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 – Resistivity Counter and Passive Integrated Transponder Arrays in the Chowade River and Cypress Creek

Construction Year 3 (2017)

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September 4, 2018

Peace River Bull Trout Spawning Assessment – Resistivity Counter and Passive Integrated Transponder Arrays in the Chowade River and Cypress Creek (Mon-1b, Task 2b)

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Prepared for: BC Hydro – Site C Clean Energy Project

Ramos-Espinoza*, D., Burnett, N.J., Buchanan, J., and Putt, A. 2018. Peace River Bull Trout Spawning Assessment – Resistivity Counter and Passive Integrated Transponder Arrays in the Chowade River and Cypress Creek (Mon-1b, Task 2b). Report prepared for BC Hydro – Site C Clean Energy Project – Vancouver, BC. InStream Fisheries Research, Vancouver, BC. 69 pages.

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Executive Summary

Bull Trout migrations in the Chowade River and Cypress Creek were monitored in 2017 using resistivity counters and PIT arrays. After accounting for counter accuracy and kelting, we estimated that 22 and 27 Bull Trout migrated upstream past the counter sites in the Chowade River and Cypress Creek, respectively, between August 15 and October 02 (representing only a portion of the upstream spawning migration). Installation of equipment halfway through the upstream migration period prevented the collection of a complete dataset; however, the entire kelting (the migration of fish downstream after spawning) period was monitored. We estimated 319 and 91 Bull Trout kelts moved downstream past the Chowade River and Cypress Creek counter sites, respectively, between September 05 and October 02. Kelt migration timing appeared to be unimodal with approximately 50 percent of the total downstream migration at both sites occurring by September 16.

Counter data did not indicate a relationship between peak signal size and fish size, and we were unable to assign species by applying peak signal size cutoffs. Instead, all counter records were verified as true counts and identified to species through the video validation process. Video data were collected between August 17 and October 01 in the Chowade River and between August 15 and October 05 at Cypress Creek and were used to validate the counter data. All counter records between August 15 and October 05 (except for September 29 and 30 in the Chowade River) were reviewed and verified at both sites. Video validation indicated a counter accuracy for up counts of large bodied fish (Bull Trout) of 69% in the Chowade River and 55% at Cypress Creek, and unvalidated counter records were adjusted accordingly. Counter accuracies below 70% were likely a result of inappropriate counter gain settings, and modifications will be implemented in 2018 to address this concern.

PIT arrays were continuously operated from August 15 to October 05 in both the Chowade River and Cypress Creek. Due to electrical interference within the systems, we were only able to operate two antennas in each tributary for 12 days in the Chowade River and 6 days in Cypress Creek. Detection probabilities for each antenna were estimated through detailed read-range surveys, and indicated the arrays were highly effective at detecting PIT-tagged fish. Detection probabilities at both sites were >95% for 23 and 32mm tags and >77% for 12 mm tags. The PIT arrays detected 32 (10 Bull Trout and 22 Rainbow Trout) and 23 (13 Bull Trout and 10 Rainbow Trout) fish in the Chowade River and Cypress Creek, respectively. Detected fish were tagged through Mon-1b, Task 2c (Site C Reservoir Tributaries Fish Population Indexing Survey) and Mon-2, Task 2a (Peace River Large Fish Indexing Survey) of the Site C Fisheries and Aquatic Habitat Monitoring and Follow-up Program.

During the data collection period, river conditions were relatively stable (stage height varied by 16 cm in the Chowade River and 12 cm in Cypress Creek), resulting in favourable conditions for operating the resistivity counters and PIT arrays. Design improvements and power system modifications in 2017 were highly successful, and all equipment operated for the duration of the study period apart from a two-day video outage in the Chowade

River. We will continue to modify and improve the PIT power system in 2018 to improve the read range of 12 mm tags and manage electrical interference to allow for two antennas to be operated concurrently at each site throughout the migration period.

Acknowledgements

The Site C Peace River Bull Trout Spawning Assessment is funded by BC Hydro's Site C Clean Energy Project. We would like to thank Brent Mossop and Dave Hunter at BC Hydro, Kevin Rodgers, Dieter Mark, and all the support staff at Canadian Helicopters. InStream staff critical to the project include Doug Braun, Cole Martin, LJ Wilson, Mike Chung, Gillian Pool and Collin Middleton.

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1 Project Background

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

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

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

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

Historic data on Bull Trout in the Halfway River have been collected through various spawner assessment methods, including aerial, ground and snorkel surveys of Bull Trout redds. Redd surveys were conducted in 2016 (Braun et al. 2017b) and 2017 (Putt et al. 2018) and will continue to allow for comparison with baseline peak count data (Diversified Environmental Services and Mainstream Aquatics Ltd. 2009; 2011; 2013). Redd survey data will be supplemented with estimates of spawner abundance and movement data from electronic fish counters (i.e., resistivity counters) and passive integrated transponder (PIT) telemetry. Counter data will be compared to redd count estimates (Putt et al. 2018) and used to develop an understanding of the relationship between the number of Bull Trout spawners and the number of redds. In 2016, a pilot study was implemented to test the feasibility of installing and operating a remote resistivity counter and PIT array system. The pilot study was conducted in the Chowade River because of the historic high abundance of Bull Trout relative to other spawning streams in the Halfway Watershed and relative ease of accessibility (RL & L. Environmental Services Ltd. 1995, Diversified Environmental Services and Mainstream Aquatics Ltd. 2009; 2011; 2013). Results from the pilot study indicated that resistivity counters and PIT arrays could be effectively installed and operated in the Halfway Watershed (Braun et al. 2017a), and in 2017, the scope of the project was increased to include the Chowade River and Cypress Creek.

2 Introduction

Accurate abundance estimates are important for assessing the current and future status of fish populations. Historically, population estimates in the Chowade River, Cypress Creek, and other spawning tributaries of the Halfway River have been estimated from visual surveys of redds (Diversified Environmental Services and Mainstream Aquatics Ltd. 2009; 2011; 2013, Braun et al. 2017b, Putt et al. 2018). More recently, population indexing of juvenile salmonids in the Halfway Watershed has been conducted using electroshocking (Golder 2016, 2017). Visual surveys of redds can provide precise estimates of redd abundance and can be useful for monitoring changes in population abundance over time, but it is difficult to assess how accurately redd abundance estimates approximate spawning populations without knowing the number of spawners per redd (Dunham et al. 2001, Gallagher and Gallagher 2005). Population indexing for juveniles can provide catch information, but may not allow for accurate estimates of juvenile survival or recruitment. Alternative enumeration approaches, including resistivity counters and PIT arrays, can provide independent estimates of spawner abundance, migration timing, spawning duration, stage-specific survival (i.e., juvenile to subadult, subadult to adult), juvenile recruitment and fish size.

Resistivity counters can be up to 90% accurate for enumerating salmonids (Braun et al. 2016, Casselman et al. 2015), and offer advantages over other electronic fish counters including: relatively low purchase costs, low power demands, low maintenance, small footprint, and sensor customization to stream characteristics. However, resistivity counters are not appropriate in all streams, may not always meet the study objectives for monitoring programs (Braun et al. 2016), and their site-specific feasibility needs to be assessed. PIT telemetry uses arrays of antennas (i.e., an array consists of two or more antennas that allow users to determine direction of fish movement) to detect passive tags implanted into fish, and can be an effective method for tracking migration behaviour, growth, and survival (Brännäs et al. 1994). Furthermore, PIT telemetry allows for individual-based monitoring and tracking of fish throughout their life cycle.

The objective of this study was to enumerate spawning Bull Trout using resistivity counters and PIT arrays in the Chowade River and Cypress Creek. Specifically, the resistivity counters aimed to enumerate Bull Trout spawners, collect information on direction of movement (upstream or downstream), migration timing, spawning duration, and the size of spawners. The PIT arrays aimed to detect tagged Bull Trout and Rainbow Trout (*Oncorhynchus mykiss*) moving past (upstream or downstream) the counter site to determine the migration patterns and timing of adult and juvenile salmonids. Mon-1b, Task 2b will provide information for other FAHMFP monitoring programs modelling fish survival, movement and abundance.

3 Methods

We used resistivity counters, PIT arrays, and video cameras to monitor Bull Trout movement in the Chowade River and Cypress Creek from mid-August to the beginning of October. The resistivity counter counted upstream and downstream movements of fish past the site, while the video cameras continuously monitored the counter pads (video data were used to validate the counter data). A two-antenna PIT array was also installed to detect the directional movements of PIT-tagged Bull Trout and Rainbow Trout moving upstream or downstream past the site.

3.1 Study Sites

Pilot studies in 2016 identified two study sites in the Upper Halfway Watershed, one in the Chowade River and one in Cypress Creek. Sites were selected because they provided access needed for the installation and removal of equipment and were downstream of the known extent of Bull Trout spawning (Diversified Environmental Services and Mainstream Aquatics Ltd. 2009; 2011; 2013). Counter sites were also characterized by suitable stream characteristics for deploying and effectively operating the resistivity counters and PIT arrays (i.e., good flow conditions, substrate and riverbed profile). We selected sites with reduced visibility from the access point to reduce potential public interference. In 2017, counter and PIT installations began on August 09 and were completed at both sites by August 17. The installation date was three weeks later than in 2016 and thus a substantial portion of the upstream migration was likely missed based on the timing of upstream movements observed previously (Braun et al. 2017a). The equipment was operated until October 01 in the Chowade River and October 05 at Cypress Creek, when the migration period was complete.

3.1.1 Chowade River

The resistivity counter and two-antenna PIT array in the Chowade River began operating on August 17, at the same location as the pilot study in 2016, 21.7 river kilometers upstream of the Halfway River confluence (Figure 1).

The Chowade River is a fifth order stream with a mainstem length of 87.1 km. Resident fish species include Bull Trout, Rainbow Trout, Arctic Grayling (*Thymallus arcticus*), Mountain Whitefish (*Prosopium williamsoni*) and Slimy Sculpin (*Cottus cognatus*). Adult Bull Trout typically migrate upstream past the counter site from late July to early September, and their downstream migration occurs from late August to early October (R.L. & L. Environmental Services Ltd. 1995 and Braun et al. 2017a).

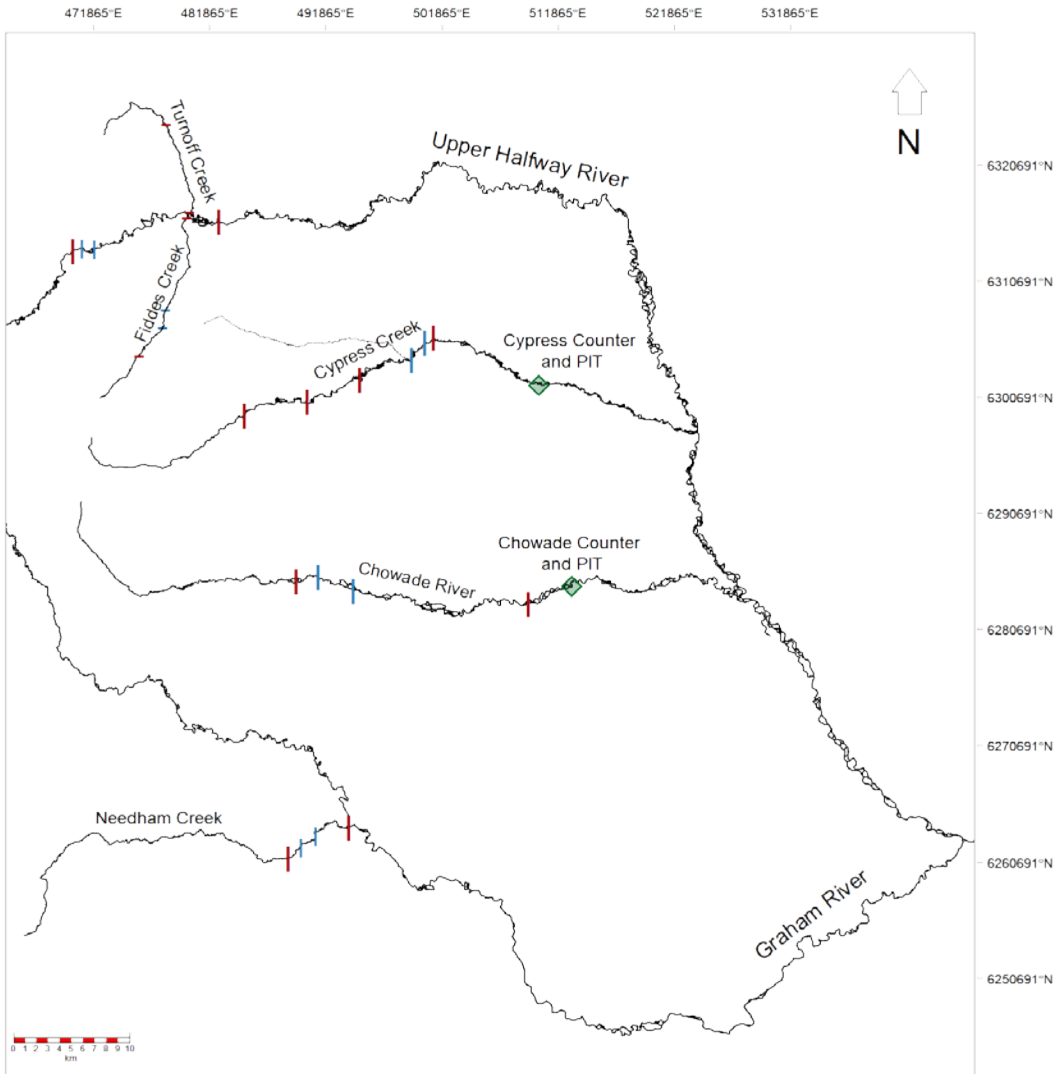


Figure 1. Map of the Halfway Watershed above the Graham River and all fourth order and larger streams. Red lines and blue lines are the boundaries for aerial and ground redd surveys (respectively) conducted as part of Mon-1b Task 2b in 2017. Green diamonds indicate the locations of the resistivity counters and PIT arrays.

3.1.2 Cypress Creek

The resistivity counter and two-antenna PIT array in Cypress Creek began operating on August 15, at 16.9 river kilometers upstream of the Halfway River confluence (Figure 1). Cypress Creek is a fifth order stream with a mainstem length of 81.7 km. Resident fish species are similar to those observed at the Chowade River and include Bull Trout, Rainbow Trout, Arctic Grayling, Mountain Whitefish and Slimy Sculpin (Golder 2016, Golder 2017). Adult Bull Trout are believed to typically migrate upstream past the counter site from late July to early September, and their downstream migration occurs from late August to early October (Mainstream Aquatics Ltd. and Euchner, 2009).

3.2 Environmental Conditions

We recorded water depth at both study sites from installation to removal to relate water depth at the study sites to discharge in the Upper Halfway River (Water Survey of Canada Station 07FA003). Two HOBO U20 (Onset Computer Corporation, Bourne, MA, USA) water level loggers were deployed at each site. One logger was installed in a stilling well within the wetted stream width (recording stage height), while a second logger was installed on-shore (recording ambient air pressure) to calibrate the wetted logger. Hourly water depth was calculated from the pressure measurements using HOBOware Pro (Version 3.7.10).

Discharge and water level data for the hydrometric station located in the Halfway River (Station Name: Halfway River above Graham River; Station No: 07FA003) downstream of the confluence between the Chowade River and Halfway River were provided by the Water Survey of Canada. Data collected in 2017 were used to determine if the Halfway River hydrometric station, which provides real-time data outputs, could serve as a proxy for the water depth at the Chowade River and Cypress Creek counter sites. We examined the relationship between the Halfway River discharge and water depth at each counter site using Pearson's correlation coefficient (r). A strong relationship between two sites would suggest that the Halfway River could be used as an indicator of the water depth at the counter site and would help inform pre-season planning and in-season management of the counter, such as installation dates, site visit timing, and potential data gaps.

3.3 Remote Power Systems

One of the main operational challenges in 2016 was power outages due to poor weather conditions and inadequate power supply (see Braun et al. 2017a). Power was insufficient to maintain the equipment used on site. This system was designed to allow the daily power generation (assuming 8 hours of solar radiation) to be greater than the daily power draw and thus ensure the system operational. If solar conditions were poor or non-existent, the battery bank would only operate the system for two to three days. Power systems in 2017 were redesigned so that if poor solar conditions occurred, the battery bank would allow the systems (i.e., resistivity counter, video validation equipment, PIT array) to operate for seven days to match the time between site visits.

At each site, three separate battery banks paired with the appropriate number of solar panels were used to power the resistivity counter, video validation equipment and PIT array (Table 1 and Figure 2). This allowed us to compartmentalize and maintain consistent power to high priority equipment, specifically the resistivity counters and PIT arrays. Each battery bank was capable of supplying enough power, independent of solar power generation, to last a minimum of seven days, based on equipment power demands field tested by IFR staff in spring 2017. The number of solar panels would provide a surplus of power for charging, using a conservative estimate of 4 hours of solar radiation *versus* the 8 hours assumed in 2016 calculations. Our assumptions were key for operations in September when solar radiation decreases due to shorter days and the decrease in the solar window. If solar conditions had been poor and the system had been exhausted when crews arrived for a site visit, an on-site generator was used to recharge the battery banks.

This allowed crews to top up the battery bank while on site and thus ensure each week began with a fully charged battery bank.

Table 1. Description of the power system design for the Chowade River and Cypress Creek in 2017.

Power system	Daily power draw (Ah)	7-day power draw (Ah)	Solar design	Number of 12 V batteries	Capacity of the battery bank (Ah)	Daily charge potential (Ah)		Calculated duration (days) of equipment with no solar	Field test duration (days) of equipment with no solar
						7 hours of effective solar time	4 hours of effective solar time		
Counter	36	252	One solar panel	2	364	70	40	10.1	14.0
PIT array	156	1092	Three solar panels	6	1092	245	140	7.0	9.0
Computer and DVR	168	1176	Three solar panels	7	1274	245	140	7.6	7.0

Figure 2. Power system configurations used in the Chowade River and Cypress Creek, 2017. Panel A shows the solar panel setup, panel B depicts the video validation and computer battery bank, panel C depicts the battery bank used for the resistivity counters and PIT arrays, and panel D depicts the resistivity counter and computer/DVR system.

3.4 Resistivity Counter Operations

The Logie 2100C resistivity counter (Thurso, Caithness, Scotland) operates in conjunction with up to four electrode sensors (e.g., flat pad sensors) that span the channel width to detect the upstream and downstream movement of fish over the sensors. The counter measures the resistance between two pairs of electrodes: one pair consists of the downstream electrode and the center electrode, and the other pair consists of the upstream electrode and the center electrode. The measured resistance is a function of water conductivity. There is a change in resistance when a fish swims over the electrodes (the fish is more conductive than the water it displaces), and this change is recorded by the counter. A fish moving over the sensor pad creates a change in resistance which is then interpreted by the counter algorithm to determine if it is consistent with that of a fish and the direction is recorded along with a date and time stamp.

Each counter record can be classified as one of the following: (1) up, (2) down, or (3) event. If the change in resistance is determined to not follow a typical trace but the values reach some predefined threshold value, the record is classified as an event instead of an up or down count. Events can be due to a fish interacting with the electrodes but not completely passing over the three electrodes or from electrical noise. For each record (ups, downs or events), the counter also records the peak signal size (PSS) that corresponds to the peak of a sinusoidal curve that is created when a fish passes over the sensor pad (Figure 3). PSS is related to mass and can thus be used as a proxy for fish size (McCubbing et al. 2000) or species if there is a clear difference in size among species.

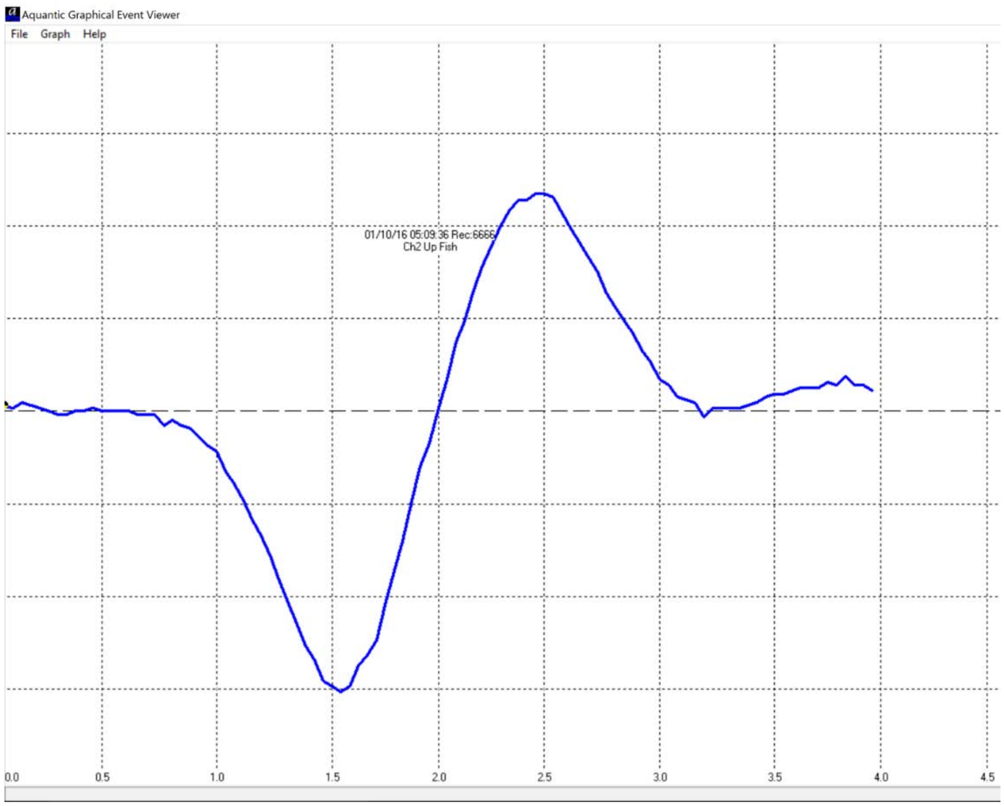


Figure 3. Example graphical trace (sinusoidal curve) showing a true up movement with two equal but opposite peaks, indicating the size and direction of the fish movement. The counter algorithm applies specific criteria to each record, which allow for some flexibility in the ratio of the peaks.

Flat pad sensor units (8’ x 2’) were constructed out of nonconductive material and were used as the support structure for the three electrodes. The white background used on the sensor pads in the pilot year was removed to reduce drag and the likelihood of sensor pads drifting away during high water events. Instead, we fixed two, 6” strips of white puck board between each set of electrodes, enabling higher visibility for video validation while reducing the risk of the sensor pads being scoured during high water events.

Six sensor pads covered the entire channel width (14.6 m) of the Chowade River. We used a sensor configuration of four channels. Channels 1 to 3 were placed where the water was deepest and the majority of fish movement was expected, while Channel 4 spanned a larger section of the river using two connected 8-foot pads (Figure 4). Four sensor pads covered the channel width (12 m) of Cypress Creek. We used a sensor configuration of four channels and all channels spanned equal sections of the channel (Figure 4). PIT antenna placement and design is discussed in detail in Section 3.5.1.

Electrical equipment, consisting of the resistivity counter, Digital Video Recorder (DVR), computer, PIT reader and power system, was positioned on the river right bank at both sites. All of the equipment was stored in four large, steel 4-foot job site boxes. A custom-built desktop computer that served as a DVR and resistivity counter interrogation unit was operated 24 hours a day and was housed alongside the resistivity counter (Figure 2D). Four video cameras were placed directly above the sensor pads on a cableway system (Figure 4) and centered to capture the full span of the pad. Additionally, background LED lights were installed along-side the cameras in 2017 to reduce glare and 'spot lighting' effects during high contrast conditions at night. The DVR was operated 24 hours a day and all four cameras recorded video in five-minute segments and the footage was stored in dedicated hard drives within the computer.

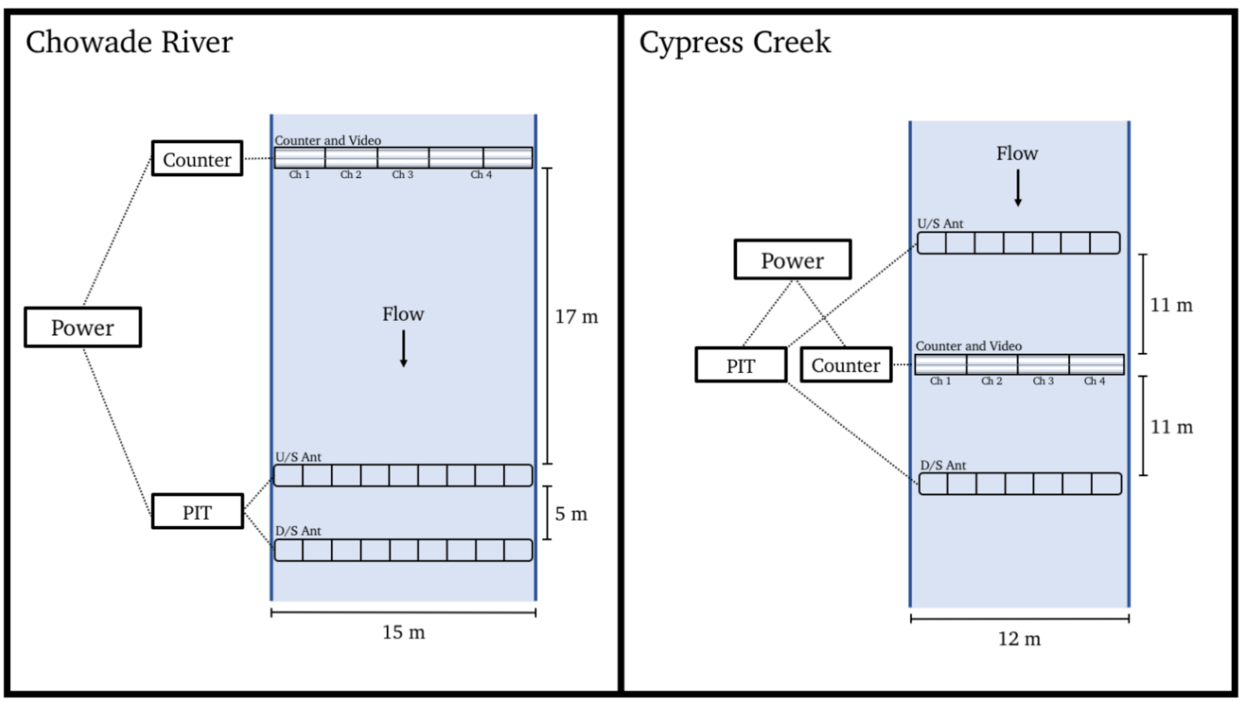


Figure 4. Configuration of the resistivity counter sensor pads, power system and video validation system in the Chowade River and Cypress Creek, 2017.

3.4.1 Counter Validation

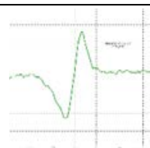
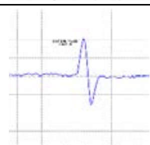
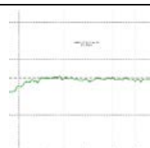
Raw counter data (i.e., graphical traces of up movements, down movements, and unclassified events) were validated using the video record to determine the number of true positives, false positives, and false negatives (Table 2), and to calculate counter accuracy. We used a multi-step validation process that included both targeted validation of counter up and down counts, and random validation of additional video data (see validation process detailed in Figure 5). In the rare event that video data were unavailable to validate a counter event (e.g., due to power outages, high turbidity, or camera issues), the counter record in question was included in the final count but could not be included in the accuracy estimate.

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

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

Raw Counter Measurement

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

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

Targeted Video Validation

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

Random Video Validation

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

Calculate Error Rates and Accuracy

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

Figure 5. Counter validation protocol used in 2017.

During targeted validation, each graphical trace (up or down) was verified by watching the corresponding video data and an additional one minute of video before and after. The two-minute time bracket accounted for minor time-stamp discrepancies between the counter and the video records (the two systems were synchronized regularly but may still retain residual discrepancies) and allowed the analyst to verify movements that were recorded by the counter as multiple records (this occurs when a fish moves slowly over the counter or travels in an erratic manner). Fifteen hours of video footage were reviewed for targeted validation for the Chowade River, and 5 hours of video footage for Cypress Creek. The disparity of effort between sites was due to the higher number of counter records (and therefore fish) in the Chowade River relative to Cypress Creek.

We also reviewed a subset of randomly-selected video segments to determine the number of false negatives (i.e., a fish was observed on the video but the counter recorded no trace). For each full day of video, 20 randomly-selected 10-minute segments of video were reviewed and false negatives were recorded. The amount of video watched was based on estimated population size, number of fish expected to be validated, total number of hours available to be validated, and time constraints (Braun et al. 2016). Over 165 hours of video footage were reviewed for random validation for the Chowade River and 179 hours were reviewed for Cypress Creek, representing approximately 16% of the total video available for analysis at each site. The total number of false negatives was determined by expanding the validated count based on the proportion of video validated (combined validation hours from targeted and random validation, Chowade River – 180 hours, Cypress Creek – 184 hours) and total hours of video data collected.

The numbers of true positives (TP), false positives (FP), and false negatives (FN) were used to calculate counter accuracy, summarized by direction (up and down), species (Bull Trout, Mountain Whitefish, etc.), and counter channel:

Equation 1
$$A = \frac{TP}{TP + FP + FN}$$

Accuracies were used to assess the performance of the counter, and to adjust the counter estimate to obtain final estimates of abundance (see details in Section 3.4.3).

3.4.2 Length Measurements and Species Determination

A length measurement was taken from each fish observed during video validation to aid with species determination and to develop a length vs PSS relationship for both the Chowade River and Cypress Creek. The true length of a fish measured on the video was determined using the ratio of the on-screen pad length and on-screen fish length:

Equation 2 $$FL_T = \frac{FL_m}{PL_m}\ x\ PL_T$$

where FL_T is the true fish length, FL_m is the fish length as measured on the video screen, PL_m is the distance between electrodes at the point where the fish crossed as measured on the video screen, and PL_S is the true distance between the upper and lower electrodes on the counter pad (60 cm).

During video validation, fish were identified to species (Bull Trout, Mountain Whitefish, or Rainbow Trout) based on length (R.L. & L. Environmental Services Ltd. 1995), colouration (e.g., white-leading edge of the pectoral fins for Bull Trout), and body shape (e.g., narrow and small-bodied for Mountain Whitefish). In the unlikely event that the species could not be identified or agreed upon by two independent analysts (e.g., during low visibility conditions), the species was classified as unknown.

3.4.3 Migration Timing

The Bull Trout migration can be categorized as three different movement behaviours observed at the Chowade River and Cypress Creek study sites:

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

These three movement behaviours overlap during the spawning migration, and the approximate date of the kelting onset must be determined prior to estimating abundances for up-migrating and kelting Bull Trout.

The onset of the kelt out-migration in the Upper Halfway Watershed varies annually, but typically begins in late August or early September (R.L. & L. Environmental Services Ltd. 1995). Prior to the kelting onset, downstream movements were considered recycling, or the movement of fish up and down over the counter sensors and these down counts were subtracted from the up counts. Recycling and kelting can be distinguished because the number of recycling events generally mirrors that of daily up-counts, while kelting generally follows a normal distribution. The parameters of the normal distribution can be estimated by fitting a normal probability density function to downstream migration data. This approach has been successfully used to estimate the timing and abundance of Steelhead Trout (*O. mykiss*) kelts in the Bonaparte River (Ramos-Espinoza et. al. 2017).

We fit a normal probability density function to daily down counts from September 01 to October 02 by minimizing the sum of squares of the predicted and observed count data. We selected these dates to represent the start and end of the kelting period based on data previously collected in the Upper Halfway Watershed (R.L. & L. Environmental Services

Ltd. 1995). We estimated the mean, standard deviation and a scale parameter, which transformed the probabilities into daily counts. We then used these parameters to predict the daily number of kelts migrating downstream throughout the full migration period between September 01 to October 02. The fitted mean of the normal distribution represents the peak date of the kelt migration while the sum of the scale parameter provides an estimate of the total number of kelts. We defined the date of kelting onset as the date when 5% of the kelts had migrated according to the daily kelt abundances predicted by the normal model.

In future years, recycling and downstream movements can be confirmed using PIT detection data. Data from individual PIT-tagged Bull Trout can be used to determine the date when the individual migrated upstream, whether recycling events were associated with the upstream migration, and the exact date when kelting occurred.

3.4.4 Abundance Estimates

Bull Trout abundance estimates were generated for both upstream and kelting migrations past the counter site. In 2017, the upstream abundance estimate captured only a portion of the run (i.e., Bull Trout began migrating prior to counter installation), while the kelting abundance encompassed the entire kelting period. The estimated abundance for the upstream migration was calculated using:

Equation 3
$$E_U = \sum_{t=1}^{k} \left(\frac{\mathrm{U_t}}{\mathrm{A_u}} - \frac{D_t}{\mathrm{A}_d} \right) + \sum_{t=k}^{n} \frac{\mathrm{U_t}}{\mathrm{A_u}}$$

where E_U is the up-migration abundance estimate, U_t is the total number of counter upstream counts, D_t is the corresponding number of downstream counts, A_u is the upstream counter accuracy, A_d is the downstream counter accuracy, k is the date of kelting onset, and n is the date of the latest confirmed Bull Trout up-count. The estimated abundance for the kelting migration was calculated using:

Equation 4
$$E_k = \sum_{t=k}^{j} \frac{\mathrm{D_k}}{\mathrm{A_d}}$$

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

3.5 PIT Telemetry Operations

3.5.1 Antenna Design, Power and Operations

PIT arrays were operated in the Chowade River and Cypress Creek in 2017 to detect fish tagged under Mon-1b, Task 2c (Site C Reservoir Tributaries Fish Population Indexing Survey) and Mon-2, Task 2a (Site C Peace River Large Fish Indexing Survey). Due to high flows in 2016 (Braun et al. 2017a) that created poor conditions for maintaining PIT antennas, we aimed to design PIT antennas in 2017 with a robust frame that could withstand high flow events. Following discussions with Oregon RFID, we constructed four rigid framed pass-over antennas to create two-antenna arrays at each site. Antennas were designed to lie flat on the streambed and were anchored with Duckbill earth anchors so that fish would have to swim over the antennas to be detected. Antennas were 13.5 × 1.25 m in the Chowade River and 10.5 × 1.25 m at Cypress Creek and were constructed out of 1.5” ABS pipe with cross braces every 1.5 m to maintain a rigid frame (Figure 6A). Sandbags were placed on each cross brace to pin the antennas to the streambed (Figure 6B). Each antenna frame housed 10-gauge stranded copper wire that was connected to a remote tuner box (Oregon RFID, Portland, OR) and a multi reader (Oregon RFID) via twin-axial cable. We manually tuned and tested antennas to ensure optimal read range and tag reading performance. Antennas were fully operational by August 17 and 16 in the Chowade River and Cypress Creek, respectively.

Antennas were powered by a battery bank that was maintained by solar panels (Table 1). Our power systems provided sufficient power to operate two antennas continuously, however we experienced unforeseen technical challenges associated with electrical components interacting with each other and creating electrical noise. Such noise affected the read range of the antennas and the operation of the resistivity counter. As a result, the read range of one of the two antennas was marginal while the read range of the other antenna was dramatically reduced. Consequently, we were only able to effectively run two antennas from September 10 to 22 and September 17 to 22 in the Chowade River and Cypress Creek, respectively. One antenna ran continuously at each site outside of these time periods until the removal of equipment in early October.

We installed the Chowade River PIT array 17 m downstream of the resistivity counter to avoid electrical interference with the resistivity counter (Figure 4). We were unable to install the antennas upstream and downstream of the counter pads (i.e., ‘straddle’ the counter pads) due to unsuitable streambed characteristics upstream that would not promote active upstream movements by tagged fish through the read range. Comparatively, we installed the antennas at Cypress Creek 11 m upstream and 11 m downstream of the counter pads due to suitable streambed characteristics throughout the read range (Figure 4). Antennas were placed farther away from the counter pads in the Chowade River as the larger antennas (13.5-m *versus* 10.5-m long in Cypress Creek) produced larger magnetic fields that interacted with the counter pads from a greater distance.

We discuss ways in which we attempted to address this issue during data analysis as well as operational considerations for future years to permit continuous monitoring from both antennas at each site (see Section 5.2).

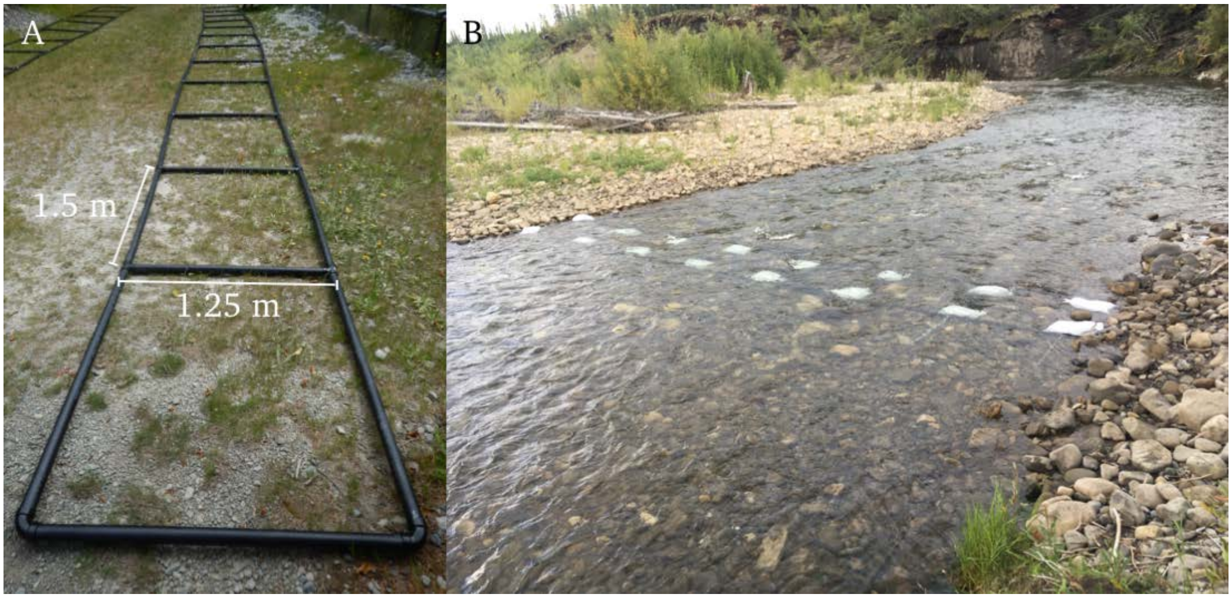


Figure 6. PIT antenna design (A) and deployment (B) at Cypress Creek, 2017.

3.5.2 Read Range Surveys

We conducted detailed read range testing of the antennas during each site visit to develop an understanding of the read range of the PIT arrays during the monitoring period. Five surveys were conducted at each site between the end of August and early October. During a survey, we measured the following parameters (in meters) at each cross brace of the frame (every 1.5 m) along the length of the antenna:

(1) Water depth – distance from streambed to water surface
(2) Antenna depth – distance from top of antenna to water surface
(3) Detection range of 12, 23 and 32 mm PIT tags – distance from the antenna to the depth at which the antenna could no longer detect the test tag

We measured water depth to account for variation across surveys and antenna depth to account for sections of the antennas that did not lie flat on the streambed. We then determined the proportion of the water column that was readable for the three sizes of PIT tags deployed under other FAHMFP monitoring programs. Summarizing these data across the five surveys yielded an estimate of the proportion of the water column that was readable.

3.5.3 Movement Ecology

We summarized the movement of fish detected on the Chowade River and Cypress Creek PIT arrays to identify critical time periods in which upstream and downstream movements occurred as well as patterns in diel movement (Appendix A). Tagging and sampling information for PIT-tagged fish was obtained from Dustin Ford (Golder Associates Ltd.) and is summarized in Appendix B.

We used detections from both upstream and downstream antennas to determine direction of movement when both antennas were operational. During times in which only one antenna was operational, we attempted to determine the direction of movement by identifying PIT-tagged fish in the resistivity counter and video data. Considerable time discrepancies between the PIT reader and the resistivity counter and video at Cypress Creek made it challenging to confirm direction of movement. We comment on ways to address this issue in future years in Section 5.2 below.

3.5.4 Data Analysis

Data were downloaded from PIT readers during each weekly site visit and safely stored on the on-site computer. We collated raw PIT files using the PITR package (Harding et al. 2018) developed by IFR. Detection efficiency was calculated using PITR during the time periods in which two antennas were running at each site. Further data analysis and summary was performed in RStudio (Version 1.1.383; RStudio, Inc. 2017).

4 Results

4.1 Chowade River

4.1.1 Environmental Conditions

Discharge measured in the Halfway River and the water depth measured at the Chowade River counter site were strongly correlated (when Halfway River discharge is log transformed: $r=0.86$; $p<0.001$) (Figure 7A). Average water depth at the counter site between August 15 and September 30 was 0.27 m (range: 0.22 to 0.38 m), which was favorable for the deployment and operation of instream equipment (Figure 7B).

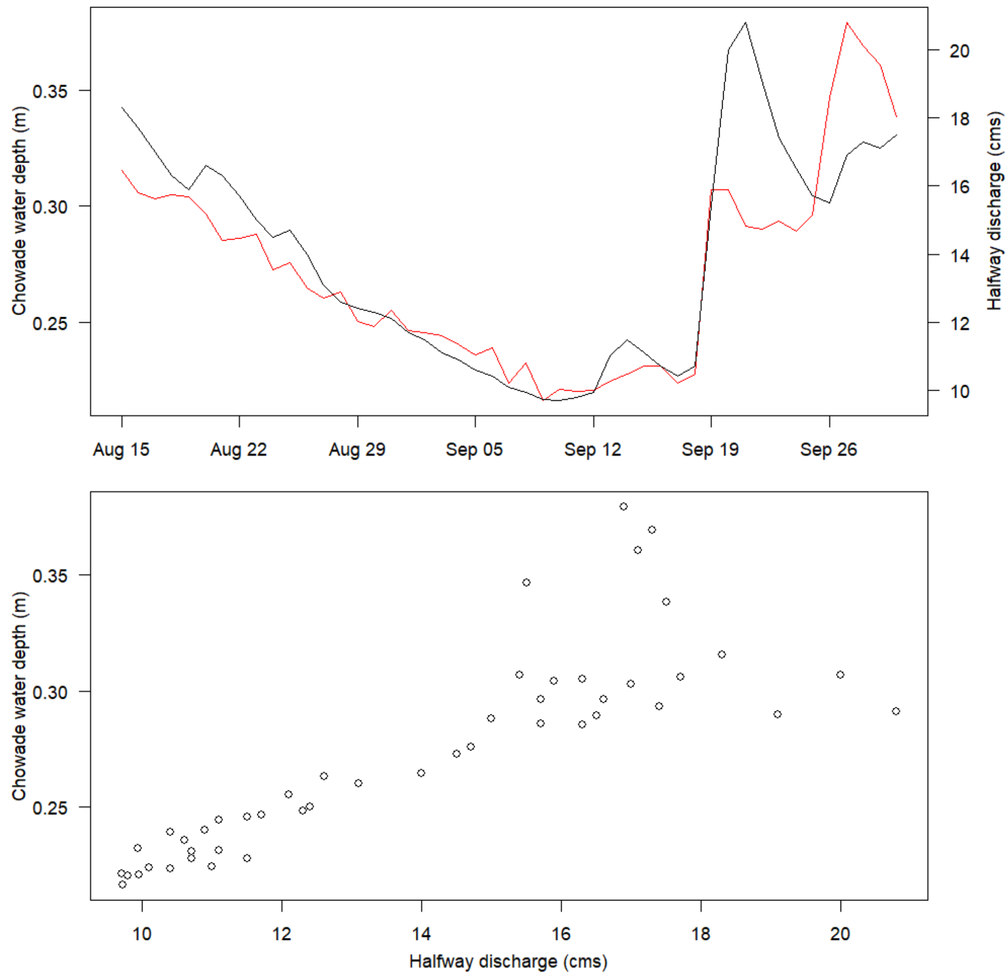


Figure 7. (A) Daily means of Halfway River discharge (black line) and Chowade River water depth (red line). (B) The relationship between the Halfway River discharge (Station 07FA003) and water depth at the Chowade River counter site from August 15 to September 30, 2017.

4.1.2 Resistivity Counter

4.1.2.1 Counter Validation

During counter video validation, fish were identified and sorted by species into (1) large Bull Trout (≥40 cm), (2) Mountain Whitefish, and (3) Rainbow Trout (Figure 8 A & B). An additional category included small bodied fish (<40 cm) that could not be identified to species (Rainbow Trout, Arctic Grayling and Bull Trout) (Figure 8C). In 2017, the addition of the LED lights and new background improved the quality of the night footage and all fish were identified as Rainbow Trout, Bull Trout, or Mountain Whitefish. No fish were included in the small-bodied fish category (Figure 9).

It was difficult to enumerate Mountain Whitefish due to their schooling behaviour (Figure 8B). Rainbow Trout and Arctic Grayling may have been present but were difficult to identify because there were few distinguishing characteristics that could be viewed on the overhead cameras (Figure 8C); therefore these species were included in the small-bodied fish category. Bull Trout usually appeared large-bodied with the white-leading edges on the pectoral fins obvious when viewed from above. Mountain Whitefish appeared smaller-bodied with pointed noses and generally crossed the counter pads in large schools. A small portion of fish could not be verified/identified on video (5 of 533 images). Unidentified fish generally crossed the pads at night in low visibility areas and could not be clearly observed for confident identification or the fish did not fit the characteristics of any of the classifications listed above.

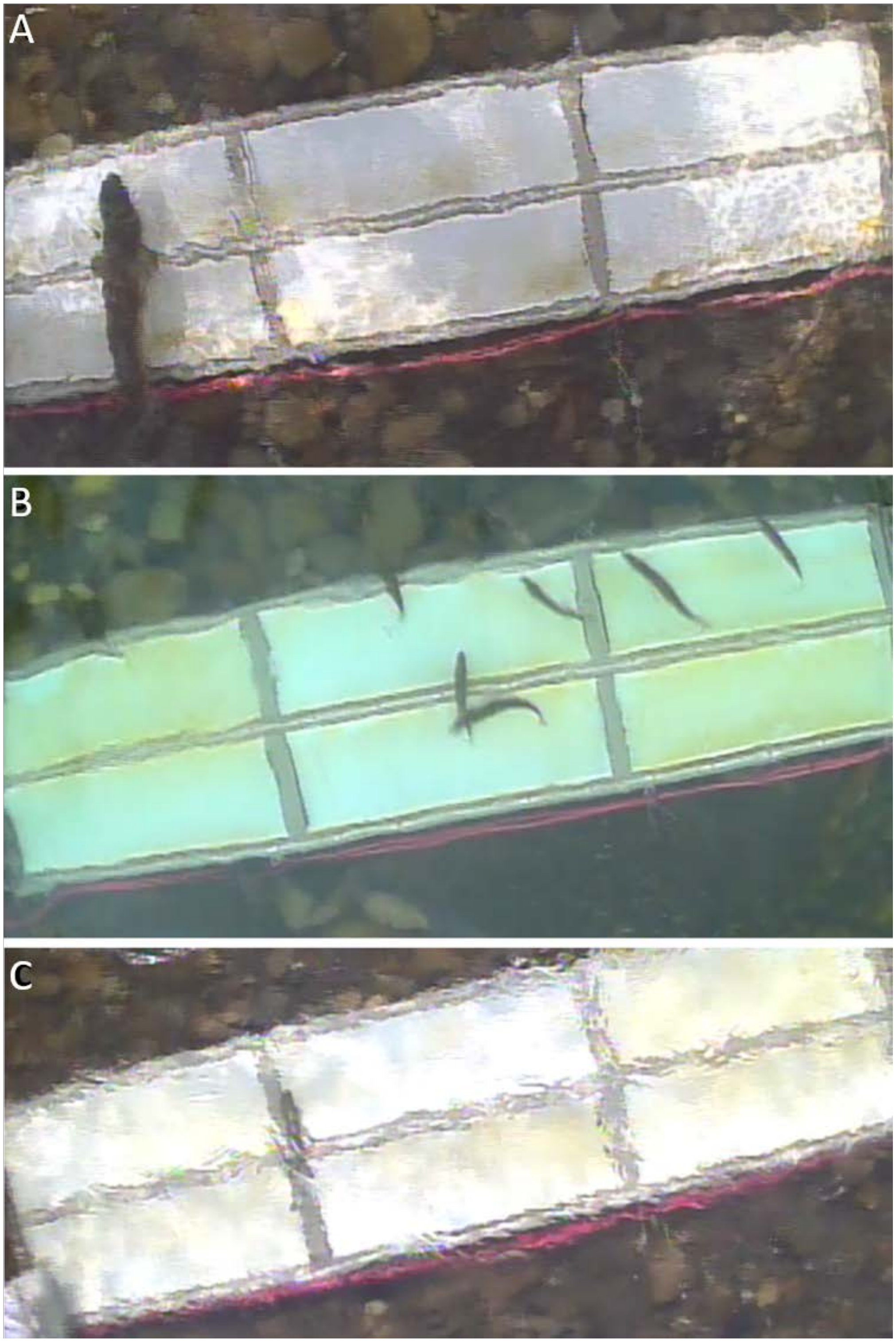


Figure 8. Example of species identification from video footage: (A) large-bodied Bull Trout, (B) small school of Mountain Whitefish, and (C) species unknown.

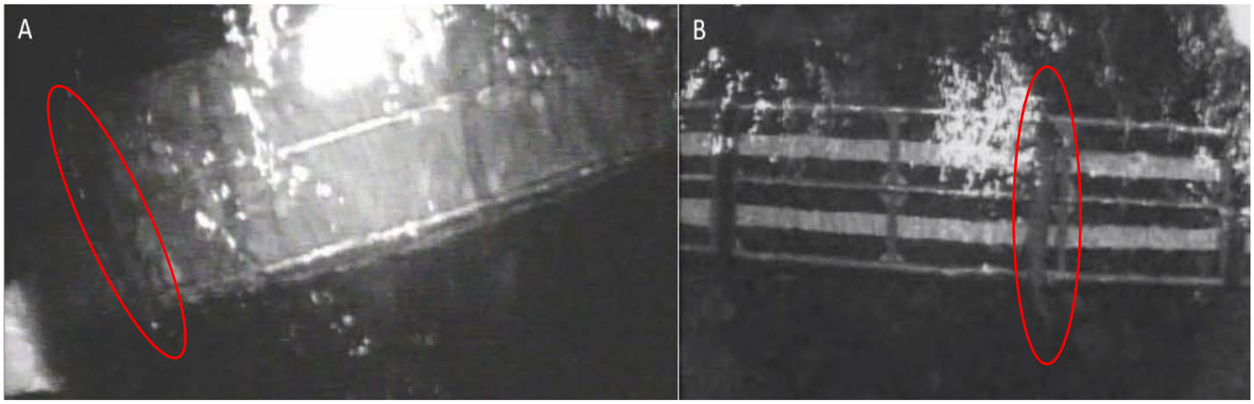


Figure 9. Photos comparing the night video from 2016 (A) and 2017 (B). Note the reduced glare ('spot lighting' effects) and clearer image in 2017. Note that there is a large Bull Trout in each of the frames (circled in red).

Fish lengths estimated from video footage were similar to lengths measured in the Chowade River in 2016 (Table 2). Using the fish identified to species from the video, we examined the relationship between the standard length measured from the video and the PSS measured by the counter. We did not find a comparable positive relationship between standard length and PSS to that observed in 2016. Only Channels 2 and 4 had a positive PSS vs length relationship, and we determined a PSS cutoff of ≥60 distinguished Bull Trout and Mountain Whitefish (Figure 10) and minimized the overlap between the two species' PSS size distributions (Figure 11). Due to the inconsistencies between channels and because we were able to verify all the fish using video, we relied on video validation to assign species to each trace.

Table 3. Comparison of fish lengths estimated in the Chowade River through video validation in 2016 and 2017. All fish were identified to species in 2017 so no data exists in the small salmonids category.

	2016				2017			
Species	**N**	**Mean (mm)**	**Range**	**SD**	**N**	**Mean (mm)**	**Range**	**SD**
Mountain Whitefish	187	240	110-490	70	156	323	120-494	44
Rainbow Trout	-	-	-	-	11	326	300-343	17
Bull Trout	30	700	410-930	120	361	613	300-1080	143
Small- bodied Fish<40 cm (may include Rainbow Trout, Arctic Grayling, and Bull Trout)	2	330	300-360	40	-	-	-	-

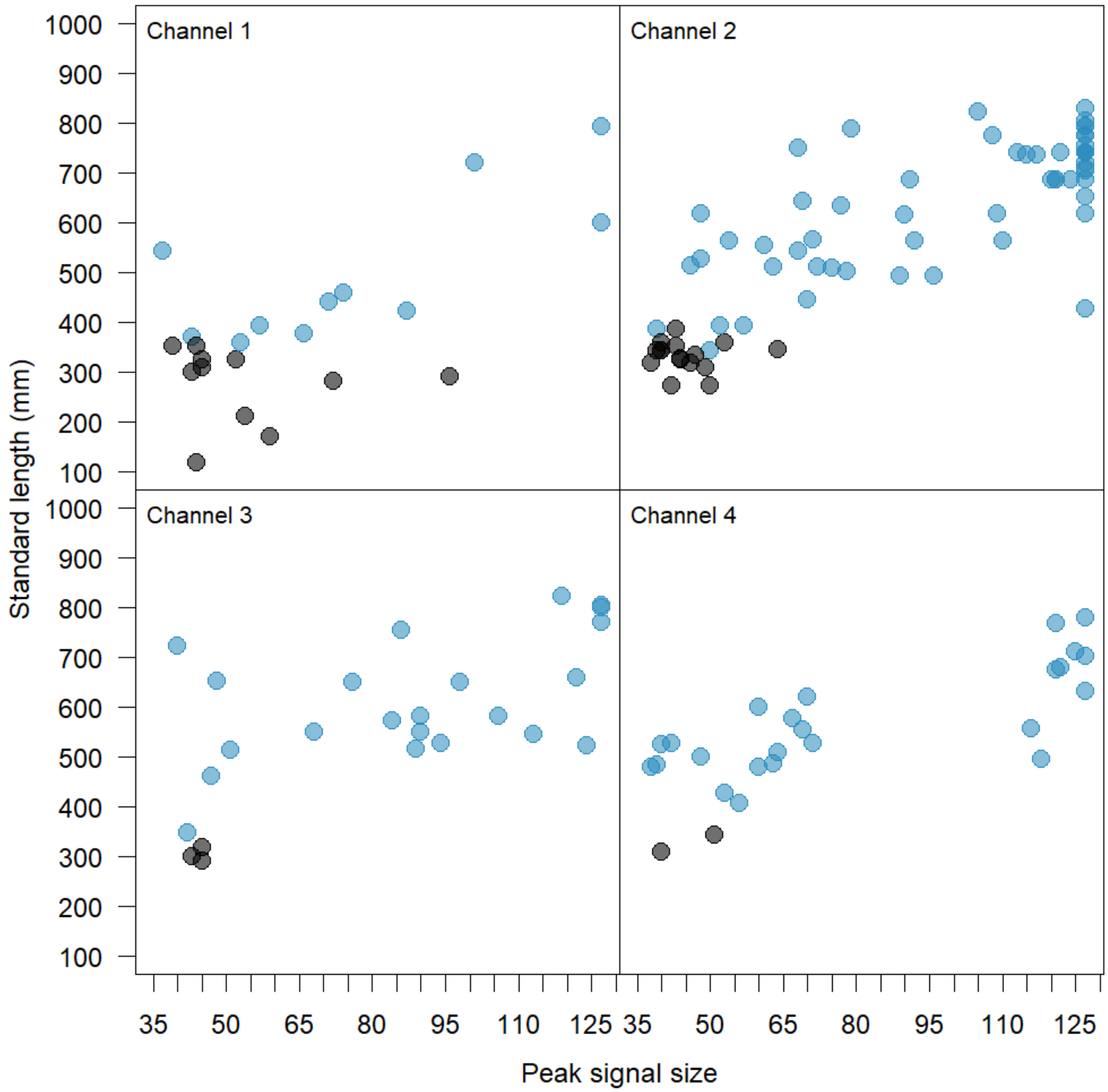


Figure 10. Peak signal size relationship to standard length (mm) of Bull Trout (blue) and Mountain Whitefish (grey) observed moving upstream during video validation on each counter channel.

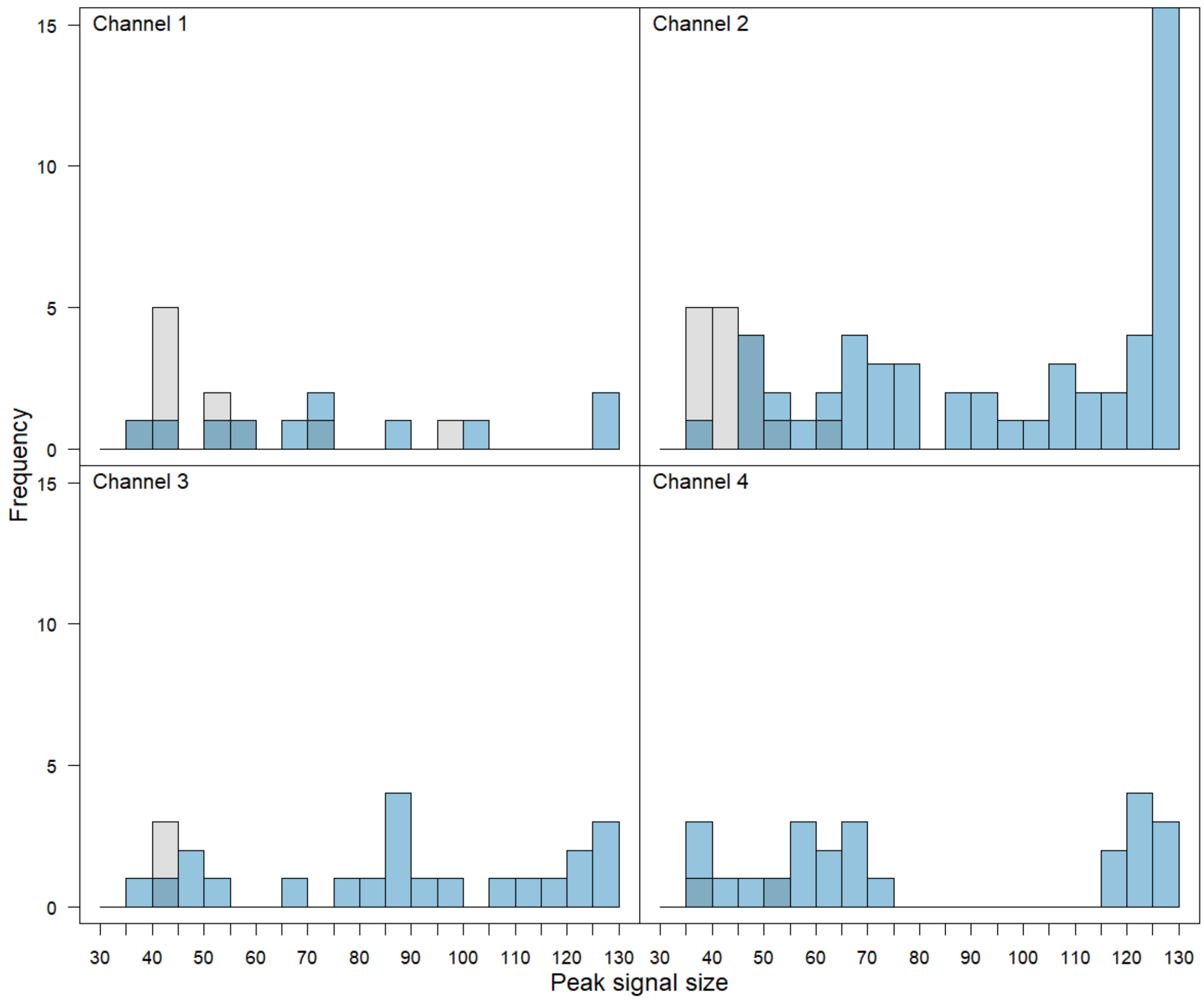


Figure 11. Frequency distribution of peak signal sizes for confirmed Bull Trout (blue) and Mountain Whitefish (grey) observed during video validation.

The counter underestimated the number of Bull Trout moving upstream over the counter with an accuracy of 69% (Figure 5; Table 4). Downstream movements were also underestimated for Bull Trout with an accuracy of 45%. As expected, the accuracy for Mountain Whitefish was much lower at 22 and 4% (both underestimating) for up and down counts, respectively.

Table 4. Summary of counter accuracy data for Bull Trout and Mountain Whitefish, Chowade River 2017. Summary of counter accuracy data for Bull Trout and Mountain Whitefish, Chowade River 2017.

Species	Direction	True (+)	False (+)	False (-)*	Accuracy (%)
Bull Trout	Up	112	0	50	69 (under est.)
Bull Trout	Down	202	0	244	45 (under est.)
Mountain Whitefish	Up	24	2	81	22 (under est.)
Mountain Whitefish	Down	21	3	469	4 (under est.)

*Expanded from random video validation of 16% of video footage

Channels 2, 3, and 4 had similar upstream accuracies ranging from 64 to 69%, but Channel 2 was most actively used by Bull Trout (49% of upstream movements) and had an accuracy of 69% (Table 5 and Figure 12). Channel 1 was not used as frequently by fish for upstream movements but had an accuracy of 100% with no false positives or false negatives observed. For downstream movements, both Channels 2 and 3 were used more frequently but each had different accuracies (38 and 54%, respectively) (Figure 12). Channels 1 and 4 had similar downstream accuracies of 43 and 46%, respectively. Low and variable downstream and upstream accuracies were likely due to the different water depths where the pads were located. Channel 2 was located in the deepest section of the river.

Table 5. Summary of counter accuracy data for Bull Trout on each counter channel, Chowade River 2017.

Direction	Channel 1	Channel 2	Channel 3	Channel 4	Avg (SD)
Up	100%	69%	64%	66%	75% (17%)
Down	43%	38%	54%	46%	45% (7%)

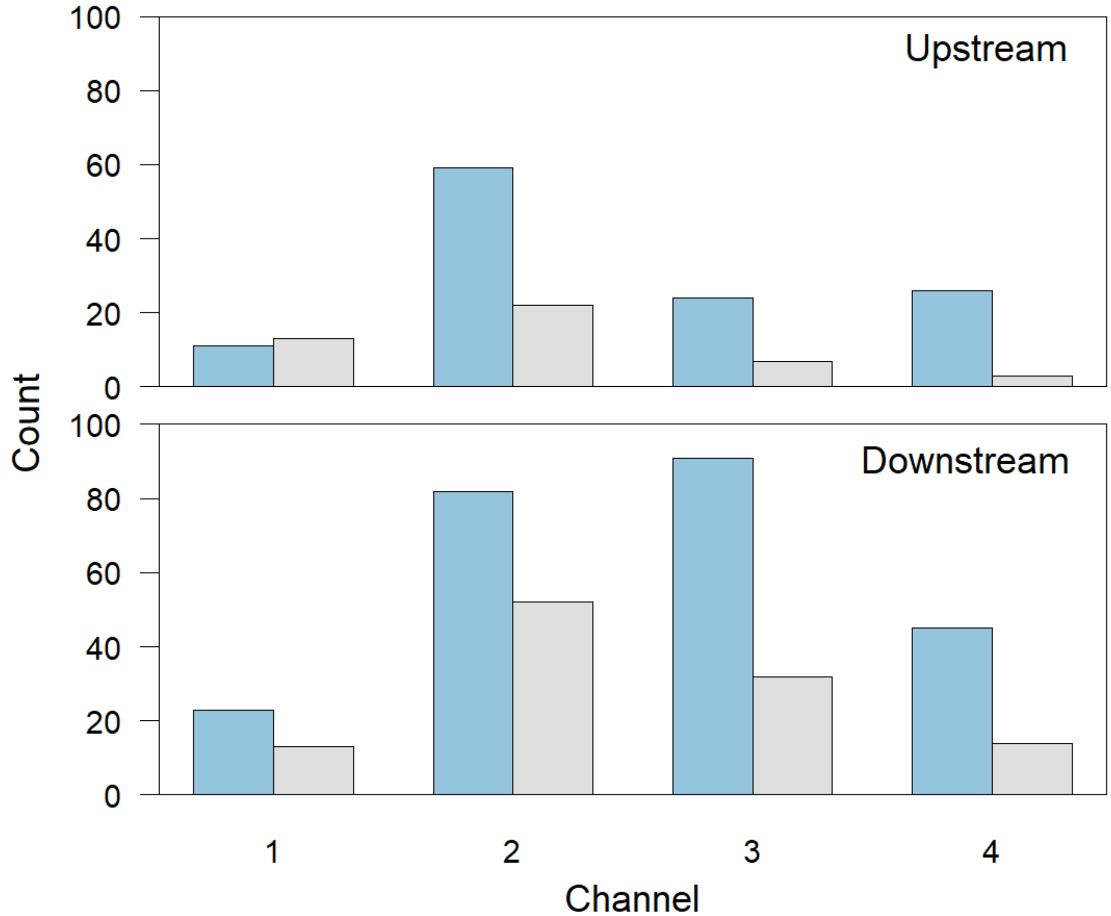


Figure 12. Distribution of confirmed Bull Trout (blue) and Mountain Whitefish (grey) among channels, separated by upstream (top panel) and downstream (bottom panel) movements, Chowade River 2017.

4.1.2.2 Migration Timing

The first Bull Trout detected by the counter moving upstream was on August 17 at 23:48. The first downstream movement by a Bull Trout was on August 17 at 23:22. The last observed Bull Trout was on October 02 at 05:05, also moving downstream. Most Bull Trout moved upstream during nighttime (low light) hours, where 338 individuals moved between 18:00 and 06:00 and only 23 individuals moved between 06:00 and 18:00. The majority of Mountain Whitefish also moved at night, where 26 schools moved during the day and 130 moved at night (Figure 13).

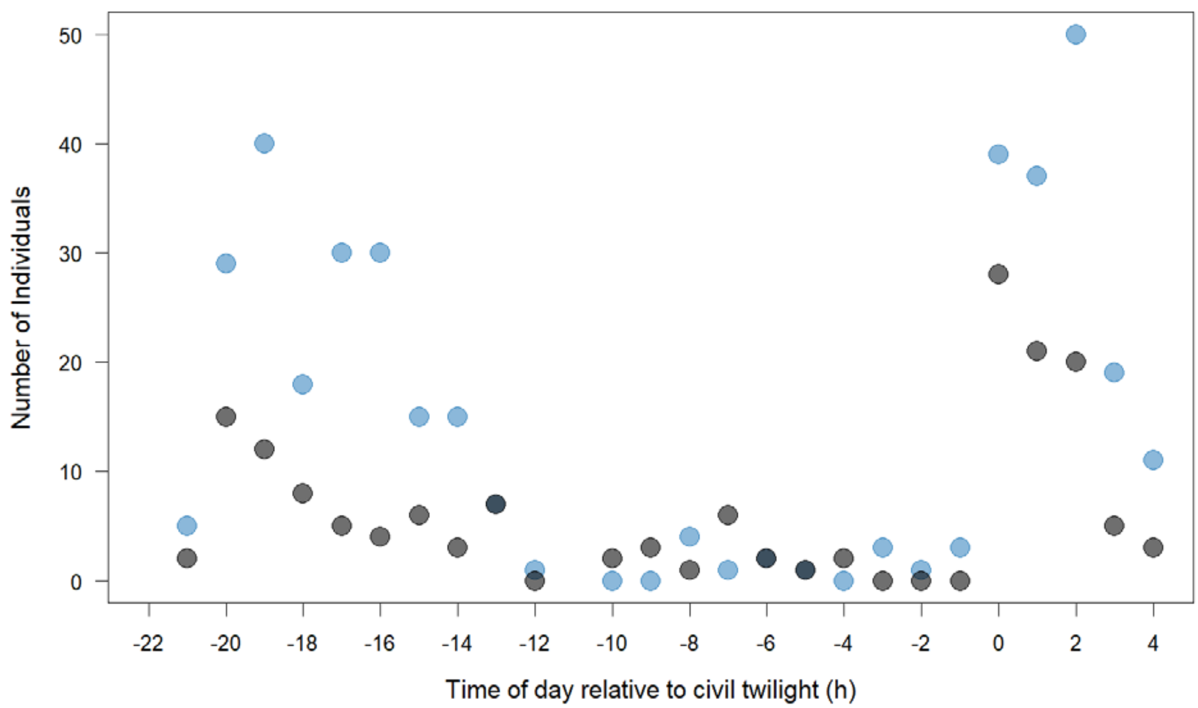


Figure 13. Number of Bull Trout (blue) and Mountain Whitefish (dark grey) observed from video during each hour over the counter pads in Chowade River from August 17 to October 02, 2017.

The normal model estimated the onset of the kelt out-migration to be September 05 (Figure 14). The estimated mean kelt out-migration date was 30.1 (i.e., September 16) days after the start of the migration and a standard deviation of 7.1 days.

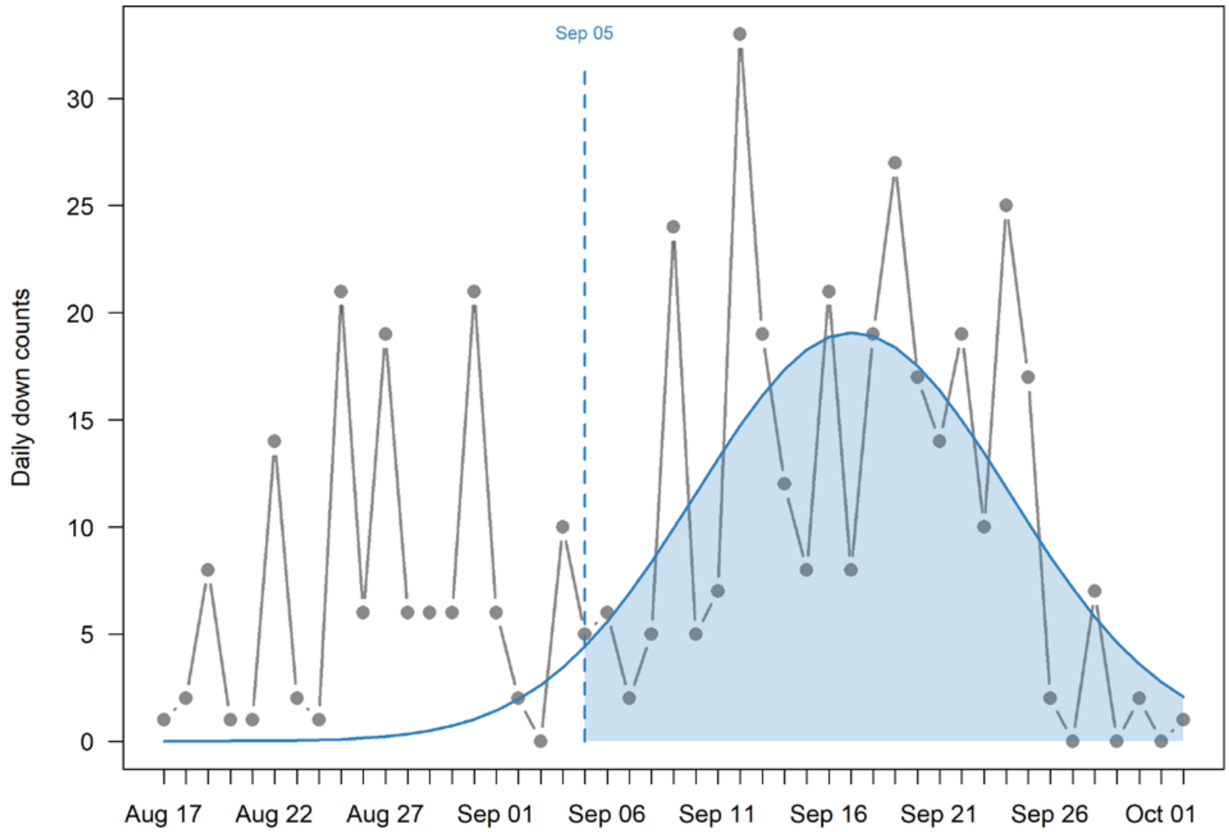


Figure 14. Plot of corrected daily down counts of verified Bull Trout (grey points and lines) and modelled kelt out-migration timing (solid blue line and shaded blue area). The normal model parameters were estimated using data from September 01 to October 02 and were used to predict the kelt out-migration before and after those dates. The vertical dashed blue line marks the date at which the normal model estimated 5% of the kelts to have out-migrated, which is assumed to be the onset of the kelt out-migration. Chowade River, 2017.

4.1.2.3 Abundance Estimate

The Chowade River resistivity counter recorded 162 total Bull Trout upstream movements and 446 downstream movements, which include the upstream migration, kelting and recycling. After accounting for recycling, counter accuracy and kelting, we estimated a total of 22 Bull Trout upstream migrants (Equation 3) between August 17 and October 02 (representing a portion of upstream migration) and 319 kelts (Equation 4) between September 05 and October 02 (encompassing the entire kelting period; Figure 15B and C). The kelt abundance estimate agrees with the scale parameter estimate of 338 predicted by the normal model of kelt timing.

We missed a large portion of the upstream migration in 2017 (Figure 15). Multiple Bull Trout were counted on the first day following installation, and rather than seeing an increase in counts, we observed a decrease in up counts and an increase in down counts (Figure 15B). We can, however, use the kelt estimate of 319 (counter) or 338 (modelled) as a surrogate estimate with the caveat that not all spawners kelt.

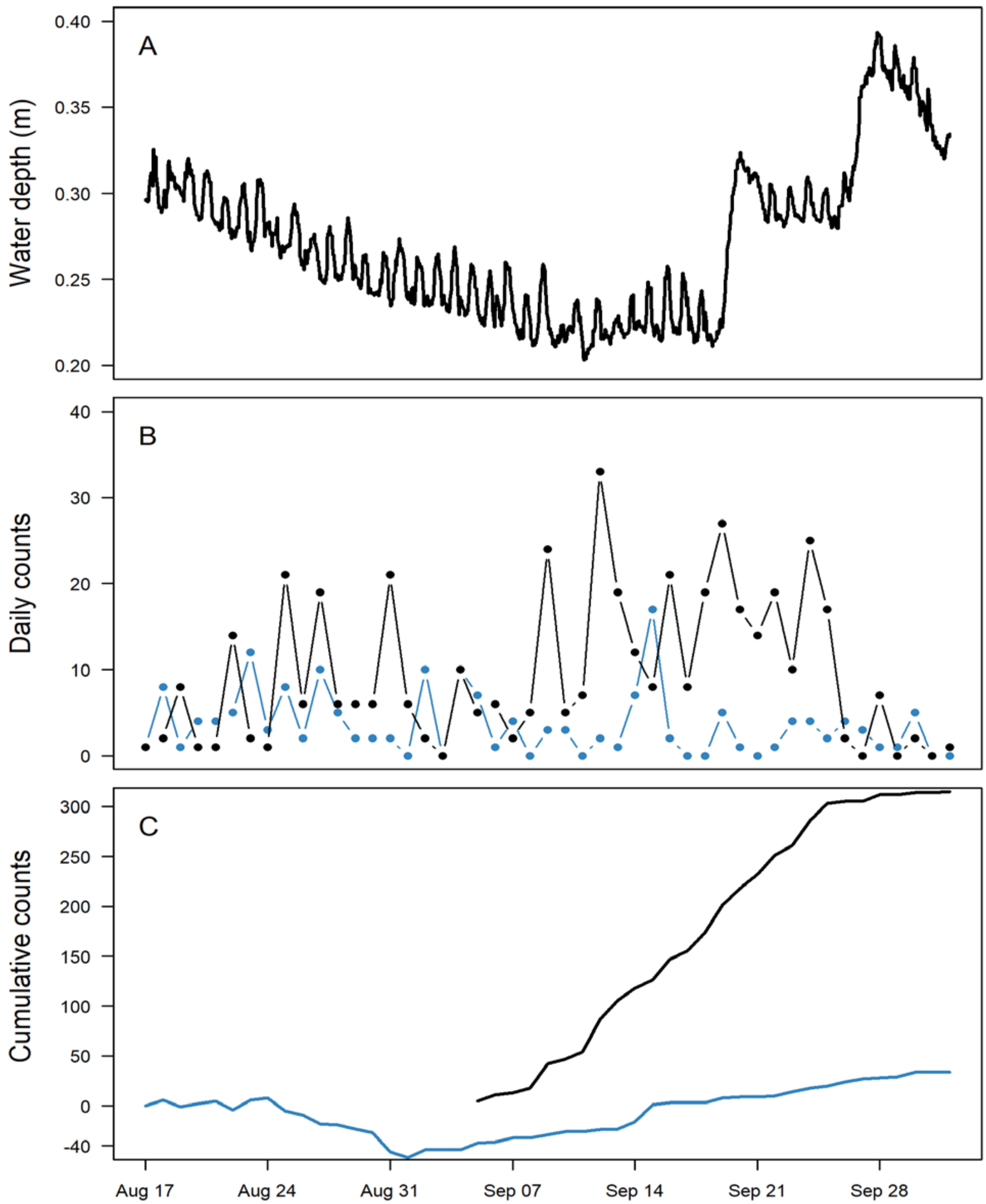


Figure 15. (A) Water depth (m) plotted to assess whether specific water levels corresponded with specific fish movements. (B) Bull Trout daily up (blue) and down (black) counts, and (C) cumulative net up counts (blue line) from August 17 to October 02 and cumulative down counts of kelts (black line) from September 05 to October 02 in the Chowade River 2017.

4.1.3 PIT Telemetry

4.1.3.1 Read Range Surveys

Read ranges of the 23 and 32 mm PIT tags met or exceeded the water depth along the length of the two antennas in the Chowade River (Figures 16 and 17). The proportion of the water column within which 23 and 32 mm PIT tags could be detected generally exceeded 90% (mean: 98% for 23 mm, 100% for 32 mm tags across all surveys). Read ranges of the 12 mm PIT tags were 40% of the water depth at the thalweg, but overall the proportion of the water column within which 12 mm PIT tags could be detected was >75% across the five surveys. Read ranges across the five surveys were more variable for 12 mm tags than for 23 and 32 mm tags due to changing water and solar charging conditions.

Detection efficiency was 100% for the PIT array in the Chowade River (18 of 18 tags detected), however two antennas were running only for a portion of the monitoring period (Table 6).

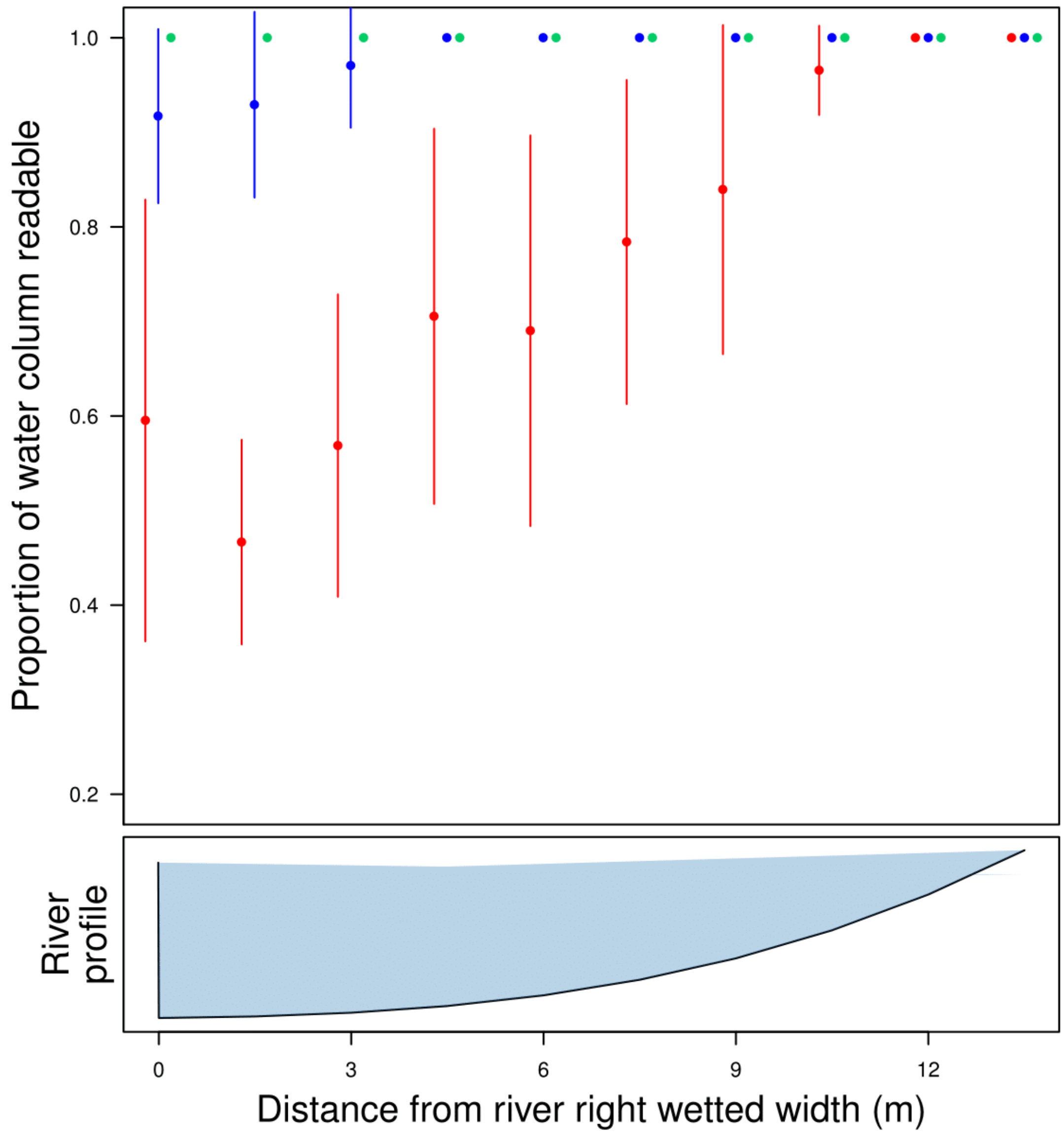


Figure 16. Top panel depicts the proportion of the water column (mean ± SD) in the Chowade River that could effectively read 12 mm (red), 23mm (blue) and 32 mm (green) PIT tags. Bottom panel depicts the river channel profile at the site.

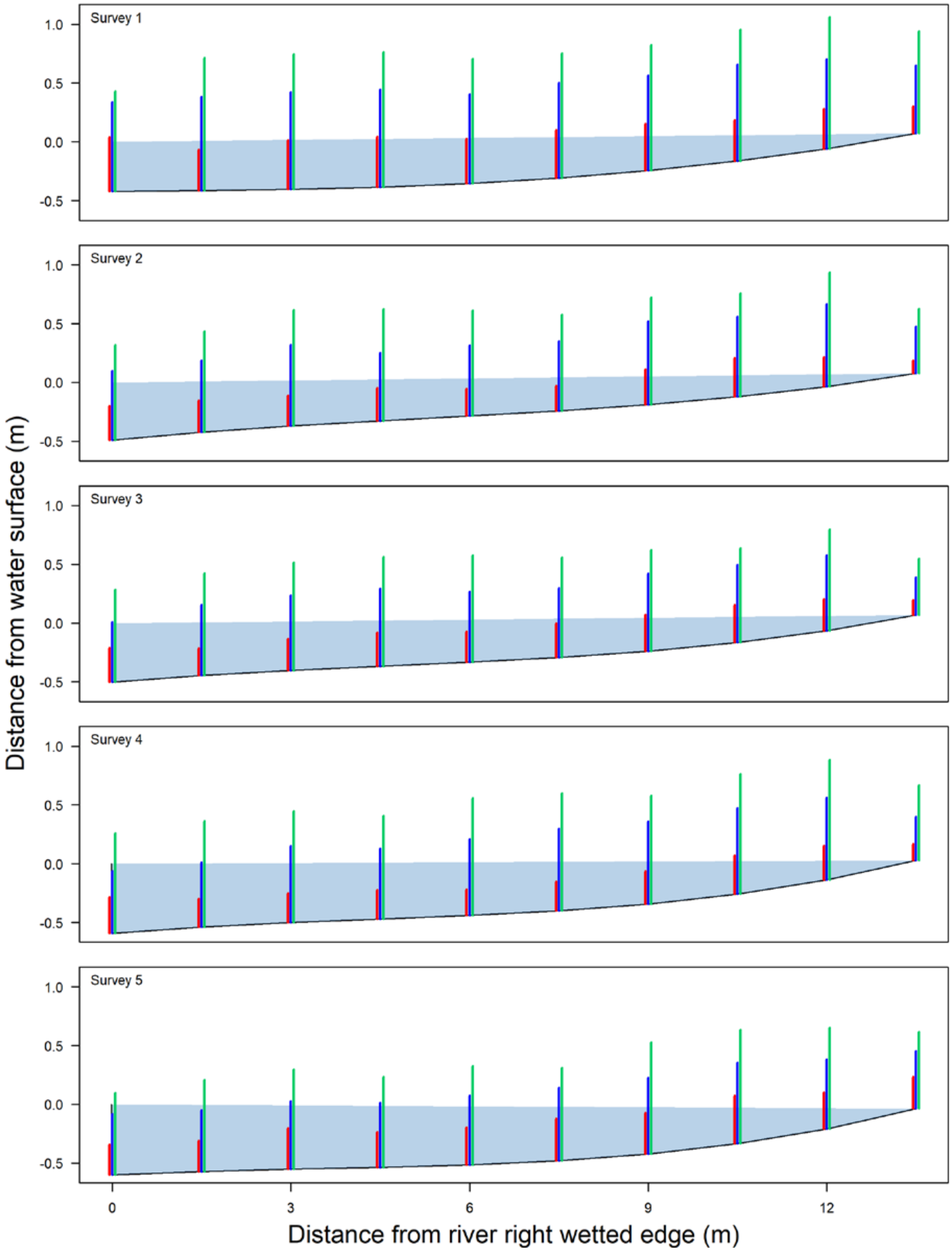


Figure 17. Read range of 12 mm (red), 23 mm (blue) and 32 mm (green) PIT tags across the five weekly surveys of the Chowade River PIT array.

Table 6. Detection efficiency of the Chowade River and Cypress Creek PIT arrays. Numbers in parentheses represent the number of individuals detected out of the total number of individuals known to have passed by the arrays.

PIT array	Number of tags detected	Number of tags missed	Time period	Detection efficiency
Chowade River	18	0	Sep 10 to 22	100% (18/18)
Cypress Creek	2	0	Sep 17 to 22	100% (2/2)

Note: Detection efficiency can only be computed post hoc for the period of time in which two antennas were running at each site.

4.1.3.2 Detection Summary

We detected 32 (10 Bull Trout, 22 Rainbow Trout) fish on the Chowade River PIT array. Detections originated from 23 and 32 mm PIT tags deployed through other FAHMFP monitoring programs. Bull Trout fork lengths at the time of tagging and sampling ranged from 380 to 922 mm for the tags detected (Appendix B). Rainbow Trout fork lengths ranged from 247 to 397 mm for the tags detected. Of the 32 fish detected in the Chowade River, 24 (75%) were tagged upstream of the Chowade River counter site; the remaining 8 fish (all Bull Trout) were tagged in the Peace River (7) or downstream of the counter site (1) (Appendices A and B).

4.1.3.3 Movement Ecology

Movement of PIT-tagged Bull Trout and Rainbow Trout in the Chowade River (Figure 18) occurred almost entirely during nighttime hours. Upstream and downstream movements by Bull Trout in the Chowade River occurred between August 22 and September 10 and September 13 and 26, respectively (Figure 19). PIT-tagged Rainbow Trout moved downstream in the Chowade River between September 9 and 26, with a peak downstream movement occurring in the third week of September.

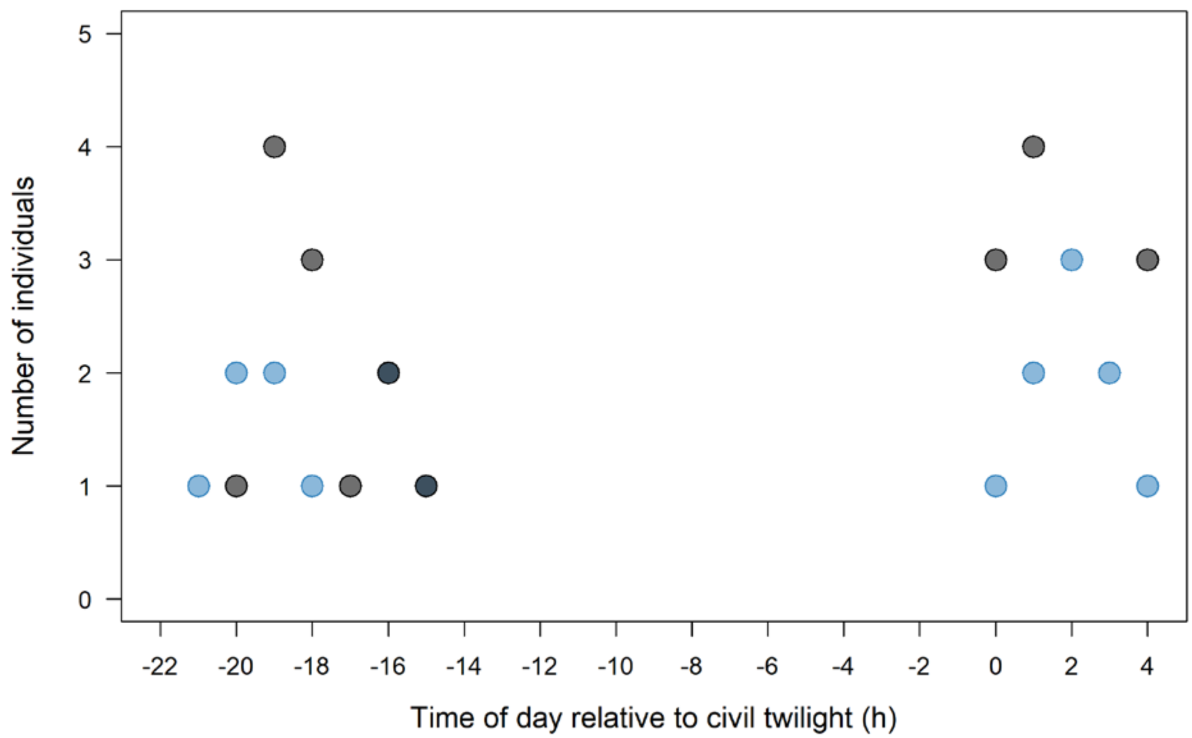


Figure 18. Number of Bull Trout (blue) and Rainbow Trout (dark grey) detected on the Chowade River PIT array during each hour from August 17 to October 02, 2017.

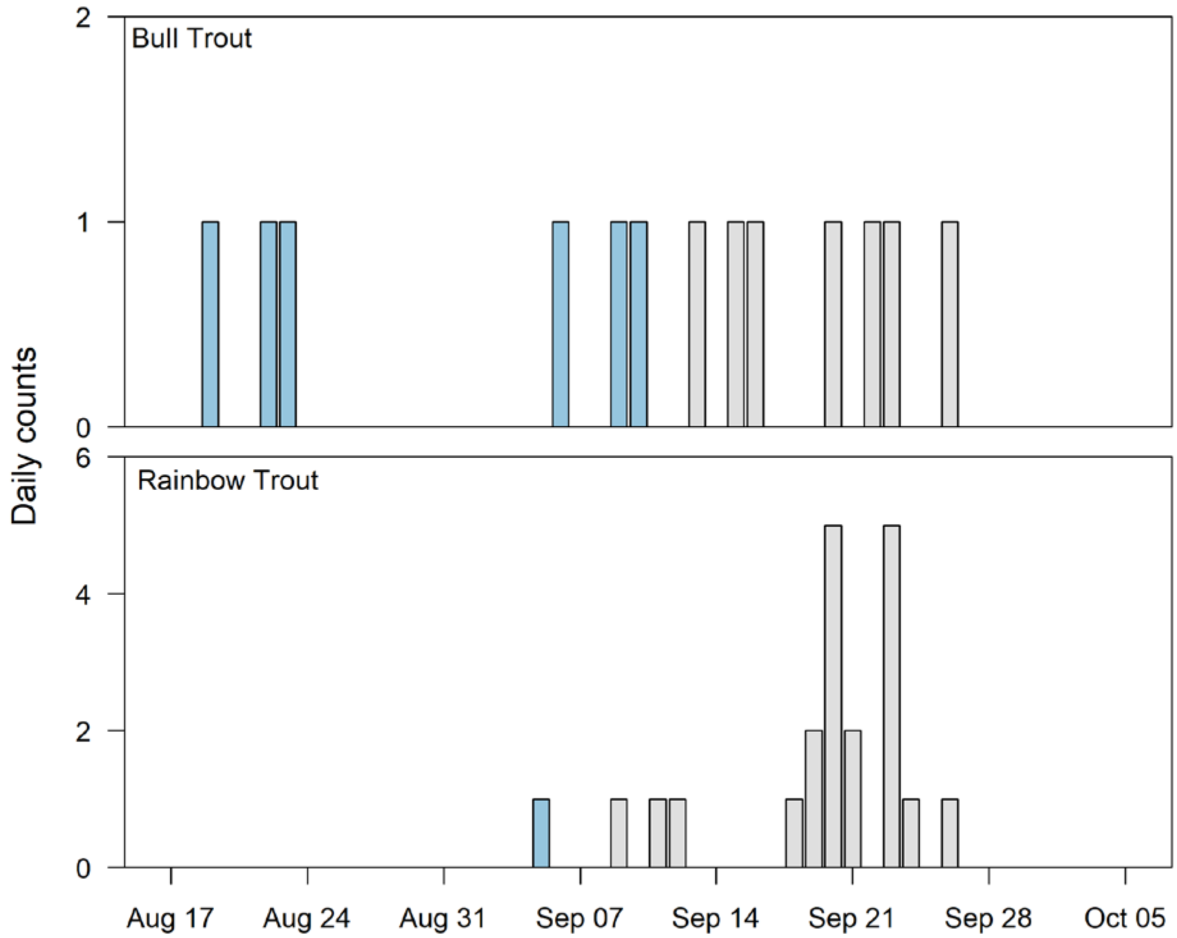


Figure 19. Upstream (blue) and downstream (grey) movements by PIT-tagged Bull Trout (top panel) and Rainbow Trout (bottom panel) on the Chowade River PIT array. Note the different y-axis scales.

4.2 Cypress Creek

4.2.1 Environmental Conditions

Discharge measured in the Halfway River and the water depth measured at the Cypress River counter site were strongly correlated (when Halfway River discharge is log transformed: $r=0.84$; $p<0.001$) (Figure 20). Average water depth at the counter site between August 16 and October 02 was 0.25 m (range: 0.215 m to 0.342 m) and were favorable for the deployment and operation of instream equipment (Figure 20B).

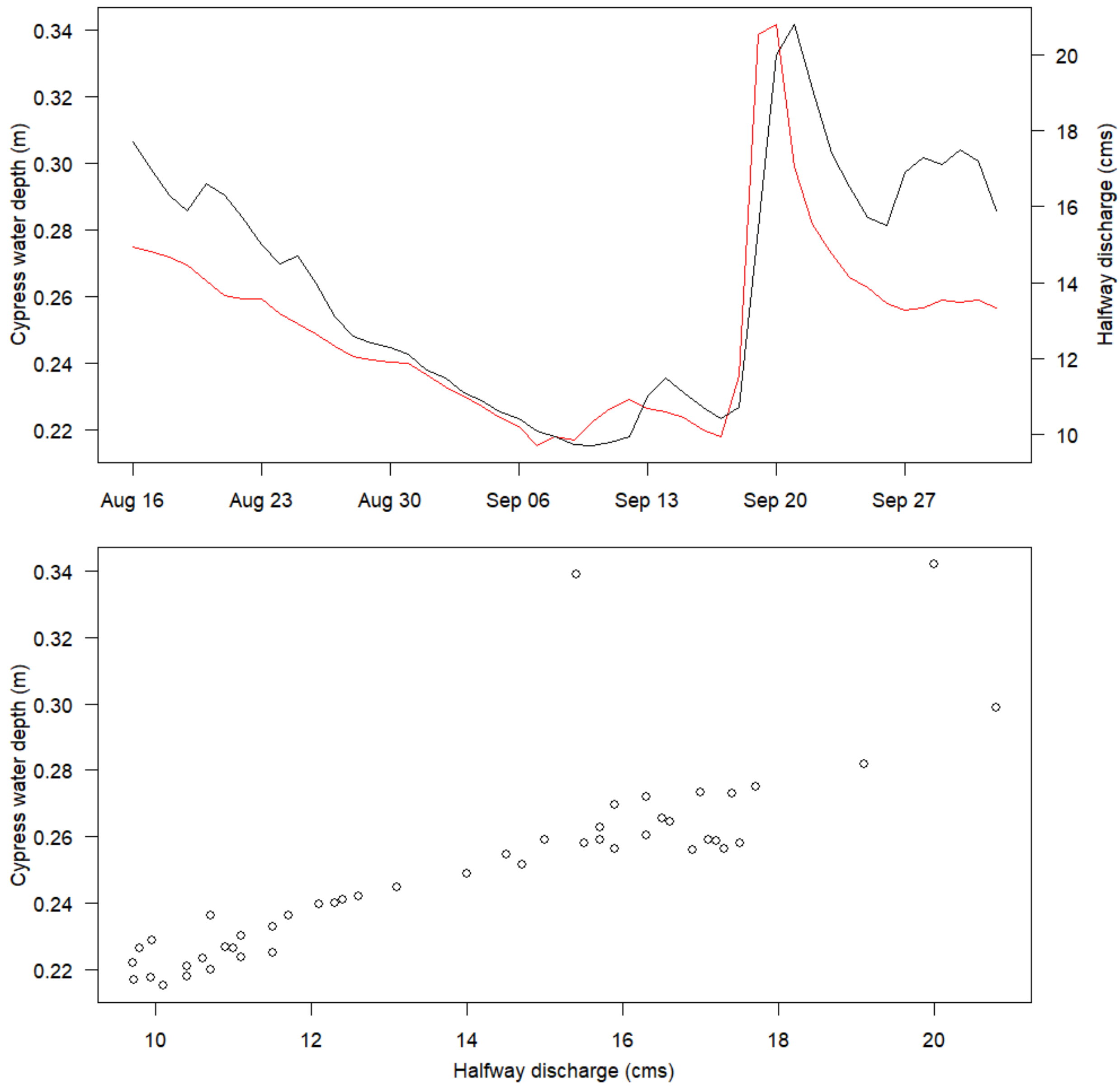


Figure 20. A) Daily means of Halfway River discharge (black line) and Cypress Creek water depth (red line). B) The relationship between the Halfway River discharge (Station 07FA003) and water depth at the Cypress River counter site from August 15 to September 30 2017.

4.2.2 Resistivity Counter

4.2.2.1 Counter Validation

The two most abundant species observed in Cypress Creek were Bull Trout (n=76) (Table 7) and Mountain Whitefish (n>200) (Table 12). It was difficult to obtain an exact number of Mountain Whitefish because of their schooling behaviour (Figure 8B). Rainbow Trout and

Arctic Grayling may have also been present but were difficult to identify because there were few distinguishing characteristics that could be viewed on the overhead cameras (Figure 8C) and therefore all these species were included in the small bodied fish category.

Fish lengths estimated from video footage were similar to lengths observed at the Chowade River in 2016 and 2017 (Table 3 and Table 7). Using the fish identified to species from the video, we examined the relationship between the standard length measured from the video and the PSS measured by the counter. Overall, we did not find a positive relationship between standard length and PSS; however, Channels 2 and 4 showed a positive relationship for upstream movement where we determined a PSS cutoff of ≥50 distinguished between Bull Trout and Mountain Whitefish (Figure 21) and minimized the overlap between the two species' PSS size distributions (Figure 22). Due to the inconsistencies between channels and small sample sizes, we relied on video validation to assign species.

Table 7. Comparison of fish lengths estimated in Cypress Creek through video validation in 2017. Note that the small salmonids were difficult to identify but also difficult to measure due to conditions on site.

	2017			
Species	**N**	**Mean (mm)**	**Range**	**SD**
Mountain Whitefish	207	259	83-463	70
Rainbow Trout	9	308	171-400	73
Bull Trout	76	556	308-844	133
Small-bodied Fish <40 cm (may include Rainbow Trout, Arctic Grayling, and Bull Trout)	3	-	-	-

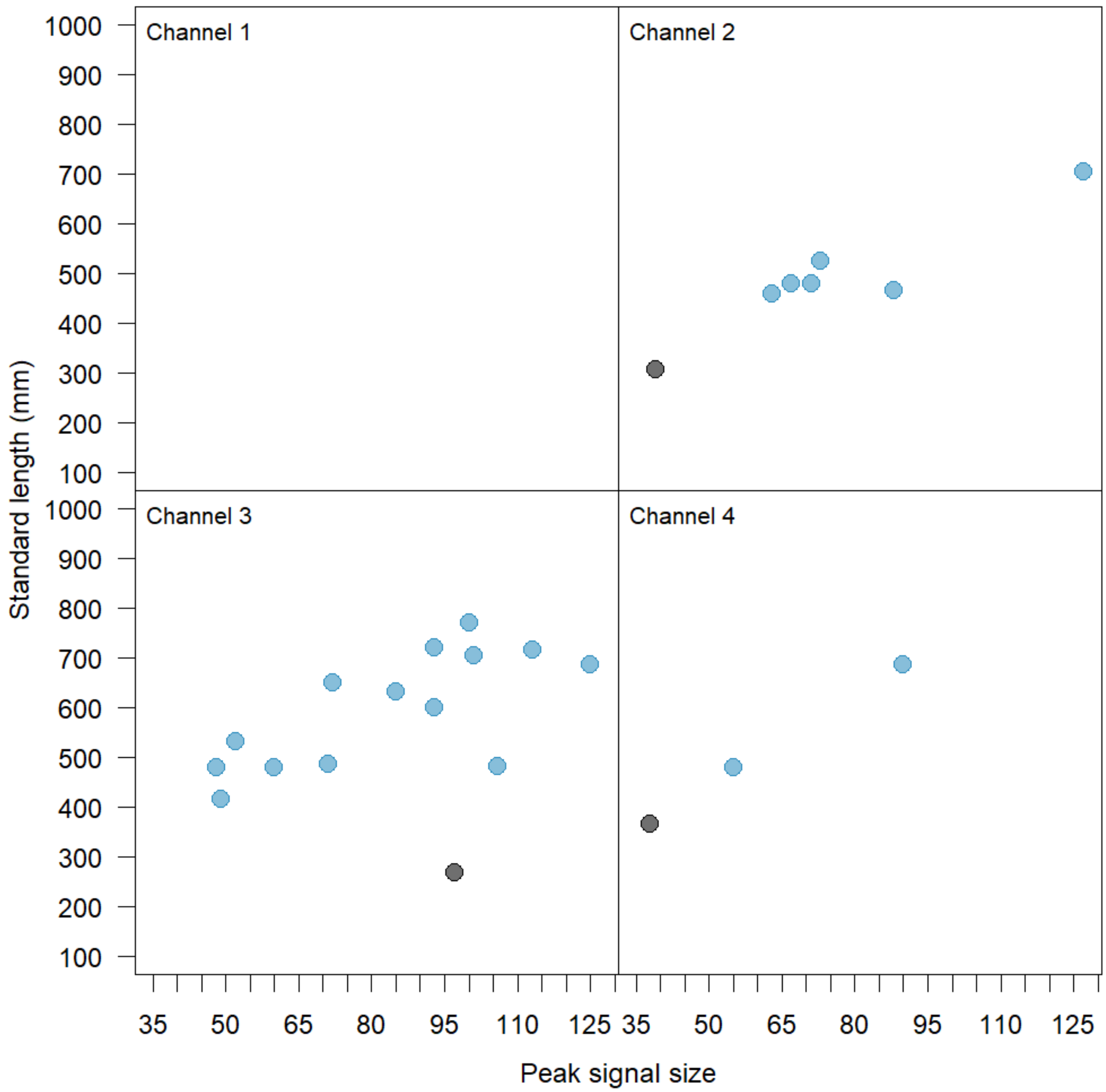


Figure 21. Peak signal size relationship to standard length (mm) of Bull Trout (blue) and Mountain Whitefish (grey) observed moving upstream during video validation on each counter channel at Cypress Creek 2017.

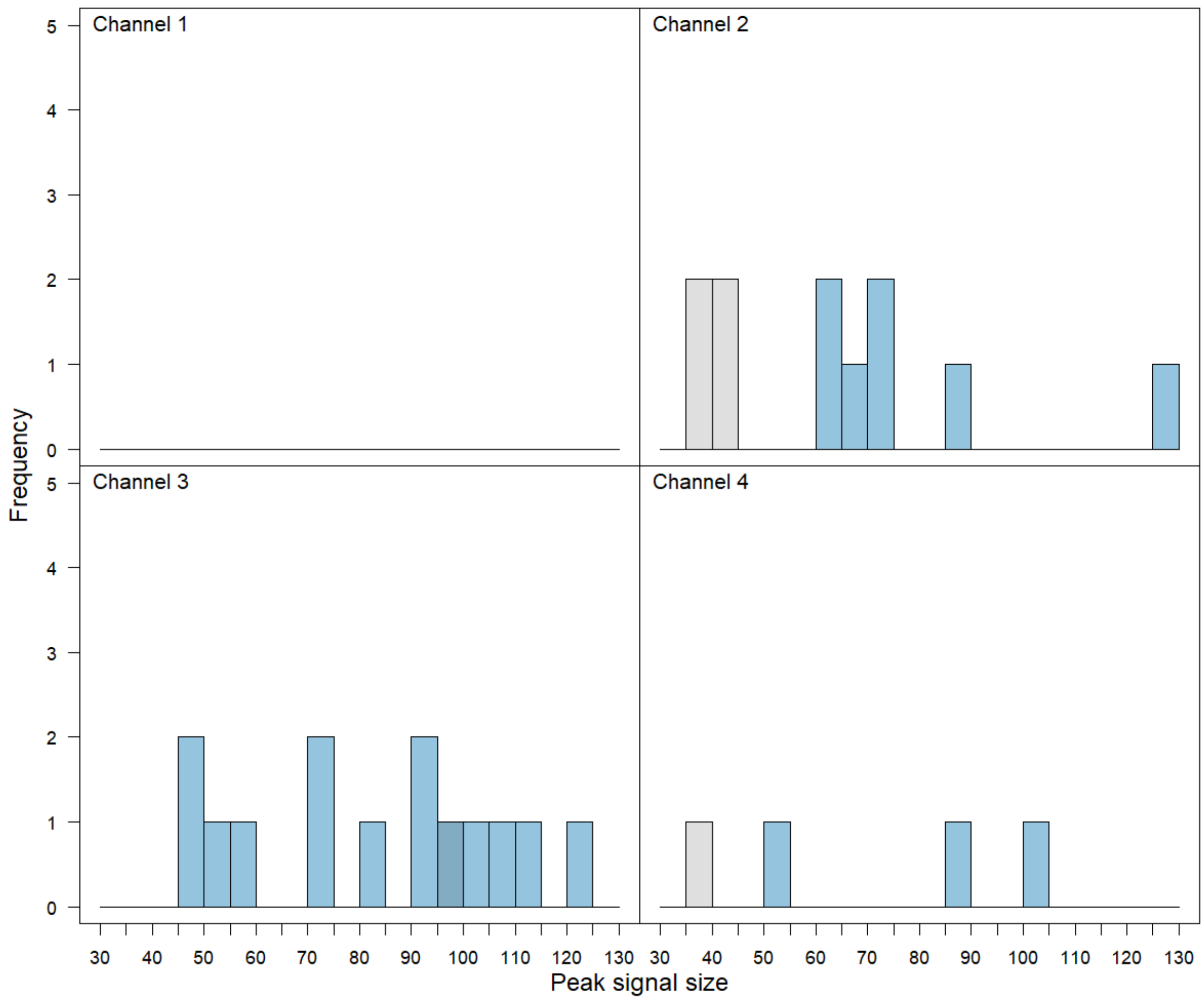


Figure 22. Frequency distribution of peak signal sizes for confirmed Bull Trout (blue) and Mountain Whitefish (grey) observed during video validation at Cypress Creek in 2017.

The Cypress Creek resistivity counter underestimated the number of Bull Trout moving upstream over the counter with an accuracy of 55% (Figure 5; Table 8). Downstream movements were also underestimated for Bull Trout with an accuracy of 47%. As expected, the accuracy for Mountain Whitefish was much lower, underestimating the number of Mountain Whitefish with an accuracy of 8 and 1% for up and down counts, respectively.

Channel 3 was most actively used by Bull Trout (63%) for upstream movements which had an accuracy of 53% (Table 9 and Figure 23). There were no upstream movements of Bull Trout observed on Channel 1 and there were no false positives or false negatives observed on Channel 2 for upstream movements (100% accuracy). Channel 4 had the lowest upstream accuracy (32%). For downstream movements, both Channels 2 and 3 were used more frequently than Channels 1 and 4.

Table 8. Summary of counter accuracy data for Bull Trout and Mountain Whitefish at Cypress Creek in 2017 as determined from video validation.

Species	Direction	True (+)	False (+)	False (-)*	Accuracy (%)
Bull Trout	Up	23	0	19	55 (under est.)
Bull Trout	Down	42	3	44	47 (under est.)
Mountain Whitefish	Up	3	2	31	8 (under est.)
Mountain Whitefish	Down	3	8	363	1 (under est.)

*Expanded from random video validation of 16% of video footage

Table 9. Summary of counter accuracy data for Bull Trout on each counter channel, Cypress Creek 2017.

Direction	Channel 1	Channel 2	Channel 3	Channel 4	Avg (SD)
Up	-	100%	53%	32%	62% (35%)
Down	100%	54%	55%	0%	52% (40%)

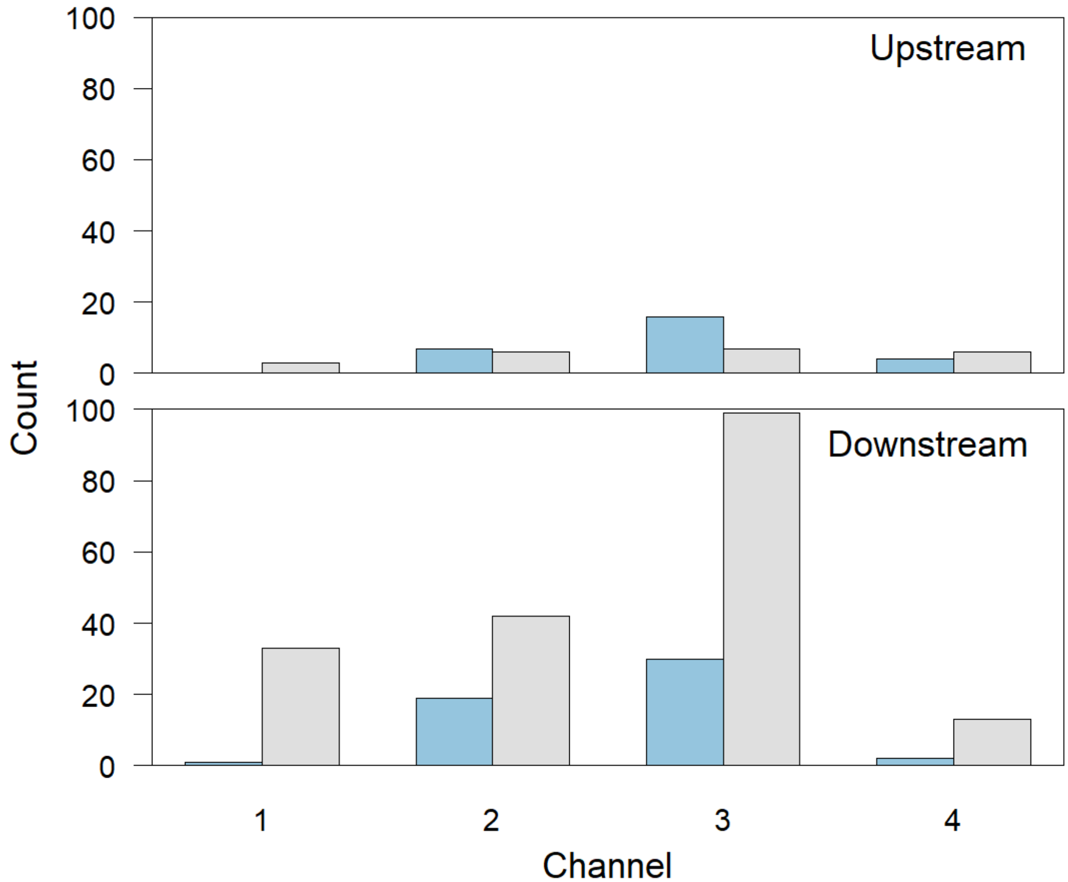


Figure 23. Distribution of confirmed Bull Trout (blue) and Mountain Whitefish (grey) among channels, separated by upstream (top panel) and downstream (bottom panel) movements Cypress Creek 2017.

4.2.2.2 Migration Timing

The first Bull Trout detected by the counter moving upstream was on August 15 at 21:11. The first downstream movement by a Bull Trout was also on August 15 at 23:02. The last observed Bull Trout was on September 29 at 1:07, also moving downstream. Most Bull Trout moved upstream during nighttime hours, where 69 individuals moved between 18:00 and 06:00 and only 11 individuals moved between 06:00 and 18:00. The majority of Mountain Whitefish also moved at night, where 16 schools moved during the day and 193 moved at night (Figure 24).

The normal model could not estimate a mean kelt out-migration date because the data were sparse. The onset of the kelt out-migration was visually estimated to be September 05 (Figure 25) using expert knowledge and inferences from data collected in the Chowade River (see Section 4.1.2).

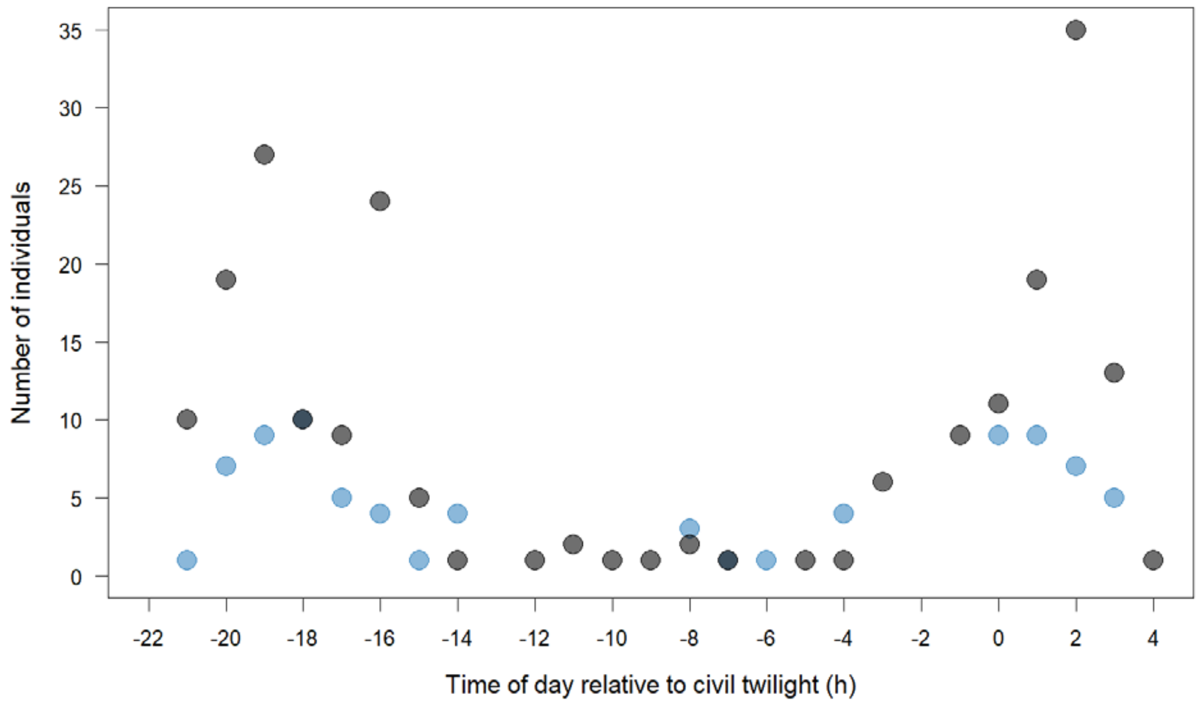


Figure 24. Number of Bull Trout (blue) and Mountain Whitefish (dark grey) observed from video during each hour over the counter pads at Cypress Creek from August 15 to October 3, 2017.

4.2.2.3 Abundance Estimate

The Cypress Creek counter recorded 48 Bull Trout upstream movements and 114 downstream movements, which include the upstream migration, kelting, and recycling. After accounting for counter accuracy and kelting, we estimated 27 Bull Trout upstream migrants (Equation 3) between August 15 and October 03 (representing a portion of the upstream migration) and 91 kelts (Equation 4) between September 05 and October 03, 2017 (encompassing the entire kelting period; Figure 25B and C).

Similar to the Chowade River, we missed a large portion of the upstream migration in 2017 (Figure 25). Several Bull Trout were counted the first day the counter was installed, and we saw an increase in down counts rather than an increase in up counts (Figure 25B). Alternatively, we can use the kelt estimate of 91 Bull Trout (counter) as a surrogate estimate with the caveat that not all spawners kelt.

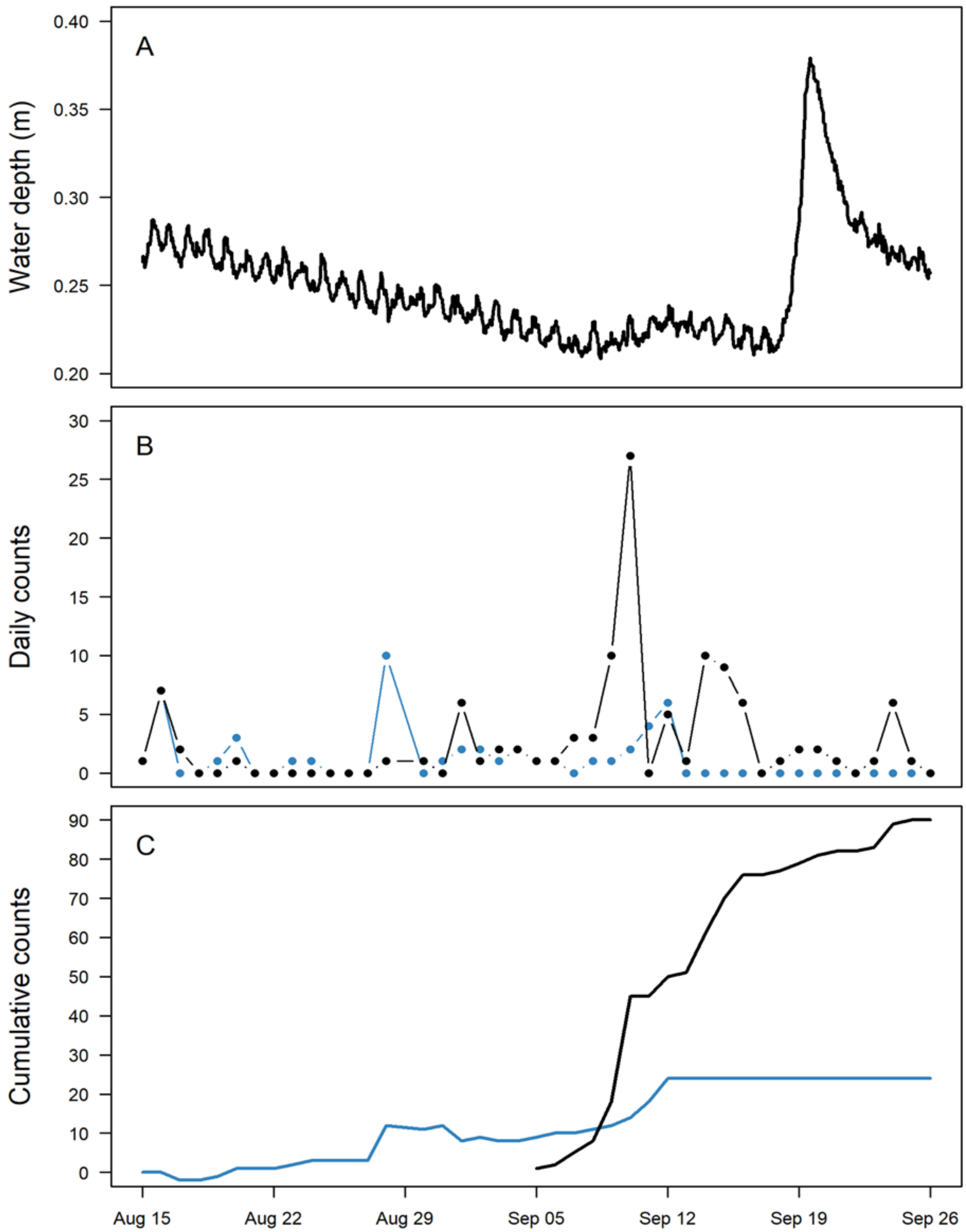


Figure 25. A) Water depth (m), plotted to assess whether specific water levels correspond with specific fish movements, B) Bull Trout daily up (blue) and down (black) counts, and C) the cumulative net up counts (blue line) from August 15 to October 02, and cumulative down counts of kelts (black line) from September 5 to October 2 in Cypress Creek 2017.

4.2.3 PIT Telemetry

4.2.3.1 Read Range Surveys

Read ranges of the 23 and 32 mm PIT tags met or exceeded the water depth along the length of the antennas in Cypress Creek (Figure 26 and 27). The proportion of the water column within which 23 and 32 mm PIT tags were detectable was 100% for both tag sizes across all surveys. Mean read range of the 12 mm PIT tags was reduced to ~39% at the thalweg, but overall the proportion of the water column within which 12 mm PIT tags could be detected was >79% across the five surveys. Read ranges across the five surveys were more variable for 12 mm tags than for 23 and 32 mm tags due to changing water and solar charging conditions.

Detection efficiency was 100% for the PIT arrays in Cypress Creek (2 of 2 tags detected), however two antennas were running only for a portion of the monitoring period (Table 6).

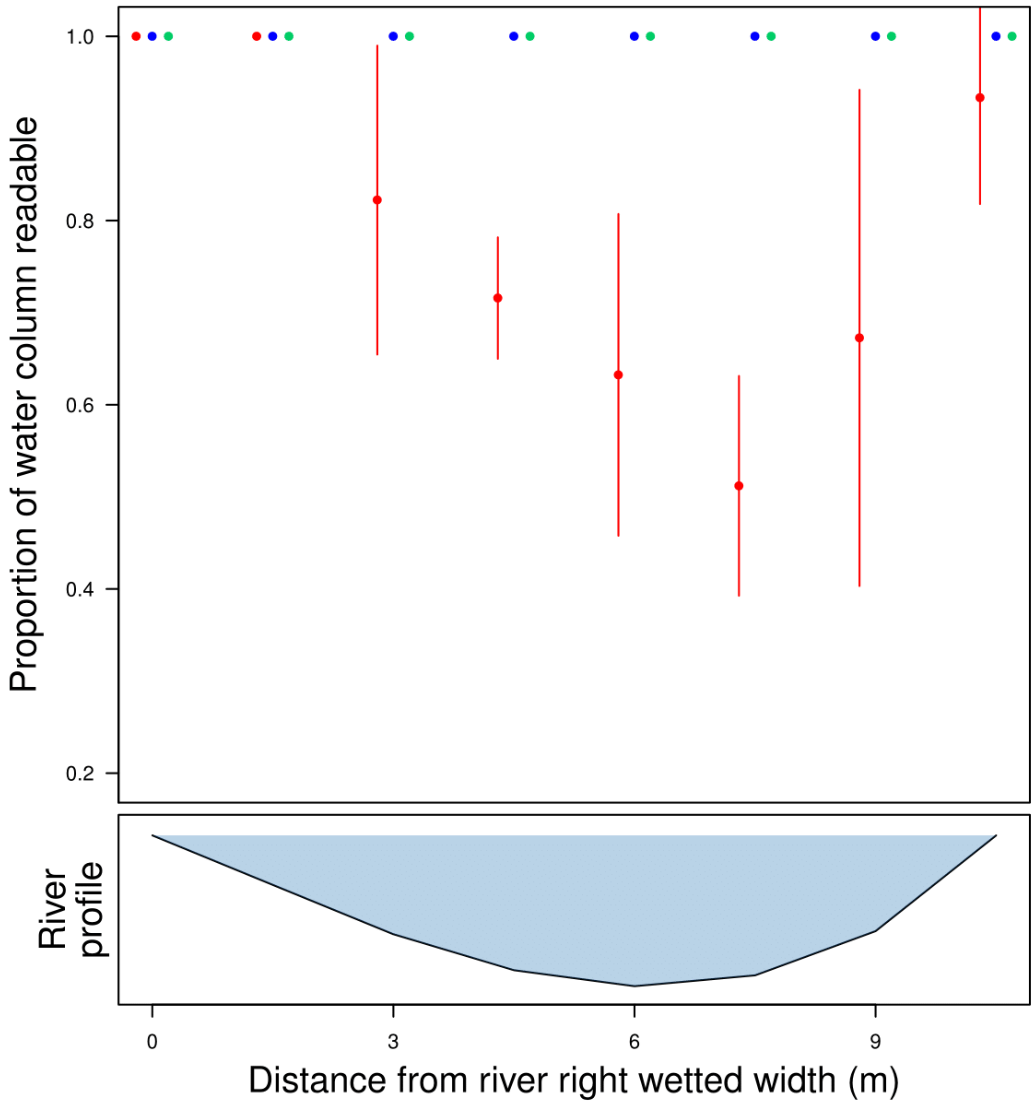


Figure 26. Top panel depicts the proportion of the water column (mean ± SD) in Cypress Creek that could effectively read 12 mm (red), 23 mm (blue), and 32 mm (green) PIT tags. Bottom panel depicts the river channel profile at the Cypress Creek site, 2017.

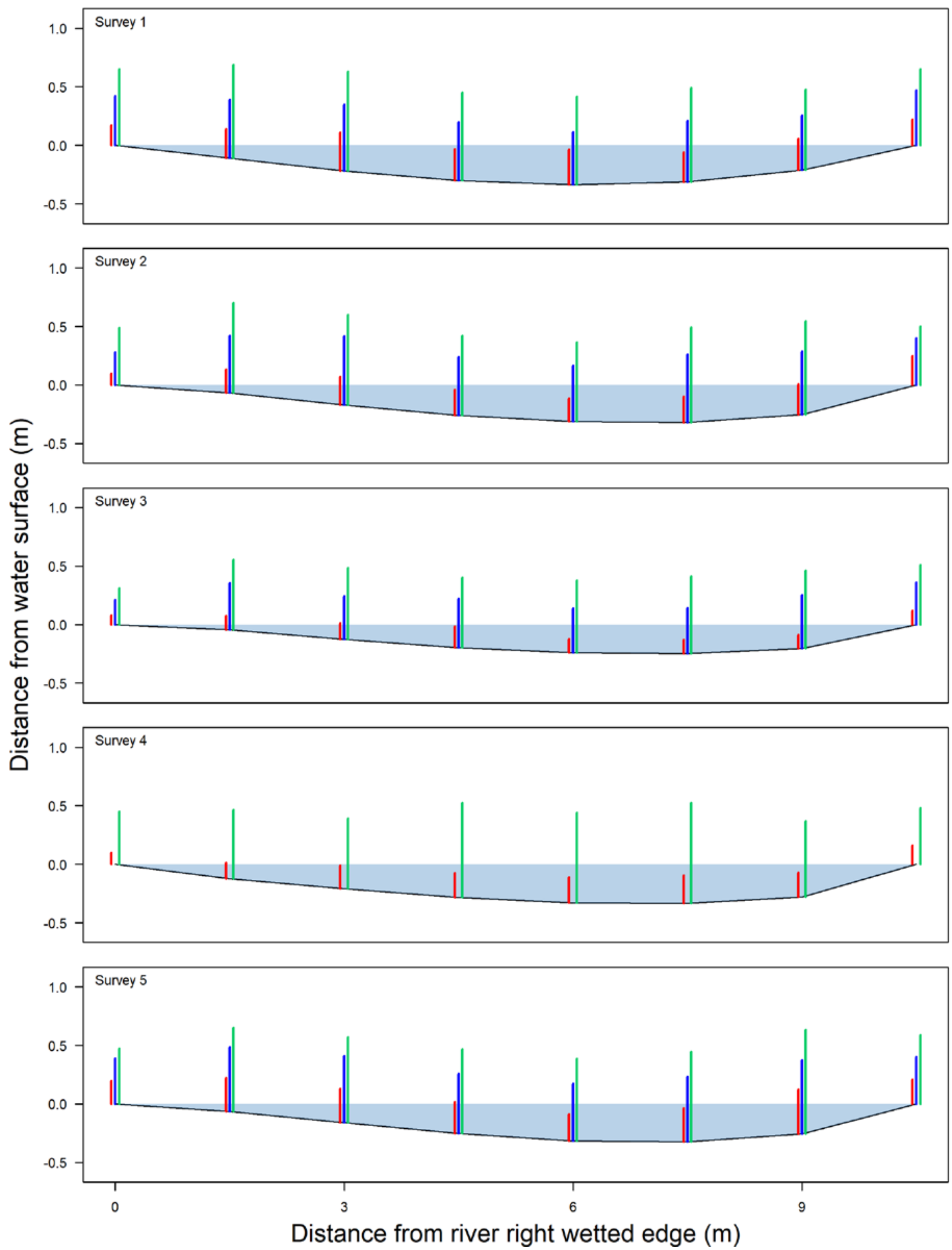


Figure 27. Read range of 12 mm (red), 23 mm (blue), and 32 mm (green) PIT tags across the five weekly surveys of the Cypress Creek PIT array in 2017. Note the read range of 23 mm PIT tags was not measured during Survey 4.

4.2.3.2 Detection Summary

We detected 23 (13 Bull Trout, 10 Rainbow Trout) fish on the Cypress Creek PIT array. Detections originated from 12, 23 and 32 mm PIT tags deployed through other FAHMFP monitoring programs. Bull Trout detected fork lengths at the time of tagging and sampling ranged from 95 to 564 mm in Cypress Creek. Of the 23 fish detected in Cypress Creek, 21 (91%) were tagged upstream of the Cypress Creek counter site; the remaining two fish were tagged in the Peace (one Bull Trout) and Halfway (one Rainbow Trout) Rivers (Appendices A and B).

4.2.3.3 Movement Ecology

Movement of PIT-tagged Bull Trout and Rainbow Trout in Cypress Creek (Figure 28) occurred almost entirely during hours of darkness, and were consistent with the timing of movement in the Chowade River. Downstream movements by Bull Trout occurred between September 07 and October 02 (Figure 29). Movement behaviours and direction of movement were difficult to confirm at Cypress Creek due to considerable time drift between the PIT reader and the resistivity counter and video. No PIT-tagged fish made movements between the PIT arrays in the Chowade River and Cypress Creek in 2017.

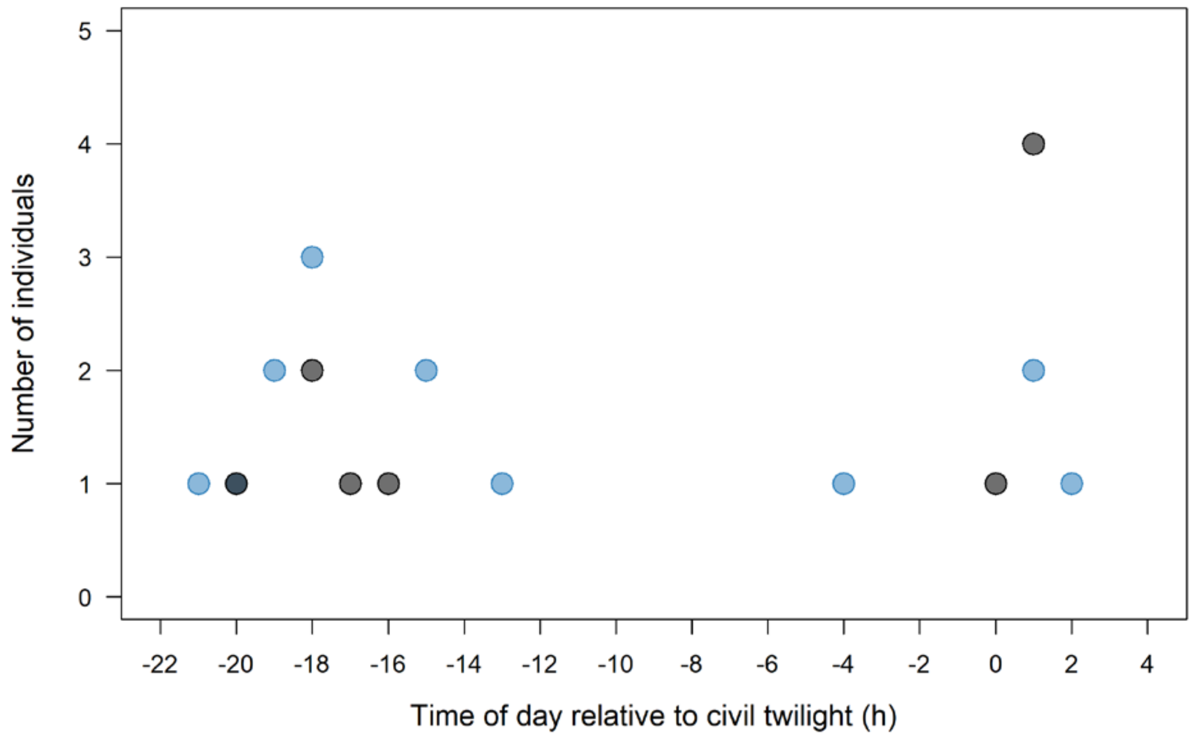


Figure 28. Number of Bull Trout (blue) and Rainbow Trout (dark grey) detected on the Cypress Creek PIT array during each hour from August 15 to October 02, 2017.

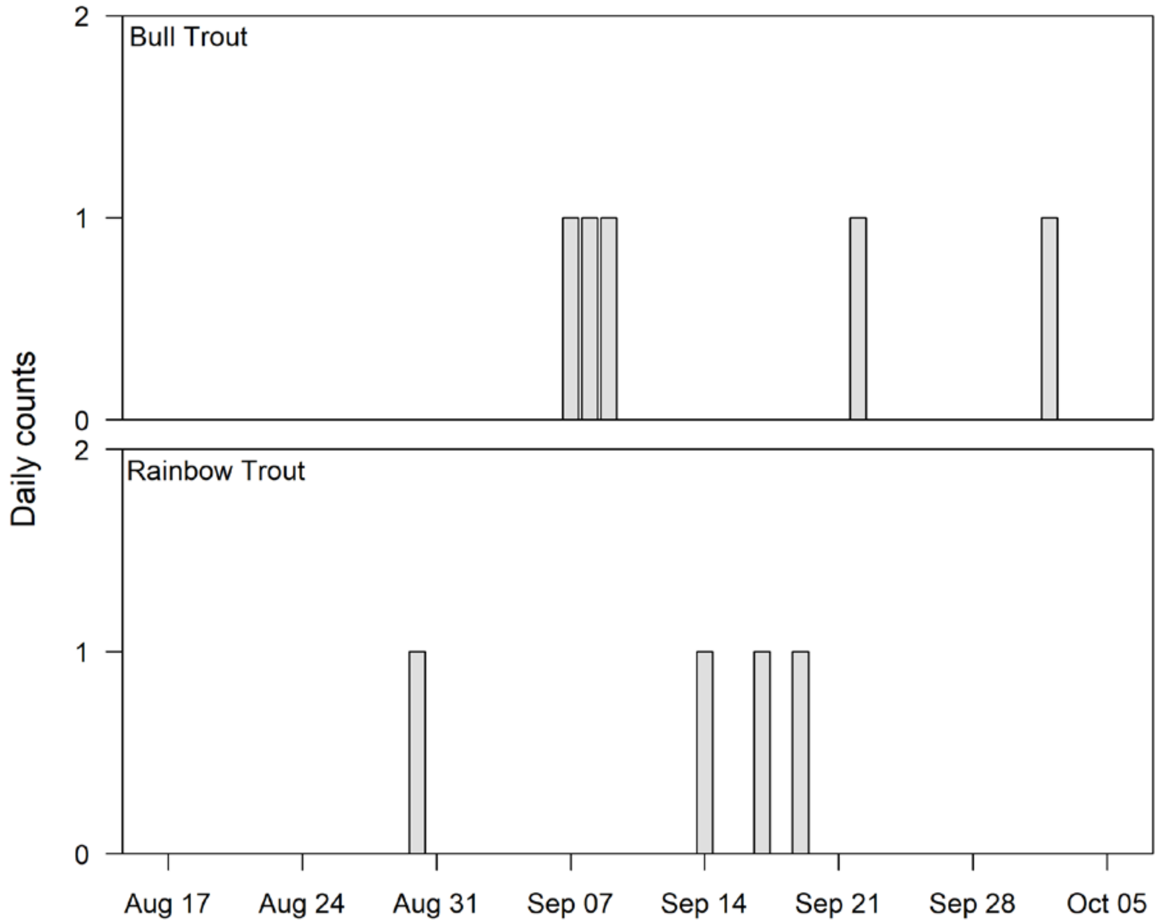


Figure 29. Downstream movements by PIT tagged Bull Trout (top panel) and Rainbow Trout (bottom panel) on the Cypress Creek PIT array. No upstream movements were observed in 2017.

5 Discussion

We enumerated Bull Trout in the Chowade River and Cypress Creek using resistivity counters and PIT arrays. We used video validation for species identification and to determine fish size and counter accuracy. We discuss the results of the resistivity counter considering: (1) the accuracy of the counter; (2) the ability to determine fish size and species from the counter and video data; (3) abundance estimates (up-migration and kelting); and (4) kelting timing. PIT arrays successfully detected PIT-tagged Bull Trout and Rainbow Trout moving past the two study sites, and we discuss the implications of the PIT antenna read range for tags applied in other monitors. We also provide recommendations towards improving both counter and PIT array technologies to increase the accuracy of data collected in future monitoring years.

5.1 Resistivity Counters

The resistivity counters in the Chowade River and Cypress Creek provided data on fish species, size distributions, migration timings, and Bull Trout. We estimated that between August 17 and October 02, 22 Bull Trout migrated upstream past the counter in the Chowade River, while 27 Bull Trout migrated upstream past the counter in Cypress Creek between August 15 and October 02. These up-migration abundances do not represent the entire upstream migration because the counters were installed part way through the Bull Trout spawning migration. Similar results were observed in 1994 when R.L.&L. Environmental Services (1995) installed a fish fence in the Chowade River on August 22 and counted only 15 upstream migrants and 296 downstream migrants. According to Ministry of Environment Bull Trout telemetry data, Bull Trout upstream movements in the Chowade River and Cypress Creek can occur as early as the middle of July (AMEC & LGL, 2010). In future years, all reasonable effort will be made to ensure counter equipment is operational before the end of July.

Although the entire upstream migration was not captured in 2017, we were able to enumerate the full kelt out-migration. We estimated that 318 and 91 Bull Trout kelts migrated downstream past the counter sites in the Chowade River (between September 05 and October 02) and Cypress Creek (between September 05 and October 02), respectively. Kelt estimates have successfully been used as a proxy for adfluvial Bull Trout spawner abundance in other streams in British Columbia where equipment could not be deployed in time to capture the full upstream migration (Andrusak 2009). If a resident population exists (i.e., Bull Trout that do not move downstream to the Peace River) or if individuals die after spawning, they will not be accounted for in the kelt abundance estimate. It is important to enumerate both the upstream and downstream migrations to determine what proportion of up-migrants undergo kelting, and confirm if kelting abundance can be used to approximate spawner abundance. Another key element is assessing whether the proportion of Bull Trout that kelt changes from year to year and the factors that drive this variability. Understanding the natural variability or process error in abundance will be critical for detecting potential changes in abundance throughout the monitoring period.

Up-count accuracy was 69% for Bull Trout in the Chowade River, which is similar to other validated flat pad counter sensors in systems with similar site and fish characteristics

(Ramos-Espinoza et al. 2011, Burnett et al. 2017). For example, the accuracy for flat pad counter sensors used to enumerate Coho Salmon (*Oncorhynchus kisutch*) in the Lower Bridge River in 2016 was 70% for up counts (Burnett et al. 2017). In the Chilcotin River, flat pad sensor accuracies for Chinook Salmon (*Oncorhynchus tshawytscha*) were greater than 80% for up counts and >53% for down counts (Ramos-Espinoza et. al. 2011). The accuracy estimated for Cypress Creek was relatively low (55%), which could be due to inappropriate counter gain settings or may be an artifact of the small sample size. The resistivity counters continually monitor bulk resistance and conductivity, and the counter uses conductivity to adjust internal gain and counter sensitivity. If conductivity is high, gain settings are decreased to lower the sensitivity of the sensors. We experienced conductivity probe issues in 2017 and set a default gain (conductivity was measured during weekly site visits and gain was adjusted accordingly). Gain settings were set conservatively, and the default gain may not have been appropriate for Cypress Creek. This is corroborated by the higher number of false negatives (fish missed by counter) and the low number of false positives (<5) from the Cypress Creek counter. In 2018, gain settings at both sites will be adjusted to increase the sensitivity of the counter.

The total number of kelts (91) observed in Cypress Creek was considerably lower than observed in the Chowade River (318). These kelt estimates are similar to redd abundance estimates of 90 for Cypress Creek and 320 for the Chowade River (Putt et al., 2018), amounting to 1 fish per redd. In other systems, such as the Kaslo River and Crawford Creek (Andrusak 2009), the number of kelts per redd can vary from 1.8 to 2.2. We do not have sufficient data to determine why the number of kelts per redd is lower in the Chowade River and Cypress Creek than in other systems, although high spawner mortality or a large resident Bull Trout population are possible explanations. Future years of counter data, redd abundance estimates, and PIT-tag recapture data will inform Halway River Bull Trout ecology and improve the accuracy and reliability of up-migration and kelt abundance estimates.

Counter accuracies are generally higher for populations moving upstream relative to downstream because fish generally move along the river bottom when swimming against the current. Down count accuracies for both the Chowade River and Cypress Creek were 45 and 47%, respectively. Although down count accuracies are typically lower, inappropriate gain settings may have further lowered accuracy. If the counter were operating optimally we would expect accuracies to be between 60 to 70% (Ramos-Espinoza et al. 2011). If we are to use the kelt estimate as an alternate abundance estimate, it will be important to improve the accuracy of the counter for downstream movements. Detailed field testing of the counter gain settings in 2018 will aim to improve down count accuracies and decrease uncertainty in kelting estimates.

The target enumeration species was migratory adult Bull Trout, and the counter sensors were designed accordingly. Other species (Mountain Whitefish and Rainbow Trout) were observed moving past the sites in the Chowade River and Cypress Creek while the counters were operational. The counter sensors would need to be reconfigured to enumerate smaller-bodied fish such as Rainbow Trout and Mountain Whitefish, which would reduce counter accuracy for larger-bodied Bull Trout and weaken the relationship between PSS and standard length. In general, counter accuracy decreases when the size range of fish being targeted increases. To maintain a high accuracy for detecting Bull Trout, the counter system (gain and electrode spacing) was configured to target fish within the Bull Trout size range for sexually mature individuals observed in the Chowade River in 2016 (mean standard length: 700 mm; range: 410 – 930 mm) (Braun et al. 2017a). These settings resulted in lower accuracies for Mountain Whitefish and Rainbow Trout; however, these are non-target species for this monitor and the trade-off was therefore acceptable.

Bull Trout showed a strong diurnal movement pattern and were most frequently detected by the counter during nighttime hours. The additional lights installed in 2017 and improvements to the sensor backgrounds benefited nighttime validation by improving species identification during the periods of highest fish movement. During time periods when solar radiation is low (end of season when days get shorter and weather is variable), it may be possible to preserve power by reducing the amount of video recorded during daylight hours. The low numbers of Bull Trout moving over the sensor pads during the day suggests that reducing daytime video would not substantially affect the number of Bull Trout available to be validated.

Sizing and species identification were achieved through video validation. Size distributions estimated through video validation were consistent with those observed in 2016 (Braun et al. 2017a) and during the operation of the fish fence in the Chowade River in 1994 (R.L. & L. Environmental Services Ltd. 1995). Species was determined using length, shape and schooling behaviour. For example, Bull Trout were large-bodied and generally moved over the counter one at a time, whereas Mountain Whitefish were relatively small and crossed the pads in large schools. Some Mountain Whitefish, Rainbow Trout and Arctic Grayling may have been misidentified as Bull Trout due to overlapping size ranges (R.L. & L. Environmental Services Ltd. 1995) or if the fish was small (species cannot be determined using video when they are <400mm). Despite these uncertainties, improved nighttime video quality in 2017 greatly increased our confidence in species identification. We were able to determine the species of all fish observed on video in the Chowade River and all but three fish in Cypress Creek.

Fish length (measured via video footage) was weakly correlated with PSS in 2017 and could not be used to determine size cutoffs for species identification. When separated by channel, some degree of correlation was observed. Weak PSS vs length correlations resulted from inappropriate counter gain settings and/or the location of individual sensor pads in the stream channel. If gain settings are not set correctly, a large Bull Trout (>700 mm) may register a PSS value lower than 127, or the typical maximum value for large-bodied fish. Additionally, if a sensor pad is located in the deepest part of the stream channel, a fish swimming along the bottom would produce a higher PSS than a fish of the same size swimming higher in the water column. The poor relationship between fish size and PSS did not influence Bull Trout abundance estimates in 2017 because all fish could be identified to species using the video data (i.e., we did not need to use PSS to infer size). Changes recommended for 2018 should strengthen the relationship between PSS and length. It is important to develop a PSS vs length relationship to accommodate potential gaps in video data in future years.

High water levels in the Chowade River and Cypress Creek can impede the installation and operation of resistivity counters and PIT arrays (Braun et al. 2017a), and it would be advantageous to monitor real-time discharge in these tributaries (not currently available). We found a strong correlation between Water Survey of Canada real-time discharge in the Halfway River and stage height at both counter sites, suggesting that Halfway River discharge is a useful proxy for water depth in the Chowade River and Cypress Creek. By relating Halfway River discharge to tributary stage height, we can determine when water depth is low enough to install the counters and when it is possible to fix or remove in-river equipment. This information is particularly important due to the remoteness of the counter sites and the time required to access the sites. Water levels in the Chowade River and Cypress Creek in 2017 were low and stable (ideal for deployment and operation of counters and PIT arrays) compared to conditions in 2016. In the Chowade River, stages differed by 0.47 m in 2016 compared to only 0.02 m in 2017.

The power system used to operate the resistivity counter, computer/DVR, video and PIT telemetry equipment did not experience any outages during the 2017 Bull Trout migration. Power system upgrades were highly effective at compartmentalizing the power and managing the battery banks, and the generator back up system was effective at maintaining adequate power during and after low solar conditions. Field crews were able to top up the battery banks with the on-site generator and reduce the risk of subsequent power outages.

5.2 PIT Telemetry

We were able to effectively operate and maintain PIT arrays throughout the 2017 Bull Trout kelting period in both Cypress Creek and the Chowade River. The design modifications made to the antennas were highly effective and improved both detection range and deployment in 2017 relative to 2016. With both PIT antennas operational at one site, read ranges of one of the antennas was low due to electrical interference between the solar components. Consequently, we could only effectively run two antennas concurrently for 12 days in the Chowade River and 6 days in Cypress Creek. In 2018, the power systems will be modified to reduce electrical interference and allow for the operation of two antennas at each site throughout the migration period. To reduce interference, each antenna will have a dedicated power system that will be isolated from all other power systems on site, and the antennas will be synchronized to ensure that there is no time drift between readers. Additionally, all electrical devices on-site will be time-synced weekly to the computer clock and staff will record the time difference at the time of sync.

The PIT arrays were extremely effective at detecting PIT-tagged fish in both the Chowade River and Cypress Creek. Detailed range testing indicated that the proportion of the water column that could detect tags was >95% for 23 mm and 32 mm tags and ~75% for 12 mm tags. Importantly, the proportion of water column where tags can be detected does not represent detection probability. Detection probability is a combination of the detection proportion and the location of fish movement. For 32 mm and 23 mm tags, the detection proportion was close to 100%, so the detection probability was also close to 100% regardless of the location of fish movement. For 12 mm tags however, because the detection proportion was ~75%, the location of movement becomes important for determining detection probability. To maximize detection probability, increasing the detection proportion for 12 mm tags will be prioritized in 2018 (via the power modification detailed above). When both antennas were operational, detection efficiencies of the arrays (i.e., the ability of both antennas to detect a tag moving through the study site) were 100% in both tributaries. Maximizing detection probability for all tag sizes and operating two antennas concurrently in both tributaries for the entire migration period will inform other FAHMFP monitoring programs that evaluate changes in Bull Trout population abundance over time.

PIT data collected in 2017 only represents a two-month snapshot of the life history of fish in the Chowade River and Cypress Creek, and the movement history prior to being detected on the PIT arrays is unknown. Additional years of PIT data will continue to inform fish movement and behavior in conjunction with other monitors. Additional PIT data will provide critical information about movement ecology, key life history events (e.g., juvenile outmigration), and stage-specific survival and transition probabilities (e.g., juvenile to subadult, subadult to adult) in tributaries of the Halfway Watershed. Expanding the scope of the PIT monitoring (e.g., monitoring a longer time period) could provide new information about resident and migratory populations and their short- and long-term migrations, and inform the sampling activities and timing of other FAHMFP monitoring programs.

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7 Appendix A. Individual fish PIT detections at Chowade River and Cypress Creek 2017.

Appendix_A_chowad
e_tracks.pdf

Appendix_A_cypress
_tracks.pdf

8 Appendix B. Bull Trout Tributary Tagging Data.

Appendix
B-Trib_Tagging_and_