Bridge River Project Water Use Plan

Lower Bridge River Adult Salmon and Steelhead Enumeration

Implementation Year 5

Reference: BRGMON-3

Study Period: April 1, 2016 to December 31, 2016

InStream Fisheries Research Inc.
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Bridge-Seton Water Use Plan

Implementation Year 5 (2016):

Lower Bridge River Adult Salmon and Steelhead Enumeration

Reference: BRGMON-03

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Lower Bridge River Adult Salmon and Steelhead Enumeration, 2016

BlueView P900-45 multibeam sonar used to enumerate Chinook and Coho Salmon in 2016.

Executive Summary

The Lower Bridge River Adult Salmon and Steelhead Enumeration monitor (BRGMON-3) evaluates the effects of different flow releases from Terzaghi Dam on adult salmon productivity. BRGMON-3 aims to develop new, and refine historic, approaches for estimating abundance and egg deposition. Data collected from the Lower Bridge River Aquatic monitor (BRGMON-1) and BRGMON-3 will be used to develop stock recruitment models which will evaluate the effects of dam flow releases independently from other factors such as marine survival and adult exploitation.

In 2016, 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 peaked at 97 $m^3 s^{-1}$ in June, which was approximately 5 times higher than in previous study years. The Lower Bridge River fish counter (five-channel Crump weir sensor resistivity counter) was designed to withstand a peak flow of 20 $m^3 s^{-1}$, and thus the high flow releases in 2016 caused extensive damage to the resistivity counter sensors, 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.

Data from visual streamwalk surveys in 2016 were used to provide area-under-the-curve (AUC) type abundance estimates of Chinook and Coho Salmon in the Lower Bridge River. Observer efficiency and residence time estimates were generated using radio telemetry mark-recapture. We radio tagged six Steelhead Trout, 15 Chinook Salmon and 40 Coho Salmon in 2016. Using AUC methods, a total spawner abundance estimate of 265 Chinook and 473 Coho Salmon were derived for the area upstream of the confluence with the Yalakom River (Reaches 3 and 4). Historic visual count data were compiled and preliminary 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 to 3,106 Chinook Salmon, and from 79 to 3,563 Coho Salmon from 1997 to 2016. No historical visual count data were available for Steelhead Trout prior to 2014.

In 2016, we tested alternative methods of enumeration (i.e., multibeam sonar and flat pad sensor resisitivity counter) on a pilot basis to determine the most effective method for future study years in which high flows are anticipated. Using a P900-45 BlueView multibeam sonar, we assessed two weeks of the 5-week-long Chinook Salmon spawning period and estimated that 193 and 111 Chinook and Sockeye Salmon (respectively) spawned upstream of the counter site from August 30 to September 12, 2016. An

abundance estimate from a flat pad sensor resistivity counter was generated for Coho Salmon for the entire spawning period (October 6 to November 28). In 2016, a total of 1090 Coho Salmon were estimated to have spawned upstream of the counter site. During the two week period that the multibeam sonar and flat pad resisitivity counters were being operated side-by-side (October 24 to November 6), 283 and 358 Coho Salmon were estimated to have spawned upstream of the multibeam sonar and flat pad resisitivity counters, respectively. During the final synthesis process of BRGMON-3, we will compare AUC- and counter-derived (resistivity and sonar) estimates of abundance once additional counter data has been collected and the methods and site have been fully tested.

We sampled Chinook Salmon redds for a third straight study year to characterize the preferred habitat characteristics (water depth, velocity and substrate characteristics) and determine the distribution of redds throughout Reaches 3 and 4 of the Lower Bridge River. We found that Chinook Salmon sought out the same water depths and velocities across the three study years. We found a significant increase in the geometric mean (D_{50}) of the substrate sampled in the tailspill of the redds, however the substrate measured in 2016 is still within the preferred size range of Chinook Salmon. We note that this increase is likely associated with the mobilization of smaller sized substrate during high flow releases from Terzaghi Dam in 2016. Ten temperature loggers were buried adjacent to sampled redds to monitor accumulated thermal units over the incubation period (September 2016 to February or March 2017). Data from these temperature loggers will be reported in the following annual report.

We analyzed scale samples from 28 Steelhead Trout (2014-2016), 53 Chinook Salmon (2013-2016) and 132 Coho Salmon (2011-2016) that were captured and tagged during this monitoring program. Steelhead Trout displayed a complex life history consisting of six distinct age classes. We found that the two major age classes present in 2014 and 2015 samples were dominated by the 2009 brood. Scales collected from Chinook Salmon indicated that the majority (93%, 40/43) of the returning adults were 1.3+ (age 4), indicating that fish outmigrated as yearlings (stream-type) having spent one winter in freshwater and returned to spawn after spending three winters in the ocean. Age data for Coho Salmon identified three dominant age classes in the LBR, with age 1.1+ being dominant (71%, 94/133) and 2.1+ being subdominant (29%, 38/133). Both age classes displayed similar juvenile life histories, whereby juveniles spent 1-2 years (winters) in freshwater before outmigrating as smolts.

We discuss potential options for enumerating adult salmonids in the LBR and each methods' technical, logistical and cost considerations. Ultimately a cost-benefit analysis will inform the most cost-effective method for enumeration in future, high-flow years.

BRGMON-3 Status of Objectives, Management Questions and Hypotheses after Year 5

Study Objectives	Management Questions	Management Hypotheses	Year 5 (Fiscal Year 2016) 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 site, requiring the use of alternative enumeration techniques for 2016 and future, high flow study years. Future abundance estimates will be generated using a combination of counter technologies 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 has been collected for three 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 Transponders
PSS	Peak Signal Size
SER	St'át'imc Eco-Resources Ltd.
WUP	Water Use Plan

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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 (*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 - 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 upstream shotcrete 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.

In 2016, the modified operations involved several flow variances in the LBR, including a peak hydrograph of 97 $m^3 s^{-1}$ in June (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, 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 to determine the most effective method for future study years in which high flows are anticipated.

1.2 Management Questions

BRGMON-3's management questions ask:

1) How informative is the use of juvenile salmonid standing crop biomass is as the primary indicator of impact of flow?
2) What is the quality and quantity of spawning habitat in the Lower Bridge River after the flow release?

. 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.

1.3 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 $m^3 s^{-1}$, 3 $m^3 s^{-1}$, and 6 $m^3 s^{-1}$), and improve our understanding of the influence of instream flow on salmon spawning and rearing habitat quantity and quality in the LBR. In 2016, however, we monitored spawner abundance and distribution in relation to a new high flow treatment (22 $m^3 s^{-1}$/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. Results presented herein pertain to the high flow treatment and not to the original WUP flow treatments outlined above.

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 adult fish responses to test flows. BRGMON-3 specific objectives include documenting the abundance of 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 spawning habitat.

BRGMON-3 monitors abundance and distribution of spawning salmonids in the LBR, with 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, Bridge-Seton WUP Monitoring Terms of Reference 2012), supplemental surveys are conducted to estimate spawning abundances of Sockeye Salmon (*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) 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).

High flow releases in 2016 caused extensive damage to the counter site and did not permit the enumeration of Steelhead Trout due to the water level greatly exceeding the extent of the counter sensors (Figure 4). In 2016, IFR tested alternative methods of enumeration to determine the most effective method for future, high-flow study years.

Since 2001, visual counts of salmonids in the LBR have occurred annually using methods developed and implemented by BRGMON-1 and prior to 2000 using several methods, including stream-side visual counts. The survey area extends from Terzaghi Dam to the Yalakom River – Bridge River confluence (Figures 3 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 caused extensive damage to the PIT antennas. Consequently, IFR and BC Hydro agreed to reinstate the use of radio telemetry in 2016 as a means 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 conducted an assessment of Chinook Salmon spawner habitat quantity and quality from 2014 to 2016. 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.

2.2.1 Fish Capture, Tagging and Sampling

Fish capture by angling was completed by teams of two SER fisheries technicians. Tag application and effort was distributed throughout each species migration periods: March to May 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 MCF2-3A radio tag (46 × 16 × 16 mm; Lotek Wireless Inc., Ontario, Canada). SER fisheries technicians did not angle for Steelhead Trout at the Bridge-Fraser confluence (as in previous study years) due to safety concerns associated with the high flow releases. In 2016, 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 mortality radio tag (44 × 16 × 16 mm; Sigma Eight Inc., Ontario, Canada) 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 2016. External visual identification (i.e., spaghetti) tags were applied to Chinook and Coho Salmon in 2016 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 2). Stations consisted of Lotek SRX_400 receivers 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. Radio receivers were tested in August 2016 to ensure optimal read range and tag reading performance (Appendix 3). Detection efficiency results are presented in Table 4.

Mobile tracking was conducted weekly in Reaches 3 and 4 using a hand-held Lotek 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 24 to June 3 for Steelhead Trout, August 18 to October 6 for Chinook Salmon and October 13 to December 8 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 calculated the time (in days) tagged fish took to migrate from release to the reach where fish likely spawned (hereafter, assumed spawning reach). We also present the migration rates (in km day^{-1}) of Coho Salmon 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

During tagging and sampling, scale samples were obtained from Steelhead Trout, and Chinook and Coho Salmon for ageing purposes. It has been difficult to collect quality scale samples from Chinook Salmon (few non-resorbed samples have been collected to date), as scales are resorbed at the time of capture and additional handling in the high air and water temperatures causes physiological stress. Scale samples were placed in coin envelopes marked with identification data (e.g., radio and PIT code) for future cross-reference. After a period of air-drying, scales were removed from the envelopes, cleaned and placed directly on glass slides and read under a microscope. Digital photographs were taken and archived for future reference. Age was determined using the methods outlined in Ward and Slaney (1988), in which two people independently determined age without knowledge of the size, time and location of capture of the sampled fish. Samples were discarded when a consensus between both persons could not be reached.

Age designation for salmon and steelhead was assigned in accordance to the European age designation system (Koo 1962), which expresses age or age classes as two numbers separated by a decimal. The first number represents the number of years or winters the fish spent in freshwater and the second number represents the number of years or winters spent in the ocean. Collectively the two numbers can be added together to provide a total age or age class at maturity. For example, a 1.2 represents a 3-year-old fish that spent 1 year (or 1 winter) in the freshwater environment and 2 years (or 2 winters) in the ocean and spawned in their fourth year of life.

Reading scales that have been resorbed can be very challenging. Resorbed scales were aged using DFO's resorbtion scale criteria (MacLellan and Gillespie 2015), allowing readers to make a determination on whether any number of annual zones are missing.

We present the age data from all fish captured and tagged during this monitoring program (2011-2016). Age data from twenty-eight Steelhead Trout (2014-2016), 43 Chinook Salmon (2013-2016) and 132 Coho Salmon (2011-2016) are presented in the Results (see Section 3.2). Considering that some radio- and PIT-tagged Coho Salmon migrate further up the Fraser River post-release, we decided to only include the ages of Coho Salmon that migrated and spawned in the LBR. Data were summarized as length-at-age (i.e., fork length vs. age) and the distribution of age classes across study years.

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 and Coho Salmon in Reaches 3 and 4 (Figures 3 and 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 2016.

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 (September 2016 to February or March 2017). 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. Data loggers are accurate to ± 0.2 ºC. Loggers will be retrieved at the end of the incubation period and prior to high flows in the spring of 2017. Consequently, ATU data will be presented in the following annual report.

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 2016, 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 2016 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. In 2016, we determined the date of death of tagged fish using the burst rate of the mortality radio tags. Chinook Salmon were not spaghetti tagged in 2014 or 2015, and thus observer efficiency could not be estimated. In 2016, we used the mean observer efficiency (0.50) and residence time (11.5 days) across study years for use in AUC estimation (Tables 2 and 3) due to low sample sizes and high variance among streamwalk surveys. For example, we observed 6 of the 7 tagged fish in the survey area on September 1 (Appendix 2) and no tagged fish during the other 10 streamwalk surveys. However, we used the observer efficiency and residence time data collected in 2016 to calculate the mean observer efficiency and residence time across study years.

Residence time was estimated using a combination of the burst rate of the mortality radio tags and review of the migration history of each tagged individual. Residence times were averaged by species and survey year and calculations consisted only of fish that were tagged outside of the visual survey area or inside the survey area but within 50 m of the downstream boundary (Table 1).

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 2 and 3). 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 2016, we used the mean observer efficiency (0.23) and residence time (19 days) across study years for use in AUC estimation (Tables 2 and 3) due to low sample sizes and high variance among streamwalk surveys. However, we used the observer efficiency and residence time data collected in 2016 to calculate the mean observer efficiency and residence time across study years.

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 and 2016 were used in the historical AUC modelling of Coho Salmon abundance (Tables 2 and 3).

2.3.2 Resistivity Counter Abundance Estimate

Abundance of Coho Salmon in 2016 was estimated using a flat pad sensor resistivity counter (Figure 6) from October 6 to November 28, 2016. Notably, this counter setup uses the same underlying principles used in other study years (2013-2015; McCubbing et al. 2014, Melville et al. 2015, Burnett et al. 2016) and differs only in the type of in-river sensor (i.e., flat pad vs. Crump weir).

Spurious debris or wave action data (i.e., many events over a short period of time on a single channel) were removed from raw datasets. Aquantic's proprietary graphics software was used to reclassify misclassified counter records (i.e., false positives and false negative counts created by noise). Each individual trace was viewed; this serves as a form of pseudo-validation of the counter algorithm. Pseudo-validation relies on a dependent form of validation – in this case, we use the counter graphics (collected by the counter) to validate the counter records. We validated 270 hours of video data to calculate the counter accuracy. We validated the first 15 minutes (every two hours) of counter data from October 11 to November 16. We selected these date ranges based on peak migration timing of Coho Salmon in 2014 (Melville et al. 2015) and 2015 (Burnett et al. 2016). Video data were collected using two Swann infrared cameras connected to a battery-powered four channel Swann DVR (Figure 6). Counter accuracy was calculated as follows:

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

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

All Coho Salmon up and down counts were determined using peak signal size (PSS) cut-offs. Each record on the counter (up, down or events) contains a unique PSS that corresponds to the peak of a sinusoidal curve that is created when a fish passes over the counter sensor. PSS is related to mass and thus is a proxy for fish size. We plotted the relationship between fish length (recorded from the video) and PSS and identified the fish length with the smallest overlap between resident fish species and Coho Salmon. We then determined the corresponding PSS value for the fish length. 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, stream walks, video observations and a previous telemetry study (Webb et al. 2002).

2.3.3 Multibeam Sonar Abundance Estimates

We could not repair the damage sustained to the resistivity counter Crump weir sensors on site prior to the onset of the Chinook Salmon migration for two main reasons: (1) the extent of damage was substantial and would have required a rebuild of the in-river counter sensors and video validation equipment, and (2) the flows in the LBR were too high to permit such a rebuild (8 $m^3 s^{-1}$ on August 15). As an alternate approach, we piloted a BlueView P900-45 multibeam sonar to enumerate Chinook and Coho Salmon for two weeks during historic peak migration timing in the LBR (Figure 7) to provide a minimum abundance estimate for 2016. We fixed the P900-45 multibeam sonar unit to a custom-built aluminium mount, positioned it at half of the water depth (21 cm for Chinook Salmon, 19 cm for Coho Salmon) and oriented it horizontally (0° tilt angle) across the channel (Figure 7).

Multibeam sonar users typically manually count each individual observed crossing the sonar beam to enumerate a population (Hermann Enzenhofer, personal communication). However, due to the large time investment required to count every fish in the sonar videos, Echoview software (Version 6.1; Echoview Software Pty Ltd., Hobart, Australia) was used as a post-processing tool to reduce the time associated with detecting fish (reviewed in Braun et al. 2016).

BlueView sonar video files were imported into Echoview and the raw data were displayed as a virtual echogram video; objects were plotted in relation to the angle of the beams and distance to the sonar head. To increase the accuracy 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 applied this template to each sonar video file using Echoview's automating scripts. Background noise was removed and fish were automatically detected from the sonar files at a rate of 0.3 Gigabytes (GB) per hour. Approximately 504 GB of data was collected during the 14 days the multibeam sonar was running. Echoview automatically processed the data in 1680 hours (70 days) with minimal human supervision. During this step, Echoview highlights sections of sonar data that may contain fish-like movements that are then ready to be verified.

Echoview's analysis was then verified by an experienced analyst to ensure the validity of the fish detected after the automation process. During this step, a user manually examines each fish detected by the software; the validation was completed in 35 hours (4 days). After the verification, the timestamps, length, and positioning data from each individual fish was exported by Echoview into a .csv file for further analysis in R. Due to the age of the BlueView unit, its low operating frequency (900 kHz), and Echoview's internal software issues reading BlueView sonar data, the exported length data was precise but was biased low. For a subset of fish, we measured lengths using the proprietary BlueView software (ProViewer 4), which was deemed accurate from our ProViewer measurements of a test fish of known size. To predict the length of all other fish, we used a linear model that related ProViewer fish lengths to the Echoview estimated lengths. We also included the distance from the sonar head (in meters) as a covariate. Considering Sockeye Salmon are present in the LBR during the Chinook Salmon migration period, we applied a size cut-off between Sockeye and Chinook Salmon to the predicted lengths to determine the number of Chinook Salmon crossing the sonar beam. Tagging data from BRGMON-3 (n = 98 fish tagged from 2012-2016) and BRGMON-14 (n = 752 in 2013) was used to inform the size cut-off decision.

3.0 Results

3.1 Radio Telemetry

3.1.1 Steelhead Trout

Fish Capture, Tagging and Sampling

Six female Steelhead Trout were angled and radio tagged from March 7 to April 8 at the Seton-Fraser confluence (Appendix 1). Mean fork lengths of radio-tagged females were 685 mm (range: 600 to 765 mm). Three additional female Steelhead Trout were captured and PIT-tagged from October 5 to October 28 during angling for Coho Salmon at the Bridge-Fraser confluence. Mean fork lengths of these PIT-tagged individuals were 774 mm (range: 620 to 867 mm).

Radio Telemetry

Of the 6 Steelhead Trout captured and tagged from March to April, two individuals were detected by radio telemetry in the LBR: both individuals (tags 47 and 54) resided and potentially spawned in Reach 3 near Russel Springs (Figure 8 and Table 5). We could determine the migration rate of one radio-tagged Steelhead Trout (tag 54) in the LBR due to the presence of detections at the Bridge-Fraser confluence (Station 1) and upstream of the Yalakom-Bridge confluence. Radio tag 54 had a migration rate (1.4 km day^{-1}; Table 5) consistent with Steelhead Trout radio-tagged in previous years (see Burnett et al. 2016). Radio tag 47 was not detected on Station 1 and thus we could not determine entry timing into the LBR.

Of the four individuals that did not enter the LBR, three individuals were detected in the Seton River via radio and PIT telemetry. Radio tags 55 and 63 passed Seton Dam on April 13 and 4, respectively. Radio tag 60 was tagged and released on April 8 and was first detected in the Seton Generating Station tailrace from April 17 to 18 and April 24 to May 9 by a Seton Entrainment radio receiver. Next, tag 60 was detected at Seton Dam from May 18 to 29, making a single downstream movement to the Cayoosh PIT antenna on May 28. This individual was detected on May 20 and May 29 on the PIT antenna in the fishway entrance at Seton Dam.

3.1.2 Chinook Salmon

Fish Capture, Tagging and Sampling

Fifteen Chinook Salmon (8 males and 7 females) were captured and radio tagged from August 16 to August 31 at the Yalakom-Bridge confluence (Appendix 1). Mean fork lengths of radio-tagged males and females were 734 mm (range: 680 to 770 mm) and 786 mm (range: 689 to 915 mm), respectively (Figure 9).

Radio Telemetry

Of the 15 Chinook Salmon captured and tagged at the Yalakom-Bridge confluence, 14 individuals moved upstream in the LBR: 13 spawned in Reach 3 between the Yalakom River and Hell Creek (25.5 to 28.8 rkm), and one spawned in Reach 4 between Cobra and Bluenose (34.4 to 38.2 rkm) (Table 6). Chinook Salmon had a mean residence time of 9.4 days (range: 5.9 – 16.6 days) in Reaches 3 and 4 of the LBR (Table 6).

3.1.3 Coho Salmon

Fish Capture, Tagging and Sampling

Forty Coho Salmon (23 males and 17 females) were captured and radio tagged from October 3 to November 5 (Appendix 1). Mean fork lengths of radio-tagged males and females were 691 mm (range: 540 to 810 mm) and 625 mm (range: 480 to 765 mm), respectively (Figure 10).

Radio Telemetry

Of the 40 Coho Salmon captured and tagged, 31 individuals moved upstream in the LBR: 17 spawned in Reach 3, and 11 spawned in Reach 4 (Table 7). We could not determine the spawning reach of three radio-tagged Coho Salmon due to sparse fixed and mobile tracking data likely the result of cryptic spawning behaviour. Specifically, the 28 radio-tagged Coho Salmon spawned in near equal proportions across streamwalk sections: five spawned between Yalakom River and Hell Creek (25.5 to 28.8 rkm), three spawned between Hell Creek and Russel Springs (28.8 to 30.7 rkm), five spawned between Russel Springs and Fish Fence (30.7 to 33.2 rkm), four spawned between Fish Fence and Cobra (33.2 to 34.4 rkm), five spawned between Cobra and Bluenose (34.4 to 38.2 rkm), two spawned between Bluenose and Eagle (38.2 to 38.8 rkm) and four spawned between Longskinny and Plunge Pool (39.3 to 40.0 rkm) (Table 7). Coho Salmon had a mean residence time of 21.6 days (range: 9.4 – 34.0 days) in Reaches 3 and 4 of the LBR. Coho Salmon that showed directed upstream migrations in the LBR exhibited a mean migration rate of 4.4 km day^{-1} (range: 1.3 to 17.1 km day^{-1}) from release to the assumed spawning reach (Table 7).

3.2 Ageing of Adult Salmon and Steelhead

3.2.1 Steelhead Trout

Steelhead Trout scales were collected from 2014 to 2016. In total, 32 scale samples were analyzed: 12 from 2014, 17 from 2015 and 3 from 2016. Two scales sampled in 2014 were regenerated and were not used in the present analysis.

Maiden (first time spawners) LBR Steelhead Trout returned most frequently at ages 4 and 5 (Figure 11). Six distinct age classes were identified among all the fish sampled. In 2014, 2.2+ accounted for 38% of the aged fish (Figure 12), then 3.1+ and 3.2+ (both 25%), and 2.1+ (13%). Two of the aged fish in 2014 were repeat spawners (3.1S2 and R.2S1). In 2015, there was a shift in the age classes: 3.2+ accounted for 50% of the aged fish, followed by 2.2+ (25%) and 3.3+ (13%). One repeat spawner was observed in 2015 (Appendix 4). In 2016, few fish were captured, and of the three fish that moved into the LBR, two were 3.2+ and one was 2.3+. Of the 24 scales sampled in 2014 and 2015, 58% (14/24) correspond to the 2009 brood year, 25% (6/24) to the 2010 brood year, and 17% (4/24) to the 2008 brood year (Appendix 4).

3.2.2 Chinook Salmon

Chinook Salmon scales were collected from 2013 to 2016. In total, 63 scale samples were analyzed: 11 from 2013, 15 from 2014, 17 from 2015 and 10 from 2016. Ten (1 from 2013, 2 from 2014, 5 from 2015 and 2 from 2016) of the 63 scales were removed from the sample due to high amounts of scale resorption and regeneration or failed reading consensus between the two analysts.

Two distinct age classes were identified among the Chinook Salmon scales. Most of the LBR spawners returned at age 4 (1.3), and few individuals returned at age 3 (1.2) (Figure 13). All of the scales read displayed a yearling (stream-type) life history with juveniles spending one winter in freshwater (Figure 14). Length-at-age was consistent between years, with age 4 fish generally being larger than 700 mm and age 3 fish smaller than 700 mm (Figure 13).

3.2.3 Coho Salmon

Coho Salmon scales were collected from 2011 to 2016. In total, 139 scales were analyzed: 18 from 2011, 26 from 2012, 16 from 2013, 31 from 2014, 16 from 2015 and 32 from 2016. Seven scales (1 from 2013, 3 from 2014 and 3 from 2016) were removed from the sample due to high amounts of scale resorption or regeneration or failed reading consensus between the two analysts.

LBR Coho Salmon returned most frequently at ages 2 and 3 (Figure 15). Three distinct age classes were identified among the Coho Salmon scales. All age classes displayed similar juvenile life histories, whereby juveniles spent 1-2 years (winters) in freshwater before outmigrating as smolts. In 2011, 1.1+ accounted for 72% of the aged fish and 2.1+ accounted for the remaining 28% (Figure 16). In 2012 there was a more even split among the age classes, with age 1.1+ making up 58% of the aged fish, followed by 2.1+ at 42%. In 2013, 1.1+ accounted for 94% of the aged fish and age 2.1+ accounted for the remaining 6%. In 2014, 1.1+ accounted for 68% of the aged fish, 2.1+ at 29% and one individual at 1.2+. In 2015, 63% of the scales were aged as 1.1+ with the remaining scales (38%) aged as 2.1+. In 2016, 76% of the scales were aged as 1.1+ and 2.1+ accounted for the remaining 24% (Figure 16). Overall, there did not appear to be a size difference between the age classes observed (ranged from 480 to 815 mm for age 2 and 460 to 840 mm for age 3) (Figure 15).

3.3 Visual Surveys

3.3.1 Steelhead Trout

Streamwalks were not conducted for Steelhead Trout in 2016.

3.3.2 Chinook Salmon

Visual counts of Chinook Salmon were conducted from August 18 to October 3, at which point spawning was assessed to be complete and only one individual was observed. Fish were first observed on August 18 between Hell Creek and Russel Springs, with a peak live fish count of 72 fish observed on September 1. Most fish on the September 1 streamwalk were observed from Fish Fence to Cobra (33.2 to 34.4 river km, 22 fish) and from Hell Creek to Russel Springs (28.8 to 30.7 river km, 25 fish; Appendix 2). Relative abundance of spawners was highest from Fish Fence to Cobra, where counts represented 31% of total counts, and lowest from Cobra to Bluenose (34.4 to 38.8 river km) where there were no fish observed (Appendix 2).

Water visibility was variable throughout the Chinook Salmon migration period, ranging from 3 m in early September to 0.2 m in early October (Appendix 2).

3.3.3 Coho Salmon

Visual counts of Coho Salmon were conducted from October 3 to December 8, at which point spawning was assessed to be complete and no individuals were observed. We observed a peak live fish count of 124 fish on November 17. Most fish were observed from Eagle to Plunge Pool (38.8 to 40.0 river km) between November 3 and 24 (Appendix 2). Relative abundance of spawners was highest from Longskinny to Plunge Pool (39.3 to 40.0 river km), where 46% of total counts were observed, and lowest from Cobra to Eagle (34.4 to 38.8 river km) and from the 25.5 to 26.0 river km where there were no counts observed (Appendix 2).

Water visibility was consistently low throughout the Coho Salmon migration period, ranging from 0.2 m in early October to 0.5 m in November (Appendix 2).

3.3.4 Sockeye Salmon

Visual counts of Sockeye Salmon were conducted from August 25 to September 29, and were in low abundance (63 individuals total). Peak count was 31 fish on September 1, and decreased to 0 fish on September 22. Most (90%) of the Sockeye Salmon observed on streamwalks were located from 33.2 to 40.0 river km (Appendix 2).

Water visibility was variable throughout the Sockeye Salmon migration period, ranging from 3 m in early September to 0.2 m in early October (Appendix 2).

3.4 Chinook Salmon Habitat Evaluation

3.4.1 Redd Characteristics

Twenty-six Chinook Salmon redds were observed in Reach 3 (n = 24) and 4 (n = 2) of the LBR in 2016. Redds sampled in 2016 had similar average water depths (0.4 m in 2014, 0.5 m in 2015, 0.4 m in 2016; Figure 17) and velocities (0.78 m s^{-1} in 2014, 0.74 m s^{-1} in 2015, 0.66 m s^{-1} in 2016; Figure 18) as redds sampled in 2014 and 2015. The geometric mean (D_{50}) of the substrate sampled in the tailspill of each redd (i.e., substrate mobilized by spawning Chinook Salmon) was twice as large in 2016 (mean = 67 mm, SD

= 17) than the substrate sampled in 2015 (mean = 32 mm, SD = 10) (t_{41} = - 8.9, *P-value* = 3.9×10^{-11}) (Figure 19). Further, we observed a significant increase (*D* = 0.8, *P-value* = 9.2×10^{-9}) in the distribution of the substrate D_{50} (Figure 19).

3.4.2 Redd Distribution

Ninety-two percent (24/26) of the Chinook Salmon redds sampled in 2016 were in Reach 3. Redd locations have been consistent across study years (2014 to 2016), where Chinook Salmon spawn predominantly around Hippy Pool (25.5 river km), Hell Creek (28.8 river km), Russel Springs (30.7 river km) and Cobra (34.4 river km) (Figure 20). We did, however, observe new colonization in 2016 at Fraser Lake (33.5 river km) and Longskinny (39.3 river km) (Figure 20). Consistent with 2014 and 2015, 88% (21/24) of the redds sampled in 2016 were in run habitat, with the remaining three redds (12%) located in riffle habitat (Table 8).

3.5 AUC Abundance Estimates

3.5.1 Chinook Salmon

2016

Using an observer efficiency of 0.5 (Table 2), a residence time of 10.5 days (Table 3), and a survey start date of August 18, we calculated the maximum likelihood estimate of 265 Chinook Salmon (95% confidence limits: 98-431) in 2016 between the Yalakom River and Terzaghi Dam (Figure 21 and Table 9).

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 9).

3.5.1 Coho Salmon

2016

Using an observer efficiency value of 0.23 (Table 2), a residence time of 19 days (Table 3), and a survey start date of October 15, we calculated the maximum likelihood estimate of 473 Coho (95% confidence limits: 302-643) in 2016 between the Yalakom River and Terzaghi Dam (Figure 23 and Table 10).

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 79 fish in 1999 to a maximum of 3,563 in 2011 (Figure 24 and Table 10).

3.6 Multibeam Sonar Abundance Estimates

3.6.1 Predicted Fork Lengths for Chinook Salmon

Standard lengths measured using ProViewer software were highly accurate (test fish length = 62 cm, mean ProViewer length = 61.8 cm, SD =2.4 cm). Lengths estimated by Echoview were positively related to the ProViewer lengths but were biased low (Figure 25A). The linear model used to predict fish lengths included the Echoview lengths (Figure 25A) and the distance from the sonar beam (Figure 25B) and explained a large portion of the variance in the ProViewer lengths ($R^2 = 0.85$, *P-value* < 0.001) (Figure 25C).

3.6.2 Chinook Salmon

Using fork length data from Gates Creek Sockeye Salmon (*n* = 752, BRGMON-14 [2013]) and Bridge River Chinook Salmon (*n* = 98, BRGMON-3 [2013-2016]), we determined that a size cut-off of 650 mm would minimize the amount of overlap between Sockeye and Chinook Salmon (Figure 26). We considered the fork lengths of Sockeye and Chinook Salmon to be 500-650 mm and ≥ 650 mm, respectively (Figure 25D). Chinook Salmon were detected passing through the sonar beam from August 30 to September 12, 2016 (Figure 27). No counts were recorded on September 5 due to the unit malfunctioning. Peak counts were observed from September 2 to 8 (Figure 27). Five hundred and thirty-two individuals passed upstream and 339 individuals passed downstream of the multibeam sonar, yielding an abundance estimate of 193 Chinook Salmon upstream of the counter site during this two-week period.

3.6.3 Sockeye Salmon

Sockeye Salmon were detected passing through the sonar beam from August 30 to September 12, 2016 (Figure 28). No counts were recorded on September 5 due to the unit malfunctioning. Peak counts were observed from September 2 to 7 (Figure 28). Two hundred and twenty individuals passed upstream and 109 individuals passed downstream of the multibeam sonar, yielding an abundance estimate of 111 Sockeye Salmon upstream of the counter site during this two-week period.

3.6.4 Predicted Fork Lengths for Coho Salmon

Lengths estimated by Echoview were positively related to the ProViewer lengths but were biased low (Figure 29A). The linear model used to predict fish lengths included the Echoview lengths (Figure 29A) and the distance from the sonar beam (Figure 29B) and explained a large portion of the variance in the

ProViewer lengths ($R^2 = 0.68$, *P-value* < 0.001) (Figure 29C). We note that the reduced model fit for Coho Salmon ($R^2 = 0.68$ vs. $R^2 = 0.85$ in Chinook Salmon) could provide a source of error in the predicted lengths and thus the abundance estimates generated by the multibeam sonar.

3.6.5 Coho Salmon

Using fork length data from video validation (Figure 30), 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 October 24 to November 6, 2016. No counts were recorded on October 28 due to the unit malfunctioning. Three hundred and eighty-two individuals passed upstream and 99 individuals passed downstream of the multibeam sonar, yielding an abundance estimate of 283 Coho Salmon upstream of the counter site during this two-week period.

3.7 Resistivity Counter Abundance Estimate

3.7.1 Coho Salmon

Video Validation

Sixty-nine Coho Salmon and 103 resident fish were observed during the 270 hours of video validation. Up count and down count accuracy of the flat pad resistivity counter was 70% (14/20) and 44% (16/36), respectively. Video validation was used to generate PSS cut-offs between Coho Salmon and resident fish species (see Section 2.3.2). PSS cut-offs for up and down counts for Channels 1 and 2 were both 60 (Figure 30). Of the 172 fish observed through video validation, 40% (69/172) were identified as Coho Salmon and 60% (103/172) as Bull Trout and Rainbow Trout.

Counter Estimate

Coho Salmon were detected passing over the flat pad resistivity counter from October 6 to November 28, 2016 (Figure 31). Peak counts were observed from October 13 to November 7 (Figure 31). After accounting for counter accuracy, 1266 individuals passed upstream and 176 individuals passed downstream of the flat pad resistivity counter, yielding an abundance estimate of 1090 Coho Salmon upstream of the counter site.

We compared the up, down and net up counts generated from the multibeam sonar and flat pad resistivity counters (Figure 32). During the two weeks that the two units were being operated side-by-side (October 24 to November 6), 382 individuals passed upstream and 99 individuals passed downstream of the multibeam sonar, yielding an abundance estimate of 283 Coho Salmon upstream of the counter site. Four hundred and one individuals passed upstream and 43 individuals passed downstream of the flat pad resistivity counter during the same time period, yielding an abundance estimate of 358 Coho Salmon upstream of the counter site. In general, the daily counts generated from the multibeam sonar and flat pad resistivity counters mirrored each other, with the exception of down counts on three high abundance days (October 25 and 31, November 6; Figure 32B). Consistent with previous study years, the multibeam sonar and flat pad resistivity counters recorded recycling behaviour in which periods of a high number of up counts (Figure 32A) coincide with a high number of down counts (Figure 32B).

4.0 Discussion

4.1 Steelhead Trout

In February 2016 the LBR hydrograph (e.g., timing of flow variances, peak flow) was uncertain, and with little knowledge of the anticipated flow conditions, we deployed the resisitivity counter in an attempt to enumerate Steelhead Trout. However, by mid March, flows in the LBR had reached the flow capacity (15-20 m^3 s^{-1}) of the resisitivity counter, creating large quantities of erroneous data due to noise and rendering the technology ineffective. By the end of March, the water level at the resistivity counter site greatly exceeded the extent of the counter sensors. Despite the potential for other enumeration techniques (e.g., visual streamwalk counts), the high turbidity and flows in the spring on the ascending limb of the hydrograph did not permit visual-based counting methods. Consequently, we were unable to generate an abundance estimate for Steelhead Trout in 2016. We discuss a potential option for the enumeration of Steelhead Trout in future study years in Section 5 (Summary and Recommendations) of this report.

We intended to use existing PIT telemetry infrastructure (two PIT arrays; counter site and Reach 3-4 break) to determine the spawning distribution and residence time of Steelhead Trout in the LBR. However, the damage sustained to the PIT antennas during high flow releases required the application of radio telemetry instead. Of the six Steelhead Trout that we captured, tagged and released at the Seton-Fraser confluence, two individuals migrated up the LBR in early to mid May when flows were approximately 55 m^3 s^{-1}. Both individuals resided and potentially spawned near Russel Springs in Reach 3, which is an important finding considering that radio-tagged Steelhead Trout in the past spawned predominantly in Reach 4 of the LBR (Burnett et al. 2016). We advocate for the continued use of radio telemetry in future, high-flow study years to develop an understanding of the potential impacts of the ascending limb of the hydrograph on the spawning distribution and migration timing of Steelhead Trout.

Analysis of the age data indicated that LBR Steelhead Trout display various life histories. In total, six age classes were observed and ranged from a 1.1+ to 3.3+. Age 2.2+ fish were dominant in 2014, whereas age

3.2+ fish were dominant in 2015. Both age classes originate from the same brood year (2009), indicating that the 2009 LBR Steelhead Trout brood had high egg-to-fry survival. It is unknown as to the cause(s) for such high survival (e.g., freshwater or marine survival), and we note that a more robust sample size would increase our confidence in making these inferences. Further analysis and collaboration with BRGMON-1 will provide further insight into the river conditions during the brood (2009) and rearing (2009-2012) years of these fish. In 2016, few fish were captured, and of the three fish that moved into the LBR, two were age 3.2+.

4.2 Chinook Salmon

We were unable to examine the extent of damage to the resistivity counter site until flows reached approximately 20 $m^3 s^{-1}$ in late July. Following an inspection of the site, we could not repair the damage prior to the onset of the Chinook Salmon migration for two main reasons: (1) the extent of damage was substantial and would have required a rebuild of the in-river counter sensors and video validation equipment, and (2) the flows in the LBR were too high to permit such a rebuild (8 $m^3 s^{-1}$ on August 15). Normally we cannot repair and modify counter sensors in the LBR until flows reach 1.5 $m^3 s^{-1}$, which occurred at the end of the Chinook Salmon migration period in early October. Consequently, we piloted a BlueView P900-45 multibeam sonar to enumerate Chinook Salmon for two weeks during historic peak migration timing. Using Echoview software to analyze the sonar data, we found that 193 Chinook Salmon spawned upstream of the multibeam sonar from August 30 to September 12. Sonar technology was successful at identifying fish moving through the sonar beam, however, estimated fish sizes by Echoview were biased low. This bias could be attributed to various factors, including the age of the sonar unit, its sampling frequency (i.e., low frequency) and/or incompatibility between BlueView data and Echoview software. Higher frequency sonars (BlueView M900-2250 and DIDSON 300) provide more detailed images, which result in improved sizing information. After discussion with Echoview about the sizing bias, it was suggested that there may be compatibility issues between data from older BlueView models and how Echoview uses the data to estimate fish size. Potential solutions to this issue range from sizing all fish identified by Echoview using the BlueView ProViewer software, modeling fish size (as we have done in this report) with increased samples sizes, or purchasing a newer, high resolution sonar unit. Of course these solutions range in capital and labour costs and the level of uncertainty associated with the abundance estimate. Ultimately a more detailed assessment of the cost-effectiveness of each option would require further investigation.

We also generated an abundance estimate from the visual streamwalk counts of Chinook Salmon using AUC methods. Using a mean observer efficiency and residence time collected across study years, the Reach 3 and 4 Chinook Salmon AUC spawner abundance was estimated at 266 fish. Moving forward, there are several potential enumeration techniques that would be effective for Chinook Salmon, some of which are discussed in Section 5 (Summary and Recommendations) of this report. Pink Salmon will be highly abundant in the LBR in 2017, and thus the counter site and technology will have to facilitate single-file movement past the counter to create effective counting conditions.

Similar to Steelhead Trout, we intended to use PIT telemetry to determine the spawning distribution and residence time of Chinook Salmon in the LBR. Damage to the PIT antennas, however, required the use of radio telemetry to address the management questions. Consistent with previous study years, we found that radio-tagged Chinook Salmon spawned predominantly between the Yalakom River and Hell Creek (25.5 to 28.8 rkm) in Reach 3 (McCubbing et al. 2014, Melville et al. 2015, Burnett et al. 2016). To corroborate this finding, the vast majority of the Chinook Salmon redds surveyed in Reaches 3 and 4 were located in run habitat in Reach 3. More specifically, the redds were congregated in four distinct groupings in the LBR: Hippy Pool (25.5 river km), Hell Creek (28.8 river km), Russel Springs (30.7 river km) and Cobra (34.4 river km). We observed new colonization in 2016 at Fraser Lake (33.5 river km) and Longskinny (39.3 river km), a finding that is likely attributable to the mobilization of spawning substrate into these areas due to the high flow releases (E. Ellis, Embark Engineering, personal communication). Water depths and velocities at the sampled redds were consistent with previous study years, however the size of the spawning substrate (i.e., geometric mean, D_{50}) in 2016 was significantly larger (2 times larger, on average) than in 2015. Despite this marked increase, we highlight that the substrate sampled in 2016 is still well within the preferred size range of Chinook Salmon (substrate between 13 and 102 mm; reviewed in Bjornn and Reiser 1991). In fact, the shift in the distribution of the substrate sizes may benefit Chinook Salmon in odd years when there is a risk of redd superimposition and subsequent egg displacement (and potential mortality) caused by Pink Salmon (Burnett et al. 2016) that spawn in and mobilize smaller substrate (Riebe et al. 2014). Continued effort to survey Chinook Salmon redds in future study years, and continued collaboration with the Sediment Monitor, will shed valuable insight into the potential impacts of the high flow releases from Terzaghi Dam on spawning distribution and physical habitat characteristics.

Age data identified two distinct age classes (ages 3 and 4) of Chinook Salmon returning to the LBR. Most of the returning adults were 1.3+ (age 4), a finding that is consistent with historical observations (Richard Bailey, personal communication). In more recent years, there has been discussion of whether there has been a shift in the life history strategy of LBR Chinook Salmon from stream-type to ocean-type due to the low numbers of juveniles observed in BRGMON-1 stock assessment surveys. Our data, however, suggests that there has been no change in the life history of LBR Chinook Salmon from 2008 to 2012.

Continued collection of scales and otoliths will shed valuable insight into whether a life history change has occurred in more recent years (i.e., 2012-2016).

4.3 Coho Salmon

In 2016 we counted Coho Salmon using three enumeration methods: (1) flat pad sensor resisitivity counter for the entire migration period (October 6 to November 28), (2) multibeam sonar technology for two weeks during historic peak migration timing (October 24 to November 7), and (3) visual streamwalk counts and AUC abundance estimation. We piloted the use of a flat pad resisitivity counter primarily due to concerns that a reduced water depth during the Coho Salmon migration period might render sonar technology ineffective. We highlight that the counter technology (resisitivity) previously used at this site remained unchanged, however the in-river counter sensor (flat pad vs. Crump weir sensor) was tested due to the damage sustained to the Crump weir sensors and the lower cost and ease of deployment. We found that 1090 Coho Salmon spawned upstream of the counter site in 2016, and highlight that this figure is well within the bounds of historic estimates of spawner abundance in the LBR. Importantly, the flat pad resisitivity counter data revealed that we captured the peak of the migration period with the multibeam sonar. Daily counts from the multibeam sonar and flat pad resistivity counters mirrored each other during the two-week period the units were being operated side-by-side. However, the multibeam sonar was more effective and accurate at recording down counts compared to the flat pad resisitivity counter. Notably, the reduced down count accuracy of flat pad sensor units (44% in the current study year) is a result of fish having variable swim heights in the water column during downstream movements. Taken together, we highlight that the main contributor to the difference in the observed net up counts between the multibeam sonar (283 fish) and flat pad resisitivity (358 fish) counters is the ability of each unit to successfully detect down counts. Using AUC methods, the Reach 3 and 4 Coho Salmon spawner abundance was estimated at 482 fish. Notably, the flat pad resistivity counter estimate for Coho Salmon (1090 individuals) indicated that, as in previous study years (Burnett et al. 2016), the AUC-derived estimate of abundance was biased low (2-fold lower). Finally, we discuss a potential option for the enumeration of Coho Salmon in future study years in Section 5 (Summary and Recommendations) of this report.

In 2016, we used radio telemetry to determine the spawning distribution and residence time of Coho Salmon in the LBR. We found that radio-tagged Coho Salmon spawned in near equal proportions in Reaches 3 and 4, a finding that is consistent with previous study years (Burnett et al. 2016). Age data for Coho Salmon identified three dominant age classes (1.1+ ,1.2+ and 2.1+) in the LBR, with age 1.1+ being dominant and 2.1+ being subdominant.

5.0 Summary and Recommendations

Data presented herein summarizes the findings of BRGMON-3 in 2016 under a high flow treatment (22 $m^3 s^{-1}$/y) 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. We successfully piloted the use of multibeam sonar technology to enumerate Chinook and Coho Salmon in 2016, and highlight that this technology may prove to be an effective method of enumeration in future study years. We advocate for the continued use of radio telemetry (for all species) and redd surveys (for Chinook Salmon) to monitor the distribution of spawners in relation to managed flow releases in Reaches 3 and 4 of the LBR.

Overall, there are several potential techniques that would be effective at enumerating adult salmonids in the LBR, but each technology has a suite of technical, logistical and cost considerations. One proposed approach might be to use a combination of counter technologies (reviewed in Braun et al. 2016), whereby a multibeam sonar counts fish on river left and a resisitivity counter with a Crump weir sensor counts fish on river right. Both technologies would be video validated to determine counter accuracy, and a remote, self-sustaining power source would be required. Such a setup would effectively enumerate Steelhead Trout, and Chinook and Coho Salmon, however in-river infrastructure would be needed on river left to facilitate single-file movement past the counter in odd years with a high abundance of co-migrating Pink Salmon. Finally, we note that regardless of the counter technology, 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. Irrespective of the enumeration method going forward, we will develop a relationship between streamwalk and more accurate counter-derived estimates of abundance and use this relationship to refine historic abundance estimates. Ultimately a cost-benefit analysis will help inform the most cost-effective method for enumeration in future, high-flow study years.

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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 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. 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*
2012	Chinook	58%
2013	Chinook	28%
2014	Chinook	28%
2015	Chinook	NA*
2016	Chinook	86%
	Mean	50%
2012	Coho	25%
2013	Coho	27%
2014	Coho	NA*
2015	Coho	NA*
2016	Coho	17%
	Mean	23%

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

Table 3. Residence time of radio- and PIT-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
2012	Chinook	5	10
2013	Chinook	22	11
2014	Chinook	8	12
2016	Chinook	8	9
		Mean	10.5
2012	Coho	13	16
2013	Coho	18	19
2016	Coho	26	22
		Mean	19

Table 4. Detection efficiency of fixed radio receivers in the Lower Bridge River.

Species	Location of radio receiver	Detection efficiency
Steelhead Trout	Station 1	50% (1/2)
	Station 3	100% (2/2)
	Station 4	NA
Chinook Salmon	Station 1	NA
	Station 3	100% (13/13)
	Station 4	100% (2/2)
Coho Salmon	Station 1	71% (5/7)
	Station 3	75% (21/28)
	Station 4	91% (10/11)

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. No Chinook Salmon or Steelhead Trout passed by Station 1 and 4, respectively.

Table 5. Spawning distribution of radio-tagged Steelhead Trout in the Lower Bridge River in 2016.

Tag no.	Tagging location	Tagging rkm	Assumed spawning reach	Assumed spawning section	Migration rate (km day^{-1})	Residence time (days)
47	Seton – Fraser Confluence	NA	Reach 3	Russel Springs	NA	5.9
54	Seton – Fraser Confluence	NA	Reach 3	Russel Springs	1.4	8.1

Note: Russel Springs (30.7 rkm)

Table 6. Spawning distribution of radio-tagged Chinook Salmon in the Lower Bridge River in 2016.

Tag no.	Tagging location	Tagging river km	Assumed spawning reach	Assumed spawning section	Residence time (days)
100	Bridge – Yalakom Confluence	25.5	3	Yalakom to Hell	16.6
101	Bridge – Yalakom Confluence	25.5	3	Yalakom to Hell	7.4
102	Bridge – Yalakom Confluence	25.5	3	Yalakom to Hell	5.9
103	Bridge – Yalakom Confluence	25.5	3	Yalakom to Hell	9.0
104	Bridge – Yalakom Confluence	25.5	3	Yalakom to Hell	7.8
105	Bridge – Yalakom Confluence	25.5	4	Cobra to Bluenose	NA
106	Bridge – Yalakom Confluence	25.5	3	Yalakom to Hell	NA
107	Bridge – Yalakom Confluence	25.5	3	Yalakom to Hell	11.9
108	Bridge – Yalakom Confluence	25.5	NA	NA	NA
109	Bridge – Yalakom Confluence	25.5	3	Yalakom to Hell	NA
110	Bridge – Yalakom Confluence	25.5	3	Yalakom to Hell	NA
111	Bridge – Yalakom Confluence	25.5	3	Yalakom to Hell	NA
120	Bridge – Yalakom Confluence	25.5	3	Yalakom to Hell	NA
121	Bridge – Yalakom Confluence	25.5	3	Yalakom to Hell	9.2
122	Bridge – Yalakom Confluence	25.5	3	Yalakom to Hell	7.5

Mean	NA	9.4
Minimum	NA	5.9
Maximum	NA	16.6

Note: Yalakom River to Hell Creek (25.5 to 28.8 rkm), Cobra to Bluenose (34.4 to 38.2 rkm)

Table 7. Spawning distribution of the 31 radio-tagged Coho Salmon known to have migrated upstream post-release in the Lower Bridge River in 2016.

Tag no.	Tagging location	Tagging river km	Assumed spawning reach	Assumed spawning section	Migration rate (km day^{-1})	Residence time (days)
151	Yalakom Confluence	25.0	3	Russel to Fish Fence	NA	14.9
152	Bridge Confluence	0.0	4	Cobra to Bluenose	2.1	12.5
154	Bridge River Bridge	0.5	NA	NA	NA	NA
158	Yalakom Confluence	25.0	4	Longskinny to Plunge Pool	3.7	20.0
159	Bridge River Bridge	0.5	4	Cobra to Bluenose	2.2	23.6
160	Yalakom Confluence	25.0	3	Hell to Russel	NA	34.0
161	Horseshoe Bend	23.0	3	Hell to Russel	NA	28.1
162	Hippy Pool	25.5	NA	NA	NA	18.0
163	Yalakom Confluence	25.0	3	Fish Fence to Cobra	1.5	25.0
164	Bridge Confluence	0.0	3	Fish Fence to Cobra	1.3	13.6
165	Yalakom Confluence	25.0	3	Yalakom to Hell	NA	19.9
166	Yalakom Confluence	25.0	4	Cobra to Bluenose	2.8	26.9
167	Hippy Pool	25.5	3	Yalakom to Hell	NA	24.0
168	Hippy Pool	25.5	3	Russel to Fish Fence	NA	23.9
169	Yalakom Confluence	25.0	4	Longskinny to Plunge Pool	2.5	20.9
170	Bridge River Bridge	0.5	3	Russel to Fish Fence	3.1	27.7
172	Yalakom Confluence	25.0	4	Longskinny to Plunge Pool	5.2	9.4
173	Yalakom Confluence	25.0	3	Yalakom to Hell	NA	NA
174	Yalakom Confluence	25.0	4	Bluenose to Eagle	4.0	23.9
175	Yalakom Confluence	25.0	3	Hell to Russel	NA	30.9
176	Hippy Pool	25.5	3	Russel to Fish Fence	NA	NA
177	Horseshoe Bend	23.0	NA	NA	NA	22.9
179	Yalakom Confluence	25.0	4	Longskinny to Plunge Pool	2.7	NA
181	Yalakom Confluence	25.0	4	Bluenose to Eagle	8.6	NA
182	Yalakom Confluence	25.0	3	Fish Fence to Cobra	NA	25.9
183	Hippy Pool	25.5	3	Yalakom to Hell	NA	15.9
184	Yalakom Confluence	25.0	4	Cobra to Bluenose	NA	16.56
185	Yalakom Confluence	25.0	3	Russel to Fish Fence	NA	30.0
186	Yalakom Confluence	25.0	3	Yalakom to Hell	NA	16.0
187	Hippy Pool	25.5	3	Fish Fence to Cobra	NA	18.9
188	Hippy Pool	25.5	4	Cobra to Bluenose	17.1	18.9

Mean	NA	4.4	21.6
Minimum	NA	1.3	9.4
Maximum	NA	17.1	34.0

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. 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%)

Table 9. Chinook Salmon AUC abundance estimates for the Lower Bridge River from 1993-2016.

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	-1094	5104
1998	0.5	0.139	10.5	0.65	873	254	Visual helicopter	376	1370
1999	0.5	0.139	10.5	0.65	2576	847	Visual helicopter	916	4235
2001	0.5	0.139	10.5	0.65	1784	981	Visual helicopter	-139	3708
2004	0.5	0.139	10.5	0.65	3106	1139	Visual helicopter	873	5339
2005	0.5	0.139	10.5	0.65	591	232	Visual streamwalk	137	1045
2006	0.5	0.139	10.5	0.65	399	124	Visual streamwalk	157	642
2007	0.5	0.139	10.5	0.65	309	108	Visual streamwalk	97	520
2008	0.5	0.139	10.5	0.65	164	94	Visual streamwalk	-21	349
2009	0.5	0.139	10.5	0.65	21	7	Visual streamwalk	6	35
2010	0.5	0.139	10.5	0.65	208	67	Visual streamwalk	76	340
2011	0.5	0.139	10.5	0.65	82	33	Visual streamwalk	18	146
2012	0.58	0.139	10	0.65	364	114	Visual streamwalk	140	588
2013	0.28	0.139	11	0.65	168	90	Visual streamwalk	-8	343
2014	0.28	0.139	12	0.65	591	314	Visual streamwalk	-24	1206
2015	0.5	0.139	10.5	0.65	158	68	Visual streamwalk	24	293
2016	0.5	0.139	10.5	0.65	265	85	Visual streamwalk	98	431

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

Table 10. Coho Salmon AUC abundance estimates for the Lower Bridge River from 1997-2016.

Year	OE	OE SE	Residence time	Residence time SE	Abundance	Abundance SE	Method of estimation	Lower 95 CI	Upper 95 CI
1997	0.23	0.031	19	1.73	600	1376	Visual helicopter	-2098	3298
1998	0.23	0.031	19	1.73	1045	407	Visual helicopter	248	1843
1999	0.23	0.031	19	1.73	79	NA	Visual helicopter	NA	NA
2001	0.23	0.031	19	1.73	1001	176	Visual helicopter	657	1345
2003	0.23	0.031	19	1.73	1179	191	Visual helicopter	805	1552
2004	0.23	0.031	19	1.73	226	56	Visual helicopter	117	335
2005	0.23	0.031	19	1.73	716	147	Visual streamwalk	429	1003
2006	0.23	0.031	19	1.73	653	132	Visual streamwalk	395	912
2008	0.23	0.031	19	1.73	99	19	Visual streamwalk	61	137
2009	0.23	0.031	19	1.73	1551	297	Visual streamwalk	968	2134
2010	0.23	0.031	19	1.73	449	95	Visual streamwalk	263	635
2011	0.23	0.031	19	1.73	3563	746	Visual streamwalk	2100	5026
2012	0.25	0.031	16	1.73	1662	434	Visual streamwalk	811	2513
2013	0.27	0.031	19	1.73	2974	479	Visual streamwalk	2036	3912
2014	0.23	0.031	19	1.73	410	86	Visual streamwalk	241	580
2015	0.23	0.031	19	1.73	168	30	Visual streamwalk	110	226
2016	0.23	0.031	19	1.73	473	87	Visual streamwalk	302	643

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

8.0 Figures

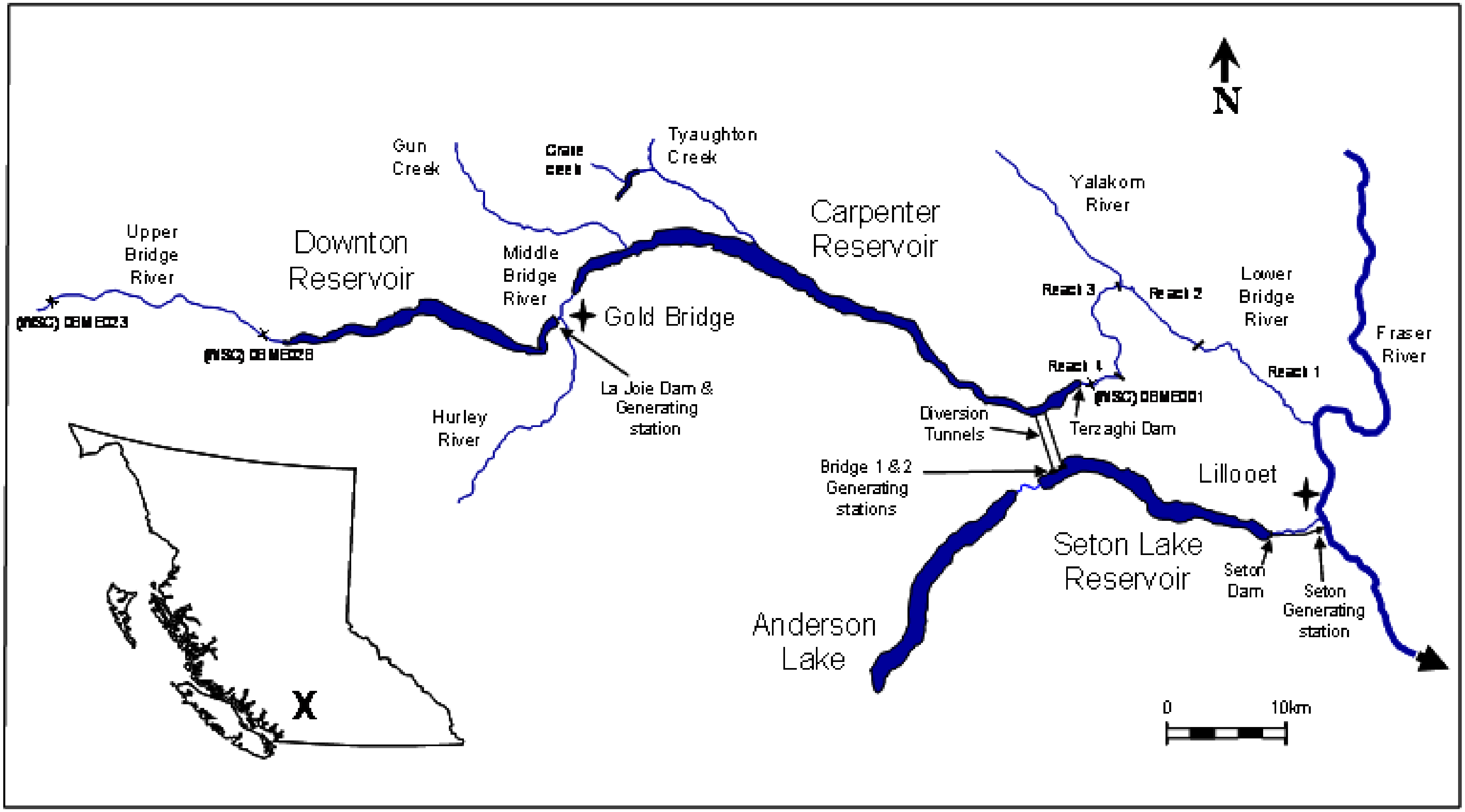


Figure 1. Bridge and Seton Watersheds showing Terzaghi Dam and the diversion tunnels to Bridge River Generating Stations 1 and 2.

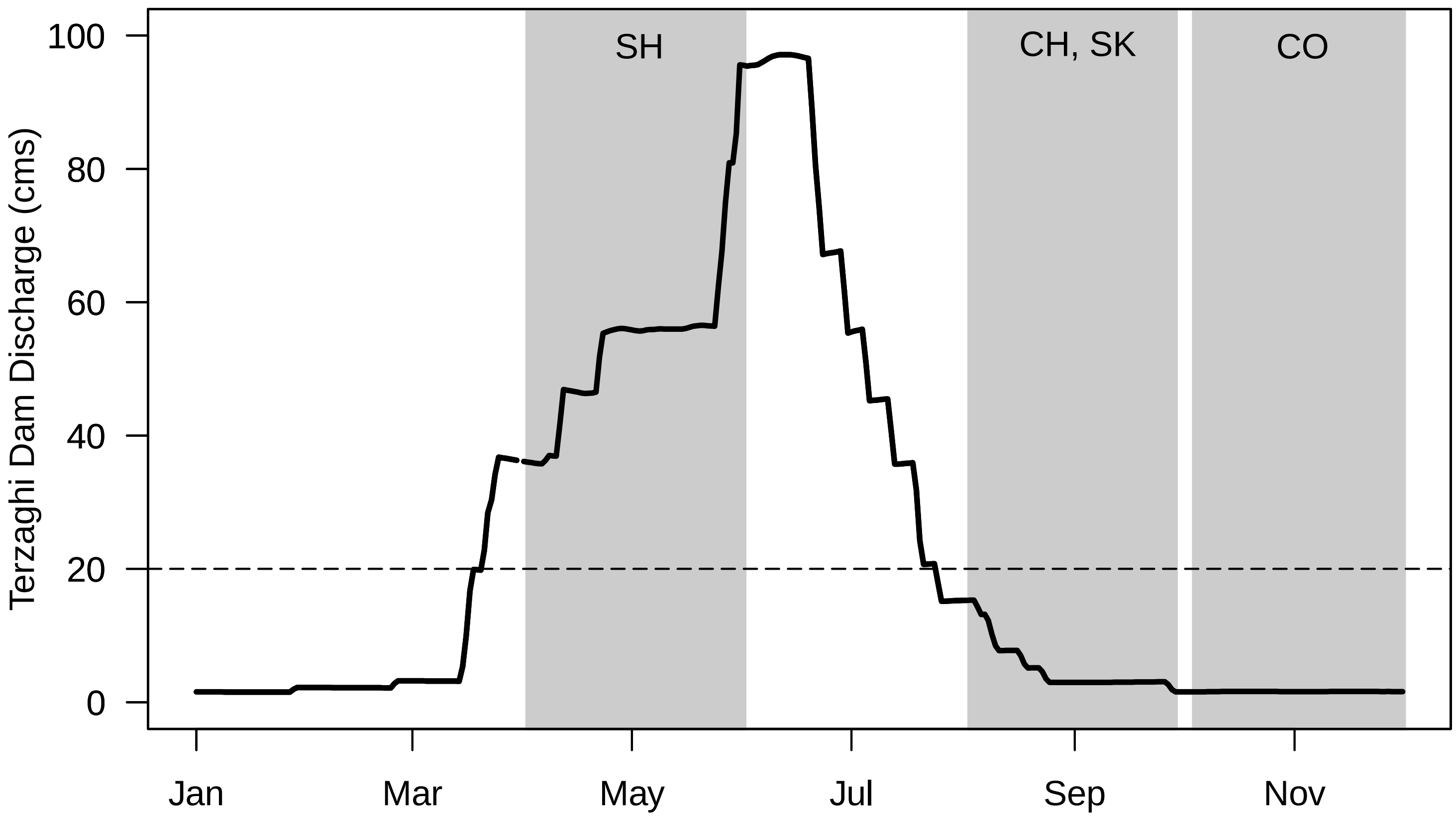


Figure 2. Discharge from Terzaghi Dam into the Lower Bridge River in 2016. Migration timing of anadromous salmonids are represented by shaded rectangles. SH = Steelhead Trout, CH = Chinook Salmon, SK = Sockeye Salmon, and CO = Coho Salmon. Dashed line represents the highest discharge at which the resistivity counter can effectively operate.

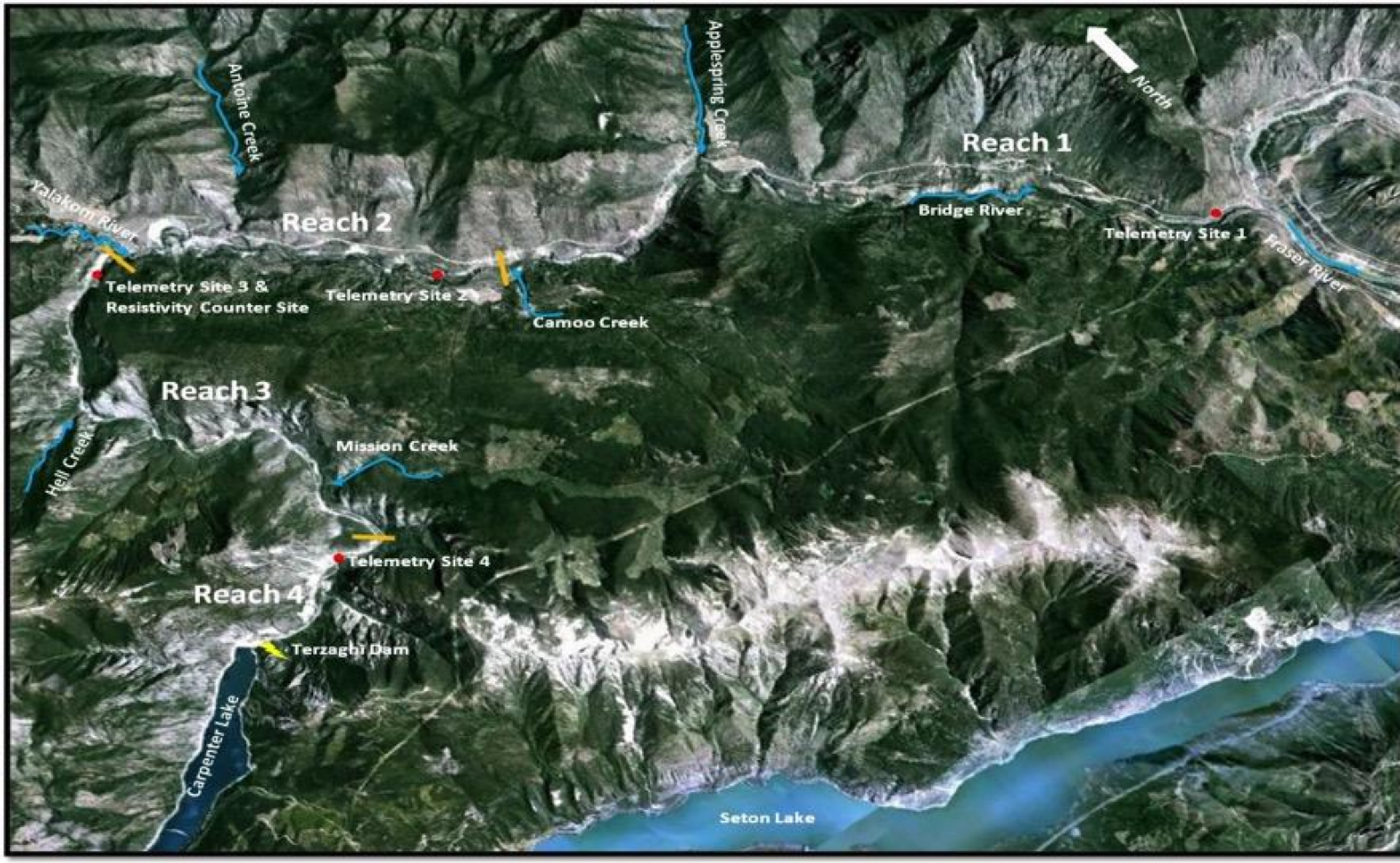


Figure 3. Bridge River study area showing reach breaks (orange lines) and fixed radio telemetry stations (red dots).

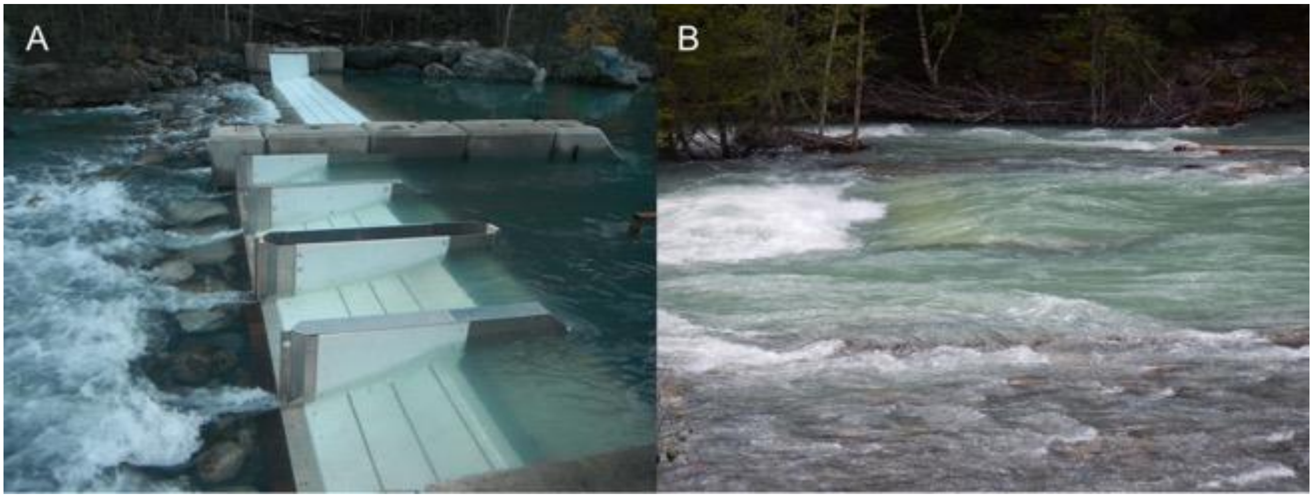


Figure 4. Lower Bridge River resistivity counter site at 1.5 $m^3\ s^{-1}$ in October 2013 (A) and during high flow releases (67 $m^3\ s^{-1}$) in June 2016 (B).

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

Figure 6. Flat pad resistivity counter (instream) and video validation equipment (overhead) used to count Coho Salmon in the Lower Bridge River in 2016. Multibeam sonar mount is in the foreground.

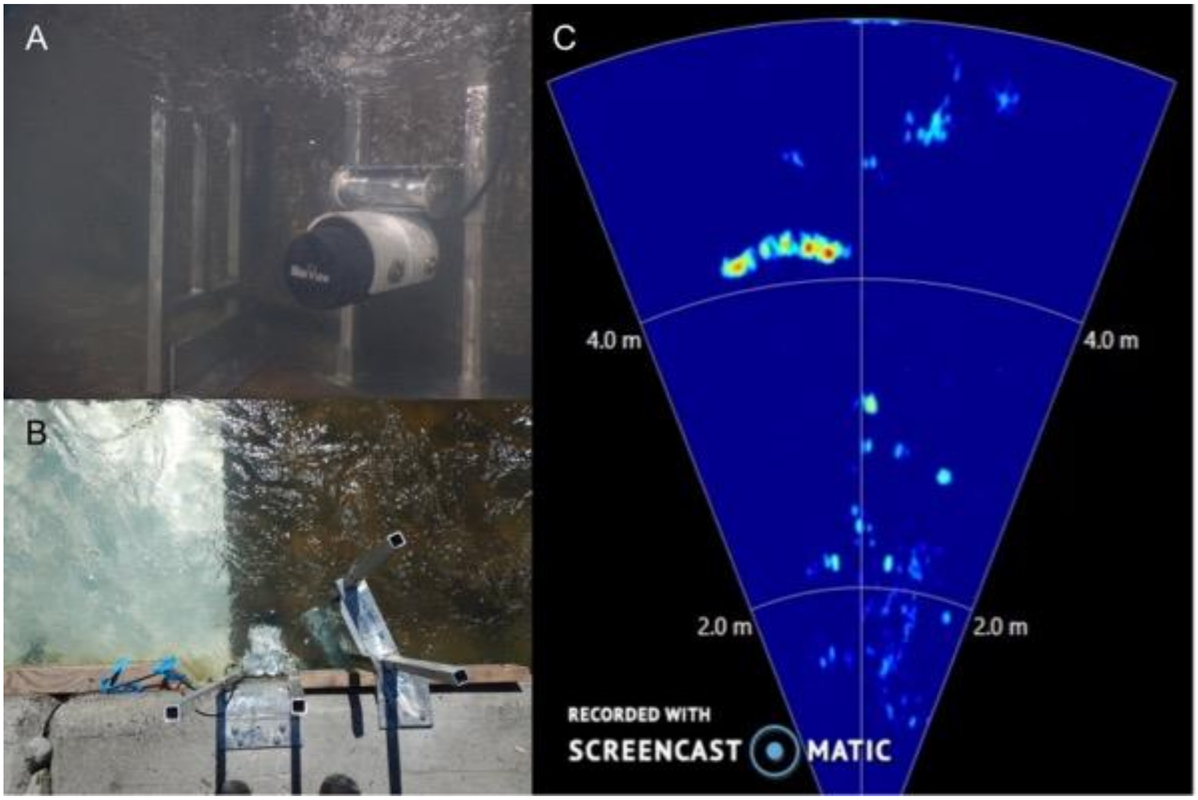


Figure 7. Underwater (A) and bird's-eye view (B) of the BlueView P900-45 multibeam sonar deployed at the Lower Bridge River counter site for counting Chinook (August 30 to September 12) and Coho (October 24 to November 7) Salmon in 2016. (C) An 80 cm Chinook Salmon crosses the sonar beam on August 30, 2016.

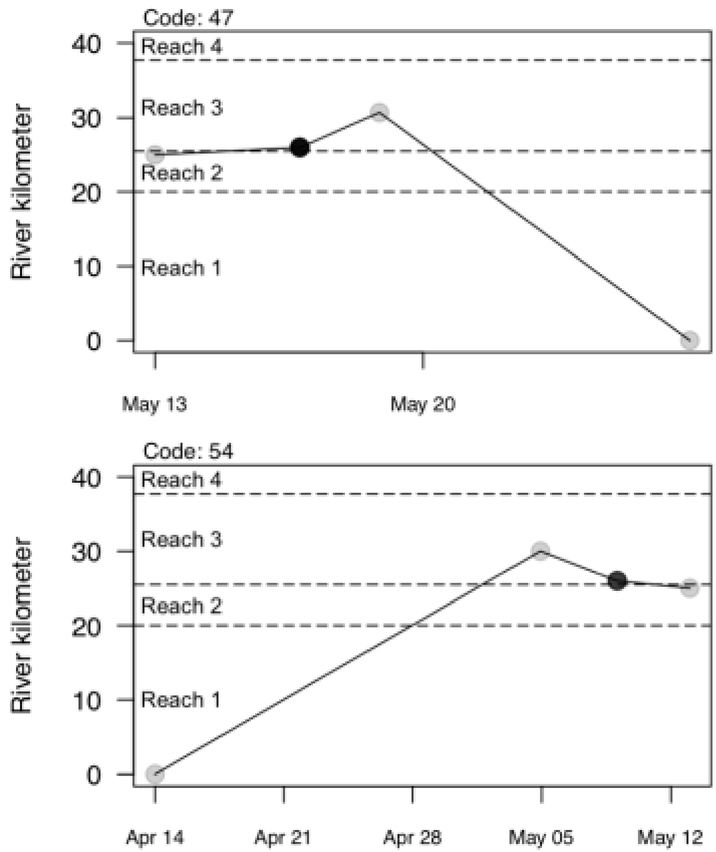


Figure 8. Migration histories (river kilometer vs. date) of radio-tagged Steelhead Trout in the Lower Bridge River in 2016. Black and grey points correspond to detections from fixed and mobile tracking, respectively. Dashed lines indicate boundaries between different reaches**.**

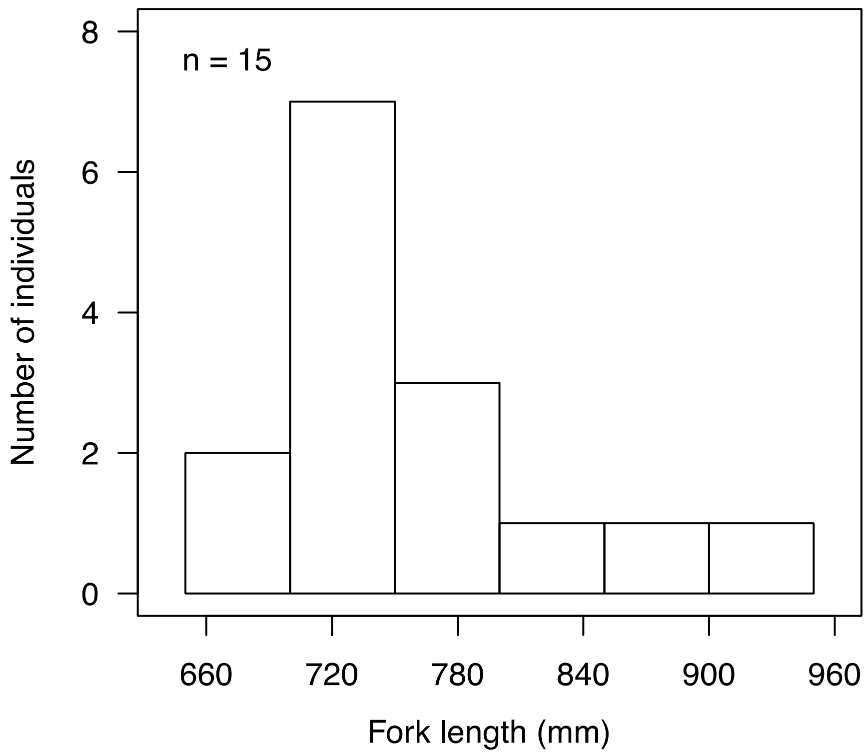


Figure 9. Frequency distribution of the fork lengths of radio-tagged Chinook Salmon in 2016.

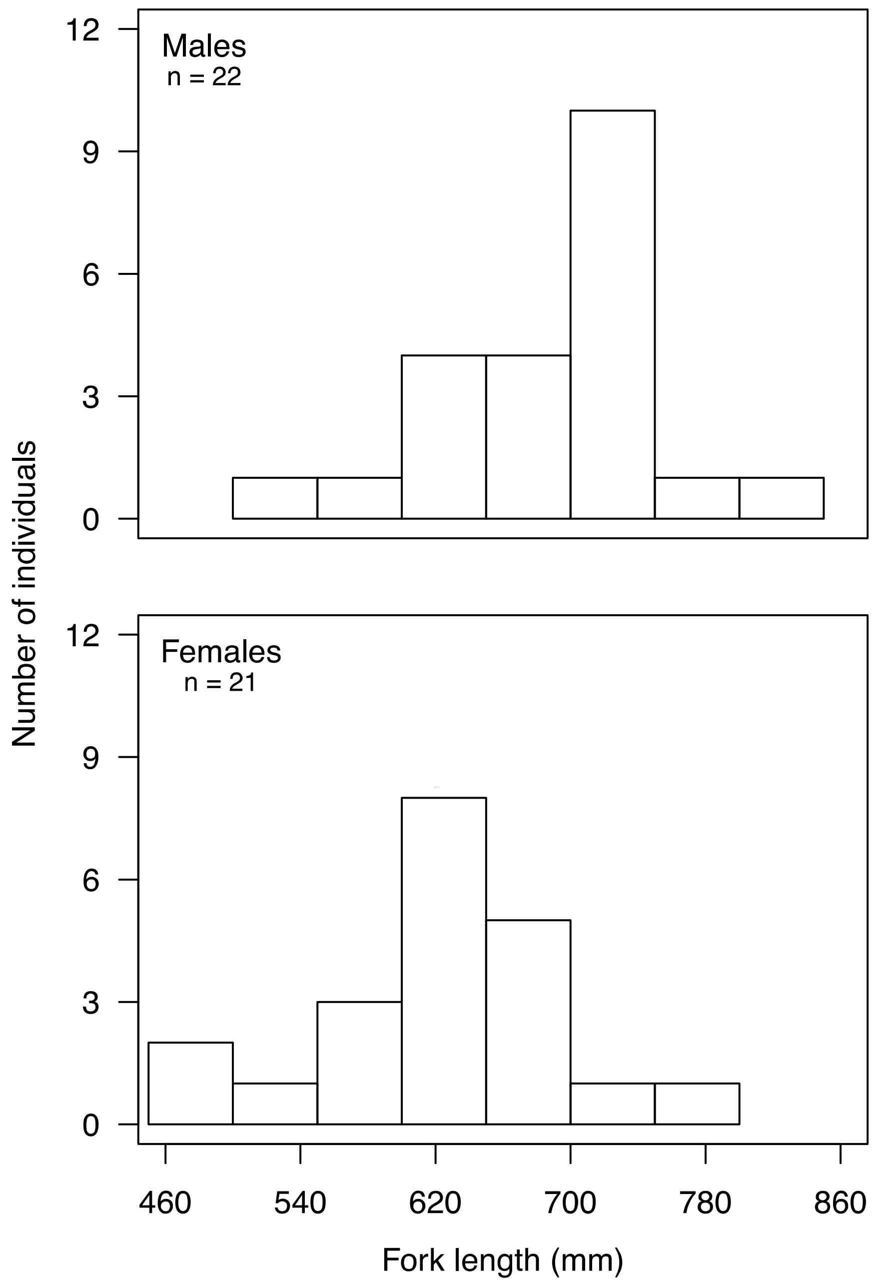


Figure 10. Frequency distribution of the fork lengths of radio-tagged Coho Salmon in 2016.

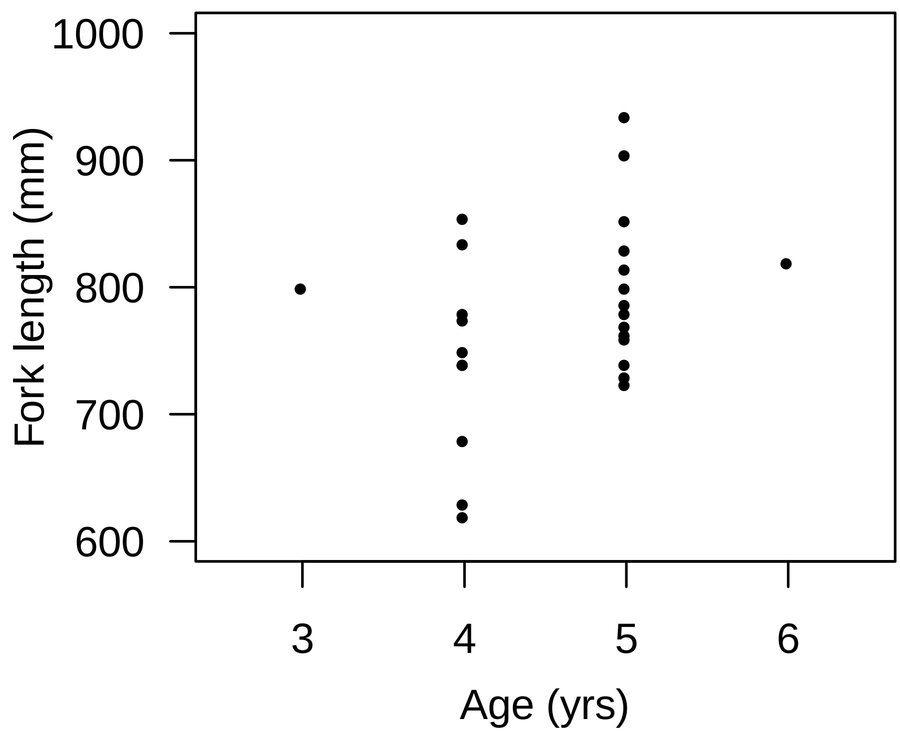


Figure 11. Length-at-age of Steelhead Trout sampled from 2014 to 2016 (n = 28).

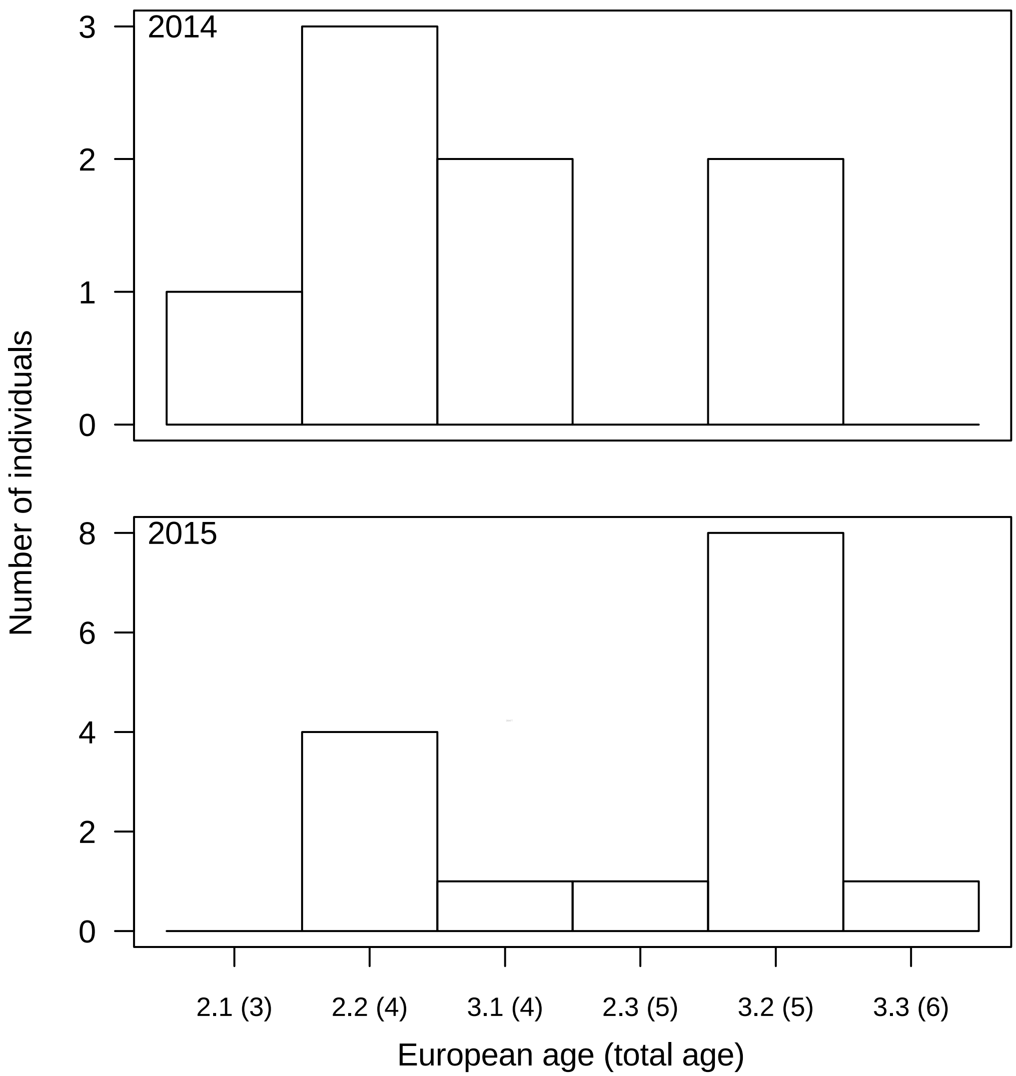


Figure 12. Frequency distribution of Steelhead Trout age classes from 2014 and 2015.

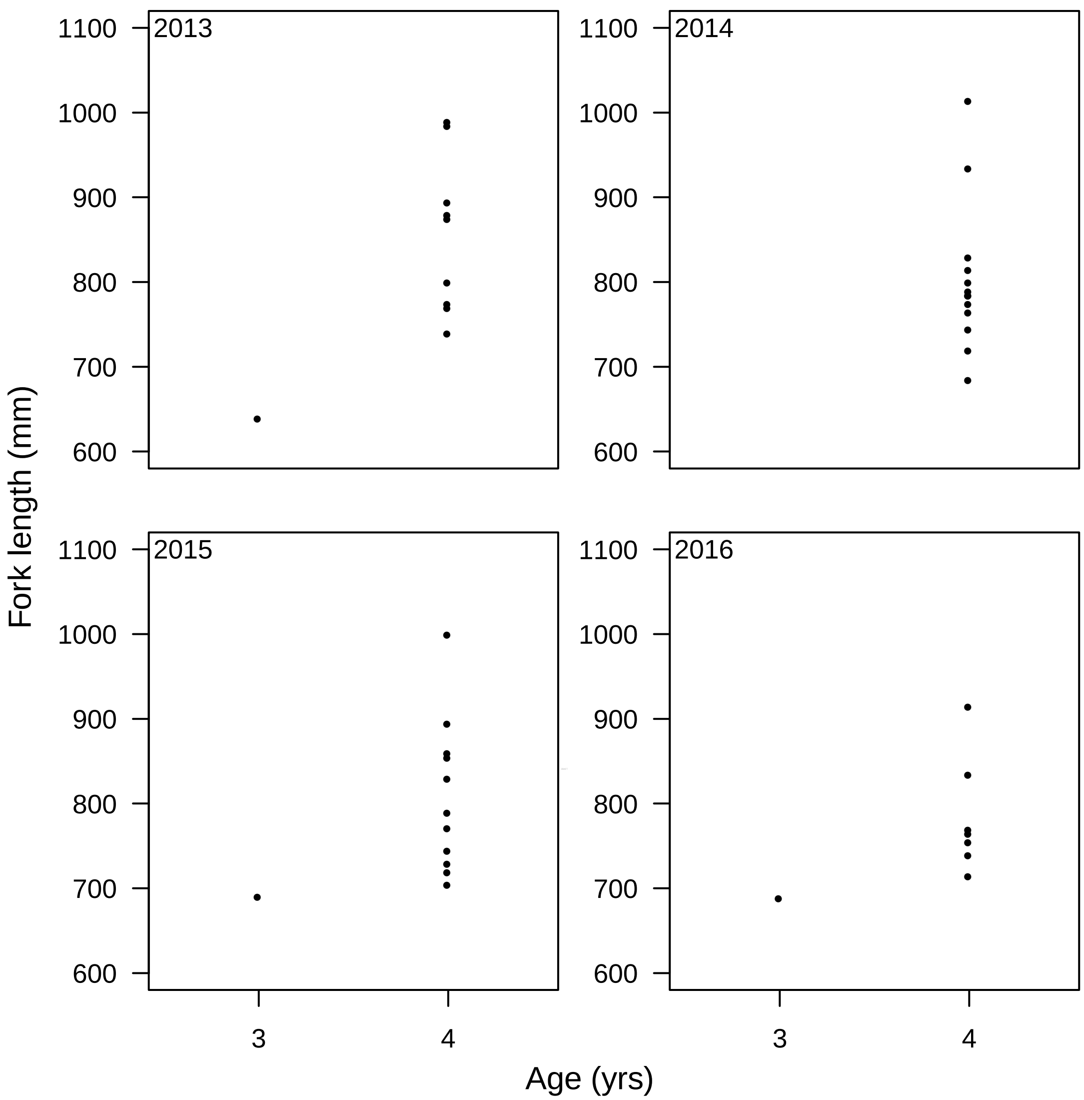


Figure 13. Length-at-age of Chinook Salmon sampled from 2013 to 2016 (n = 43).

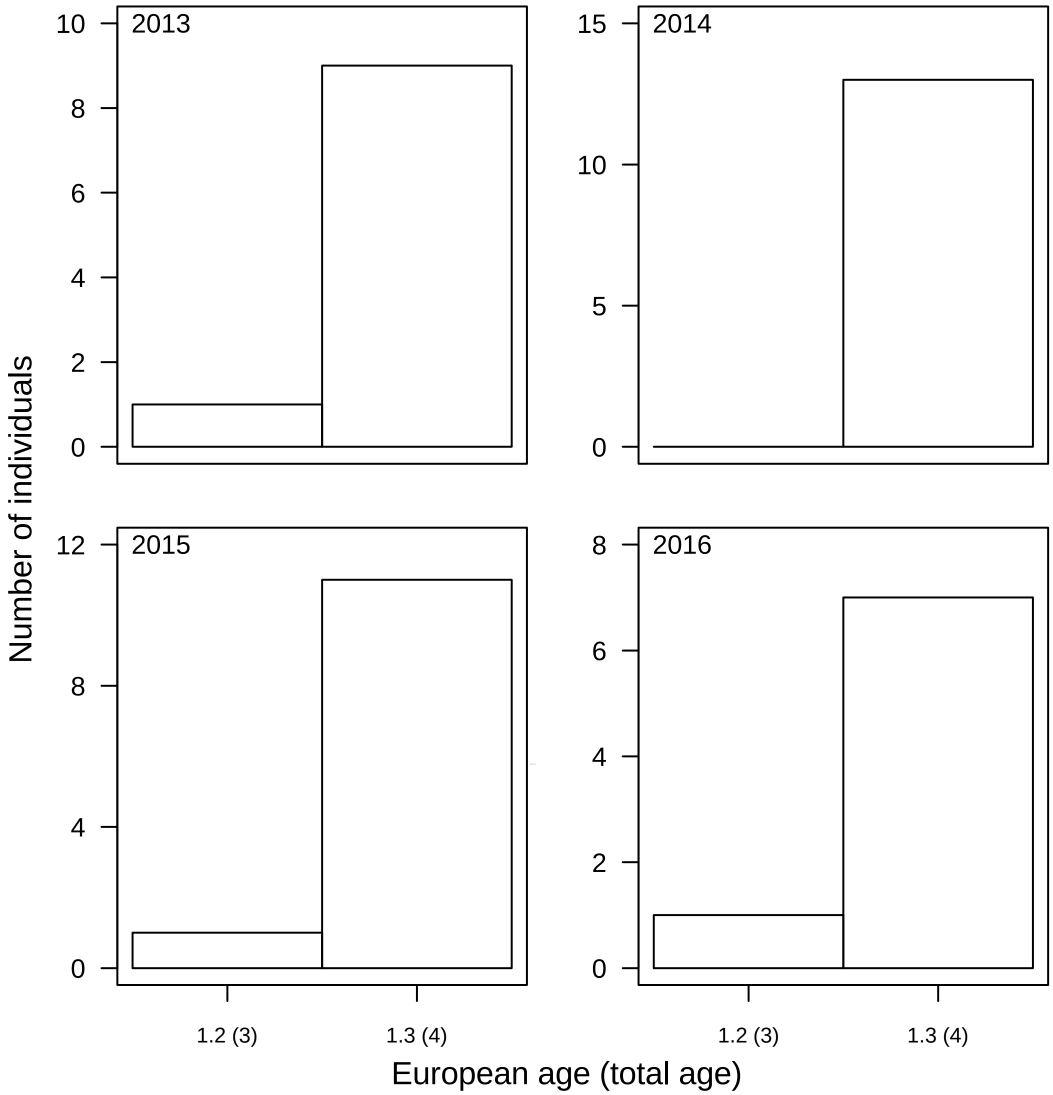


Figure 14. Frequency distribution of Chinook Salmon age classes from 2013 to 2016.

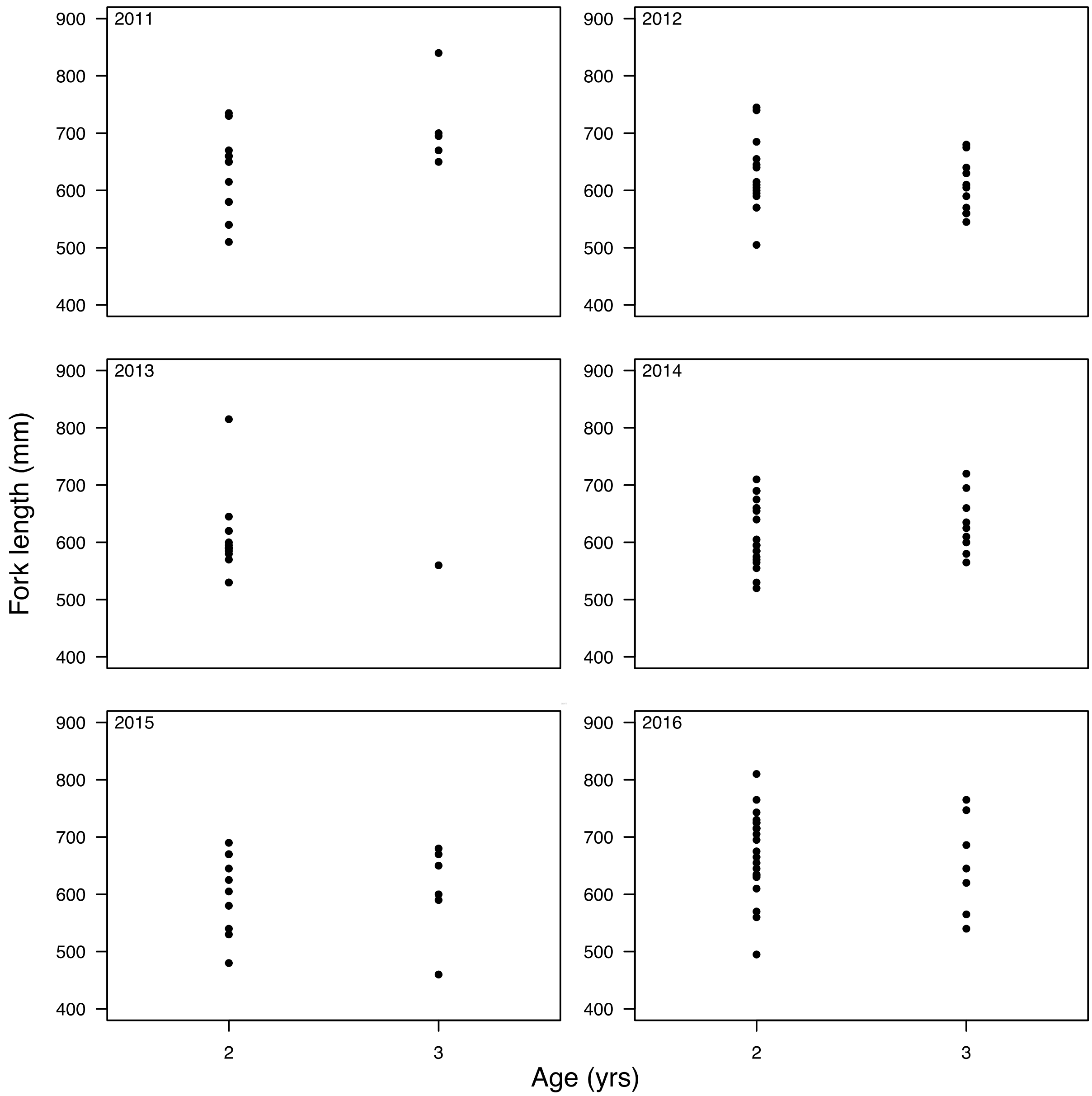


Figure 15. Length-at-age of Coho Salmon sampled from 2011 to 2016 (n = 132).

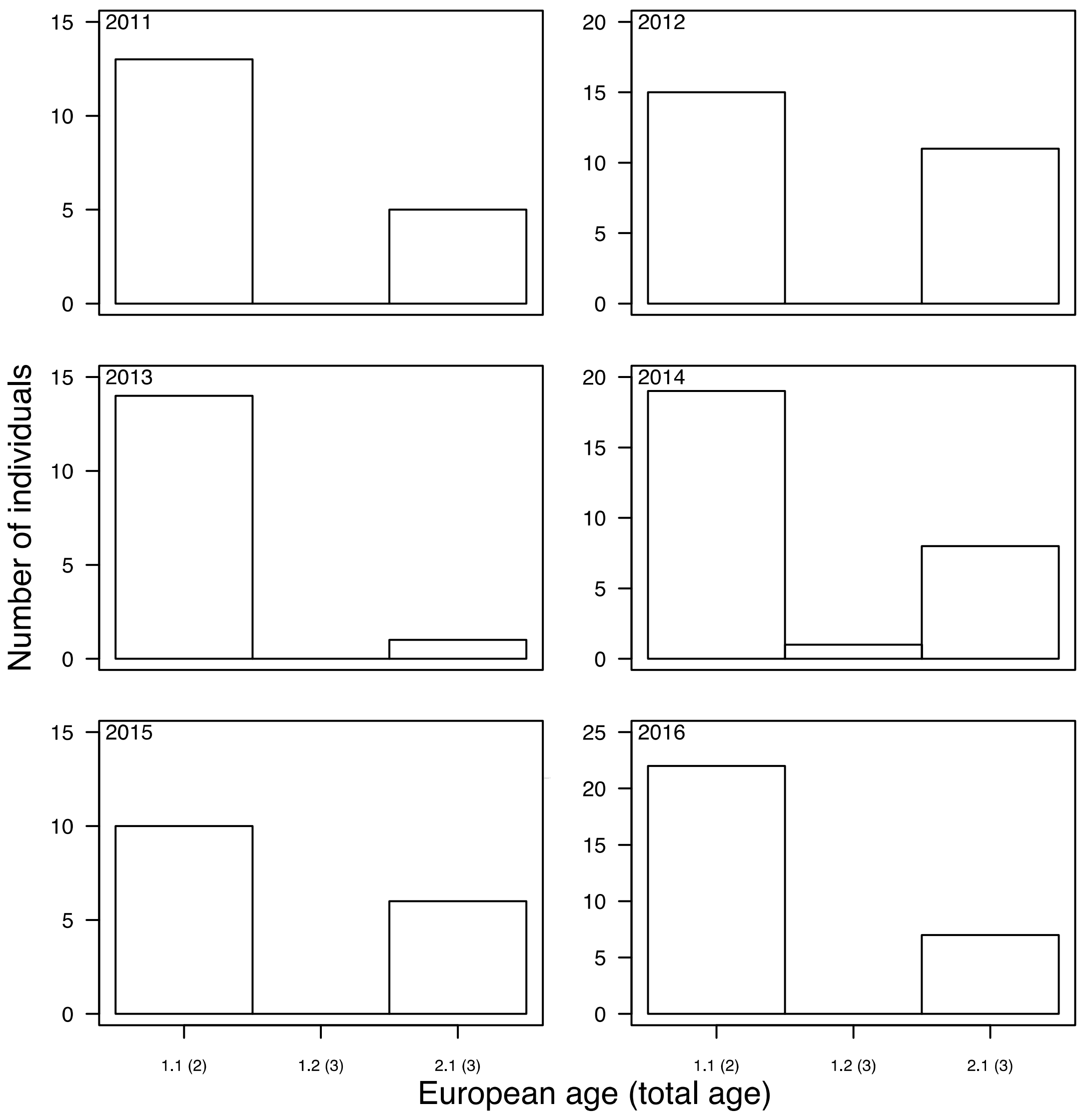


Figure 16. Frequency distribution of Coho Salmon age classes from 2011 to 2016.

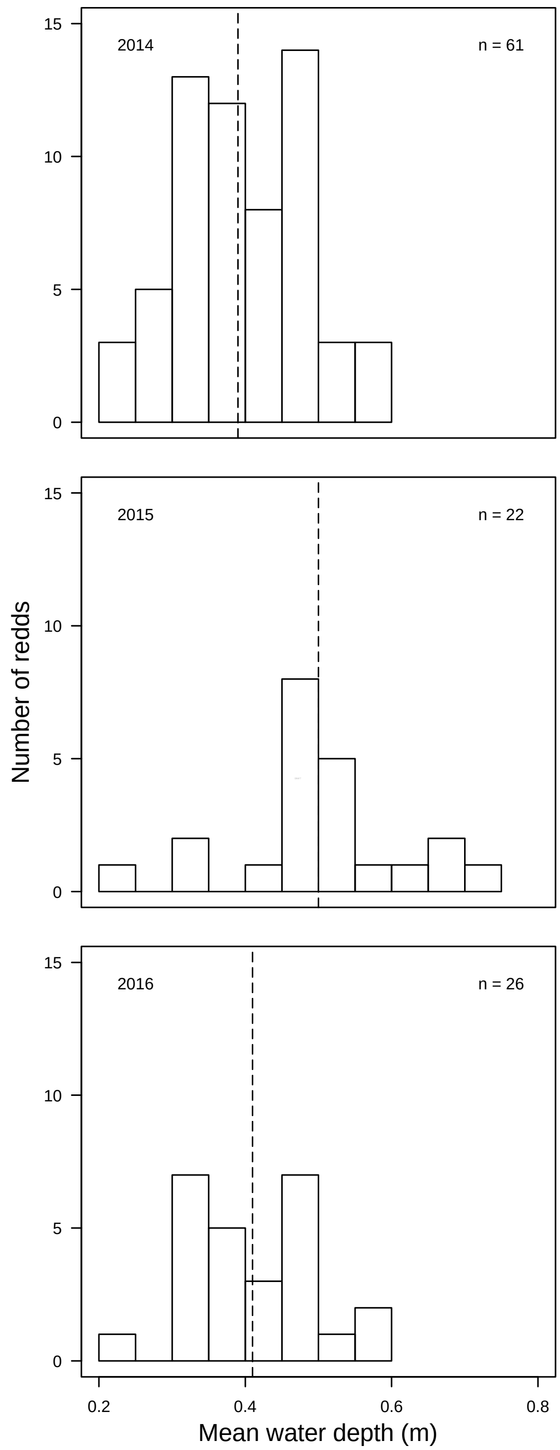


Figure 17. Frequency distribution of mean water depths (m) measured at Chinook Salmon redds in the Lower Bridge River from 2014 to 2016. Dashed lines denote the annual mean water depth.

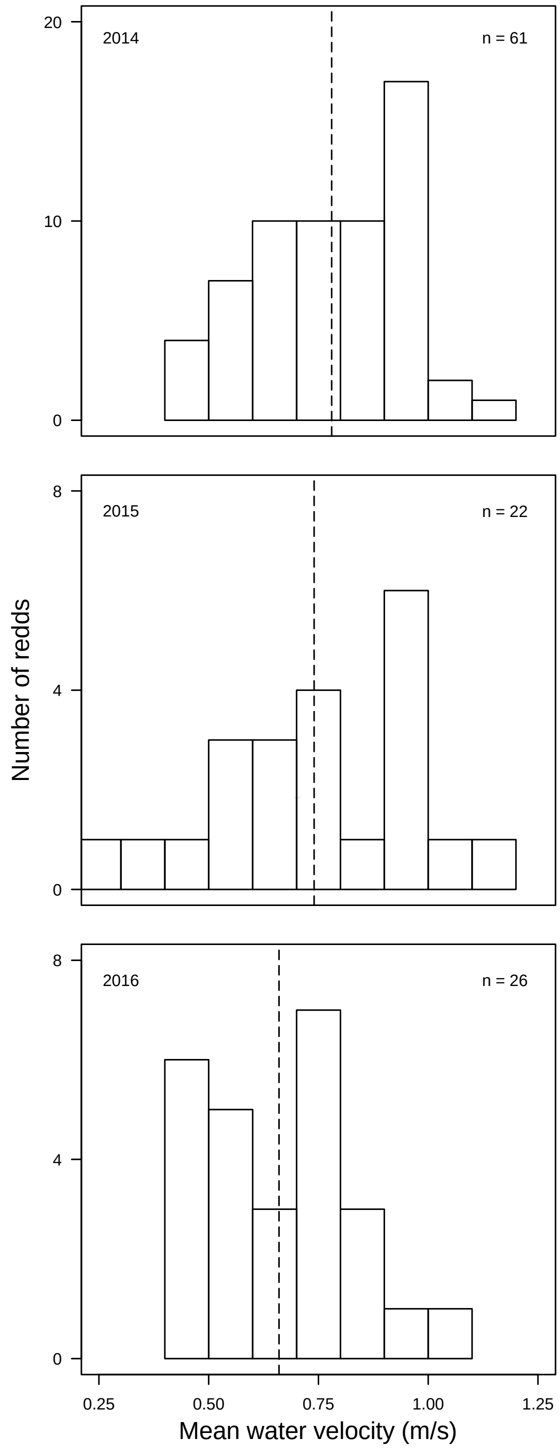


Figure 18. Frequency distribution of mean water velocity (m s^{-1}) measured at Chinook Salmon redds in the Lower Bridge River from 2014 to 2016. Dashed lines denote the annual mean water velocity.

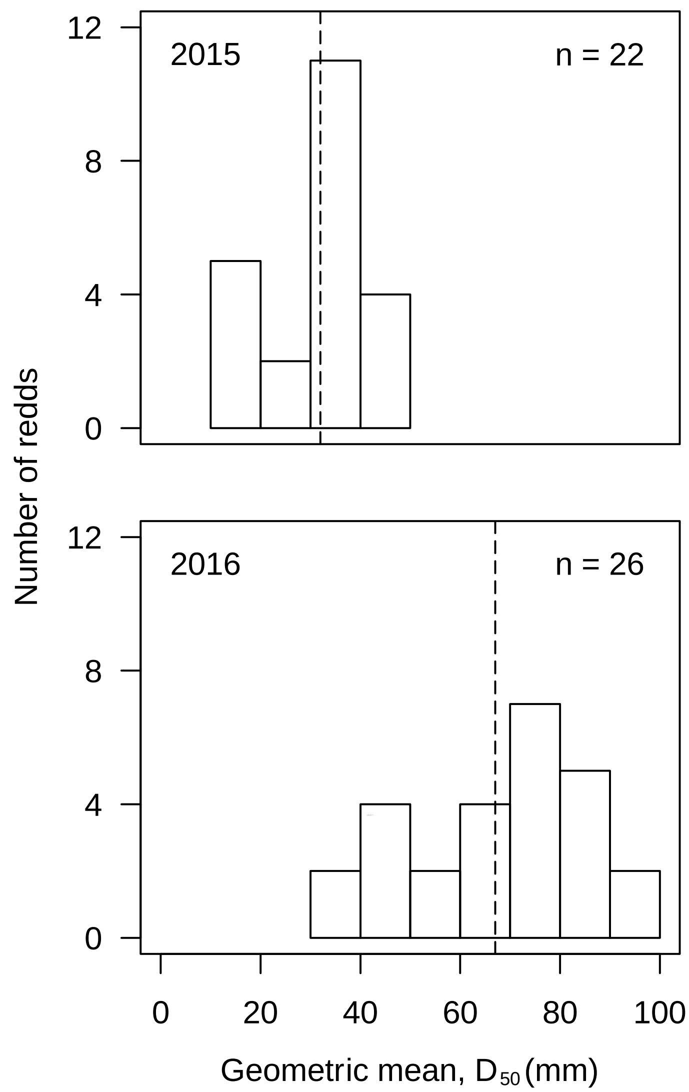


Figure 19. Frequency distribution of the geometric mean (D_{50}) of substrate measured at the tailspill of Chinook Salmon redds in the Lower Bridge River in 2015 and 2016. Dashed lines denote the annual mean D_{50}.

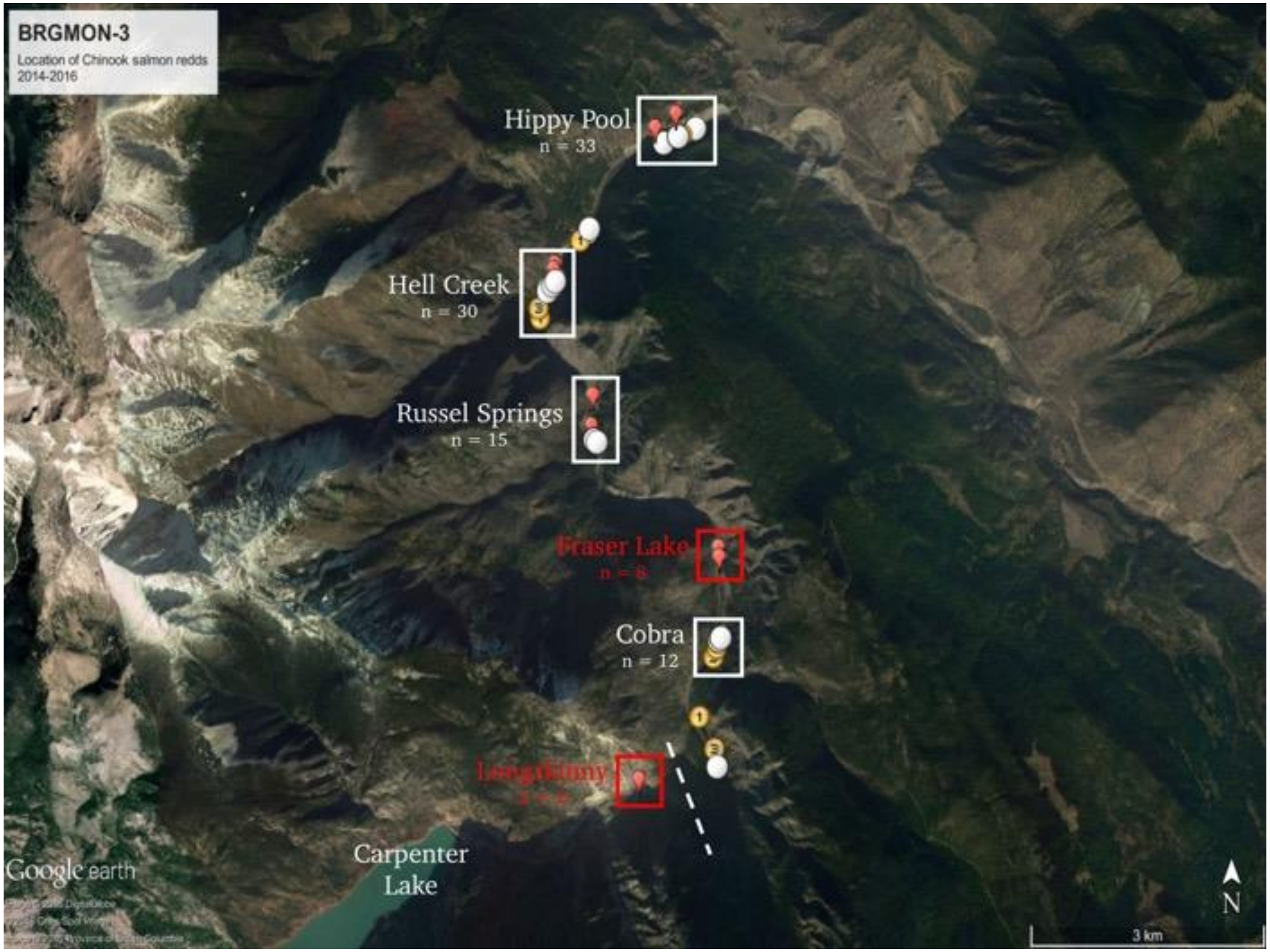


Figure 20. Location of Chinook Salmon redds in the Lower Bridge River in 2014 (yellow), 2015 (white) and 2016 (red). Numbered yellow points denote the number of redds found at a specific location in 2014. White boxes indicate common areas of locating redds. Red boxes indicate areas of new colonization in 2016. White dashed line indicates the boundary between Reach 3 and 4.

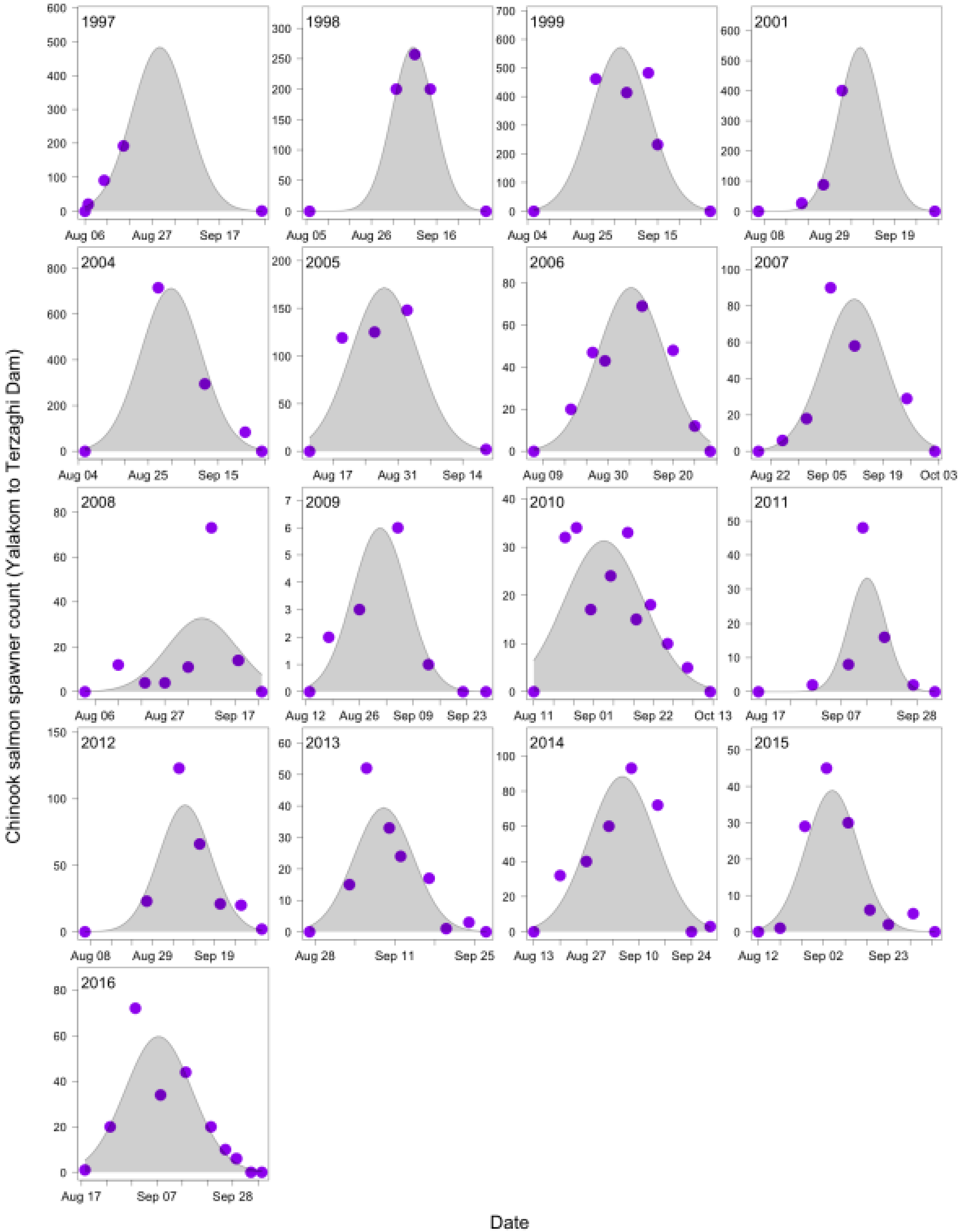


Figure 21. Comparison of Chinook Salmon adult spawner counts (purple points) to the modelled arrival timing (grey shaded area) in the Lower Bridge River from 1997 to 2016. Note that there are different date ranges between years.

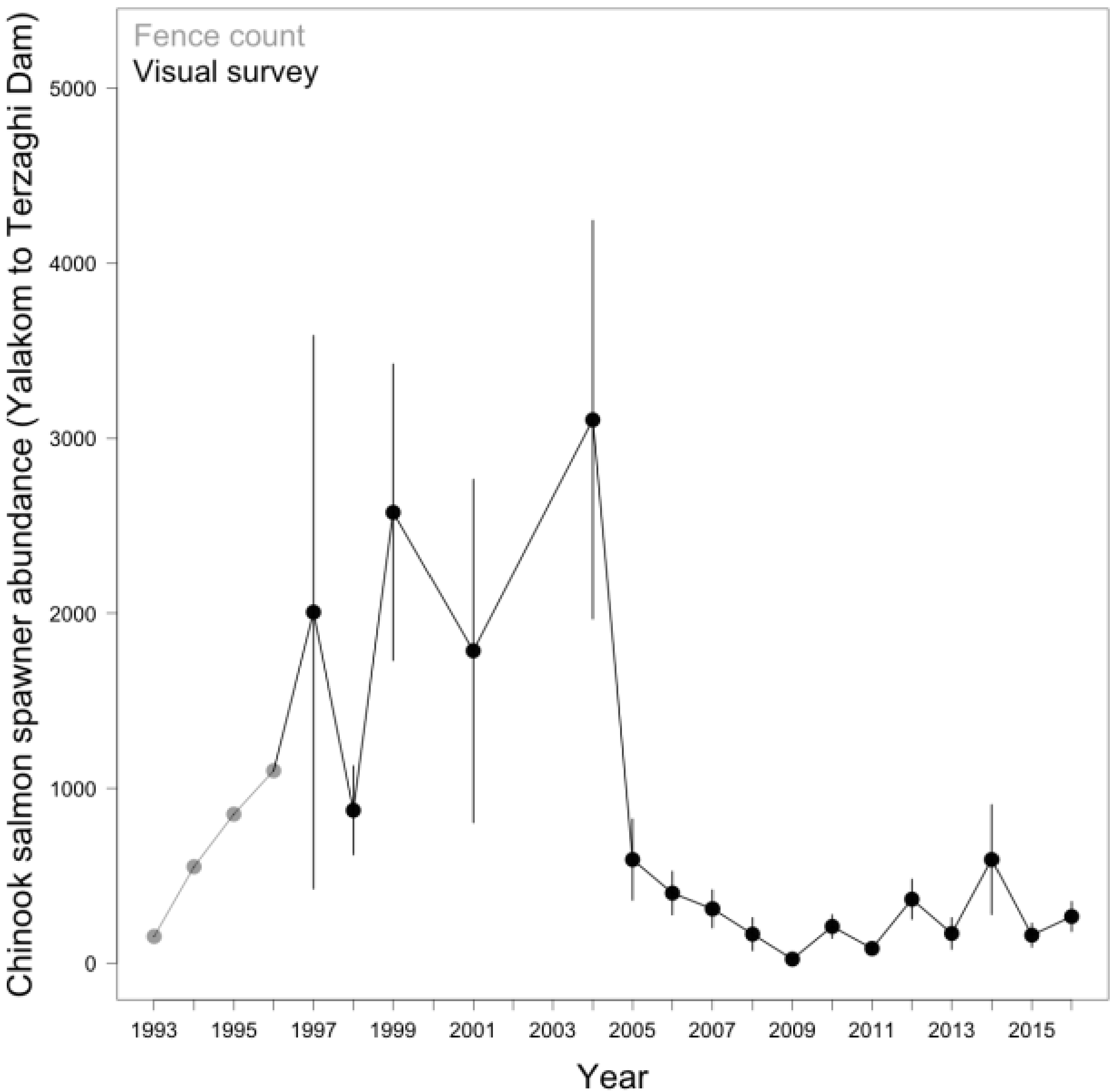


Figure 22. AUC and fence estimates for Chinook Salmon in the Lower Bridge River from 1993 to 2016. Vertical lines represent standard error.

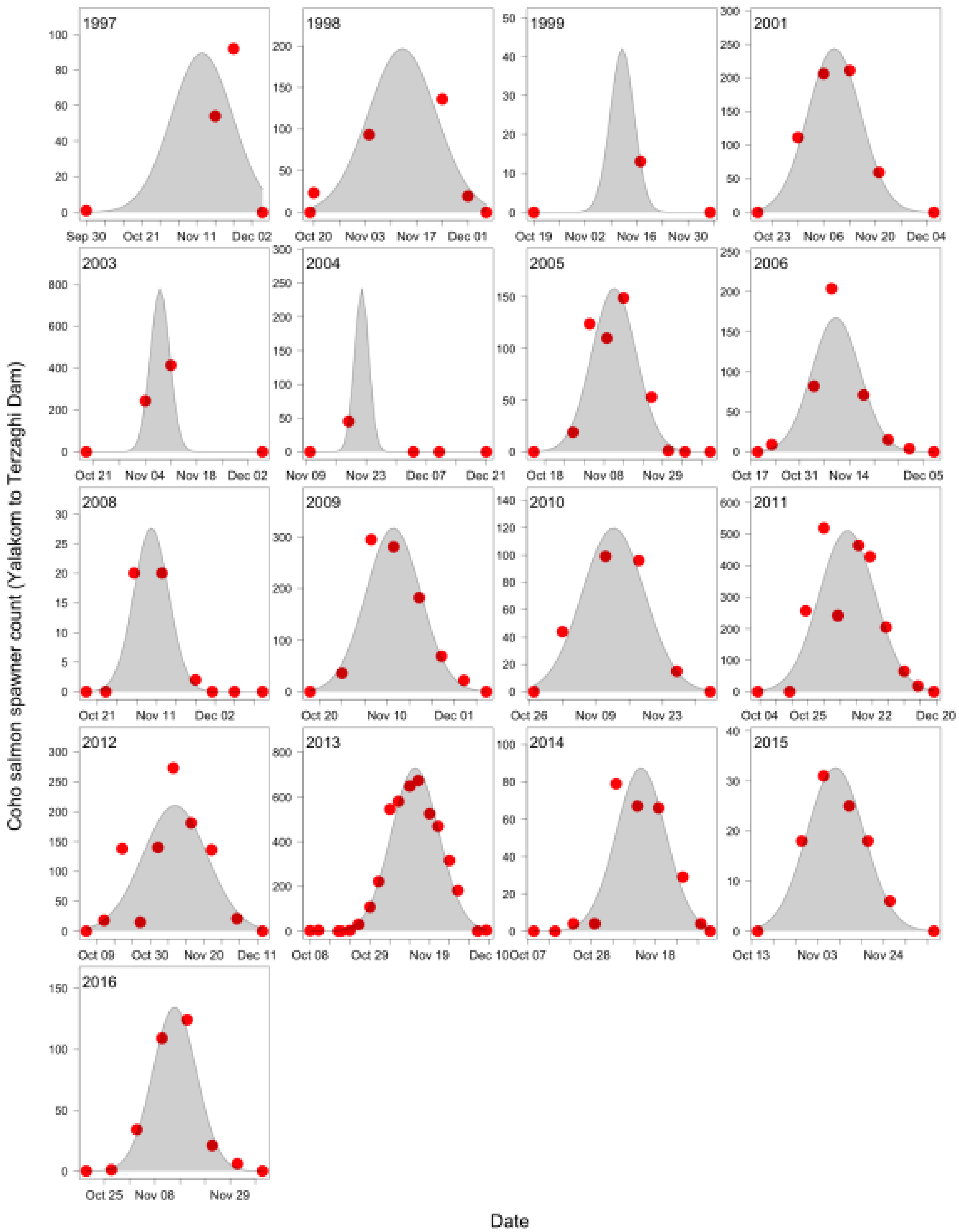


Figure 23. Comparison of Coho Salmon adult spawner counts (red points) to the modelled arrival timing (grey shaded area) in the Lower Bridge River from 1997 to 2016. Note that there are different date ranges between years.

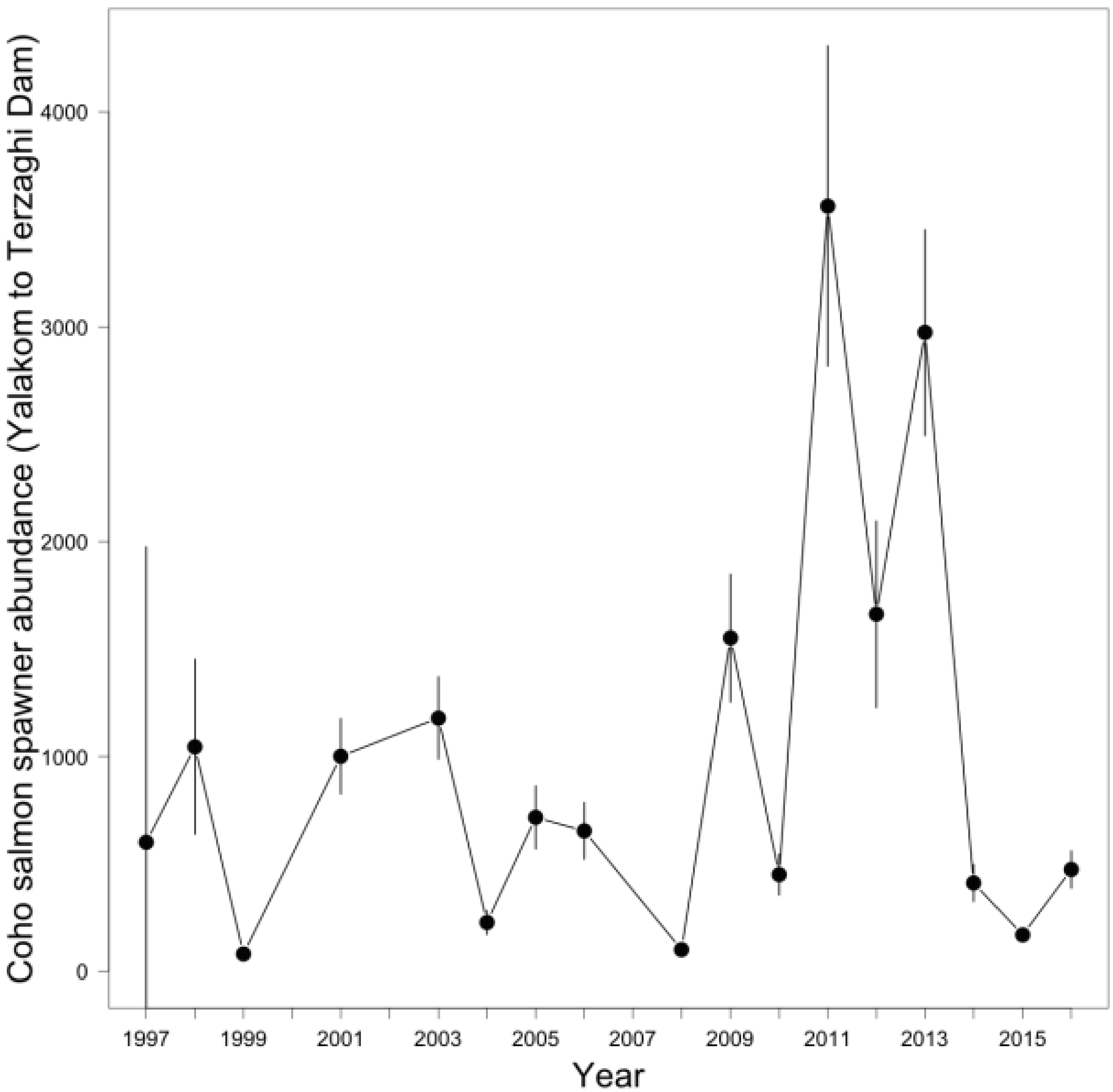


Figure 24. AUC estimates for Coho Salmon in the Lower Bridge River from 1997 to 2016. Vertical lines represent standard error.

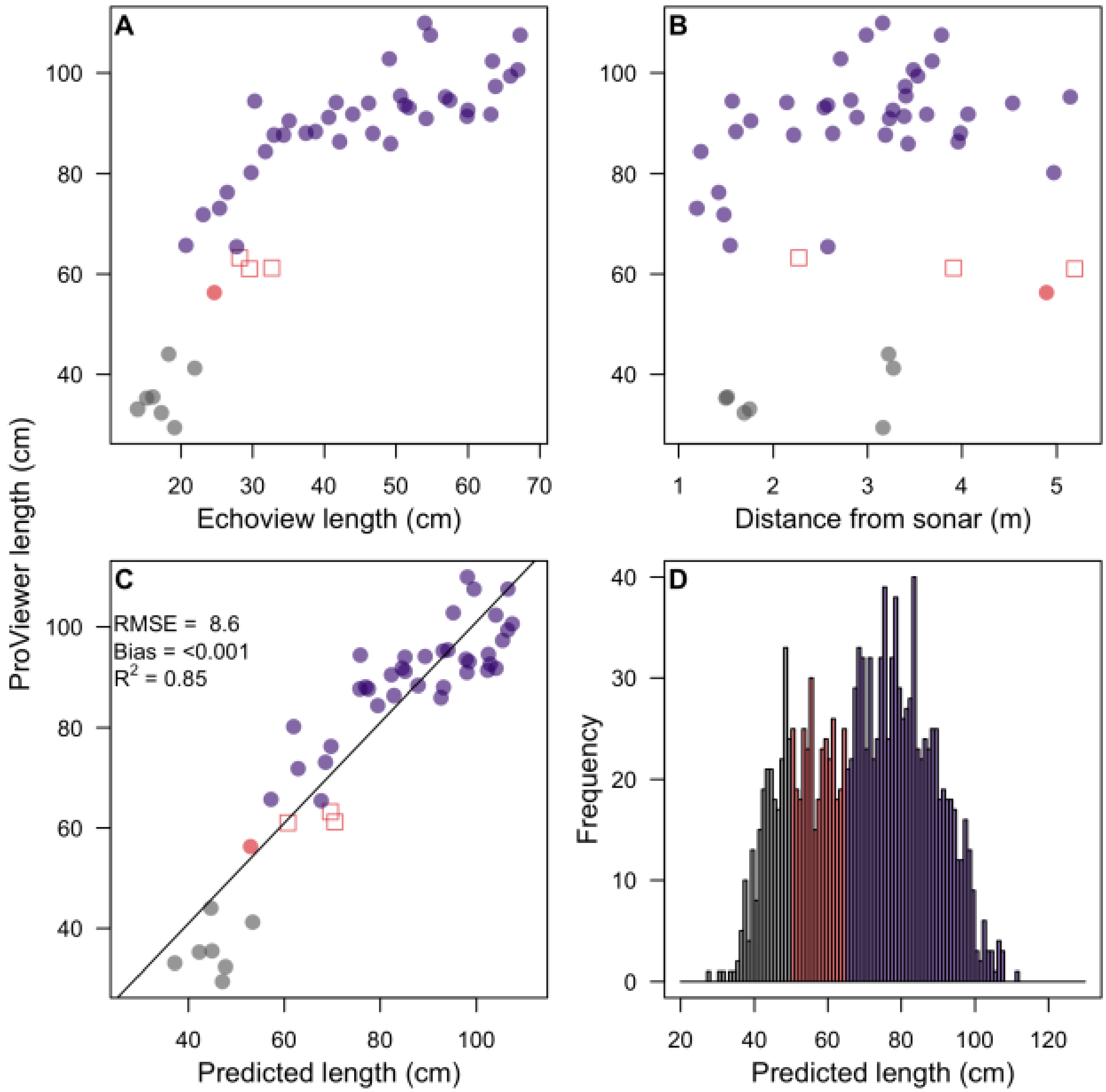


Figure 25. ProViewer lengths in relation to (A) Echoview lengths and (B) distance from sonar. (C) Observed ProViewer lengths in relation to predicted lengths from a linear model that included Echoview length and distance from sonar. Black line indicates unity (1:1). (D) Histogram of the predicted lengths 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.

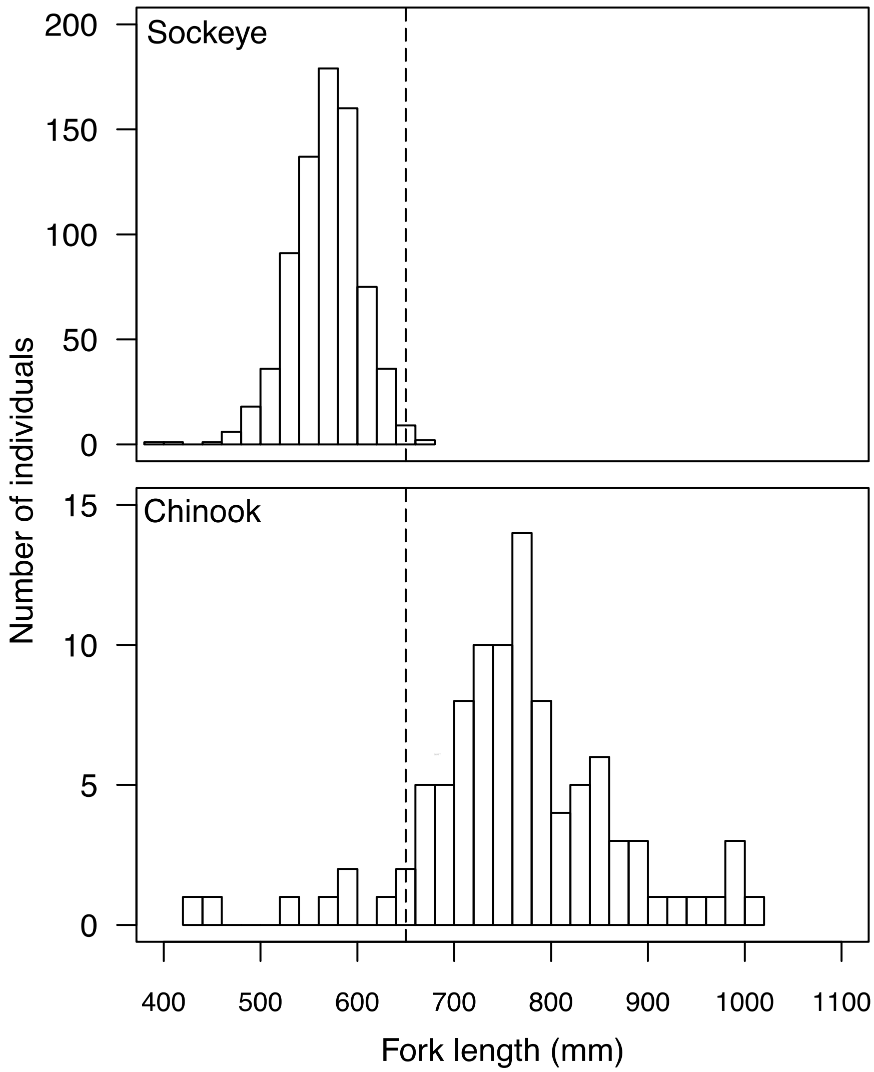


Figure 26. Fork length cut-off (dashed line; 650 mm) between Sockeye (top panel; Gates Creek Sockeye Salmon, n = 752) and Chinook Salmon (bottom panel; Bridge River Chinook Salmon, n = 98).

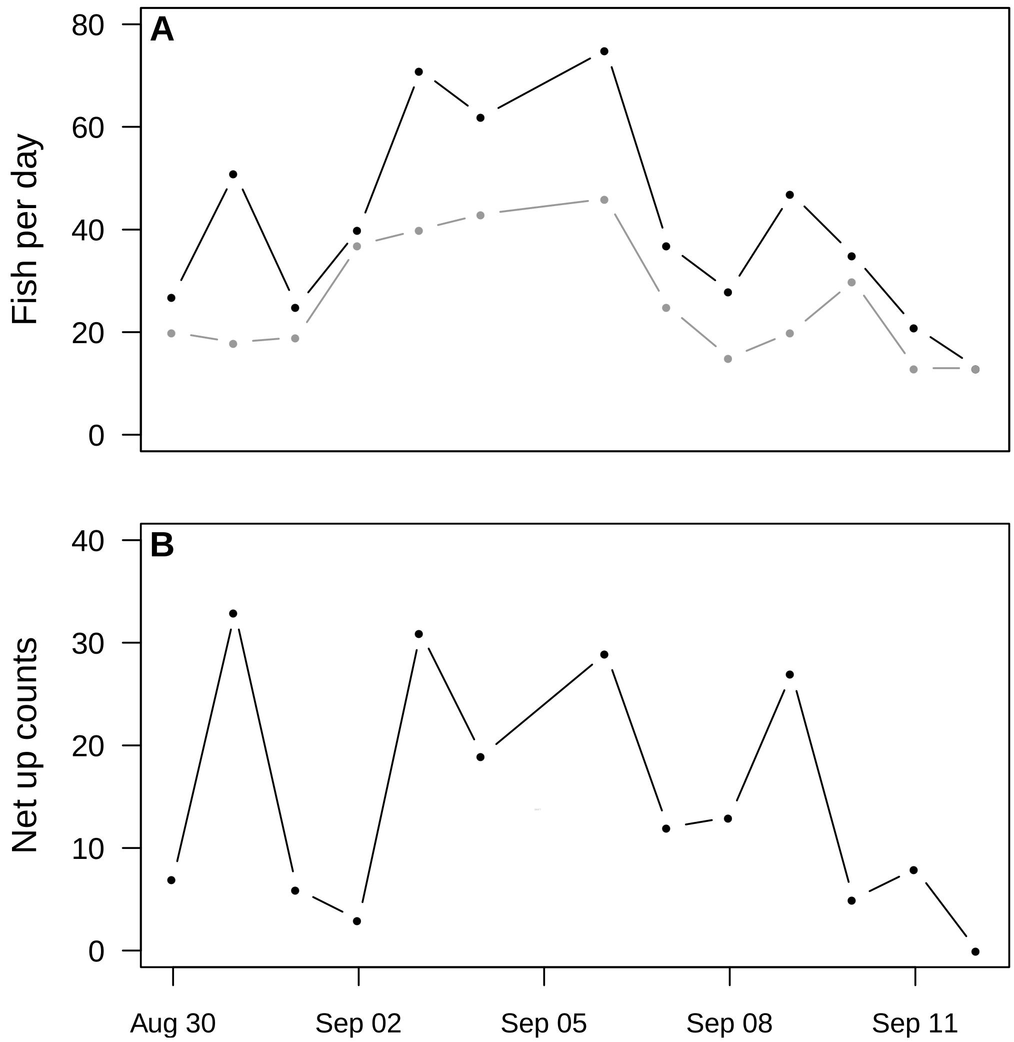


Figure 27. (A) Sonar-derived daily up (black) and down (grey) and net up (B) counts for Chinook Salmon in the Lower Bridge River in 2016.

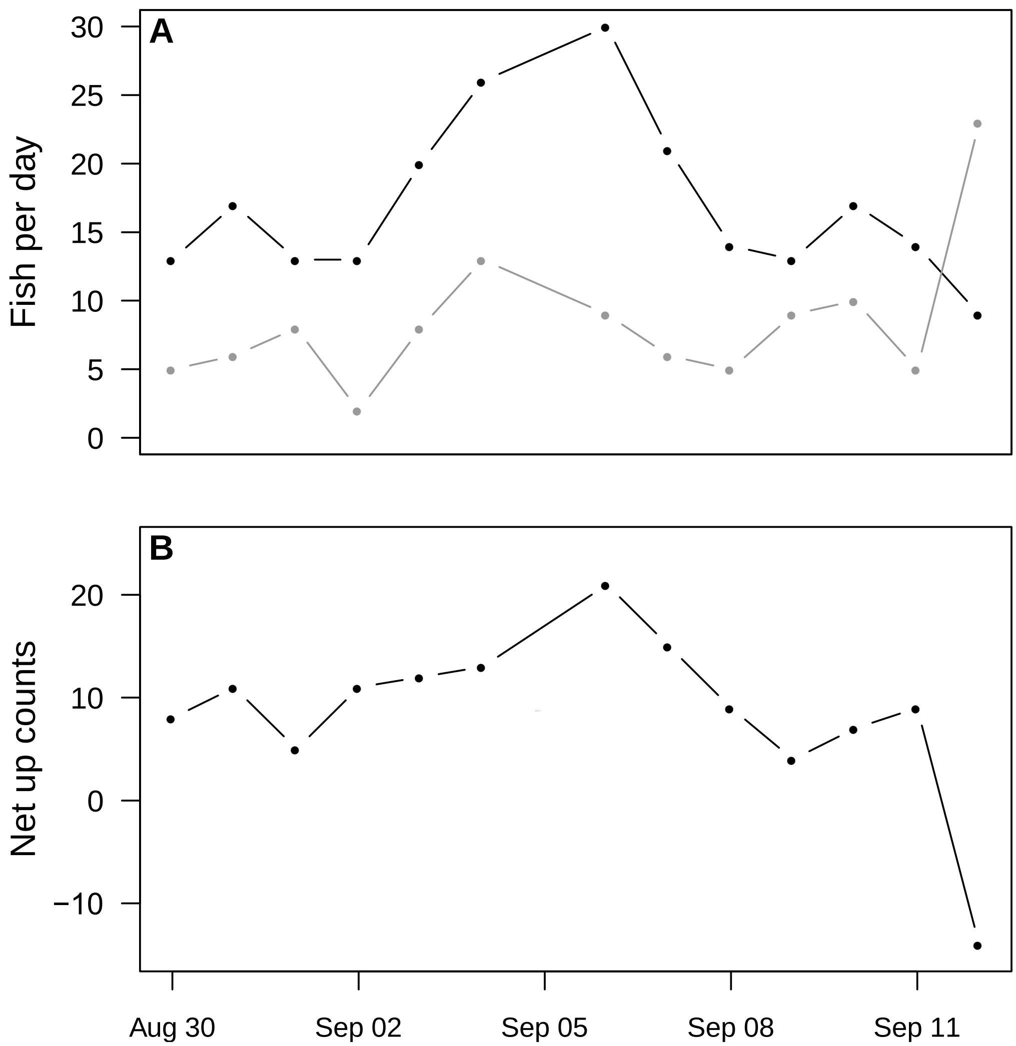


Figure 28. (A) Sonar-derived daily up (black) and down (grey) and net up (B) counts for Sockeye Salmon in the Lower Bridge River in 2016.

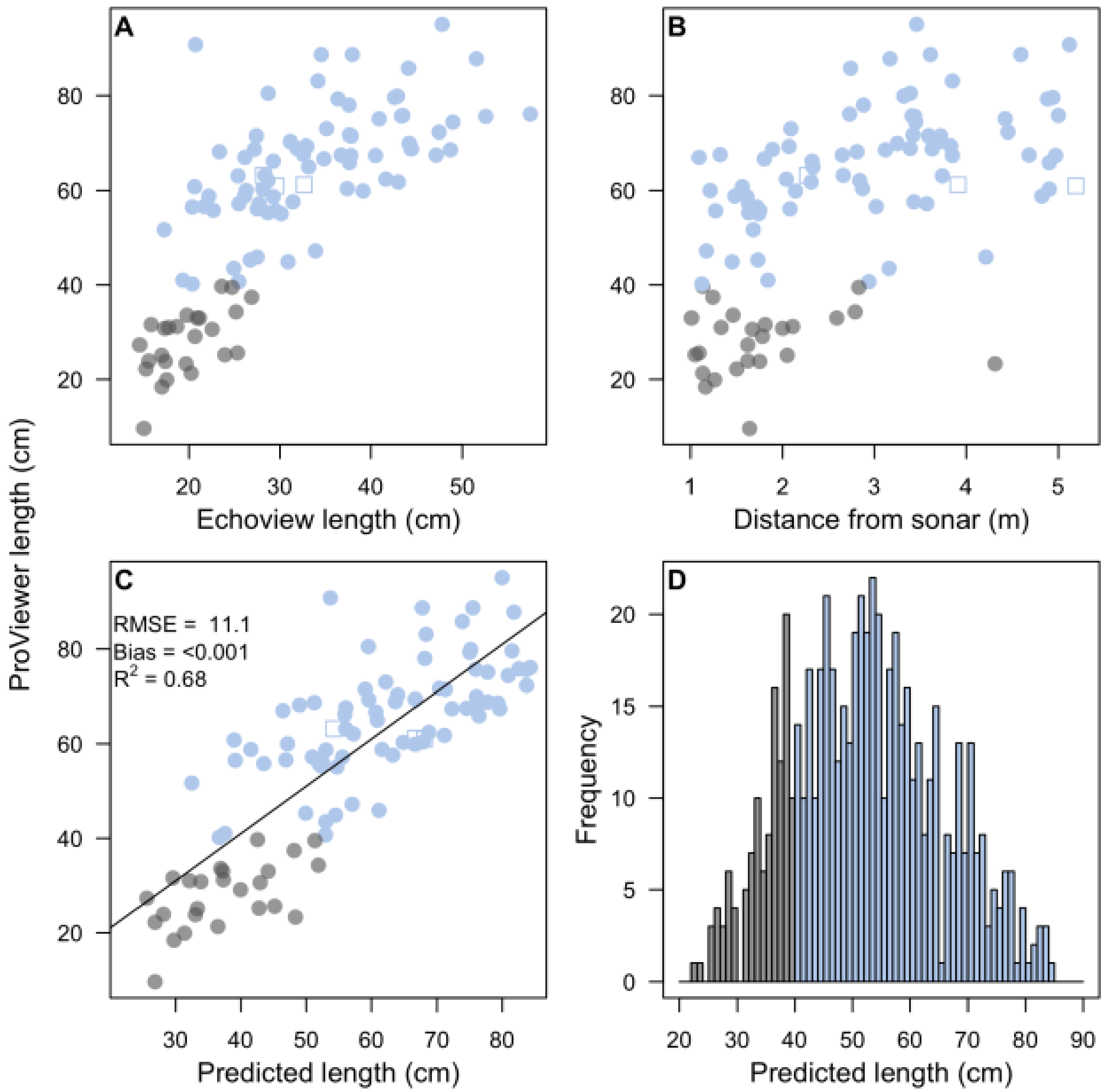


Figure 29. ProViewer lengths in relation to (A) Echoview lengths and (B) distance from sonar. (C) Observed ProViewer lengths in relation to predicted lengths from a linear model that included Echoview length and distance from sonar. Black line indicates unity (1:1). (D) Histogram of the predicted lengths 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.

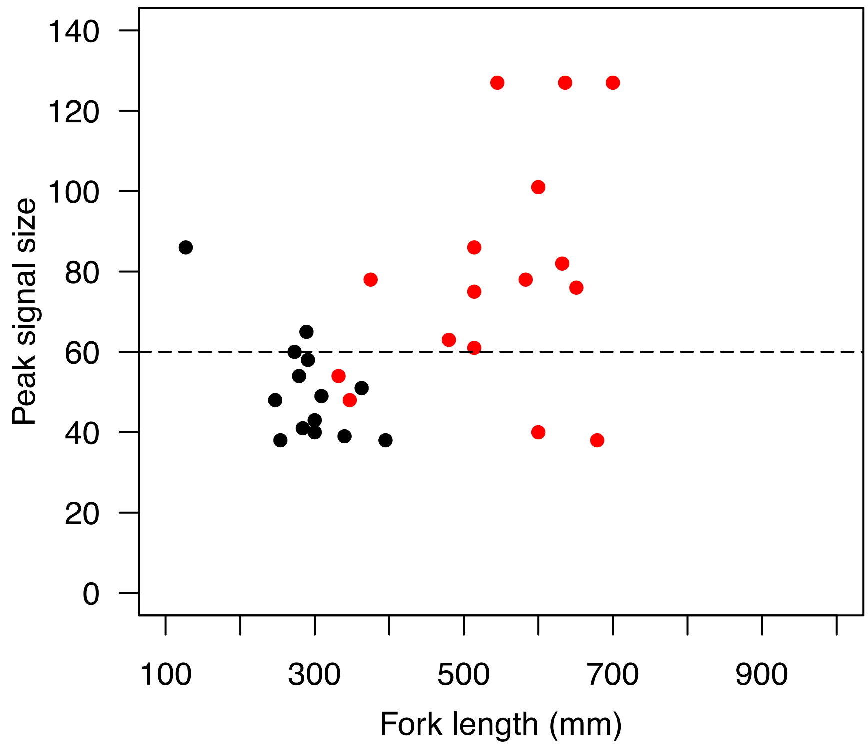


Figure 30. Peak signal size cut-off (dashed line) between Coho Salmon (red dots) and resident Bull Trout and Rainbow Trout (black dots) in the Lower Bridge River in 2016.

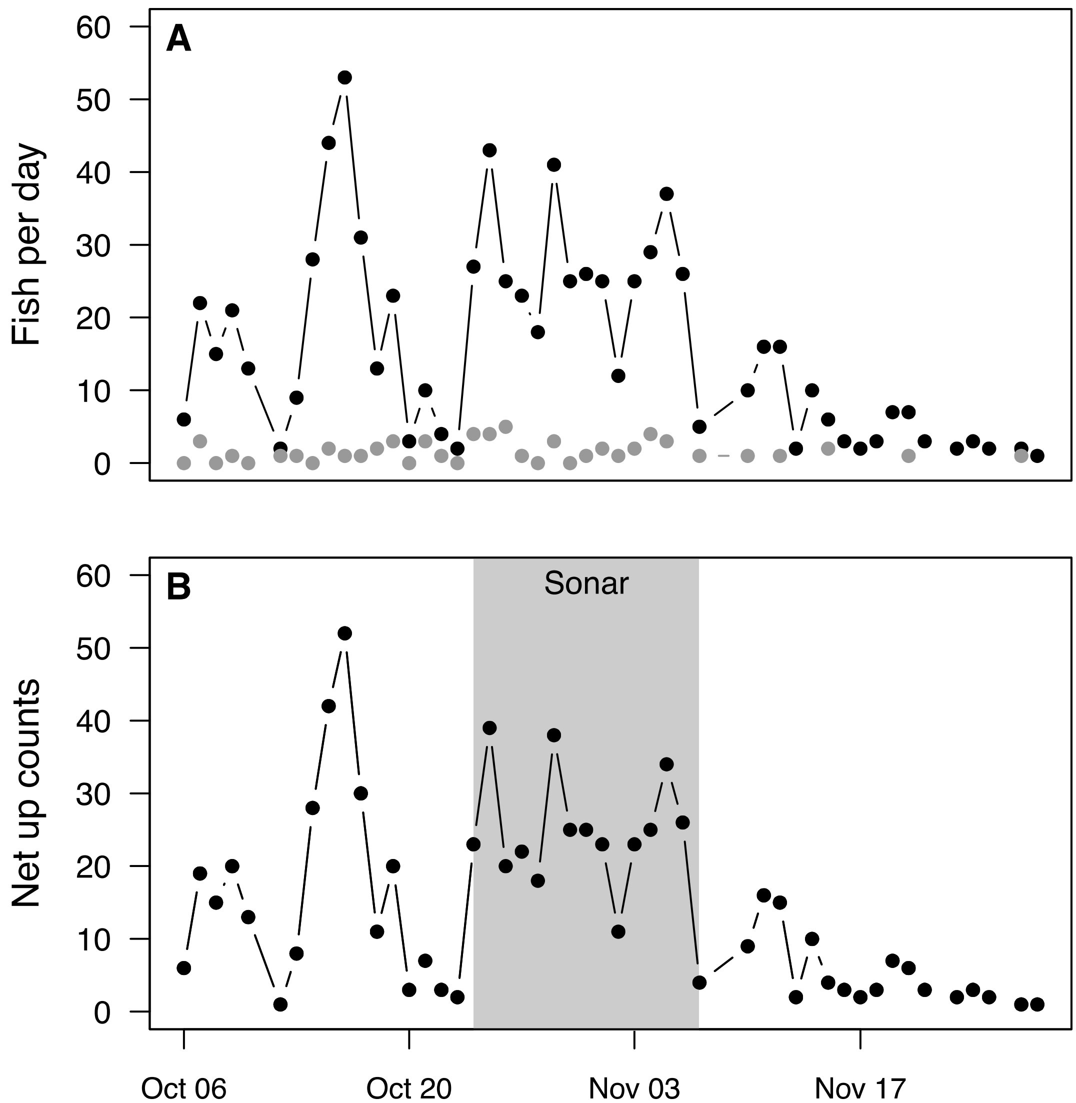


Figure 31. (A) Resistivity-derived daily up (black) and down (grey) and net up (B) counts for Coho Salmon in the Lower Bridge River in 2016. Shaded rectangle shows the dates the multibeam sonar was deployed in 2016.

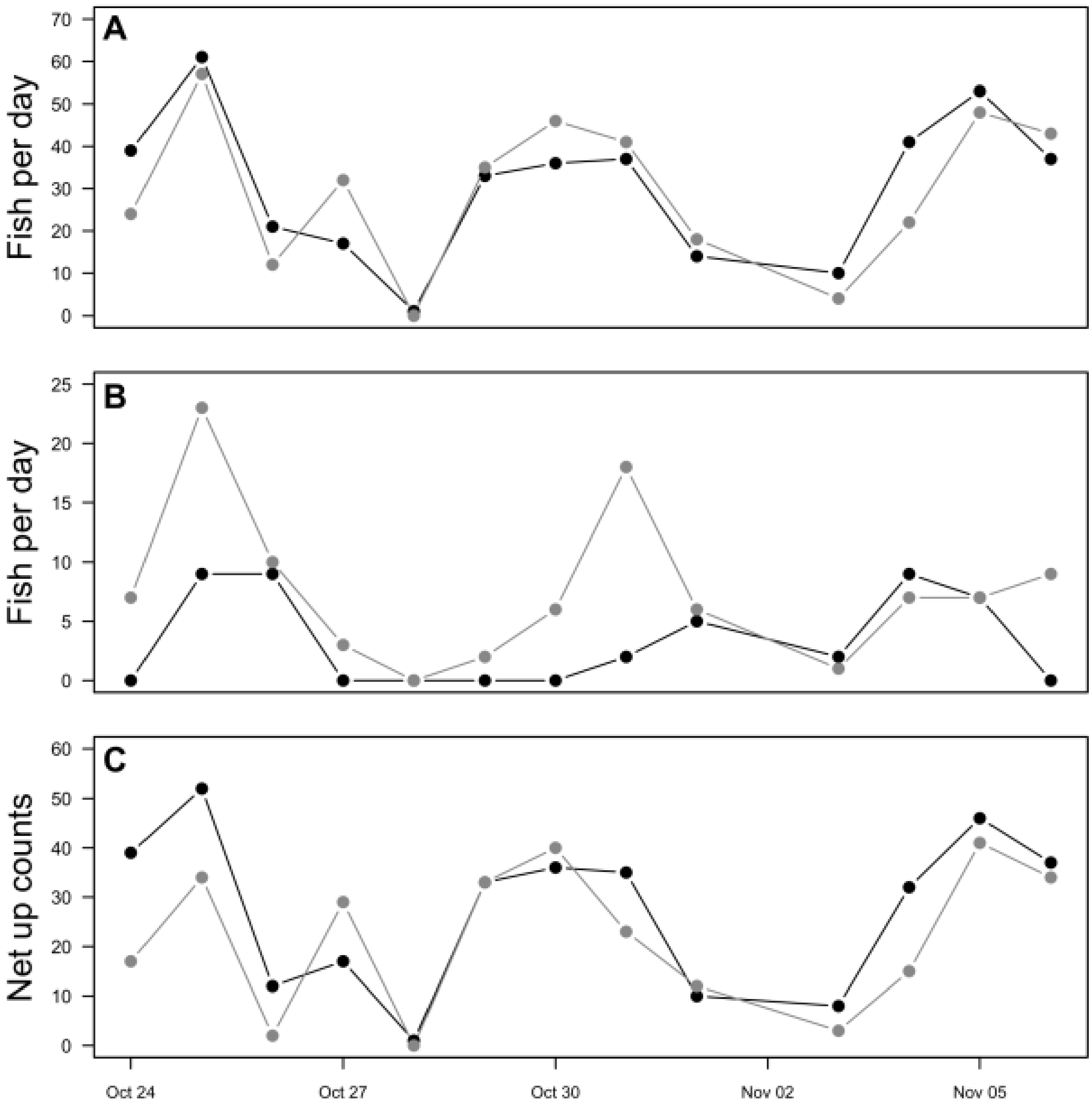


Figure 32. Resistivity- (black) and sonar-derived (grey) daily up (A), down (B) and net up (C) counts for Coho Salmon in the Lower Bridge River in 2016.

9.0 Appendices

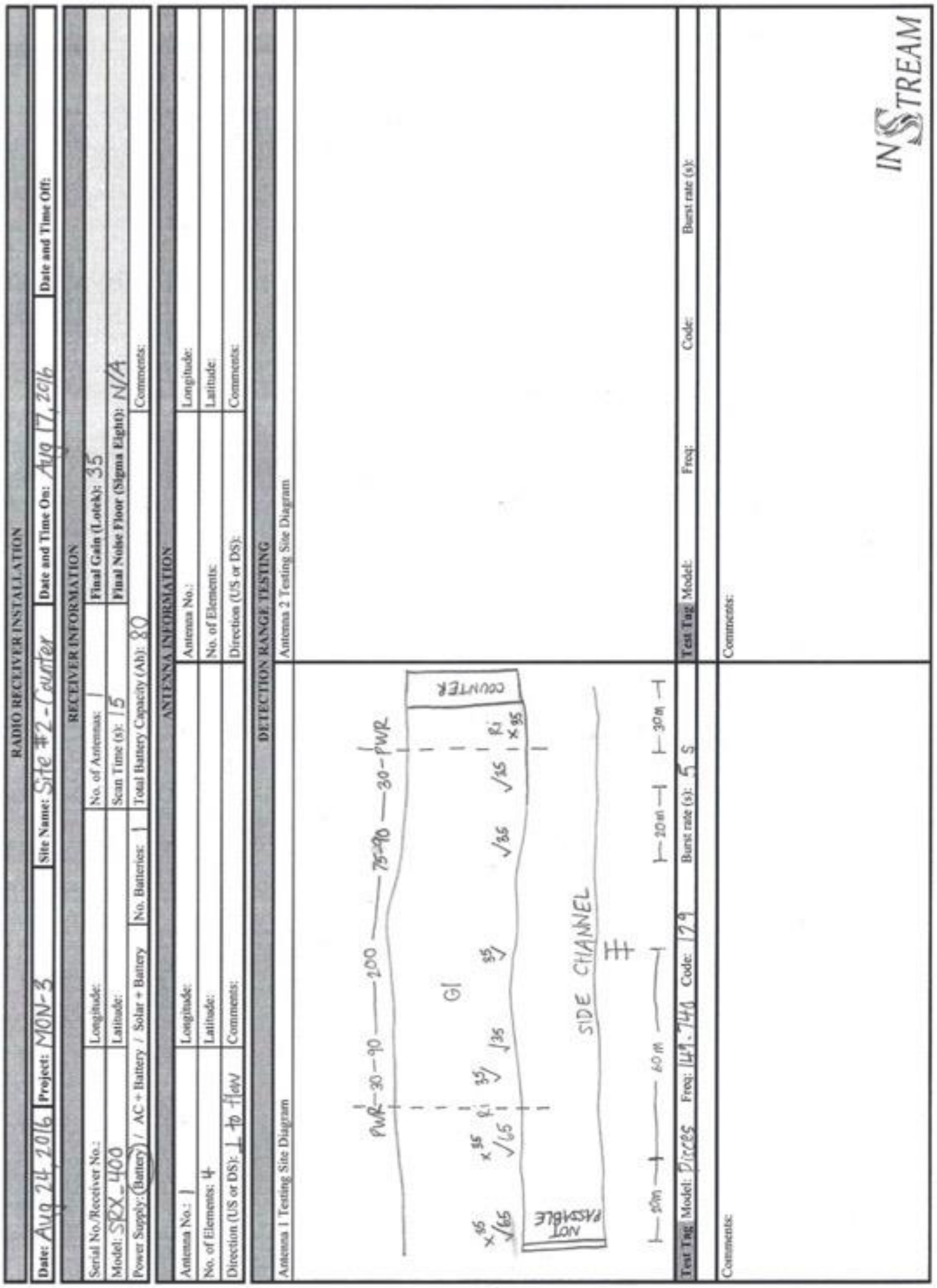
Appendix 1. Sampling and tagging data from the Lower Bridge River in 2016.

2016_MON3_Tagging_Data.xlsx

Appendix 2. Visual streamwalk data from the Lower Bridge River in 2016.

2016_MON3_Streamwalk_Data.xlsx

Appendix 3. Read range testing performed on radio receivers in the Lower Bridge River.



RADIO RECEIVER INSTALLATION

Date: Aug 24 2016 | Project: MON-3 | Site Name: Site #2 - Counter | Date and Time On: Aug 17, 2016 | Date and Time Off:

RECEIVER INFORMATION

Serial No./Receiver No.: | Longitude: | No. of Antennas: 1 | Final Gain (Lotek): 35

Model: SRX_400 | Latitude: | Scan Time (s): 15 | Final Noise Floor (Sigma Eight): N/A

Power Supply: Battery / AC + Battery / Solar + Battery | No. Batteries: 1 | Total Battery Capacity (Ah): 80 | Comments:

ANTENNA INFORMATION

Antenna No.: 1 | Longitude: | Antenna No.: | Longitude:

No. of Elements: 4 | Latitude: | No. of Elements: | Latitude:

Direction (US or DS): ⊥ to flow | Comments: | Direction (US or DS): | Comments:

DETECTION RANGE TESTING

Antenna 1 Testing Site Diagram | Antenna 2 Testing Site Diagram

Test Tag Model: Pisces Freq: 149.744 Code: 179 Burst rate (s): 5 s | Test Tag Model: Freq: Code: Burst rate (s):

Comments: | Comments:

INSTREAM

RADIO RECEIVER INSTALLATION

Date: Aug 24, 2016	**Project:** MON-3	**Site Name:** Site #3 - Reach 3-4	**Date and Time On:** Aug 17, 2016	**Date and Time Off:**

RECEIVER INFORMATION

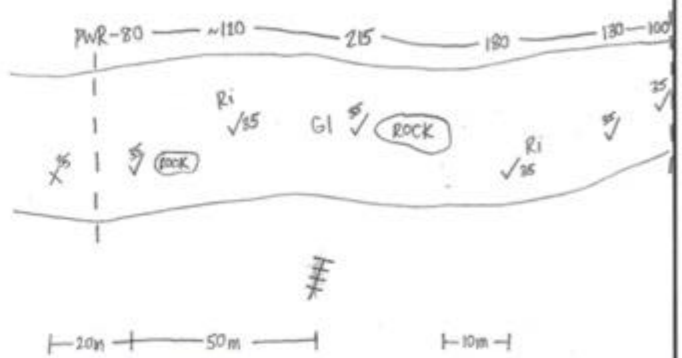
Serial No./Receiver No.:	Longitude:	No. of Antennas: 1	**Final Gain (Lotek):**
Model: SPX-400	Latitude:	Scan Time (s): 15	**Final Noise Floor (Sigma Eight):** N/A
Power Supply: Battery / AC + Battery / Solar + Battery	No. Batteries: 1	Total Battery Capacity (Ah): 80	Comments:

ANTENNA INFORMATION

Antenna No.: 1	Longitude:	Antenna No.:	Longitude:
No. of Elements: 4	Latitude:	No. of Elements:	Latitude:
Direction (US or DS): ⊥ to flow	Comments:	Direction (US or DS):	Comments:

DETECTION RANGE TESTING

Antenna 1 Testing Site Diagram	Antenna 2 Testing Site Diagram



Test Tag Model: Picros	Freq: 149.740	Code: 129	Burst rate (s): 5 s	**Test Tag** Model:	Freq:	Code:	Burst rate (s):

Comments:	Comments:

INSTREAM

Appendix 4. Summary of Steelhead Trout age data.

Sampling year	Fork length (mm)	Sex	Total age (yrs)	European age	Brood year
2014	780	F	4	2.2	2009
2014	620	F	4	3.1	2009
2014	680	F	4	3.1	2009
2014	800	F	3	2.1	2010
2014	855	F	4	2.2	2009
2014	905	M	5	3.2	2008
2014	815	F	5	3.2	2008
2014	750	F	4	2.2	2009
2015	740	F	4	2.2	2010
2015	770	F	5	3.2	2009
2015	835	M	4	2.2	2010
2015	740	F	4	2.2	2010
2015	800	F	5	3.2	2009
2015	787	F	5	3.2	2009
2015	780	F	5	3.2	2009
2015	775	F	4	2.2	2010
2015	853	M	5	3.2	2009
2015	724	F	5	3.2	2009
2015	630	F	4	3.1	2010
2015	760	F	5	3.2	2009
2015	935	M	5	2.3	2009
2015	740	F	5	3.2	2009
2015	820	F	6	3.3	2008
2015	-	F	6	3.3	2008
2016	730	F	5	3.2	2010
2016	763	F	5	2.3	2010
2016	830	F	5	3.2	2010