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 9 (2023)

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

2023 Peace River Bull Trout Spawning Assessment (Mon-1b, Task 2b)

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Executive Summary

We report findings of the 2023 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 2023, GAUC redd abundance estimates ranged from 1 in Turnoff Creek to 501 (SE = 223) 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 2023, average aerial observer efficiency of Bull Trout redds was low and variable among tributaries, ranging from 0.13 in Cypress Creek to 0.27 in Fiddes Creek. Average redd survey life, defined as the period during which a redd is observable, was 19.6 days (SE 2.3 days).

Resistivity counter data suggest the Chowade River kelt migration began on September 8, with a unimodal peak on September 17. After accounting for counter accuracy, the Bull Trout kelt abundance was 117. The Cypress Creek kelt migration also followed a normal distribution, beginning on September 7 and peaking on September 17, with a kelt abundance of 77 Bull Trout. Downstream movements peaked later in 2023 relative to previous years; kelt abundance may be underestimated as a portion of the kelt migrations likely occurred after monitoring equipment was removed.

We also monitored fish behaviour in the Chowade River and Cypress Creek using PIT arrays that detected directional movements of tagged fish. The Chowade River PIT array detected 46 tags, while the Cypress Creek array detected 20 tags. Bull Trout residence time averaged 15.1 days (SD 13.0 days) in the Chowade River. Residence time could not be determined for Cypress Creek Bull Trout due to low detection numbers.

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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 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 questions 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 (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).

The 2023 monitoring year marks the third year of river diversion, which may provide a barrier to fish migrating past the Project (Cook et al. 2023). 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 was previously 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. 2023), 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. 2023). 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 also informs 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. 2023). 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 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 consistent in all tributaries, and we assumed water clarity did not substantially influence OE during visual surveys.

[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 2023) using packages *ggplot2* (Wickham 2016), *sf* (Pebesma 2018; Pebesma and Bivand 2023), and *ggsn* (Santos Baquero 2019).

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 geolocation 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 positional 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 Fish 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)
$$y_{ij} \sim N(\mu_{ij}, \sigma^2)$$

$$\mu_{ij} = \beta_0 + \beta_{0_i} + (\beta_1 + \beta_{1_i}) * redd\_age_{ij}$$

where β_0 and β_1 are normally distributed intercept and slope parameters incorporating random variation for the *j*th observation at tag ID *i*. 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 2023) 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)
$$\hat{E} = \frac{\hat{F}}{l * v}$$

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 22.8 rkm and 15.9 rkm, respectively, upstream of their confluences with the Halfway River (Figure 2.1). The Chowade River counter was moved upstream in 2023 to be situated upstream of a large side channel that has taken more of the mainstem flow within recent years. The side channel had minimal flow when the previous counter site was selected, but in 2022 and 2023 we estimated that approximately half of the river flow was diverted to the side channel. The Chowade River and Cypress Creek are dynamic and ever-changing systems, and the Chowade River counter site has been moved twice since monitoring began in 2016. Counter sites are carefully selected to maximize river coverage and detection efficiency, and equipment is calibrated for each site and year to ensure kelt estimates are comparable among years.

Counter 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

[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).

counters consisted of four channels configured to span the full width of the tributary (Figure 2.2). We used flat pad sensors with two 6” strips of white puck board that increased 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 to spawning grounds in the Chowade River and Cypress Creek from mid-July to early September, and downstream migration occurs from late August to early October (R.L. & L. Environmental Services Ltd. 1995, Braun et al. 2017a). It is typically not possible to monitor the upstream migration due to high and unpredictable discharge in early to mid-July. Flows during the August to October kelt period are usually lower and more conducive to equipment installation and operation, and we generate an estimate of kelts in each year.

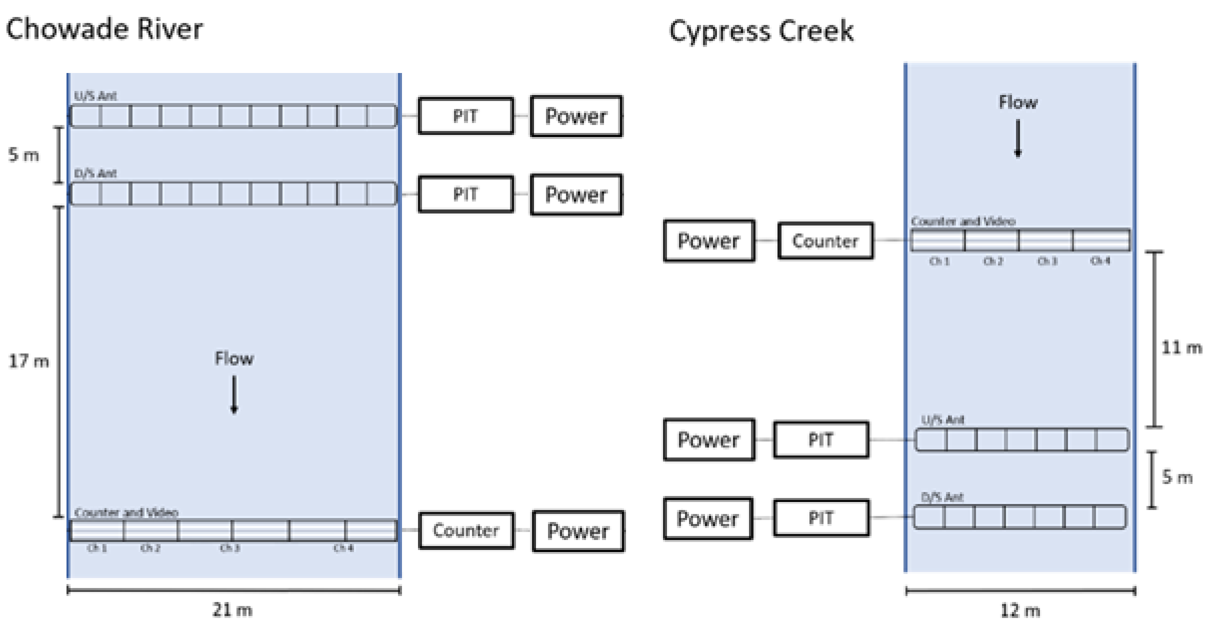

Figure 2.1 Approximate configuration of the resistivity counter sensor pads, PIT arrays, power system and video validation system in the Chowade River and Cypress Creek.

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, movement patterns, 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 efficiency. First, we performed 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 total FNs. Total random validation was approximately 10% of the video record, with a higher relative proportion of night video being validated (most Bull Trout movements occur at night).

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

[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 are described in Putt and Ramos-Espinoza 2021, and Putt et al. 2022.

(2.1) $$V \sim multinomial(N, \theta)$$

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.

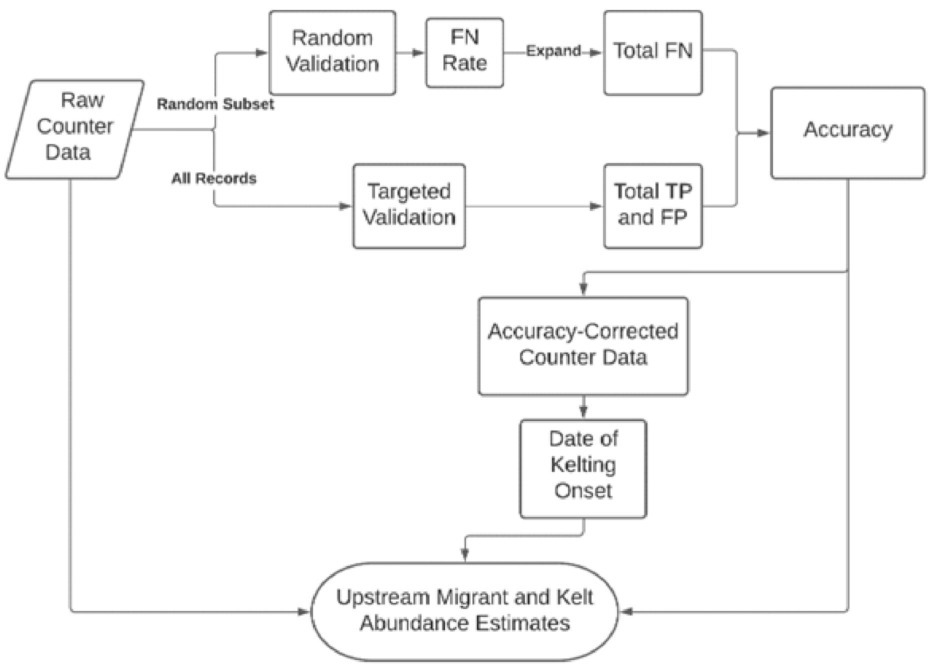

Figure 2.2 Method to validate resistivity counter data and determine accuracy-corrected abundance of upstream migrants and kelts.

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):

(2.2)

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

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 and a single reader (Oregon RFID, Portland, OR), 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 WSP.

3. Results

Monitoring for Mon-1b, Task 2b occurred from July 22 to October 7. The Chowade River and Cypress Creek resistivity counters and PIT arrays were operational from July 25 to October 1 and July 22 to October 1, respectively. Aerial and ground redd surveys occurred between September 5 and October 7. Water levels in the Halfway River watershed during Bull Trout spawning migrations were lower relative to average values from 2016 to 2022 (i.e., the extent of Mon-1b, Task 2b monitoring; Figure 3.1).

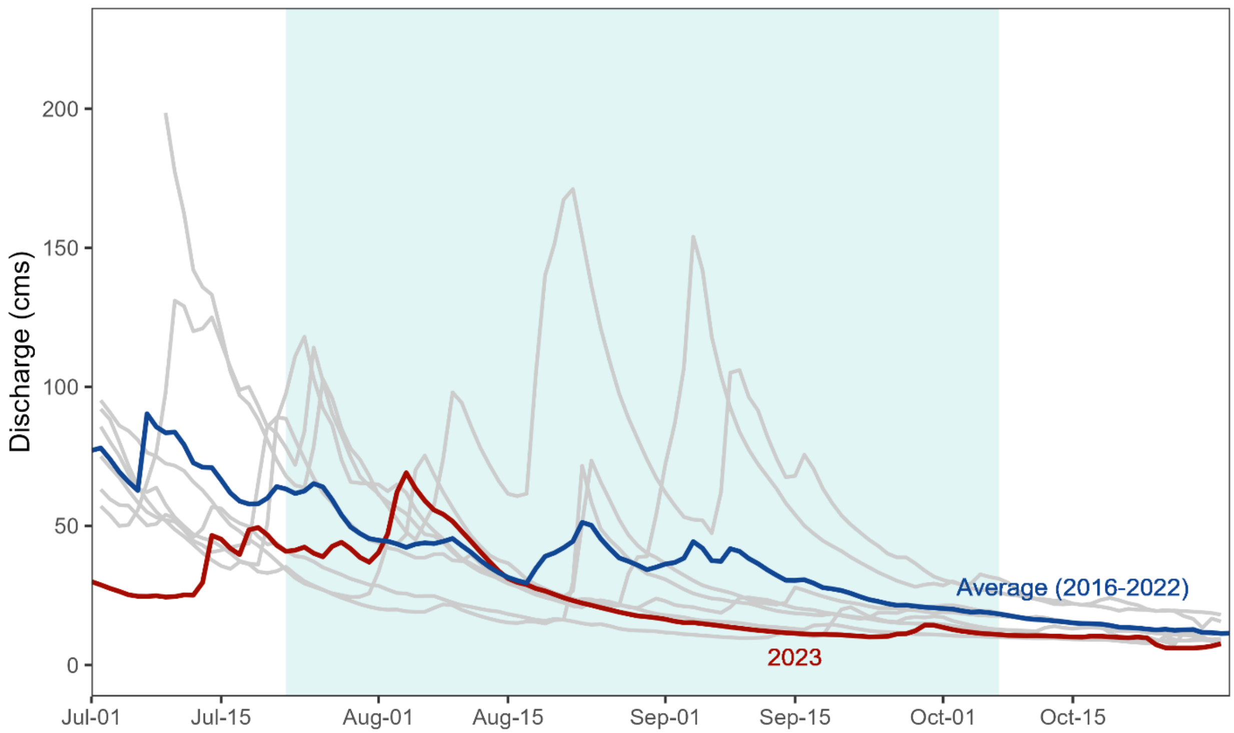

Figure 3.1 Discharge (cms) from the Halfway River above the Graham River (Water Survey of Canada monitoring site 07FA003) from 2016 to 2023. Red line represents 2023 discharge and blue line is the average discharge from 2016 to 2022 (grey lines are individual years from 2016 – 2022). Shaded area represents the Mon-1b, Task 2 monitoring period.

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]. Surveys typically occur within a four-week period, but weather conditions prevented crews from performing aerial surveys on Fiddes or Turnoff Creeks during the second week of surveys. A fifth week was required to ensure all tributaries had at least four surveys (the upper Halfway River had five aerial surveys in 2023).

3.1.1 Redd Distribution

Redd distributions were relatively consistent among years in the tributaries surveyed. In 2023, redds were observed throughout the Chowade River survey reach, with the highest densities observed in the upper third (rkm 43 – rkm 48) (Figure 3.2). Aerial redd densities were similar among monitoring years, with redds typically being concentrated between rkm 38 and rkm 48 (Figure 3.3). The distribution of redds in Cypress Creek was different in 2023 relative to previous years. As in previous years, redds were observed between rkm 29 and 32, but few redds were observed between rkms 48 and 52, where redd densities are typically high (Figure 3.4, Figure 3.5). In the upper Halfway River, redds were almost exclusively observed above rkm 15 (with one exception; Figure 3.6 and Figure 3.7), while distributions were less consistent in Fiddes Creek (Figure 3.6, Figure 3.8). Only one redd was observed during aerial surveys in both Turnoff and Needham Creek in 2023 (Figure 3.9, Figure 3.10, Figure 3.11).

[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]

[Figure 3.11 – 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 (< 0.35) and highly variable (%CV > 50) for all tributaries. In 2023, aerial OE was lower than previous years, particularly in the Chowade River and Cypress Creek. Variability in aerial OE can increase uncertainty in redd abundance since OE standard error is incorporated into the GAUC model.

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	0.81 (21.7)	0.14 (102.4)
Cypress Creek	0.85 (8.3)	013 (54.3)
Fiddes Creek	0.94 (13.3)	0.34 (94.4)
Upper Halfway River	0.97 (5.7)	0.23 (62.3)
Needham Creek	-	0[a]

a: Aerial count/uncorrected ground count for singe peak count survey. In 2023, zero redds were observed in the ground reach during the aerially survey.

Survey Life

A total of 106 bristle tags were applied to redds during ground surveys and used to estimate SL. We estimated mean SL for all redds using an LME model of normalized survey day in relation to redd age (Figure 3.12). The optimal random effect structure was a random intercept for tag ID (Appendix B). The fixed effect of tributary was significant, and suggested Cypress Creek redds aged slower in 2023 relative to previous years (ANOVA Chi-Squared p-value <0.001; ΔAIC > 2). This pattern was opposite to previous years and low water conditions made redd ageing difficult in 2023 throughout the Halfway Watershed. We used the average SL among all tributaries during AUC modelling to account for this uncertainty. The estimated SL was 19.3 days with a standard error of 2.29 days, which was within the range of previous estimates (Table 3.2).

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
2023	19.6	2.3

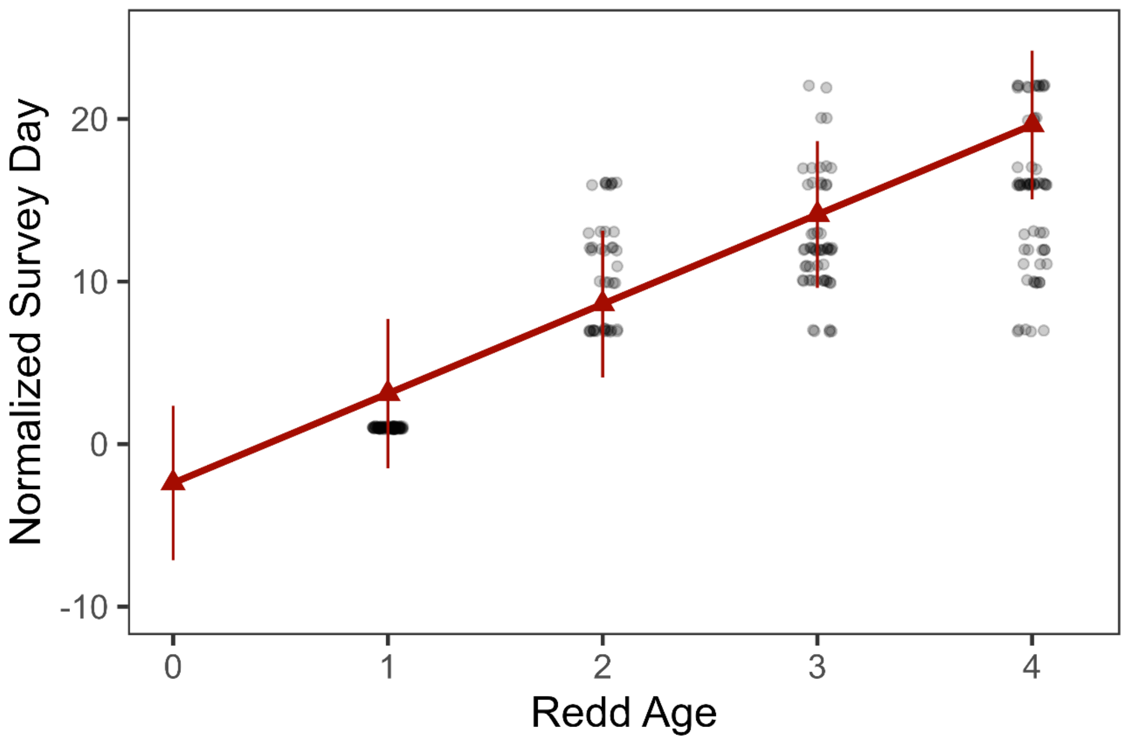

Figure 3.2 Redd age within all tributaries by normalized survey day, with points jittered for presentation. Red line shows mean SL for all redds, and vertical error bars are the 95% confidence interval based on a normal approximation. Negative normalized survey days correspond to days between the redd being built and the first observation (age-1).

GAUC Abundance

Redd counts were highly variable in 2023, one of the lowest water years within the current study period (Figure 3.1). GAUC estimates ranged from one redd in Turnoff Creek to 501 redds in the Chowade River (Table 3.3). Only one redd was observed during aerial surveys of Turnoff Creek, resulting in the lowest redd abundance estimate on record. Crews noted a large number of beaver dams and other potential barriers to migration, suggesting Bull Trout spawning in Turnoff Creek was inhibited by low water conditions. The total number of redds estimated for all tributaries combined was 664. Precision (%CV) for all tributaries, ranged from 51.6% in Cypress Creek to 60.4% in the upper Halfway River. The GAUC model fit the count data well except for Cypress Creek (Figure 3.13), 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 estimated by this monitoring program were lower than the most recent historic peak counts in 2010 and 2012 (Figure 3.14).

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	501 (223)	210	1197	55.5	0.14 (0.06)	19.6 (2.3)	99
Cypress Creek	91 (44)	36	233	51.6	0.13 (0.03)	19.6 (2.3)	16
Fiddes Creek	23 (9)	11	49	60.9	0.34 (0.12)	19.6 (2.3)	29
Turnoff Creek	1	-	-	-	-	-	1
Upper Halfway River	48 (19)	21	106	60.4	0.23 (0.06)	19.6 (2.3)	39
Needham Creek	-	-	-	-	-	-	18

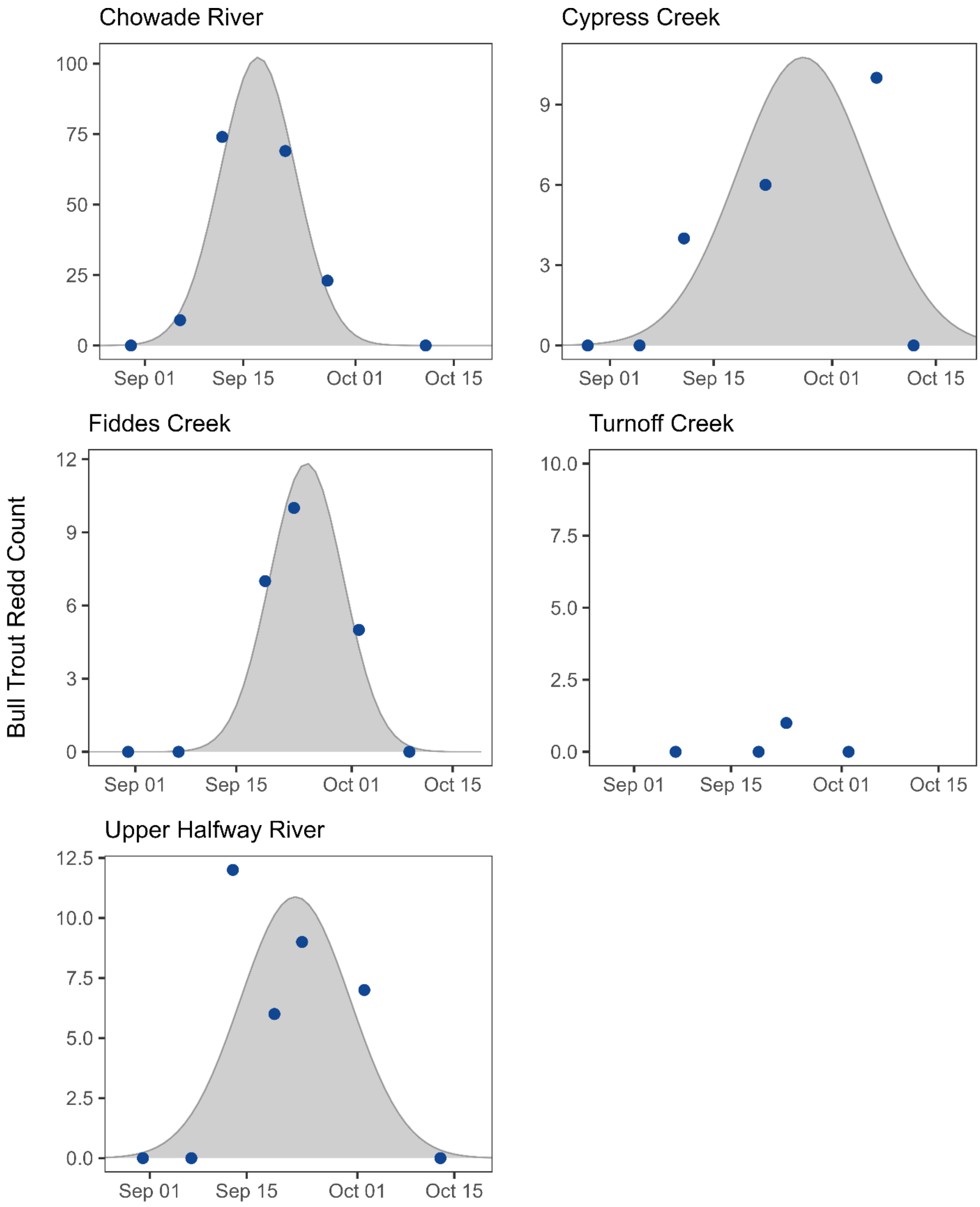

Figure 3.3 Bull Trout redd counts (blue points) and modelled survey period (grey shaded area) in Halfway River tributaries. Zero counts bounding the spawning period were added during GAUC modelling and do not represent observed counts. The GAUC model was not run in Turnoff Creek as only one redd was observed within the survey period.

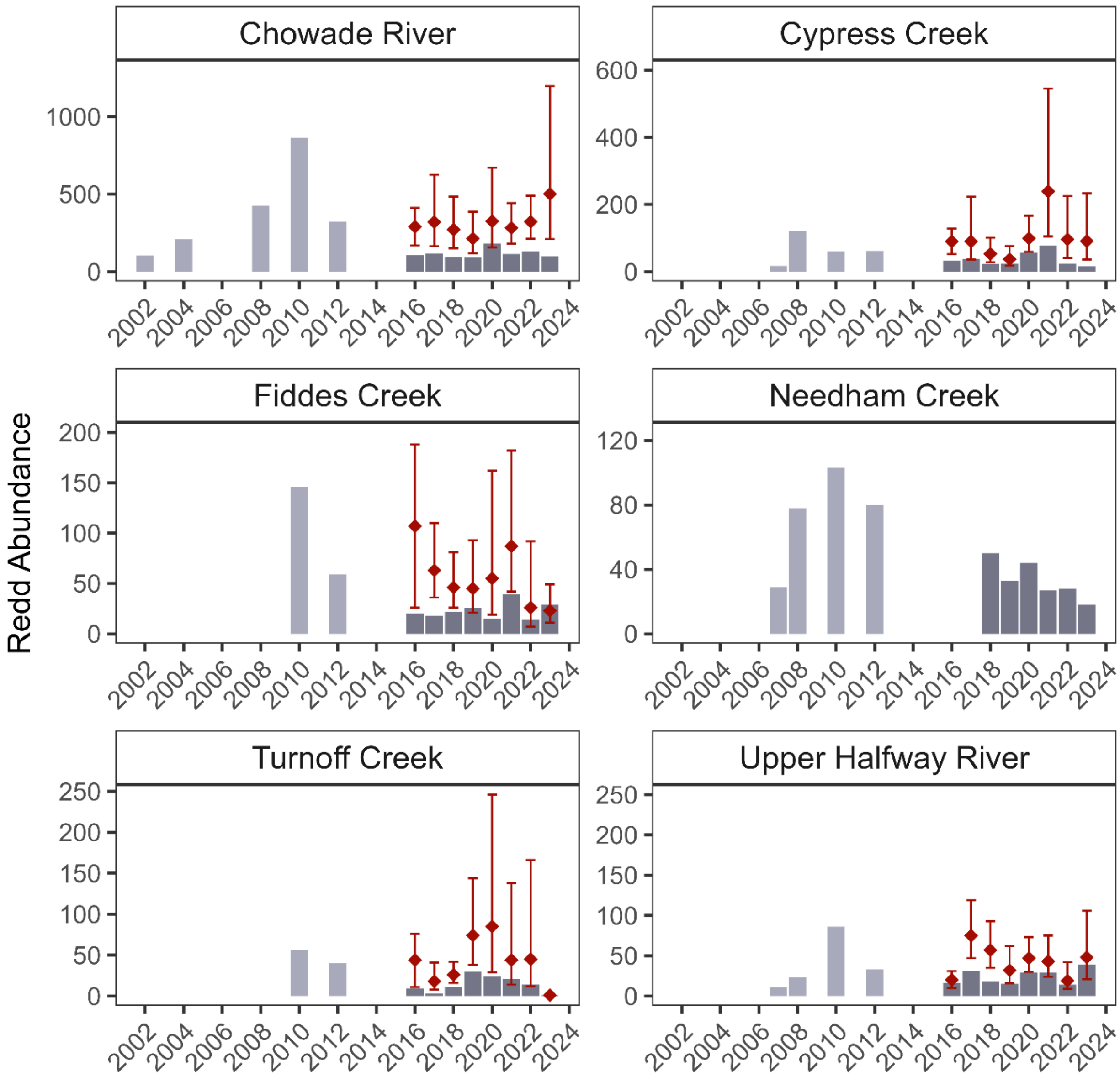

Figure 3.4 Bull Trout peak count redd indices from 2002 to 2014 (light grey bars; Diversified Environmental Services and Mainstream Aquatics Ltd. 2009, 2011, and 2013); from 2016 to 2023 (dark grey bars; this monitor). GAUC abundance with CI are shown as red diamonds.

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 3.15). 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.

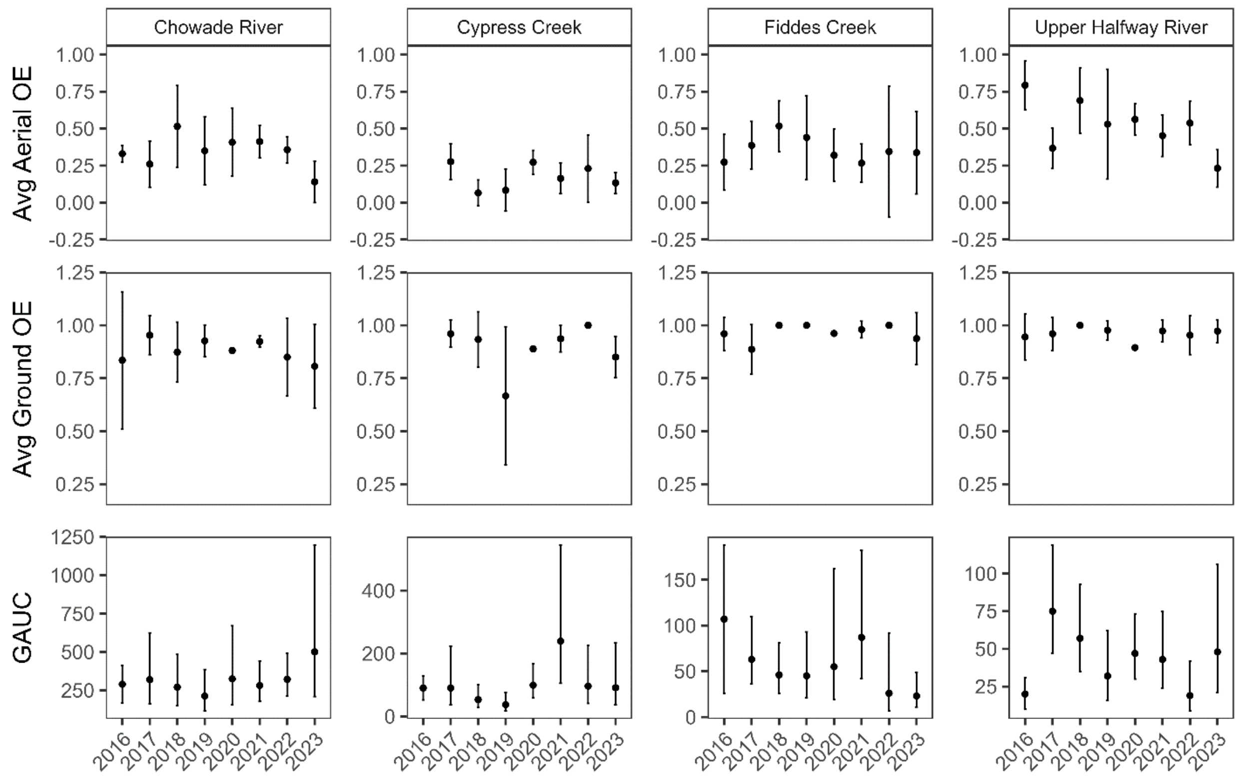

Figure 3.5 Mean aerial OE, mean ground OE, and GAUC abundance (error bars are 95% confidence intervals) in the Halfway Watershed.

3.2 Resistivity Counters

3.2.1 Chowade River

The Chowade River resistivity counter operated from July 25 to October 1. Bull Trout (n = 192), Mountain Whitefish (n = 212), and Rainbow Trout (n = 313) were confirmed during video validation. Total length for Bull Trout ranged from 470 mm to 995 mm (mean = 728 mm, SD = 113 mm), Mountain Whitefish ranged from 120 mm and 420 mm (mean = 253 mm, SD = 55 mm), and Rainbow Trout ranged from 250 mm to 625 mm (mean = 354 mm, SD = 48 mm). Total length data from 2023 were within the range of previous monitoring years (Appendix C).

Counter accuracy varied among channels from 39% to 100% for downstream movements and 76% to 100% for upstream movements (Table 3.4). False negatives occurred at a greater frequency compared to false positives, suggesting the counter underestimated the true number of movements. Most movements occurred on channels 1 and 2, located in the thalweg on river right (Figure 3.15).

The normal density function estimated that the 2023 Bull Trout kelt outmigration began on September 8 and peaked on September 17 (SD = 5.29 days; Figure 3.17). After accounting for counter accuracy and the date of kelt onset, kelt abundance for the Chowade River was 117 (Figure 3.18). The ratio of kelts to redds (estimated via GAUC) was 0.2 and the lowest observed to date (Table 3.5). Although the date of the onset of upstream spawning migration is uncertain, the resistivity counter was installed relatively early in 2023 and likely recorded a large portion of upstream movements. The total cumulative upstream count for Bull Trout was 132 during the enumeration period (Figure 3.17).

Table 3.4 Chowade River counter accuracies for Bull Trout.

Channel	Direction	Accuracy
1	D	39%
1	U	76%
2	D	55%
2	U	100%
3	D	100%
3	U	100%
4	D	100%
4	U	100%

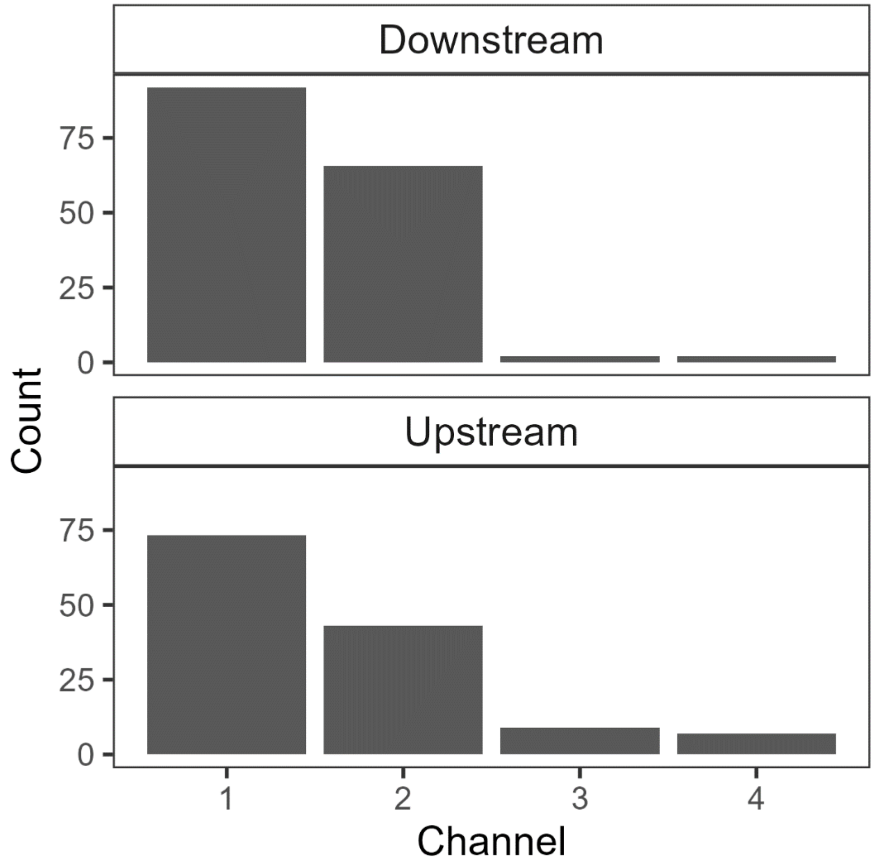

Figure 3.6 Accuracy-corrected counts of Bull Trout moving upstream and downstream past the Chowade River resistivity counter.

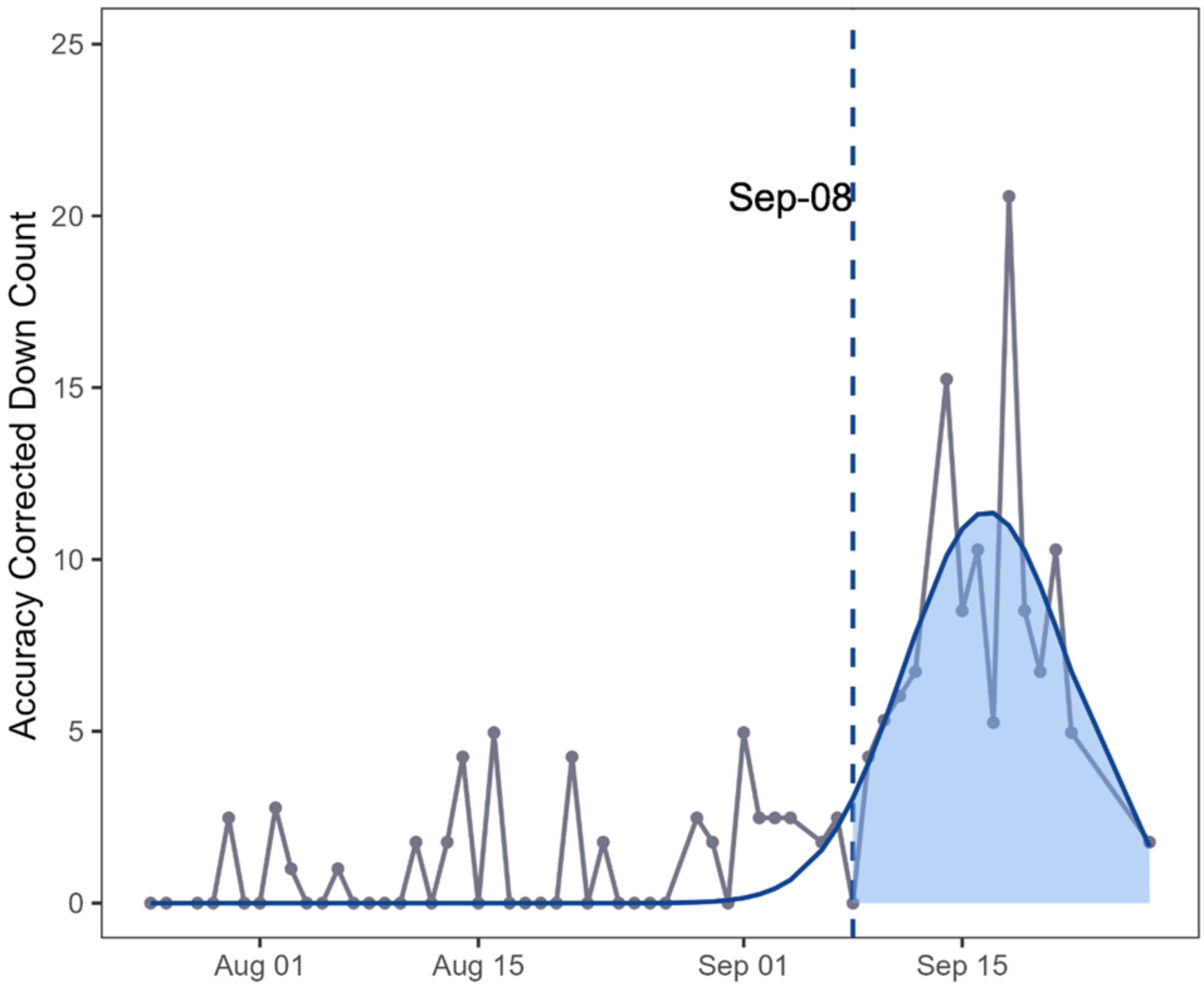

Figure 3.7 Accuracy corrected daily down counts of verified Bull Trout (grey points and lines) and modelled kelt out-migration timing (solid blue line and blue shading) in the Chowade River. The vertical dashed line marks the date which the normal model estimated 5% of the kelts had out-migrated, which was assumed to be the onset of the kelt out-migration.

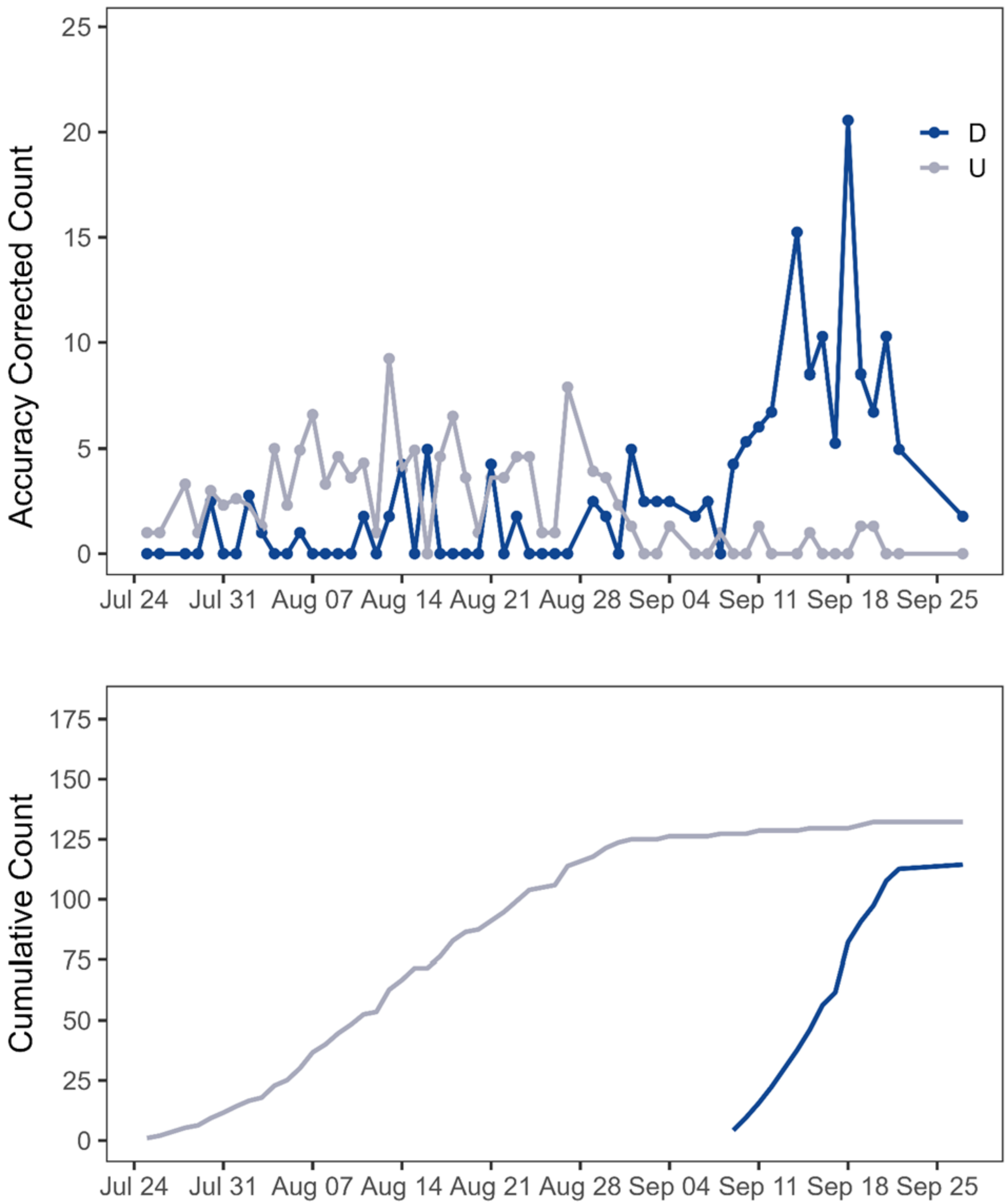

Figure 3.8 Top panel: accuracy corrected up and down counts of Bull Trout moving past the Chowade River resistivity counter. Bottom panel: cumulative up and down counts. Cumulative down counts were set as zero until September 8, the onset of the kelt out-migration.

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)
2023	117	501 (210 - 1197)	0.2 (0.1 - 0.6)

3.2.2 Cypress Creek

The Cypress Creek resistivity counter operated from July 22 to October 1. Bull Trout (n = 235), Mountain Whitefish (n = 103), and Rainbow Trout (n = 135) were confirmed during video validation. Bull Trout total lengths ranged from 430 mm to 970 mm (mean = 669 mm, SD = 98.7 mm), Mountain Whitefish ranged from 120 mm and 430 mm (mean = 280 mm, SD = 69 mm), and Rainbow Trout ranged from 300 mm to 640 mm (mean = 393 mm, SD = 74 mm). Total length data from 2023 were within the range of previous monitoring years (Appendix C).

Counter accuracy varied among channels from 67% to 100% for downstream movements and 87% to 98% for upstream movements (Table 3.6). As with the Chowade River counter, false negatives occurred at a greater frequency compared to false positives, suggesting the counter underestimated abundance. Movements occurred predominantly on channels 2 and 3, the centermost channels within the Cypress Creek thalweg (Figure 3.19).

The normal density function estimated that the 2023 Bull Trout kelt outmigration began on September 7 and peaked on September 17 (SD = 5.69 days; Figure 3.20). After accounting for counter accuracy and the date of kelt onset, kelt abundance for Cypress Creek was 77 Bull Trout (Figure 3.21). The ratio of kelts to redds (estimated via GAUC) was 0.8 (Table 3.7). Cumulative net upstream movements over the full monitoring period were 166.

Table 3.6 Cypress Creek counter accuracies for Bull Trout.

Channel	Direction	Accuracy
1	D	100%
1	U	83%
2	D	100%
2	U	84%
3	D	86%
3	U	98%
4	D	67%
4	U	95%

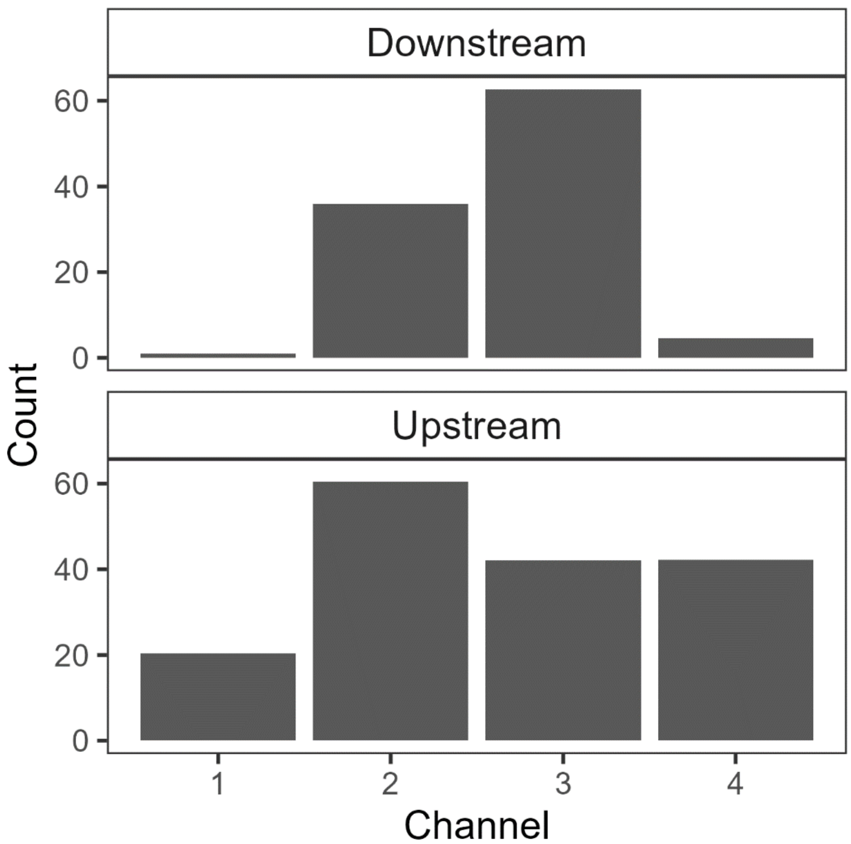

Figure 3.9 Accuracy-corrected counts of Bull Trout moving upstream and downstream past the Cypress Creek resistivity counter.

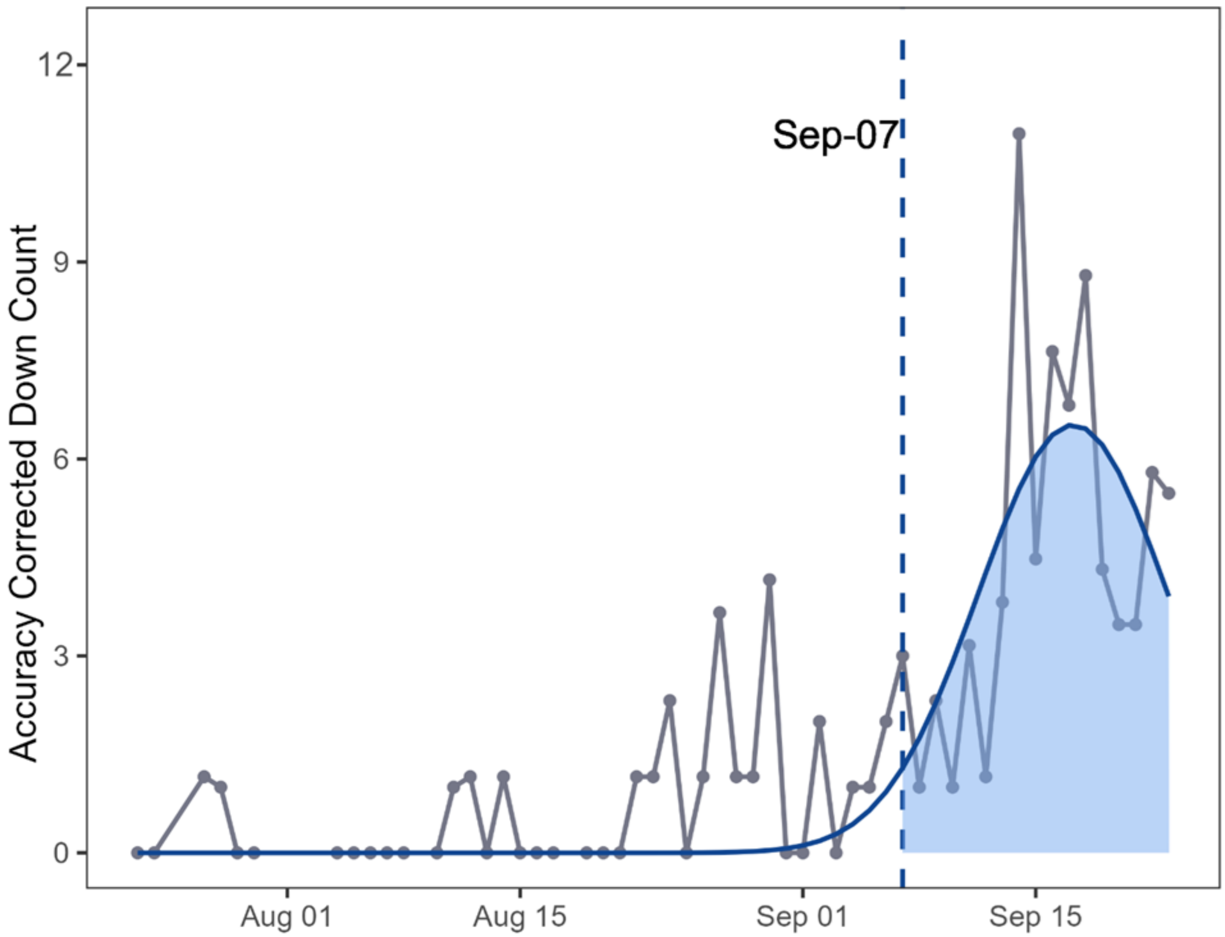

Figure 3.10 Accuracy corrected daily down counts of verified Bull Trout (grey points and lines) and modelled kelt out-migration timing (solid blue line and blue shading) in Cypress Creek. Vertical dashed line marks the date which the normal model estimated 5% of the kelts had out-migrated, which was assumed to be the onset of the kelt out-migration.

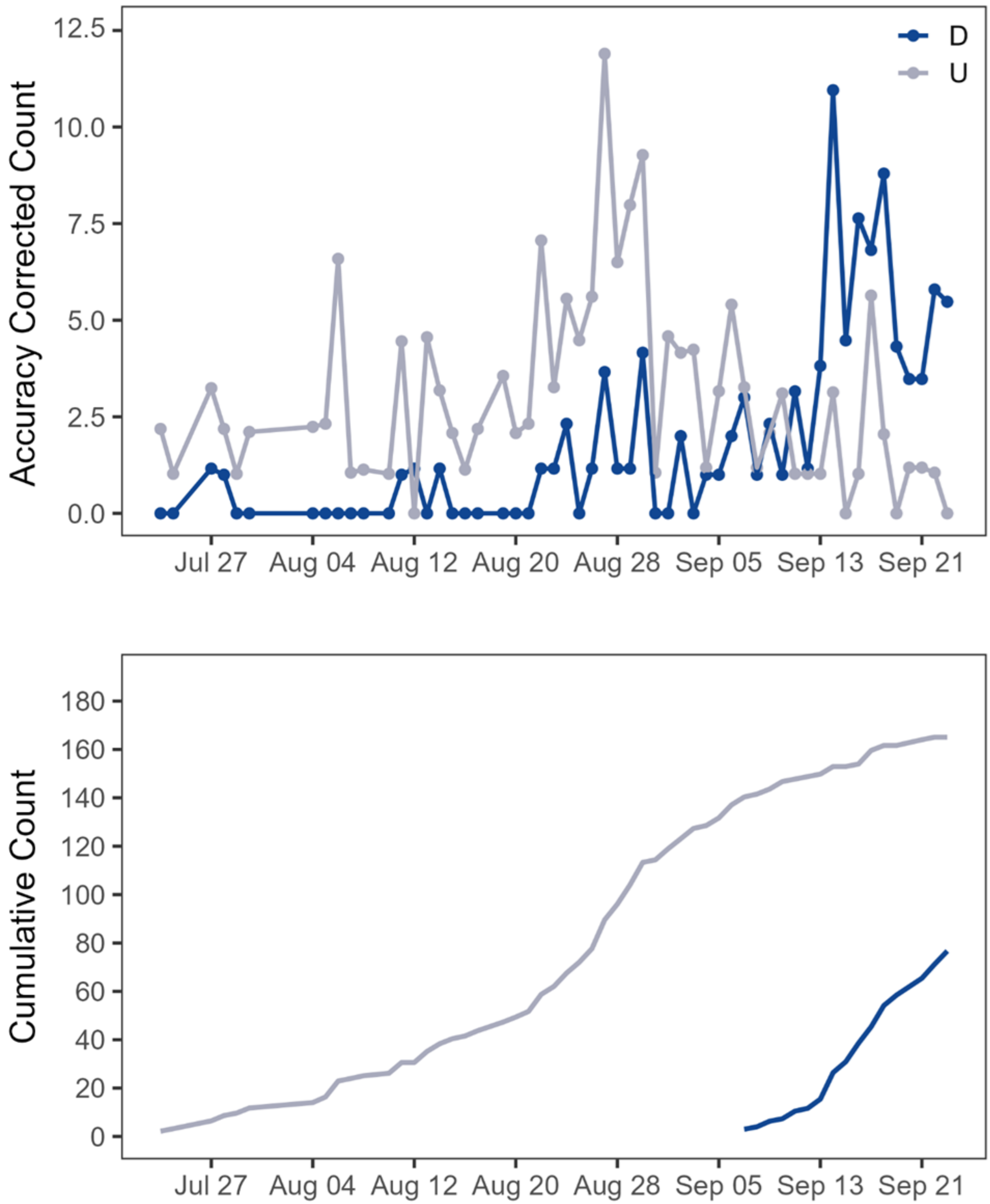

Figure 3.11 Top panel: accuracy corrected up and down counts of Bull Trout moving past the Cypress Creek resistivity counter. Bottom panel: cumulative up and down counts. Cumulative down counts were set as zero until September 7, the onset of the kelt out-migration.

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)
2023	77	91 (36-233)	0.8 (0.3-2.1)

3.3 PIT Array

3.3.1 Range Testing

Read ranges for 32 mm PIT tags met or nearly met the water depth along the length of both antennas in the Chowade River, and 32 mm tags were detectable in at least 97% of the water column throughout the monitoring period (Figure 3.22). The read range of 23 mm tags was also high, as >90% of the water column was detectable during the monitoring period. The mean proportion of the water column within which 12 mm tags were detectable was 0.79 (downstream antenna) and 0.69 (upstream antenna), while for 14 mm tags it was 0.87 (downstream) and 0.80 (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 >80% throughout the monitoring period (Figure 3.23). The mean proportion of the water column within which 12 mm tags were detectable was 0.75 (downstream) and 0.55 (upstream), while for 14 mm tags it was 0.89 (downstream) and 0.69 (upstream) (Figure 3.22).

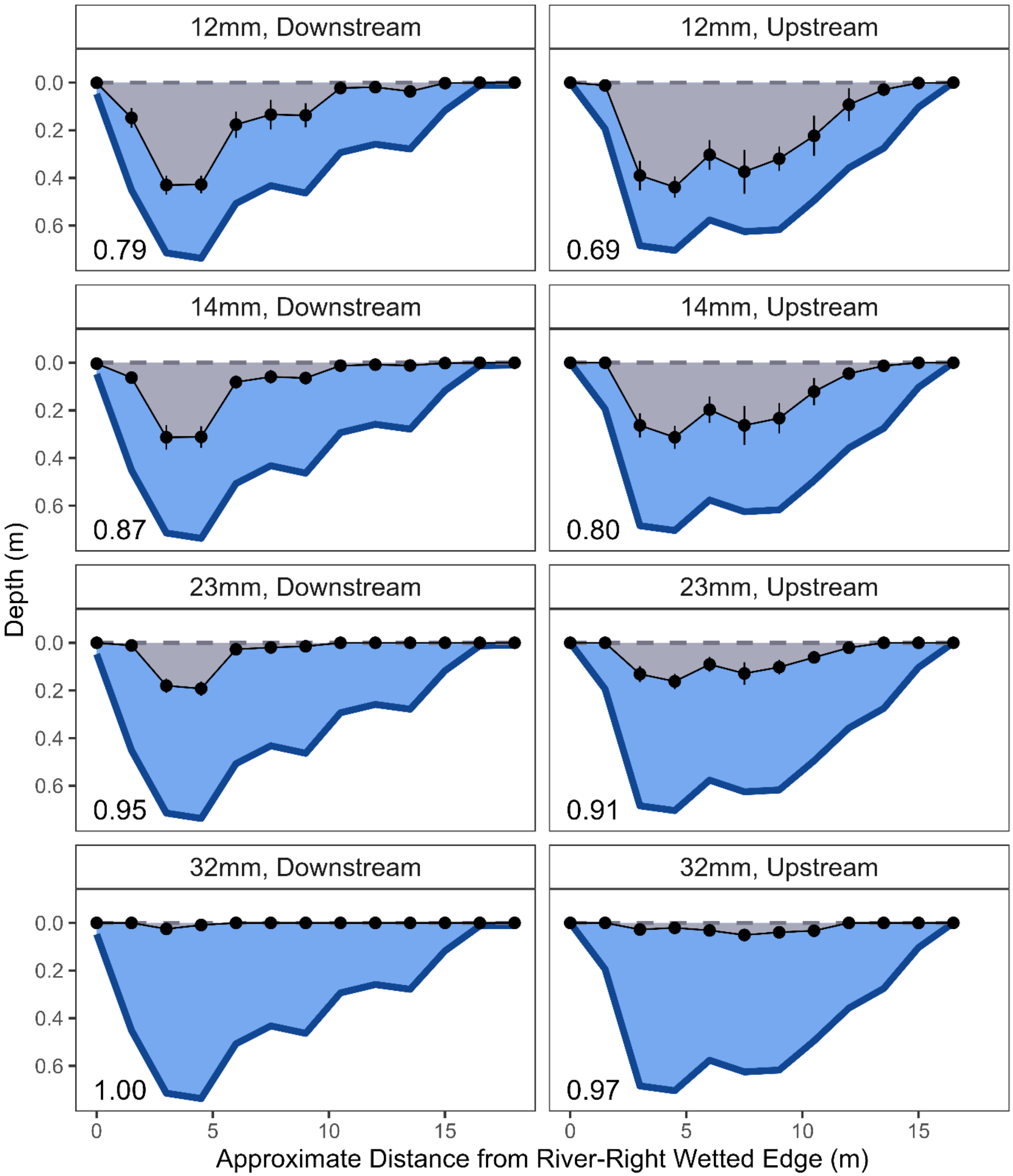

Figure 3.12 Proportion of the water column (points show mean ± SD) in the Chowade River within which PIT tags (12 mm, 14 mm, 23 mm, and 32 mm) were detectable throughout the monitoring period. Blue shading represents areas where tags are detectable (the number within the blue area is the mean detectable proportion of the water column), while grey shading designates areas where tags are not detectable.

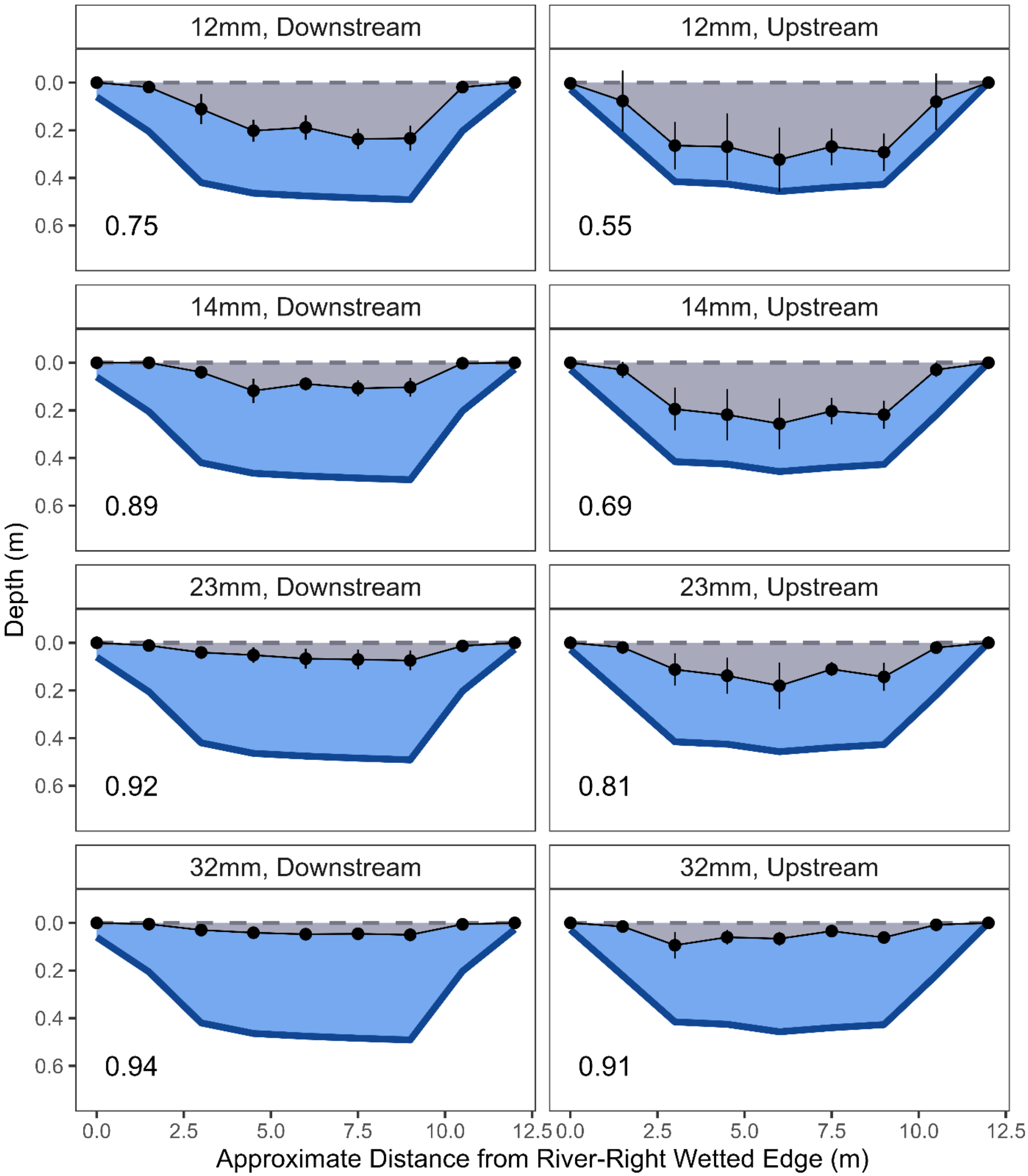

Figure 3.13 Proportion of the water column (points show mean ± SD) in Cypress Creek within which PIT tags (12 mm, 14 mm, 23 mm, and 32 mm) were detectable throughout the monitoring period. Blue shading represents areas where tags are detectable (the number within the blue area is the mean detectable proportion of the water column), while grey shading designates areas where tags are not detectable.

3.3.2 Tag Detections

At the Chowade River PIT array, upstream detection efficiency (for all species and tag sizes) was 98%, while downstream detection efficiency was 91%. Forty-six unique tags were detected by the array, including 33 Bull Trout, 4 Rainbow Trout, and 8 unknowns[5]. Passage direction was determined for 41 of the tag IDs detected at the Chowade River PIT array (the remaining tags were only detected by one antenna; Appendix D). Sixteen Bull Trout were detected moving upstream then downstream (with a time difference of greater than three days), with upstream detections from August 8 to September 11 and downstream detections from September 11 to September 28. The average residence time of Bull Trout spawning upstream of the Chowade River PIT array was 15.1 days (SD 13.0, range 11.0-0.2).

In Cypress Creek, upstream detection efficiency was 86%, while downstream detection efficiency was 32% (and consistently low throughout the monitoring period). Twenty unique tags were detected (17 Bull Trout, 2 Rainbow Trout, and 1 Mountain Whitefish), and direction was determined for six tags (1 Rainbow Trout and 5 Bull Trout; Appendix D). Three Bull Trout were detected moving upstream (between August 14 and September 20) then downstream (between August 27 and September 22), but the longest residence time was 7.1 days. This suggests the spawning migration of Cypress Creek PIT Bull Trout was not comprehensively captured by the PIT array, potentially due to low downstream detection efficiency.

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 on previous observations of Bull Trout spawning, including peak redd counts in five tributaries from 2002 to 2012 (Diversified

[5] Eight PIT IDs detected by the Chowade River array appeared in the PIT tag database only once and were identified at the temporary upstream passage facility (TUF) as Arctic Grayling, Mountain Whitefish, or sucker species. Species identification issues at the TUF suggest some of these fish were mis-labeled and we have designated their species as unknown until additional detection information becomes available.

Environmental Services and Mainstream Aquatics Ltd. 2009; 2011; 2013), spawner assessments and 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 2023 monitoring year marks the third year of river diversion which may provide a migration barrier to fish migrating downstream and upstream past the Project (Cook et al. 2023). While only a small 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.

In 2023, aerial OE was particularly low and variable relative to previous years, which contributed to elevated uncertainty in GAUC abundance for some tributaries (particularly for the Chowade River). Flow conditions were unusually low throughout the Peace River watershed, making redd ageing challenging (the standard error of survey was high relative to previous years) and resulting in heighted plant growth. Combined, these challenges led to larger uncertainty in OE, SL, and GAUC abundance throughout the study area.

Survey life contributes to GAUC estimates by accounting for double counting across visual surveys. Mean survey life in 2023 (19.6 days) was within the range of SL calculated in previous years, but the standard error of SL (2.3 days) was relatively high due to challenging survey conditions from low water levels. LME results suggest SL may vary marginally among tributaries, likely due to variability in flow, temperature, substrate characteristics, and productivity.

SL and OE are important contributors to GAUC estimates, and variability in these parameters, as well as variability in weekly counts, contribute to GAUC uncertainty. Although GAUC estimates are relatively robust to changes in SL and OE, uncertainty in GAUC abundance can be sensitive to standard errors of SL and OE. Each year, SL and OE are carefully considered, and several analysis methods have been compared to ensure these parameter estimates are robust among methods. As additional project years are completed, SL and OE information can be shared among years (e.g., using multilevel analyses), which will likely increase precision in these parameters and subsequent GAUC abundance, but should not substantially alter mean estimates.

4.1.2 Kelt Enumeration

Resistivity counter accuracy was moderate for downstream counts and high for upstream counts (74% and 94% for the Chowade River, 88% and 91% for Cypress Creek, respectively). Despite moderate downstream accuracy, kelt estimates have high precision due to extensive validation efforts. Upstream and downstream counter accuracy were relatively consistent with previous monitoring years and comparable salmonid enumeration programs in British Columbia (Ramos-Espinoza et al. 2011). Resistivity counter accuracy is typically lower for downstream movements relative to upstream movements because fish moving downstream travel higher (and faster) in the water column, are therefore further from the counter electrodes. High densities of nontarget species (e.g., Mountain Whitefish) can also reduce counter accuracy because the counters are calibrated for large-bodied fish and struggle to distinguish among schooling individuals. Relatively low water levels in the Peace River region in 2023 resulted in moderate to high counter accuracy and a robust estimate of both upstream and downstream Bull Trout migrations (during the monitoring period).

Abundance estimates were generated for both upstream and downstream migrants in 2023, but it is unclear whether the full spawning migrations were recorded in either study system. Low flows in 2023 allowed for earlier equipment installation relative to previous years, and a larger portion of the upstream migration was recorded by the resistivity counter. For the first time, upstream counts estimated by the resistivity counters were higher than kelt estimates, which may indicate the counters were removed prior to the conclusion of the kelt migration.

Monitoring in 2023 confirmed that the upstream migration occurs over a much longer period relative to the contracted downstream migration of kelts. Counter data suggest the upstream migrations begin in early to mid-July (also in Baxter 1997) and continue into mid-September, while downstream migration begin in early September and conclude in early October. Installing resistivity counters and radio telemetry receivers in early to mid-July will continue to inform the timing of the upstream and downstream Bull Trout spawning migrations and help to describe relative numbers of upstream migrants, kelts, and redds within the Peace River region.

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 2023 along with GAUC abundance estimates. Peak counts collected during this monitoring program are several magnitudes lower than peak count estimates from 2010 and 2012, but methodological differences (survey type, duration, timing, and area surveyed) among historic counts and between historic and modern counts make it difficult to assess trends in peak counts through time. In this monitor, GAUC estimates are consistently higher than peak counts, suggesting historic counts likely 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 2023 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).

Preliminary radio telemetry analyses of tagged Bull Trout spawners indicate diverse behaviours of Bull Trout in the Halfway River watershed (Hatch et al. 2024). Tagged Bull Trout have migrated into the same tributary in consecutive years (presumably to spawn), while others have migrated into different tributaries, and some have exhibited skip-spawning behaviour (Hatch et al. 2024). Continued telemetry monitoring (PIT and radio) within this monitor and under other components of the FAHMFP will build behavioural and life history knowledge of Bull Trout in the Halfway River watershed, including spawning behaviour, site fidelity, and survival.

None of the PIT tags detected by the arrays in 2023 had been previously detected during spawning migrations in either the Chowade River or Cypress Creek. However, 11 of the tag IDs detected by the Cypress Creek PIT array in 2023 were applied to Bull Trout or Rainbow Trout during backpack electrofishing in Cypress Creek in 2022 and 2023. Similarly, nine of the tags detected by the Chowade River PIT array were applied during Chowade River backpack electroshocking between 2019 and 2023. Most of these PIT tags were applied to juvenile fish, indicating these individuals may have matured in 2023 then underwent downstream migrations following spawning. All other tags detected by the arrays were applied during large boat electroshocking in the Peace River, or at the TUF.

Using redd abundance to detect changes in Bull Trout spawner abundance assumes redd counts are correlated with adult spawner abundance, and changes to redd abundance represent corresponding changes in population abundance. Kelt to redd ratios for the Chowade River (0.2) and Cypress Creek (0.8) were very low in 2023 for Chowade River and moderate for Cypress Creek. Average kelt to redd ratios from 2017 to 2023 were 1.03 (sd 0.67) for the Chowade River and 1.01 (sd 0.78) for Cypress Creek. These ratios are low relative to literature values from western North America (~1-4 spawners/redd; Howell and Sankovich 2012; Andrusak 2009; Al-Chokachy et al. 2005; Dunham et al. 2001). Clearly, the relationship between spawners, kelts, and redds in the Halfway River watershed is complex and undefined. Additional years of enumeration and assessments of spawner behaviour could help to inform these relationships, which are critical for understanding how changing redd abundance impact Bull Trout populations.

Previous research suggests redd counts and spawner abundance can be 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 uncertainty around the estimates.

Detecting trends in Bull Trout abundance can be particularly challenging over short assessment periods (e.g., <10 years). Bull Trout typically 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.

4.2 Migration Timing

Bull Trout upstream migration timing remains uncertain for tributaries of the Halfway Watershed. Angling surveys in 1995 suggest 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 Bull Trout detected by the fixed radio telemetry stations in the Chowade River and Cypress Creek were also detected on the PIT arrays (K. Hatch, LGL, personal communication). The PIT arrays continue to detect juvenile Bull Trout tagged upstream of the counter sites, informing juvenile emigration from natal tributaries. Juvenile emigration is variable, with some individuals migrating in the year they were tagged, while others delay emigration for several years. Future survey years will provide natal fidelity when these Bull Trout reach maturity and undergo their first spawning migrations as mature adults.

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 2023, many areas of high-quality spawning habitat had zero redds in some years. 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).

Preliminary telemetry data suggest Bull Trout exhibit diverse spawning behaviour, including repeat spawning within the same tributary, spawning in different tributaries in consecutive years, and skip-spawning (Hatch et al. 2024). This variation is likely related to Bull Trout behaviour variability and annual environmental conditions within the watershed. Discharge may affect spawner timing and distribution (e.g., Sinnatamby et al. 2018), and discharge during the Bull Trout migration has varied considerably from 2016 to 2023 (Figure 3.1). 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 Site- and Year-Specific Characteristics

Monitoring under Mon-1b, Task 2b was highly successful in 2023 for both the Chowade River and Cypress Creek. Low flows facilitated early installation of resistivity counters and PIT arrays, and no outages or data gaps occurred over the monitoring period. The Chowade River monitoring site was moved in 2023 to ensure the full river was monitored (the site was moved upstream of a growing side channel). The new site was successful, as evidenced by high counter accuracy and high PIT array detection efficiency.

Algal growth has been increasing in Cypress Creek in recent years, and high macrophyte density in 2023 likely negatively affected monitoring efficiency. High volumes of filamentous macrophytes floated downstream past the counter site and became entangled in counter pads and PIT antennas (Appendix E). The algal growth has been submitted to the BC Algae Watch portal to determine species (submission ID: AW791). Increased drag from macrophyte debris caused the PIT antennas to distort, causing reduced detection efficiency. Also, macrophytes obscured redds and redd markers during redd surveys, likely reducing aerial and ground detection efficiency relative to previous years. Site-specific conditions, such as increased macrophyte growth, are assessed each year and site modifications are made whenever possible to maximize monitoring efficiency.

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.

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.

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.

Cook, K.V., P. Moniz, D. Ramos-Espinoza. 2023. Site C Fishway Effectiveness Monitoring Program (Mon-13) & Trap and Haul Fish Release Location Monitoring Program (Mon 14). Construction Year 8 (2022). Report by InStream Fisheries Research, Squamish, BC, for BC Hydro, Burnaby, BC. 201 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, S. Crawford, and C. Wong. 2024. Site C Clean Energy Project – Site C Reservoir Tributaries Fish Community and Spawning Monitoring Program (Mon-1b) Task 2a – Peace River Arctic Grayling and Bull Trout Movement Assessment; and Task 2d – Site C Fish Movement Assessment – Construction Year 9 (2023). Report for BC Hydro, Vancouver BC. [*report in preparation*]

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.

Pebesma, E. 2018. Simple features for R: standardized support for spatial vector data. The R Journal 10 (1), 439-446, https://doi.org/10.32614/RJ-2018-009.

Pebesma, E., and R. Bivand. 2023. Spatial data science: with applications, in R. Chapman and Hall/CRC. https://soi.org/10.1201/9780429459016.

Putt, A., Ramos-Espinoza, D., 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 + 5 appendices.

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. 2023. 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.

Santos Baquero, O. 2019. ggsn: north symbols and scale bars for maps created with ‘ggplot2’ or ‘ggmap’. R package version 0.5.0, https://CRAN.R-project.org/package=ggsn.

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.

Wickham 2016. ggplot2: elegant graphics for data analysis. Spirnger-Verlag New York, 2016.

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	7	0	0.81	9.65	0.00
	2	47	22	0.81	64.8	0.34
	3	63	9	0.81	86.9	0.10
	4	44	7	0.81	60.7	0.12
Cypress Creek	1	0	0	0.85	0	-
	2	15	3	0.85	17.4	0.17
	3	34	2	0.85	39.4	0.05
	4	34	7	0.85	39.4	0.18
Fiddes Creek	1	5	0	0.94	0	0.00
	2	12	-	0.94	5.3	-
	3	12	2	0.94	12.6	0.16
	4	4	3	0.94	4.21	0.71
	5	4	2	0.94	4.21	0.48
Upper Halfway River	1	2	0	0.97	2.1	0.00
	2	11	2	0.97	11.3	0.18
	3	18	6	0.97	18.6	0.32
	4	17	6	0.97	17.5	0.34
	5	12	4	0.97	12.4	0.32
Needham Creek	1	17	0	-	-	0.00[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
##   1689.5   1703.9   -840.8   1681.5      262
##
## Scaled residuals:
##     Min      1Q  Median      3Q     Max
## -2.0222 -0.5663 -0.1877  0.3382  3.0394
##
## Random effects:
##  Groups   Name        Variance Std.Dev.
##  tag_id   (Intercept)  4.788   2.188
##  Residual             28.350   5.324
## Number of obs: 266, groups:  tag_id, 105
##
## Fixed effects:
##             Estimate Std. Error t value
## (Intercept)  -2.4043     0.8496   -2.83
## redd_age      5.5079     0.2893   19.04
##
## Correlation of Fixed Effects:
##          (Intr)
## redd_age -0.886
```

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
2023	192	728	470-995	113
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
2023	212	253	120-420	55
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
2023	313	354	250-625	48

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	38-844	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
2023	235	669	430-970	99
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
2023	103	280	120-430	70
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
2023	135	393	300-640	74

Appendix D: PIT Detection Histories

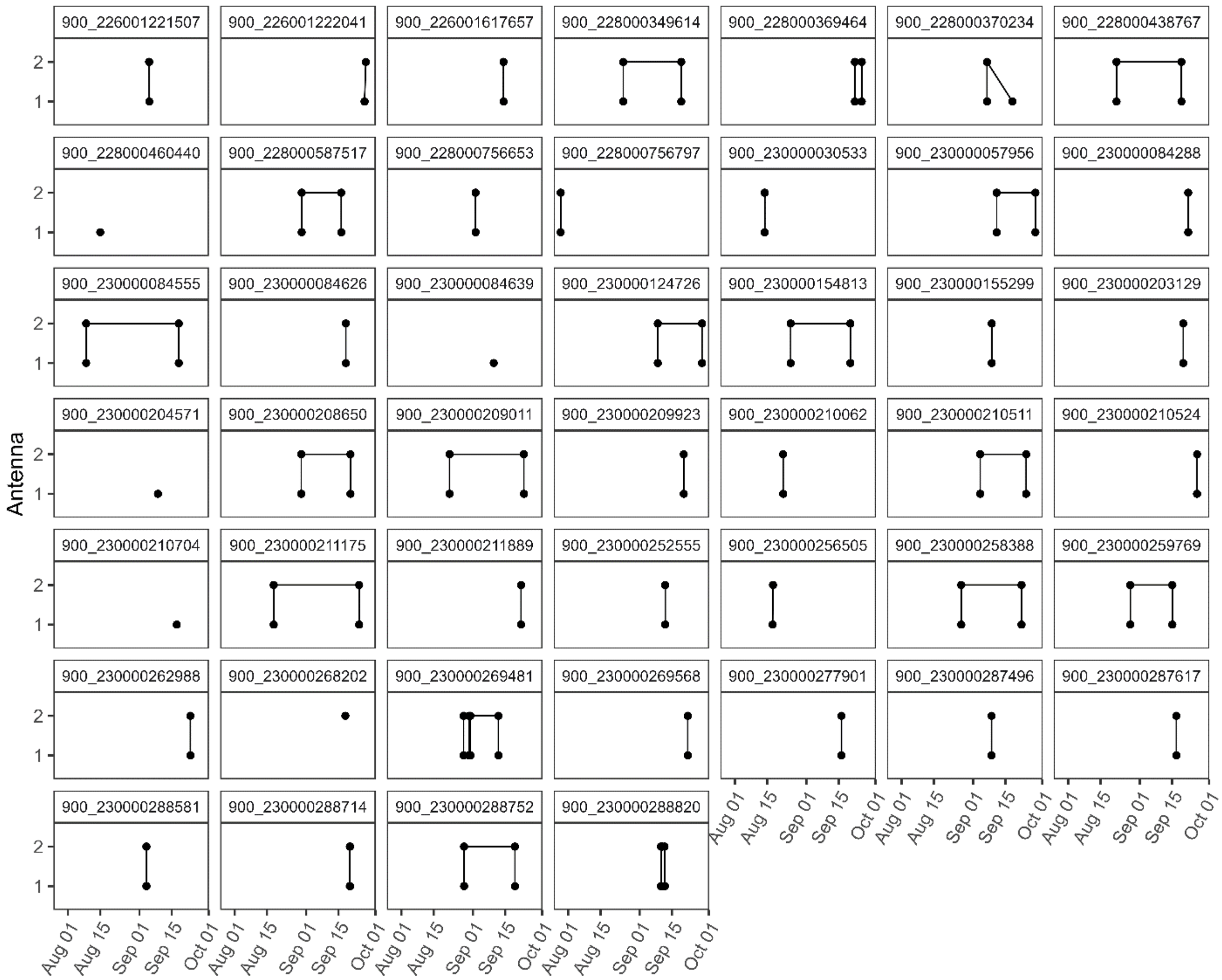

Figure D1. Detection histories of PIT tags detected by the Chowade River array. Antenna 1 is the downstream antenna, while Antenna 2 is the upstream antenna.

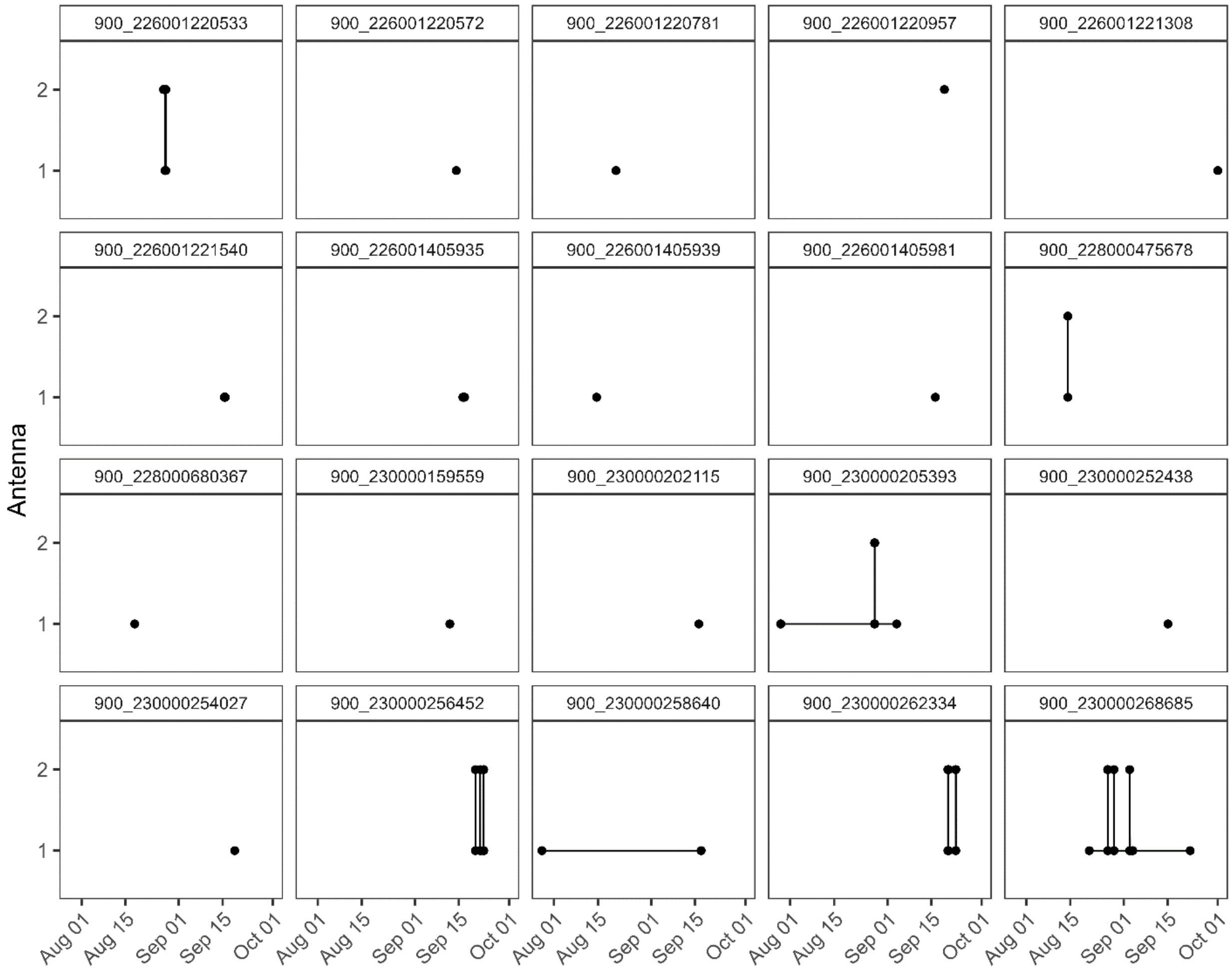

Figure D2. Detection histories of PIT tags detected by the Cypress Creek array. Antenna 1 is the downstream antenna, while Antenna 2 is the upstream antenna.

Appendix E: Cypress Creek Algal Growth

Algae or macrophytes (species unknown) entangled in Cypress Creek PIT antennas (left) and resistivity counter pads (right).