a battery-powered Swann digital video record DVR4575 (Swann ®). Additionally, two white (3 watt, 300 Lumen) LED lights were installed to improve the quality of the video footage at night (Figure 7).

Due to operator error, there were six days during the Steelhead Trout migration when no graphics data was collected from the resistivity counter. For these six days, all the counter records were viewed and verified on the video and a separate counter accuracy was calculated for this period.

2.3.2.2 Abundance Estimate

After validation was complete, counter accuracy was calculated as follows:

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

where A is the accuracy, TP is the number of true positives, FP is the number of false positives, and FN is the number of false negatives.

All Steelhead Trout up and down counts were verified during video analysis. Species-specific net up counts are calculated as follows:

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

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 the counter accuracy for detecting upstream migrating fish, and A_{down} is the counter accuracy for detecting downstream migrating fish. n is the end date of the species' upstream migration. We estimate *n* using video validation and known species run timing. Overlaps in species migration timing make it difficult to determine the start and end date for each species. Species-specific migration start- and end-dates were determined by collating information from other data sources, which included radio telemetry, streamwalks, video observations and a previous telemetry study (Webb et al. 2002).

2.3.3 Multibeam Sonar Abundance Estimates

Following the pilot study conducted in 2016 (Burnett et al. 2017), we used an ARIS Explorer 1800 (Sound Metrics Corporation, Bellevue, Washington, USA) to enumerate Steelhead Trout, and Chinook and Coho Salmon. We fixed the ARIS unit to a custom-built aluminium mount, positioned it at half of the water depth and oriented it horizontally (0° tilt angle) across the channel.

Multibeam sonar users typically manually count each fish observed crossing the sonar beam to enumerate a population (Holmes et al. 2006). However, due to the large time investment required to review the sonar video collected, Echoview software (Version 8; Echoview Software Pty Ltd., Hobart, Australia) was used as a post-processing tool to reduce the time associated with detecting fish (previous versions reviewed in Braun et al. 2016.(A)]. Approximately 2550 GB of data was collected during the Steelhead Trout migration [March 29 to May 8); 1550 GB of data was collected during the Chinook Salmon migration (August 15 to September 19); and 1300 GB of data was collected during the Coho Salmon migration (November 12 to December 7). Due to a range of factors (computer malfunction, power loss, corrupted data and data loss), a portion of the data collected during the Chinook and Coho migration was lost. Data was lost from September 21 to October 01 at the end of the Chinook Salmon migration period and October 10 to November 11 for the Coho Salmon migration period. The data loss did not affect the ability to estimate spawner abundance for Chinook Salmon as the migration period was nearly complete, but unfortunately, we could not estimate a total spawner abundance for Coho Salmon.

ARIS sonar files were imported into Echoview and the raw data were displayed as a virtual echogram; objects were plotted in relation to the angle of the beams and distance to the sonar head. To increase the efficiency of Echoview's internal fish detection algorithm, a data manipulation template was created in Echoview to remove background noise and thus increase the clarity of the video data. We then applied this template to each sonar file using Echoview's automating scripts. Background noise was removed at a rate of 1.1 GB per hour. Echoview automatically processed all the collected data (Steelhead, Chinook and Coho) in 4909 hours (204 days) with minimal human supervision. During this step, Echoview highlighted sections of sonar data that contained fish-like movements that were then verified by an experienced analyst.

Echoview's verification process ensured the validity of the fish detected after the automation process. During this process, the analyst manually examined each fish-like movement detected by the software. Increased water levels create acoustically noisy data therefore due to higher water levels in the spring, a significantly higher portion of time was spent validating Steelhead Trout data in 2017.

After the verification process, the timestamps, length, and positioning data from each individual fish was exported for further analysis in R (R core team, 2016). Due to the nature of the site and flow dynamics (acoustically noisy), the Echoview software did not provide accurate length data for the fish. The exported length data was precise but was biased low. For a subset of fish (~10 %), we measured lengths using the sonar's proprietary software (ARISFish, Sound Metrics Corporation, Bellevue, Washington, USA). ARISFish measurements were deemed accurate through measurements of a test fish of known size. To predict the length of all other fish (not measured), we used a linear model that related ARISFish lengths to the Echoview estimated lengths. We also included the distance from the sonar head (in meters) as a covariate. Considering Sockeye and Pink Salmon are also present in the LBR during the Chinook and Coho Salmon migration period, we applied a size cut-off between each species to the predicted lengths to determine the number of Chinook and Coho Salmon crossing the sonar beam. Tagging data from BRGMON-9 (n = 70 in 2017), BRGMON-3 (n = 101 fish tagged from 2012-2017) and BRGMON-14 (n = 752 in 2013) was used to inform the size cut-off decision.

Sonar data were not collected for 10 days (September 21 to October 01) at the end of the Chinook Salmon migration period. Although we believe that the upstream migration was nearly complete, we used a normal probability density function to predict daily net up counts when there was missing sonar data [(Braun et al. 2016.(B)]. We estimated the parameters for the normal distribution (mean date of run timing [September 12], standard deviation [7.1 days] and a scale parameter [335]) of net up counts by fitting a normal probability density function to net up counts from August 23 to October 01. We selected these dates based on historical migration data collected through this monitoring program. Our estimated scale parameter transforms probabilities into daily net up counts. Next, we used a least squares fitting method to minimize the sum of squares between the observed and predicted counts. We report two abundance estimates in the Results (Section 3.5 (1) using observed net up counts as well as predicted net up counts on days with missing counter data, and (2) using predicted net up counts alone (i.e., estimated scale parameter). There were insufficient data for Coho Salmon to model and thus only a partial count (November 12 to December 3) was estimated.

3.0 Results

3.1 Radio Telemetry

3.1.1 Steelhead Trout

Fish Capture, Tagging and Sampling

Twenty-one Steelhead Trout (2 males and 19 females) were angled and radio tagged from February 21 to March 30 at the Seton-Fraser confluence (Appendix 1). Mean fork length of radio-tagged males and females were 740 mm (range: 710 to 770 mm) and 766 mm (range: 635 to 915 mm), respectively. SER technicians captured two additional female Steelhead Trout on October 12 and 16 during angling for Coho Salmon at the Bridge-Fraser confluence, they were not radio tagged. Mean fork length of these individuals was 673 mm (fork lengths = 635 and 710 mm).

Radio Telemetry

Of the 21 Steelhead Trout captured and radio tagged from February to March, 16 individuals were detected on fixed stations and/or mobile tracking in the LBR. Fish spawned throughout Reaches 3 (n = 6) and 4 (n = 10) throughout May (Figure 8 and Table 6). Specifically, the 16 radio-tagged Steelhead Trout spawned across several streamwalk sections: one spawned between the Yalakom River and Hell Creek (25.5 to 28.8 rkm), one spawned between Russel Springs and Fish Fence (30.7 to 33.2 rkm), four spawned between Cobra and Bluenose (34.4 to 38.2 rkm), one spawned between Cobra and Eagle (34.4 to 38.8 rkm), one spawned between Bluenose and Eagle (38.2 to 38.8 rkm), three spawned between Eagle and Longskinny (38.8 to 39.3 rkm), one spawned between Bluenose and Plunge Pool (38.2 to 40.0 rkm), one spawned between Longskinny and Plunge Pool (39.3 to 40.0 rkm), and three fish did not have sufficient data to determine spawning location (Table 7). Of the 16 Steelhead Trout that spawned in the LBR, four individuals (25%, 124, 127, 140 & 140)) exhibited kelting behaviour and exited the system between May 8-23, prior to the onset of the high flow releases in June (Figure 8).

Radio-tagged Steelhead Trout had a mean residence time of 19 days (range: 4 – 34 days) in Reaches 3 and 4 of the LBR. Steelhead Trout that showed directed upstream migrations in the LBR exhibited a mean migration rate of 2.6 km day^{-1} (range: 1.0 to 4.6 km day^{-1}) from the Bridge-Fraser confluence to the assumed spawning reach (Table 7). Of the five Steelhead Trout that did not enter the LBR, one individual was detected in the Seton River via PIT telemetry and the remaining four had unknown fates.

3.1.2 Chinook Salmon

Fish Capture, Tagging and Sampling

Despite applying the same angling effort as in past monitoring years, we were only able to capture three Chinook Salmon (1 male and 2 females), all at the Yalakom-Bridge confluence (Appendix 1). Mean fork length of radio-tagged fish was 861 mm (range: 786 to 953 mm).

Radio Telemetry

Of the three Chinook Salmon captured and tagged at the Yalakom-Bridge confluence, one individual moved upstream in the LBR and likely spawned in Reach 4 in mid September (Figure 9). One individual remained close to where it was captured and may have spawned there (Reach 3) and the last individual was not observed anywhere again until the end of October when it was detected at the fixed station in Reach 1 (near confluence with the Fraser River).

3.1.3 Coho Salmon

Fish Capture, Tagging and Sampling

Twenty Coho Salmon (13 males and 7 females) were captured and radio tagged from October 6 to 29 at either the Bridge River confluence or at the "Hippie Pool" (n = 15 and 5, respectively; Appendix 1). Mean fork length of radio-tagged males and females were 614 mm (range: 570 to 685 mm) and 587 mm (range: 515 to 640 mm), respectively.

Radio Telemetry

Of the 20 Coho Salmon captured and tagged, 7 individuals moved upstream in the LBR: 5 spawned in Reach 3, and 2 spawned in Reach 4 (Figure 10 and Table 8). Specifically, the 7 radio-tagged Coho Salmon spawned across six streamwalk sections (Table 8). Coho Salmon had a mean residence time of 23 days (range: 10 – 33 days between October 20 – December 3) in Reaches 3 and 4 of the LBR. Coho Salmon that showed directed upstream migrations in the LBR exhibited a mean migration rate of 7.3 km day^{-1} (range: 1.6 to 20.3 km day^{-1}) from release to the assumed spawning reach (Table 6).

3.2 Visual Surveys

3.2.1 Steelhead Trout

Streamwalks were not conducted for Steelhead Trout in 2017.

3.2.2 Chinook Salmon

Visual counts of Chinook Salmon were conducted from August 18 to October 12, at which point spawning was assessed to be complete and no fish were observed. Fish were first observed on September 7, and a peak live fish count of 35 fish occurred on September 14 (Appendix 2). Relative abundance of spawners was highest from Fish Fence to Cobra (section 4; 33.2 to 34.4 rkm), where counts represented 35% of total counts, and lowest from Bluenose to Eagle (section 6; 38.2 to 38.8 rkm) where no fish were observed (Appendix 2 and Figure 11).

Like previous monitoring years, water visibility was variable throughout the Chinook Salmon migration period, ranging from 2 m in late August to 0.4 m in early October (Appendix 2).

3.2.3 Coho Salmon

Visual counts of Coho Salmon were conducted from September 28 to December 15, at which point spawning was assessed to be complete and no individuals were observed. We observed a peak live fish count of 74 fish on November 17. Most fish (87%, 245/283) were observed from Eagle to Plunge Pool (38.8 to 40.0 river km) between November 10 and 30 (Appendix 2). Relative abundance of spawners was highest from Longskinny to Plunge Pool (39.3 to 40.0 river km), where 67% of total counts were observed, and lowest in other streamwalk sections (Eagle to Bluenose, Bluenose to Cobra, Hell Creek to Counter, Counter to the Yalakom River) where no fish were observed (Figure 12).

Water visibility was consistently low (range: 0.4 to 0.6 m) throughout the Coho Salmon migration period (Appendix 2).

3.2.4 Sockeye Salmon

Visual counts of Sockeye Salmon were conducted from September 1 to October 19 and were in high abundance (261 individuals total). Peak count was 82 fish on September 21 and decreased to 0 fish on October 19. Most (82%, 214/261) of the Sockeye Salmon observed on streamwalks were located from Longskinny to Plunge Pool (39.3 to 40.0 rkm) (Appendix 2).

Water visibility was variable throughout the Sockeye Salmon migration period, ranging from 1.4 m in early September to 0.4 m in early October (Appendix 2).

3.2.5 Pink Salmon

Visual counts of Pink Salmon were conducted from September 1 to October 26 and were in high abundance (2,261 individuals total). Peak count was 891 fish on September 21 and decreased to 0 fish on October 26. Pink Salmon were observed across all streamwalk sections in Reaches 3 and 4 (Appendix 2).

Water visibility was variable throughout the Pink Salmon migration period, ranging from 1.4 m in early September to 0.4 m in early October (Appendix 2).

3.3 Chinook Salmon Habitat Evaluation

3.3.1 Redd Characteristics

Thirteen Chinook Salmon redds were observed in Reaches 3 (n = 12) and 4 (n = 1) of the LBR. Redds sampled in 2017 had similar average water depths (0.4 m in 2014, 0.5 m in 2015, 0.4 m in 2016, 0.4 m in 2017; Figure 13) and velocities (0.78 m s^{-1} in 2014, 0.74 m s^{-1} in 2015, 0.66 m s^{-1} in 2016, 0.69 m s^{-1} in 2017; Figure 14) as redds sampled from 2014 to 2016. Substrate geometric mean (D_{50}) was, on average, twice as large in 2016 (mean = 67 mm, SD =

17) and 2017 (mean = 54 mm, SD = 12) than the substrate sampled in 2015 (mean = 32 mm, SD = 10) (one-way ANOVA, F (2, 58) = 39.2, P = 1.7 × 10^{-11}) (Figure 15).

3.3.2 Redd Distribution

Chinook Salmon continue to use key spawning locations identified from 2014 to 2016. Ninety-two percent (12/13) of the Chinook Salmon redds sampled in 2017 were in Reach 3. Redd locations across study years (2014 to 2017), where Chinook Salmon spawn include areas near Hippy Pool (25.5 river km), Hell Creek (28.8 river km), Russel Springs (30.7 river km), Fraser Lake (33.5 rkm) and Cobra (34.4 river km) (Figure 16),however higher densities of redds were observed in some of these locations (Fraser Lake) in 2017 and no redds were sampled near the counter site and Hippy Pool. (Figure 16). Consistent with past years, 69% (9/13) of the redds sampled were in run habitat, with the remaining four redds (31%) located in riffle habitat (Table 9).

3.3.3 Redd Temperature

Temperature profiles from buried and surface loggers were identical, indicating little to no influence of groundwater on Chinook Salmon egg incubation at the three monitoring sites (Figures 17, 18 and 19). Variation in water temperature was negligible within a site, however variation in water temperature among sites was substantial (Figure 20) – mean ATUs at the Bridge River Counter (26.5 rkm) (Figure 17), Fraser Lake (33.5 rkm) (Figure 18) and Longskinny (39.3 rkm) (Figure 19) were 710, 838, and 1029 ATU, respectively. Based on the installation of the loggers on September 24, 2016, we predicted a 50% emergence date at Longskinny of January 21, 2017 (95% confidence intervals: January 14 to January 29, 2017) (Figure 19). ATUs in Reach 3 (Bridge River Counter and Fraser Lake) were insufficient to reach 50% emergence prior to the removal of loggers on February 22, 2017.

3.4 AUC Abundance Estimates

3.4.1 Chinook Salmon

2017

Using an observer efficiency of 0.5 (Table 3), a residence time of 10.5 days (Table 6), and a survey start date of September 1, we calculated the maximum likelihood estimate of 120 Chinook Salmon (95% confidence intervals: 61-239) in 2017 between the Yalakom River and Terzaghi Dam (Figure 21 and Table 4).

Historic

Count data obtained from DFO was used to reconstruct AUC estimates for Chinook Salmon from the Yalakom confluence to Terzaghi Dam (Reaches 3 and 4) since 1993. Chinook were counted at a fish fence from 1993 to 1996, so AUC methodology was not applied, and these counts were considered a total population assessment.

Population abundance during this time varied from a minimum estimate of 21 fish in 2009 to a maximum of 3,106 in 2004 (Figure 22 and Table 4).

3.4.1 Coho Salmon

2017

Using an observer efficiency value of 0.19 (Table 3), a residence time of 23 days (Table 6), and a survey start date of October 12, we calculated the maximum likelihood estimate of 451 Coho (95% confidence intervals: 324-628) in 2017 between the Yalakom River and Terzaghi Dam (Figure 23 and Table 5).

Historic

Count data obtained from DFO was used to reconstruct AUC estimates for Coho from the Yalakom confluence to Terzaghi Dam (Reaches 3 and 4) since 1997. Population abundance during this time varied from a minimum estimate of 78 fish in 1999 to a maximum of 3,539 in 2011 (Figure 24 and Table 5).

3.5 Counter Abundance Estimates

3.5.1 Steelhead Trout (Resistivity Counter and Multibeam Sonar)

Resistivity Counter

The resistivity counter was installed on March 23 and was operated until May 08 when it was removed due to forecasted high flows of 35 m^3/s that could cause damage to the equipment in the water. During this time 1,035 hours of video were recorded, of which, 170 were validated (60 hours of targeted validation and 110 hours of random validation) from March 23 to May 08.

Species were identified through the video validation where possible. We observed two species during video validation – Steelhead Trout (n = 40) and resident fish species (n = 7). Fish lengths were estimated from video footage and were used to differentiate species. Steelhead Trout were assumed to have fork lengths greater than or equal to 600 mm (BRGMON-3 tagging data) and resident fish species (Rainbow Trout or Bull Trout) were assumed to be less than 600 mm.

For the counter data corrected for algorithm errors (42 days), the counter accuracy was 69%. The counter had a higher number of false positive detections resulting in an overestimate in the number of Steelhead Trout moving upstream over the counter (Table 10). Downstream movements were also overestimated for Steelhead Trout with a counter accuracy of 83%.

For the counter data that was uncorrected for algorithm errors (6 days of missing graphics data), the counter accuracy was 50%. The counter had a higher number of false negatives resulting in an underestimate in the number of Steelhead Trout moving upstream over the counter (Table 11). Downstream movements were underestimated with a counter accuracy of 80%.

The first Steelhead Trout detected by the counter moving upstream was on April 25 at 19:44 (Figure 25A). The first downstream movement by a Steelhead Trout was on April 27 at 14:22. The last observed Steelhead Trout was on May 8 at 11:04, and was moving upstream. Therefore, a portion of the upstream migration and downstream kelt migration in 2017 was missed due to the removal of gear on May 8 (Figure 25).

The LBR resistivity counter recorded 28 Steelhead Trout upstream movements and 7 downstream movements. After accounting for counter accuracy, we estimated a total of 22 Steelhead Trout upstream migrants between March 23 and May 08 (Figure 25B).

Multibeam Sonar

Very few steelhead trout were observed in the sonar data. Standard lengths of fish were measured using the sonar's proprietary software (ARISFish). Due to the small sample size, all fish were measured and a size cut-off of 600 mm fork length (BRGMON-3 tagging data) was assigned to differentiate between resident fish species and Steelhead Trout. The sonar operated from March 29 to May 08, but Steelhead Trout were only detected passing through the sonar beam from April 22 to April 26. Five individuals passed upstream and one individual passed downstream of the multibeam sonar, yielding an estimate of four Steelhead Trout that migrated upstream past the counter site during this one-week period.

Combining the resistivity counter and multibeam sonar estimates yields a minimum abundance estimate of 26 individuals spawning upstream of the counter site.

3.5.2 Chinook Salmon (Resistivity and Multibeam Sonar)

Resistivity Counter Video Validation

The resistivity counter ran for the entire Chinook Salmon migration period. Overall, 63 hours of video were randomly validated from August 22 to September 20. During this period there were no Chinook Salmon observed migrating over the resistivity counter. The species observed were Pink Salmon and resident fish species (Rainbow and Bull Trout). For this reason, it was assumed that Chinook Salmon did not use the resistivity channel section to migrate (Figure 3) and the movement of fish occurred solely on river left (monitored by the ARIS multibeam sonar).

Multibeam Sonar

Standard lengths were measured using the sonar's proprietary software (ARISFish). These measurements were highly accurate in 2016 (Burnett et al. 2017) and the same procedures were followed in 2017. Lengths estimated by Echoview were positively related to the ARISFish lengths but were biased low (Figure 26A). The linear model used to predict fish lengths included the Echoview lengths (Figure 26A) and the distance from the sonar beam (Figure 26B) and explained a large portion of the variance in the ARISFish lengths. Further exploration of the models for a direction (up and down) term indicated a difference between the two directions, and thus two models were used to predict lengths for up and down movements of fish (Up-R^2 = 0.68, Down-R^2 = 0.72, *i*P < 0.001) (Figure 26C).

Using fork length data from Seton River Pink Salmon (n = 70, BRGMON-9 [2017]), Gates Creek Sockeye Salmon (*n* = 752, BRGMON-14 [2013]) and Bridge River Chinook Salmon (*n* = 101, BRGMON-3 [2013-2017]), we determined that a size cut-off of 650 mm fork length (same cut-off used in previous year) would minimize the amount of overlap between Pink, Sockeye and Chinook Salmon (Figure 27). We considered the fork lengths of Pink, Sockeye and Chinook Salmon to be 450-650 mm, 500-650 mm and ≥ 650 mm, respectively (Figure 28D). Due to the overlap of sizes between Pink and Sockeye Salmon, it was not possible to differentiate the two species. Chinook Salmon were detected passing through the sonar beam from August 22 to September 20, 2017 (Figure 28). No counts were recorded after September 20 due to the loss of data. Peak counts were observed from September 7 to 12 (Figure 28). Seven hundred and seventy-three individuals passed upstream and 433 individuals passed downstream of the multibeam sonar, yielding an abundance estimate of 340 Chinook Salmon upstream of the counter site during this four-week period.

The normal probability density function estimated a mean Chinook Salmon upstream migration date of 18.9 (i.e., September 11) days after the start of the migration and a standard deviation of 5.7 days (Figure 29). The estimate for the scale parameter was 335 from August 22 to October 01, which can also be used as an estimate of the number of upstream migrating Chinook.

3.5.3 Coho Salmon (Multibeam Sonar)

Like Chinook Salmon, lengths estimated by Echoview were positively related to the ARISFish lengths but were biased low (Figure 30A). The linear model used to predict fish lengths included the Echoview lengths (Figure 30A) and the distance from the sonar beam (Figure 30B) and explained a sizable portion of the variance in the ARISFish lengths. Further exploration of the models for a direction (up and down) term indicated a difference between the two directions, and thus two models were used to predict lengths for up and down movements of fish (Up-R^2 = 0.59, Down-R^2 = 0.67, P < 0.001) (Figure 30C). We note that the reduced model fit for Coho Salmon (R^2 = 0.59 and 0.67) could provide a source of error in the predicted lengths and thus the abundance estimates generated by the multibeam sonar.

Using fork length data from 2016 (Burnett et al. 2017) and catch data from the telemetry component of the monitoring program, we determined that a size cut-off of 400 mm would minimize the amount of overlap between Coho Salmon and resident Bull Trout and Rainbow Trout (Figure 30). We considered the fork lengths of resident fish species and Coho Salmon to be < 400 mm and ≥ 400 mm, respectively. Coho Salmon were detected passing through the sonar beam from November 12 to December 7, 2017 (Figure 31). Due to the loss of data there are no counts reported from October 12 to November 11. Two hundred and sixty-five individuals passed upstream and 199 individuals passed downstream of the multibeam sonar, yielding an abundance estimate of 66 Coho Salmon upstream of the counter site during this four-week period. Note that this is not a complete estimate of abundance, due to the sparsity of the data, we could not produce a normal probability density function to provide an estimate of Coho Salmon abundance upstream of the multibeam sonar.

4.0 Discussion

This program continues to collect data needed to support the Aquatic Ecosystem Monitoring Program. Abundance estimates for Steelhead, Chinook and Coho Salmon have been calculated with varying degrees of success since 2012. Steelhead abundance estimates were effectively calculated in 2014 and 2015 but due to increased discharges throughout the migration period that prevented the operation of the electronic counting equipment in 2016 and in 2017 only a partial estimate was calculated. Chinook spawner abundance has successfully been estimated using the GAUC method since the induction of this monitor and continues to provide am important long-term dataset with consistent methodology. Electronic counter estimates were calculated for Chinook in 2014 and 2015 (resistivity counter). In 2016, a partial estimate was presented and in 2017 a full estimate was successfully calculated using sonar technology. Coho Salmon spawner abundance has been estimated using the same methods used for Chinook. From 2012 to 2017 GAUC estimates have been produced and from 2013 to 2015 resistivity counter estimates were produced. In 2017 data loss prevented the production of a full sonar estimation.

This monitoring program has also begun to address the uncertainties regarding the quality of spawning habitat for Chinook Salmon in the Lower Bridge River. Redd surveys completed from 2014 to 2017 have identified and characterised the habitat conditions used by spawning Chinook. This along with future monitoring activities (Habitat suitability studies) will aim to address the quantity and quality of the habitat in Reaches 3 and 4 of the Lower Bridge River.

High discharges from Terzaghi Dam continued in 2017 and are projected to continue in the future. This spawner abundance data collected under this monitor can not be used as a direct indicator of habitat condition, and changes in spawner abundance will not be used as a response to flow impacts, but combined with juvenile productivity data collected through the Aquatic Ecosystem Monitoring and the juvenile life history and movements it will improve the quality of the primary aquatic benefit response measure (juvenile standing crop). Synthesized age data collected under the BRGMON-3 monitoring program from 2011 to 2017 will be reported with the scales collected in 2018 to produce a complete dataset of age data for fish prior to the high flow releases (2016 and beyond) in the LBR.

4.1 Steelhead Trout

To date, the highest number of Steelhead Trout were captured and radio-tagged in 2017, providing an adequate sample size to monitor run timing, residence time and spawning location. Seventy-six percent of the fish captured and tagged entered the Bridge River and the fish appeared to spawn throughout Reaches 3 and 4 in locations consistent with previous monitoring years (Burnett et al. 2017). The majority of radio-tagged fish (88%) moved past the counter site (Reach 2/3 break) before May 15, when flows were below 15 $m^3 s^{-1}$ and 25% (4/16 fish) displayed kelting behaviour and spawned (and exited the LBR) prior to the onset of the high flows in late May, and early June.

Counter (resistivity and multibeam sonar) estimates for Steelhead Trout were low but were incomplete. The counters were removed from the LBR on May 8, 2017 following communication from BC Hydro that a ramp up to a discharge (35 $m^3 s^{-1}$) that would not permit the safe removal of counter equipment. This prevented us from enumerating the remaining portion of the Steelhead Trout migration and thus the estimate (26 fish) presented here should be considered a minimum count. Telemetry data suggest that the counters were likely operating during a portion of the peak migration, as most of the radio tagged fish moved upstream past counter site before May 15. Delaying the increase in discharge above the counter operating threshold of 20 $m^3 s^{-1}$ until mid to late May would allow for the enumeration of the entire upstream migration of Steelhead Trout in the LBR.

Steelhead Trout enumeration will continue to be a challenge during high flow periods because they migrate during the ascending limb of the discharge curve (freshet). The telemetry component of the study will continue to provide valuable information about Steelhead Trout migration timing and spawning location in the LBR and inform how high discharge during this critical life stage is affecting steelhead spawning behaviour and success. High discharge during the steelhead spawning period will likely have a negative effect on spawning migration and selection of spawning location as the discharges will force steelhead to expend more energy and some spawning locations may not be available. If spawning is successful, redds may also be scoured during the high discharge or dewatered during the ramp down in July-August.

4.2 Chinook Salmon

Despite consistent effort, angling produced poor results for Chinook Salmon in 2017 (lowest to date). Poor catches may be related to continued low returns (low population abundance) of Chinook Salmon to the Bridge River, and poor angling conditions as the holding area just upstream of the Yalakom confluence used for angling has been filled in by gravel reducing the amount of fishable water. This observation was corroborated by the streamwalk data with relatively low counts observed during the visual survey and fewer fish observed holding in the section upstream of the Yalakom River confluence and counter site. Only one of the tagged individuals moved upstream and thus it was inappropriate to base observer efficiency (OE) and survey life (SL) from one fish. Instead, we used OE and SL estimates from past years for AUC modelling for Chinook Salmon in 2017.

The Chinook spawning period is not affected by the flow periods in the LBR and thus the electronic counting equipment was effectively operated. Chinook Salmon spawner abundance above the counter site (resistivity and multibeam sonar) was 340 fish. Video validation indicated that Chinook Salmon did not pass over the resistivity sensor and thus the estimate was derived solely from the multibeam sonar data. Due to data loss, we only had data up until September 20, but we assume that most of the upstream movement had occurred by that date (i.e., last Chinook Salmon was observed on September 15 in 2015 and 95% of run completed by September 26 in 2016) and the loss of data was minimal. The normal density probability function supports this assumption, producing an estimate of 335 spawners upstream of the counter site. Streamwalk data also corroborates this assumption with 86% of individuals observed above the counter site by September 20. During pink years (i.e. 2015 and 2017) there are some complexities and challenges associated with identifying <500 Chinook Salmon out of 10s of thousands of Pink Salmon. We again used a size cut-off to differentiate between species that informed by data collected through this monitor (Chinook sizing) and other monitors (BRGMON-9 for Pink sizing and BRGMON-14 for Sockeye).

The AUC model fit for Chinook Salmon in 2017 was 120 fish and the estimated abundance (120) was in the range of what has been observed in the past five years (range 92 – 591). The AUC estimate has low uncertainty (narrow CIs) and is about three-fold (2.8) lower than the counter abundance estimate. Similar results were observed in 2015 and 2014, when the AUC estimates were 2.5 and 2.0 times lower respectively than the resistivity counter estimate (Melville et al. 2015 and Burnett et al. 2016). The discrepancy between the two estimates could be linked back to the limitation of visual count surveys and their subjective nature, which relies on the ability of each surveyor to minimize the error associated with their observations. The primary source of error is observer efficiency (bias towards over- or under-estimating spawner abundance on any survey). Observer efficiency can vary among individual observers, survey days and systems (Grant et al. 2007, Muhlfeld et al. 2006). OE is the ratio of the number of spawners observed *versus* the true number of spawners present. This source of error is common to any form of visual stock assessment survey methodology but the degree to which it contributes to error in population estimates depends on the unique set of survey conditions such as water clarity, depth, light conditions, habitat complexity and spawner density as well as the experience of the observers (Gallagher and Gallagher 2005). In the Lower Bridge River observer efficiency could not be calculated in 2017 due to the low number of fish tagged (N=3) and observed and a mean value (across all years) was used in the AUC calculation. This value could be an overestimation and thus could be underestimating the population. For example, if an OE of 0.28 was used (as was observed in 2014) the estimates of spawners would be 215 individuals. Additional data will inform the range in OE for various river conditions, particularly in years with smaller spawner sample sizes, and can be used to improve the precision of GAUC estimates from previous years.

Redd surveys showed similar results to 2016. Water depths and velocities at redds have remained the same across the four years, but like 2016, the geometric mean of substrate has increased 2-fold from spawning substrate used by Chinook prior to high flows. The smaller substrate may have been mobilized during the high flows and the distribution of substrate is getting bigger. Although there has been a loss of smaller substrate, the larger substrate remaining is still suitable for Chinook Salmon spawning (Riebe et al. 2014). The distribution of redds in the LBR is similar to what has been observed in previous years with most of the same areas still being used by spawners, but it appears that there has been a shift in the proportion of fish using specific areas following high flow periods (2016 and 2017). It appears that more Chinook are using the upstream range of Reach 3 (Fraser Lake). Redd data continues to provide valuable spawning habitat information and has been used to inform the specific location of supplemental habitat surveys that are occurring in 2018. Habitat-based Instream Flow Incremental Methodology (IFIM) will be used to assess the quantity and quality of suitable spawning habitat for Chinook salmon in the LBR.

Buried and surface temperature loggers deployed adjacent to redds show that groundwater is not influencing egg incubation; no variation in surface and sub-surface water temperature was observed at any redds, however, there is considerable variation in temperature at redds across the length of the LBR. In the winter during the incubation of Chinook Salmon eggs, water temperature decreases as it moves down the LBR due to low air temperatures; thus, we would expect that eggs would hatch, and juveniles would emerge earlier (as early as December) in upstream reaches where low air temperatures have not had as significant an effect on water temperature. During our study period (late September to early March), ATUs to emerge were achieved in Reach 4, but not in Reach 3; this may, in part, explain the spawning distribution of Chinook Salmon in the LBR (most fish seek out areas in Reach 3 to spawn). There may be selection preference for fish to spawn in Reach 3 *versus* Reach 4 because hatching and emerging early likely has significant survival consequences (i.e., limited food, cold water conditions).

4.3 Coho Salmon

Angling efforts for coho salmon throughout Reach 1, 2 and 3 produced moderate results with 20 individuals tagged. Only seven of those individuals moved into and spawned in Reaches 3 and 4 of the LBR. One individual may have spawned in Reach 2 and the remaining 12 fish did not move past the lower receiver near the Bridge-Fraser confluence. These 12 fish may have moved upstream to their natal streams further up the Fraser River watershed. Radio tagged fish appear to be spawning throughout Reaches 3 and 4 in locations consistent with previous monitoring years (Burnett et al. 2016 and Burnett et al. 2017). Tagged individuals were re-sighted during streamwalks and we were able to generate year-specific estimates of observer efficiency and survey life for AUC modelling. The AUC model fit was good and the abundance estimate (451) was similar to that observed in 2016 with low uncertainty (narrow CIs).

The multibeam sonar abundance estimate for coho salmon (66 fish) was incomplete due to the loss of data from October 10 to November 11 and a large number of fish likely passed the counter site before November 12. Based on results from previous years (2014 to 2016), we would expect that the counter estimate be two to three times that of the AUC estimate. This discrepancy would also likely be due to observer efficiency as discussed in Chinook section above. Data collected (counter and AUC) in following years of monitoring will help inform this observation. IFR has taken steps to reduce the risk of future data loss. Data recorded from the sonar will be backed up more frequently and there will be more redundancies in data. The internal memory of the computer used at the site has been increased to store all of the data and there will always be two other hard copies of the data in two different locations. This will ensure that if one of the hard drives fails or is stolen there will be a second copy of the data.

5.0 Summary and Recommendations

Data presented herein summarizes the findings of BRGMON-3 in 2017 under a high flow treatment different than routine WUP operations. Briefly, high flow releases from Terzaghi Dam required modification to the monitoring approach to continue to generate estimates of spawner distribution and abundance. After the successful pilot study of the multibeam sonar technology to enumerate Chinook and Coho Salmon in 2016, this technology was used to enumerate Steelhead Trout, Chinook and Coho Salmon in 2017. We continue to advocate for the continued use of radio telemetry (for all species) and redd surveys (for Chinook Salmon and potentially other species) to monitor the distribution of spawners in relation to managed flow releases in Reaches 3 and 4 of the LBR.

The combination of counter technologies (i.e., multibeam sonar counts fish on river left and a resisitivity counter with a Crump weir sensor counts fish on river right) was successfully used in 2017 to enumerate Steelhead Trout and Chinook Salmon, but we note that flows in the LBR need to remain at or below 20 $m^3 s^{-1}$ until mid May in order to generate an estimate of Steelhead Trout abundance. Moving forward, we will continue to develop a relationship between streamwalk and more accurate counter-derived estimates of abundance and use this relationship to refine historic abundance estimates.

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7.0 Tables

Table 1. Streamwalk sections and locations of fixed radio telemetry stations for the Lower Bridge River.

River km	Location description
0.0	Bridge – Fraser River Confluence
0.7	Fixed Radio Telemetry Station 1
25.5	Downstream Boundary of Streamwalk Section 1 Bridge – Yalakom River Confluence
25.9	Fixed Radio Telemetry Station 3 Resistivity and Multibeam Sonar Counter
28.8	Downstream Boundary of Streamwalk Section 2
30.7	Downstream Boundary of Streamwalk Section 3
33.2	Downstream Boundary of Streamwalk Section 4
34.4	Downstream Boundary of Streamwalk Section 5
37.3	Fixed Radio Telemetry Station 4
38.2	Downstream Boundary of Streamwalk Section 6
38.8	Downstream Boundary of Streamwalk Section 7
39.6	Downstream Boundary of Streamwalk Section 8
40.0	Upstream Boundary of Section 8 Terzaghi Dam

Table 2. Detection efficiency of fixed radio receivers in the Lower Bridge River.

Species	Location of radio receiver	Detection efficiency
Steelhead Trout	Station 1	94% (15/16)
	Station 3	75% (12/16)
	Station 4	100% (10/10)
Chinook Salmon	Station 1	NA
	Station 3	NA
	Station 4	NA
Coho Salmon	Station 1	100% (4/4)
	Station 3	100% (7/7)
	Station 4	80% (4/5)

Numbers in parentheses represent the number of individuals detected out of the total number of individuals known to have passed by fixed radio telemetry stations. NA represents the absence of data to determine detection efficiency.

Table 3. Visual fish count observer efficiency data derived from telemetry data on the Lower Bridge River.

Year	Species	Observer efficiency
2014	Steelhead	27%
2015	Steelhead	NA*
2016	Steelhead	NA*
2017	Steelhead	NA*
2012	Chinook	58%
2013	Chinook	28%
2014	Chinook	28%
2015	Chinook	NA*
2016	Chinook	86%
2017	Chinook	NA
	Mean	50%
2012	Coho	25%
2013	Coho	27%
2014	Coho	NA*
2015	Coho	NA*
2016	Coho	17%
2017	Coho	19%
	Mean	23%

*Observer efficiency could not be computed due to the absence of external visual identification tags

Table 4. Chinook Salmon AUC abundance estimates for the Lower Bridge River from 1993-2017.

Year	OE	OE SE	Residence time	Residence time SE	Abundance	Abundance SE	Method of estimation	Lower 95 CI	Upper 95 CI
1993	NA	NA	NA	NA	151	0	Fence count	151	151
1994	NA	NA	NA	NA	550	0	Fence count	550	550
1995	NA	NA	NA	NA	851	0	Fence count	851	851
1996	NA	NA	NA	NA	1100	0	Fence count	1100	1100
1997	0.5	0.139	10.5	0.65	2005	1581	Visual helicopter	427	9406
1998	0.5	0.139	10.5	0.65	873	254	Visual helicopter	494	1543
1999	0.5	0.139	10.5	0.65	2576	847	Visual helicopter	1352	4906
2001	0.5	0.139	10.5	0.65	1784	981	Visual helicopter	607	5244
2004	0.5	0.139	10.5	0.65	3106	1139	Visual helicopter	1514	6374
2005	0.5	0.139	10.5	0.65	591	232	Visual streamwalk	274	1274
2006	0.5	0.139	10.5	0.65	399	124	Visual streamwalk	217	733
2007	0.5	0.139	10.5	0.65	309	108	Visual streamwalk	156	613
2008	0.5	0.139	10.5	0.65	164	94	Visual streamwalk	53	507
2009	0.5	0.139	10.5	0.65	21	7	Visual streamwalk	10	41
2010	0.5	0.139	10.5	0.65	208	67	Visual streamwalk	110	392
2011	0.5	0.139	10.5	0.65	82	33	Visual streamwalk	38	179
2012	0.58	0.139	10	0.65	364	114	Visual streamwalk	196	674
2013	0.28	0.139	11	0.65	168	90	Visual streamwalk	59	479
2014	0.28	0.139	12	0.65	591	314	Visual streamwalk	209	1673
2015	0.5	0.139	10.5	0.65	158	68	Visual streamwalk	68	370
2016	0.5	0.139	10.5	0.65	265	85	Visual streamwalk	141	497
2017	0.5	0.139	10.5	0.65	120	42	Visual streamwalk	61	239

OE = observer efficiency, SE = standard error, CI = confidence interval.

Table 5. Coho Salmon AUC abundance estimates for the Lower Bridge River from 1997-2017.

Year	OE	OE SE	Residence time	Residence time SE	Abundance	Abundance SE	Method of estimation	Lower 95 CI	Upper 95 CI
1997	0.22	0.024	20	1.58	596	1366	Visual helicopter	7	53292
1998	0.22	0.024	20	1.58	1038	393	Visual helicopter	494	2182
1999	0.22	0.024	20	1.58	78	NA	Visual helicopter	NA	NA
2001	0.22	0.024	20	1.58	994	150	Visual helicopter	739	1336
2003	0.22	0.024	20	1.58	1171	158	Visual helicopter	899	1525
2004	0.22	0.024	20	1.58	224	51	Visual helicopter	143	352
2005	0.22	0.024	20	1.58	711	131	Visual streamwalk	496	1020
2006	0.22	0.024	20	1.58	649	117	Visual streamwalk	455	925
2008	0.22	0.024	20	1.58	98	17	Visual streamwalk	70	139
2009	0.22	0.024	20	1.58	1541	261	Visual streamwalk	1105	2148
2010	0.22	0.024	20	1.58	446	85	Visual streamwalk	306	649
2011	0.22	0.024	20	1.58	3539	670	Visual streamwalk	2441	5130
2012	0.25	0.024	16	1.58	1662	409	Visual streamwalk	1026	2691
2013	0.27	0.024	19	1.58	2974	415	Visual streamwalk	2262	3910
2014	0.22	0.024	20	1.58	408	78	Visual streamwalk	281	592
2015	0.22	0.024	20	1.58	167	25	Visual streamwalk	124	225
2016	0.22	0.024	20	1.58	469	75	Visual streamwalk	343	643
2017	0.19	0.024	23	1.58	451	76	Visual streamwalk	324	628

O E = observer efficiency, SE = standard error, CI = confidence interval.

Table 6. Residence time of radio-tagged fish in the Lower Bridge River.

Year	Species	N	Mean residence time (days)
2014	Steelhead	8	17
2015	Steelhead	10	15
2016	Steelhead	2	7
2017	Steelhead	16	19
2012	Chinook	5	10
2013	Chinook	22	11
2014	Chinook	8	12
2016	Chinook	8	9
2017	Chinook	NA	NA
		Mean	10.5
2012	Coho	13	16
2013	Coho	18	19
2016	Coho	26	22
2017	Coho	7	23
		Mean	19

Table 7. Spawning distribution of radio-tagged Steelhead Trout in the Lower Bridge River in 2017.

Tag no.	Tagging location	Tagging river km	Assumed spawning reach	Assumed spawning section	Migration rate (km day^{-1})	Residence time (days)
123	Seton – Fraser Confluence	NA	3	Unknown	1.0	4
124	Seton – Fraser Confluence	NA	3	Russel to Fish Fence	2.0	9
125	Seton – Fraser Confluence	NA	3	Unknown	3.2	23
127	Seton – Fraser Confluence	NA	3	Cobra to Bluenose	2.1	8
128	Seton – Fraser Confluence	NA	4	Bluenose to Eagle	2.3	28
129	Seton – Fraser Confluence	NA	4	Cobra to Bluenose	2.9	25
131	Seton – Fraser Confluence	NA	4	Bluenose to Plunge Pool	NA	23
132	Seton – Fraser Confluence	NA	4	Eagle to Longskinny	3.8	34
133	Seton – Fraser Confluence	NA	4	Cobra to Bluenose	1.6	11
134	Seton – Fraser Confluence	NA	3	Unknown	NA	9
136	Seton – Fraser Confluence	NA	4	Eagle to Longskinny	1.6	33
137	Seton – Fraser Confluence	NA	4	Eagle to Longskinny	3.0	15
140	Seton – Fraser Confluence	NA	4	Cobra to Bluenose	4.6	24
141	Seton – Fraser Confluence	NA	4	Longskinny to Plunge Pool	2.4	23
142	Seton – Fraser Confluence	NA	4	Cobra to Eagle	2.7	18
143	Seton – Fraser Confluence	NA	3	Yalakom to Hell	2.8	10

Mean	NA	2.6	19
Minimum	NA	1.0	4
Maximum	NA	4.6	34

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).

Table 8. Spawning distribution of radio-tagged Coho Salmon in the Lower Bridge River in 2017.

Tag no.	Tagging location	Tagging river km	Assumed spawning reach	Assumed spawning section	Migration rate (km day^{-1})	Residence time (days)
10	Bridge River Bridge	0.5	3	Russel to Fish Fence	3.4	18
11	Bridge River Bridge	0.5	4	Longskinny to Plunge Pool	1.6	26
14	Bridge River Bridge	0.5	3	Cobra to Bluenose	7.8	10
20	Hippie Pool	25.5	3	Fish Fence to Cobra	NA	22
22	Bridge River Bridge	0.5	3	Fish Fence to Cobra	20.3	31
27	Hippie Pool	25.5	3	Yalakom to Hell	NA	33
28	Hippie Pool	25.5	4	Bluenose	3.5	19
			Mean	NA	7.3	23
			Minimum	NA	1.6	10
			Maximum	NA	20.3	33

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)

Table 9. Number of Chinook Salmon redds located in Reach 3 of the Lower Bridge River. **Number of Chinook Salmon redds located in Reach 3 of the Lower Bridge River.**

Year	Habitat Class		
	Run	Riffle	Pool
2014	41 (67%)	18 (30%)	2 (3%)
2015	15 (60%)	10 (40%)	0 (0%)
2016	21 (88%)	3 (12%)	0 (0%)
2017	9 (69%)	4 (31%)	0 (0%)

Table 10. Overall accuracy of resistivity counter during Steelhead migration in Lower Bridge River, determined through targeted and random video validation.

Direction	True Positive	False Positive	Video Negative	False Negative	Accuracy	Estimate
Up	18	8	0	0	0.69	over
Down	5	1	0	0	0.83	over

Table 11. Overall accuracy of resistivity counter for the six-day period where no graphics data were available to pseudo-validate the counter algorithm during Steelhead migration in Lower Bridge River.

Direction	True Positive	False Positive	Video Negative	False Negative	Accuracy	Estimate
Up	9	3	0	6	0.50	under
Down	2	2	0	1	0.40	under

8.0 Figures

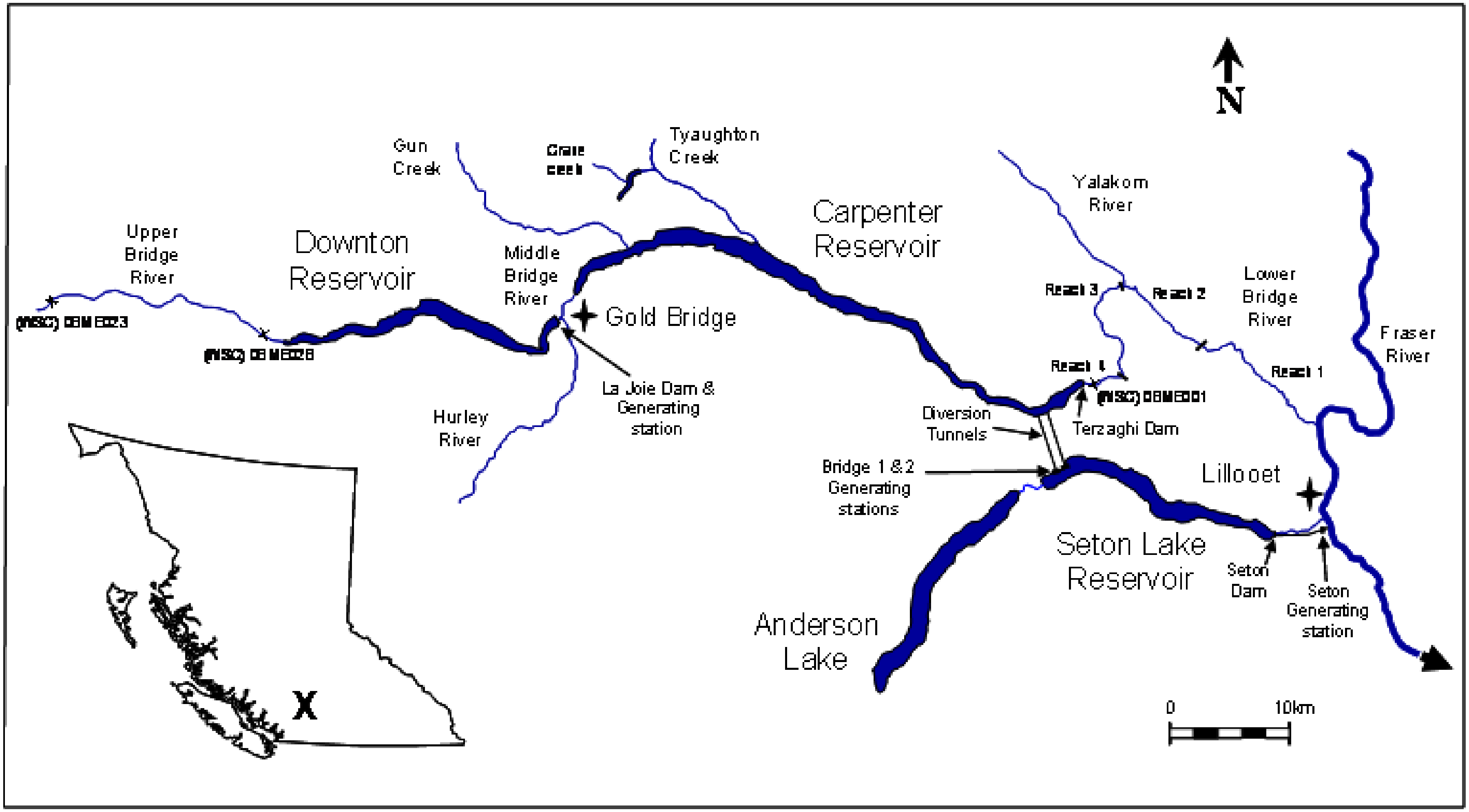

Figure 1. Bridge and Seton Watersheds showing Terzaghi Dam and the diversion tunnels to Bridge River Generating Stations 1 and 2.

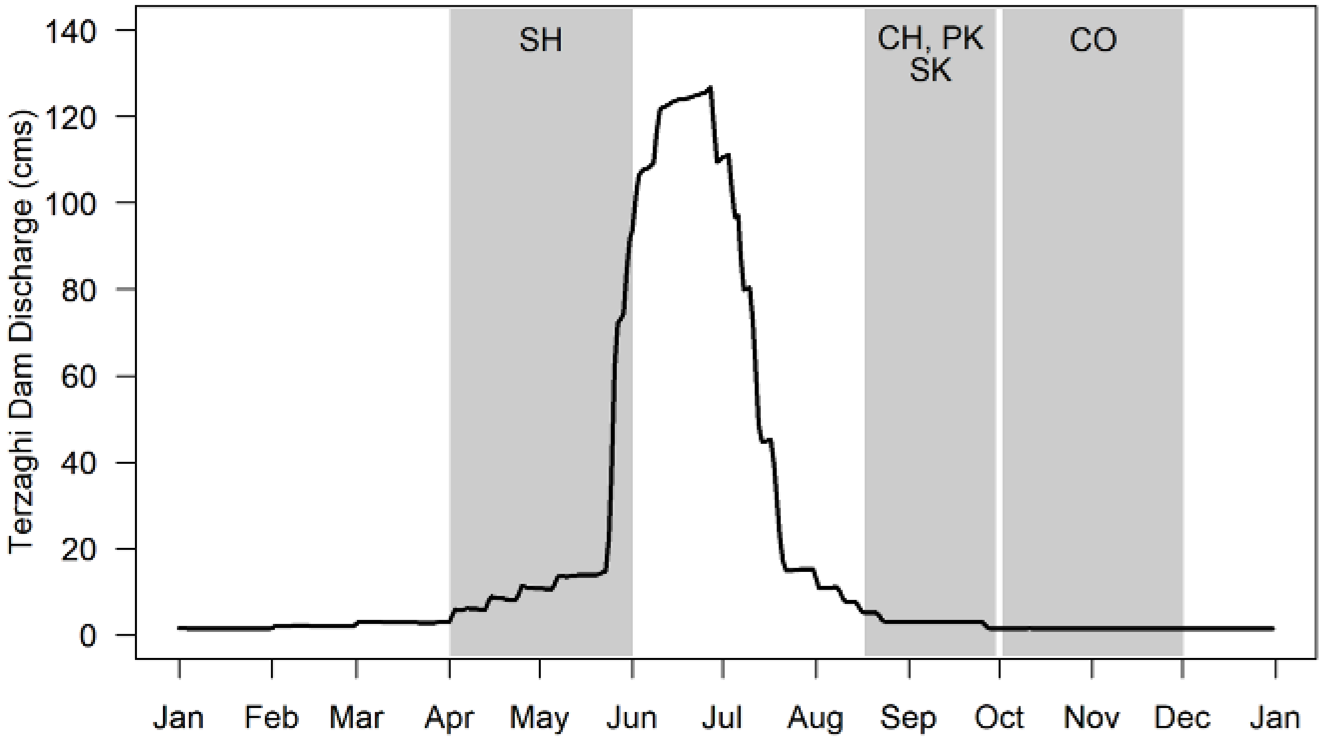

Figure 2. Discharge from Terzaghi Dam into the Lower Bridge River in 2017. Migration timing of anadromous salmonids are represented by shaded rectangles. SH = Steelhead Trout, CH = Chinook Salmon, PK = Pink Salmon, SK = Sockeye Salmon, and CO = Coho Salmon.

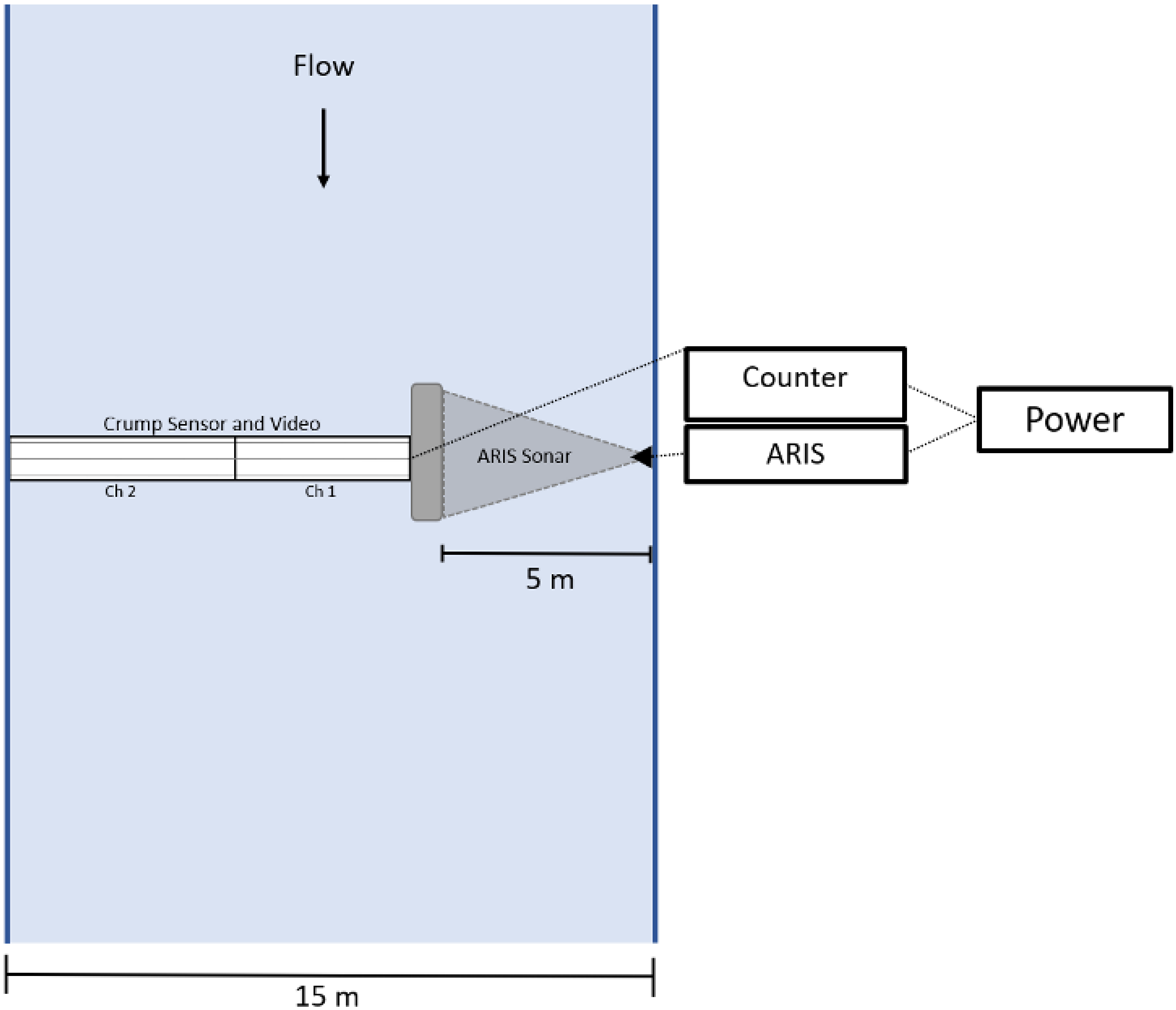

Figure 3. Configuration of the resistivity counter crump sensor, video validation system, multibeam sonar, and power system in the LBR, 2017.

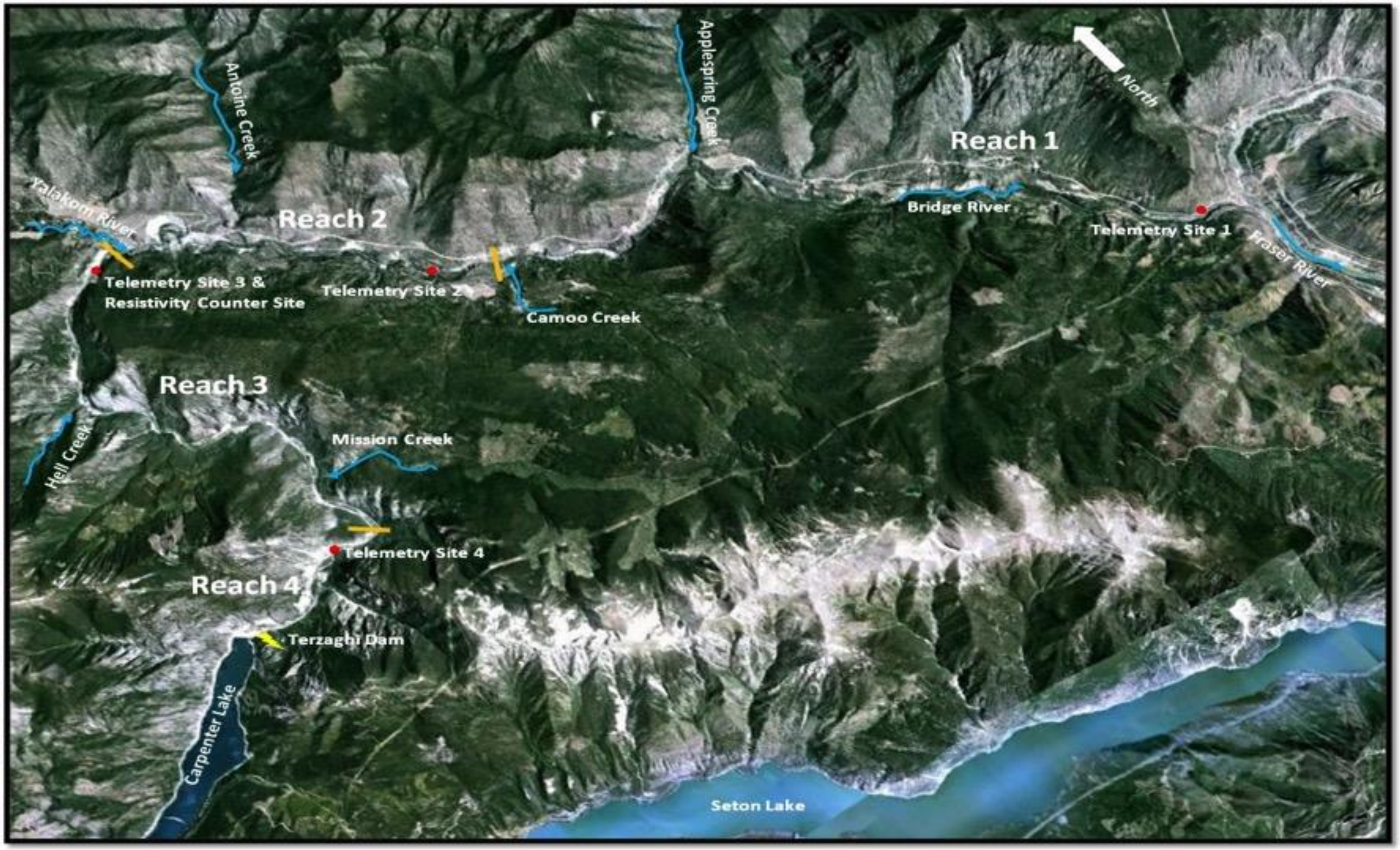

Figure 4. Bridge River study area showing reach breaks (orange lines) and fixed radio telemetry stations (red dots).

Figure 5. Bridge River streamwalk section boundaries (orange dots) and fixed radio telemetry stations (red dots).

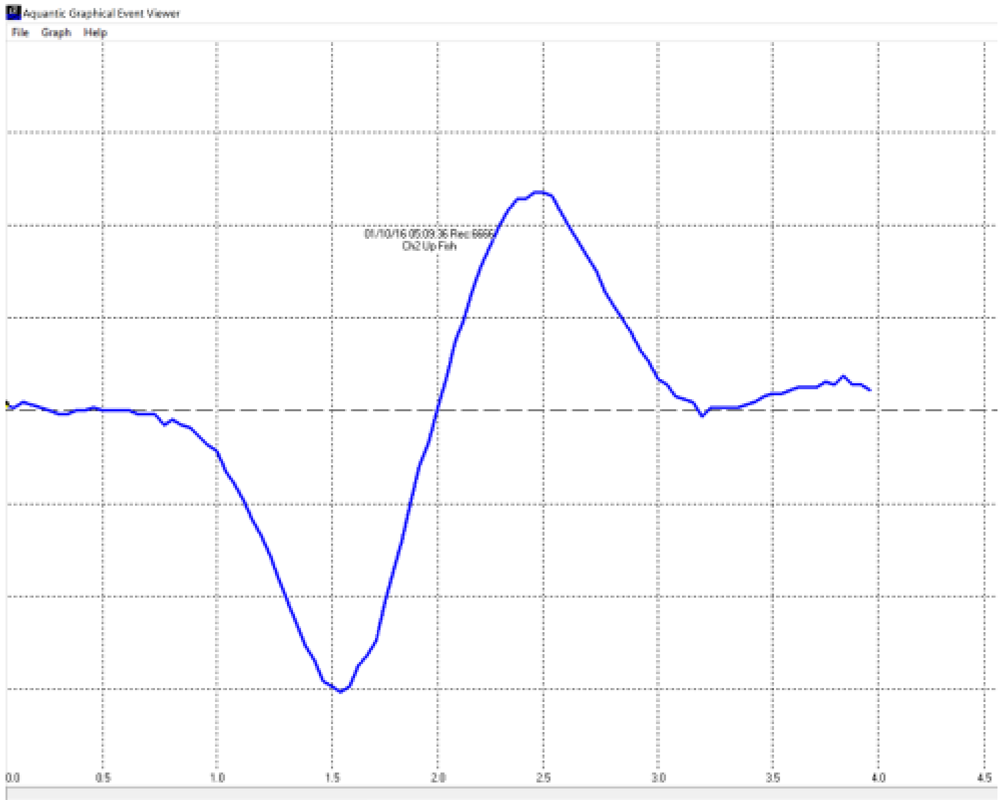

Figure 6. Example graphical trace (sinusoidal curve) showing a true up movement with two equal but opposite peaks, indicating the size and direction of the fish movement. The counter algorithm applies specific criteria to each record, which allow for some flexibility in the ratio of the peaks.

Figure 7. Screen shots of video footage from the Bridge River resistivity crump sensor in 2017. Top panel shows footage without the addition of white lights, whereas the bottom panel shows footage with white lights added.

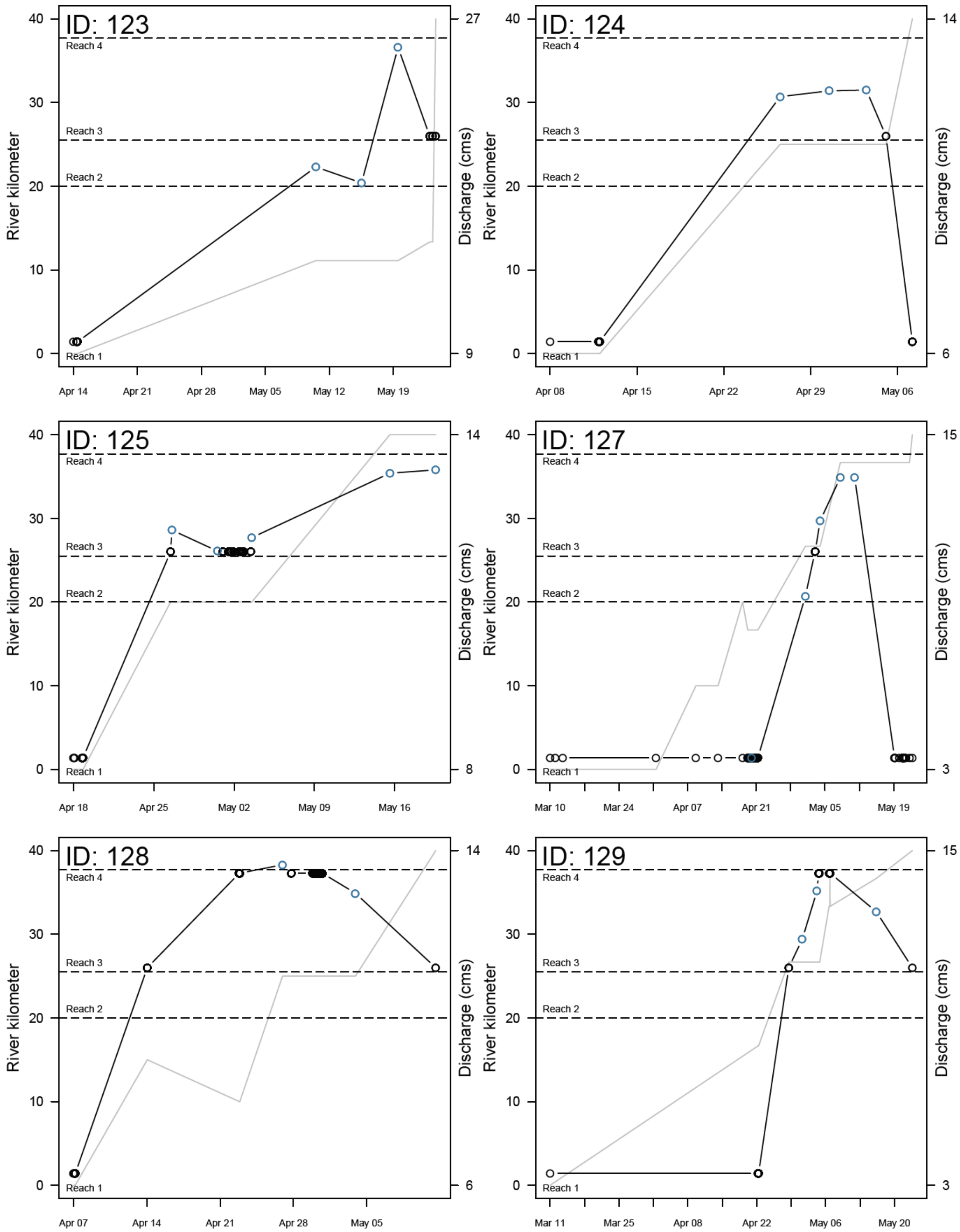

Figure 8. Detection histories of radio tagged adult Steelhead Trout in the Lower Bridge River in 2017. Black lines connect the data collected from fixed (black) and mobile (blue) telemetry. Grey lines correspond to the discharge in the Lower Bridge River at Terzaghi Dam. Dashed lines indicate boundaries between different reaches.

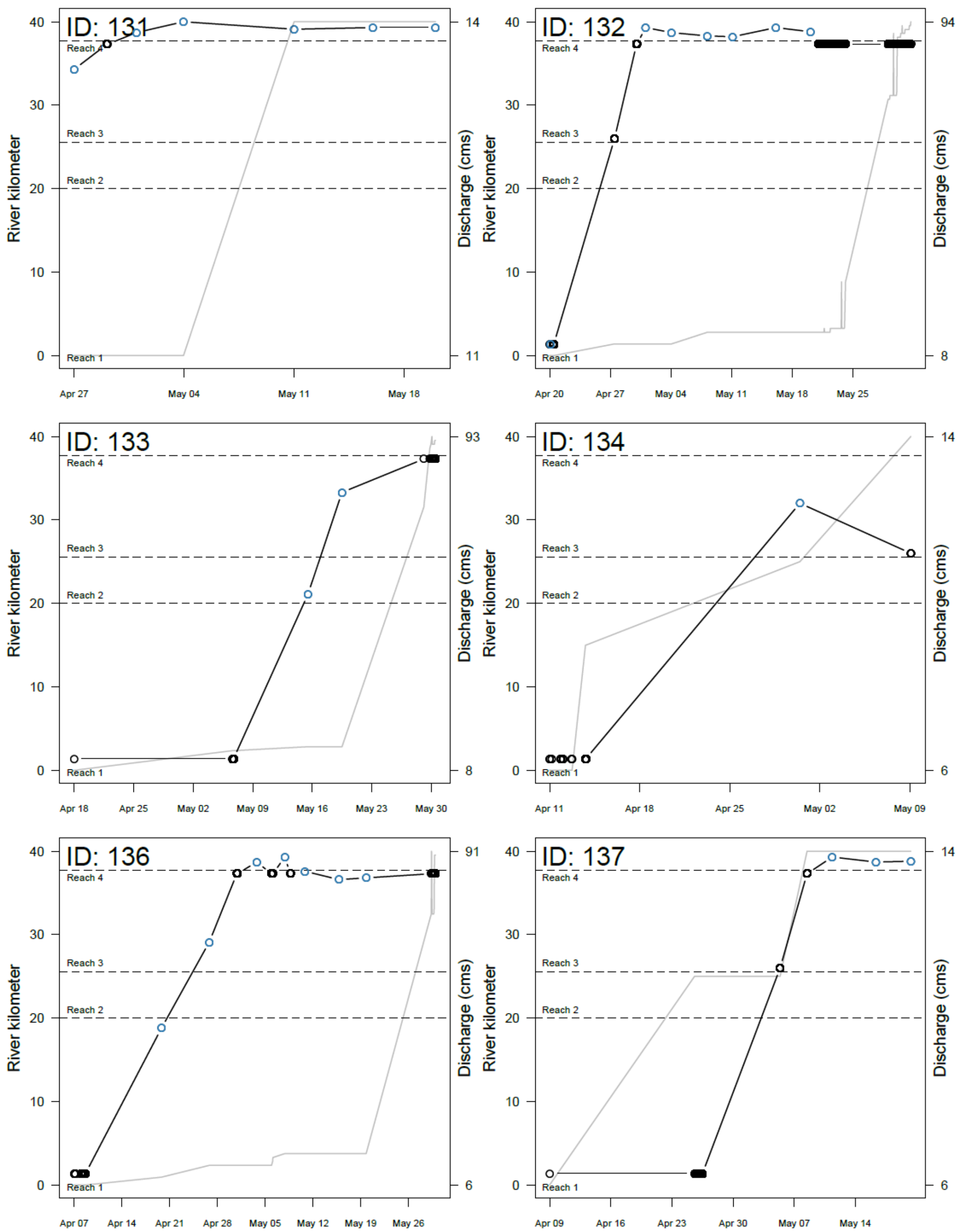

Figure 8 (Cont'd). Detection histories of radio tagged adult Steelhead Trout in the Lower Bridge River in 2017. Black lines connect the data collected from fixed (black) and mobile (blue) telemetry. Grey lines correspond to the discharge in the Lower Bridge River at Terzaghi Dam. Dashed lines indicate boundaries between different reaches.

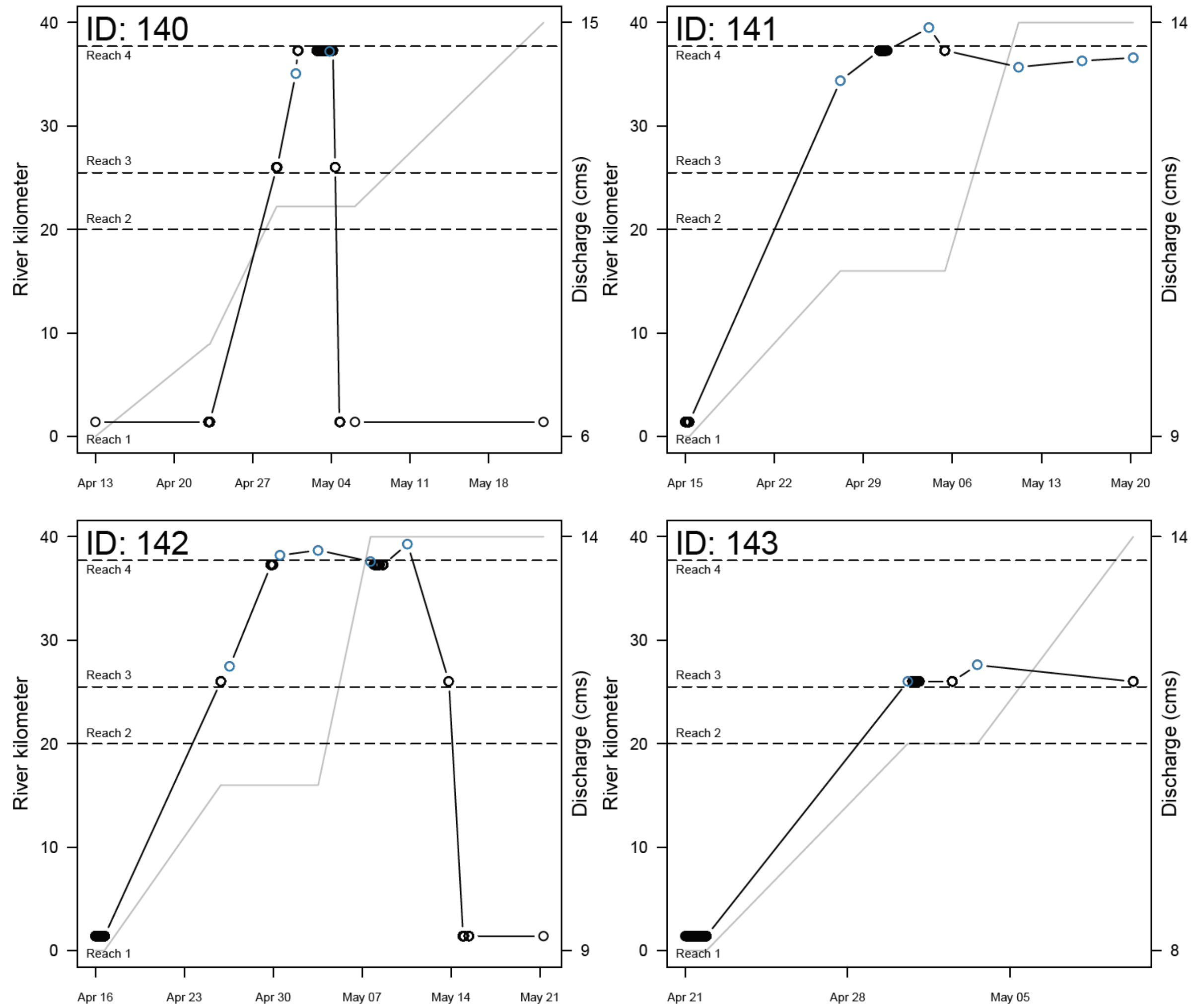

Figure 8 (Cont'd). Detection histories of radio tagged adult Steelhead Trout in the Lower Bridge River in 2017. Black lines connect the data collected from fixed (black) and mobile (blue) telemetry. Grey lines correspond to the discharge in the Lower Bridge River at Terzaghi Dam. Dashed lines indicate boundaries between different reaches.

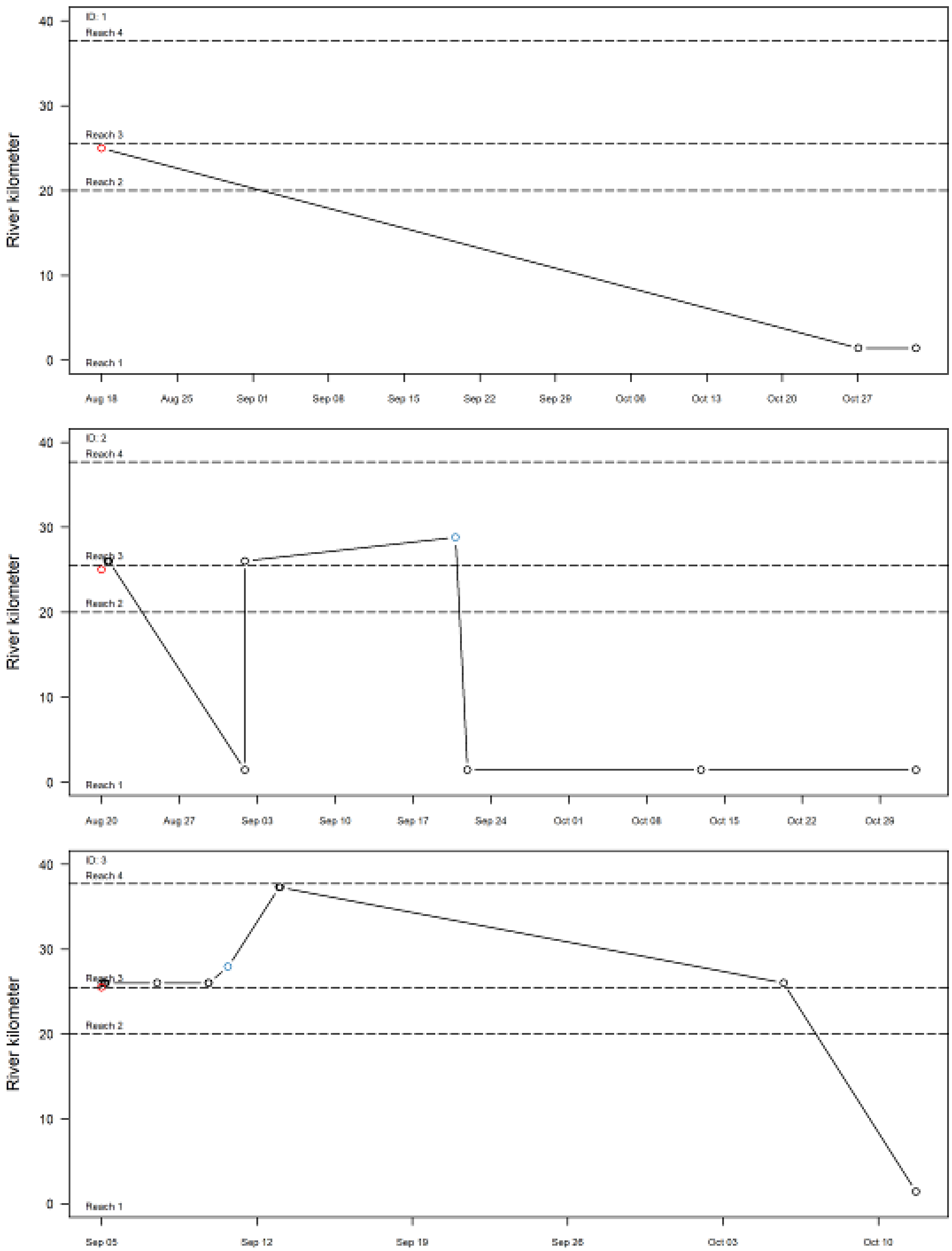

Figure 9. Detection histories of radio tagged adult Chinook Salmon in the Lower Bridge River in 2017. Black lines connect the release information (red) with data collected from fixed (black) and mobile (blue) telemetry. Dashed lines indicate boundaries between different reaches. Discharge in the Lower Bridge River was 3 cms throughout the migration with spawning period.

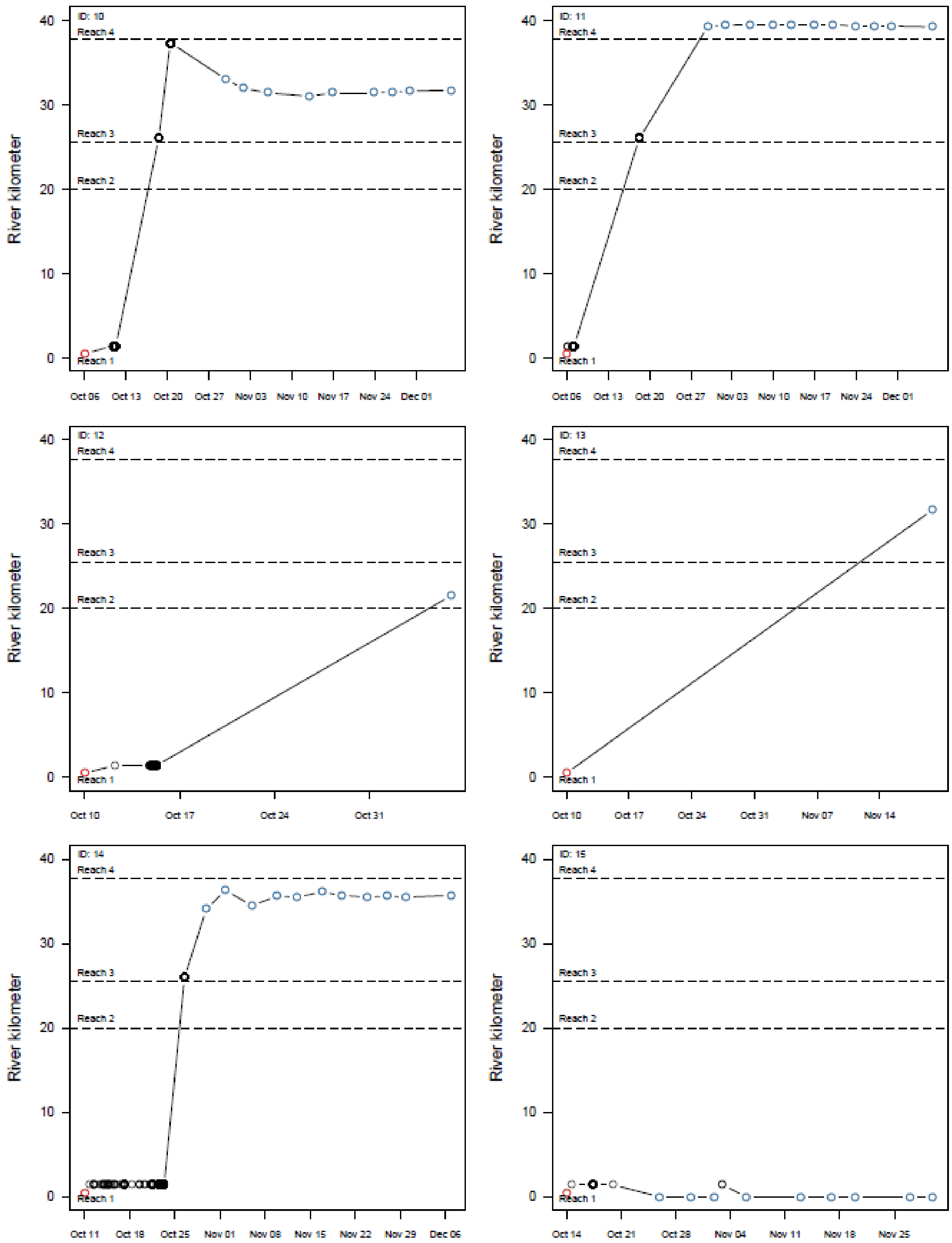

Figure 10. Detection histories of radio tagged adult Coho Salmon in the Lower Bridge River in 2017. Black lines connect the release information (red) with data collected from fixed (black) and mobile (blue) telemetry. Dashed lines indicate boundaries between different reaches. Discharge in the Lower Bridge River was 1.5 cms throughout the migration and spawning period.

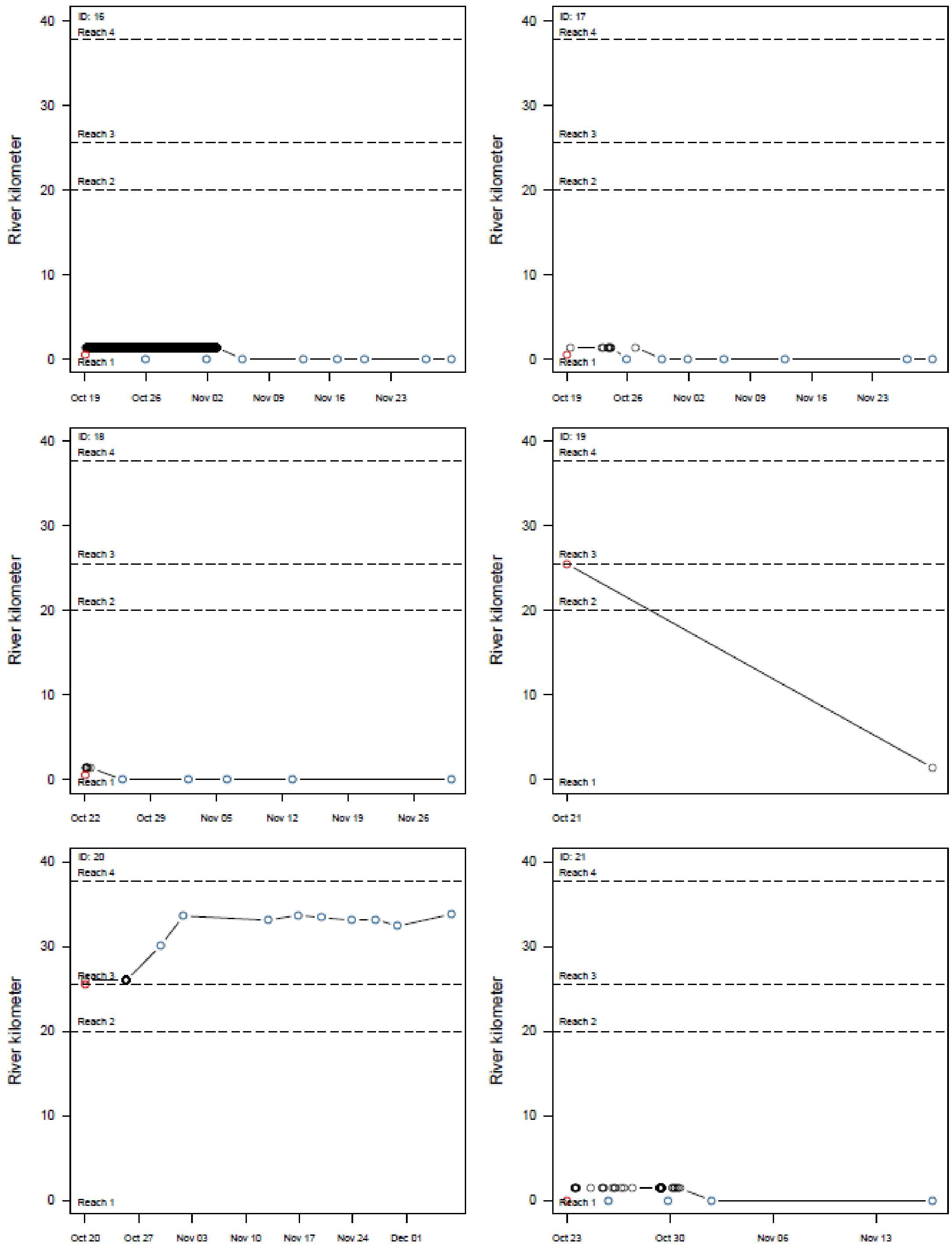

Figure 10 (Cont'd). Detection histories of radio tagged adult Coho Salmon in the Lower Bridge River in 2017. Black lines connect the release information (red) with data collected from fixed (black) and mobile (blue) telemetry. Dashed lines indicate boundaries between different reaches. Discharge in the Lower Bridge River was 1.5 cms throughout the migration and spawning period.

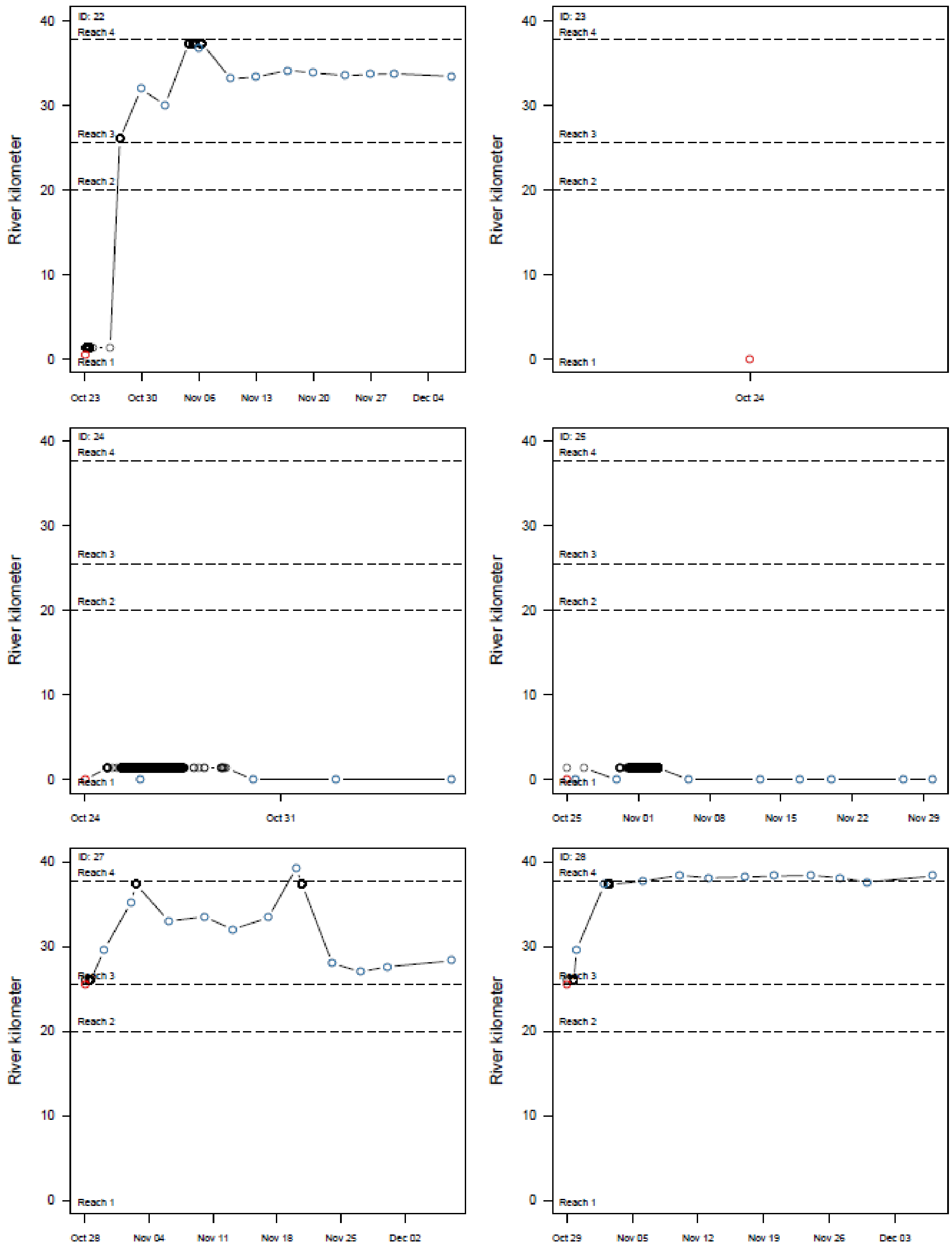

Figure 10 (Cont'd). Detection histories of radio tagged adult Coho Salmon in the Lower Bridge River in 2017. Black lines connect the release information (red) with data collected from fixed (black) and mobile (blue) telemetry. Dashed lines indicate boundaries between different reaches. Discharge in the Lower Bridge River was 1.5 cms throughout the migration and spawning period.

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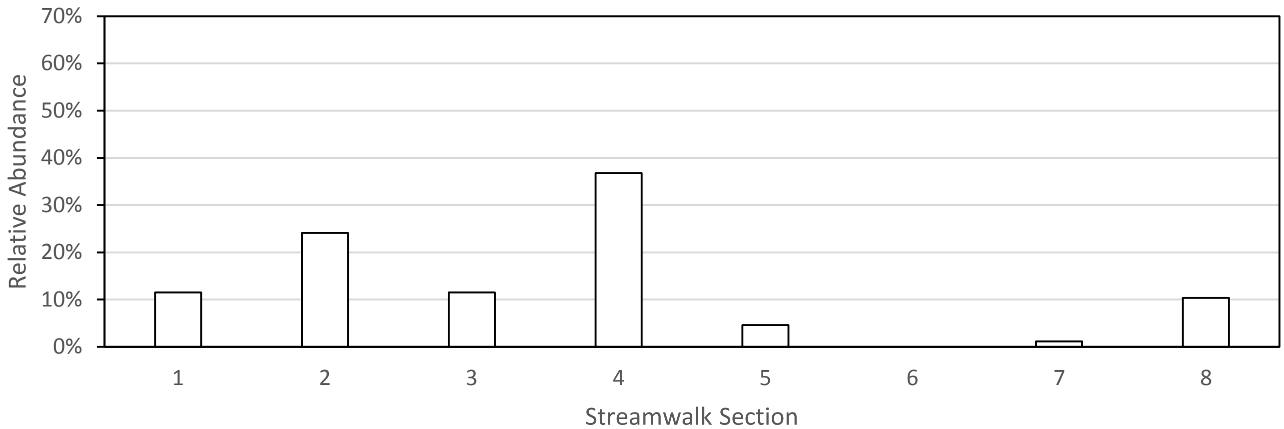

Figure 11.Relative proportion of Chinook spawners observed in the various streamwalk sections of Reaches 3 and 4 in the LBR in 2017. Sections are numbered in ascending order from the Yalakom confluence to Terzaghi Dam. Sections 1–5 are in Reach 3 and sections 6-8 are in Reach 4.

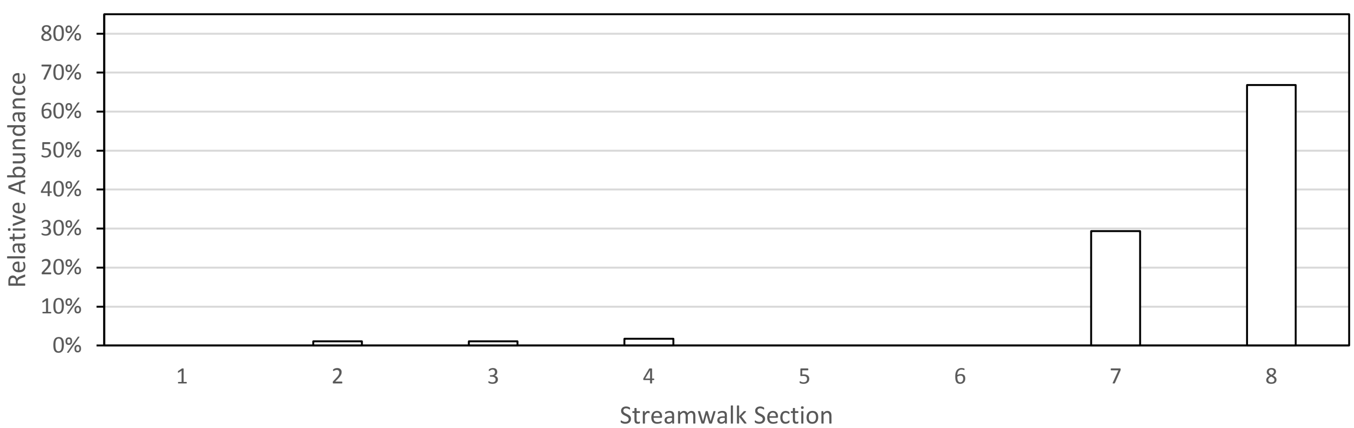

Figure 12. Relative proportion of Coho spawners observed in the various streamwalk sections of Reaches 3 and 4 in the LBR in 2017. Sections are numbered in ascending order from the Yalakom confluence to Terzaghi Dam. Sections 1–5 are in Reach 3 and section 6-8 are in Reach 4.

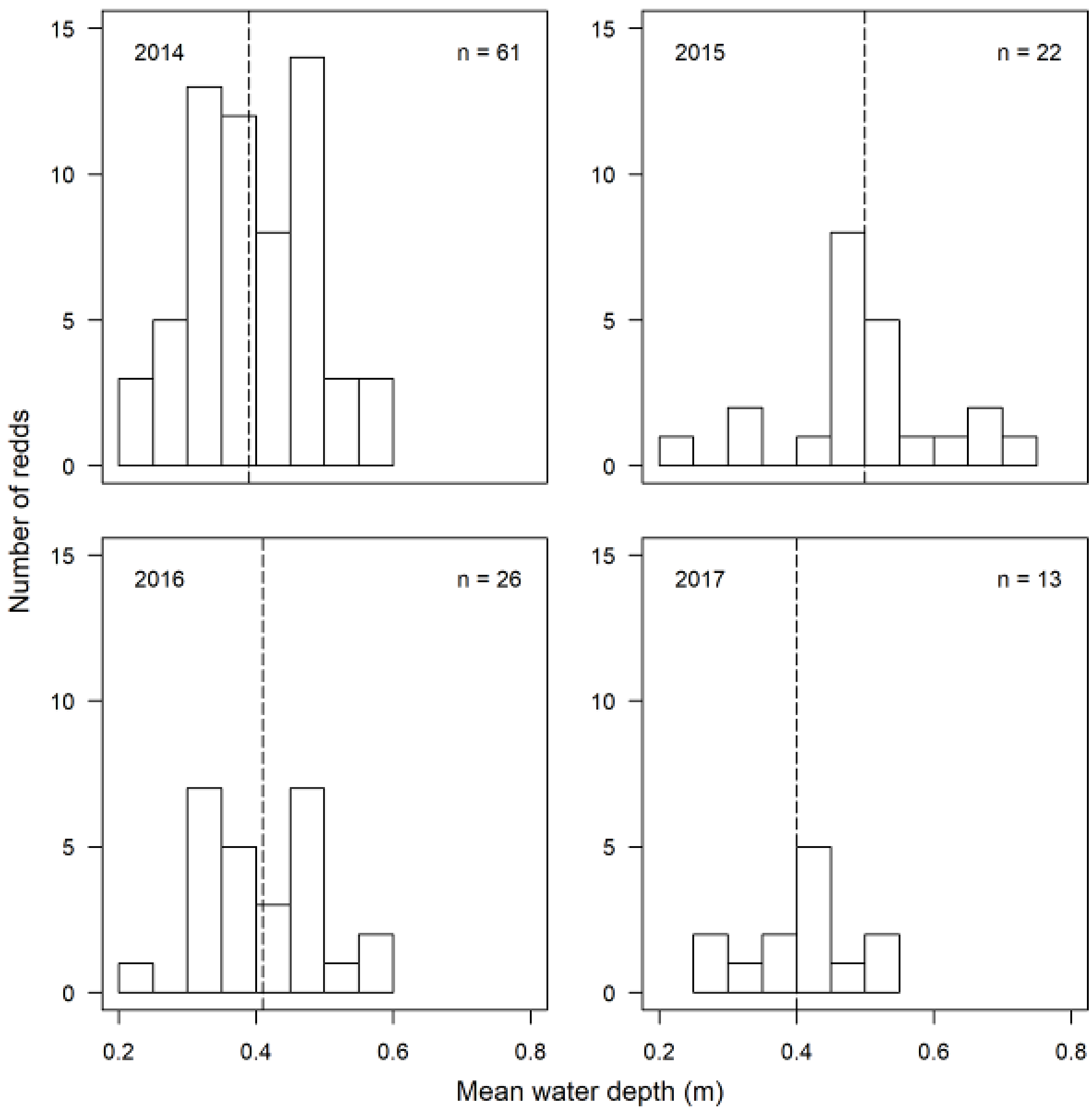

Figure 13. Frequency distribution of mean water depths (m) measured at Chinook Salmon redds in the Lower Bridge River from 2014 to 2017. Dashed lines denote the annual mean water depth.

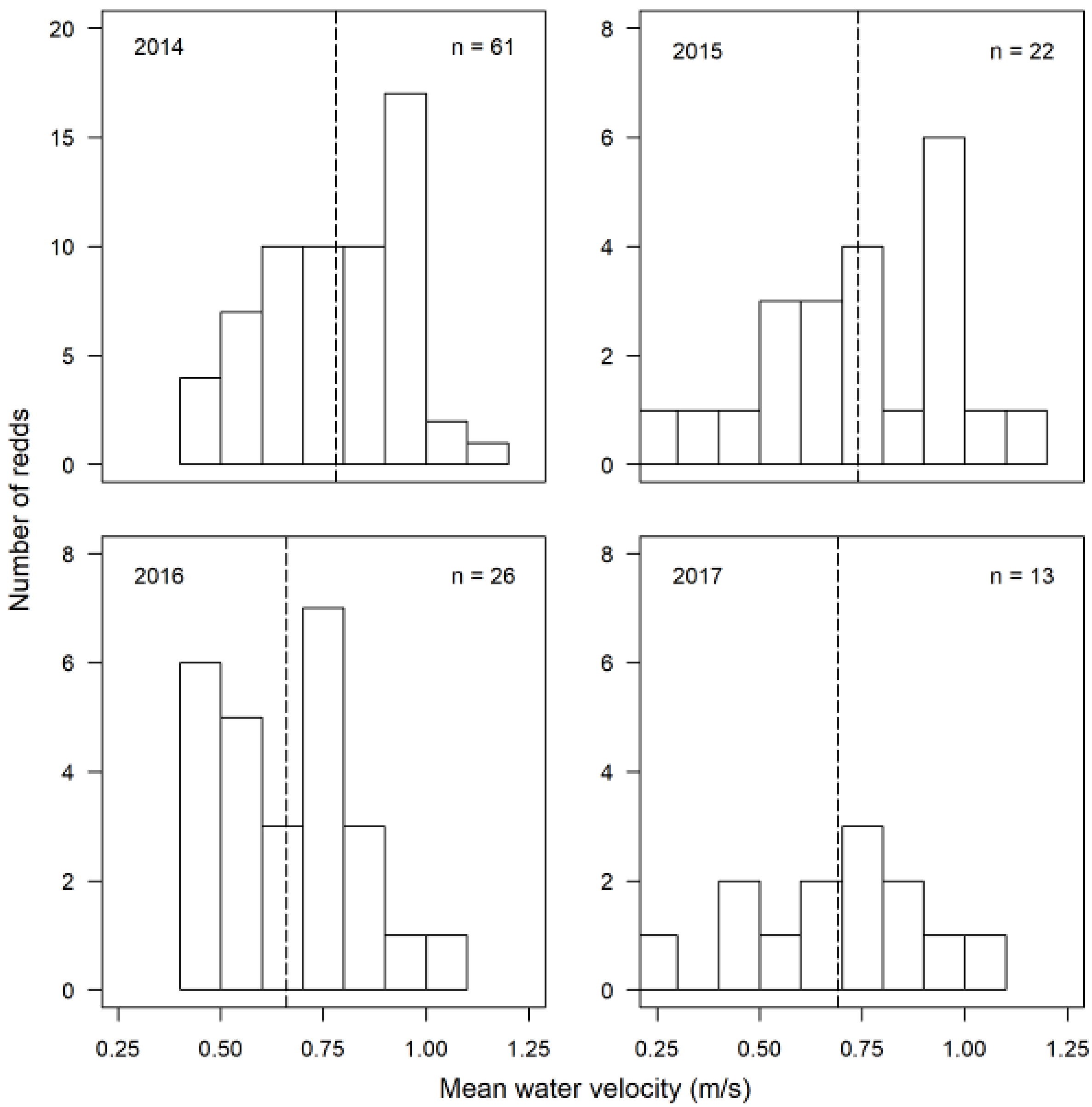

Figure 14. Frequency distribution of mean water velocity (cms) measured at Chinook Salmon redds in the Lower Bridge River from 2014 to 2017. Dashed lines denote the annual mean water velocity.

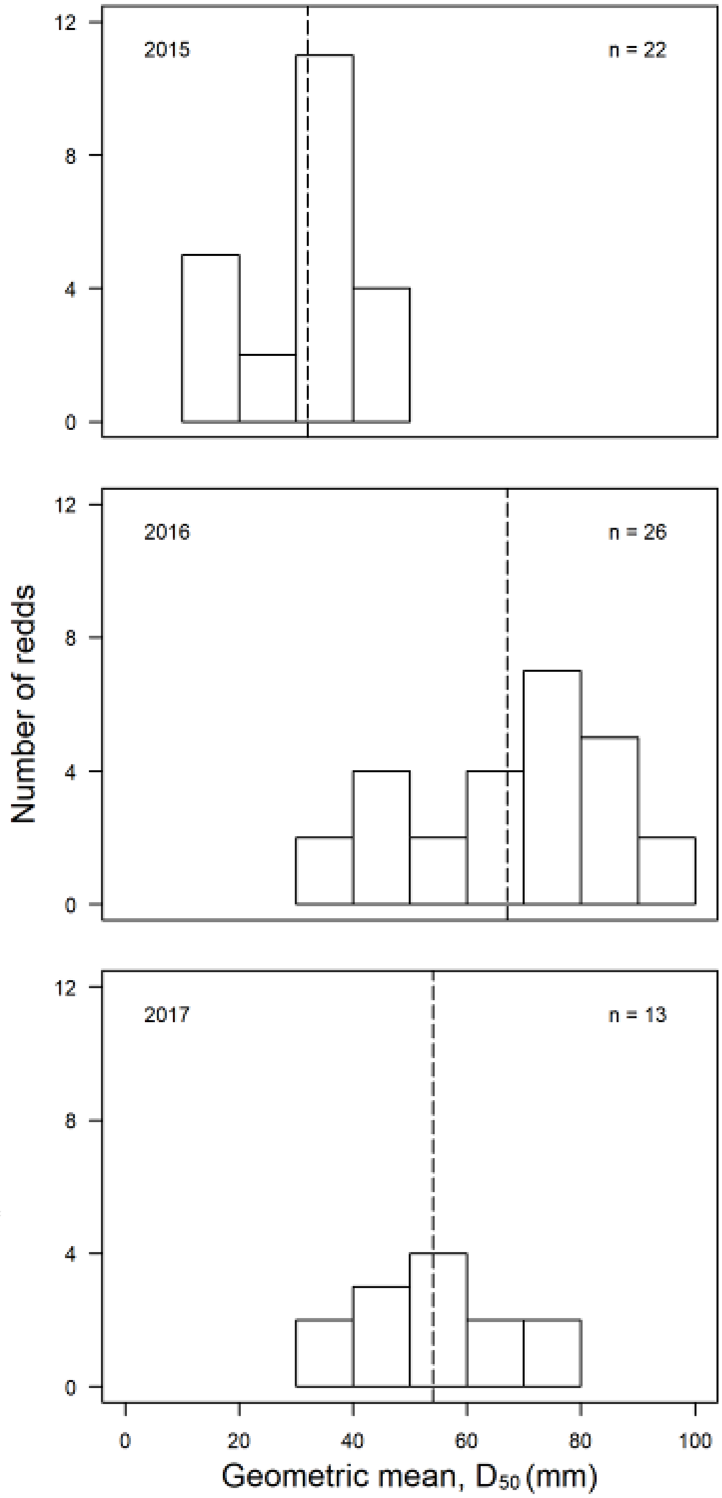

Figure 15. Frequency distribution of the geometric (D_{50}) of substrate measured at the tailspill of Chinook Salmon redds in the Lower Bridge River from 2015 to 2017. Dashed lines denote the annual mean D_{50}.

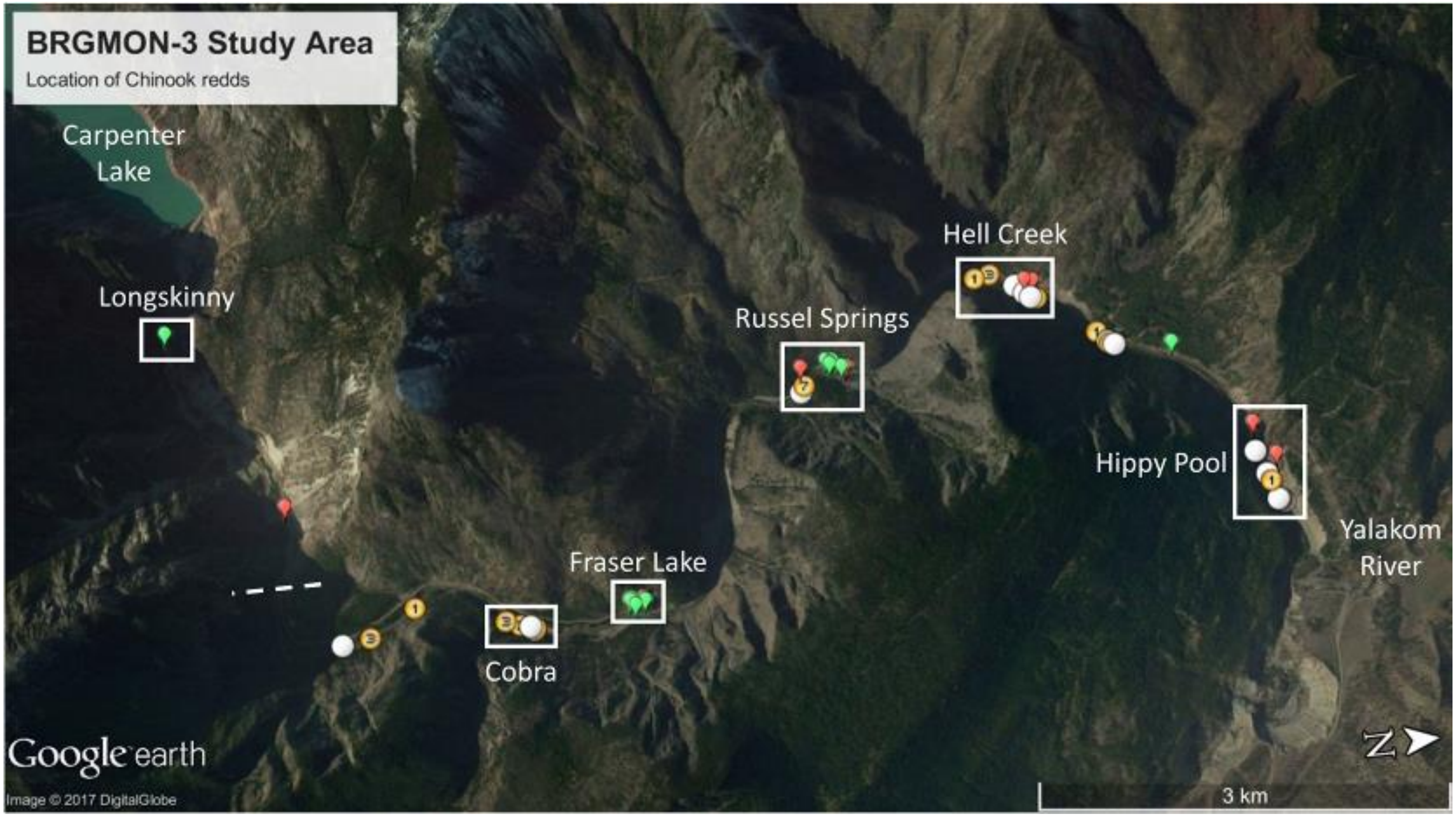

Figure 16. Location of Chinook Salmon redds in the Lower Bridge River in 2014 (yellow), 2015 (white), 2016 (red) and 2017 (green). Numbered yellow points denote the number of redds found at a specific location 2014. White boxes indicate common areas of locating redds. White dashed lines indicate the boundary between Reach 3 and 4.

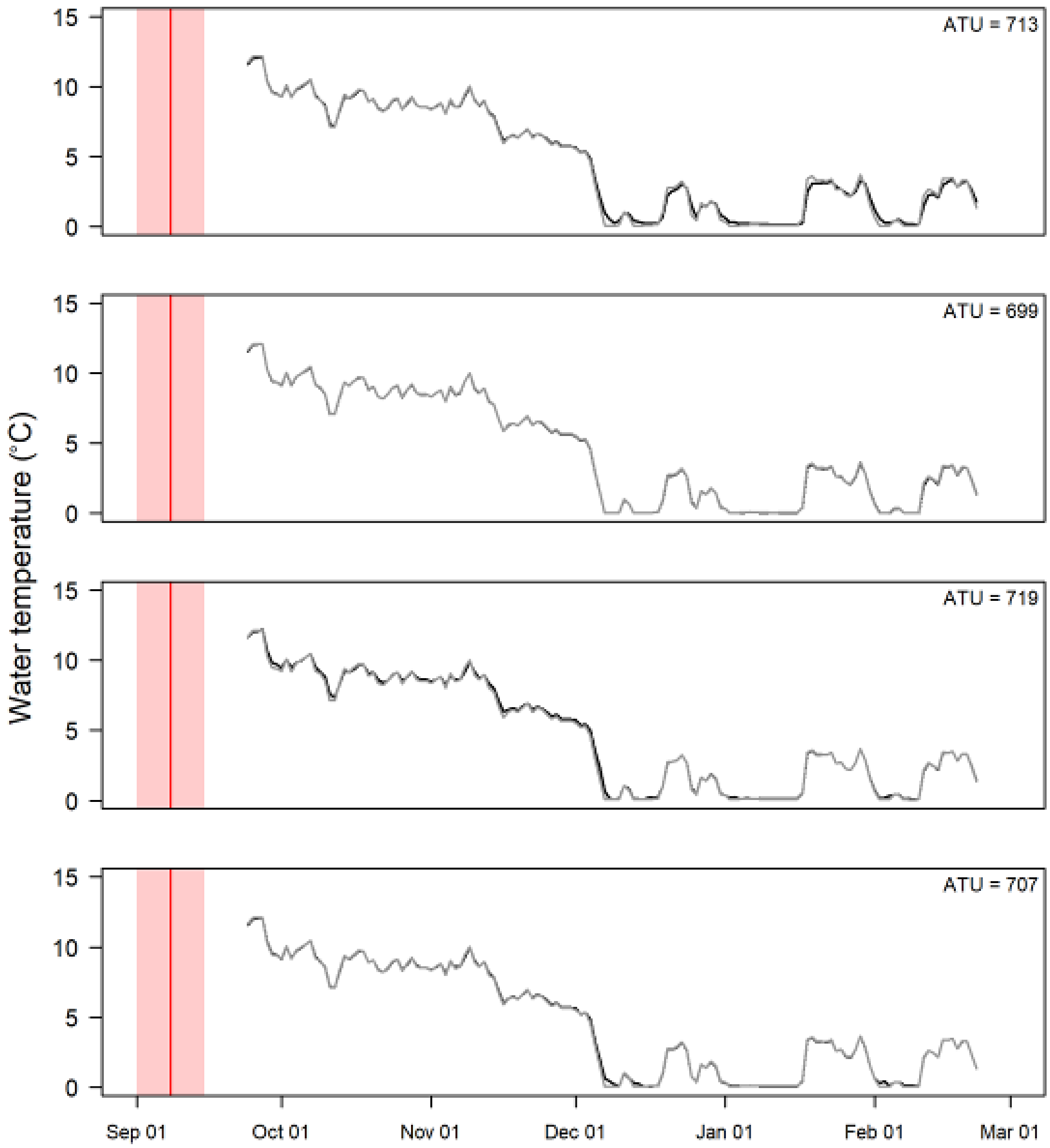

Figure 17. Water temperature at four Chinook Salmon redds upstream of the Bridge River Counter (Reach 3, 26.5 rkm). Black and grey lines correspond to temperature profiles from loggers buried 30 cm below the streambed and at 60% of the water depth, respectively. Loggers were removed February 22, 2017 prior to an increase in flow to 3 cms. Logger ATU at time of removal is shown in the top right corner of each panel. Vertical red lines and rectangles represent the mean and range of peak spawning (respectively) I the Lower Bridge River from 2011 to 2017.

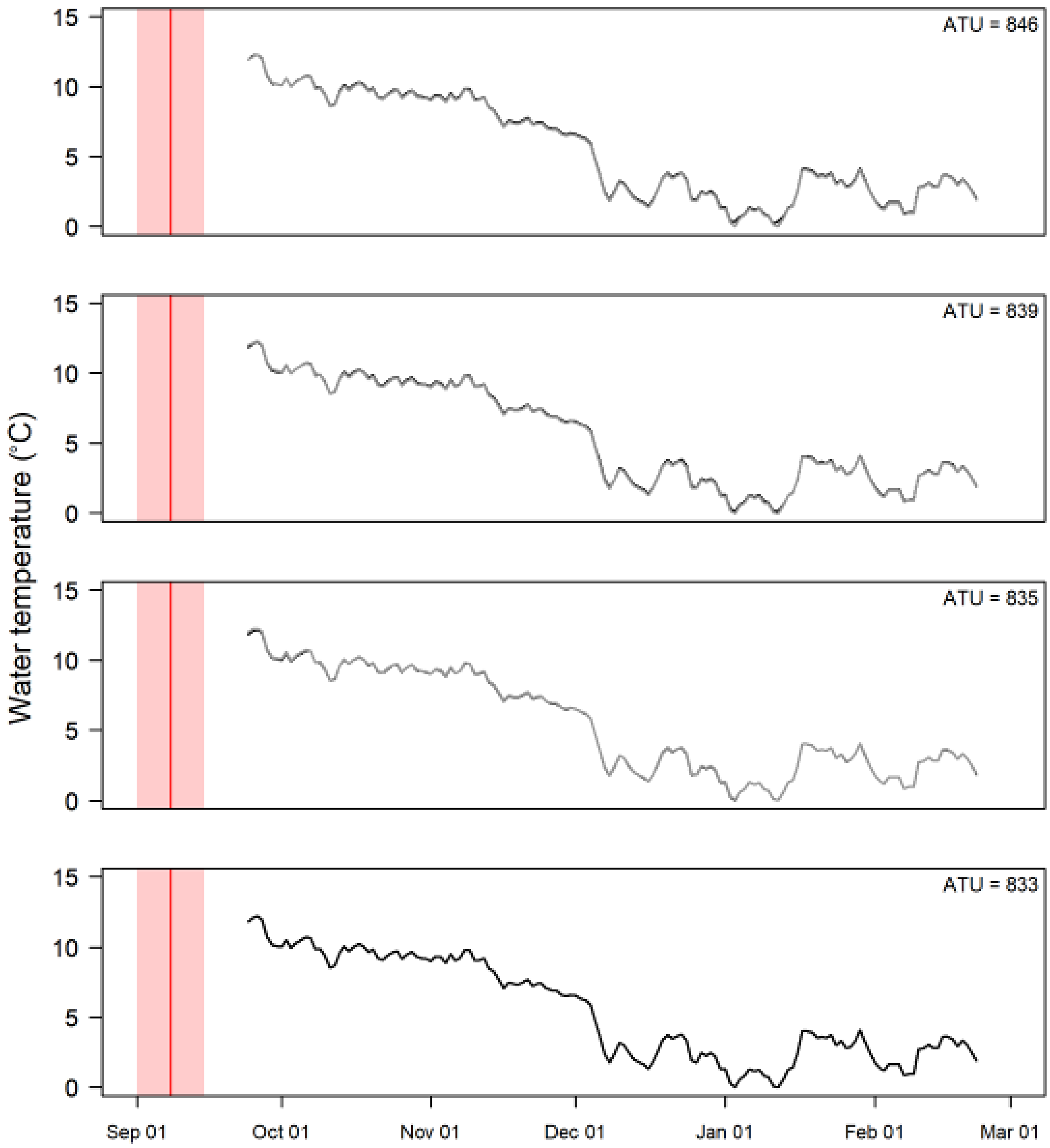

Figure 18. Water temperature at four Chinook Salmon redds at Fraser Lake (Reach 3, 33.5 rkm). Black and grey lines correspond to temperature profiles from loggers buried 30 cm below the streambed and at 60% of the water depth, respectively. Loggers were removed February 22, 2017 prior to an increase in flow 3 cms. Logger ATU is shown in the top right corner of each panel. Vertical red lines and rectangles represent the mean and range of peak spawning (respectively) in the Lower Bridge River from 2011 to 2017.

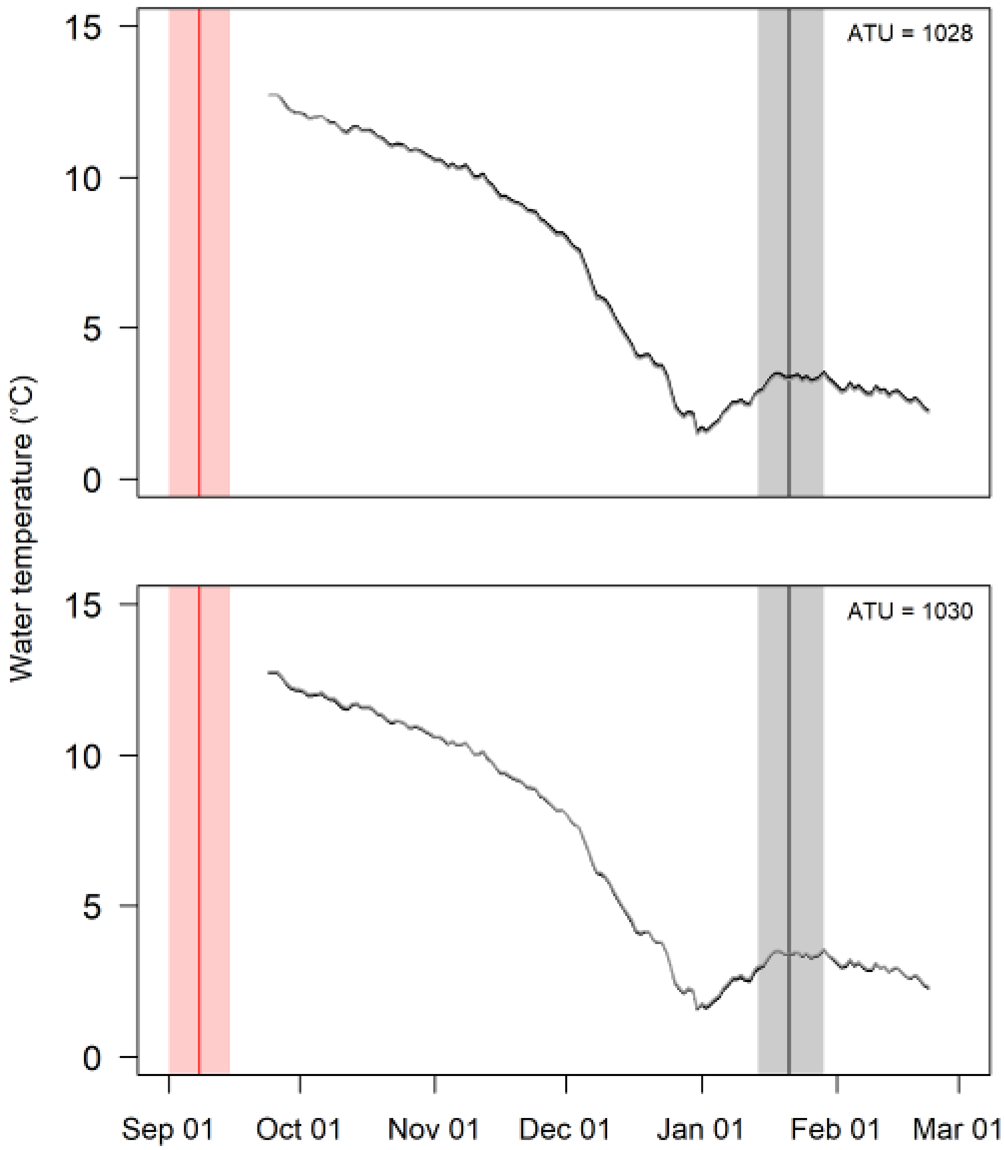

Figure 19. Water temperature at two Chinook Salmon redds at Longskinny (Reach 4, 39.3 rkm). Black and grey lines correspond to temperature profiles from loggers buried 30 cm below the streambed and at 60% of the water depth, respectively. Loggers were removed February 22, 2017 prior to an increase in flow to 3 m^3s^{-1}. Logger ATU is shown in the top right corner of each panel. Vertical red lines and rectangles represent the mean and range of peak spawning (respectively) in the Lower Bridge River from 2011 to 2017. Vertical black line represents the ATUs required (931 ATU) to reach 50% emergence (Geist et al. 2006). Grey rectangle represents ATU 95% confidence intervals (906 to 955 ATU).

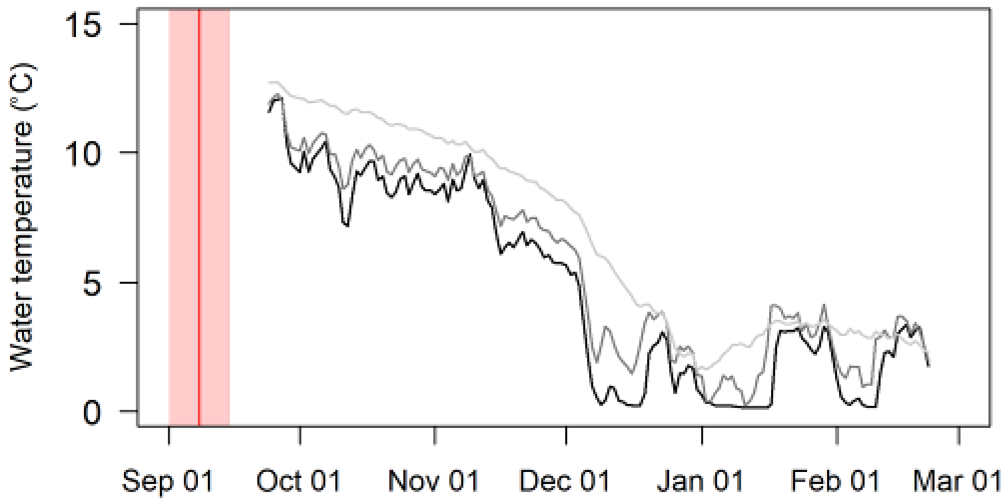

Figure 20. Comparison of mean temperature profiles of buried loggers placed at the Bridge River Counter (black; Reach 3, 26.5 rkm), Fraser Lake (dark grey; Reach 3, 33.5 rkm) and Longskinny (light grey; Reach 4, 39.3 rkm). Loggers were removed February 22, 2017 prior to an increase in flow to 3 m^3s^{-1}. Vertical red lines and rectangles represent the mean and range of peak spawning (respectively) in the Lower Bridge River from 2011 to 2017.

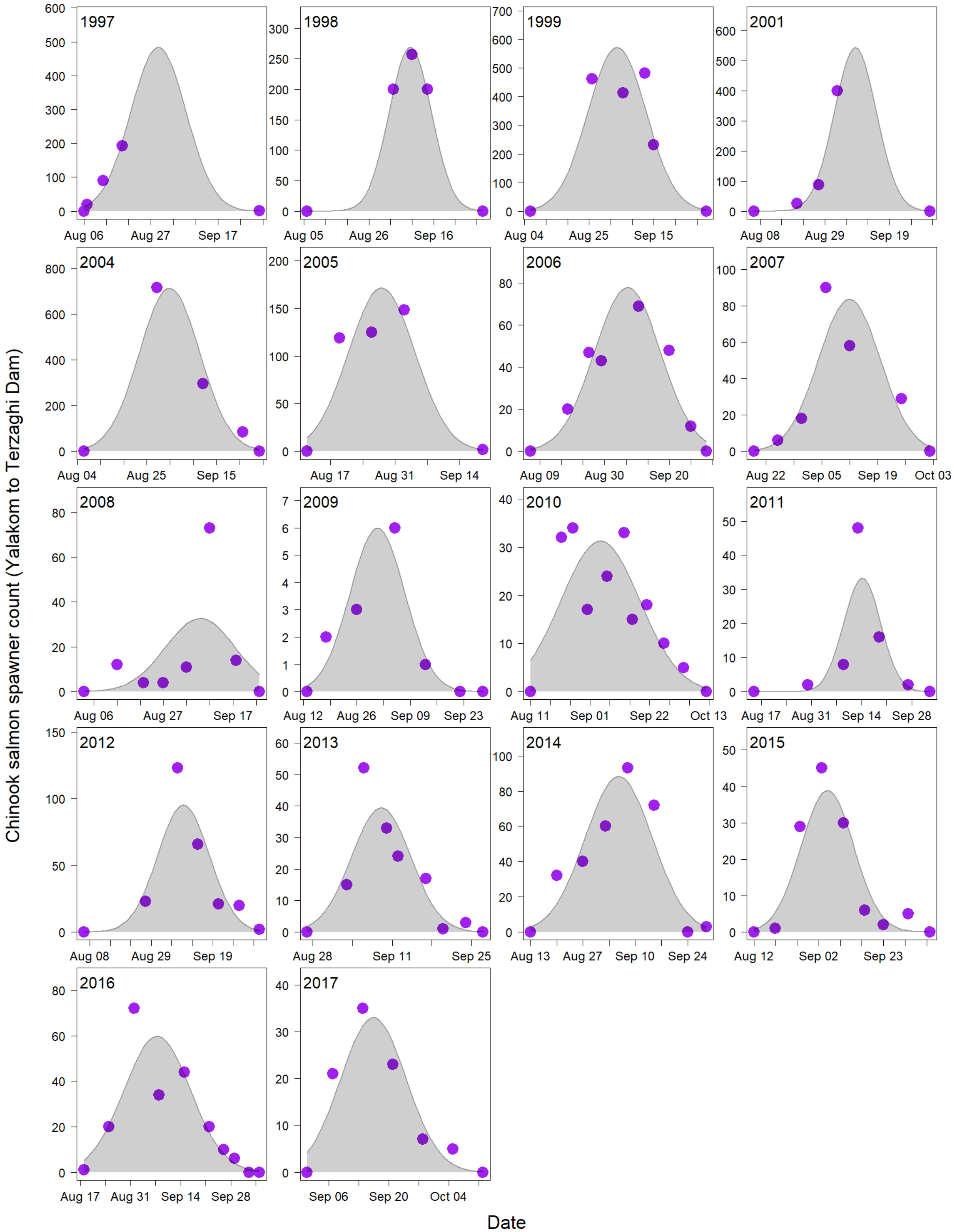

Figure 21. Comparison of Chinook Salmon adult spawner counts (purple points) to the modelled arrival timing (grey shaded area) in the Lower Bridge River from 1997 to 2017. Note that there are different date ranges between years.

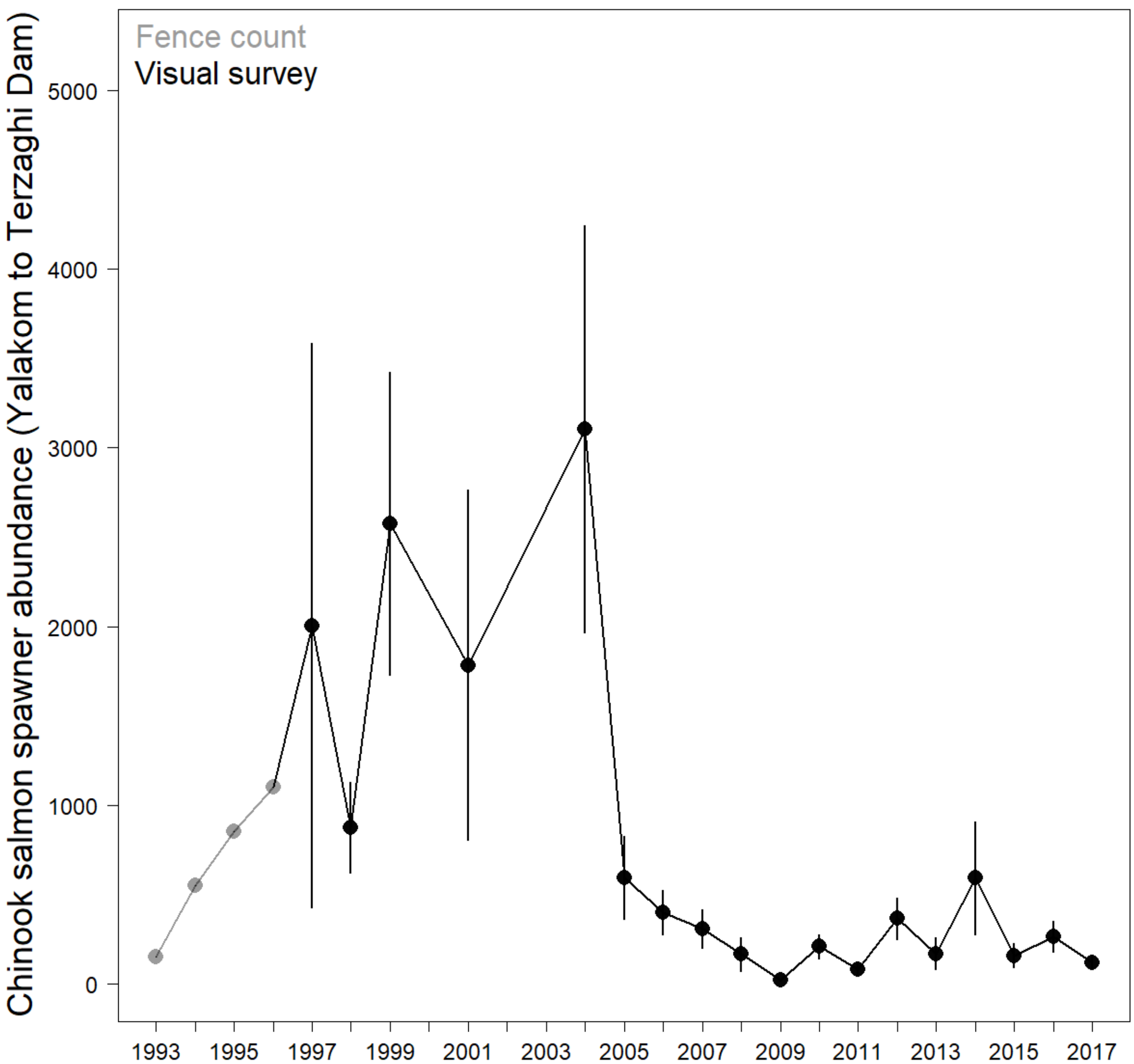

Figure 22. AUC and fence estimates for Chinook Salmon in the Lower Bridge River from 1993 to 2017. Vertical lines represent standard error.

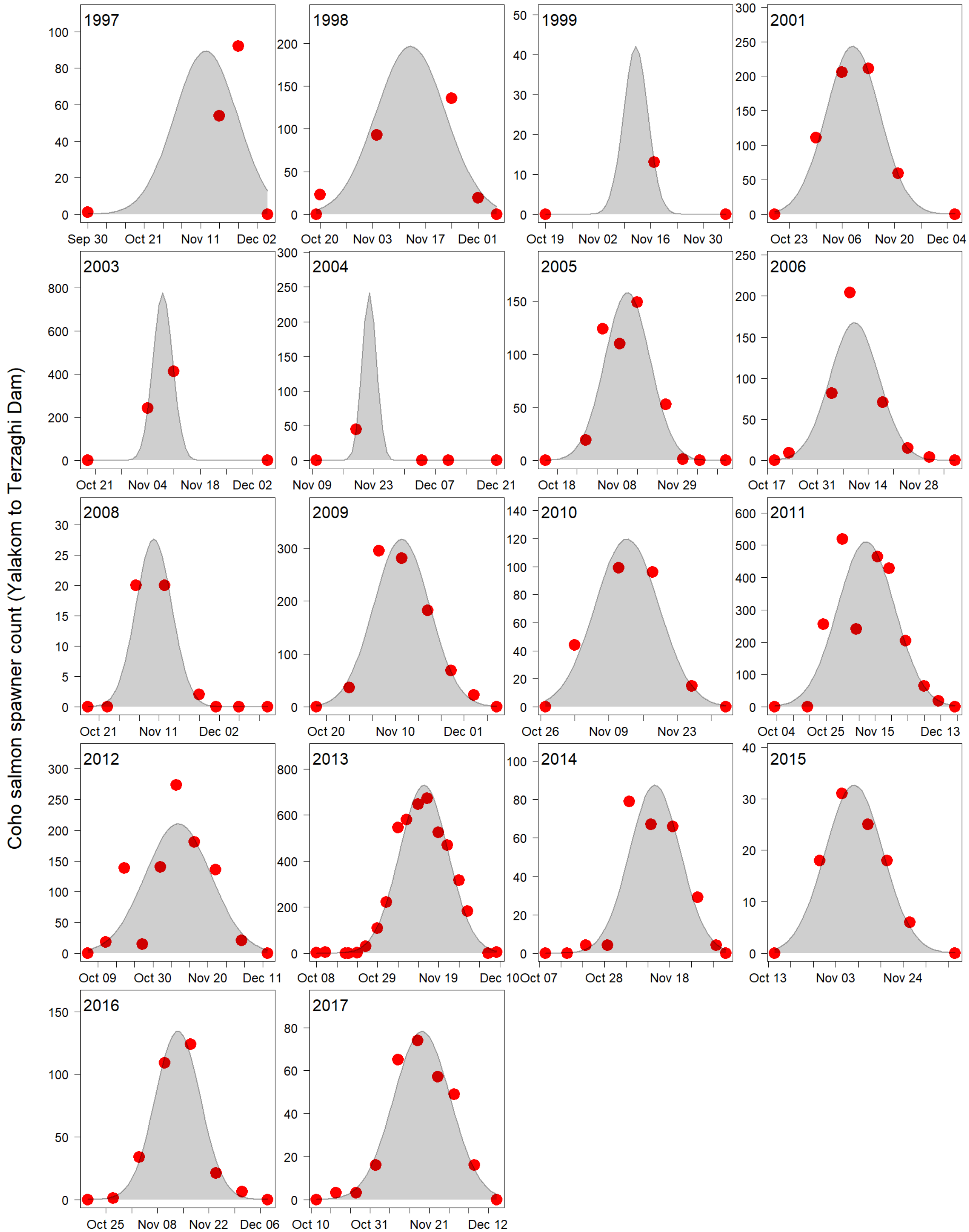

Figure 23. Comparison of Coho Salmon adult spawner counts (red points) to the modelled arrival timing (grey shaded area) in the Lower Bridge River from 1997 to 2017. Note that there are different date ranges between years.

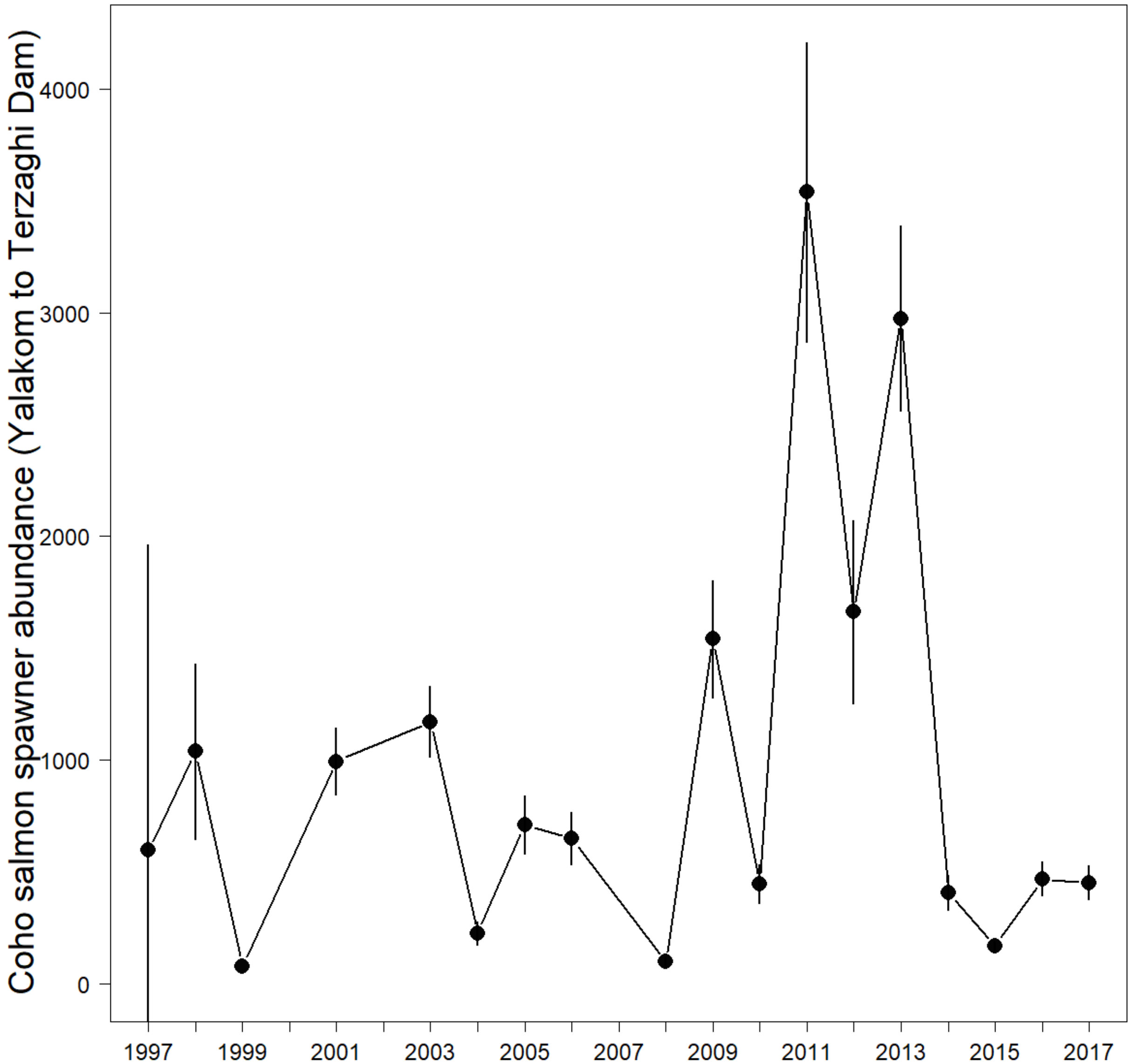

Figure 24. AUC estimates for Coho Salmon in the Lower Bridge River from 1997 to 2017. Vertical lines represent standard error.

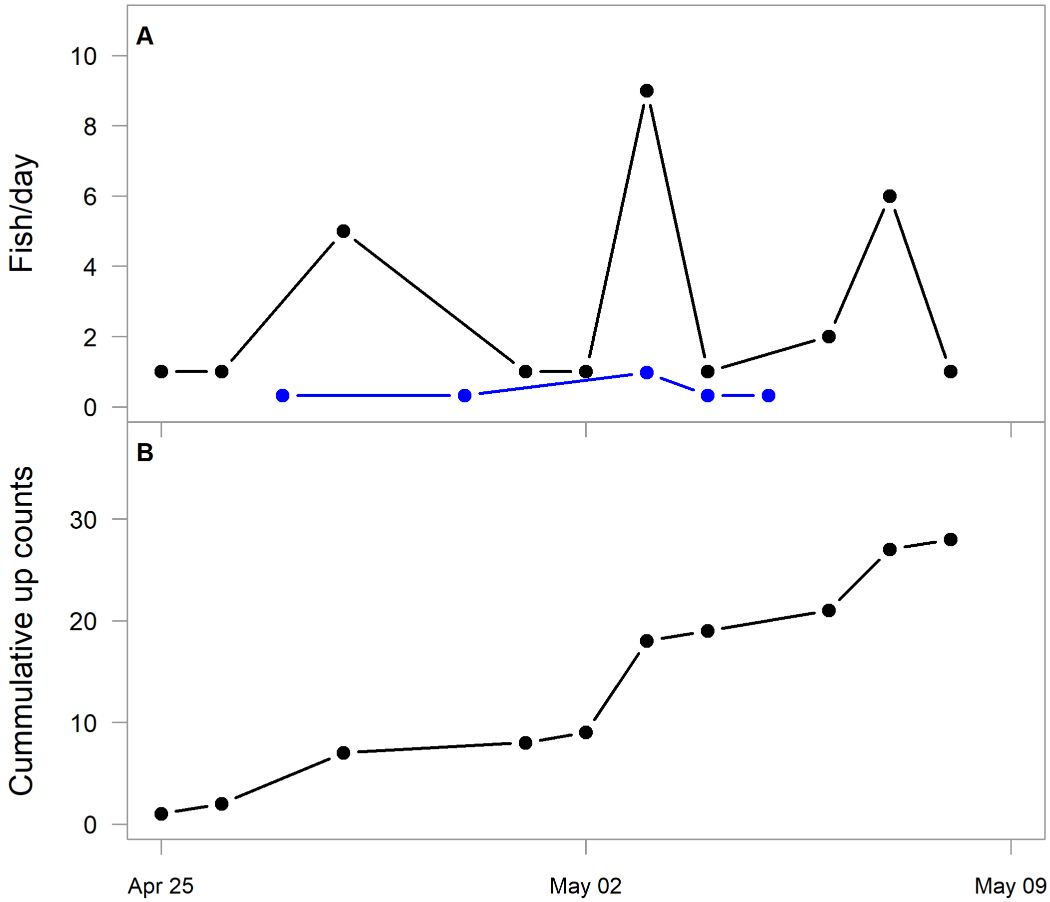

Figure 25. (A) Steelhead Trout daily up (black) and down (blue) counts, and (B) cumulative up counts (blue line) from April 25 to May 08, 2017 at Bridge River.

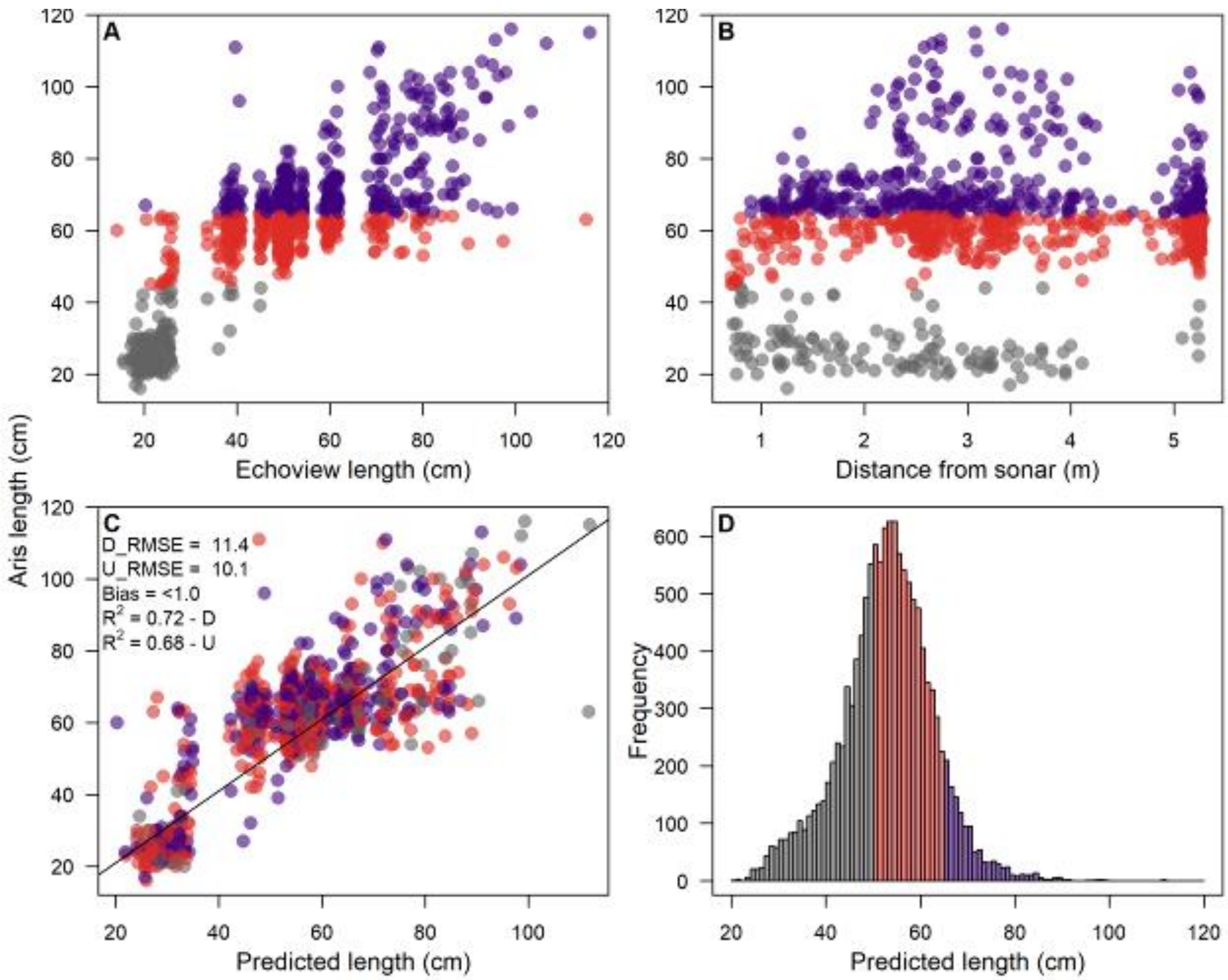

Figure 26. ARISfish lengths in relation to (A) Echoview lengths and (B) distance from sonar. (C) Observed ARISfish lengths in relation to predicted lengths from a linear model that included Echoview length and distance from sonar. Black line indicates unity (1:1). (D) Histogram of the predicted lengths of fish counted by Echoview. Purple, red and grey correspond to Chinook Salmon, Sockeye Salmon and resident fish species, respectively. Dots are fish observed using Echoview, red squares correspond to the test fish used for size calibration.

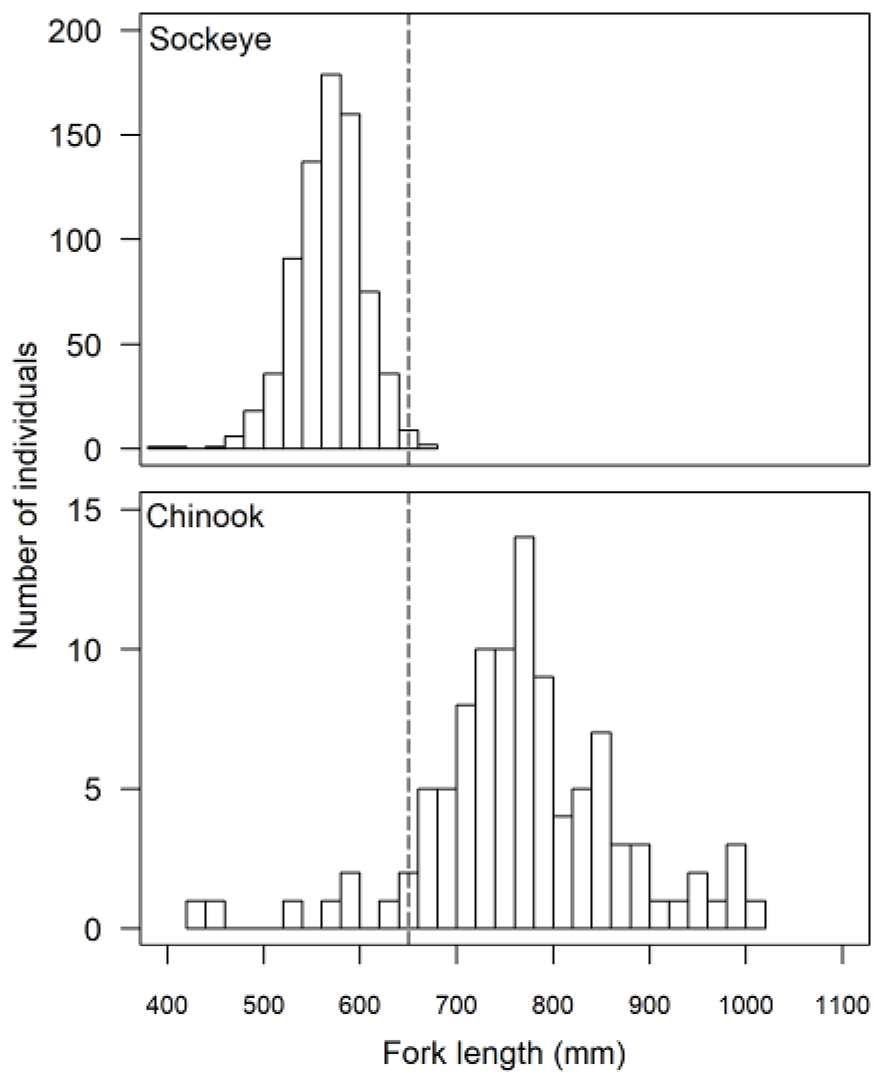

Figure 27. Fork length cut-off (dashed line; 650 mm) between Sockeye (top panel; Gates Creek Sockeye Salmon, n = 752) and Chinook Salmon (bottom panel; Bridge River Chinook Salmon, n = 101).

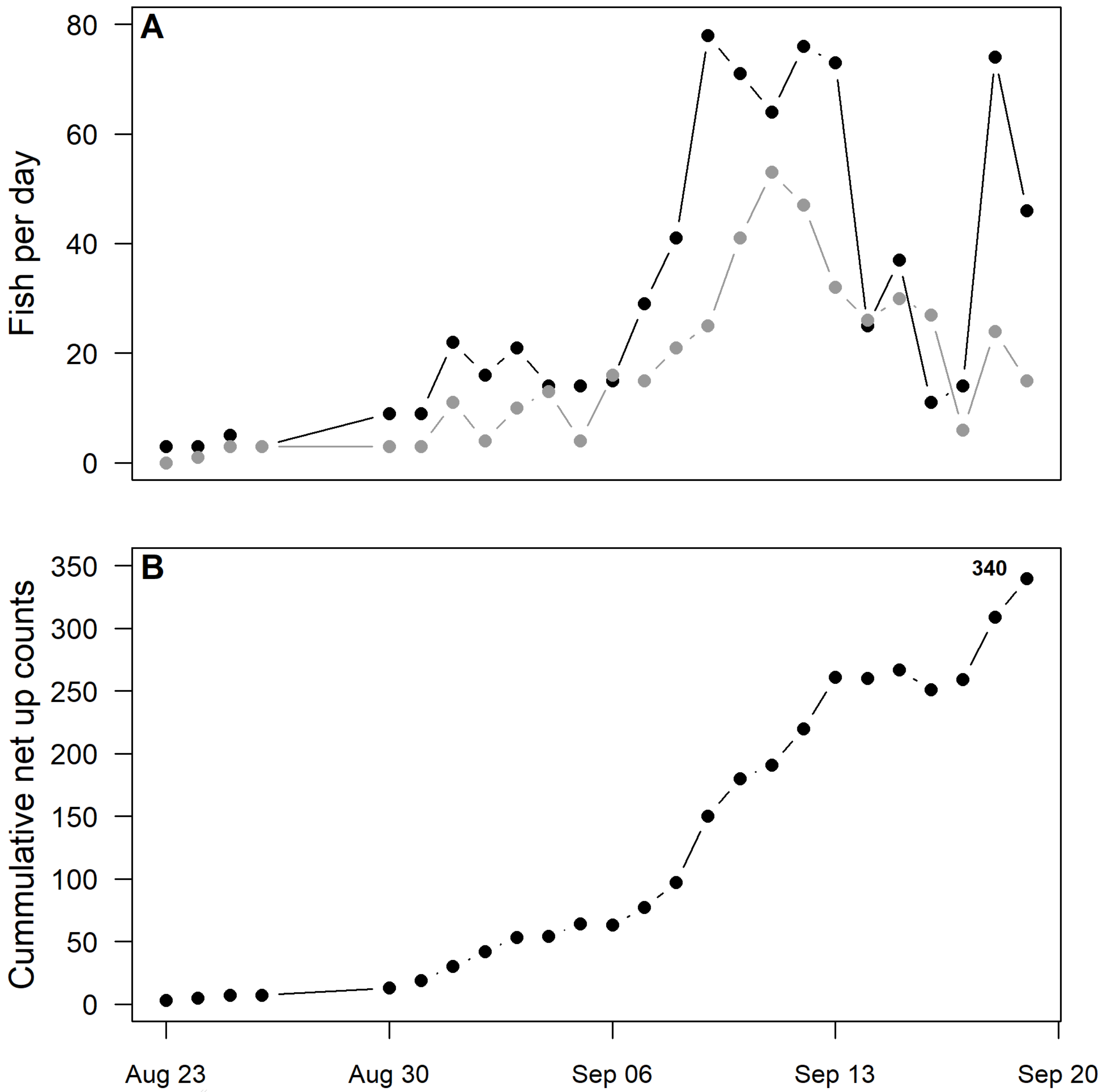

Figure 28. (A) Multibeam sonar-derived daily up (black) and down (grey) and cumulative net up (B) counts for Chinook Salmon in the Lower Bridge River in 2017. Note that September 20 was not the end of the upstream migration. Data from September 21 to October 01 is not presented due to data loss.

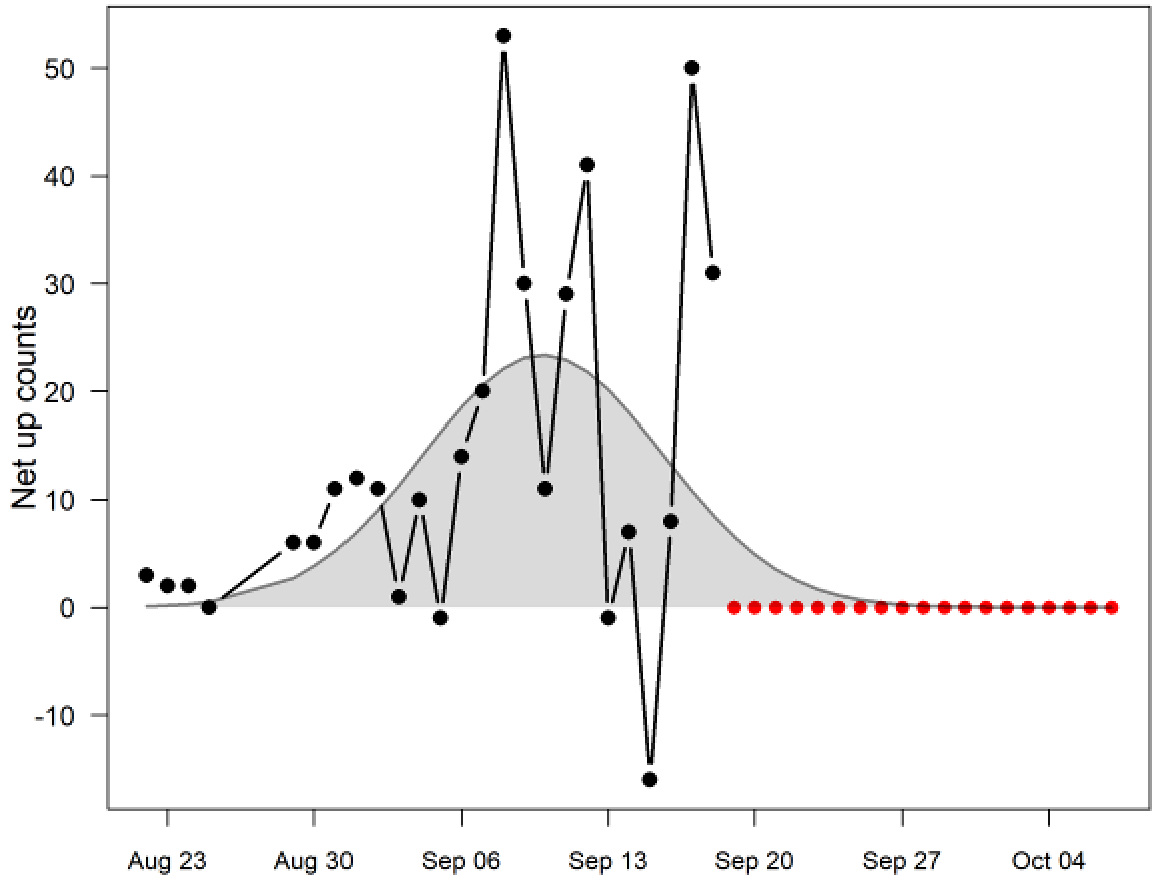

Figure 29. Net up counts for Chinook Salmon in the lower Bridge River in 2017. Modelled net up counts are shown by the solid grey line and shaded grey area. Normal model parameters were estimated using data from Aug 23 to September 20 (solid black points) and were used to predict the net up counts for days with missing data (solid red points).

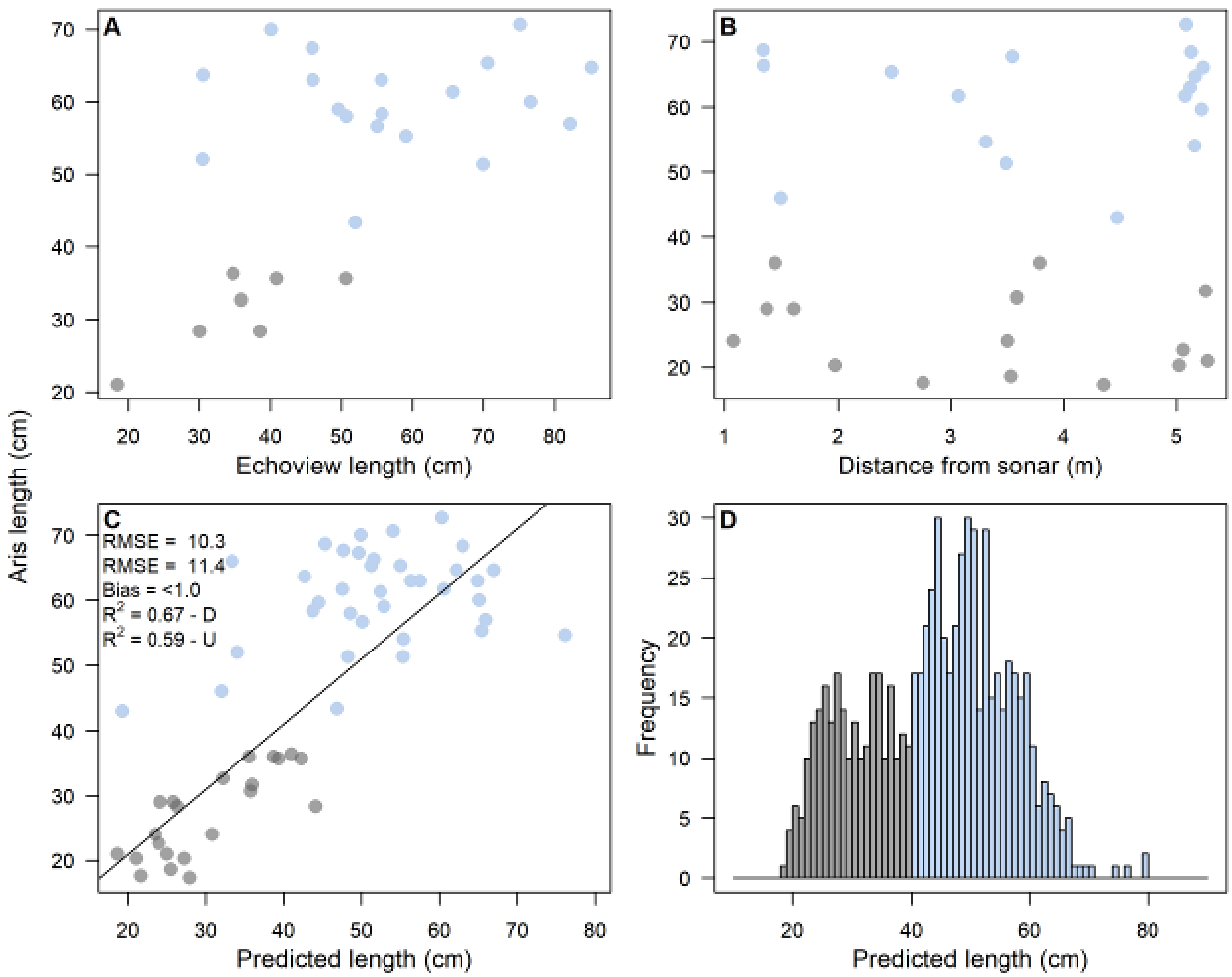

Figure 30. ARISfish lengths in relation to (A) Echoview lengths and (B) distance from sonar. (C) Observed ARISfish lengths in relation to predicted lengths from a linear model that included Echoview length and distance from sonar. Black line indicates unity (1:1). (D) Histogram of the predicted lengths of fish counted by Echoview. Blue and grey correspond to Coho Salmon and resident fish species, respectively. Dots are fish observed using Echoview, blue squares correspond to the test fish used for size calibration.

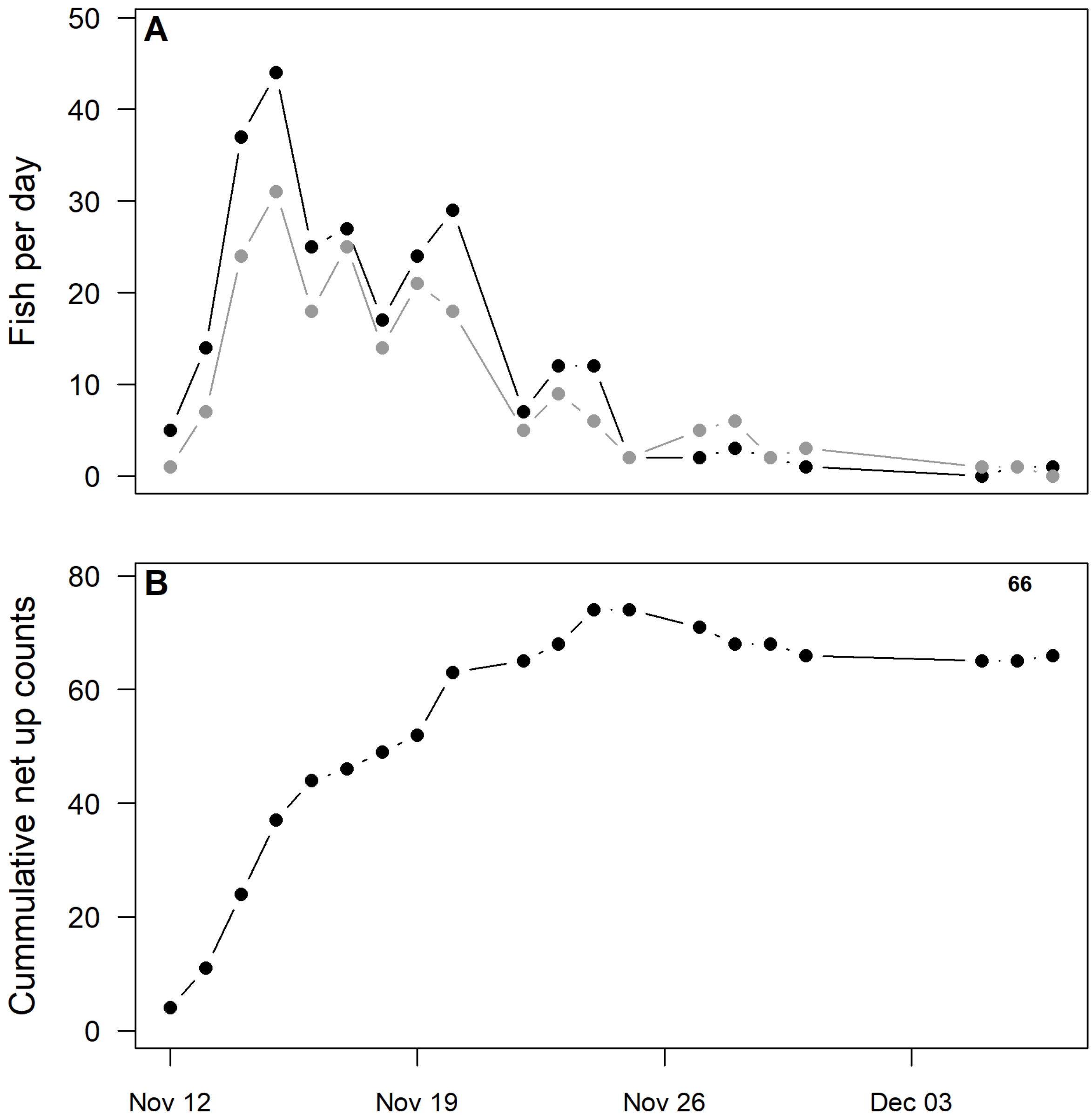

Figure 31. (A) Multibeam sonar-derived daily up (black) and down (grey) and cumulative net up (B) counts for Coho Salmon in the Lower Bridge River in 2017. Note that November 12 was not the beginning of the upstream migration. Data from October 10 to November 11 is not presented due to data loss.

9.0 Appendices

Appendix 1. Sampling and tagging data from the Lower Bridge River in 2017.

2017_MON3_Tagging_Data.xlsx

Appendix 2. Visual streamwalk data from the Lower Bridge River in 2017.

2017_MON3_Stream
walk_Data.xlsx