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Site C Clean Energy Project

Site C Fishway Effectiveness Monitoring Program (Mon-13)

Construction Year 6 (2020)

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Executive Summary

Hydroelectric dams, such as the Site C Clean Energy Project (the Project) on the Peace River in northeastern British Columbia, obstruct riverine connectivity and pose significant challenges for migratory fishes. Fish movements have, and will continue to be, affected during the construction and operation of the Project. During the river diversion phase of construction, BC Hydro will operate the temporary upstream fish passage facility (herein, TUF), which includes a weir-orifice fishway combined with trap and haul facilities. The Site C Fishway Effectiveness Monitoring Program (Mon-13) aims to monitor the biological effectiveness of the TUF to reduce key uncertainties and inform operations. Key uncertainties in the operation of the TUF include the effectiveness of attracting fish from the Peace River into the fishway and the attraction flows required to do so.

A telemetry system with strategic detection locations that tracks the movements of tagged fish (an array) is the only feasible means to understand the factors that may limit or facilitate fish passage. Using an extensive radio and passive integrated transponder (PIT) telemetry array, we monitored the movements of five target species (Arctic Grayling, Bull Trout, Burbot, Mountain Whitefish, and Rainbow Trout) tagged under other components of the Fisheries and Aquatic Habitat Monitoring and Follow-Up Program (Task 2c of Mon-1b Site C Reservoir Tributaries Fish Population Indexing Survey and Task 2a of Mon-2 Peace River Large Fish Indexing Survey). Mon-13 will determine species-specific and temporal variation among the three distinct states of movement within and around the TUF: approach to the fishway, fishway entry, and fishway passage. We designed the array such that fixed radio telemetry stations (fixed stations) determined the proportion of fish approaching the fishway that successfully entered, while PIT antennas detected movements within the fishway. Resulting data aim to provide preliminary estimates of attraction efficiency (the proportion of fish approaching the fishway that are attracted to the fishway) and passage efficiency (the proportion of fish attracted to the fishway that entered the structure and successfully passed).

Fishways must attract a diverse assemblage of fish species and enable upstream passage while ensuring minimal energy expenditure. Supplemental flows are typically required to attract fish and facilitate passage, but high flows can also be detrimental. Therefore, Mon-13 also focused on understanding the attraction flows required to maximize approach and entry. Attraction flows at the TUF are provided by an auxiliary water supply (AWS) flowing through two entrance gates, which can be supplemented by a high velocity jet (HVJ) located adjacent to the fishway entrance.

These two components of attraction flow will be experimentally manipulated on a predetermined schedule to understand how effects may differ among species present at a given time.

Construction timelines combined with environmental conditions dictated when the TUF was operated in 2020, the first year of operations. The TUF operated between October 1 and 31, 2020 (herein, Operational Period); however, a 10-day Standby Period (October 20 to 30, 2020) was required due to cold weather. The 2020 Operational Period, therefore, encompasses a ~20-day period. During the Operational Period, the proposed flow schedule was to alternate three times daily between four distinct attraction flow scenarios that encompassed all combinations of AWS of either 4.25 m^3/s or 8.5 m^3/s and no HVJ, or HVJ supplementation of 1.5 m^3/s. Attraction flows did approximate the predetermined schedule but there were small variations both in the timing and magnitude of flows. River discharge and, hence, water surface elevations in the TUF increased throughout the Operational Period.

Monitoring in 2020 primarily focused on maximizing the functionality and efficiency of the array. Unfortunately, despite all efforts to shield PIT antennas from radiated and conducted noise, operation of the TUF had a substantial impact on PIT antenna performance. Of the seven PIT antennas deployed, reliable detection data during the Operational Period was only available from one of the two entrance antennas (West Entrance). The radio array functioned as intended, and detection data were available from all five target species. Bull Trout, Arctic Grayling, and Rainbow Trout were primarily detected by fixed stations (Burbot to a much lesser extent) and the PIT array primarily detected Mountain Whitefish, for which there were no radio telemetry data. This divergence in the species assemblages detected by the two technologies, combined with low sample sizes for many detection areas, required analyses to be primarily descriptive, and conducted separately across the two technologies.

PIT and radio telemetry data were summarized to assess fish presence spatially and temporally throughout the monitoring period, which encompassed the entire period of data collection from activation of the first receiver to last detection included in the dataset (August 1 - December 7, 2020). Radio-tagged Arctic Grayling, Bull Trout, and Rainbow Trout spent the most time within the array, and while Arctic Grayling and Bull Trout were detected throughout the study area, Rainbow Trout were primarily detected in the most downstream zone of the study area (i.e., farthest from the fishway). Relative to other species, Bull Trout more often used the diversion tunnel outlet area. Only one Burbot was detected throughout the entire monitoring period in the most upstream area along the right bank opposite the TUF. Three Bull Trout and one Arctic

Grayling were detected within the Attraction Zone, a defined area outside of the fishway entrance where we suspect fish can detect attraction flows. Many of the fish detected proximate the fishway entrance made multiple directional upstream movements towards the TUF. One radio-tagged Bull Trout went into the entrance pool. However, given the relatively limited sample size of radio telemetry data collected proximate to the fishway, movement around and within the fishway entrance was best described with PIT data. Among target species, Arctic Grayling (n = 1), Bull Trout (n = 2), and Mountain Whitefish (n = 116) were detected during the Operational Period. It was common for tagged fish to be detected multiple times at the fishway entrance, particularly Mountain Whitefish. Radio tagged fish detected at the fishway entrance also commonly made multiple movements towards the fishway.

Mountain Whitefish were the only target species undergoing a spawning migration during the Operational Period. Daily numbers of Mountain Whitefish detected increased to a maximum of 22 on October 14, 2020. However, poor performance of PIT antennas meant many PIT-tagged fish were likely missed. Indeed, groups of Mountain Whitefish were regularly observed milling at both the fishway entrance and the uppermost pool (Pool 25) directly downstream of the vee-trap. Detection data still revealed informative trends. For example, the greatest number of Mountain Whitefish were detected at the highest attraction flows (AWS = 8.5 m^3/s, HVJ = 1.5 $^3/s$). Of the 117 PIT-tagged Mountain Whitefish detected, three successfully passed the fishway and were scanned in the sorting facility. Although no other tagged target species successfully passed the fishway, radio telemetry data were sufficient to run preliminary analyses to begin to estimate attraction efficiencies for Arctic Grayling and Bull Trout during the Operational Period using Kaplan-Meier survival analyses. Preliminary estimates of attraction efficiencies were 17% for Arctic Grayling and 25% for Bull Trout. It is notable, however, that these estimates are based on small sample sizes and neither species was undergoing a spawning migration at the time, which could result in low motivation to move upstream of the Project.

Monitoring in 2020 demonstrated that with increased monitoring time and fish activity (i.e., detection data), Mon-13 will effectively address the management question and associated hypotheses. With the data available from the 20-day Operational Period in 2020, we were able to partially address the hypotheses. Hypothesis 1 states that target species locate and use the fishway. Using a combination of radio and PIT detection data, we confirmed that Arctic Grayling, Bull Trout, and Mountain Whitefish can locate the fishway and that Mountain Whitefish and Arctic Grayling can use the fishway. Hypothesis 2 states that attraction and passage efficiencies are as predicted in the Environmental Impact Statement (80% and 76%, respectively). We reject this hypothesis for the 2020 Operational Period, with the caveat that data were limited, and the monitoring period was brief. Additional monitoring of a larger sample of tagged fish over a longer monitoring period that includes the spawning migrations of other target species will provide increased clarity.

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We respectfully acknowledge this research is being conducted on the traditional territory of Treaty 8 First Nations. We also acknowledge the history of the Dunne Zaa people in the Fort St. John area, and the original Fort St. John Beaver Band who are now the Blueberry River First Nations and Doig River First Nation.

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List of Abbreviations and Acronyms

AWS	Auxiliary water supply
EIS	Environmental impact statement
FAHMFP	Fisheries and Aquatic Habitat Monitoring and Follow-Up Program
HDPE	High density polyethylene
HVJ	High velocity jet
OPP	Operational parameters and procedures
PIT	Passive integrated transponder
PUF	Permanent Upstream Fish Passage Facility
SD	Standard deviation
TUF	Temporary Upstream Fish Passage Facility
VFD	Variable frequency drive
WSE	Water surface elevation

Glossary

Approach Zone – A distinct area in which fish are considered candidates for fishway passage. Typically, this is where fish first detect influence of the tailrace. For Mon-13, the Approach Zone encompasses the entire area upstream of the Approach Gate to the downstream cofferdam and the entrance of the fishway, including the diversion tunnel outlet.

Array – A telemetry tracking system with strategic detection points that detect passing tagged animals. For Mon-13, a combined passive integrated transponder (PIT) and radio telemetry array was deployed to monitor tagged fish as they approached, entered, and passed the fishway.

Attempt – As used in survival analyses. For Mon-13, a continuous presence of a tagged fish on the radio telemetry array for a predetermined extent. Each tagged individual may have multiple attempts within the array.

Attraction efficiency – The proportion of fish approaching a fishway that are attracted to the fishway. For Mon-13, the proportion of modelled attempts detected in the Approach Zone that successfully reached the Attraction Zone by the end of the Operational Period.

Attraction Zone – The area between a fishway entrance and where fish can detect attraction flows. For Mon-13, the Attraction Zone equates to the range of a dipole antenna deployed on the outside of the fishway between the two entrance gates.

Entrance efficiency – The proportion of fish attracted to a fishway that enter the structure. Entrance efficiency is not monitored under Mon-13.

Farfield Attraction Zone – An area proximate fishway entrances that has a wider range than the Attraction Zone. For Mon-13, the Farfield Attraction Zone equates to the range of an aerial antenna installed outside of the TUF entrance.

Efficiency metrics – Metrics that define the proportion of fish successfully passing from one state to the next, including attraction efficiency, entrance efficiency, and passage efficiency (all defined herein).

Monitoring Period – The entire period when data were collected, irrespective of fishway operations, from initiation of data collection to last detection included in the analyses provided herein; August 1 - December 7, 2020.

Occupancy – A continuous presence of a tagged fish on the PIT telemetry array for a predetermined extent. Each tagged individual may have multiple occupancies within the array.

Operational Period – The period when the fishway was operational and attraction flows were provided; October 1 to 31, 2020, excluding the 10-day Standby Period.

Overwintering Period – Cessation of Operational Period to last detection included in the analyses provided herein (December 7, 2020).

Passage efficiency – The proportion of fish that enter and successfully ascend a fishway.

Standby Period – The period when the fishway was temporarily not operational and attraction flows were not provided. In 2020, the fishway was on standby from October 20-30, 2020, after which operations were resumed.

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 Fishway Effectiveness Monitoring Program (Mon-13) represents one component of the FAHMFP and aims to monitor the biological effectiveness of the temporary upstream fish passage facility (TUF) to reduce key uncertainties and inform operations. Key uncertainties in the operation of the TUF include the effectiveness of attracting fish from the Peace River into the fishway and the attraction flows required to do so. Data collected under Mon-13 will be used to directly address the following management question and hypotheses:

Does the TUF provide effective upstream passage for migrating Arctic Grayling, Bull Trout, Burbot, Mountain Whitefish, and Rainbow Trout that are attempting to migrate upstream during the construction of the Project?

> H_1: Arctic Grayling, Bull Trout, Burbot, Mountain Whitefish, and Rainbow Trout locate and use the fishway.
>
> H_2: Fishway attraction and passage efficiency are as predicted in the Environmental Impact Statement (EIS; attraction efficiency of 80% and passage efficiency of 76%).

Using both radio and passive integrated transponder (PIT) telemetry, we monitor the movements of the five target species (Arctic Grayling, Bull Trout, Burbot, Mountain Whitefish, and Rainbow Trout). All tagged fish currently in the system have been tagged under other components of the FAHMFP, including Mon-1b, Task 2c (Site C Reservoir Tributaries Fish Population Indexing Survey) and Mon-2, Task 2a (Peace River Large Fish Indexing Survey). If increased sample sizes are needed, it is also within the scope of Mon-13 to tag target species that successfully ascend the TUF and transport them downstream. Mon-13 explores species-specific and temporal variation among the three distinct states of movement within and around the TUF: approach to the fishway, fishway entry, and fishway passage. Resulting data allow us to begin to explore preliminary estimates of attraction efficiency (the proportion of modelled attempts detected in the Approach Zone that successfully reached the Attraction Zone by the end of the Operational Period) and passage efficiency (the proportion of fish attracted to the fishway that entered the structure and successfully passed). While Mon-13 refers only to monitoring fish passage at the TUF, results will also inform the design and operation of the permanent upstream fish passage facility (PUF).

Being a new and dynamic study site, Mon-13 has, and will continue to be, conducted within an adaptive framework where the proposed study design may be modified based on advances in the understanding of the aquatic ecosystem, improvements in field and analytical techniques, and/or limitations due to concurrent construction activities. In 2020, the focus of Mon-13 was to fabricate, install, maintain, and test the array, optimize array performance, and monitor the movements of tagged fish within the study area.

1.2 Fish Passage at Site C Dam

One of the most significant consequences of obstructions on riverine systems is the altering of longitudinal connectivity. Connectivity is crucial to the maintenance and expression of life history diversity among fish populations, particularly for migratory fishes seeking upstream areas to reproduce or feed (Cooke et al. 2012). Hydroelectric dams, ubiquitous across the modern riverine landscape, present a major obstruction to riverine connectivity. Larger dams typically create extensive reservoirs and are often too high to provide cost-effective means for volitional fish passage, conditions that pose significant challenges for migratory fishes (Beamish and Northcote 1989; Nehlsen et al. 1991). The consequential reduction in life-cycle success has eliminated species from river basins across the globe.

Fish movements have, and will continue to be, affected during the construction and operation of the Project. During the river diversion phase of construction, BC Hydro will operate the TUF, which includes a weir-orifice fishway combined with trap and haul facilities. Key uncertainties in the operation of the TUF include the effectiveness of attracting fish from the Peace River into the fishway and the attraction flows required to do so. Mon-13 aims to monitor the biological effectiveness of the TUF for select target species to reduce key uncertainties and inform operations. Arctic Grayling, Bull Trout, Burbot, Mountain Whitefish, and Rainbow Trout were chosen as target species because they have known spawning areas upstream of the Project and are, therefore, likely to migrate through the area. Additionally, these five species were identified during the environmental assessment process as important for Indigenous groups and anglers and are indicator species in local provincial management objectives (BC Ministry of Environment 2009; BC Government 2011).

There has been extensive effort to create or improve passage for migratory fishes at barriers, and especially at dams (Fuentes-Pérez et al. 2016; Burnett et al. 2017; Baumgartner et al. 2018; Silva et al. 2018). One of the biggest challenges to providing effective fish passage at riverine barriers is developing structures and design concepts that will pass a broad range of species (Thiem et al. 2012; Silva et al. 2018; Birnie-Gauvin et al. 2019). Considering the species assemblage of the Peace River watershed expected to require upstream passage at the Project, a combined Half Ice Harbour weir-orifice fishway with a 1(V):10(H) slope coupled with trap and haul facilities was selected as the most suitable design (BC Hydro 2020). Weir-orifice fishways are constructed using a series of ascending pools that divide the total project head into passable increments and are separated by weirs and submerged orifice openings (National Marine Fisheries Service 2011). Such a design permits passage of both surface- and bottom-oriented species; fish can move through adjacent pools by either swimming over weirs or along the bottom through submerged orifices.

Rainbow Trout and Bull Trout are both strong swimmers that are expected to pass via both orifices and weirs. Rainbow Trout have been documented successfully passing various types of fish ladders (Hatry et al. 2013). Bull Trout are known to make regular upstream and downstream movements through impounded sections of the Columbia River, including repeated ascents of weir and orifice fishways (Stevenson et al. 2009; Gallion and Skalicky 2014). Arctic Grayling and Burbot are relatively weak swimmers and are, therefore, expected to primarily use orifices for passage. Burbot exhibit weak jumping abilities and relatively poor swimming endurance, but have been documented to successfully pass vertical slot, Denil, and nature-like fishways (Schwalme et al. 1985; Slavík and Bartoš 2002). Arctic Grayling similarly prefer slow horizontal water velocities and near-zero vertical velocities (Kupferschmidt et al. 2019). There is little research on fishway passage for Mountain Whitefish, but they have been documented using vertical slot ladders and Denil fishways (Kiffney et al. 2018; Platt 2019).

To be effective, fishways must attract fish to the entrances, enable fish to swim upstream, and achieve both with minimal energy expenditure. Most successful fishways have entrances located as close to a dam as possible and are oriented at an angle to the flow such that fish can move in the current as directly as possible into the entrance(s) (Williams et al. 2012); the location and orientation of the TUF relative to the flow of the diverted Peace River reflect this objective (Figure

1.1). Generally, additional flows are required to attract fish to the fishway entrance. Maintaining attraction flows appropriate for diverse assemblages of fish species that display different movement behaviours is a particularly challenging aspect of operating a fish passage facility; even within well-designed fishways, not all fish will pass equally well (Caudill et al. 2007; Thiem et al. 2012; Bunt et al. 2016).

Migrating fish are naturally drawn to areas of higher flow, which is a key determining factor in locating a fishway. However, high flows consisting of excessive turbulence or extreme water velocities can pose a significant challenge for many sizes and species of fish (Burnett et al. 2014; Bunt et al. 2016). High attraction flows may have latent or indirect negative effects. For example, high flows may cause migratory delays, which can have important ecological implications (e.g., increase energetic expenditure, attract predators, facilitate disease transfer; Caudill et al. 2007), and maintaining position in high flows may lead to exhaustion or require protracted recovery periods (Burnett et al. 2017).

Establishing appropriate attraction flows is difficult and requires testing a range of scenarios throughout the season to understand how potential effects may differ among species present at a given time (Cooke and Hinch 2013). To determine appropriate attraction flows, it is common to test distinct flow scenarios (e.g., Burnett et al. 2017). Fishway attraction flows at the TUF are provided by an auxiliary water supply (AWS) flowing into the entrance pool and though the fishway entrance, which can be supplemented by additional flow from a high velocity jet (HVJ) located adjacent to the fishway entrance (Figure 1.2). This supplemental attraction serves to attract fish from the farfield (tens of meters away) to the nearfield area surrounding the fishway entrance (< 10 meters; BC Hydro 2020). Flows provided by the AWS can be programmed to various magnitudes up to 10 m^3/s and are continuously modified to maintain a consistent discharge despite flow fluctuations in the Peace River. The HVJ can either be programmed to be on (up to 1.5 m^3/s) or off. Throughout this monitor, combinations of these two components of attraction flow will be experimentally manipulated on a predetermined schedule to better understand the fishway attraction flows that maximize passage. Results from computational fluid dynamics models of the attraction flows from the TUF into the Peace River can be found in McMillen (2014), with model results from cases 203 to 214 most representative of existing conditions.

Figure 1.1 Aerial photo of the diverted Peace River and the temporary upstream fish passage facility (TUF) at the Site C Clean Energy Project. The Peace River is diverted through tunnels, which do not provide upstream fish passage. Photo provided by BC Hydro, June 8, 2021.

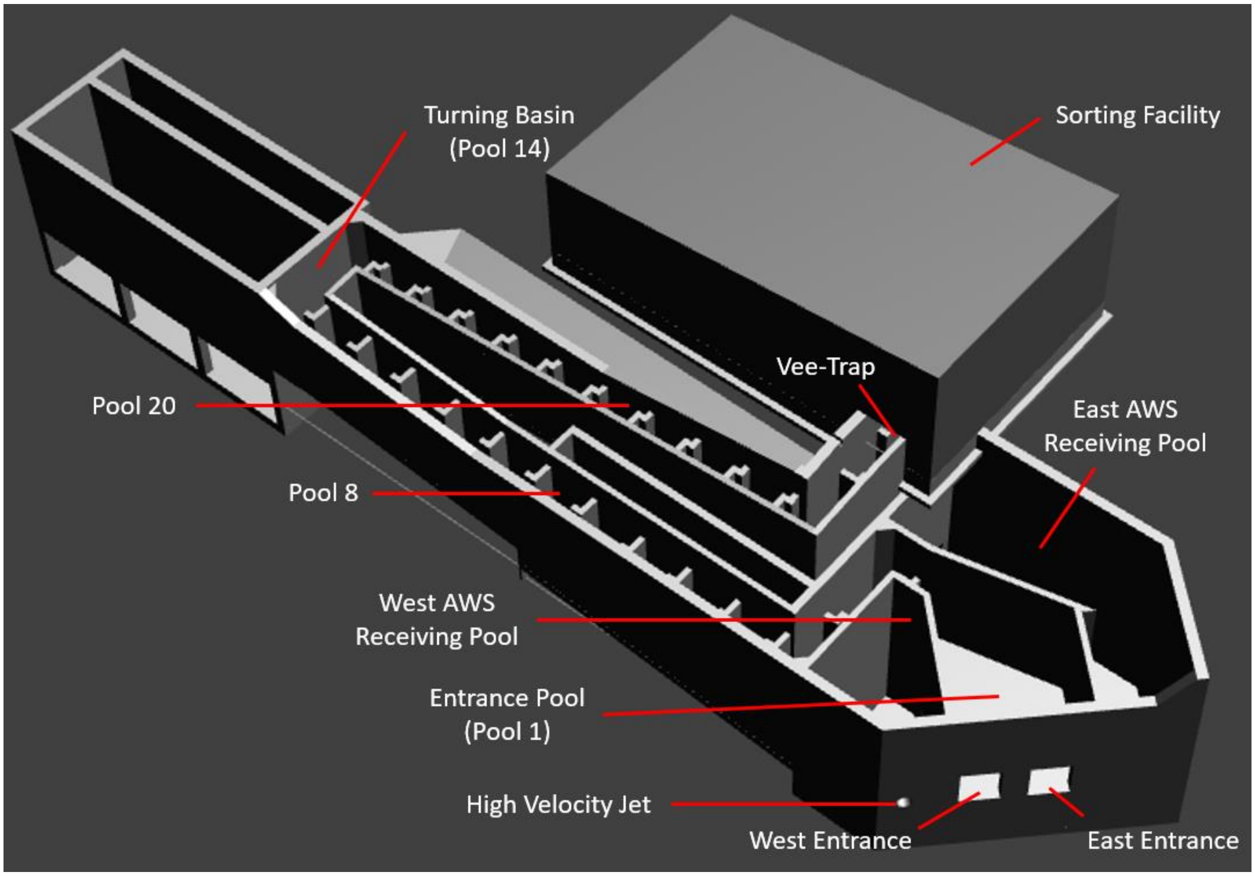


Figure 1.2 A drawing of the temporary upstream fish passage facility (TUF) located on the east bank of the diversion tunnel outlet. Upstream migrating fish enter the TUF via one of the two entrance gates and are processed and sorted for transport within the sorting facility. Fishway attraction flows at the TUF are provided by an auxiliary water supply (AWS) flowing into the east and west receiving pools and then into the entrance pool and though the fishway entrance, which can be supplemented by additional flow from a high velocity jet (HVJ) located adjacent to the fishway entrance

1.3 Quantifying Passage Success

Fishway efficiency metrics are a benchmark for evaluating the biological effectiveness of fishways. Efficiency metrics consider the number of fish found to ascend a fishway as well as those that failed to find the entrance to the fishway, or that entered but failed to successfully ascend the fishway (Cooke and Hinch 2013). Quantifying efficiency metrics requires understanding the proportion of a given species approaching the fishway that successfully detect attraction flows at a fishway entrance (attraction efficiency), enter the fishway (entrance efficiency), and pass through the fishway in completion (passage efficiency; Table 1.1). Approach, entry, and passage are distinct states with temporal components and success at each is likely to be species-specific (Castro-Santos and Perry 2012; Silva et al. 2018).

Understanding movement among passage states and generating reliable efficiency estimates requires delineating corresponding spatial zones along the trajectory of upstream migration using a telemetry tracking system with strategic detection points (herein, an 'array'). Defining boundaries of spatial zones is an important first step in designing a fish passage study. The term "zone" refers to areas that define passage states. Fish become candidates for passage once detected within the Approach Zone, and the Attraction Zone is where we suspect fish can detect attraction flows. The array also includes a Farfield Attraction Zone, which has a wider range than the Attraction Zone. Once fish have crossed into the Approach Zone, the proportion of fish successfully passing from one state to the next (i.e., efficiency metrics) can be calculated. We adopted the definitions for zones and efficiency metrics detailed in Bunt et al. (2012) and Cooke and Hinch (2013), modified according to the specific requirements of Mon-13 (Table 1.1).

The completion of the various stages of fishway passage is not an instantaneous event, but the result of competing and continuous processes whereby fish may be exposed to multiple environmental and operational conditions during fishway approach, entry, and passage. Only telemetry data produce the continuous time series required for questions of fish passage (e.g., the calculation of efficiency metrics), which are best analyzed with survival analyses that can accommodate time-varying covariates, such as time-to-event analyses (TTE; Castro-Santos and Haro 2003; Castro-Santos and Perry 2012; Silva et al. 2018).

Both PIT and radio telemetry were used to track movements of tagged fish as they approached, entered, and passed the fishway. However, access to a fishway may be blocked or restricted by various factors including, but not limited to, turbulence, velocity barriers, or distracting flows in areas away from fishway entrances (Bunt et al. 1999). Therefore, the Mon-13 telemetry array was also designed to understand factors potentially limiting successful fish passage by monitoring areas used by those fish not attracted to the fishway or those that approach the fishway but do not pass from one state to the next.

Table 1.1: Definitions of zones within the study area and efficiency metrics associated with each zone. Definitions were adapted from Bunt at al. (2012) and Cooke and Hinch (2013). Predicted efficiency metrics for the Project are specified in Volume 2, Appendix Q of the Site C Environmental Impact Statement (EIS)[1].

Spatial Zone		Efficiency Metric	
Approach Zone	A defined area in which fish are considered candidates for fishway passage. Typically, this is where fish first detect influence of the tailrace.	No efficiency metric. Only fish entering this zone will be considered for analysis.	
Attraction Zone	An area between the fishway entrance and where fish can detect attraction flow. This is typically within 3 m of fishway entrances. Under Mon-13, the spatial extent of the Attraction Zone is defined by the range of a dipole antenna.	**Attraction efficiency**	The proportion of modelled attempts detected in the Approach Zone that successfully reached the Attraction Zone by the end of the Operational Period. The EIS[1] predicts an attraction efficiency of 80%.
Entrance	The entrance pool, accessed by two separate entrance gates.	**Entrance efficiency**	The proportion of tagged fish attracted to the fishway that entered the structure. The EIS does not predict an entrance efficiency, and it is not a focus of this monitor.
Fishway	The entire fishway, from entrance to collection in the sorting facility.	**Passage efficiency**	The proportion of tagged fish that entered and successfully ascended the fishway. The EIS[1] predicts a passage efficiency of 76%.

[1] Available at: https://www.ceaa-acee.gc.ca/050/documents_staticpost/63919/85328/Vol2_Appendix_Q.pdf

1.4 Study Area

The Project is located within the Peace River, approximately 10 km southwest of Fort St. John. Originating in the Rocky Mountains of northeastern British Columbia (BC), the Peace River is ~2,000 km long and flows to the northeast through northern Alberta, joining the Athabasca River in the Peace-Athabasca Delta. The entire study area for Mon-13 is a small reach of this large river, including riverine habitat approximately 2 river kilometers (rkm) downstream of Taylor, BC, upstream to the point that fish passage is blocked by the Project within the mainstem Peace River. Fish movement that occurs following transport and release at locations upstream of the Project is covered by a complimentary monitoring program (Site C Trap and Haul Release Location Monitoring Program; Mon-14). No tagging or downstream transport occurred in 2020 under Mon-13, eliminating the need to monitor the upstream progress of these released fish. Therefore, the study area in 2020 was constricted to an area approximately 1.5 rkm downstream of the Project, which includes the Approach Zone and the detection range of a single downstream receiver. See Section 2.2 (Telemetry Array) for a full description of the array.

The study area also includes the TUF and the sorting facility (Figure 1.2). The entrance to the TUF has two entrance gates, referred to as the West Entrance and East Entrance, that lead into an entrance pool. The Half Ice Harbor weir-orifice fishway has a 1(V):10(H) slope and 25 distinct pools, each with a weir and an orifice. Pool 14 is a turning basin, where ascending fish must make two 90-degree turns to continue upstream. The final pool (Pool 25) has a one-way vee-trap on the upstream end that leads fish into a pre-sort holding pool. A rail-mounted mechanical fish crowder and fish lock crowd and elevate fish into the sorting facility (an enclosed building). All fish ascending the fishway are processed and sampled by the fishway operator. Following sampling in the sorting facility, fish are sorted according to destination and are no longer monitored under the objectives of Mon-13.

The study area is an active construction site that changed considerably throughout monitoring in 2020. This, combined with environmental conditions, dictated the Operational Period of the TUF. The most significant construction activity in 2020 was river diversion. Full encroachment of the final rockfill berm was completed on October 3, 2020; at this point the mainstem Peace River was fully blocked to fish migration and all water flowed through the diversion tunnels, which do not provide upstream passage. Construction and fishway operation timelines have significant implications for fish behavior that must be considered in analyses and data interpretations.

2. Methods

To meet the objectives of Mon-13, a combined passive integrated transponder (PIT) and radio telemetry array was deployed to monitor tagged fish as they approached, entered, and passed the TUF. Environmental conditions likely relevant to probability of successful (or failed) passage were also monitored.

2.1 Fishway Operations

The intended annual Operational Period for the TUF is April 1 to October 31 during the construction phase of the Project. In 2020, timing of TUF operations were dictated by construction timelines (Table 2.1). Construction of the rockfill berm across the mainstem Peace River began on June 22, 2020. Although this constricted the river, fish could still move freely past the Project in both directions. The TUF began operating on October 1, 2020, and the mainstem Peace River was closed with full encroachment of the rockfill berm on October 3, 2020.

The TUF may need to be put on standby or be shut down under certain environmental conditions. The facility was designed to operate when water surface elevations (WSEs) in the tailrace at the fishway entrance are between 408.4 to 410.5 m (McMillen Jacobs & Associates and BC Hydro 2019). Additionally, operations may be constrained by cold air and water temperatures that can damage mechanical equipment and present a risk to fish health. Cessation of operations is anticipated when water temperatures are 3°C or below, or when average daily air temperatures remain below freezing to the point where ice formation prevents safe operations or puts target species at risk, estimated at -6°C and below (McMillen Jacobs & Associates and BC Hydro 2019). In 2020, the TUF was put on standby between October 20 14:20 and October 30 12:50 due to consistently cold temperatures (Table 2.1). The exact timing of the shutdown was determined by fishway flow data collected by flow meters deployed within the TUF that are managed by BC Hydro.

During operations, the AWS and HVJ were experimentally manipulated as outlined in the Manual of Operational Parameters and Procedures (OPP; McMillen Jacobs & Associates and BC Hydro 2019). Four distinct attraction flow scenarios were selected that encompassed all combinations of AWS of either 4.25 m^3/s or 8.5 m^3/s and no HVJ, or HVJ supplementation of 1.5 m^3/s. Flows were changed three times daily – at 00:00, 08:00, and 16:00 (Table 2.2). Such frequent changes were designed to overcome the expected challenges associated with understanding the effects of attraction flows on passage success under variable background conditions. Peace River flows fluctuate continuously, and fish may exhibit species-specific movement behaviors that may also vary with other environmental conditions.

Level sensors deployed at the TUF are monitored by BC Hydro to keep attraction flows consistent and running according to the operational schedule (McMillen Jacobs & Associates and BC Hydro 2019). BC Hydro managed all fishway operations data (e.g., fishway and attraction flows, WSEs, mechanical operations), which were collected and collated during fishway operations at 1-minute intervals. Variables extracted for analyses of fish passage included WSE in the diversion tunnel outlet (as recorded in the tailrace; LT-600), AWS flow, and HVJ flow.

Table 2.1 A timeline of completion of the major construction activites during the 2020 monitoring period for Mon-13 and the Operational Period of the temporary upstream fish passage facility (TUF).

Date	Event
June 22, 2020	Building of rockfill berm begins, the first structure to constrict the Peace River.
September 11, 2020	Diversion tunnel inlet and outlet cofferdams breached (river connected with the flooded inlet and outlet areas).
September 23, 2020	Wet testing of pumps begins; the fishway is accessible to fish.
September 30, 2020	Opened diversion tunnel inlet gates (river flows through diversion tunnels for first time).
October 1, 2020	TUF Operational Period begins with upstream fish passage provided through trap and haul.
October 3, 2020	Mainstem Peace River closed with full encroachment of rockfill berm.
October 20-30, 2020	TUF operations on standby due to cold weather.
October 31, 2020	TUF Operational Period ends.

Table 2.2 The planned operational schedule for attraction flows within the temporary upstream fish passage facility for a single, four-day cycle. Four days are required to run through all possible interactions between flow treatment and time of day.

	Day 1			Day 2			Day 3			Day 4		
	0:00-8:00	08:00-16:00	16:00-0:00	0:00-8:00	08:00-16:00	16:00-0:00	0:00-8:00	08:00-16:00	16:00-0:00	0:00-8:00	08:00-16:00	16:00-0:00
Attraction Flow (m^3/s)	4.25	4.25	8.5	8.5	4.25	4.25	8.5	8.5	4.25	4.25	8.5	8.5
HVJ Flow (m^3/s)	0	1.5	0	1.5	0	1.5	0	1.5	0	1.5	0	1.5

2.2 Telemetry Array

2.2.1 Overall Design

Radio telemetry was used to monitor tagged fish approaching and entering the fishway, while PIT antennas detected movements within the fishway. Successful passage was confirmed by the facility operator that processed and sorted each fish, scanned for PIT tags, and recorded various biological information. The radio array consisted of ten fixed radio telemetry stations (herein 'fixed stations') deployed within the study area on the Peace River (Figure 2.1) and within the TUF (Figure 2.2). Each fixed station had either one or two 3-element Yagi aerial antennas, which had large detection areas, or two submerged dipole antennas, which provided small detection areas (~10 m) for a specific defined area of interest (Figure 2.3).

In addition to tracking tagged fish as they approach and enter the fishway, fixed stations also identify areas where fish may congregate prior to, or instead of, entering the Attraction Zone. The locations of fixed stations were chosen to meet specific objectives (Table 2.3). These fixed stations are supplemented by a radio telemetry array that extends throughout the entire Peace River and its tributaries and is maintained by LGL, Ltd. (Task 2d of Mon-1b Site C Fish Movement Assessment; Figure 2.1). The data resulting from this larger array will help interpret movement data obtained by Mon-13 fixed stations by, for example, confirming directionality and intention of movements (e.g., if migrating to spawning grounds). The PIT telemetry array consisted of seven antennas that were designed, fabricated, and installed by InStream Fisheries Research. PIT antennas were custom built to fit within key locations of the TUF to detect fish passing through entrance gates, select weir and orifices, and into the sorting facility.

Installation of the radio telemetry array began on August 9, 2020, and all fixed stations aside from the Turning Basin were deployed by September 13, 2020 (Table 2.3). PIT antennas were installed and tested between June and September of 2020 and began recording data on September 13, 2020. The Overwintering Period began when TUF operations ceased on October 31, 2020, and all PIT antennas were deactivated. Six fixed stations remained operational during the Overwintering Period, including Mainstem 2, Approach Zone A and B, Cofferdam, Diversion Tunnel, and Entrance Aerial (Figure 2.1 and Figure 2.2). At the time of writing, these stations have run continuously; however, only detection data up to December 7, 2020 are included herein, thus defining the extent of the Overwintering Period.

Table 2.3 An overview of the purpose and operational dates of deployed PIT antennas and fixed radio telemetry stations ('fixed stations'). Fixed stations used to inform presence relevant to passage states have a named detection zone in parentheses, if it differs from the station name. Deactivation date is 'NA' if still operational at the time of writing. LB and RB refer to left and right bank, respectively.

Type	Fixed Station (Detection Zone)	Purpose	Activated Date	Deactivated Date
Radio	Mainstem 2 (Outside Approach)	Detects tagged fish as they approach study area. Coupled with an LGL fixed station to form a gate.	August 2, 2020	NA
Radio	Approach LB	Approach Zone LB and RB combined form the Approach Gate, which delineates the Approach Zone. Once detected in the Approach Zone, tagged fish are candidates for analyses of fishway passage.	August 2, 2020	NA
Radio	Approach RB		August 3, 2020	NA
Radio	RB Cofferdam	Determines if tagged fish are milling on the RB of mainstem proximate the downstream cofferdam.	August 3, 2020	NA
Radio	Tunnel Outlet	Detect fish that approach the diversion tunnel outlet prior to or instead of the fishway entrance.	September 14, 2020	January 19, 2021
Radio	Entrance Aerial (Farfield Attraction)	Defines the Farfield Attraction Zone. Identifies which tagged fish are approaching the fishway entrance.	September 15, 2020	NA
Radio (Dipole)	Outside Entrance (Attraction Zone)	Defines the Attraction Zone. Identifies tagged fish within immediate vicinity of the fishway entrance.	September 13, 2020	November 9, 2020
PIT	West Entrance	A PIT antenna frames each entrance of the fishway. Detection on an entrance antenna does not confirm entry.	September 13, 2020	November 1, 2020
PIT	East Entrance			
Radio (Dipole)	Entrance Pool	Detects tagged fish within the entrance pool, confirming entrance.	September 13, 2020	November 1, 2020
PIT	Pool 8	Antennas in the weir and orifice of Pool 8 detect tagged fish as they pass through into Pool 9.	September 13, 2020	November 1, 2020
Radio	Turning Basin	Detects tagged fish within the turning basin (Pool 14).	October 23, 2020	November 1, 2020
PIT	Pool 20	Antennas in the weir and orifice of Pool 20 detect tagged fish as they pass through into Pool 21.	September 13, 2020	November 1, 2020
PIT	Vee-Trap	Detects tagged fish as they pass through the vee-trap and into the pre-sort holding pool.	September 13, 2020	November 1, 2020

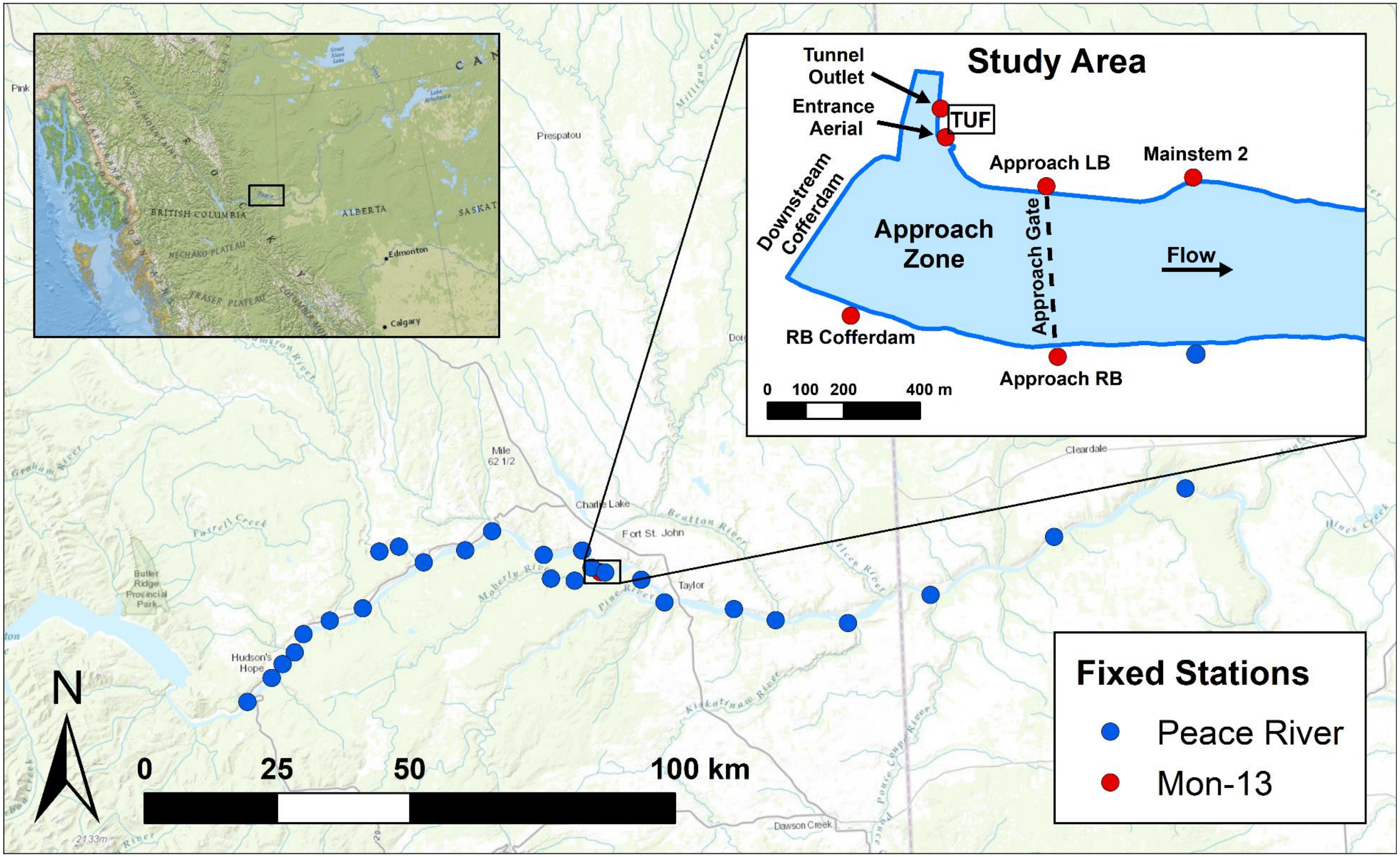


Figure 2.1 Fixed radio telemetry stations (fixed stations) deployed throughout the Peace River watershed to detect radio-tagged fish. The main map shows the watershed-scale array maintained by LGL, Ltd., except for stations deployed Cypress Creek and Chowade River, tributaries of the Halfway River beyond the northeastern extent of this map. The zoomed in area shows the Mon-13 study area, with the six fixed stations deployed on the mainstem Peace River. Fixed stations are also deployed within the temporary upstream fish passage facility (TUF; not shown).

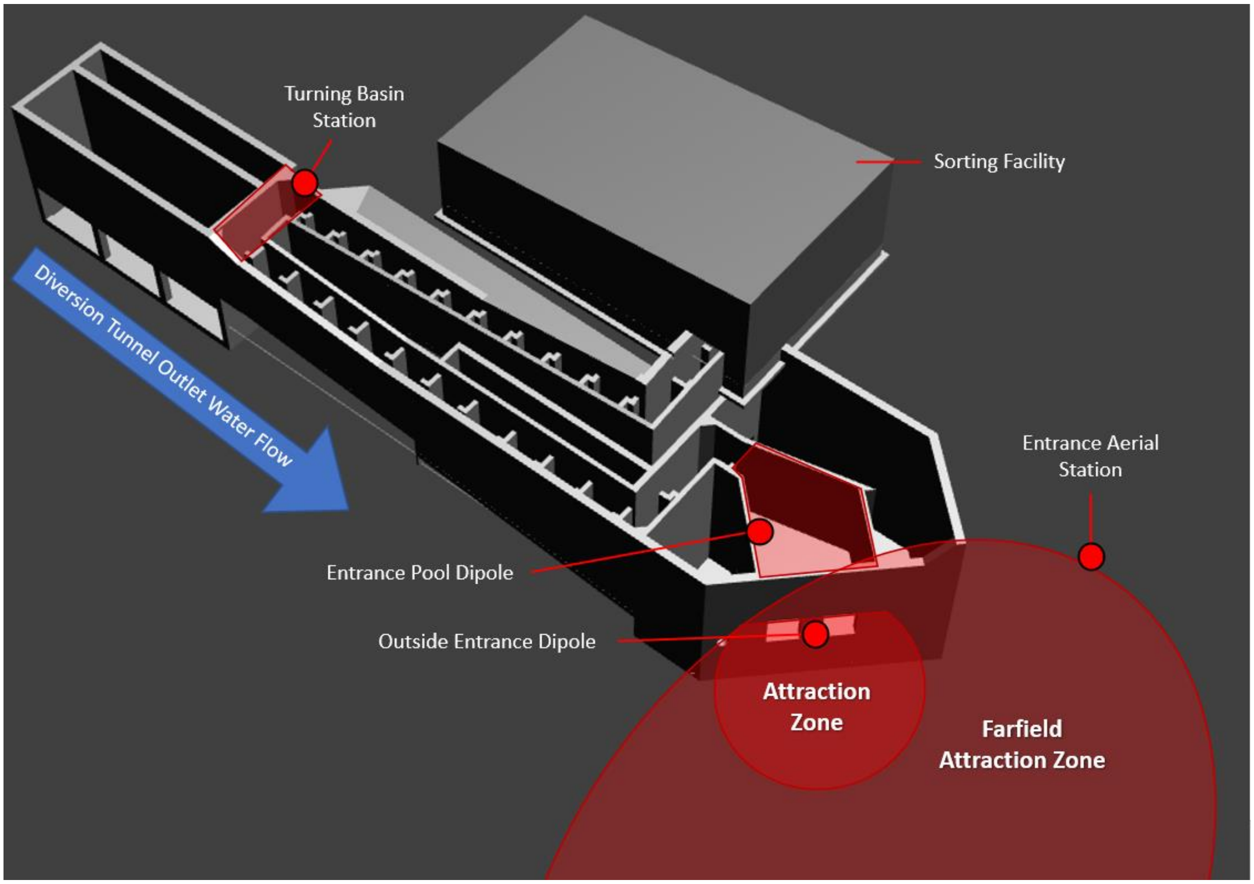


Figure 2.2 Map of fixed radio telemetry stations deployed within the temporary upstream fish passage facility, and the detection zones that they cover.

Figure 2.3 An aerial antenna (left) and two dipole antennas (right) at fixed stations within the Mon-13 study area. A dissolved oxygen logger and a light and temperature logger are also contained within the dipole housing (right).

2.2.2 Fixed Station Components

Each fixed station included an SRX800-MD4 Lotek receiver (Lotek Wireless) and either one or two aerial antennas or two dipole antennas (all antennas manufactured by Sigma Eight, Inc.). Fixed stations with aerial antennas were elevated ~2.5 m on a 10’ mast secured by a 5’ tripod assembly (Figure 2.3). The number, direction, and gain of aerial antennas varied among individual fixed stations according to the specific objectives of each site (Table 2.4). All fixed stations without access to mains power at the TUF were powered by two 100 W 5.56 Amp solar panels (EWS-100P-36, Enerwatt) that trickle charged a battery bank (2, 12V AGM 105 Ah batteries, Rolls Battery Engineering) through a solar charge controller (SunSaver 12V 20 Amp, SunSaver). Fixed stations that had access to mains power were equipped with a backup battery bank with enough power for the antennas to be operational for approximately one week in the event of power loss or disruption. Two dipoles were connected to a single receiver using a combiner at the fixed stations deployed outside of the fishway entrance and inside the entrance pool (Sigma Eight, Inc.). Combining dipoles in this way increased the detection range and provided a backup in case of damage. Dipoles were securely affixed to a High-Density Polyethylene (HDPE) shuttle that was lowered along a pre-installed aluminum Unistrut rail to approximately 1 m above the floor of the fishway (Figure 2.3).

All radio receivers operational during the Overwintering Period were connected to cell modems (BulletLTE-NA2, Microhard Systems) for remote downloading. The use of cell modems for remote downloading will be used on all receivers moving forward. The receiver, battery bank, charge controller, and cell modem were all housed within aluminum or stainless-steel enclosure boxes (Saip Electric Group Co., Ltd.).

Table 2.4 The type, direction, and gain of antenna(s) at each fixed radio telemetry station ('fixed station'). A higher gain typically indicates a larger detection range.

Fixed Station	Antenna Type	Antenna No.	Antenna Direction	Antenna Gain
Mainstem 1	Aerial	1	West (Mainstem)	64
	Aerial	2	East (Side channel)	64
Mainstem 2	Aerial	1	Downstream	64
	Aerial	2	Upstream	64
Approach Zone A	Aerial	1	Across	64
Approach Zone B	Aerial	1	Across	64
Cofferdam	Aerial	1	Across	45
	Aerial	2	Upstream	60
Tunnel Outlet	Aerial	1	Downstream	46
Entrance Aerial	Aerial	1	Across	50
Outside Entrance	Dipole	Dipole	NA	30
Entrance Pool	Dipole	Dipole	NA	40
Turning Basin	Aerial	1	Into water column	11

2.2.3 PIT Antenna Components

PIT antennas were custom fabricated and anchored within the TUF using an HDPE housing that encased all antenna wire (Figure 2.4). Extensive testing was conducted during fabrication for all antennas using all sizes of PIT tags (12-, 23- and 32-mm) to determine configurations that optimized performance. Each antenna was paired with an ATC Auto Tuner and an ORSR Single Antenna Reader (OregonRFID). Readers were powered using a bank of 182 Ah batteries (SMS-AGM400, NorthStar Battery). Power to the readers was filtered (Passive Line Noise Filter, OregonRFID), and where noise was a concern (entrance gates, vee-trap), an AC Linear Power Supply was used to further clean the power source. Antennas were further shielded with layers of ferrite tile under the HDPE. Battery banks were trickle charged by mains power and provided power for approximately one week in the case of mains power interruption.

Figure 2.4 Photos of completed PIT antennas installed within the dewatered temporary upstream fish passage facility prior to operations.

2.3 Testing Array Performance

All fixed stations and PIT antennas were tested during the Operational Period for functionality and ability to meet the objectives of each detection area upon deployment.

2.3.1 Fixed Stations

Preliminary range testing of fixed stations was executed upon deployment. The range of aerial antennas was tested by extending and retracting a tag various distances from the fixed station using a rod and reel. To test the dipole antennas, a test tag affixed to a pole was positioned throughout the area of interest at various heights in the water column. The primary goal of testing was to confirm settings were appropriate for the goal of each antenna/fixed station (Table 2.5).

Testing also provided an indication of the read range of each antenna. In collaboration with LGL, Ltd., detailed range testing of each aerial station will be conducted by boat using all tag types currently used in the Peace River during the spring of 2021. It is worth noting that in this first year of reporting, data interpretations are limited by our current understanding of detection ranges of fixed stations. Detailed range testing will provide a more accurate understanding of fish behaviour moving forward.

A beacon tag (MFT-3B, Lotek Wireless) was installed at each fixed station (out of water and within five meters) to test performance and ensure any temporary or permanent outages were accounted for in data analyses. Beacon tags have a 10 s pulse rate for 1 minute every hour, and thus provide a continuous indicator of performance without overwhelming the receiver. Beacon tags transmit (and should be detected) three times per hour for dual-antenna fixed stations and six times per hour for single-antenna fixed stations. The daily number of beacon tag detections per hour was calculated for each fixed station by dividing daily detections by the total hours in that day (i.e., 24 hours, except for first and last day of a download period). Although deviations around the whole number are expected, a value much lower than six for single-antenna fixed stations and three for dual-antenna fixed stations indicates that there may be an issue with the fixed station. A complete outage would be shown by no data for a given date. Consistent detection of beacon tags at a consistent power at each station indicates that there were no issues with performance at any stations.

Table 2.5 Objective of preliminary testing conducted at each fixed radio telemetry station within and around the temporary upstream fish passage facility (TUF). Testing ensured that settings were appropriate for the goal of each fixed station. DS and US refer to downstream and upstream, respectively.

Fixed Station	Goal of Preliminary Testing
Mainstem 2	• Ensure DS and US antennas detect tags in appropriate directions. • Determine approximate horizontal range
Approach Zone A and B	• Determine approximate horizontal range.
Cofferdam	• Ensure DS and US antennas detect tags in appropriate directions. • Determine approximate horizontal range.
Tunnel Outlet	• Ensure that tags are only detected in the diversion tunnel outlet. • Ensure that tags within the TUF or proximate the TUF entrances are not detected.
Entrance Aerial	• Ensure that tags are not detected in the diversion tunnel outlet.
Outside Entrance	• Ensure tags are only detected outside of the TUF and not within.
Entrance Pool	• Primarily ensure that tags outside of the TUF are not detected. • While achieving the first goal, maximize the detection range within the entrance pool.
Turning Basin	• Ensure tags are not detected anywhere outside of the fishway while maximizing detection range.

2.3.2 PIT antennas

PIT antennas underwent extensive testing prior to installation, following installation, and during operation of the TUF. Antenna performance during the Operational Period was lower than anticipated based on prior testing. Four antennas failed to detect tags during the Operational Period – East Entrance, Weir 20, Orifice 20, and Vee-trap. A standardized testing protocol was initiated on September 28, 2020 (during wet testing of the TUF) and repeated weekly. Initially, only 32-mm tags were tested; testing of 12- and 23-mm tags began on October 14, 2020. An apparatus was built that allowed for estimating the distance from each antenna a test tag could be detected (read range) in as many directions as possible. The goal of the testing was to determine how read range may be influenced by TUF operations (i.e., flow scenario). To increase the number of flow scenarios assessed, all antennas were tested across two flow scenarios on a single testing day (i.e., just prior to a change in operations and just after).

We had concerns regarding electrical noise entering the readers and affecting antenna performance. Therefore, Oregon RFID PIT readers were programmed to assign a relative and unitless value to detected noise during each tag detection, a potentially informative tool for troubleshooting antenna performance. Being a relative measure, recorded noise values can only be compared between identical antennas (i.e., each pair of entrance, weir, and orifice antennas) and within individual antennas over time.

2.4 Environmental Parameters

Discharge data were obtained from the Water Survey of Canada (WSC) gauge at Peace River above Pine River (07FA004). Temperature and light levels in air and water were measured using data loggers (HOBO MX2202 Pendant Wireless Temperature / Light Data Logger, Onset Computer Corporation) deployed in three locations proximate the fishway entrance: in air, submerged outside the fishway entrance, and submerged within the fishway entrance pool. Dissolved oxygen of the water immediately outside of the fishway entrance and within the entrance pool was also recorded using data loggers (HOBO U26-001 D, Onset Computer Corporation). Loggers recorded data on five-minute intervals. Loggers on the inside and outside of the fishway entrance served as replicates in case of loss or damage. Resulting data were very similar between locations; only data from loggers installed outside of the fishway entrance were retained for presentation here.

2.5 Data Download and Management

All fixed stations and PIT readers were downloaded weekly. Data were downloaded onto a tablet connected to a network such that it was immediately backed-up on a cloud-based storage. Once all data downloads were complete, a secondary back-up was created on a hard drive stored in a secure location. Additionally, raw radio telemetry files were transferred weekly to LGL to be included in the Site C Fish Movement Assessment Radio Telemetry Database, providing further backup.

FAHMFP databases include tagging, detection, and recapture data for both radio and PIT tagged fish collected from several sources since 2001. Golder Associates implanted all PIT and radio tags throughout the Peace River and its tributaries and collected all metadata associated with capture, tagging, and recapture of tagged fish (Golder Associates Ltd 2018). LGL manages all fixed stations throughout the watershed aside from those described in Section 2.3, which are described in their annual report to BC Hydro (LGL Limited, 2020). Palmer Environmental Consulting Group operated the fishway and, in doing so, collected all metadata from fish that successfully ascended the fishway, scanned fish for existing tags, implanted PIT tags when there was no pre-existing HDX tag, and transported fish according to the OPP (McMillen Jacobs & Associates and BC Hydro 2019). As a result, databases of distinct data types are maintained by Golder Associates, LGL, Palmer Environmental Consulting Group, and InStream Fisheries Research and data compilation efforts are collaborative (Figure 2.5).

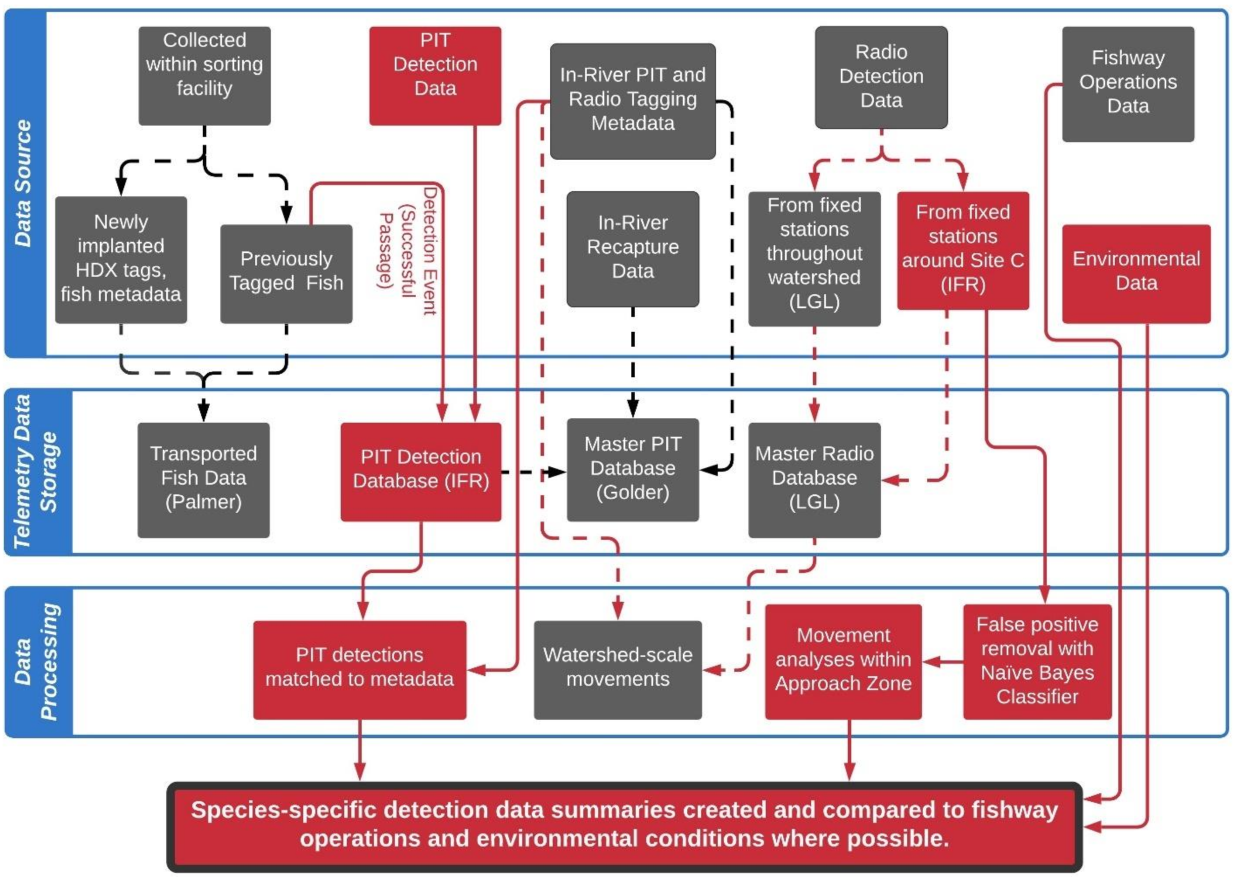


Figure 2.5 The process of data collection, storage and processing within the Fisheries and Aquatic Habitat Monitoring and Follow-up Program relevant to the data included in this report. Red boxes represent data held by InStream Fisheries Research (IFR), while grey boxes represent data held by other collaborating consultants. Red arrows show data processes conducted for Mon-13, and solid arrows indicate those conducted by IFR (dashed by other consultants).

2.6 Analysis

Ultimately, the data collected under Mon-13 will be analyzed using a comprehensive time-to-event (TTE) survival analysis for each species including time-varying covariates to understand conditions that facilitate successful fishway passage. The dataset from this first year of monitoring was too limited to do so, and presented analyses and summaries are primarily exploratory and form the basis of what we hope to accomplish with multivariate TTE analyses. With data collected in 2020, we aimed to understand how the study design and array performance could be improved upon, describe general movement patterns for target species, and identify key factors to consider in TTE analyses moving forward. All analyses and data summaries were created with R Studio V1.2.5042 (R Core Team 2020).

2.6.1 PIT Antenna Performance

Analyses of PIT antenna testing explored factors that may influence antenna performance, information relevant to future monitoring and array development in the TUF and the PUF. Two parameters were evaluated: noise and read range, both of which can be compared among flow scenarios and tag size (12-, 23-, or 32-mm). Although fishway attraction flows were planned to transition between discrete combinations of the HVJ being off or on and AWS flows of 4.25 m^3/s or 8.5 m^3/s, operations data reveal AWS flow transitions to be more continuous and variable. The objective is nonetheless to evaluate discrete flow scenarios, and therefore, AWS flows between 3.75 and 4.75 m^3/s were categorized as 4.25 m^3/s, those between 8 and 9 m^3/s were categorized at 8.5 m^3/s. Data collected at flows outside of these ranges were excluded from further analyses.

Sample sizes of noise data were only sufficient to make statistical comparisons with detection data from the West Entrance. A two-way ANOVA with weighted means (given unequal sample sizes) evaluated the fixed effects of AWS flow, HVJ flow, and tag size, and the interaction of AWS and HVJ flows on noise values recorded during tag detection. Assumptions of homogeneity of variances and normality were assessed by observing model diagnostics (i.e., residuals versus fits plot, residual normality plot, and distribution of residuals).

Read range data were more limited than noise data because only one read range estimate for each antenna was produced for each testing trial. Additionally, tags were not always detected. No statistical testing was conducted.

2.6.2 Radio Telemetry Data

False Positive Removal

Detection data from the stations deployed by InStream Fisheries Research were filtered using BIO-Telemetry Analysis Software (BIOTAS), a false-positive identification algorithm recently developed by K. Nebiolo from Kleinschmidt Associates and T. Castro-Santos from the United States Geological Survey (Nebiolo 2021). A publication detailing the framework is currently in press (Nebiolo and Castro-Santos, in press) and is summarized herein. The framework is comprised of a supervised learning algorithm based on a Naïve Bayes classifier (Minsky 1961). Supervised learning algorithms use data with known classification (training data) to classify unknown data using an objective likelihood score.

Five predictor variables were used to develop a classifier that would discriminate between true and false positive detections. Predictor variables included power, hit ratio, consecutive record length, noise ratio, and the difference in the lag between detections. Power refers to the received signal strength of a given detection. To calculate hit ratio and consecutive record length, a detection history was created for each tag during a fixed number of pulse intervals immediately preceding and following a given detection. Detection histories show the pattern of missed and recorded detections and delineates the window of time over which to quantify the amount of noise detected. The hit ratio is the ratio of the number of detections within a history divided by the length of the detection history and the consecutive record length is the longest contiguous subset of recorded detections in the detection history. The noise ratio is the number of plausible study tag hits divided by the total number of detections within a 1-minute interval around the current detection. The last predictor, the lag between detections, refers to the tag pulse rate. All tags currently deployed in the Peace River have a 10 second pulse rate. Therefore, the lag between detections should be 10 seconds and the difference in lag should be zero. To use these five predictors to calculate likelihood of false detection, continuous variables were binned into multinomial probability distribution.

Training data were comprised of known true positives (detections of study, test, and beacon tags) and known false positives (spurious detections from tags known not to be in the watershed). First, distributions of each predictor variable were created for both known true and known false detections to classify the potentially valid data. An iterative approach was then used to classify data. In the first iteration, it was assumed that all study tags were valid. On subsequent iterations detections classified as false positive in the previous iteration were discarded from the training data and each new iteration used these new functions to re-classify. The process was not considered complete until convergence, when no new observations were identified as false positive. The resulting true positives constituted the final dataset.

Detection Data Summaries

Radio detection histories for individuals (i.e., tagged fish) were separated into attempts. An attempt refers to continuous presence of a tagged fish on the radio telemetry array, inclusive of all receivers deployed under Mon-13. If an individual left the array and returned, it was considered a new attempt. Delineation of attempts was achieved by first calculating lags within the final dataset for each combination of receiver and tag code. Where fixed stations had two antennas (Mainstem 2, Cofferdam), detections from both were combined. Data were combined because the sequence of detections on the numerous fixed stations in this array were used to determine directionality rather than the sequence of detection on distinct antennas. Binning lag times for each receiver and plotting as histograms reveals distinct slopes that correspond with tagged fish occupying a state of passing the given fixed station. The point at which a distinct spline (slope change) occurs reveals the duration that most fish were in the detection field of that receiver; detection data were filtered for a lag duration specific to the data recorded by each receiver. If correct lag durations are selected, there should be little overlap between an event on one fixed station and the next upstream or downstream fixed stations. Lag duration cutoffs selected for each fixed station were as follows: 100 seconds (Mainstem 2), 250 seconds (Approach RB and LB, Entrance Aerial), 350 seconds (Tunnel Outlet), 30 seconds (Outside Entrance Dipole), 60 seconds (Entrance Pool Dipole). Attempts on the whole array (all fixed stations) were determined using the same methodology of binning lag times. An attempt threshold for the array was set at 25,000 seconds.

An attempt does not necessarily refer to a directed movement towards the fishway or an attempt to enter and ascend the fishway. For example, an individual could be detected continuously at the most downstream station of the array (Mainstem 2) and not make any movements towards other upstream stations during an attempt. An attempt could also represent downstream movement. The attempt duration, defined as the difference between the first and last detection on the array for a given attempt, was also calculated. Attempt durations for an individual were summed to determine the total duration on the array and within a given detection area (i.e., the detection range of a fixed station). Herein we refer to seven distinct detection areas: Outside Approach, Approach Gate, RB Cofferdam, Tunnel Outlet, Farfield Attraction Zone, Attraction Zone, and Entrance Pool. Habitat use within the study area can be informed by comparing attempt durations within each detection area. However, data were not directly comparable among areas given differences in detection range and deployment duration.

Detection data summaries were created by species, location, and time period to better understand fish behaviour through the monitoring period. Informed decisions were made to classify the type, timing, and/or intention of movement (Table 2.6). Detection data were presented from three distinct periods: Pre-Operations, Operational, and Overwintering. The exact timing of transition from one period to the next was determined with fishway flow data (e.g., fishway operations ceased when fishway flow ceased). Dependent on the question at hand, the 10-day Standby Period was excluded from some data summaries created for the Operational Period. For example, detection data recorded during the Standby Period were excluded from analyses exploring fish movement towards the fishway because upstream movements occurring without fishway flow do not inform fishway effectiveness. However, data collected during the Standby Period were not excluded from count data (e.g., numbers of fish in an area during the Operational Period).

Table 2.6 Detection data summaries and analyses to determine movements patterns for tagged target species within the study area required a classification of time periods, movement types, and detection locations, described below.

Category	Term	Definition
Time Periods	Pre-Operations	From initiation of data collection to when fishway operations began. Variable among fixed stations (Table 2.3).
	Operational Period	When the fishway was operational and attraction flows provided; October 1 to 31, 2020, excluding the Standby Period.
	Standby Period	When the fishway was not operational and there was no attraction flow; October 20-30, 2020
	Overwintering	Cessation of Operational Period to last detection included in dataset (December 7, 2020).
	Monitoring Period	The entire period of data collection, irrespective of fishway operations, from initiation of data collection to last detection included in dataset; August 1 - December 7, 2020.
Movement Timing	Attempt	Continuous presence of a tagged fish on the radio telemetry array inclusive of all receivers. Individuals may have multiple attempts.
	Attempt Duration	The duration of each attempt.
	Total Duration	The sum of all attempt durations for a given individual.
Approach Zone Delineations	Outside Approach	The detection area of the Mainstem 2 fixed station, considered outside of the Approach Zone.
	Approach Zone	The entire area upstream of the Approach Gate to the downstream cofferdam, diversion tunnel outlet, and TUF. Fish detected in Approach Zone were candidates for analyses of fishway passage.
	Approach Gate	Combined detection area of Approach Zone RB and LB.

Survival Analyses

In survival analyses, a binary variable is used to denote whether an individual's passage time was observed or not, allowing calculation of probability functions without attributing passage routes or times to censored attempts (Castro-Santos and Haro 2003). A censored attempt simply indicates that it has been removed from the candidate pool; criteria for censoring are determined a priori. Passage times to a given detection point and associated survival probability functions (i.e., proportion successful, efficiency metrics) are described by assessing passage times across meaningful intervals and calculating probability functions (Castro-Santos and Haro 2003). TTE survival analyses can accomplish this across multiple distinct time intervals while accommodating time-varying covariate effects. Given a dataset limited by both sample sizes and data collection time (i.e., a 20-day Operational Period), we employed Kaplan-Meier survival analyses for the entire Operational Period without covariates. In Kaplan-Meier survival analyses, when a passage event occurs, the survivorship function is estimated based on the cumulative product of the conditional proportion passing functions (Castro-Santos and Haro 2003). The proportion passing (survivorship) equates to efficiency metrics. Kaplan-Meier survival analyses essentially form the building block of a TTE analyses.

As would be done in a TTE, we used Kaplan-Meier survival analyses to describe times from the Approach Zone to the Farfield Attraction Zone, Attraction Zone, and Entrance Pool and determined attraction efficiencies for target species with sufficient data. Unlike a TTE analyses, these models do not include time-varying covariates and “events” (e.g., detection within the Attraction Zone) are discrete with individual models fit to each event. Data collected outside of the Operational Period (e.g., Standby Period) was excluded from analyses so that only fish that may have been attracted to the fishway when the facility was operating were considered. Packages “survival” (Therneau 2021) and “survminer” (Kassambara et al. 2020) were used.

All distinct attempts detected within the Approach Zone were included as model candidates, for which outcomes were binary coded as failure (0) or success (1) of migrating from the Approach Zone to a given area of interest. Candidates were censored (0) if they either removed themselves from the candidate pool by dropping backwards or remained within the Approach Zone until the end of the Operational Period without detection within the area of interest. Species was included in models to compare species-specific differences.

We first determined when each candidate entered and exited the Approach Zone. If a candidate was detected in the area of interest during the Operational Period, its outcome was success (1) and the time to this “event” equates to the difference between first detection on the Approach Zone (t_0) and arrival at the target detection area. If a candidate moved downstream of the Approach Zone and was detected by the Mainstem 2 fixed station (i.e., the Outside Approach Zone), it was censored, meaning its outcome was failure (0), and it was removed from the analysis. For those fish leaving the Approach Zone, censoring time equates to the time of first detection on Mainstem 2. Assignment of candidate outcomes (0 or 1) allowed for cycling within the Approach Zone. That is, candidates were not expected to move directly between the Approach Gate and detection areas of interest but could be anywhere within the Approach Zone (e.g., a candidate that moved in the Tunnel Outlet detection zone prior to detection within a field of interest was not censored at time of entry into the Tunnel Outlet zone). Censoring only occurred once a candidate was detected by the Mainstem 2 fixed station, or upon termination of the Operational Period.

Analyses were conducted separately for each area of interest, creating three discrete models to assess timing and success of attempts: from the Approach Zone to the Farfield Attraction Zone (1), from the Approach Zone to the Attraction Zone (2), and from the Approach Zone to the Entrance Pool (3). Each model produced a species-specific Kaplan-Meier survival curve. Curves show the change in the proportion of candidates reaching each area of interest from the Approach Zone over time as a continuous metric during the Operational Period. The first table below the survival curves for each area shows the cumulative number of candidates reaching the area of interest within discrete time intervals. The second table shows the cumulative number of candidates censored from the model. The Attraction Zone model determines the attraction efficiency for the Operational Period (i.e., the proportion of modelled attempts detected in the Approach Zone that successfully reached the Attraction Zone by the end of the Operational Period).

2.6.3 PIT Telemetry Data

PIT detection data were filtered to remove any test tag codes and then separated into occupancies on the array. An occupancy refers to a continuous presence of a tagged fish on the PIT telemetry array. Delineation of occupancy was achieved using the same methodology used for radio detection data (see *Detection Data Summaries*). However, given the inconsistent and low number of detections on the PIT array, only detections on the West Entrance were delineated using this method. Lags between detections on the West Entrance antenna were calculated for each tag code and plotted as a histogram. A distinct slope was identified at 5 seconds. Therefore, lags between detections of > 5 seconds were considered new occupancies on the array. Such a short duration is logical for PIT antennas that have a small read range.

3. Results

Presented results encompass fishway operations, array performance metrics, environmental conditions, and detection data from target species (Arctic Grayling, Bull Trout, Burbot, Mountain Whitefish, and Rainbow Trout). Movement data are presented in order of approach to the fishway. We first summarize overall fish numbers detected on the array, before detailing movements in the Approach Zone, proximate fishway entrances, and, lastly, of fish that passed the fishway. Data from other non-target species are summarized in less detail.

3.1 Fishway Operations

In 2020, attraction flows did not follow the proposed schedule exactly (Figure 3.1). AWS flows were variable, especially in the first week of operations. Although the proposed AWS flow schedule was to regularly alternate between 4.25 and 8.5 m^3/s, the AWS was off during several periods (0 m^3/s) and was briefly as high as 9.93 m^3/s. HVJ flows were more consistent with the proposed alternating schedule of either off or supplementing AWS flows with an additional 1.5 m^3/s. WSE at the tailrace changed by over a meter throughout the Operational Period (range = 409.81 to 410.98 m; Figure 3.1).

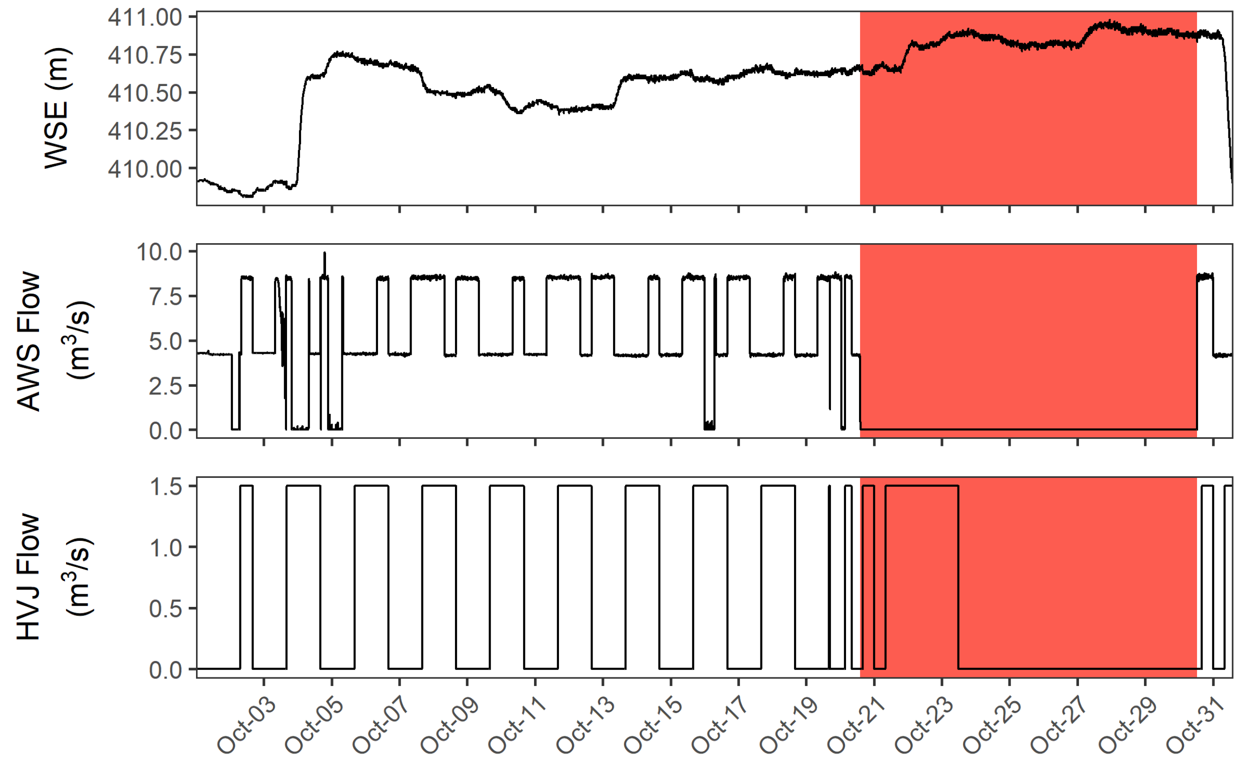


Figure 3.1 Water surface elevations (WSEs) in the diversion tunnel outlet (top) and fishway attraction flows discharged from the temporary upstream fish passage facility (middle, bottom) throughout the month of October. WSE was recorded at the tailrace from the BC Hydro operated sensor LT-600. Attraction flows provided for the auxiliary water supply (AWS) or high velicity jet (HVJ) fishway flows are provided by BC Hydro. Red highlighting shows the 10-day Standby Period.

3.2 Array Performance

3.2.1 Fixed Stations

Performance of fixed stations was determined by the average daily number of beacon tag detections per hour. No outages were observed for any fixed station (see Appendix A).

3.2.2 PIT Antennas

Across all flow scenarios and antennas, there were 418 recorded noise readings (Table 3.1). Noise results were only available for 23- and 32- mm tags; there were few detections of 12-mm tags. Statistical analyses on the West Entrance PIT antenna revealed a statistically significant effect of HVJ use on recorded noise levels (two-way ANOVA; $p < 0.0001$). Unexpectedly, noise values were reduced when the HVJ was on (Figure 3.2). There were no significant effects of AWS flow ($p = 0.1$), the interaction between AWS and HVJ flow (0.09), or tag size (0.06). Directionality of the relationships between recorded noise and HVJ use were not consistent among antennas (Table 3.1; e.g., Weir 8 noise readings were higher when the HVJ was on). Low sample sizes precluded statistical testing on other antennas. Further testing of antennas is required to understand if the detected statistical significance is meaningful.

The West Entrance, Orifice 8, and Weir 8 performed best in terms of the proportion of trials detecting tags, followed by Weir 20 and Orifice 20; the Vee-trap and East Entrance never detected tags (Figure 3.3; top). It was unclear if flow scenario influenced read range. Read range for 32-mm tags was highest at the West Entrance antenna but was highly variable, ranging from 0 to 35 cm. At other antennas, read range was at most 25 cm, but more commonly between 5 and 15 cm (Figure 3.3; bottom). As expected and observed in preliminary testing, read range generally increased with increasing tag size (data not shown).

Table 3.1 Noise values recorded from PIT readers in the TUF during detection of 23- and 32-mm PIT tags among attraction flows from either the auxiliary water supply (AWS) or high velocity jet (HVJ). A noise value is a relative and unitless value indicative of conducted and radiated noise. It can only be compared between identical antennas or within antennas. Antennas not listed had no data.

Reader	AWS Flow	HVJ Flow	Recorded Noise Values (mean ± SD)	
			23-mm Tags	32-mm Tags
West Entrance	4.25	0	62.2 ± 2.9 (n = 10)	63.7 ± 4.1 (n = 24)
	4.25	1.5	61.5 ± 3.4 (n = 19)	62 ± 4 (n = 49)
	8.5	0	62.5 ± 3.9 (n = 24)	64.5 ± 4.8 (n = 31)
	8.5	1.5	59.5 ± 4.7 (n = 33)	60.6 ± 5.3 (n = 62)
Orifice 8	4.25	0	NA	91.2 ± 3.2 (n = 29)
	4.25	1.5	NA	89.2 ± 4 (n = 26)
	8.5	0	88.8 ± 1.7 (n = 4)	88.9 ± 4.5 (n = 11)
	8.5	1.5	87.8 ± 0.5 (n = 4)	91.6 ± 2.6 (n = 8)
Weir 8	4.25	0	NA	82.1 ± 2.5 (n = 14)
	4.25	1.5	NA	81.7 ± 4.4 (n = 9)
	8.5	0	76.9 ± 2 (n = 7)	77 ± 2.7 (n = 14)
	8.5	1.5	83.3 ± 1.1 (n = 7)	84.9 ± 1.1 (n = 9)
Weir 20	4.25	0	NA	95 ± 0.8 (n = 7)
	4.25	1.5	NA	93.8 ± 2.9 (n = 10)
	8.5	0	NA	NA
	8.5	1.5	NA	95.9 ± 1.6 (n = 7)

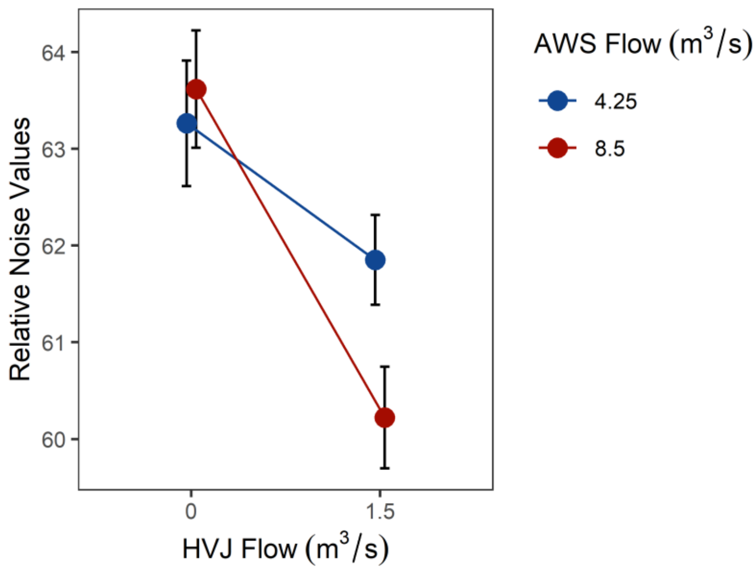


Figure 3.2 Recorded noise values at the West Entrance PIT antenna with attraction flow scenario (combinations of the Auxiliary Water Supply [AWS] at 4.25 or 8.5 m^3/s and High Velocity Jet [HVJ] off or on at 1.5 m^3/s). Data combined for 23- and 32-mm tags given no significant effect of tag type. Error bars show standard error.

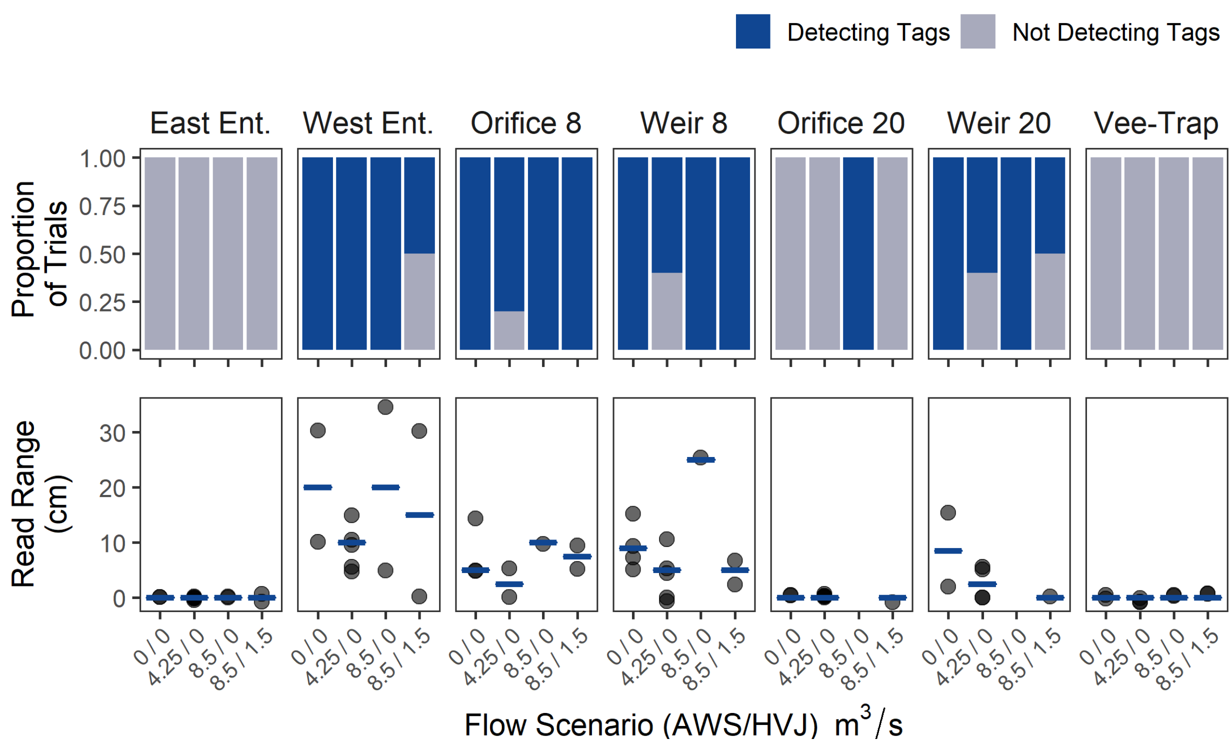


Figure 3.3 Proportion of testing trials that detected tags (top) and read range of individual trials (bottom) across flow scenarios for 32-mm PIT tags. Points show data from individual trials and the blue horizontal bar the mean across trials. With few (sometimes one) trial(s) per flow scenario, proportion data should be interpreted with caution. The East Entrance and Vee Trap antennas never detected tags. Read range data only provided for successful trials (i.e., when a tag was detected).

3.3 Environmental Conditions

River discharge was highly variable during the monitoring period (Figure 3.4). Flows were at their highest in August (>2000 m^3/s) but dropped to below 1000 m^3/s on September 2. Flows again dropped to ~400 m^3/s at the end of September to support the final closure of the rockfill berm, just prior to the start of the Operational Period, and increased again to 700 m^3/s on October 4, the day after river closure. From there, discharge continually increased throughout the Operational Period. There was another rapid decrease of ~500 m^3/s for a 28-hr period at the end of the Operational Period to support Highway 29 construction at the Halfway River. Flows gradually increased with some variability throughout the Overwintering Period.

Water temperature, dissolved oxygen, and underwater light levels showed predictable seasonal patterns through the Operational Period, with temperature decreasing, dissolved oxygen increasing, and light reflecting diel cycles (Figure 3.5). Water temperatures ranged from 6.5°C to 11.8°C. During the 10-day Standby Period water temperatures did not exceed 8.0°C. Dissolved oxygen ranged from 10.2 mg/L to 11.7 mg/L. Given consistent seasonal changes in temperature and dissolved oxygen, and an increase in river discharge through the Operational Period, recorded environmental variables are highly correlated.

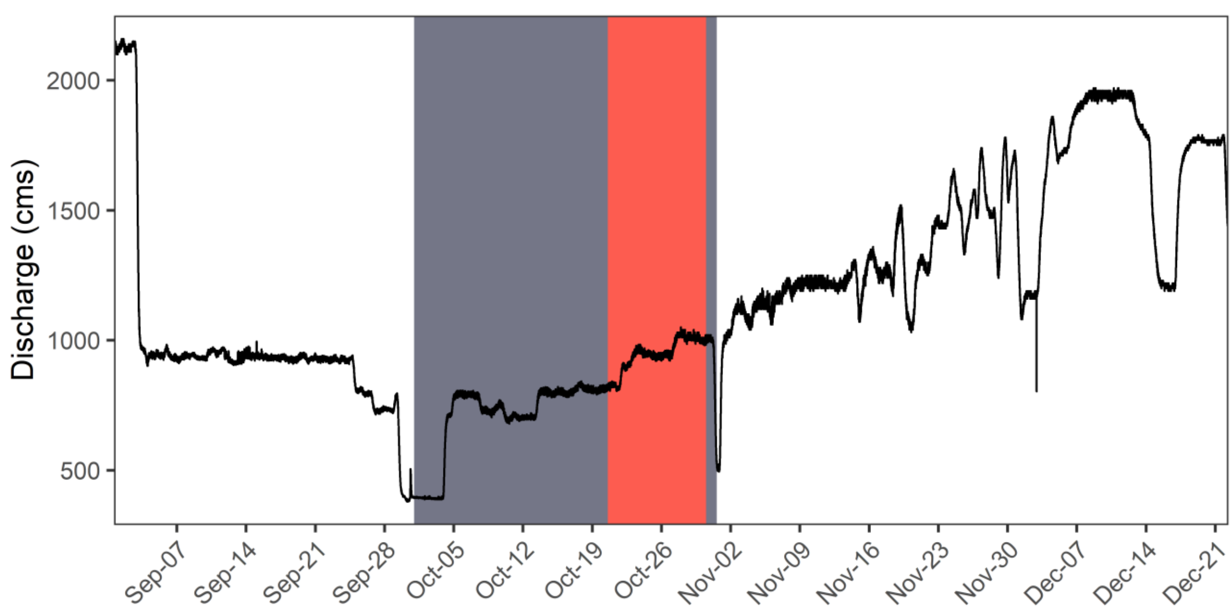


Figure 3.4 Peace River discharge as measured at the Water Survey of Canada gauge at Peace River above Pine River (07FA004). The grey and red shaded areas show the operational and standby periods, respectively.

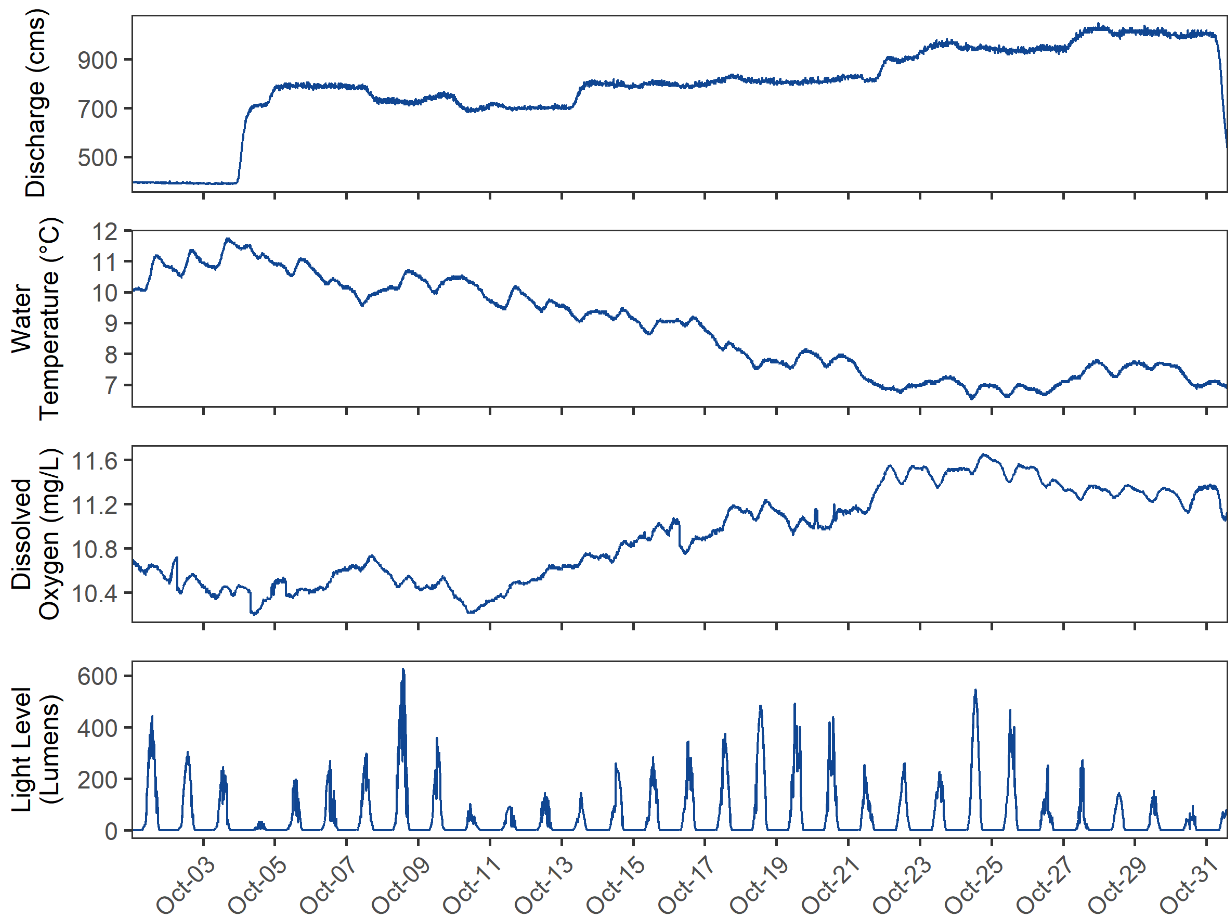


Figure 3.5 Peace River discharge as measured at the Water Survey of Canada gauge at Peace River above Pine River (07FA004) and dissolved oxygen, water temperature and underwater light levels recorded at the fishway entrance during the Operational Period.

3.4 Fish Detected on Array

Detection data were available from all five target species. Four non-target species were also detected (Lake Whitefish, Largescale Sucker, Longnose Sucker, and Walleye). Divergences in the species assemblages detected by the PIT antennas and by fixed stations were observed (Figure 3.6). While Walleye, Bull Trout, and Arctic Grayling were primarily detected by fixed stations, these species were rarely detected by PIT antennas. Over 75% of detections on the PIT array were Mountain Whitefish, for which there was no radio telemetry data. This can be attributed to both the distribution of tag types and of species-specific migration characteristics during the monitoring period. For example, 206 Bull Trout have been implanted with radio tags since July of 2019, but only 28 Mountain Whitefish have been tagged, and tagging this species did not start until August 2020. Additionally, while some Mountain Whitefish were actively migrating upstream to spawn during the Operational Period, this behaviour is not expected from Bull Trout and other target species until the spring and summer of 2021.

Numbers of radio-tagged target species detected by fixed stations varied across time periods (Figure 3.7). More Bull Trout were detected within the Outside Approach and Approach Gate (which delineates the Approach Zone) during Pre-Operations than in later time periods. For Arctic Grayling, more individuals were detected within the Approach Zone during the Operational Period, and few were detected during the Overwintering Period. A single Burbot was detected throughout the entire monitoring period within the Outside Approach, Approach Gate, and RB Cofferdam detection areas. Rainbow Trout were primarily detected within the Outside Approach detection area across all time periods, though numbers were reduced during the Overwintering Period. It is worth noting that raw count data from Pre-Operations were influenced by the total data collection time of each receiver (i.e., how long they were operating during this period, detailed in Table 2.3).

Target species were detected on the PIT antennas when the fishway was not operating, both prior to operations and during the 10-day Standby Period (Table 3.2). The high number of fish detected during the Standby Period was mostly likely due to increased read range of PIT antennas, and not because there were more fish present. WSE was high during the Standby Period, making more of the fishway wetted and accessible despite the lack of flow.

Few radio-tagged fish entered the fishway: three Bull Trout and three Walleye were detected inside the entrance pool. All radio-tagged fish were also PIT tagged. All but one Bull Trout were detected on the West Entrance PIT antenna. The divergent species assemblages detected between the two telemetry technologies and the low numbers of radio-tagged fish entering the fishway highlight the data discontinuity present. PIT and radio telemetry datasets have, therefore, been analyzed separately. Radio telemetry data were used to inform approach and fishway entry and PIT telemetry data were used to inform movement within the fishway.

Table 3.2 Counts of PIT-tagged target species detected by antennas within the fishway during distinct monitoring periods. Pre-Operations extended from the date antennas turned on until the fishway Operational Period, October 1 to 31, 2020, excluding the 10-day Standby Period (October 20 to 30, 2020).

Species	Pre-Operations	Operational	Standby Period
Arctic Grayling	0	1	2
Bull Trout	0	2	1
Mountain Whitefish	2	116	144

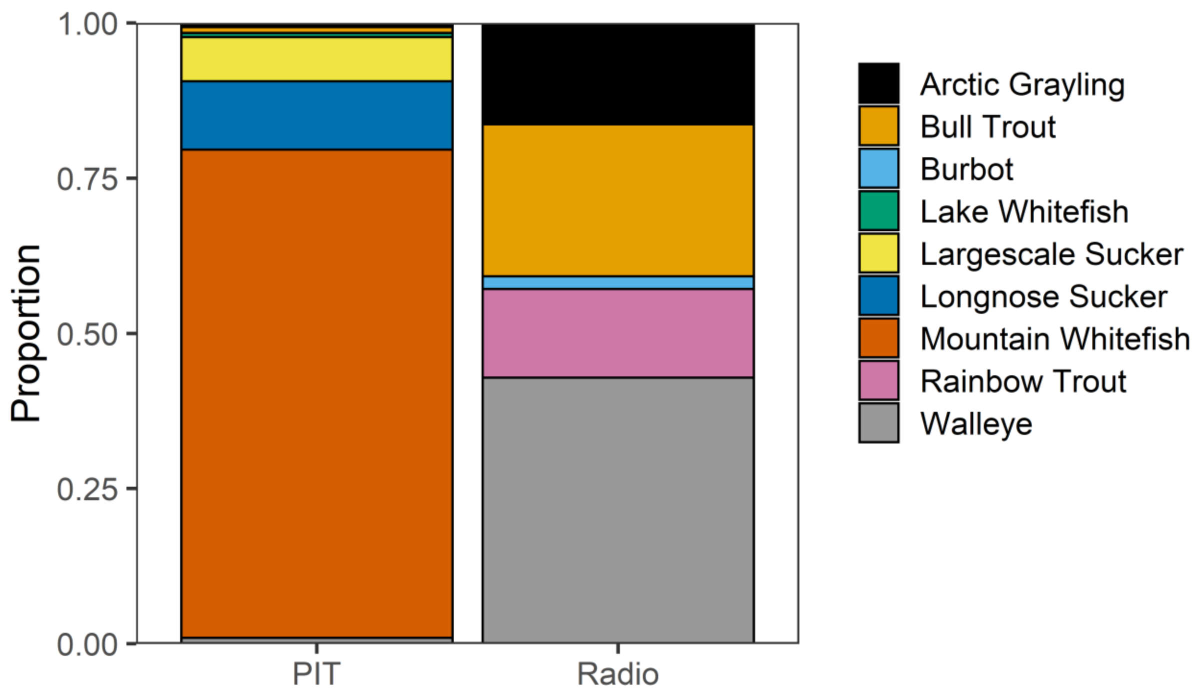


Figure 3.6 Proportions of each species detected by PIT and radio arrays during the Operational Period.

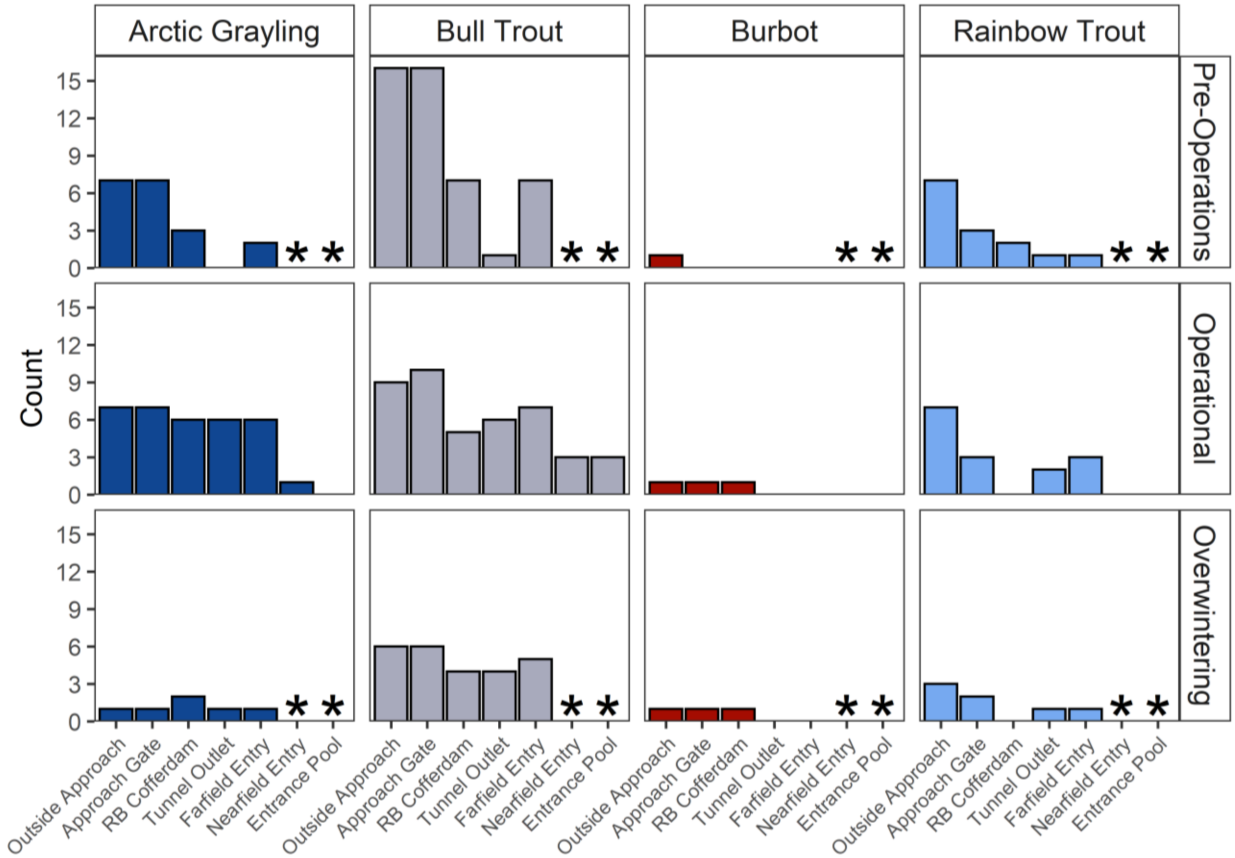


Figure 3.7 Counts of radio-tagged target species detected at each fixed radio station during distinct monitoring periods. Pre-Operations extends from station deployment until Operational Period, October 1 to 31, 2020, after which the Overwintering Period extends until December 7, 2020. Here the Operational Period includes the 10-day Standby Period. The Nearfield Entry and Entrance Pool stations were not deployed during the Pre-Operations and Overwintering Periods (indicated by asterisk). Detections shown at the rightmost stations in the graph (i.e., in and around the fishway) are generally expected to be a subset of the leftmost stations (e.g., Outside Approach).

3.5 Movement within Approach Zone

Results on fishway approach and entry were informed by radio telemetry data. There were approximately 1.56 million radio telemetry detections on the array during the monitoring period (August 1 - December 7, 2020). Approximately 9.16% of these detections were classified as false positives and removed from further analyses, resulting in a final dataset of just over 1.42 million detections. With this final dataset, we explored both general movements patterns within the Approach Zone and movements towards the fishway entrance. Tagged fish become candidates for analyses of fishway passage once detected on the Approach Zone.

3.5.1 Activity on the Array

The number of attempts per individual and attempt duration informs how different species used the study area. For example, only one Burbot was detected throughout the entire monitoring period that made 23 attempts. The one Burbot was in the array for just under 9 days, with a maximum attempt duration of 2.8 days (Table 3.3) and attempts being more numerous and longer in October than in September or November (Figure 3.8). Comparatively, Arctic Grayling, Bull Trout, and Rainbow Trout made fewer attempts per individual and resided within the array longer (Table 3.3). The mean number of attempts per individual for Arctic Grayling and Bull Trout were 2.1 and 4.8 with mean durations of 2.1 and 1.2 days, respectively (Table 3.3). Durations were similar among months for Arctic Grayling and Bull Trout (Figure 3.8); though one attempt lasting over 42 days for Arctic Grayling beginning in August did increase the mean for that month. Relative to Arctic Grayling and Bull Trout, Rainbow Trout made more attempts per individual and spent more time on the array (Table 3.3). Rainbow Trout also spent more time on the array in September and October than August and November (Figure 3.8).

Comparing attempt durations among detection areas can infer habitat use, though differences in detection range and deployment duration must be considered. Radio-tagged Arctic Grayling, Bull Trout, and Rainbow Trout were detected within the Outside Approach and Approach Gate areas for the greatest amount of time (Figure 3.9). While this could be indicative of habitat preferences, these fixed stations also have the largest detection areas and were deployed for the longest time. The one Burbot was detected for the longest duration in the RB Cofferdam area. Along with Arctic Grayling, attempts were longer in this area compared to Bull Trout and Rainbow Trout. Bull Trout seemed to show a greater preference for the diversion tunnel outlet relative to other species (Figure 3.9). Few Rainbow Trout were detected in areas other than the Outside Approach.

Mean attempt durations within detection zones proximate to the fishway entrance were short for all species (e.g., < 3 hours at the Farfield Attraction Zone) and only Bull Trout and Arctic Grayling were detected within the Attraction Zone and Entrance Pool. This was expected of dipole antennas, which have small and precise detection ranges. As a result, most detections were single events (i.e., attempt duration of 0) rather than detection histories that show continuous residency. However, one Bull Trout did spend a continuous 49 minutes within the Attraction Zone.

Table 3.3 Study area use summaries for radio-tagged target species detected during the monitoring period. An attempt refers to a continuous presence on the radio telemetry array, and an individual tagged fish may have multiple attempts. Total durations refer to durations across all attempts.

Species	Attempts	Individuals	Mean Attempts per Individual ± SD	Attempt Durations (Days)		Total Durations (Days)	
				Max.	Mean	Max.	Mean
Arctic Grayling	30	14	2.1 ± 2.7	42.5	2.1	51.8	4.5
Bull Trout	140	29	4.8 ± 7.7	17.4	1.2	64.9	5.9
Burbot	23	1	23.0	2.8	0.4	8.7	8.7
Rainbow Trout	80	12	6.7 ± 10.2	15.1	1.4	98.3	9.4
Walleye	115	28	4.1 ± 6.2	24.5	0.6	33.0	2.7

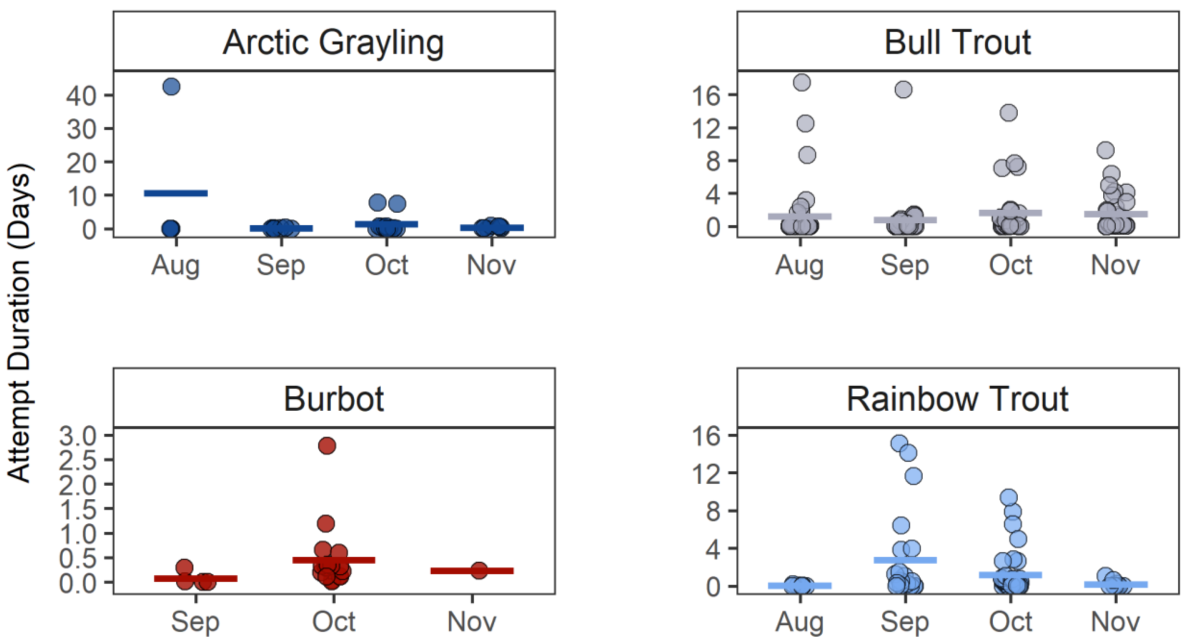


Figure 3.8 Durations of each attempt by month for all radio-tagged target species detected during the monitoring period. Points represent individual attempts and lines their mean. An attempt refers to a continuous presence on the array. Attempts lasting longer than a month were plotted in the month they began. Data from December were excluded because they encompassed only seven days.

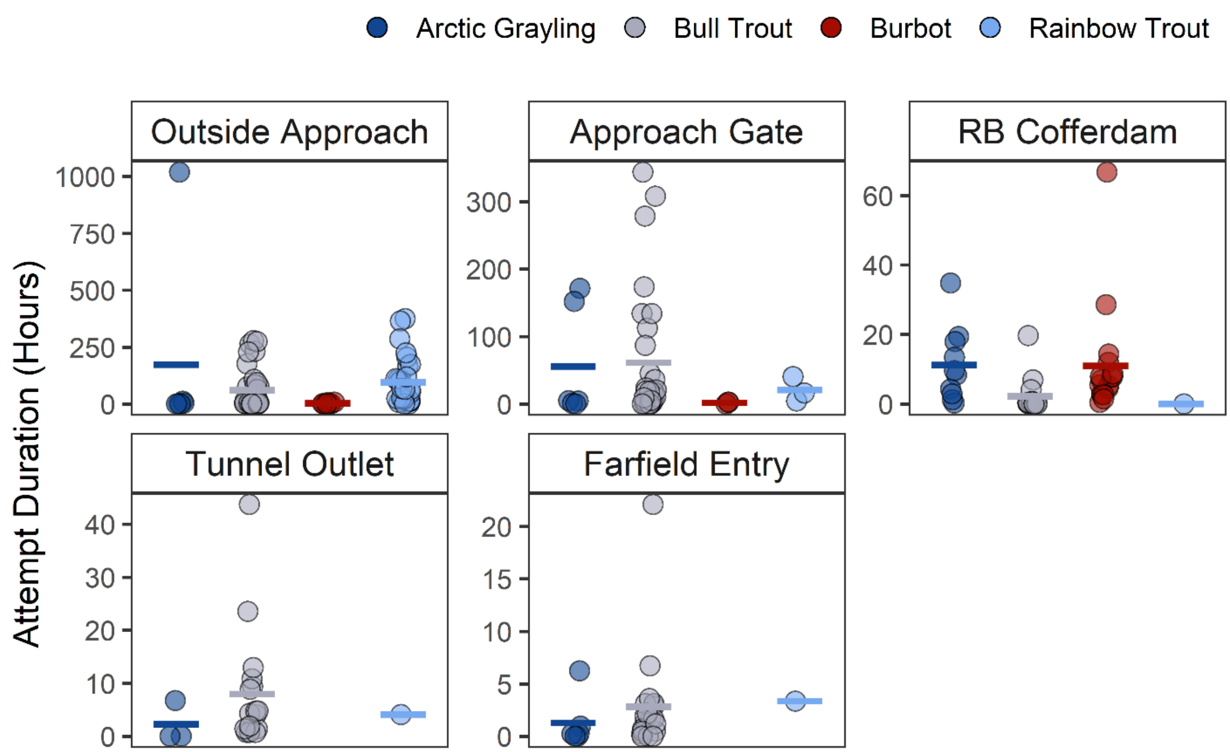


Figure 3.9 Durations of each attempt at each detection location for radio-tagged target species throughout the monitoring period. Points represent individual attempts and lines their means. An attempt refers to a continuous presence on the array. Detection areas are not directly comparable given differences in deployment location and detection range.

3.5.2 Movements Towards Fishway

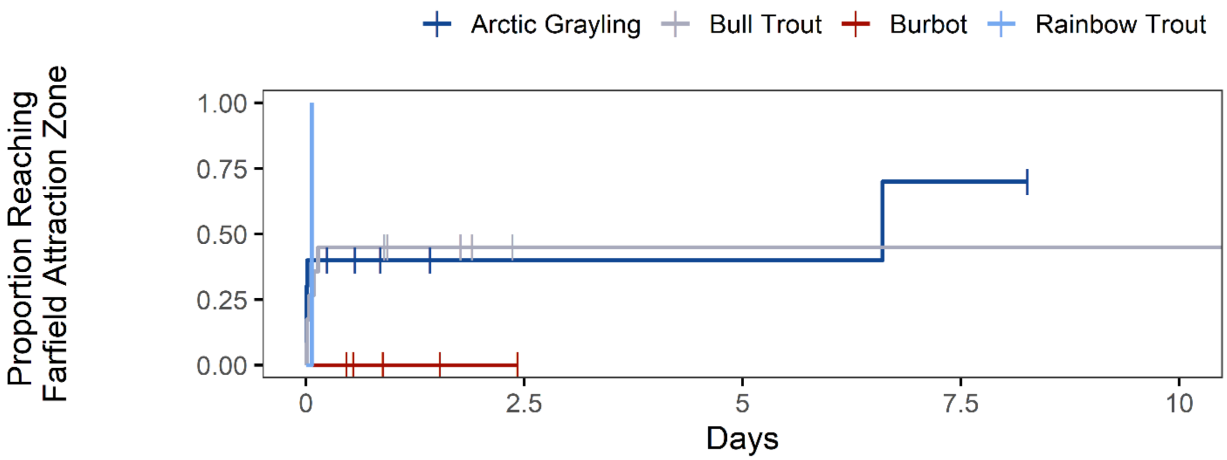
Time to detection in the Farfield Attraction Zone, Attraction Zone, and Entrance Pool from within the Approach Zone during the Operational Period were determined with Kaplan-Meier survival analyses. Analyses were conducted separately for each area. Note that the initial number of candidates is not the same for each of those analyses because some attempts began within one of the three stations. For example, three attempts began in the Farfield Attraction Zone when the Operational Period began and therefore could not be candidates for arrival into that zone.

All but one of the 11 attempts that reached the Farfield Attraction Zone did so in under 4 hours from time of first detection within the Approach Zone (from a total of 28 candidates; Figure 3.10). The exception was an Arctic Grayling attempt that took 6.6 days. Arctic Grayling and Bull Trout were the most numerous species reaching the Farfield Attraction Zone. Success to the Farfield Attraction Zone was 100% for Rainbow Trout during the Operational Period; however, this was calculated from just one attempt. Depending on where fish were in the Approach Zone when fishway operations began, distance to the Farfield Attraction Zone may have been small (e.g., if they were in the diversion tunnel outlet).

Movements to the Attraction Zone, encompassed by a dipole with a much smaller detection area, is more informative for fishway effectiveness compared to the Farfield Attraction Zone (Figure 3.11). Attempts detected on the Attraction Zone included three Bull Trout and one Arctic Grayling. Preliminary estimates of attraction efficiencies (i.e., the proportion of modelled attempts detected in the Approach Zone that successfully reached the Attraction Zone by the end of the Operational Period) were 17% for Arctic Grayling and 25% for Bull Trout. These preliminary estimates were calculated from 11 and 14 candidates for each species, respectively. As with the Farfield Attraction Zone, times from first detection within the Approach Zone to first detection within the Attraction Zone during the Operational Period were relatively short – less than 4 hours for all Bull Trout attempts and 13.6 hours for the one Arctic Grayling.

Of detected radio-tagged fish, only Bull Trout successfully entered the fishway (detected in the entrance pool; Figure 3.12). Three attempts entered, and durations were 3.2, 11.5 and 20.3 hours. No Burbot attempts successfully made it to any of the three areas of interest.

Generally, fish detected within detection areas proximate the fishway entrance (i.e., Farfield Attraction Zone, Attraction Zone, and Entrance Pool) made multiple movements towards these detection areas within a single attempt, and across multiple attempts throughout the Operational Period (Figure 3.13, Appendix B). This was especially true for Bull Trout.



Cumulative Number Reaching Farfield Attraction Zone

	0	2.5	5	7.5	10
Arctic Grayling	0	4	4	5	5
Bull Trout	0	5	5	5	5
Burbot	0	0	0	0	0
Rainbow Trout	0	1	1	1	1

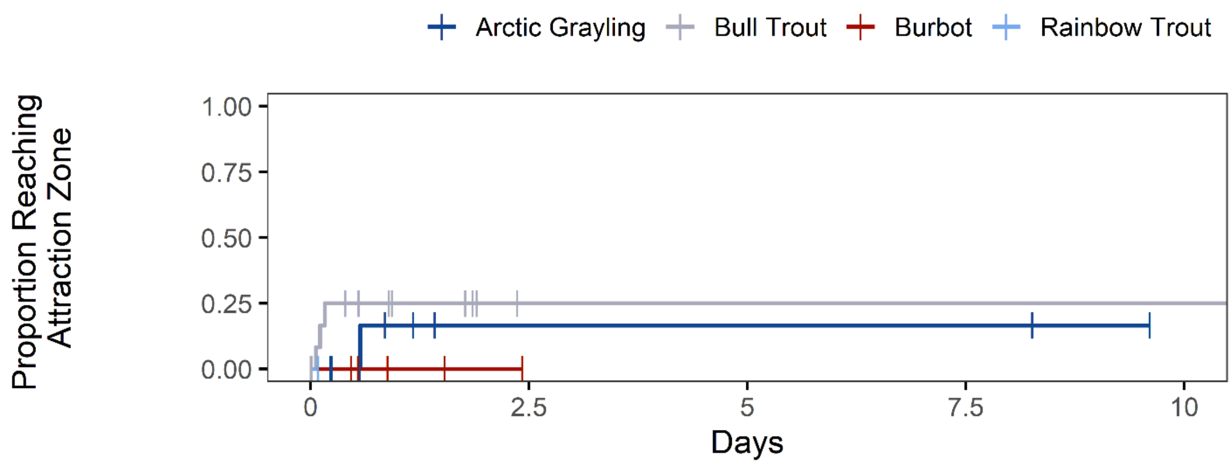
Days

Cumulative Number Censored

	0	2.5	5	7.5	10
Arctic Grayling	0	4	4	4	5
Bull Trout	0	6	6	6	6
Burbot	0	5	5	5	5
Rainbow Trout	0	0	0	0	0

Days

Figure 3.10 Results from a Kaplan-Meier survival analysis showing the proportion of attempts reaching the Farfield Attraction Zone from the Approach Zone during the Operational Period. An attempt was censored (removed from the pool of candidate attempts; indicated by a dash) if the fish dropped backwards or remained within the Approach Zone until the end of operations. The top graph shows the continuous timescale of successful and censored attempts while the middle and bottom tables show the cumulative number of attempts successfully reaching the Fairfield Attraction Zone and the cumulative number of censored attempts, respectively.



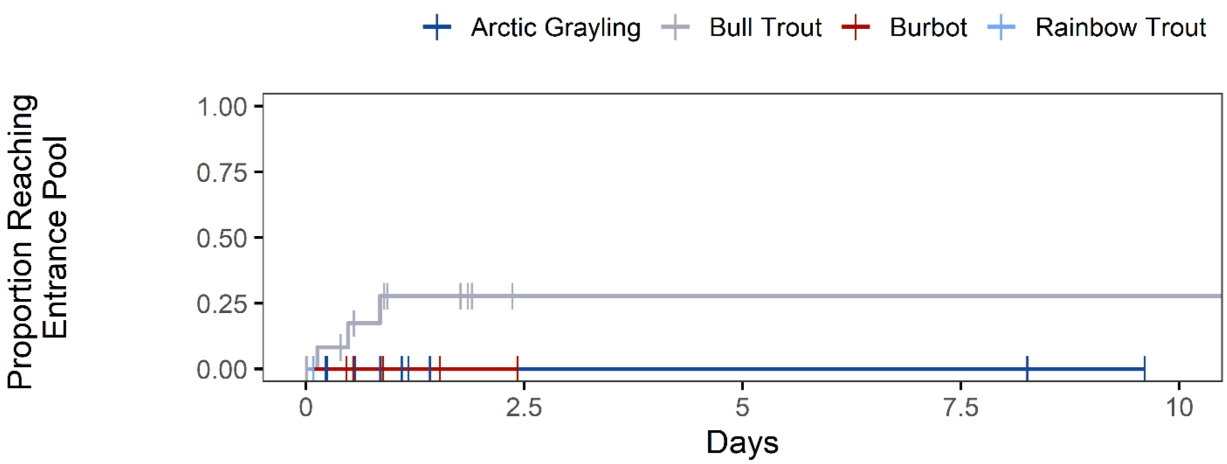
Cumulative Number Reaching Attraction Zone

Days	0	2.5	5	7.5	10
Arctic Grayling	0	1	1	1	1
Bull Trout	0	3	3	3	3
Burbot	0	0	0	0	0
Rainbow Trout	0	0	0	0	0

Cumulative Number Censored

Days	0	2.5	5	7.5	10
Arctic Grayling	0	8	8	8	10
Bull Trout	0	10	10	10	10
Burbot	0	5	5	5	5
Rainbow Trout	0	1	1	1	1

Figure 3.11 Results from a Kaplan-Meier survival analysis showing the proportion of attempts reaching the Attraction Zone from the Approach Zone during the Operational Period. An attempt was censored (removed from the pool of candidate attempts; indicated by a dash) if the fish dropped backwards or remained within the Approach Zone until the end of operations. The top graph shows the continuous timescale of successful and censored attempts while the middle and bottom tables show the cumulative number of attempts successfully reaching the Attraction Zone and the cumulative number of censored attempts, respectively.



Cumulative Number Reaching Entrance Pool

Days	0	2.5	5	7.5	10
Arctic Grayling	0	0	0	0	0
Bull Trout	0	3	3	3	3
Burbot	0	0	0	0	0
Rainbow Trout	0	0	0	0	0

Cumulative Number Censored

Days	0	2.5	5	7.5	10
Arctic Grayling	0	9	9	9	11
Bull Trout	0	10	10	10	10
Burbot	0	5	5	5	5
Rainbow Trout	0	1	1	1	1

Figure 3.12 Results from a Kaplan-Meier survival analysis showing the proportion of attempts reaching the entrance pool of the temporary upstream fish passage facility from the Approach Zone during the Operational Period. An attempt was censored (removed from the pool of candidate attempts; indicated by a dash) if the fish dropped backwards or remained within the Approach Zone until the end of operations. The top graph shows the continuous timescale of successful and censored attempts while the middle and bottom tables show the cumulative number of attempts successfully reaching the entrance pool and the cumulative number of censored attempts, respectively.

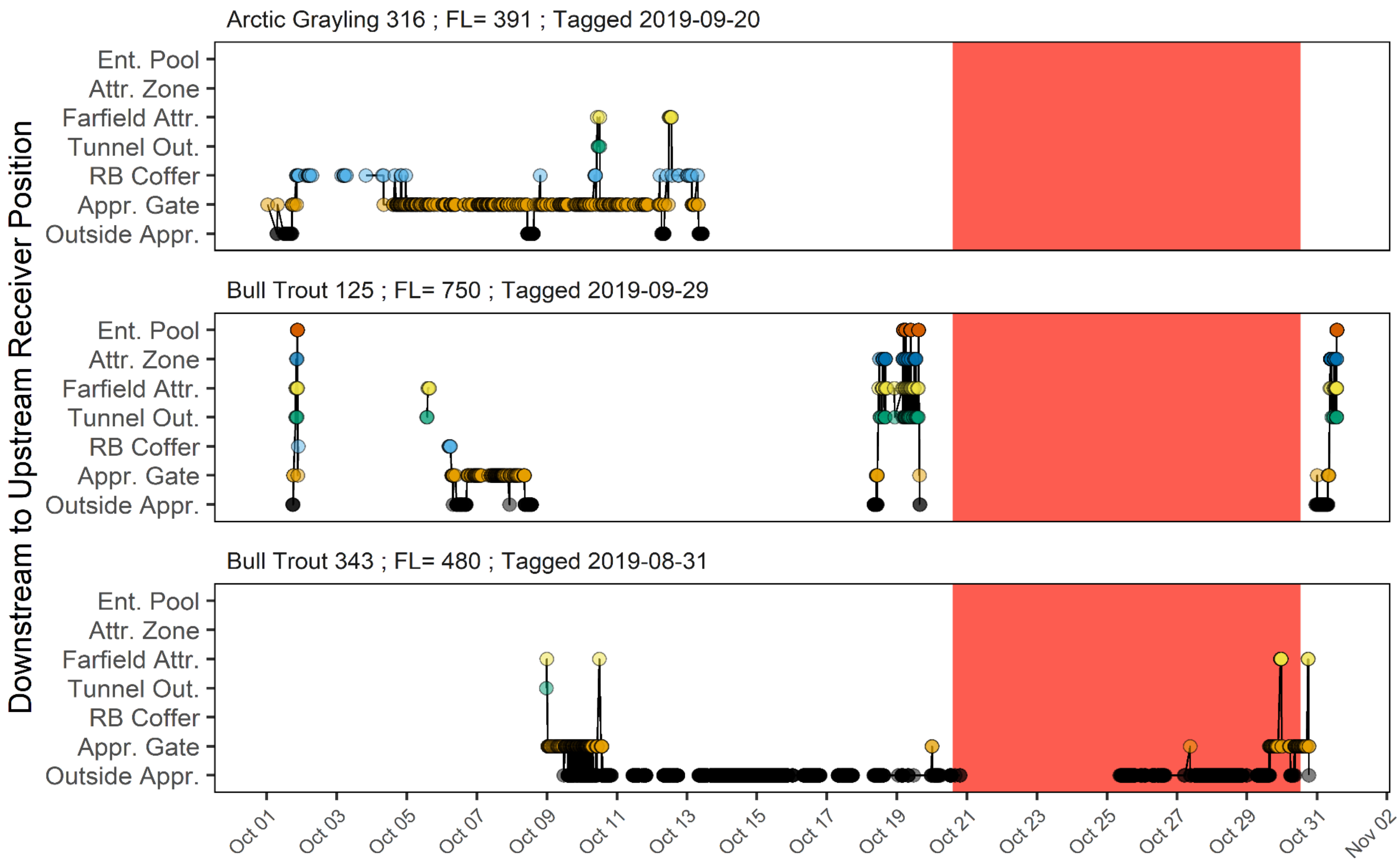


Figure 3.13 Complete detection histories for select radio-tagged fish detected proximate the fishway entrance (i.e., Farfield Attraction Zone [Farfield Attr.], Attraction Zone [Attr. Zone], and/or Entrance Pool [Ent. Pool]) during October. Fish detected within these areas tended to make multiple repeated upstream direction movements towards them. Red shading shows 10-day Standby Period. Information above panels shows radio tag code, fork length (FL), date of initial capture and tagging.

3.6 Movement Proximate Fishway Entrance

With few radio-tagged fish detected by dipole antennas, behaviour of tagged fish at the fishway entrance was best informed by PIT data. Most detection data were recorded on the West Entrance PIT antenna. The East Entrance, Pool 20, and Vee-trap Antennas did not detect any tagged fish during the Operational Period, and Pool 8 antennas only intermittently detected tags. Although detection data from the West Entrance antennas did provide some insight into fish behaviour, a subsequent upstream detection was required to confirm whether fish entered the fishway.

3.6.1 Outside of Operational Period

Entrance PIT antennas collected data from September 13 until November 1, 2020. Before the fishway was operating, Mountain Whitefish (n = 2), Walleye (n = 5), and Longnose Sucker (n = 3) were detected on the West Entrance PIT antenna. PIT-tagged fish were detected on the West Entrance and in Orifice 8 when operations stopped during the Overwintering Period. During the 21.8 hours data were recorded following operations, one Arctic Grayling and 23 Mountain Whitefish were detected.

There was considerable activity on PIT antennas throughout the Standby Period from October 20 to 30, 2020, including Arctic Graying and Mountain Whitefish on Orifice 8, Weir 8, and Orifice 20. In total, 292 PIT-tagged fish of six species were detected within and/or outside the fishway during the Standby Period (data not shown). These numbers are relatively higher than those observed during the Operational Period, likely because of the increased read range of the PIT antennas during this time; data are therefore not comparable between Operational and Standby Periods.

3.6.2 During Operational Period

A total of 167 PIT-tagged fish of six species were detected on fishway PIT antennas during the Operational Period. Target species detected included Arctic Grayling (n = 1), Bull Trout (n = 2), and Mountain Whitefish (n = 116). Most fish were only detected once but 40 PIT-tagged individuals were detected more than once. Detected fish did not hold for long periods within the detection range of the West Entrance; average occupancy duration was just over one second and the maximum was 31.8 seconds. Conversely, durations between occupancies often spanned several days. The mean duration between first and last occupancy on the West Entrance antenna was 3.8 days and the maximum was 13.3 days (Figure 3.14). Among non-target species (Largescale Sucker n = 13, Longnose Sucker n = 32, and Walleye n = 3), mean number of occupancies ranged from 3 (Longnose Sucker) to 5 (Largescale Sucker).

Mountain Whitefish were the focus of all analyses given their relative abundance. Daily numbers of Mountain Whitefish detected increased to a maximum of 22 on October 14, 2020 (Figure 3.15, top). There were repeat detections on 13 of 18 days prior to the Standby Period. The proportion of repeat detections did not increase through the Operational Period (Figure 3.15, bottom), as would be expected if fish were continuously milling at the fishway entrance. Observations of raw data reveal the greatest number of Mountain Whitefish to be consistently detected at the highest flow (i.e., AWS of 8.5 m^3/s and HVJ of 1.5 m^3/s; Figure 3.16).

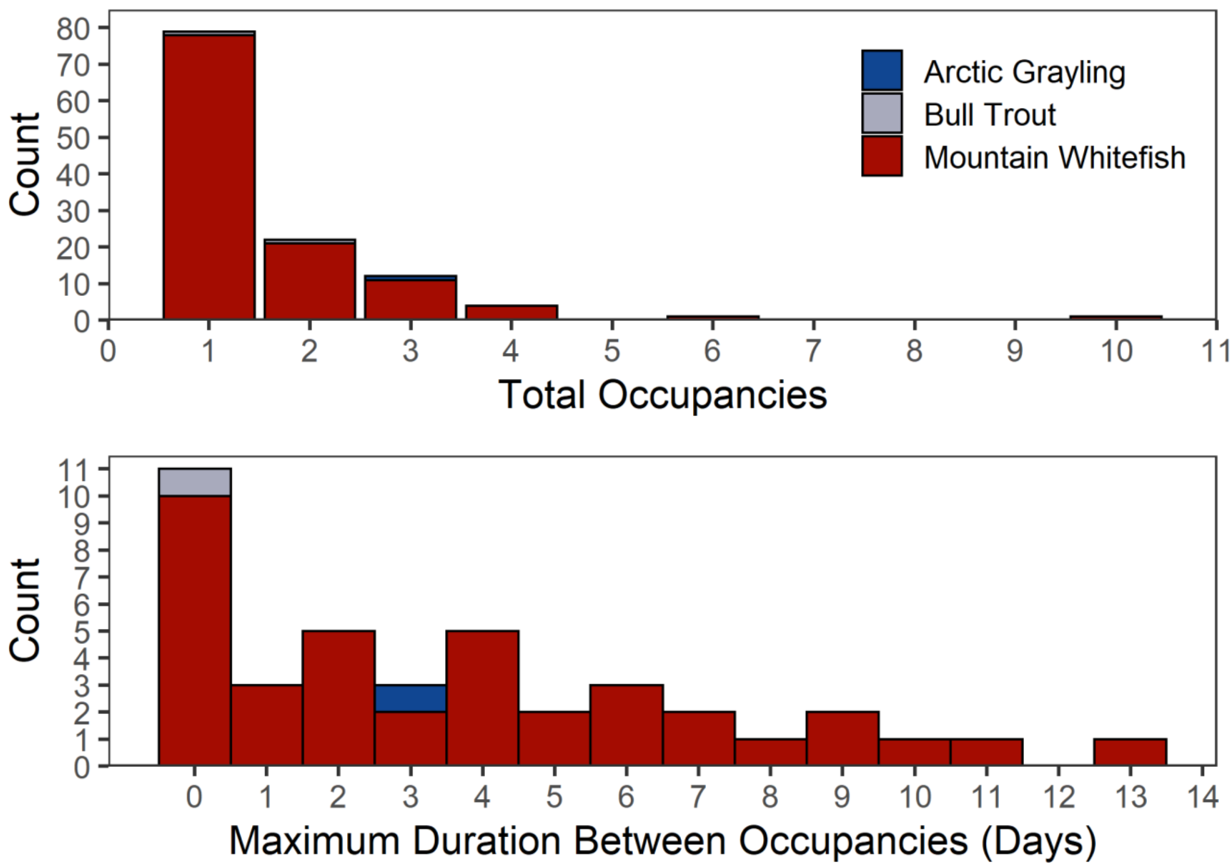


Figure 3.14 The time difference (in days) between the first and last occupancy for individual PIT-tagged fish detected by the West Entrance PIT antenna.

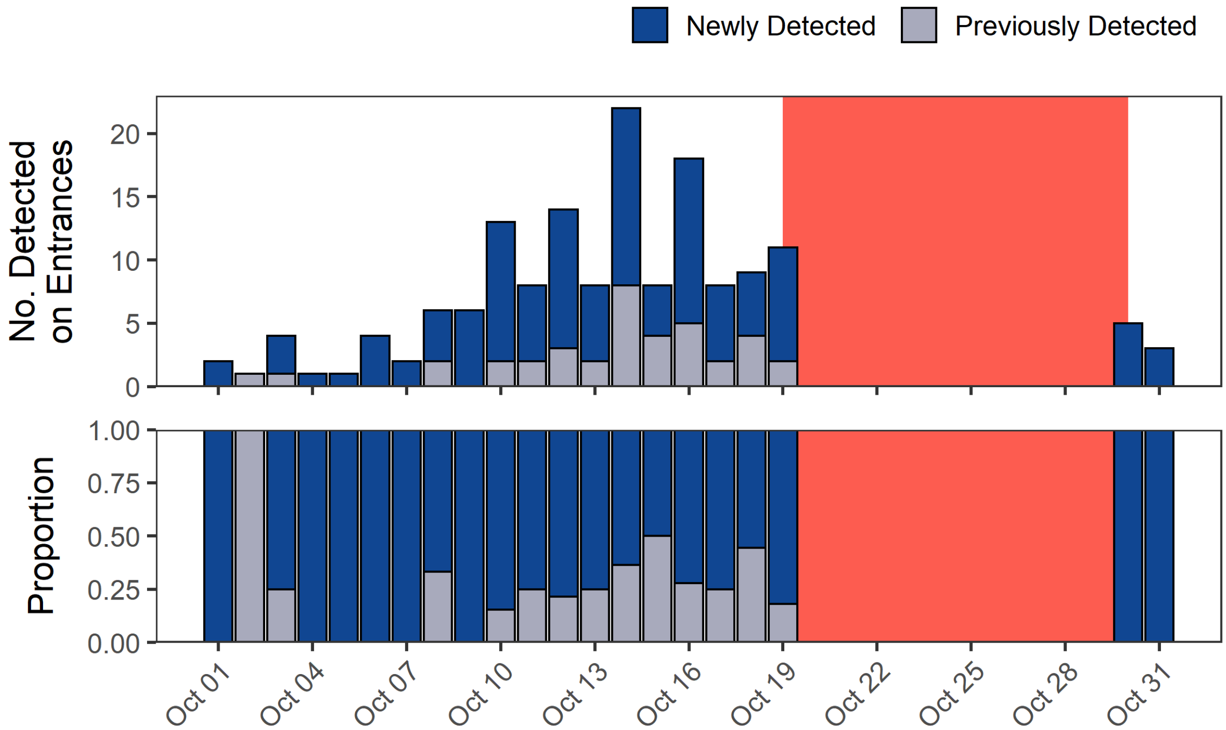


Figure 3.15 Daily number of Mountain Whitefish detected on the West Entrance PIT antenna (top). Blue bars show the number of new fish detected daily and grey bars the number previously detected. These same data are shown as proportions in the bottom pannel. Detections during the Operational Period were not visible on the graph when the relatively high number of detections during the Standby Period were included; therefore, data during the Standby Period (shaded in red) are not shown.

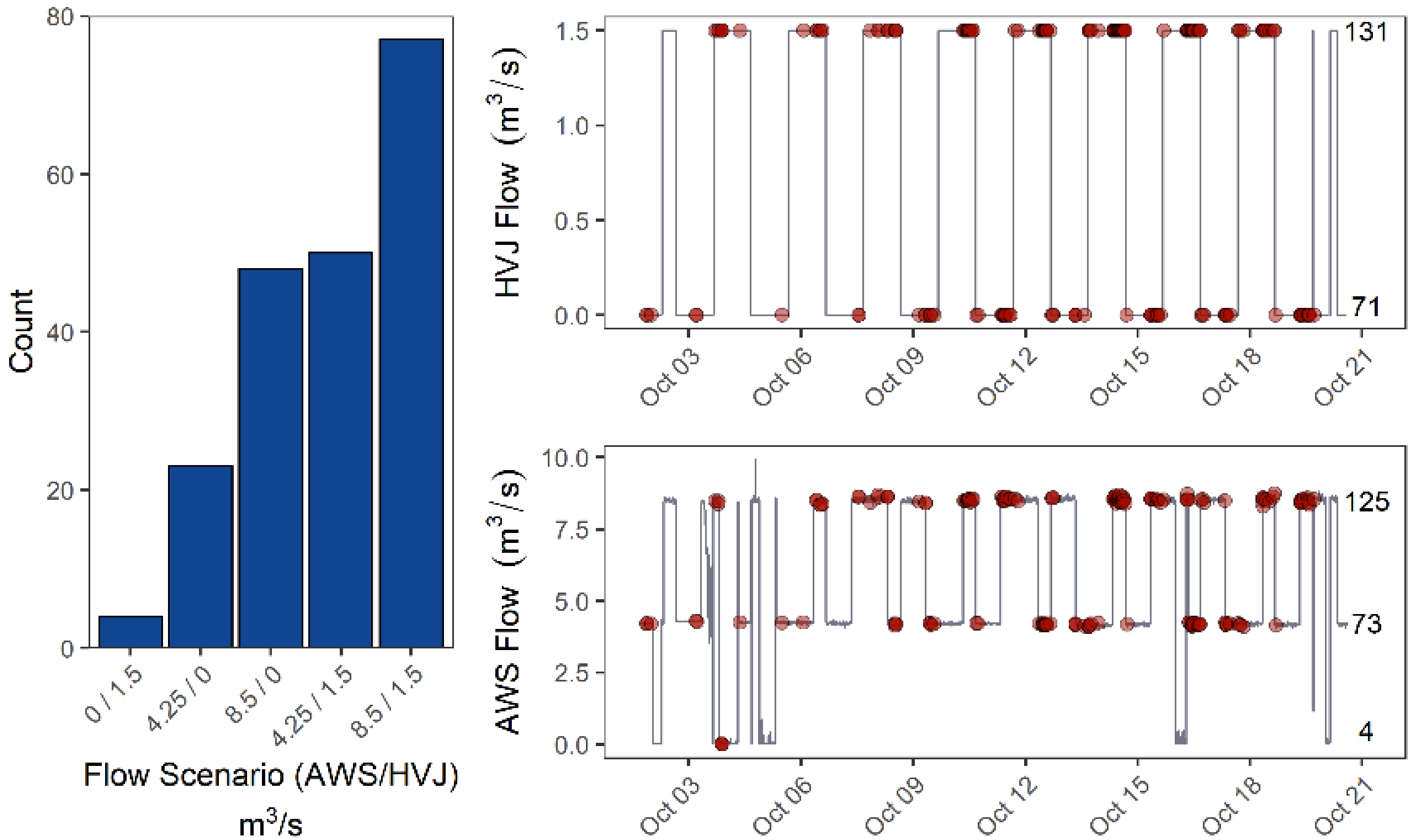


Figure 3.16 A summary of detections of PIT-tagged Mountain Whitefish on the West Entrance PIT antenna, including a count of detections at each combination of flow scenario (left) and details of when each detection was recorded during flow schedules of the Auxiliary Water Supply (AWS; right top) and High Velocity Jet (HVJ; right bottom). Red points show each detection. Only Operational Period prior to the Standby Period is shown to better display data resolution, but detections also occured in the ~1.5 days of post-shutdown operations. Sample sizes for each flow scenarios (on right) reflect number of Mountain Whitefish detected throughout the Operational Period.

3.7 Fishway Passage

Movement within the fishway can only be informed by the few detections on Pool 8 PIT antennas (given no detection data from other more upstream antennas), and scans in the sorting facility of PIT-tagged fish that successfully passed. There were 16 detections on Pool 8 antennas from 10 individual Mountain Whitefish, several of which were detected on both weir and orifice antennas. Three tagged Mountain Whitefish successfully passed the fishway and were scanned in the sorting facility; one was detected previously at the West Entrance and Pool 8, one just at the West Entrance, and the other not previously detected.

Detections on Pool 8 antennas occurred on October 10 (n = 1), October 11 (n = 1), and October 19 (n=14). It is curious that so many detections occurred on October 19, just one day prior to standby. We know the standby process began prior to the cessation of fishway flows (what was used to delineate the Standby Period), and there was no evidence of a similar pulse of PIT activity on the West Entrance. We cannot be sure if the increase in detections on Pool 8 antennas on October 19 was due to the relative abundance and presence of tagged fish, fish behaviour, and/or a proxy of PIT antenna functionality. Results are described but we caution they may not be representative of the population.

Eight Mountain Whitefish either detected within Pool 8 or scanned in the sorting facility were also detected on the West Entrance, providing some indication of timing and movement behaviour within the fishway (Figure 3.17). For example, results showed fish moving together: on October 19, two fish (MW1 and MW6) were detected on the West Entrance around 09:00 and on the Pool 8 weir and orifice antennas around 12:30, while another fish (MW4) moved between the West Entrance and Weir 8 during a similar timeframe. Detection data from within the fishway were available for two of three fish scanned in the sorting facility. Time of last detection on the West Entrance to time of scanning was 41.4 hours (MW3) and 34 hours (MW8); the latter of which had two occupancies (i.e., a previous detection on the West Entrance).

Based on available data, 2.6% of PIT-tagged Mountain Whitefish detected during the Operational Period passed the fishway. This is based on 116 Mountain Whitefish detected on the West Entrance antenna during the Operational Period and three documented as successfully passing the fishway, two of which were previously detected. That is, the percentage of successful candidates (3) from the total known candidate pool at the fishway entrance (i.e., 116 + 1 missed detection = 117). Among this candidate pool, it cannot be confirmed with just detection on the West Entrance PIT antenna if tagged fish had entered the fishway or not.

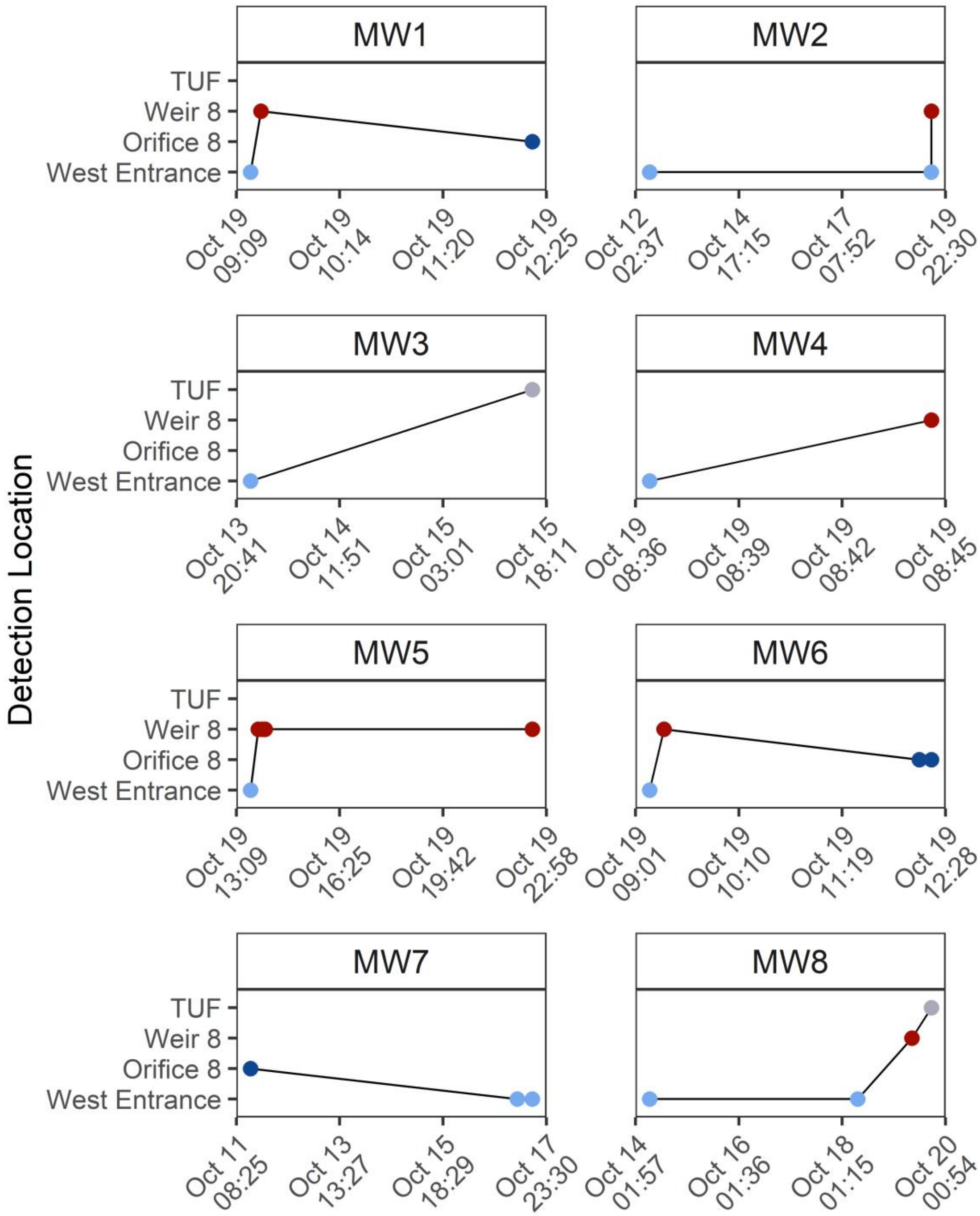


Figure 3.17 Detection histories of the eight Mountain Whitefish detected on either within Pool 8 (either Weir 8 or Orifice 8 PIT antennas) or scanned in the sorting facility (TUF) that were also detected on the West Entrance PIT antenna.

4. Discussion

The objective of Mon-13 is to evaluate the biological effectiveness of the TUF for upstream passage of migrating Arctic Grayling, Bull Trout, Burbot, Mountain Whitefish, and Rainbow Trout. Mon-13 will inform TUF operations and address key uncertainties regarding the attraction flows required to facilitate passage. Specifically, the monitoring aims to test hypotheses regarding the ability of target species to locate and use the fishway, and that fishway attraction and passage efficiencies of 80% and 76% are met or exceeded, as predicted in the EIS (BC Hydro 2012). Resulting data may identify limitations to passage and are directly applicable to the management of the TUF, potentially dictating in-season changes to operations.

A focus of this first year of monitoring was to ensure the experimental design and array were appropriate to determine species-specific and temporal variation among fishway approach, entry, and passage. The radio array functioned as intended and although performance of PIT antennas was poor, detection data were available from all five target species and will be used to inform the management questions. We confirmed that Mountain Whitefish, Arctic Grayling, and Bull Trout can locate the fishway from within the Approach Zone, and many individuals did so repeatedly. Mountain Whitefish in spawning condition passed the fishway, but the number of PIT-tagged individuals that successfully passed relative to the total detected was low. While it is promising that results could be obtained after just a 20-day Operational Period, data quantity is limited, and many uncertainties remain; additional monitoring is required to meet the objectives of Mon-13.

Although all target species were active on the array to some extent, few species were undergoing spawning migrations during the Operational Period. The TUF was primarily used by suckers and Mountain Whitefish, which have not been a priority for radio tagging efforts. A discontinuity within the telemetry dataset resulted whereby those species with radio tags were not actively migrating upstream during the Operational Period and those actively migrating upstream did not have radio tags. Thus, radio telemetry data informed approach and fishway entry, while PIT telemetry data informed movement within the fishway. The management question and associated two hypotheses will be addressed individually for each species.

4.1 Fishway Passage States

In the order that data are available by species, results for the distinct passage states of approach, entry, and passage are discussed individually for each target species.

4.1.1 Mountain Whitefish

The duration and timing of the upstream spawning migration period for Peace River Mountain Whitefish was unclear upon initiation of Mon-13, and uncertainties remain. A tracking study where 8 of 116 tagged Mountain Whitefish moved past the Project in 2006 and 2008 suggested that Mountain Whitefish likely spawn between August and October (AMEC Earth & Environmental and LGL Limited 2008, 2009). Adult Mountain Whitefish broadcast spawn in large groups in the fall, and spawn timing is thought to be predominately dictated by water temperature, with spawning occurring when water temperatures drop below 5.5°C (Northcote and Ennis 1994). The Peace River tends to reach this temperature in mid-November (as recorded at the Pine and Moberly confluences; Golder Associates Ltd. 2021). However, Peace River Mountain Whitefish were undergoing spawning migrations during the Operational Period of the TUF, when water temperatures ranged from 6.5 to 11.8°C.

Spawning activity was confirmed through observations of spawning characteristics among Mountain Whitefish successfully ascending the TUF. Although recording spawning characteristics was not standard monitoring for the facility operators, comments on datasheets included observations of tubercles, in addition to milt and eggs being released upon PIT tag insertion. These observations were also made by InStream Fisheries Research when in the sorting facility. Adding to the evidence that Mountain Whitefish were undergoing spawning migrations were continuous observations of large groups congregating within and around the fishway. In contrast to the temperature-mediated spawning argument for Mountain Whitefish, a multi-year study on the spawning behaviour of Mountain Whitefish in the Madison River, Wisconsin, concluded that other factors present spawning cues for Mountain Whitefish (Boyer et al. 2017). In that study, spawning consistently began in late October and movement patterns were similar among years despite varying water temperatures.

Mountain Whitefish were present at the TUF when operations ceased on October 31. Though we cannot confirm if these fish were moving upstream to spawn, the Operational Period may not encompass the full Mountain Whitefish spawning migration. Additionally, standby periods, as occurred in late-October 2020, may disrupt their spawning migrations. The TUF Operational Period was set based on the expected upstream fish migration window (BC Hydro 2020), and extending the Operational Period beyond late October is likely not possible given the negative effects of cold air and water temperatures to both fish health and TUF operations (e.g., freezing pumps; McMillen Jacobs & Associates and BC Hydro 2019). Air temperatures dropped to -10°C during the Standby Period in mid-October, and some pumps had frozen prior to this low. There remain many uncertainties regarding the timing and extent of Mountain Whitefish spawning migrations and of population dynamics (e.g., the proportion of fish resident to the Peace River mainstem). Further monitoring throughout the full Operational Period (April 1 to October 31) is needed to better understand these uncertainties and how Mountain Whitefish spawning migrations may be impacted by TUF operations.

With no radio-tagged Mountain Whitefish detected within the study area, no data were available to evaluate approach or attraction to the TUF. Consistent and repeated detections on the fishway entrance antennas throughout the Operational Period provide evidence that Mountain Whitefish are attracted to the fishway entrance. Their detection on both weir and orifice PIT antennas is also promising and confirms that multiple passage routes are available to this species. However, preliminary results from the 2020 Operational Period indicate that relatively few Mountain Whitefish successfully ascended the fishway into the sorting facility. Of the 117 PIT-tagged Mountain Whitefish known to be either within the TUF or at the entrance to the TUF, three (2.6%) successfully ascended the fishway. We regularly observed large groups of Mountain Whitefish milling at the entrance of the fishway, which may indicate a potential barrier to upstream passage, but could also be indicative of resident rather than migratory behaviour. Groups of Mountain Whitefish were also observed milling within the uppermost pool of the fishway (Pool 25) directly downstream of the vee-trap, which may indicate a potential barrier to passage within the fishway. Specifically, there seemed to be no attraction for fish moving upstream into the vee-trap, and the vee-trap opening was wide enough that fish were observed going in and out of the trap. The presence and location of potential barriers to passage within the TUF for Mountain Whitefish and other species is inconclusive to date and based on observations; the topic will be evaluated comprehensively as Mon-13 continues.

4.1.2 Bull Trout and Arctic Grayling

Results from Bull Trout and Arctic Grayling, primarily derived from radio telemetry, are discussed together given limited detection data for both species and similarity in movement patterns. Few Arctic Grayling or Bull Trout migrated into the fishway, and no tagged individuals ascended the fishway. As a result, we have some understanding of movement patterns within the approach and attraction zones, but little indication of behaviour within the fishway or measures of passage efficiency. Attraction efficiency – the proportion of modelled attempts detected in the Approach

Zone that successfully reached the Attraction Zone by the end of the Operational Period – was 17% for Arctic Grayling and 25% for Bull Trout (n = 11 and 14 modelled attempts, respectively).

Efficiency metrics will vary with motivation to migrate upstream. Motivation is driven by numerous internal and external factors and cannot be measured directly (Bizzotto et al. 2009; Castro-Santos et al. 2013; Romão et al. 2018). Some fish simply lack motivation to migrate, biasing efficiency metrics (Cooke and Hinch 2013). It is unknown how motivation may have affected the attraction efficiency for Arctic Grayling and Bull Trout. However, we do expect efficiency to increase as the monitoring period encompasses the spring and summer spawning migration period for these species (Goerig and Castro-Santos 2017).

Rates of movement from the Approach Zone to the Attraction Zone were typically only a magnitude of hours among Arctic Grayling and Bull Trout. Additionally, the few fish that located the fishway entrance tended to make multiple repeated movements towards the fishway entrance. These relatively quick and repeated upstream movements towards the fishway may indicate a high motivation to be upstream of the Project (Cooke and Hinch 2013; Goerig and Castro-Santos 2017; Romão et al. 2018). However, it is also likely that the observed repeated movements towards the fishway, particularly by Bull Trout, were to feed on prey (e.g., Mountain Whitefish) schooling at the entrance, a behaviour observed of predators at other barriers (Agostinho et al. 2012; Alcott et al. 2021, Rillahan et al. 2021), including Bull Trout (Furey et al. 2016). Nonetheless, the occurrence of repeated movements towards the Attraction Zone outside of the spawning season suggests that Arctic Grayling and Bull Trout can effectively locate the TUF. We may expect increases in attraction efficiency for these species when motivation to migrate is high during the pre-spawning migration period, and temporal variation in the number of directional upstream movements will be an important metric to consider in future analyses.

Habitat use differed between Bull Trout and Arctic Grayling. Compared to other species, Bull Trout made more movements towards, and resided longer within, the Tunnel Outlet detection area. The diversion tunnel outlet is characterized by high water velocities relative to the surrounding Peace River mainstem. Conversely, Arctic Grayling were detected within the RB Cofferdam detection area (along with the one detected Burbot) more often than other species. With these observations being based on few fish from a short Operational Period, data are still too limited to draw any conclusions from these patterns. However, it is a possibility that the high flows of the diversion tunnel outlet may act as an alternate upstream attractant to the fishway attraction flows for Bull Trout, while Arctic Grayling may use the opposite mainstem bank as a refuge from high water velocities. Both the Tunnel Outlet and RB Cofferdam detection areas will be monitored in future years.

Currently, data are too limited to address the management question for these two species. However, detection data do suggest that Bull Trout and Artic Grayling are able to locate the fishway.

4.1.3 Burbot and Rainbow Trout

Few Rainbow Trout or Burbot were detected in the Approach Zone during the Operational Period. Besides one individual that moved into the Farfield Attraction Zone from the Approach Zone, radio-tagged Rainbow Trout were mostly detected in the Outside Approach zone. The suspected spawning migration timing for Rainbow Trout is in the spring (Mainstream Aquatics Ltd. 2012). Thus, the lack of upstream movements is not surprising. Only one Burbot was detected through the entire monitoring period; this individual made 23 distinct attempts but was never detected on the left bank of the study area near the TUF. The detected Burbot made repeated movements between the Outside Approach and RB Cofferdam detection areas. Little can be concluded from the movement patterns of one fish, but the repeated nature of the movements agrees with findings from Kinbasket Reservoir, where significant repeatability in home range, movement, and site-fidelity were observed among Burbot (Harrison et al. 2015).

No upstream passage or movement towards the fishway was observed among Burbot. Few adult Burbot have been radio-tagged in the Peace River (n = 18 in 2019 and n = 7 in 2020). Burbot have not been well studied within the Peace River, or elsewhere, and their use of the area surrounding the Project is sporadic (Golder Associates Ltd and W.J. Gazey Research 2018). Burbot are winter active and spawn in the late winter/early spring (McPhail 2000). Although generally considered sedentary, long pre-spawning migrations have been reported among some Burbot populations (Breeser et al. 1988; Mainstream Aquatics Ltd. 2012). In the Peace River, downstream of the Project near the Dunvegan Hydroelectric Project, radio tagging showed an increase in the frequency of upstream movements between January and March (Mainstream Aquatics Ltd. 2012). It is unknown if, or when, pre-spawning migrations may occur among Burbot inhabiting the mainstem Peace River surrounding the Project, but there is a possibility that the TUF Operational Period does not encompass the migratory period for Burbot.

4.2 Optimal Attraction Flows

One of the key uncertainties related to operating the TUF is the magnitude of attraction flows provided by the AWS and/or HVJ required to maximize fishway effectiveness. Although the dataset is still too limited to do so, we plan to evaluate attraction flow by comparing species-specific attraction and passage efficiency metrics across various flow scenarios in TTE analyses. Detection of Mountain Whitefish on the West Entrance PIT antenna do provide some indication of flow preferences. Most Mountain Whitefish detections occurred at the highest flow combination (AWS of 8.5 m^3/s, supplemented by the HVJ at 1.5 m^3/s) and relatively few were detected in the low flow scenario (AWS of 4.25 m^3/s without HVJ supplementation). This may suggest a preference for higher flow among Mountain Whitefish. However, the result is based on observations of raw data, and we are still disentangling the relationships between flow scenarios and PIT antenna performance (and hence probability of detecting PIT tagged fish).

4.3 Functionality of Telemetry Arrays

Given lessons learned in 2020, we have high confidence that both radio and PIT arrays will effectively address the management question with some modifications. The radio telemetry array provided extensive and overlapping coverage of the entire study area, allowing for distinction of fine-scale movement patterns and habitat use. A limitation of the design was that habitat use was not directly comparable among detection areas due to divergent gain settings (set according to the specific objectives of each site) and that some the fixed stations had dual antennas while others had single. Full range testing of each station was not completed in 2020; therefore, gain settings were selected conservatively to maximize detection range while ensuring key objectives of each fixed station were met. Moving forward, we will refine these gain settings to allow for more fine-scale spatial analyses and comparisons among detection areas.

PIT antennas underwent regular testing and required extensive troubleshooting. Poor performance was likely caused by electrical noise entering the readers, either through the power source (conducted) or through the antenna (radiated), likely from the VFDs and other pumps. Conducted noise is caused by small voltage variations on the power cables while radiated noise comes in through the antenna and feedline cables and was most often generated by nearby electric equipment. The TUF was constructed as a temporary facility, and as such, the cables, wiring, and power sources for the VFD pumps were not shielded or protected to the standard that would be in place for a permanent facility (BC Hydro, personal communication), which likely increased the electrical noise beyond what would normally be seen in other established fishways operating PIT equipment. It is widely recognized among experts and researchers working with PIT technology that VFDs and pumps, commonly used in fishways, interfere with PIT antennas, and can greatly impact their functionality. Large VFDs and pumps are used throughout the TUF to consistently regulate flow and water levels. Several steps can be taken to reduce interference from this equipment, including the use of electromagnetic interference (EMI) filters designed to filter out high frequency interference and the use of non-ferrite enclosures and conduit (T. Castro-Santos and Oregon RFID, personal communication, Swarr 2018). Even with known preventative measures employed, electronic interference from VFDs can still be problematic (E.g., Swarr 2018). With testing, antenna design can be modified to reduce radiated noise interference from VFDs and other electrical equipment.

We will continue systematic antenna testing, including monitoring noise readings produced by the Oregon RFID readers. Testing suggested that use of the HVJ may affect performance of the West Entrance PIT antenna. However, the directionality of this relationship was unexpected: relative noise values decreased when the HVJ was on. The analysis categorized the HVJ as either on or off, but perhaps the timing of the change in HVJ operations is more important. Increased noise decreases the read range of the PIT antennas. This evidence of an interaction between noise and flow scenario indicates that noise is a covariate to consider in future multivariate analyses assessing the probability of passage.

4.4 Conclusions

In 2020, Mon-13 started to collect data on the approach, entry, and passage of Arctic Grayling, Bull Trout, Burbot, Mountain Whitefish, and Rainbow Trout at the TUF. The monitoring period encompassed a 20-day Operational Period, in which Mountain Whitefish were the only species undergoing a spawning migration. Promisingly, detection of Arctic Grayling, Bull Trout, and Mountain Whitefish within the Attraction Zone indicate that these species can locate the fishway. There were continuous and repeated detections of PIT-tagged Mountain Whitefish on one of the two entrance PIT antennas, and radio telemetry data revealed Arctic Grayling and Bull Trout to make repeated directed movements towards the fishway. However, attraction efficiencies modeled in survival analyses for Arctic Grayling and Bull Trout were considerably lower than predicted in the EIS; we expect these estimates to increase with future monitoring that encompasses their pre-spawning migration period. In terms of fishway passage, data are only available for Mountain Whitefish, and poor performance of the PIT array precluded a full analysis of passage efficiency. Few of the Mountain Whitefish detected at the TUF entrance and/or within the TUF successfully ascended the fishway. This, combined with regular observations of groups of Mountain Whitefish both outside and within the TUF may suggest barriers to passage exist for this species. However, further monitoring throughout the full Operational Period (April 1 to October 31) is needed to better understand resident versus migratory behaviour of Mountain Whitefish in the Peace River mainstem, and whether barriers to passage exist within the TUF.

In response to the management question of if the TUF provides effective upstream passage for target species attempting to migrate upstream, data collected to date are still too limited to reach conclusions for Arctic Grayling, Bull Trout, Burbot, and Rainbow Trout. For Mountain Whitefish, few successfully passed despite clear attraction to the fishway. Further monitoring is required such that a comprehensive data analysis can be completed to understand and quantify any potential limitations to attraction, entry, and passage for all target species.

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Appendix A: Fixed Station Performance

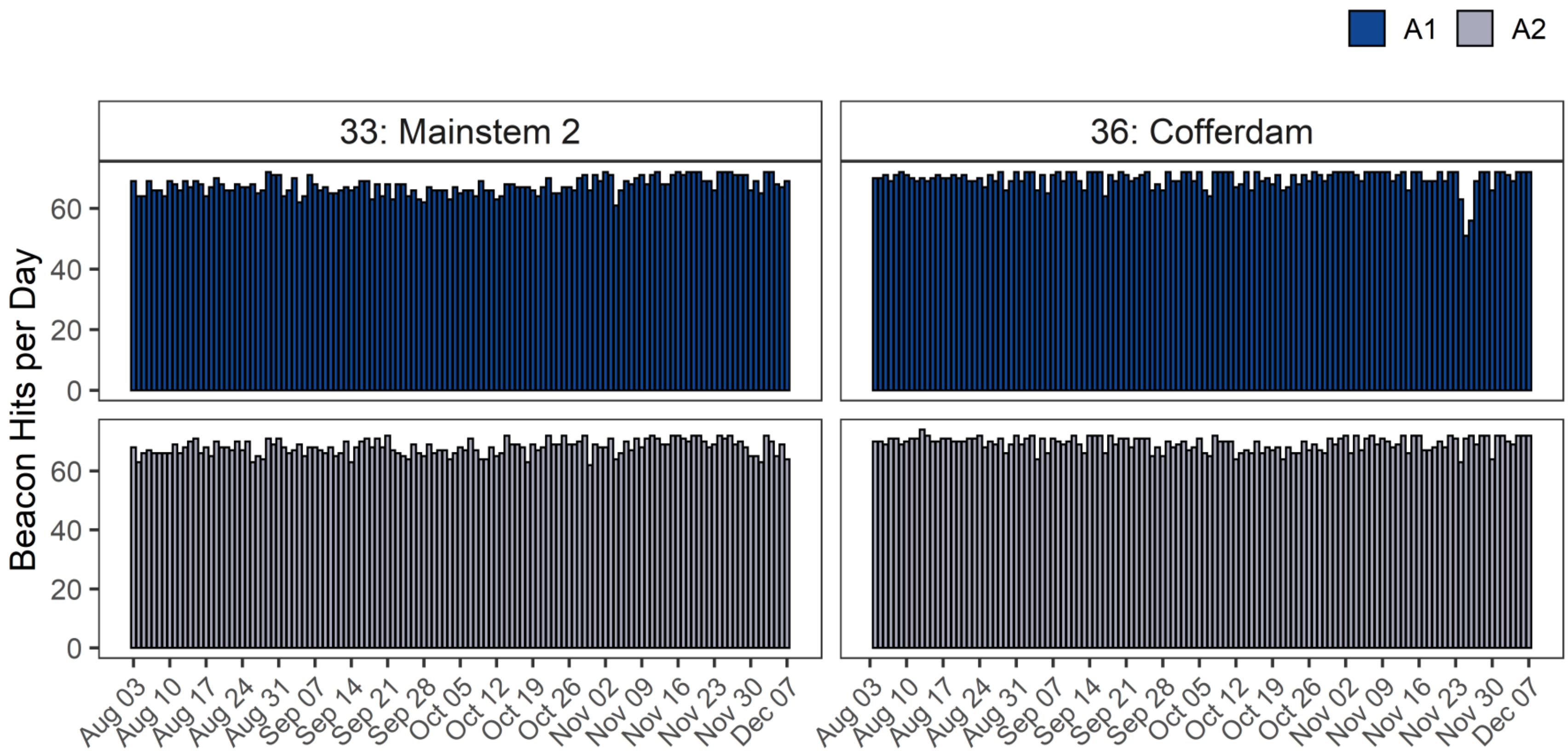

Figure A1 Count of beacon tag signals detected (hits) each day throughout the entire monitoring period for fixed radio telemetry stations with two antennas (A1 = upstream, A2 = downstream).

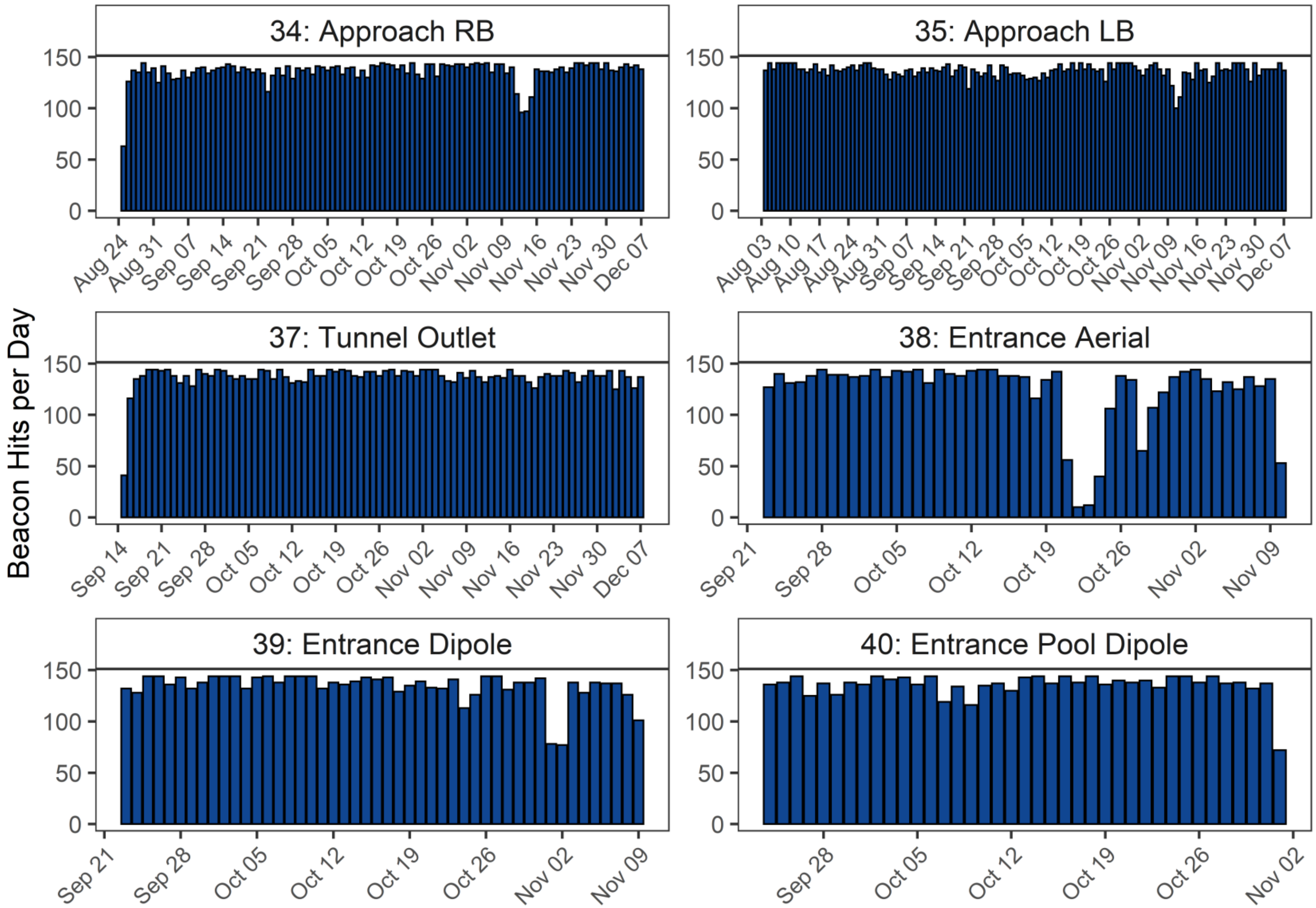

Figure A2 Count of beacon tag signals detected (hits) each day throughout the entire monitoring period for fixed radio telemetry stations with single antennas. Note that fixed station 34: Approach RB was deployed on August 3, but a beacon tag was not deployed until August 25.

Appendix B: Detection Histories

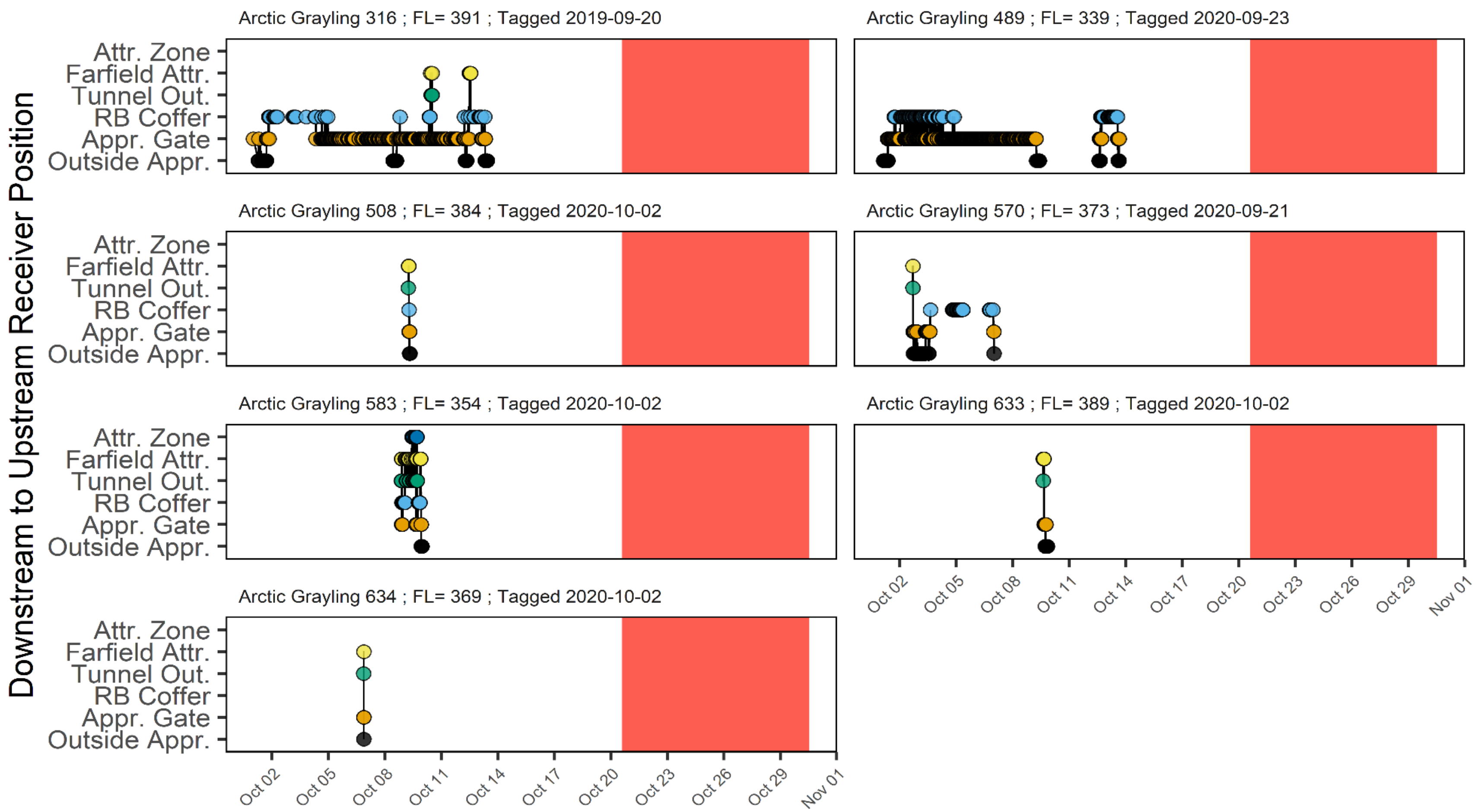

Figure B1 Detection histories for radio-tagged Arctic Grayling and detected by the Mon-13 array during October. The red shaded area shows the 10-day Standby Period. Fish only detected in one location not shown.

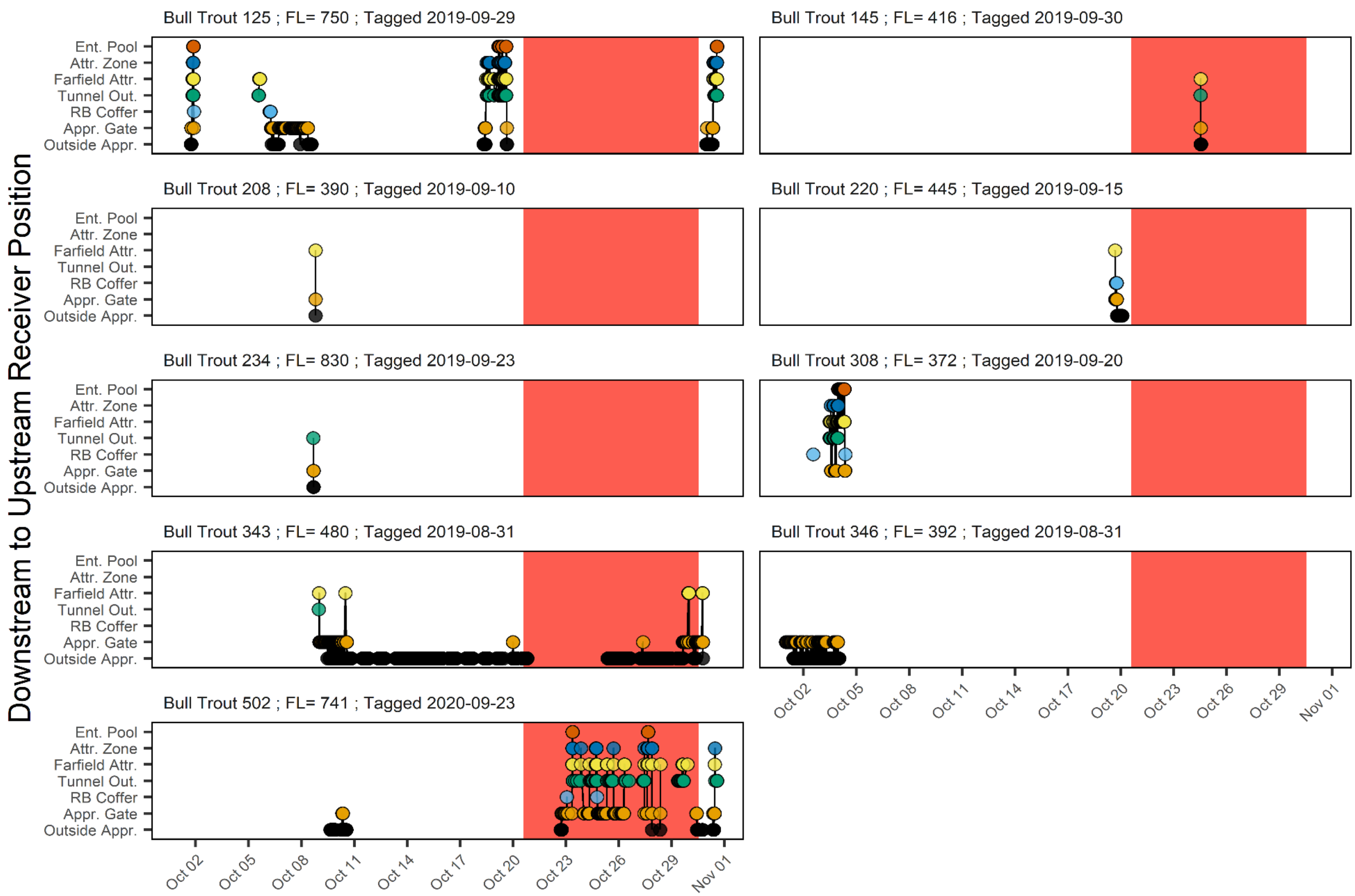

Figure B2 Detection histories for radio-tagged Bull Trout detected by the Mon-13 array during October. The red shaded area shows the 10-day Standby Period. Fish only detected in one location not shown.

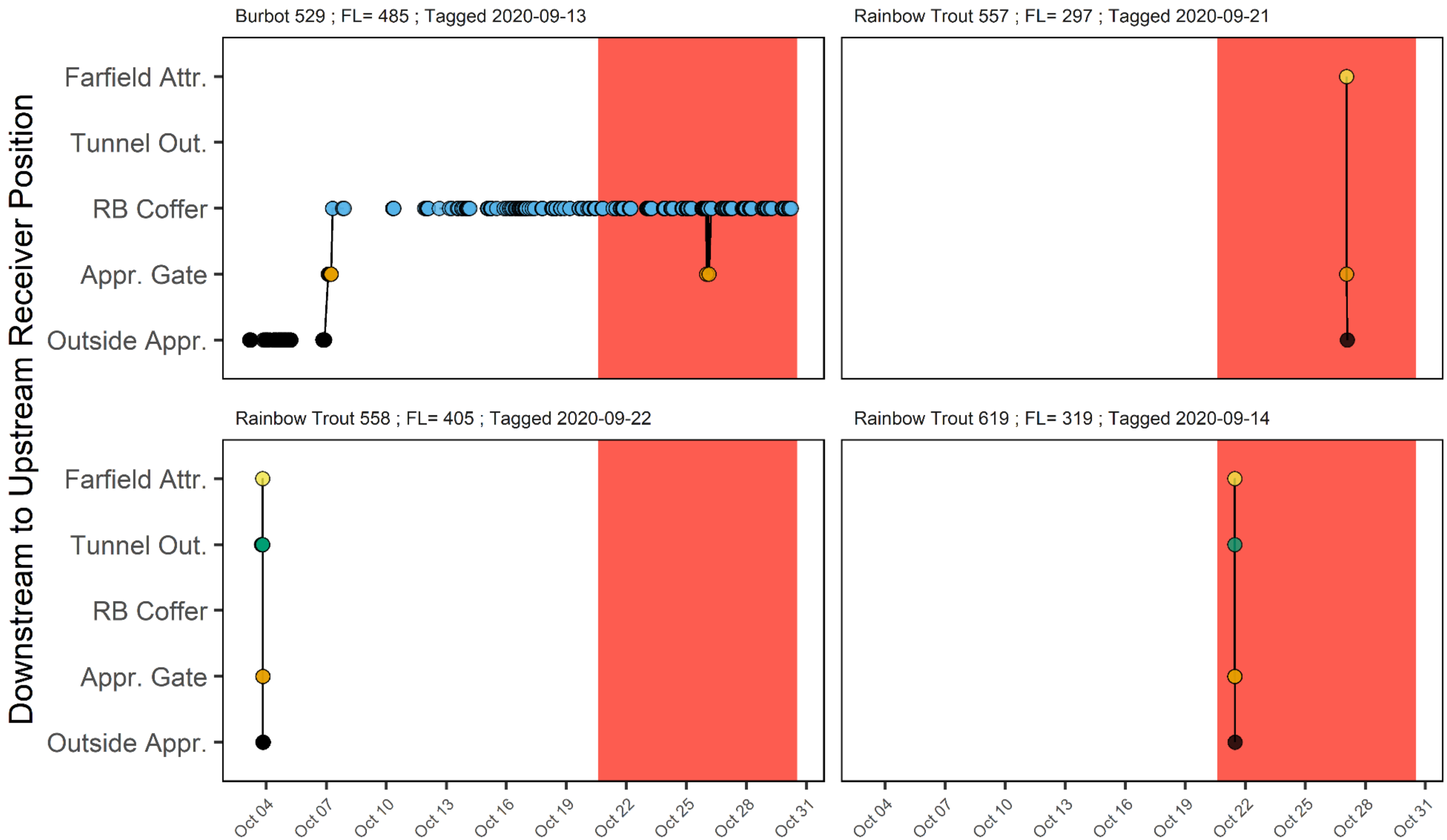

Figure B3 Detection histories for Burbot and Rainbow Trout detected by the Mon-13 array during October. The red shaded area shows the 10-day Standby Period. Fish only detected in one location not shown.