Bridge River Project Water Use Plan

Lower Bridge River Adult Salmon and Steelhead Enumeration

Implementation Year 4

Reference: BRGMON-3

Study Period: April 1 2015 to March 31 2016

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May 27, 2016

Bridge-Seton Water Use Plan

Implementation Year 4 (2015):

Lower Bridge River Adult Salmon and Steelhead Enumeration

Reference: BRGMON-03

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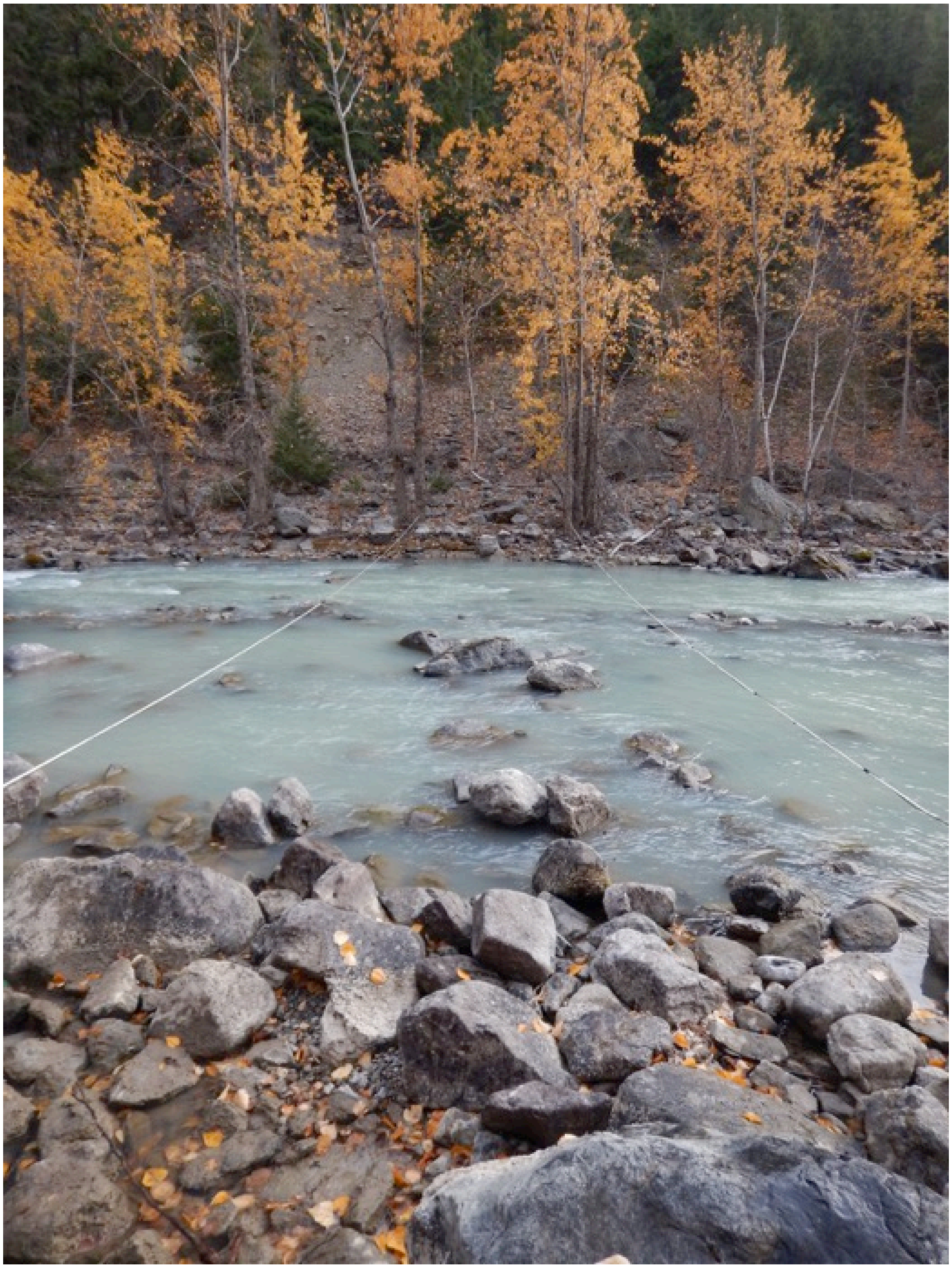
Lower Bridge River Adult Salmon and Steelhead Enumeration, 2015



Executive Summary

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

In 2015, data from visual streamwalk surveys were used to provide area-under-the-curve (AUC) type abundance estimates of Chinook and Coho Salmon in the lower Bridge River. Residence time data were generated using radio- and PIT-telemetry mark-recapture. Nineteen Chinook Salmon and 18 Steelhead Trout were radio-tagged, and 48 Coho Salmon were PIT tagged in 2015.

Using AUC methods, a total spawner abundance estimate of 182 Chinook and 162 Coho Salmon were derived for the area upstream of the confluence with the Yalakom River (Reach 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 confluence. AUC estimates from 1993 to 2015 ranged from 151 to 3,479 Chinook Salmon, and from 76 to 3,422 Coho Salmon from 1997 to 2015. Examination of the sensitivity of AUC estimates indicated that small variations or error in calculating observer efficiency or residence time data can greatly affect abundance estimates. No historical visual count data were available for Steelhead Trout prior to 2014.

Abundance estimates from the resistivity counter were generated for Steelhead Trout, and Chinook, Pink and Coho Salmon. In 2015, a total of 73 Steelhead Trout, 481 Chinook, 40,870 Pink and 566 Coho Salmon were estimated to have spawned upstream of the resistivity counter site. We will compare AUC- and counter-derived estimates of abundance once additional counter data has been collected and the site has been fully tested. Moving forward, visual counts may cease as the counter is expected to provide improved escapement accuracy for Reaches 3 and 4.

In 2015, we recorded habitat characteristics in Chinook Salmon redds prior to and after high density Pink Salmon spawning to examine the potential effect(s) of redd superimposition. We found significant effects of Pink Salmon spawning on Chinook Salmon redd structure: redds became narrower and tailspill water depth increased, causing a subsequent reduction in tailspill water velocity. Overall, population-level

effects of Pink Salmon spawning on Chinook Salmon redds and egg survival are poorly understood, and warrant further investigation.

Collaborating with BRGMON-1, we overlaid the location of 86 Chinook Salmon redds with habitat assessment data from Reaches 3 and 4 under a dam flow release of 3 $m^3 s^{-1}$ (McHugh and Soverel 2016). Chinook Salmon prefer the micro-habitat conditions within runs and riffles in Reach 3, whereby the preferred water depths and velocities are consistent with what is reported in the literature. Using habitat characteristics (water depth and velocity) as spawning criteria for Chinook Salmon, we estimate that there is an absolute maximum of 25 hectares of suitable habitat available for spawning in Reach 3 and 4. Ultimately, there appears to be spawning habitat of sufficient quality and quantity available to Chinook Salmon, and we highlight that the quantity of spawning habitat likely does not limit fry production under the 3.0 $m^3 s^{-1}$ flow condition.

BRGMON-3 Status of Objectives, Management Questions and Hypotheses after Year 4

Study Objectives	Management Questions	Management Hypotheses	Year 4 (Fiscal Year 2015) Status
Evaluate effects of Terzaghi Dam operations on the spawning habitat and distribution of Steelhead Trout, and Chinook and Coho Salmon, and to generate spawning 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.	A time series of adult spawner abundance for Chinook and coho Salmon from historic streamwalks has been generated. Confidence in the accuracy of these estimates is limited due to varying methods and visibility, but they are useful for providing a trend in lower Bridge River spawner abundance relative to the trends in other Fraser River salmon stocks over the course of the monitoring period. Differences between these trends may be attributable to effects on the LBR populations related to the flow trials. Continued monitoring is required to adequately evaluate Hypothesis 1. Two years of resistivity counter data (Steelhead Trout, and Chinook and Coho Salmon) have been collected and future estimates will be validated abundance estimates, which provide accurate consistent estimates compared 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 two years. Data will be combined with habitat data collected by BRGMON-1 to evaluate the total area available to spawners and the maximum number of spawners required to fully seed the available area. Radio and PIT telemetry has identified the distribution of Steelhead Trout, and Chinook and Coho Salmon using Reach 3 and 4. Data will answer Hypothesis 2 when data collection and analysis is complete.

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Glossary of Terms

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

Acknowledgements

SER fisheries technicians Ron James, Storm Peter, Edward Serroul, and Avaleen Adolph provided essential field service. St'át'imc Eco-Resources Ltd. (SER) administrators provided logistical and administrative support for this project. Richard Bailey from the Department of Fisheries and Oceans (DFO) Canada provided historical abundance data.

1.0 Introduction

1.1 Background

The Bridge River is a hydroelectric power producing tributary of the middle Fraser River, serving as important habitat for salmon and steelhead, and has historic and current significance for the St'át'imc First 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 to 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 four kilometer section of the Bridge River channel immediately downstream of Terzaghi Dam remained continuously dewatered; groundwater and small tributaries accounted for the total in-river discharge below the dewatered reach (~ 1 $m^3 s^{-1}$ averaged across the year; Longe and Higgins 2002).

The lack of a continuous flow release from Terzaghi Dam was an issue of long-standing concern for the St'át'imc First Nation, federal and provincial regulatory agencies, and the 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 base 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 from Terzaghi Dam to the lower Bridge River began on August 1, 2000.

A condition of the Interim Flow Order (IFO) was the continuation of environmental monitoring studies in response to concerns raised 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 aquatic ecosystem of the LBR. 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 measured ecosystem responses to the flow trials (Sneep and Hall 2011).

The IFO continued until the Water Use Plan (WUP) for the Bridge-Seton system was approved by the St'át'imc First 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 First Nation in 2009 and 2010 were adopted, 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 to 6 $m^3 s^{-1}$/y from May 1, 2011 to April 15, 2015. 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 flow.

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 are required so that any differences can 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 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 Bridge River Salmon and Steelhead abundance and distribution to assist in evaluating the usefulness of historical archived data.

1.2 Management Questions

BRGMON-3's fundamental management question relates to how informative is the use of juvenile salmonid standing crop biomass as an indicator of flow impact. BRGMON-3 addresses this management question 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 relating it to 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. Ultimately, this monitor will provide the data needed to 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.

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 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 changes in 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 (*Onchorhynchus mykiss*), 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. Supplemental surveys are conducted to estimate spawning population abundance of Sockeye Salmon (*O. nerka*) and Pink Salmon (*O. gorbuscha*). Rigorous estimates of Chinook Salmon abundance are particularly important because the time series of juvenile stock assessment data may be confounded by hypothesized temperature-mediated changes in juvenile life history due to elevated winter temperatures induced by dam flow releases (BRGMON-1, Bridge-Seton WUP Monitoring Terms of Reference 2012).

Construction of a fish enumeration facility near the downstream end of Reach 3 was completed in October 2013, where a five-channel (Channel 1 on river left and Channel 5 on river right) Aquantic (Scotland, UK) electronic resistivity counter enumerates Steelhead Trout, and Chinook and Coho Salmon abundance upstream of the counter site through to 2021 (Figure 2). Resistivity counters can provide accurate estimates (with confidence limits of ± 10% of true abundance) in other systems (McCubbing and Bison 2009).

Resistivity counter accuracies are typically determined using true validation (e.g., independently validated using video). In addition, Aquantic’s proprietary graphics software provides a graphical trace of each counter record to ensure that the counter algorithm has correctly identified a fish. Each individual trace can be viewed, and thus serves as a form of pseudo-validation. 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.

Since 2001, visual counts of salmonids in the LBR have occurred annually using methods developed and implemented in BRGMON-1 and prior to 2000 using several methods including stream-side visual counts. The survey area extends from Terzaghi Dam to the confluence with the Yalakom River (Figure 2 and Table 1), and is used in the present monitoring program as the location for estimating abundance, distribution, and biological characteristics of spawning salmonids.

Prior to 2013, historic fish counts are available from BRGMON-1 and 3 visual surveys and DFO visual surveys, helicopter surveys, and fence counts. Abundance estimates for these counts are calculated through area-under-the-curve (AUC) estimation (English et al. 1992, Hilborn et al. 1999, Millar et al. 2012) using observer efficiencies and residence times determined by radio telemetry and visual surveys conducted since 2011. Counter estimates will be compared in the future to aid in back-calculating historic estimates of abundance from AUC alone (Troffe et al. 2008). 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.

In 2014 and 2015, InStream Fisheries Research Ltd. (IFR) conducted an assessment of Chinook Salmon spawner habitat quantity and quality. Two years of Chinook Salmon redd habitat surveys have been completed in the LBR at minimum, where spawner densities and the locations of tagged spawners are related to habitat mapping at concurrent dam flow releases and GIS data from BRGMON-1.

2.2.1 Tag Application and Bio-sampling

Fish capture by angling was completed by teams of two SER fisheries technicians. Steelhead Trout were tagged at the Seton-Fraser and Bridge-Fraser confluences. Chinook Salmon were tagged immediately downstream of the counter site at the Bridge-Yalakom confluence. Coho Salmon were primarily tagged in Reach 1 (Bridge-Fraser confluence to Camoo Creek). Tag application was distributed throughout each species migration periods: March to May for Steelhead, August to September for Chinook, and October to November for Coho. Efforts were 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 and Chinook Salmon received a gastrically implanted MCF2-3A radio tag (Lotek Engineering Inc., Ontario, Canada) and a Passive Integrated Transponder (PIT) tag. In 2014, radio tagging of Coho Salmon was suspended and only PIT tags were applied. Radio tags are a more invasive tagging method compared to PIT tags, and based on the previous three years of data collection, it was determined that additional data on residence time would provide little improvement to the accuracy of AUC estimates. Accurate estimates of observer efficiency are difficult to obtain given the limited radio tags applied per year and the low number of tags observed during streamwalk surveys.

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. It has been difficult to collect quality scale samples from Chinook Salmon (few non-resorbed samples have been collected to date), as at the time of capture, scales are resorbed and additional handling in the high air and water temperatures causes physiological stress. 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. Scale sample results for 2014 to 2016 will be presented in next years' WUP monitoring report.

2.2.2 Radio and PIT Telemetry

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 two, 6-element Yagi antennas oriented upstream and downstream to determine directionality. Fixed stations were installed prior to tagging and operated during the Chinook Salmon (August to October) and Steelhead Trout (March to June) 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 Chinook Salmon and Steelhead Trout migration and spawning behaviour in the LBR.

Mobile tracking was conducted twice a week for Steelhead Trout and weekly for Chinook Salmon in Reaches 3 and 4 using a hand-held Lotek SRX_400 receiver (Figure 3). Tracking was carried out from March 3 to May 4 for Steelhead Trout and August 27 to October 1 for Chinook Salmon. Radio tracking was conducted by vehicle or 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).

PIT Telemetry

Steelhead Trout and Chinook Salmon were tracked by means of PIT telemetry using a single pass-over PIT antenna at the resistivity counter site in 2015. IFR installed more sophisticated PIT arrays in the LBR in October 2015 to track Coho Salmon. Two pass-through and two pass-over PIT antennas were installed at the resistivity counter site to confirm the direction of movements of tagged fish. Two pass-through PIT antennas were installed at the Reach 3-4 break to determine direction of movement and reach-specific habitat use by tagged fish.

Using radio- and PIT- telemetry data, we calculated the time (in days) tagged fish took to migrate from release to the reach where fish likely spawned (hereafter, spawning reach). We also present migration rate (in km day^{-1}) to account for the different release sites and thus variable distances from release to the spawning reach.

External visual identification tags were not applied to study subjects in 2015 due to the inability in previous study years to locate tagged individuals in Reach 3 and 4. We use historic estimates of observer efficiency in the LBR to generate AUC-derived abundance estimates.

2.2.3 Visual Counts

Visual surveys followed methods used in previous assessments, where two observers walked in a downstream direction on the riverbank 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, Pink, Sockeye, and Coho Salmon in Reaches 3 and 4 (Figure 3). Surveys started on August 19 for the salmon species, and continued until November 26 when fish activity ceased based on streamwalk, telemetry and resistivity counter observations. Surveys for Steelhead Trout in previous years were deemed ineffective due to high turbidity and flows in the LBR; thus, visual surveys were not completed for Steelhead Trout in 2015.

2.2.4 Spawner Habitat Evaluation

We evaluated Chinook Salmon redds prior to and after high density Pink Salmon spawning to determine the effect of redd superimposition on Chinook Salmon redd structure. Generally, redd superimposition is thought to be a major source of salmon embryo mortality due to eggs being displaced and crushed by mobilized substrate (Hendry et al. 2004, Quinn 2011). Water depth, velocity and redd dimensions were measured at each redd. Twenty-two redds in Reach 3 were first located and sampled on September 8-10 and 16. Redds were marked with rebar and geo-referenced using a hand-held GPS receiver, and then re-sampled on September 29 following Pink Salmon spawning. We completed these surveys when flows from Terzaghi Dam were held constant at 3 $m^3 s^{-1}$ throughout the month (Figure 4) to negate the potential for flow changes to influence redd structure. Little effort was made to locate redds in Reach 4, as radio telemetry and streamwalk data indicated that Chinook Salmon spawn predominantly in Reach 3.

Specifically, water depth was measured at three locations around the redd (depression or leading edge, tail spill and adjacent), and velocities were measured adjacent to the redd and at the tail spill (Reibe et al. 2014). Measurements adjacent to the redd were assumed to be representative of stream conditions 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. Paired *t*-tests were used to compare the mean water depth, mean water velocity and dimensions of the 22 redds before and after Pink Salmon spawning. We also quantified redd characteristics as percent change, whereby a positive and negative percent change represents an increase and decrease (respectively) in water depth (m), water velocity ($m\ s^{-1}$) or redd dimension (m^2).

Sections of the LBR where high numbers of Chinook Salmon were observed spawning were sampled and assumed to represent preferred spawning habitat (i.e., not marginal habitats). Redd locations were then cross referenced with GIS habitat data collected by Coldstream Ecology (McHugh and Soverel 2016) to identify hydrological units and habitat classes where Chinook Salmon were spawning. Data collected by McHugh and Soverel (2016) are applicable to the location and physical habitat characteristics of Chinook Salmon redds assessed by IFR in 2014 and 2015. We determined the amount of spawning habitat (in hectares) available to Chinook Salmon in Reach 3 and 4 by only summarizing the BRGMON-1 3 $m^3\ s^{-1}$ habitat data that conforms to the water depth and velocity requirements reported in the literature (Collings et al. 1972, Vronskiy 1972) and observed from Chinook Salmon redds in Reach 3.
Steelhead Trout and Coho Salmon redds were not sampled in 2015 due to high flows and turbidity, which prohibited locating redds to measure physical habitat characteristics.

2.3 Analysis Methods

2.3.1 Area Under the Curve Estimates of Spawner Abundance

In 2015, 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 estimates obtained from radio telemetry. Abundance of Chinook and Coho Salmon in 2015 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) $$\hat{E} = \frac{\hat{C}_t}{l * v}$$

$\hat{E}$ 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 software.

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. We determined the date of death of tagged fish to be the first day of significant downstream movement (> 1 km), or the day that the fish ceased movement completely according to fixed telemetry and mobile tracking data. Chinook Salmon were not spaghetti tagged in 2014 or 2015, and thus observer efficiency could not be estimated. In 2015, the mean observer efficiency for Chinook Salmon (0.38) from the three years of study (2012-2014) was used in AUC estimation.

Residence time was estimated as the number of days post tagging that a tagged fish was observed moving in an upstream direction followed by either a large (> 1 km) directional movement downstream or remaining in place for several weeks after completing the upstream movement. 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 2). In 2015, the average residence time for Chinook Salmon from the three years of study (2012-2014) was used in AUC estimation.

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.

No historical data exist for observer efficiency or residence time. Mean and standard error of observer efficiency and residence time from 2012-2014 were used in the historical AUC modelling of both helicopter and streamwalk counts (Tables 2 & 3).

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. Coho Salmon were not radio tagged in 2015, as high turbidity precluded measurement of observer efficiency. Therefore, the mean observer efficiency and residence time from previous years were used in AUC modeling (Table 3).

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 efficiency and residence time from 2012 and 2013 radio tagging were used in the historical AUC modelling of Coho Salmon abundance (Table 3).

2.3.2 Salmon Resistivity Counter Enumeration

Abundance of Steelhead Trout, and Chinook, Pink and Coho Salmon were estimated using data from the resistivity counter following the methods described in McCubbing and Bison (2009) on the Deadman River (1999-2008). Briefly, spurious debris or wave action data (i.e., a large number of events over a short period of time on a single channel) were removed from raw datasets. Next, target species were identified using size cut-offs (see details below) and counter accuracy was estimated through video validation where data were available. Video data were collected throughout the migration period for Chinook and Coho Salmon using an infrared camera (Swann) connected to a battery-powered four channel DVR (Swann DVR). Video validation provided estimates of upstream and downstream counter accuracy, which were used to expand the number of up and down counts detected by the counter into abundance estimates. Finally, the total estimated abundance above the counter was calculated as:

(4) $$E = \sum_{t=1}^{k}\left(\frac{U_t}{q_{up}} - \frac{D_t}{q_{down}}\right) + \sum_{t=k}^{\infty}\left(\frac{U_t}{q_{up}}\right)$$

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, q_{up} is the counter accuracy for detecting upstream migrating fish, and q_{down} is the counter accuracy for detecting downstream migrating fish. k is defined as the day Steelhead Trout kelts begin moving in a downstream direction, and is estimated using movement data obtained through radio and PIT telemetry. We estimated k for Pink Salmon as we observed down counts greatly exceeding up counts (yielding a negative net up count) later in the migration when there was a mass die-off of spawned-out fish (see Results, Section 3.5.3). We did not estimate k for Chinook and Coho Salmon, as the relative proportion of downstream oriented spawned fish that are detected passing over the counter is low (< 1%). Therefore, we use Equation 5 to estimate abundance of Chinook and Coho Salmon above the counter:

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

where 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).

Steelhead Trout

Video data were not collected during the Steelhead Trout migration due to high turbidity and flow. Individual graphical traces for up and down counts were reviewed and compared to the counter records to generate channel-specific, counter accuracies (see Monitoring Approach, Section 2.2). Steelhead Trout abundance in 2015 was estimated using the raw counter data and subtracting the number of down counts from the total number of up counts over the migration period until the first observed kelting date by a radio-tagged Steelhead Trout.

Resistivity counter data were not collected for 13 days (May 6, 11, 13, 14, 18, 19, 21-26, 29) of the migration period due to power failure. We used a normal probability density function to predict daily net up counts when there was missing resistivity counter data (Braun et al. 2016). We estimated the parameters for the normal distribution (mean date of run timing [April 24], standard deviation [10.5 days] and a scale parameter [59]) of net up counts by fitting a normal probability density function to net up counts from April 9 to June 4. Our estimated scale parameter transforms probabilities into daily net up counts. Next, we used a least squares fitting method to minimize the sum of squares between the observed and predicted counts. We report two abundance estimates in the Results (Section 3.5.1): (1) using observed net up counts as well as predicted net up counts on days with missing counter data, and (2) using predicted net up counts alone (i.e., estimated scale parameter).

Chinook Salmon

Enumeration of Chinook Salmon in 2015 was complicated by a high abundance of co-migrating Pink Salmon. Due to an overlap in peak signal size (PSS), we could not simply apply a PSS cut-off to differentiate Chinook and Pink Salmon for the entirety of their overlapping run timing.

Table 4 outlines the methods used to generate daily estimates of Chinook Salmon abundance over the counter. We used a PSS cut-off of 50 (Melville et al. 2015) to differentiate Chinook Salmon and resident fish species (Bull Trout, Rainbow Trout) from August 22 to 27, 2015. Pink Salmon were not observed during weekly stream walks until September 3, however these visual surveys were not frequent enough to determine the date and time when Pink Salmon started to pass over the counter. We observed a significant increase in up counts on the resistivity counter on August 28, 2015 (i.e., n = 56 on August 27, n = 168 on August 28) and considered this to be the initial arrival timing of Pink Salmon at the resistivity counter site. Using video validation, we applied a daily species ratio of Chinook to Pink Salmon (Table 5) on up- and down-count data from August 28 to September 16, 2015.

We video validated the first 5 minutes (every hour) of counter data from September 2 to 16 to verify counter efficiency and species classification. Video recorded during daylight hours (07:00 – 19:00) was used to generate counter accuracy as we are confident that we observed all fish passing over the counter. Sixty-one Chinook Salmon and 1210 Pink Salmon were observed during video validation. We selected these date ranges based on when we had both video and counter data available.

Flows passing over Channel 4 (i.e., 2 cm water level) of the resistivity counter did not permit Chinook Salmon to pass. To corroborate this, no Chinook Salmon were observed passing over Channel 4 during video validation. Channel 3 was blocked to passage by stop logs. Consequently, we only included up and down counts from Channels 1 and 2 (on river left) to generate the abundance estimate of Chinook Salmon.

Pink Salmon

Pink Salmon passed over Channels 1, 2 and 4 of the resistivity counter from August 28 to October 8, 2015. No Pink Salmon were observed on video after October 8.

Table 4 outlines the methods used to generate daily estimates of Pink Salmon abundance over the counter. We applied a daily species ratio (Table 5) of Pink Salmon to Chinook Salmon on up- and down-count data from Channels 1 and 2 from August 28 to September 16, 2015. Counts after September 16 on Channels 1 and 2 were adjusted by counter accuracy (i.e., comparing video and counter data) alone. Counts from August 28 to October 8 on Channel 4 were assumed to be Pink Salmon and were adjusted by counter accuracy alone.

Coho Salmon

Resistivity counter data were not collected for 5 days of the migration period due to power failure: October 17-18, and 23-25. Video validation was used to generate PSS cut-offs between Coho Salmon and resident fish species on each channel for up and down counts.

We did not observe Pink Salmon on the video after October 8, and no Coho Salmon prior to October 8. Consequently, we considered the Coho Salmon migration period in 2015 to extend from October 9 to November 28.

Twenty-three and a half hours of video data were used to verify resistivity counter accuracy for Coho Salmon. Forty Coho Salmon and 14 resident fish were observed during the 23.5 hours of video validation. We video validated the first half hour (every two hours) of counter data from October 15-16, 20-21 and 30-31 to verify counter efficiency and species classification. We selected these date ranges based on peak migration timing of Coho Salmon in 2014 (Melville et al. 2015).

3.0 Results

3.1 Radio and PIT Telemetry

3.1.1 Steelhead Trout

Tag Application and Bio-sampling

Eighteen Steelhead Trout (3 males and 15 females) were angled and radio tagged from February 27 to April 19 at the Seton-Fraser and Bridge-Fraser confluences. Mean fork lengths of radio-tagged males and females were 784 mm (range: 835 to 935 mm) and 779 mm (range: 630 to 935 mm), respectively. Of the 18 radio tags, 13 were applied at the confluence of the Seton-Fraser confluence, and 5 were applied at the Bridge-Fraser confluence (Appendix 1).

Twelve Steelhead Trout (1 male and 11 females) were captured and PIT-tagged from October 15 to November 6 during angling for Coho Salmon at the Bridge-Fraser confluence. Mean fork lengths of the PIT-tagged females were 741 mm (range: 620 to 867 mm) (Appendix 1). None of these individuals were detected on the PIT arrays at the counter site and the Reach 3-4 break from October 2015 to April 2016.

Radio and PIT Telemetry

Of the 18 Steelhead Trout captured and tagged from February to April, ten individuals were detected by radio telemetry in the LBR: two spawned in Reach 3, and eight spawned in Reach 4 (Table 6). On average, radio-tagged fish took 32 days (range: 9 to 62 days) to migrate from release to the spawning reach (Table 6). Steelhead Trout exhibited a mean migration rate of 1.6 km day^{-1} (range: 0.7 to 4.1 km day^{-1}) from release to the spawning reach. One radio-tagged Steelhead Trout (Code 71) that was captured and tagged on March 19 at the Seton-Fraser confluence was not detected by radio telemetry (fixed and mobile) in the LBR, but was detected on the PIT antenna at the resistivity counter site on April 17. Considering the high detection efficiency of radio receivers in the LBR in 2015 (Table 7), we suspect that this individual regurgitated its radio transmitter sometime after release and prior to entry into the LBR.

Of the seven Steelhead Trout that did not enter the LBR, five individuals were detected in the Seton River on the radio receiver at the Lower Spawning Channel. Two of these five Steelhead Trout (Codes 46 and 50) were detected entering the Lower Spawning Channel by the single PIT antenna. Finally, one of these four individuals (Code 67) was detected on the two-antenna PIT array in the Seton Dam fishway and successfully ascended the structure on April 29.

3.1.2 Chinook Salmon

Tag Application and Bio-sampling

Nineteen Chinook Salmon (7 males and 12 females) were captured and radio tagged from August 19 to September 4 at the Yalakom-Bridge confluence. Mean fork lengths of radio-tagged males and females were 783 mm (range: 570 to 1000 mm) and 759 mm (range: 590 to 930 mm), respectively (Appendix 1).

Radio Telemetry

Of the 19 Chinook Salmon captured and tagged at the Yalakom-Bridge confluence, 15 individuals moved upstream in the LBR: 14 spawned in Reach 3, and one spawned in Reach 4 (Table 8). On average, radio-tagged fish took 6 days (range: 0 to 14 days) to migrate from release to the spawning reach (Table 8). Chinook Salmon exhibited a mean migration rate of 0.20 km day^{-1} (range: 0.03 to 1.7 km day^{-1}) from release to the spawning reach. Three radio-tagged Chinook Salmon moved downstream towards the Fraser River and a determination of spawning location was not possible. Of the 19 radio-tagged Chinook Salmon, one individual was detected at Station #1 (Figure 2) and represents the only tagged fish to have moved downstream following tagging.

3.1.3 Coho Salmon

Tag Application and Bio-sampling

Forty-eight Coho Salmon (20 males and 28 females) were captured and PIT tagged from October 15 to November 10. Mean fork lengths of PIT-tagged males and females were 599 mm (range: 460 to 715 mm) and 541 mm (range: 410 to 680 mm), respectively (Appendix 1).

PIT Telemetry

Of the 48 Coho Salmon captured and tagged in the LBR, 14 individuals moved upstream in the LBR: six spawned in Reach 3, and eight spawned in Reach 4 (Table 9). On average, PIT-tagged fish took 17 days (range: 1 to 38 days) to migrate from release to their spawning reach (Table 9). Coho Salmon exhibited a mean migration rate of 1.7 km day^{-1} (range: 0.1 to 3.4 km day^{-1}) from release to the spawning reach.

Of the 34 Coho Salmon that did not enter the LBR, five individuals were detected on PIT readers in the Seton River: (1) one fish (Code 900_230000010015) entered the Lower Spawning Channel on November 9 and exited on November 25 – this fish likely spawned in the channel; (2) two fish (Codes 183225801 and 183225445) passed Seton Dam on October 18 and 20, respectively; (3) one fish (Code 183227082) was detected at the entrance of the Seton Dam fishway on November 11 and later entered the Upper Spawning Channel on November 12; and (4) one fish (Code 183225362) entered the Upper Spawning Channel on October 29. We assume the 34 Coho Salmon that did not enter the LBR to have continued on to upstream tributaries of the Fraser River.

3.2 Visual Surveys

3.2.1 Steelhead Trout

Stream walks were not conducted for Steelhead Trout in 2015.

3.2.2 Chinook Salmon

Visual counts of Chinook Salmon were conducted from August 19 to October 1, at which point spawning was assessed to be complete and few individuals (5) were observed. Fish were first observed holding on August 19 at the Yalakom River confluence, with peak live fish count (45 fish) observed on September 3. The majority of fish were observed in streamwalk section 1 (Appendix 2) between the Yalakom River and Hell Creek (31 fish). Relative abundance of spawners was highest in streamwalk section 1 (Yalakom River to 28.8 rkm), where counts represented 62% of total counts, and lowest for section 6 where counts represented 0% of total counts (Appendix 2).

Water visibility was adequate (0.2 to 0.7 m) for Chinook Salmon counting throughout the survey (Appendix 2).

3.2.3 Coho Salmon

Visual counts of Coho Salmon started on October 29 – three weeks later than in previous study years. Surveys were conducted until November 26, at which point spawning was assessed to be complete and few individuals (6) were observed. We observed a peak live fish count (31 fish) on November 5. Most fish were observed above 39.3 rkm in streamwalk section 8 between November 5 and 19 (Appendix 2). Relative abundance of spawners was highest in streamwalk section 8 (39.3 rkm to Terzaghi Dam), where counts represented 62% of total counts, and lowest for sections 1 to 3 where counts represented 1% of total counts (Appendix 2).

Water visibility was adequate (0.3 to 1.0 m) throughout the survey (Appendix 2).

3.2.4 Sockeye Salmon

Sockeye Salmon were visually counted from August 19 to October 1, and were in low abundance (152 individuals total). Peak count was 39 fish on September 10, and decreased to 0 fish on October 29. Most (66%) of the spawning observed on streamwalks was located in streamwalk section 8 below Terzaghi Dam (Appendix 2).

Water visibility was adequate (0.2 to 1.0 m) throughout the survey (Appendix 2).

3.2.5 Pink Salmon

Pink Salmon were visually counted from August 27 to October 1, and were in high abundance (3877 individuals total). Peak count was 1496 fish on September 17, and decreased to 234 fish on October 1. Most (66%) of the spawning observed on stream walks was located between Hell Creek and the resistivity counter site (26.0 to 28.8 rkm) (Appendix 2).

Water visibility was adequate (0.2 to 1.0 m) throughout the survey (Appendix 2).

3.3 Spawner Habitat Evaluation

3.3.1 Superimposition of Chinook Salmon Redds

Discharge from Terzaghi Dam remained constant (3 $m^3 s^{-1}$) throughout the survey period (Figure 4), negating the potential effect of flow changes on redd structure. Further, we found no differences in water depth from the bed to water surface (t_{21} = -1.17, P = 0.26) and water surface to the top of the marker rebar (t_{21} = 0.83, P = 0.42) before and after Pink Salmon spawning surveys.

Tailspill depth significantly increased (t_{21} = -5.20, $P = 3.71 \times 10^{-5}$) following the spawning activity of Pink Salmon, causing a significant decrease (t_{21} = 3.67, $P = 1.42 \times 10^{-3}$) in tailspill velocity (Figure 5). Redd width significantly decreased (t_{21} = 2.87, $P = 9.14 \times 10^{-3}$) after Pink Salmon spawning. No other redd characteristics showed significant changes between the two surveys (leading edge depth: t_{21} = -0.38, P = 0.71; leading edge velocity: t_{21} = 0.82, P = 0.42; adjacent depth: t_{21} = -1.09, P = 0.29; adjacent velocity: t_{21} = 1.62, P = 0.12; redd length: t_{21} = 0.44, P = 0.66).

3.3.2 Chinook Salmon Redd Distribution

Eighty-six Chinook Salmon redds were located in Reach 3 of the LBR in 2014 and 2015. Two thirds (60-67%) of the redds were located in run habitat, and one third (30-40%) were located in riffle habitat (Table 10). Chinook Salmon redds were located in two major sections of Reach 3 (Figure 6): (1) Yalakom River (25.5 river km) to Hell Creek (28.8 river km) (Figures 7 and 8), and (3) Cobra Creek (34.4 river km) (Figure 9).

3.3.3 BRGMON-1 Habitat Assessment in the LBR at 3 $m^3 s^{-1}$

BRGMON-1 conducted a detailed habitat assessment of Reaches 3 and 4 (Figure 10) of the LBR in 2015 (McHugh and Soverel 2016). Data collected by McHugh and Soverel (2016) are applicable to the location and physical habitat characteristics of Chinook Salmon redds assessed by IFR in 2014 and 2015. Table 11 shows the total available spawning habitat (in hectares) for Chinook Salmon at 3 $m^3 s^{-1}$ based on water depths and velocities reported in the literature (depth: ≥ 0.3 m [Collings et al. 1972]; velocity: 0.2 – 1.5 m s^{-1} [Vronskiy 1972]) and observed from actual Chinook Salmon redds in Reach 3 (depth: ≥ 0.2 m [Figure 11]; velocity: 0.3 – 1.1 m s^{-1} [Figure 12]). Generally, Chinook Salmon in Reach 3 of the LBR appear to prefer similar water depths and velocities as to what is stated in the literature (Collings et al. 1972, Vronskiy 1972).

We present spawning habitat area in runs and riffles as Chinook Salmon predominantly spawn in these habitat units in the LBR (Table 11). In addition, we present total available spawning habitat in any habitat class (i.e., pool, run, riffle, cascade, side channel) that meets the water depth and velocity requirements stated above in case habitat units other than runs and riffles conform to the spawning habitat criteria (e.g., pools, Table 11). Using spawning habitat requirements in the literature, we found that there is approximately 20.7 ha and 4.4 ha of suitable spawning habitat in Reach 3 and 4 (respectively) under the 3.0 $m^3 s^{-1}$ hydrograph, or 25.1 ha in total. Further, this area of suitable spawning habitat represents 88%, 59% and 81% of the total available habitat in Reach 3 and 4 (Table 11), respectively. Similarly, using spawning habitat requirements from actual Chinook Salmon redds in the LBR, we found that there is approximately 19.2 ha (82% of total) and 3.7 ha (49% of total) of suitable spawning habitat in Reach 3 and 4 (respectively), or 22.9 ha (74% of total) in total.

3.4 Abundance Estimates using AUC

3.4.1 Chinook Salmon

2015

Using an observer efficiency value of 0.38, a residence time of 12.3 days, and a survey start date of August 12, we calculate the maximum likelihood estimate of 182 Chinook (95% confidence limits: 89-274) in 2015 between the Yalakom River and Terzaghi Dam (Figure 13 and Table 12).

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 period varied from a minimum estimate of 23 fish in 2009 to a maximum of 3,479 in 2004 (Figure 14 and Table 12).

3.4.1 Coho Salmon

2015

Using an observer efficiency value of 0.26, a residence time of 17.5 days, and a survey start date of October 15, we calculated the maximum likelihood estimate of 162 Coho (95% confidence limits: 139-184) in 2015 between the Yalakom River and Terzaghi Dam (Figure 15 and Table 13).

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 period varied from a minimum estimate of 76 fish in 1999 to a maximum of 3,422 in 2011 (Figure 16).

3.5 Abundance Estimates using Resistivity Counter Detections

3.5.1 Steelhead Trout

Video Validation

No video validation was undertaken in 2015.

Counter Estimate

Steelhead Trout were detected passing over the resistivity counter from April 9 to June 4, 2015 (Figure 17). Radio-tagged Steelhead Trout kelted between May 10 and May 21, and thus any down counts observed after May 10 were not included in generating the estimate of net up counts. Peak counts were observed from mid April to mid May (Figure 17).

Using observed net up counts (66 individuals) as well as predicted net up counts (7 individuals) on days with missing counter data, we estimate that 73 Steelhead Trout passed upstream of the counter. Using predicted net up counts alone (solid grey line, Figure 17), the normal probability density function estimated that 59 Steelhead Trout passed upstream of the counter.

3.5.2 Chinook Salmon

Video Validation

Up count accuracy was 85% (404/479) and 97% (143/146) on Channels 1 and 2, respectively. Too few fish (13 individuals) were observed passing down over the counter (Channels 1 and 2) to generate an accurate down count accuracy. Consequently, we applied the down count accuracy of 81% from the Deadman River (Crump weir sensor; McCubbing and Ignace 2000) to Channels 1 and 2.

Video validation identified 93% (1096/1181) of the upstream migrating fish as Pink Salmon, 4% (44/1181) as Chinook Salmon, and 3% (30/1181) as Bull Trout and Rainbow Trout.

Counter Estimate

Chinook Salmon were detected passing over the resistivity counter from August 22 to September 15, 2015 (Figure 18A). Peak counts were observed the last week of August and first week of September (Figure 18A); this is consistent with the date range Chinook Salmon were angled from the Bridge – Yalakom confluence (August 19 to September 4), peak live count on September 3 (Appendix 2) and migration timing observed in previous study years (Melville et al. 2015).

Five hundred and forty-two individuals passed upstream and 61 individuals passed downstream of the counter, yielding an abundance estimate of 481 Chinook Salmon upstream of the counter.

3.5.3 Pink Salmon

Video Validation

We used the same up and down count accuracies on Channels 1 and 2 for Pink Salmon as we did for Chinook Salmon (see Section 3.5.2). Up count accuracy was 85% (122/143) on Channel 4. We applied a down count accuracy of 81% for Channel 4.

Counter Estimate

Pink Salmon were detected passing over the resistivity counter from August 28 to October 9, 2015 (Figure 19A). Peak counts were observed between September 6 and 20 (Figure 19A). Down counts started to greatly exceed up counts (yielding a negative net up count) on September 26; this phenomenon likely corresponds to a mass die-off of spawned-out Pink Salmon. Consequently, we present only up counts for Pink Salmon from September 26 to October 8 (Figure 19A, B). 45,938 individuals passed upstream and 5,064 individuals passed downstream of the counter, yielding an abundance estimate of 40,874 individuals upstream of the counter.

3.5.4 Coho Salmon

Video Validation

Up and down count accuracies for Channels 1, 2 and 3 were 100%, as viewing the 21,730 graphical traces of each counter record served as a form of pseudo-validation. 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 Channel 1 were both 70. Cut-offs for up and down counts for Channel 2 were 72 and 62, respectively. Cut-offs for up and down counts for Channel 3 were both 95.

Counter Estimate

Coho Salmon were detected passing over the resistivity counter from October 9 to November 28, 2015 (Figure 20A). Peak counts were observed from October 28 to November 5 (Figure 20A); this is consistent with the date range PIT-tagged Coho Salmon were detected at the resistivity counter (October 29 to November 10) and migration timing observed in previous study years (Melville et al. 2015).

Six hundred and ninety-three individuals passed upstream and 127 individuals passed downstream of the counter, yielding an abundance estimate of 566 individuals upstream of the counter. We were unable to collect resistivity counter data for five days (October 17-18, 23-25) of the migration period.

4.0 Discussion

In 2015, the primary goal of BRGMON-3 was to provide reliable, unbiased and precise estimates of salmonid spawner abundance along with behavioural data on spawning distribution and timing. In this report, we build on a 20-year dataset and create historical estimates of abundance so that time series data on river discharge and juvenile production can be compared without the confounding effects of adult seeding levels. We explain the shortcomings in this evaluation at present, and the need for ongoing data collection to refine these new estimates. Using data collected in BRGMON-1 and BRGMON-3, we will ultimately evaluate the egg and juvenile seeding levels between the Yalakom River confluence and Terzaghi Dam (Reaches 3 and 4), the upper limit of anadromous fish spawning. Reaches 3 and 4 are predominantly regulated by discharges through Terzaghi Dam and minor tributary influences.

Abundance and behavioural data were collected for Steelhead Trout, and Chinook, Coho and Pink Salmon in 2015. Nineteen Chinook Salmon and 18 Steelhead Trout were radio-tagged, and 48 Coho Salmon were PIT-tagged for continued data collection on spawning distribution and residence time. We installed, and continue to operate, an electronic resistivity counter in October 2013 approximately 200 m upstream of the Yalakom – Bridge River confluence to enumerate all target species. Stream walk data were collected in the same manner as previous years (pre-WUP monitoring, DFO data on file, McCubbing et al. 2013).

Migration of Steelhead Trout over the resistivity counter was evaluated for the second year in 2015. Prior to the first year of BRGMON-3, little was known about the migration ecology of Steelhead Trout in the LBR. In 2001, a study by Webb et al. (2002) indicated that 10 of the 13 radio-tagged fish migrated above the Yalakom River prior to May 5. We confirmed this in 2014 (Melville et al. 2015) and 2015 (current study), when a similar migration pattern was observed in radio-tagged individuals. Tagged Steelhead Trout spawned predominantly in Reach 4 of the LBR, migrating from release to assumed spawning reach at an average rate of 1.6 km day^{-1}. None of the 12 Steelhead Trout PIT tagged in October and November 2015 during angling for Coho Salmon near the confluence with the Fraser River were detected on PIT antennas in the Bridge and Seton Watersheds at the time of writing this report. We suspect that these individuals likely migrated further up the Fraser River to other watersheds (e.g., Chilcotin River).

Due to higher discharges throughout the migration period (up to 15 $m^3 s^{-1}$; Figure 4) and expected turbid waters, video validation was not attempted in 2015. Due to the lack of video validation, up and down count accuracies for the resistivity counter during Steelhead Trout migration could not be determined and correction factors for up and down counts could not be calculated. Steelhead Trout spawner abundance data in 2015 from the resistivity counter are provisional, as validation of species type passing over the counter is not yet available for the LBR under the current discharge regime and other validation techniques (e.g., sonar) will be tested in the future. We detected Steelhead Trout passing over the counter from April 9 to June 4, with peak counts occurring between mid April and mid May. Our abundance estimate using the predicted net up counts alone was lower than when using the observed net up counts and the predicted net up counts on days with missing data. We believe that this is due to the high variability in daily net up counts throughout the run, especially later in the migration period when the model predicted truncated counts but the counter actually observed up to three fish per day. In other words, the model was poor at predicting net up counts after May 10 because it was a poor fit to the latter part of the migration. According to the model, we missed 7 individuals during the 13 days of missing data; these 7 individuals account for approximately 10% of the spawner abundance in 2015.

Efforts to tag Chinook Salmon in Reach 1 of the LBR, that would allow for the production of a full river abundance estimate, continued to be unsuccessful despite almost daily visual checks in suitable angling locations for migrant fish. Unsuccessful fishing for Chinook Salmon in Reach 1 from 2011 to 2015 is likely related to low population abundance and a short duration of residence in the lower reaches of the LBR. Fish that are captured during aboriginal fisheries in the Fraser River at the mouth of the Bridge River are poor candidates for tagging, as the majority of individuals are not likely destined to spawn in the LBR, instead migrating to upstream tributaries of the Fraser River. Based on these observations, evaluation of full river abundance estimates may remain a challenging endeavour for Chinook at current abundance numbers without the use of alternate methods outside of the scope of this project.

Reach 3 and 4 Chinook Salmon AUC spawner abundances were estimated at 182 fish in 2015, 591 in 2014, 168 in 2013, 364 fish in 2012 and 92 fish in 2011, representing a five-fold variation in estimates among years (Table 12). In 2015, the resistivity counter estimate for Chinook Salmon was 478 individuals, indicating that the AUC-derived estimate of abundance was biased low (2.5 fold lower). We believe that this abundance estimate is biased low due to an inflated observer efficiency generated from few tagged individuals per study year. In other words, the observer efficiency that we have used in AUC calculations is in fact higher than what we believe observer efficiency in Reach 3 and 4 of the Bridge River to be (as low as 0.28 in 2014). Tagged Chinook Salmon spawned predominantly in Reach 3 of the LBR, migrating from release to assumed spawning reach at an average rate of 0.2 km day^{-1}. We believe this reduced migration rate is the result of capture location (i.e., Reach 2-3 break; Yalakom River), where individuals are preparing for spawning and selecting a potential redd site.

In 2015, an additional goal of the project was to evaluate the quantity and quality of Chinook Salmon spawning habitat as it relates to spawner abundance. Similar to 2014, we collected information on habitat requirements – water depth, velocity, and dominant substrate – in which Chinook Salmon spawn in the LBR. In addition, we recorded habitat characteristics prior to and after high density Pink Salmon spawning to examine the potential effect(s) of redd superimposition. Little scientific research has been directed towards understanding the effects of redd superimposition; however, there is convincing evidence that eggs become displaced due to the digging activity of females, subsequently causing high embryo mortality (Hendry et al. 2004). We found significant effects of Pink Salmon spawning on redd structure: Chinook Salmon redds became narrower and tailspill water depth increased, causing a subsequent reduction in tailspill water velocity. It is unknown whether changes in tailspill water depth and velocity would have an effect on embryo survival; however, considering the detectable reduction in redd width and that we observed Pink Salmon redds within the surveyed Chinook Salmon redds, it is likely that Chinook Salmon eggs were displaced and lost due to the digging activity of female Pink Salmon. Future efforts to estimate egg-to-fry survival under BRGMON-1 could be confounded by egg displacement through redd superimposition. In addition, we note that larger fish dig larger redds and can mobilize larger substrate compared to smaller fish (Riebe et al. 2014); thus, we would expect the effects of redd superimposition by Pink Salmon to be smaller than by other Chinook Salmon (Hendry et al. 2004). Overall, understanding the population-level effects of Pink Salmon spawning activity on the LBR Chinook Salmon population is currently unknown, and may warrant further investigation (i.e., starting in 2017).

With two years of data on redd location and four years of data on spawning distribution, we are confident that Chinook Salmon spawn predominantly in Reach 3 of the LBR. Overlaying the location of the 86 redds sampled in 2014 and 2015 with the habitat assessment of Reaches 3 and 4 under Terzaghi Dam discharge of 3 $m^3 \cdot s^{-1}$ (McHugh and Soverel 2016) revealed two major areas of Chinook Salmon spawning. More specifically, these fish seem to prefer the micro-habitat conditions within runs and riffles, whereby the preferred water depths and velocities are consistent with what is reported in the literature (Collings et al. 1972, Vronskiy 1972). We applied water depth and velocity requirements to Reach 3 and 4 habitat units under the 3.0 $m^3 \cdot s^{-1}$ flows that Chinook Salmon spawn, yielding an estimate of > 20 ha (74-81% of total available habitat) of habitat available to spawning. Consistent with spawning distribution findings from radio telemetry and streamwalk surveys, we found that a significantly higher proportion of the total available habitat in Reach 3 was suitable for spawning compared to Reach 4. It is possible that Chinook Salmon are spawning predominately in Reach 3 simply because the habitat characteristics are more aligned with their preferred spawning habitat. We highlight, however, that these criteria are spatially coarse, where a single or average of multiple water depth and velocity measurements was intended to represent an entire habitat unit. McHugh and Soverel (2016) did not collect any data on substrate characteristics during their habitat assessment. Inclusion of such data (substrate between 13 and 102 mm; reviewed in Bjornn and Reiser 1991) would likely further reduce the spawning habitat available to Chinook Salmon. Regardless, there appears to be spawning habitat of sufficient quality and quantity available to Chinook Salmon. We note that the quantity of spawning habitat likely does not limit fry production.

Efforts to PIT-tag Coho Salmon in Reaches 1 and 2 of the LBR were successful in 2015 (48 in 2015, 33 in 2014, 70 in 2013, 32 in 2012 and 18 in 2011). We interpret the increase in fish capture since 2011 to angler experience and increased effort. Across all study years, fish were tagged over a period of approximately 4 weeks. Reach 3 and 4 Coho Salmon AUC spawner abundances were estimated to range from 162 in 2015 to 3,422 in 2011 (Table 13). Precision of these data is unclear, as observer efficiency is low due to cryptic behaviours prior to, and perhaps during, spawning. Our calculated residence time of 13 days in 2015 is consistent with those reported in other interior BC watersheds (10 days in South Thompson, and 12 days in North Thompson; R. Bailey, personal communication; 10.6 days in the Nechako River; Nechako Fisheries Conservation Program). Efforts to increase confidence in observer efficiency and residence time data will be undertaken by PIT-tagging fish and using daily derived abundance estimates from the resistivity counter facility. In 2015, the resistivity counter estimate for Coho Salmon was 566 individuals, indicating that the AUC-derived estimate of abundance was biased low (3.5 fold lower). Tagged Coho Salmon spawned in both Reach 3 and 4 of the LBR, migrating from release to spawning reach at an average rate of 1.7 km day^{-1}.

With the fish counter installation now complete, enumeration of Steelhead Trout, and Chinook, Coho, Sockeye and Pink Salmon will be conducted annually at this site. Counts are being validated and are expected to be within 10% of true abundance (McCubbing and Ignace 2000, McCubbing and Gillespie 2008). Once these data are sufficiently described, comparison between counter- and AUC-derived estimates of abundance will be completed and visual counts may cease as the counter will provide improved and more accurate estimates of abundance at reduced cost compared to traditional methods (McCubbing and Espinoza 2012). Data collected during the period when both methods are being used will allow for improved back-calculations of historical abundances based on archived visual count data, five years of which was collected during the previous WUP discharge regime (annual water budget of 3 $m^3 s^{-1}$). Back calculating will require multiple years (5 to 10 years) of observer efficiency data, which may be difficult to obtain based on turbidity conditions experienced during Steelhead Trout, and Chinook and Coho Salmon migration in the LBR. Residence time data will provide an accurate evaluation of population trends based on current observed annual changes in these parameters and their relationship to fish density and water turbidity.

5.0 Summary and Recommendations

Data presented herein summarizes the findings of BRGMON-3 in 2015 under the 6 $m^3 \cdot s^{-1}$/y hydrograph. At the time of writing this report, however, there was a change in the proposed hydrograph in the lower Bridge River flow in 2016. Consequently, we do not present recommendations in this report as the flow regime, terms of reference and scope of work have yet to be finalized for future 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, 2015.

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 Fixed Radio Telemetry Station # 2 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. Residence time of tagged fish in the lower Bridge River.

Year	Species	N	Mean residence time (days)
2011	Coho	NA	NA
2012	Coho	13	16
2013	Coho	18	19
2015	Coho	10	13
2012	Chinook	5	10
2013	Chinook	22	11
2014	Chinook	8	12
2014	Steelhead	8	17
2015	Steelhead	10	15

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

Year	Species	Observer efficiency
2011	Coho	NA
2012	Coho	25%
2013	Coho	27%
2012	Chinook	58%
2013	Chinook	28%
2014	Chinook	0%
2015	Chinook	NA*
2014	Steelhead	27%
2015	Steelhead	NA*

*Observer efficiency could not be computed in 2015 due to the absence of external visual identification tags.

Table 4. Methods used to correct resistivity counter records for Chinook and Pink Salmon.

Date range	**Method**	
	Chinook	Pink
August 22 to 27	PSS cut-off of 50 to exclude resident fish, counter accuracy[2]	NA
August 28 to September 16	Daily species ratio[1], counter accuracy[2]	Daily species ratio[1], counter accuracy[2]
September 17 to October 8	NA	Counter accuracy[2]

[1]Daily species (i.e., Chinook:Pink) ratio applied to resistivity counter data (see Table 5).
[2]See Sections 3.5.2 and 3.5.3.

Table 5. Daily ratio of Chinook Salmon to Pink Salmon observed during video validation.

Date	No. Chinook	No. Pink	Chinook:Pink
2015-08-28	NA	NA	0.12[1]
2015-08-29	NA	NA	0.12[1]
2015-08-30	NA	NA	0.12[1]
2015-08-31	NA	NA	0.12[1]
2015-09-01	NA	NA	0.12[1]
2015-09-02	5	43	0.12
2015-09-03	NA	NA	0.09
2015-09-04	2	39	0.05
2015-09-05	7	47	0.15
2015-09-06	4	68	0.06
2015-09-07	3	113	0.03
2015-09-08	2	111	0.02
2015-09-09	1	144	0.01
2015-09-10	1	75	0.01
2015-09-11	NA	NA	0.01[2]
2015-09-12	NA	NA	0.01[2]
2015-09-13	NA	NA	0.01[2]
2015-09-14	0	179	0
2015-09-15	1	110	0.01

[1]Daily Chinook:Pink ratio from September 2 was applied to counter data from August 28 to September 1
[2]Daily Chinook:Pink ratio from September 11 was applied to counter data from September 11 to 13

Table 6. Spawning distribution of radio-tagged Steelhead Tout in the lower Bridge River in 2015.

Tag no.	Tagging location	Tagging rkm	Assumed spawning reach	Days to migrate to spawning reach	Migration rate (km day^{-1})
31	Bridge - Fraser Confluence	0.0	Reach 4	9	4.1
32	Seton – Fraser Confluence	NA	Reach 4	62	0.7
41	Seton – Fraser Confluence	NA	Reach 3	22	1.6
44	Bridge – Fraser Confluence	0.0	Reach 4	30	1.2
47	Bridge – Fraser Confluence	0.0	Reach 4	19	2.0
58	Bridge – Fraser Confluence	0.0	Reach 4	24	1.6
60	Seton – Fraser Confluence	NA	Reach 4	36	1.3
65	Seton – Fraser Confluence	NA	Reach 3	47	0.7
66	Seton – Fraser Confluence	NA	Reach 4	36	1.3
75	Seton – Fraser Confluence	NA	Reach 4	37	1.2
			Mean	32	1.6
			Minimum	9	0.7
			Maximum	62	4.1

Table 7. Detection efficiency of fixed radio receivers and PIT-telemetry arrays.

	Location of receiver or array	**Detection efficiency**
Radio telemetry (Steelhead and Chinook)	Station 1	92% (12/13)
	Station 3	100% (29/29)
	Station 4	100% (9/9)
PIT telemetry (Coho)	Counter Site$_2$	100% (14/14)
	Reach 3 – 4 Break$_2$	100% (8/8)

Subscripted numbers represent the quantity of PIT antennas pooled to calculate the detection efficiencies. Numbers in parentheses represent the number of individuals detected out of the total number of individuals known to have passed through PIT antennas.

Table 8. Spawning distribution of radio-tagged Chinook Salmon in the lower Bridge River in 2015.

Tag no.	Tagging location	Tagging river km	Assumed spawning reach	Days to migrate to spawning reach	Migration rate (km day^{-1})
37	Bridge – Yalakom Confluence	25.5	Reach 3	14	0.03
44	Bridge – Yalakom Confluence	25.5	Reach 3	6	0.07
50	Bridge – Yalakom Confluence	25.5	Reach 3	4	0.10
1041	Bridge – Yalakom Confluence	25.5	Reach 3	8	0.05
1042	Bridge – Yalakom Confluence	25.5	Reach 3	8	0.05
1043	Bridge – Yalakom Confluence	25.5	Reach 3	9	0.04
1048	Bridge – Yalakom Confluence	25.5	Reach 3	4	0.10
1049	Bridge – Yalakom Confluence	25.5	Reach 3	3	0.13
1052	Bridge – Yalakom Confluence	25.5	Reach 3	0	NA
1053	Bridge – Yalakom Confluence	25.5	Reach 3	0	NA
1065	Bridge – Yalakom Confluence	25.5	Reach 3	5	0.08
1066	Bridge – Yalakom Confluence	25.5	Reach 3	7	0.06
1067	Bridge – Yalakom Confluence	25.5	Reach 3	9	0.04
1068	Bridge – Yalakom Confluence	25.5	Reach 4	7	1.69
1069	Bridge – Yalakom Confluence	25.5	Reach 3	3	0.13
			Mean	6	0.20
			Minimum	0	0.03
			Maximum	14	1.70

Table 9. Spawning distribution of PIT-tagged Coho Salmon in the lower Bridge River in 2015.

Tag no.	Tagging location	Tagging river km	Assumed spawning reach	Days to migrate to spawning reach	Migration rate (km day^{-1})
900_230000010001	Bridge – Fraser Confluence	0.0	Reach 3	13	2.0
183226242	Bridge – Fraser Confluence	0.0	Reach 4	13	2.9
183225617	Bridge – Fraser Confluence	0.0	Reach 4	16	2.3
183227052	Bridge – Yalakom Confluence	25.5	Reach 3	1	0.4
183226632	Bridge – Fraser Confluence	0.0	Reach 4	11	3.4
183226534	Bridge River Bridge	0.5	Reach 4	38	1.0
900_230000010025	Bridge – Yalakom Confluence	25.5	Reach 3	5	0.1
183225134	Bridge – Fraser Confluence	0.0	Reach 3	21	1.2
183225189	Bridge – Fraser Confluence	0.0	Reach 4	25	1.5
183227045	Bridge – Fraser Confluence	0.0	Reach 4	22	1.7
183225388	Bridge River Bridge	0.5	Reach 3	15	1.7
900_230000018150	Bridge – Fraser Confluence	0.0	Reach 4	33	1.1
183225262	Bridge – Fraser Confluence	0.0	Reach 4	11	3.4
183225892	Bridge – Fraser Confluence	0.0	Reach 3	20	1.3
			Mean	17	1.7
			Minimum	1	0.1
			Maximum	38	3.4

Table 10. 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%)

Table 11. Total available spawning habitat (hectares, ha) for Chinook Salmon at 3 $m^3 s^{-1}$ in the lower Bridge River based on depths and velocities reported in the literature and observed from actual Chinook Salmon redds. Numbers in parentheses represent the percentage of suitable spawning habitat out of the total available habitat.

Source	**Reach**	**Habitat Class**		
		Run (ha)	Riffle (ha)	All (ha)[1]
Literature[2]	3	7.12	12.15	20.70 (88%)
	4	1.55	2.27	4.43 (59%)
	Total	8.67	14.42	25.12 (81%)
Lower Bridge River Chinook Redds[3]	3	6.66	12.15	19.20 (82%)
	4	1.23	2.27	3.69 (49%)
	Total	7.89	14.42	22.89 (74%)

[1]Any habitat class (pool, run, riffle, cascade, side channel) that meets the depth and velocity requirements outlined below.
[2]Literature-reported depth (≥ 0.3 m; Collings et al. 1972) and velocity (0.2 – 1.5 m s^{-1}; Vronskiy 1972) requirements for Chinook Salmon to spawn.
[3]Depth (≥ 0.2 m) and velocity (0.3 – 1.1 m s^{-1}) requirements observed at Chinook Salmon redds in the LBR in 2014 and 2015 (Figures 11 and 12).

Table 12. Chinook AUC abundance estimates for the lower Bridge River from 1993-2015.

Year	o.e.	o.e. SE	Residence time	Residence time SE	Abundance	Abundance SE	Method of estimation	Lower 95 CI	Upper 95 CI
1993	NA	NA	NA	NA	151	NA	fence count	151	151
1994	NA	NA	NA	NA	550	NA	fence count	550	550
1995	NA	NA	NA	NA	851	NA	fence count	851	851
1996	NA	NA	NA	NA	1100	NA	fence count	1100	1100
1997	0.38	0.1	12.3	1.86	2246	1651	visual helicopter	-991	5482
1998	0.38	0.1	12.3	1.86	978	53	visual helicopter	873	1083
1999	0.38	0.1	12.3	1.86	2885	471	visual helicopter	1961	3809
2001	0.38	0.1	12.3	1.86	1999	940	visual helicopter	157	3841
2004	0.38	0.1	12.3	1.86	3479	802	visual helicopter	1907	5052
2005	0.38	0.1	12.3	1.86	662	178	visual streamwalk	313	1010
2006	0.38	0.1	12.3	1.86	447	54	visual streamwalk	341	553
2007	0.38	0.1	12.3	1.86	346	70	visual streamwalk	209	483
2008	0.38	0.1	12.3	1.86	184	92	visual streamwalk	4	364
2009	0.38	0.1	12.3	1.86	23	5	visual streamwalk	14	32
2010	0.38	0.1	12.3	1.86	233	35	visual streamwalk	163	302
2011	0.38	0.1	12.3	1.86	92	25	visual streamwalk	42	142
2012	0.58	0.1	10	1.86	364	70	visual streamwalk	227	501
2013	0.28	0.1	11	1.86	168	32	visual streamwalk	105	230
2014	0.28	0.1	12	1.86	591	105	visual streamwalk	386	796
2015	0.38	0.1	12.3	1.86	182	47	visual streamwalk	89	274

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

Table 13. Coho AUC abundance estimates for the lower Bridge River from 2011-2015.

Year	o.e.	o.e. SE	Residence time	Residence time SE	Abundance	Abundance SE	Method of estimation	Lower 95 CI	Upper 95 CI
1997	0.26	0.01	17.5	1.5	576	1319	visual helicopter	-2008	3161
1998	0.26	0.01	17.5	1.5	1004	356	visual helicopter	307	1701
1999	0.26	0.01	17.5	1.5	76	NA	visual helicopter	NA	NA
2001	0.26	0.01	17.5	1.5	961	67	visual helicopter	830	1092
2003	0.26	0.01	17.5	1.5	1132	15	visual helicopter	1102	1162
2004	0.26	0.01	17.5	1.5	217	40	visual helicopter	138	296
2005	0.26	0.01	17.5	1.5	688	87	visual streamwalk	518	858
2006	0.26	0.01	17.5	1.5	627	76	visual streamwalk	478	777
2008	0.26	0.01	17.5	1.5	95	11	visual streamwalk	74	116
2009	0.26	0.01	17.5	1.5	1490	155	visual streamwalk	1186	1793
2010	0.26	0.01	17.5	1.5	431	59	visual streamwalk	316	547
2011	0.26	0.01	17.5	1.5	3422	458	visual streamwalk	2524	4320
2012	0.25	0.01	16	1.5	1662	339	visual streamwalk	997	2327
2013	0.27	0.01	19	1.5	2974	206	visual streamwalk	2570	3378
2014	0.26	0.01	17.5	1.5	394	53	visual streamwalk	290	499
2015	0.26	0.01	17.5	1.5	162	11	visual streamwalk	139	184

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

8.0 Figures

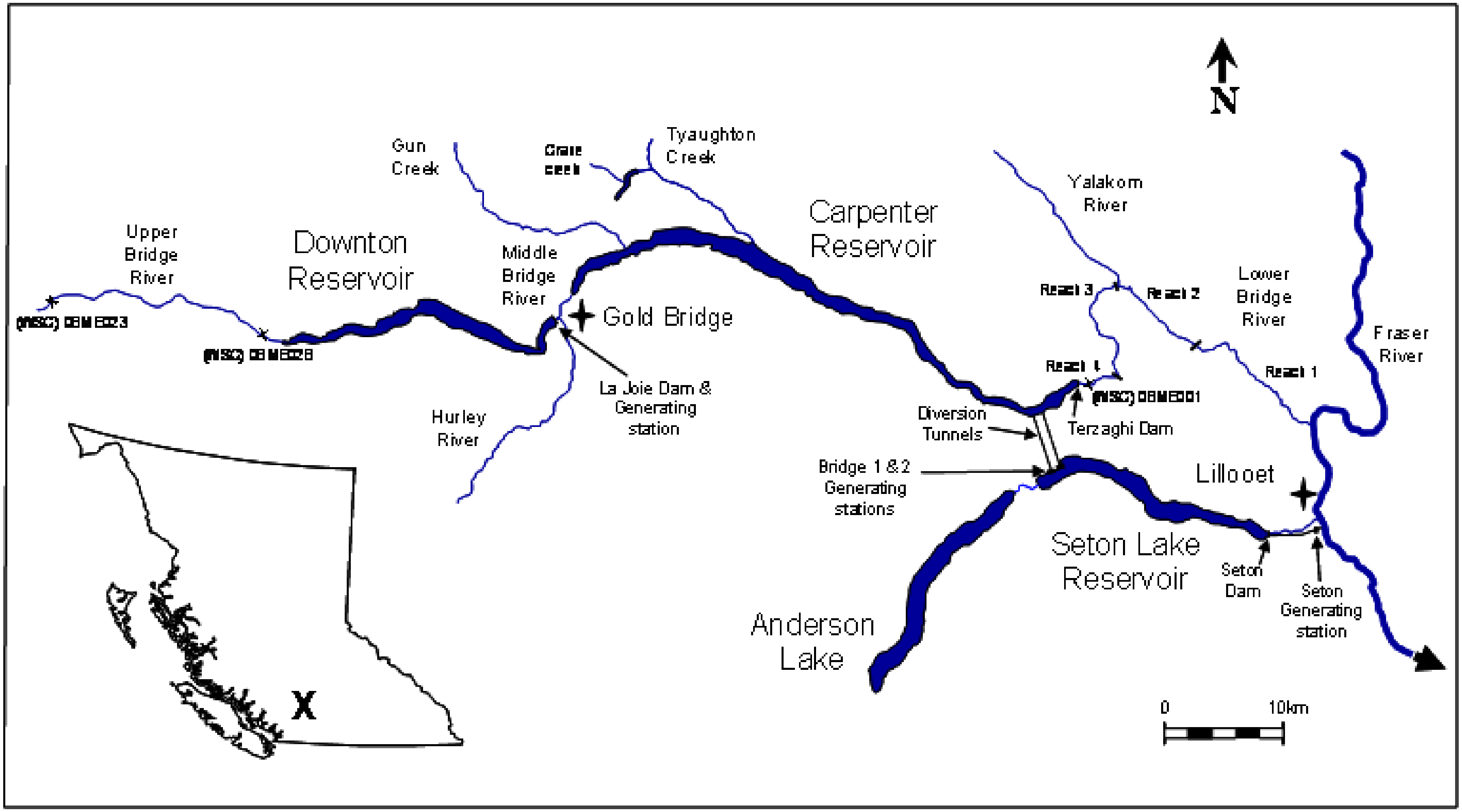


Figure 1. Bridge and Seton Watersheds showing Terzaghi Dam and the diversion tunnels to Bridge River Generating Stations #1 and #2.

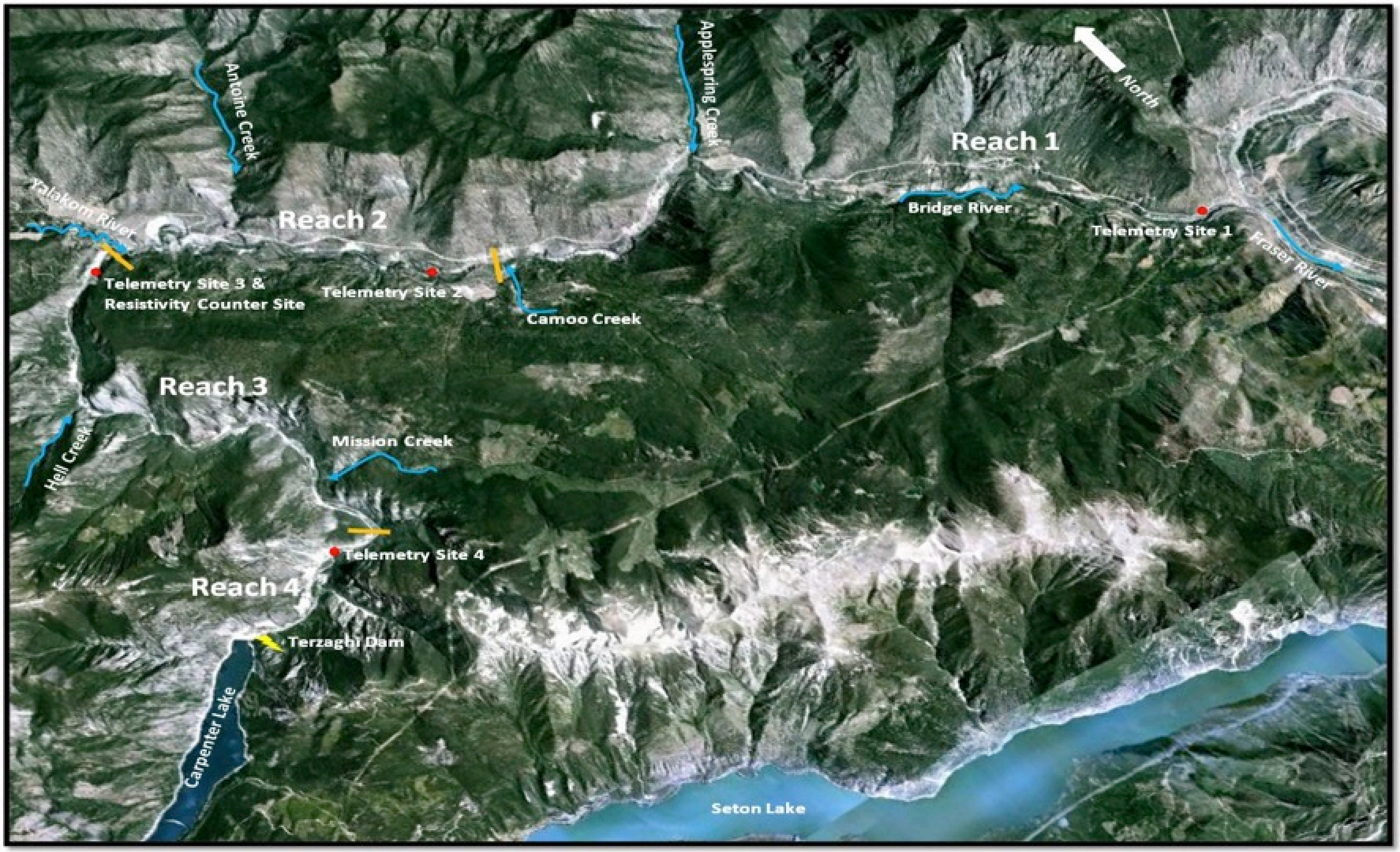


Figure 2. Bridge River study area showing reach breaks (orange lines) and fixed radio telemetry stations (red dots).

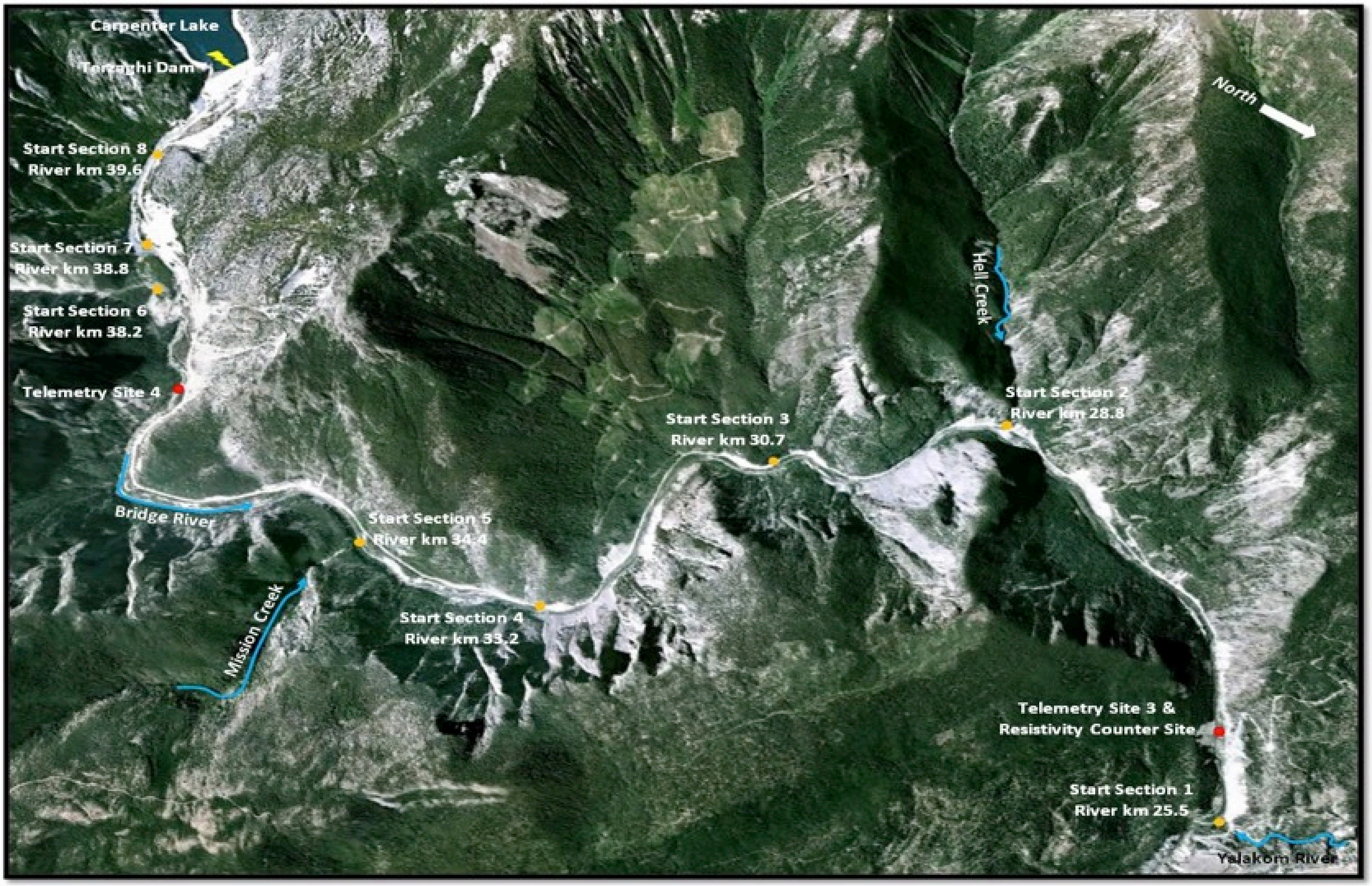


Figure 3. Bridge River streamwalk section boundaries (orange dots) and fixed radio telemetry stations (red dots).

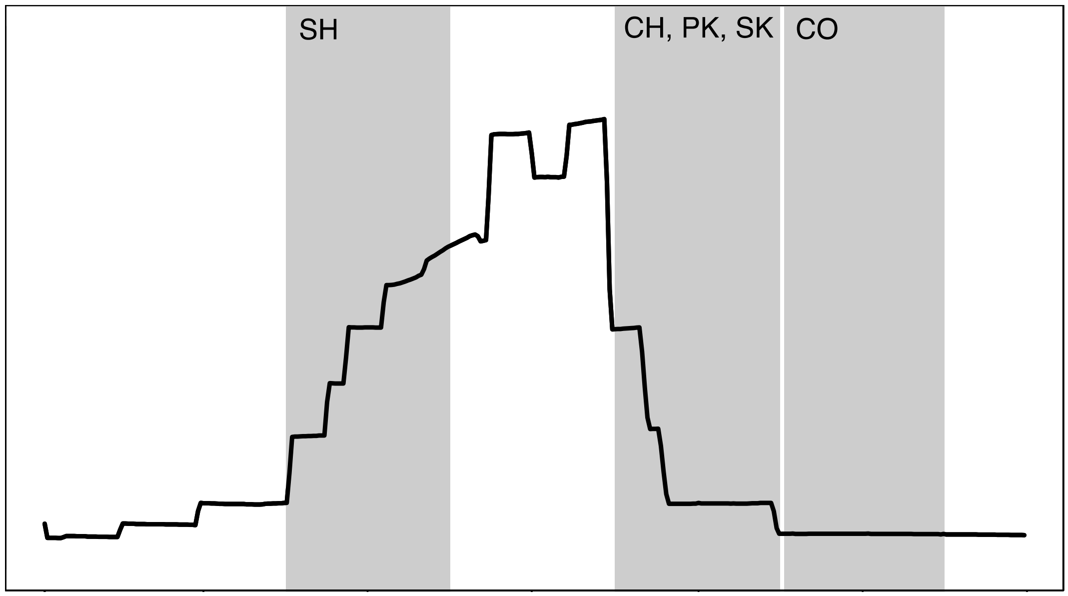
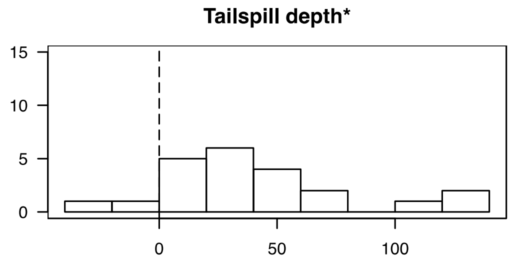


Figure 4. Discharge from Terzaghi Dam into the lower Bridge River in 2015. Migration timing of anadromous salmonids are represented by shaded rectangles. SH = Steelhead Trout, CH = Chinook Salmon, PK = Pink Salmon, SK = Sockeye Salmon, and CO = Coho Salmon.



ent change

Figure 5. Percent change of eight Chinook Salmon redd characteristics from high density Pink Salmon spawning. Positive percent changes represent an increase; negative percent changes represent a decrease. Asterisks denote a significant change in a redd characteristic (Paired *t*-test, $P < 0.05$).

Figure 6. Location of Chinook Salmon redds in the lower Bridge River in 2014 (yellow) and 2015 (white). Numbered yellow points denote the number of redds found at a specific location in 2014. Colours denote different habitat classes: pool = blue, run = green, riffle = orange, cascade = red, side channel = white, island = black, bar = yellow.

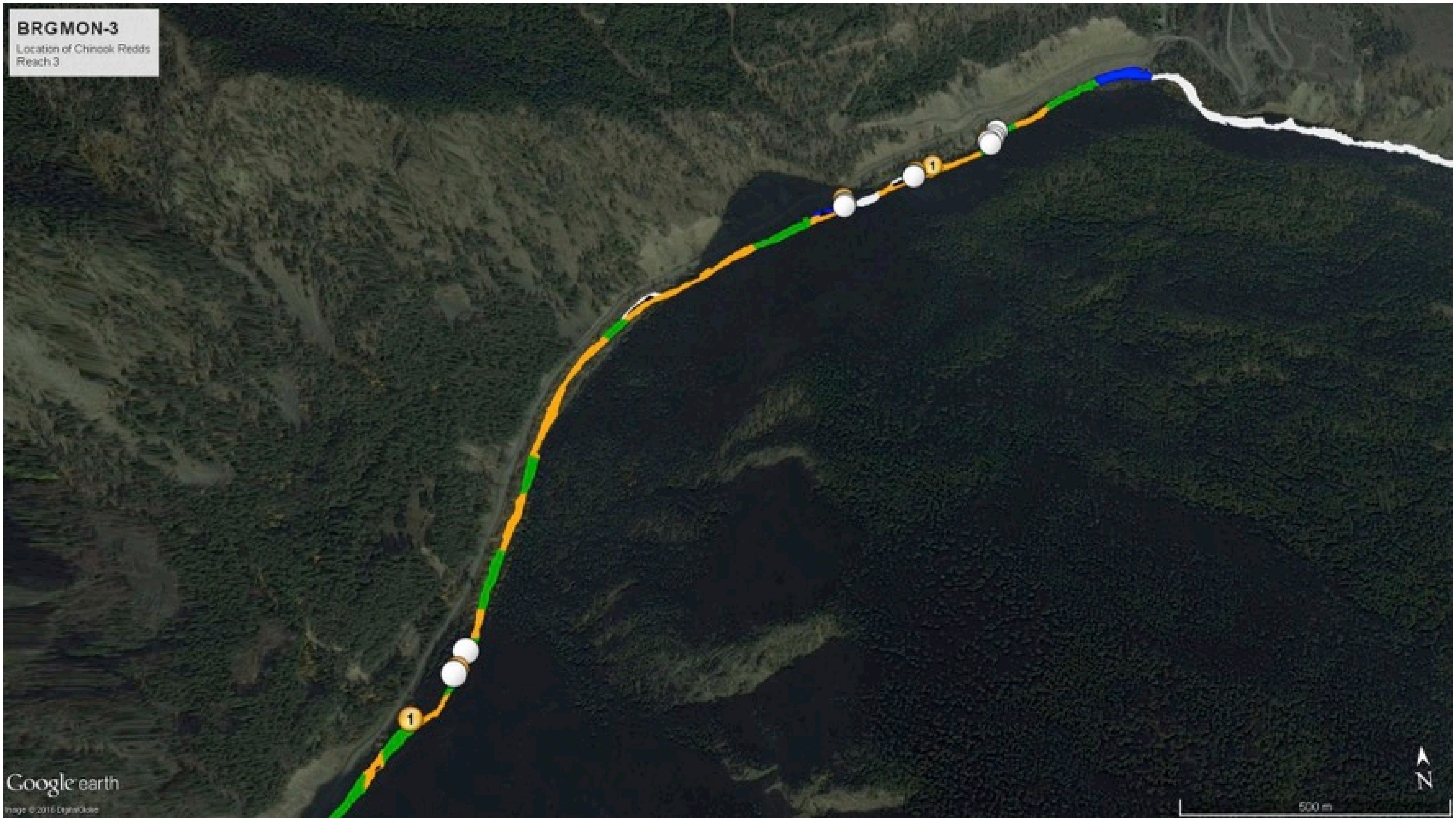


Figure 7. Map of the lower section of Reach 3 showing the distribution of habitat classes (pool = blue, run = green, riffle = orange, side channel = white). Chinook Salmon redds located in 2014 (yellow) and 2015 (white) are denoted by points. Numbered yellow points denote the number of redds found at a specific location in 2014.

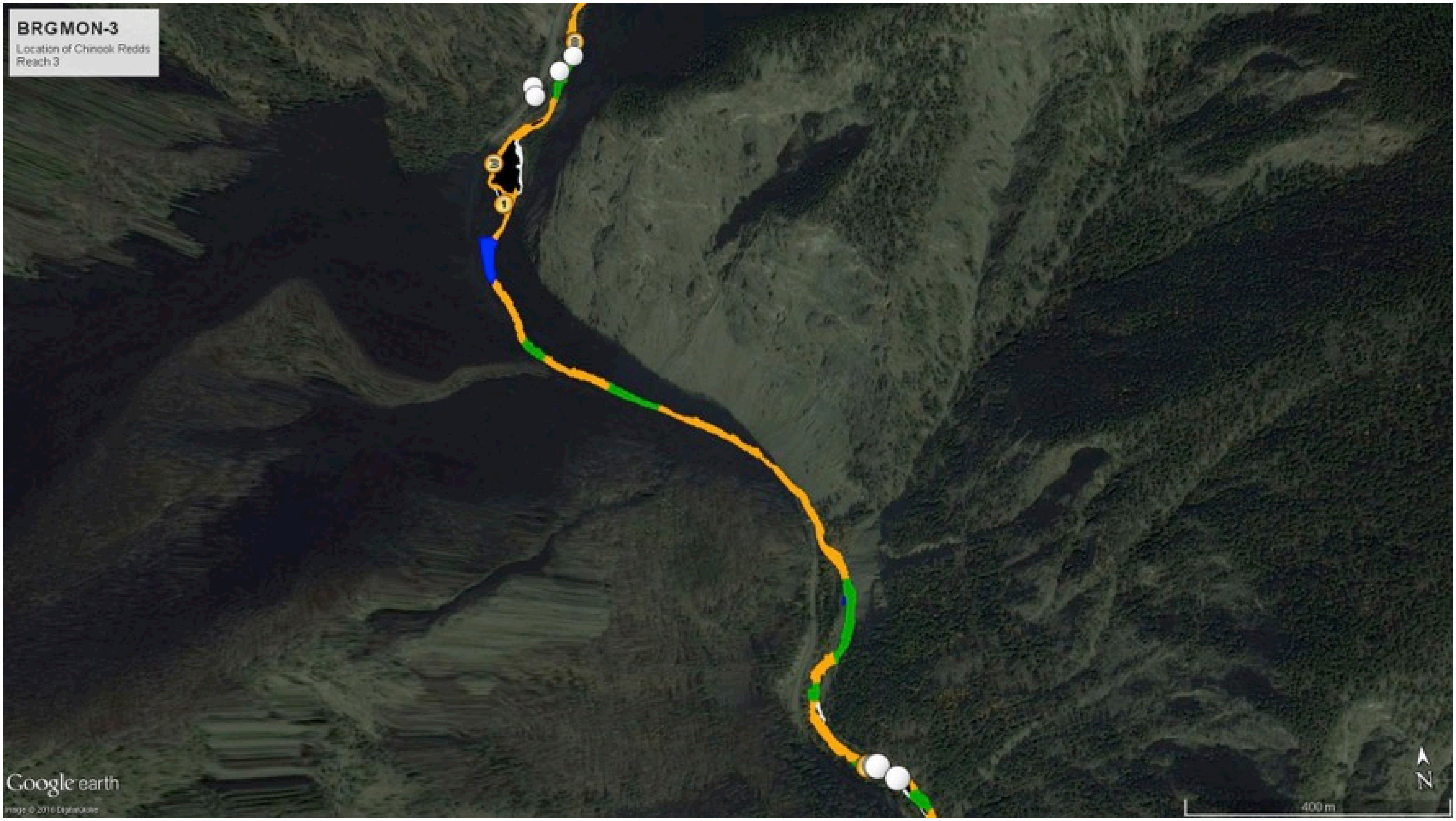


Figure 8. Map of the middle section of Reach 3 showing the distribution of habitat classes (pool = blue, run = green, riffle = orange, side channel = white). Chinook Salmon redds located in 2014 (yellow) and 2015 (white) are denoted by points. Numbered yellow points denote the number of redds found at a specific location in 2014.

Figure 9. Map of the middle section of Reach 3 showing the distribution of habitat classes (pool = blue, run = green, riffle = orange, cascade = red, side channel = white). Chinook Salmon redds located in 2014 (yellow) and 2015 (white) are denoted by points. Numbered yellow points denote the number of redds found at a specific location in 2014.

Figure 10. Habitat classes in Reaches 3 and 4 of the lower Bridge River at a dam flow release of 3 $m^3 s^{-1}$. Colours denote different habitat classes: pool = blue, run = green, riffle = orange, cascade = red, side channel = white, island = black, bar = yellow.

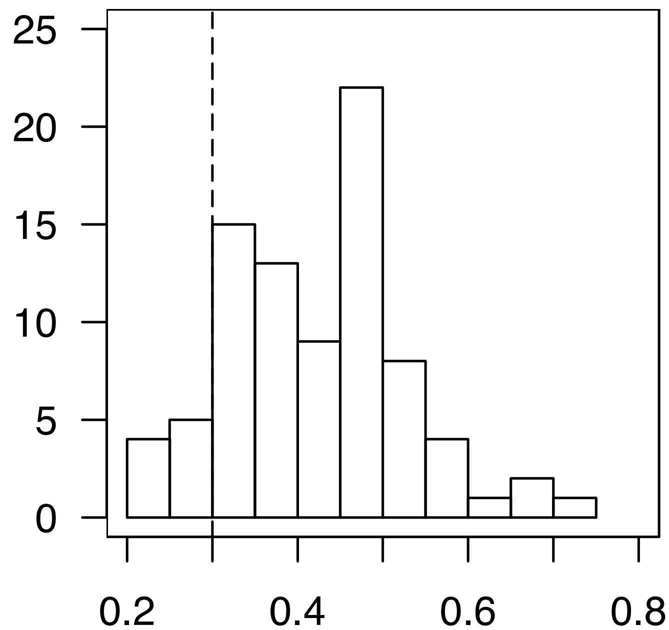


Figure 11. Frequency distribution of mean water depths (m) measured at Chinook Salmon redds in the lower Bridge River during the 2014 and 2015 spawning period. Dashed line denotes the minimum water depth (0.3 m) required for Chinook Salmon to spawn (Collings et al. 1972).

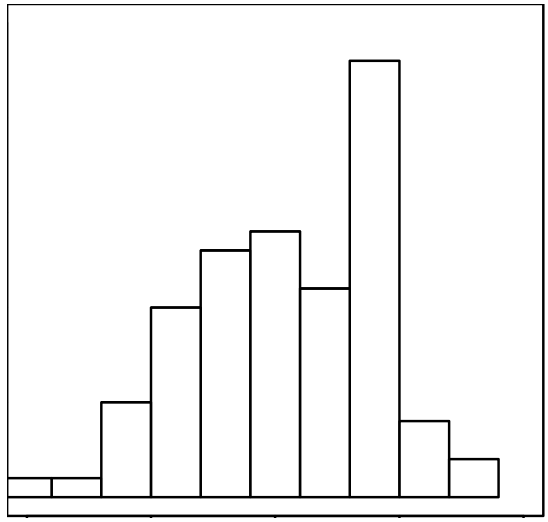


Figure 12. Frequency distribution of mean water velocity (m s^{-1}) measured at Chinook Salmon redds in the lower Bridge River during the 2014 and 2015 spawning period.

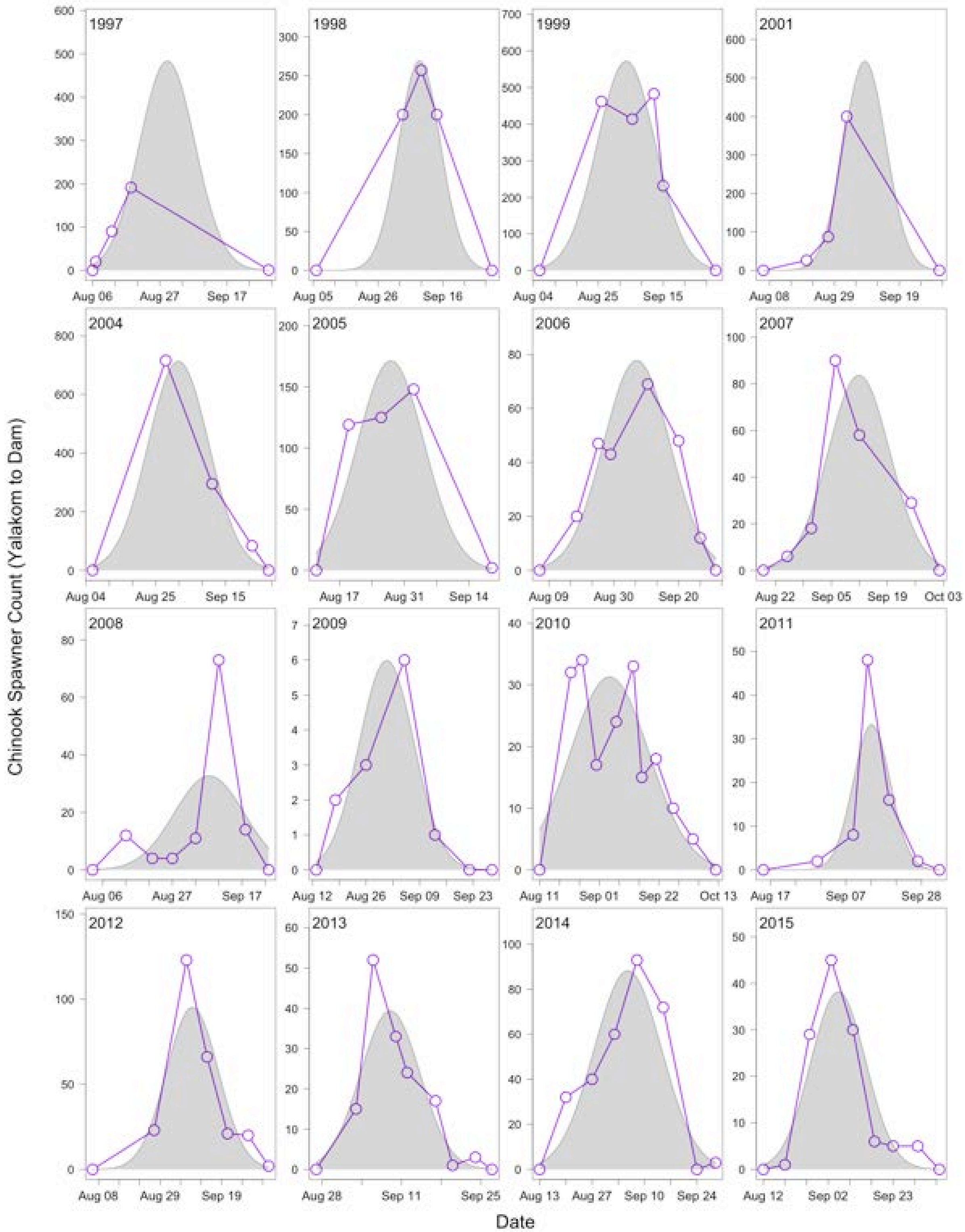


Figure 13. AUC estimate curves for Chinook Salmon spawning in the lower Bridge River from 1997 to 2015 (grey polygons) and observed visual counts (purple circles).

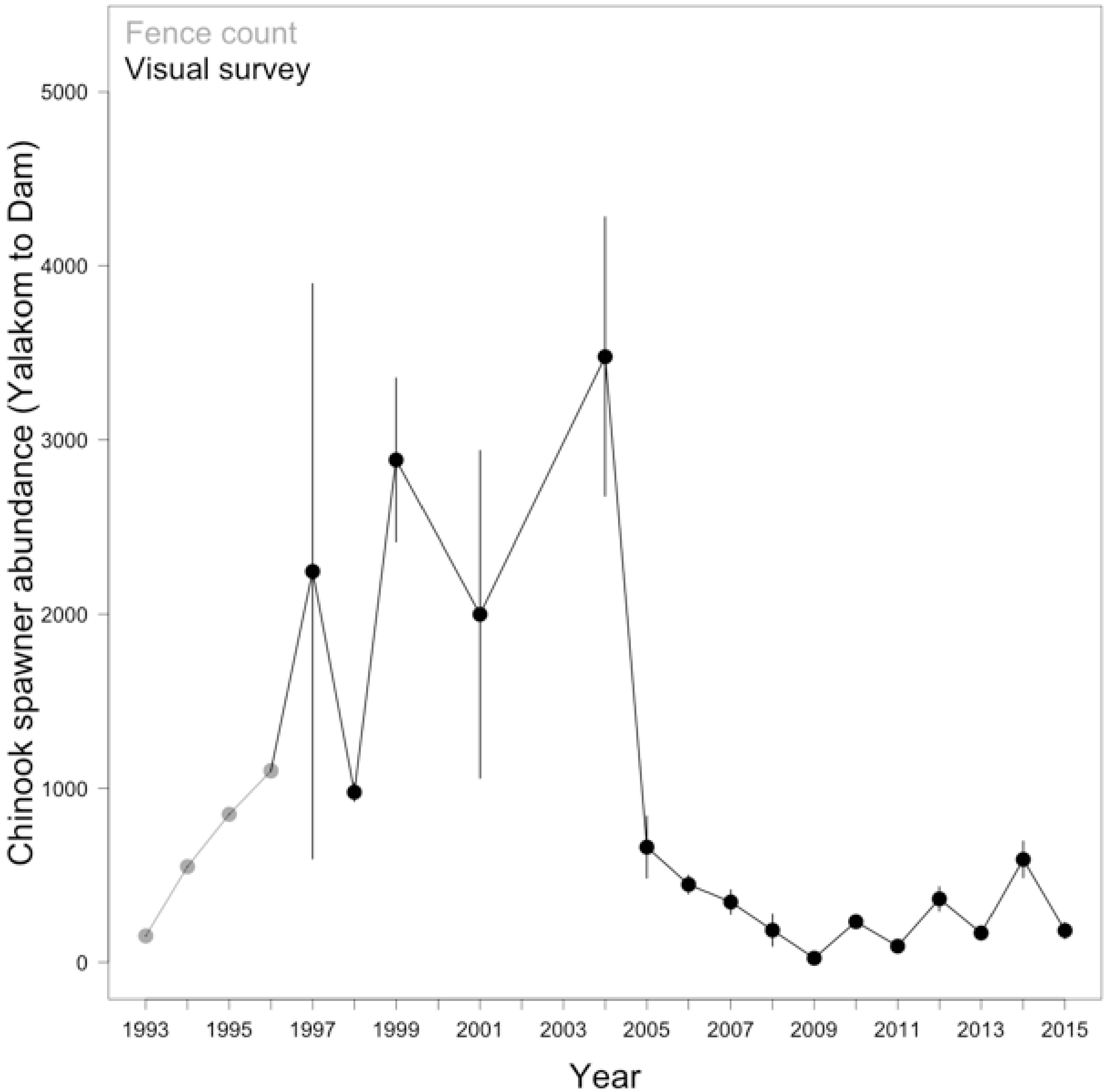


Figure 14. AUC and fence estimates for Chinook Salmon in the lower Bridge River from 1993 to 2015. Vertical lines represent 95% confidence intervals.

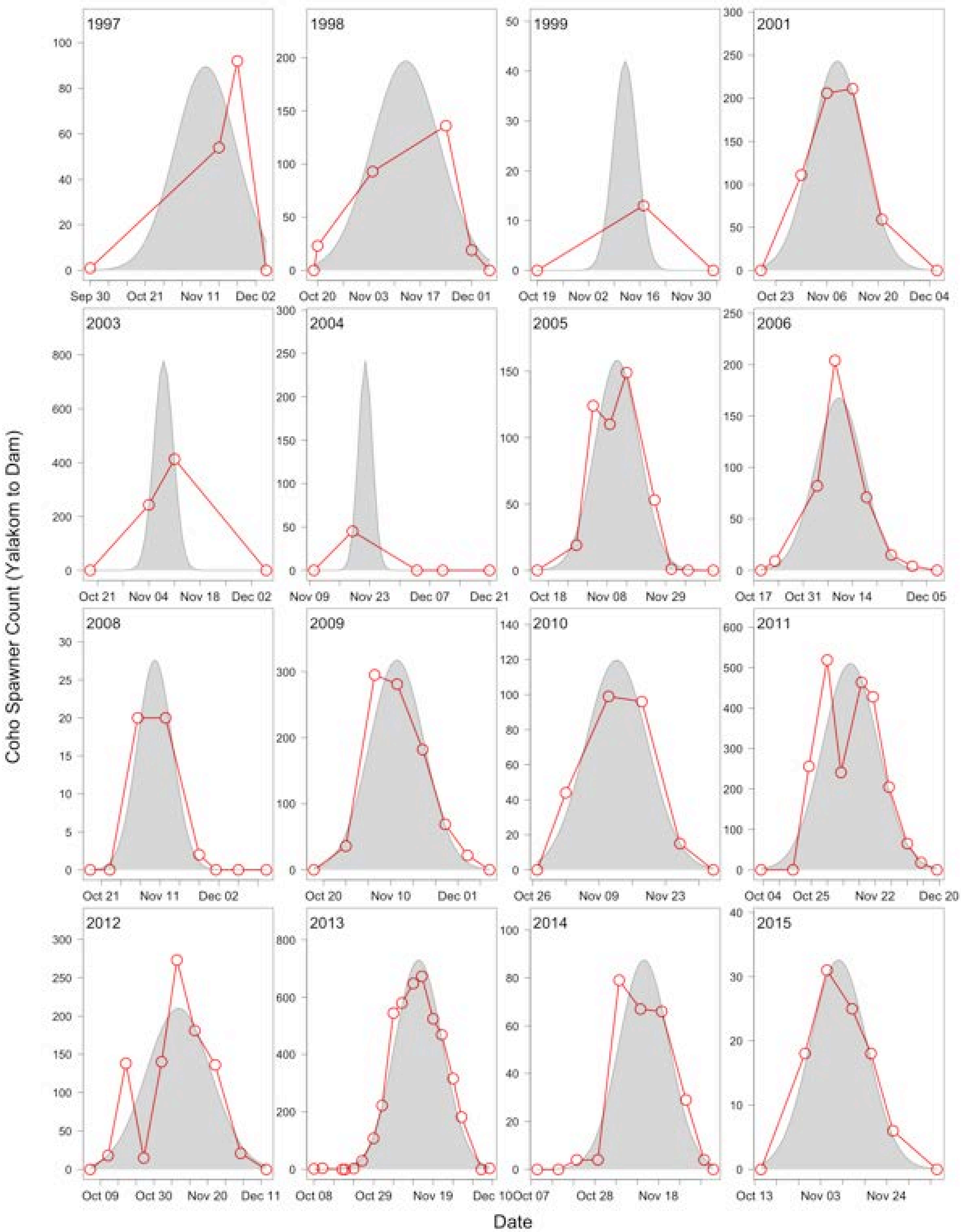


Figure 15. AUC estimate curves for Coho Salmon spawning in the lower Bridge River from 1997 to 2015 (grey polygons) and observed visual counts (red circles).

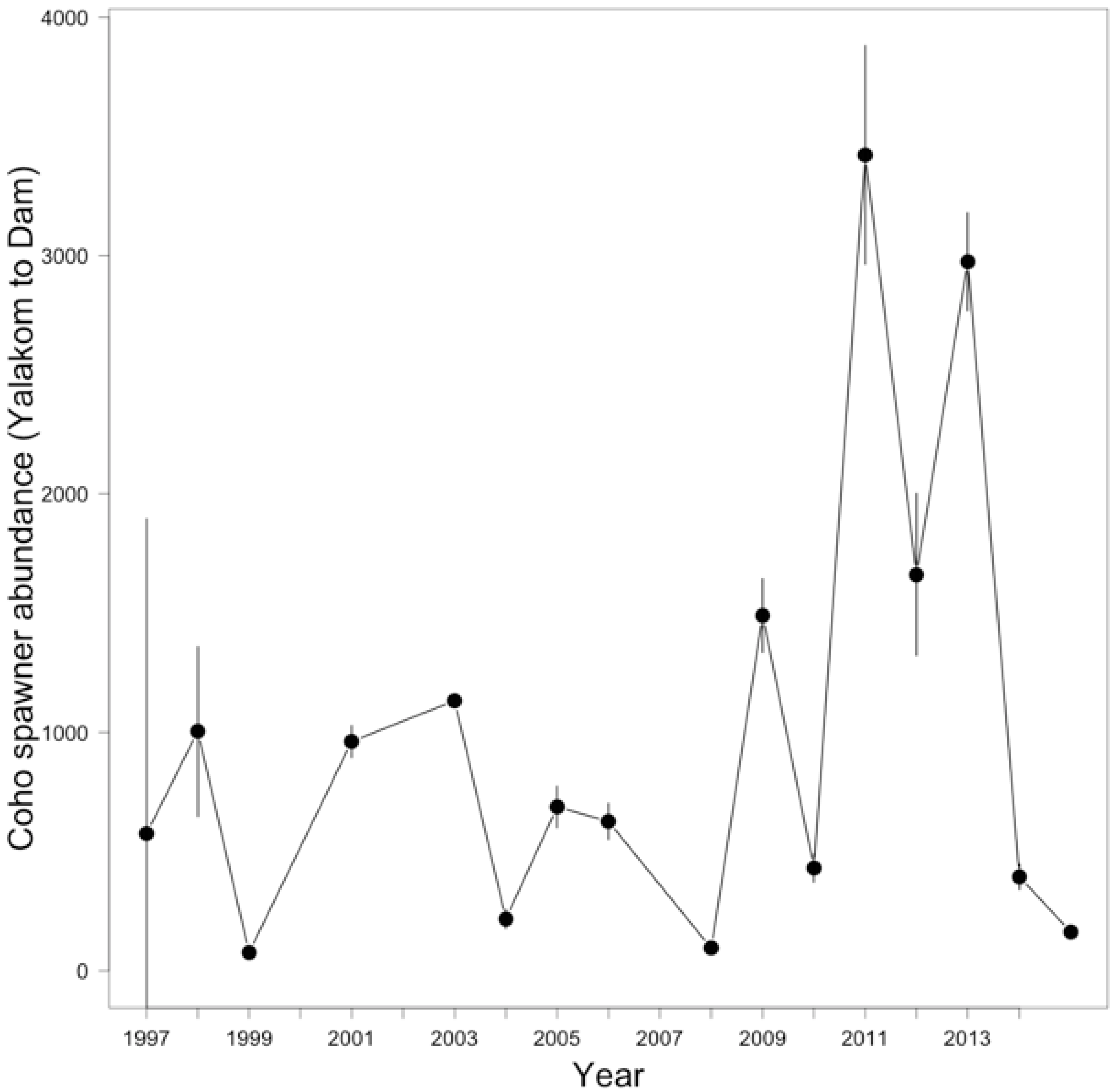


Figure 16. AUC estimates for Coho Salmon in the lower Bridge River from 1997 to 2015. Vertical lines represent 95% confidence intervals.

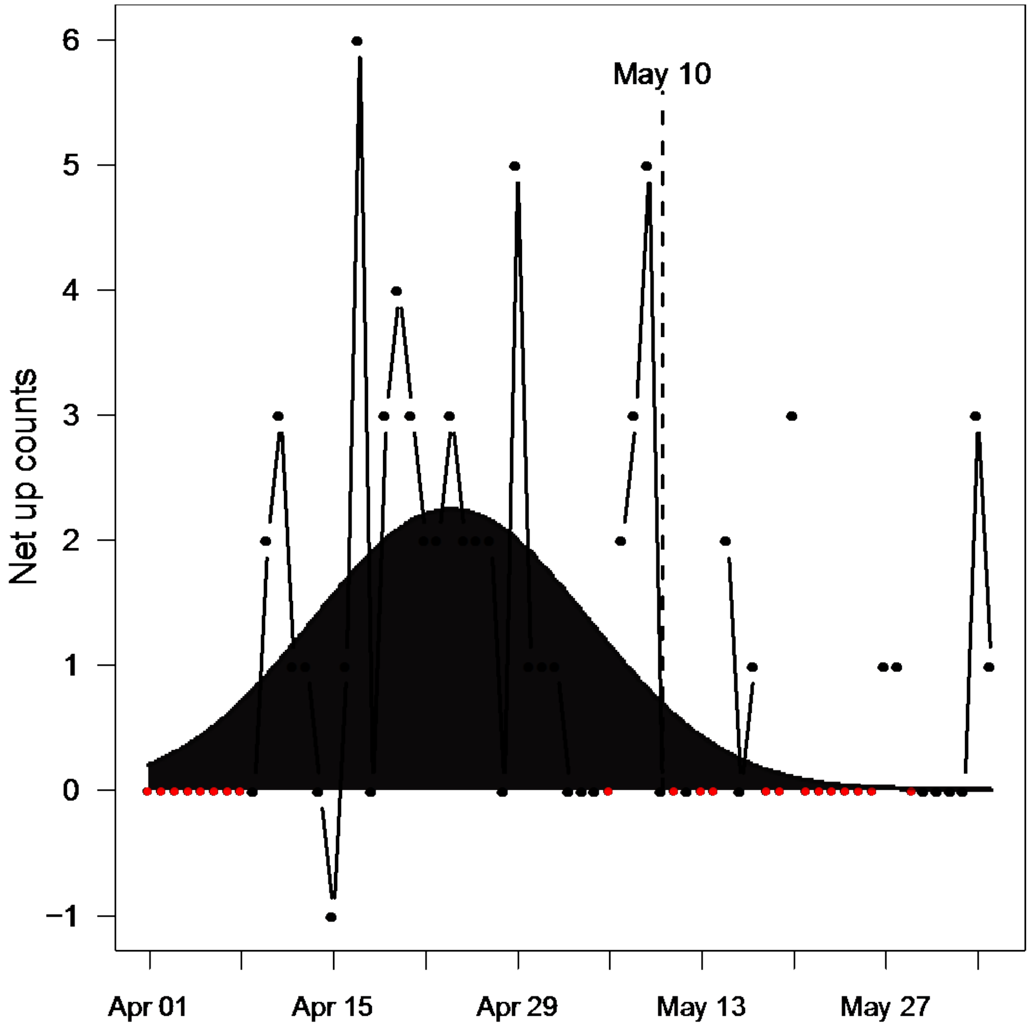


Figure 17. Net up counts for Steelhead Trout in the lower Bridge River in 2015. Modelled net up counts are shown by the solid grey line and shaded grey area. Normal model parameters were estimated using data from April 9 to June 4 (solid black points) and were used to predict the net up counts for days with missing data (solid red points). Vertical dashed line (May 10) marks the first observed kelting date by a radio-tagged Steelhead Trout in 2015.

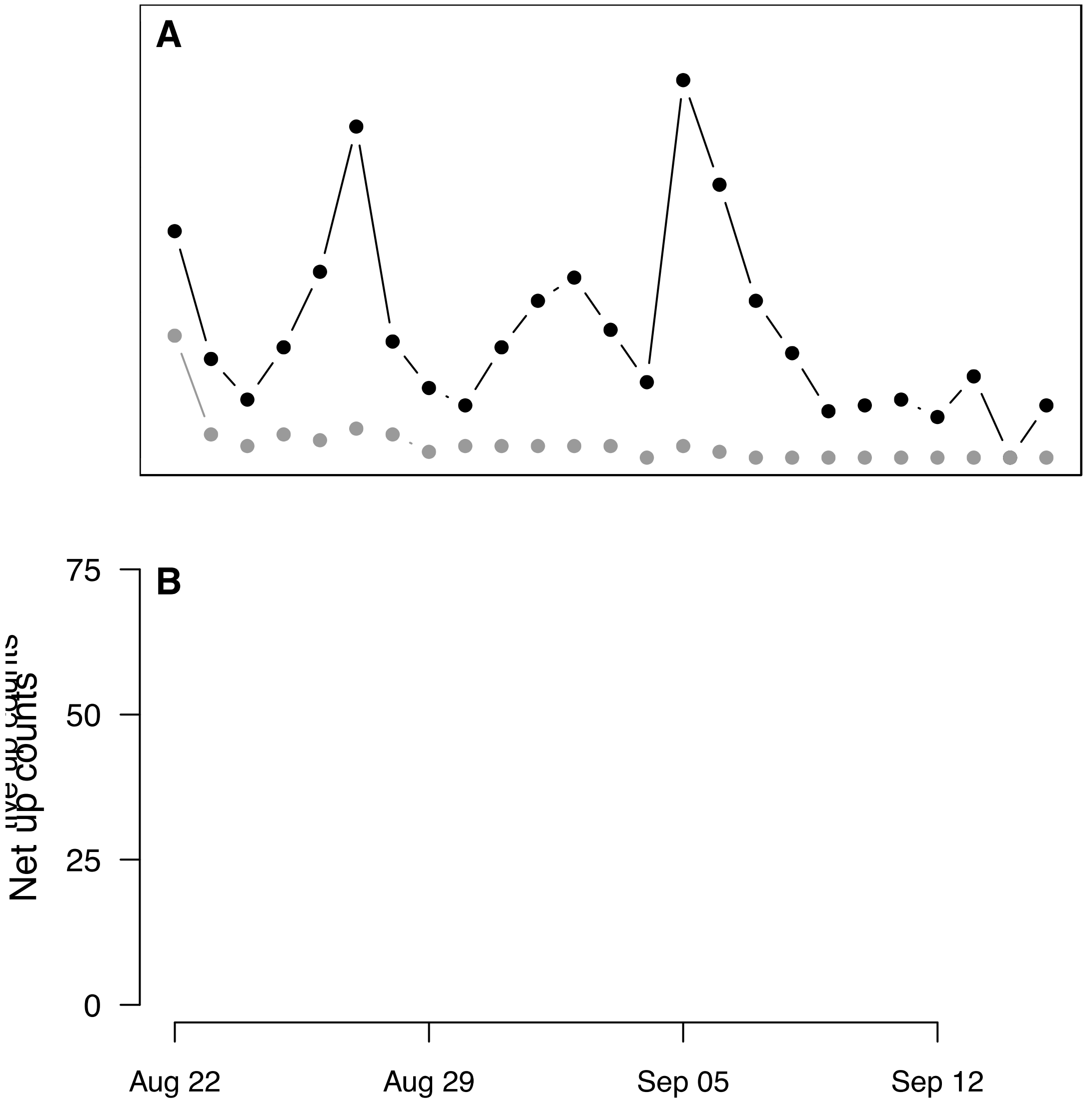
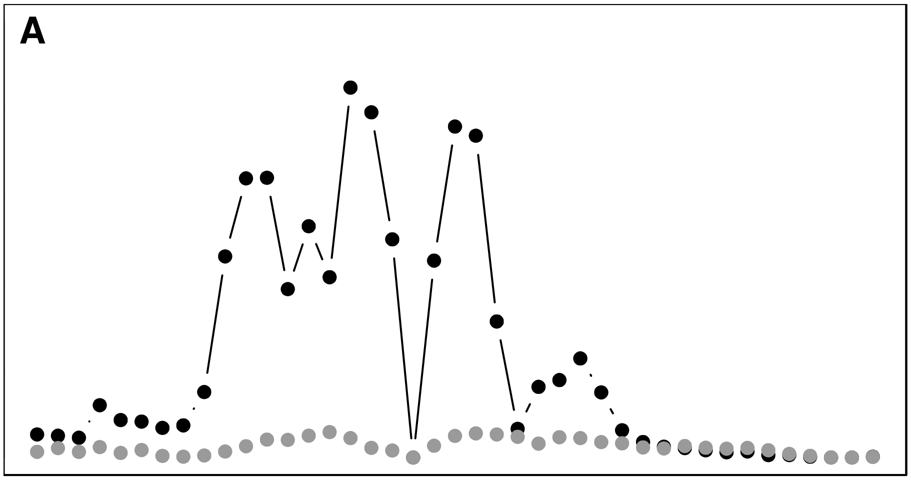


Figure 18. (A) Daily up (black) and down (grey) counts for Chinook Salmon in the lower Bridge River in 2015. (B) Net up counts for Chinook Salmon.



B

ounts

Figure 19. (A) Daily up (black) and down (grey) counts for Pink Salmon in the lower Bridge River in 2015. (B) Net up counts for Pink Salmon.

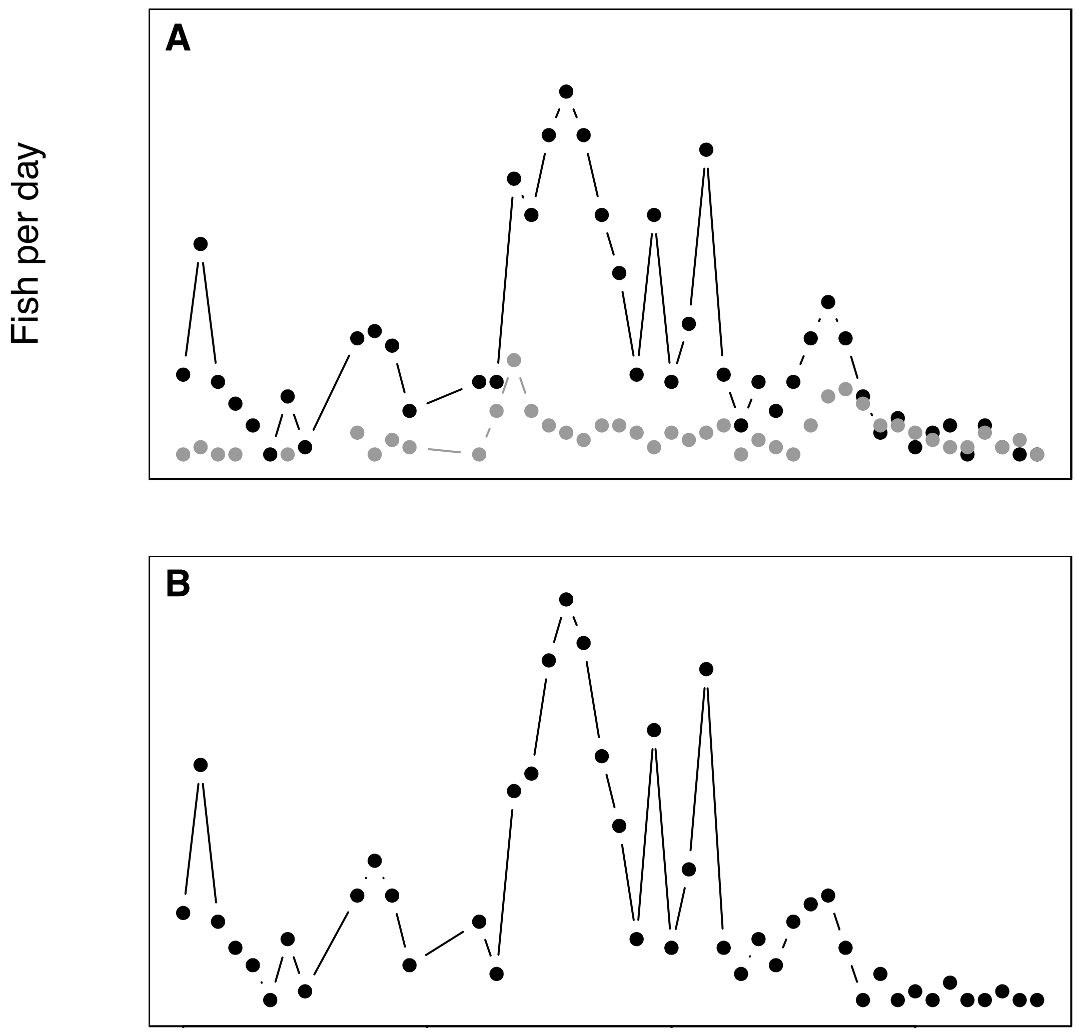


Figure 20. (A) Daily up (black) and down (grey) counts for Coho Salmon in the lower Bridge River in 2015. (B) Net up counts for Coho Salmon.

9.0 Appendices

Appendix 1. Summary of sampling and tagging data from the lower Bridge River in 2015.

2015_MON3_Tagging_Data.xlsx

Appendix 2. Streamwalk data from the lower Bridge River in 2015.

2015_MON3_Streamwalk_Data.xlsx