Site C Clean Energy Project

Site C Reservoir Tributaries Fish Community and Spawning Monitoring Program (Mon-1b)

Task 2b – Peace River Bull Trout Spawning Assessment

Construction Year 5 (2019)

Note: This report has been redacted for the protection of Bull Trout (*Salvelinus confluentus*)

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Site C Reservoir Tributaries Fish Community and Spawning Monitoring Program – 2019 Peace River Bull Trout Spawning Assessment (Mon-1b, Task 2b)

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Executive Summary

We report findings of the 2019 Peace River Bull Trout Spawning Assessment (Mon-1b, Task 2b), including Bull Trout redd abundance estimates for tributaries of the Halfway Watershed, and kelt abundance for the Chowade River obtained from resistivity counter data. Both methodologies provide abundance indices for Bull Trout spawning in the Halfway Watershed and inform spawn timing, spawner size and spawner distribution.

We used a Gaussian area-under-the-curve (GAUC) method combining aerial and ground surveys to estimate Bull Trout redd abundance and peak counts in the Chowade River, Cypress Creek, Fiddes Creek, Turnoff Creek, and the upper Halfway River. In 2019, GAUC redd abundance estimates ranged from 45 (standard error [SE] 17) in Fiddes Creek to 213 (SE 65) in the Chowade River. GAUC estimates were within the range of baseline peak count estimates for the Halfway Watershed from 2002 to 2012; however, a comparison of peak count and GAUC estimates suggests peak counts likely underestimate redd abundance.

The GAUC method incorporates error in observer efficiency and survey life to generate a robust abundance estimate. In 2019, average aerial observer efficiency was variable between the tributaries, ranging from 0.35 in the Chowade River to 0.53 in the upper Halfway River. Average redd survey life, or the period during which a redd is observable, was estimated as 21.2 days (SE 1.96 days).

We also monitored Bull Trout kelt abundance in the Chowade River using a resistivity counter. Resistivity counters have been used in the Chowade River and Cypress Creek since 2016; however, high water in 2019 prevented installation of the Cypress Creek resistivity counter. High water also prevented the installation of PIT telemetry equipment in 2019. The Chowade River kelt migration began on September 2, with a unimodal peak on September 16, and after accounting for counter accuracy, the Bull Trout kelt abundance was 144. We were unable to estimate the number of Bull Trout migrating upstream because high flows in mid-July delayed equipment installation; however, the full kelt estimate can be used as an index of spawner abundance.

We measured Bull Trout lengths from video data for the Chowade River, and estimated fork lengths for tributaries of the Halfway River using literature relationships between redd area and fork length. Mean total length from video data was 637 mm (range 223-943 mm), while mean fork lengths estimated from redd areas ranged from 375 mm in Fiddes Creek to 634 mm in Needham Creek. Comparing mean lengths to historic data from the Chowade River suggest fork lengths predicted from redd areas may underestimate true fork lengths. The range of fork lengths measured and predicted during this study highlight the variability in spawner size in the Halfway Watershed. Large females contribute disproportionately to egg deposition and potential recruitment, and it is important to monitor both abundance and spawner size distributions in response to the construction and operation of the Site C Clean Energy Project.

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1 Introduction

1.1 Project Background

BC Hydro developed the Site C Fisheries and Aquatic Habitat Monitoring and Follow-up Program (FAHMFP) in accordance with Provincial Environmental Assessment Certificate Condition No. 7 and Federal Decision Statement Condition Nos. 8.4.3 and 8.4.4 for the Site C Clean Energy Project (the Project). The Site C Reservoir Tributaries Fish Community and Spawning Monitoring Program (Mon-1b) represents one component of the FAHMFP and aims to determine the effects and effectiveness of mitigation measures of the Project on fish populations (and their habitat) that migrate to tributaries of the reservoir. A subcomponent of this program (Task 2b) assesses spawning populations of Bull Trout (*Salvelinus confluentus*) in the Halfway Watershed. Data collected for this task will be used to directly address the following management question and hypotheses:

How does the Project affect Peace River fish species that use Site C Reservoir tributaries to fulfil portions of their life history over the short (10 years after Project operations begin) and long (30 years after Project operations begin) terms?

H_0: There will be no change in Bull Trout spawner abundance in the Halfway River relative to baseline estimates.

H_1: Bull Trout spawner abundance in the Halfway River will decline by 20 to 30% relative to baseline estimates.

The objective of the Peace River Bull Trout Spawning Assessment (Mon-1b, Task 2b) is to assess the abundance, timing, and distribution of Bull Trout spawning in the Halfway Watershed. We monitor Bull Trout spawning populations by (1) enumerating redds using a Gaussian Area-Under-the-Curve (GAUC) method that accounts for observer error and survey life, and (2) resistivity counters and PIT arrays in the Chowade River and Cypress Creek that monitor adults during their upstream and kelt migrations. Monitoring builds upon Bull Trout spawning assessments conducted prior to construction of the Project, including a fish fence operated in the Chowade River in 1994 (R.L. & L. Environmental Services LTD. 1995); angling and redd surveys in the mid-1990s (Baxter 1997); and aerial, ground, and snorkel surveys of peak redd abundance (2002-2012; Diversified Environmental Services and Mainstream Aquatics Ltd. 2009; 2011; 2013).

1.2 Redd Enumeration

Redd abundance is the primary metric to assess changes in Bull Trout populations through construction and operation of the Project. Bull Trout redd abundance in the Halfway Watershed has previously been assessed using redd count surveys in key spawning tributaries (Diversified Environmental Services and Mainstream Aquatics Ltd. 2009; 2011;

2013). Historically, redd counts in the Halfway Watershed combined aerial helicopter surveys, snorkel surveys, and stream walks to generate peak redd count indices. Unlike visual surveys that count the number of spawning adults, redd count surveys provide an index of effective population size (i.e., number of reproducing adults; Gallagher et al. 2007).

Redd counts are inherently subjective and rely on the ability of each surveyor to minimize observation error. The primary sources of error are: (1) observer efficiency (OE; the ratio of redds observed *versus* the true number of redds present), (2) not accounting for redd survey life (SL; the length of time a redd can is detectable by an observer), (3) poor temporal coverage of surveys, and (4) poor spatial coverage.

Unlike peak count indices, AUC methods can incorporate OE and SL when estimating population abundance. This approach is widely used to enumerate spawners or redds in a river from visual count data (Hilborn et al. 1999). For example, Millar et al. (2012) developed a GAUC approach using a normally-distributed timing model that accounts for uncertainty in OE and SL. This approach outperformed other commonly used AUC approaches, and was robust to assumptions of a normal timing model when estimating Pink Salmon (*Oncorhynchus gorbuscha*) abundance (Millar et al. 2012). We use this GAUC method to enumerate redds in tributaries of the Halfway River, which improves upon historic peak count indices.

1.3 Bull Trout Enumeration in the Chowade River and Cypress Creek

Although redd abundance can describe changes in Bull Trout populations over time, it may not correlate with spawner abundance (i.e., the total number of Bull Trout that spawned; Dunham et al. 2001, Gallagher and Gallagher 2005). We operated resistivity counters and PIT arrays on the Chowade River and Cypress Creek, tributaries of the Halfway River with large populations of spawning Bull Trout (Diversified Environmental Services and Mainstream Aquatics Ltd 2013, Ramos-Espinoza et al. 2019). The dual technology approach allowed for enumeration of upstream migrating Bull Trout and kelts (the number of fish that migrate back downstream after spawning), identification of key migration timings, and a better understanding of spawner to redd abundance.

There are limited data describing the Bull Trout spawning migration in the Halfway Watershed. Observations during angling surveys in the early 1990s suggested Bull Trout spawning began during the last week of August and peaked in the second week of September, but no spawner count data were collected (Baxter 1997). Initial data from resistivity counters and PIT arrays since 2016 (Braun et al. 2017a, Ramos-Espinoza et al. 2018, 2019) indicate the upstream migration may begin and peak earlier than suggested by Baxter (1997) and may not follow the normal distribution model commonly observed for salmonids.

It is challenging to monitor upstream migrants in the Halfway Watershed because river discharges are high for a large portion of the migration, preventing the use of fences or electronic counters. In the absence of upstream enumeration in the Chowade River and Cypress Creek. Bull Trout kelt estimates have been used as indices of spawner abundance. This method has successfully been used in other streams in British Columbia (Andrusak 2009). Annual variation in kelt abundance is also important for understanding life history dynamics of Bull Trout (e.g., Monnot et al. 2008) and can be used to develop ratios of redd to kelt abundance. Initial evidence from the Chowade River and Cypress Creek resistivity counters suggests the kelt migration occurs over a short period and closely follows a normal distribution, facilitating an accurate and reliable estimate (e.g., Ramos-Espinoza et al. 2019). We estimate annual kelt abundance as an index of spawner abundance, but we attempt to install the resistivity counter in mid-July of each monitoring year to collect data on upstream migration timing, spawner abundance, and the relationship between upstream migrant and kelt abundance.

We use resistivity counters and PIT telemetry to monitor Bull Trout migrants, migration timing, survival and transition probabilities (i.e., juvenile to subadult, subadult to adult), and fish size. Resistivity counters are composed of in-river electrode sensors that create an electrical field in the water column. The field is disrupted when a fish swims over the sensor, from which the counter detects directional movement of individual fish. Resistivity counters can be highly accurate for enumerating salmonids (Braun et al. 2016) and are cost-effective, adaptable, and easy to maintain.

We also monitor adult migrants using directional PIT antennas in the Chowade River and Cypress Creek. PIT telemetry is a method of detecting passive tags implanted into fish. When PIT-tagged fish pass over or through a PIT antenna, the magnetic field created by the antenna excites the tag, which transmits its identification code back to the reader. We use two antennas (forming a PIT array) at each site to determine the direction of movement for PIT tagged fish. PIT arrays can be an effective method for tracking migration behaviour, growth, and survival (Brännäs et al. 1994), and allow for monitoring and tracking of individual fish throughout their life cycle. PIT arrays in the Chowade River and Cypress Creek detected movements of Bull Trout and Rainbow Trout (*O. mykiss*) tagged by other monitoring programs to inform migration patterns and spawning timing.

1.4 Spawner Size and Fecundity

Large female Bull Trout produce more eggs (Kindsvater et al. 2016) and build larger redds (Riebe et al. 2014) than smaller females, and therefore contribute disproportionately to juvenile recruitment. It is important to consider spawner size in addition to redd and spawner abundance to monitor changes in spawner size distributions and provide a more direct link to juvenile data collected under Mon-1b, Task 2c (Site C Reservoir Tributaries Fish Population Indexing Survey). We collected redd size data during redd enumeration surveys and measured the total lengths of Bull Trout captured on video during counter validation. These size metrics allow us to compare Bull Trout sizes among years and tributaries and provide valuable insight into Bull Trout fecundity and potential recruitment.

2 Methods

2.1 Redd Enumeration

2.1.1 Visual Surveys

We performed weekly redd count surveys on Cypress Creek, the Chowade River, the upper Halfway River[1], Fiddes Creek, and Turnoff Creek over a four-week period [REDACTED] (Figure 2-1[2]). We also performed a single aerial and ground survey in Needham Creek [REDACTED] to generate a peak redd count.

Two experienced biologists conducted redd counts consisting of aerial surveys in all known spawning reaches and ground surveys in high-density spawning reaches. Redds were identified as areas with disturbed and cleaned substrate, with a crest at the upstream end of the disturbed area, a tailspill area with accumulated substrate, and a depression between the crest and tailspill (Gallagher et al. 2007). These criteria were confirmed by periodic observations of active spawning during both aerial and ground surveys. Bull Trout redds were often found in overlapping clusters, and the number of redds per cluster was defined as the number of crest-tailspill pairs.

Aerial surveys were conducted via helicopter flying 50 to 100 m above ground at 15 to 40 km hr^{-1} (Trouton 2004). Aerial surveys covered the entire length of potential spawning habitat (Braun et al. 2017b), and were continuous except in Cypress Creek, where two separate surveys were conducted to omit a short section of unsuitable habitat. Redds observed from the air were counted and georeferenced using a handheld GPS accurate to ± 3 m. For the Chowade River, Cypress Creek and the upper Halfway River, aerial surveys were conducted by flying in an upstream direction, but flight direction for Fiddes and Turnoff Creeks varied depending on light and wind conditions (direction was selected to maximize visibility). Aerial surveys were typically conducted at mid-day when the sun was directly overhead and visibility conditions were optimal. Water clarity was visually assessed to be >2 m and turbidity was <4 NTU in all tributaries, suggesting turbidity does not substantially influence OE in tributaries of the Halfway River.

Ground surveys were located as to maximize the number of redds marked and ranged in length from 1.5 to 4 km (Table 2-1). The length of the ground surveys reflected redd

[1] We define the upper Halfway River as the portion of the Halfway River from its source to the confluence of the Halfway and Graham Rivers.

[2] All map images were created in R (R Core Team 2017) using packages *rgdal* (Bivand et al. 2017), *GISTools* (Brundson and Chen 2014), and *sp* (Bivand et al. 2013).

densities, the location of safe helicopter landing areas, and the ability of crews to perform the survey within the available time. Surveys began at the upstream boundary and progressed downstream to the lower boundary, including all side channels within. All redds were counted and geo-referenced using a handheld GPS. No ground survey was conducted on Turnoff Creek because the helicopter could not safely land.

During ground surveys, all accessible redds were marked with a unique number attached to a green bristle tag to estimate OE and SL. Unique redd numbers were tracked throughout the monitoring period and removed when the redd was no longer identifiable. During a survey each numbered redd was recorded along with the date, GPS location, age class, and whether the redd was observable (Gallagher et al. 2007). The location and number of unmarked redds was also noted. The lengths and widths of all redds were recorded to the nearest centimeter, where length was the distance between the upper crest and the end of the tailspill, and width was the distance of disturbed substrate measured perpendicular to the length axis.

Table 2-1. Summary of redd survey reaches. Distances are in river km.

Tributary	Ground Survey Length (km)	Direction Walked	Aerial Survey (km)	Direction Flown
Chowade River	4.0	Downstream	27.0	Upstream
Cypress Creek	2.5	Downstream	18.5	Upstream
Fiddes Creek	2.0	Downstream	14.8	Variable
Turnoff Creek	-	-	15.0	Variable
Upper Halfway River	1.5	Downstream	22.5	Upstream
Needham Creek	2.2	Downstream	8.1	Upstream

[Figure 2-1 REDACTED]

2.1.2 Observer Efficiency

Survey- and tributary-specific ground OE was estimated by dividing the number of marked redds observed by the number of marked redds available to be observed (similar to mark-recapture methods; Melville et al. 2015). Total redd abundance in the ground reach was then calculated for each survey as the number of observed redds divided by the mean ground survey OE. This method assumes no tag loss, which we verified using a fixed number of test tags in each tributary. Test tags were deployed in areas with substrate and flow characteristics suitable for Bull Trout spawning and recovered during the final survey.

Aerial OE was estimated by comparing aerial redd counts within the ground reach boundaries to the total redd abundance in the ground reach (estimated using ground OE).

For example, if 12 redds were observed in the ground reach and the ground OE was 0.75, the total redd abundance in the ground reach would be 12/0.75 = 16. If 8 redds were observed over the ground reach during the aerial survey, the aerial OE would be 8/16 = 0.5. Ground surveys were not conducted on Turnoff Creek and we used OE values from Fiddes Creek (with similar substrate and flow characteristics) during GAUC estimation.

2.1.3 Survey Life

Survey life (the number of days a redd is observable and available to be counted) was estimated by tracking redd ages over consecutive ground surveys. Redd age class was recorded following the methods of Gallagher et al. (2007):

> Age-0 = the date the redd was first constructed (not measurable during surveys);
>
> Age-1 = new since last survey but clear (the first measurable age class);
>
> Age-2 = still measurable but already measured, negligible periphyton growth;
>
> Age-3 = no longer measurable due to degrading edges and periphyton growth, but still apparent; and
>
> Age-4 = no redd apparent, only a tag (at which point the tag will be removed).

We estimated average SL across all surveyed tributaries using a linear mixed effects (LME) model of survey date *versus* redd age class. The linear model related normalized survey day (day 1 was the day a redd was first observed and tagged) to the assigned redd age class. We defined SL as the predicted normalized survey day at which redds became age-4, or no longer apparent. Optimal random effects structure was tested using AIC model selection and likelihood ratio testing, including both random intercept and slope for tag ID (i.e., each numbered redd) and a fixed effect of redd age class. The most complex model for predicting the normalized survey day was:

$$y_i \sim N\left(\alpha_{j[i]} + \beta_{j[i]} redd\_age_i, \sigma_y^2\right) \quad for\ i = 1 \ldots N \tag{1.1}$$

where $\alpha_{j[i]}$ and $\beta_{j[i]}$ are normally distributed intercept and slope parameters incorporating random variation for each tag ID *j* (*i* represents the sample number). All linear mixed effects modelling was performed in R (R Core Team 2017) using *lme4* (Bates et al. 2015).

Survey life can be specific to individual tributaries as a result of unique physical and biological characteristics (e.g., substrate, flow, periphyton growth, etc), and examining the effect of tributary on SL modelling is important for understanding how redds age in the Halfway Watershed. We will delay the use of tributary-specific survey life models due to the complex nature of redd ageing and the increased data requirements when incorporating fixed effects into LME models. Tributary-specific SL and other candidate model formulations will be explored during synthesis modelling, and previous redd abundance estimates can be adjusted accordingly if necessary.

Trail Cameras

We installed trail cameras (Defender 850, Browning, Morgan, Utah, USA) with polarizing filters on four redds in the Chowade River and four redds in the upper Halfway River to verify SL assumptions and examine Bull Trout spawning behaviour. While redd age was assessed only once per week during ground surveys, the trail cameras provided high resolution daily redd ages. We installed the cameras on age-1 redds with active Bull Trout spawning behaviour. Time lapse photos were taken each hour for the entire survey period, and additional photos were taken when the camera's motion-sensing feature was triggered.

A clear daily image was selected for each redd, and four analysts independently estimated daily redd age. Because redds age continuously, half ages were sometimes used to describe transitional periods that were difficult to categorize. We performed linear regressions of survey date *versus* daily redd age and visually compared predicted SL (for each analyst and for the average of the analysts) to average SL estimated using Equation 1.1. This comparison helps to determine whether LME modelling of only four observations of redd age provides a reasonable estimate of average SL.

2.1.4 GAUC Abundance Estimates

We used a GAUC method to generate redd abundance estimates for each tributary. Redd count data were modelled using a quasi-Poisson distribution with spawn-timing described by a normal distribution, and parameter estimates evaluated using maximum likelihood estimation (described in Millar et al. 2012). The advantage of the GAUC approach over conventional AUC and peak count indices is the ability to incorporate variance in OE and SL, fit spawn-timing using maximum likelihood, and estimate uncertainty in redd abundance.

The number of redds observed at time t (C_t) is

$$C_t = a\ exp\left[-\frac{(t-m_s)^2}{2\tau_s^2}\right] \tag{1.2}$$

where a is the maximum height of the redd count curve, m_s is the date of peak redds, 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 1.2 becomes $\sqrt{2\pi\tau_s}$ and the AUC described by Equation 1.2 can be expressed as

$$F = a\sqrt{2\pi\tau_s} \tag{1.3}$$

where F is the number of observed fish. The final redd abundance ($\hat{E}$) is then estimated (using maximum likelihood) by applying OE (v) and SL (l) to the expected number of observed redds ($\hat{F}$)

(1.4)

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

where $\hat{F} = \hat{a}\sqrt{2\pi\hat{\tau}_s}$, $\hat{a}$ and $\hat{\tau}$ are the ML estimates of a and τ_s.

Equation 1.3 can be re-expressed as a linear model, allowing the estimation to be performed as a log-linear equation with an over-dispersion correction factor. The correction accounts for instances where the variance of the redd observations exceeds the expected value. The expected number of observed fish ($\hat{F}$) can be estimated by

(1.5)

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

where β_0, β_1, β_2 are the regression coefficients of the log-linear model. Uncertainty in OE and SL are incorporated into the estimated redd abundance using the covariance matrix of the modeled parameters (β_0, β_1, β_2) via the delta method (described in Millar et al. 2012).

Mean abundance estimates and input parameters are presented along with standard error, 2.5% and 97.5% confidence limits, and percent relative uncertainty (%RU), calculated as

(1.6)

$$\%RU = \left(\frac{|u - \mathrm{SE}|}{u}\right) \cdot 100$$

where u is the mean abundance estimate and SE is the standard error of the mean.

We examined the effect on GAUC estimation of adding zero counts to the beginning and end of the spawning period (Appendix 1). An initial zero count was added one week before the first survey (because surveys were conducted weekly), and a final zero count was added to the date when the last new redd was observed plus the SL (e.g., if the last age-1 redd was observed during Survey 3 and SL was 14 days, the final zero would be 14 days after Survey 3).

To create a continuous dataset integrating peak counts from 2002 to 2012, we calculated a peak count index for each tributary following the methods described in Diversified Environmental Services and Mainstream Aquatics Ltd. (2013). Historic redd counts consisted of stream walks and/or snorkeling in accessible high-density spawning areas, and aerial surveys covering either the full survey length[3], or areas not covered by ground surveys. Peak count surveys were generally conducted during one or two survey weeks [REDACTED] (Diversified Environmental Services and Mainstream Aquatics Ltd. 2011,

[3] The full survey lengths for historic surveys are similar, but not identical to, aerial surveys completed in 2016 through 2019 (see Diversified Environmental Services and Mainstream Aquatics Ltd. 2013).

2013). The peak count index was calculated by summing redds observed [REDACTED] (i.e., the historic survey period) on survey one but not on survey two to the total number of redds observed on survey two. To generate a peak count comparable to historic methods, we summed the total number of redds observed during ground surveys with aerial counts that occurred outside of the ground survey reach for surveys during the historic survey period. Due to the spacing of our surveys, the peak count generally included data from only one survey week.

2.1.5 Redd Area, Predicted Spawner Size, and Fecundity

We measured redd length (L) and width (W) to the nearest centimeter during ground surveys, and calculated redd area (A) assuming an elliptical shape

$$A = \pi LW \tag{1.7}$$

We compared mean redd areas between survey years and tributaries (and their interaction) using a two-way ANOVA.

We predicted fork length from redd area using the relationship from Riebe et al. (2014), which compared redd area and fork length for three species of Pacific salmon (Sockeye [*O. nerka*], Pink, and Chinook Salmon [*O. tshawytscha*])

$$A = 3.3\left(\frac{L}{600}\right)^{2.3} \tag{1.8}$$

where A is redd area in m^2, L is the female fork length in mm and 600 is a reference value representing the average fork length of fish in Riebe et al. (2014). Equation 1.8 was re-expressed to solve for fork length

$$L = \left(\frac{600^{2.3}\mathrm{A}}{3.3}\right)^{0.434783} \tag{1.9}$$

We used probability density functions to compare predicted fork length to total lengths measured during video validation of the Chowade River resistivity counter data (detailed in Section 2.2.3). This comparison will help validate assumptions of redd size and predicted fork length.

We then used predicted fork lengths to estimate fecundity using length and egg number data for six Bull Trout populations published in McPhail and Baxter (1996; see details in Putt et al. 2018). The linear equation used to estimate the number of eggs was

$$\ln(E) = -8.434 + 2.606\ln(\mathrm{L}) \tag{1.10}$$

where E is the number of eggs per female and L is the female's fork length in millimeters.

2.2 Resistivity Counters and PIT Telemetry in the Chowade River and Cypress Creek

2.2.1 Resistivity Counters

We installed resistivity counters and PIT arrays in the Chowade River and Cypress Creek 21.7 river kilometers (rkm) and 16.9 rkm, respectively, upstream of their confluences with the Halfway River (Figure 2-1). Counter sites were selected for their ease of access for equipment installation, suitable stream characteristics for counter and PIT operation (e.g., flow, substrate size), and their location downstream of known Bull Trout spawning areas (Diversified Environmental Services and Mainstream Aquatics Ltd. 2009; 2011; 2013).

Adult Bull Trout typically migrate up the Chowade River and Cypress Creek from mid-July to early September, and their downstream migration occurs from late August to early October (R.L. & L. Environmental Services Ltd. 1995, Braun et al. 2017a). Ideally, resistivity counters and PIT arrays should be installed to monitor the entire spawning migration; however, July flows are unpredictable in the Halfway River, and high flows can prevent equipment installation. Flows during the August to October kelting period are typically lower and more conducive to counter and PIT operation, allowing us to generate a complete kelt estimate.

2.2.2 Stage and Discharge Monitoring

We examined the relationship between Halfway River discharge and stage height in the Chowade River and Cypress Creek using Pearson's correlation coefficients to inform future pre-season planning and in-season counter management (e.g., site visit timing, potential data gaps). Water level can also affect counter accuracy, and stage heights can be used to inform counter effectiveness and troubleshoot accuracy issues.

We monitored stage height at both counter sites from August 25 to October 2, 2019. We did not monitor stage height from late July to August 24 because the loggers were incorrectly programmed. Stage height was constantly recorded using paired level loggers (HOBO U20, Onset Computer Corporation, Bourne, MA, USA). One logger was installed in a stilling well within the wetted stream width, while an onshore logger recorded ambient air pressure (used to calibrate the stream logger). Discharge and stage height for the Halfway River downstream of the Chowade-Halfway confluence were obtained from the Water Survey of Canada (Station No: 07FA003).

2.2.3 Resistivity Counters

We monitored Bull Trout spawners and kelts in the Chowade River using a Logie 2100C resistivity counter (Thurso, Caithness, Scotland) validated using continuous video monitoring (see Counter Validation). The counter consisted of four channels configured to span the full width of the tributary (Figure 2-2). We used flat pad sensors with three electrodes and two 6" strips of white puck board that increased visibility during video validation and reduced the risk of pad displacement during high water events.

High water levels in 2019 inhibited installation and operation of resistivity counters in both Cypress Creek and the Chowade River. In the Chowade River, Channels 1 through 3 were installed and operational by August 8. Channel 4 was damaged by a rain event shortly after installation, and high flows prevented repairs until September 25. All video cameras were operational from August 8 through October 1 (when the counter was removed), and we were able to use video data to obtain an estimate of kelts for Channel 4 (see Abundance Estimates). We were unable to install the Cypress Creek resistivity counter due to continued high water unsuitable for safe equipment installation, and therefore no Cypress Creek counter data were collected in 2019.

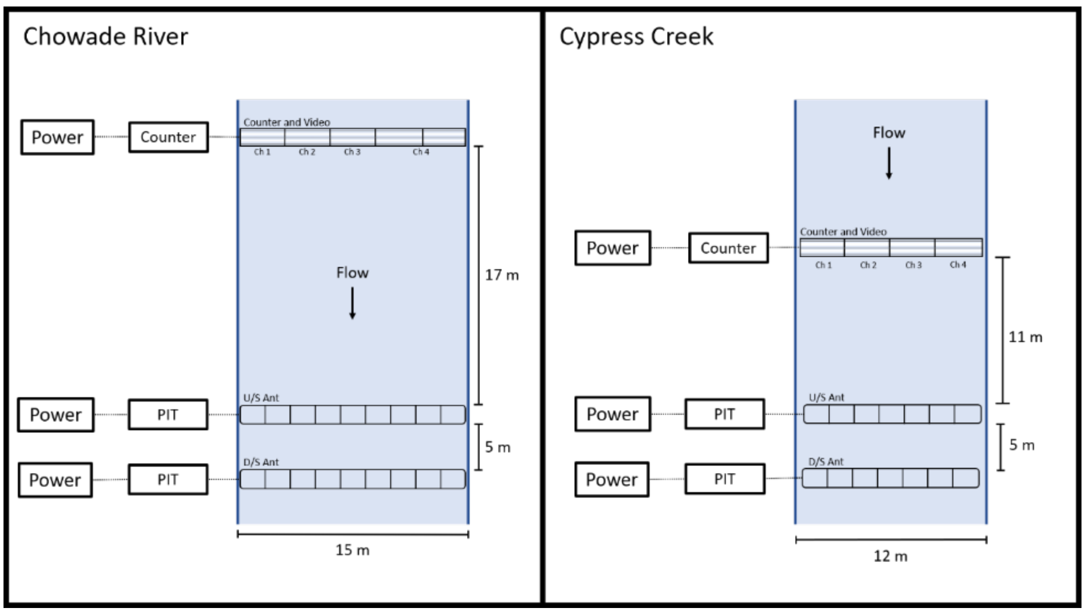


Figure 2-1. Configuration of the resistivity counter sensor pads, power system and video validation system in the Chowade River and Cypress Creek.

Counter Validation

We continuously operated a video monitoring system at the Chowade River counter site to validate the resistivity counter data and collect data for the inoperative channel (Channel 4). The cameras were placed directly above the sensor pads (one camera per pad) on a cableway system that also supported LED lights for nighttime recording.

Raw counter data were validated using video data to determine the number of true positives, false positives, false negatives, and to identify fish species (Table 2-2). We used a multi-step validation process that included targeted validation of counter up and down counts, and random validation of additional video data (see details in Figure 2-3).

During targeted validation, each counter record (up or down), manifested as a graphical trace (as shown in Figure 2-3), was validated by watching the corresponding video data and one minute before and after. Twenty-four hours of targeted footage were reviewed for the Chowade River in 2019 to determine the number of true positive and false positive movements. We also reviewed a subset of randomly selected video segments to determine the number of false negative movements. For each full day of video, 22 randomly selected 10-minute segments of video were reviewed (see Braun et al. 2017a for details), for a total of 217 hours (16% of the video record).

The number of true positives (TP), false positives (FP), and false negatives (FN) were used to calculate counter accuracy (A) for Bull Trout, summarized by direction (up and down) and counter channel

$$A = \frac{TP}{TP + FP + FN} \tag{2.1}$$

Accuracies were used to assess the performance of the counter, and to adjust the counter estimate to obtain final kelt estimates.

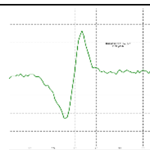
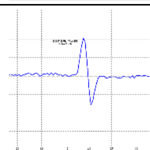
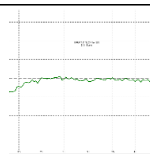
We measured the length of each fish observed during video validation to calculate average kelt size. The true length of a fish measured on the video was determined using the ratio of the on-screen pad length and on-screen fish length. Fish were identified to species (Bull Trout, Mountain Whitefish, or Rainbow Trout) based on length (R.L. & L. Environmental Services Ltd. 1995), colouration, and body shape. If a species could not be identified it was categorized as unknown.

Table 2-2. Definition of error rates used to classify counter records during validation.

Error Category	Resistivity Counter	Video Review
True Positive	Graphical trace (up or down)	Fish observed and movement agrees with up or down classification
False Positive	Graphical trace (up or down)	No fish movement occurred
False Negative	No graphical trace	Fish movement occurred
Unclassified	Graphical trace (up or down)	Video data not available

Raw Counter Measurement

- Counter measures a change in resistance as fish passes over the counter site
- Each trace is examined by a reviewer and classified as an up, down, or event

Up		Fish is moving upstream, passing over all three electrodes
Down		Fish is moving downstream, passing over all three electrodes
Event		Partial or incomplete movement of fish over the counter electrodes (in any direction) caused by a fish nosing up, falling back, or sitting on electrodes. Events may also be caused by air entrainment or debris flow over the electrodes.

Targeted Video Validation

- All up and down records are reviewed on video
- Reviewer watches record plus 1 minute before and after record
- Record is classified as either:
  - **True positive**
  - **False positive**

Random Video Validation

- Subset of randomly-selected video segments is reviewed
- For each 24-hour period, 20 randomly selected 10-minute segments are reviewed
- Fish movement observed on video but without paired graphical trace are classified as **false negative**

Calculate Error Rates and Accuracy

- Determine the total number of true positives (TP), false positives (FP), and false negatives (FN), summarized by:
  - Movement direction (up and down)
  - Species (Bull Trout, Mountain Whitefish, etc)
  - Counter channel
- Calculate accuracy (A) for each category

Figure 2-2. A description of the counter validation protocol.

Kelt Migration Timing

We observed three unique movement behaviours during the Bull Trout spawning migration:

1. Up-migration: Moving upstream to spawn;
2. 'Recycling': Movement back and forth across the counter site; and
3. Kelting: Moving downstream after spawning completion.

These movements can overlap, and therefore the approximate date of the kelting onset must be determined prior to estimating spawner or kelt abundance. Prior to the pre-determined date of kelting onset, downstream movements are considered recycling and are subtracted from up counts. Recycling and kelting can be distinguished because the number of recycling events generally mirrors that of daily up-counts, while kelting generally follows a normal distribution. Kelting onset and peak kelting dates were pre-determined by fitting a normal probability density function to daily down counts from September 1 to October 1. We estimated the mean, standard deviation and a scale parameter for the normal distribution. The fitted mean represented the peak date of the kelt migration while the scale parameter provided an estimate of kelt abundance (which can also be compared to the resistivity counter kelt abundance). We defined the date of kelting onset as the date when 5% of the kelts had migrated according to the daily kelt abundances predicted by the normal model.

Abundance Estimates

A Bull Trout kelting abundance estimate was generated for the Chowade River counter site:

$$E_k = \sum_{t=k}^{j} \frac{\mathrm{D_k}}{\mathrm{A_d}} \qquad (2.4)$$

where E_k is the kelt estimate, D_k is the number of downstream counts, A_d is the downstream counter accuracy, k is the date of kelting onset and j is the date of the last confirmed Bull Trout down-count.

To account for Channel 4 not being operational from installation (August 8) to August 25, we manually counted movements on Channel 4 using the video record and added this count to the accuracy-corrected count (E_k) for Channels 1 through 3. We watched all Channel 4 video collected at night (18:00 to 06:00) from August 10 to 17 (targeting the upstream migration) and September 1 to October 1 (kelting period). Only nighttime hours were watched as Bull Trout primarily migrate at night in the Chowade River (e.g., Ramos-Espinoza al. 2019). The Channel 4 estimate is an underestimate of the true number of fish that migrated on that channel as we did not validated all hours and dates; however, we expect the validated count to closely represent the true number based on previous knowledge of Bull Trout upstream and downstream migration timing in the Chowade River (e.g., Ramos-Espinoza et al. 2019).

2.2.4 PIT Telemetry

PIT arrays have been operated in the Chowade River and Cypress Creek in past years to detect fish tagged under Mon-1b, Task 2c (Site C Reservoir Tributaries Fish Population Indexing Survey) and Mon-2, Task 2a (Peace River Large Fish Indexing Survey) (see details in Ramos-Espinoza et al. 2019). High water in 2019 prevented the installation of PIT antennas in the Chowade River and Cypress Creek and therefore no PIT telemetry data were collected in 2019.

The scope of the monitor was expanded in 2019 to include PIT antenna operation throughout the winter of 2019/2020. We installed two PIT antennas in Cypress Creek and the Chowade River on October 2 and October 3, respectively (Figure 2-2) and maintained these antennas throughout the winter. Antenna specifications can be found in Ramos-Espinoza et al. 2019. Sites were visited at minimum monthly from October 2019 to January 2020 for maintenance and data downloads. Detailed read range testing of the antennas was also conducted when possible during each site visit to determine the proportion of the water column that was readable for the three sizes of PIT tags deployed under other monitoring programs (see details in Ramos-Espinoza et al. 2019). Range testing efforts were often inhibited by ice build up, and results are therefore not presented. Testing was nonetheless continued, as testing under such challenging conditions adds to our understanding of antenna performance, which is valuable for future monitoring initiatives in the Halfway Watershed.

We collated raw PIT files using the PITR package for R (Harding et al. 2018) developed by InStream Fisheries Research. Using the PITR package, movement of fish detected on the Chowade River and Cypress Creek PIT arrays were summarized. The use of two antennas made it possible to determine movement direction for any fish detected by both antennas.

2.2.5 Remote Power Systems

Resistivity counters, video validation equipment, and PIT arrays were powered by four battery banks charged by solar panels. Each battery bank was charged by solar panels but was designed to supply power for a minimum of seven days without charge. The required number of batteries and solar panels was calculated using a conservative estimate of four hours of daily solar radiation. We used a generator to charge batteries during extended periods of poor solar conditions.

3 Results

3.1 Redd Enumeration

3.1.1 Redd Distribution

Redd surveys were conducted weekly [REDACTED] (see dates in Figure 3-1, Figure 3-2, and Figure 3-3) for all tributaries but Needham Creek, which was surveyed for a peak count [REDACTED]. For tributaries with multiple surveys, the highest densities of redds were observed during the two mid-timed surveys (Figure 3-1, Figure 3-2, and Figure 3-3). Examining redd distributions can identify high-quality spawning habitat and verifies that ground surveys were performed in areas of adequate redd abundance, having implications for reliability of OE calculations. In the Chowade River, a large number of redds observed during aerial surveys were concentrated within the ground survey boundary (Figure 3-1), whereas in Cypress Creek, low densities of redds were more evenly distributed throughout the entire aerial reach (Figure 3-2). In Fiddes Creek, a higher density of redds was observed outside of the ground survey boundaries than within, though numbers were likely still adequate to accurately determine OE (Figure 3-3). Such temporal observations are not available for Needham Creek, having only one survey. The single survey did suggest, however, that Needham Creek has extensive habitat suitable for spawning (Figure 3-4).

[Figure 3-1 REDACTED]

[Figure 3-2 REDACTED]

[Figure 3-3 REDACTED]

[Figure 3-4 REDACTED]

3.1.2 Redd Abundance

Observer Efficiency

Ground OE was calculated for Surveys 2, 3, and 4 using redd re-sighting data. Mean ground OE was greater than 0.9 for all sites except Cypress Creek (0.50), where low OE was likely due to a small sample size (n = 4; Table 3-1). Aerial OE was highly variable and ranged from 0.0 to 1.0 among tributaries and surveys. Mean aerial OE was similar among the Chowade River (0.35, coefficient of variation [CV] 67%), Fiddes Creek (0.44, CV 66%), and the upper Halfway River (0.53, CV 72%). As with ground OE, aerial OE was substantially lower and more variable in Cypress Creek (0.08, CV 173%). With only one survey conducted in Needham Creek, neither OE nor a true ground abundance could be calculated, and the aerial OE was approximated as the aerial count divided by the uncorrected ground count. The uncorrected ground count was lower than the true ground abundance, and therefore aerial OE for Needham Creek was likely biased high.

Low and variable ground OEs in Cypress Creek have occurred in almost all project years due to low spawner and redd abundance and fewer visible redds (i.e., more redds located in covered areas) relative to the other tributaries. With more redds outside of the ground survey reach than within, the aerial OE may not be representative of the entire tributary. We used the aerial OE from the Chowade River to determine the GAUC abundance for Cypress Creek in 2019 to avoid overestimation of redd abundance.

Table 3-1. Ground counts, aerial counts, and observer efficiencies.

Tributary	Number of Redds Marked	Mean Ground OE	Survey	Ground Count	Total Redds[a]	Aerial Count[b]	Aerial OE[c]
Chowade River	53	0.91	1	17	18.8	8	0.43
			2	45	49.7	32	0.64
			3	55	60.8	13	0.21
			4	46	50.8	6	0.12
Fiddes Creek	10	1.00	1	7	7	5	0.71
			2	10	10	2	0.20
			3	11	11	2	0.18
			4	6	6	4	0.67
Upper Halfway River	15	0.97	1	6	6.2	1	0.16
			2	14	14.4	15	1.04
			3	17	17.5	10	0.57
			4	14	14.4	5	0.35
Cypress Creek	4	0.50	1	0	0	0	NA
			2	4	8	2	0.25
			3	2	4	0	0.00
			4	2	4	0	0.00
Needham Creek	-	-	3	17	-	6	0.35[d]

a: Ground count / ground observer efficiency
b: Aerial count within ground reach
c: Aerial count / total redds
d: We used aerial count/ground count to calculate OE for Needham Creek

Survey Life

A total of 81 tags were applied to age-1 redds during ground surveys in Fiddes Creek, Cypress Creek, the Chowade River, and the upper Halfway River. Of these 81 tagged redds, 62% (50 redds) progressed to age-4 during the survey period (66% in the Chowade River, 50% in Cypress Creek, 70% in Fiddes Creek, and 43% in the upper Halfway River).

We estimated the mean SL for all redds in 2019 (including redds that did not progress to age-4) using a LME model of normalized survey day *versus* redd age (Figure 3-5). The optimal random effect structure was a random intercept for tag ID (Appendix 2). The estimated SL was 21.2 days with a standard error of 1.93 days.

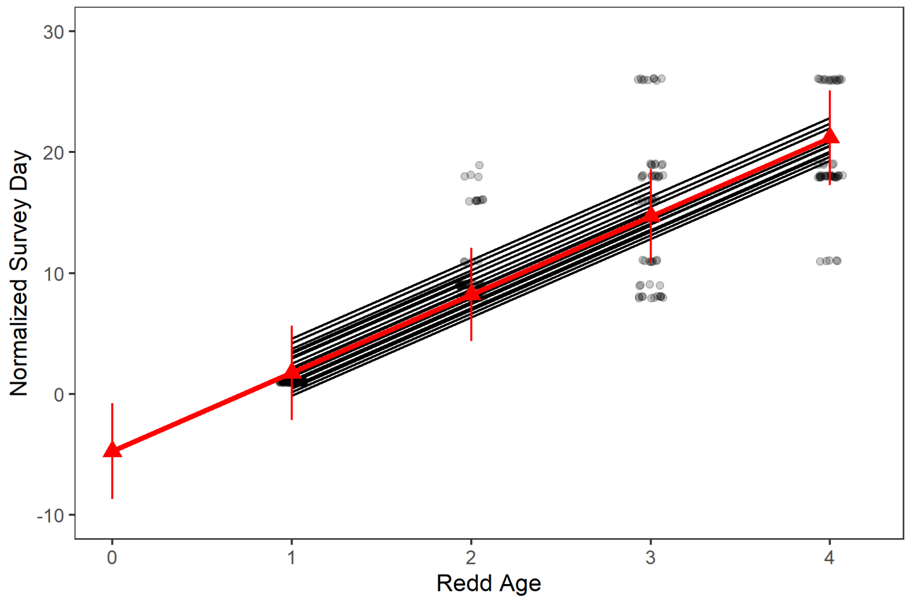


Figure 3-1. Redd age within all tributaries by normalized survey day, with points jittered for presentation. Black lines represent individual redds (i.e., shows random effect of redd ID on intercept). Red line shows mean for all redds, and vertical error bars are the 95% confidence interval based on a normal approximation. Negative normalized survey days correspond to the number of days between the redd being built (age-0) and the first observation by surveyors. A normalized survey day of 1 is when the redd was first observed by surveyors. See Equation 1.1 for model details.

Trail Cameras

Four of the eight deployed wildlife trail cameras provided clear daily photographs that could be used for ageing (two each in the Chowade and upper Halfway Rivers; see example in Appendix 3). Daily redd ages were used to model redd-specific and analyst-specific SL (Table 3-2). SL modelling for Analyst 1 is shown in Figure 3-6 and compared to SL estimated from redd survey data. Estimated SL for the four redds was similar among analysts, despite minor discrepancies among daily redd ages. The mean SL of all four redds across all analysts was 20.1 days (SD 4.0 days), which was similar to mean SL estimated using all redd survey data (21.2 days).

Table 3-2 Survey life (days) estimated using daily redd ages from wildlife camera data on four redds in the Chowade and upper Halfway Rivers. Four independent analysts assessed daily redd ages, which were then used to model survey life.

Redd	Analyst 1	Analyst 2	Analyst 3	Analyst 4	Avg (SD)
Chowade Redd 1	21.2	25.9	21.8	23.1	23.0 (2.1)
Chowade Redd 2	14.8	16.8	16.0	15.7	15.8 (0.8)
Halfway Redd 1	20.9	29.9	19.8	20.1	22.7 (4.8)
Halfway Redd 2	17.9	19.8	16.9	21.6	19.1 (2.1)

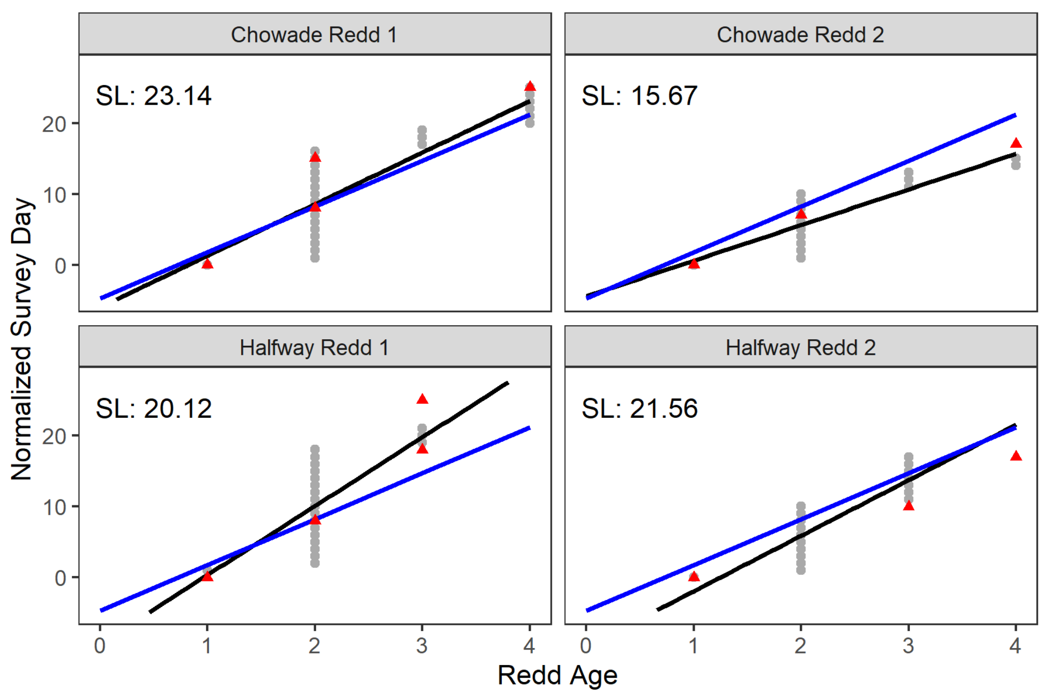


Figure 3-2. Survey life (SL) modelling (aged by Analyst 1) for redds in the Chowade and upper Halfway Rivers with wildlife cameras. Points represent redd ages estimated from photographs (grey circles) and during ground surveys (red triangles). The black line is the estimated mean SL for each individual redd, while the blue line represents the mean SL model estimated for all redds and tributaries in 2019.

GAUC Abundance Estimates

GAUC redd abundance estimates for 2019 ranged from 32 redds in the upper Halfway River to 213 redds in the Chowade River (Table 3-3). The total number of redds estimated for all tributaries combined was 401. Relative uncertainty in abundance estimates varied minimally among tributaries, ranging from 62.2% to 69.5% and the GAUC model provided a relatively good fit to count data for all tributaries (Figure 3-7).

Peak count estimates consistently underestimated redd abundance relative to the GAUC method, and peak counts from 2016 to 2019 were lower than the most recent historic peak counts in 2010 and 2012 (Figure 3-8, Appendix 4).

Table 3-3. GAUC estimates for Bull Trout redd abundance. Observer efficiency (OE) and survey life (SL) means and standard errors (SE) are input parameters for the AUC models. The 95% confidence limits (CL) are the 2.5 and 97.5% confidence bounds.

Tributary	GAUC Abundance (SE)	2.5% CL	97.5% CL	%RU	Aerial OE (SE)	Survey Life (SE)	Peak Count Index
Chowade River	213 (65)	118	386	69.5	0.35 (0.095)	21.2 (1.96)	92
Cypress Creek	37 (14)	18	76	62.2	0.35 (0.095)	21.2 (1.96)	24
Fiddes Creek	45 (17)	21	93	62.2	0.44 (0.118)	21.2 (1.96)	26
Turnoff Creek	74 (25)	38	144	66.2	0.44 (0.118)	21.2 (1.96)	30
Upper Halfway River	32 (11)	16	62	65.6	0.53 (0.155)	21.2 (1.96)	15
Needham Creek	-	-	-	-	-	-	33

[Figure 3-7 REDACTED]

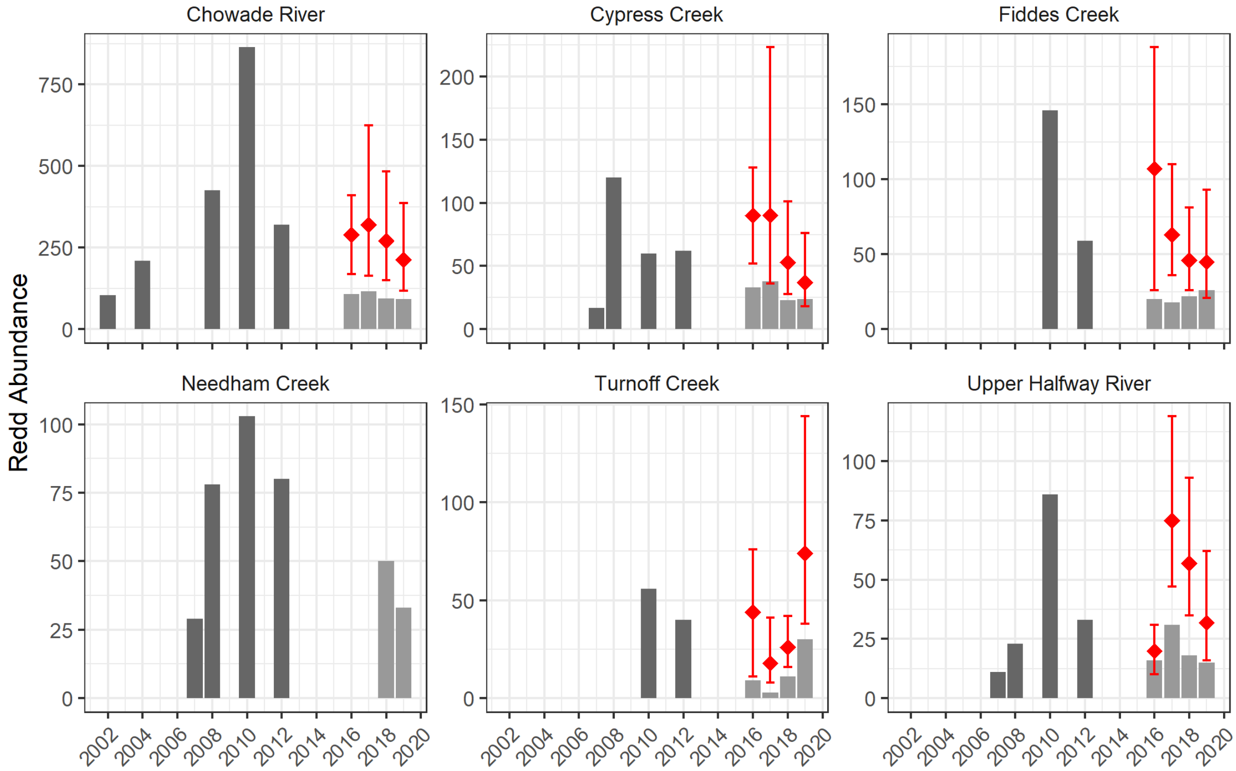


Figure 3-3. Bull Trout peak count redd indices from 2002 to 2014 (dark grey bars; Diversified Environmental Services and Mainstream Aquatics Ltd. 2009, 2011, and 2013) and from 2016 to 2019 (light grey bars; this monitor). GAUC estimates with CI for 2016 to 2019 are shown as redd diamonds.

3.1.3 Annual OE and GAUC

We compared OE (averaged across the four surveys) and GAUC redd abundance among study years in the Halfway Watershed (Figure 3-9). Ground OE was relatively consistent among survey years, but aerial OE and GAUC were variable in all tributaries. The confidence intervals for all measurements suggest substantial overlap in estimates among years.

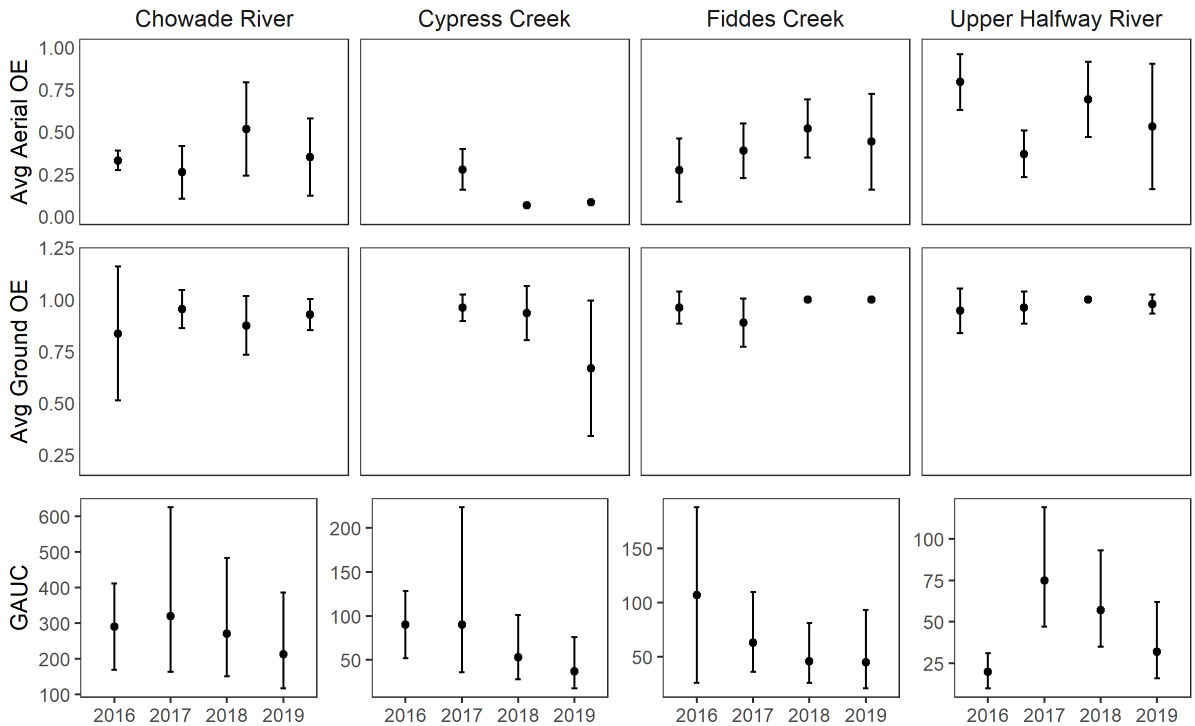


Figure 3-4. Mean aerial OE, ground OE, and GAUC estimates (error bars represent 95% confidence intervals) in the Halfway Watershed from 2016 to 2019.

3.1.4 Redd Area, Predicted Spawner Size, and Fecundity

We observed substantial variation in mean redd area both within and among tributaries, corresponding to variable estimates of spawner size and fecundity. The largest redds (and subsequently adult fork lengths and egg numbers) were observed in the upper Halfway River, Needham Creek, and the Chowade River (Figure 3-10; Table 3-4). We compared mean redd areas across survey years and sites using a two-way ANOVA and found both site and year were weakly significant predictors of mean redd area (ANOVA p-values 0.005 and 0.002, respectively), but that the interaction between site and year was not significant (ANOVA p-value 0.11). Predicted fecundity was highly variable (Table 3-4), and although coarse, highlights the importance of spawner size on Bull Trout recruitment.

Fork lengths predicted from redd size in the Chowade River overlapped substantially with total lengths measured during video validation of Chowade River resistivity counter data, but mean predicted fork lengths were lower than measured total lengths (Figure 3-11).

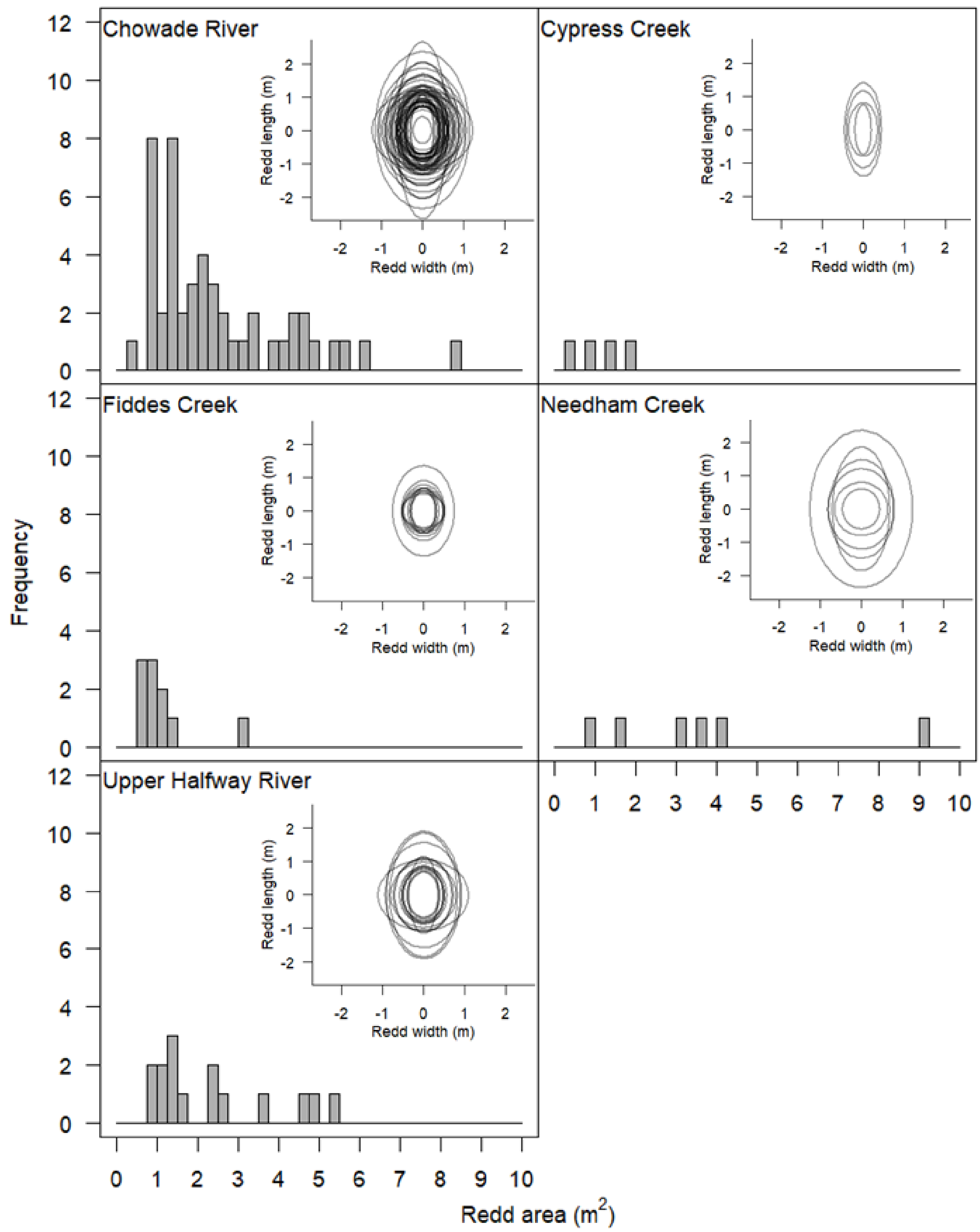


Figure 3-5. Frequencies of redd area by tributary. Insets represent the shape of redds based on lengths and widths and an assumed elliptical shape. Redds are centered at the origin of the inset plots (0,0).

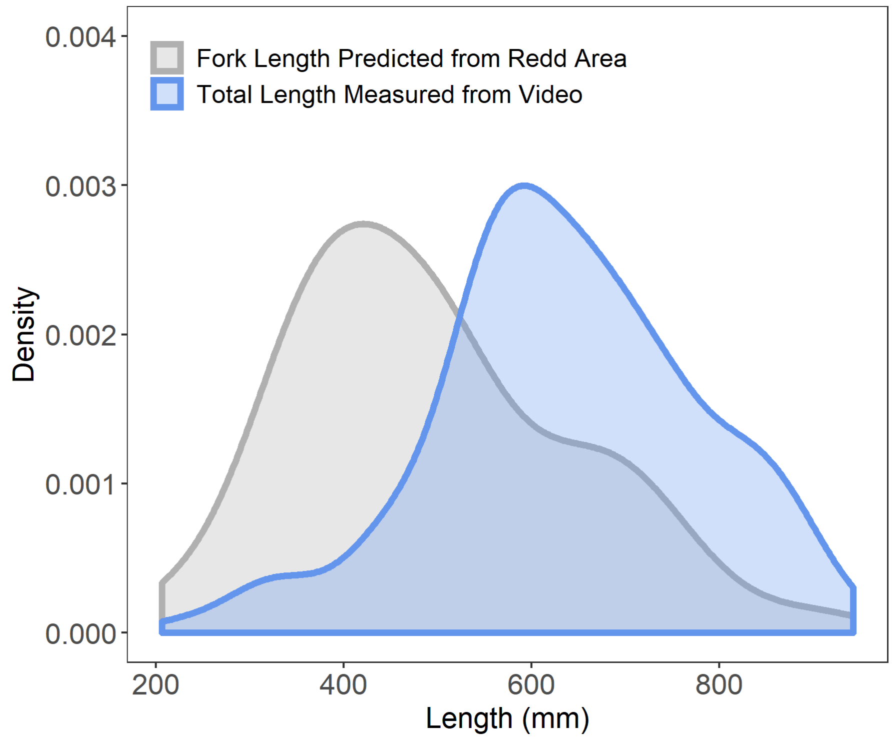


Figure 3-6. Probability density functions for fork lengths predicted from redd area data and total lengths measured during video analysis at the Chowade River resistivity counter site in 2019.

Table 3-4. Summary of predicted mean fork lengths and egg number from redd area by tributary using Equations 1.6, 1.7 and 1.8. Ranges are in parentheses.

Tributary	Fork Length (mm)	Egg Number
Chowade River	531 (205-905)	2747 (230-11023)
Cypress Creek	385 (257-481)	1188 (415-2123)
Fiddes Creek	375 (269-590)	1110 (467-3615)
Upper Halfway River	519 (324-741)	2588 (758-6547)
Needham Creek	634 (333-938)	4360 (814-12101)

3.2 Resistivity Counter and PIT Telemetry in the Chowade River and Cypress Creek

3.2.1 Stage and Discharge Monitoring

As in all previous monitoring years, Halfway River discharge (log-transformed) was strongly correlated with stage height measured at the Chowade River counter site ($r = 0.92$; $p < 0.001$) and at the Cypress Creek counter site ($r = 0.96$, $p < 0.001$; Figure 3-12). Stage loggers were not operational from late July to August 24, and we used the modelled relationships between stage and discharge to estimate stage height during this period (Figure 3-12).

We began installing the Chowade River counter in late July, when Halfway River discharge was 67.8 cms; however, high water levels challenged the installation and the counter was not fully operational until August 08. In 2017 and 2018, the Chowade River counter was installed when Halfway River discharge was 17.0 cms and 28.2 cms, respectively. In future years, the counter will be installed when discharge in the Halfway River is <30 cms. For Cypress Creek, the maximum Halfway River discharge at which safe installation can occur is currently estimated to be 41.5 cms. In 2019, Halfway River discharge did not decrease below 41.5 cms and we were unable to safely install the Cypress Creek counter.

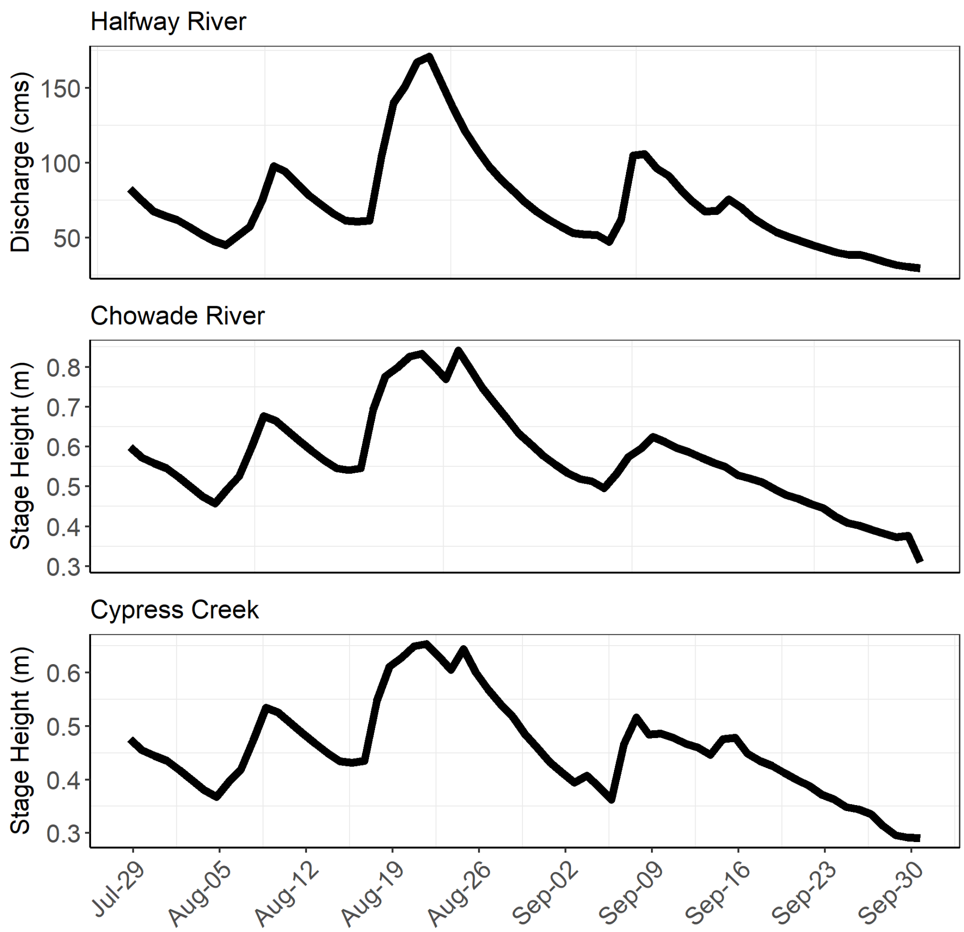


Figure 3-7. Daily means of Halfway River discharge (Station 07FA003; top) and stage height in the Chowade River and Cypress Creek between August 25 and October 1, 2019. Stage heights from July 29 to August 24 are estimated based on modelled relationships between stage and the logarithm of discharge.

3.2.2 Chowade River Resistivity Counter

Counter Validation

We estimated channel-specific and direction-specific counter accuracy using video validation of counter records (Table 3-6). Average up-accuracy for Channels 1 through 3 (Channel 4 was not operational) was 91%, and down-accuracy was 57%, suggesting the counter underestimated downstream movements more than upstream movements. We expected down-accuracy to be lower than up-accuracy because Bull Trout travel lower in the water column while moving upstream and are therefore closer to the counter sensors. In 2019, the majority of upstream Bull Trout movements occurred on Channel 1, while downstream movements were relatively evenly distributed across the four channels (Figure 3-13). As predicted, Channel 1 accuracy was low relative to Channels 2 and 3 for both upstream and downstream movements, likely because Channel 1 is the deepest of the monitored channels.

Mean total lengths of Bull Trout, Mountain Whitefish, and Rainbow Trout observed in the video record are shown in Table 3-5. Fish that could not be identified during video validation included 16 small-bodied (<40 cm) and 1 large-bodied (> 40 cm) fish.

Table 3-5. Fish total lengths estimated in the Chowade River through video validation in 2016 - 2019.

	N	Mean (mm)	Range (mm)	SD (mm)
Bull Trout				
2016	30	700	410-930	120
2017	361	613	300-1080	143
2018	525	632	300-1036	152
2019	157	637	223-943	139
Mountain Whitefish				
2016	187	240	110-490	70
2017	156	323	120-494	44
2018	180	323	211-480	55
2019	30	297	206-405	52
Rainbow Trout				
2016	-	-	-	-
2017	11	326	300-343	17
2018	10	387	265-587	101
2019	28	420	200-586	91

Table 3-6. Chowade River counter accuracies (2019) for Bull Trout on Channels 1 through 4. Channel 4 was not operational in 2019.

Direction	Channel 1	Channel 2	Channel 3	Channel 4
Up	73%	100%	100%	-
Down	37%	70%	64%	-

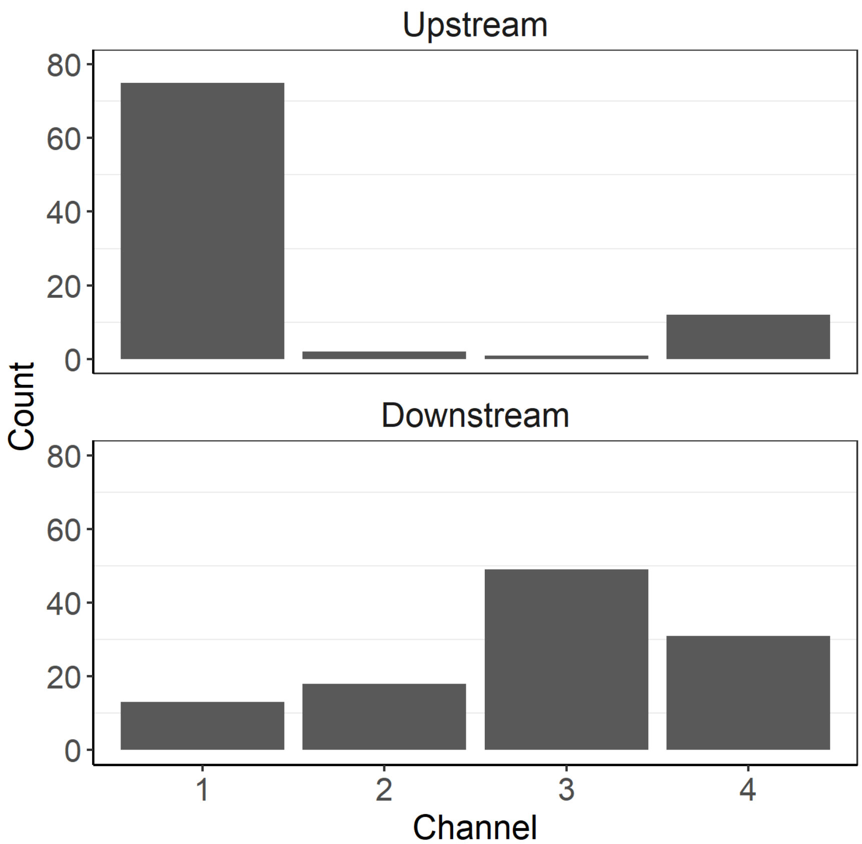


Figure 3-8. Accuracy-corrected counts of Bull Trout upstream and downstream movements separated by counter channel in the Chowade River, 2019 (August 8 to October 1). All movements on Channel 4 were video validated in 2019.

Kelt Migration Timing

We used a normal density model to estimate kelting timing for the Chowade River using accuracy-corrected count data from Channels 1 through 3. We did not include data from Channel 4 (obtained from extensive video enumeration), as we considered these data to slightly underestimate the true count from Channel 4. We assume data from Channels 1 through 3 will be representative of the kelting timing. The normal density function estimated that the Bull Trout kelt out-migration began on September 2 (Figure 3-14) and peaked on

September 16 (SD 8.3 days). These kelt-timing parameters were used to define the onset of kelting behaviour and estimate kelt abundance.

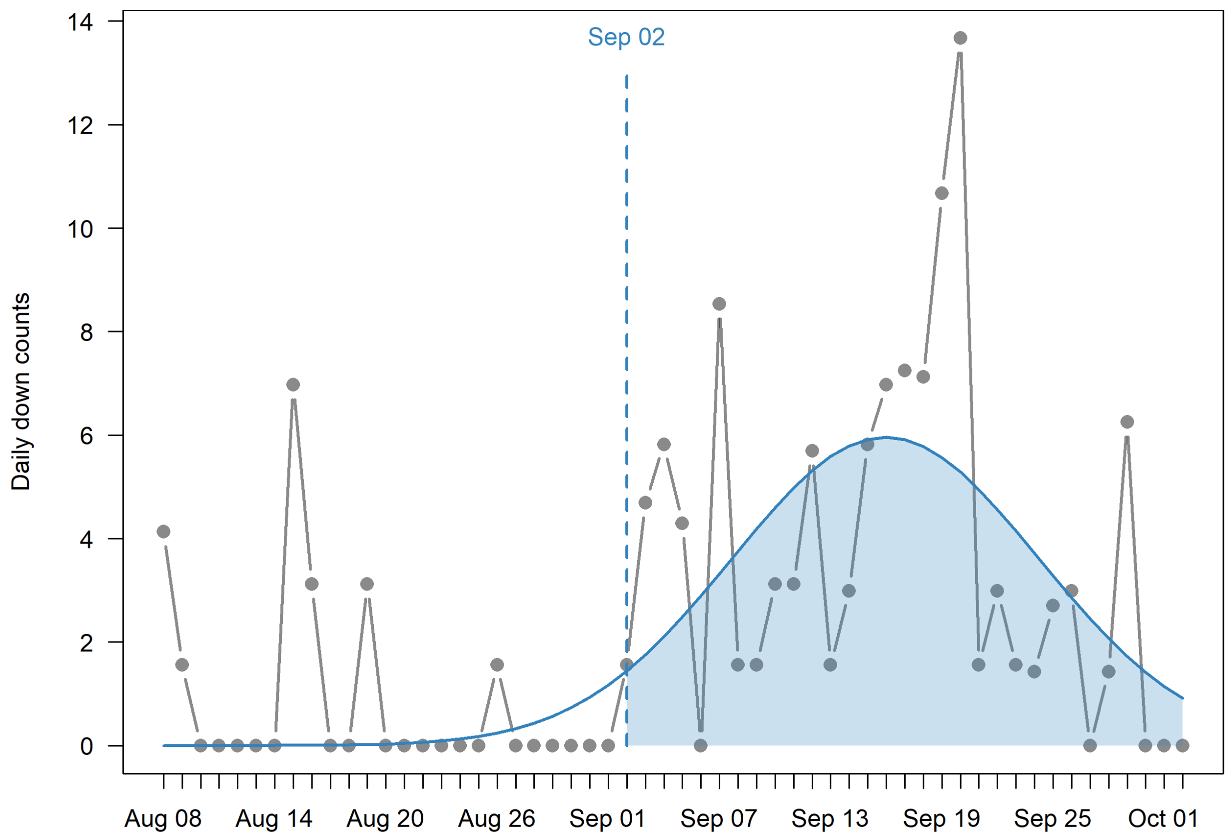


Figure 3-9. Plot of corrected daily down counts of verified Bull Trout (grey points and lines) and modelled kelt out-migration timing (solid blue line and shaded blue area) in Chowade River, 2019. The normal model parameters were estimated using data from September 1 to October 1 and were used to predict the kelt out-migration before and after those dates. The vertical dashed blue line marks the date at which the normal model estimated 5% of the kelts to have out-migrated, which is assumed to be the onset of the kelt out-migration.

Kelt Abundance Estimate

After accounting for counter accuracy and the date of kelting onset (Equation 2.4), the kelt abundance for the Chowade River was 144 Bull Trout. This estimate is a combination of abundance for Channels 1 through 3 estimated using Equation 2.4 (117), and the fully validated count for Channel 4 generated during video validation (27).

We could not generate an upstream abundance due to the late counter installation; however, the counter detected 93 Bull Trout moving upstream past the counter (after accounting for counter accuracy) between August 8 and October 1 (Figure 3-15).

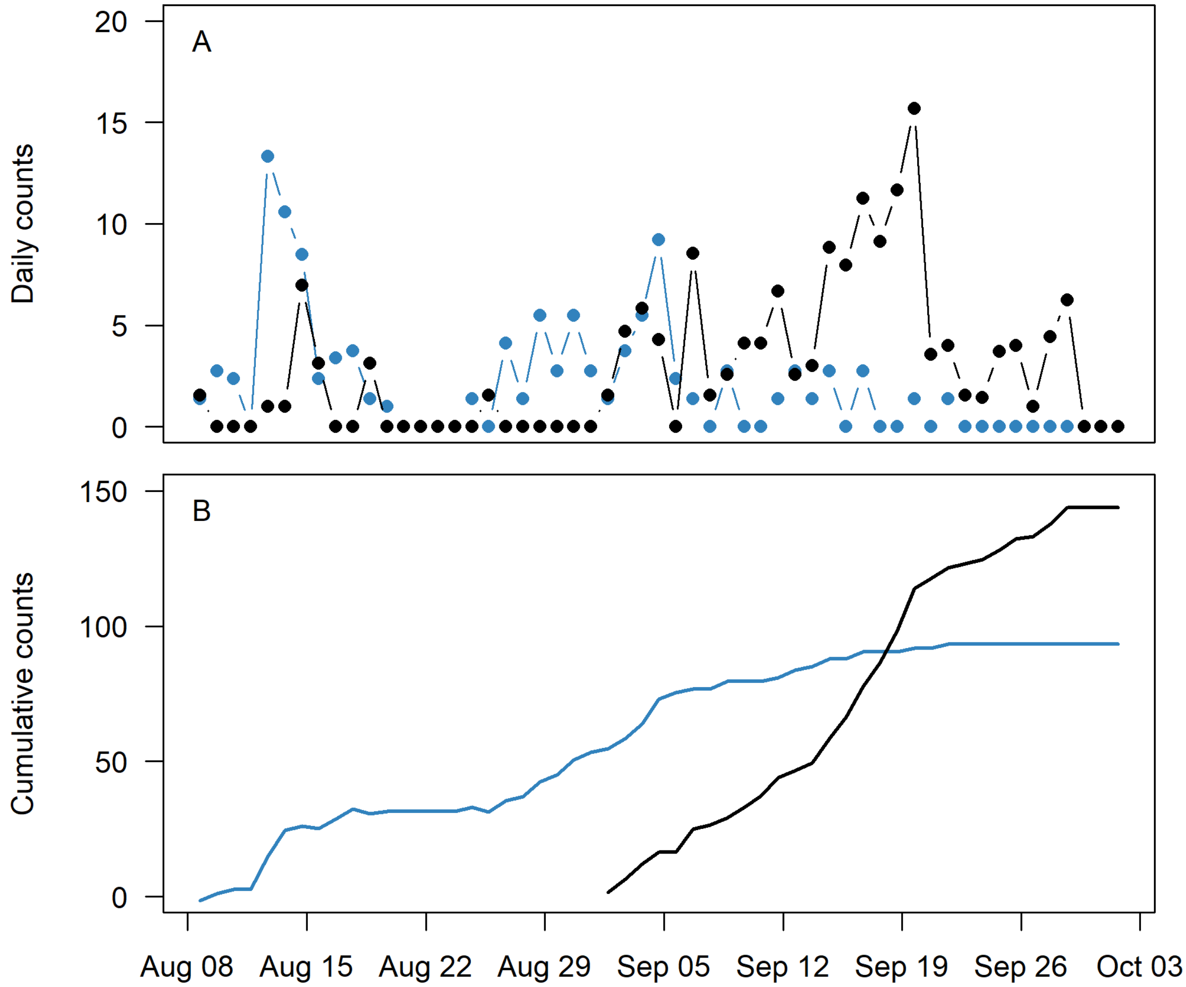


Figure 3-10. (A) Bull Trout daily accuracy-corrected up (blue) and down (black) counts, and (B) cumulative net up counts (blue line) from August 8 to October 1 and cumulative down counts of kelts (black line) from September 2 to October 1 in the Chowade River 2019.

3.2.3 PIT Telemetry

Despite uncertainties regarding power capacity during the winter months due to poor solar conditions, the first year of operating the PIT arrays beyond the Bull Trout migration period was successful. Power outages did occur, but not to the extent that damaged equipment and operations continued autonomously when solar conditions improved.

Data were collected throughout the winter and into the spring (from October 2019 to late May 2020) and all three tag sizes were detected. Ten unique tag codes were detected in the Chowade River. Five of these tags were detected on both antennas, thus providing directionality. Two fish made upstream movements on October 26 and three made downstream movements on October 4 and October 8. In Cypress Creek, eight unique tag codes were detected, from which direction could be determined for four (upstream movements on October 6 and November 2 and downstream movements on November 18 and December 10). Detections occurring later in the season at Cypress Creek relative to Chowade River could reflect the better solar conditions at Cypress Creek, and thus fewer and shorter power outages. Compiled data have been provided to Golder and Associates for further analysis under Mon-1b Task 2c and Mon-2 Task 2a.

4 Discussion

The objective of the Peace River Bull Trout Spawning Assessment (Mon-1b, Task 2b) is to assess the abundance, migration timing and distribution of Bull Trout spawning in the Halfway Watershed. The results of this monitoring program build upon previous knowledge of Bull Trout spawning in the Halfway Watershed, including peak redd counts in five tributaries from 2002 to 2012 (Diversified Environmental Services and Mainstream Aquatics Ltd. 2009; 2011; 2013), spawner assessment and fish fence data from the Chowade River in 1994 and 1995 (R.L. & L. Environmental Services LTD. 1995; Baxter 1997), and radio telemetry data collected throughout the Peace Region (e.g., AMEC Earth & Environmental and LGL Ltd. 2010).

4.1 Abundance

We estimated three abundance metrics for adult Bull Trout in the Halfway Watershed in 2019: redd abundance and peak count indices in the Chowade River, Cypress Creek, the upper Halfway River, Fiddes Creek, Turnoff Creek, and Needham Creek (peak count only); and kelt abundance in the Chowade River and Cypress Creek. Here we discuss redd and kelt enumeration methods, trends in abundance relative to historic peak counts, and implications of kelt to redd ratios. The abundance of upstream migrating Bull Trout could not be estimated for the Chowade River or Cypress Creek in 2019 due to high flows preventing equipment operation.

4.1.1 Redd Enumeration

Understanding and quantifying sources of error is integral to producing an accurate and precise redd abundance estimate using the GAUC method. Ground OE has been consistently high in most tributaries from 2016 to 2019, which agrees with literature suggesting detailed ground surveys are a relatively accurate redd counting method (Dunham et al. 2001). In contrast, low and variable ground OEs have occurred in Cypress Creek. Although low and variable ground OE may be related to a small sample size of marked redds, anecdotal evidence suggests a high prevalence of redds in the Cypress Creek ground reach are constructed in covered areas. Redds in covered areas, such as beneath logs or cut banks, are virtually impossible to observe from the air, resulting in low aerial OE. We observed mid-channel redds in Cypress Creek outside of the ground reach, suggesting the survey reach may not be representative of the entire spawning area, and we recommend expanding the ground

OE survey area to increase the number of marked redds and better represent redd characteristics in the full spawning reach.

Aerial OE is typically lower and more variable than ground OE, which is expected given tributary-specific river conditions (flow, temperature, turbidity), visual survey conditions (water depth, clarity, and glare), helicopter survey conditions (e.g., glare, survey height, and survey speed) and redd distributions. Variability in aerial OE can contribute substantially to overall uncertainty in the GAUC estimates. Additional years of OE data will inform the range of aerial OE for all tributaries, particularly those with fewer redds, and provide a more comprehensive understanding of Bull Trout abundance.

Survey life contributes to GAUC estimates by accounting for double counting across visual surveys. Average SL has ranged from 18.5 days (SE 2.2) in 2018 to 24.2 days (SE 2.3) in 2017, and anecdotal evidence suggests SL may vary among tributaries (e.g., SL in Cypress Creek appears to be shorter relative to all other tributaries). Having used two distinct methods to measure SL that produced similar results, the observed variation in survey life is likely related to tributary characteristics (e.g., flow, temperature, and productivity) rather than variation in methods and data collection.

4.1.2 Kelt Enumeration

An estimated 144 Bull Trout kelts migrated downstream past the Chowade River counter site between September 2 and October 1, 2019. Confidence in this estimate is high given extensive validation effort, despite moderate downstream counter accuracy (57%). Understanding errors associated with enumeration is critical to detecting changes in abundance and rigorous methodology is in place to quantify the accuracy of counter estimates. Upstream counter accuracy in 2019 was similar to or higher than other salmonid enumeration programs in British Columbia. For example, flat pad counters in the Lower Bridge and Chilcotin Rivers had upstream accuracies of 70% and >80%, respectively. Downstream accuracies were also similar to other studies such as in the Chilcotin River, where downstream accuracies are typically 50% or greater (Burnett et al. 2017, Ramos-Espinoza et. al. 2011).

Under optimal conditions, we would expect downstream accuracies to be between 60% and 70% (e.g., Ramos-Espinoza et al. 2011), and the low downstream accuracies (<60%) observed in the Halfway Watershed are likely a result of fish behaviour and site morphology. Bull Trout move faster and travel higher in the water column when migrating downstream, making it more difficult for the counter to detect their movement. The Cypress Creek counter is within a fast-moving riffle, and the Chowade River counter in an area with a pronounced thalweg, both of which likely affected counter accuracy. We will continuously work to improve accuracy through counter pad innovation and testing to more accurately determine kelt abundance.

High water levels may affect Bull Trout swimming behaviour in the Chowade River, particularly during the upstream migration. In high-water years such as 2016 and 2019, most upstream movements occurred along the river margins. In lower-water years, such as 2018, movements were more concentrated proximate to the thalweg. The effect of discharge on swimming behaviour has important implications for the resistivity counter data and video validation and should be considered when making year to year comparisons.

Although PIT arrays were not installed until early October due to the continued high discharge, PIT antennas successfully detected tagged fish throughout the winter despite low light conditions and minor power outages. With little known about the movement of fish in the Halfway Watershed during the winter, the data provide important baseline information of life history characteristics to inform future monitoring.

4.1.3 Spawner Abundance in the Halfway Watershed

Bull Trout peak redd counts have occurred periodically since 2002, and we repeated peak counts from 2016 to 2019 along with GAUC abundance estimates. With only four years of GAUC abundance estimates, trends cannot be assessed at this time. However, peak counts collected during this monitor are several magnitudes lower than peak count estimates from 2010 and 2012. This is particularly apparent in the Chowade River; in 2010 the estimated peak count was over 800 redds, but in 2016 through 2019, peak count was consistently below 200 redds. In fact, the decline in redd abundance may be even larger, as a comparison of peak counts and GAUC estimates suggest historic counts may have underestimated true redd abundance.

Variability in peak redd counts may be partially related to count methodologies, which highlights the importance of a robust enumeration methodology (e.g., GAUC and/or resistivity counters). Historic peak counts were subject to minor variations in counting methods, counting personnel, and survey lengths. Also, we found peak counts from 2016 through 2019 were sensitive to which and how many surveys were included in the peak spawning window. This sensitivity highlights the uncertainty inherent in peak counts and suggests GAUC estimates are a more accurate and consistent method of redd abundance estimation. Variable redd abundance may also be related to high rates of process error inherent in Bull Trout population estimates. A power analysis found high rates of process error (i.e., natural variation in population size) in historic Bull Trout redd counts in the Halfway Watershed (Ma et al. 2015), and process error is generally known to be high in Bull Trout spawner estimation (e.g., Kovach et al. 2018, Maxwell 1999). Finally, changes in peak counts may be related to regional weather patterns, fishing pressure, or additional impacts that have not been identified. For example, Diversified Environmental Services and Mainstream Aquatics (2013) noted a decline in spawning activity and redd building from 2010, which they suggested may have been related to extreme hydrological events in 2011 and 2012, and an increasing trend of recreational fishing in the region (Diversified Environmental Services and Mainstream Aquatics Ltd 2013).

It is still unknown whether Bull Trout in the Halfway Watershed consistently return to the same tributary to spawn. Genetic analyses suggest that Bull Trout in the Halfway River are genetically distinct from Bull Trout in the Pine River (Geraldes and Taylor 2020) and telemetry data (PIT and radio) currently being collected by other monitoring programs will help to describe individual Bull Trout spawning movements. Due to uncertainties in spawner behaviour it may be necessary to combine GAUC redd counts across all tributaries in addition to consistently monitoring all tributaries to determine potential changes in abundance. To fully capture redd abundance for a mixed population, it is important that all critical spawning tributaries are included in redd count surveys. Peak redd counts suggest Needham Creek has a large number of Bull Trout spawners relative to other tributaries surveyed.

Using redd abundance to detect changes in Bull Trout spawner abundance assumes that redd counts are correlated with adult spawner abundance, and that a change in redd counts represents a corresponding change in population abundance. Monitoring the annual ratio of kelt to redd abundance is important to understand how changes in redd abundance relate to overall changes in Bull Trout populations.

We generated a kelt to redd ratio for the Chowade River using kelt abundance from the resistivity counter and GAUC redd abundance. The ratio of kelts to redds in the Chowade River was 0.9 (95% CL 0.5-1.8) in 2017, 2.1 (1.2-3.7) in 2018, and 0.7 (0.4-1.2) in 2019. In Cypress Creek, the ratio was 1.0 (0.4-2.5) and 2.5 (1.3-4.7) in 2017 and 2018, respectively. Kelt to redd ratios are low relative to literature values of spawners to redds from western North America (~1-4 spawners/redd; Howell and Sankovich 2012; Andrusak 2009; Al-Chokachy et al. 2005; Dunham et al. 2001). The number of kelts is likely lower than the full spawner abundance, which suggests our kelt to redd ratios are underestimates. Given that limited years of paired redd counts and kelt abundances are available for the Halfway Watershed, it is premature to draw conclusions regarding the ratios generated by Mon-1b, Task 2b. We will continue to explore the relationship between spawners, kelts, and redd abundance in future monitoring years using redd counts, counter estimates, and PIT recapture data (i.e., kelting proportion, survivorship, etc.).

Previous research suggests that redd counts and spawner abundance are correlated but highly variable (Al-Chokachy et al. 2005; Dunham et al. 2001). Variability in the ratio of spawners to redds can result from observation error or process error, which is a combination of innate variability and environmental stochasticity. For example, the spatial distribution of redds, size of redds and spawners, spawner density, life histories (e.g., the proportion of resident vs migratory spawners), skip-spawning rates, and spawning stream characteristics (e.g., substrate composition, turbidity, and discharge) can all influence spawner to redd ratios (Howell and Sankovich 2012; Al-Chokachy et al. 2005). Observation error of both redd and spawner counts can result from the survey timing and frequency, the spatial extent of surveys, surveyor experience, and stream characteristics during surveys (Howell and Sankovich 2012). However, although observation error is inherent to count estimates, our GAUC and electronic counter estimation methods account for error and reduce uncertainties around the estimates.

Detecting trends in Bull Trout abundance can be particularly challenging over short assessment periods (e.g., <10 years). Bull Trout are considered to have a five-year generation time, which can result in a substantial lag-time between the occurrence of a stressor and a response in redd or spawner abundance (Howell and Sankovich 2012). Spawner to redd ratios are also spatially variable, and changes in Bull Trout abundance can occur due to stressors proximate to spawning areas (e.g., beaver dams, landslides) or regional stressors (e.g., disruption to overwintering habitat or migration routes; Kovach et al. 2018; High et al. 2008). Separating the effects of localized changes to spawning tributaries from the effects of regional stressors such as the construction and operation of the Project will add additional uncertainty to trend analyses. Bull Trout spawner assessments used in this monitor prioritize accurate and precise estimates of both redd abundance and spawner abundance to maximize the power to detect a decline in the Halfway River Bull Trout population.

4.2 Migration Timing

Timing of the Bull Trout upstream migration remains uncertain for tributaries of the Halfway Watershed. Angling surveys in 1995 suggested Bull Trout first appear in the Chowade River in early August and peak spawning occurs [REDACTED] (Baxter 1997). Resistivity counters have not yet been installed in time to monitor the full upstream migration, but counter data from early August (Braun et al. 2017a, Ramos-Espinoza et al. 2019) suggest that the upstream migration may begin in July and peak earlier than previously suggested by Baxter (1997). In addition, it appears the upstream migration may not follow a typical normal distribution, as observed for downstream kelts, and that the tail end of the upstream migration may extend into September.

Peak redd building and kelting dates in the Halfway Watershed have been relatively consistent in recent years, but there is evidence that redd building may be occurring later than suggested by historic surveys. In the 2000s, redd count data suggested peak redd building occurs [REDACTED] (e.g., Diversified Environmental Services and Mainstream Aquatics Ltd 2011), while the GAUC model from this monitor predicted peak redd building to occur [REDACTED] (2016 to 2019). Kelting dates agree with a later redd building peak; the normal kelting model predicted peak kelting to occur [REDACTED] in all monitoring years. These comparisons, although coarse, suggest that redd building may occur later in September relative to historic peak counts.

4.3 Distribution

According to redd surveys, Bull Trout spawner distributions appear to be variable both within and among Halfway River tributaries. Although some areas consistently saw redd activity from 2016 to 2019, many areas of high-quality spawning habitat were not used in each year. For example, in the Chowade River, redds have been observed throughout the aerial survey reach, with clusters of redds observed in several areas of apparent high-quality habitat (this was particularly pronounced in 2016 and 2017). In 2018 and 2019, however, redds were observed almost exclusively in the upper 5 km of the aerial survey reach, suggesting Bull Trout were not using all available spawning habitat. Historic peak count surveys also noted annual changes in Bull Trout distributions, and increased spawning outside of wildlife habitat areas created in 2000 to protect critical Bull Trout spawning habitat (Diversified Environmental Services and Mainstream Aquatics Ltd 2011, 2013).

A multitude of factors could describe temporal variation in spawner distribution. The observed variability in spawner abundance estimates among years may explain distributions. Indeed, it is still uncertain whether Bull Trout return to the same spawning tributary each year, which could have implications for tributary-specific and system-wide changes in redd abundance. Additionally, anecdotal evidence suggests that discharge may affect spawner distribution throughout the watershed and across just three years of monitoring, discharge during the Bull Trout migration has varied considerably. Preliminary data suggest that years with high discharge are associated with higher GAUC redd abundance in smaller tributaries such as Fiddes and Turnoff Creeks. Changes in water temperature or groundwater discharge are also known to be important to distribution and abundance of spawning salmonids (e.g., Baxter and McPhail 1999). We will continue to monitor redd distribution in the Halfway Watershed to investigate the complex nature of redd site selection.

4.4 Spawner Size and Fecundity

Although redd and kelt abundance can serve as indices of spawner abundance, they may not accurately reflect juvenile recruitment given variations in fecundity with fish size (Riebe et al. 2014, Kindsvater et al. 2016). Therefore, if spawner size distributions change across time, abundance alone may not reflect changes in Bull Trout population dynamics.

A comparison of fork lengths estimated from redd areas with fork lengths from historic surveys and total lengths estimated from video validation suggest the relationship in Reibe et al. (2014) may underestimate fork lengths in the Halfway Watershed. Fork lengths estimated from redd areas in the Chowade River (531 mm, range 205-905 mm) were smaller than mean fork lengths measured during angling surveys in the Chowade River in 1994 and 1995 (Baxter 1997; female: 609.75 mm, range ~400-800 mm; male 630.03 mm, range ~300-900 mm), and fork lengths obtained during fish fence monitoring in 1994 (R. L. and L. Environmental Services Ltd. 1995; 604 mm, range 370-905 mm). Fork lengths estimated from redd areas in the Chowade River were also ~200 mm smaller than those measures by the Chowade River resistivity counter.

Having accurate size distribution data is important to understanding current and future population dynamics. Predicted fecundities show that larger female Bull Trout can contribute thousands more eggs and potential recruits to the Halfway River population relative to smaller individuals. We acknowledge that fecundity estimates presented herein are coarse calculations; however, the large variation in fecundity could affect juvenile recruitment and population dynamics in future years, particularly if Bull Trout size distributions are affected by the construction and operation of the Project. Refining these relationships could be a valuable contribution to better understanding future variations in Bull Trout population estimates as construction of the Project, and future monitoring, continues.

4.5 Conclusion

Accurately and consistently estimating abundance, and detecting changes in abundance, of Halfway River Bull Trout is critical to understanding potential population-level effects of the Project. Since 2016, we have produced redd abundance estimates and kelt abundances for tributaries of the Halfway River, which build upon historic peak counts dating back to the early 2000s. Our GAUC method is more accurate and robust relative to peak counts, increasing the probability of detecting future changes in Bull Trout populations.

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Appendices

Appendix 1. Sensitivity of GAUC estimates to the addition of zero counts before the first survey and after the last survey. Mean estimates and standard errors are presented.

	Abundance			
Tributary	**Zeros at start and end**	**Zero at end**	**Zero at start**	**No zeros**
Chowade River	271 (80)	272 (85)	312 (90)	338 (101)
Cypress Creek	53 (17)	58 (19)	56 (23)	-
Fiddes Creek	46 (13)	53 (15)	48 (16)	-
Turnoff Creek	26 (6)	29 (7)	26 (7)	32 (10)
Upper Halfway River	57 (14)	59 (16)	60 (18)	75 (45)

Appendix 2. Linear mixed model summary results for redd age data from 2019.

Model 1: Mean survey life model for redd age data from 2019

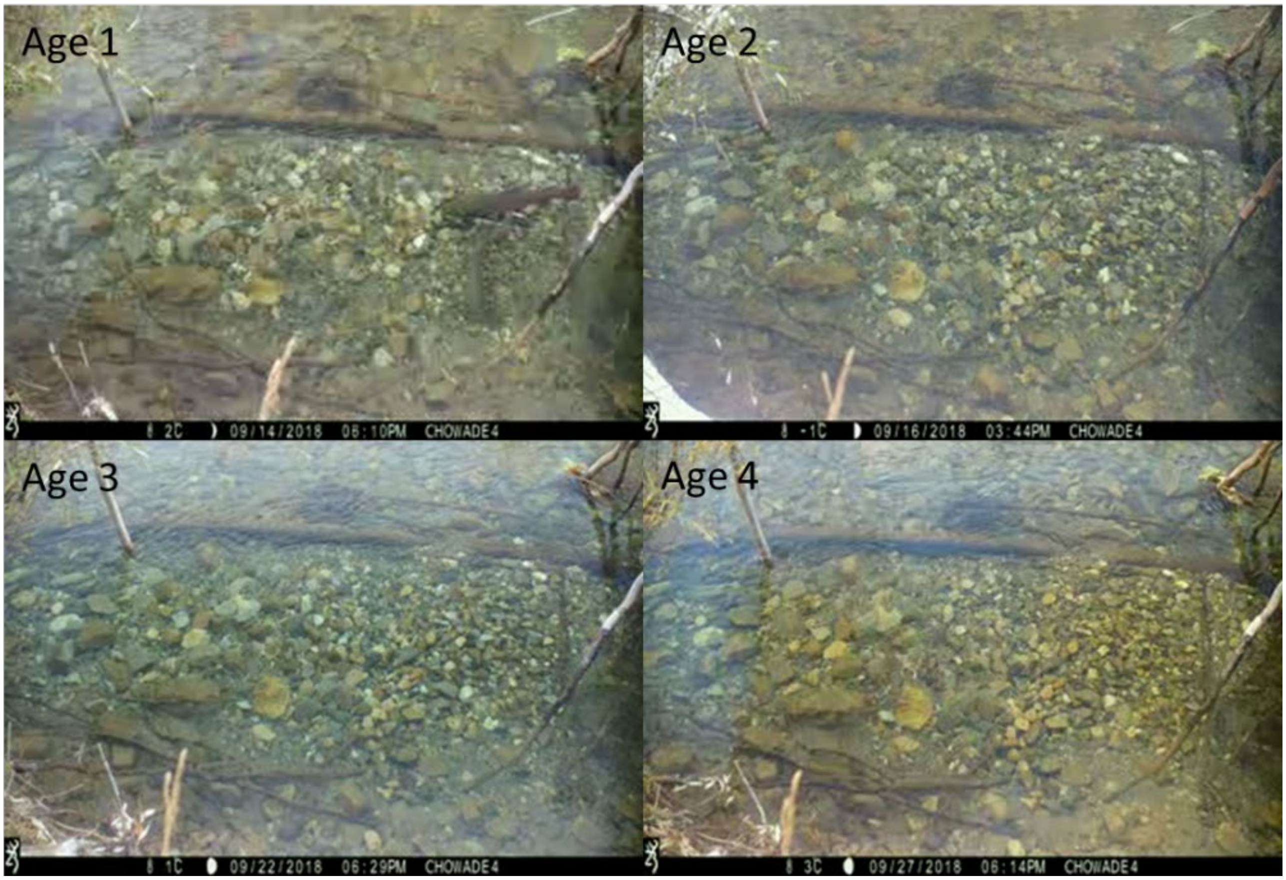
Equation: normalized day ~ redd age + (1 | tag ID)			
Data Used: All tributary data pooled from 2019 only			

Fixed Effects	**Estimate**	**Standard Err**	**t value**
Intercept	-4.73	0.58	-8.12
Redd Age	6.48	0.21	30.85

Random Effects	**Variance**	**Standard Dev**
Tag ID (intercept)	3.61	1.90
Residual	13.54	3.68

Number of observations: 248; number of tag ID groups: 81

Appendix 3. Example photos from a Chowade River trail camera showing a redd progressing from age-1 to age-4.



Appendix 4: Bull Trout Peak Count Indices

Surveys for peak counts varied in the length of stream surveyed and survey method among years within tributaries. NS denotes a year in which no surveys were conducted.

Peak Count Indices

Tributary	2002	2004	2007	2008	2010	2012	2016	2017	2018	2019
Chowade River	104	210	NS	425	864	321	108	116	94	92
Cypress Creek	NS	NS	17	120	60	62	33	38	23	24
Fiddes Creek	NS	NS	NS	NS	146	59	20	18	22	26
Turnoff Creek	NS	NS	NS	NS	56	40	9	3	11	30
Upper Halfway River	NS	NS	11	23	86	33	16	31	18	15
Needham Creek	NS	NS	29	78	103	80	NS	NS	50	33