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 8 (2022)

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

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April 26, 2023

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2022 Peace River Bull Trout Spawning Assessment (Mon-1b, Task 2b)

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April 26, 2023

A. Putt, D. Ramos-Espinoza, and M. Chung. 2023. Site C Reservoir Tributaries Fish Community and Spawning Monitoring Program – 2022 Peace River Bull Trout Spawning Assessment (Mon-1b, Task 2b). Report prepared for BC Hydro – Site C Clean Energy Project – Vancouver, BC, 66 pages and 5 appendices.

Executive Summary

We report findings of the 2022 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 and Cypress Creek 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 2022, GAUC redd abundance estimates ranged from 19 (SE = 8) in the upper Halfway River to 322 (SE = 69) 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 underestimate redd abundance.

The GAUC method incorporates error in observer efficiency and survey life to generate a robust abundance estimate. In 2022, average aerial observer efficiency of Bull Trout redds was variable among tributaries, ranging from 0.23 in Cypress Creek to 0.54 in the upper Halfway River. Average redd survey life, defined as the period during which a redd is observable, was estimated as 16.1 days (SE 1.8 days).

Resistivity counter data suggested that the Chowade River kelt migration began on September 2, with a unimodal peak on September 15, and after accounting for counter accuracy, the Bull Trout kelt abundance was 151. The Cypress Creek kelt migration also followed a normal distribution and began on September 4 and peaked on September 17, with a kelt abundance of 131 Bull Trout.

We also monitored adult fish in the Chowade River and Cypress Creek using PIT arrays that detected directional movements of tagged fish. The Chowade River PIT array detected 17 tags (16 Bull trout and one Rainbow Trout), while the Cypress Creek array detected 18 tags (all Bull Trout). Bull Trout residence time could not be estimated due to antenna and reader malfunctions early in the season.

Acknowledgements

We acknowledge this research is being conducted on the traditional territory of Treaty 8 First Nations of Dunne Zaa, Cree and Tse'khene cultural descent. The Peace River Bull Trout Spawning Assessment is funded by BC Hydro's Site C Clean Energy Project. We would like to thank Brent Mossop and Nich Burnett at BC Hydro for administering this project. We would also like to thank Kevin Rodgers and all staff at Canadian Helicopters for making our flights safe and effective. Many additional InStream staff were critical to the project including LJ Wilson, Luke Irwin, Jordan Bastin, Cypress Hunder-Rookes, Paige Freeman, Jamie Martz and Ben Wade. Thanks to Josh Korman, Eric Parkinson, and Douglas Braun for valuable comments and discussions on study design.

Table of Contents

List of Tables

List of Figures

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 Site C Reservoir. A subcomponent of this program (Task 2b) assesses Bull Trout (*Salvelinus confluentus*) spawning populations in the Halfway Watershed. Data collected for this task will be used to directly address management question and hypotheses:

How does the Project affect Peace River fish species that use Site C Reservoir tributaries to fulfill 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 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 downstream (kelting) 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).

The 2022 monitoring year marks the second year of river diversion, which may provide a barrier to fish migrating past the Project (Cook et al. 2021). While only a smaller proportion of Bull Trout are known to migrate past the Project (Taylor et al. 2013), any potential barriers to migrating fish may impact the number of spawners observed in tributaries of the Halfway River.

1.2 Redd Enumeration

Redd abundance is the primary metric to assess changes in Bull Trout populations resulting from construction and operation of the Project. Bull Trout redd abundance in the Halfway Watershed has previously been assessed using redd surveys in key spawning tributaries (Diversified Environmental Services and Mainstream Aquatics Ltd. 2009; 2011; 2013). Historic redd surveys combined aerial helicopter surveys, snorkel surveys, and stream walks to generate peak redd count indices. While these peak counts provide an index of Bull Trout population status, they do not incorporate measurement error and have low spatial and temporal coverage, making it difficult to accurately assess changes in population status over time.

Area-under-the-curve (AUC) methods are widely used to estimate spawner or redd abundance from visual count data (Hilborn et al. 1999). Unlike peak count indices, AUC methods incorporate measurement error (i.e., aerial observer efficiency; OE) and survey life (the length of time a redd is detectable by an observer; SL) to estimate total population abundance. For example, Millar et al. (2012) developed a Gaussian AUC 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 normal model assumptions 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 (Putt et al. 2022), which improves upon historic peak count indices by estimating total redd abundance over the full spatial and temporal extent of the Bull Trout spawning period.

1.3 Resistivity Counters and PIT Arrays

Although redd abundance describes changes in Bull Trout spawning over time, the relationship between redd abundance and spawner abundance in the Halfway Watershed is currently unknown (Dunham et al. 2001, Gallagher and Gallagher 2005). We operate resistivity counters and PIT arrays in the Chowade River and Cypress Creek to enumerate upstream and downstream (kelting) migrating Bull Trout, inform the relationship between redd abundance and spawner abundance, and estimate key demographic parameters (survival between life stages, recruitment, etc.; Putt et al. 2022). Resistivity counters are composed of in-river electrode sensors that create an electrical field in the water column. Resistance is a function of water conductivity, and the resistance field is disrupted when a fish swims over the electrodes (the fish is more conductive than the water it displaces). The magnitude and direction of the change in resistance is interpreted by the counter to determine whether the disruption was a fish movement, and in what direction the fish was travelling. Resistivity counters are a highly accurate enumeration tool and are cost-effective, adaptable, and easy to maintain (Putt et al. 2021 and Braun et al. 2016).

It has been 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, Bull Trout kelt estimates have been used as indices of spawner abundance for the Chowade River and Cypress Creek (as in Andrusak 2009). Annual variation in kelt abundance is also important for understanding life history dynamics of Bull Trout (Monnot et al. 2008) and can be used to develop ratios of redd to kelt abundance. Evidence from the Chowade River and Cypress Creek resistivity counters suggests that the kelt migration occurs over a short period and closely follows a normal distribution, facilitating an accurate and reliable estimate (e.g., Putt et al. 2022). We estimate annual kelt abundance as an index of spawner abundance, but we attempt to install the resistivity counters 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 also monitor adult migrants in the Chowade River and Cypress Creek using directional PIT arrays, located at the resistivity counter sites, to inform migration timing and estimate demographic parameters including survival and stage transition probabilities (Brännäs et al. 1994). We use two PIT antennas at each site to determine the direction of movement for PIT-tagged fish. PIT arrays in the Chowade River and Cypress Creek detected movements of fish tagged by other monitoring programs to inform migration patterns and spawning timing.

2. Methods

2.1 Redd Enumeration

2.1.1 Visual Survey Methods

We performed weekly redd count surveys on Cypress Creek, the Chowade River, the upper Halfway River[1], Fiddes Creek, and Turnoff Creek during the Bull Trout spawning 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. 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 by 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. Aerial surveys were typically conducted at mid-day when the sun was directly overhead, and visibility conditions were optimal. Turbidity measurements were relatively

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[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).

consistent in all tributaries, and we assumed water clarity did not substantially influence OE during visual surveys.

Ground surveys were located to maximize the number of redds marked, and ground reaches ranged from 1.5 to 4.3 km (Table 2.1). The length of ground surveys reflected redd densities, safe helicopter landing zones, and the ability of crews to perform surveys within the available time. Survey boundaries have been consistent since 2016, except in Cypress Creek, where the survey was extended by ~2 km in 2021 to mitigate low sample sizes in prior surveys. Surveys began at upstream boundaries and progressed downstream to lower boundaries, 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 tag ID attached to a green bristle tag to estimate OE and SL. Unique tag IDs were tracked throughout the monitoring period and removed when the redd was no longer identifiable. During each survey, tag IDs were recorded along with their GPS location and age class (Gallagher et al. 2007). The location and number of unmarked redds was noted. Lengths and widths of all redds were recorded to the nearest centimeter, where length was the distance between upper crest and 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	4.3	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 Redd Distribution

We visually displayed redd distributions using positioning data for redds observed during aerial and ground surveys. We plotted survey-specific redd locations for each tributary to examine the change in redd locations over time and identify critical spawning areas. We also summarized redds by river kilometer (rkm) across all surveys to compare distributions among survey years. River kilometers were measured along the course of the tributary. For the Chowade River, Cypress Creek, Fiddes Creek, and Turnoff Creek, rkm 0 was the confluence with the Halfway River. For Needham Creek, rkm 0 was the confluence with the Graham River, and for the upper Halfway River, rkm 0 was the beginning of the aerial survey (~235 km from the confluence with the Peace River). We created rkm sections along an east-west axis for Fiddes and Turnoff creeks, and along a north-south axis for all other tributaries (see Appendix A in Putt et al. 2022). This method yielded simple river sections that could be compared among years, and comparable to river kilometers used by the Site C Movement Assessment (Mon-1b, Task 2d; Hatch et al. 2022).

2.1.3 Redd Abundance

Observer Efficiency

Survey- and tributary-specific ground OE were 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 assumed 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 then estimated as the aerial redd count within the ground reach divided by the total ground abundance (i.e., ground count corrected for ground OE). 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.

Survey Life

Survey life (the number of days a redd was 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-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.

We estimated mean SL across all surveyed tributaries using a linear mixed effects (LME) model of survey date in relation to redd age class. The model related normalized survey day (day 1 was the day a redd was first observed and tagged) to 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 structures (random intercept and random slope for tag ID) were tested using AIC model selection and likelihood ratio testing. The most complex model was:

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

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). Survey life can vary among tributaries due to physical and biological characteristics such as substrate, flow, and periphyton growth (Gallagher et al. 2007), and we examine tributary as a fixed effect during survey life modelling. All linear mixed effects modelling was performed in R (R Core Team 2017) using *lme4* (Bates et al. 2015).

GAUC Abundance

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 (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

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

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

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

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 expected number of observed redds ($\hat{F}$)

(1.4) $$\hat{E} = \frac{\hat{\mathrm{F}}}{l * v}$$

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)

(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. 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, 2013). Peak count indices were calculated by summing redds observed [REDACTED] (i.e., the historic survey period) on Survey 1 but not on Survey 2 to the total number of redds observed on Survey 2. To generate a peak count comparable to historic methods, we summed redds observed during ground surveys with aerial counts that occurred outside of the ground survey reach. Due to the spacing of our surveys, the peak count generally included data from only one survey week.

2.2 Resistivity Counters

We monitored Bull Trout spawners and kelts in the Chowade River and Cypress Creek using Logie 2100C resistivity counters (Windsford, UK). Counters in the Chowade River and Cypress Creek were located at 21.7 rkm and 15.9 rkm, respectively, upstream of their confluences with the Halfway River (Figure 2.1). These sites were selected for their ease of access for equipment installation, suitable stream characteristics (e.g., flow, substrate size), and location downstream of known Bull Trout spawning areas (Diversified Environmental Services and Mainstream Aquatics Ltd. 2009; 2011; 2013). The counters 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”

[3] The full survey lengths for historic surveys are similar, but not identical to, aerial surveys completed in 2016 through 2020 (see Diversified Environmental Services and Mainstream Aquatics Ltd. 2013).

strips of white puck board that increase visibility during video validation and reduced the risk of pad displacement during high water events.

All electronic equipment was powered by custom solar-powered battery banks. Each battery bank was designed to supply power to their respective equipment for a minimum of seven days without solar charge. The required number of batteries and solar panels was calculated using a conservative estimate of four hours daily solar radiation. We used a generator to charge batteries during extended periods of poor solar conditions.

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). Due to unpredictable flows that usually occur annually in July, we have not typically installed counters in the Chowade River and Cypress Creek early enough to monitor the full upstream migration. Flows during the August to October kelt period are usually lower and more conducive to equipment installation and operation, and we generated an estimate of kelts in each year.

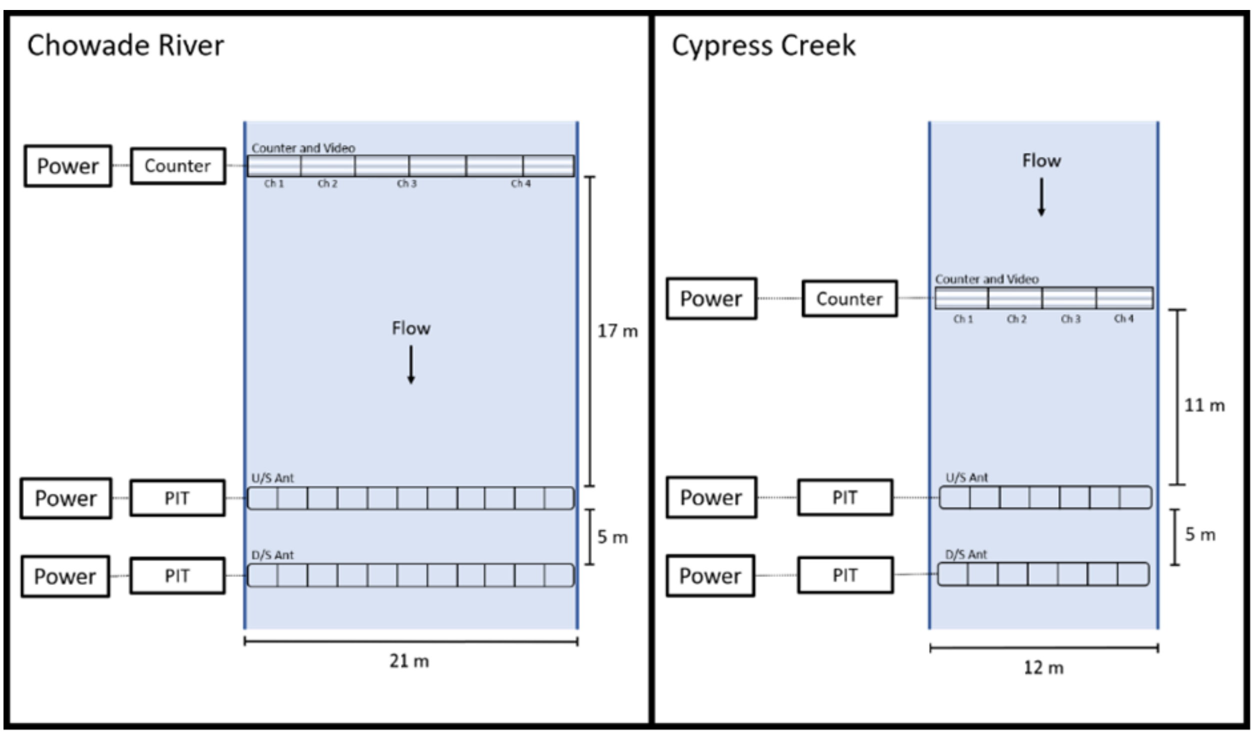

Figure 2.1. Approximate configuration of the resistivity counter sensor pads, PIT arrays, power system and video validation system in the Chowade River and Cypress Creek.

2.2.1 Counter Validation

We continuously operated a video monitoring system at each counter site to validate resistivity counter data and determine fish species. Video cameras were placed directly above sensor pads (one camera per pad) on a cableway system with LED lights for nighttime recording.

Fish species were determined by fish length (R.L. & L. Environmental Services Ltd. 1995), body size, and coloration. We measured each fish observed during video validation and used the ratio of the on-screen counter pad length and on-screen total fish length (nose to end of tail) to determine fish size.

We summarized counter errors for Bull Trout according to three categories:

1. True Positive (TP): The counter recorded a movement, and a fish was observed during video validation.
2. False Positive (FP): The counter recorded a movement, but a fish was not observed during video validation.
3. False Negative (FN): The counter did not record a movement, but a fish was observed during video validation.

Typically, TP, FP, and FN rates are determined by randomly validating video segments; however, due to relatively small Bull Trout populations in the Chowade River and Cypress Creek, we used a multi-step validation process to maximize validation efficiency. First, we performed a targeted validation of all counter up and down records to determine the number of TPs and FPs. Each counter record was validated by watching the corresponding video data 30 seconds before to 30 seconds after the counter record. We then performed additional random validation to estimate a FN rate, which was expanded to the full study period to estimate the total number of FNs. From 2016 to 2019, we validated ~15% of video data during random validation. Since 2020, we decreased our validation effort to ~10% (~67% of previous validation efforts) but increased the proportion of night video being validated. The resulting protocol decreased validation time but maintained a similar number of total records validated, resulting in minimal impacts to estimation precision (Putt et al. 2021).

Counter accuracy[4] was calculated by assuming that all TP, FP, and FN observations were multinomially distributed random variables:

$$V \sim \boldsymbol{mult}(\boldsymbol{N}, \boldsymbol{\theta}) \quad (2.1)$$

Where V is a vector of the total number of TPs, FPs, and FNs (V_{TP}, V_{FP}, V_{FN}), θ is a vector of estimated probabilities of being in each of the three states (θ_{TP}, θ_{FP}, θ_{FN}), and N is the total number of observations from the counter-validation comparison $(TP + FP + FN)$. Counter accuracy is defined as, θTP, or as the proportion of fish passing the counter that are correctly recorded by the counter algorithm.

2.2.2 Estimating Abundance

We used resistivity counter data to estimate Bull Trout abundance in the Chowade River and Cypress Creek using the method outlined in Figure 2.3.

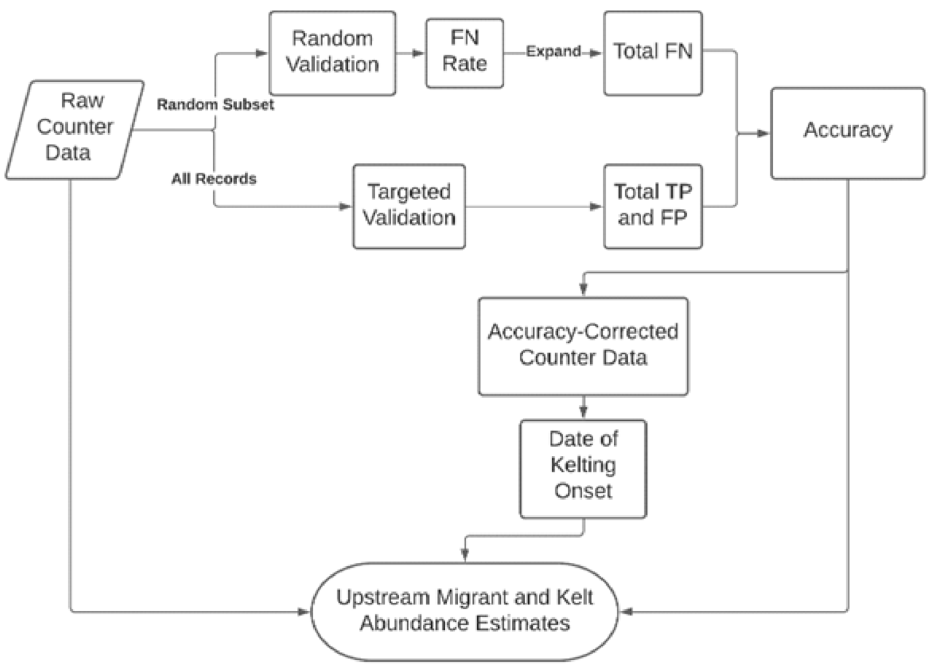

Figure 2.2 Method to validate resistivity counter data and determine accuracy-corrected abundance of upstream migrants and kelts.

[4] Prior to 2021, counter accuracies were calculated using a binomial method derived from a confusion matrix model. Benefits of moving to the multinomial method is described in Putt and Ramos-Espinoza 2021, and Putt et al. 2022.

Determining Kelt Onset

Estimating spawner or kelt abundance is not as simple as summing upstream or downstream movements recorded by the counter. Fish often move up and down past a counter site multiple times during their migration, and movements can be described as:

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

A kelt date must be determined to differentiate kelting and recycling and estimate abundance for either movement direction. When estimating upstream migrant abundance, downstream movements prior to the kelt date are assumed to be recycling and are subtracted from up counts (i.e., to remove fish that have not yet committed to migrating upstream). Total upstream abundance is therefore ups minus downs prior to the kelt date, plus total ups following the kelt date. When estimating kelt abundance, downs prior to the kelt date are not included, and total kelt abundance is the sum of downs after the kelt date.

Kelt onset and peak kelt dates were estimated by fitting a normal probability density function to accuracy-corrected daily down counts. We estimated the mean, standard deviation, and scale parameter for the normal distribution. The fitted mean represented the peak date of kelt migration, while the scale parameter provided an estimate of kelt abundance (which can also be compared to resistivity counter kelt abundance). Using daily abundance predicted by the normal model, we defined the date of kelt onset as the date when 5% of kelts had migrated downstream.

Abundance Estimates

We estimated accuracy-corrected kelt abundance for the Chowade River and Cypress Creek (Putt et al. 2021):

$$E_k = \sum_{i=1}^{I} \sum_{k=1}^{K} \frac{\mathrm{D_{k,i}}}{\mathrm{A_{d,i}}} \tag{2.2}$$

where E_k is the kelt estimate, D_k is the downstream counts for each day from the onset of the kelt migration (k) to the date of the last confirmed Bull Trout down-count (K), and A_D is downstream counter accuracy. The subscript i represents counter channel, from 1 to I channels, which allows channel specific accuracies to be applied to downstream counts.

We were unable to estimate an upstream migrant abundance due to a potentially incomplete upstream migration dataset. In future years, upstream abundance (corrected for cycling prior to the kelt onset) may also be estimated (Putt et al. 2021):

(2.3)
$$E_{Up} = \sum_{i=1}^{I}\left(\sum_{t=1}^{T}\left(\frac{U_{t,i}}{A_{u,i}}\right) - \sum_{t=1}^{K-1}\left(\frac{D_{t,i}}{A_{u,i}}\right)\right)$$

where U_t and D_t are the upstream and downstream counts for each day (t) from day 1 to the final day of the migration (T), and A_{ui} is the channel-specific upstream accuracy.

2.3 PIT Arrays

Directional PIT arrays were installed in the Chowade River and Cypress Creek (two antennas per tributary) to monitor fish tagged under other components of the FAHMFP. Each antenna spanned the full width of the tributary and was approximately 1.25 m wide with structural cross braces every 1.5 m. Antennas lay flat on the streambed so that fish were detected as they swam over the antenna. Each antenna was connected to a remote tuner box (Oregon RFID, Portland, OR) and a single reader (Oregon RFID) via twin-axial cable, and readers were synchronized to minimize interference and optimize antenna read range (i.e., the distance above an antenna within which a tag is detectable).

We conducted detailed read-range testing during site visits (every 7 to 10 days) to determine seasonal read-ranges for each antenna. We determined read ranges for 12 mm, 14 mm, 23 mm, and 32 mm PIT tags at 1.5 m increments along the length of each antenna and determined the proportion of the water column within with each tag size was detectable. We also summarized the mean detectable area of the water column across all surveys. For example, if the mean detectable area for a 12 mm tag was 75%, a 12 mm tag had a very high probability of being detected within 75% of the water column, but the probability of detection was near zero within the remaining 25% of the water column (typically near the surface above deeper areas of the water column).

We collated and summarized PIT data using the ORFID package for R (Marques and Putt 2022) developed by Fishtag Consulting and InStream Fisheries Research. We determined detection efficiency – the percentage of tags detected by both antennas in the array – for both upstream and kelt migrations (for all tag sizes combined). Detections were summarized to determine movement direction and residence time for fish that were detected moving upstream and downstream past the arrays. Species information and tagging biodata were obtained from Golder Associates (now WSP).

3. Results

3.1 Redd Enumeration

Redd surveys (aerial and ground) were conducted weekly [REDACTED], except for Needham Creek, which was surveyed for a peak count (aerial and ground) [REDACTED].

3.1.1 Redd Distribution

Redd distributions were relatively consistent among years in the tributaries surveyed. In 2022, redds were observed throughout the Chowade River survey reach, with the highest densities observed in the upper third (rkm 42 – rkm 50) (Figure 3.1). Aerial redd densities were similar among monitoring years, with redds typically being concentrated between rkm 38 and rkm 48 (***Figure 3.2***). In Cypress Creek, redds were concentrated between rkm 48 and 52, and rkm 30 and 32 (Figure 3.3), which was consistent among monitoring years (Figure 3.4). In the upper Halfway River, redds were almost exclusively observed above rkm 15 (with minor exceptions; Figure 3.5 and Figure 3.6), while distributions were less consistent in Fiddes and Turnoff creeks (Figure 3.5, Figure 3.7, and Figure 3.8). Finally, redds were distributed relatively evenly in Needham Creek, with potential concentrations between rkm 3 and 4 and rkm 6 and 7 (Figure 3.9 and Figure 3.10).

[Figure 3.1 REDACTED]

[Figure 3.2 REDACTED]

[Figure 3.3 REDACTED]

[Figure 3.4 REDACTED]

[Figure 3.5 REDACTED]

[Figure 3.6 REDACTED]

[Figure 3.7 REDACTED]

[Figure 3.8 REDACTED]

[Figure 3.9 REDACTED]

[Figure 3.10 REDACTED]

3.1.2 Redd Abundance

Observer Efficiency

Mean ground OE was high (> 0.8) with relatively low variability for all tributaries (Table 3.1; Appendix A). Mean aerial OE was low (< 0.55) and highly variable (> 25%) for all tributaries. Variability in aerial OE can increase uncertainty in redd abundance since OE standard error is incorporated into the GAUC model. Cypress and Fiddes Creeks had the highest variability in OE. The results from Cypress Creek could be attributed to the high frequency of redd clusters, which were likely more difficult to distinguish from the air. In Fiddes Creek, environmental conditions (larger substrate size, low water clarity, higher survey height) likely increased OE variability relative to other tributaries.

Table 3.1 Mean ground and aerial observer efficiency with percent coefficient of variation (%CV).

Tributary	Mean Ground OE (%CV)	Mean Aerial OE (%CV)
Chowade River	0.85 (18.93)	0.36 (25.2)
Cypress Creek	1.00 (0.00)	0.23 (100.3)
Fiddes Creek	1.00 (0.00)	0.35 (130.6)
Upper Halfway River	0.95 (8.48)	0.54 (27.9)
Needham Creek	-	0.36[a]

a: Aerial count/uncorrected ground count for singe peak count survey.

Survey Life

A total of 57 bristle tags were applied to age-1 redds during ground surveys and used to estimate SL. We estimated mean SL for all redds using a LME model of normalized survey day in relation to redd age (Figure 3.11). The optimal random effect structure was a random intercept for tag ID (Appendix B). The fixed effect of tributary did not improve the model fit (ANOVA Chi-Squared p-value 0.08; ΔAIC < 2), and the average SL was used for all tributaries during AUC modelling. The estimated SL was 16.10 days with a standard error of 1.81 days.

Survey life has been estimated since 2016; however, only three surveys were completed in 2016 and SL was likely biased low. From 2017 to 2022, SL was between 16 days and 24 days. This range suggests relatively consistent survey life among years and agrees with annual variation in SL observed during field surveys.

Table 3.2 Annual survey life and standard error for Halfway River tributaries.

Year	Survey Life	Survey Life SE
2016	13.7	1.8
2017	24.2	2.3
2018	18.5	2.2
2019	21.2	1.9
2020	17.9	2.0
2021	16.5	2.1
2022	16.1	1.8

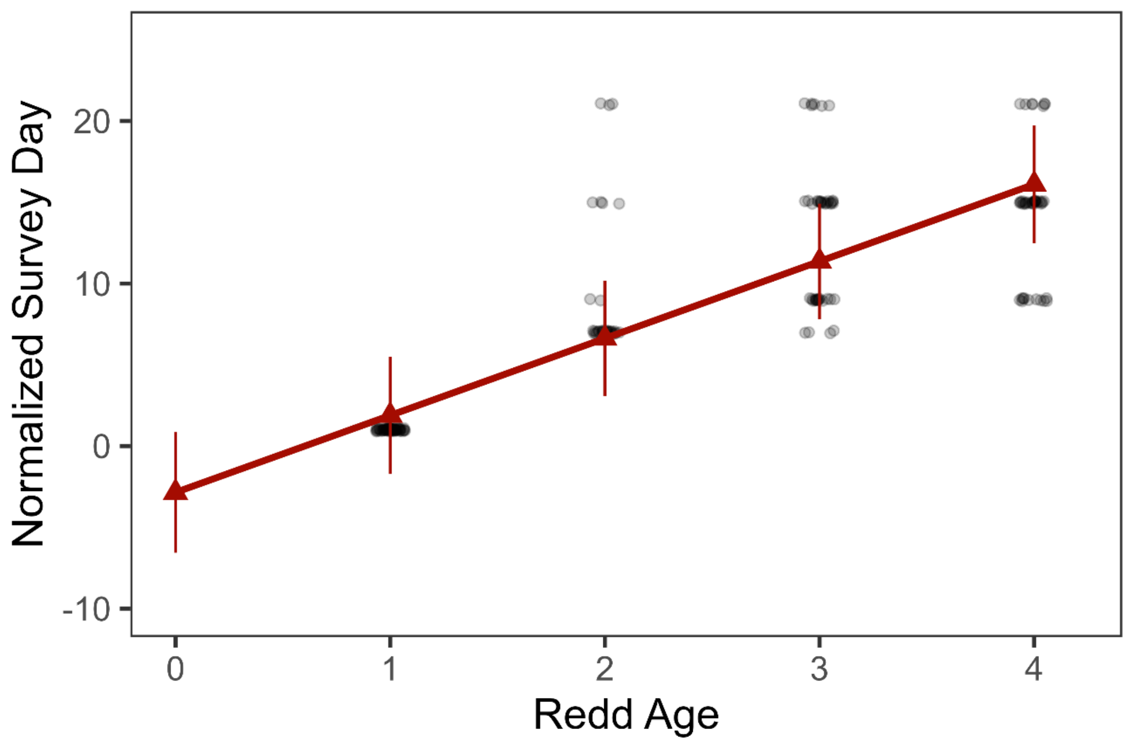

Figure 3.1 Redd age within all tributaries by normalized survey day, with points jittered for presentation. Red line shows mean SL for all redds, and vertical error bars are the 95% confidence interval based on a normal approximation. Negative normalized survey days correspond to days between the redd being built and the first observation (age-1).

GAUC Abundance

GAUC estimates ranged from 19 redds in the upper Halfway River to 322 redds in the Chowade River (Table 3.3). The total number of redds estimated for all tributaries combined was 508.

Precision (%CV) for all tributaries, ranged from 33.3% in Turnoff Creek to 78.6% in the Chowade River. The GAUC model fit the count data well except for Fiddes Creek (Figure 3.12), where aerial counts did not closely follow a typical normal distribution pattern (trailing zeros were necessary to fit the GAUC model).

Peak count estimates consistently underestimated redd abundance relative to the GAUC method, and peak counts from 2016 to 2022 were lower than the most recent historic peak counts in 2010 and 2012 (Figure 3.13).

Table 3.3 GAUC redd abundance, relative uncertainty in abundance, Mean OE (with SE), and peak counts for Bull Trout in the Halfway Watershed.

Tributary	GAUC Abundance (SE)	2.5% CL	97.5% CL	%CV	Aerial OE (SE)	Survey Life (SE)	Peak Count Index
Chowade River	322 (69)	212	490	78.6	0.36 (0.04)	16.1 (1.8)	130
Cypress Creek	96 (42)	41	225	56.2	0.23 (0.09)	16.1 (1.8)	24
Fiddes Creek	26 (17)	7	92	34.6	0.35 (0.18)	16.1 (1.8)	14
Turnoff Creek	45 (30)	12	166	33.3	0.35 (0.18)	16.1 (1.8)	14
Upper Halfway River	19 (8)	9	42	57.9	0.54 (0.06)	16.1 (1.8)	14
Needham Creek	-	-	-	-	-	-	23

[Figure 3.12 REDACTED]

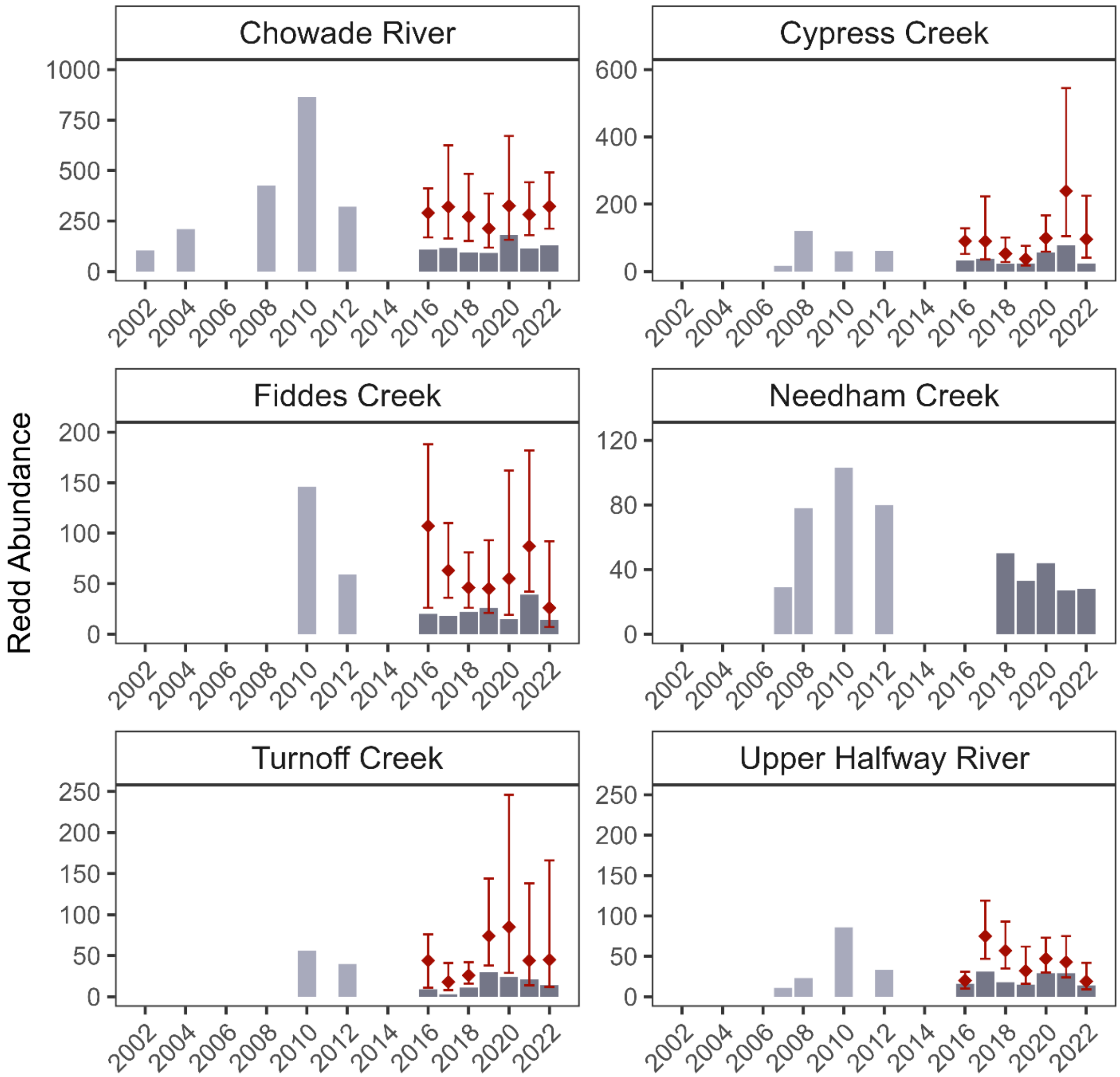

Figure 3.2 Bull Trout peak count redd indices from 2002 to 2014 (dark grey bars; Diversified Environmental Services and Mainstream Aquatics Ltd. 2009, 2011, and 2013); from 2016 to 2022 (light grey bars; this monitor). GAUC abundance with CI are shown as red diamonds.

3.1.3 Monitoring Time Series of OE and GAUC Abundance

We compared OE (mean across the four surveys) and GAUC redd abundance among study years in the Halfway Watershed (Figure 3.14). Ground OE was relatively consistent among survey years, but aerial OE and GAUC were variable. The confidence intervals for all measurements suggest substantial overlap among years.

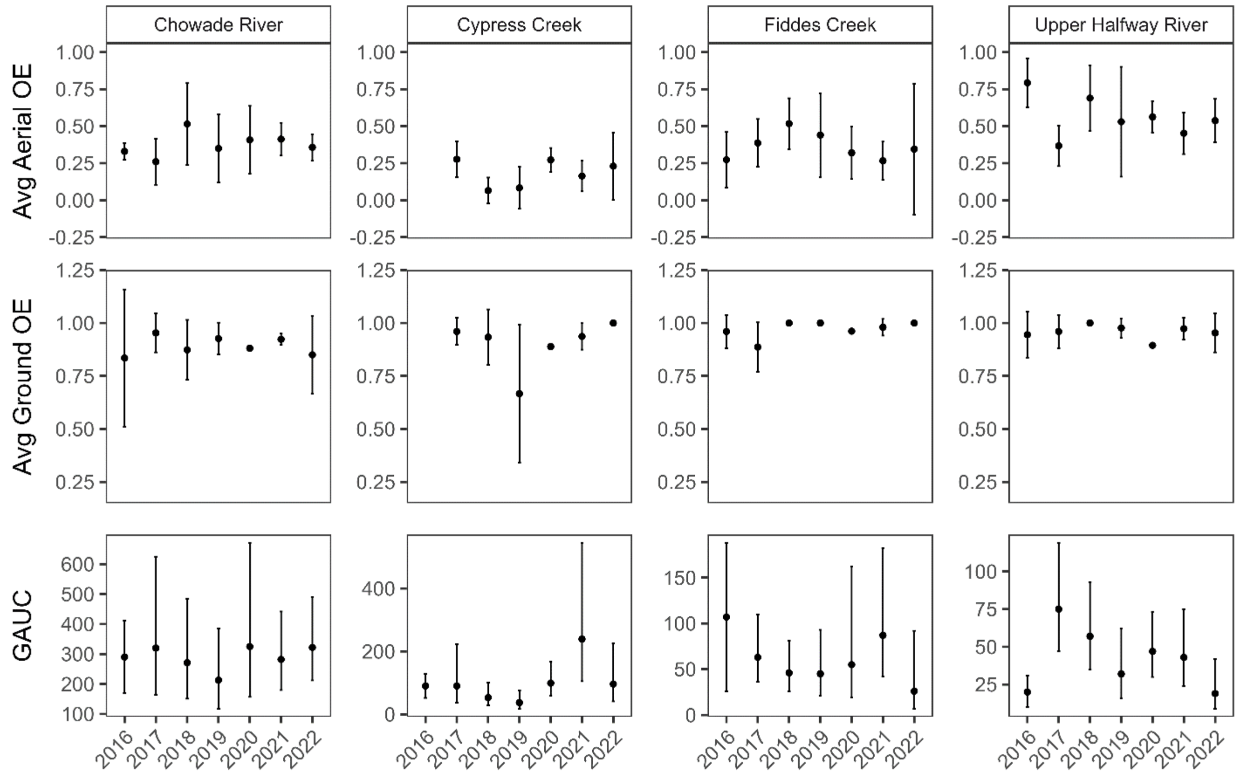

Figure 3.3 Mean aerial OE, mean ground OE, and GAUC abundance (error bars are 95% confidence intervals) in the Halfway Watershed from 2016 to 2022.

3.2 Resistivity Counters

3.2.1 Chowade River

The Chowade River resistivity counter operated from August 5 to October 3. Bull Trout (n = 205), Mountain Whitefish (n = 1,507), and Rainbow Trout (n = 109) were observed crossing the counter during video validation. Total length for Bull Trout ranged from 354 mm to 1080 mm (mean = 622 mm, SD = 123 mm), Mountain Whitefish ranged from 150 mm and 540 mm (mean = 410 mm, SD = 62 mm), and Rainbow Trout ranged from 263 mm to 563 mm (mean = 402 mm, SD = 49 mm). Total length data from 2022 and previous monitoring years were comparable based on visual observations (Appendix C).

Counter accuracy varied among channels from 11 to 100% for downstream movements and 38 to 100% for upstream movements (Table 3.4). False negatives occurred at a greater frequency compared to false positives for the majority of channel-direction combinations, suggesting the counter underestimated the true number of movements. Most movements occurred on channels 1, 2 and 3 (Figure 3.15).

The normal density function estimated that the 2022 Bull Trout kelt outmigration began on September 2 and peaked on September 15 (SD = 7.28 days; Figure 3.16). After accounting for counter accuracy and the date of kelt onset, kelt abundance for the Chowade River was 151 Bull Trout (Figure 3.17). The ratio of kelts to redds (estimated via GAUC) was 0.5 and the lowest observed to date (Table 3.5). We could not generate a complete upstream abundance due to the counter being installed during the upstream migration. Also in 2022, extensive recycling behavior was observed in August; this made enumerating the cumulative net upstream difficult and resulted in a count of -5 Bull Trout. Total cumulative upstream count for Bull Trout was 181 during the enumeration period (Figure 3.17).

Table 3.4 Chowade River counter accuracies for Bull Trout.

Channel	Direction	Accuracy
1	D	11%
1	U	38%
2	D	20%
2	U	94%
3	D	64%
3	U	90%
4	D	100%
4	U	100%

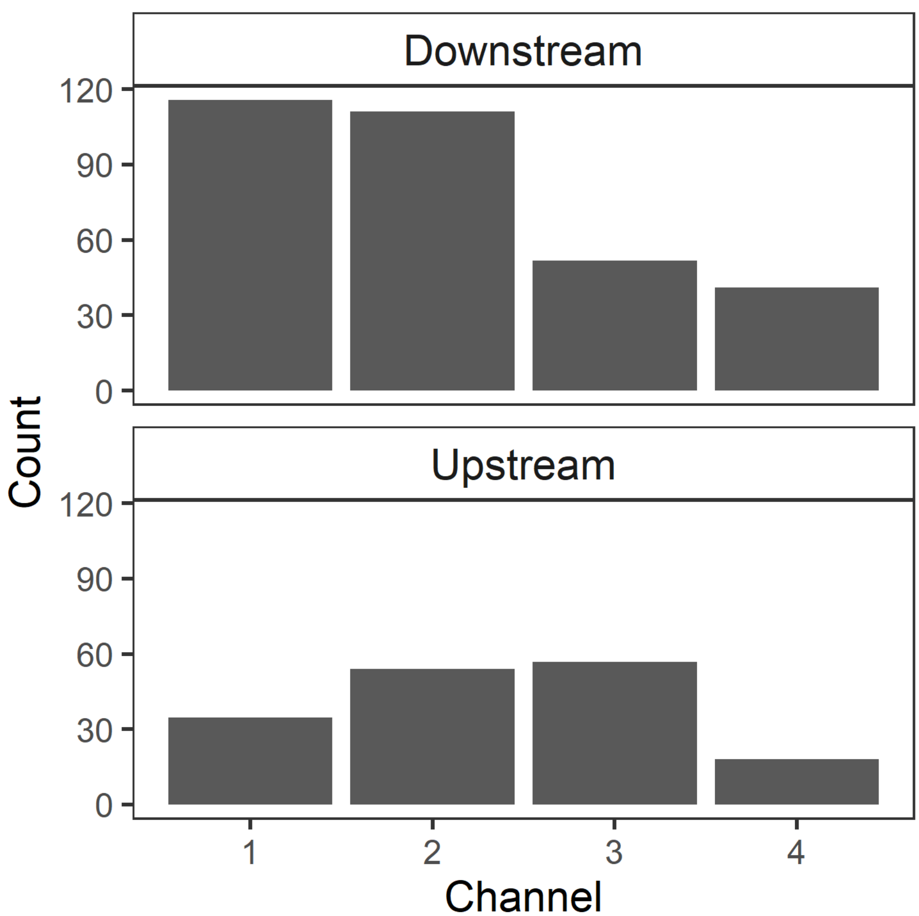

Figure 3.4 Accuracy-corrected counts of Bull Trout moving upstream and downstream past the Chowade River resistivity counter.

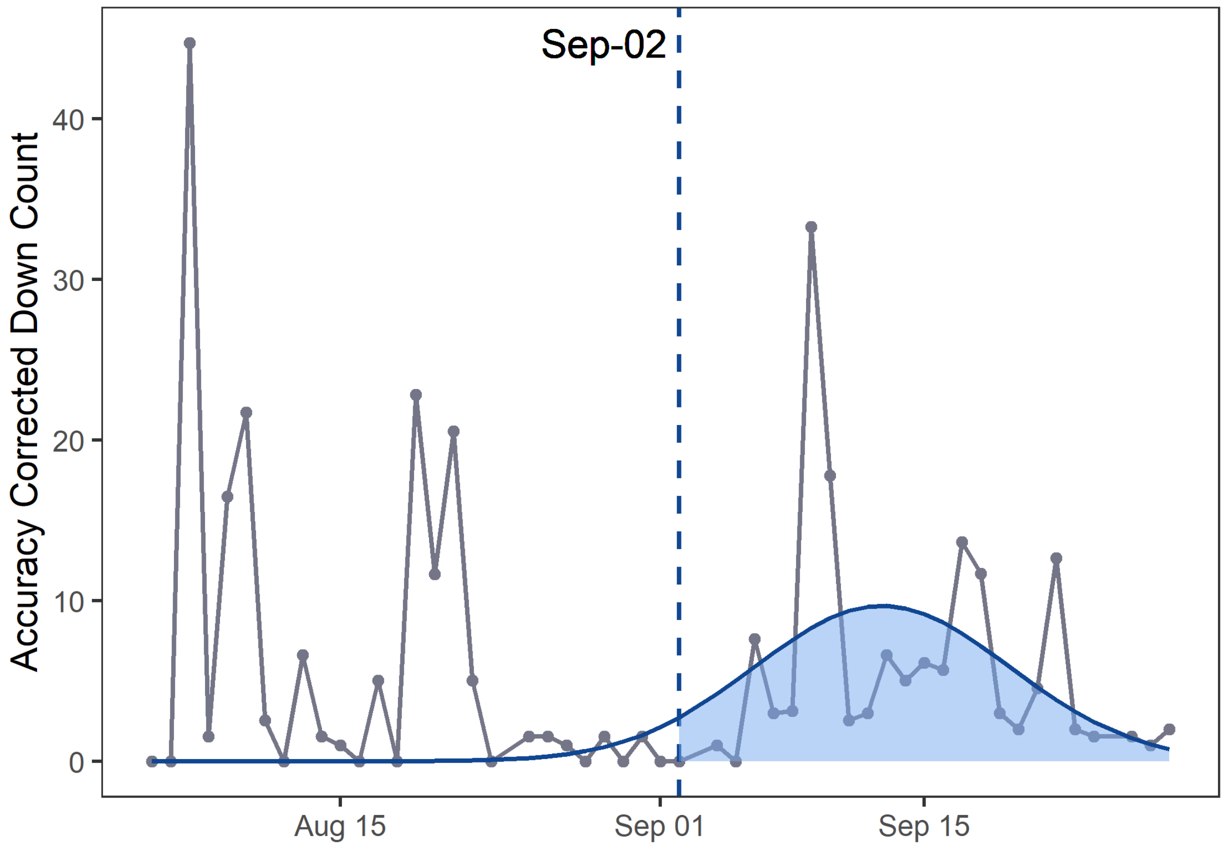

Figure 3.5 Accuracy corrected daily down counts of verified Bull Trout (grey points and lines) and modelled kelt out-migration timing (solid blue line and blue shading) in the Chowade River. The vertical dashed line marks the date which the normal model estimated 5% of the kelts had out-migrated, which was assumed to be the onset of the kelt out-migration.

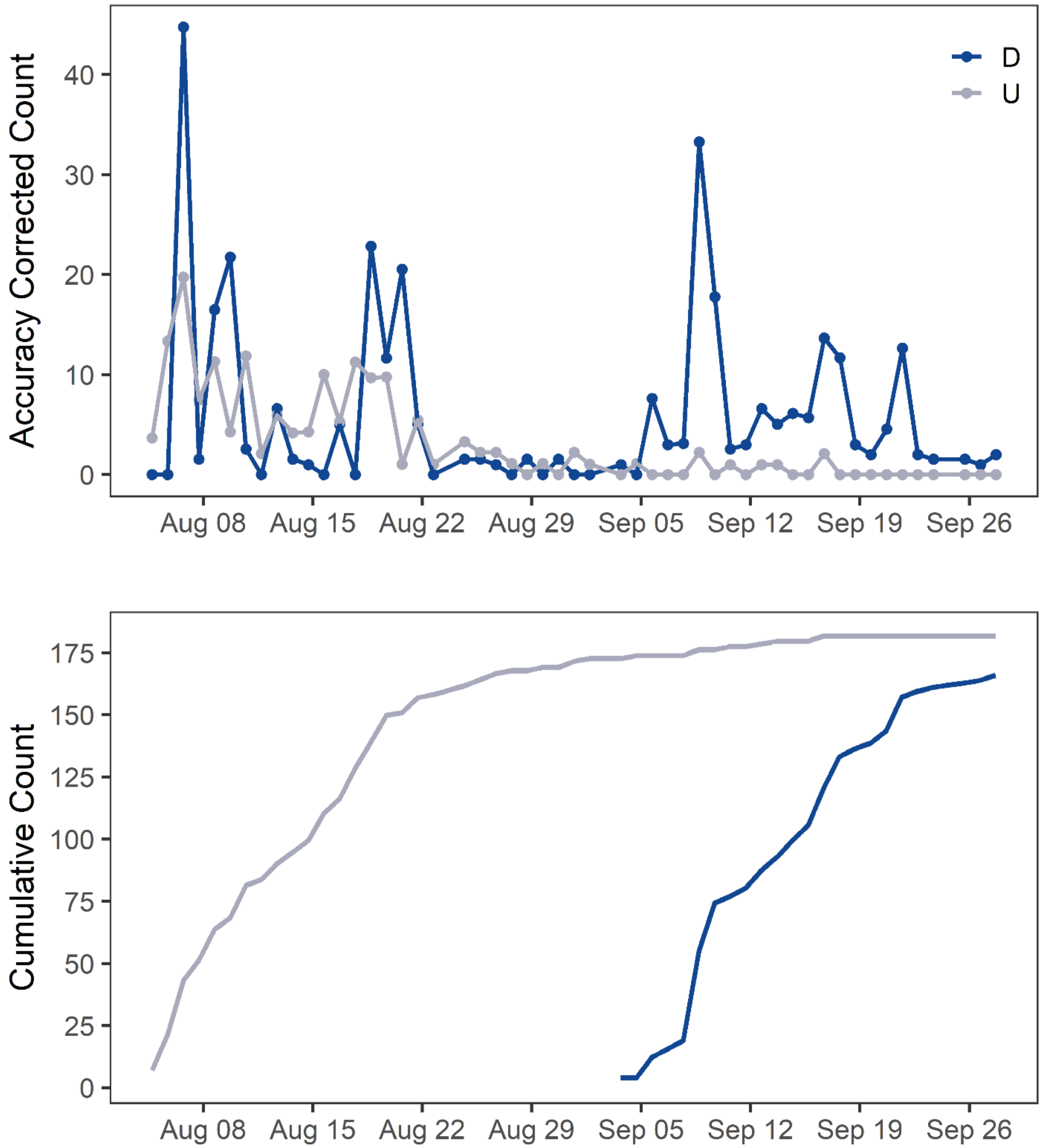

Figure 3.6 Top panel: accuracy corrected up and down counts of Bull Trout moving past the Chowade River resistivity counter. Bottom panel: cumulative up and down counts. Cumulative down counts were set as zero until Sep. 2, the onset of the kelt out-migration.

Table 3.5 Kelt abundance estimated by the Chowade River resistivity counter, redd abundance with 95% CI from GAUC estimation, and kelt to redd ratios (the number of kelts per redd) with 95% confidence intervals.

Year	Kelt Abundance	GAUC Redd Abundance (95% CI)	Kelt:Redd Ratio (95% CI)
2017	319	320 (164-625)	1.0 (0.5-1.9)
2018	564	271 (151-484)	2.1 (1.2-3.7)
2019	144	213 (118-386)	0.7 (0.4-1.2)
2020	568	325 (157-671)	1.7 (0.8-3.6)
2021	279	282 (180 – 442)	0.9 (0.6 - 1.6)
2022	151	322 (212 – 490)	0.5 (0.3 - 0.7)

3.2.2 Cypress Creek

The Cypress Creek resistivity counter operated from August 3 to October 5 continuously with no issues. Bull Trout (n = 269), Mountain Whitefish (n = 369), and Rainbow Trout (n = 26) were all observed crossing the counter during video validation. Bull Trout total lengths ranged from 320 mm to 900 mm (mean = 596 mm, SD = 125 mm), Mountain Whitefish ranged from 197 mm and 407 mm (mean = 354 mm, SD = 41 mm), and Rainbow Trout ranged from 197 mm to 460 mm (mean = 387 mm, SD = 70 mm). Total length data from 2022 and previous monitoring years were comparable based on visual observations (Appendix C).

Counter accuracy varied among channels from 41 to 100% for downstream movements and 54 to 100% for upstream movements (Table 3.6). Most movements occurred predominantly on channels 2 and 3 (Figure 3.18).

The normal density function estimated that the 2022 Bull Trout kelt outmigration began on September 4 and peaked on September 17 (SD = 7.57 days; Figure 3.19). After accounting for counter accuracy and the date of kelt onset, kelt abundance for Cypress Creek was 131 Bull Trout (Figure 3.20). The ratio of kelts to redds (estimated via GAUC) was 1.4 (Table 3.7). Cumulative net upstream movements over the full monitoring period were 108.

Table 3.6 Cypress Creek counter accuracies for Bull Trout.

Channel	Direction	Accuracy
1	D	41%
1	U	54%
2	D	87%
2	U	100%
3	D	57%
3	U	89%
4	D	100%
4	U	79%

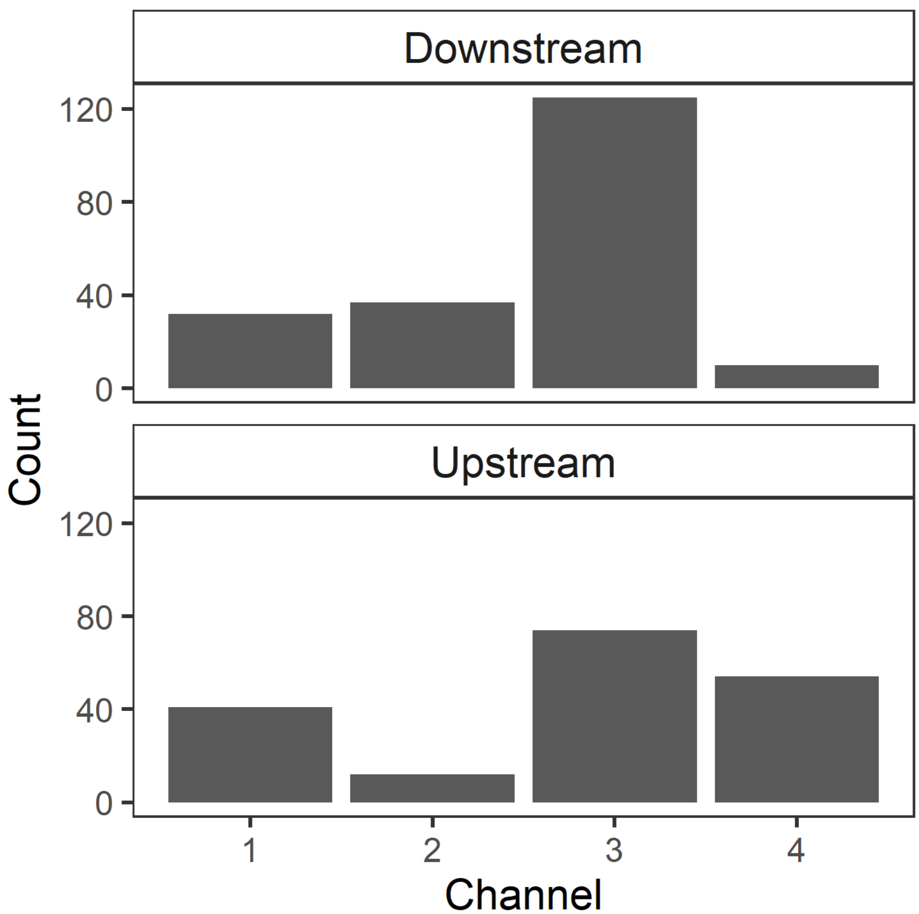

Figure 3.7 Accuracy-corrected counts of Bull Trout moving upstream and downstream past the Cypress Creek resistivity counter.

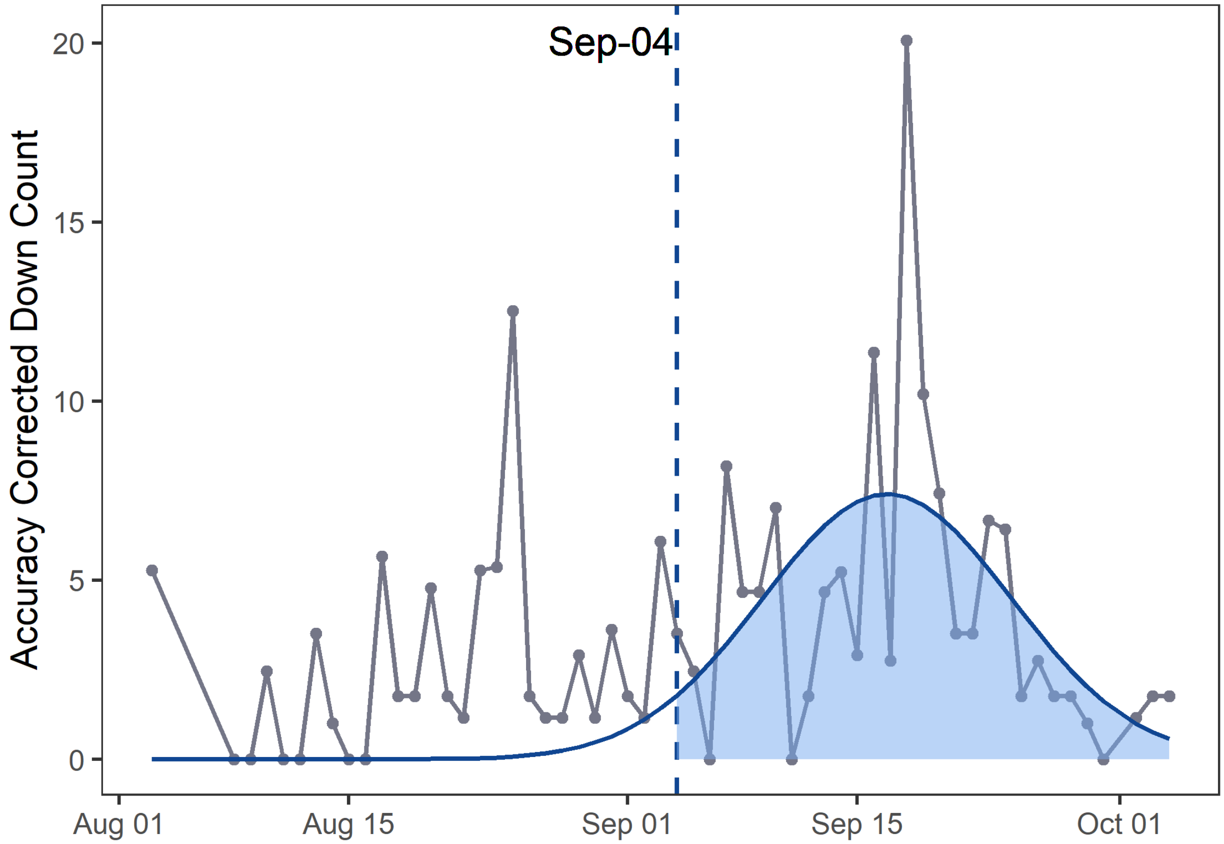

Figure 3.8 Accuracy corrected daily down counts of verified Bull Trout (grey points and lines) and modelled kelt out-migration timing (solid blue line and blue shading) in Cypress Creek. Vertical dashed line marks the date which the normal model estimated 5% of the kelts had out-migrated, which was assumed to be the onset of the kelt out-migration.

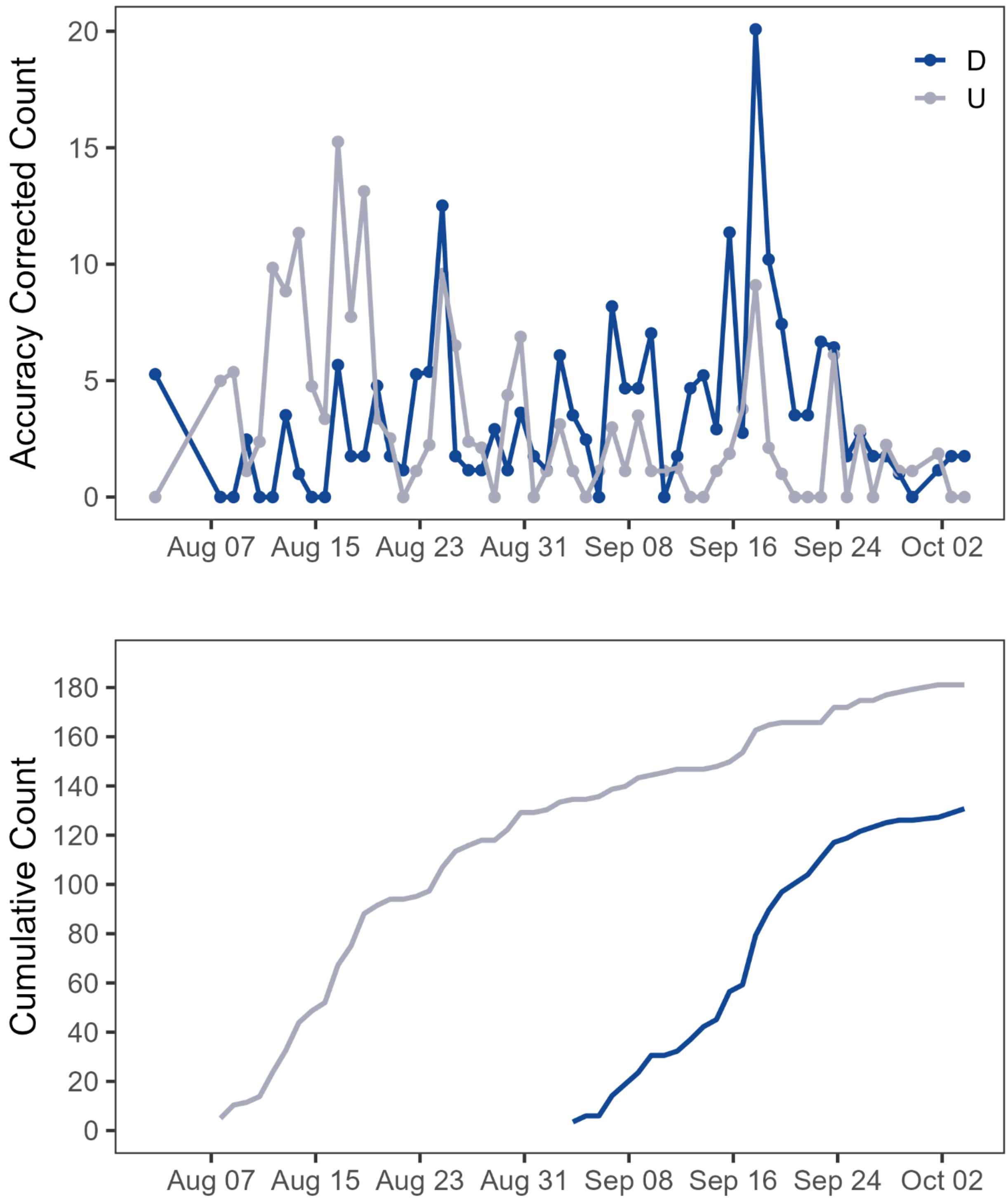

Figure 3.9 Top panel: accuracy corrected up and down counts of Bull Trout moving past the Cypress Creek resistivity counter. Bottom panel: cumulative up and down counts. Cumulative down counts were set as zero until September 4, the onset of the kelt out-migration.

Table 3.7 Kelt to redd ratios (the number of kelts per redd) and 95% confidence intervals using kelt abundance estimated by the Cypress Creek resistivity counter, and redd abundance and 95% CI from GAUC estimation.

Year	Kelt Abundance	GAUC Redd Abundance (95% CI)	Kelt:Redd Ratio (95% CI)
2017	91	90 (36 - 223)	1.0 (0.4 - 2.5)
2018	132	53 (28 - 101)	2.5 (1.3 - 4.7)
2019	-	37 (18 - 76)	-
2020	55	99 (59 - 167)	0.6 (0.3 - 0.9)
2021	73	239 (105 - 545)	0.3 (0.13 - 0.69)
2022	131	96 (41 - 225)	1.4 (0.6 – 3.2)

3.3 PIT Arrays

3.3.1 Range Testing

Read ranges for 32 mm PIT tags met or exceeded the water depth along the length of both antennas in the Chowade River, and 32 mm tags were detectable in 100% of the water column throughout the monitoring period (Figure 3.21). The read range of 23 mm tags was also close to 100% for the entire monitoring duration. The mean proportion of the water column within which 12 mm tags were detectable was 0.83 (downstream antenna) and 0.84 (upstream antenna), while for 14 mm tags it was 0.97 (downstream) and 0.94 (upstream) (Figure 3.21).

In Cypress Creek, the proportion of the water column within which 23 mm and 32 mm tags could be detected was nearly 100% throughout the monitoring period (Figure 3.22). The mean proportion of the water column within which 12 mm tags were detectable was 0.83 (downstream) and 0.78 (upstream), while for 14 mm tags it was 0.96 (downstream) and 0.91 (upstream) (Figure 3.22).

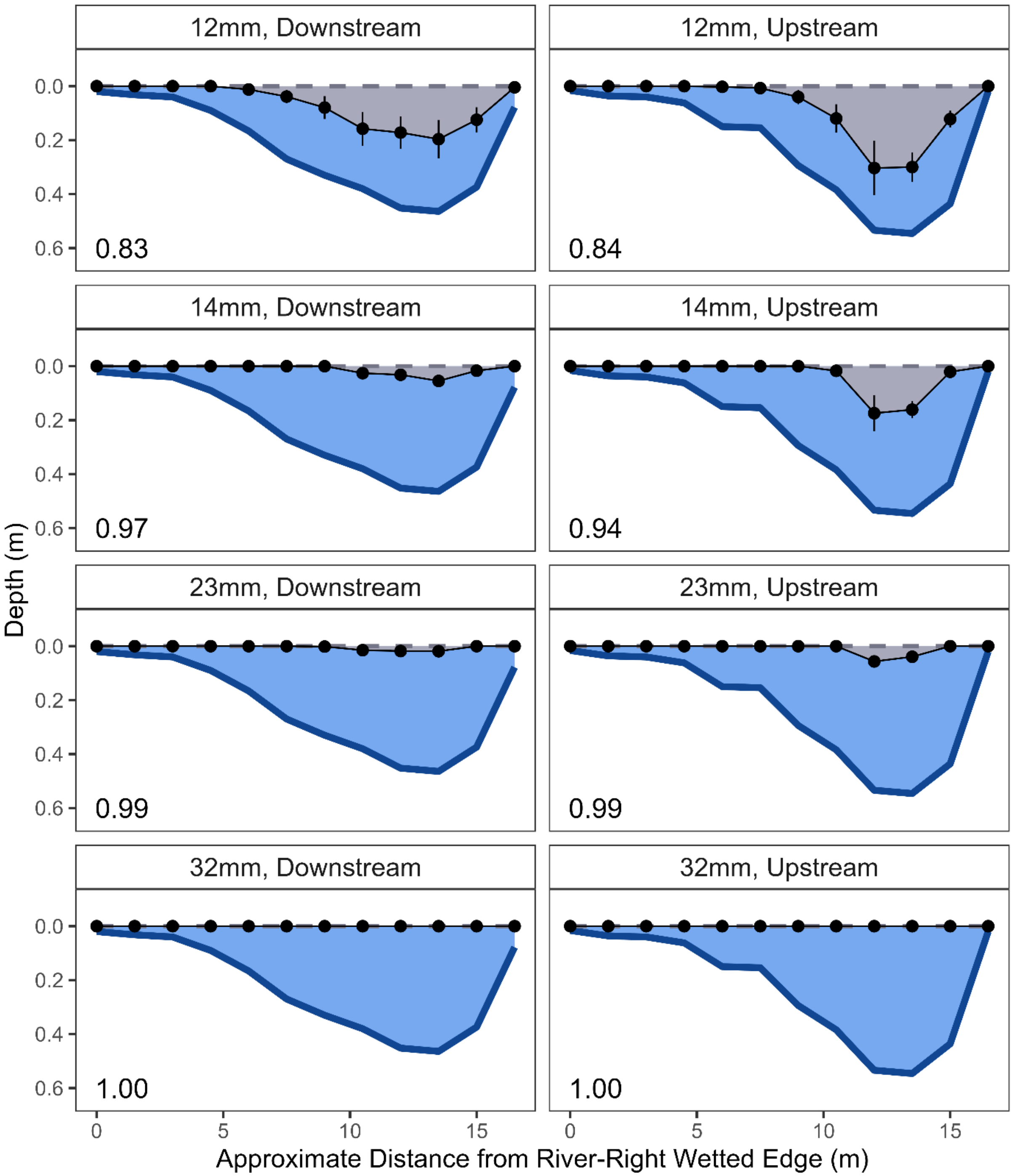

Figure 3.10 Proportion of the water column (points show mean ± SD) in the Chowade River within which PIT tags (12 mm, 14 mm, 23 mm, and 32 mm) were detectable throughout the monitoring period. Blue shading represents areas where tags are detectable (the number within the blue area is the mean detectable proportion of the water column), while grey shading designates areas where tags are not detectable.

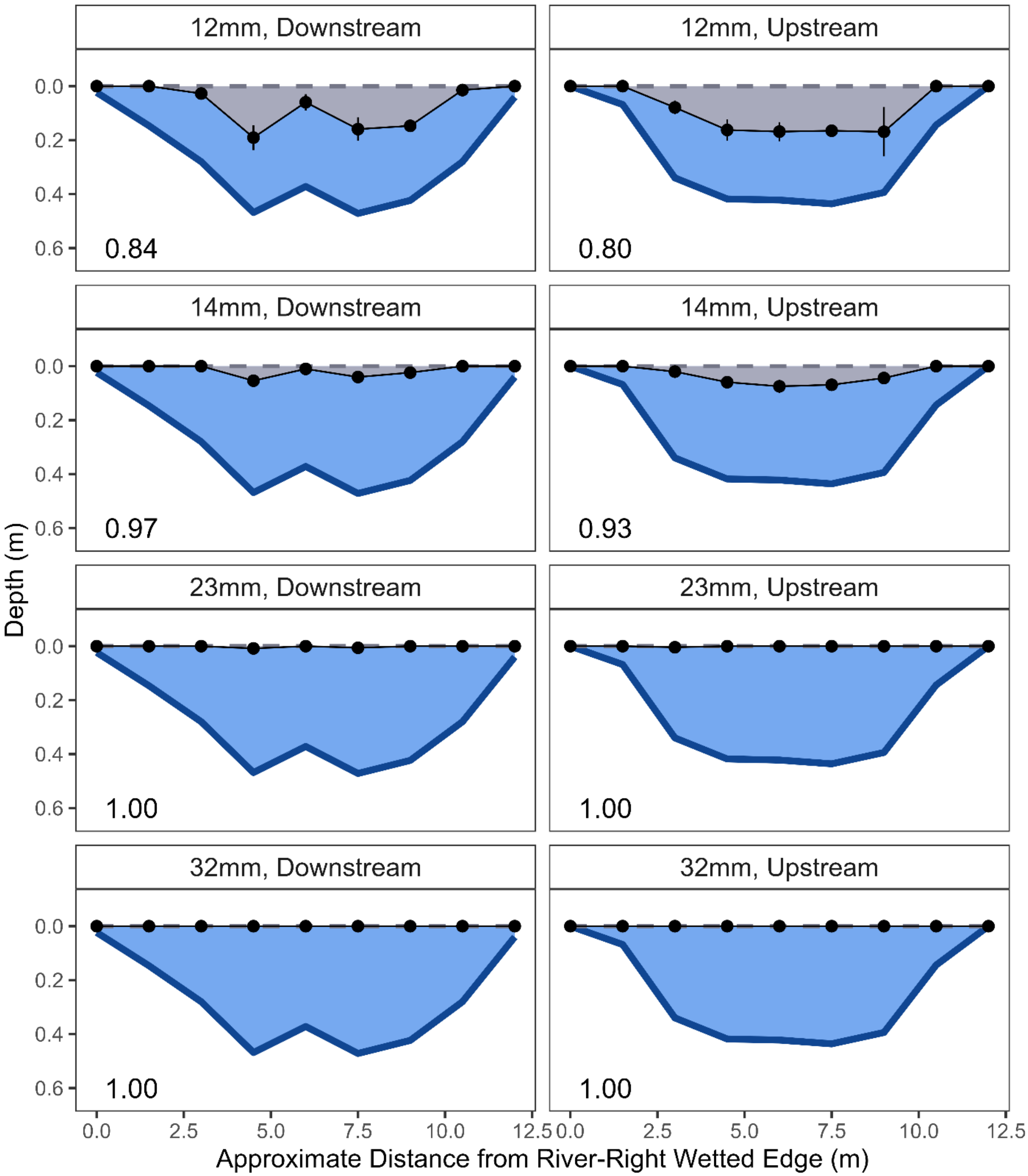

Figure 3.11 Proportion of the water column (points show mean ± SD) in Cypress Creek within which PIT tags (12 mm, 14 mm, 23 mm, and 32 mm) were detectable throughout the monitoring period. Blue shading represents areas where tags are detectable (the number within the blue area is the mean detectable proportion of the water column), while grey shading designates areas where tags are not detectable.

3.3.2 Tag Detections

The Chowade River downstream antenna reader malfunctioned, and data could not be recovered, and only upstream antenna data are available until August 31, when the downstream reader was replaced. Seventeen unique tags were detected by the Chowade River PIT array (16 Bull Trout and 1 Rainbow Trout,) and direction could be determined for 5 tags (the remaining tags were only detected on one antenna; Appendix D). Three tags (2 Bull Trout and 1 Rainbow Trout) were only detected moving downstream, while two tags (both Bull Trout) were only detected moving upstream. The Rainbow Trout was originally tagged during the Site C Reservoir Tributaries Fish Population Indexing Survey (Mon-1b, Task 2c) in August 2020, similarly one Bull Trout was tagged in July 2021 approximately 20 km upstream of the counter site. Upstream movements occurred from September 1 to September 27, while downstream movements occurred from September 12 to September 27. Bull Trout primarily moved upstream from August 13 to September 13 (one Bull Trout was detected moving upstream on September 24) and moved downstream from September 2 to September 24. Upstream detection efficiency (for all species and tag sizes) over the entire monitoring period was 29%, while downstream detection efficiency was 100%. From August 31 to removal on October 4, when both antennas were operating, upstream and downstream efficiency were 71% and 100%, respectively.

The Cypress Creek upstream antenna was damaged by a high flow event shortly after it was installed (the damage was discovered on August 16), and only one antenna was operating until the upstream antenna was repaired on September 2. During the entire monitoring period, eighteen unique tags were detected by the Cypress Creek PIT array (all Bull Trout), and direction was determined for nine of them (Appendix D). One Bull Trout was detected moving upstream; on September 26, but it was not detected moving downstream. Six Bull Trout moved downstream between September 10 and September 28, but none of these were detected moving upstream, and likely migrated prior to the installation of the PIT array. Two Bull Trout were detected moving upstream and then downstream. One did so on the same day (September 18), while the second moved upstream on September 28 and downstream on October 2, spending 3.9 days above the array. Five of the Bull Trout detected were juveniles that were tagged under Mon-1b, Task 2c. One was tagged in 2020, one in 2021 and the remaining three were tagged upstream of the counter site in late July of 2022. Upstream detection efficiency (for all species and tag sizes) over the entire monitoring period was 90%, while downstream detection efficiency was 53%. From September 2 to removal on October 5, when both antennas were operating, upstream and downstream efficiency were 100% and 82%, respectively.

4. Discussion

The objective of Mon-1b, Task 2b is to assess the abundance, migration timing and distribution of Bull Trout spawning in the Halfway Watershed. We estimated 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. The results of this monitoring program build upon previous observations of Bull Trout spawning, 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 from 1996 to 1999 throughout the Peace Region (e.g., AMEC Earth & Environmental and LGL Ltd. 2010).

The 2022 monitoring year marks the second year of river diversion which may provide a migration barrier to fish migrating downstream and upstream past the Project (Cook et al. 2021). While only a smaller proportion of Bull Trout are known to migrate past the Project (Taylor et al. 2013), any potential barriers to migrating fish may impact the number of spawners observed in the Halfway tributaries.

4.1 Abundance

4.1.1 Redd Enumeration

Understanding and quantifying sources of error is integral to producing an accurate and precise estimate of redd abundance using the GAUC method. Ground OE was high in all tributaries surveyed, which agrees with literature suggesting detailed ground surveys are an accurate redd counting method (Dunham et al. 2001). 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. This was particularly apparent in Fiddes and Turnoff Creeks, which were the most challenging tributaries to survey from the air due to abundant vegetation, glare, higher survey altitude, and had less obvious concentrations of spawning substrate. 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. Survey life in 2022 (mean 16.1 days, SE 1.8) was the lowest calculated since 2016, suggesting redds may have aged faster in 2022 relative to previous years. Anecdotal evidence suggests SL may vary among tributaries (e.g., SL in Cypress Creek appears to be shorter relative to all other tributaries). Variation in survey life is likely related to tributary characteristics (e.g., annual flow, temperature, and productivity) rather than variation in methods and data collection. SL is an important consideration when estimating redd abundance as it prevents double counting of redds and provides insight into spawning condition within and among years. We have successfully estimated SL using several different methods since 2016, and the consistent collection of SL and redd ageing data will allow for more complex SL analysis during future data syntheses.

4.1.2 Kelt Enumeration

Counter accuracy was moderate for downstream counts and high for upstream counts (49% and 81% for the Chowade River, 71% and 81% for Cypress Creek, respectively). Despite the moderate accuracies, confidence in the counter estimates is high due to the extensive validation efforts. Understanding errors associated with enumeration is critical to detecting changes in abundance, and rigorous methodology is in place to estimate accuracy of counter estimates. Both upstream and downstream counter accuracy were similar to previous years' accuracies and similar to other salmonid enumeration programs in British Columbia (Ramos-Espinoza et al. 2011). In both the Chowade River and Cypress Creek, the decreased counter accuracy was a result of false negatives for downstream movements. This is likely related to high fish densities of non-target species (particularly Mountain Whitefish), where two or more individuals interacted with a specific channel at the same time. Fish tend to move higher in the water column (further away from sensors) and faster when they move downstream. This caused the counter to misinterpret simultaneous signals and miss movements (i.e., multiple concurrent signals can be difficult for the counter to correctly separate into individual traces).

Abundance estimates were generated using downstream migrating kelts in 2022. The river flow in 2022 allowed us to install and collect data earlier in the migration and likely resulted in a larger portion of the upstream migration being enumerated. Despite the earlier install date, it was likely not early enough to provide a full abundance estimate of upstream migrants. Higher rates of recycling in the Chowade River during the month of August also complicated the enumeration, making it hard to estimate a net upstream count. Additionally, a side channel that originates upstream of the counter site and rejoins the mainstem downstream of the counter site has grown in size and now has a higher proportion of water moving through it. IFR has monitored the flow of the side channel annually and although unlikely, it is possible fish may have migrated around the counter site using the side channel. This may corroborate the discrepancy between the total number of up counts, redds estimated and kelt (151) counts. At Cypress Creek, upstream movements continued well into September and based on residence time observed with the PIT antennas, we believe the kelt migration may have continued into October. This is corroborated by the discrepancy between the total number of up (181) and kelt (131) counts. There is a possibility the entirety of downstream migrating kelts at both counter sites were not fully captured before the counting equipment was removed.

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 2022 along with GAUC abundance estimates. Peak counts collected during this monitoring program 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 during the current survey period, peak count has been 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. Historically, peak counts were subject to minor variations in counting methods, personnel, and survey length. Also, we found peak counts from 2016 through 2022 were sensitive to the type and number of surveys that were included in the peak spawning window. This sensitivity highlights the inherent uncertainty in peak counts and suggests GAUC estimates may be a more accurate and consistent method of estimation. Variable redd abundance may also be related to high rates of process error (i.e., natural variation in population size). A power analysis found high process error 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 starting from 2010, which they suggested may have been related to an increasing trend of recreational fishing in the region, and extreme hydrological events in 2011 and 2012 (Diversified Environmental Services and Mainstream Aquatics Ltd 2013).

It is 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 distinct from Bull Trout in the Pine River (Geraldes and Taylor 2020) and telemetry data (PIT and radio) currently being collected under other components of the FAHMFP will help to describe individual Bull Trout spawning movements, site fidelity, and survival. One individual Bull Trout's movement suggests significant migration patterns (Appendix E).

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 many Bull Trout spawners relative to other tributaries surveyed, and additional GAUC data for this tributary would provide a more robust estimate of redd abundance for the Halfway watershed.

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 helps determine how changes in redd abundance relate to overall changes in Bull Trout populations. Kelt to redd ratios for the Chowade River (0.5) and Cypress Creek (1.4) were low in 2022 for Chowade River and moderate for Cypress Creek, 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, and these kelt to redd ratios are likely underestimates. 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 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 or process error. 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 monitoring program prioritize accurate and precise estimates of both redd abundance and spawner abundance to maximize the power to detect a decline in Halfway River Bull Trout.

With river diversion (Peace River) occurring in the fall of 2020, 2022 marks the second year where we might expect to observe changes to spawner abundance. Results from 2022 indicated that redd abundance from both Chowade River and Cypress Creek fall within the ranges observed pre-diversion from 2016 to 2020. Kelt abundances for Chowade River was below the ranges observed pre-diversion from 2016 to 2020, and kelt abundance for Cypress Creek was within the ranges observed pre-diversion.

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) suggest that the upstream migration may begin in July and peak earlier than previously suggested by Baxter (1997). In addition, 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.

Radio telemetry data currently being collected in the Halfway Watershed informs migration timing, residence time, and site fidelity (Hatch et al. 2022). All radio tagged and pit tagged Bull Trout detected by the LGL Chowade and Cypress telemetry antennas were detected on the Chowade and Cypress PIT arrays (K. Hatch, LGL, personal communication). The PIT arrays continues to detect juvenile Bull Trout that were sampled through the Site C Reservoir Tributaries Population Indexing Survey, upstream of the counter sites, providing some valuable information as to when juveniles are migrating out of the system. It appears that there is some variability, with some juveniles leaving the same year they are tagged, while others up to two years later. This information will provide insight as to where these juveniles are going (if they are sampled through other programs) and how long they take before returning to spawn and if they return to their natal streams.

4.3 Distribution

According to redd surveys, Bull Trout spawner distributions show minor variations both within and among tributaries of the Halfway River. Although some areas consistently saw redd activity from 2016 to 2022, many areas of high-quality spawning habitat were not used in each year. 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, including variability in spawner abundance. Also, it is 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 and distribution. Discharge may affect spawner timing and distribution (e.g., Sinnatamby et al. 2018), and discharge during the Bull Trout migration has thus far varied considerably. Preliminary data suggest years with high discharge may be associated with higher GAUC redd abundance in smaller tributaries such as Fiddes and Turnoff Creeks. Changes in water temperature or groundwater discharge can also affect the 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 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.

5. References

Al-Chokhachy, R., Budy, P., and Schaller, H. 2005. Understanding the significance of redd counts: a comparison between two methods for estimating the abundance of and monitoring Bull Trout populations. *North American Journal of Fisheries Management* 25:1505-1512.

AMEC Earth & Environmental and LGL Ltd. 2010. Analysis and Assessment of the Ministry of Environment's Peace River Bull Trout and Arctic Grayling Radio Telemetry Database 1996 to 1999. Report prepared for BC Hydro, Vancouver, BC.

Andrusak, G.F. 2009. Kaslo River and Crawford Creek Adult Bull Trout Spawner Assessment. Prepared for the Fish and Wildlife Compensation Program, Columbia Basin, Nelson BC, the Habitat Conservation Trust Fund of BC and the Ministry of Environment, Nelson, BC. 38 pp.

Bates, D., Maechler, M., Bolker, B., and Walker, S. 2015. Fitting Linear Mixed-Effects Models Using lme4. Journal of Statistical Software, 67(1), 1-48. Doi:10.18637/jss.v067.i01.

Baxter, J.S. 1997. Aspects of the reproductive ecology of Bull Trout (*Salvelinus confluentus*) in the Chowade River, British Columbia. Thesis submitted to the Faculty of Graduate Studies, University of British Columbia. 110 p.

Baxter, J., and McPhail, J. 1999. The influence of redd site selection, groundwater upwelling, and over-winter incubation temperature on survival of bull trout (*Salvelinus confluentus*) from egg to alevin. *Can. J. Zool.* 77(8): 1233-1239. Doi:10.1139/z99-090.

Bivand, R., Keitt, T., and Rowlingson, B. 2017. Rdgal: Bindings for the Geospatial Data Abstraction Library. R package version 1.2-15. https://CRAN.R-Project.org/package=rgdal.

Bivand., R.S., Pebesma, E., and Gomez-Rubio, Virgilio. 2013. Applied spatial data analysis with R, Second edition. Springer, NY. http://www.asdar-book.org/

Brännäs, E., H. Lundqvist, E. Prentice, M. Schmitz, K. Brännäs, and B. S. Wiklund. 1994. Use of the passive integrated transponder (PIT) in a fish identification and monitoring system for fish behavioral studies. Transactions of the American Fisheries Society 123:395–401.

Braun, D.C., D. McCubbing, D. Ramos-Espinoza, M. Chung, L. Burroughs, N.J. Burnett, J. Thorley, J. Ladell, C. Melville, B. Chillibeck, and M. Lefebre. 2016. Technical, logistical, and economic considerations for the development and implementation of a Scottish salmon counter network. Report prepared for Marine Scotland Science. InStream Fisheries Research, Vancouver, BC. 267 p. + 3 Apps.

Braun, D.C., Ramos-Espinoza, D., Burnett, N.J., Chung, M. and Buchanan, J. 2017a. Peace River Bull Trout Spawning Assessment 2016 - A Pilot Study to Assess the Feasibility of a Resistivity Counter and Passive Integrative Transponder Antenna in the Chowade River (Mon-1b, Task 2b). Report prepared for BC Hydro – Site C Clean Energy Project – Vancouver, BC. InStream Fisheries Research, Vancouver, BC. 30 pages.

Braun, D.C., J.M.S. Harding, LJ Wilson, C. Martin, and M. Chung. 2017b. Peace River Bull Trout Spawning Assessment – 2016 Bull Trout Redds Counts (Mon-1b, Task 2b). Report prepared for BC Hydro – Site C Clean Energy Project – Vancouver, BC. 28 pages + 3 appendices.

Brundsdon, C., and Chen, H. 2014. GISTools: Some further GIS capabilities for R. R package version 0.7-4. https://CRAN.R-project.org/package=GISTools

Cook, K.V., P. Moniz, A. Putt, D. Ramos-Espinoza. 2021. Site C Fishway Effectiveness Monitoring Program (Mon-13) – Construction Year 6 (2020). Report by InStream Fisheries Research, Squamish, BC, for BC Hydro, Burnaby, BC. 88 p + appendices.

Diversified Environmental Services and Mainstream Aquatics Ltd. 2013. Upper Halfway River Watershed Bull Trout Spawning Survey 2012. Prepared by T. Euchner, Diversified Environmental Services, Fort St. John, BC in association with Mainstream Aquatics Ltd., Edmonton for BC Hydro. Report No. 10016.

Diversified Environmental Services and Mainstream Aquatics Ltd. 2011. Upper Halfway River Watershed Bull Trout Spawning Survey 2010. Prepared by T. Euchner, Diversified Environmental Services, Fort St. John, BC in association with Mainstream Aquatics Ltd., Edmonton for BC Hydro. Report No. 10016.

Diversified Environmental Services and Mainstream Aquatics Ltd. 2009. Upper Halfway River Watershed Bull Trout Spawning Survey 2008. Prepared by T. Euchner, Diversified Environmental Services, Fort St. John, BC in association with Mainstream Aquatics Ltd., Edmonton for BC Hydro. Report No. 08008.

Dunham, J., Rieman, B., and Davis, K. 2001. Sources and magnitude of sampling error in redd counts for Bull Trout. *North American Journal of Fisheries Management* 21:343-352.

Gallagher, S.P., and C.M. Gallagher. 2005. Discrimination of Chinook and coho salmon and steelhead redds and evaluation of the use of redd data for estimating escapement in several unregulated streams in northern California. North American Journal of Fisheries Management. 25: 284-300.

Gallagher, S., P.K. Hahn, and D.H. Johnson. 2007. Redd counts. Pages 197–234 in D. H. Johnson, B. M. Shrier, J. S. O'Neil, J. A. Knutzen, X. Augerot, T. A. O'Neil, and T. N. Pearsons, editors. Salmonid field protocols handbook: techniques for assessing status and trends in salmon and trout populations. American Fisheries Society, Bethesda, Maryland.

Geraldes, A., and E. Taylor. 2020. Site C Fish Genetics Study. Report prepared for BC Hydro – Site C Clean Energy Project – Vancouver, BC. 44 pages + 2 appendices.

Hatch, K., D. Robichaud, B. Cox, and S. Crawford. 2022. Site C Reservoir Tributaries Fish Community and Spawning Monitoring Program (Mon-1b), Task 2d – Site C Movement Assessment. Construction Year 7 (2021). Report prepared for BC Hydro – Site C Clean Energy Project – Vancouver, BC. 114 pp.

High, B., Meyer, K.A., Schill, D.J., Mamer, E.R.J. 2008. Distribution, abundance, and population trends of Bull Trout in Idaho. *North American Journal of Fisheries Management* 28: 1687-1701.

Hilborn, R., B.G. Bue, and S. Sharr. 1999. Estimating spawning escapements from periodic counts: a comparison of methods. Canadian Journal of Fisheries and Aquatic Sciences. 56: 888–896.

Howell, P.J., and Sankovich, P.M. 2012. An evaluation of redd counts as a measure of Bull Trout population size and trend. *North American Journal of Fisheries Management* 32: 1-13.

Kovach, R.P., Armstrong, J.B., Schmetterling, D.A., Al-Chokhachy, R., and Muhlfield, C.C. 2018. Long-term population dynamics and conservation risk of migratory bull trout in the upper Columbia River basin. *Canadian Journal of Fisheries and Aquatic Science* 75: 1960-1968.

Ma, B.O., Parkinson, E., Olson, E., Pickard, D.C., Connors, B., Schwarz, C., and D. Marmorek. 2015. Site C Monitoring Plan Power Analysis. Final report. Prepared for BC Hydro by ESSA Technologies Ltd. 64 pp + appendices.

Marques, H., and Putt, A. 2022. ORFID: Manage and Summarize Data from Oregon RFID ORMR and ORSR Antenna Readers. R package version 1.0.2, https://CRAN.R-project.org/package=ORFID.

Maxwell, B. 1999. A power analysis on the monitoring of Bull Trout stocks using redd counts. *North American Journal of Fisheries Management*, 19: 860-866.

Melville, C., D. Ramos-Espinoza, D. Braun, and D.J.F. McCubbing. 2015. Lower Bridge River adult salmon and steelhead enumeration, 2014. Report prepared for St'át'imc Eco-Resources and BC Hydro. 80 p.

Millar, R.B., S. McKechnie, C.E. Jordan, and R. Hilborn. 2012. Simple estimators of salmonid escapement and its variance using a new area-under-the-curve method. Canadian Journal of Fisheries and Aquatic Sciences. 69: 1002–1015.

Monnot, L., Dunham, J. B., Home, T. and P. Koetsier. 2008. Influences of body size and environmental factors on autumn downstream migration of Bull Trout in the Boise River, Idaho. North American Journal of Fisheries Management. 28: 231-240, pp 231-240.

Putt, A., Ramos-Espinoza, D., and M. Chung. 2022. Site C Reservoir Tributaries Fish Community and Spawning Monitoring Program – 2021. Peace River Bull Trout Spawning Assessment (Mon 1b, Task 2b). Report prepared for BC Hydro – Site C Clean Energy Project – Vancouver, BC. 69 pages + 6 appendices.

Putt, A.E., Ramos-Espinoza, D., Braun, D.C., and J. Korman. 2021. Methods of estimating abundance and associated uncertainty from passive count technologies. North American Journal of Fisheries Management: 42(1), 96-108.

R Core Team. 2017. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Ramos-Espinoza, D., McCubbing, D., and Chamberlain, M. 2011. Estimating Chinook escapement to medium sized rivers using combined resistivity and multibeam sonar fish counters (Presentation). American Fisheries Society 140th Annual Meeting.

R.L. & L. Environmental Servicies LTD. 1995. Fish migrations in the Chowade River, B.C. Fall 1994. Report prepared for Ministry of Environment, Lands and Parks, British Columbia: 34 pages + 4 appendices.

Sinnatamby, R.N., M.C. Pinto, F.D. Johnston, C.J. Mushens, H.G.M. Ward, and J.R. Post. 2018. Seasonal timing of reproductive migrations in adfluvial bull trout: an assessment of sex, spawning experience, population density, and environmental factors. *Can. J. Fish. Aquat. Sci*. 75(12): 1-12.

Taylor, E.B., Yau., M.M., and A.B. Mattock. 2013. Population structure in three species of co-distributed salmonid fishes in the peace river and tributaries near a major proposed hydroelectric development in northeastern British Columbia, Canada. River Research and Applications. DOI: 10.1002/rra.2712.

Trouton, N.D. 2004. An investigation into the factors influencing escapement estimation for Chinook salmon (*Oncorhynchus tshawytscha*) on the lower Shuswap River, British Columbia. Master of Science thesis.

Appendix A: Aerial and Ground Redd Counts

Table A1 Survey-specific ground counts, aerial counts, ground OE, expanded ground counts, and aerial OE.

Tributary	Survey	Ground Count	Aerial Count (within ground reach)	Avg Ground OE	Expanded Ground (ground count / mean ground OE)	Aerial OE (aerial count / expanded ground count)
Chowade River	1	34	13	0.84	40.5	0.32
	2	73	43	0.84	86.9	0.49
	3	49	19	0.84	58.4	0.33
	4	26	9	0.84	31.0	0.29
Cypress Creek	1	2	0	1.00	2	0.00
	2	12	2	1.00	12	0.17
	3	15	3	1.00	15	0.20
	4	11	6	1.00	11	0.55
Fiddes Creek	1	9	1	1.00	9	0.11
	2	11	3	1.00	11	0.27
	3	9	0	1.00	9	0.00
	4	2	2	1.00	2	1.00
Upper Halfway River	1	2	1	0.93	2.2	0.46
	2	8	6	0.93	8.6	0.70
	3	6	4	0.93	6.5	0.62
	4	5	2	0.93	5.4	0.37
Needham Creek	1	22	8	-	-	0.36[a]

a: Aerial count/ground count for single peak count survey.

Appendix B: Summary of Linear Mixed Model for Survey Life

Table B1 Summary output for the linear mixed effect model of survey life.

```
## Linear mixed model fit by maximum likelihood  ['lmerMod']
## Formula: norm_jday ~ redd_age + (1 | tag_id)
##    Data: redd_dat
## Control: lmerControl(optimizer = "Nelder_Mead")
##
##      AIC      BIC   logLik deviance df.resid
##    969.1    981.8   -480.6    961.1      170
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -1.6538 -0.4994 -0.1389  0.1729  3.4897
##
## Random effects:
##  Groups   Name        Variance Std.Dev.
##  tag_id   (Intercept)  3.016   1.737
##  Residual             12.228   3.497
## Number of obs: 174, groups:  tag_id, 57
##
## Fixed effects:
##             Estimate Std. Error t value
## (Intercept)  -2.8552     0.6532  -4.371
## redd_age      4.7394     0.2278  20.802
##
## Correlation of Fixed Effects:
##          (Intr)
## redd_age -0.841
```

Appendix C: Total Lengths from Video Validation

Table C1 Fish total lengths estimated in the Chowade River through video validation.

	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
2020	436	623	240-970	122
2021	438	642	500-1000	90
2022	205	622	354-1080	123
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
2020	821	289	80-480	78
2021	1223	286	20-520	69
2022	94	410	150-540	62
Rainbow Trout				
2016	-	-	-	-
2017	11	326	300-343	17
2018	10	387	265-587	101
2019	28	420	200-586	91
2020	71	380	230-550	62
2021	269	353	160-530	67
2022	106	402	263-563	49

Table C2 Calculated Fish standard lengths estimated in Cypress Creek through video validation.

	N	Mean (mm)	Range (mm)	SD (mm)
Bull Trout				
2017	76	556	308-844	133
2018	230	496	279-900	97
2020	48	594	430-920	127
2021	129	642	550-940	85
2022	269	596	321-900	125
Mountain Whitefish				
2017	207	259	83-463	70
2018	20	323	243-380	32
2020	304	207	80-390	68
2021	204	302	100-540	93
2022	39	354	197-407	41
Rainbow Trout				
2017	9	308	171-400	73
2018	3	354	292-450	84
2020	71	278	180-440	61
2021	59	318	170-450	65
2022	26	387	197-460	70

Appendix D: PIT Detection Histories

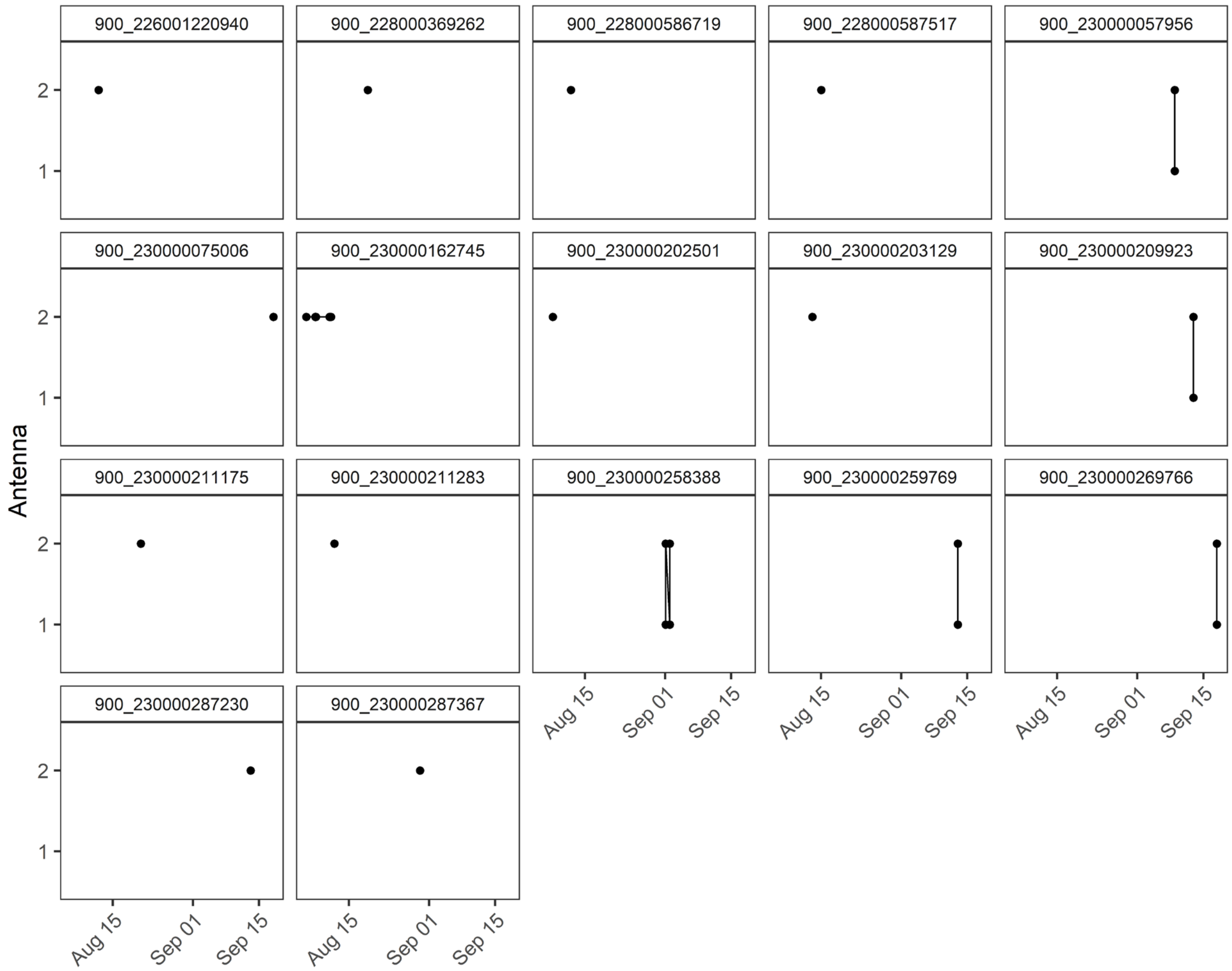

Figure D1 Detection histories of PIT tags detected by the Chowade River array. Antenna 1 is the downstream antenna, while Antenna 2 is the upstream antenna.

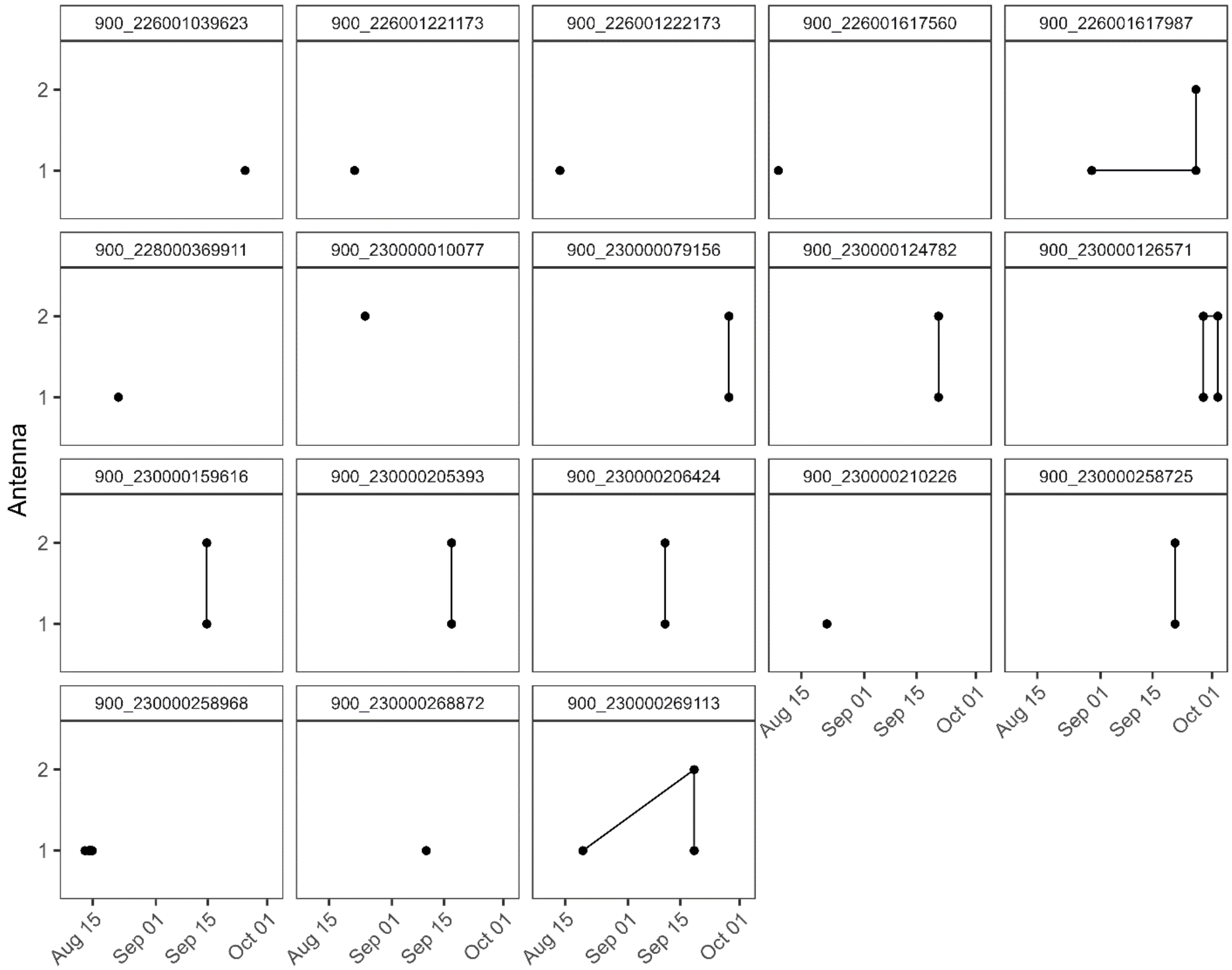

Figure D2: Detection histories of PIT tags detected by the Cypress Creek array. Antenna 1 is the downstream antenna, while Antenna 2 is the upstream antenna.

Appendix E: Wide Scale Bull Trout Movements

Table 5.1 Movement pattern of Bull Trout, PIT#: 900230000211283. Data compiled from WSP and IFR, 2023. (D. Ford, WSP, personal communication)

Care-taker	Date Time	Location	Stream	Capture Method	Release Site	Length (mm)	Weight (g)
WSP	2021-05-26 14:33:00	SiteC Contingent Fish Capture	Peace	Large Boat Shocking	Halfway	690	3717
WSP	2022-07-14 8:29:00	Temporary US Fish Passage Facility	Peace	TUF	Halfway	707	4205
IFR	2022-08-11 22:13:38	Chowade	Chowade	Resistivity	Chowade	690	
IFR	2022-08-11 22:13:59	Chowade	Chowade	Resistivity	Chowade	690	
IFR	2022-08-11 22:22:42	Chowade	Chowade	PIT Arrays	Chowade		
WSP	2022-10-14 11:45:05	Offset Effectiveness Monitoring - Side Channel 108R	Peace	Small Boat Shocking	PCR-OCES02	760	4486