

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 7 (2021)

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

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September 2022

Site C Reservoir Tributaries Fish Community and Spawning Monitoring Program

2021 Peace River Bull Trout Spawning Assessment (Mon-
1b, Task 2b)

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A. Putt, D. Ramos-Espinoza, 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 and 6 appendices.

Executive Summary

We report findings of the 2021 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 2021, GAUC redd abundance estimates ranged from 43 (SE = 12) in the upper Halfway River to 282 (SE = 65) in the Chowade River. GAUC estimates were within the range of baseline peak count estimates for the Halfway Watershed from 2002 to 2012; however, a comparison of peak count and GAUC estimates suggests peak counts underestimate redd abundance.

The GAUC method incorporates error in observer efficiency and survey life to generate a robust abundance estimate. In 2021, average aerial observer efficiency of Bull Trout redds was variable between tributaries, ranging from 0.16 in Cypress Creek to 0.45 in the upper Halfway River. Average redd survey life, defined as the period during which a redd is observable, was estimated as 16.54 days (SE 2.04 days).

Resistivity counter data suggested that the Chowade River kelt migration began on September 8, with a unimodal peak on September 17, and after accounting for counter accuracy, the Bull Trout kelt abundance was 271. The Cypress Creek kelt migration also followed a normal distribution and began on September 7 and peaked on September 18, with a kelt abundance of 73 Bull Trout. Cumulative upstream migrants in the Chowade River and Cypress Creek were 188 and 117, respectively (August 01 – September 30).

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 59 tags, while the Cypress Creek array detected 34 tags. Bull Trout residence time in the Chowade River was 22.5 ± 18.3 days, and 28.9 ± 14.7 days for Cypress Creek.

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, Dave Hunter 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 Cole Martin, LJ Wilson, Luke Irwin, Jordan Bastin, and Angela Ratzburg. Thanks to Josh Korman, Eric Parkinson, and Douglas Braun for valuable comments and discussions on study design.

Table of Contents

List of Tables	vii
List of Figures	viii
1. Introduction	12
1.1 Project Background.....	12
1.2 Redd Enumeration.....	13
1.3 Resistivity Counters.....	13
1.4 PIT Telemetry.....	15
2. Methods	15
2.1 Redd Enumeration.....	15
2.1.1 Visual Survey Methods.....	15
2.1.2 Redd Distribution.....	17
2.1.3 Redd Abundance.....	17
2.2 Resistivity Counters in the Chowade River and Cypress Creek.....	21
2.2.1 Counter Validation.....	22
2.2.2 Estimating Abundance.....	24
2.3 PIT Arrays in the Chowade River and Cypress Creek.....	27
3. Results	27
3.1 Redd Enumeration.....	27
3.1.1 Redd Distribution.....	28
3.1.2 Redd Abundance.....	28
3.1.3 Monitoring Time Series of OE and GAUC Abundance.....	32
3.2 Resistivity Counters.....	34
3.2.1 Chowade River.....	34
3.2.2 Cypress Creek.....	38
3.3 PIT Arrays.....	42
3.3.1 Range Testing.....	42
3.3.2 Tag Detections.....	45
4. Discussion	45
4.1 Abundance.....	46
4.1.1 Redd Enumeration.....	46

4.1.2	Kelt Enumeration.....	47
4.1.3	Spawner Abundance in the Halfway Watershed	48
4.2	Migration Timing.....	50
4.3	Distribution.....	51
4.4	Conclusion.....	51
5.	References.....	52
	Appendix A: River Kilometer Delineations.....	57
	Appendix B: Aerial and Ground Redd Counts.....	60
	Appendix C: Summary of Linear Mixed Model for Survey Life.....	61
	Appendix D: Total Lengths from Video Validation.....	62
	Appendix E: PIT Detection Histories	64
	Appendix F: Comparison of Counter Accuracies using Confusion Matrix Method and Multinomial Method.....	66

List of Tables

Table 2.1 Summary of redd survey reaches. Distances are in river km.....	17
Table 3.1 Mean ground and aerial observer efficiency with percent coefficient of variation (%CV).	29
Table 3.2 Annual survey life and standard error for Halfway River tributaries.	29
Table 3.3 GAUC redd abundance, relative uncertainty in abundance, Mean OE (with SE), and peak counts for Bull Trout in the Halfway Watershed.	31
Table 3.4 Chowade River counter accuracies for Bull Trout.....	35
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.	38
Table 3.6 Cypress Creek counter accuracies for Bull Trout.....	39
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.	42

List of Figures

Figure 2.1. Map of key Bull Trout spawning tributaries within the upstream portion of the Halfway River Watershed. Red bars indicate Bull Trout aerial survey boundaries (there were two aerial survey sections in Cypress Creek), within which ground surveys were conducted (boundaries not shown). Green diamonds show locations of the resistivity counters and PIT arrays in the Chowade River and Cypress Creek

Figure 2.2. Approximate configuration of the resistivity counter sensor pads, PIT arrays, power system and video validation system in the Chowade River and Cypress Creek. 22

Figure 2.3 Method to validate raw resistivity counter data and determine accuracy-corrected abundance of upstream migrants and kelts..... 25

Figure 3.1 Bull Trout redd locations in the Chowade River (flowing west to east) observed during aerial and ground surveys. The size of the points indicates the number of redds at each location. Red lines and blue lines indicate aerial and ground survey boundaries, respectively, while the green diamond indicates the location of the Chowade River resistivity counter.

Figure 3.2 Redds per kilometer (aerial and ground) in the Chowade River. Red shading represents approximate extent of the ground survey reach. Gaussian AUC estimates and 95% confidence intervals are included for reference

Figure 3.3 Bull Trout redd locations in Cypress Creek (flowing west to east) observed during aerial and ground surveys. The size of the points indicates the number of redds at each location. Red lines and blue lines indicate aerial and ground survey boundaries, respectively, while the green diamond indicates the location of the Cypress Creek resistivity counter

Figure 3.4 Annual redds per kilometer (summed across all aerial and ground surveys) in Cypress Creek. Red shading represents approximate extent of the ground survey reach. Gaussian AUC estimates and 95% confidence intervals are included for reference.

Figure 3.5 Bull Trout redd locations in the upper Halfway River (flowing west to east), Fiddes Creek (flowing south to north), and Turnoff Creek (flowing north to south) observed during

aerial and ground surveys. The size of the points indicates the number of redds at each location. Red lines and blue lines indicate aerial and ground survey boundaries, respectively.

Figure 3.6 Annual redds per kilometer (summed across all aerial and ground surveys) in the upper Halfway River. Red shading represents approximate extent of the ground survey reach. Gaussian AUC estimates and 95% confidence intervals are included for reference

Figure 3.7 Annual redds per kilometer (summed across all aerial and ground surveys) in Fiddes Creek. Red shading represents approximate extent of the ground survey reach. Gaussian AUC estimates and 95% confidence intervals are included for reference

Figure 3.8 Annual redds per kilometer (summed across all aerial and ground surveys) in Turnoff Creek. Gaussian AUC estimates and 95% confidence intervals are included for reference.

Figure 3.9 Bull Trout redd locations in Needham Creek (flowing west to east) observed during aerial and ground surveys. The size of the points indicates the number of redds at each location. Red lines and blue lines indicate aerial and ground survey boundaries, respectively.

Figure 3.10 Annual redds per kilometer (summed across all aerial and ground surveys) in Needham Creek. Red shading represents approximate extent of the ground survey reach.

Figure 3.11 Redd age within all tributaries by normalized survey day, with points jittered for presentation. Black lines represent individual redds (showing the random effect of redd ID on the intercept). 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 (age-0) and the first observation (age-1).

..... 30

Figure 3.12 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

Figure 3.13 Bull Trout peak count redd indices from 2002 to 2014 (dark grey bars; Diversified Environmental Services and Mainstream Aquatics Ltd. 2009, 2011, and 2013) and from 2016 to 2022 (light grey bars; this monitor). GAUC abundance with CI are shown as redd diamonds..... 32

Figure 3.14 Mean aerial OE, mean ground OE, and GAUC abundance (error bars are 95% confidence intervals) in the Halfway Watershed from 2016 to 2021..... 33

Figure 3.15 Accuracy-corrected counts of Bull Trout moving upstream and downstream past the Chowade River resistivity counter..... 35

Figure 3.16 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. 36

Figure 3.17 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..... 37

Figure 3.18 Accuracy-corrected counts of Bull Trout moving upstream and downstream past the Cypress Creek resistivity counter. 39

Figure 3.19 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. 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. 40

Figure 3.20 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..... 41

Figure 3.21 Proportion of the water column (points show mean \pm SD) in the Chowade River within which PIT tags (12 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..... 43

Figure 3.22 Proportion of the water column (points show mean \pm SD) in Cypress Creek within which PIT tags (12 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..... 44

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?

H₀: There will be no change in Bull Trout spawner abundance in the Halfway River relative to baseline estimates.

H₁: 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 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 2021 monitoring year marks the first full 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 tributaries of the Halfway River.

1.2 Redd Enumeration

Redd abundance is the primary metric to assess changes in Bull Trout populations through construction and operation of the Project. Bull Trout redd abundance in the Halfway Watershed has previously been assessed using redd count surveys in key spawning tributaries (Diversified Environmental Services and Mainstream Aquatics Ltd. 2009; 2011; 2013). Historically, redd counts in the Halfway Watershed combined aerial helicopter surveys, snorkel surveys, and stream walks to generate peak redd count indices. Unlike visual surveys that count spawning adults, redd count surveys provide an index of effective population size (i.e., number of reproducing adults; Gallagher et al. 2007).

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

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

1.3 Resistivity Counters

Although redd abundance can describe changes in Bull Trout populations over time, it may not correlate with spawner abundance (i.e., total number of Bull Trout that spawned; Dunham et al. 2001, Gallagher and Gallagher 2005). We operated resistivity counters and PIT arrays on the

Chowade River and Cypress Creek, tributaries of the Halfway River with large populations of spawning Bull Trout (Diversified Environmental Services and Mainstream Aquatics Ltd 2013, Putt et al. 2020). The dual technology approach allowed for enumeration of upstream migrating Bull Trout and kelts (fish that migrate back downstream after spawning), identification of key migration timing, and a better understanding of spawner to redd abundance.

There are limited data describing Bull Trout spawning migrations in the Halfway Watershed. Observations during angling surveys in the early 1990s suggested Bull Trout spawning began during the last week of August and peaked in the second week of September, but no spawner count data were collected (Baxter 1997). Initial data from resistivity counters and PIT arrays since 2016 (Braun et al. 2017a, Ramos-Espinoza et al. 2018, 2019, Putt et al. 2020, 2021) indicate upstream migration may begin and peak earlier than suggested by Baxter (1997) and may not follow the normal distribution model commonly observed for salmonids.

It is challenging to monitor upstream migrants in the Halfway Watershed because river discharges are high for a large portion of the migration, preventing the use of fences or electronic counters. In the absence of upstream enumeration, Bull Trout kelt estimates have been used as indices of spawner abundance for the Chowade River and Cypress Creek. This method has successfully been used in other streams in British Columbia (Andrusak 2009). Annual variation in kelt abundance is also important for understanding life history dynamics of Bull Trout (e.g., Monnot et al. 2008) and can be used to develop ratios of redd to kelt abundance. Initial evidence from the Chowade River and Cypress Creek resistivity counters suggests kelt migration occurs over a short period and closely follows a normal distribution, facilitating an accurate and reliable estimate (e.g., Ramos-Espinoza et al. 2019). We estimate annual kelt abundance as an index of spawner abundance, but we attempt to install the resistivity 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 use resistivity counters to enumerate Bull Trout migrants and monitor migration timing and fish size. Resistivity counters are composed of in-river electrode sensors that create an electrical field in the water column. The field is disrupted when a fish swims over the sensor, from which the counter detects directional movement of individual fish. Resistivity counters can be highly accurate for enumerating salmonids (Braun et al. 2016) and are cost-effective, adaptable, and easy to maintain.

1.4 PIT Telemetry

We also monitor adult migrants in the Chowade River and Cypress Creek using directional PIT antennas to inform migration timing and survival and transition probabilities (i.e., juvenile to subadult, subadult to adult; Brännäs et al. 1994). When PIT-tagged fish pass over or through a PIT antenna, the magnetic field created by the antenna excites the tag, which transmits its identification code back to the reader. We use two antennas (forming a PIT array) at each site to determine the direction of movement for PIT-tagged fish. PIT arrays 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 River¹, Fiddes Creek, and Turnoff Creek during the Bull Trout spawning period [REDACTED] (Figure 2.1²). 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

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).

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 via helicopter flying 50 to 100 m above ground at 15 to 40 km hr⁻¹ (Trouton 2004). Aerial surveys covered the entire length of potential spawning habitat (Braun et al. 2017b), and were continuous except in Cypress Creek, where two separate surveys were conducted to omit a short section of unsuitable habitat. Redds observed from the air were counted and georeferenced using a handheld GPS accurate to ± 3 m. For the Chowade River, Cypress Creek and the upper Halfway River, aerial surveys were conducted by flying in an upstream direction, but flight direction for Fiddes and Turnoff creeks varied depending on light and wind conditions. 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 (Putt et al. 2020), and we assumed water clarity did not substantially influence OE during visual surveys.

Ground surveys were used to maximize redds marked and reaches ranged from 1.5 to 4.3 km in length (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 were consistent with previous years, except for Cypress Creek, where the survey was extended by ~2 km to mitigate low sample sizes in prior surveys. This method was used successfully in the 2021 survey to ensure adequate sample size and we plan to continue to use the extended reach in coming years. 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. 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). This method yielded simple river sections that could be compared among years.

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 bristle 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-0 = the date the redd was first constructed (not measurable during surveys);

Age-1 = new since last survey but clear (the first measurable age class);

Age-2 = still measurable but already measured, negligible periphyton growth;

Age-3 = no longer measurable due to degrading edges and periphyton growth, but still apparent; and

Age-4 = no redd apparent.

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:

$$(1.1) \quad y_i \sim N(\alpha_{j[i]} + \beta_{j[i]} \text{redd_age}_i, \sigma_y^2) \text{ for } i = 1 \dots N$$

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). All linear mixed effects modelling was performed in R (R Core Team 2017) using *lme4* (Bates et al. 2015).

Survey life can be specific to individual tributaries due to physical and biological characteristics such as substrate, flow, and periphyton growth (Gallagher et al. 2007) and examining the effect

of tributary on SL modelling is important for understanding how redds age in the Halfway Watershed. We will delay the use of tributary-specific survey life models due to the complex nature of redd ageing and the increased data requirements when incorporating fixed effects into LME models. Tributary-specific SL and other candidate model formulations will be explored during synthesis modelling, and previous redd abundance estimates adjusted accordingly.

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, and parameter estimates evaluated using maximum likelihood estimation (described in Millar et al. 2012). The advantage of the GAUC approach over conventional AUC and peak count indices is the ability to incorporate variance in OE and SL, fit spawn-timing using maximum likelihood, and estimate uncertainty in redd abundance.

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

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

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

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

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})

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

where $\hat{F} = \hat{a}\sqrt{2\pi\hat{\tau}_s}$, \hat{a} and $\hat{\tau}_s$ 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

$$(1.5) \quad \hat{F} = \sqrt{\frac{\pi}{-\hat{\beta}_2}} \exp\left(\beta_0 - \frac{\hat{\beta}_1^2}{4\hat{\beta}_2}\right)$$

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)

$$(1.6) \quad \%RU = \left(\frac{|u - SE|}{u}\right) \cdot 100$$

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 length³, or areas not covered by ground surveys. Peak count surveys were generally conducted during one or two survey weeks [REDACTED] (Diversified Environmental

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).

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 in the Chowade River and Cypress Creek

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” 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.

An assessment of a side channel running adjacent to the Chowade River counter site was performed prior to the installation of the fish counter. The entire length of the side channel was walked to ensure a route circumventing the Chowade fish counter did not exist. The channel was

deemed to be not passable by fish due to the significant woody debris blockage at the upstream entrance of the channel.

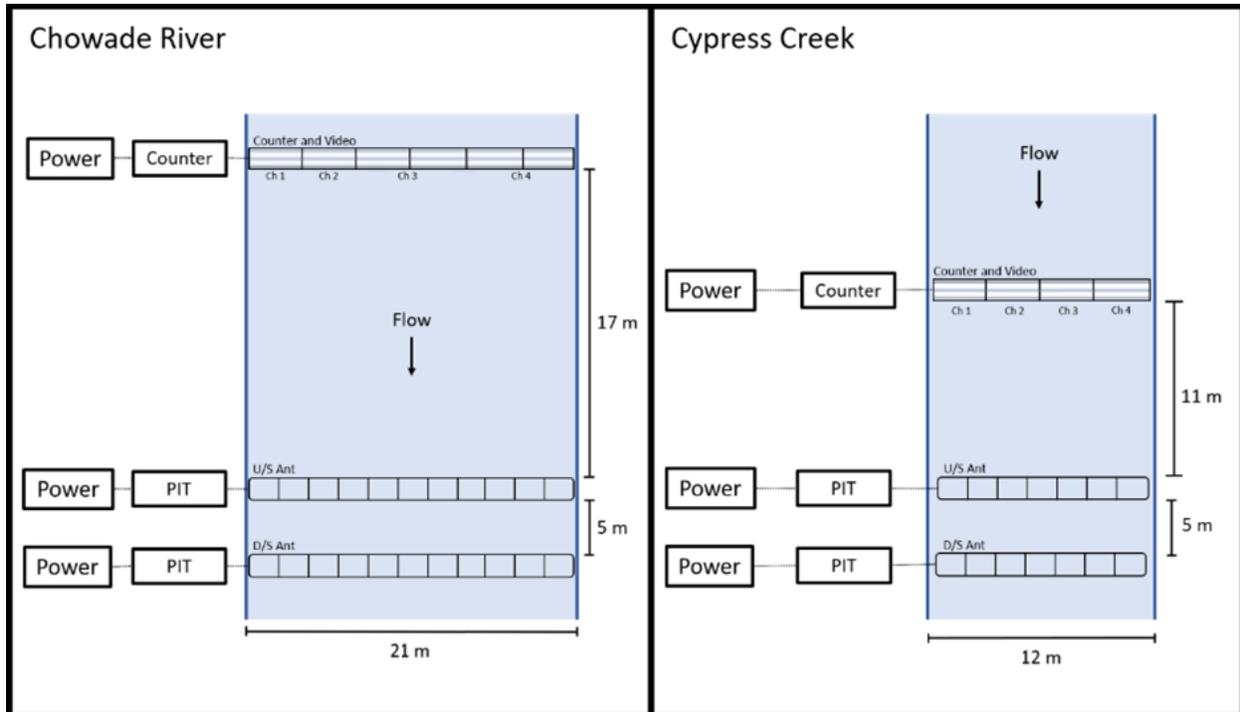


Figure 2.1. Approximate configuration of the resistivity counter sensor pads, PIT arrays, power system and video validation system in the Chowade River and Cypress Creek.

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 was determined by fish length (R.L. & L. Environmental Services Ltd. 1995), body size, and colouration. 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 one minute before to one minute 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).

From 2016 to 2020, counter accuracy was calculated using a binominal method derived from a confusion matrix model. In 2021, an alternative estimation method utilizing multinomial accuracy was introduced and was used to estimate the 2021 data. In the original method, the number TP, FP, and expanded FN were summarized by direction (up and down), species (Bull Trout, Mountain Whitefish, Rainbow Trout), and counter channel. These values were used to calculate channel- and direction-specific counter accuracy (A) for Bull Trout in the original binominal method (Equation 2.1).

$$(2.1) \quad A = \frac{TP}{TP + FP + FN}$$

The new multinomial method continues to use the same TP, FP and FN counter error estimates to calculate counter accuracies. Accuracy was calculated by assuming that all TP, FP, and FN observations were multinomially distributed random variables (equation 2.2):

$$(2.2) \quad V \sim \text{mult}(N, \theta)$$

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 ($\theta_{TP}, \theta_{FP}, \theta_{FN}$), and N is the total number of observations from the counter-validation comparison ($TP + FP + FN$). Counter accuracy is defined as, θ_{TP} , or as the proportion of fish passing the counter that are correctly recorded by the counter algorithm. Given that the θ values must sum to 1.0, accuracy can also be expressed as equation 2.3:

$$(2.3) \quad A = \theta_{TP} = 1 - \theta_{FP} - \theta_{FN}$$

While the original method illustrated by equation 2.1 provided a satisfactory estimate, the new multinomial method increases applicability to different circumstances (operational and biological), where FP rates may be higher than FN rates. Moreover, the new method does not require us to make assumptions about the TN error. This reduces the associated uncertainties around the calculated errors. To ensure data accuracy and consistency, we validated the new method by re-analyzing 2020 data using the new method. The accuracy estimates remained unchanged in the analysis (Appendix F). IFR is continuing to develop the multinomial uncertainty method to include circumstances where targeted and random validation is completed. Having the accuracy data calculated with the multinomial method, will allow for an easy transition to estimating uncertainty when the time comes.

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. From 2017 to 2021, we estimated abundance of downstream migrating kelts. While the river flows in 2021 allowed us to install and collect data earlier in the migration, it was likely still not early enough to estimate the full abundance of upstream migrants.

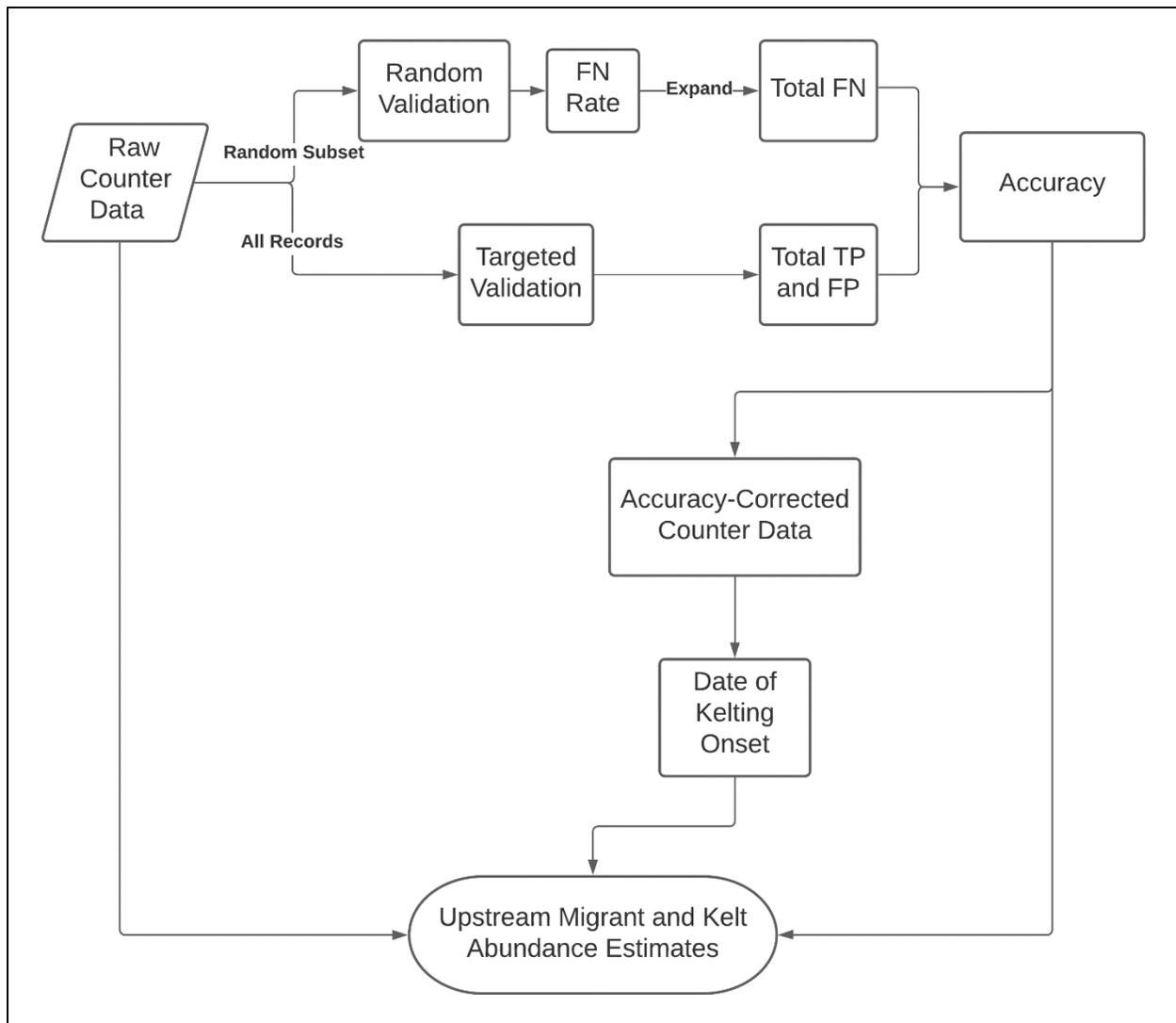


Figure 2.2 Method to validate raw resistivity counter data and determine accuracy-corrected abundance of upstream migrants and kelts.

Determining Kelt Onset

Summing upstream or downstream movements alone is often not the most accurate method of estimating migratory abundance. 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:

$$(2.4) \quad E_k = \sum_{i=1}^I \sum_{k=1}^K \frac{D_{k,i}}{A_{d,i}}$$

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:

$$(2.5) \quad E_{Up} = \sum_{i=1}^I \left(\sum_{t=1}^T \left(\frac{U_{t,i}}{A_{u,i}} \right) - \sum_{t=1}^{K-1} \left(\frac{D_{t,i}}{A_{u,i}} \right) \right)$$

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 in the Chowade River and Cypress Creek

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, 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 which 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 PITR package for R (Harding et al. 2018) developed by 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.

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 2021, 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 28 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 (> 0.9) with low variability ($< 2.6\%$) for all tributaries (Table 3.1; Appendix B). Mean aerial OE was low (< 0.5) 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. In 2021, redd sample size was again sufficient in the Cypress Creek ground survey to estimate ground and aerial OE (before ground survey reach was expanded in 2020, OE from the Chowade River was used within GAUC calculations).

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	0.92 (2.5)	0.41 (27.5)
Cypress Creek	0.94 (0.06)	0.12 (90.01)
Fiddes Creek	0.98 (0.03)	0.2 (81.24)
Upper Halfway River	0.97 (0.04)	0.45 (31.79)
Needham Creek	-	0.35 ^a

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

Survey Life

A total of 133 bristle tags were applied to age-1 and age-2 redds during ground surveys in Fiddes and Cypress Creeks, and the Chowade and upper Halfway Rivers. We estimated mean SL for all redds using an 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 C). The estimated SL was 16.5 days with a standard error of 2.1 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 2021, 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

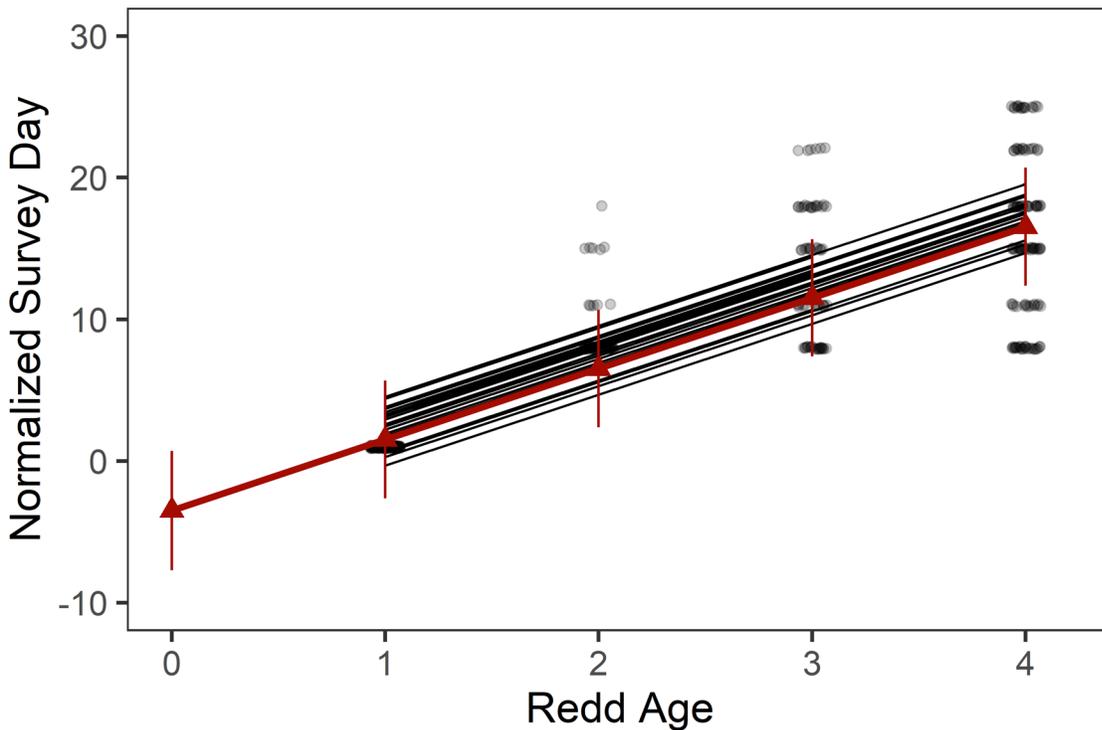


Figure 3.1 Redd age within all tributaries by normalized survey day, with points jittered for presentation. Black lines represent individual redds (showing the random effect of redd ID on the intercept). Red line shows mean SL for all redds, and vertical error bars are the 95% confidence interval based on a normal approximation. Negative normalized survey days correspond to days between the redd being built (age-0) and the first observation (age-1).

GAUC Abundance

GAUC estimates ranged from 43 redds in the upper Halfway River to 319 redds in Cypress Creek (Table 3.3). The total number of redds estimated for all tributaries combined was 820. Precision (%CV) for all tributaries, ranged from 33.9% in Turnoff Creek to 76.9% in the Chowade River. The GAUC model fit the count data well except for the Upper Halfway River (Figure 3.12), where aerial

counts did not closely follow a typical normal distribution pattern (trailing zeros were required to fit the GAUC model).

Peak count estimates consistently underestimated redd abundance relative to the GAUC method, and peak counts from 2016 to 2021 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	282 (65)	180	442	76.9	0.41 (0.05)	16.5 (2.1)	114
Cypress Creek	239 (100)	105	545	58.2	0.16 (0.05)	16.5 (2.1)	78
Fiddes Creek	87(33)	42	182	62.1	0.3 (0.07)	16.5 (2.1)	39
Turnoff Creek	44 (26)	14	138	40.9	0.3 (0.07)	16.5 (2.1)	21
Upper Halfway River	43 (12)	24	75	72.1	0.45 (0.07)	16.5 (2.1)	29
Needham Creek	-	-	-		-	-	-

[Figure 3-12 REDACTED]

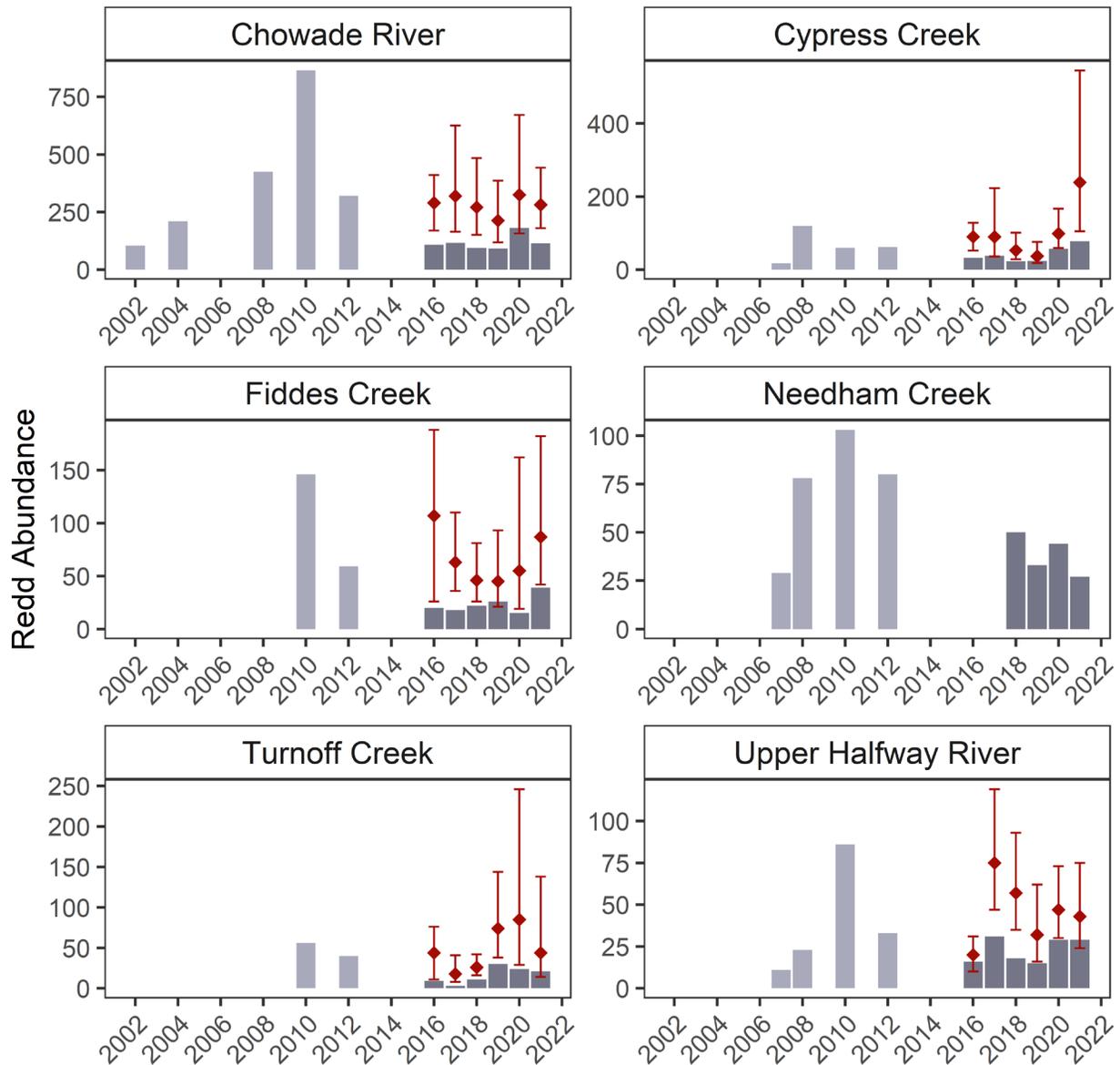


Figure 3.2 Bull Trout peak count redd indices from 2002 to 2014 (dark grey bars; Diversified Environmental Services and Mainstream Aquatics Ltd. 2009, 2011, and 2013) and from 2016 to 2022 (light grey bars; this monitor). GAUC abundance with CI are shown as red diamonds.

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.

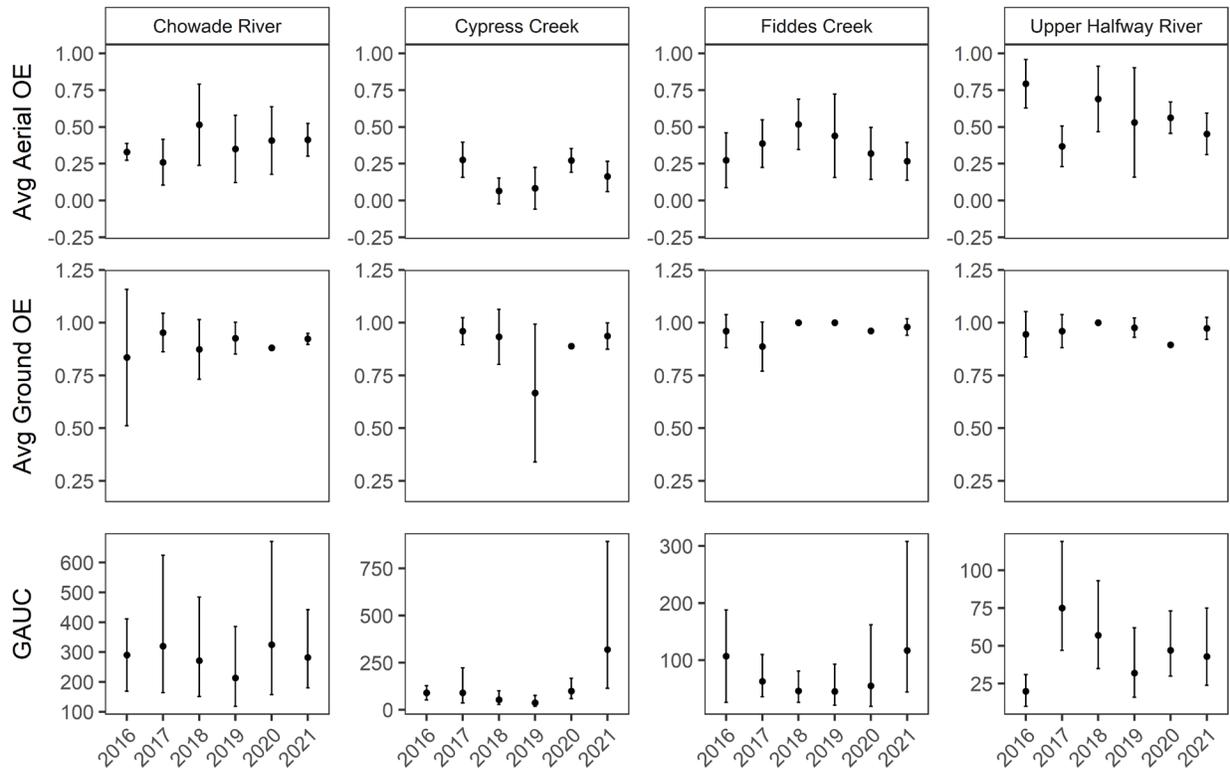


Figure 3.3 Mean aerial OE, mean ground OE, and GAUC abundance (error bars are 95% confidence intervals) in the Halfway Watershed from 2016 to 2021.

3.2 Resistivity Counters

3.2.1 Chowade River

The Chowade River resistivity counter operated from July 31 to October 2. Bull Trout ($n = 438$), Mountain Whitefish ($n = 1,223$), and Rainbow Trout ($n = 269$) were observed crossing the counter during video validation. Total length for Bull Trout ranged from 500 mm to 1000 mm (mean = 642 mm, SD = 90.3 mm), Mountain Whitefish ranged from 20 mm and 520 mm (mean = 286 mm, SD = 69 mm), and Rainbow Trout ranged from 160 mm to 530 mm (mean = 353 mm, SD = 67 mm). Total length data from 2021 and previous monitoring years were comparable based on visual observations (Appendix D).

Counter accuracy varied among channels from 93 to 100% for downstream movements and 83 to 100% for upstream movements (Table 3.4). False negatives occurred at a greater frequency compared to false positives for most channel-direction combinations, suggesting the counter underestimated the true number of movements. Most movements occurred on channels 2, 3, and 4. Water depth above channel 1 was shallow throughout the data collection period (mean water depth = SD = ; Figure 3.15).

The normal density function estimated that the 2021 Bull Trout kelt outmigration began on September 8 and peaked on September 17 (SD = 5.5 days; Figure 3.16). After accounting for counter accuracy and the date of kelt onset, kelt abundance for the Chowade River was 271 Bull Trout (Figure 3.17). The ratio of kelts to redds (estimated via GAUC) was 0.9 (Table 3.5). We could not generate a complete upstream abundance due to the counter being installed during the upstream migration; however, the cumulative net upstream movement of Bull Trout (i.e., ups minus downs) over the full monitoring period was 188 (representing a partial upstream abundance; Figure 3.17).

Table 3.4 Chowade River counter accuracies for Bull Trout.

Channel	Direction	Accuracy
1	D	100%
1	U	100%
2	D	93%
2	U	97%
3	D	96%
3	U	92%
4	D	93%
4	U	83%

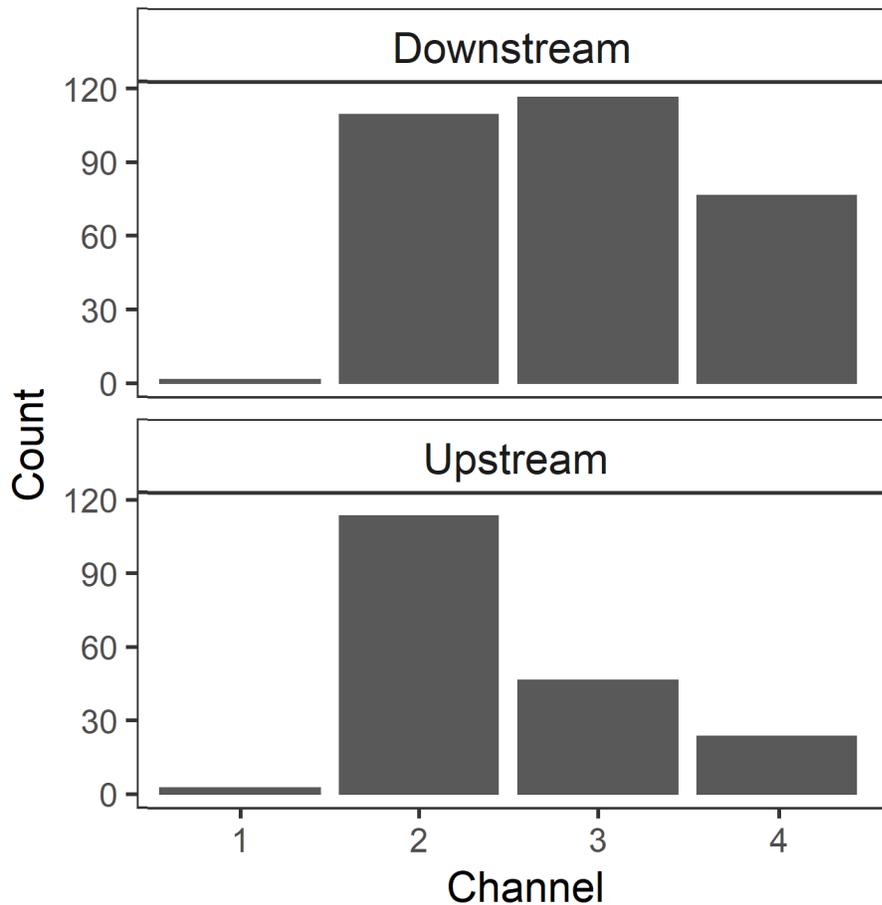


Figure 3.4 Accuracy-corrected counts of Bull Trout moving upstream and downstream past the Chowade River resistivity counter.

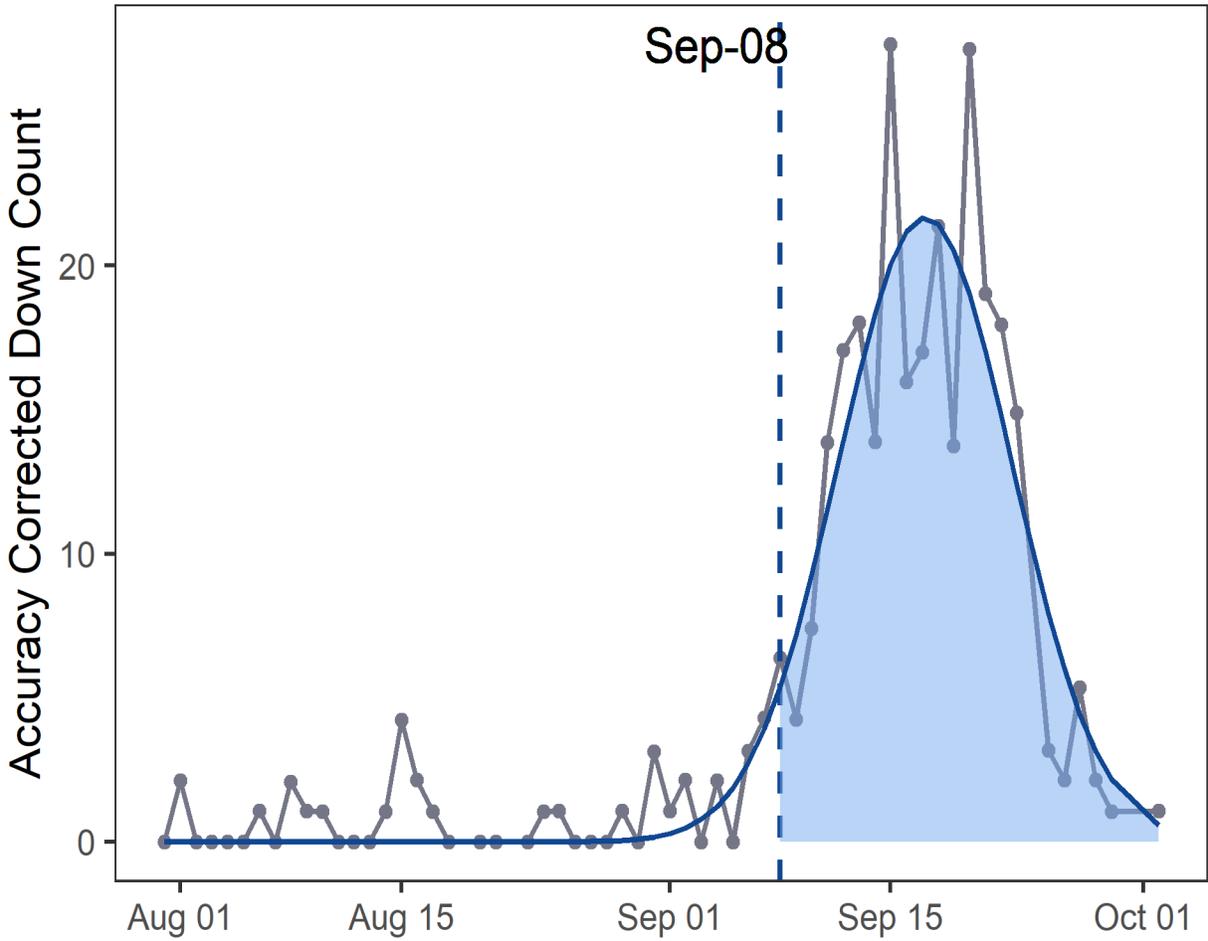


Figure 3.5 Accuracy corrected daily down counts of verified Bull Trout (grey points and lines) and modelled kelt out-migration timing (solid blue line and blue shading) in the Chowade River. The vertical dashed line marks the date which the normal model estimated 5% of the kelts had out-migrated, which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

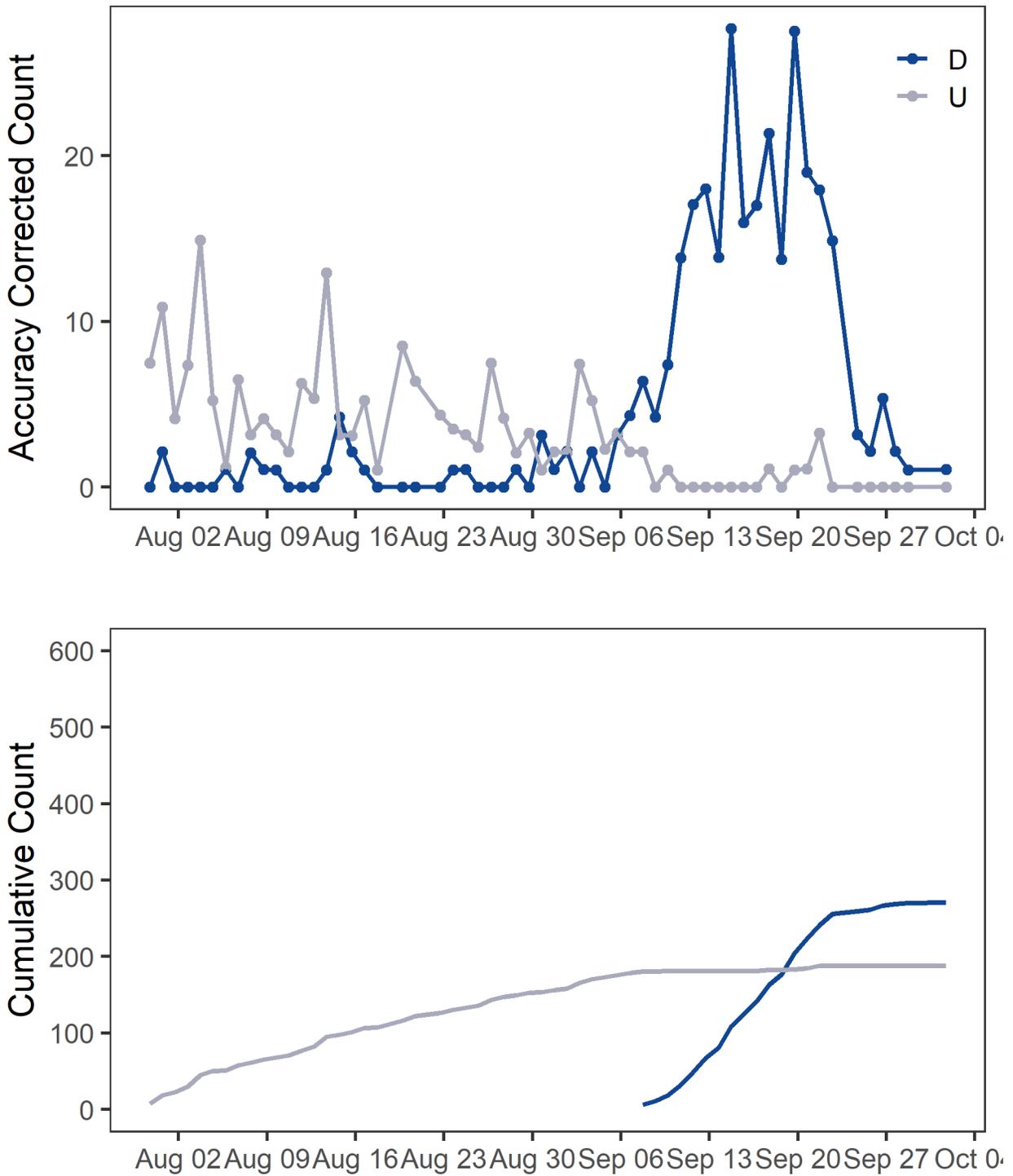


Figure 3.6 Top panel: accuracy corrected up and down counts of Bull Trout moving past the Chowade River resistivity counter. Bottom panel: cumulative up and down counts. Cumulative down counts were set as zero until September 8, the onset of the kelt out-migration.

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)

3.2.2 Cypress Creek

The Cypress Creek resistivity counter operated from July 29 to October 3 continuously with no issues, but video and graphical data were lost from August 9 at 21:45 to August 11 at 16:15, and September 10 at 20:46 to September 16 at 21:42 due to electronic issues (data were adjusted). Bull Trout (n = 129), Mountain Whitefish (n = 779), and Rainbow Trout (n = 64) were all observed crossing the counter during video validation. Bull Trout total lengths ranged from 550 mm to 940 mm (mean = 642 mm, SD = 84.9 mm), Mountain Whitefish ranged from 100 mm and 540 mm (mean = 301 mm, SD = 93 mm), and Rainbow Trout ranged from 170 mm to 450 mm (mean = 318 mm, SD = 65 mm). Total length data from 2021 and previous monitoring years were comparable based on visual observations (Appendix D).

Counter accuracy varied among channels from 43 to 100% for downstream movements and 100% for upstream movements (Table 3.6). The counter was accurate for upstream counts on all channels. Downstream counts on channel 1 and 4 were 100% accurate, while channel 2 and 3 had an accuracy of 75% and 37%, respectively. Most upstream movements occurred on channel 3, while downstream movements predominantly occurred on channels 2 and 3 (Figure 3.18).

The normal density function estimated that the 2021 Bull Trout kelt outmigration began on September 7 and peaked on September 18 (SD = 6.13 days; Figure 3.19). After accounting for counter accuracy and the date of kelt onset, kelt abundance for Cypress Creek was 73 Bull Trout (Figure 3.20). The ratio of kelts to redds (estimated via GAUC) was 0.6 (Table 3.7). Cumulative net upstream movements over the full monitoring period were 117.

Table 3.6 Cypress Creek counter accuracies for Bull Trout.

Channel	Direction	Accuracy
1	D	100%
1	U	100%
2	D	75%
2	U	100%
3	D	37%
3	U	100%
4	D	100%
4	U	100%

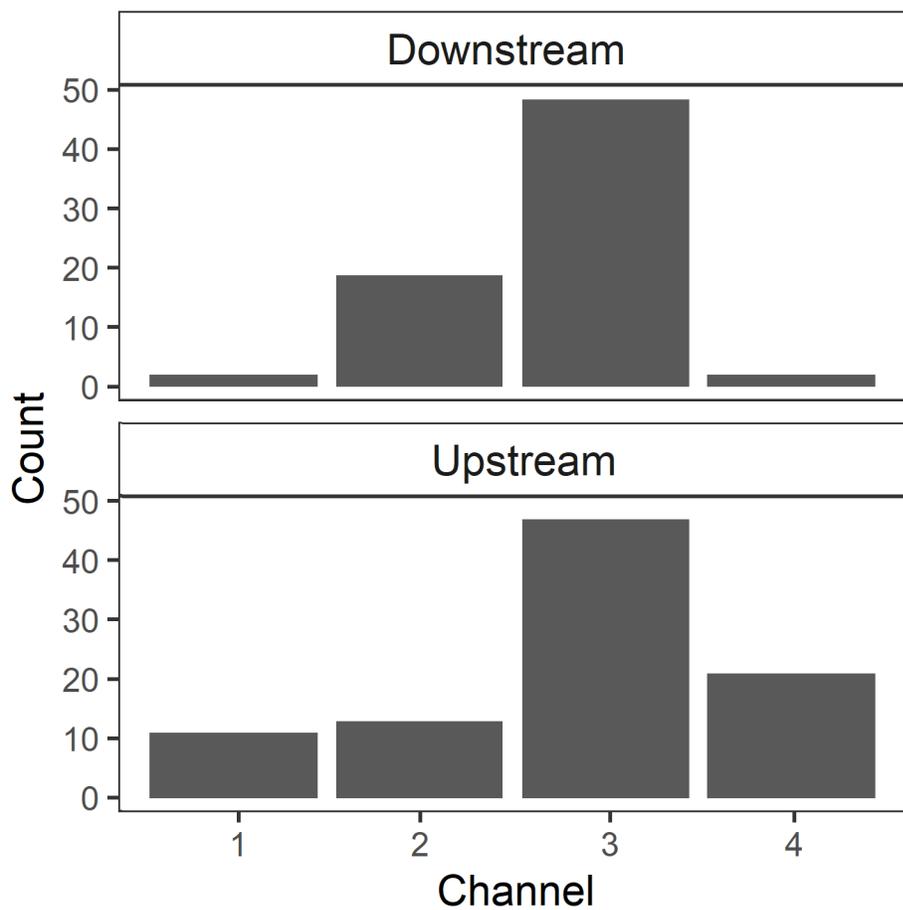


Figure 3.7 Accuracy-corrected counts of Bull Trout moving upstream and downstream past the Cypress Creek resistivity counter.

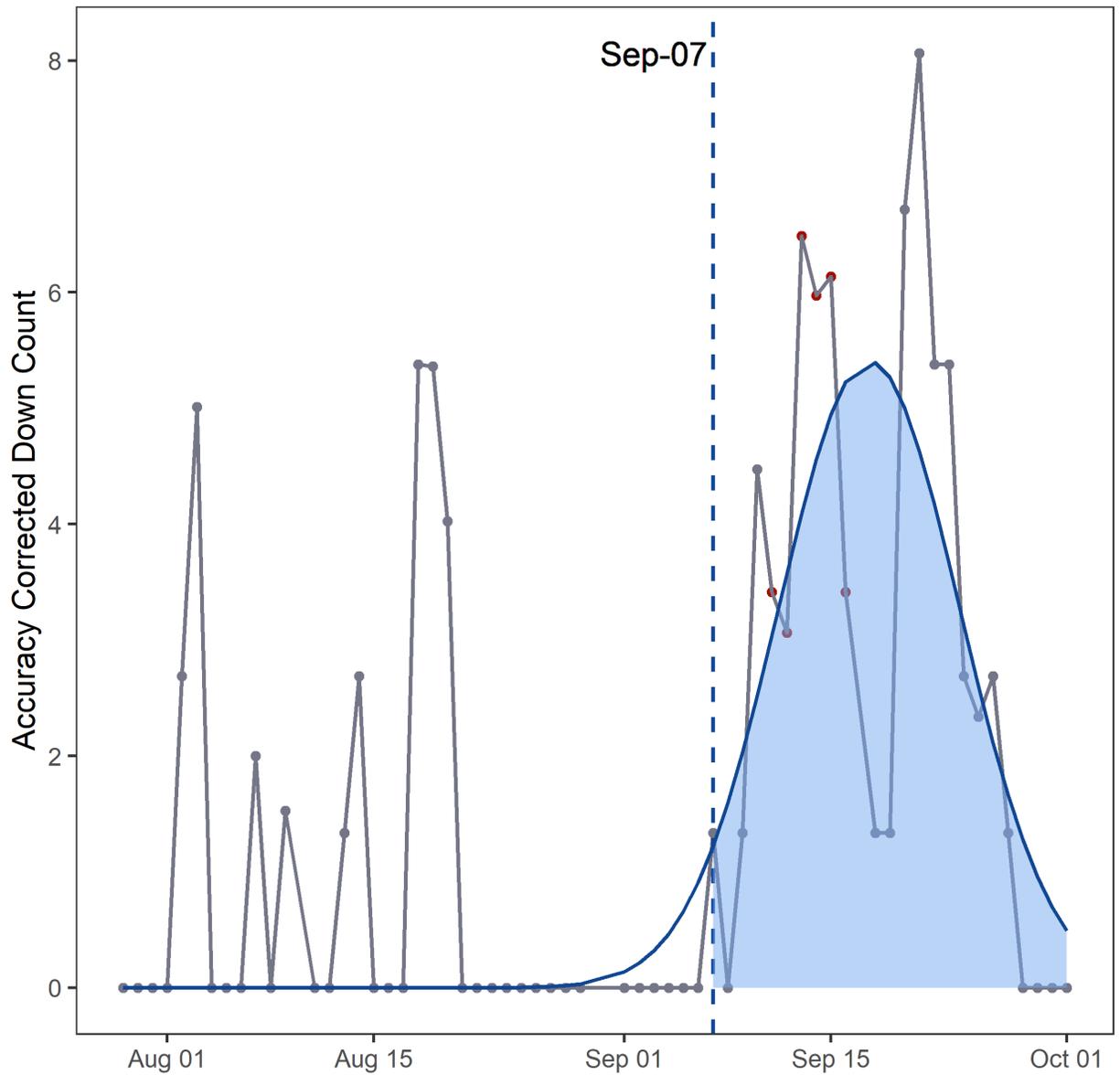


Figure 3.8 Accuracy corrected daily down counts of verified Bull Trout (grey points and lines) and modelled kelt out-migration timing (solid blue line and blue shading) in Cypress Creek. The vertical dashed line marks the date which the normal model estimated 5% of the kelts had out-migrated, which was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

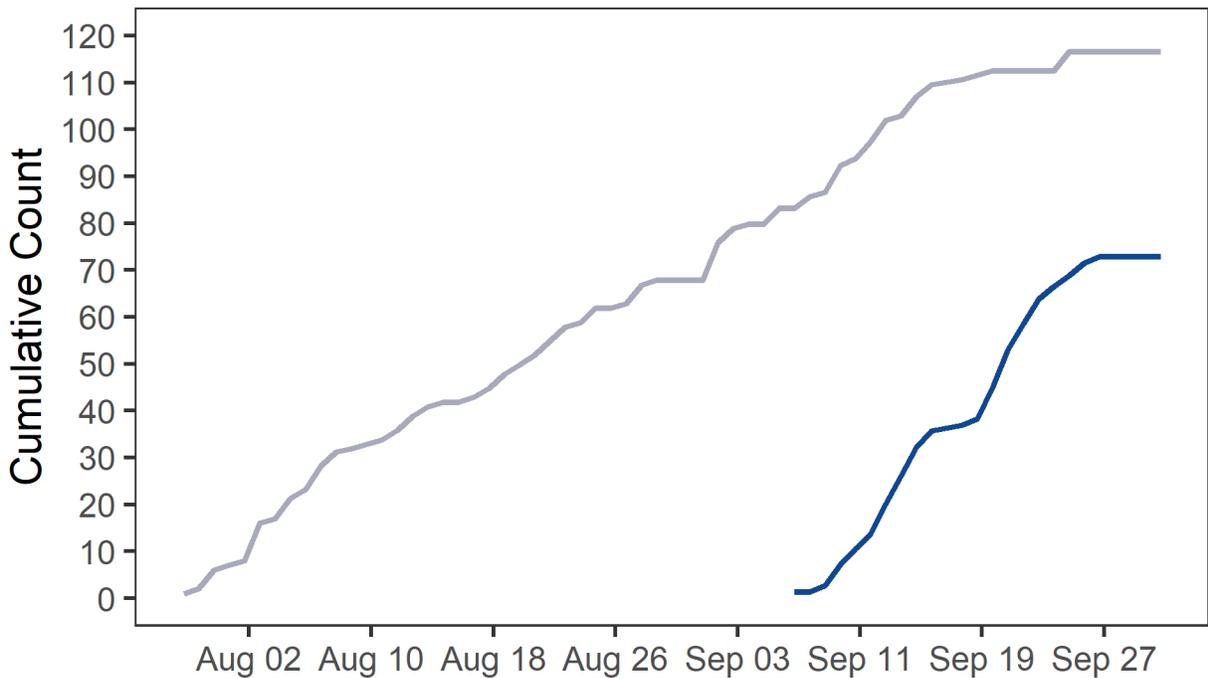
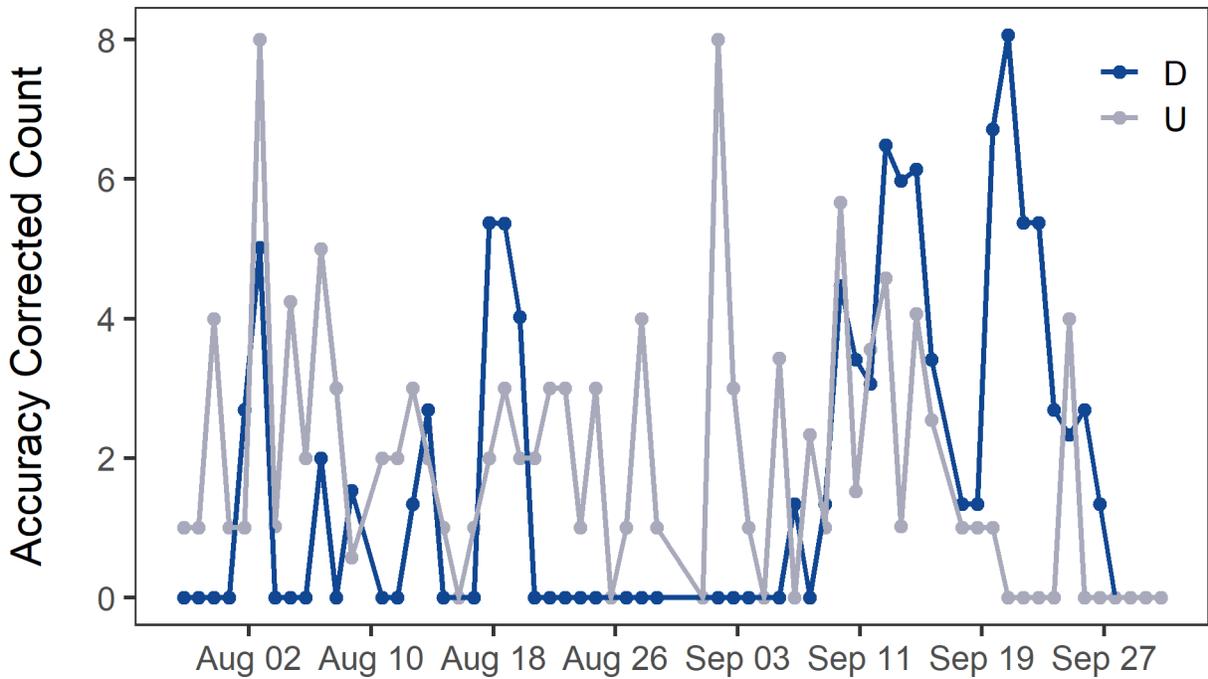


Figure 3.9 Top panel: accuracy corrected up and down counts of Bull Trout moving past the Cypress Creek resistivity counter. Bottom panel: cumulative up and down counts. Cumulative down counts were set as zero until September 7, the onset of the kelt out-migration.

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)

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). Read ranges for 12 mm and 23 mm PIT tags were ~30% and ~80% of the water depth at the thalweg, respectively. The mean proportion of the water column within which 12 mm tags were detectable was 0.69 (downstream antenna) and 0.73 (upstream antenna), while for 23 mm tags it was 0.94 (downstream) and 0.93 (upstream).

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). Read ranges for 12 mm PIT tags were ~60% of the water depth at the thalweg, while overall, the proportion of the water column within which 12 mm tags were detectable was 0.84 (downstream) and 0.73 (upstream).

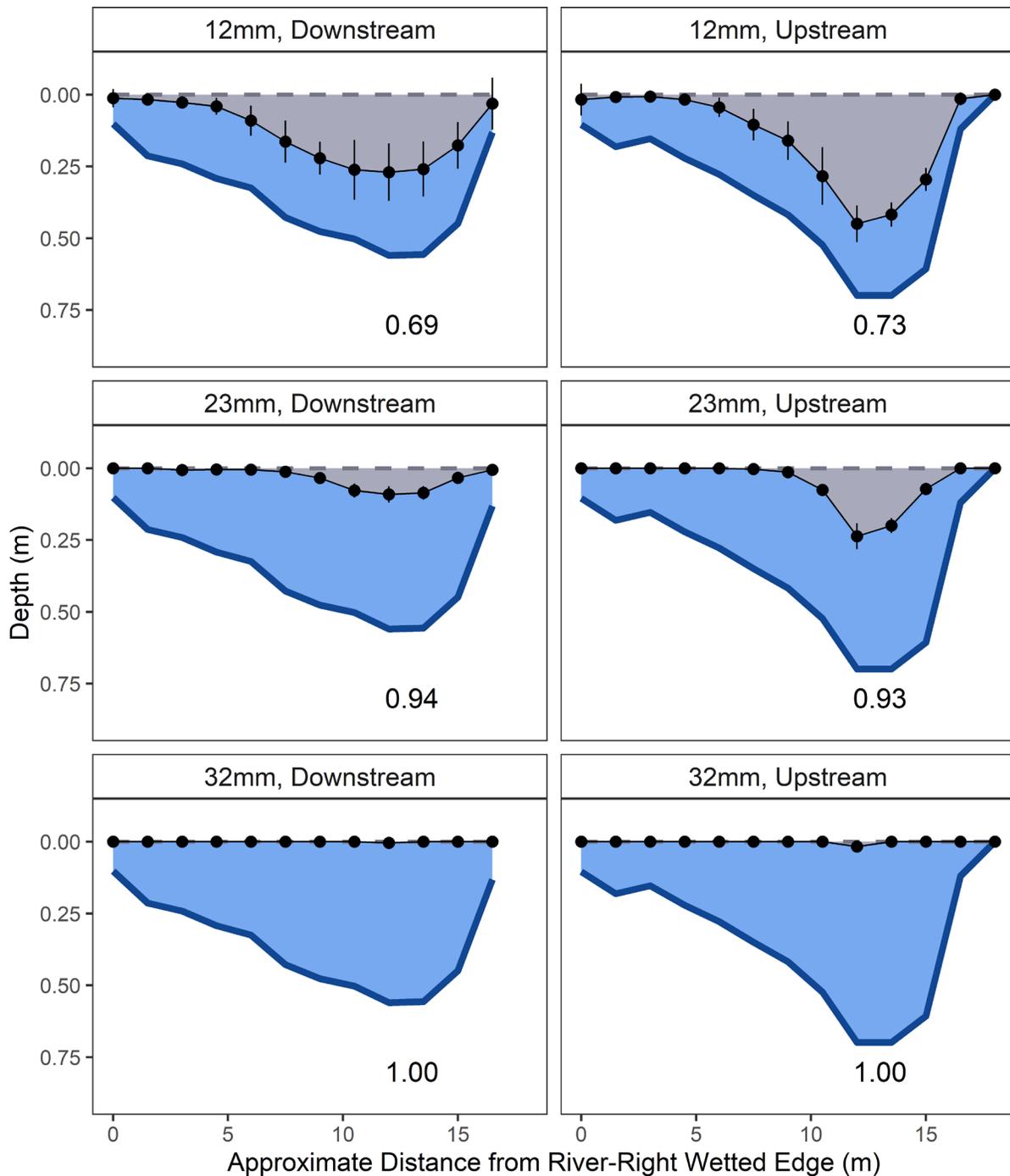


Figure 3.10 Proportion of the water column (points show mean \pm SD) in the Chowade River within which PIT tags (12 mm, 23 mm, and 32 mm) were detectable throughout the monitoring period. Blue shading represents areas where tags are detectable (the number within the blue area is the mean detectable proportion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

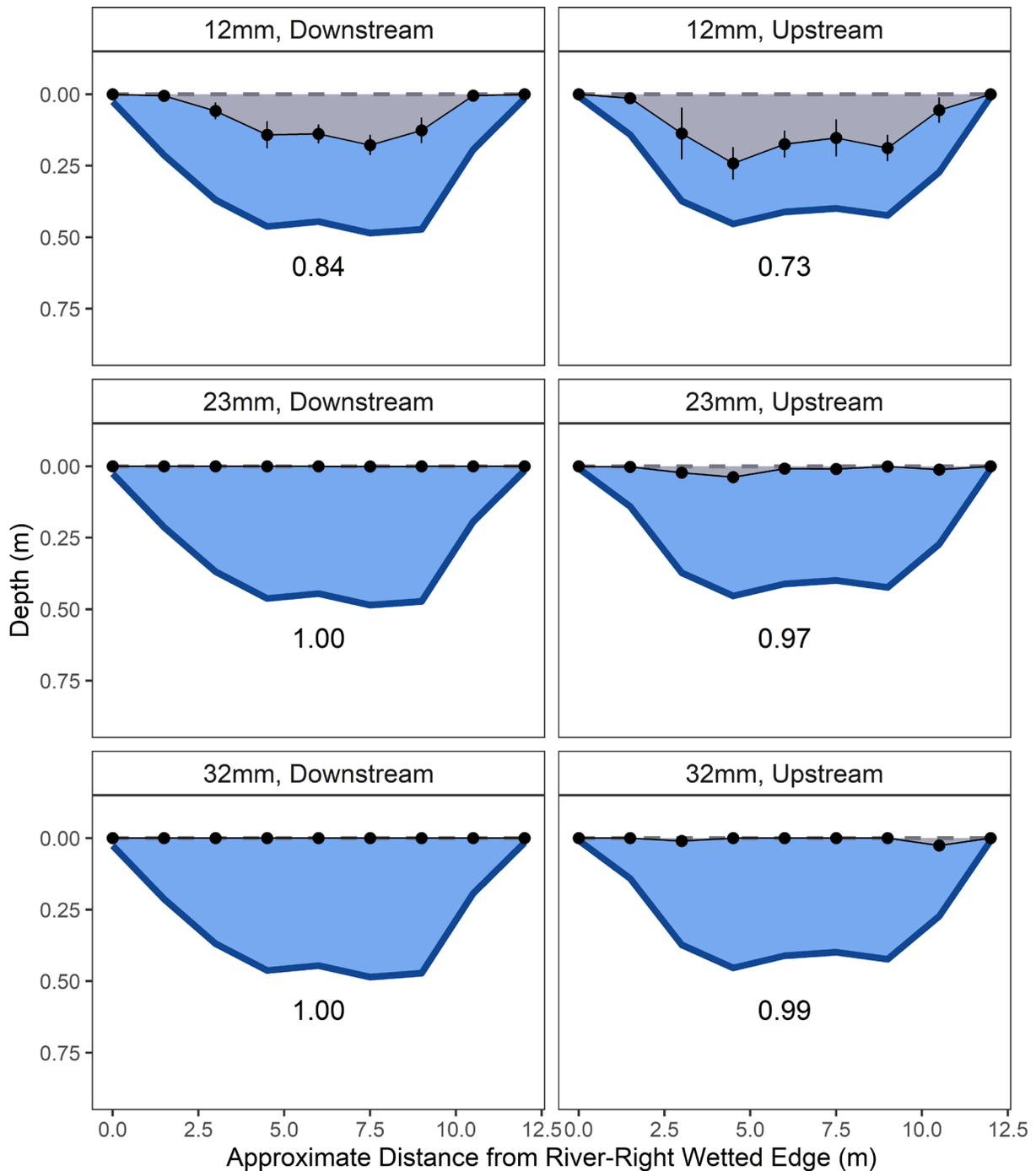


Figure 3.11 Proportion of the water column (points show mean \pm SD) in Cypress Creek within which PIT tags (12 mm, 23 mm, and 32 mm) were detectable throughout the monitoring period. Blue shading represents areas where tags are detectable (the number within the blue area is the mean detectable proportion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

3.3.2 Tag Detections

57 unique tags were detected by the Chowade River PIT array (52 Bull Trout, 2 Mountain Whitefish, and 3 Rainbow Trout, and direction could be determined for 38 tags (the remaining tags were only detected on one antenna; Appendix E). Twenty-two tags (18 Bull Trout and 4 Rainbow Trout) were only detected moving downstream, while four tags (all Bull Trout) were only detected moving upstream. The remaining 12 tags (35% of all Bull Trout detected by the array) were first detected moving upstream, then subsequently detected moving downstream. The mean and standard deviation time difference between upstream and downstream movements (i.e., Bull Trout residence time) was 22.5 ± 18.3 days.

Tagged Bull Trout in the Chowade River 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 95%, while downstream detection efficiency was 93%.

Thirty-three unique tags were detected by the Cypress River PIT array (30 Bull Trout, and 3 Rainbow Trout), and direction was determined for 13 of them (Appendix E). Two Bull Trout were detected moving upstream; one moved upstream on September 3 but was not detected moving downstream, and one moved upstream on August 13 and again on September 8, but its final downstream movement was not detected. Six Bull Trout moved downstream between September 10 and September 19, but none of these were not detected moving upstream, and likely migrated prior to the installation of the PIT array. Bull Trout residence time was 28.9 ± 14.7 days. Upstream detection efficiency (for all species and tag sizes) over the entire monitoring period was 86%, while downstream detection efficiency was 100%.

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 2021 monitoring year marks the first full 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 in 2021, which agrees with literature suggesting detailed ground surveys are an accurate redd counting method (Dunham et al. 2001). Ground OE has previously been low and variable in Cypress Creek, but an expansion of the ground reach in 2020 resulted in a more consistent ground OE, which is likely reflective of a larger redd sample size during ground surveys. Adjustments to the Cypress Creek ground survey appear to have increased redd sample size and will likely reduce uncertainty in the Cypress Creek redd abundance estimate, while still being comparable to estimates from previous years.

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 2021 (mean 16.5 days, SE 2.0) was the lowest calculated since 2016, suggesting redds may have aged faster in 2021 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

Confidence in resistivity counter estimates is high due to extensive validation effort. Counter accuracy was high for both downstream and upstream counts (96% and 93% for the Chowade River, 78% and 100% for Cypress Creek, respectively). 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 higher than previous years and also higher than other salmonid enumeration programs in British Columbia. For example, flat pad counters in the Lower Bridge and Chilcotin rivers had upstream accuracies of 70% and >80%, respectively, while downstream accuracies in the Chilcotin River were 50% or greater (Ramos-Espinoza et al. 2011). In both the Chowade and Cypress River, the decreased counter accuracy was a result of false negatives. 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. 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).

From 2017 to 2021, abundance estimates were generated using downstream migrating kelts. Unlike the previous years, the 2021 Cypress Creek kelt abundance was lower than up migration numbers. In 2021 the river flows allowed us to install and collect data earlier in the migration and likely captured a larger portion of the upstream migration, but it was likely not early enough to provide a full abundance estimate of upstream migrants. There is also a possibility the entirety of downstream migrating kelts were not fully captured at Cypress Creek. Unlike in Chowade, upstream movements continued well into September at Cypress Creek and based on residence time observed with the PIT antennas, we believe that the kelt migration may have continued into

October. This is corroborated by the discrepancy between the total number of up (117) and kelt (73) counts.

For 2021, counter accuracy was estimated using a newly developed multinomial method (Putt et al. 2021). While developing a method to incorporate uncertainty around counter estimates, IFR identified that the previous counter accuracy method (confusion matrix method, used from 2016 to 2020) may not be appropriate in all counter analysis situations (higher FP, or when FP=FN). Accuracy estimates from previous years remained unchanged when the 2020 data was processed using the new multinomial method (Appendix F), suggesting that while the equations may be different, the updated method should not change the accuracy results drastically.

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 2021 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 in 2016 through 2020, peak count was consistently below 200 redds. In fact, the decline in redd abundance may be even larger, as a comparison of peak counts and GAUC estimates suggest historic counts may have underestimated true redd abundance.

Variability in peak redd counts may be partially related to count methodologies, which highlights the importance of a robust enumeration methodology. Historically, peak counts were subject to minor variations in counting methods, personnel, and survey length. Also, we found peak counts from 2016 through 2021 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 FAHMFPP will help to describe individual Bull Trout spawning movements, straying rates, and survival. To fully capture redd abundance for a mixed population, it is important that all critical spawning tributaries are included in redd count surveys. Peak redd counts suggest Needham Creek has a large number of Bull Trout spawners relative to other tributaries surveyed, 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 (1.7) and Cypress Creek (0.6) were low in 2021 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, 2021 was the first year where we might expect to observe changes to spawner abundance. Results from 2021 indicated that redd and kelt abundances were within the ranges observed pre-diversion from 2016 to 2020.

4.2 Migration Timing

Timing of the Bull Trout upstream migration remains uncertain for tributaries of the Halfway Watershed. Angling surveys in 1995 suggested Bull Trout first appear in the Chowade River in early August and peak spawning occurs [REDACTED] (Baxter 1997). Resistivity counters have not yet been installed in time to monitor the full upstream migration, but counter data from early August (Braun et al. 2017a, Ramos-Espinoza et al. 2019) suggest that the upstream migration may begin in July and peak earlier than previously suggested by Baxter (1997). In addition, 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 will inform migration timing, residence time, and site fidelity (Hatch et al. 2020, 2021). Of the 39 PIT tagged Bull Trout detected by Chowade River array, 10 were also radio tagged, as was one of the 10 PIT tagged Bull Trout detected by the Cypress Creek array. Detection data from fixed radio telemetry stations and mobile tracking will confirm PIT antenna detection efficiency and determine what proportion of the upstream migration is monitored by the resistivity counters in each monitoring year.

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 2021, 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.

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Appendix A: River Kilometer Delineations

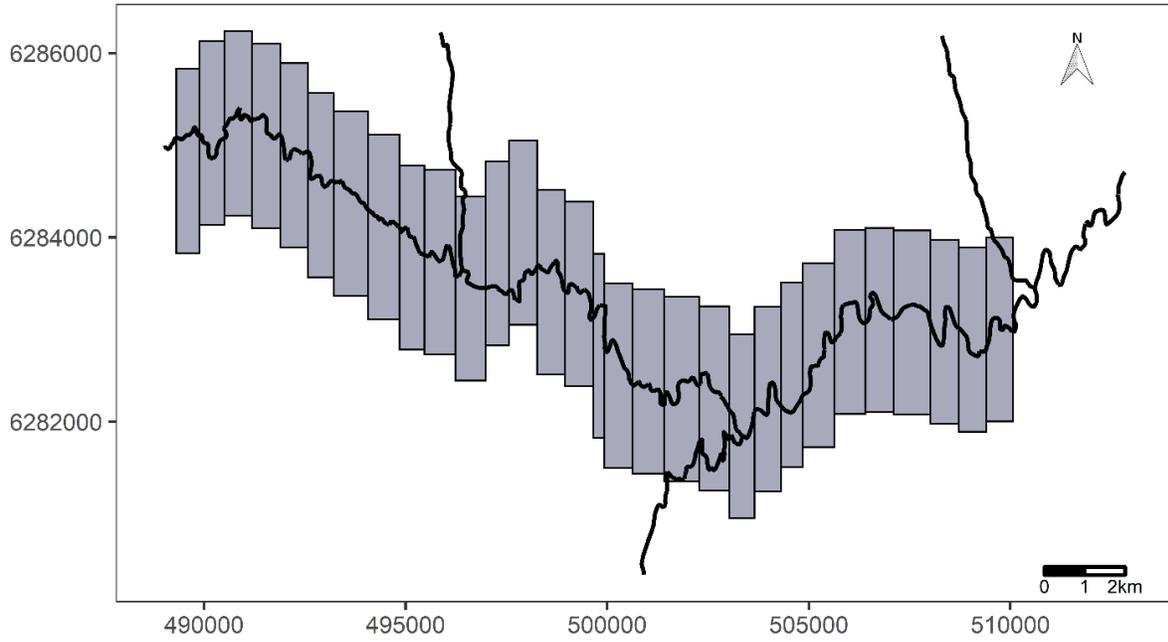


Figure A1 River kilometer delineation for the Chowade River.

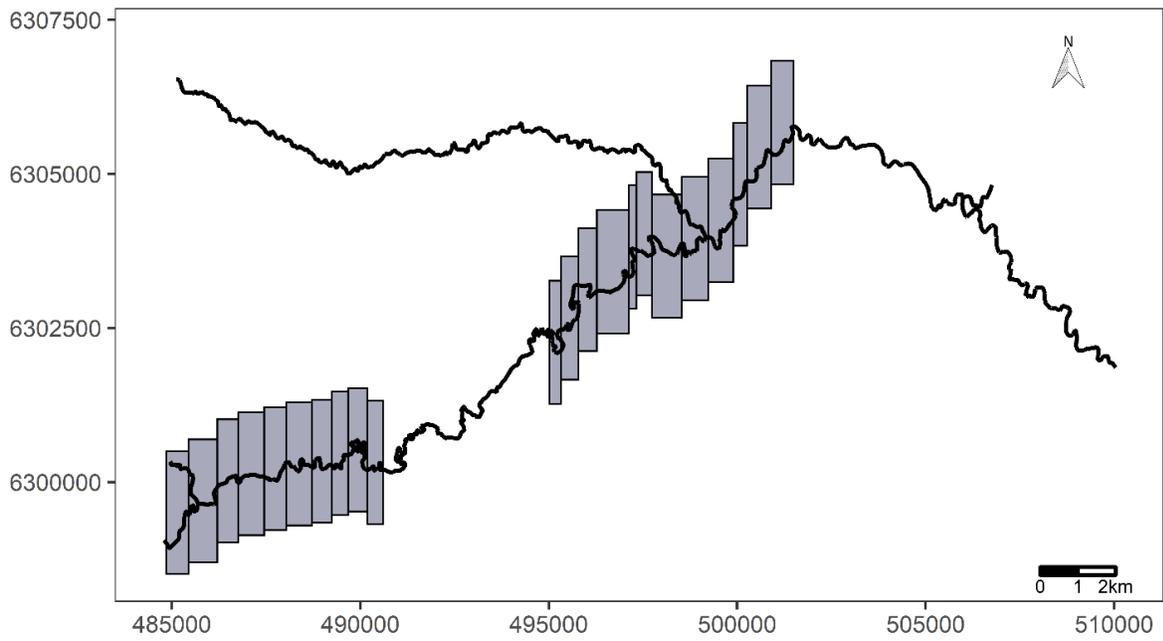


Figure A2 River kilometer delineations for Cypress Creek.

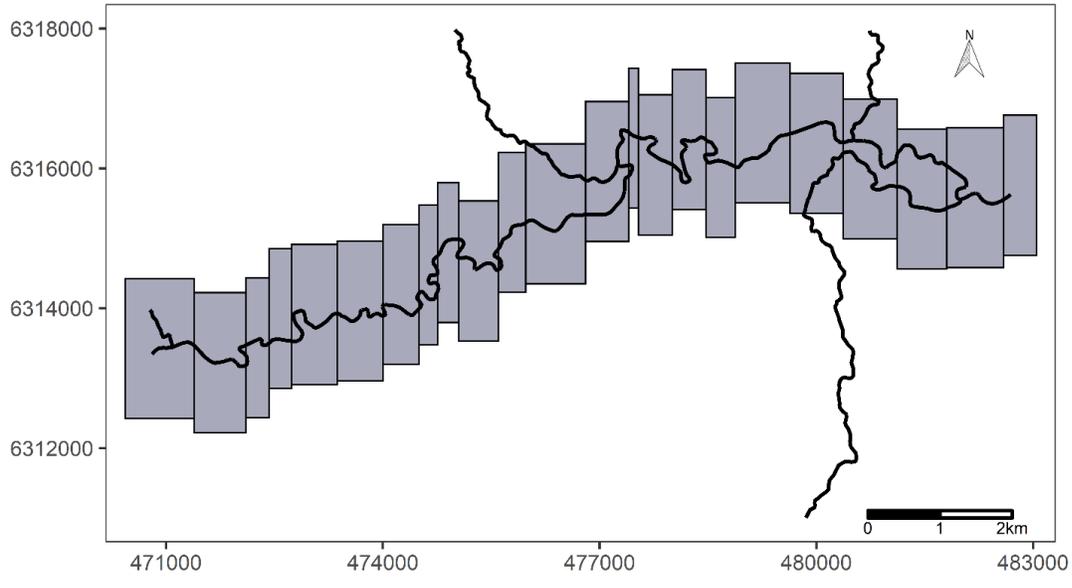


Figure A3 River kilometer delineations for the upper Halfway River.

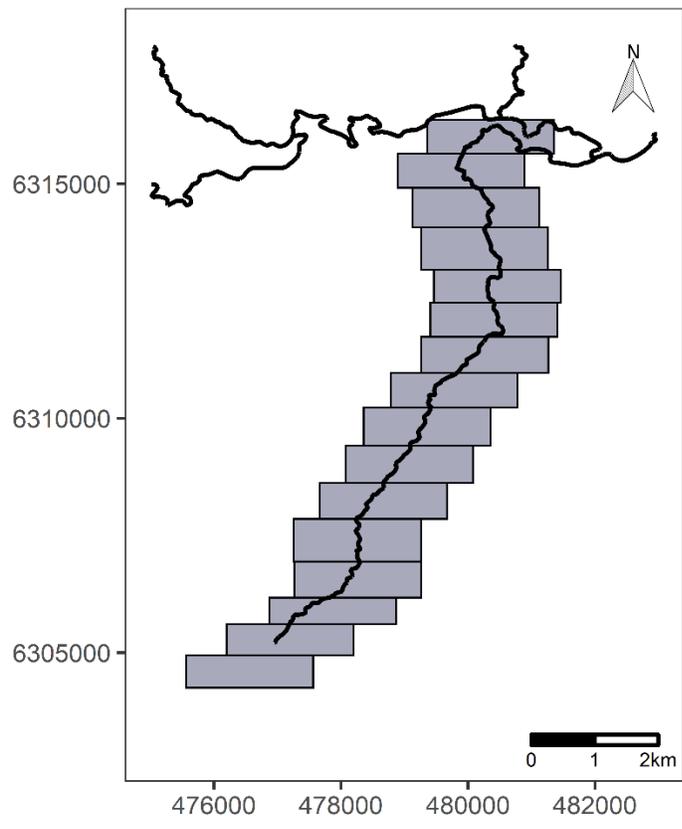


Figure A4 River kilometer delineations for Fiddes Creek.

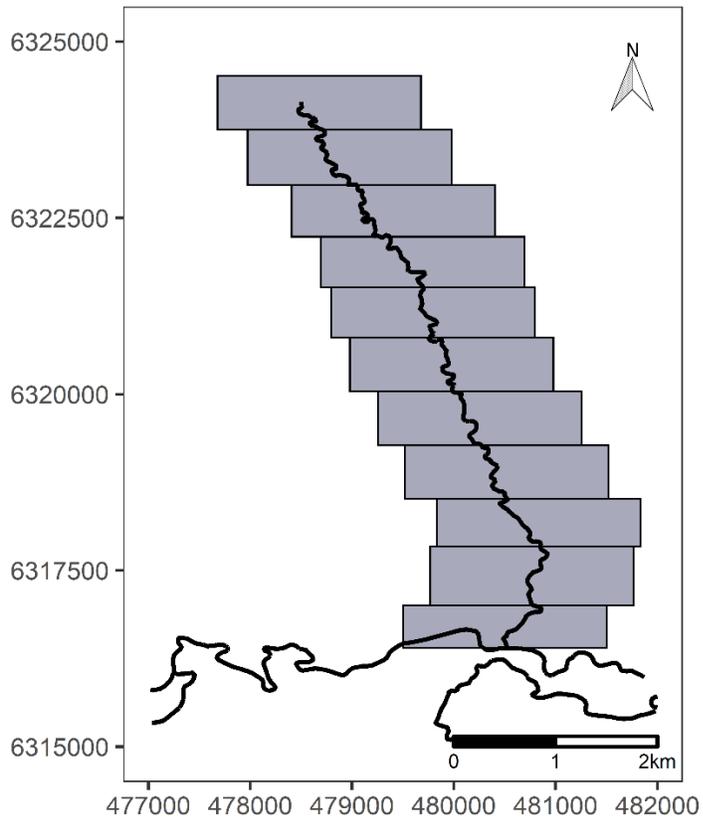


Figure A5 River kilometer delineations for Turnoff Creek.

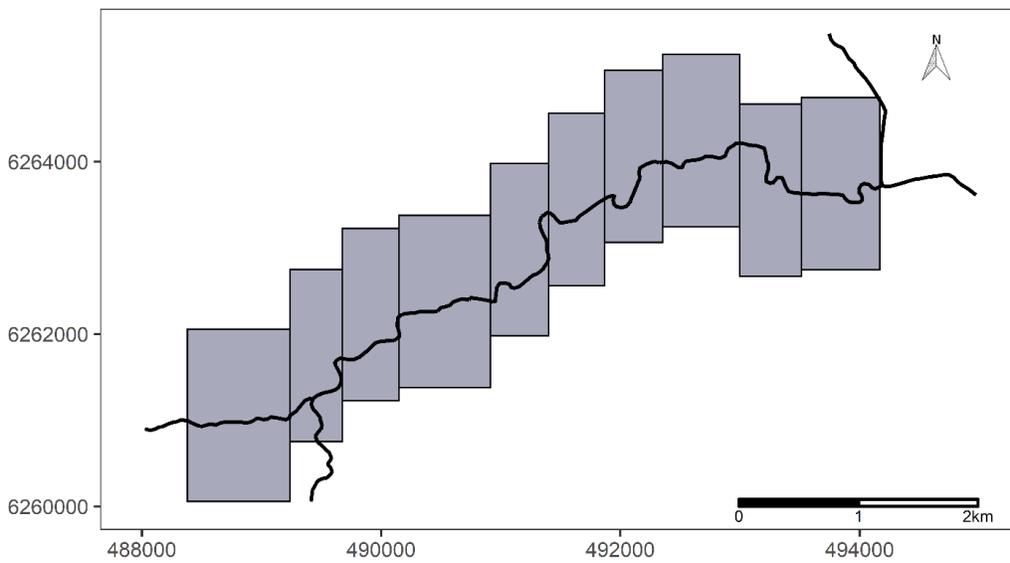


Figure A6 River kilometer delineations for Needham Creek.

Appendix B: Aerial and Ground Redd Counts

Table C1 Survey-specific ground counts, aerial counts, ground OE, expanded ground counts, and aerial OE.

Tributary	Survey	Ground Count	Aerial Count (within ground reach)	Ground OE	Expanded Ground (ground count / mean ground OE)	Aerial OE (aerial count / expanded ground count)
Chowade River	1	25	14			0.5
	2	69	37			0.33
	3	78	28			0.3
	4	49	16			
Cypress Creek	1	19	3	-		0.15
	2	36	10	0.95		0.26
	3	33	3	0.87		0.08
	4	18	0	0.86		NA
Fiddes Creek	1	13	4	-		0.3
	2	16	6	0.88		0.36
	3	16	0	1.00		0.14
	4	7	1	1.00		NA
Upper Halfway River	1	11	6	-		0.53
	2	24	6	1.00		0.24
	3	21	12	0.86		0.55
	4	18	9	0.86		0.49
Needham Creek	1	-	18	-	-	0.35 ^a

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

Appendix C: Summary of Linear Mixed Model for Survey Life

Table D1 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
2095.6	2111.3	-1043.8	2087.6	370

Scaled residuals:

Min	1Q	Median	3Q	Max
-1.9119	-0.4121	-0.1200	0.3962	2.5788

Random effects:

Groups	Name	Variance	Std.Dev.
tag_id	(Intercept)	4.216	2.053
Residual		12.277	3.504

Number of obs: 374, groups: tag_id, 131

Fixed effects:

	Estimate	Std. Error	t value
(Intercept)	-3.4868	0.4392	-7.938
redd_age	5.0078	0.1462	34.255

Correlation of Fixed Effects:

	(Intr)
redd_age	-0.810

Appendix D: Total Lengths from Video Validation

Table E1 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
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
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

Table E2 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
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
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

Appendix E: PIT Detection Histories

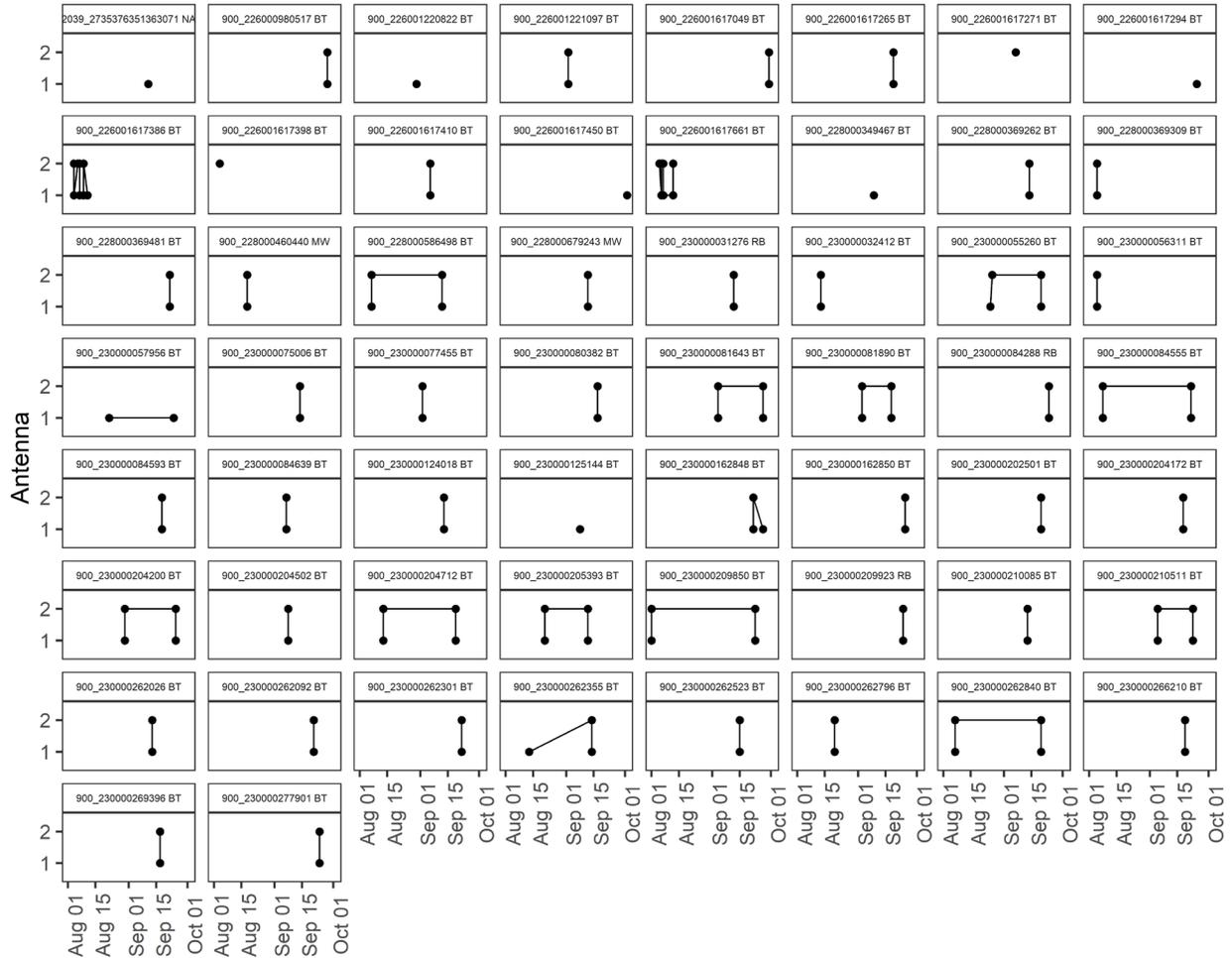


Figure F1 Detection histories of PIT tags detected by the Chowade River array. Antenna 1 is the downstream antenna, while Antenna 2 is the upstream antenna.

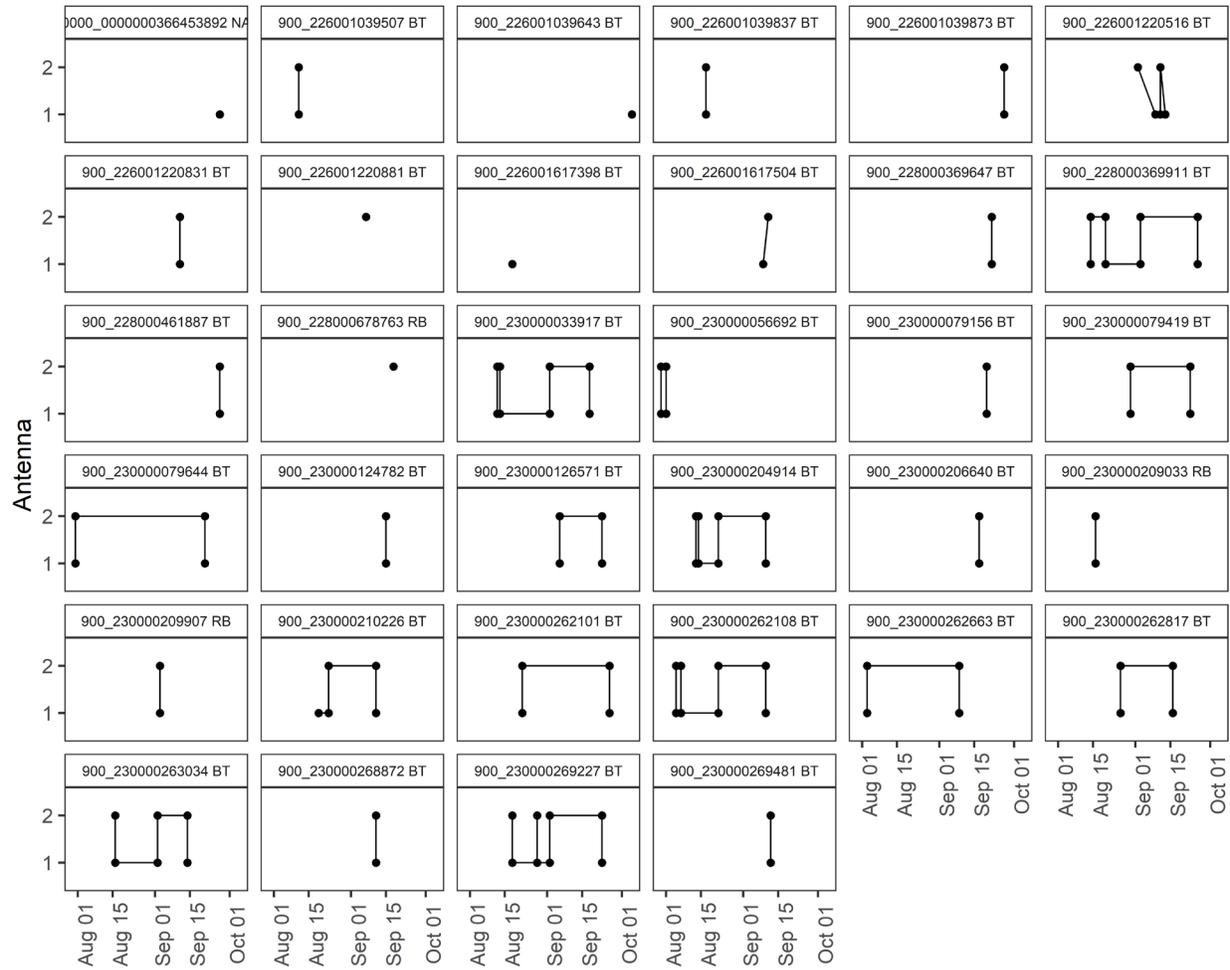


Figure F2: Detection histories of PIT tags detected by the Cypress Creek array. Antenna 1 is the downstream antenna, while Antenna 2 is the upstream antenna.

Appendix F: Comparison of Counter Accuracies using Confusion Matrix Method and Multinomial Method

Objective

Comparing the 2020 Chowade counter estimate and counter accuracy using two analysis methods: the confusion matrix method and multinomial method. During research and development in 2020, while developing a method to incorporate uncertainty around counter estimates IFR discovered that the current confusion matrix method may not be appropriate in all counter analysis situations. A new multinomial method was developed and utilizes an updated accuracy calculation. Both methods for analyzing counter data produce very similar results. When comparing the accuracy and estimate of the submitted 2020 Chowade data, there was no change in counter accuracy or fish estimate.

Introduction and Analysis Background

The Chowade River counter data are validated using a targeted and random approach. First, we validate each counter up and down record to determine the exact number of true positive (TP) fish and false positive (FP) fish for all species across the entire migration period. Next, we perform random validation to determine the number of false negative (FN) fish. In 2020, we reduced our total validation percent from ~15% (performed in 2019) to ~10%, but IFR increased the proportion of night video that was randomly validated. This resulted in a similar sample size (or greater) for FN fish calculation relative to 2019.

Using the FN rate from the random validation, we expand the FNs to the full monitoring period to determine the approximate number of FN in the dataset. From here we can calculate accuracy to describe the counter performance, determine the kelt date, and estimate total Bull Trout kelt abundance. These methods remain unchanged in the new method.

Analysis Method: Original Confusion Matrix Method

The estimation method follows the traditional confusion matrix method used between 2016 to 2020. Adapted from the medical field.

- TPs, FPs, and FNs numbers were used to calculate counter accuracy, summarized by direction (up and down), species, and counter channel:

Equation 1

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

- TN are hard to define and describe in count data, and both were assumed to be equal in above equation.

- Calculate channel-specific accuracy for both up and down movements.
- Apply daily species ratios and channel/direction-specific accuracy to the raw counter estimate to estimate abundance.

Analysis Method: Updated Multinomial

The new estimation method follows the multinomial accuracy method, including the calculation of Bayesian credibility intervals: For the Chowade and Cypress datasets we cannot yet estimate uncertainty, because we complete random and targeted validation. Currently the method is only possible for random validation only.

- We assume that all error types, TP, FP, and FN observations are multinomially distributed random variables: $v \sim Mult(Cval, \theta)$
 - where v is a vector of the total number of TPs, FPs, and FNs (v_{TP} , v_{FP} , and v_{FN}) in the validation data set; θ is a vector of estimated probabilities of being in each of the three states (θ_{TP} , θ_{FP} , and θ_{FN}); and $Cval$ is the total number of observations in the counter validation data ($v_{TP} + v_{FP} + v_{FN}$).
- We define counter accuracy, θ_{TP} , as the proportion of fish passing the counter that are correctly recorded by the counter algorithm. Given that the θ values must sum to 1.0, the following accuracy equation 2 demonstrates both FPs and FNs degrade counter accuracy

Equation 2

$$\theta_{TP} = 1 - \theta_{FP} - \theta_{FN}$$

- Abundance (or run size) is calculated by correcting the unvalidated counter record based on the probabilities of both types of error (θ_{FP} and θ_{FN}):

$$\hat{N}_{Run} = \frac{c \cdot (1 - \theta_{FP})}{(1 - \theta_{FN})}$$

- Calculate channel-specific accuracy (multinomial probabilities for TP, FP, and FN) for both up and down movements.
- Apply daily species ratios and channel/direction-specific accuracy to the raw counter estimate to estimate abundance.
- The main difference with this method is that we do not need to define or estimate TN. All the error types must add to one.

Analysis Results: Original Confusion Matrix Method

The results of the confusion matrix method, as reported in the submitted 2020 report.

```
accuracy <- val %>%
  group_by(period, Chan, Graphics.Validation) %>%
  summarize(TP = sum(tp),
            FP = sum(fp),
            FN = sum(fn),
            .groups = 'drop') %>%
  tidyr::pivot_wider(names_from = period, values_from = TP:FN) %>%
  mutate(TP = TP_day + TP_night,
         FP = FP_day + FP_night) %>%
  select(-TP_day, -TP_night, -FP_day, -FP_night) %>%
  # Apply the video percentages separately for day and night.
  mutate(valpct_night = 12.54,
         valpct_day = 7.28,
         FN_night_exp = FN_night*100/valpct_night,
         FN_day_exp = FN_day*100/valpct_day,
         FN = FN_night_exp + FN_day_exp,
         accuracy = TP/(TP + FP + FN))
```

We need to determine whether the counter over or underestimated the true count. When $FN > FP$, the value is an underestimate and we divide by accuracy. When $FP > FN$, the counter overestimated and we multiply by accuracy.

This is our final accuracy table.

```
accuracy <- accuracy %>%
  mutate(estimate = case_when(FP > FN ~ "over", TRUE ~ "under")) %>%
  select(Chan, Graphics.Validation, TP, FP, FN, accuracy, estimate)
```

Chan	Graphics.Validation	TP	FP	FN	accuracy	estimate
1	D	28	2	55.82	0.33	under
1	U	31	6	0.00	0.84	over
2	D	59	10	71.77	0.42	under
2	U	41	7	0.00	0.85	over
3	D	98	4	109.43	0.46	under
3	U	71	3	69.56	0.49	under
4	D	29	1	63.80	0.31	under
4	U	46	3	31.90	0.57	under

Kelt abundance estimated using the full data set is 571.39.

Compared to the kelt abundance from BT validation (568.42) and the normal model (576.9).

Analysis Results: Updated Multinomial

The updated multinomial method produced the exact same results as the confusion matrix method.

```
accuracy <- val %>%
  group_by(period, Chan, Graphics.Validation) %>%
  summarize(TP = sum(tp),
            FP = sum(fp),
            FN = sum(fn),
            .groups = 'drop') %>%
  tidyr::pivot_wider(names_from = period, values_from = TP:FN) %>%
  mutate(TP = TP_day + TP_night,
         FP = FP_day + FP_night) %>%
  select(-TP_day, -TP_night, -FP_day, -FP_night) %>%
  # Apply the video percentages separately for day and night.
  mutate(valpct_night = 12.54,
         valpct_day = 7.28,
         FN_night_exp = FN_night*100/valpct_night,
         FN_day_exp = FN_day*100/valpct_day,
         FN = FN_night_exp + FN_day_exp,
         NT = TP + FP + FN,
         qFP = FP/NT,
         qFN = FN/NT,
         accuracy = 1 - qFP - qFN)
```

We need to determine whether the counter over or underestimated the true count. When $FN > FP$, the value is an underestimate and we divide by accuracy. When $FP > FN$, the counter overestimated and we multiply by accuracy.

This is our final accuracy table.

```
accuracy <- accuracy %>%
  mutate(estimate = case_when(FP > FN ~ "over", TRUE ~ "under")) %>%
  select(Chan, Graphics.Validation, TP, FP, FN, accuracy, estimate)
```

Chan	Graphics.Validation	TP	FP	FN	accuracy	estimate
1	D	28	2	55.82	0.33	under
1	U	31	6	0.00	0.84	over
2	D	59	10	71.77	0.42	under
2	U	41	7	0.00	0.85	over
3	D	98	4	109.43	0.46	under
3	U	71	3	69.56	0.49	under
4	D	29	1	63.80	0.31	under
4	U	46	3	31.90	0.57	under

Kelt abundance estimated using the full data set is 571.39.

Compared to the kelt abundance from BT validation (568.42) and the normal model (576.9).