Site C Clean Energy Project

Site C Fishway Effectiveness Monitoring Program (Mon-13) &

Trap and Haul Fish Release Location Monitoring Program (Mon-14)

Construction Year 7 (2021)

Pete Moniz, MSc, RPBio
InStream Fisheries Research Inc.

Katrina Cook, PhD, RPBio
InStream Fisheries Research Inc.

Daniel Ramos-Espinoza, BSc
InStream Fisheries Research Inc.

November 2022

Site C Fishway Effectiveness Monitoring Program (Mon-13) & Trap and Haul Fish Release Location Monitoring Program (Mon-14)

Construction Year 7 (2021)

Pete Moniz*, Katrina Cook, Daniel Ramos-Espinoza

Prepared for:

BC Hydro – Site C Clean Energy Project

Prepared by:

InStream Fisheries Research
1121A Enterprise Way
Squamish BC, V8B 0E8

*Corresponding author

November 2022

Moniz, P., K. Cook, D. Ramos-Espinoza. 2022. Site C Fishway Effectiveness Monitoring Program (Mon-13) & Trap and Haul Fish Release Location Monitoring Program (Mon-14) – Construction Year 7 (2021). Report by InStream Fisheries Research, Squamish, BC, for BC Hydro, Vancouver, BC. 108 p + appendices.

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. During the river diversion phase of construction, BC Hydro operates the Project's temporary upstream fish passage facility (TUF) annually from April 1 to October 31. The TUF includes a weir-orifice fishway combined with a trap and haul facility to capture and truck a diverse assemblage of fish species upstream of the Project. To facilitate fishway use, attraction flows are provided at the TUF by an auxiliary water supply (AWS) flowing through two entrance gates, which are supplemented by a high velocity jet (HVJ) located adjacent to the fishway entrance. These two components of attraction flow are manipulated on a predetermined schedule to understand how effects may differ among species.

Here we report findings from two components of the Site C Fisheries and Aquatic Habitat Monitoring and Follow-Up Program (FAHMFP): monitoring the biological effectiveness of the TUF (Mon-13) and trap and haul program (Mon-14). Under both monitors, the movements of five target species, including Arctic Grayling, Bull Trout, Burbot, Mountain Whitefish, and Rainbow Trout were monitored using a combination of radio and passive integrated transponder (PIT) telemetry arrays within the TUF and upstream and downstream of the Project.

A focus of the 2021 operational period was to ensure that the experimental design and existing telemetry arrays were appropriate for evaluating the movements of target species as they approached, entered, and passed the TUF (Mon-13), and were then transported and released upstream of the Project (Mon-14). Under Mon-13, we quantified the effects of environmental factors, including supplementary attraction flows, on rates of movements near and within the TUF using time-to-event (TTE) analyses, and calculated species-specific proportions of tagged target species entering and successfully passing the fishway. Under Mon-14, we summarized release conditions and tracked post-release movements of radio-tagged target species transported upstream of the Project from the TUF.

The TUF was operational for 81% of the 2021 operational period (April 1 to October 31). There were six occurrences of temporary shutdown, including a nearly month-long period between June 29 and July 25. The proposed AWS flow schedule was to regularly alternate between 4.25 and 8.5 m^3/s; however, AWS flows were 0.5 m^3/s higher or lower than these two settings for a total of 404 hours (16.8 days) of the operational period. 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. The water surface elevation (WSEL) at the tailrace of the fishway entrance changed by 2.5 m (range = 409.4 to 411.9 m) during the operational period and exceeded the upper end of the fishway's design criteria (410.5 m) for a total of 131 days (i.e., 61% of the operational period).

The Mon-13 radio telemetry array functioned as intended throughout the 2021 operational period and performance of the PIT array improved from 2020. PIT detection data were available from all nine antennas, including five new antennas added in pool 23, pool 24, and at the vee-trap. Using both radio and PIT detection data, we confirmed that all five target species were able to locate and enter the fishway, and that many individuals did so repeatedly throughout the operational period. Radio telemetry data were sufficient to run TTE models using time-varying covariates for both Bull Trout and Mountain Whitefish. Arctic Grayling, Bull Trout, Mountain Whitefish, and Rainbow Trout successfully passed the fishway; however, passage success as determined using PIT detection data was low for all species.

Movements between spatial zones within the Mon-13 study area were primarily driven by season, diel period, and factors related to the Peace River (e.g., discharge, tailrace WSEL) for radio-tagged Bull Trout and Mountain Whitefish. Bull Trout moved between spatial zones more often during the summer, while Mountain Whitefish moved more often during the fall. It should be noted, however, that most Mountain Whitefish detected on the radio telemetry array were implanted with radio tags in the fall of 2021 when most detections occurred. Both species moved between spatial zones more often during the day compared to dawn, dusk, or at night. Bull Trout entered the fishway more rapidly and moved out of and away from the fishway more slowly the more often they had already been to those areas, while Mountain Whitefish were the opposite, suggesting potential learned behaviour and a possible influence of predator-prey interactions on movement behaviors. Bull Trout also entered the fishway more rapidly when the WSEL at the tailrace were within the fishway's design criteria compared to when it was above design criteria.

The AWS appeared to have a stronger influence on rates of fish movement compared to the HVJ during the 2021 operational period. Supplementary attraction flows did not appear to have a strong influence on rates of movement towards or away from the TUF for Bull Trout; however, Bull Trout did enter the fishway more rapidly and more often with increased AWS flows. Additionally, Mountain Whitefish moved away from the fishway entrance more rapidly with lower AWS flows. HVJ flows and the ratio of total attraction flow to Peace River discharge did not have a significant effect on rates of movement for either species.

Species-specific attraction and passage efficiency were calculated for tagged target species detected on the Mon-13 array using definitions provided in the Environmental Impact Statement (EIS). Specifically, attraction efficiency was defined as the proportion of a population that is attracted to and enters the fishway, passage success as the proportion of fish that successfully pass through the fishway, and passage efficiency as the product of those two values. We estimated attraction efficiency using radio telemetry data and passage success using PIT telemetry data. Species-specific attraction efficiency ranged from 0% (Arctic Grayling and Burbot) to 29.2% (Mountain Whitefish). Attraction efficiency for Bull Trout and Rainbow Trout were 19.3 and 5.1%, respectively. Species-specific passage efficiency ranged from 0% (Arctic Grayling, Burbot, Rainbow Trout) to 2.8% (Mountain Whitefish). Passage efficiency for Bull Trout was 0.6%.

Under Mon-14, we tracked the post-release movements of five radio-tagged Bull Trout and six radio-tagged Mountain Whitefish transported upstream of the Project during the 2021 operational period. Bull Trout were released in the Halfway River approximately 1 km upstream of its confluence with the Peace River and Mountain Whitefish in the Peace River approximately 2 km upstream of the Project. Three of the Bull Trout continued migrating upstream towards their assumed spawning grounds, while the remaining two spent less than three days in the Halfway River before swimming back downstream into the Peace River and past the Project 2.8 and 4.8 days after release. Two Mountain Whitefish continued their upstream migration towards assumed spawning grounds, two were never detected again, and two stayed within the vicinity of the release location for just over three days before migrating back downstream past the Project.

A supplementary (‘contingent’) trap and haul program was also introduced in 2021 to capture and transport fish upstream of the Project when the TUF was not operational (i.e., shutdown) or when Peace River water levels were above the fishway’s design criteria. Under this program, Arctic Grayling, Bull Trout, Mountain Whitefish, and Rainbow Trout were captured during boat electroshocking surveys in the Peace River in the vicinity of the TUF, radio-tagged, and released upstream of the Project at the same two locations as fish transported from the TUF. Although the results from this program cannot be used to evaluate the effectiveness of the TUF or its associated trap and haul program, it is noteworthy that individuals from each of the four target species continued their upstream migration to their assumed spawning grounds after release, including five Arctic Grayling, 14 Bull Trout, two Mountain Whitefish, and eight Rainbow Trout.

Results from the 2021 operational period should be interpreted with caution given several significant constraints to both programs. For example, the nearly month-long shutdown period began in late June as many radio-tagged target species first reached the Mon-13 study area. It is unclear how this shutdown may have affected TTE results or estimates of attraction and passage efficiencies. Additionally, tailrace WSELs were above the fishway's design criteria for most of the operational period, which we were able to account for in the TTE analyses, but not in our estimates of attraction and passage efficiencies. Finally, relatively low numbers of target species successfully passing the fishway resulted in small sample sizes used to estimate efficiency metrics and trap and haul effectiveness. Despite these challenges, results from the 2021 operational period suggest that all five target species can locate the TUF, that Arctic Grayling, Bull Trout, Mountain Whitefish, and Rainbow can successfully pass it, and that Bull Trout and Mountain Whitefish transported upstream of the Project from the TUF can and will continue their upstream spawning migration after release.

Acknowledgements

The Site C Fishway Effectiveness Monitoring Program and Trap and Haul Fish Release Location Monitoring Program are funded by BC Hydro's Site C Clean Energy Project. We would like to thank Brent Mossop and Nich Burnett at BC Hydro for administering this project.

All InStream Fisheries Research staff provided essential field and logistical support throughout the planning and execution of this monitor, most notably LJ Wilson, Cole Martin, Luke Irwin, and Jordan Bastin. Staff from LGL Inc., and Golder Associates Ltd. have been invaluable collaborators. The assistance and continued support from Jason Smith, Kyle Hatch, and Dave Robichaud from LGL, Inc., and Dustin Ford and Demitria Burgoon from Golder Associates Ltd. are greatly appreciated. We also thank the West Moberly First Nation, especially Kayla Brown for their contributions. Support provided by Ted Castro-Santos from the United States Geological Survey was instrumental to experimental design and analyses.

We acknowledge this research is being conducted on the traditional territory of Treaty 8 First Nations of Dunne Zaa, Cree and Tse'khene cultural descent.

Table of Contents

List of Tables

List of Figures

List of Abbreviations and Acronyms

AWS	Auxiliary water supply
EIS	Environmental impact statement
FAHMFP	Fisheries and Aquatic Habitat Monitoring and Follow-Up Program
FDX	Full-duplex
HR	Hazard ratio
HDPE	High density polyethylene
HDX	Half-duplex
HVJ	High velocity jet
OPP	Operational parameters and procedures
PIT	Passive integrated transponder
PUF	Permanent Upstream Fish Passage Facility
TTE	Time-to-event
TUF	Temporary Upstream Fish Passage Facility
WSEL	Water surface elevation

Glossary

Approach – As used in time-to-event behaviour analyses. For Mon-13, a state transition from the approach zone to the entry zone.

Approach zone – A distinct spatial zone within the study area used to determine when tagged fish occupying the array were considered candidates for fish passage. For Mon-13, the approach zone encompasses the entire area upstream of the outside approach 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. For Mon-14, a watershed-wide radio telemetry array deployed under Mon-1b was used to monitor post-release movements of tagged fish released upstream of the Project.

Attraction efficiency – The proportion of fish approaching a fishway that are attracted to the fishway. For Mon-13, the proportion of radio-tagged individuals of given species detected within the approach zone that successfully approached and entered the fishway.

Departure – As used in time-to-event behaviour analyses. For Mon-13, a state transition from the entry zone to the approach zone.

Detection range – The field within which an antenna can detect a radio tag in the water.

Entry – As used in time-to-event behaviour analyses. For Mon-13, a state transition from the entry zone into the fishway.

Entry zone – A distinct spatial zone within the study area between a fishway entrance and where fish can detect attraction flows and enter the fishway. For Mon-13, the entry zone is defined by the detection range of dipole antennas deployed on the outside of the fishway entrance.

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

Fallback – The behaviour of passing downstream through a dam shortly after upstream passage or transport, prior to reaching spawning or rearing areas. For Mon-14, when a radio-tagged individual was detected downstream of the Project within 48-hours of upstream release.

Fishway – A distinct spatial zone within the study area from the entrance pool to collection in the sorting facility. For Mon-13, the fishway as a spatial zone is defined by the detection range of dipole and PIT antennas deployed throughout the fishway.

Mortality – For Mon-14, when a radio-tagged individual was not detected after release or repeatedly detected at or directly downstream of its release location. True mortalities could not be confirmed under Mon-14, as tag loss or sedentary behaviour in deep or shielded habitat can result in similar detection patterns as inferred mortalities.

Occupancy – As used in time-to-event behaviour analyses. For Mon-13, continuous activity of a tagged fish on the radio telemetry array. Each tagged individual may have multiple occupancies on the array.

Operational period – The intended operational period of the TUF, irrespective of shutdown periods, from April 1 to October 31.

Outside approach zone – A distinct zone within the study area downstream of the approach zone used to determine when a tagged fish left and/or re-entered the study area.

Passage efficiency – The proportion of tagged fish that approach, enter, and successfully ascend a fishway. For Mon-13, the product of attraction efficiency and passage success.

Passage success – The proportion of tagged fish that enter and successfully ascend a fishway. For Mon-13, the proportion of PIT-tagged individuals of a given species known to have entered the fishway that that were successfully crowded into the fish lock and processed by the facility operator.

Read range – The distance from a PIT antenna a test tag is able to be detected.

Rejection – As used in time-to-event behaviour analyses. For Mon-13, a state transition from the fishway to the entry zone.

State transition – As used in time-to-event behaviour analyses. For Mon-13, movement of tagged fish from one defined spatial zone to another.

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). BC Hydro began diverting the Peace River through diversion tunnels in October 2020 to facilitate construction of the Project, and while doing so, began operation of the temporary upstream fish passage facility (TUF), which includes a weir-orifice fishway combined with a trap and haul facility. The purpose of the TUF is to provide for upstream fish passage from April 1 through October 31 during each year of the river diversion phase of the Project until reservoir inundation occurs in the fall of 2023, at which time the TUF will be decommissioned, and BC Hydro will start operating the permanent upstream fish passage facility (PUF).

The Site C Fishway Effectiveness Monitoring Program (Mon-13) and Trap and Haul Fish Release Location Monitoring Program (Mon-14) represent two components of the FAHMFP. The programs aim to address key uncertainties including the effectiveness of attracting fish from the Peace River into the fishway and the attraction flows required to do so (Mon-13; Chapter 1), and the effectiveness of various fish release locations in the Site C Reservoir and tributaries and the movement of individual fish following release (Mon-14; Chapter 2).

Under these monitors, radio and passive integrated transponder (PIT) telemetry will be used to monitor the movements of five target species - Arctic Grayling, Bull Trout, Burbot, Mountain Whitefish, and Rainbow Trout. These species were chosen because they have known spawning areas upstream of the Project and are likely to migrate through the area. Additionally, these species were identified during the environmental assessment process as important to Indigenous nations and anglers and are indicator species in local provincial management objectives (BC Ministry of Environment 2009; BC Government 2011).

The Project is a new and dynamic study site. Mon-13 and -14 have, and will continue to be, conducted within an adaptive framework where study designs 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 and environmental conditions. While Mon-13 and -14 refer to monitoring fish attraction, passage, transport, and release from the TUF, results will also inform the design and operation of the PUF.

1. Site C Fishway Effectiveness Monitoring Program (Mon-13)

1.1 Introduction

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.

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 (NMFS 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.

To be effective, fishways must attract fish to the entrance, enable fish to enter and 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 (Williams et al. 2012); the location and orientation of the TUF relative to the flow of the Peace River through the diversion tunnel outlet reflect this objective (Figure 1). Generally, additional flows are required to attract fish to fishway entrances. 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 through the fishway entrance into the diversion tunnel outlet. The AWS can be supplemented by additional flow from a high velocity jet (HVJ) located adjacent to the fishway entrance (Figure 2). This supplemental flow 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 diversion tunnel outlet. The HVJ can either be programmed to be on (up to 1.5 m^3/s) or off. Results from a representative computational fluid dynamics model of attraction flows from the AWS and HVJ into the diversion tunnel outlet are shown in Figure 3. Throughout this monitor, combinations of these two components of attraction flow will be experimentally manipulated on a predetermined schedule to better understand how attraction flow may improve passage rates for target species.

Data collected under Mon-13 will be used to directly address the following management question:

> 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?

Associated with the management question are two hypotheses:

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[1]; attraction efficiency of 80% and passage efficiency of 76%).

In addition, Mon-13 will use time-to-event (TTE) analyses to explore how environmental factors, including supplementary attraction flows, influence passage rates for each target species.

Figure 1 Aerial photo of the diverted Peace River and the temporary upstream fish passage facility (TUF) at the Site C Clean Energy Project, located on the east bank of the diversion tunnel outlet. The Peace River is diverted through two tunnels which do not allow for upstream fish passage. Photo provided by BC Hydro, June 8, 2021.

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

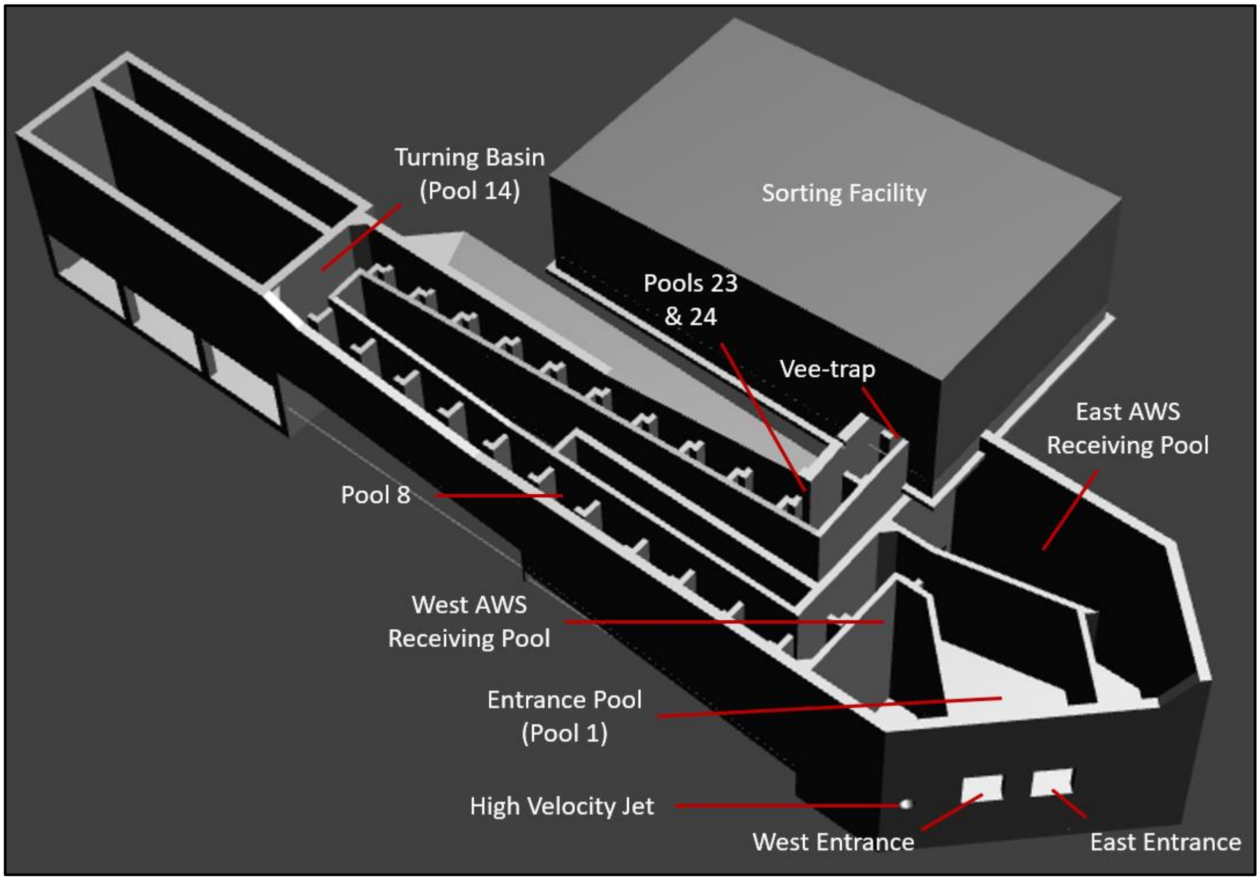

Figure 2 A drawing of the temporary upstream fish passage facility (TUF). Upstream migrating fish enter the TUF via one of the two entrance gates and are processed and sorted for transport within the sorting facility. Fishway attraction flows are provided by an auxiliary water supply (AWS) flowing into the two receiving pools and then into the entrance pool and through fishway entrances. A high velocity jet located adjacent to the fishway entrance provides supplemental attraction flow.

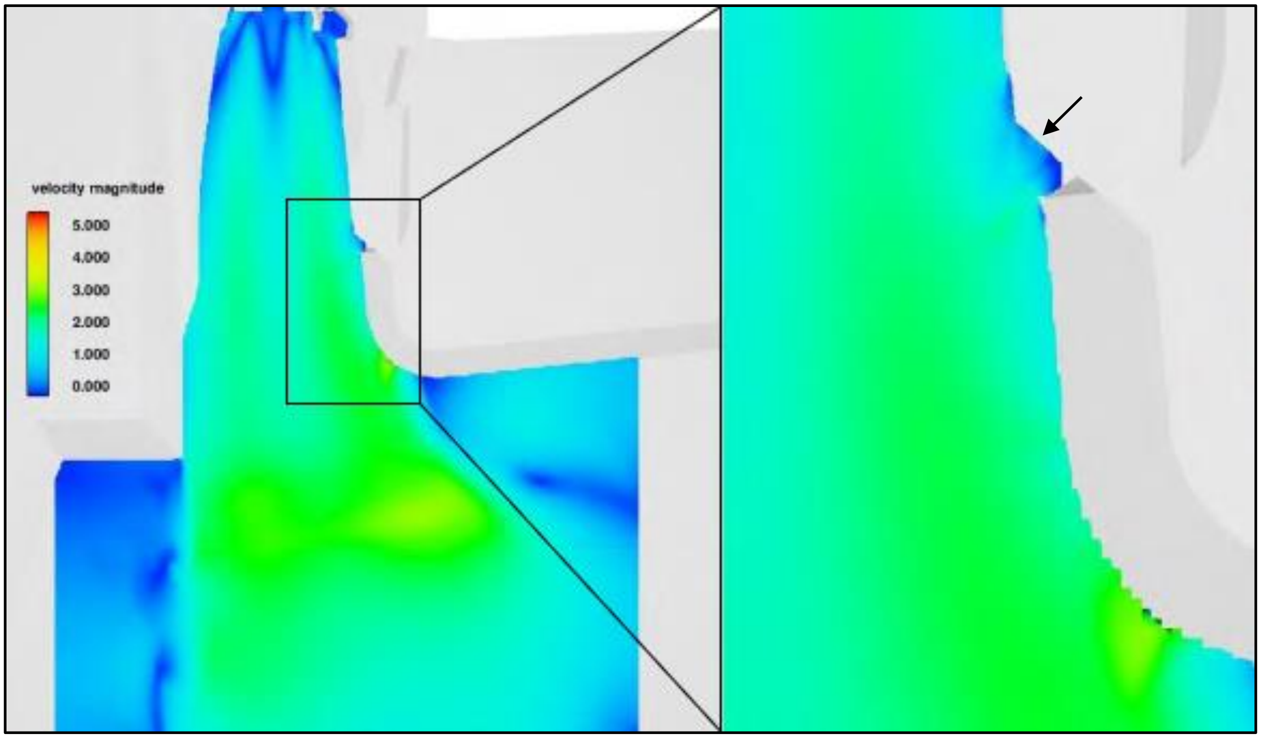

Figure 3 Results from a representative computational fluid dynamics model of attraction flows from the entrance of the temporary upstream fish passage facility (indicated by arrow) into the diversion tunnel outlet (Case 214; McMillen 2014). In this model, the diversion tunnel outlet was set to 1104 m^3/s, while attraction flows from the auxiliary water supply and high velocity jet were set to 8 and 2 m^3/s, respectively.

1.2 Quantifying Biological Effectiveness

Under Mon-13, the biological effectiveness of the TUF is evaluated by monitoring how tagged fish move between distinct spatial zones. Attraction and passage efficiency, as specified in H_2, refers to the proportion of a given species that successfully approach and enter the fishway (attraction efficiency) and then pass through the fishway in completion (passage efficiency). Fishway efficiency metrics are often seen as a benchmark of biological effectiveness (Cooke and Hinch 2013), but fail to integrate the temporal dynamics inherent to fish passage. Approach, entry, and passage are distinct state transitions (Castro-Santos and Perry 2012; Silva et al. 2018), each influenced by time-varying environmental factors (Goerig and Castro-Santos 2017; Alcott et al. 2021). Integrating these temporal components into assessments of biological effectiveness is made possible using TTE analyses.

In a TTE analysis, each state transition can be characterized by at least two competing rates: the rate at which the fish advances to the next state, and an opposing rate at which they abandon a state and retreat to the previous one (Castro-Santos and Haro 2010; Castro-Santos and Perry 2012; Silva et al. 2018; Alcott et al. 2021). Factors (e.g., supplementary attraction flows) that increase rates of advancement and/or decrease retreat rates between any two states will increase overall passage rates. While efficiency metrics are useful for providing a broad overview of fishway effectiveness, passage efficiency will never be fixed in time for any species or fishway. TTE analysis of passage rates that account for time-varying covariates is a much more comprehensive means to assess biological effectiveness (Castro-Santos and Perry 2012; Silva et al. 2018). Under Mon-13, both methods will be used to monitor the biological effectiveness of the TUF.

Understanding state transitions and generating reliable efficiency estimates requires delineating spatial zones along the trajectory of an upstream migration using a telemetry tracking system with strategic detection points (hereafter ‘array’). The Mon-13 radio and PIT telemetry array is divided into four zones to support a multi-state competing risk framework (Figure 4; Table 1). From downstream to upstream, the four zones include: 1) the ‘outside approach’, used to determine when a tagged fish arrives, leaves, and/or re-enters the study area; 2) the ‘approach zone’, used to determine when tagged fish within the array are considered candidates for fish passage; 3) the ‘entry zone’, used to determine when tagged fish reach the fishway entrance and where they can presumably detect attraction flows; and 4) the ‘fishway’, used to determine when a fish enters the fishway. TTE analyses of radio telemetry data were used to evaluate what and how environmental factors, including supplementary attraction flows, influenced rates of advancement from the approach zone to the entry zone (approach rate) and from the entry zone to the fishway (entry rate), as well as the competing rates of retreat from the fishway to the entry zone (rejection rate) and from the entry zone to the approach zone (departure rate). Attraction and passage efficiency were calculated using both radio and PIT detection data.

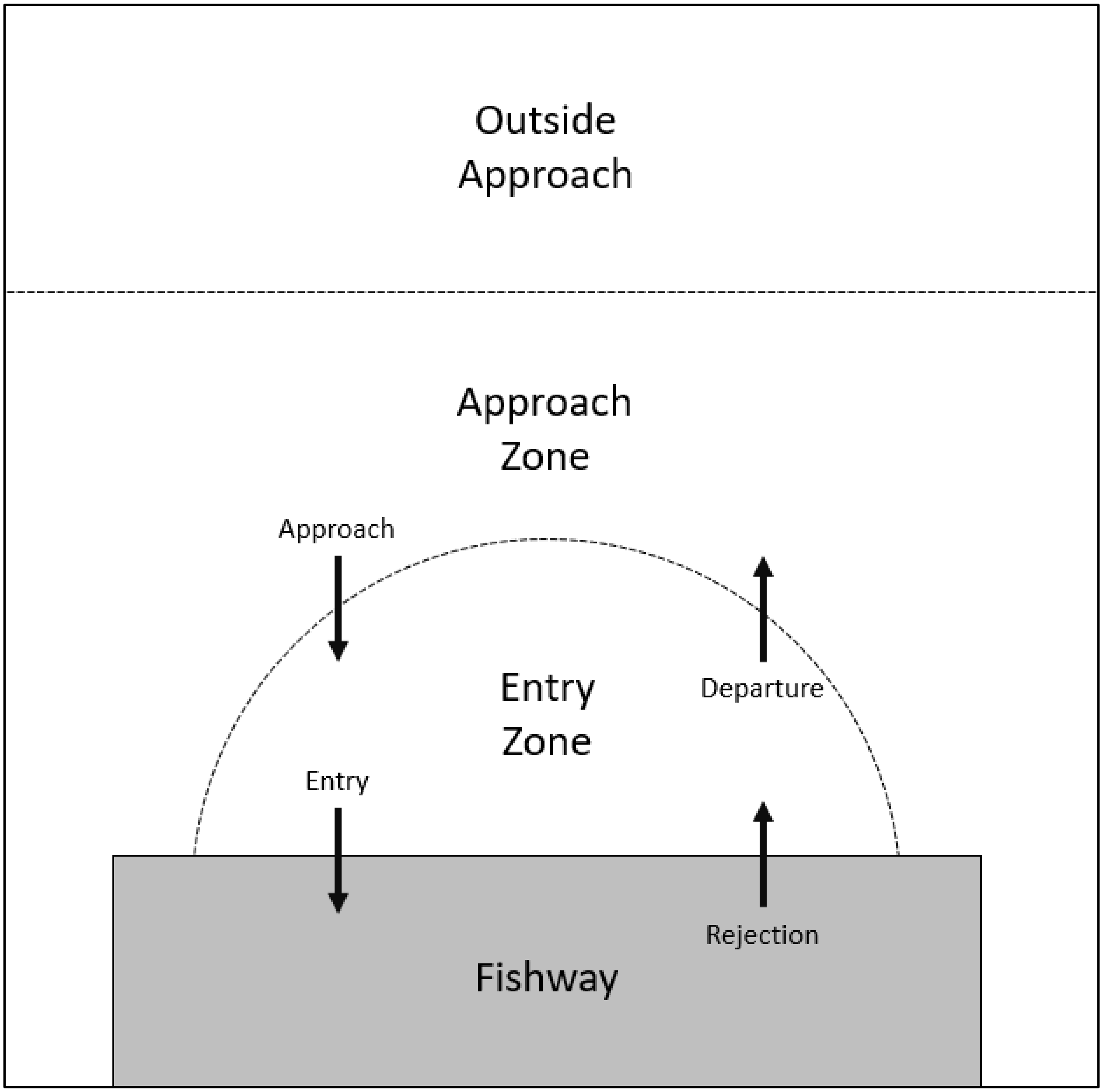

Figure 4 Schematic of competing risks framework for time-to-event analyses of radio telemetry data. Each spatial zone represents the transitional states between which tagged fish can move. Tagged fish become candidates for the analysis once in the approach zone.

Table 1 Definitions of spatial zones within the study area from downstream to upstream.

Spatial Zone	Definition
Outside approach	A distinct zone within the study area used to determine when a tagged fish arrives, leaves, and/or re-enters the study area.
Approach zone	A distinct zone within the study area used to determine when tagged fish are considered candidates for fish passage.
Entry zone	A distinct zone between the fishway entrance where fish can presumably detect attraction flows, typically within 3 m of fishway entrances. For Mon-13, the entry zone is defined by the detection range of dipole antennas deployed on the outside of the fishway entrance.
Fishway	The entire fishway, from the entrance pool to collection in the sorting facility.

1.3 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, 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 Mon-13 study area is a small reach of this large river, including all riverine habitat approximately 1.5 rkm downstream of the Project (Figure 5), as well as the TUF and sorting facility (Figure 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 that are crowded are processed and sampled by the facility operator. Following sampling in the sorting facility, fish are sorted according to release location and are no longer monitored under the objectives of Mon-13.

1.4 Methods

To meet the objectives of Mon-13, a combined radio and PIT telemetry array was deployed to monitor tagged fish as they approached, entered, and passed the TUF. Operational and environmental factors that may facilitate or limit fish passage were also monitored. All analyses and data summaries were created using R Studio V1.4.1103 (R Core Team 2021).

1.4.1 Fishway Operations and Environmental Conditions

The intended annual operational period for the TUF is April 1 to October 31. Within this period, there were six instances when the fishway had to be temporarily shut down in 2021 (detailed in Table 2). For example, the TUF is designed to automatically shut down when the water surface elevation (WSEL) in the entrance pool exceeds 412.0 m for more than 60 seconds (McMillen Jacobs & Associates and BC Hydro 2022), which happened once in late April. Between June 11 and June 16 and then again between June 29 and July 25, the TUF was temporarily shut down to address a suspected oil leak after a visible sheen was observed on the water's surface within the fishway. Operations resumed after water quality testing confirmed an absence of hydrocarbons. All data collected during shutdown periods were removed from datasets used in analyses, unless otherwise stated below.

During the operational period, the AWS and HVJ were experimentally manipulated as outlined in the Manual of Operational Parameters and Procedures (OPP; McMillen Jacobs & Associates and BC Hydro 2022). 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 3). 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.

Environmental data were collected from a variety of sources. Sensors deployed throughout the TUF were used to collect attraction flow, WSEL at the tailrace of the fishway (Sensors LT_600 and LT_601), and water temperature within the pre-sort holding pool (Sensor TT_601) at 1-minute intervals for the duration of the operational period (McMillen Jacobs & Associates and BC Hydro 2022). Peace River discharge data recorded at 5-minute intervals were obtained from the Water Survey of Canada gauge at Peace River above Pine River (07FA004). Dissolved oxygen levels were recorded at 10-minute intervals using a data logger (HOBO U26-001 D, Onset Computer Corporation) deployed immediately outside of the fishway entrance on April 20. Dissolved oxygen data were collected until September 16 when the logger's memory reached capacity. Daily diel data, including civil dawn start, sunrise, sunset, and civil dusk end times were obtained using the 'suncalc' package in R (Thieurmel and Elmarhraoui 2019).

Table 2 Start and end dates and times of shutdown periods and their reasoning during the 2021 operational period of the temporary upstream fish passage facility (TUF). Start and end times were obtained from BC Hydro's monthly Temporary Upstream Fish Passage Facility Operations Reports[1].

Start Date and Time	End Date and Time	Reason
April 20 13:15	April 21 06:30	Water levels in the Peace River exceeded the operating range of the TUF
June 11 18:05	June 16 12:51	Suspected hydrocarbon leak within the fishway
June 29 11:23	July 25 10:03	Suspected hydrocarbon leak within the fishway
July 26 06:00	July 26 06:57	Project-wide power outage
September 8 09:26	September 16 14:04	Pump and fish lock repairs
October 7 13:56	October 7 17:37	Fish lock and pre-sort holding pool maintenance

[1] Available at: https://www.sitecproject.com/document-library/environmental-and-socio-economic-plans-and-reports

Table 3 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
AWS (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 (m^3/s)	0	1.5	0	1.5	0	1.5	0	1.5	0	1.5	0	1.5

1.4.2 Telemetry Array

Overall Design

Radio telemetry data were used to monitor tagged fish approaching and entering the fishway, while both radio and PIT telemetry data were used to monitor 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 telemetry array consisted of 12 fixed radio telemetry stations (hereafter 'fixed stations') deployed within the study area on the Peace River (Figure 5) and within the TUF (Figure 6). Each fixed station had either one or two 3-element Yagi aerial antennas, which had large detection areas, or either one or two submerged dipole antennas, which provided small detection areas (~3-10 m) for a specific defined area of interest (Figure 7).

The PIT telemetry array consisted of nine antennas that were designed, fabricated, and installed by InStream Fisheries Research (IFR; Figure 8). PIT antennas were custom built to fit within key locations of the TUF to detect fish passing through entrance gates and select orifices, over select weirs, and through the vee-trap. All fixed stations and PIT antennas were deployed by April 1, 2021, except for the tunnel outlet fixed station, which was deployed on April 5, 2021. All dipole fixed stations and PIT antennas were demobilized after the end of the operational period on October 31, 2021. The RB cofferdam fixed station was demobilized on August 8, 2021 due to construction activities in the area. All remaining fixed stations were left operational through the winter.

Fixed Station Components

Each fixed station included an SRX800-MD4, SRX1200-MD2, and/or SRX1200-D2 Lotek receiver (Lotek Wireless) and either one or two aerial or dipole antennas (all antennas manufactured by Sigma Eight). SRX800 receivers were replaced with SRX1200 receivers partway through the operational period at the tunnel outlet, turning basin, and vee-trap fixed stations. Fixed stations with aerial antennas were elevated ~2.5 m on a 10' mast secured by a 5' tripod assembly (Figure 7). The location and number of aerial antennas varied among individual fixed stations according to the specific objectives of each site (Table 4). All fixed stations without access to mains power 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. Dipole antennas were connected directly to a single receiver at each of the fixed stations located at the TUF. Two dipole antennas were deployed at the entrance pool fixed station as 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 7). All SRX800 receivers were connected to cell modems (BulletLTE-NA2, Microhard Systems) for remote downloading. The receiver, battery bank, charge controller, and cell modem were all housed within aluminum or stainless-steel enclosure boxes (Saip Electric Group Company).

A beacon tag (MFT-3B, Lotek Wireless) was installed at or near each fixed station to monitor temporary outages. Beacon tags were programmed to emit a coded radio signal once every 10 seconds for one minute each hour (i.e., six transmissions per hour). All fixed stations were originally programmed to scan for one frequency and were therefore expected to detect all six beacon tag transmissions every hour. Starting between July 19 and 21, 2021, fixed stations were programmed to scan between two alternating frequencies every 10 seconds and were therefore expected to detect three beacon transmission every hour. Using these detection data, three outages were observed during the 2021 operational period (Hatch et al. 2022). The first outage was at the tunnel outlet fixed station from August 19 to 26 after a suspected short circuit caused the breaker to switch off. The second was at the outside RB fixed station from September 13 to October 2 after the station's solar panel was blocked by a fallen tree. The final outage was at the approach RB fixed station from October 13 to 21 after a suspected short circuit caused the breaker to switch off.

PIT Antenna Components

PIT antennas were custom fabricated and anchored within the TUF using an HDPE housing that encased all antenna wire (Figure 8). Extensive testing was conducted during fabrication for all antennas using all sizes of half-duplex (HDX) PIT tags deployed under the FAHMFP (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 (Oregon RFID). Readers were powered using a bank of 182 Ah batteries (SMS-AGM400, NorthStar Battery). Power to the readers was filtered (Passive Line Noise Filter, Oregon RFID), and where noise from mains power was a concern (e.g., both entrance antennas), an AC Linear Power Supply was used to further clean the power source. Both entrance antennas were also shielded with layers of ferrite tile to reduce potential interference from the stainless-steel channels holding them in place at the entrance gates. Battery banks were trickle charged by mains power and provided power for approximately one week in the case of mains power interruption.

There were several modifications made to the PIT telemetry array in 2021 to improve its performance. Specifically, new antennas were installed in pools 23 and 24 and at the vee-trap that were smaller and less susceptible to radiated noise compared to the large pass-through style antennas used in pool 20 and at the vee-trap in 2020 (Table 5; Figure 8). Rather than detecting fish as they passed through the antennas, these antennas detected fish as they swam over (weir 23 and 24), under (orifice 23 and 24), and by (vee-trap) the antenna. Although the same two entrance gate antennas used in 2020 were used again in 2021, their heights were reduced slightly to make them less susceptible to radiated noise. Pool 8 remains inundated year-round restricting access to the weir and orifice 8 antennas; therefore, no improvements could be made to the design of these antennas in 2021.

Table 4 Fixed radio telemetry stations ('fixed stations') used in this study from downstream to upstream. LB and RB refer to the left and right bank of the Peace River, respectively.

Fixed Station Name	Spatial Zone	Receiver Model	Antenna Type	Antenna No.	Purpose
Outside LB	Outside approach	SRX800-MD4	Aerial	2[1]	The combined detection range of these two fixed stations defined the outside approach, which was used to determine when fish left and/or re-entered the array.
Outside RB	Outside approach	SRX800-MD4	Aerial	1	
Approach LB	Approach zone	SRX800-MD4	Aerial	1	The combined detection range of these two fixed stations were used to form the approach zone gate, which delineates the approach zone from the outside approach. Tagged fish detected in the approach zone were considered candidates for fish passage.
Approach RB	Approach zone	SRX800-MD4	Aerial	1	
RB cofferdam	Approach zone	SRX800-MD4	Aerial	2	To determine if fish remained along the RB opposite of the fishway.
Tunnel outlet	Approach zone	SRX800-MD4, SRX1200-MD2	Aerial	1	To determine if fish were approaching the diversion tunnel outlet prior to or instead of the fishway entrance.
Entrance aerial	Approach zone	SRX800-MD4	Aerial	1	To determine if fish were nearing the fishway entrance.
Outside entrance	Entry zone	SRX800-MD4	Dipole	1	To define the entry zone.
Entrance pool	Fishway	SRX800-MD4	Dipole	2[2]	To determine if tagged fish entered the fishway.
Pool 8	Fishway	SRX800-MD4	Dipole	1	To determine if fish reached pool 8 of the fishway.
Turning basin	Fishway	SRX800-MD4, SRX1200-D2	Dipole	1	To determine if fish reached the turning basin (pool 14) of the fishway.
Vee-trap	Fishway	SRX800-MD4, SRX1200-D2	Dipole	1	To determine if fish reached pool 25 of the fishway.

[1] Detection data from the upstream-pointed antenna were not used in Mon-13 analyses to maintain a symmetric detection range with the outside RB fixed station directly across the channel.

[2] Given difficulty in accessing these antennas in season, two dipole antennas were combined to create one detection field and redundancy in case of failure.

Table 5 PIT antennas used in this study from downstream to upstream. PIT detections at and upstream of the weir and orifice 8 antennas were used to confirm that fish had entered the fishway.

Antenna Name	Antenna Design	Purpose
West entrance	Pass-through	Antennas framed each entrance of the fishway and were used to determine if tagged fish were near (< 1m) the fishway entrances. Detections at the entrance antennas did not confirm entry.
East entrance	Pass-through	
Weir 8	Pass-through	To determine if tagged fish were using the weir going into pool 9.
Orifice 8	Pass-under / Pass-over	To determine if tagged fish were using the orifice going into pool 9.
Weir 23	Pass-over	To determine if tagged fish were using the weir going into pool 23.
Orifice 23	Pass-under	To determine if tagged fish were using the orifice going into pool 23.
Weir 24	Pass-over	To determine if tagged fish were using the weir going into pool 24.
Orifice 24	Pass-under	To determine if tagged fish were using the orifice going into pool 24.
Vee-trap	Pass-by	To determine if tagged fish passed through the vee-trap leading into the pre-sort holding pool.

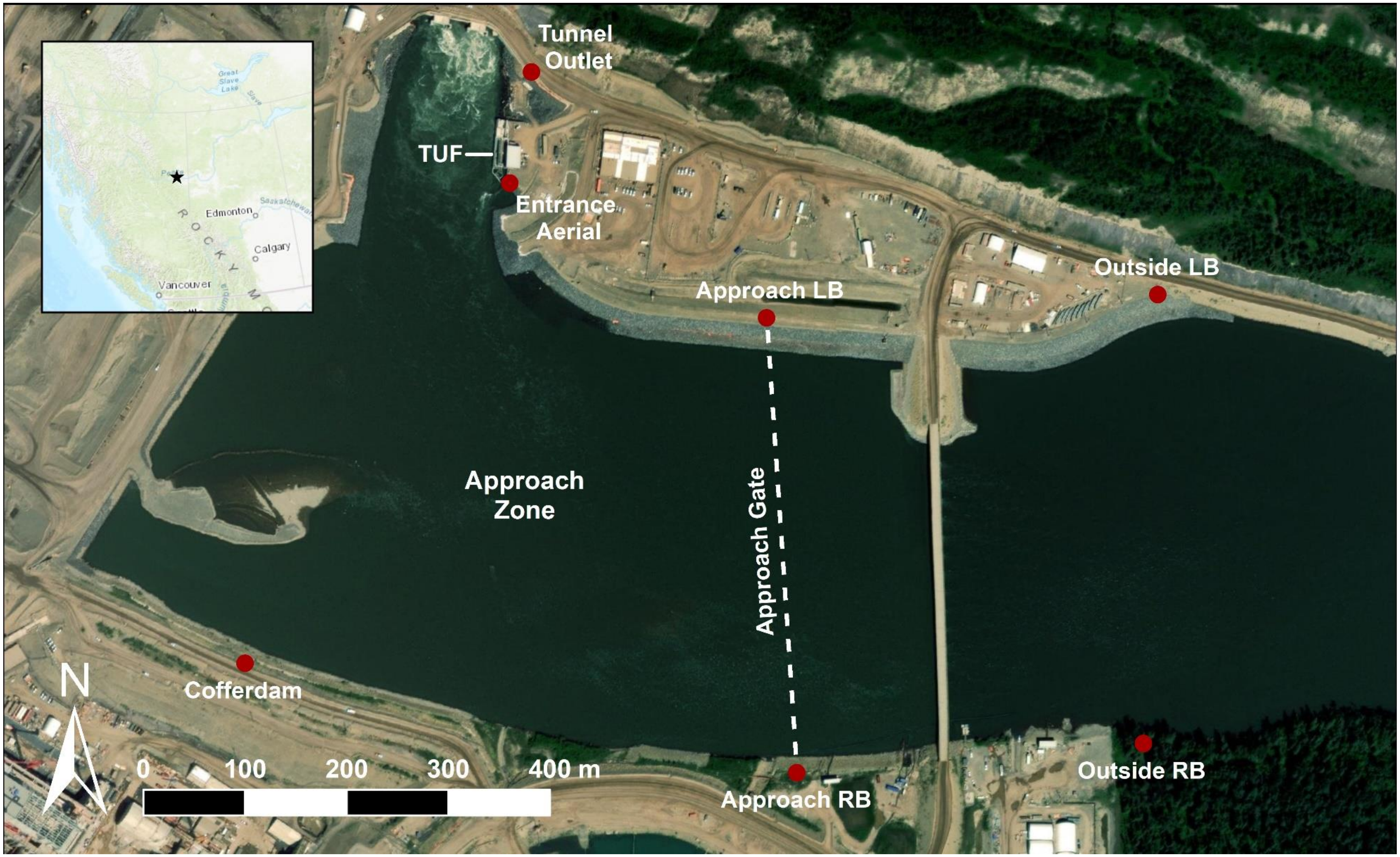

Figure 5 The Mon-13 study area showing the seven aerial fixed radio telemetry stations (fixed stations) deployed along the mainstem Peace River used to detect radio-tagged fish approaching the temporary upstream fish passage facility (TUF). Submerged dipole fixed stations are also deployed within the TUF (not shown for clarity). Tagged fish detected in the approach zone (i.e., at and/or upstream of the approach gate) were considered candidates for fish passage.

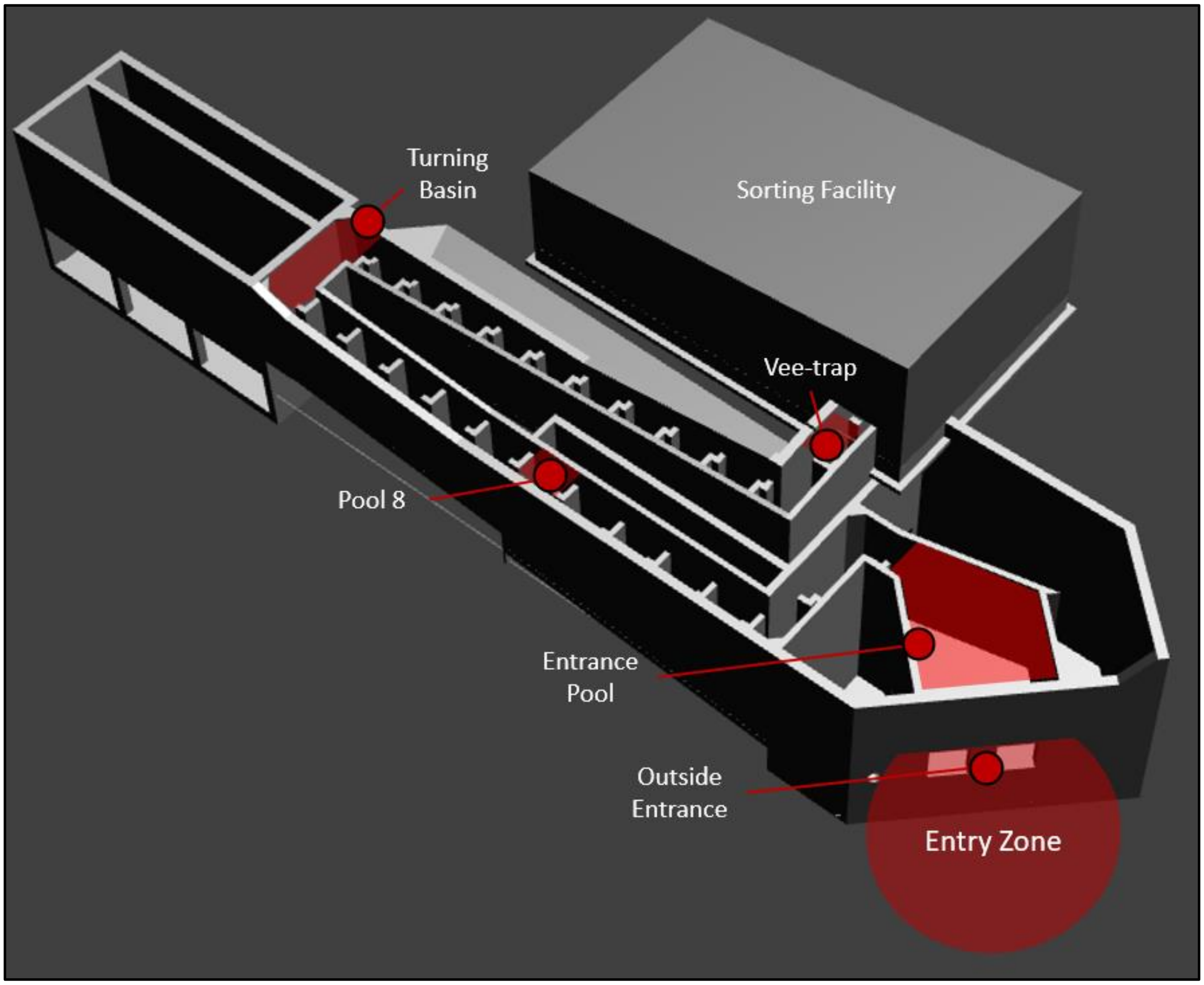

Figure 6 Map of fixed radio telemetry stations with dipole antennas deployed within the temporary upstream fish passage facility, and their approximate detection ranges.

Figure 7 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 affixed to the dipole housing (right).

Figure 8 Photos of completed PIT antennas installed within the dewatered temporary upstream fish passage facility prior to operations.

1.4.3 Testing Array Performance

Fixed Stations

Range testing of all fixed stations within and near the fishway was executed, where feasible, upon deployment. The primary goal of testing was to confirm settings were appropriate for the objective of each fixed station or pair of fixed stations (Table 6). Testing also approximated the detection range of each station, defined here as the field within which an antenna can detect a radio tag in the water.

To test the four approach and outside LB and RB fixed stations, a series of three upstream to downstream 'tag drag' drifts were conducted by Golder Associates Ltd. (Golder) from a jet boat on April 23, 2021. Drifts began as far upstream as was possible within the study area. Once in position, two Lotek NTF-6-2 test tags (programmed with a 3-second pulse rate) were activated and deployed 1 m below the water surface, and the boat was powered down and allowed to drift downstream with the current. The three drifts ended approximately 250 m or more downstream of the outside LB and RB stations. A GPS unit onboard the boat continuously collected spatial and temporal data points as the boat and test tags drifted through the study area. GPS data were spatiotemporally interpolated by LGL Ltd. (LGL) to produce coordinates for each second of each drift. Detection data collected at the four fixed stations (excluding data from the upstream pointed antenna of the outside RB fixed station) were paired with the interpolated GPS data by time and mapped using ArcMap 10.8.1 (ESRI 2020). Polygons were manually drawn from each fixed station around all detection coordinates to produce an approximate detection range for each station. The tunnel outlet and entrance aerial fixed stations could not be tested because boat access was not permitted within the diversion tunnel outlet due to hazardous conditions. Additionally, the RB cofferdam fixed station could not be tested because the stagnant water near the station did not allow the boat to drift past the station.

To test the dipole antennas, a test tag (Lotek NTF-6-2; 3-second pulse rate) was affixed to a 5-m aluminum rod and positioned throughout the area of interest. Testing was performed both inside and outside of the fishway. Testing within the fishway was performed at various heights in the water column in pools upstream and downstream of each dipole antenna. To test the detection range of the outside entrance fixed station (i.e., the spatial extent of the entry zone), the same test tag was affixed 1 m below a floating GPS device (STRIKER Cast, Garmin) which was attached to the line on a fishing rod and casted downstream of the fishway entrance. Coordinates of the GPS unit were recorded at the approximate edge of the fixed station's detection range.

PIT Antennas

PIT antennas underwent extensive testing prior to installation, immediately following installation, and approximately weekly throughout the operational period to determine if and how fishway operations impacted antenna performance. The AWS and HVJ flows are supplied by pumps controlled by variable-frequency drives, which emit electromagnetic radiation known to interfere with PIT antenna performance (Swarr 2018; Cook et al. 2021). Given our interest in how attraction flows influence passage success, it was important to understand if antenna performance varied with AWS and/or HVJ flows. Therefore, the goal of the testing during the 2021 operational period was to not only determine the read range of each PIT antenna, but also to determine if and how the read range of each antenna differed between attraction flow scenarios for all tag sizes deployed under the FAHMFP.

Testing was performed using 12-, 23-, and 32-mm HDX PIT tags insulated in PVC piping affixed to a 5-m aluminum rod to measure the distance from each antenna a test tag could be detected (read range). Read range was measured according to the design of the antenna (e.g., measured directly above ‘pass-over’ antennas, below ‘pass-under’ antennas) and calculated as a percentage of the full read range for that antenna (Table 7). Here, full read range is defined as the maximum possible distance from an antenna a tag could be detected within, over, under, or by and antenna. For pass-through antennas, the full read range was the distance from the inside edge of an antenna to its center. For pass-under and pass-by antennas, full read range was the distance from the antenna to a physical boundary below or next to the antenna. There was no physical upper boundary to the pass-over antennas (weir 23 and 24); therefore, a full read range of 30 cm was used to calculate percent read range. This distance reasonably covers the area above the antenna where fish would be expected to pass over and allows for a clearer comparison with the similarly designed pass-under antennas, which were 30 cm above the pool floor. Given small and non-normally distributed sample sizes of perfect read ranges, nonparametric Kruskal-Wallis tests were used to determine if there were differences in ranges among attraction flow scenarios for each antenna and tag size. If statistically significant, post-hoc multiple comparisons Dunn's tests were conducted.

Detection efficiencies were calculated for each antenna (vee-trap) or pair of antennas (east/west entrance, weir/orifice 8, weir/orifice 23, weir/orifice 24) as the proportion of PIT-tagged fish scanned by the facility operator that were detected by an antenna or pair of antennas. To account for fish that were detected by an antenna, only to leave the fishway, return later, and then fully ascend the fishway, detections that occurred more than 48 hours before a fish was scanned by the facility operator were not considered in efficiency calculations. We chose 48 hours given that the maximum time a radio-tagged fish spent in the fishway before exiting was 30 hours (see Section 1.5.4) and that a fish could spend up to an additional 18 hours in the pre-sort holding pool before being sorted and scanned by the facility operator. Efficiencies were calculated using the number of fish scanned by the facility operator rather than the number of known detections upstream of each antenna because of the complications associated with fish moving rapidly in both directions, often undetected, and leaving and then returning to the fishway.

Table 6 Objective and method for range testing fixed radio telemetry stations ('fixed stations') within and around the temporary upstream fish passage facility. Testing ensured that settings were appropriate for the objective of each fixed station.

Fixed Station(s)	Objective	Method
Outside LB and outside RB	Ensure detection range of paired fixed stations reached across the full channel width.	Boat drift
Approach LB and approach RB	Ensure detection range of paired fixed stations reached across the full channel width.	Boat drift
Outside entrance	Ensure tags are only detected outside of the TUF and not within and estimate approximate detection range.	Rod and floating GPS unit
Entrance pool, pool 8, turning basin, vee-trap	Ensure tags are not detected anywhere outside of the fishway while maximizing detection range.	Rod

Table 7 Measurements used to determine the read range of each PIT antenna. Full read range was the distance from each antenna to the maximum possible read range for that antenna. Read ranges measured in the field were analyzed as percentages of the full read range of each antenna.

Antenna(s)	Read Range Measurement	Full Read Range (cm)
East/west entrance	Inside of top edge downward towards center of antenna	87
Weir 8	Inside of top edge downward towards center of antenna	95
Orifice 8	Inside of top edge downward towards pool floor	55
Weir 23/24	Top edge upward	30
Orifice 23/24	Bottom edge downward towards pool floor	30
Vee-trap	Side edge outward horizontally towards opposite end of vee-trap	30

1.4.4 Telemetry Data Download and Management

All fixed stations and PIT readers were downloaded approximately weekly during the operational period. 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 monthly to LGL to be included in the Site C Fish Movement Assessment Radio Telemetry Database and to BC Hydro, providing further backup.

Several databases include tagging, detection, and recapture data for both radio and PIT tagged fish collected from several sources since 2001. Palmer Environmental Consulting Group (Palmer) 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 to be released upstream according to the OPP (McMillen Jacobs & Associates and BC Hydro 2022). Fish that successfully ascended the fishway and met species-specific tagging criteria (see Section 2.4.1) were also implanted with a radio tag by IFR before being released upstream by Palmer. Aside from the tagging and metadata collection done by Palmer and IFR at the TUF, Golder implanted radio and PIT tags in fish throughout the Peace River and its tributaries and collected metadata associated with capture, tagging, and recapture of tagged fish (Golder Associates Ltd 2022). IFR managed all fixed stations described in Section 1.4.2, except for the outside RB fixed station, which was managed by LGL as described in their annual report to BC Hydro (Hatch et al. 2022). As a result, databases of distinct data types are maintained by Palmer, IFR, Golder, and LGL, and data compilation efforts are collaborative (Figure 9).

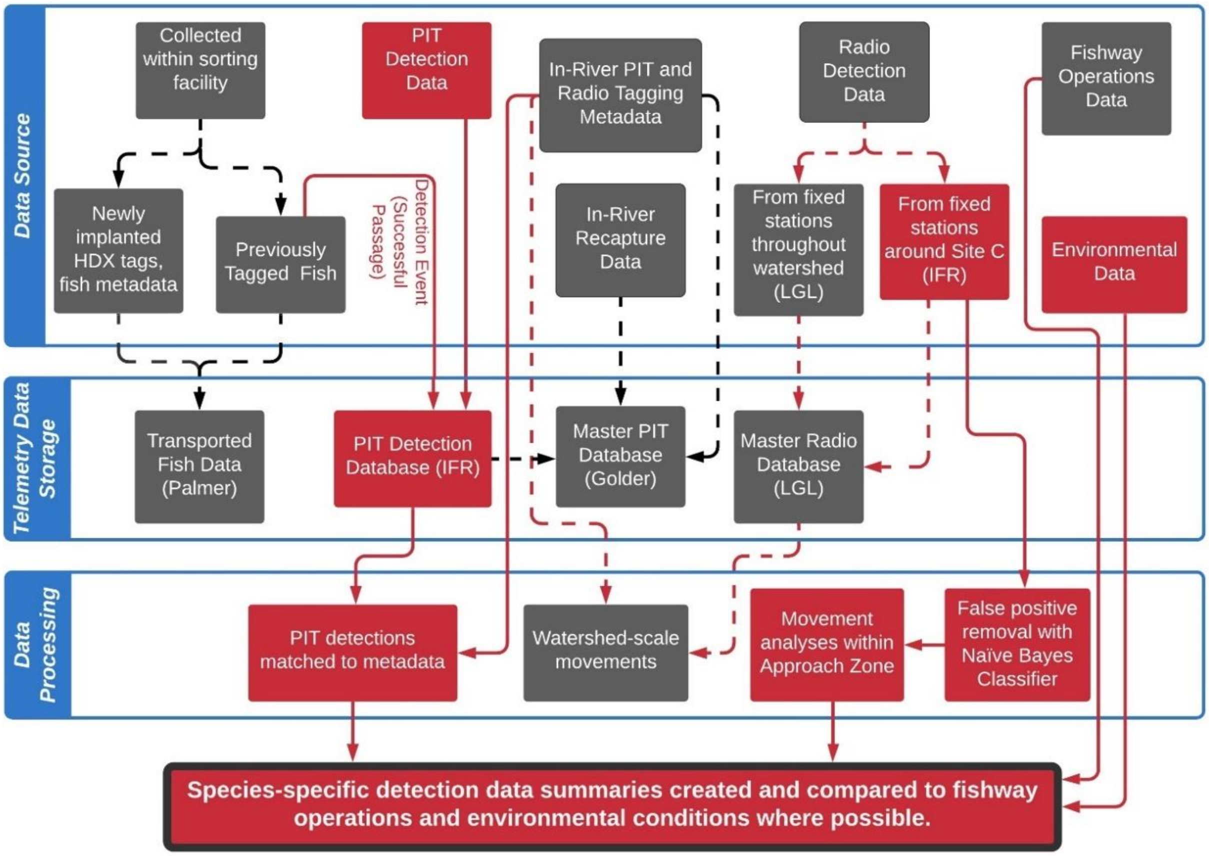

Figure 9 The process of data collection, storage and processing within the Fisheries and Aquatic Habitat Monitoring and Follow-up Program relevant to the data included in this report. Red boxes represent data held by InStream Fisheries Research (IFR), while grey boxes represent data held by other collaborating consultants. Red arrows show data processes conducted for Mon-13, and solid arrows indicate those conducted by IFR (dashed by other consultants).

1.4.5 Telemetry Data Processing

Data Filtering

Radio telemetry data from the 12 fixed stations were filtered using BIO-Telemetry Analysis Software (BIOTAS). BIOTAS is an open-source algorithm that provides a transparent, objective, and repeatable method for false-positive identification, removal, and data management for large-scale radio telemetry projects (Nebiolo 2021; Nebiolo and Castro-Santos 2022). The framework is comprised of a supervised learning algorithm based on a Naïve Bayes classifier (Minsky 1961). Supervised learning algorithms use data with known classifications (training data) to classify unknown data using an objective likelihood score.

A combination of seven possible predictor variables were used to develop a classifier that would discriminate between valid and false-positive detections for each fixed station. The five non-binary predictor variables included power, consecutive record length, hit ratio, noise ratio, and the difference in the lag between detections. Power refers to the received signal strength of a given detection. To calculate consecutive record length and hit ratio, 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 consecutive record length is the longest continuous subset of recorded detections in the detection history, and the hit ratio is the ratio of the number of detections within a history divided by the length of 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 difference in lag is calculated as the difference of the difference in time between sequential detections. Two binary predictor variables were used that classified whether the detection occurred in series with a previous detection, and whether there were consecutive detections within the detection history for that tag code. Predictor variables were then used to calculate the likelihood of a valid versus a false-positive detection for each recorded detection.

Training data were comprised of assumed valid detections (i.e., detections of deployed study tags) and known false-positive detections (i.e., spurious detections from tags known not to be in the watershed and noise detections). First, distributions of each predictor variable were created for both valid and known false-positive detections to classify the potentially valid data. An iterative approach was then used to classify data. In the first iteration, detections were classified as valid or false positives based on the distributions of predictor variables created from the training data. 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.

A 10-fold cross validation procedure was used to assess the accuracy of initial classifications for each fixed station's detection dataset using a combination of the predictor variables. The procedure was performed with each station's dataset using all seven predictor variables, all combinations of six predictor variables (i.e., each variable removed), and for the top five predictor variables. Although BIOTAS calculates several accuracy metrics during the validation procedure, the false positive rate was used to compare classification accuracy (Nebiolo and Castro-Santos

2022). The false positive rate is the proportion of detections classified as valid that are known to be false positives. The set of predictor variables that minimized the false positive rate was used for the final iterative classification process. When the false positive rate was the same for multiple sets of predictor variables, the set that was most conservative (i.e., removed the most potential false positives) during the initial classification was used. Filtered datasets for each fixed station were then combined into a single dataset.

Radio telemetry data were then manually filtered at the tunnel outlet, entrance aerial, entrance pool, and pool 8 fixed stations. The entrance pool fixed station detected some tagged fish known to be in pool 25 near the vee-trap fixed station; therefore, detections at this station that came directly before or after a detection at the vee-trap fixed station were removed. The pool 8 fixed station detected tagged fish both inside and outside of the fishway; therefore, detections at this station that did not come directly before or after another detection within the fishway were removed. The tunnel outlet and entrance aerial stations also detected tagged fish both inside and outside of the fishway. Detections at these stations that came directly before or after detections inside the fishway were therefore removed. Finally, radio-tagged fish that only had a single detection on the Mon-13 array were assumed to be false positives and were removed. The resulting detections constituted the final radio telemetry dataset.

PIT detection data from the nine antennas throughout the fishway were collated and filtered to remove all detections of test and false positive ‘ghost’ tags. The remaining dataset was cross-referenced with Golder’s Master PIT Database (Figure 9) to match detected tag codes with their available capture and biological information. Tag codes that could not be found in Golder’s database were cross-referenced with PIT tag deployment data from Palmer, Ecofish Research Ltd, and Triton Environmental Consultants. Detections of 28 tag codes that could not be identified were removed from the final dataset and were not included in analyses.

Interval Analysis

Interval analysis was used to separate detection histories of tagged fish into unique occupancies on the array (Castro-Santos and Perry 2012; Alcott et al. 2021). Here, an occupancy refers to continuous activity of a tagged fish on the radio telemetry array, inclusive of all fixed stations used in this study. To do this, the log-density of the interval between detections at each fixed station was plotted against the interval duration, where changes in slope indicated a shift from the effects of detection efficiency to effects of behavior (e.g., departing and returning events; Langton et al. 1995; Alcott et al. 2021). Intervals were identified for each fixed station to remove overlapping detections. The same process was then applied to the entire array to identify the interval between detections that would indicate a fish no longer occupied the array. All detection data collected during the operational period (including those collected during shutdown periods) were used to establish station- and array-specific intervals.

Intervals selected for each fixed station were as follows: 1800 seconds (outside RB and LB), 1600 seconds (approach RB and LB), 2400 seconds (RB cofferdam), 2600 seconds (tunnel outlet), 2000 (aerial entrance), 360 seconds (outside entrance), 240 (entrance pool and pool 8), 80 seconds (turning basin), 360 seconds (vee-trap). An interval of 86,400 seconds (1 day) was chosen for the entire array, meaning that if a fish occupying the array was not detected for this time or longer, the fish's next detection would be classified as a new occupancy on the array.

An occupancy 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 stations of the array (outside approach zone) and not make any movements towards other upstream stations during an occupancy. An occupancy could also represent downstream movement, or brief movement between fixed stations followed by an extended period of inactivity.

1.4.6 Biological Effectiveness

Time-to-Event Analysis

To quantity the effects of environmental factors on rates of movements between spatial zones (Figure 4; Table 1), we used Cox proportional hazards regression ('Cox regression') in a competing risks framework (Alcott et al. 2021) using the 'survival' package in R (Therneau 2022). Cox regression is a form of TTE analysis that explicitly accounts for both observed and censored data when quantifying competing rates (i.e., advancement and retreat; Castro-Santos and Perry 2012; Alcott et al. 2021). For Mon-13, when a fish advanced from one zone to the next, that observation was considered complete for the upstream advancement rate and censored for the downstream retreat rate. Conversely, when fish retreated to a downstream zone, the observation was complete for the retreat rate and censored for the advancement rate.

Observations were also censored during changes in environmental conditions because the state transition failed to occur before the condition changed. A TTE technique called the 'counting-process framework' (Allison 1995) allows for inclusion of both complete and censored observations for all fish that were present within each zone during their entire occupancy period, explicitly accounting for covariates that change over time (Castro-Santos and Perry 2012; Alcott et al. 2021). For Mon-13, continuous time-varying covariates (e.g., attraction flows, Peace River discharge, tailrace WSEL, water temperature) were divided into 1-hour 'exposure intervals', where an average value for each covariate was calculated and assigned to each hour of the day. During changes in daily diel periods (e.g., night to dawn, dawn to day, day to dusk, dusk to night), intervals were divided into two sub-hourly intervals. Therefore, there were a minimum of 28 possible exposure intervals each full day that a candidate fish occupied a zone within the array. Intervals occurring during shutdown periods were removed from analyses. Observations were censored when a candidate fish did not advance or retreat to another zone by the end of the interval, or when it left the array or became inactive (see Interval Analysis).

All state transition rates were analyzed for each fish. A single fish could transition between the same two zones more than once during a given occupancy on the array. Rates of approach were calculated as the duration of time between first detection at the approach zone to first detection at the entry zone. Rates of departure were calculated as the duration of time between first and last detection within the entry zone before a fish retreated to the approach zone, while rates of entry were calculated as the time between first detection at the entry zone to first detection at the entrance pool fixed station within the fishway. Finally, rates of rejection were calculated as the duration of time between the first detection at the entrance pool fixed station after a fish entered and the last detection at the entrance pool fixed station before a fish retreated to the entry zone.

Given that fish were considered to have successfully passed the fishway once they were crowded into the fish lock and processed by the facility operator, which occurred at three discrete periods daily, TTE analyses could not be used to evaluate the influence of time-varying covariates on rates of passage within the fishway. For example, a fish that was crowded at 0830 could have fully ascended the fishway and entered the pre-sort holding pool at any point between that crowd and the last crowd the previous afternoon, encompassing multiple hourly and sub-hourly sets of time-varying covariates (exposure intervals). Movement behaviour within the fishway was instead summarized more generally using radio telemetry data (discussed in more detail below).

To account for the statistical dependence among repeated transitions from the same fish, transition rates were analyzed using mixed effects Cox regression models with individual as a random effect (e.g., frailty term; Armstrong and Herbert 1997; Therneau et al. 2003). The random effect for each individual measures its deviation from the baseline transition rate, after controlling for fixed effects, where negative values represent less-than-average transition rates and positive values measure higher-than-average rates (Goerig and Casto-Santos 2017). Thirteen explanatory variables were considered as fixed effects in candidate models (Table 8). Dissolved oxygen was not included because it was highly correlated with other variables and data did not encompass the full operational period. Although fishway attraction flows were planned to transition between four discrete combinations of the HVJ being off or on and AWS flows of 4.25 or 8.5 m^3/s, AWS flow transitions were more continuous and variable. Therefore, AWS flows between 3.75 and 4.75 m^3/s were categorized as 4.25 m^3/s, and 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 categorized as 'other'. The total number of completed state transitions for each species was summarized by season, diel period, whether the tailrace WSEL was within or above the TUF's design criteria, and attraction flow scenario.

A suite of candidate TTE Cox regression models consisting of all possible combinations of the 13 explanatory variables as fixed effects and individual as a random effect was developed for each species and state transition (sample size permitting) according to the following criteria: 1) no model could contain variables that were correlated (i.e., $r > 0.4$) or that had logical linkages (e.g., day and season, AWS and total attraction flow; 2) no model could contain categorical variables with too few completed transitions per level to successfully run the model; and 3) no model contained interaction terms. Interaction terms were not used given the relatively small species- and state-transition-specific sample sizes. This resulted in a maximum suite of 271 possible candidate models. Species- and transition-specific datasets with fewer than 10 individual fish were not modelled. Candidate models were selected by minimizing the Akaike's information criterion (AIC). Any model with a $\Delta AIC<2$ from the top model was considered a reasonable competing candidate model (Anderson and Burnham 2004). Fixed effects coefficients and their associated hazard ratio (HR) and 95% confidence interval were extracted from the top model for each species and state transition. Schoenfeld residuals of the final models were examined to confirm that effects were consistent over time (Hosmer et al. 1999). Cumulative incidence curves representing the proportion of available fish making each state transition were plotted over time for each species.

Ultimately, conditions that increase rates of advancement and/or decrease rates of retreat between any two states will increase overall passage rates for that species. Results from these analyses are directly applicable to the management of the TUF, potentially dictating in-season changes to operations, including modifications of the magnitude and timing of supplementary attraction flows.

Table 8 All possible explanatory variables used in Cox regression models to evaluate time-to-event behaviour in a multi-state competing risk framework.

Factor	Description
Transition Number	The cumulative number of advance or retreat transitions per individual (including those observed during shutdown periods). This number increased each time an individual left the zone of interest and then returned (e.g., a fish approaching the entry zone, then departing the entry zone to the approach zone).
Day	The number of days since the beginning of the operational period (April 1).
Diel Period	Four-level categorical variable, including dawn, day, dusk, and night. Daily transition times between periods were obtained using the 'suncalc' package in R (Thieurmel and Elmarhraoui 2019).
Season	Three-level categorical variable, including spring, summer, and fall. In 2021, spring ran from the beginning of the operational period to June 19, summer from June 20 to September 21, and fall from September 22 to the end of the operational period (October 31).
AWS	Median hourly AWS discharge. Values recorded at the TUF.
HVJ	Median hourly HVJ discharge. Values recorded at the TUF.
Total Attraction Flow	Sum of the median hourly AWS and HVJ discharge. Values recorded at the TUF.
Attraction Flow Scenario	Five-level categorical variable of possible attraction flow scenarios, including 4.25/0, 4.25/1.5, 8.5/0, 8.5/1.5, and other. 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. AWS flows outside of these ranges were categorized as 'other'.
Peace River Discharge	Mean hourly discharge of the Peace River. Values recorded at the Water Survey of Canada gauge at Peace River above Pine River (07FA004).
Attraction Flow to Discharge Ratio	Median hourly combined attraction flow (AWS + HVJ) divided by the mean hourly Peace River discharge.
Water Temperature	Mean hourly water temperature within the fishway. Values recorded at the TUF (Sensor TT_601).
WSEL	Mean hourly WSEL at the tailrace of the fishway. Values recorded at the TUF (Sensors LT_600 and LT_601).
Design Criteria	Two-level categorical variable, including when the mean hourly WSEL at the tailrace of the fishway was within design criteria (≤ 410.5 m) or not.

Efficiency Metrics

Passage efficiency is the product of attraction efficiency and passage success. As defined in the EIS (BC Hydro 2012), attraction efficiency is the proportion of a population that is attracted to and enters the fishway, while passage success is the proportion of those fish that successfully pass through the fishway. We calculated attraction efficiency for each target species with radio telemetry data and passage success with PIT detection data. Attraction efficiency is the number of radio-tagged fish that entered the fishway, as confirmed by detection on one of the dipole antennas within the fishway, divided by the total number of that species detected within the approach zone, entry zone, and/or fishway. Passage success was calculated as the number of PIT-tagged fish that were processed by the facility operator divided by the total number of that species that were known to have entered the fishway (i.e., were processed by the facility operator and/or detected within the fishway). Movements of tagged fish towards and into the fishway were best characterized by radio telemetry data; therefore, PIT detection data was not used to estimate attraction efficiencies. However, given the disproportionately higher number of PIT-tagged fish detected within and successfully passing the fishway compared to radio-tagged fish, passage success was estimated exclusively using PIT detection data. PIT detections at the two entrance antennas did not confirm fish entry and were therefore excluded in estimates of passage success. All radio and PIT telemetry data collected during shutdown periods were excluded from both attraction efficiency and passage success calculations. Attraction efficiency was multiplied by passage success to estimate the passage efficiency for each target species.

1.4.7 Fish Movement

Although not directly used to measure the biological effectiveness of the TUF, movements near and within the fishway were summarized to provide additional context to its effectiveness. Specifically, the timing of each target species moving towards and into the fishway were summarized using both radio and PIT telemetry data. Additionally, species-specific movement behaviours within the fishway were summarized using radio telemetry data.

1.5 Results

Results presented herein include fishway operations and environmental conditions, array performance metrics, measures of biological effectiveness for each target species (Arctic Grayling, Bull Trout, Burbot, Mountain Whitefish, and Rainbow Trout), and general summaries of their seasonal movements within the study area and movement behaviour within the fishway.

1.5.1 Fishway Operations and Environmental Conditions

The TUF was operational for 173.8 of the 213.6 days (81%) between start up on April 1 and shut down on October 31. During this time, AWS flows were variable, especially in April, June, and September (Figure 10; Figure 11). Although the proposed AWS flow schedule was to regularly alternate between 4.25 and 8.5 m^3/s, AWS flows were lower than 3.75 m^3/s for a total of 233 hours (9.7 days), between 4.75 and 8 m^3/s for a total of 132 hours (5.5 days), and higher than 9.0 m^3/s for a total of 39 hours (1.6 days). 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 (Figure 10; Figure 11). The WSEL at the tailrace of the fishway entrance changed by 2.5 m (range = 409.4 to 411.9 m) during the operational period and exceeded the upper end of the fishway's design criteria (410.5 m) for a total of 131 days (i.e., 61% of the operational period; Figure 10; Figure 11).

River discharge was highly variable during the operational period (Figure 12; Figure 13). Flows were at their highest in April and July (> 2000 m^3/s) but dropped to below 450 m^3/s on several occasions in August and September. Rapid fluctuations in discharge were common from late August through October compared to earlier in the operational period when flows were more consistent. The ratio of total attraction flow (i.e., sum of AWS and HVJ flows) to river discharge ranged from 0.0 when the AWS flows were not functioning properly up to 0.02 during periods between August and early October when Peace River flows were low.

Water temperature, dissolved oxygen, and diel periods showed predictable seasonal patterns throughout the operational period (Figure 12; Figure 13). Water temperature ranged from 2.5 to 15.4°C, increasing through spring into summer and then decreasing in September and October. Dissolved oxygen levels were inversely related to water temperature, ranging from 9.5 to 13.8 mg/L. Days were longest in June (maximum 17.7 hours between sunrise and sunset) and shortest in October (minimum 9.2 hours between sunrise and sunset).

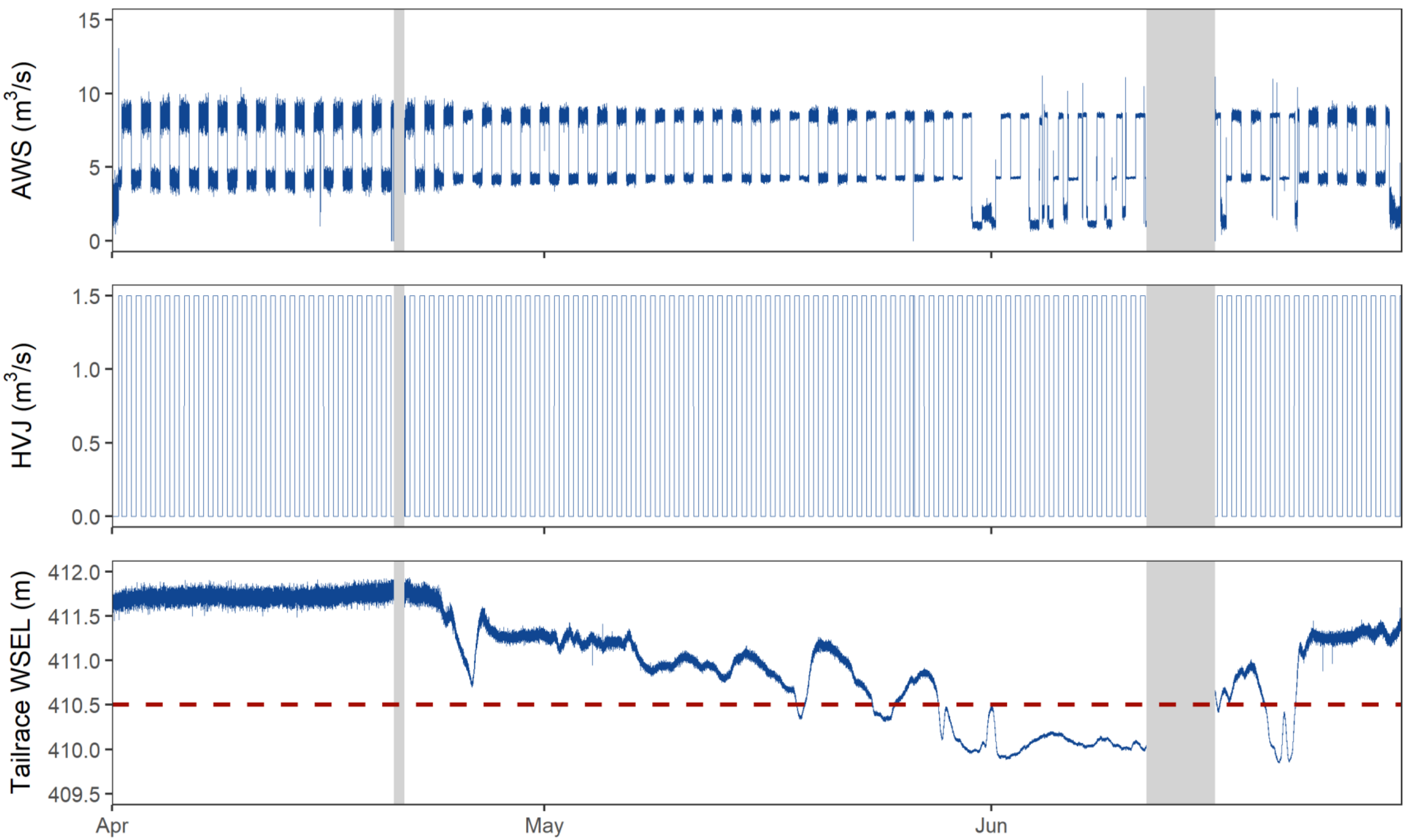

Figure 10 Fishway attraction flows from the temporary upstream fish passage facility (TUF; top, middle) and the water surface elevations (WSELs) at the fishway tailrace (bottom) from the start of the 2021 operational period (April 1) to the start of the third shutdown period (June 29). Axiliary water supply (AWS), High velocity jet (HVJ), and WSEL data were provided by BC Hydro. WSELs were calculated as the average water level recorded between sensors LT-600 and LT-601 located at the tailrace of the TUF. The red dotted line indicates the upper limit of the design criteria of the fishway. Grey areas indicate shutdown periods.

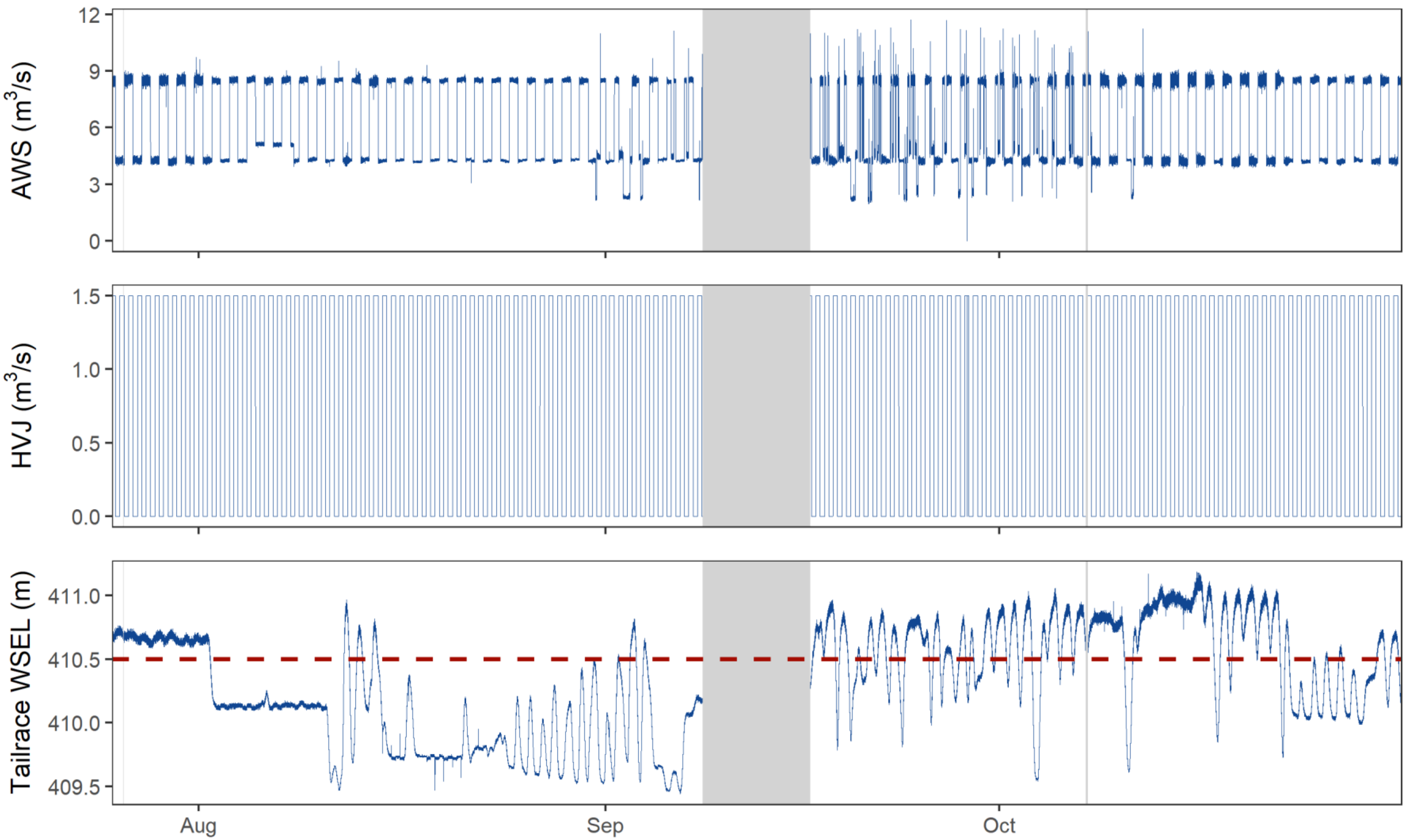

Figure 11 Fishway attraction flows from the temporary upstream fish passage facility (TUF; top, middle) and the water surface elevations (WSELs) at the fishway tailrace (bottom) from the end of the third shutdown period (July 25) to the end of the 2021 operational period (October 31). Axiliary water supply (AWS), High velocity jet (HVJ), and WSEL data were provided by BC Hydro. WSELs were calculated as the average water level recorded between sensors LT-600 and LT-601 located at the tailrace of the TUF. The red dotted line indicates the upper limit of the design criteria of the fishway. Grey areas indicate shutdown periods.

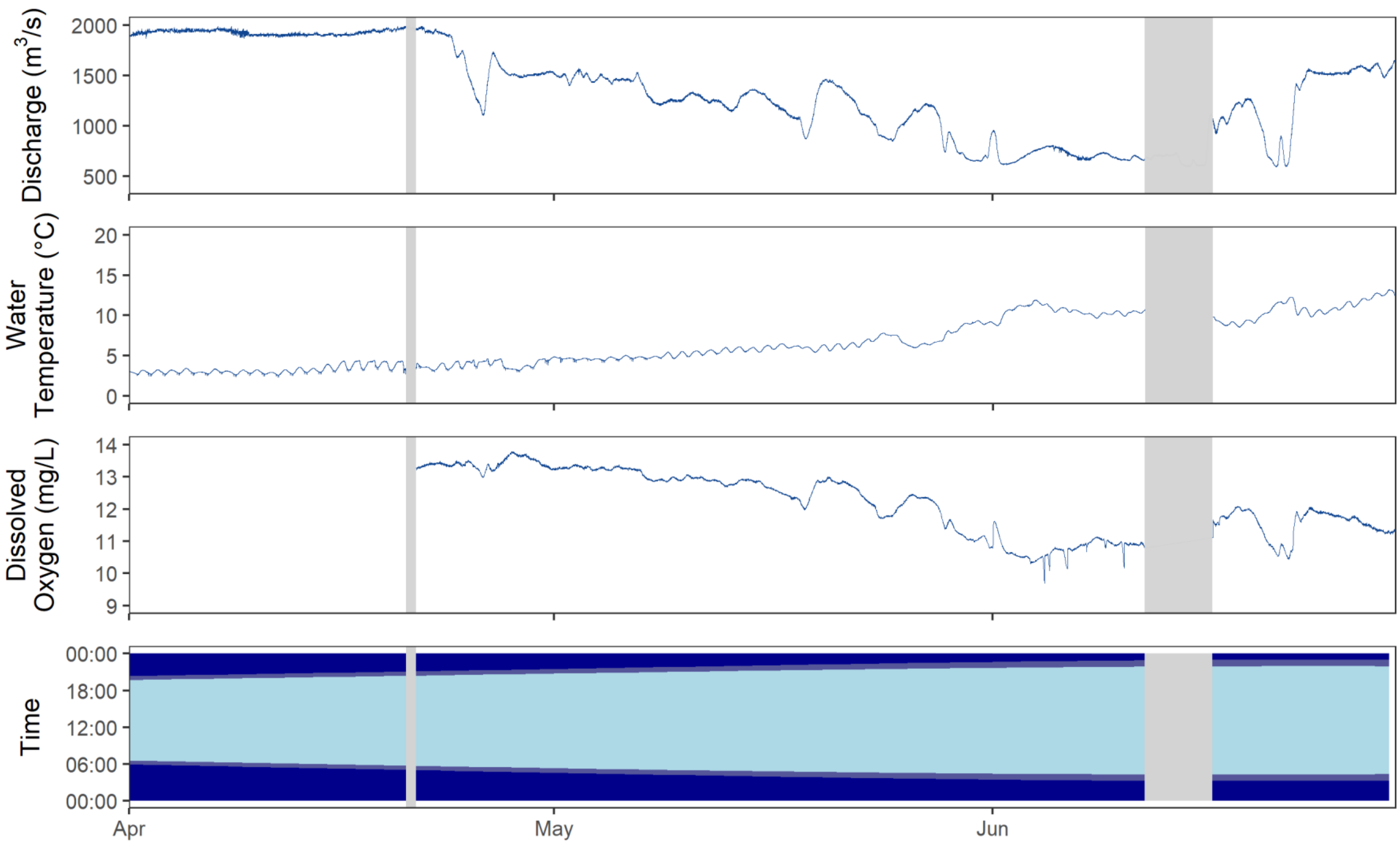

Figure 12 Environmental conditions at the temporary upstream fish passage facility rom the start of the 2021 operational period (April 1) to the start of the third shutdown period (June 29). Peace River discharge was measured at the Water Survey of Canada gauge at Peace River above Pine River (07FA004). Water temperature data were recorded by a sensor managed by BC Hydro located within the fishway. Dissolved oxygen levels were recorded by a data logger located at the entrance of the fishway. Diel periods were obtained using the 'suncalc' package in R. Grey areas indicate shutdown periods.

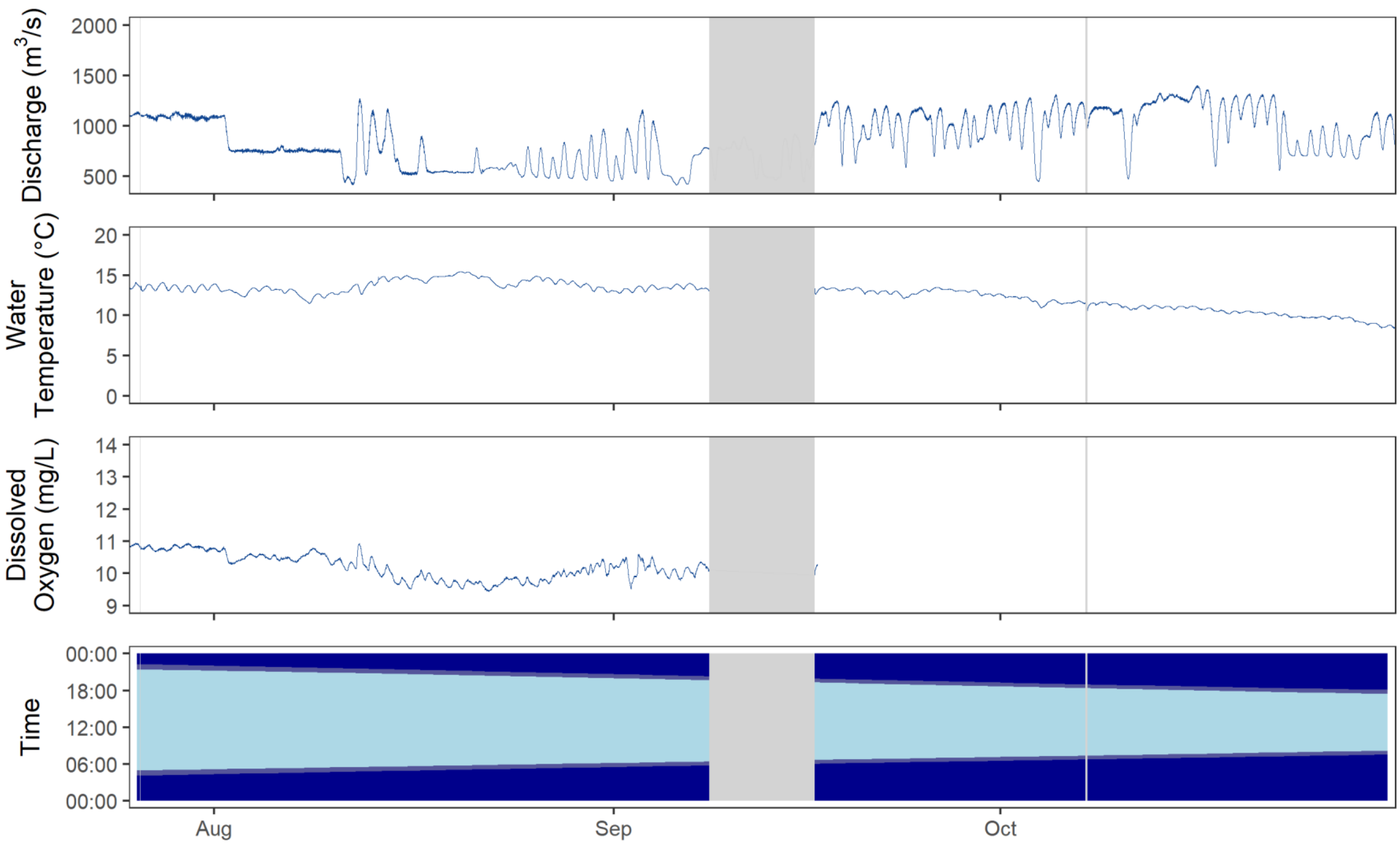

Figure 13 Environmental conditions at the temporary upstream fish passage facility from the end of the third shutdown period (July 25) to the end of the 2021 operational period (October 31). Peace River discharge was measured at the Water Survey of Canada gauge at Peace River above Pine River (07FA004). Water temperature data were recorded by a sensor managed by BC Hydro located within the fishway. Dissolved oxygen levels were recorded by a data logger located at the entrance of the fishway. Diel periods were obtained using the 'suncalc' package in R. Grey areas indicate shutdown periods.

1.5.2 Array Performance

Fixed Stations

Boat drifts confirmed that detection ranges of the approach and outside LB and RB paired fixed stations reached across the full channel width (Figure 14). Detection ranges of the approach LB and RB fixed stations overlapped by over 100 m in some areas, while ranges of the outside LB and RB fixed stations overlapped by 150 to over 200 m. It should be noted, however, that test tags were deployed 1 m below the water surface during testing, and that detection ranges for radio-tagged fish located deeper in the water column are likely smaller than what was observed.

Testing of dipole fixed stations confirmed that the settings were appropriate for the goal of each station (Table 4; Table 6). The floating GPS confirmed that the outside entrance fixed station had a detection range of 3 to 4 m downstream of the fishway entrance.

PIT Antennas

Percent read range was measured during 32 testing trials throughout the operational period using 12-, 23-, and 32-mm HDX PIT tags. Antennas generally performed better than during the 2020 operational period, except for the east entrance antenna, which continued to perform poorly. Although few antennas were able to detect 12-mm tags, as expected, percent read ranges did increase with increasing tag size (Appendix A: PIT Read Range Results). Most antennas had a median percent read range of less than 30% for all tag sizes among the four attraction flow scenarios. However, percent read ranges at the orifice 24 antenna were relatively high among all four flow scenarios for both 23- and 32-mm tags. Percent read range was considerably higher at the weir 8 antenna when the HVJ was off, and this difference was statistically significant for 23-mm ($H = 11.80$, $P = 0.008$) and 32-mm ($H = 14.35$, $P = 0.002$) tags. For 32-mm tags specifically, the weir 8 antenna had close to a full read range when the HVJ was off, but practically no read range when it was on. No other statistically significant differences in read ranges were detected among attraction flow scenarios.

The facility operator recaptured and scanned 46 fish implanted with 23-mm PIT tags and 16 with 32-mm tags that were used to calculate detection efficiencies of each antenna or pair of antennas throughout the fishway (Table 9). In general, detection efficiencies for 23-mm tags were poor (< 5%) for most antennas, except for the weir/orifice 24 antennas, which detected 56.5% of the scanned tags. As expected, detection efficiencies for 32-mm tags were higher compared to 23-mm tags, except for the vee-trap antenna, which did not detect any of the 32-mm tags scanned by the facility operator. Excluding detections at the east and west entrance antennas, the PIT array detected 58.7 and 62.5% of the 23- and 32-mm tags, respectively. Although not presented in Table 9, it should be noted that the orifice 24 antenna alone detected 43.5 and 43.8% of the 23- and 32-mm tags scanned by the facility operator, respectively. These results should be interpreted with caution given the relatively small sample size of PIT-tagged fish considered and that most were Mountain Whitefish, which may behave differently (and therefore have different detection efficiencies) compared to other target species.

Table 9 PIT antenna detection efficiencies for 23- and 32-mm tags. Detection efficiencies were calculated as the proportion of PIT-tagged fish scanned by the facility operator that were detected by an antenna or pair of antennas as they ascended the fishway. The facility operator scanned 46 fish implanted with 23-mm tags and 16 with 32-mm tags during the 2021 operational period.

Antenna(s)	23-mm		32-mm	
	Detected (n)	Efficiency (%)	Detected (n)	Efficiency (%)
East/west entrance	0	0.0	2	12.5
Weir/orifice 8	0	0.0	6	37.5
Weir/orifice 23	0	0.0	1	6.25
Weir/orifice 24	26	56.5	7	43.8
Vee-trap	2	4.3	0	0.0
Array[1]	27	58.7	10	62.5

[1] Not including the east and west entrance antennas.

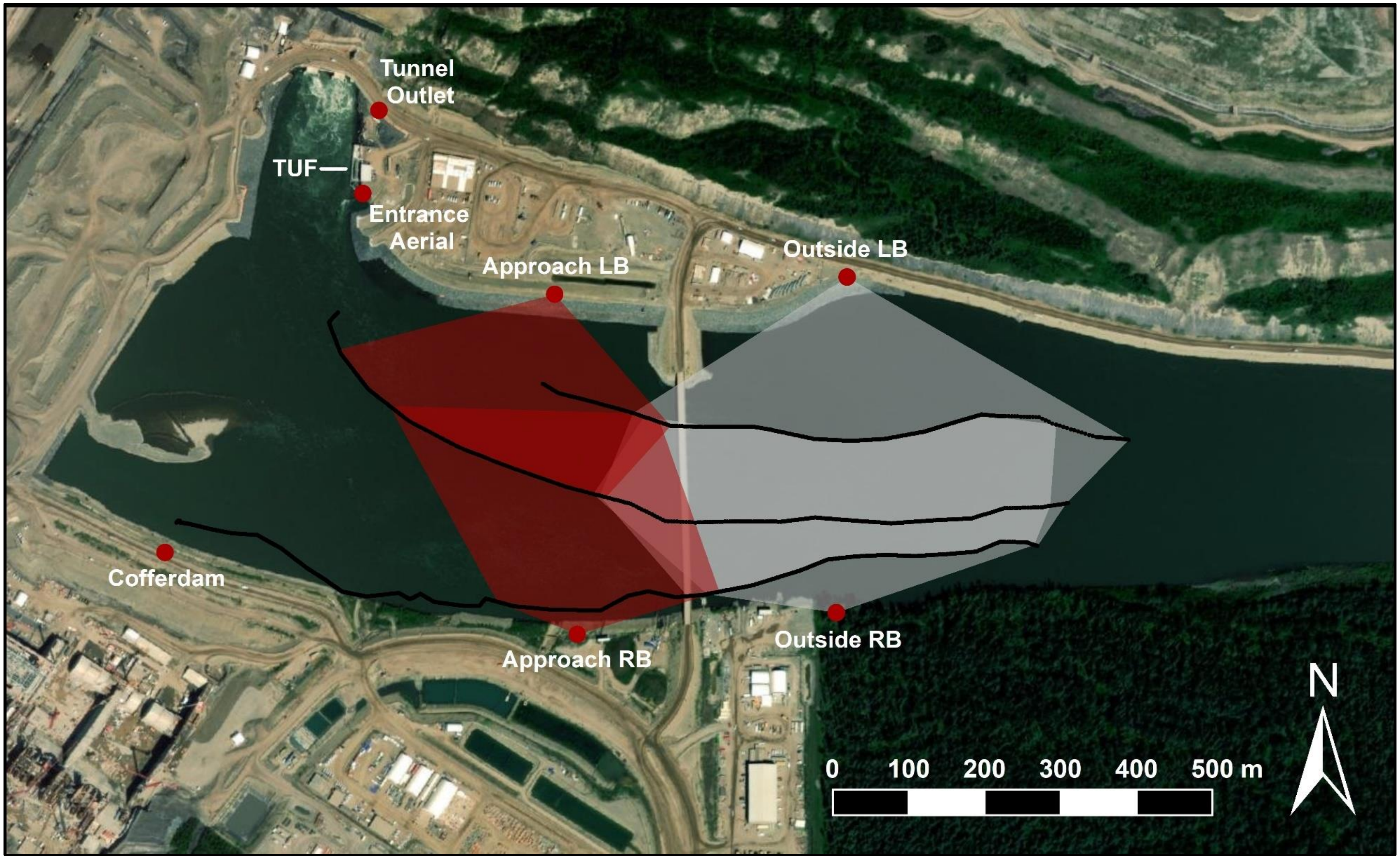

Figure 14 Approximate detection ranges of the paired approach gate (red) and outside approach (gray) fixed stations. GPS tracks of the boat and test tags used for range testing are shown as black lines. The tunnel outlet, entrance aerial, and RB cofferdam fixed stations were not tested in 2021 due restricted access within the diversion tunnel outlet and stagnant water near the RB cofferdam fixed station.

1.5.3 Biological Effectiveness

There were over 5.6 million radio telemetry detections on the array during the 2021 operational period. False positives made up 10.7% of the dataset and were removed from further analyses. With this final dataset, we explored movements between and within the approach zone, entry zone, and fishway and quantified species-specific attraction efficiencies.

There were nearly 100,000 PIT detections on the array during the 2021 operational period. Less than 1% of the detections were either false positive ‘ghost’ tags or tag codes that could not be identified and were removed from further analyses. The final PIT telemetry dataset was used to explore movements into and within the fishway and quantify species-specific passage success.

Time-to-Event Analysis

We explored the effects of environmental factors on rates of movement between spatial zones by assessing suites of candidate TTE models. For Bull Trout, we were able to produce TTE models for both movement between the approach zone and entry zone (approach and departure), and between the entry zone and fishway (entry and rejection). For Mountain Whitefish, we were able to produce approach and departure models. Although we describe state transitions for radio-tagged Rainbow Trout, TTE analyses were not conducted for this species given the low number of individuals detected. Results of TTE analyses are presented by species and state transition and are summarized in Table 10.

Individual as a random effect was included in each TTE model. The magnitude of a significant random effect is indicative of the influence of the individual on the results. The distribution of the coefficients of the random effect indicates how similar effects are across individuals.

Approach to Entry Zone (Approach)

All five target species were detected within the approach zone during the operational period; however, only Bull Trout, Mountain Whitefish, and Rainbow Trout advanced to the entry zone. There were 25 Bull Trout that together made 933 completed state transitions from the approach zone to the entry zone, 15 Mountain Whitefish that made 252 transitions, and six Rainbow Trout that made 48 transitions. Bull Trout and Rainbow Trout approached the fishway more often during the summer compared to spring and fall, while Mountain Whitefish approached the fishway more often in the fall (Table *11*). All three species approached the fishway more often during the day compared to dawn, dusk, or at night. The number of completed approach transitions were relatively even among the four attraction flow scenarios for all three species.

The rate at which 50% of available Bull Trout and Mountain Whitefish advanced from the approach zone to the entry zone (i.e., approach rate) was 13.4 and 8.6 hours, respectively (Figure B1; Figure B2).

The final set of competing TTE models for Bull Trout approach rates consisted of five models, all of which included season, diel period, and river discharge as explanatory variables (Table C1). The second-most top model also included the number of previous approach transitions. The bottom three models included an attraction flow term; however, ΔAIC values were high (> 1.8), indicating that these parameters were of low importance relative to other variables. Bull Trout approached the fishway more rapidly during the summer and during dawn and day (Table D1). Rates of approach increased as discharge in the Peace River decreased, and, according to the second model, the more often an individual had already reached the entry zone (post-hoc model results not shown). Individual as a random effect was significant and had high variance (> 2) in all five models. Additionally, coefficients of the random effect showed a slightly bimodal distribution. These results provide insight into individual-level behaviour. For example, three out of the 25 Bull Trout reaching the entry zone (12% of individuals) accounted for 37% of the completed approach transitions, with each re-entering the entry zone from the approach zone over 100 times.

A large set of candidate models resulted from TTE analyses of approach rates for Mountain Whitefish (n = 13; Table C1), indicating that no one model was a clear good fit to the data. However, all models included the number of previous approach transitions, diel period, and either tailrace WSEL or Peace River discharge as explanatory variables. Mountain Whitefish approached the fishway much more rapidly during the day than during dawn or at night, and rates of approach increased as tailrace WSELs decreased (Table D1). Interestingly, rates of approach were higher the fewer times an individual had already made an approach transition. Random effect was significant with a moderate variance (1.1) and the coefficients showed a unimodal distribution.

Entry to Approach Zone (Departure)

All radio-tagged Bull Trout, Mountain Whitefish, and Rainbow Trout that reached the entry zone eventually retreated to the approach zone at least once, making a total of 888, 246, and 41 completed departure transitions, respectively. It should be noted that the number of departure transitions differed from the number of approach transitions because state transitions that took place during shutdown periods were not included in analyses and because some fish were not detected at the entry zone (i.e., were not detected by the outside entrance fixed station) after exiting to the approach zone. General patterns in the number of completed departure transitions by each species were similar to approach transitions, with more transitions occurring during the summer and during the day (Table 11).

The rate at which 50% of available Bull Trout and Mountain Whitefish retreated from the entry zone to the approach zone (i.e., departure rate) was 22.4 and 7.3 minutes, respectively (Figure B1; Figure B2).

The final set of competing TTE models for Bull Trout departure rates consisted of ten models, all of which included season and diel period as explanatory variables (Table C2). Nine of the models also included the number of previous transitions and seven included at least one term related to flows in the Peace River, including tailrace WSELs and whether tailrace WSELs were within the fishway's design criteria. Five of the six bottom models included an attraction flow term; however, ΔAIC values were relatively high (> 1.5), indicating that these factors were of low importance relative to other variables. While attraction flow scenario was included in the second-most top model, coefficients and resulting HRs for each level of the variable failed to converge; therefore, the influence of attraction flow scenario on departure rates could not be interpreted. Bull Trout departed the entry zone more rapidly during the spring, at dawn, with increased tailrace WSELs, and the fewer times an individual had already departed the entry zone (Table D2). According to the third and fourth top model (post-hoc model results not shown), departure rates also increased as water temperature within the fishway and discharge in the Peace River increased. Individual as a random effect was significant in all ten models; however, the variance of the random effect was relatively low (< 0.6), and coefficients showed a unimodal distribution.

Season and diel period were not included in the suite of candidate models for Mountain Whitefish departure rates given the low number of completed departure transitions in at least one level of both variables. The final set of competing TTE models for Mountain Whitefish departure rates consisted of five models, all of which included day as an explanatory variable, along with one attraction flow term (Table C2). The number of previous departure transitions was also included in three of the models, including the top model. Rates of departure were higher with lower attraction flows, particularly from the AWS, and the more often an individual fish had already departed the entry zone (Table D2). Departure rates were also higher earlier in the operational period. Individual as a random effect was not significant in any of the five models.

Entry Zone to Fishway (Entry)

Radio-tagged Bull Trout, Mountain Whitefish, and Rainbow Trout all advanced from the entry zone into the fishway during the operational period. There were 15 Bull Trout that together made 138 completed transitions from the entry zone to the fishway, seven Mountain Whitefish that made 11 transitions, and two Rainbow Trout made 22 transitions. Most Bull Trout and Rainbow Trout entry transitions were during the summer, while Mountain Whitefish entered more often in the fall (Table 11). All three species entered the fishway more often during the day and when the tailrace WSEL was within the fishway's design criteria. More Bull Trout entered the fishway when the AWS attraction flows were at 8.5 m^3/s compared to when they were 4.25 m^3/s, and although the sample size was relatively small, more Mountain Whitefish entered when the HVJ was off compared to when it was on.

The rate at which 50% of available Bull Trout advanced from the entry zone to the fishway (i.e., entry rate) was 45.3 hours (Figure B1). It should be noted, however, that there was one additional Bull Trout that advanced to the fishway but was not detected at the entry zone (i.e., was not detected by the outside entrance fixed station) and therefore could not be included in the TTE models.

All six competing models for Bull Trout entering the fishway included season, diel period, design criteria, and an attraction flow term as explanatory variables (Table C3). The number of previous entry transitions was also included in the top two models. The top four models included either AWS or total attraction flow, while the bottom two included AWS and HVJ. Bull Trout entered the fishway more rapidly in the summer and during the day (Table D3). Rates of entry increased the more times an individual fish had already entered the fishway and with higher attraction flows, particularly from the AWS. Entry rates were over five times faster when tailrace WSELs were within the fishway's design criteria. Individual as a random effect was significant in the top models; however, the variance of the random effect was moderate (< 0.9), and coefficients showed a unimodal distribution.

Fishway to Entry Zone (Rejection)

All radio-tagged Bull Trout, Mountain Whitefish, and Rainbow Trout that reached the fishway eventually retreated to the entry zone at least once, together making 142, 11, and 22 completed rejection transitions, respectively. It should be noted that the number of rejection transitions differ from the number of entry transitions because state transitions that took place during shutdown periods were not included in analyses and because some fish were not detected at the entrance pool fixed station as they exited the fishway. General patterns in the number of completed rejection transitions by each species were similar to entry transitions (Table 11).

The rate at which 50% of available Bull Trout rejected the fishway was 10.6 minutes (Figure B1). The final set of competing TTE models for Bull Trout rejection rates consisted of five models, all of which included the number of previous rejection transitions, season, and discharge as explanatory variables (Table C4). There was one attraction flow term in each of the bottom four models, but the most parsimonious model did not include an attraction flow term. Bull Trout rejected the fishway more rapidly during the fall, with increased Peace River discharge, and the fewer times and individual had already rejected the fishway (Table D4). According to the bottom four models, Bull Trout rejected the fishway more rapidly as attraction flows decreased (post-hoc model results not shown). Individual as a random effect was significant in all five models; however, the variance of the random effect was relatively low (< 0.6), and coefficients showed a unimodal distribution.

Table 10 Summary of time-to-event model results for Bull Trout and Mountain Whitefish. Important covariates are those appearing in the models selected as best representing the data based on ΔAIC model weights and statistical significance.

Species	State Transition	Important Covariates	Details
Bull Trout	Approach to Entry (Approach)	Season, diel period, discharge	Rates of approach were highest in the summer and during dawn and day. Rates increased as discharge in the Peace River decreased.
	Entry to Approach (Departure)	Number of previous transitions, season, diel period, WSEL, temperature	Rates of departure were highest in the spring and during dawn. Rates increased the fewer times an individual had already reached the entry zone, as WSEL/discharge in the Peace River increased, and as water temperature in the fishway increased.
	Entry to Fishway (Entry)	Number of previous transitions, season, diel period, design criteria, AWS flow, total attraction flow	Rates of entry were highest in the summer, during dawn and the day, and when the tailrace WSEL was within design criteria. Rates increased the more often an individual had already reached the fishway and with lower attraction flows, particularly from the AWS.
	Fishway to Entry (Rejection)	Number of previous transitions, season, discharge	Rates of rejection were highest in the fall. Rates increased the fewer times an individual had already reached the fishway and as discharge in the Peace River decreased.
Mountain Whitefish	Approach to Entry (Approach)	Number of previous transitions, season, diel period, WSEL, discharge	Rates of approach were highest in the fall and during the day. Rates increased the fewer times an individual had already reached the entry zone and as WSEL/discharge in the Peace River decreased.
	Entry to Approach (Departure)	Number of previous transitions, day, AWS flow, total attraction flow	Rates of departure were higher earlier in the operational period. Rates increased the more often an individual had already reached the entry zone and with lower attraction flows, particularly from the AWS.

Table 11 Completed state transitions made by Bull Trout, Mountain Whitefish, and Rainbow Trout during the 2021 operational period by season, diel period, whether the tailrace water surface elevation (WSEL) was within or above the fishway's design criteria, and by attraction flow scenario. Spring ran from the beginning of the operational period (April 1) to June 19, summer from June 20 to September 21, and fall from September 22 to the end of the operational period (October 31). Diel periods were obtained using the 'suncalc' package in R. Attraction flows were provided by an auxiliary water supply (AWS) and high velocity jet (HVJ).

		Season			Diel Period				WSEL Category		Attraction Flow Scenario (AWS/HVJ)				
Species	State Transition	Spring	Summer	Fall	Dawn	Day	Dusk	Night	Within	Above	4.25/0	4.25/1.5	8.5/0	8.5/1.5	Other
Bull Trout	Approach	263	573	97	55	765	18	95	619	314	205	201	205	219	103
	Departure	264	532	92	31	745	27	85	586	302	199	208	178	205	98
	Entry	1	124	13	4	114	2	18	122	16	20	26	48	40	4
	Rejection	1	125	16	4	111	6	21	123	19	21	25	45	45	6
Mountain Whitefish	Approach	9	3	240	4	242	4	2	124	128	60	67	59	53	13
	Departure	8	3	235	2	236	5	3	128	118	62	65	56	53	10
	Entry	0	0	11	1	10	0	0	8	3	5	0	3	1	2
	Rejection	0	0	11	1	7	0	3	7	4	3	3	3	0	2
Rainbow Trout	Approach	1	47	0	1	46	0	1	40	8	13	8	15	11	1
	Departure	1	40	0	1	39	0	1	33	8	9	8	12	11	1
	Entry	0	22	0	0	20	0	2	22	0	6	3	7	6	0
	Rejection	0	22	0	1	20	0	1	22	0	4	5	4	9	0

Efficiency Metrics

Given the design of the two arrays and number of tagged fish that successfully passed the fishway, radio telemetry data were best used to calculate species-specific attraction efficiencies, while PIT telemetry data were best used to calculate passage success. Passage efficiency was calculated as the product of attraction efficiency and passage success for each species.

All five target species were detected within the approach zone during the 2021 operational period (Table 12). Of the 83 radio-tagged Bull Trout that reached the approach zone, 16 approached and entered the fishway, resulting in an attraction efficiency of 19.3%. Seven of the 24 and two of 39 radio-tagged Mountain Whitefish and Rainbow Trout entered the fishway, resulting in attraction efficiencies of 29.2 and 5.1%, respectively. None of the 21 radio-tagged Arctic Grayling or 12 Burbot detected within the approach zone were detected at the entry zone or fishway, resulting in attraction efficiencies of 0%.

All five target species were detected by PIT antennas within the fishway (not including the two entrance antennas) during the 2021 operational period, including a single Burbot detected at the orifice 8 antenna on June 2 (Table 12). Among the five species, there were 659 individuals known to have entered the fishway (i.e., those detected within the fishway, and those scanned by the facility operator; not including detections during shutdown periods). Mountain Whitefish made up 94.7% of this sample, including 17 PIT-tagged fish scanned by the facility operator that were not detected within the fishway. There were 30 PIT-tagged Bull Trout detected on the array, as well as two Arctic Grayling and two Rainbow Trout. Although not evaluated under Mon-13, it is worth noting that four non-target species were also detected by the PIT array, including 339 individual Largescale Sucker, 1219 Longnose Sucker, 34 Walleye, and 42 White Sucker.

Passage success was calculated as the proportion of PIT-tagged individuals of a given species known to have entered the fishway (i.e., detected within the fishway and/or processed by the facility operator) that were successfully crowded into the fish lock and processed by the facility operator. Of the five target species, Arctic Grayling, Bull Trout, Mountain Whitefish, and Rainbow Trout were processed by the facility operator during the 2021 operational period, of which one Arctic Grayling, five Bull Trout, and 66 Mountain Whitefish were previously PIT-tagged. Three of the five PIT-tagged Bull Trout were hand-netted from the uppermost pool of the fishway for processing and were therefore not considered to have successfully passed the fishway. One PIT-tagged Bull Trout and six Mountain Whitefish only had full-duplex (FDX) tags when scanned, and because these tags are not detectable by the PIT array, they were removed from the passage success calculations. The resulting estimates of passage success are 50, 3.3, and 9.6% for Arctic Grayling, Bull Trout, and Mountain Whitefish, respectively (Table 12). No PIT-tagged Arctic Grayling or Burbot were scanned by the facility operator, resulting in a passage success of 0%. Despite low passage success, 598 of the 659 (90.7%) PIT-tagged fish known to have entered the fishway were detected at or upstream of pool 23, including both Arctic Grayling and Rainbow Trout, 29 of the 30 Bull Trout, and 565 of the 625 Mountain Whitefish (Figure 15). Based on these results, 89.6% of detected target species failed to successfully pass the fishway once detected at or upstream of pool 23.

Table 12 Number of radio- and PIT-tagged fish detected within each spatial zone of the Mon-13 study area during the 2021 operational period (excluding shutdown periods) and associated estimates of attraction efficiency, passage success, and passage efficiency. Attraction efficiency was calculated as the proportion of radio-tagged individuals of given species detected within the approach zone that successfully approached and entered the fishway. Passage success was calculated as the proportion of PIT-tagged individuals of a given species known to have entered the fishway (i.e., detected within the fishway and/or processed by the facility operator) that that were successfully crowded into the fish lock and processed by the facility operator. Passage efficiency was calculated the product of attraction efficiency and passage success for each species.

	Radio-tagged Fish				PIT-tagged Fish			
Species	Approach zone	Entry zone	Fishway	Attraction efficiency	Fishway	Processed	Passage success	Passage efficiency
Arctic Grayling	19	0	0	0.0%	2	1	50%	0.0%
Bull Trout	83	25	16	19.3%	30	1	3.3%	0.6%
Burbot	12	0	0	0.0%	1	0	0%	0.0%
Mountain Whitefish	24	15	7	29.2%	624[1]	60	9.6%	2.8%
Rainbow Trout	39	6	2	5.1%	2	0	0%	0.0%

[1] Includes 17 PIT-tagged fish processed by facility operator that were not detected on the PIT array.

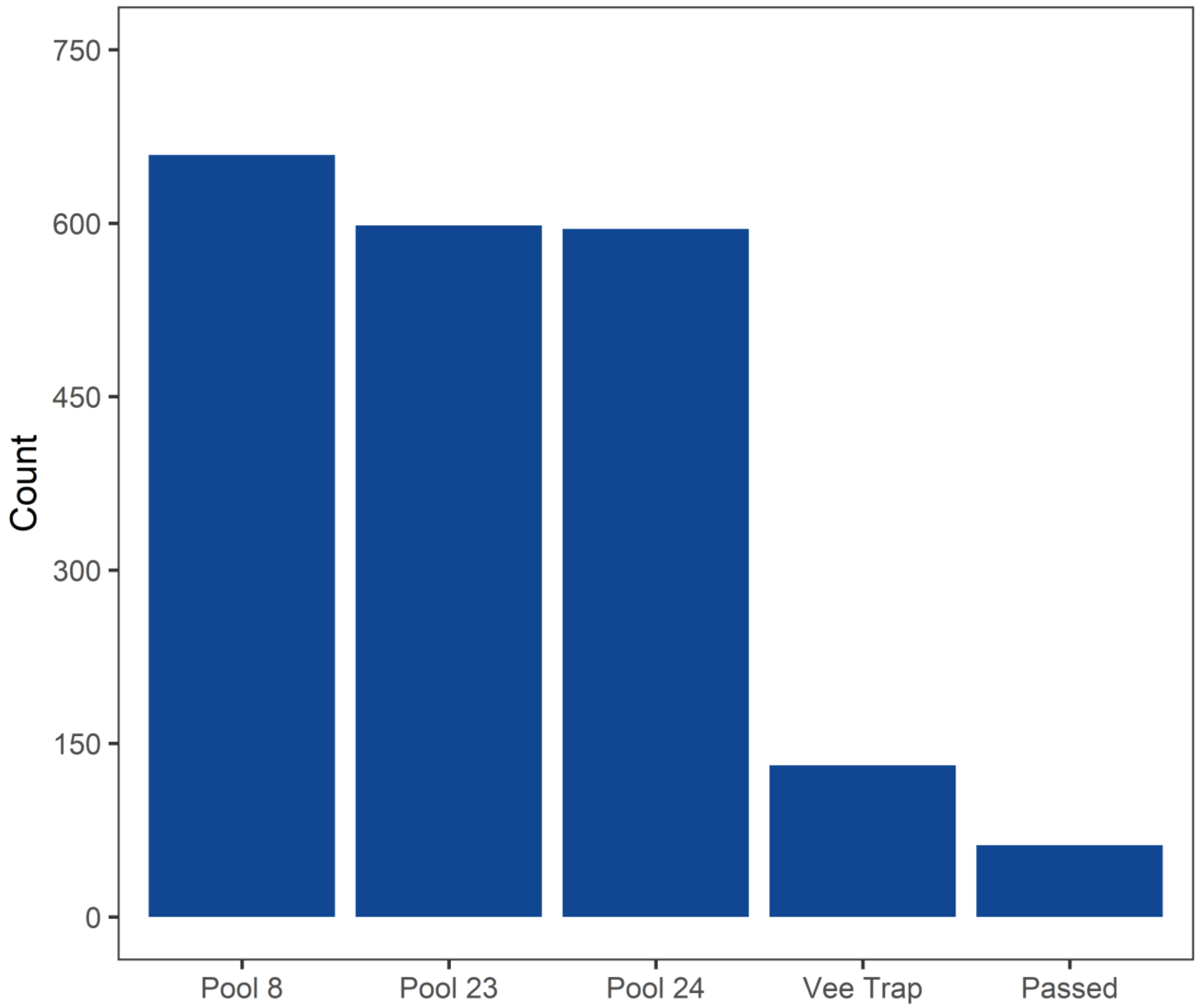

Figure 15 Counts of individual PIT-tagged fish of all five target species detected at or upstream of each pair of antennas (pool 8, 23, 24) or antenna (vee-trap) along the fishway during the 2021 operational period. Passed fish were fish scanned by the facility operator after being successfully crowded into the fish lock.

1.5.4 Fish Movements

Although not directly used to measure the biological effectiveness of the TUF, movements near and within the fishway were summarized to provide additional context to its effectiveness. Specifically, the timing of each target species moving towards and into the fishway were summarized, as well as the movement behaviour of radio-tagged fish once they entered the fishway.

Seasonal Movements

All five target species reached the approach zone by the end of the spring (June 20) during the 2021 operational period (Figure 16), with the first detection of radio-tagged Arctic Grayling, Bull Trout, Mountain Whitefish, and Rainbow Trout occurring as early as April. Most individual radio-tagged Arctic Grayling, Burbot, Bull Trout, and Rainbow Trout were initially detected within the approach zone in May and June, while Mountain Whitefish were first detected primarily in late September through October. Although two radio-tagged Bull Trout were detected within the fishway as early as June, most initial detections of Bull Trout and Rainbow Trout within the fishway were in late July and August after the nearly month-long shutdown period through most of July (Figure 17). Interestingly, radio-tagged Bull Trout were detected within the fishway throughout September and October when the spawning period was over (Putt et al. 2021; Hatch et al. 2022). Although radio-tagged Mountain Whitefish were first detected in the fishway primarily in late September through October, most of these individuals were implanted with radio tags in September 2021.

Most initial detections of both PIT-tagged Bull Trout and Mountain Whitefish within the fishway occurred in late July and August after the month-long shutdown period (Figure 18). PIT-tagged Bull Trout were detected in pool 24 as early as April 29 and as late as September 23, while PIT-tagged Mountain Whitefish were detected throughout the fishway during all months of the operational period. Too few PIT-tagged Arctic Grayling (n = 2), Burbot (n = 1), and Rainbow Trout (n = 2) were detected within the fishway to draw any meaningful conclusions about species-specific seasonal use of the fishway. Although not presented here, the same general seasonal patterns in initial radio and PIT detections were observed when data collected during shutdown periods were included.

Movements Within the Fishway

There were a wide variety of movement behaviours within the fishway during the 2021 operational period, with some radio-tagged fish leaving immediately after entering and others ascending the fishway multiple times. The total time spent in the fishway by an individual was up to 6.3 days. The median time spent during a single visit to the fishway (i.e., time from first detection to last detection within the fishway) was 9 minutes for the 16 Bull Trout that entered (n = 146, range = 5 seconds to 30.0 hours), 37 minutes for the seven Mountain Whitefish (n = 11, range = 0 to 9.9 hours), and 18 minutes for the two Rainbow Trout (n = 22, range = 0 to 12.9 hours). Of this group, ten Bull Trout, three Mountain Whitefish, and one Rainbow Trout made at least one upstream movement within the fishway and were detected at the pool 8, turning basin, and/or vee-trap fixed stations. Eight Bull Trout, two Mountain Whitefish, and one Rainbow Trout were detected by the vee-trap fixed station at the uppermost pool of the fishway. The median time each Bull Trout spent within the detection range of the vee-trap fixed station was 7.6 hours (range = 2.9 hours to 4.6 days). The two Mountain Whitefish were detected there for a total of 4.3 and 12.2 hours, and the Rainbow Trout was detected for 20.5 hours. Most of these fish ascended the fishway more than once (i.e., reached the uppermost pool, swam back down to the entrance pool, and then reached the uppermost pool again), including the Rainbow Trout that swam completely up and down the fishway nine times. The median time it took fish to fully ascend the fishway (i.e., first detection at the entrance pool fixed station to first detection at the vee-trap fixed station) was 38 minutes for Bull Trout (n = 22, range = 14 to 88 minutes) and 23 minutes for Rainbow Trout (n = 8, range = 16 to 36 minutes). Three Mountain Whitefish took 42, 49 and 53 minutes. It should be noted that these results do not include five additional ascensions where fish were not detected in the entrance pool before ascending the fishway. Only two radio-tagged fish were captured and processed at the TUF in 2021, both Bull Trout that were hand-netted from the uppermost pools in August.

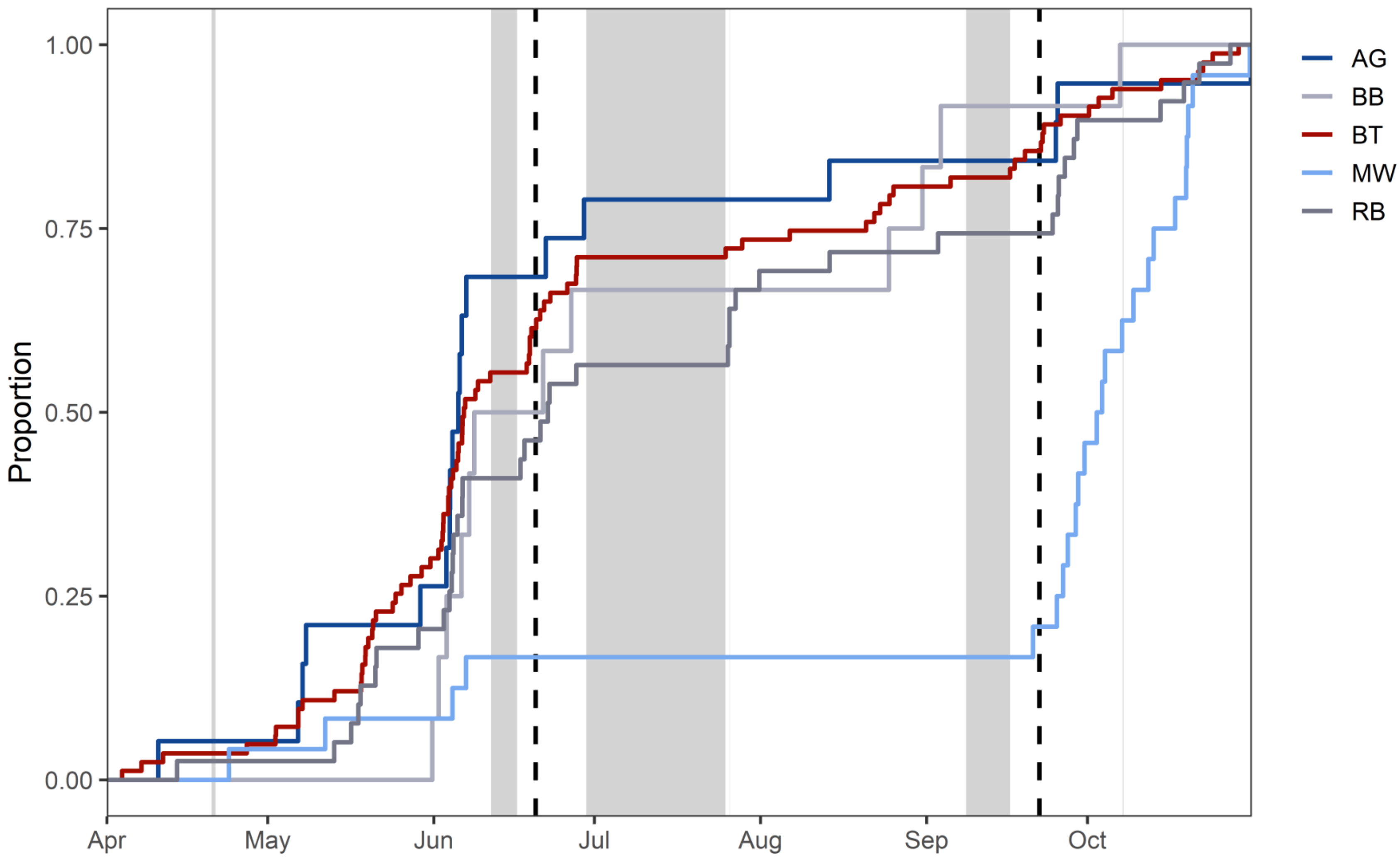

Figure 16 Cumulative proportion of initial detections of radio-tagged Arctic Grayling (AG), Burbot (BB), Bull Trout (BT), Mountain Whitefish (MW), and Rainbow Trout (RB) within the approach zone of the Mon-13 array during the 2021 operational period. Grey areas indicate shutdown periods. Dashed vertical lines indicate changes in season.

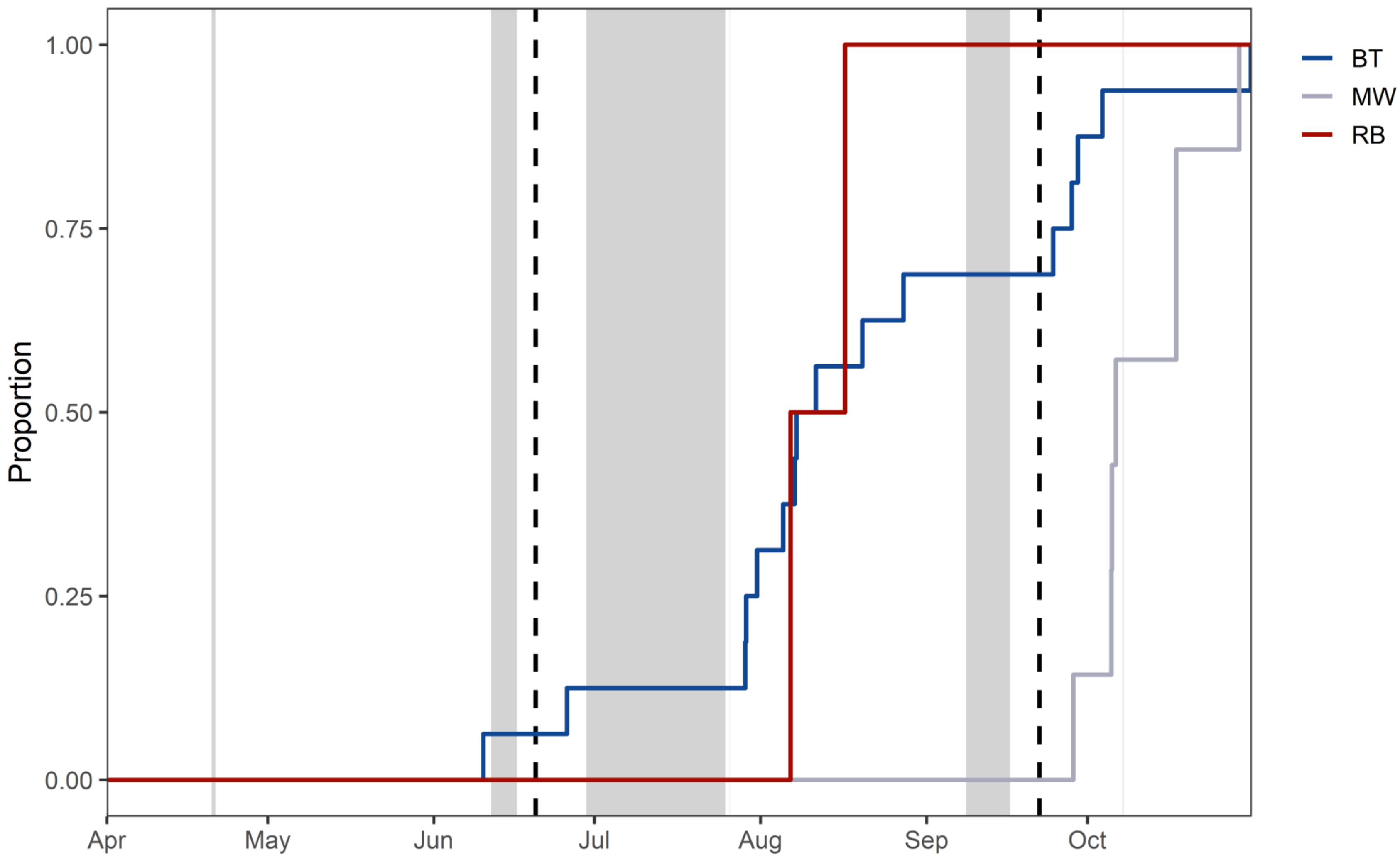

Figure 17 Cumulative proportion of initial detections of radio-tagged Bull Trout (BT), Mountain Whitefish (MW), and Rainbow Trout (RB) within the fishway during the 2021 operational period. Grey areas indicate shutdown periods. Dashed vertical lines indicate changes in season.

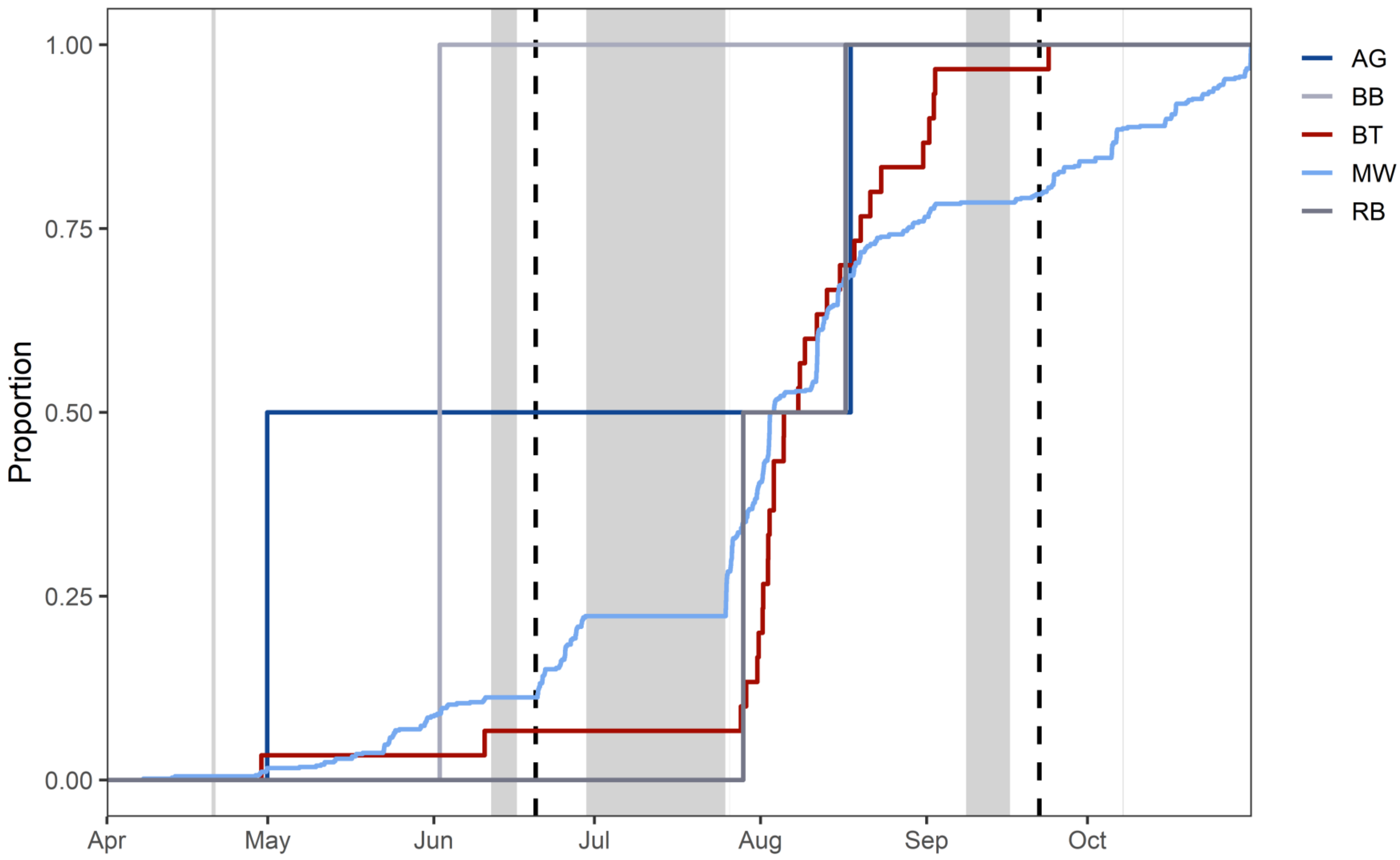

Figure 18 Cumulative proportion of initial detections of PIT-tagged Arctic Grayling (AG), Burbot (BB), Bull Trout (BT), Mountain Whitefish (MW), and Rainbow Trout (RB) within the fishway during the 2021 operational period. Grey areas indicate shutdown periods. Dashed vertical lines indicate changes in season.

1.6 Discussion

The objective of Mon-13 is to evaluate the biological effectiveness of the TUF for the 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 whether fishway attraction and passage efficiencies of 80% and 76% are met or exceeded, as predicted in the EIS (BC Hydro 2012). An additional focus of Mon-13 is to explore how environmental factors, including supplementary attraction flows, influence passage rates for each target species. Resulting data are directly applicable to the management of the TUF, potentially dictating in-season changes to operations, including modifications of the magnitude and timing of supplementary attraction flows.

A focus of this second year of monitoring was to ensure the experimental design and array were appropriate for TTE analyses of fishway approach and entry using a competing risks framework, and to explore environmental factors that may influence passage rates. The 2021 operational period was the first full season of TUF operations, allowing for a more robust assessment of the biological effectiveness of the TUF and a better understanding of how each target species uses it compared to the 2020 operational period. However, there were several temporary shutdowns during the operational period, including a nearly month-long shutdown that began in late June as many radio-tagged target species first reached the approach zone. Additionally, WSELs at the tailrace of the fishway were above the fishway's design criteria for most of the 2021 operational period, likely reducing its effectiveness.

Despite these challenges, the radio telemetry array functioned as intended and performance of the PIT array improved compared to 2020. PIT detection data were available from all nine antennas, including five new antennas added in pool 23, pool 24, and at the vee-trap. Using both radio and PIT detection data, we confirmed that all five target species were able to locate and enter the fishway, and that many individuals did so repeatedly throughout the operational period. Radio telemetry data were sufficient to run TTE models using time-varying covariates for Bull Trout and Mountain Whitefish. Arctic Grayling, Bull Trout, Mountain Whitefish, and Rainbow Trout successfully passed the fishway; however, passage success was low for all species. As more data are collected under Mon-13 and tagging efforts continue through various components of the FAHMFP, we will continue to refine our evaluations of the biological effectiveness of the TUF.

1.6.1 Biological Effectiveness

Biological effectiveness of the TUF was evaluated by monitoring how tagged fish moved between distinct zones within the study area, including the approach zone, entry zone, and fishway. Specifically, we quantified the effects of environmental factors, including supplementary attraction flows, on rates of movement between zones using TTE analyses. Our goal was to use radio telemetry data to run four models per species, representing rates of approach to and departure from the entry zone, as well as entry to and rejection of the fishway. Given sample size constraints, all four models were achieved for Bull Trout and rates of approach and departure were modelled for Mountain Whitefish.

We also evaluated biological effectiveness by calculating efficiency metrics for all five target species as the proportion of tagged fish that moved from the approach zone to the entry zone and fishway (attraction efficiency) and from the fishway to successful passage (passage success). These two metrics were then multiplied to quantify an overall passage efficiency.

Time-to-Event Analysis

Transition rates for Bull Trout were primarily driven by season, diel period, and factors related to the Peace River (i.e., discharge, tailrace WSELs, and whether tailrace WSELs were within the TUF's design criteria). Bull Trout entered the fishway more rapidly and departed the entry zone and rejected the fishway more slowly the more often they had already been to those zones (discussed in more detail below). Supplementary attraction flows did not appear to have a strong influence in approach or departure rates; however, Bull Trout did enter the fishway more often and more rapidly with increased attraction flows, particularly from the AWS. Bull Trout also entered the fishway more often and more rapidly when WSEL in the tailrace were within the fishway's design criteria compared to when it was above design criteria. It is worth noting that HVJ flows and total attraction flow to discharge ratio did not have a significant effect on transition rates for Bull Trout. Therefore, the AWS appears to be more important in terms of attracting Bull Trout into the fishway compared to the HVJ. As more radio telemetry data are collected from Bull Trout under Mon-13, it may become possible to model interactive effects between supplementary attraction flows and other factors found to be influential to Bull Trout approach and entry (e.g., season, diel period), potentially giving us a better understanding of these relationships.

Like Bull Trout, transition rates for Mountain Whitefish were primarily driven by season, diel period, Peace River discharge and tailrace WSELs. Mountain Whitefish approached the fishway more slowly and departed the entry zone more rapidly the more often they had already been to the entry zone (discussed in more detail below). Supplementary attraction flows did not appear to have a strong influence in approach rates; however, Mountain Whitefish departed the entry zone more slowly with higher supplementary attraction flows, particularly from the AWS. Most completed approach and departure transitions occurred in late September and October, when Mountain Whitefish are assumed to be migrating upstream past the Project to spawn (AMEC Earth & Environmental and LGL Limited 2008, 2009; Mainstream 2012); however, less than half of the radio-tagged Mountain Whitefish that reached the entry zone entered the fishway, and only three of those were detected making upstream movements within the fishway. These results may indicate that some of the radio-tagged Mountain Whitefish that reached the entry zone were exhibiting a residential rather than migratory behaviour. It should also be noted, however, that most Mountain Whitefish detected on the radio telemetry array were implanted with radio tags in September 2021 when most detections at the entry zone and fishway occurred. A second full year of monitoring will build upon this currently limited dataset for Mountain Whitefish.

All TTE analyses were performed using radio telemetry data from the entire operational period (excluding shutdown periods), which likely encompass multiple seasonal behaviours. We currently do not have sufficient data to define a distinct spawning migration period for any target species. Inclusion of ‘season’ and ‘day’ as explanatory variables are an attempt to control for this, but these may not be biologically relevant. For example, neither variable can differentially categorize a Bull Trout undergoing a spawning migration from a Bull Trout not motivated to move upstream. The bimodal distribution of the estimated random effect coefficients for Bull Trout approaching the fishway may indicate a divergence in fish behaviour. Goerig and Casto-Santos (2017) found a similar bimodal distribution of random effects in Brook Trout migrating upstream through culverts and concluded that lower values represented less motivated individuals and higher values more motivated individuals. Our data is not of the resolution to draw similar conclusions, but the bimodal distribution does indicate a distinct group of more active fish and a comparatively smaller group of less active fish. Although not presented here, when Bull Trout approach rates were modelled using only data collected in the summer, coefficients of the random effects were unimodal. This indicates that undetected seasonal differences in movement patterns exist. The two modes of the complete dataset may correspond to highly motivated Bull Trout actively migrating upstream to spawn in the summer and those that may have been milling at the entrance of the fishway in the spring and fall, potentially feeding on prey. We caution making inferences to the population at large, however, given that the entire dataset used to model Bull

Trout approach rates was based on 25 fish making 933 approach transitions, and that the subsequent ‘summer-only’ exploratory analysis included 15 fish making 573 transitions.

Another interesting finding from the TTE analyses was the influence of the number of previous transitions on transition rates. For example, we found that Bull Trout entered the fishway more rapidly and retreated from the entry zone and fishway more slowly the more often they had already been to those zones. This result may suggest learned behaviour, such as identification of the TUF as a potential route of upstream passage. Another potential explanation is that Bull Trout may have identified the fishway as a reliable source of concentrated prey, a behaviour previously observed of Bull Trout downstream of man-made barriers (Furey et al. 2016; Furey and Hinch 2017). Interestingly, the opposite behaviour was observed of Mountain Whitefish, a common prey item of Bull Trout (Fraley and Shepard 1989; McPhail and Baxter 1996; Beauchamp and Van Tassell 2001; Stewart et al. 2007), which were consistently present within the fishway throughout the 2021 operational period. Radio-tagged Mountain Whitefish approached the fishway more slowly and departed the entry zone more rapidly the more often they had already been to the entry zone. Given the documented predator-prey relationship between Bull Trout and Mountain Whitefish (Swanberg 1997; Muhlfeld et al. 2003) and known opportunistic feeding behaviour of Bull Trout, we hypothesize that predator-prey interactions may be influencing competing rates of advancement and retreat at the TUF for these two species. The influence of predator-prey interactions on passage rates has been observed in other fish passage studies (Alcott et al. 2021). As additional data are collected under Mon-13, it may become possible to test this hypothesis further.

Relationships between diel period and transition rates were also interesting, and contrary to our expectations. Bull Trout, Mountain Whitefish, and Rainbow Trout completed more state transitions during the day compared to other diel periods (Table *11*). This result is surprising given that both Bull Trout and Rainbow Trout have typically been observed to be most active during dawn, dusk, or at night (Downs et al. 2006; Barnett and Paige 2013; Watson et al. 2019; Namen et al. 2022). Relatively little is known about the diel movement patterns of Mountain Whitefish (Taylor and Lewis 2011); however, radio telemetry data collected under Mon-13 strongly suggests that they are most active near and within the fishway during the day, even in the fall when days are shorter than nights. The cumulative incidence curve of Mountain Whitefish approach rates further suggests diurnal behaviour, with cyclical patterns of approximately 8 to 10 hours of more rapid movement followed by a period of inactivity (Figure B1). The need for visual cues because of challenging hydraulic conditions, foraging opportunities (Bull Trout), and/or predator avoidance

(Mountain Whitefish and Rainbow Trout) near and within the fishway may explain these potential shifts to diurnal movement behaviour (Reebs et al. 1995; Reebs 2002; Keefer et al. 2013).

Efficiency Metrics

The 2021 operational period was the first full season that efficiency metrics could be estimated for the TUF. The EIS defines attraction efficiency as the proportion of a population that is attracted to and enters the fishway, passage success as the proportion of those fish that successfully pass through the fishway, and passage efficiency as the product of those two values (BC Hydro 2012). Attraction efficiencies, estimated with radio telemetry data, ranged from 0% (Arctic Grayling and Burbot) to 29.2% (Mountain Whitefish). Attraction efficiency for Bull Trout and Rainbow Trout were 19.3 and 5.1%, respectively. Passage success, as calculated from PIT detections from within the fishway, was 0% for Burbot and Rainbow Trout and 50% for Arctic Grayling. Passage success was 9.6% for Mountain Whitefish, which is an improvement over the 2.6% estimated in 2020 from 20 days of PIT telemetry data (Cook et al. 2021). Passage efficiency ranged from 0% (Arctic Grayling, Burbot, Rainbow Trout) to 2.8% (Mountain Whitefish). Passage efficiency for Bull Trout was 0.6%. These results should be interpreted with caution, however, given the low number of Arctic Grayling, Burbot, and Rainbow Trout that entered and successfully passed the fishway.

The EIS predicted that attraction and passage efficiencies of 80% and 76% would be met or exceeded by all five target species (BC Hydro 2012). Although the TUF failed to meet these standards, they are relatively high compared to what has been observed at other fish passage facilities (Roscoe and Hinch 2010; Noonan et al. 2012; Bunt et al. 2016). For example, in their review, Noonan et al. (2012) found average upstream passage efficiencies of 61.7% for salmonids and 21.1% for non-salmonids across many fishway types, species, and geographical areas. However, Ferguson et al. (2007) suggest that upstream passage facilities should allow 90 to 100% of migrating adult fish to pass in a safe and rapid manner to mitigate habitat fragmentation. Therefore, it may not be that the attraction and passage efficiencies predicted in the EIS are high, but rather that most fishways globally fail to achieve effective passage standards. Regardless, direct comparisons of efficiency metrics between fishways will always be difficult. Differences in sites, species, fish motivation, and monitoring techniques need to be considered (Cooke and Hinch 2013). While there is merit in quantifying efficiency metrics to meet benchmarks and for comparison with other systems, passage efficiency will never be fixed in time for any species or fishway. A more comprehensive means to assess biological effectiveness is through modeling that accounts for rates of passage, such as TTE analyses.

Results from the 2021 operational period should be interpreted with caution, however, given several significant constraints to the study. For example, the nearly month-long shutdown period began in late June as many radio-tagged target species first reached the approach zone. It is unclear how this shutdown may have affected TTE results or estimates of attraction and passage efficiencies from the 2021 operational period. Additionally, tailrace WSELs were above the fishway's design criteria for 61% of the operational period, which we were able to account for in the TTE analyses, but not in our estimates of attraction and passage efficiencies. Furthermore, the actual number of PIT-tagged fish entering the fishway was likely higher than what was detected given the imperfect read ranges and efficiencies of the PIT antennas and because there were no PIT antennas in the first seven pools of the fishway. As a result, proportions of PIT-tagged fish that entered and then successfully passed the fishway may be lower than what is reported here.

1.6.2 Factors Influencing Passage

Using radio telemetry data collected during the 2021 operational period, we were able to successfully use TTE analyses to evaluate how environmental factors, including supplementary attraction flows, influence rates of movement between spatial zones within the Mon-13 array for Bull Trout and Mountain Whitefish. However, TTE analyses could not be performed for Arctic Grayling, Burbot, or Rainbow Trout given the limited or absence of detection data for these species within or at the entrance of the fishway. The limited data collected from Burbot is not surprising given the relatively low number of radio-tagged individuals in the system (n = 26) and that Burbot are known to be most active in the winter, spawning in the late winter/early spring (McPhail 2000; Mainstream 2012; Hatch et al. 2022). Additionally, although Arctic Grayling and Rainbow Trout are known to spawn during the spring in tributaries upstream of the Project (Mainstream 2012), radio telemetry data collected from 2019 through 2021 suggest that both species make relatively indiscriminate seasonal movements within the Peace River (Hatch et al. 2022). As more data are collected from year to year and more fish are radio- and PIT-tagged through other components of the FAHMFP, sample sizes of target species detected within the Mon-13 study area may allow for more precise estimates of efficiency metrics and how environmental factors influence fish passage rates. Increased sample sizes of radio-tagged fish approaching and entering the fishway may also allow us to explore how interacting environmental factors, season-specific behaviour, and predator-prey relationships influence fish passage.

There are several factors that may have influenced the low proportion of tagged fish entering and successfully passing the fishway during the 2021 operational period. One of the more obvious reasons were the relatively high flows in the Peace River causing WSELs at the tailrace of the fishway to rise above the design criteria of the TUF for the majority of April and May, parts of June and July, and periodically through August, September, and October. When this occurred, downstream pools within the fishway became submerged, decreasing water velocities between pools to below recommended transport velocities (NMFS 2011), potentially limiting the functionality of the fishway. Although not monitored in 2021, when the Peace River discharge was high, turbulent and non-uniform velocity gradients were observed by IFR staff at the entrance of the fishway during range testing of the east and west entrance PIT antennas. These turbulent and non-uniform velocity gradients near the entrance may be distracting to fish as they approach and attempt to enter the fishway (Enders et al. 2005; Pavlov et al. 2000; Brown et al. 2006; Liao 2007). For example, both Bull Trout and Rainbow Trout approached and entered the fishway less frequently when tailrace WSELs were above the fishway's design criteria compared to when they were within criteria. Future monitoring years could include the use of an acoustic doppler current profiler to profile the velocity fields both within and at the entrance of the fishway at a range of Peace River discharges and attraction flow scenarios to better understand the velocity field fish experience as they approach, enter, and pass the fishway.

Another apparent limitation to fish passage during the 2021 operational period was the low proportion of fish that successfully passed the fishway once they reached the uppermost pools. We observed that 89.6% of PIT-tagged target species failed to successfully pass the fishway once detected at or upstream of pool 23. Radio telemetry data also showed that most radio-tagged fish that reached the vee-trap fixed station in pool 25 travelled up and down the fishway more than once and would reside in the uppermost pool for extended periods. One radio-tagged Bull Trout spent over 4.6 days in pool 25 before eventually being hand-netted out of the pool by the facility operator. These results were supported by visual observations by the facility operator and IFR staff. For example, large groups of fish could be seen milling within pool 25 downstream of the vee-trap, including Bull Trout and Mountain Whitefish, shortly after the shutdown that ended in late July. Some of these fish were also observed swimming in and out of the pre-sort holding pool past the vee-trap. Although not observed directly, the facility operator suspected that some fish were able to escape through a gap between the pre-sort holding pool and fish lock as the fish lock was being raised up to the sorting facility. Further supporting this suspicion is that water from the fish lock is drained into the east and west AWS receiving pools where fish should not be able to access but were captured with abrasions during the 2021 operational period. Improving the effectiveness of the vee-trap (i.e., increased one-way, upstream movement into the pre-sort holding pool) and preventing fish from escaping the pre-sort holding pool would likely increase passage success and overall passage efficiency for all species reaching the upper pool of the fishway.

Predation both inside and at the entrance of the fishway likely limited successful fish passage for some target species during the 2021 operational period. Predation on concentrated prey near man-made barriers in rivers is a behaviour commonly observed of birds (Agostinho et al. 2012), aquatic mammals (Fryer 1998; Tackley et al. 2008), and piscivorous fish (Schwalme and Mackay 1985; Boulêtreau et al. 2018; Alcott et al. 2021, Rillahan et al. 2021), including opportunistic Bull Trout (Furey et al. 2016, Furey and Hinch 2017). In September and October 2021, several river otters were repeatedly observed by the facility operator and IFR staff predating on fish (e.g., Mountain Whitefish) inside the fishway. Although not observed directly, Bull Trout may have predated on fish at the entrance and within the fishway, particularly the individuals detected in late September and October when Bull Trout were no longer migrating upstream to spawn (Putt et al. 2021; Hatch et al. 2022). In addition to Bull Trout, there were 50 individual adult Walleye detected by the radio and/or PIT array inside and at the entrance of the fishway during June through early October, likely after they finished spawning in the Beatton River, a tributary of the Peace River downstream of the Project (Mainstream 2012, Smith et al. 2022). Like Bull Trout, Walleye are known to be opportunistic feeders (Rieman et al. 1991; Vigg et al. 1991; McMahon and Bennett 1996) and may have made post-spawn upstream migrations to the fishway to feed on concentrated prey species. Monitoring predation in fishways can be challenging but should continue to be considered in future years.

1.6.3 Conclusions

The 2021 operational period was the first full season of TUF operations, allowing for a more robust estimate of the biological effectiveness of the TUF and a better understanding of how each target species uses it compared to the 2020 operational period. The radio telemetry array functioned as intended and although performance of the PIT array was poor, it did improve from 2020 and PIT detection data were available from all nine antennas.

Using both radio and PIT detection data, we confirmed that all five target species were able to locate and enter the fishway, and that many individuals did so repeatedly throughout the operational period. Results from TTE analyses suggest that Bull Trout and Mountain Whitefish appear to move between spatial zones near and within the TUF more often during the day compared to other diel periods and that Bull Trout enter the fishway more often and more rapidly with higher attraction flows from the AWS and when WSELs at the tailrace of the fishway are within design criteria. These results provide some evidence that increasing attraction flows may increase rates of entry for Bull Trout. We also confirmed that Arctic Grayling, Bull Trout, Mountain Whitefish, and Rainbow Trout can successfully pass the fishway; however, the passage efficiency for all four species was low. The common occurrence of fish being detected in the uppermost pools of the fishway but not passing suggest that the vee-trap is not functioning as designed and may be a barrier to passage.

Given the shutdown periods, relatively high Peace River flows, and relatively small number of radio- and PIT-tagged fish entering and passing the TUF in 2021, results presented herein should be interpreted with caution.

2. Site C Trap and Haul Fish Release Location Monitoring Program (Mon-14)

2.1 Introduction

Capturing and transporting fish (hereafter ‘trap and haul’) can be used to mitigate some of the effects of altered migration corridors by providing fish access to rivers around impassable dams and large reservoirs (DeHaan and Bernall 2013; Sigourney et al. 2015). Studies on the effects of trap and haul as a means of dam passage for migratory fishes have primarily focused on anadromous juvenile and adult Pacific salmon (Lusardi and Moyle 2017; Kock et al. 2021), while effects on other species and life histories are much less understood.

Despite being a relatively common method for relocating fish upstream of dams during their spawning migration, trap and haul can have unintended negative consequences. For example, trap and haul has been linked to pre-spawn mortality, movement into unfavorable habitats, and the inability to continue migration beyond their release locations, potentially leading to death (Keefer et al. 2010; Liedtke et al. 2013). In choosing a release location for transported fish, a balance must be maintained between proximity to their assumed spawning grounds and minimizing stress associated with transport. At the Project, for example, fish released too far upstream may experience unnecessary levels of stress associated with increased transport times, potentially leading to reduced likelihood of successfully reaching their spawning grounds, or even death (Portz et al. 2006). Conversely, releasing fish closer to the Project would result in shorter transport times, potentially reducing stress and mortality, but may increase the likelihood of falling back downstream of the Project after release and prior to reaching their intended spawning grounds (Kock et al. 2021).

Trap and haul programs typically use collection facilities located at a dam tailrace for capturing adult migrants for upstream transport (NMFS 2011). At the TUF, fish that fully ascend the fishway are processed in the sorting facility, sorted into a transport tank, loaded onto a transport vehicle, and released by the facility operator in one of three pre-determined release locations upstream of the Project (McMillen Jacobs & Associates and BC Hydro 2022).

The Site C Trap and Haul Fish Release Location Monitoring Program (Mon-14) aims to evaluate the effectiveness of the Project’s trap and haul program using radio telemetry to track the movements of tagged fish after they are transported from the TUF and released upstream of the

Project. Data collected under Mon-14 will be used to directly address the following management question:

> What are effective locations within the Site C Reservoir and tributaries to release Arctic Grayling, Bull Trout, Burbot, Mountain Whitefish, and Rainbow Trout captured at the Site C Trap and Haul Facility?

Associated with the management question are two hypotheses:

> H_1: Arctic Grayling, Bull Trout, Burbot, Mountain Whitefish, and Rainbow Trout migrants captured at the Site C Trap and Haul Facility and released into Site C Reservoir will continue their migration with no fall back through the dam or mortality (within 48 hours) after release.

> H_2: There will be no differences in the behaviour or survival among Arctic Grayling, Bull Trout, Burbot, Mountain Whitefish, and Rainbow Trout released at different locations within Site C Reservoir or tributaries.

Given the dearth of information regarding the effects of trap and haul on potamodromous species, Mon-14 is uniquely positioned to not only address the management question specific to this monitor, but also contribute to the broader understanding of trap and haul as a conservation tool.

2.2 Quantifying Trap and Haul Effectiveness

Quantifying trap and haul effectiveness is complex and highly dependent on a multitude of variables, including the species and life stages being transported, capture and transport methods, and the metrics used to evaluate success. Ultimately, several years of data will be collected through Mon-14 and used to determine the relative effects of capture, transport, and release conditions on the effectiveness of the Project's trap and haul program. Conditions that most successfully lead to released fish continuing their assumed upstream spawning migration will be suggested for use during the operations phase of the Project. This report provides information on the first full operational period of the TUF (April 1 to October 31, 2021) during the construction phase of the Project.

Given that 2021 marked the first year of data collection under Mon-14 and that relatively few radio-tagged fish were transported upstream from the TUF, coarse analyses of post-release movement were used to begin to characterize the effectiveness of the Project's trap and haul program. Specifically, for each radio-tagged target species released upstream of the Project, we used an expansive radio-telemetry array primarily operated under the Site C Fish Movement Assessment (Mon-1b, Task 2d; Hatch et al. 2022) to determine the proportion of tagged fish that successfully reached their assumed spawning grounds. For those that were unsuccessful, we determined the proportions that were assumed to be post-release mortalities, that fell back within 48-hours of release, or that made other post-release movements. It should be noted, however, that it is nearly impossible to confirm true mortalities in any telemetry study, as tag loss or sedentary behaviour in deep or shielded habitat can result in similar detection patterns as inferred mortalities.

A supplementary ('contingent') trap and haul program was also introduced in 2021 to capture and transport fish upstream of the Project when the TUF was not operational (i.e., shutdown) or when Peace River water levels were above the TUF's design criteria (Golder 2022). Post-release movements of transported fish were classified as described above. Where possible, comparisons between the two programs were made, and data from both were combined to assess the overall effectiveness of trap and haul as a method for providing upstream fish passage at the Project. However, only data collected from trap and hauled fish captured at the TUF were used to address management hypotheses.

2.3 Study Area

The study area for Mon-14 is significantly larger than that of Mon-13 and includes over 200 rkm of the Peace River, from Many Islands, Alberta, upstream to Peace Canyon Dam, including the TUF (Figure 19). The study area also includes the two largest tributaries of the Peace River upstream of the Project, the Halfway River and Moberly River. The Halfway River drains 9,402 km^2 of the eastern slopes of the Rocky Mountains (Mainstream 2012). From its headwaters, the river flows south for 304 rkm to its confluence with Peace River, approximately 40 rkm upstream of the Project. The Halfway River and its tributaries are the primary spawning grounds for Bull Trout upstream of the Project (Mainstream 2012; Putt et al. 2021; Geraldes and Taylor 2022). The Moberly River has a watershed of 1,833 km^2. From its headwaters near Rosetta Ridge, it flows east for approximately 65 rkm into Moberly Lake, where it then flows out of Moberly Lake and runs northeast for another 92 rkm to its confluence with the Peace River <1 rkm upstream of the Project (Mainstream 2012). The Moberly River is the primary spawning grounds for Arctic Grayling upstream of the Project (Mainstream 2012; Geraldes and Taylor 2022).

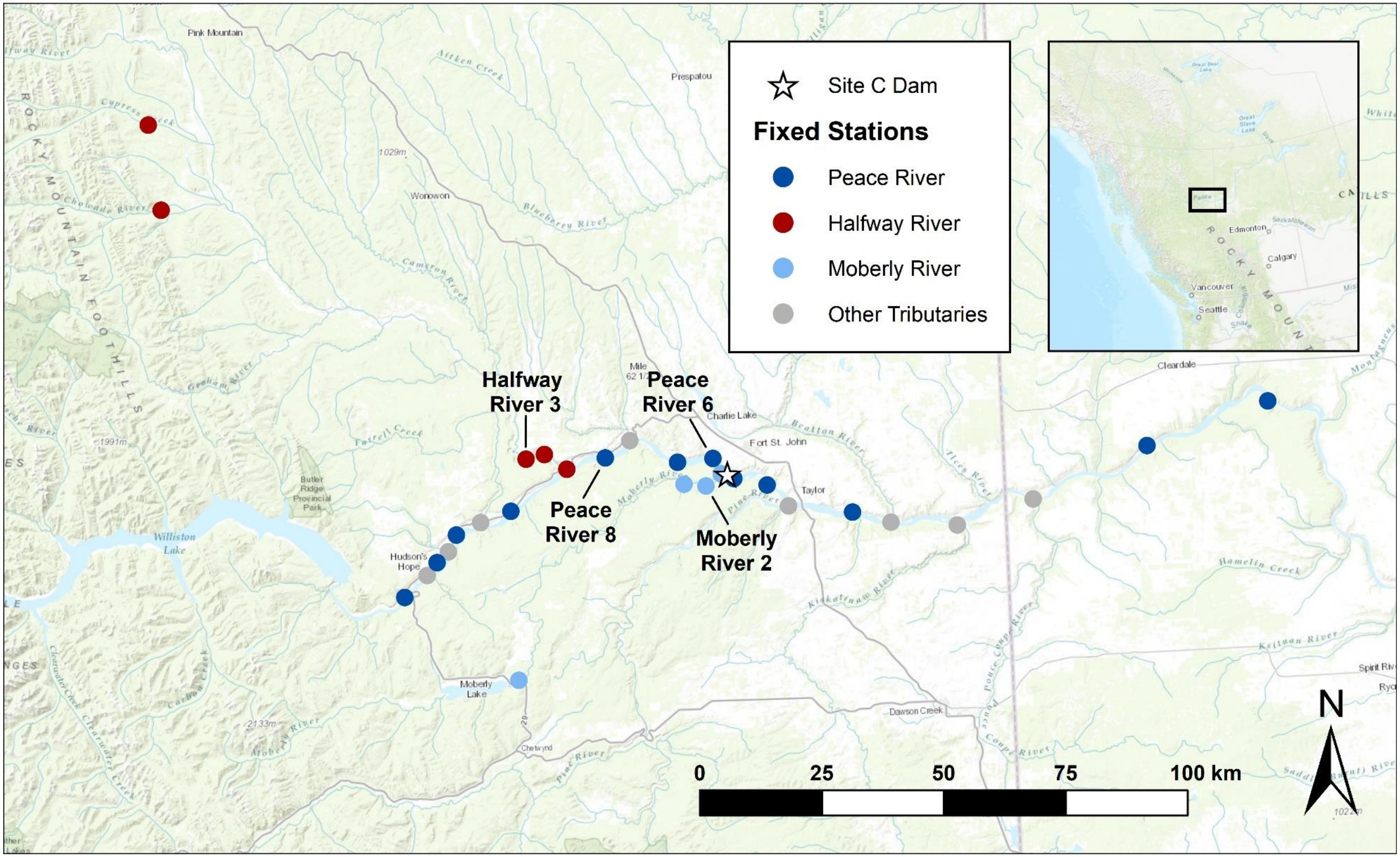

Figure 19 Study area with fixed radio telemetry stations (fixed stations) deployed throughout the Peace River watershed used to detect post-release movements of radio-tagged fish. Fixed stations operating under Mon-13 at or near the temporary upstream fish passage facility are not shown for clarity. Fixed stations used to classify spawning success (discussed below) are labeled.

2.4 Methods

2.4.1 Fishway Trap and Haul

All fish that successfully ascended the TUF and reached the trap and haul facility were processed, transported, and released upstream of the Project following the protocols described in the OPP (McMillen Jacobs & Associates and BC Hydro 2022). Adult target species that were not already radio tagged and met species-specific criteria (Table 13) were assumed to be migrating upstream to spawn and were passed to IFR staff by the facility operator to be processed and implanted with a radio tag. Fish were initially held (typically for less than 30 minutes) in a ~725 L stainless steel tank located within the facility that was continuously fed by fresh water from the Peace River. Fish were then anaesthetized using clove oil emulsified with ethanol (1:9 ratio), measured, sampled for ageing structures (e.g., scales, fin ray) and genetics, and tagged with a 23- or 32-mm PIT tag. Fish were radio-tagged in a manner consistent with industry standard practices (Liedtke et al. 2012) and the sampling and tagging protocol implemented under other components of the FAHMFP (Golder 2021). All fish were tagged using Lotek NTF-6-2 tags programmed with either a 5- or 10-second pulse rate (dimensions = 25 x 9 mm; dry weight = 4.0 g; estimated lifespan = 565 to 931 days depending on pulse rate). Tagged fish were held in recovery tanks and monitored at the facility for at least 30 minutes before being placed into one of the TUF's three transport tanks to be transported and released upstream of the Project.

During the TUF's operational period between April 1 to October 31, 2021, radio-tagged Bull Trout and Mountain Whitefish were released by the facility operator upstream of the Project at one of two release locations (Figure 20). Radio-tagged Bull Trout captured at the TUF were driven 52 km and released at the Halfway River release location approximately 1 km upstream of its confluence with the Peace River. Radio-tagged Mountain Whitefish captured at the TUF were driven 7 km and released at the Peace River release location approximately 2 km upstream of the Project. Both release locations are also used as boat launches with gently sloping banks and relatively low water velocities throughout the year.

Fish captured at the TUF were transported in one of three 2150-L transport tanks hoisted and placed onto a transport truck once per day. Each tank was equipped with a primary and secondary oxygen tank attached to oxygen diffusers. Transport tanks were filled with fresh river water pumped from the Peace River immediately prior to being loaded with fish. Water temperature and oxygen levels were recorded when fish were first loaded into the transport tanks and when arriving at the release locations. Once at the release location and after ensuring that the difference in water temperature between the transport tank and receiving environment was less than 8°C, the transport tank's slide gate was opened, and fish were released into the river through a flexible tube. A more detailed description of the transport and release methods can be found in the OPP (McMillen Jacobs & Associates and BC Hydro 2022).

Table 13. Criteria used to determine whether adult target species captured at the temporary upstream fish passage facility would be radio-tagged in 2021. All tagged fish were over 200 g to maintain a maximum tag burden of 2%.

Species	Timing[1]	Spawning Characteristics
Arctic Grayling	April 1 – June 30	NA
Bull Trout	April 1 – August 31	NA
Burbot	September 1 – October 31	NA
Mountain Whitefish	September 1 – October 31	Tubercles
Rainbow Trout	April 1 – June 30	NA

[1] Based on assumed spawning migration timing (Mainstream 2012; Hatch et al. 2022).

2.4.2 Contingent Trap and Haul

The TUF is designed to operate when the WSEL at the tailrace is between 408.4 and 410.5 m. During the TUF's expected 2021 operational period, WSELs exceeded the upper end of the fishway's design criteria for a total of 131 days (i.e., 61% of the time; see Section 1.5.1). As a result, BC Hydro commissioned Golder to conduct boat electroshocking surveys in the Peace River in the vicinity of the TUF to capture and transport fish upstream of the Project (hereafter 'contingent trap and haul'; Golder 2022). The goal of the contingent trap and haul program was to provide supplemental fish passage to mitigate for the potential lack of biological effectiveness of the TUF when WSELs were above design criteria, or when the TUF was not operational (Table *2*). Capture and processing methods under contingent trap and haul were identical to the methods employed under the Peace River Large Fish Indexing Survey (Mon-2, Task 2a). A detailed description of those methods is provided in Golder (2021), while a summary of the methods specific to the contingent trap and haul program can be found in Golder (2022).

Target species captured through the contingent trap and haul program that met species-specific timing criteria were transported and released upstream of the Project using the same two release locations as fish transported from the TUF. Arctic Grayling and Rainbow Trout captured and transported upstream between April 1 and June 30 were assumed to be migrating upstream to spawn, while those captured and transported upstream between July 1 and October 31 were assumed to be migrating to forage. Bull Trout captured and transported between April 1 and

August 15 and Mountain Whitefish transported in October were assumed to be migrating upstream to feed or to spawn. Although Arctic Grayling were assumed to be migrating upstream to spawn in the Moberly River (Mainstem 2012), ice and access issues at the intended Moberly River release location prevented fish from being released there. Instead, Arctic Grayling were released the Peace River release location, approximately 1.5 km upstream of the Moberly River confluence. Bull Trout, assumed to be migrating upstream to spawn in the Halfway River (Mainstem 2012), were also released at the Peace River release location in April when ice prevented fish from being released in the Halfway River.

Fish were transported from the Project's downstream boat launch in one of two 1210-L tanks (BarrPlastics; Abbotsford, BC, Canada) modified to include a 31 cm slide gate outlet. Both were equipped with 75 L medical grade oxygen tanks with adjustable 15 LPM flow regulators attached to MBD900 Microbubble Plate Diffusers (Point Four Systems Inc.; Coquitlam, BC, Canada). Transport tanks were filled with river water at the boat launch immediately prior to being loaded with fish. Water temperature and oxygen levels were recorded when fish were first loaded into the transport tanks and when arriving at the release locations. A fish health check was conducted midway through transports to the Halfway River release location, which included a visual check to see if any fish appeared unhealthy (e.g., floating belly-up on the surface of the water) and recording the water temperature and dissolved oxygen levels in the tank. Once at the release location and after ensuring that the difference in water temperature between the transport tank and receiving environment was less than 8°C, the tank's slide gate was opened and fish were released into the river through an approximately 5 m long, soft, PVC-coated polyester fabric tube. A more detailed description of the transport and release methods used for the contingent trap and haul program can be found in Golder (2022).

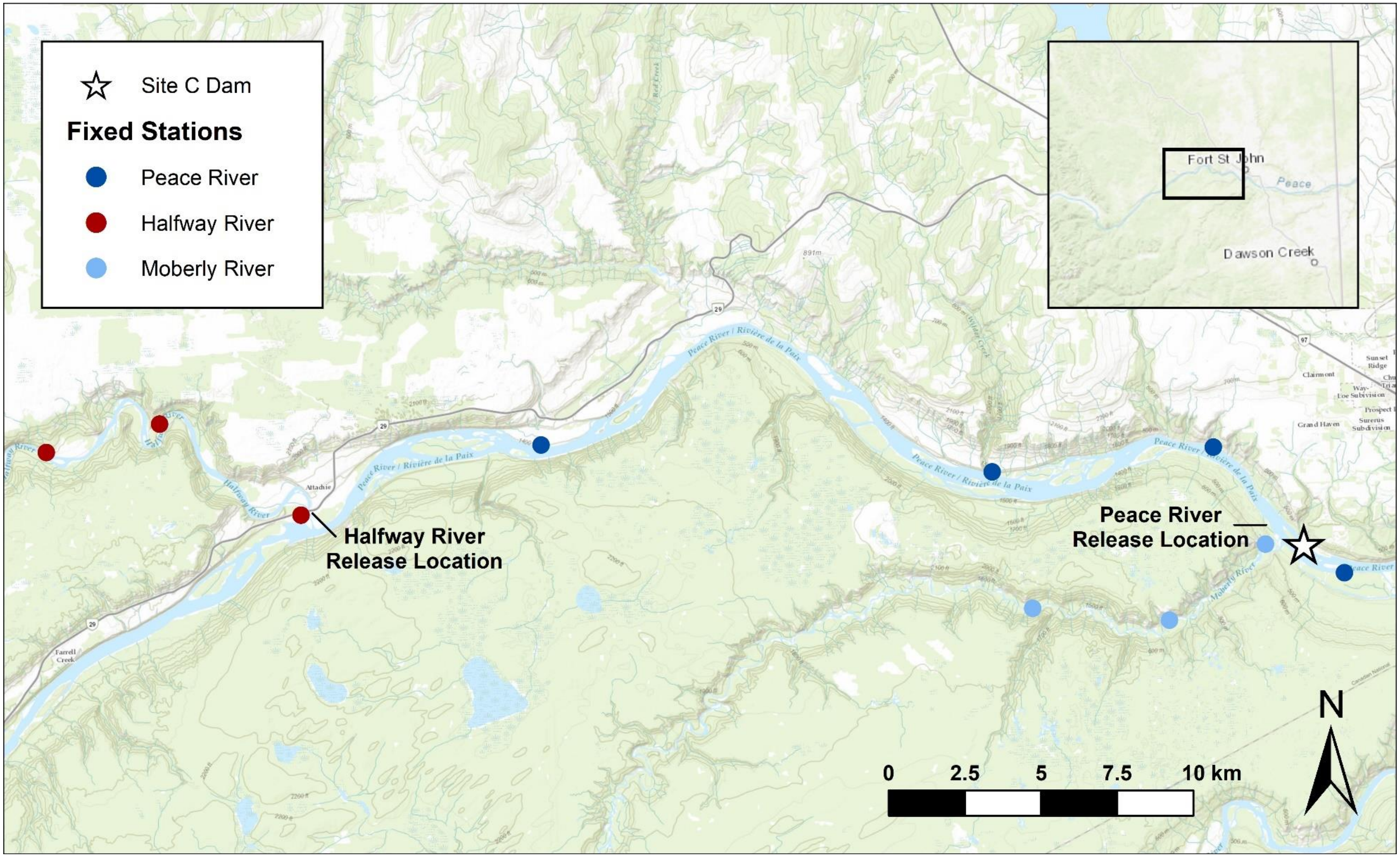

Figure 20 The Halfway River and Peace River release locations used to release fish transported from the temporary upstream fish passage facility (TUF) and through the contingent trap and haul program. Nearby fixed radio telemetry stations (fixed stations) are shown for reference. Fixed stations operating under Mon-13 at or near the TUF are not shown for clarity.

2.4.3 Radio Telemetry

Detection data were collected from radio-tagged fish released upstream of the Project by an array of fixed stations and by mobile tracking surveys. The array consisted of 42 fixed stations operating under several components of the FAHMFP (Figure 19; Hatch et al. 2022). Most of the detection data used for tracking post-release migrations to spawning grounds upstream of the Project were collected by fixed stations operating under the Site C Fish Movement Assessment (Mon-1b, Task 2d), with stations throughout the Peace River watershed from Many Islands, Alberta upstream to Peace Canyon Dam. Fixed stations were deployed at the entrance of each major tributary of the Peace River between these two points and approximately halfway between each tributary entrance. Two additional fixed stations were located along both the Halfway and Moberly Rivers within and at the boundary of the expected inundation zone of the Site C Reservoir. There were 17 fixed stations located upstream of the Project operating under Mon-1b, Task 2d for most of the operational period; 13 were deployed by April 1, 2021, another three were deployed by April 11, 2021, and the remaining station (Halfway River 2) was deployed on July 22, 2021. Most of these fixed stations were demobilized by October 27, 2021. Two additional fixed stations located in Halfway River spawning tributaries (Chowade River and Cypress Creek) were operational between July 30 and October 6, 2021 to monitor Bull Trout spawning migrations.

Each fixed station operating under Mon-1b, Task 2d included an SRX800-MD4 Lotek receiver (Lotek Wireless) connected to two or three, three-element Yagi antennas and, where feasible, remote connectivity equipment. Stations were powered by two 80 W solar panels wired to a 10-amp solar controller maintaining two 100 Ah deep cycle AGM batteries. Receivers, remote connectivity equipment, and batteries were all housed in aluminum environmental boxes that were sealed and locked. A detailed description of station components operating under Mon-1b, Task 2d can be found in Hatch et al. (2022).

The Mon-13 fixed station array in and around the TUF (Figure 5) provided data for fish that migrated back downstream of the Project after release. A detailed description of this array and the station components can be found above in Section 1.4.2. An additional fixed station was deployed at the diversion tunnel inlet in March 2021 to better assess downstream movement of radio tagged fish. The inlet fixed station and five of the fixed stations operating under Mon-13 have been collecting data continuously since April 1, 2021, while stations within the fishway were operational from April 1 through October 31, 2021.

Mobile tracking surveys were conducted to supplement the data collected by the fixed station array using fixed-wing and helicopter aerial surveys, primarily during key migratory periods for Arctic Grayling and Bull Trout in the Moberly and Halfway rivers (Hatch et al. 2022). During each mobile survey, antennas were mounted to the aircraft and connected to receivers in the cabin. The Moberly River was surveyed six times by helicopter during peak Arctic Grayling spawning between May 5 and June 14, 2021. Surveys covered the Moberly River from its confluence with the Peace River upstream to Moberly Lake. The Halfway River was surveyed five times by fixed-wing aircraft during peak Bull Trout spawning between September 7 and 23, 2021. Surveys covered most of the Halfway River, including 12 of its upper tributaries downstream to the confluence with the Peace River. Five additional fixed-wing watershed-wide mobile surveys were conducted between November 27, 2021, and January 27, 2022, that covered the entire study area.

Radio telemetry data used in this study were collected between April 2021 and January 2022. Data downloads and fixed station maintenance occurred at least once a month. All data were filtered and summarized by LGL following methods detailed in Hatch et al. (2022). The filtering process included the removal of duplicate data and detections prior to release or after removal of a known radio tag code, pulse rate filtration, detection frequency filtration, and manual examination of individual detection histories. Downloaded telemetry data were backed up to a cloud server and manually examined before analysis. A more detailed description of the fixed station array, station components, mobile tracking surveys, and data management and processing can be found in Hatch et al. (2022).

2.4.1 Analysis

Effectiveness of the trap and haul program was evaluated for four of the five target species (Arctic Grayling, Bull Trout, Mountain Whitefish, and Rainbow Trout) in 2021. No radio-tagged Burbot were released upstream of the Project. Radio-tagged fish released upstream of the Project were classified as either having been successful or unsuccessful at reaching their spawning grounds. Additional classifications were used for fish that did not successfully reach their spawning grounds. Unsuccessful fish were classified as an assumed mortality, as having fallen back within 48 hours of release, or as some other post-release movement. Definitions of each classification are shown in Table 14. Proportions of each classification were calculated for the four target species using data from fish transported from the TUF and fish transported through the contingent trap and haul program. Where possible, proportions of each classification were also calculated separately and compared between programs and release locations. For transported fish that were radio-tagged under other components of the FAHMFP prior to 2021, results of genetic analysis were used to determine if they originated downstream or upstream of the Project (Geraldes and Taylor 2022).

Arctic Grayling, Mountain Whitefish, and Rainbow Trout were only released at the Peace River release location and, therefore, no comparisons between release locations could be made. Bull Trout were released at the Peace River location in the early spring and the Halfway River release location in mid-to-late spring and summer; however, differences in results between locations should be interpreted with caution given the uneven sample sizes and timing differences.

Species-specific criteria were used to determine success in reaching assumed spawning grounds after release (Table 15; Figure 19). Detection data from all fixed stations and mobile tracking surveys were used to confirm success. It should be noted, however, that as the Site C Reservoir begins to fill during the operations phase of the Project and/or additional release locations are used, species-specific criteria will likely need to be updated accordingly.

Specific criteria were used to classify success for Arctic Grayling and Bull Trout in 2021 given our understanding of which tributaries these species spawn in upstream of the Project (Mainstream 2012; Putt 2021; Geraldes and Taylor 2022; Hatch et al. 2022). Although radio-tagged Arctic Grayling are typically observed migrating well upstream of the Moberly River 3 fixed station at the inundation zone of the Site C Reservoir during their assumed spawning period (Hatch et al. 2021; Hatch et al. 2022), we classified Arctic Grayling as having successfully reached their assumed spawning grounds if they were detected at or upstream of the Moberly River 2 fixed station approximately 5 rkm upstream of the confluence with the Peace River (Figure 19). A similar classification is used by LGL under Mon-1b, Task 2d of the FAHMFP (Hatch et al. 2022). Likewise, Bull Trout are known to spawn in tributaries of the Halfway River well beyond the inundation zone of the Site C Reservoir (Mainstream 2012; Putt 2021; Hatch et al. 2022). Therefore, Bull Trout detected within the Halfway River at or upstream of the expected inundation zone (Figure 19, Halfway River 3 fixed station) were considered to have successfully reached their spawning grounds.

A more expansive spatial extent was used to classify success for Mountain Whitefish and Rainbow Trout. Mountain Whitefish are known to spawn in the Peace River mainstem and several tributaries upstream of the Project, including the Moberly and Halfway rivers (Mainstream 2012). Given the uncertainty in known spawning locations of Mountain Whitefish in the Peace River mainstem, Mountain Whitefish detected anywhere upstream of the release location (including the Halfway River) were considered to have successfully reached their spawning grounds. Additionally, like Arctic Grayling, Mountain Whitefish detected within the Moberly River at or upstream of the Moberly River 2 fixed station were considered to have successfully reached their spawning grounds. Successful Rainbow Trout were those detected anywhere at or upstream of the Peace River 8 fixed station located downstream of their known spawning tributaries, including the Halfway River and Maurice, Lynx, and Farrell creeks (Figure 19; Mainstream 2012; Geraldes and Taylor 2022).

Radio-tagged fish not detected after release by either fixed stations or mobile tracking were assumed to be post-release mortalities. We assumed this given the unlikely chance that the numerous mobile tracking surveys conducted over both release locations throughout 2021 and in January 2022 would have failed to detect tagged fish that had survived but did not move up or downstream after release. Additionally, fish that were repeatedly detected at or directly downstream of their release location were also assumed to be post-release mortalities. In both cases (i.e., no post-release detections or repeated downstream detections), we assumed that tag loss was unlikely given that all tags were surgically implanted by experienced biologists. It should be noted, however, that like with any telemetry study, it is nearly impossible to confirm true mortalities, as tag loss or sedentary behaviour in deep or shielded habitat could have resulted in similar detection patterns as inferred mortalities.

Fallback can be defined as the behaviour of passing downstream through a dam shortly after upstream passage or transport, prior to reaching spawning or rearing areas (Reischel and Bjornn 2003; Schmetterling 2003). For Mon-14, fallback was defined as any radio-tagged fish detected downstream of the Project within 48-hours of upstream release. For all fish detected downstream of the Project after release, the time between release and the first downstream detection on any fixed station (including Mon-13 or Mon-1b, Task 2d fixed stations) or during any mobile tracking survey was calculated. In accordance with the definition of fallback provided in H_1 of Mon-14, fish that migrated downstream of the Project after 48 hours of release were not classified as fallback in 2021.

Table 14. Definitions of classifications used to evaluate the effectiveness of the Project's trap and haul program in 2021. Detection data collected from all fixed stations and mobile tracking surveys from April 2021 through January 2022 were used to determine classifications.

Classification	Definition
Success	Fish detected at or upstream of a fixed station located at the downstream end of its assumed spawning grounds.
Mortality	Fish never detected after release or repeatedly detected at or directly downstream of its release location.
Fallback	Fish detected downstream of the Project within 48-hours of upstream release, as defined in H_1 of Mon-14.
Downstream	Fish detected downstream of the Project after 48-hours of upstream release without having successfully reached its spawning grounds.
Unconfirmed	Fish detected and remained upstream of the Project after release without having successfully reached its spawning grounds.

Table 15. Details of the fixed radio telemetry stations used to confirm successful spawning migration for each target species released in 2021. Detections at any fixed stations or during mobile tracking surveys upstream of these fixed stations were also used to confirm success.

Species	Fixed Station Name	Distance from Project (rkm)
Arctic Grayling	Moberly River 2	5
Bull Trout	Halfway River 3	56
Mountain Whitefish	Peace River 6 Moberly River 2	5 5
Rainbow Trout	Peace River 8	31

2.5 Results

2.5.1 Fish Characteristics and Transport Conditions

There were 61 radio-tagged fish released upstream of the Project in 2021, with one Bull Trout captured and transported twice, totaling 62 releases. Characteristics of these fish and the transport conditions of the two trap and haul programs are summarized below. Ultimately, several years of data will be collected and used to determine the relative effects of these conditions on the effectiveness of the Project's trap and haul program. Conditions that most successfully lead to released fish continuing their assumed upstream spawning migration will be suggested for use during the operations phase of the Project.

Fishway Trap and Haul

Five radio-tagged Bull Trout and six radio-tagged Mountain Whitefish were transported and released upstream of the Project by the facility operator during the operational period (Table 16). Three of the five Bull Trout were radio-tagged at the TUF by IFR, while the remaining two were previously radio-tagged under other components of the FAHMFP.

The five Bull Trout were released in the Halfway River during three separate release events on August 18, 19, and 31, 2021 (Table 16). Two of the three Bull Trout tagged at the TUF were captured and tagged on August 18 and released the following morning on August 19. Note that the TUF's transport tanks were designed to hold fish for up to 24 hours when in the sorting facility (McMillen Jacobs & Associates and BC Hydro 2022). The temperature difference between water in the transport tank and in the Halfway River during the three releases did not exceed 1.3 °C. Radio-tagged Mountain Whitefish were released in the Peace River during four separate release events on September 17 and 25, and October 30 and 31, 2021. The temperature difference between water in the transport tank and in the Peace River during the releases never exceeded 0.5 °C.

Contingent Trap and Haul

Four of the five target species were radio-tagged and released by Golder upstream of the Project during 16 contingent trap and haul sessions in 2021 (Table 16). Eight Arctic Grayling, six Bull Trout, one Mountain Whitefish, and 15 Rainbow Trout were radio-tagged and released at the Peace River release location. Two additional Mountain Whitefish and one Rainbow Trout previously radio-tagged by other components of the FAHMFP were also captured, transported, and released at the Peace River release location.

Seven Arctic Grayling were released in the Peace River during five separate release events between April 15 and May 20, 2021, and one on July 1. Bull Trout were released in the Peace River during four separate release events between April 8 and 15. The three Mountain Whitefish were released during two release events on October 13 and 21, 2021. Fifteen Rainbow Trout were released during 13 release events between April 15 and July 20, 2021 and one was released on October 13. The temperature difference between water in the transport tank and in the Peace River during all release events never exceeded 2.4 °C.

There were 18 radio-tagged Bull Trout released at the Halfway River release location through the contingent trap and haul program. Three were previously radio-tagged by other components of the FAHMFP. One individual was released at the Halfway River twice: once in April and then again in July after it was recaptured downstream of the Project. All 18 releases were between April 22 and July 20, 2021, during 12 release events. The temperature difference between water in the transport tank and in the Halfway River was 5.2°C or less among all releases, except for on July 15 when the water temperature in the Halfway River was 8.2°C higher than the water in the transport tank. On this occasion, the additional holding time required to temper the water in the transport tank was expected to be more detrimental to the health of the fish than releasing the fish without tempering the water (Golder 2022).

Table 16. Fish characteristics and release conditions for both trap and haul programs in 2021. Holding time refers to the total time from initial capture to upstream release, while transport time refers to the total drive time from initial departure of transport tank to arrival at the release location. Ranges in values are provided for each program, species, and release location.

Program	Species	Release Location	Release Events (n)	Transported Fish (n)	Holding Time (h)	Transport Time (min)	River Temp. (°C)	Sex (n)			Length (mm)	Weight (g)
								M	F	NA		
TUF	Bull Trout	Halfway River	3	1–3	2.0–20.5	62–93	12.8–16.5	2	2	1	580–865	1842–6622
	Mountain Whitefish	Peace River	4	2–92	2.6–5.3	10–15	7.2–12.9	-	2	4	360–430	493–804
Contingent	Arctic Grayling	Peace River	6	2–24	1.3–6.6	14–20	2.5–11.6	-	3	5	323–361	339–525
	Bull Trout	Peace River	4	1–3	1.1–3.3	13–20	1.5–9.8	-	-	6	425–851	878–8731
	Bull Trout	Halfway River	12	1–13	2.0–8.0	47–68	1.1–20.7	-	-	18	335–910	293–8193
	Mountain Whitefish	Peace River	2	126–136	1.3–2.6	24	9.0–9.8	-	1	2	296–370	345–634
	Rainbow Trout	Peace River	14	1–126	1.6–8.2	10–30	2.5–12.8	-	1	15	299–444	306–910

2.5.2 Post-Release Fish Movement

Post-release movements are presented for the four target species captured and transported upstream by both trap and haul programs in 2021. Movement classifications are summarized by species, and where possible, by trap and haul program and release location. Proportions and sample sizes of each classification are shown in Figure 21 by species, program, and release location. Detection history plots of each radio-tagged fish released upstream of the Project can be found in Appendix C.

Success to Spawning Grounds

Five of the eight (63%) radio-tagged Arctic Grayling released were classified as successfully reaching their spawning grounds in the Moberly River. All five fish were detected at the Moberly River 2 fixed station and then again upstream of that during mobile tracking surveys. Three fish migrated back downstream of the Project in June, presumably after spawning, while two remained upstream of the Project.

Seventeen of the 29 (59%) radio-tagged Bull Trout were classified as successfully reaching their spawning grounds in the Halfway River. Five were tagged prior to 2021 and had been genetically confirmed to have originated in the Halfway River (Geraldes and Taylor 2022). Three of the five (60%) that were transported from the TUF reached their spawning grounds, taking one day or less after release to reach the boundary of the expected inundation zone of the Site C Reservoir. One of these three fish migrated back downstream of the Project 35 days after release, presumably after spawning. Fourteen of the 24 (58%) radio-tagged Bull Trout captured and transported through the contingent trap and haul program reached their spawning grounds. Nine of the 14 migrated back downstream of the Project, presumably after spawning.

Bull Trout were the only target species released at more than one location in 2021. Six Bull Trout were released at the Peace River release location in early to mid-April through the contingent program while the Halfway River release location was iced over. Of the six released in the Peace River, three (50%) were classified as having reached their spawning grounds. Bull Trout were released at the Halfway River release location starting in late April after the river thawed. Of the 23 Bull Trout released at the Halfway River release location between late April and late August, 14 (61%) reached their spawning grounds.

Four of the nine (44%) radio-tagged Mountain Whitefish were classified as successfully reaching their assumed spawning grounds. Two were captured at and transported from the TUF and two through the contingent program. Two of the four migrated back downstream of the Project, presumably after spawning.

Eight of the 16 (50%) radio-tagged Rainbow Trout were classified as having reached their assumed spawning grounds. Four of the eight fish were detected in the Halfway River or one of its tributaries, while the other four reached the Peace River 8 fixed station located on the Peace River just downstream of the Halfway River and Maurice, Lynx, and Farrell creeks. One of the eight Rainbow Trout migrated back downstream of the project in June, presumably after spawning.

Mortality

Of the 62 releases, eight were classified as assumed mortalities, including one Arctic Grayling, four Bull Trout, two Mountain Whitefish, and one Rainbow Trout. The Arctic Grayling, Mountain Whitefish, and Rainbow Trout were never detected after release. The Arctic Grayling (Code 149.400-216) and Rainbow Trout (Code 149.400-184) were captured and released in July 2021 through the contingent program and made up 13% and 6% of released fish of their species, respectively. Both Mountain Whitefish mortalities (Codes 149.360-678 and 149.400-149) were captured and tagged at the TUF and made up 33% of the six radio-tagged Mountain Whitefish transported upstream from the TUF.

The four Bull Trout classified as mortalities were released under the contingent trap and haul program at the Halfway River release location between April 28 and May 26, 2021. One (Code 149.360-134) was a recapture that was originally radio-tagged in October 2019 under another component of the FAHMFP and was never detected after being released upstream. The other three Bull Trout were repeatedly detected downstream of the release location in the same general vicinity during at least three separate mobile tracking surveys between early September and late November 2021. One fish (Code 149.360-726) was repeatedly detected at the Halfway-Peace River confluence, while the other two (Codes 149.360-721 and 149.360-703) were repeatedly detected between the Halfway-Peace River confluence and the next downstream fixed station on the Peace River. The four mortalities comprised 14% of the 29 Bull Trout released upstream and 17% of the 24 released through the contingent trap and haul program. There were no mortalities for radio-tagged Bull Trout transported from the TUF or released at the Peace River release location.

Four additional Bull Trout that were classified as successfully reaching their spawning grounds may have either not survived, lost their tag, or became sedentary partway through their upstream spawning migration. One (Code 149.360-318) was never detected again after successfully reaching the Halfway River 3 fixed station in June 2021, while the other three were repeatedly detected in the same general location during subsequent mobile tracking surveys between September 2021 and January 2022. One fish (Code 149.360-512) was repeatedly detected on the Halfway River between the Cameron and Graham River confluences, another (Code 149.360-707) near the Cameron-Halfway River confluence, and the third (Code 149.360-710) in the Graham River. All four Bull Trout were PIT-tagged, but none were detected on the PIT antenna arrays installed in the Halfway River watershed as part of the Peace River Bull Trout Spawning Assessment of the FAHMFP (Mon-1b, Task 2b).

Fallback

One radio-tagged Bull Trout and two Rainbow Trout captured and transported through the contingent trap and haul program fell back downstream of the Project within 48 hours of release. The Bull Trout (Code 149.360-704) was first detected downstream of the Project 40.7 hours after being released in the Peace River on April 15 and made up 4% of the 24 radio-tagged Bull Trout released through the contingent program. The two Rainbow Trout (Codes 149.360-715 and 149.360-684) that fell back were released on May 20 and October 13, 2021 and made up 13% of the 16 radio-tagged Rainbow Trout released upstream. The two Rainbow Trout were first detected downstream of the Project 15.2 and 21.7 hours after release. No radio-tagged fish transported from the TUF fell back downstream of the Project within 48 hours.

Downstream Movements

Although not technically considered fallback as defined in H_1 of Mon-14, one Arctic Grayling, five Bull Trout, three Mountain Whitefish, and four Rainbow Trout migrated back downstream of the Project after 48 hours of being released upstream without having successfully reached their spawning grounds. The Arctic Grayling (Code 149.360-718) was released on May 20, 2021, and while it did not reach its assumed spawning grounds upstream of the Moberly River 2 fixed station, it did reach the mouth of the Moberly River 4.0 days after release but then migrated back downstream of the Project 4.7 days later.

Of the five additional Bull Trout that migrated back downstream of the Project after 48 hours of being released without having successfully reached their spawning grounds, four did so in less than nine days, while the remaining Bull Trout was first detected downstream after 151 days. Two of the Bull Trout (Codes 149.360-676 and 149.360-669) were transported from the TUF to the Halfway River release location on August 19 and spent less than three days in the Halfway River before swimming directly back downstream into the Peace River and past the Project 2.8 and 4.8 days after release, respectively. It should be noted that these two fish were held in transport tanks within the sorting facility overnight before being transported and released the following morning. Two other Bull Trout (Codes 149.360-691 and 149.360-709) made no upstream movements after release and were first detected downstream of the Project in 8.5 and 8.8 days, respectively. The fifth Bull Trout (Code 149.360-692) spent nearly five months in the Peace River after being released in April but was finally detected downstream of the Project on September 13, 2021. These five Bull Trout, along with the one that fell back within 48-hours of release made up 21% of the 29 total Bull Trout releases.

Three Mountain Whitefish migrated back downstream of the Project less than a week after release (Codes 149.360-670, 149.360-673, 149.400-160). All three fish were displaying spawning tubercles when captured, but none made a detected upstream movement after being released at the Peace River release location. These three Mountain Whitefish made up 33% of the nine Mountain Whitefish released.

Four Rainbow Trout migrated back downstream of the Project without having successfully reached their spawning grounds. One of the four Rainbow Trout (Code 149.360-344) migrated back downstream of the Project less than three days after release and had previously been genetically confirmed to have originated from downstream of the Project (Geraldes and Taylor 2022). The remaining three Rainbow Trout (Codes 149.360-711, 149.400-195, and 149.400-212) made little to no detected upstream movements after their release, and migrated back downstream of the Project 12.9, 24.2, and 158.8 days after release, respectively. It should be noted, however, that the Rainbow Trout that took over 158 days to migrate downstream of the Project was not detected until it had nearly reached the Pouce Coupe River confluence in Alberta, approximately 66 rkm downstream of the Project. These four Rainbow Trout, along with the two that fell back within 48-hours of release made up 38% of the 16 Rainbow Trout released.

Unconfirmed

One Arctic Grayling, two Bull Trout, and one Rainbow Trout were not classified as successfully reaching their spawning grounds but remained within the Peace River upstream of the Project after release. The Arctic Grayling (Code 149.360-697) was detected near the mouth of the Moberly River in late May 2021 but has since inhabited the Peace River upstream of the confluence. The two Bull Trout (Codes 149.360-705 and 149.360-725) were released in the Halfway River in late April and early May 2021 and were last detected in the vicinity of the Project between the diversion tunnel inlet and mouth of the Moberly River. The Rainbow Trout (Code 149.360-722) remained in the vicinity of the Project near the Peace River release location after being release on May 6, 2021. Ongoing analyses of the movements of these fish will provide insight on the multi-year effectiveness of the trap and haul program and potentially on skip-year spawning behavior of these populations.

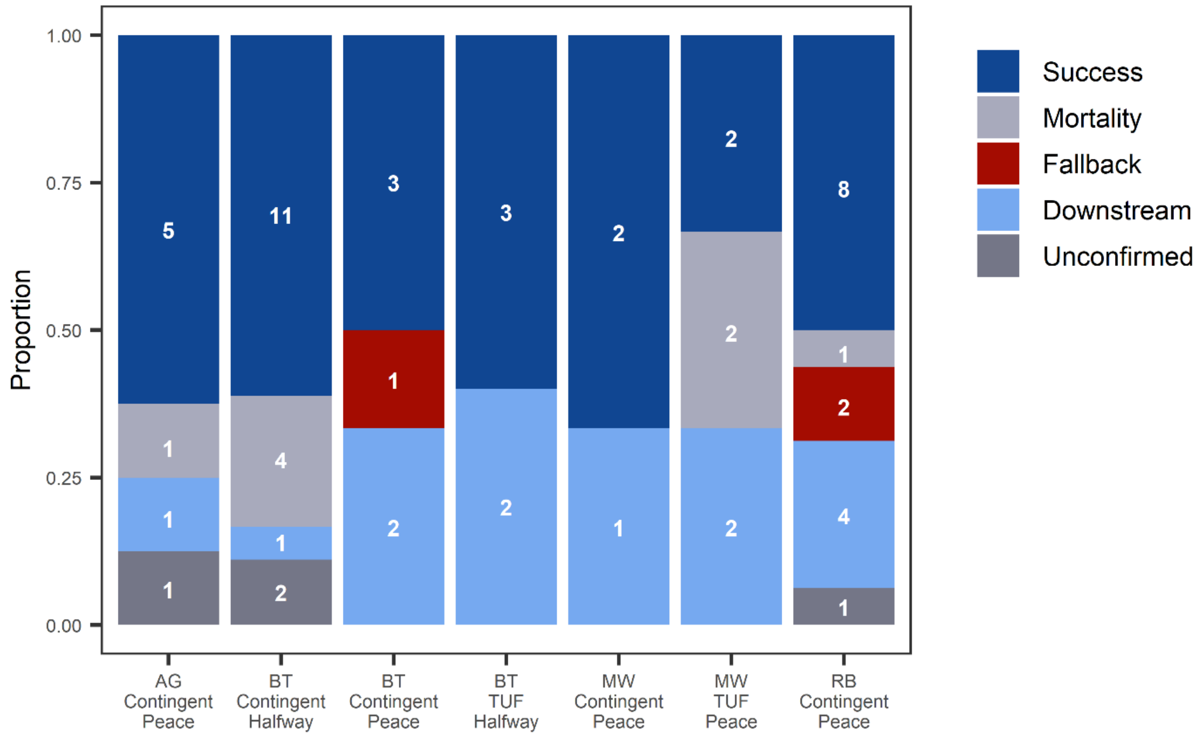

Figure 21 Proportions of movement classifications for radio-tagged Arctic Grayling (AG), Bull Trout (BT), Mountain Whitefish (MW), and Rainbow Trout (RB) transported from the temporary upstream fish passage facility (TUF) or through the contingent trap and haul program and released in either the Peace or Halfway River. Results should be interpreted with caution given the small sample sizes (shown in white).

2.6 Discussion

The objective of Mon-14 is to evaluate the effectiveness of the Project's trap and haul program using radio telemetry to track the movements of Arctic Grayling, Bull Trout, Burbot, Mountain Whitefish, and Rainbow Trout after they are transported from the TUF and released upstream of the Project. Mon-14 informs the TUF's trap and haul operations and addresses key uncertainties regarding the effectiveness of fish release locations in the Site C Reservoir and tributaries, and movements of individual fish following release. Specifically, the monitor aims to test hypotheses regarding the ability of target species to continue their migration with no fall back or mortality within 48 hours of release and to compare these outcomes between different release locations within the Site C Reservoir or tributaries. Result are directly applicable to the management of the TUF, potentially dictating in-season changes to operations, including where and when target species will be released upstream of the Project.

A focus of this first year of monitoring was to ensure the experimental design and existing radio telemetry array and mobile tracking surveys were appropriate for evaluating post-release movements for each species and release location. Ultimately the array functioned as intended. Although few radio-tagged fish were transported from the TUF in 2021, a supplementary contingent trap and haul program was introduced to capture fish from within the vicinity of the TUF using an electrofishing boat and transfer them upstream, increasing the total number and species of transported fishes that could be evaluated. Using data from both trap and haul programs, we confirmed that Arctic Grayling, Bull Trout, Mountain Whitefish, and Rainbow Trout can successfully continue their upstream migration after being captured and transported upstream of the Project. However, we also confirmed that some transported fish of each species made little to no upstream movements after release and eventually migrated back downstream of the Project before reaching their spawning grounds. While it is promising that results could be obtained after a single year of monitoring, data are limited, and results should be interpreted with caution. Future years of monitoring under Mon-14 will build off the results presented herein.

2.6.1 Trap and Haul Effectiveness

Effectiveness of the trap and haul program was evaluated for four of the five target species in 2021 whereby radio-tagged fish released upstream of the Project were classified as either having successfully reached their spawning grounds, assumed to have died, fell back, or made some other post-release movement. Results associated with each post-release classifications are discussed below.

Success to Spawning Grounds

Individuals from all four target species transported upstream of the Project successfully reached their assumed spawning grounds. Species-specific proportions of success ranged from 44% (Mountain Whitefish) to 63% (Arctic Grayling). Proportions of success were twice as high for Mountain Whitefish transported through the contingent trap and haul program (67%) compared to those transported from the TUF (33%); however, sample sizes were low. Proportions of success were similar between the two trap and haul programs for Bull Trout, while Arctic Grayling and Rainbow Trout were only released through the contingent trap and haul program. Bull Trout were the only target species released at more than one location in 2021, with releases in the Halfway River under both programs having a slightly higher proportion of success (61%) than releases in the Peace River (50%). However, these differences likely have more to do with release timing than location, as Bull Trout released in the Peace River were captured and transported through the contingent program in early April, while those transported directly to the Halfway River were released closer to their known spawning period (i.e., August and September; Putt et al. 2021). Although radio-tagged Bull Trout have been detected migrating upstream past the Project site as early as April, these upstream movements typically do not peak until May (Mainstream 2012; Hatch et al. 2021; Hatch et al. 2022). Bull Trout captured and transported in early April may not yet be physiologically ready or motivated to undergo their upstream spawning migration, which may explain the lower proportion of success for fish released at the Peace River release site.

It should also be noted that four fish, including one Arctic Grayling, two Bull Trout, and one Rainbow Trout that were not classified as successfully reaching their spawning grounds in 2021 remained within the Peace River upstream of the Project after release. Ongoing analyses of the movements of these fish using data collected in future monitoring years will confirm whether they successfully reach their spawning grounds or not. These results will provide insight on the multi-year effectiveness of the trap and haul program and potentially on skip-year spawning behavior of these populations.

Limited access to the Moberly River release location in 2021 meant that all Arctic Grayling had to be released in the Peace River approximately 1.5 rkm upstream of the confluence with the Moberly River, their known spawning tributary (Mainstream 2012). Despite this, five out of eight fish reached their assumed spawning grounds, and seven of the eight were confirmed to have at least reached the mouth of the Moberly River. These results suggest that even when released upstream of their assumed spawning tributary, Arctic Grayling are still able to locate and access the Moberly River. Although the Moberly River remains the intended release location for Arctic Grayling moving forward, these results are encouraging, as access to the Moberly River will likely continue to be limited, particularly as the reservoir is filled in future years.

Mortality

Research has shown that mortality associated with trap and haul programs can be highly variable depending on species, watershed, and year. Estimates from the literature range from 0% to >90% of released fish (Keefer et al. 2010; DeWeber et al. 2017; Bowerman et al. 2018; Kock et al. 2018;

Kock et al. 2021). In 2021, we classified eight out of the 62 releases (13%) as assumed mortalities. Species-specific proportions of mortality ranged from 6% (Rainbow Trout) to 22% (Mountain Whitefish). Program- and species-specific proportions of mortality ranged from 0% (Bull Trout) to 33% (Mountain Whitefish) for fish transported from the TUF, and 0% (Mountain Whitefish) to 17% (Bull Trout) for fish transported through the contingent trap and haul program. Although post-release mortality associated with the Project's trap and haul program will continue to be difficult to determine (see Section 2.6.2 below), ongoing analyses of the radio-telemetry data collected through various components of the FAHMFP may make classifications of mortality more conclusive over time. These additional data may also allow us to better understand what conditions increase the chances of mortality so that they can be avoided during the operations phase of the Project.

Stresses associated with trap and haul programs during capture, handling, and transport may increase the risk of mortality (Benda et al. 2015; Colvin et al. 2018); however, specific causes of mortality as a result of trap and haul have been difficult to determine (Kock 2021). Keefer et al. (2010) found that mortality of trap and hauled adult Chinook Salmon was most strongly correlated with body condition, sex, and timing of release. Specifically, the authors observed lower mortality in fish captured and transported closer to their known spawning time and suggest that releasing fish when they may be more physiologically ready could improve trap and haul success. A similar trend may be true for Bull Trout transported upstream of the Project, as all four classified mortalities in 2021 were of fish released in April and May, which is four to five months earlier than their known spawning period in the Halfway River (Mainstream 2012, Putt et al. 2021). There are currently too few data, however, to confidently determine which, if any, conditions lead to an increased chance of mortality associated with the Project's trap and haul program.

Fallback

Using the 48-hour post-release threshold for fallback, we classified 5% of the 62 post-release movements as fallback in 2021, with species-specific proportions ranging from 3% (Bull Trout) to 13% (Rainbow Trout). These results fall within the estimates of fallback observed for other trap and haul programs focused on anadromous Pacific salmon, with annual run-specific estimates ranging from 1 to 22% for adult Chinook Salmon, Sockeye Salmon, and Steelhead Trout (Reischel and Bjornn 2003; Boggs et al. 2004; Naughton et al. 2006; Kock 2016; Naughton et al. 2018; Kock 2021). All three cases of fallback within 48 hours of release were of fish transported through the contingent trap and haul program and released at the Peace River release location.

Although not considered fallback under Mon-14, an additional 13 of the 62 (21%) releases migrated back downstream of the Project after 48 hours of being release upstream without having successfully reached their spawning grounds. Ten (16%) migrated back downstream of the Project in less than 13 days, including two Bull Trout that were originally captured from within the fishway using a dipnet after circling the uppermost pool for several days. During processing, both fish were observed by IFR staff to have mouth abrasions and fin damage, potentially from repeated collisions with the fishway walls and/or aggressive behaviour from other fish in the crowded uppermost pool. After release, both fish made little to no upstream movements and eventually migrated back downstream of the Project. Although it is unclear whether the physical condition of these fish influenced their post-release movements, body condition has been found to have a strong effect on spawning success after release in other trap and haul programs (Keefer et al. 2010) and should continue to be monitored for all fish transported upstream of the Project.

2.6.2 Future Directions

Few radio-tagged fish were transported from the TUF in 2021. Of the 11 fish that were transported, only two were previously radio-tagged under other components of the FAHMFP, and both were manually netted out of fishway after unsuccessfully passing into the pre-sort holding pool and fish lock of the TUF. As more fish are radio-tagged through other components of the FAHMFP, sample sizes of target species captured at and transported from the TUF may increase in future monitoring years. However, without significant increases in the complete passage of radio-tagged fish at the TUF, the ability to answer Mon-14's management question (i.e., what are effective release locations of fish captured at the TUF) and associated hypotheses will be limited. Including data from the contingent trap and haul program may provide some useful insights into trap and haul effectiveness on the Peace River; however, due to the differences in capture, holding, and transport methods, results may not be representative of fish captured at and transported from the TUF.

Another constraint to the study is the uncertainty surrounding classifications of unsuccessful fish. For example, as is the case with most telemetry studies, true mortalities could not be determined under Mon-14, as tag loss or sedentary behaviour in deep or shielded habitat could have resulted in similar detection patterns as those classified as mortalities. Tag manufacturers (e.g., Sigma Eight Inc.) can include a mortality sensor in their radio tags, which causes a change in the tag's pulse rate once a pre-determined threshold of inactivity has been measured. Unfortunately, these tags are not compatible with the radio receivers used under the FAHMFP, and therefore could not be used in this study. Even if they could be used, however, true mortalities could not be confirmed, as tag loss or sedentary behaviour could also trigger a change in the tag's pulse rate.

Additionally, confirmation of mortality within 48 hours of release (as defined in H_1) is currently not possible under Mon-14 and would require conducting mobile tracking surveys directly upstream and downstream of the release locations within 48 hours of every release event. Nevertheless, 48 hours may not be the most appropriate threshold for evaluating the survival of fish released through the Project's trap and haul program. While Fisheries and Oceans Canada has managed commercial fisheries in the past to only consider post-release mortality occurring in the first 48 hours to be attributed to the capture event, recent research takes a more comprehensive and adaptive approach to also consider latent mortality without strict temporal thresholds (Patterson et al. 2017). Using a similarly comprehensive approach for classifying mortality under Mon-14 without a temporal threshold would align more with other studies that have evaluated mortality associated with trap and haul programs (Keefer et al. 2010; Mosser et al. 2013; Benda et al. 2015; DeWeber et al. 2017).

Similarly, a more comprehensive approach for classifying fallback may be appropriate for Mon-14 given the clear examples in 2021 of fish making little to no upstream movements after release, followed by direct downstream movement past the Project after 48 hours. Adopting a less strict definition of fallback without a temporal threshold would also better align with other fish passage research (Schmetterling 2003; Boggs et al. 2004; Naughton et al. 2006; Harris and Hightower 2011; Kock et al. 2018; Naughton et al. 2018) and would likely result in more accurate estimates of the Project's trap and haul effectiveness.

Ultimately, classifying post-release movements is a simple approach for evaluating the effectiveness of the Project's trap and haul program. Over time, more robust methods could be adopted that measure the long-term demographic stability of each target species transported upstream of the Project. For example, genetic parentage analysis could be used to estimate the cohort replacement rate (CRR) of each target species. A CRR is a measure of the number of spawning adults produced by each transported individual, where values greater than 1.0 suggests that a population is self-sustaining and stable (Lusardi and Moyle 2017; Kock et al. 2021). This metric has been used to evaluate other trap and haul programs (O'Malley et al. 2015; Evans et al. 2016; Sard et al. 2016), and although outside of the scope of Mon-14, could be estimated for each target species transported upstream of the Project with continued genetic sampling and analysis through various components of the FAHMFP.

2.6.3 Conclusions

In 2021, Mon-14 began to collect data on the post-release movements of radio-tagged Arctic Grayling, Bull Trout, Mountain Whitefish, and Rainbow Trout transported upstream of the Project. Promisingly, all four species were confirmed to have successfully reached their assumed spawning grounds after release. However, we also confirmed that some transported fish from each species likely died or made little to no upstream movements after release and eventually migrated back downstream of the Project before reaching their spawning grounds, including two Bull Trout and four Mountain Whitefish transported from the TUF. Although not all fish transported upstream of the Project continued their migration after release (H_1), more data should be collected before an attempt is made at addressing either hypothesis or the associated management question. Furthermore, removing the 48-hour threshold for classifying released fish as mortalities or their downstream movements as fallback should be considered to provide a more accurate assessment of the Project's trap and haul effectiveness.

Although results from 2021 suggest that the trap and haul can successfully pass fish upstream of the Project, ultimately, several years of data need to be collected and analyzed to fully understand the effectiveness of the program, including the chosen release locations for each of the target species. Given the relatively low number of radio-tagged fish transported from the TUF in 2021, the results presented herein should be interpreted with caution.

3. Joint Discussion

The Site C Fishway Effectiveness Monitoring Program (Mon-13) and Trap and Haul Fish Release Location Monitoring Program (Mon-14) represent two components of the FAHMFP. The programs aim to address key uncertainties associated with attraction to and passage within the TUF (Mon-13), and transport and release upstream of the Project (Mon-14). While Mon-13 and -14 refer to monitoring fish attraction, passage, transport, and release from the TUF, results will also inform the design and operation of the PUF. Together, the two monitors aim to better understand and optimize fish passage at Site C, from initial approach within the Mon-13 study area to upstream release and beyond.

To address key uncertainties associated with both monitors, the movements of five target species, including Arctic Grayling, Bull Trout, Burbot, Mountain Whitefish, and Rainbow Trout were monitored using a combination of radio and PIT telemetry arrays within the TUF and upstream and downstream of the Project. These five species were chosen 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 nations and anglers, and are indicator species in local provincial management objectives (BC Ministry of Environment 2009; BC Government 2011).

As the first full season of TUF operations, a focus of the 2021 operational period was to ensure that the experimental design and existing radio and PIT telemetry arrays were appropriate for evaluating the movements of target species as they approached, entered, passed, and were released from the TUF upstream of the Project. However, there were several temporary shutdowns during the operational period, including a nearly month-long shutdown that began in late June as many radio-tagged target species first reached the approach zone within the Mon-13 study area. Additionally, WSELs at the tailrace of the fishway were above the fishway's design criteria for most of the 2021 operational period, likely reducing its effectiveness. To mitigate for the potential lack of biological effectiveness of the TUF when WSELs were above design criteria, or when the TUF was not operational, BC Hydro commissioned Golder to conduct boat electroshocking surveys in the Peace River in the vicinity of the TUF to capture and transport fish upstream of the Project (Golder 2022). Although four of the five target species were successfully captured and transported upstream through the contingent trap and haul program, with many successfully continuing their upstream migration after release, these results cannot be used directly to evaluate the effectiveness of the TUF and its associated trap and haul program.

In addition to the challenges associated with shutdowns and WSELs outside of fishway's design criteria, another major constraint to both monitors during the 2021 operational period was the limited number of radio- and PIT-tagged fish that successfully passed the fishway. For example, despite 16 radio-tagged Bull Trout entering the fishway, only two were captured at the TUF, and both had to be manually netted out of fishway after unsuccessfully passing into the pre-sort holding pool and fish lock. These were the only two radio-tagged fish for which we have detection data as they approached, entered, and passed through the fishway and continued their migration after being transported upstream of the Project. It would be remiss to suggest these two fish represent the population, but their movements tracked from approach to release and beyond do provide valuable information on the strengths and limitations of the trap and haul program at the TUF, as well as the monitoring being conducted under the FAHMFP.

One of the two Bull Trout (Code 149.360-496) first reached the approach zone on May 18, 2021 but then returned downstream leaving the array later that day. It returned for its second occupancy on the array on May 22, reached the entry zone within a few hours, but did not yet enter the fishway. Not until its fifth occupancy on the array and after reaching the entry zone from the approach zone 77 times while the fishway was operational did it finally enter on July 31, six days after the nearly month-long shutdown period ended. Once detected at the entrance pool fixed station, it reached the vee-trap fixed station within 23 minutes at approximately 0900, where it remained for 12.5 hours (i.e., two sorting cycles) before returning downstream and out of the fishway. It returned to the fishway and reached the vee-trap fixed station six more times spending a total of 4.6 days there before finally being dip netted out of pool 25 by the facility operator on August 18. It was processed at the TUF, released at the Halfway River release location that afternoon, and detected at the inundation zone of the Site C Reservoir at the Halfway River 3 fixed station 26 hours after release. On September 16 it was detected during a mobile tracking survey 197 rkm upstream of its release location near the confluence of Fiddes Creek and the Halfway River. It migrated back downstream in early October, presumably after spawning, into the Peace River and was last detected on October 9 at the diversion tunnel inlet fixed station just upstream of the Project.

This Bull Trout is one of a small group of radio-tagged fish that reached the vee-trap, but the data adds to evidence from other fish reaching the uppermost pool that the vee-trap is delaying and may even be a barrier to fish passage at the TUF. Data collected on the PIT array support this conclusion with 89.6% of detected target species failing to successfully pass the fishway once detected at or upstream of pool 23. Improving the effectiveness of the vee-trap (i.e., increased one-way, upstream movement into the pre-sort holding pool) would likely increase passage success and overall passage efficiency of target species, thereby potentially increasing the sample sizes of radio-tagged fish transported and released upstream of the Project to be monitored under Mon-14. Currently, low sample sizes have limited the ability to address the management questions and hypotheses associated with both Mon-13 and -14.

A challenge with both monitors has and will continue to be distinguishing individuals that are activity migrating upstream, potentially to spawn, from those that are not. For example, all radio-tagged fish detected within the approach zone during the 2021 operational period were used to calculate species-specific attraction efficiencies and modelled using TTE analysis under Mon-13. Additionally, adult-sized target species captured at the TUF or by Golder under the contingent trap and haul program that met species-specific timing criteria were assumed to be migrating upstream to feed or spawn and were therefore radio-tagged (if not tagged already) and transported accordingly. Although these timing criteria were established using the best available data collected within the region (Mainstream 2012; Hatch et al. 2022), these criteria may not be appropriate for measuring the motivation of target species to be upstream of the Project. For example, Mountain Whitefish are known to spawn upstream of the Project in September and October (Mainstream 2012) but were captured at the TUF after successfully passing the fishway throughout the 2021 operational period. Additionally, more adult-sized Arctic Grayling were captured at the TUF during the summer (n = 6) than in the spring (n = 3) when they are assumed to be migrating upstream to spawn (Mainstream 2012; Hatch et al. 2022). For Bull Trout, kelt migration timing out of the Halfway River tributaries is estimated annually (Putt et al. 2021) and could potentially be used as a threshold for when Bull Trout are no longer considered to be migrating upstream past the Project. However, determining whether individuals located downstream of the Project are actively migrating upstream or not before this date will be challenging and may bias measurements of the TUF's biological effectiveness (e.g., efficiency metrics, TTE results).

It is promising that during the 2021 operational period all five target species located the TUF, that Arctic Grayling, Bull Trout, Mountain Whitefish, and Rainbow successfully passed, and that Bull Trout and Mountain Whitefish transported upstream of the Project from the TUF continued their upstream spawning migration. Nonetheless, attraction and passage efficiency metrics were much lower than those predicted in the EIS and not all fish transported above the Project continued their upstream migration. Both monitors have faced considerable limitations since inception and as a result, we recommend caution when interpreting results presented herein. Mon-13 and -14 are complementary monitors designed to inform operations of the TUF to maximize fish passage and trap and haul success. The dataset is not yet robust enough to do so, but we anticipate that with continued data collection, results will guide operational recommendations for the TUF, and potentially the PUF.

References

Agostinho, A.A., Agostinho, C.S., Pelicice, F.M., and Marques, E.E. 2012. Fish ladders: safe fish passage or hotspot for predation? Neotrop. Ichthyol. **10**(4): 687–696. doi:10.1590/S1679-62252012000400001.

Alcott, D., Goerig, E., Rillahan, C., He, P., and Castro-Santos, T. 2021. Tide gates form physical and ecological obstacles to river herring (*Alosa* spp.) spawning migrations. Can. J. Fish. Aquat. Sci. **78**(7): 869–880. doi:10.1139/cjfas-2020-0347.

Allison, P.D. 1995. Survival analysis using the SAS system: a practical guide. SAS Institute, Cary, NC.

AMEC and LGL (AMEC Earth & Environmental, and LGL Limited). 2008. Peace River tributary spring spawning migration, tributary summer juvenile rearing and radio telemetry studies 2005.

AMEC and LGL (AMEC Earth & Environmental, and LGL Limited). 2009. Peace River and Pine River radio telemetry study 2008.

Anderson, D., and Burnham, K. 2004. Model selection and multi-model inference. Second. NY: Springer-Verlag 63.

Armstrong, J.D., and Herbert, N.A. 1997. Homing movements of displaced stream-dwelling brown trout. J. Fish Biol. **50**(2): 445–449. doi:10.1111/j.1095-8649.1997.tb01372.x.

Barnett, H.K., and Paige, D.K. 2013. Movements by adfluvial bull trout during the spawning season between lake and river habitats. Trans. Am. Fish. Soc. **142**(3): 876–883 doi:10.1080/00028487.2013.763858.

Baumgartner, L.J., Boys, C.A., Marsden, T., McPherson, J., Ning, N., Phonekhampheng, O., Robinson, W.A., Singhanouvong, D., Stuart, I.G., and Thorncraft, G. 2018. Comparing fishway designs for application in a large tropical river system. Ecol. Eng. **120**: 36–43. doi:10.1016/j.ecoleng.2018.05.027.

BC Government. 2011. Fish, wildlife and ecosystem resources and objectives for the Lower Peace River Watershed – Site C Project Area.

BC Hydro. 2012. Site C Clean Energy Project technical data report volume 2 appendix Q1: Fish passage management plan. Available from https://www.ceaa-acee.gc.ca/050/documents_staticpost/63919/85328/Vol2_Appendix_Q.pdf.

BC Hydro. 2020. Fish passage management plan. Site C Clean Energy Project. Revision 2: June 2, 2020. Available from http://sitecproject.com/sites/default/files/Fish Passage Management Plan.pdf.

BC Ministry of Environment. 2009. Ministry of Environment fish and wildlife interim objectives for Site C Project Area.

Beamish, R.J., and Northcote, T.G. 1989. Extinction of a population of anadromous parasitic lamprey, *lampetra tridentata*, upstream of an impassable dam. Can. J. Fish. Aquat. Sci. **46**(3): 420–425. doi:10.1139/f89-056.

Beauchamp, D.A., and Van Tassell, J.J. 2001. Modeling seasonal trophic interactions of adfluvial Bull Trout in Lake Billy Chinook, Oregon. Trans. Am. Fish. Soc. **130**(2): 204–216. doi:10.1577/1548-8659(2001)130<0204:MSTIOA>2.0.CO;2.

Benda, S.E., Naughton, G.P., Caudill, D.D., Kent, M.L., Schreck, C.B. 2015. Cool, pathogen-free refuge lowers pathogen-associated prespawn mortality of Willamette River Chinook salmon. Trans. Am. Fish. Soc. **144**(6): 1159–1172. doi:10.1080/00028487.2015.1073621.

Birnie-Gauvin, K., Franklin, P., Wilkes, M., and Aarestrup, K. 2019. Moving beyond fitting fish into equations: progressing the fish passage debate in the anthropocene. Aquat. Conserv. Mar. Freshw. Ecosyst. **29**(7): 1095–1105. doi:10.1002/aqc.2946.

Boggs, C.T., Keefer, M.L., Perry, C.A., Bjornn, T.C., and Stuehrenberg, L.C. 2004. Fallback, reascension and adjusted fishway escapement estimates for adult Chinook Salmon and Steelhead at Columbia and Snake River dams. Trans. Am. Fish. Soc. **133**(4): 932–949. doi:10.1577/T03-133.1.

Boulêtreau, S., Gaillagot, A., Carry, L., Tétard, S., De Oliveira, E., and Santoul, F. 2018. Adult Atlantic Salmon have a new freshwater predator. PLoS ONE **13**(4): e0196046. doi:/10.1371/journal.pone.0196046.

Bowerman, T., Keefer, M.L., and Caudill, C.C. 2016. Pacific salmon prespawn mortality: patterns, methods, and study design consideration. Fisheries. **41**(12):738–749. doi:10.1080/03632415.2016.1245993.

Brown, R.S., Geist, D.R. and Mesa, M.G. 2006. Use of electromyogram telemetry to assess swimming activity of adult spring Chinook salmon migrating past a Columbia River dam. Trans. Am. Fish. Soc. **135**(2). 281–287. doi:10.1577/T05-223.1.

Bunt, C.M., Castro-Santos, T., and Haro, A. 2012. Performance of fish passage structures at upstream barriers to migration. River Res. Appl. **28**(4): 457–478. doi:10.1002/rra.

Bunt, C.M., Castro-Santos, T., and Haro, A. 2016. Reinforcement and validation of the analyses and conclusions related to fishway evaluation data from Bunt et al.: 'Performance of fish passage structures at upstream barriers to migration'. River Res. Appl. **32**(10): 2125–2137. doi:10.1002/rra.3095.

Burnett, N.J., Hinch, S.G., Bett, N.N., Braun, D.C., Casselman, M.T., Cooke, S.J., Gelchu, A., Lingard, S., Middleton, C.T., Minke-Martin, V., and White, C.F.H. 2017. Reducing carryover effects on the migration and spawning success of Sockeye Salmon through a management experiment of dam flows. River Res. Appl. **33**(1): 3–15. doi:10.1002/rra.3051.

Burnett, N.J., Hinch, S.G., Braun, D.C., Casselman, M.T., Middleton, C.T., Wilson, S.M., and Cooke, S.J. 2014. Burst swimming in areas of high flow: delayed consequences of anaerobiosis in wild adult Sockeye Salmon. Physiol. Biochem. Zool. **87**(5): 587–598. doi:10.1086/677219.

Castro-Santos, T., and Haro, A. 2003. Quantifying migratory delay: a new application of survival analysis methods. Can. J. Fish. Aquat. Sci. **60**(8): 986–996. doi:10.1139/f03-086.

Castro-Santos, T., and Haro, A. 2010. Fish guidance and passage at barriers. Fish locomotion: an eco-ethological perspective.

Castro-Santos, T., and Perry, R. 2012. Time-to-event analysis as a framework for quantifying fish passage performance. Telemetry Techniques: a user guide for fisheries research. American Fisheries Society, Bethesda, Maryland. pp. 427–452.

Caudill, C.C., Daigle, W.R., Keefer, M.L., Boggs, C.T., Jepson, M.A., Burke, B.J., Zabel, R.W., Bjornn, T.C., and Peery, C.A. 2007. Slow dam passage in adult Columbia River salmonids associated with unsuccessful migration: delayed negative effects of passage obstacles or condition-dependent mortality? Can. J. Fish. Aquat. Sci. **64**(7): 979–995. doi:10.1139/F07-065.

Colvin, M.E., Peterson, J.T., Sharpe, C., Kent, M.L., Schreck, C.B. 2018. Identifying optimal hauling densities for adult Chinook Salmon trap-and-haul operations. River. Res. Appl. **34**(9): 1158–1167. doi:10.1002/rra.3348.

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

Cooke, S.J., and Hinch, S.G. 2013. Improving the reliability of fishway attraction and passage efficiency estimates to inform fishway engineering, science, and practice. Ecol. Eng. **58**: 123–132. doi:10.1016/j.ecoleng.2013.06.005.

Cooke, S.J., Paukert, C., and Hogan, Z. 2012. Endangered river fish: factors hindering conservation and restoration. Endanger. Species Res. **17**(2): 179–191. doi:10.3354/esr00426.

DeHaan, P.W., and Bernall, S.R. 2013. Spawning success of Bull Trout capture and transported above main-stem Clark Fork River dams in Idaho and Montana. N. Am. J. Fish. Manag. **33**(6). doi:10.1080/02755947.2013.839971.

DeWeber, J.T., Peterson, J.T., Sharpe, C., Kent, M.L., Colvin, M.E., and Schreck, C.B. 2017. A hidden-process model for estimating prespawn mortality using carcass survey data. N. Am. J. Fish. Manag. **37**(1): 162–175. doi:10.1080/02755947.2016.1245223.

Downs, C.C., Horan, D., Morgan-Harris, E., and Jakubowski, R. 2006. Spawning demographics and juvenile desperal of an adfluvial Bull Trout population in Trestle Creek, Idaho. N. Am. J. Fish. Manag. **26**(1):190–200. doi:10.1577/M04-180.1.

Enders, E.C., Boisclair, D., Roy, A.G. 2005. A model of total swimming costs in turbulent flow for juvenile Atlantic Salmon (*Salmo salar*). Can. J. Fish. Aquat. Sci. **62**(5): 1079–1089. doi:10.1139/f05-007.

ESRI 2020. ArcGIS Desktop: Version 10.8.1. Redlands, CA: Environmental Systems Research Institute.

Evans, M.L., Johnson, M.A., Jacobsen, D., Wang, J., Hogansen, M., and O'Malley, K.G. 2016. Evaulating a multi-generational reintroduction program for threatened salmon using genetic parentage analysis. Can. J. Fish. Aquat. Sci. **73**(5): 844–852. doi:10.1139/cjfas-2015-0317.

Ferguson, J.W., Healey, M., Dugan, P., and Barlow, C. 2011. Potential effects of dams on migratory fish in the Mekong River: lessons from salmon in the Fraser and Columbia rivers. 2011. Environ. Manag. **47**(1): 141–159. doi:10.1007/s00267-010-9563-6.

Ferguson J.W., Sandford, B.P., Reagan, R.R., Gilbreath, L.G., Meyer, E.B., Ledgerwood, R.D., and Adams, N.S. 2007. Bypass modification at Bonneville Dam on the Columbia River improved survival of juvenile salmon. Trans. Am. Fish. Soc. **136**(6): 1487–1510. doi:10.1577/T06-158.1.

Fraley, J.J., and Shepard, B. 1989. Life history, ecology and population status of migratory Bull Trout (*Salvelinus confluentus*) in the Flathead Lake and River system. Northwest Science. **63**(4): 133–143.

Fryer, J.K. 1998. Frequency of pinniped-caused scars and wounds on adult spring–summer Chinook and Sockeye Salmon returning to the Columbia River. N. Am. J. Fish. Manag. **18**(1): 46–51. doi:10.1577/1548-8675(1998)018<0046:FOPCSA>2.0.CO;2.

Fuentes-Pérez, J.F., Sanz-Ronda, F.J., de Azagra, A.M., and García-Vega, A. 2016. Non-uniform hydraulic behavior of pool-weir fishways: a tool to optimize its design and performance. Ecol. Eng. **86**: 5–12. doi:10.1016/j.ecoleng.2015.10.021.

Furey, N.B., Hinch, S.G., Mesa, M.G., and Beauchamp, D.A. 2016. Piscivorous fish exhibit temperature-influenced binge feeding during an annual prey pulse. J. Anim. Ecol. **85**(5): 1307–1317. doi:10.1111/1365-2656.12565.

Furey, N.B. and Hinch, S.G. 2017. Bull Trout movements match the life history of Sockeye Salmon: consumers can exploit seasonally distinct resource pulses. Trans. Am. Fish. Soc. **146**(3): 450–461. doi:10.1080/00028487.2017.1285353.

Geraldes, A., and Taylor, E.B. 2022. Site C Clean Energy Project – Fish Genetics Study – 2021 Status Report for Bull Trout, Arctic Grayling and Rainbow Trout Construction Year 7 (2021). Report prepared for BC Hydro, Vancouver BC.

Goerig, E., and Castro-Santos, T. 2017. Is motivation important to brook trout passage through culverts? Can. J. Fish. Aquat. Sci. **74**(6): 885–893. doi:10.1139/cjfas-2016-0237.

Golder (Golder Associates Ltd). 2021. Peace River Large Fish Indexing Survey – 2020 Investigations. Report prepared for BC Hydro, Vancouver, British Columbia. Golder Report No. 20136470-015. 98 pages + 6 appendices.

Golder (Golder Associates Ltd). 2022. Contingent fish capture and transport. Golder Tehcnicam Memorandum No. 20136470-017. 20 pages + 3 appendices.

Harris, J.E., and Hightower, J.E. 2011. Movement patterns of american shad transported upstream of dams on the Roanoke River, North Carolina and Virginia. N. Am. J. Fish. Manag. **31**(2): 240–256. doi:10.1080/02755947.2011.572806.

Hatch, K., Robichaud, D., and Fitzgerald, C. 2021. Site C Clean Energy Project – Site C Reservoir Tributaries Fish Community and Spawning Monitoring Program (Mon-1b) Task Task 2a – Peace River Arctic Grayling and Bull Trout Movement Assessment – Task 2d – Site C Fish Movement Assessment – Construction Year 6 (2020). Report prepared for BC Hydro – Site C Clean Energy Project.

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

Hosmer, D. W., Jr., and S. Lemeshow, S. 1999. Applied survival analysis: time-to-Event (Vol. 317). Wiley-Interscience.

Keefer, M.L., Taylor, G.A., Garletts, D.F., Gauthier, G.A., Pierce, T.M., and Caudill, C.C. 2010. Prespawn mortality in adult spring Chinook salmon outplanted above barrier dams. Ecol. Freshw. Fish. **19**(3): 361–372. doi:10.1111/j.1600-0633.2010.00418.x.

Keefer, M.L., Caudill, C.C., Peery, C.A. and Moser, M.L. 2013. Context-dependent diel behavior of upstream-migrating anadromous fishes. Environ. Biol. Fishes. **96**(6): 691–700. doi:10.1007/s10641-012-0059-5.

Kock T.J., Ekstrom, B.K., Liedtke, T.L., Serl, J.D., and Kohn, M. 2016. Behavior patterns and fates of adult Steelhead, Chinook Salmon, and Coho Salmon released into the upper Cowlitz River Basin, Washington, 2005–09 and 2012: U.S. Geological Survey Open-File Report 2016–1144. doi:10.3133/ofr20161.

Kock, T.J., Ferguson, J.W., Keefer, M.L., Schreck, C.B. 2021. Review of trap-and-haul for managing Pacific salmonids (*Oncorhynchus* spp.) in impounded river systems. Rev. Fish Biol. Fish. **31**: 53-94. doi:10.1007/s11160-020-09627-7.

Kock, T.J., Perry, R.W., Pope, A.C., Serl, J.D., Kohn, M., and Liedtke, T.L. 2018. Responses of hatchery- and natural-origin adult spring Chinook Salmon to a trap-and-haul reintroduction program. N. Am. J. Fish. Manag. **38**(5): 1004–1016. doi:10.1002/nafm.10199.

Liao, J.C. 2007. A review of fish swimming mechanics and behaviour in altered flows. Philos. Trans. R. Soc. B. **362**(1487): 1973–1993. doi:10.1098/ rstb.2007.2082.

Liedtke, T.L., Beeman, J.W., and Gee, L.P. 2012. A standard operating procedure for the surgical implantation of transmitters in juvenile salmonids: U.S. Geological Survey Open-File Report 2012-1267. 50 p.

Liedtke, T.L., Kock, T.J., and Rondorf, D.W. 2013. Evaluation of the behavior and movement patterns of adult Coho Salmon and Steelhead in the North Fork Toutle River, Washington, 2005–2009: U.S. Geological Survey Open-File Report 2013–1290. doi:10.3133/ofr20131290.

Lusardi, R.A., and Moyle, P.B. 2017. Two-way trap and haul as a conservation strategy for anadromous salmonids. Fisheries. **42**(9): 478–487. doi:10.1080/03632415.2017.1356124.

Mainstream (Mainstream Aquatics Ltd). 2012. Site C Clean Energy Project - Fish and Fish Habitat Technical Data Report. Prepared for BC Hydro Site C Project, Corporate Affairs Report No. 12002F. Edmonton Alberta. 239 p.

McMahon, T.E., and Bennett, D.H. 1996. Walleye and northern pike. Fisheries. **21**(8): 6–13. doi:10.1577/1548-8446(1996)021<0006:WANP>2.0.CO;2.

McMillen. 2014. Site C Clean Energy Project Temprary Fish Passage CFD Model Report.

McMillen Jacobs & Associates and BC Hydro. 2022. Site C Clean Energy Project, Temporary Upstream Fish Passage Facility, Manual of Operational Parameters and Procedures. 49 p. + 2 Apps.

McPhail, J.D., and Baxter, J.S. 1996. A review of Bull Trout (*Salvelinus confluentus*) life-history and habitat use in relation to compensation and improvement opportunities. Fisheries Management Report No. 104 ISSN 0705-5390.

Minsky, M. 1961. Steps toward artifical intelligence. Proc. IRE: **49**(1): 8–30. doi:10.1109/JRPROC.1961.287775

Mosser, C.M., Thompson, L.C., and Strange, J.S. 2013. Survival of captured and relocated adult spring-run Chinook Salmon *Oncorhynchus tshawytscha* in a Sacramento River tributary after cessation of migration. Environ. Biol. Fish **96**: 405–417. doi:10.1007/s10641-012-0046-x.

Muhlfeld, C.C., Glutting, S., Hunt, R., Daniels, D., and Marotz, B. 2003. Winter diel habitat use and movement by subadult Bull Trout in the Upper Flathead River, Montana. N. Am. J. Fish. Manag. **23**(1): 163–171. doi:10.1577/1548-8675(2003)023<0163:WDHUAM>2.0.CO;2.

Namen, S., Rosenfeld, J, and Lannan, A.S. 2022. Diel patterns of foraging and microhabitat use by sympatric rainbow trout and bull trout: implications for adaptive differentiation and instream flow assessment. Can. J. Fish. Aquat. Sci. **79**(2) doi:10.1139/cjfas-2020-0475.

NMFS (National Marine Fisheries Service), 2011. Anadromous Salmonid Passage Facility Design. National Marine Fisheries Service (NMFS), Northwest Region, Portland, Oregon.

Naughton, G.P., Caudill, C.C., Keefer, M.L., Bjornn, T.C., Peery, C.A., and Stuehrenberg, L.C. 2006. Fallback by adult Sockeye Salmon at Columbia River dams. N. Am. J. Fish. Manag. **26**(2): 380–390. doi:10.1577/M05-015.1.

Naughton, G.P., Keefer, M.L., Clabough, T.S., Knoff, M.J., Blubaugh, T.J., Sharpe, C., and Caudill, C.C. 2018. Reservoir provides coolwater refuge for adult Chinook Salmon in a trap-and-haul reintroduction program. Mar. Freshw. Res. **69**(12):1995–2007. doi:10.1071/MF18124.

Nebiolo, K.P. 2021. BIO-Telemetry Analysis Software (BIOTAS) for use in removing false positive and overlap detections from radio telemetry projects. Version 0.0.3. Available from https://pypi.org/project/biotas/.

Nebiolo, K., and Castro-Santos, T. 2022. Using a Naïve Bayes Classifier to Remove False Positives from Radio-Telemetry Data. Anim. Biotelemetry. **10**(2). doi:10.1186/s40317-022-00273-3.

Nehlsen, W., Williams, J.E., and Lichatowich, J.A. 1991. Pacific salmon at the crossroads: atocks at risk from California, Oregon, Idaho, and Washington. Fisheries **16**(2): 4–21. doi:10.1577/1548-8446(1991)016<0004:PSATCS>2.0.CO;2.

Noonan, M.J., Grant, J.W.A., and Jackson, C.D. 2012. A quantitative assessment of fish passage efficiency. Fish and Fisheries. **13**(4): 450–464. doi:10.1111/j.1467-

2979.2011.00445.x.

Northcote, T.G., and Ennis, G.L. 1994. Mountain Whitefish biology and habitat use in relation to compensation and improvement possibilities. Rev. Fish. Sci. **2**(4): 347–371. doi:10.1080/10641269409388563.

O’Malley, K.G., Evans, M.E., Johson, M.A., Jacobsen, D., and Hogansen, M. 2015. An evaluation of spring-Chinook Salmon reintroductions above Detroit Dam, North Santiam River, using genetic pedigree analysis. Prepared for U.S. Army Corps of Engineers, Portland District, Portland, Oregon.

Patterson, D.A., Robinson, K.A., Lennox, R.J., Nettles, T.L., Donaldson, L.A., Eliason, E.J., Raby, G.D., Chapman, J.M., Cook, K.V., Donaldson, M.R., Bass, A.L., Drenner, S.M., Reid, A.J., Cooke, S.J., and Hinch, S.G. 2017. Review and Evaluation of Fishing-Related Incidental Mortality for Pacific Salmon. DFO Can. Sci. Advis. Sec. Res. Doc. 2017/010. ix +155 p.

Pavlov, D.S., Lupandin, A.I., and Skorobogatov, M.A. 2000. The effect of flow turbulence on the behavoir and distribution of fish. J. Ichtyol. **40**(Suppl. 2): 232–261.

Portz, D.E., Woodley, C.M., Cech Jr., J.J. 2006. Stress-associated impacts of short-term holding on fishes. Rev. Fish. Biol. Fisheries. **16**: 125–170. doi:10.1007/s11160-006-9012-z.

Putt, A., Ramos-Espinoza, D., and Chung, M. 2021. Site C Reservoir Tributaries Fish Community and Spawning Monitoring Program – 2020 Peace River Bull Trout Spawning Assessment (Mon-1b, Task 2b). Report prepared for BC Hydro – Site C Clean Energy Project.

R Core Team. 2021. R: A language and Environment for Statistical Computing. Vienne, Austria. Available from https://www.r-project.org/.

Reebs, S.G. 2002. Plasticity of diel and circadian activity rhythms in fishes. Rev. Fish. Biol. Fisheries. **12**(4): 349–371. doi:10.1023/A:1025371804611.

Reebs, S.G., Boudreau, L., Hardie, P., and Cunjak, R.A., 1995. Diel activity patterns of lake chubs and other fishes in a temperate stream. Can. J. Zool. **73**(7): 1221–1227. doi:10.1139/z95-146.

Rieman, B.E., Beamesderfer, R.C., Vigg, S., and Poe, T.P. 1991. Estimated loss of juvenile salmonids to predation by Northern Sqaufish, Walleyes, and Smallmouth Bass in John Day Reservoir, Columbia River. Trans. Am. Fish. Soc. **120**(4): 421–438. doi:10.1577/1548-8659(1991)120<0448:ELOJST>2.3.CO;2.

Rillahan, C.B., Alcott, D., Castro-Santos, T., and He., P. 2021. Activity patterns of anadromous fish below a tide gate: observations from high-resolution imagine sonar. Mar. Coast. Fish. **13**(3): 200–212. doi:10.1002/mcf2.10149.

Roscoe, D.W., and Hinch, S.G. 2010. Effectiveness monitoring of fish passage facilities: historical trends, geographic patterns and future directions. Fish and Fisheries. **11**(1): 12–33. doi:10.1111/j.1467-2979.2009.00333.x.

Reischel, T. S., and T.C. Bjornn. 2003. Influence of fishway placement on fallback of adult salmon at the Bonneville Dam on the Columbia River. N. Am. J. Fish. Manag. **23**(4): 1215–1224. doi:10.1577/M05-015.1.

Sard, N. M., Johnson, M. A., Jacobsen, D. P., Hogansen, M. J., O'Malley, K. G., and Banks, M. A. 2016. Genetic monitoring guides adaptive management of a migratory fish reintroduction program. Anim. Conserv. **19**(6): 570–577. doi:10.1111/acv.12278.

Schmetterling, D. A. 2003. Reconnecting a fragmented river: movements of westslope cutthroat trout and bull trout after transport upstream of Milltown Dam, Montana. N. Am. J. Fish. Manag. **23**(3): 721–731. doi:10.1577/M01-216.

Schwalme, K., Mackay, W.C., and Lindner, D. 1985. Suitability of vertical slot and denil fishways for passing north-temperature, nonsalmonid. Fish. Can. J. Fish. Aquat. Sci. **42**(11): 1815–1822. doi:10.1139/f85-227.

Sigourney, D.B., Zydlewski, J.D., Hughes, E., and Cox, O. 2015. Transport, dam passage, and size selection of adult Atlantic Salmon in the Penobscot River, Maine. N. Am. J. Fish. Manag. **35**(6): 1164-1176. doi:10.1080/02755947.2015.1099578.

Silva, A.T., Lucas, M.C., Castro-Santos, T., Katopodis, C., Baumgartner, L.J., Thiem, J.D., Aarestrup, K., Pompeu, P.S., O'Brien, G.C., Braun, D.C., Burnett, N.J., Zhu, D.Z., Fjeldstad, H.P., Forseth, T., Rajaratnam, N., Williams, J.G., and Cooke, S.J. 2018. The future of fish passage science, engineering, and practice. Fish and Fisheries. **19**(2): 340–362. doi:10.1111/faf.12258.

Smith, J., Robichaud, D., and Hatch, K. 2022. Walleye Spawning and Rearing Use Survey

(Mon-2, Task 2e) 2021. Report for BC Hydro, Vancouver, BC.

Stewart, D.B., Mochnacz, C.D., Sawatzky,T.J., Carmichael, and Reist, J.D. 2007. Fish diets and food webs in the Northwest Territories: Bull Trout (*Salvelinus confluentus*). Canadian Manuscript Report of Fisheries and Aquatic Sciences 2800: vi + 18 p.

Swanberg, T.R. 1997. Movements of and habitat use by fluvial Bull Trout in the Blackfoot River, Montana. Trans. Am. Fish. Soc. **126**(5): 735–746. doi:10.1577/1548-8659(1997)126<0735:MOAHUB>2.3.CO;2.

Swarr, T.R. 2018. Improving rock ramp fishways for small-bodied Great Plains fishes. Colorado State University.

Tackley, S.C., Stansell, R.J. and Gibbons, K.M. 2008. Pinniped predation on adult salmonids and other fish in the Bonneville Dam tailrace, 2005–2007. U.S. Army Corps of Engineers 59.

Taylor, M. and Lewis, B. 2011. CLBMON-18 Middle Columbia River Adult Fish Habitat Use Program. Study Period: Year 3 – 2010. Golder Associates (Castlegar, BC) and Carleton University (Ottawa, ON). Report prepared for BC Hydro, Revelstoke Flow Management Plan, Golder Project No. 10-1492-0082. 81 p. + 2 app.

Therneau, T. 2022. Survival Analysis. R package version 3.3-1. Available from https://cran.r-project.org/package=survival.

Therneau, T.M., Grambsch, P.M., and Pankratz, V.S. 2003. Penalized survival models and frailty. J. Comput. Graph. Stat. **12**(1): 156–175. doi:10.1198/1061860031365.

Thiem, J.D., Binder, T.R., Dumont, P., Hatin, D., Hatry, C., Katopodis, C., Stamplecoskie, K.M., and Cooke, S.J. 2012. Multispecies fish passage behaviour in a vertical slow fishway on the Richelius River, Quebec, Canada. River Res. Appl. **29**(5): 582–592. doi:10.1002/rra.

Thieurmel, B, and Elmarhraoui, A. 2019. Compute Sun Position, Sunlight Phases, Moon Position and Lunar Phase. R package version 0.5.0. Available from https://CRAN.R-project.org/package=suncalc.

Vigg, S., Poe, T.P., Prednergast, L.A., and Hansel, H.C. 1991. Rates of consumption of juvenile salmonids and alternative prey fish by Northern Squawfish, Walleye, Smallmouth Bass, and Channel Catfish in John Day Reservoir, Columbia River. Trans. Am. Fish. Soc. **120**(4):

421–438. doi:10.1577/1548-8659(1991)120<0421:ROCOJS>2.3.CO;2.

Watson, B.M., Biagi, C.A., Northrup, S.L., Ohata, M.L., Charles, C., Blanchfield, P.J., Johnston, S.V., Askey, P.J., van Poorten, B.T., and Devlin, R.H. 2019. Distinct diel and seasonal behaviours in rainbow trout detected by fine-scale acoustic telemetry in a lake environment. Can. J. Fish. Aquat. Sci. **76**(8): 1–14. doi:10.1139/cjfas-2018-0293.

Williams, J.G., Armstrong, G., Katopodis, C., Larinier, M., and Travade, F. 2012. Thinking Like a Fish: A Key Ingredient for Development of Effective Fish Passage Facilities at River Obstructions. River Res. Appl. **28**(4): 407–417. doi:10.1002/rra.1551.

Appendix A: PIT Read Range Results

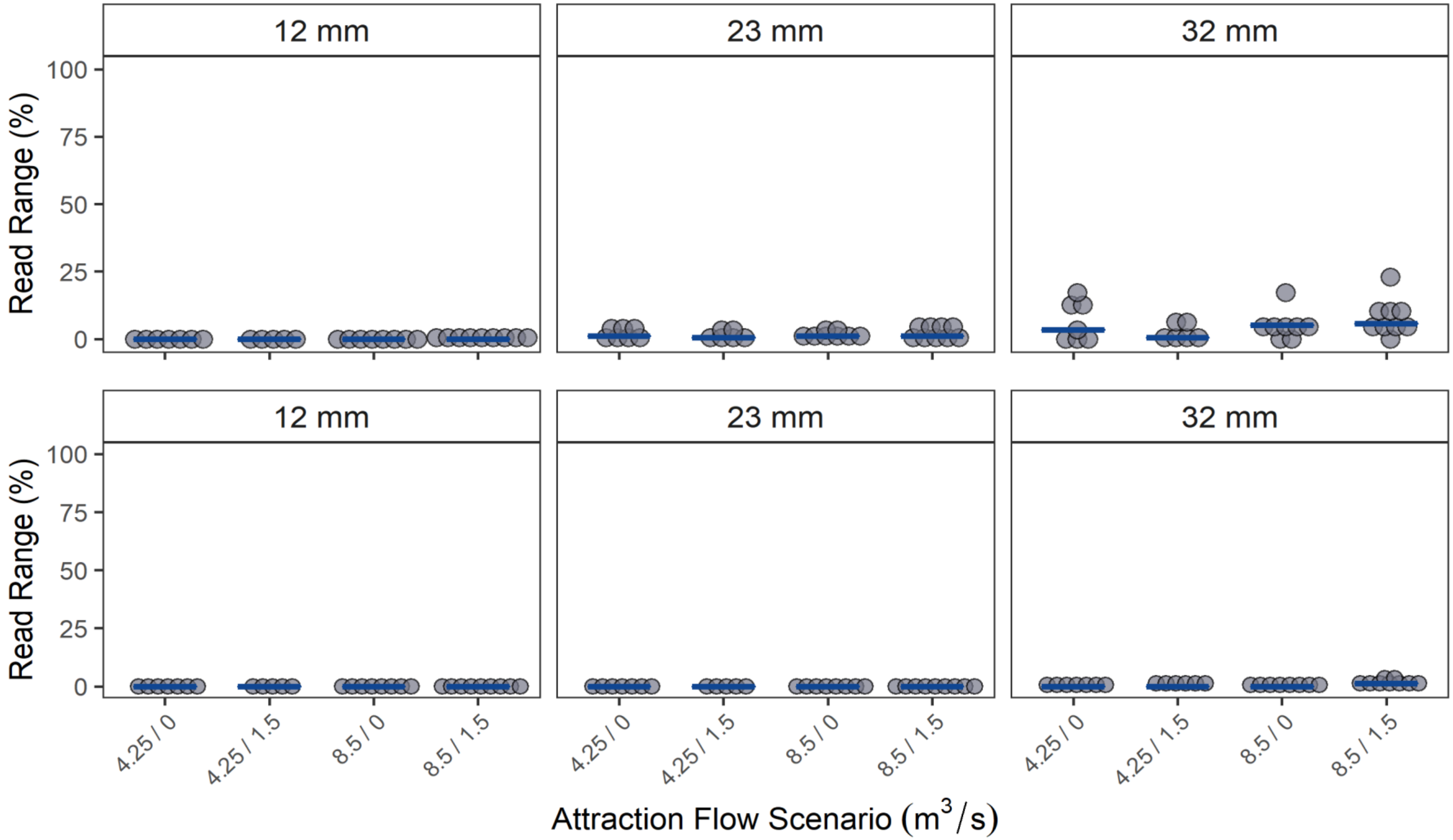

Figure A1 East (top) and west (bottom) entrance PIT antenna read ranges by tag size and attraction flow scenario. Blue lines indicate median read ranges.

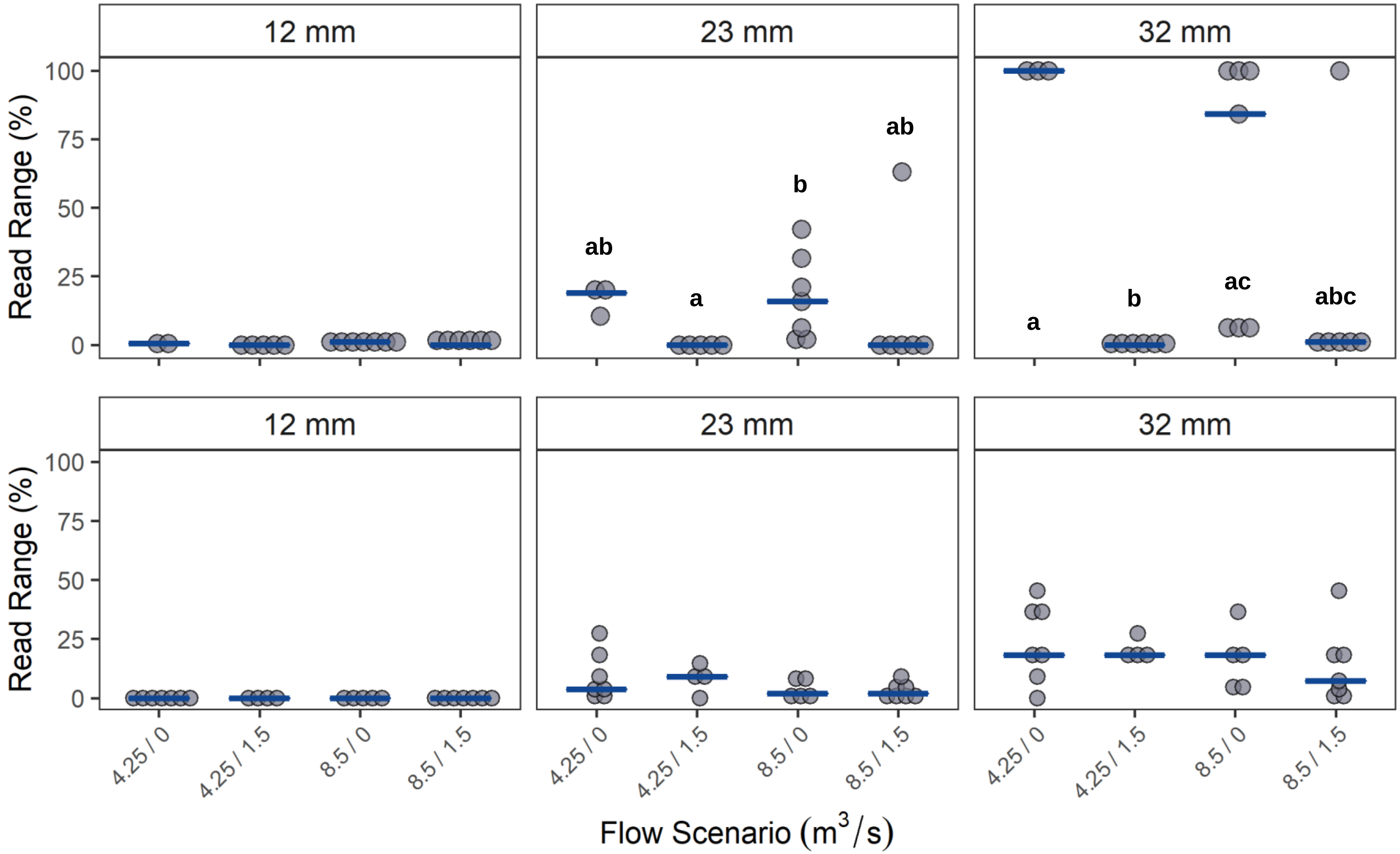

Figure A2 Weir (top) and orifice (bottom) 8 percent read ranges by tag size and attraction flow scenario. Blue lines indicate median read ranges. Letters denote statistically significant differences in percent read range among attraction flow scenarios.

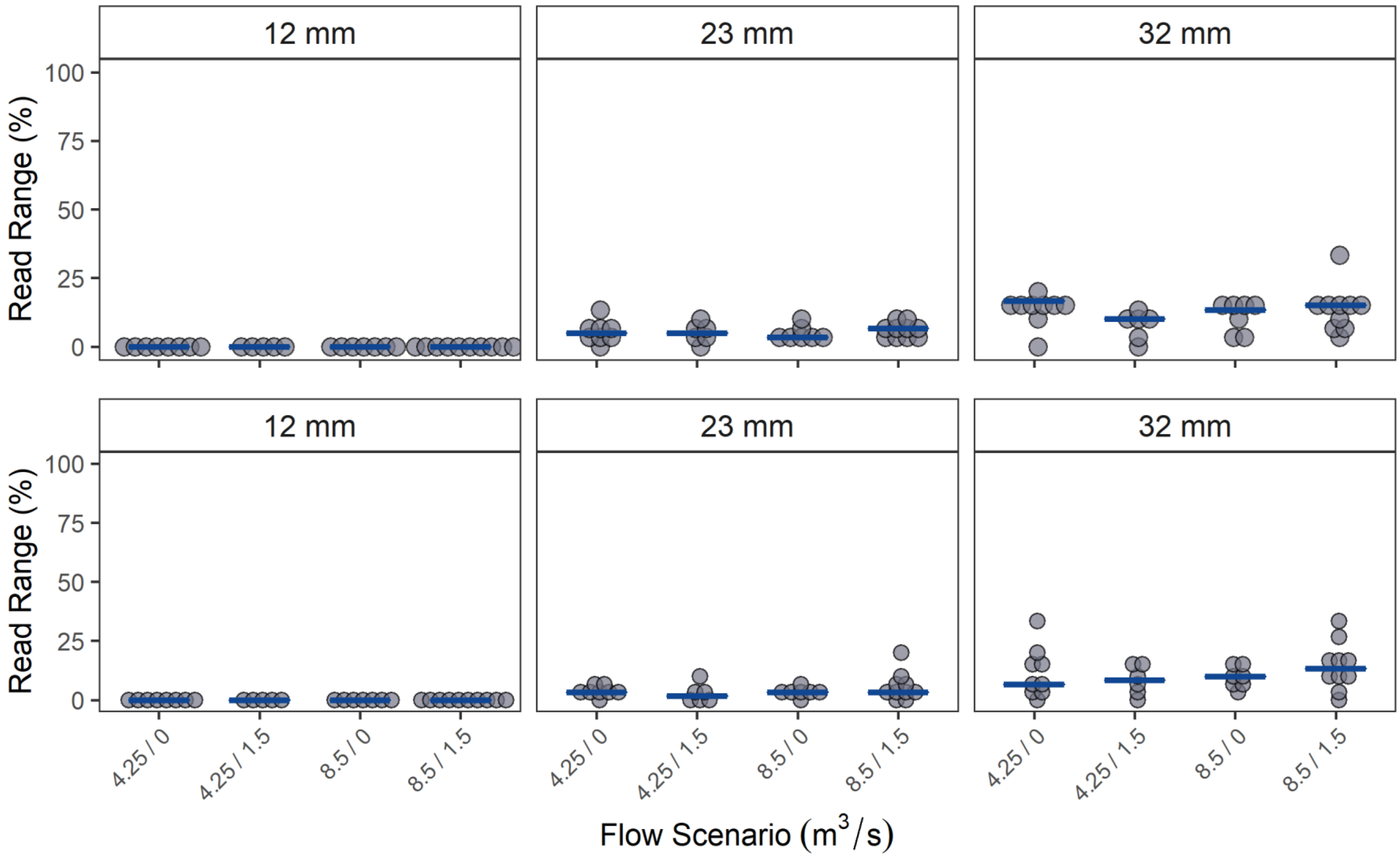

Figure A3 Weir (top) and orifice (bottom) 23 PIT antenna read ranges by tag size and attraction flow scenario. Blue lines indicate median read ranges.

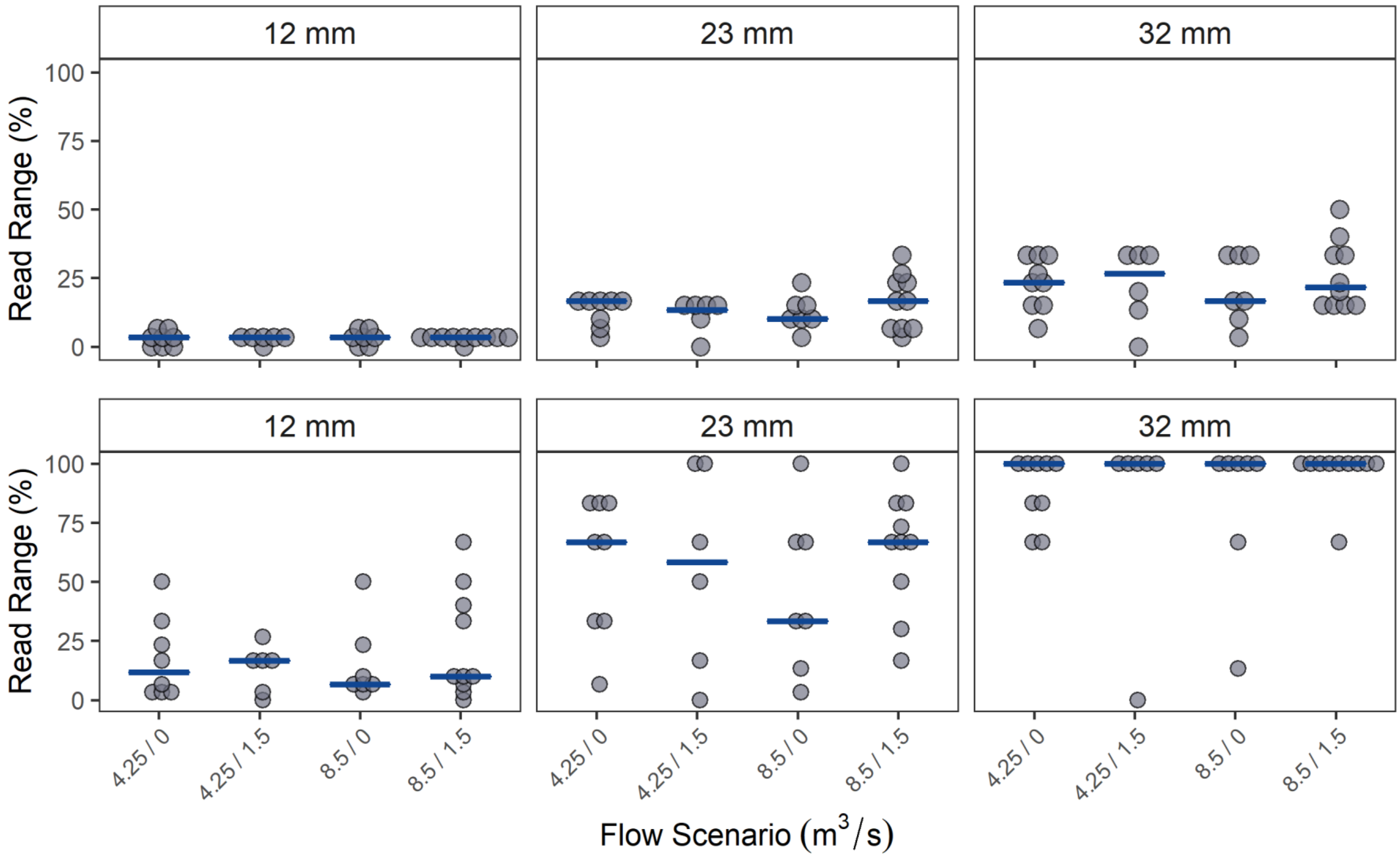

Figure A4 Weir (top) and orifice (bottom) 24 PIT antenna read ranges by tag size and attraction flow scenario. Blue lines indicate median read ranges.

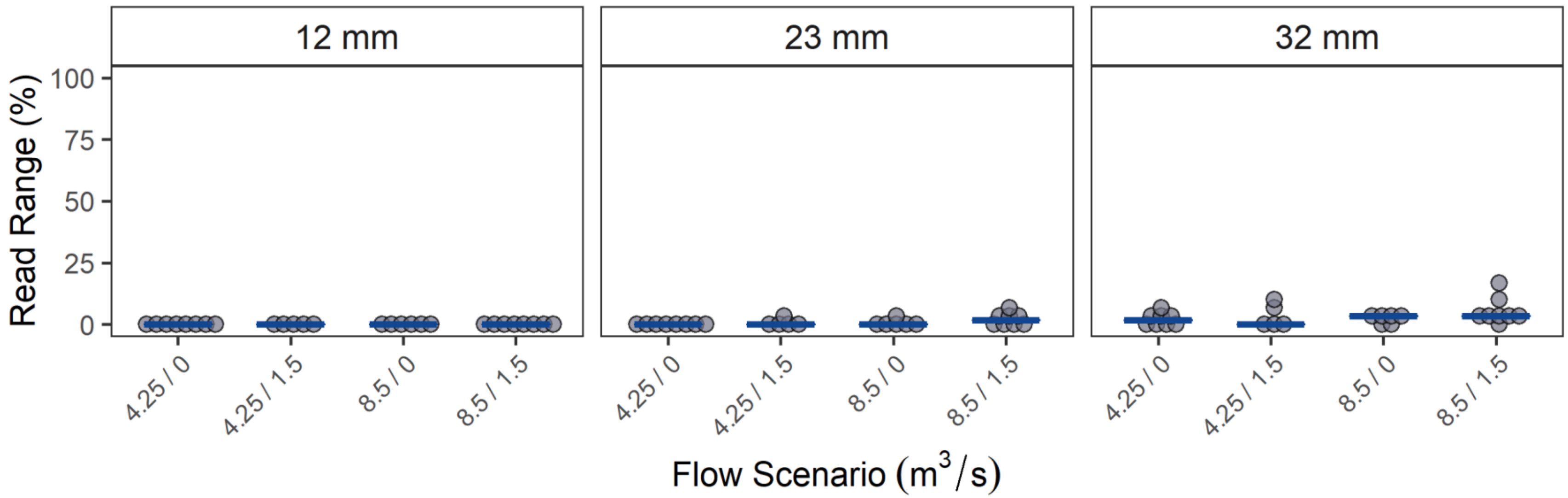

Figure A5 Vee-trap PIT antenna read ranges by tag size and attraction flow scenario. Blue lines indicate median read ranges.

Table A1 Percent read ranges of PIT antennas measured during the 2021 operational period. Results are presented for 12-, 23-, and 32-mm PIT tags and the four attraction flow scenarios from the auxiliary water supply (AWS) and high velocity jet (HVJ). Superscripts denote statistically significant differences in read ranges among flow scenarios.

Antenna	AWS Flow	HVJ Flow	Read Range (%)		
			12-mm Tags	23-mm Tags	32-mm Tags
East entrance	4.25	0	0.0 (n=7)	0.0 (n=7)	0.0 (n=7)
	4.25	1.5	0.0 (n=5)	0.0 (n=5)	0.0 (n=6)
	8.5	0	0.0 (n=8)	0.0 (n=8)	0.0 (n=8)
	8.5	1.5	0.0 (n=9)	0.0 (n=9)	1.1 (n=9)
West entrance	4.25	0	0.0 (n=7)	1.1 (n=7)	3.4 (n=7)
	4.25	1.5	0.0 (n=5)	0.6 (n=6)	0.6 (n=6)
	8.5	0	0.0 (n=8)	1.1 (n=8)	5.2 (n=8)
	8.5	1.5	0.0 (n=9)	1.1 (n=9)	5.7 (n=9)
Orifice 8	4.25	0	0.0 (n=7)	3.6 (n=7)	18.2 (n=7)
	4.25	1.5	0.0 (n=4)	9.1 (n=4)	18.2 (n=4)
	8.5	0	0.0 (n=5)	1.8 (n=5)	18.2 (n=5)
	8.5	1.5	0.0 (n=7)	1.8 (n=7)	7.3 (n=7)
Weir 8	4.25	0	0.5 (n=2)	18.9^{ab} (n=3)	100.0^{a} (n=3)
	4.25	1.5	0.0 (n=5)	0.0^{a} (n=5)	0.0^{b} (n=6)
	8.5	0	1.1 (n=7)	15.8^{b} (n=7)	84.2^{ac} (n=7)
	8.5	1.5	0.0 (n=8)	0.0^{ab} (n=8)	1.1^{abc} (n=8)

Table B1 continued.

Antenna	AWS Flow	HVJ Flow	Read Range		
			12-mm Tags	23-mm Tags	32-mm Tags
Orifice 23	4.25	0	0.0 (n=8)	3.3 (n=8)	6.7 (n=9)
	4.25	1.5	0.0 (n=5)	1.7 (n=6)	8.3 (n=6)
	8.5	0	0.0 (n=7)	3.3 (n=7)	10.0 (n=7)
	8.5	1.5	0.0 (n=10)	3.3 (n=10)	13.3 (n=10)
Wier 23	4.25	0	0.0 (n=8)	5.0 (n=8)	16.7 (n=9)
	4.25	1.5	0.0 (n=5)	5.0 (n=6)	10.0 (n=6)
	8.5	0	0.0 (n=7)	3.3 (n=7)	13.3 (n=7)
	8.5	1.5	0.0 (n=10)	6.7 (n=10)	15.0 (n=10)
Orifice 24	4.25	0	11.7 (n=8)	66.7(n=8)	100.0 (n=9)
	4.25	1.5	16.7 (n=6)	58.3 (n=6)	100.0 (n=6)
	8.5	0	6.7 (n=7)	33.3 (n=7)	100.0 (n=7)
	8.5	1.5	10.0 (n=10)	66.7 (n=10)	100.0 (n=10)
Weir 24	4.25	0	3.3 (n=8)	16.7 (n=8)	23.3 (n=9)
	4.25	1.5	3.3 (n=6)	13.3 (n=6)	26.7 (n=6)
	8.5	0	3.3 (n=7)	10.0 (n=7)	16.7 (n=7)
	8.5	1.5	3.3 (n=10)	16.7 (n=10)	21.7 (n=10)
Vee-trap	4.25	0	0.0 (n=8)	0.0 (n=8)	1.7 (n=8)
	4.25	1.5	0.0 (n=5)	0.0 (n=5)	0.0 (n=5)
	8.5	0	0.0 (n=6)	0.0 (n=6)	3.3 (n=6)
	8.5	1.5	0.0 (n=8)	1.7 (n=8)	3.3 (n=8)

Appendix B: Cumulative Incidence Curves

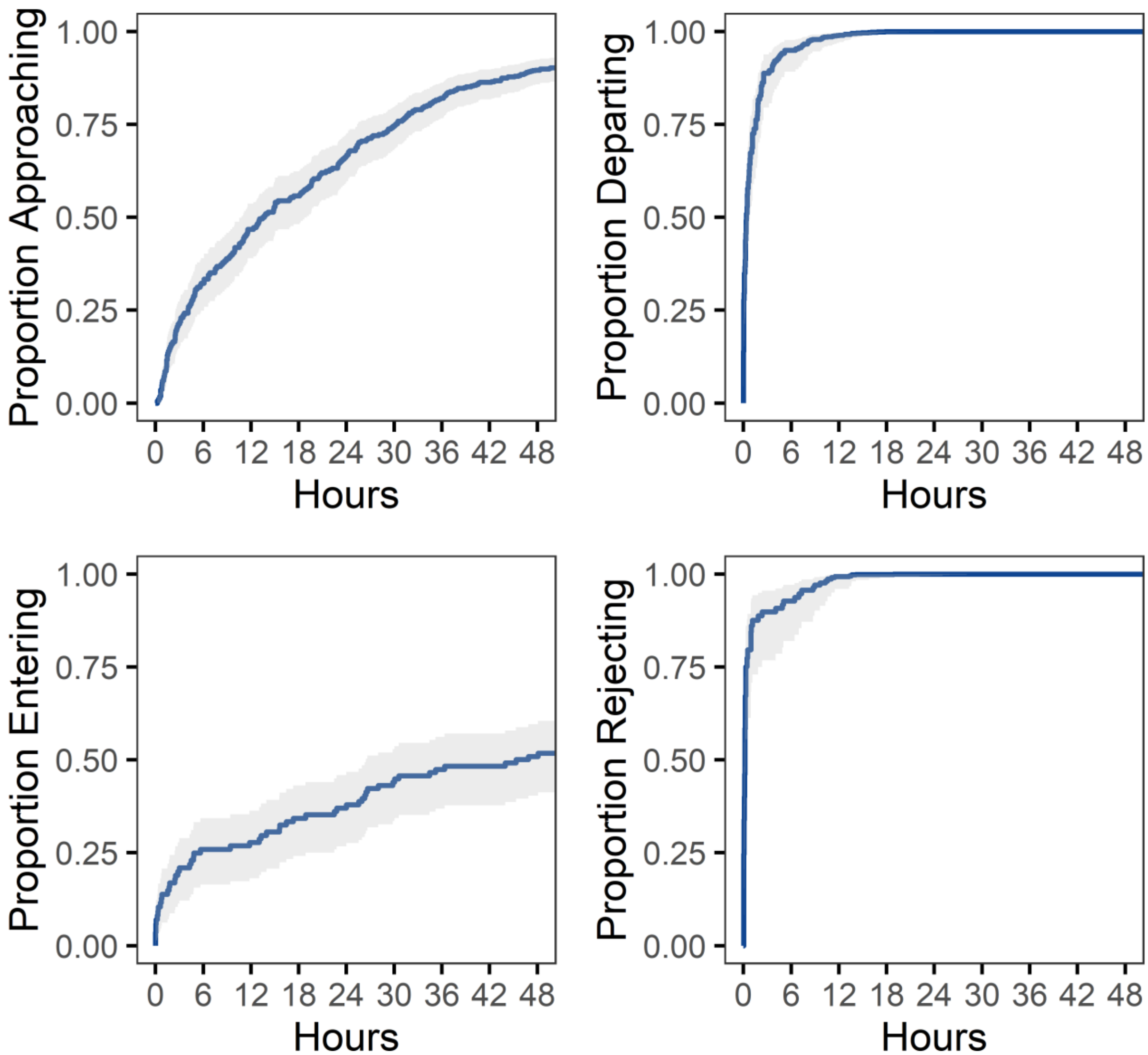

Figure B1 Cumulative incidence curves representing the proportion of available Bull Trout approaching the entry zone (top left), departing from the entry zone (top right), advancing to the fishway (bottom left), and rejecting the fishway (bottom right) over time.

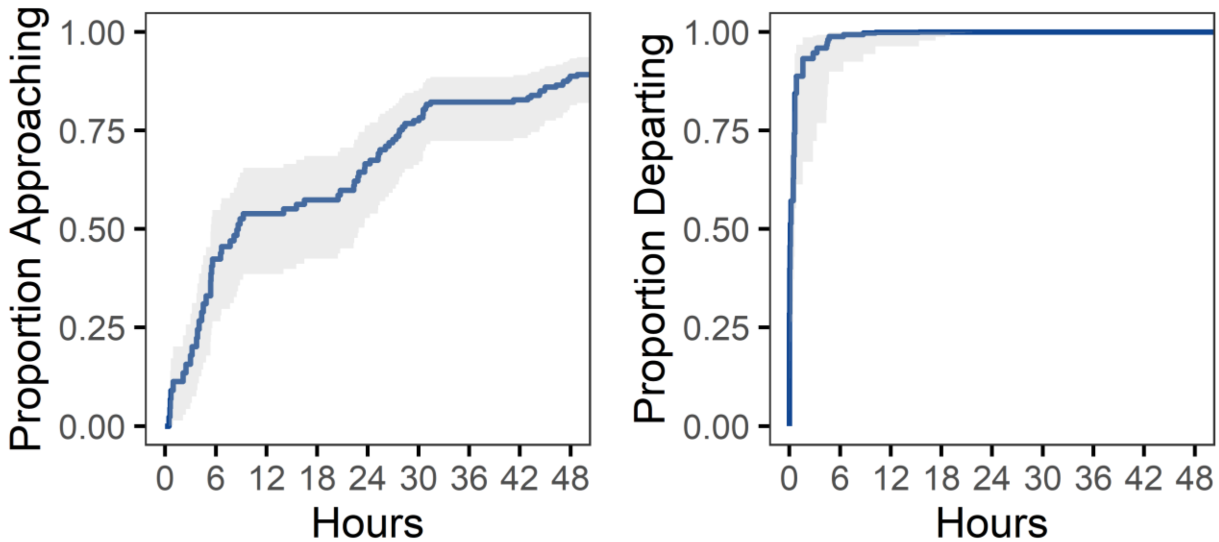

Figure B2 Cumulative incidence curves representing the proportion of available Mountain Whitefish approaching (left) and departing (right) the entry zone over time.

Appendix C: Competing Cox Time-to-Event Models

Table C1 Competing Cox time-to-event models for rates of advancement from the approach zone to entry zone (i.e., approach rate) based on Akaike information criterion (AIC). Arctic Grayling, Burbot, and Rainbow Trout were not modelled because of low sample sizes.

Species	Covariates	ΔAIC	AICw	LogLik
Bull Trout	Season + Diel + Discharge	0.00	0.200	-2500.53
	Transitions + Season + Diel + Discharge	0.23	0.178	-2500.27
	Season + Diel + Discharge + AWS	1.81	0.081	-2500.43
	Season + Diel + Discharge + Total Attraction Flow	1.82	0.080	-2500.45
	Season + Diel + Discharge + HVJ	1.98	0.074	-2500.52
Mountain Whitefish	Transitions + Diel + WSEL	0.00	0.098	-481.35
	Transitions + Diel + Discharge	0.06	0.095	-481.33
	Transitions + Season + Diel + WSEL	0.42	0.079	-482.40
	Transitions + Season + Diel + Discharge	0.47	0.077	-482.34
	Transitions + Diel + Discharge + HVJ	0.92	0.062	-480.76
	Transitions + Diel + WSEL + HVJ	1.11	0.056	-480.90
	Transitions + Diel + WSEL + AWS	1.31	0.051	-480.01
	Transitions + Season + Diel + Discharge + HVJ	1.33	0.050	-481.77
	Transitions + Season + Diel + WSEL + HVJ	1.53	0.045	-481.954
	Transitions + Diel + Discharge + AWS	1.60	0.044	-481.11
	Transitions + Diel + WSEL + Total Attraction Flow	1.75	0.041	-481.23
	Transitions + Season + Diel + WSEL + AWS	1.76	0.040	-481.09
	Transitions + Diel + Discharge + Total Attraction Flow	1.95	0.037	-481.28

Table C2 Competing Cox time-to-event models for rates of retreat from the entry zone to the approach zone (i.e., departure rate) based on Akaike information criterion (AIC). Arctic Grayling, Burbot, and Rainbow Trout were not modelled because of low sample sizes.

Species	Covariates	ΔAIC	AICw	LogLik
Bull Trout	Transitions + Season + Diel + WSEL	0.00	0.089	-673.86
	Transitions + Season + Diel + Attraction Flow Scenario	0.11	0.084	-674.43
	Transitions + Season + Diel + Temperature	0.48	0.070	-674.68
	Transitions + Season + Diel + Discharge	0.53	0.068	-674.14
	Transitions + Season + Diel + WSEL + HVJ	1.52	0.041	673.73
	Transitions + Season + Diel + Criteria	1.55	0.041	-674.73
	Transitions + Season + Diel + WSEL + AWS	1.78	0.036	-673.79
	Transitions + Season + Diel + WSEL + Attraction Flow Scenario	1.79	0.036	-670.98
	Season + Diel + Discharge + Attraction Flow Scenario	1.92	0.034	-673.84
	Transitions + Season + Diel + WSEL + Total Attraction Flow	1.93	0.034	-673.84
Mountain Whitefish	Transitions + Day + AWS	0.00	0.125	-69.33
	Day + AWS	0.47	0.099	-70.56
	Transitions + Day + Total Attraction Flow	0.47	0.099	-69.56
	Day + Total Attraction Flow	0.56	0.094	70.61
	Transitions + Day + AWS + HVJ	1.97	0.047	-69.31

Table C3 Competing Cox time-to-event models for rates of advancement from the entry zone to the fishway (i.e., entry rate) based on Akaike information criterion (AIC). Arctic Grayling, Burbot, Mountain Whitefish, and Rainbow Trout were not modelled because of low sample sizes.

Species	Covariates	ΔAIC	AICw	LogLik
Bull Trout	Transitions + Season + Diel + Criteria + Total Attraction Flow	0.00	0.185	-333.43
	Transitions + Season + Diel + Criteria + AWS	0.02	0.183	-333.68
	Season + Diel + Criteria + AWS	0.13	0.174	-331.65
	Season + Diel + Criteria + Total Attraction Flow	0.34	0.156	-331.72
	Transitions + Season + Diel + Criteria + AWS + HVJ	1.58	0.084	-333.47
	Season + Diel + Criteria + AWS + HVJ	1.77	0.076	-331.45

Table C4 Competing Cox time-to-event models for rates of retreat from the fishway to the entry zone (i.e., rejection rate) based on Akaike information criterion (AIC). Arctic Grayling, Burbot, Mountain Whitefish, and Rainbow Trout were not modelled because of low sample sizes.

Species	Covariates	ΔAIC	AICw	LogLik
Bull Trout	Transitions + Season + Discharge	0.00	0.148	-123.43
	Transitions + Season + Discharge + Attraction Flow Category	0.96	0.091	-120.10
	Transitions + Season + Discharge + HVJ	1.30	0.077	-123.27
	Transitions + Season + Discharge + Total Attraction Flow	1.59	0.066	-123.41
	Transitions + Season + Discharge + AWS	1.62	0.066	-123.46

Appendix D: Cox Time-to-Event Model Results

Table D1 Coefficient estimates (β), hazard ratio (HR) with 95% confidence interval (CI), and p-values of covariates from the top model by AIC for approach rates analyzed with Cox time-to-event models.

Species	Covariate	β	HR (95% CI)	p-value
Bull Trout	Season: Fall (null)	---	---	---
	Season: Spring	-0.405	0.667 (0.414-1.075)	0.096
	Season: Summer	0.412	1.510 (0.949-2.402)	0.082
	Diel: Dawn (null)	---	---	---
	Diel: Day	-0.055	0.947 (0.702-1.277)	0.720
	Diel: Dusk	-0.891	0.410 (0.235-0.717)	0.002
	Diel: Night	-1.533	0.216 (0.151-0.309)	<0.001
	Discharge	-0.001	0.999 (0.998-0.999)	<0.001
Mountain Whitefish	Transitions	-0.023	0.978 (0.964-0.992)	0.002
	Diel: Dawn (null)	---	---	---
	Diel: Day	1.659	5.251 (1.697-16.252)	0.004
	Diel: Dusk	0.836	2.307 (0.478-11.132)	0.300
	Diel: Night	-3.138	0.043 (0.007-0.276)	<0.001
	WSEL	-1.116	0.328 (0.211-0.509)	<0.001

Table D2 Coefficient estimates (β), hazard ratio (HR) with 95% confidence interval (CI), and p-values of covariates from the top model by AIC for departure rates analyzed with Cox time-to-event models.

Species	Covariate	β	HR (95% CI)	p-value
Bull Trout	Transitions	-0.008	0.992 (0.987-0.997)	0.001
	Season: Fall (null)	---	---	---
	Season: Spring	1.135	3.112 (1.515-6.393)	0.002
	Season: Summer	-0.027	0.974 (0.512-1.852)	0.940
	Diel: Dawn (null)	---	---	---
	Diel: Day	-0.739	0.478 (0.246 -0.927)	0.029
	Diel: Dusk	-0.324	0.723 (0.285-1.831)	0.500
	Diel: Night	-1.218	0.296 (0.141-0.621)	0.001
	WSEL	0.272	1.313 (0.947-1.799)	0.091
Mountain Whitefish	Transitions	0.024	1.024 (0.994-1.055)	0.120
	Day	-0.016	0.984 (0.973-0.996)	0.010
	AWS	-0.202	0.817 (0.684-0.976)	0.026

Table D3 Coefficient estimates (β), hazard ratio (HR) with 95% confidence interval (CI), and p-values of covariates from the top model by AIC for entry rates analyzed with Cox time-to-event models.

Species	Covariate	β	HR (95% CI)	p-value
Bull Trout	Transition	0.024	1.025 (1.001-1.049)	0.043
	Season: Fall (null)	---	---	---
	Season: Spring	-3.650	0.026 (0.003-0.223)	<0.001
	Season: Summer	0.335	1.40 (0.613-3.191)	0.430
	Diel: Dawn (null)	---	---	---
	Diel: Day	0.205	1.23 (0.421-3.575)	0.710
	Diel: Dusk	-0.571	0.565 (0.093-3.429)	0.530
	Diel: Night	-0.929	0.395 (0.123-1.266)	0.120
	Criteria: Above	---	---	---
	Criteria: Within	1.688	5.404 (2.969-9.838)	<0.001
	Total Attraction Flow	0.165	1.179 (1.083-1.283)	0.001

Table D4 Coefficient estimates (β), hazard ratio (HR) with 95% confidence interval (CI), and p-values of covariates from the top model by AIC for rejection rates analyzed with Cox time-to-event models.

Species	Covariate	β	HR (95% CI)	p-value
Bull Trout	Transitions	-0.059	0.942 (0.906-0.980)	0.003
	Season: Fall (null)	---	---	---
	Season: Spring	-2.818	0.060 (0.004-0.853)	0.038
	Season: Summer	-0.869	0.420 (0.146-1.203)	0.110
	Discharge	-0.002	0.998 (0.996-1.000)	0.013

Appendix E: Detection Histories

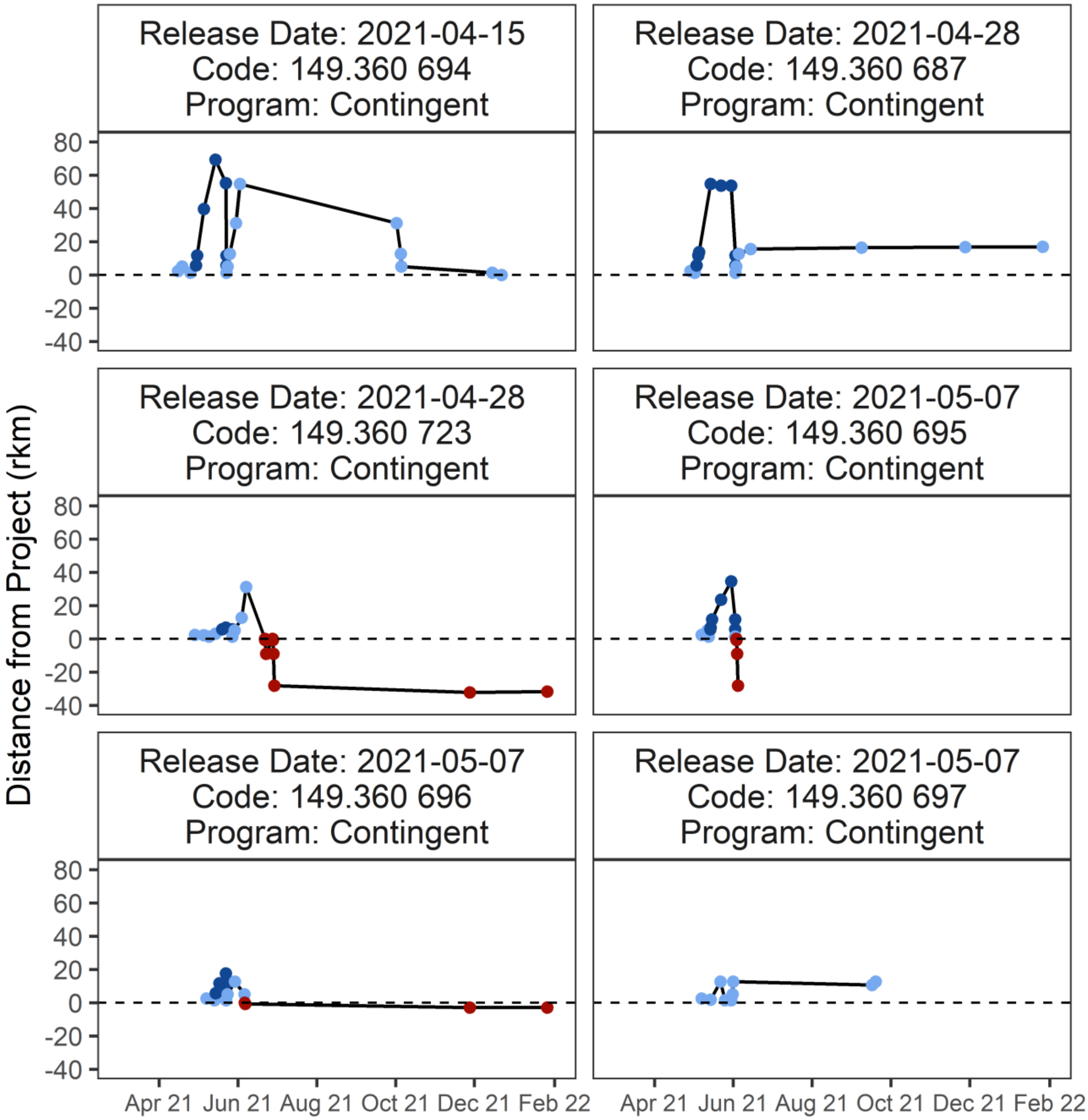

Figure E1 Detection histories for radio-tagged Arctic Grayling released upstream of the Project through the contingent trap and haul program in 2021. Detection histories begin at release and include all detections through January 2022. Plots include detections within spawning grounds (dark blue), detections upstream of the Project in non-spawning grounds (light blue), and detections downstream of the Project (red). Detections downstream of the Beatton River (~36 rkm downstream of Project) are not shown for clarity.

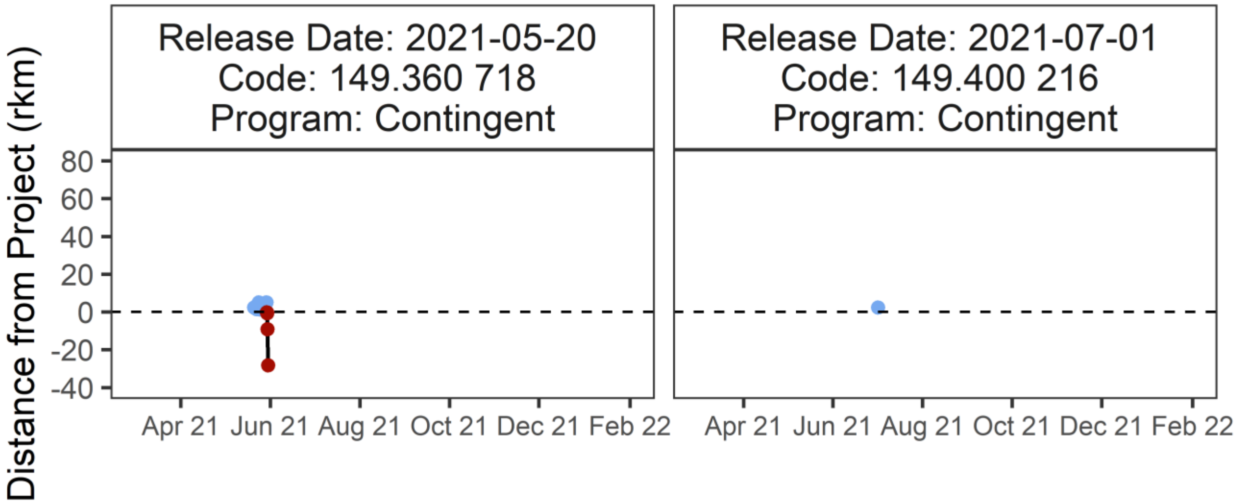

Figure E1 continued.

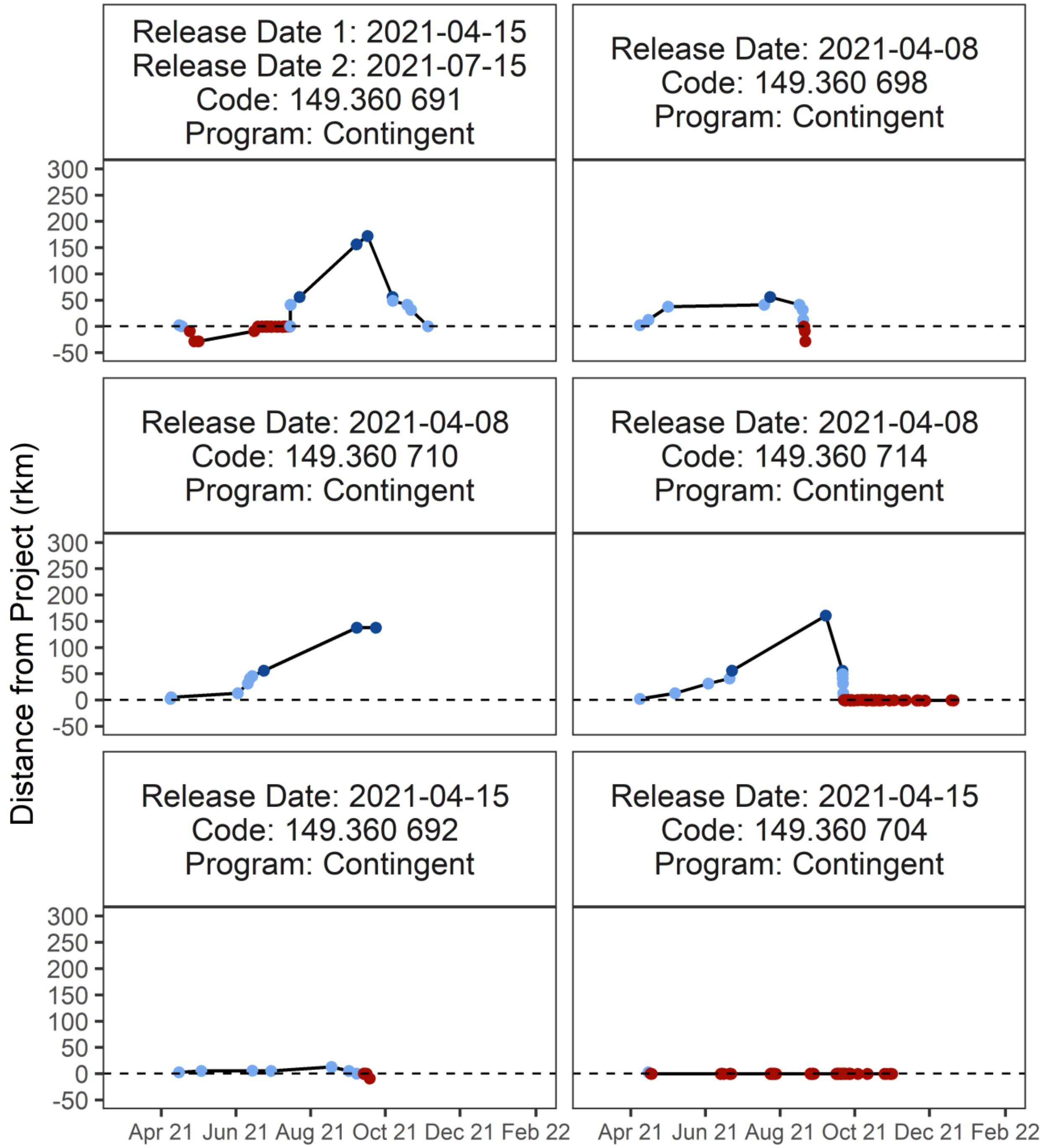

Figure E2 Detection histories for radio-tagged Bull Trout released upstream of the Project through the temporary upstream fish passage facility (TUF) or through the contingent trap and haul program in 2021. Detection histories begin at release and include all detections through January 2022. Plots include detections within spawning grounds (dark blue), detections upstream of the Project in non-spawning grounds (light blue), and detections downstream of the Project (red). Detections downstream of the Beatton River (~36 rkm downstream of Project) are not shown for clarity.

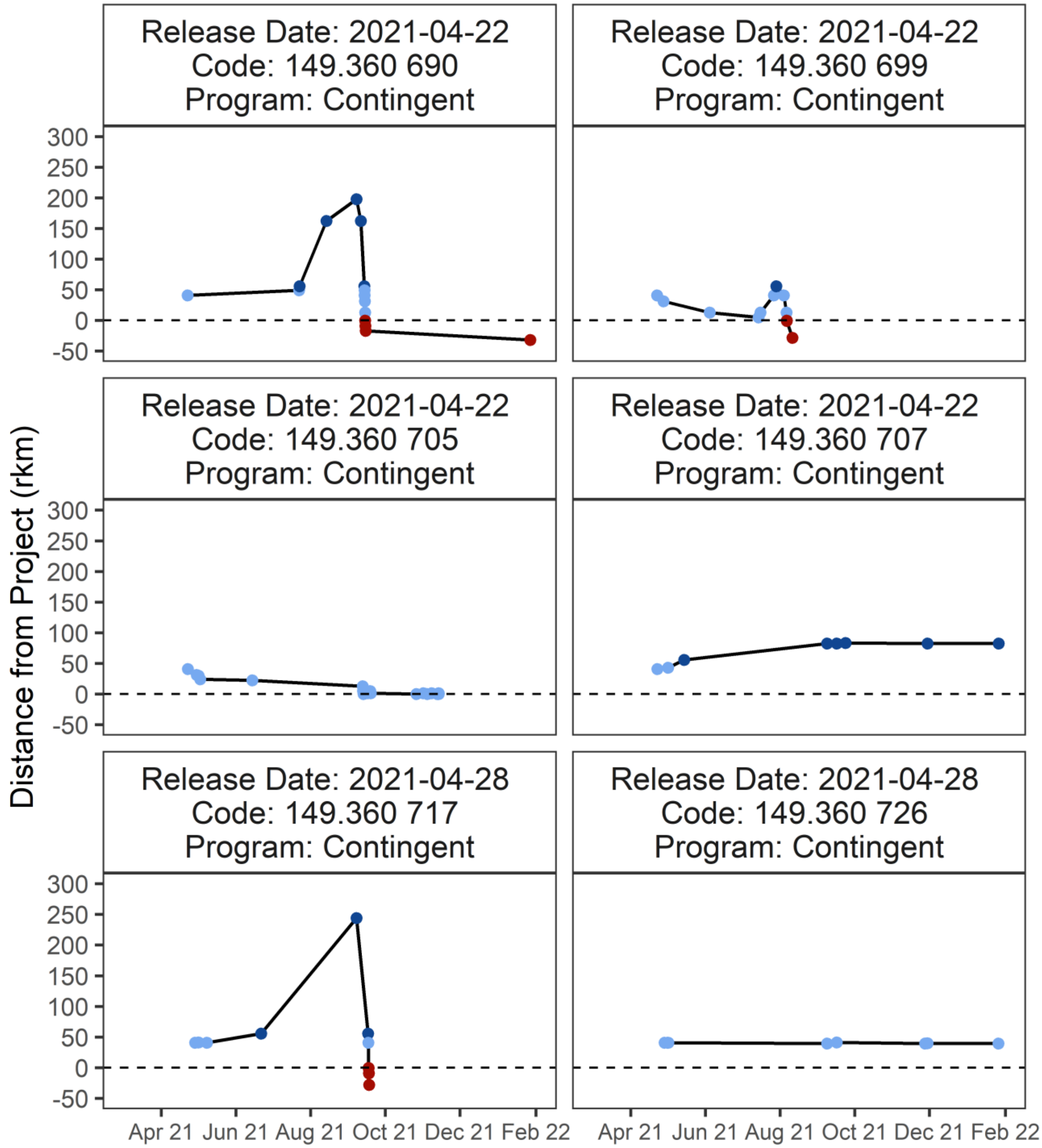

Figure E2 continued.

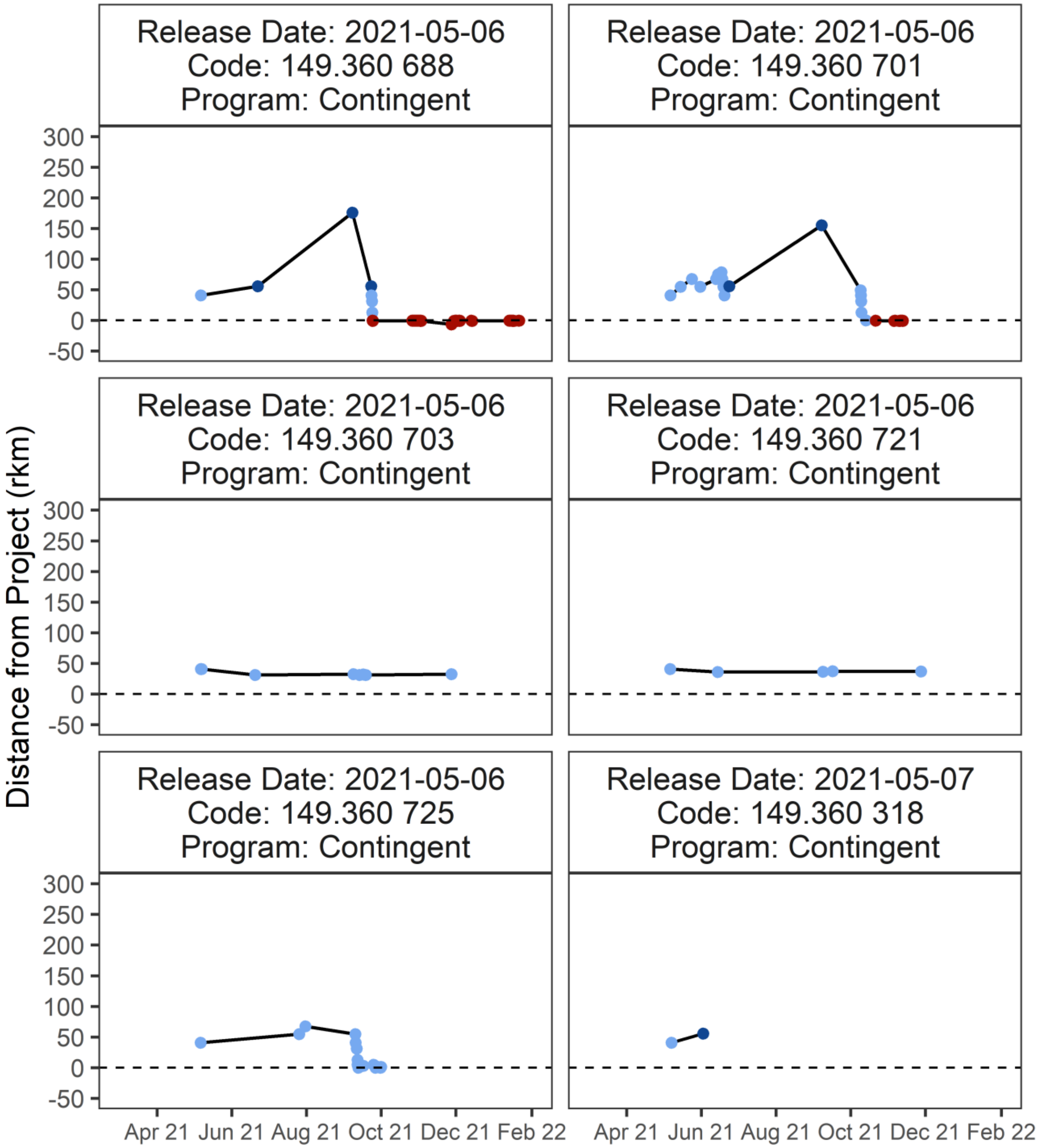

Figure E2 continued.

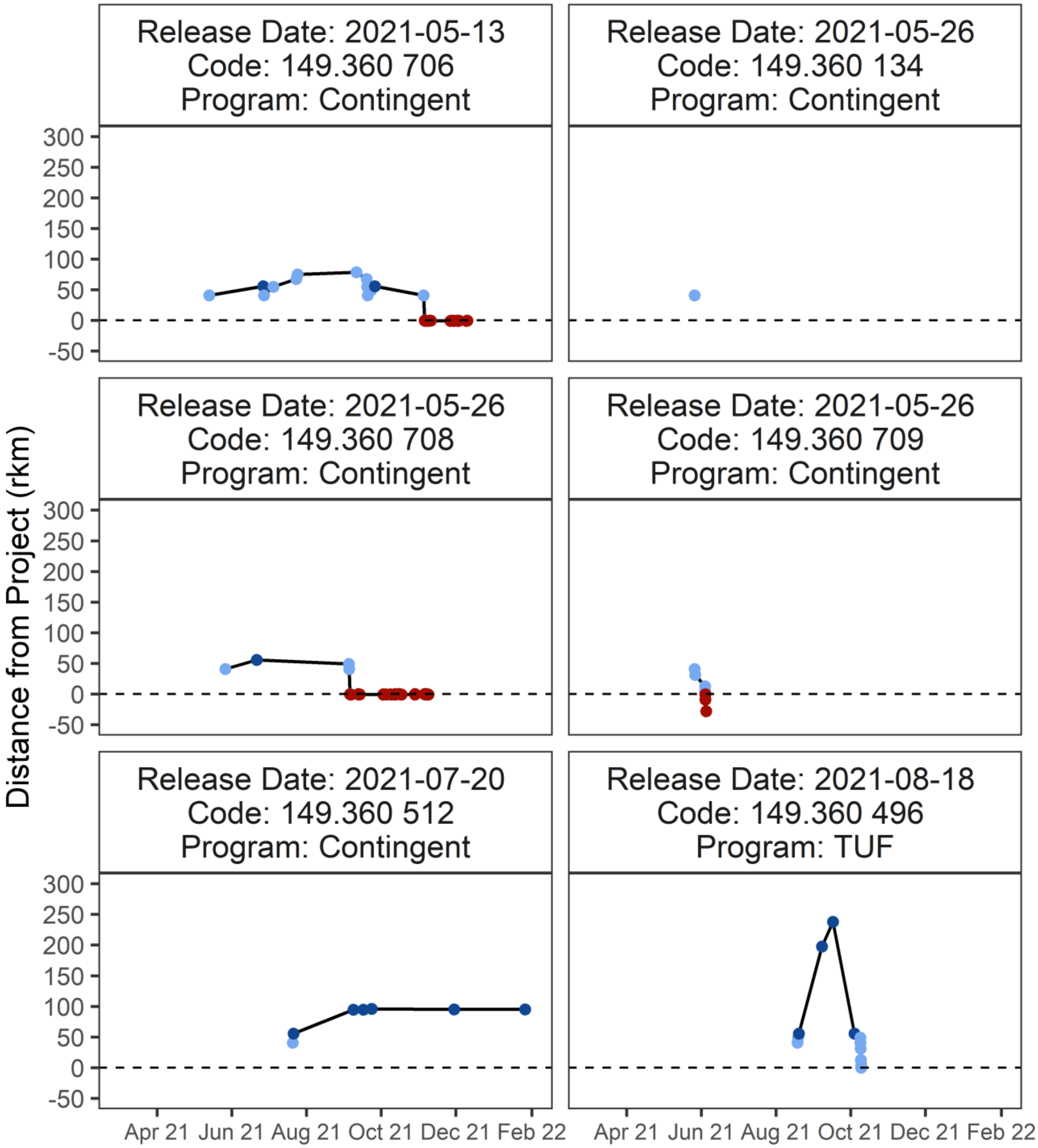

Figure E2 continued.

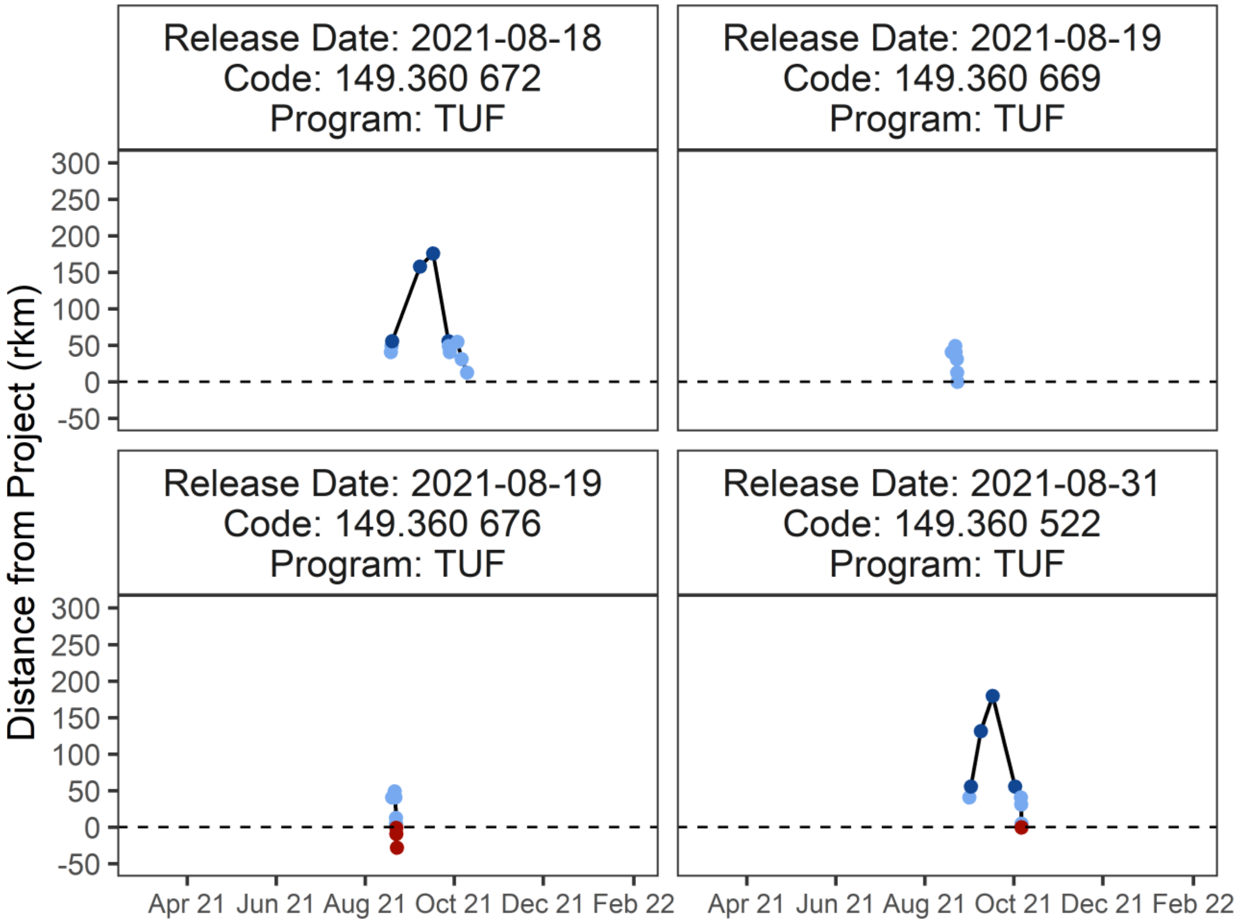

Figure E2 continued.

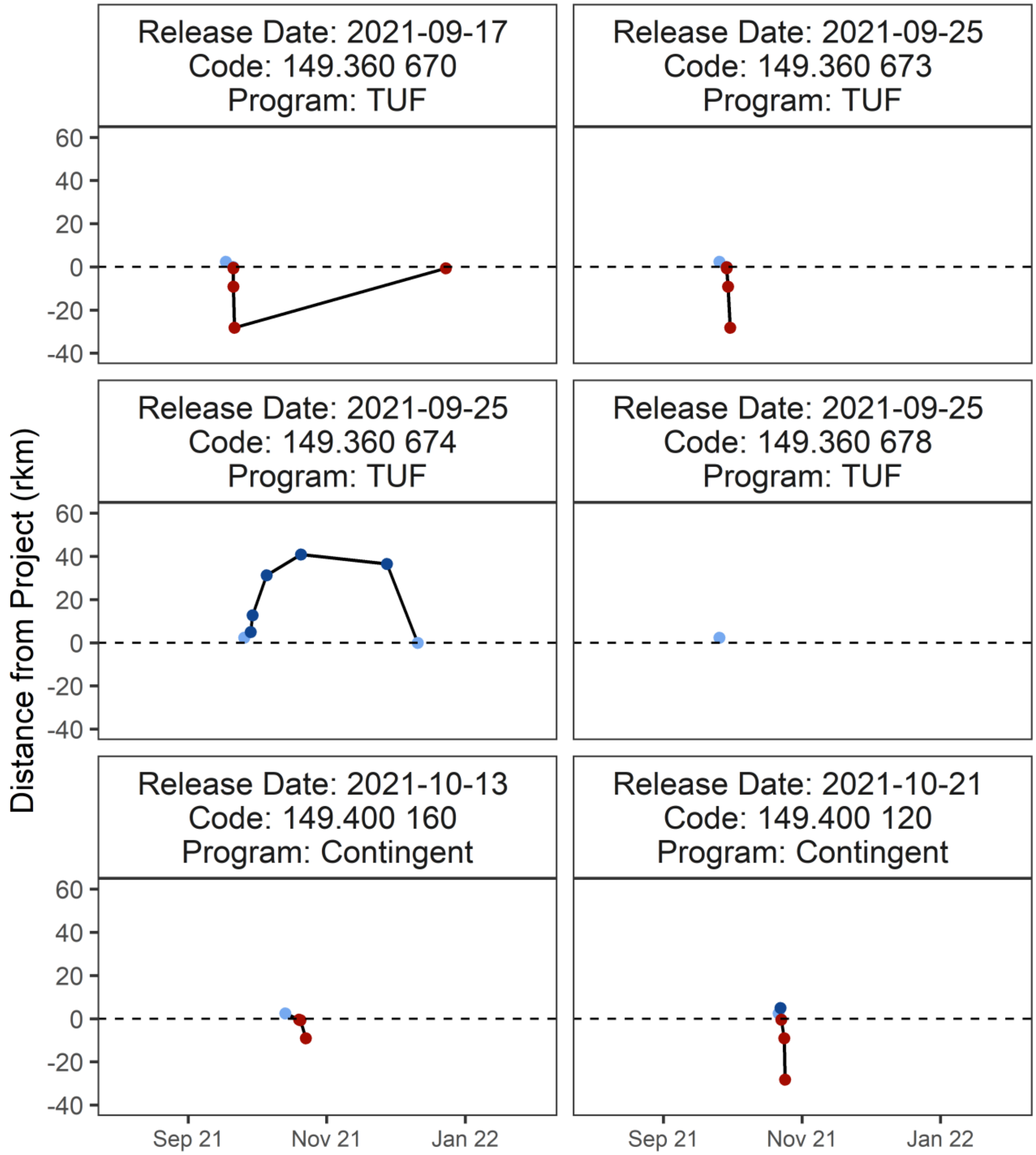

Figure E3 Detection histories for radio-tagged Mountain Whitefish released upstream of the Project through the temporary upstream fish passage facility (TUF) or through the contingent trap and haul program in 2021. Detection histories begin at release and include all detections through January 2022. Plots include detections within spawning grounds (dark blue), detections upstream of the Project in non-spawning grounds (light blue), and detections downstream of the Project (red). Detections downstream of the Beatton River (~36 rkm downstream of Project) are not shown for clarity.

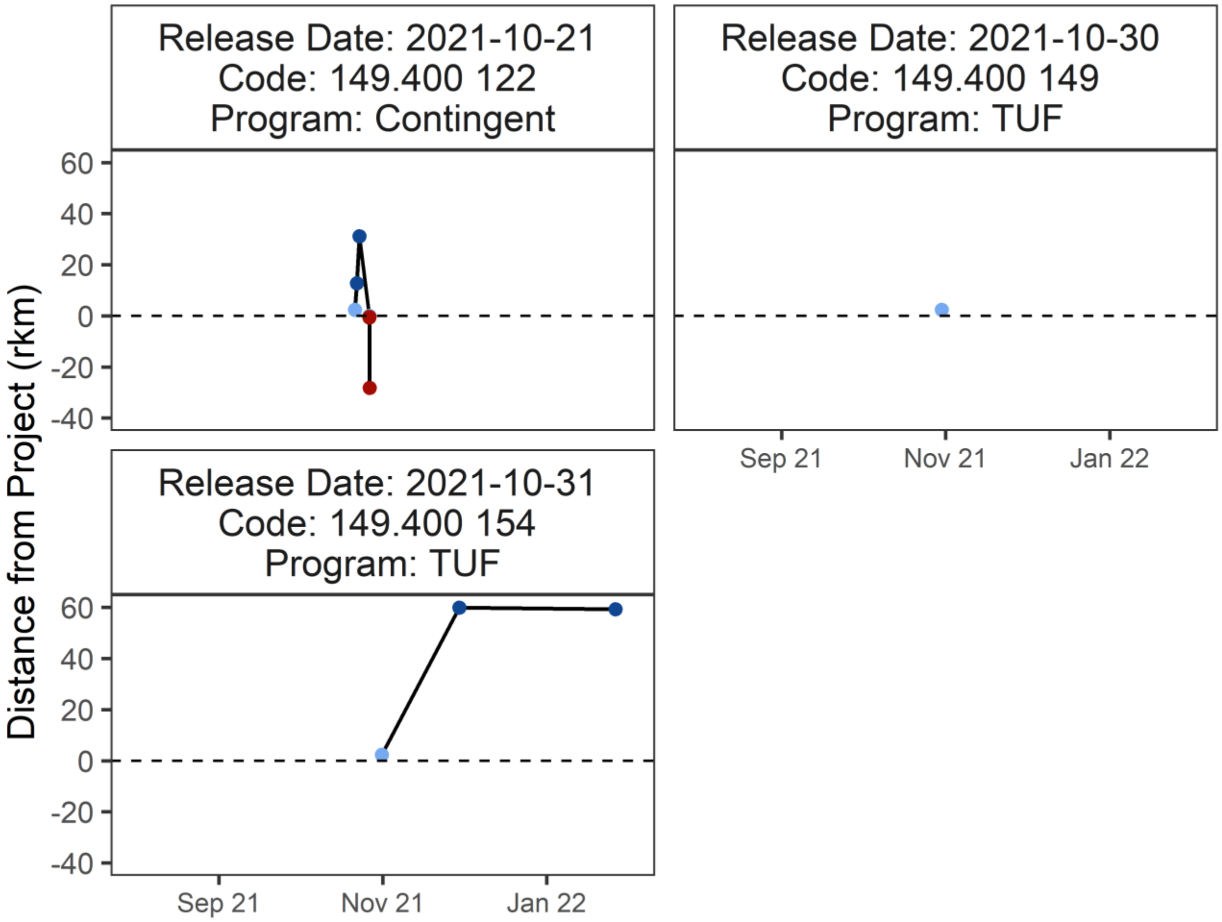

Figure E3 continued.

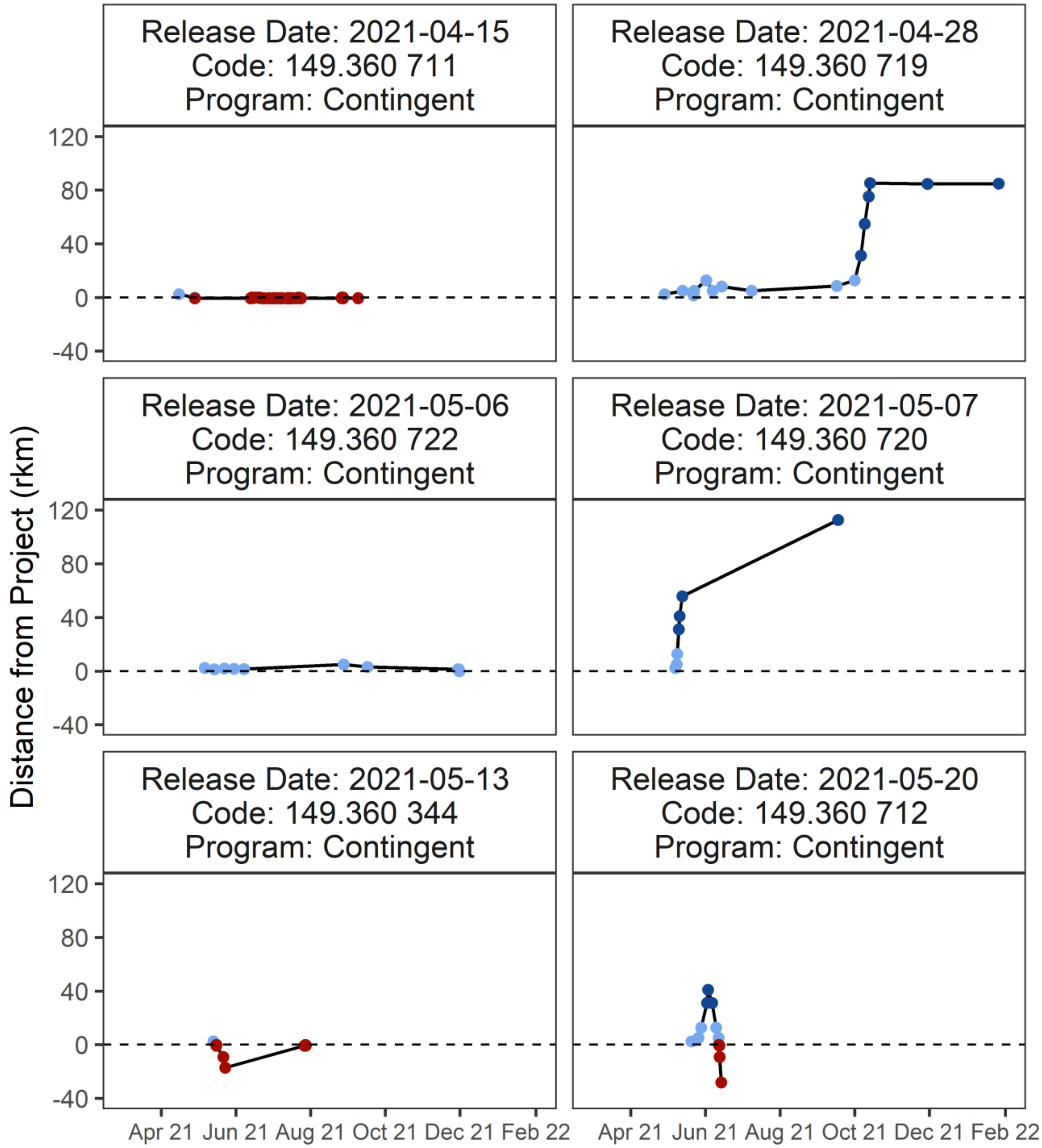

Figure E4 Detection histories for radio-tagged Rainbow Trout released upstream of the Project through the contingent trap and haul program in 2021. Detection histories begin at release and include all detections through January 2022. Plots include detections within spawning grounds (dark blue), detections upstream of the Project in non-spawning grounds (light blue), and detections downstream of the Project (red). Detections downstream of the Beatton River (~36 rkm downstream of Project) are not shown for clarity.

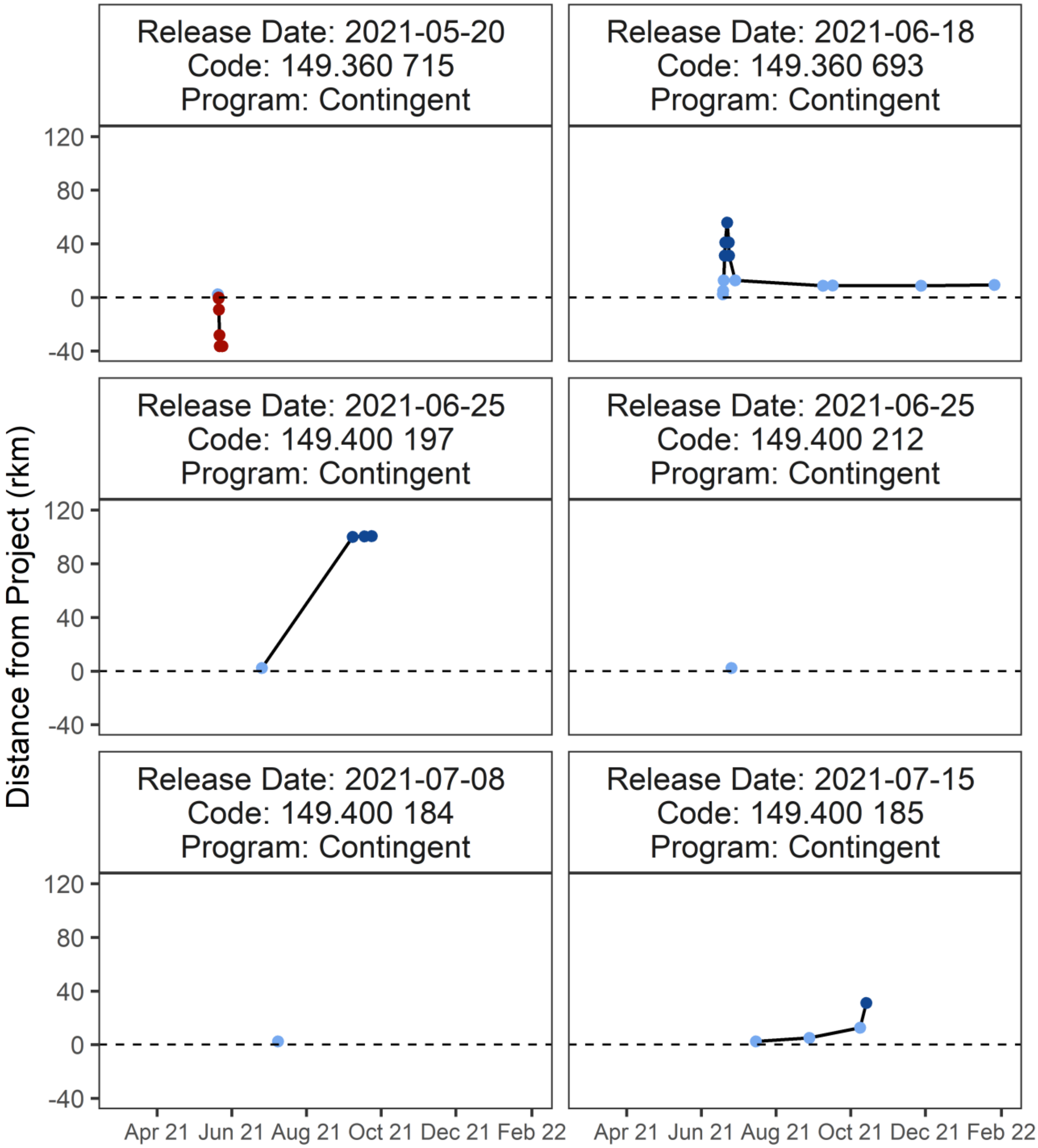

Figure E4 continued.

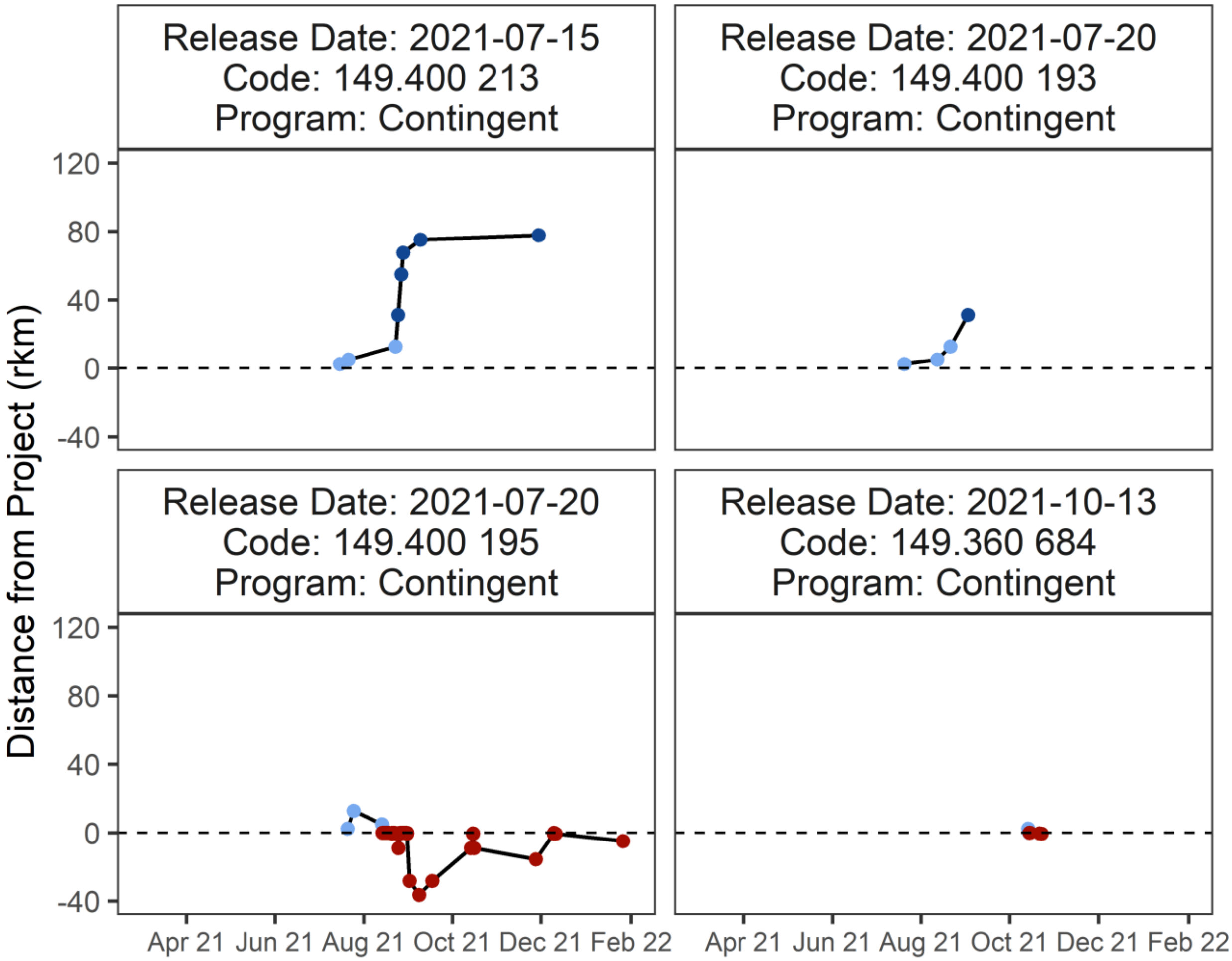

Figure E4 continued.