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 8 (2022)

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Executive Summary

Hydroelectric dams, such as the Site C Clean Energy Project (the Project) on the Peace River in northeastern British Columbia, obstruct riverine connectivity and pose significant challenges for migratory fishes. 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 flowing through two entrance gates, which are supplemented by a high velocity jet located adjacent to the fishway entrance. These two components of attraction flow are manipulated on a predetermined schedule to understand how to best facilitate attraction and passage 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. The focus on reporting in 2022 was to establish a competing risks modeling framework to explore environmental factors, including supplementary attraction flows that may have influenced rates of approach to and entry into the fishway. Under Mon-13, we achieved this objective by using time-to-event (TTE) analyses and calculated species-specific proportions of tagged target species entering and 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.

Operations of the TUF began in October of 2020, which means 2022 marked the second full year of operations. In 2022 the TUF was operational for 94% of the operational period, a continued improvement from previous years. Shutdown periods were limited to a ~10-day period in early June and two days in late June. However, attraction flows were considerably reduced starting in late September when some attraction flow pumps had to be shut off. High water levels continued to be a challenge, as in 2021, with water surface elevations at the tailrace of the fishway entrance exceeding the upper end of the fishway's design criteria for 59% of the operational period. The Mon-13 radio telemetry array functioned as intended throughout the 2022 operational period, but performance of the PIT array remained poor, as in previous years.

Since TUF operations have begun, we have confirmed that all five target species can locate and enter the fishway and apart from Burbot, ascend to the upper three pools. A total of 149 radio-tagged and 1470 PIT-tagged individuals of target species were detected during the operation period, excluding shut down periods. Detection data were most abundant and reliable from Bull Trout and Mountain Whitefish and showed that a barrier to passage exists at the top of the fishway. Among radio and/or PIT-tagged Bull Trout, 84% of individuals entering the fishway made it to upper pools but 2.2% of those successfully passed the fishway to be captured by the facility operator. The trend is similar for Mountain Whitefish: 85% of those that entered made it to upper pools of the fishway and 18% of those ascended to the sorting facility from the upper pools. Therefore, fish are making it to the top of the fishway but often fail to enter the collection facility, which requires being captured by the lift in the pre-sort holding pool.

Calculation of attraction and passage efficiency was completed to align with the management questions of Mon-13. Attraction efficiency is the proportion of radio-tagged fish that approach and enter the fishway while passage efficiency is the proportion of those entering the fishway that pass through in completion. These metrics are calculated exclusively with radio telemetry because of the poor performance of the PIT array, particularly in the lower fishway. To better use PIT telemetry data, we added a new efficiency metric in 2022: trapping efficiency, the proportion of tagged fish reaching the upper pools of the fishway that were successfully captured in the lift and ascended to the sorting facility. This metric evaluates effectiveness of the upper fishway and trapping mechanism while taking advantage of the larger PIT telemetry dataset. Species-specific attraction efficiencies were 0% (Burbot), 18% (Arctic Grayling), 22% (Rainbow Trout), 28% (Mountain Whitefish), and 31% (Bull Trout). Passage efficiencies were 0% for all species except Bull Trout (2.3%). Trapping efficiency ranged from 0% (Rainbow Trout) to 25% (Arctic Grayling) and was 2% for Bull Trout and 18% for Mountain Whitefish.

Efficiency metrics fail to inform factors that may be impacting passage and can be misleading; efficiency will never be fixed in time for any species or fishway. Therefore, we continue to rely on time-to-event (TTE) analyses to determine the biological effectiveness of the TUF and explore how environmental factors, including supplementary attraction flows, influence approach, entry and passage rates for each target species. Radio telemetry data were sufficient to run TTE models using time-varying covariates for radio-tagged Bull Trout, Mountain Whitefish and to a more limited extent, for Rainbow Trout. Movements between spatial zones downstream of the fishway were primarily driven by hydrological factors, diel period, and season. While model specifics vary from 2021 analyses, general patterns (i.e., included covariates and their direction of effect) remain consistent.

Peace River discharge and attraction flows were commonly associated with rates of both advance and retreat. These results are promising because they suggest that attraction flows and, to a lesser extent, river discharge, can be operationally managed to encourage entry into the fishway. There was a consistent effect of reduced upstream advance rates in all three species with increasing river discharge. For Bull Trout there was additionally a negative effect of the percent of attraction flow relative to total river discharge on rates of retreat out of the study area (i.e., less attraction to the fishway when there was less influence of attraction flow). Model results provide good evidence that increased attraction flows attract salmonids (Bull Trout, Rainbow Trout) towards the fishway. Consistent with results from 2021, auxiliary water supply flows provide more attraction for Bull Trout than from the high velocity jet. However, there is weak evidence for Rainbow Trout that the opposite is true. It is an important consideration that these models only encompass movement from areas downstream the fishway and into the fishway. Results can, therefore, only inform operational changes to facilitate increased approach and entry and may not increase passage.

With respect to diel period, results indicate more activity and faster upstream advance movements during daylight hours. The effect was present in all three species, but was especially apparent for Mountain Whitefish, for which data were overwhelmingly from the day period. Most models also had a seasonal component. Rates of upstream advance were fastest during the summer for Bull Trout and during the fall for Mountain Whitefish. Additionally, rates of fishway entry increased and rates of retreat from the fishway entrance decreased throughout the operational period for both Rainbow Trout and Bull Trout. This suggests that these species spent more time in the entry zone as the operational period progressed, potentially attempting passage opportunities.

Under Mon-14, across 2021 and 2022 operational periods, we tracked the post-release movements of seven radio-tagged Bull Trout and six radio-tagged Mountain Whitefish transported upstream of the Project from the TUF. 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. 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. Across the two capture programs, 116 tagged fish were released from four species. Post release movements are classified as successful (assumed to have reached spawning grounds) or unsuccessful. Among unsuccessful fish, movements were additional classified as an assumed mortality, as having fallen back within 48 hours of release, or as some other post-release movement.

Among transported Bull Trout (n = 66), 64% (n = 42) were classified as reaching spawning grounds in the Halfway, seven were classified as mortalities, two fell back, 13 made other downstream movements, and two could not be classified. Radio-tagged Bull Trout were only released into the Peace River before ice-out at the Halfway River release location, but our data suggests that this strategy is less effective than transporting them directly into the Halfway River after it has thawed. Six of the 14 (43%) radio-tagged Arctic Grayling released were classified as successfully reaching their spawning grounds in the Moberly River, one was classified as a mortality, six made downstream movements and one could not be classified. Nine radio-tagged Mountain Whitefish were transported which were classified as successful (n = 5; 56%), mortality (n = 1), fallback (n = 3). Fifteen of the 27 (56%) radio-tagged Rainbow Trout were classified as successful and were otherwise classified as a mortality (n = 1), fallback (n = 2), and having made downstream movements (n = 9). To provide a more accurate assessment of the Project’s trap and haul effectiveness we recommend removing the 48-hour threshold for classifying released fish as mortalities or their downstream movements as fallback.

It is promising that since operations began in October 2020, all five target species located the TUF and that Arctic Grayling, Bull Trout, Mountain Whitefish, and Rainbow successfully passed and continued their upstream spawning migration. However, attraction and passage efficiency metrics were much lower than those predicted in the EIS, the upper portion of the fishway presents a barrier to passage, and not all fish transported above the Project continued their upstream migration. We continue to use collected data to guide operational recommendations for the TUF and the permanent upstream fish passage facility when operations are scheduled to begin in the spring of 2024.

Acknowledgements

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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, currently planned for fall of 2023. The TUF will be decommissioned once BC Hydro begins operating the permanent upstream fish passage facility (PUF) at the Project.

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 monitoring programs, 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.

The Project is a dynamic study site that is under construction. 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, essential to the maintenance and expression of life history diversity among fish populations (Cooke et al. 2012). This is particularly the case for migratory fishes seeking upstream areas to reproduce or feed. 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). 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 Harbor 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 fishway head into passable increments and are separated by weirs and submerged orifice openings (NMFS 2023). 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 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. 2012).

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 (Bunt et al. 2012; Burnett et al. 2014). High attraction flows can have latent or indirect negative effects and may cause migratory delays, having important ecological implications. For example, high flows can 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 a high velocity jet (HVJ) that provides additional flow adjacent to the entrances. 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. 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?

Upon initial conception of this monitoring program by BC Hydro, two hypotheses were presented in association with the management question:

> 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%).

It was determined in previous reports that while all five target species can locate and use the fishway, passage rates are low (Cook et al. 2021; Moniz et al. 2022). H_2 refers to attraction and passage efficiency. Attraction efficiency is the proportion of a given species that successfully approach and enter the fishway. Passage efficiency is the proportion of those entering the fishway that pass through in completion. In addition to passage rates being low throughout the duration of this monitor, performance of the PIT telemetry array has also been poor. The result is known missed detections and much less data than anticipated when the study was designed, limiting the accuracy of calculated efficiency metrics. A new efficiency metric was added in 2022 that more accurately reflects the data available: trapping efficiency. Trapping efficiency refers to the proportion of tagged fish reaching the upper pools of the fishway that were successfully captured in the lift and ascended to the sorting facility.

While fishway efficiency metrics are often seen as a benchmark of biological effectiveness and are useful for providing a broad overview of fishway effectiveness, they fail to integrate the temporal dynamics inherent to fish passage. Efficiency will never be fixed in time for any species or fishway. We argue that a focus on efficiency metrics fails to inform on factors that may be impacting passage. As done in Moniz et al. (2022), Mon-13 will use time-to-event (TTE) analyses to determine the biological effectiveness of the TUF and explore how environmental factors, including supplementary attraction flows, influence passage rates for each target species. Although we will calculate efficiency metrics, the results of TTE analyses will be the focus of this report.

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

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.

1.1.1 Quantifying Biological Effectiveness

Under Mon-13, the biological effectiveness of the TUF is evaluated by monitoring how tagged fish move between distinct spatial zones. Approach, entry, and passage are distinct state transitions (Castro-Santos and Perry 2012; Silva et al. 2018), each influenced by time-varying environmental factors and differential exposure to covariates among individuals (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 of advancement to the next state, and an opposing rate at which they abandon a state and retreat to the previous one (Castro-Santos and Haro 2003; Castro-Santos and Perry 2012; Silva et al. 2018; Alcott et al. 2021). Factors that increase advance rates and/or decrease retreat rates between any two states will increase overall percent passage.

Understanding state transitions 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. From downstream to upstream, the four zones include: 1) the 'outside approach', used to determine when a tagged fish leaves the study area; 2) the 'approach zone', used to determine when tagged fish enters the study area and become candidates for fish passage; 3) the 'entry zone', used to determine when tagged fish can presumably detect attraction flows and reach the fishway entrance; and 4) the 'fishway', used to determine when a fish enters the fishway. TTE analyses of radio telemetry data were used to evaluate how environmental factors, including supplementary attraction flows, influenced competing rates of advancement and retreat from the approach zone (approach and withdraw), advancement and retreat from the entry zone (entry and departure) and retreat from the fishway to the entry zone (rejection; Figure 2). A model for advancing from the fishway into the sorting facility (passage) could not be modeled due to lack of data. Additionally, fish cannot continuously pass between the fishway and the sorting facility at volition; once fish enter the pre-sort holding pool they are ascended via lift at distinct intervals.

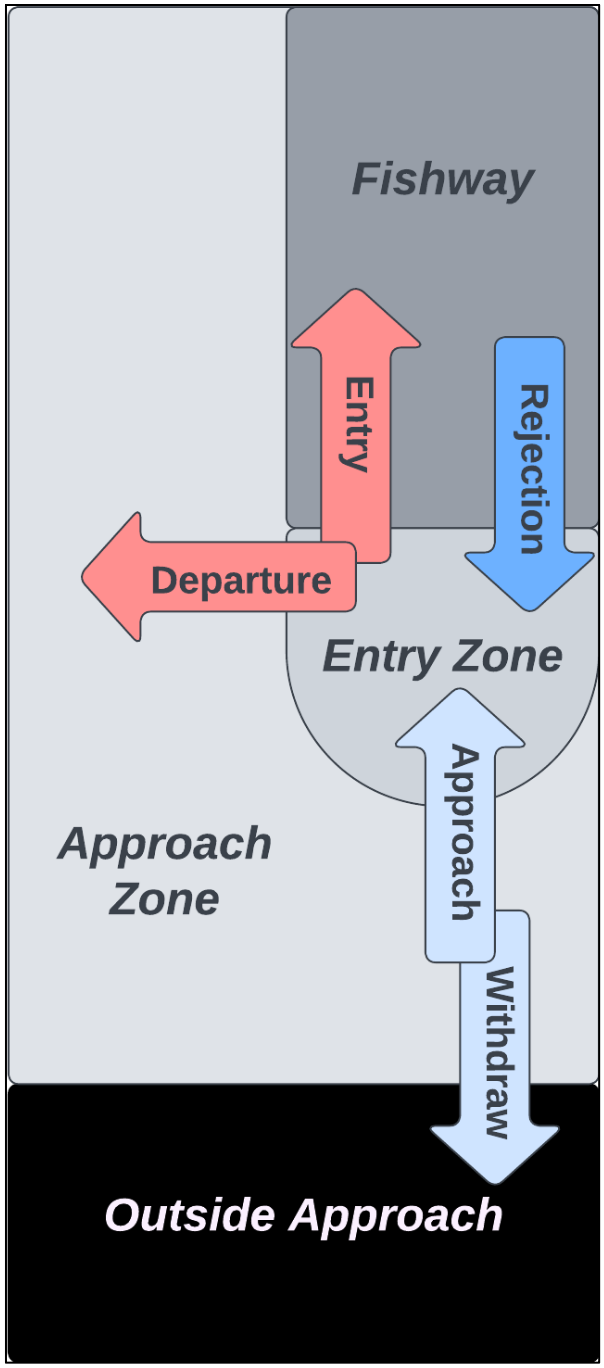

Figure 2 Schematic of competing risks framework for time-to-event analyses of radio telemetry data. Each spatial zone represents the transitional states between which tagged fish can move. Tagged fish become candidates for the analysis once in the approach zone. Paired state transition models are colored accordingly. Note that the rejection model is not paired given few successful ascents and because final passage in this system (i.e., from pre-sort holding pool to sorting facility) is not continuous but occurs at discrete intervals. Figure adapted from Alcott et al. (2021).

1.1.2 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 inclusive of the TUF and sorting facility. The TUF has two entrance gates, referred to as the west entrance and east entrance, that lead into an entrance pool (Figure 3). The HVJ is adjacent to the west entrance. 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. On June 8, 2022, BC Hydro installed a finger weir and orifice panel in the vee-trap throat to improve trapping efficiency. The elevation of the finger weir was originally set to 23 cm below the water surface to match the existing hydraulic drop between pools, but then was raised to 5 cm below the water surface to further prevent fish from swimming out of the 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.

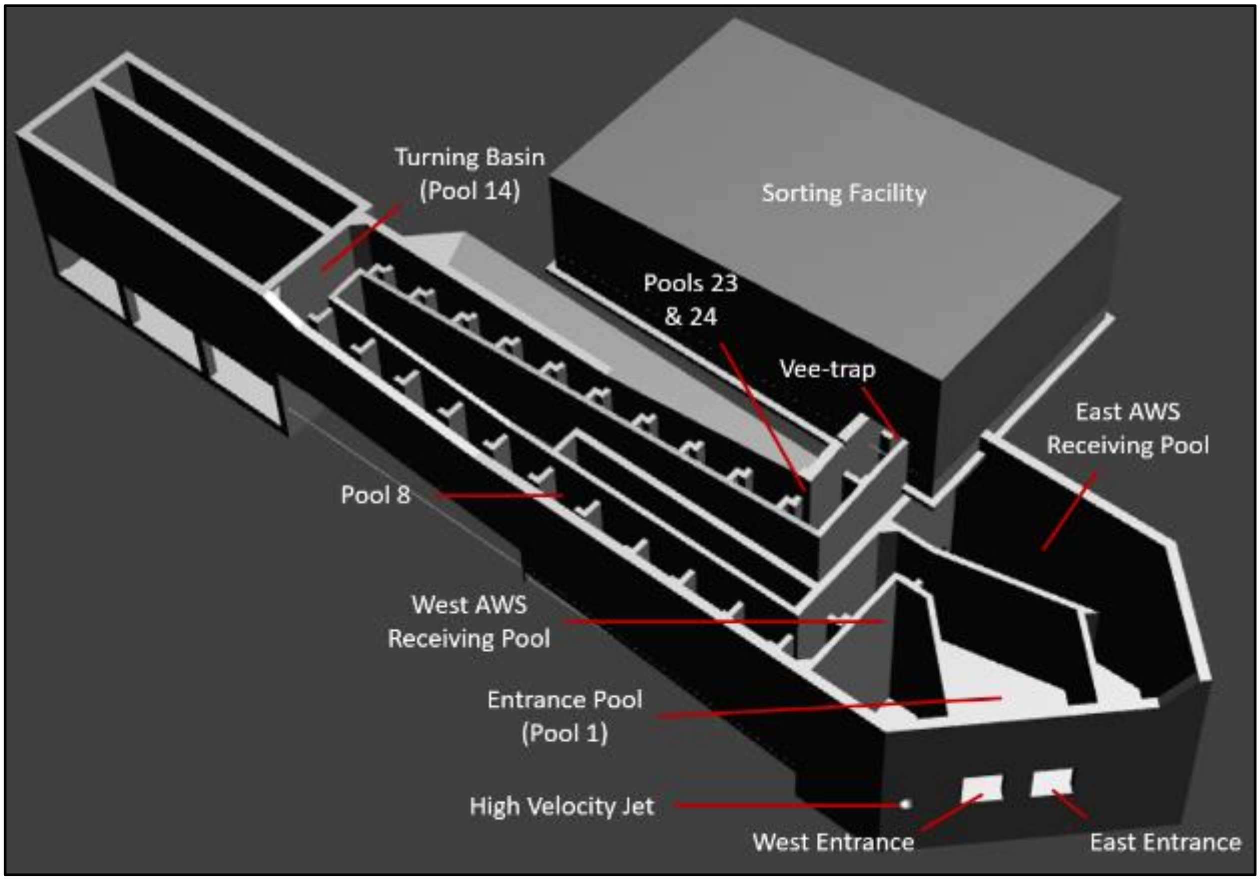

Figure 3 A drawing of the temporary upstream fish passage facility (TUF). Upstream migrating fish enter the TUF via one of the two entrance gates and are processed and sorted for transport within the sorting facility. Fishway attraction flows are provided by an auxiliary water supply (AWS) flowing into 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.

1.2 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 V 4.3.0.

1.2.1 Fishway Operations and Environmental Conditions

During the 2022 operational period (April 1 to October 31, 2022), two sources of attraction flow, the auxiliary water supply (AWS) and high velocity jet (HVJ) were experimentally manipulated as outlined in the Manual of Operational Parameters and Procedures (OPP; McMillen Jacobs &

Associates and BC Hydro 2022). The OPP outlines that four distinct attraction flow scenarios 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 1). Given that AWS flows are continually changing and rarely achieve the exact setpoints defined in the OPP (unlike the HVJ that is either on or off), we classified AWS flows as either in specification or not. We considered values within ± 0.5 m^3/s of the target to be in specification, resulting in classifications of “low AWS flows” as 3.75-4.75 m^3/s and “high AWS flows” as 8-9 m^3/s.

Environmental data were collected from a variety of sources. Sensors deployed throughout the TUF were used to collect attraction flow, water surface elevation (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). 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 2022).

There were two shutdowns during the 2022 operational period. The first began on May 29 at 14:41 and ended on June 9 at 8:30. With increased local inflows, suspended sediment clogged the water intake screens and water could not feed pumps. The second shutdown occurred from June 19 at 9:57 to June 30 at 15:41 because of excessive sediment built up in the pre-sort holding pool. All data collected during shutdown periods were removed from datasets used in analyses. Additionally, on September 28, the pumps providing AWS attraction flows began faulting due to dust intrusion and were shut down. The fishway remained operational but the pump shutdown affected the total amount of AWS attraction flow. That is, AWS attraction flow was still provided on a variable schedule but at a limited capacity (see results).

Given concerns of poor passage between the uppermost cells and the pre-sort holding pool, several physical modifications were made to the trapping mechanism at the top of the fishway starting August 2021 and continuing through the 2022 operational period to improve trapping efficiency (Table 2).

Table 1 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

Table 2. Modifications made in 2022 to the trapping mechanism between the upper pools of the temporary upstream fish passage facility and the pre-sort holding pool, which fish need to enter to be elevated into the sorting facility. Modifications were made in response to observations of groups of fish in the upper fishway but low numbers entering the sorting facility.

Date	Modification
March	Panels added to side arms of the vee-trap to concentrate the flow cue through the upstream half of the vee-trap
June 8	Installed a finger weir in the vee-trap throat. BC Hydro set the finger weir at 23 cm below the water surface to match the existing hydraulic drop between fishway pools.
June 30	Vee-trap side panels raised approximately 50 cm to increase flow at the bottom of the water column to avoid sediment building up in the pre-sort holding pool
July 19	Finger weir was raised approximately 11 cm so that the fingers were 12 cm below the water surface to prevent fish from swimming out of the pre-sort holding pool
September 17	Finger weir raised again to 5 cm below the water surface
October 14-31	Pre-sort holding pool lights alternated on or off at night from October 14 to 31

1.2.2 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 11 fixed radio telemetry stations (hereafter 'fixed stations') deployed within the study area on the Peace River (Figure 4) and within the TUF (Figure 5). 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 6).

The PIT telemetry array consisted of nine antennas that were designed, fabricated, and installed by InStream Fisheries Research (InStream; Table 4). 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 (Figure 7). All telemetry units not left over winter (i.e., dipole fixed stations and PIT antennas) were deployed by April 1, 2022, and demobilized after the end of the operational period. As in previous years, fixed stations not within the fishway were left operational through the winter of 2022/2023.

Components of fixed stations and PIT antennas including their construction and power requirements components are detailed in previous reports (Moniz et al. 2022) and summarized below (Table 3, Table 4).

Table 3 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	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	2[a]	
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	
Tunnel outlet	Approach zone	SRX800-MD4	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	SRX1200-MD2	Dipole	2[b]	To define the entry zone.
Entrance pool	Fishway	SRX1200-MD2	Dipole	2[b]	To determine if tagged fish entered the fishway.
Pool 8	Fishway	SRX1200-MD2	Dipole	1	To determine if fish reached pool 8 of the fishway.
Turning basin	Fishway	SRX1200-D2	Dipole	1	To determine if fish reached the turning basin (pool 14) of the fishway.
Vee-trap	Fishway	SRX1200-D2	Dipole	1	To determine if fish reached pool 25 of the fishway.

[a] This fixed station, operated by LGL, has two antennas but only the downstream-pointing antenna was used in our analysis to match Outside LB

[b] 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 4 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.

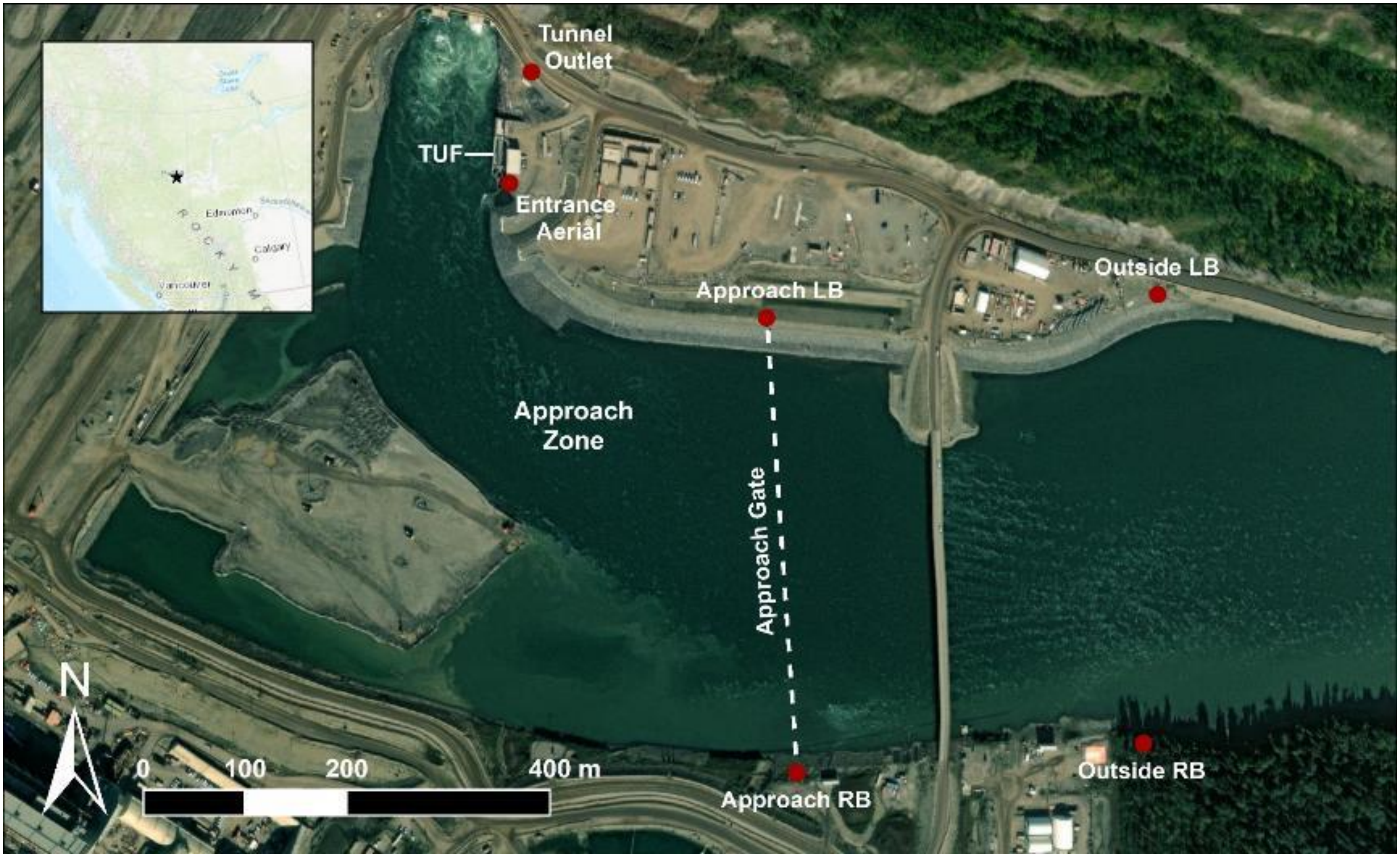

***Figure 4** The Mon-13 study area showing the six aerial fixed radio telemetry stations (fixed stations) deployed along the left bank (LB) and right bank (RB) of the mainstem Peace River and used to detect radio-tagged fish approaching the temporary upstream fish passage facility (TUF). Submerged dipole 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.*

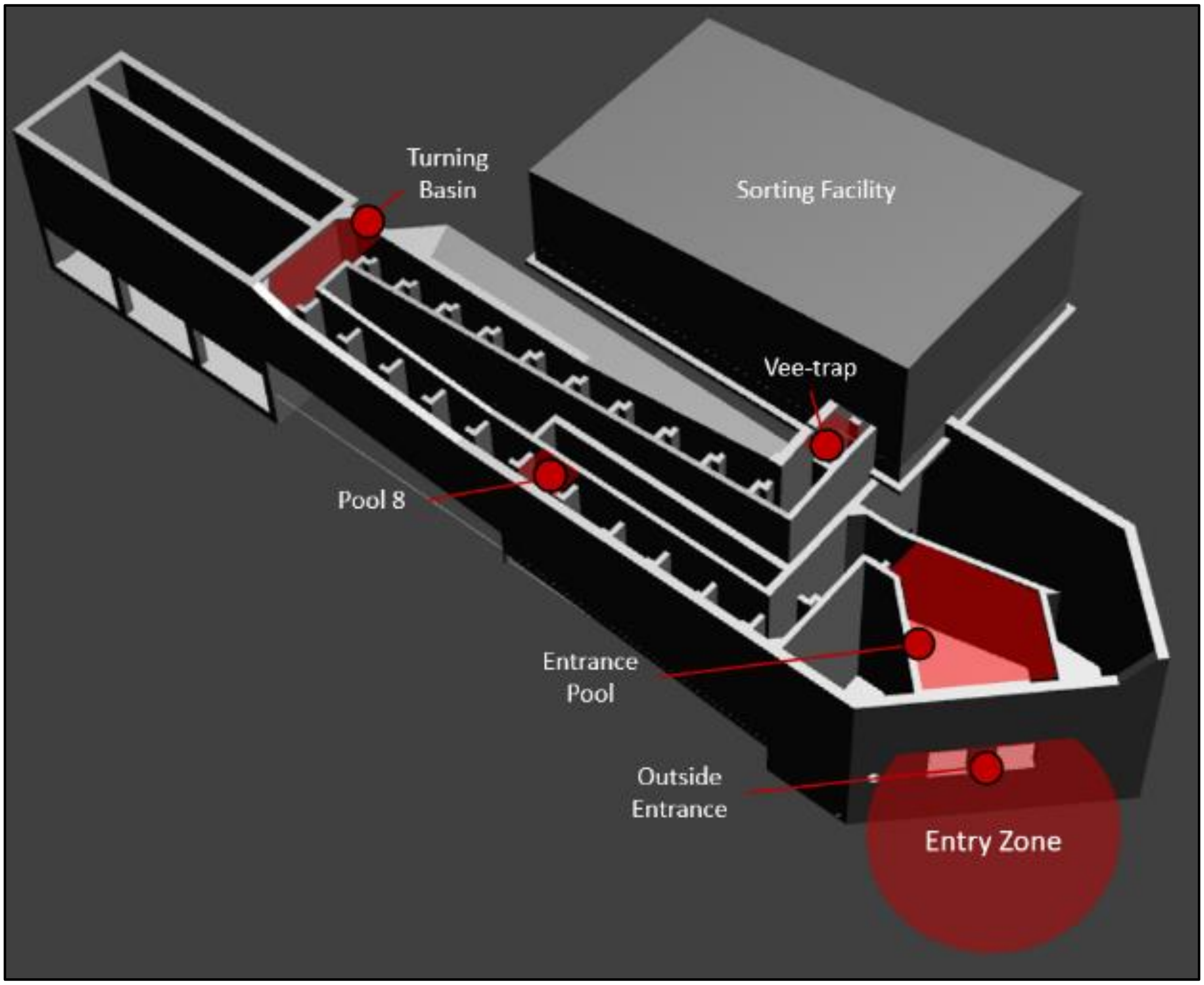

Figure 5. Map of fixed radio telemetry stations with dipole antennas deployed within the temporary upstream fish passage facility, and their approximate detection ranges.

Figure 6. 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 7. Photos of completed PIT antennas installed within the dewatered temporary upstream fish passage facility prior to operations.

1.2.3 Testing Array Performance

Fixed Stations

Limited range testing was executed at all stations upon deployment in 2020 and more comprehensive testing was undertaken in 2021 and 2022 in collaboration with WSP (formerly Golder Associates Ltd.). The four approach and outside LB and RB fixed stations were tested by conducting four upstream to downstream 'tag drag' drifts by a jet boat (see method in Hatch et al. 2023). 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. The detection range of the outside entrance fixed station (i.e., the spatial extent of the entry zone) was tested in 2021 (Moniz et al. 2022),. 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, which remained the case in 2022.

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). Except for the entrance and entrance pool dipoles, fixed stations were programmed to scan between two alternating frequencies every 10 seconds and were therefore expected to detect three beacon transmission every hour. The entrance and entrance pool dipole fixed stations each have two receivers with each scanning a single frequency. These fixed stations were, therefore, expected to detect all six beacon tag transmissions every hour.

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. 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. Like in 2021, our goal with antenna testing was to understand read range, and how this may differ among attraction flow scenarios.

Testing was performed using 12-, 14-, 23-, and 32-mm HDX PIT tags held within PVC piping to maintain proper tag orientation. The tag size being tested was affixed to a 5-m aluminum rod to measure the maximum distance from each antenna a 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 5). Here, full read range is defined as the maximum possible distance from an antenna a tag could be detected within, over, under, or by an 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 read ranges, individual non-parametric Kruskal-Wallis tests assessed statistical differences between HVJ categories of on (1.5 m^3/s) or off and AWS categories of high (8 – 9 m^3/s) or low flow (3.75 – 4.75 m^3/s). We limited the analysis to 32-mm tags because of the increased presence of zero data for other tag sizes.

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. Efficiencies were calculated using the number of fish scanned by the facility operator rather than the number of known detections upstream of each antenna (as is standard practice) because of known low detection efficiency and given complications associated with fish moving rapidly in both directions, often undetected, and leaving and then returning to the fishway. As done in 2021 (Moniz et al. 2022), detections that occurred more than 48 hours before a fish was scanned by the facility operator were not considered in detection efficiency calculations to account for fish that may have left the fishway undetected.

Table 5 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

1.2.4 Telemetry Download and Management

All fixed stations and PIT readers were downloaded approximately weekly during the operational period. Data were downloaded either remotely, or in person onto a tablet connected to a network. In both cases data were immediately backed up on a cloud-based storage. 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.

Various sources manage databases of tagging, detection, and recapture data for both radio and PIT tagged fish collected from the watershed. Palmer Environmental Consulting Group (Palmer) operated the fishway and 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 of the Project according to the OPP (McMillen Jacobs & Associates and BC Hydro 2022). WSP 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. InStream managed all fixed stations described in Section 1.4.2, except for the outside RB fixed station, which was managed by LGL. Distinct databases are maintained by Palmer, InStream, WSP, and LGL, and data compilation efforts are collaborative (Figure 8).

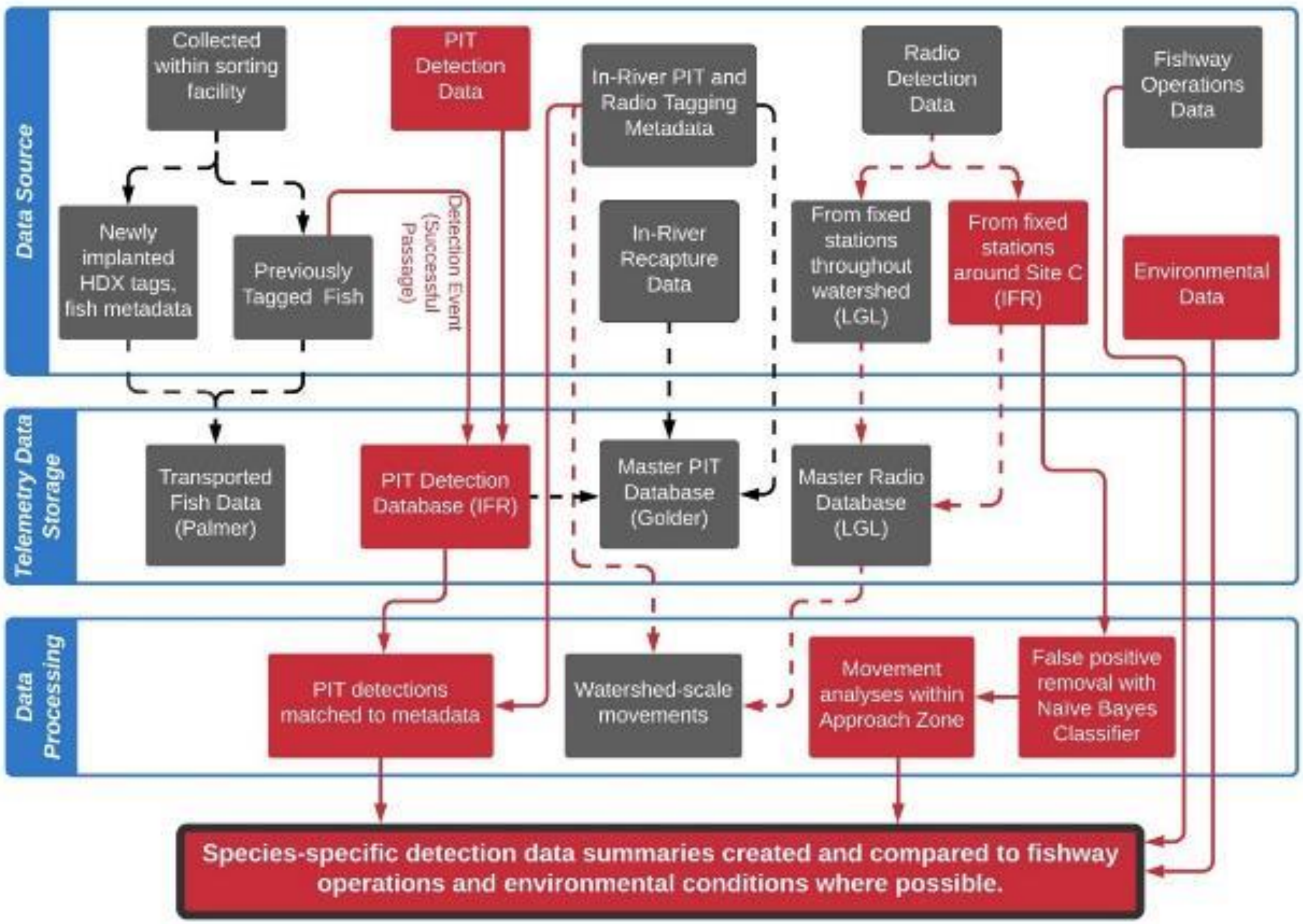

Figure 8 The process of data collection, storage and processing within the Fisheries and Aquatic Habitat Monitoring and Follow-up Program relevant to the data included in this report. Red boxes represent data held by InStream Fisheries Research, while grey boxes represent data held by other collaborating consultants. Red arrows show data processes conducted for Mon-13, and solid arrows indicate those conducted by InStream (dashed by other consultants).

1.2.5 Telemetry Data Processing

Data Filtering

Radio telemetry data from the six aerial fixed stations were filtered using BIO-Telemetry Analysis Software (BIOTAS), an open-source algorithm that provides a transparent and repeatable method for false-positive identification and removal in radio telemetry detection data. The framework is comprised of a supervised learning algorithm based on a Naïve Bayes classifier where known classifications (training data) classify raw detection 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 (Table 6). The first step in the process was to create a binary detection history 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. Predictor variables were then used to calculate the likelihood of a valid versus a false-positive detection for each recorded detection.

Training data comprised 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, we assumed that all codes corresponding with valid tags were valid. In subsequent iterations detections were classified as valid or false positives based on the distributions of predictor variables created from the training data. 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.

The five dipole fixed stations were known to have very few false-positive detections and these data were manually filtered. To do this, all detections of tags known not to be in the watershed, noise detections, and detections at each station that were not detected at a downstream station were removed. Filtered datasets for all 11 fixed stations were then combined into a single dataset.

Additional filtering was undertaken to ensure that all detection from within the fishway were from tagged fish actually within the fishway and not nearby, outside of the fishway. 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 WSP's Master PIT Database (Figure 8) to match detected tag codes with their available capture and biological information. Tag codes that could not be found in WSP's database were cross-referenced with PIT tag deployment data from Palmer, Ecofish Research Ltd, and Triton Environmental Consultants. Detections of 39 tag codes that could not be identified were removed from the final dataset and were not included in analyses.

Table 6. The seven predictor variables used to develop a classifier to discriminate between valid and false-positive detections of radio tags at each fixed radio telemetry station. The detection history refers to a binary code created for each tag that includes a fixed number of pulse intervals immediately preceding and following a given detection.

Predictor Variable	Description
Power	Received signal strength of a given detection
Consecutive record length	The longest continuous subset of recorded detections in the detection history
Hit ratio	The ratio of the number of detections within a history divided by the length of the detection history
Noise ratio	The number of plausible study tag hits divided by the total number of detections within a 1-minute interval around the detection
Detection lag	The difference of the difference in time between sequential detections
Detection in series (binary)	Did the detection occur in series with a previous detection
Consecutive detection (binary)	Were there consecutive detections within the detection history for that tag code

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; 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), 2600 seconds (tunnel outlet), 2000 (aerial entrance), 360 seconds (outside entrance), 240 (entrance pool, pool 8, and 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 undetected inactivity.

1.2.6 Analyses

Time to Event Analyses

To quantity the effects of environmental factors on rates of movements between spatial zones, we analyzed radio telemetry data with Cox proportional hazards regression ('Cox regression') in a competing risks framework (Alcott et al. 2021; Therneau et al. 2023). Cox regression is a form of time-to-event (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). 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). We divided continuous time-varying covariates (e.g., attraction flows, Peace River discharge, tailrace WSEL, water temperature) 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.

State transition rates were calculated for each tagged fish. Rates of approach were calculated as the duration of time between first detection at the approach zone to first detection at the entry zone and rates of withdrawal as the time between first and last detection within the approach zone before a fish retreated from the approach zone. 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. 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. Finally, rates of rejection included the 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. A single fish could transition between the same two zones more than once during a given occupancy on the array.

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 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).

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 Castro-Santos 2017). Nine explanatory variables were considered as fixed effects in candidate models (Table 7). Categorical variables of diel period and season are ordinal in nature (e.g., summer always follows spring and seasons progress continuously). Using sum contrasts retains this natural ordering while maximizing the power of comparisons. Each level is dummy coded and compared to the overall mean. Model outputs are provided for all but the last level because results of the last can be assumed based on those of subsequent levels (e.g., β level 4 = - β level 1 - β level 2 - β level 3).

Visualizing state transition rates by category is an important step of model interpretation, and coercing continuous variables into binned categories likewise aids in their interpretation. We do so for select covariates using the 'strata' function of the survival package (Therneau et al. 2023) such that separate baseline hazard functions are estimated for each level of a category of interest while assessing the effects of other covariates. The suite of explanatory variables included in final analyses differs from those used in 2021 in order to improve model structure and fit, but the selection was informed by those analyses. The model selection process is explained in the 'Model Selection Report' provided in Appendix A: TTE Covariate Selection Process.

To understand factors associated with rates of advancement and retreat across the state transitions of interest, a suite of candidate TTE Cox regression models consisting of all combinations of fixed effects and individual as a random effect was built for each species and state transition (sample size permitting) while ensuring no model contained correlated variables ($r > 0.4$) or variables with logical linkages (e.g., day and season). Models were also dropped if convergence could not be achieved due to too few completed transitions per level of categorical variable. No interaction terms were included given the number of fixed effects and the relatively small species- and state-transition-specific sample sizes. This resulted in a maximum of 129 possible candidate models.

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 intervals (lower and upper confidence intervals; LCI and UCI) were extracted from the top model(s) for each species and state transition. Schoenfeld residuals of the final models were examined to confirm that effects were consistent over time (assumption of proportional hazard; Hosmer and Lemeshow 1999). Cumulative incidence curves representing the proportion of available fish making each state transition were plotted over time for each species and included categorical fixed effects for a visualization of data trends were appropriate to do so.

Ultimately, conditions that increase rates of advancement and/or decrease rates of retreat between any two states will increase overall passage for that species.

Table 7 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).
Seasonal Variation	Day	The number of days since the beginning of the operational period (April 1).
	Season	Three-level ordered categorical variable, including spring, summer, and fall. 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). ‘Spring’ set as first level.
Diurnal Variation	Diel Period	Four-level ordered categorical variable, including day, dusk, night, and dawn. Daily transition times between periods were obtained using the ‘suncalc’ package in R (Thieurmel and Elmarhraoui 2022). ‘Day’ set as first level.
	Day Period	Only Bull Trout models would converge with the four-level diel period variable given a lack of data from the shorter dusk and dawn diel periods. To achieve model convergence while accounting for diel patterns, dusk was grouped with night and dawn with day creating a two-level variable of day period including just night and day.
Attraction Flow Terms	AWS	Median hourly AWS discharge. Values recorded at the TUF.
	HVJ	Median hourly HVJ discharge. Values recorded at the TUF.
	Percent Attraction Flow	Median hourly combined attraction flow (AWS + HVJ) divided by the mean hourly Peace River discharge multiplied by 100 to achieve a percentage.
River Hydrology	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). Recorded at a resolution of 10 m/s^3
	Water surface elevation (WSEL)	Mean hourly WSEL at the tailrace of the fishway. Values recorded at the TUF (Sensors LT_600 and LT_601).

Fish Movement Summaries

An interval analysis of PIT detection data could not be conducted given low detection efficiency of PIT antennas and substantial milling behavior among fish within the fishway. In an interval analysis each new entry into the fishway would be considered a new occupancy. With performance of the entrance antennas being poor, we have little confidence in when an occupancy on the PIT array ended and when a new one began. There were too few PIT-tagged fish that successfully ascended the fishway and too many missed detections for such analysis to be informative.

Instead, radio and PIT data from within the fishway were combined and raw numbers summarized. First, if a fish ascended the fishway and was scanned by the facility operator, it was considered a new individual if it re-entered (i.e., was processed, transported, migrated back downstream of the Project, and re-entered the fishway). Categorizing the fishway into linear zones – entry zone, entrance pool, cell 8, upper fishway (cell 23, 24 and vee-trap), and sorting facility – we calculated the number of target fish known to make it to each point. For example, if a tagged fish was first detected in the upper fishway we know it went undetected at some point at all downstream locations (cell 8, entrance, entry zone). Visualizing these raw numbers may reveal barriers between the entry zone and a full successful ascent.

We also summarized the number of upstream and downstream movements made by PIT and radio-tagged fish by enumerating each subsequent detected switch in direction. These numbers provide insight into milling behaviors and the diversity of inter-individual activity with each species. Finally, the fishway ascent time was calculated for radio-tagged fish detected at the vee-trap fixed station as the difference between the last detection in the entrance pool and first detection at the vee-trap station for individuals making directed upstream movements (i.e., detection at entrance, followed by turning basin and vee-trap stations). Residence time was not calculated because of uncertainties around the number of entrance and exit events for PIT-tagged fish.

Efficiency Metrics

As defined in the EIS, attraction efficiency is the proportion of a population that is attracted to and enters the fishway, passage success is the proportion of those fish that successfully pass through the fishway, and passage efficiency is the product of attraction efficiency and passage success. We calculated these efficiency metrics using radio telemetry data. Previously, we determined attraction efficiency with radio telemetry data and passage success with PIT detection data. However, with performance of the entrance antennas being so poor, we have ultimately decided this approach is not valid. Therefore, 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 radio-tagged fish processed by the facility operator divided by the total number known to have entered the fishway (i.e., were processed by the facility operator and/or detected within the fishway). Attraction efficiency was multiplied by passage success to estimate the passage efficiency for each target species. All detection data collected during shutdown periods were excluded from both attraction efficiency and passage success calculations. These metrics were calculated for each species.

PIT telemetry data were used to determine trap efficiency, the proportion of tagged fish that reached the upper fishway (cell 23, 24 and vee-trap) that were affectively trapped and sorted. By calculating trap efficiency, we avoid using PIT telemetry data from the lower fishway for which we have such low confidence but can still evaluate effectiveness of the fishway between the upper fishway and the sorting facility, an area where passage is known to be restricted.

With all proportion estimates we used the Wald method and a binomial distribution to quantify uncertainty. The Wald method approximates the sampling distribution using a normal distribution. A margin of error is determined by multiplying the standard error, computed from the observed proportion and sample size, by the confidence level (0.95). This error is added and subtracted from the observed proportion to produce a confidence interval.

1.3 Results

1.3.1 Fishway Operations and Environment

The TUF was operational for 201.6 of the 213.6 days (94%) between start up on April 1 and shut down on October 31. This is an improvement from 2021 when the fishway was operational for 81% of the operational period. The proposed attraction flow schedule was to regularly alternate AWS flows between 4.25 and 8.5 m^3/s and the HVJ between off and on (1.5 m^3/s). While HVJ flows aligned with the proposed schedule, AWS flows were variable (Figure 9). Attraction flows were mostly consistent with the schedule until the first shutdown on May 29. Once the facility was operational again (June 9), the AWS was often within the desired range, but timing was variable. Operations adhered to the schedule for most of July but were variable again in August and September. Starting September 28, pumps 1 and 2 were shut down for the rest of the operational period due to damage to the variable frequency drives. The result was AWS flows were of lower magnitude than was called for in the study design. Considering the classifications of “low AWS flows” as 3.75-4.75 m^3/s and “high AWS flows” as 8-9 m^3/s as being within specification (i.e., ± 0.5 m^3/s of the values in Table 1), as in previous years, AWS flows were out of specification 29% of the operational period. Note that after September 28, the AWS was often out of specification (Figure 9).

River discharge was highly variable during the operational period. Flows were highest (> 1500 m^3/s) in April and early May, reaching a peak of 1830 m^3/s on May 7 before receding (with variability) to < 500 m^3/s in late July. Flows showed rapid fluctuations through the rest of the summer, entered a period of relative stability through September, and then varied between ~500 and 1500 m^3/s through the rest of the operational period, reaching a low of 391 m^3/s on October 31. (Figure 10)

The water surface elevation (WSEL) at the tailrace of the fishway entrance changed by 2.4 m (range = 409.2 to 411.6 m) during the operational period and exceeded the upper end of the fishway’s design criteria (410.5 m) for a total of 125.7 days (i.e., 59% of the operational period, Figure 10).

Water temperature and diel periods showed predictable seasonal patterns throughout the operational period. Water temperature ranged from 2.7 to 18.5°C, increasing through spring into summer and then decreasing in September and October. Despite the known importance of temperature to fish physiology and behaviour, water temperature was not included as a predictor of fish movement in analyses because it was correlated with many other covariates of direct interest (see Appendix A: TTE Covariate Selection Process). Daylight hours, calculated as the time between sunrise and sunset, ranged from 17.7 (June 21) to 9.2 (October 31) hours. (Figure 10)

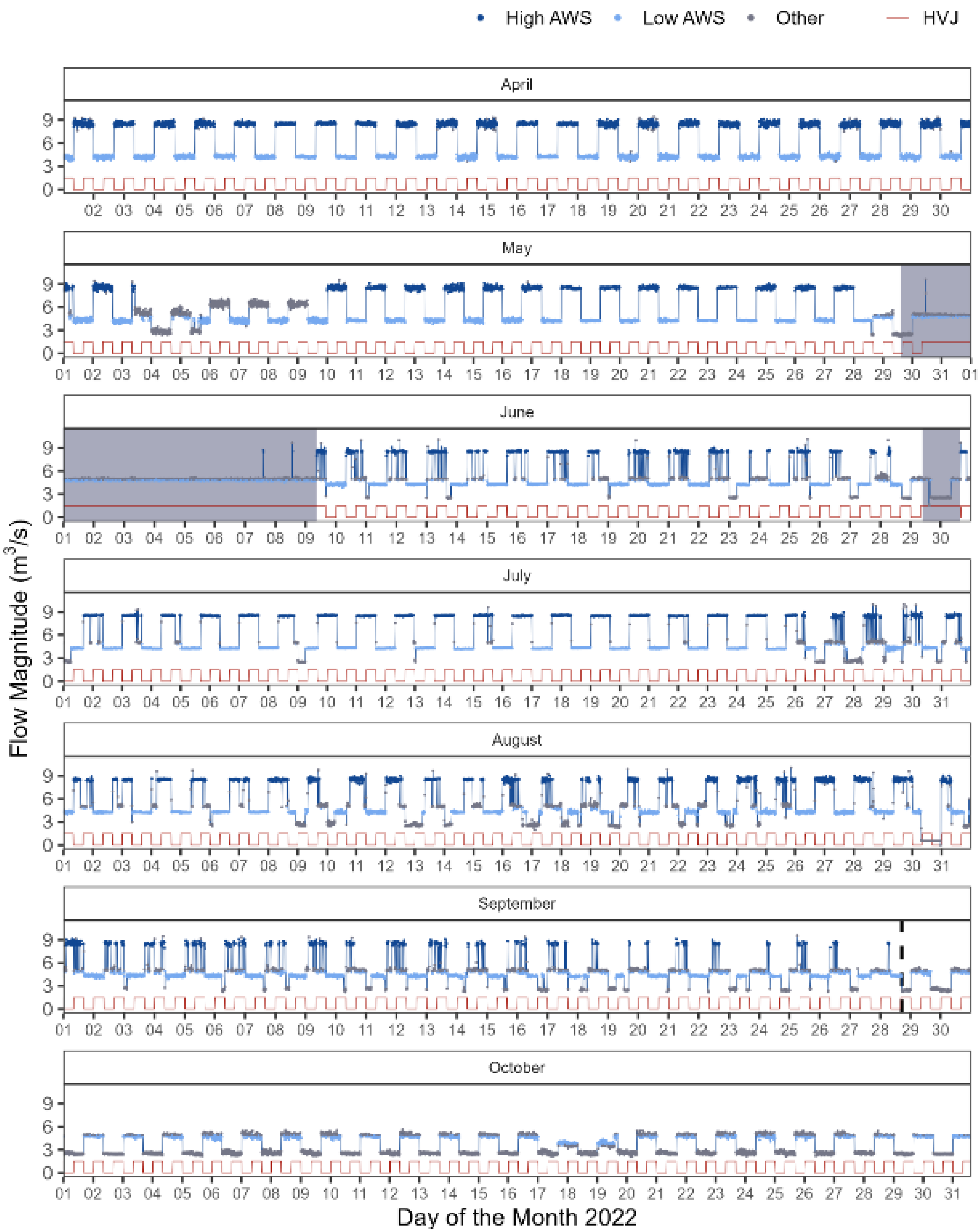

Figure 9. Fishway attraction flows from the temporary upstream fish passage facility during the operational period provided from an auxiliary water supply (AWS) and a high velocity jet (HVJ). AWS flows are classified as in specification of "low" (3.75-4.75 m³/s) or "high" (8-9 m³/s). AWS flows out of specification are shown in gray. Shutdown periods are greyed and the dashed vertical line on September 28 indicates the shutdown of two attraction flow pumps. Data provided by BC Hydro.

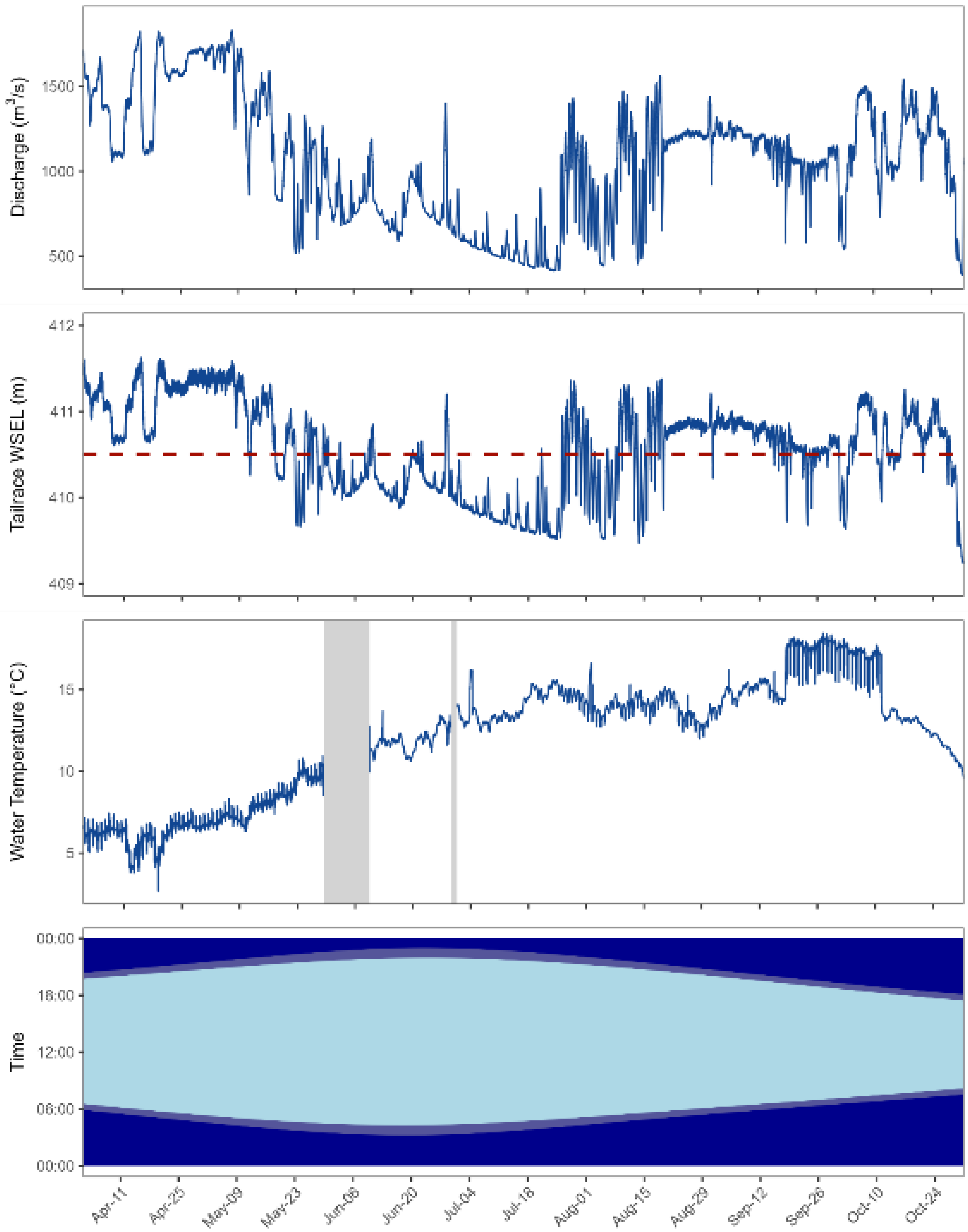

Figure 10. Environmental conditions at the temporary upstream fish passage facility during the operational period, Peace River discharge was measured at the Water Survey of Canada gauge at Peace River above Pine River (07FA004). Water surface elevations (WSEL) were calculated as the average water level recorded between sensors LT-600 and LT-601 located at the tailrace of the TUF and managed by BC Hydro. The red dotted line indicates the upper limit of the design criteria of the fishway. Water temperature data were collected from within the fishway by BC Hydro. Diel periods were obtained using the 'suncalc' package in R. Grey areas indicate shutdown periods.

1.3.2 Array Performance

Fixed Stations

There were no outages of concern; beacon tags were detected at each station every day of the operational period. However, it was not uncommon for a beacon tag detection to be missed within an hourly interval. The longest duration that a beacon tag went undetected was seven hours. This happened on May 12 at the entrance pool, pool 8, and vee-trap stations from 1400 to 1700, at the outside LB station on July 28 from 0900 to 1600 and at the outside entrance station on May 4 from 1300 to 2000. We do not know why beacon tags were not detected during these times. Those on May 4 and 12 were presumably due to user error because stations were downloaded on those days. In total, the proportion of the total operational time beacon tags were not detected by a fixed station was low, ranging from 0.2 to 3.1% (Table 8).

As in 2021, boat drifts confirmed that detection ranges of the approach and outside LB and RB paired fixed stations reached across the full channel width (Figure 11). Across both years, detection ranges of the approach LB and RB fixed stations overlapped by over 100 m in some areas. In 2022 detection ranges of the outside LB and RB fixed stations overlapped by 150 to over 200 m while in 2023 we observed much less overlap during the testing. 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.

Table 8. Beacon tags transmitting every hour monitored outages at each fixed radio telemetry station. Outage durations refer to the total hours of missed beacon detections during the operational period and the total maximum consecutive duration of missed beacon detections.

Station	Duration of Missed Beacon Detections (hours)		% of Operational Period
	Total	Maximum	
Outside LB	158	7	3.08
Approach LB	132	2	2.57
Approach RB	126	2	2.46
Tunnel outlet	106	1	2.07
Entrance aerial	143	1	2.79
Outside entrance	12	7	0.23
Entrance pool	11	7	0.21
Turning basin	122	2	2.38
Pool 8	73	7	1.42
Vee-trap	102	7	1.99

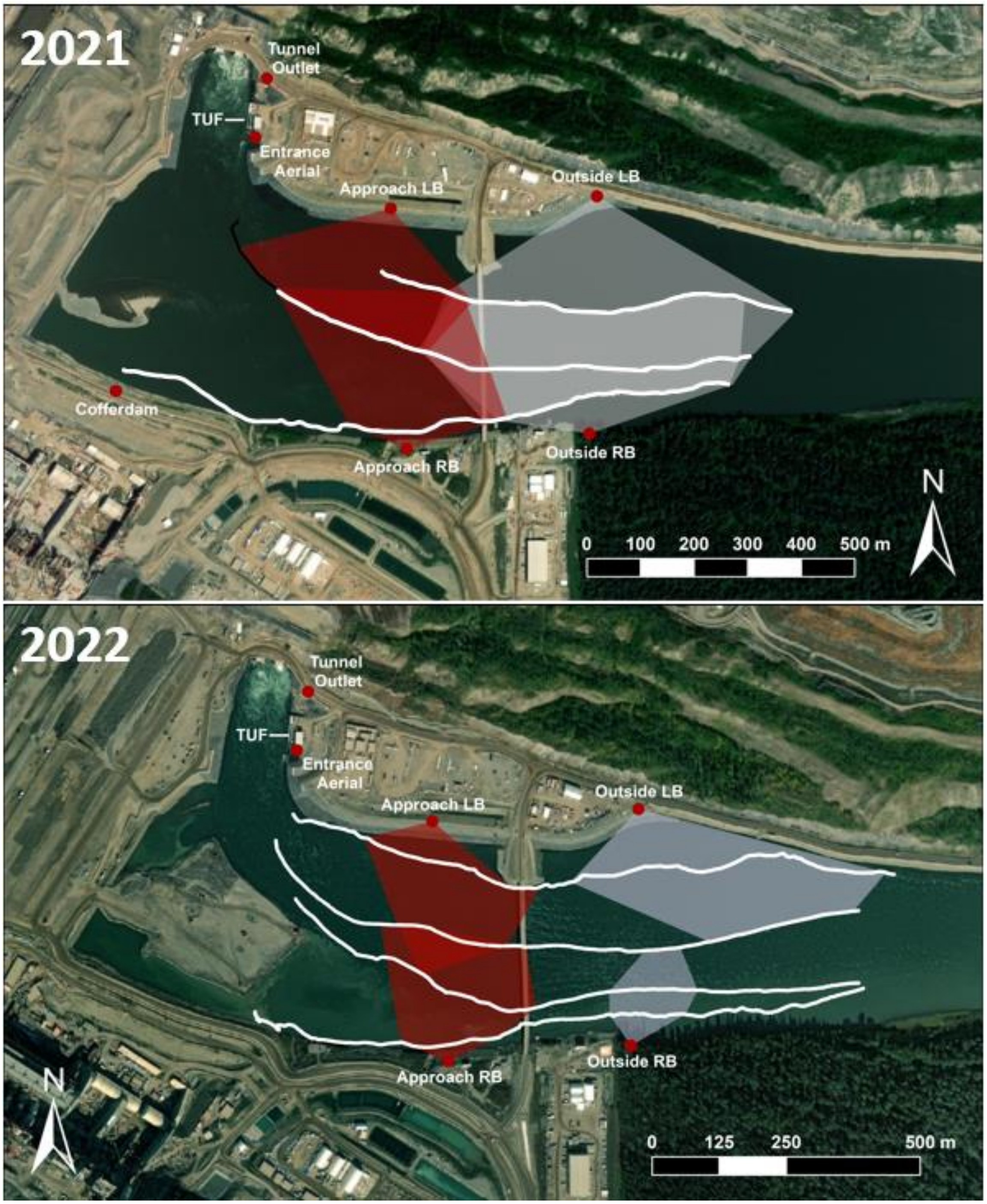

Figure 11 Approximate detection ranges of the paired approach (red) and outside approach (gray) fixed stations in 2021 and 2022 on the left bank (LB) and right bank (RB). GPS tracks of the boat and test tags used for range testing are shown as white lines. The tunnel outlet and entrance aerial have not been tested due to restricted access within the diversion tunnel outlet. The RB cofferdam station was removed prior to 2022 operations.

PIT Antennas

Read Range

Percent read range - the percentage of area intended to detect tagged fish that does detect tags - is the most useful antenna performance metric because it informs data gaps. Mean percent read range was highest for the Orifice 24 antenna at 93.5%. Other antennas were much lower, ranging from 44.2% (vee-trap) to 0.8% (east Entrance; Table 9). Mean total read range (the raw value recorded during testing) ranged from 0.7 cm (east entrance) to 28 cm (orifice 24; Table 9). Statistical analyses of precent read range comparison between attraction flow categories revealed significant differences for AWS at the orifice 8 antenna (the 'under' measure only; i.e., the maximum distance from the top of the antenna) and for HVJ at the weir 8 and east entrance antennas (Table 9). Performance of the east entrance antenna was better when the HVJ was on (percent read range mean = 1.2%, sd = 1.0) than when it was off (mean = 0.5%, sd = 1.6). Performance of the weir 8 antenna was better when the HVJ was off and there was a dramatic drop in read range when the HVJ was operating: mean percent read range was 0.9% (sd = 1.5) when the HVJ was on and 50.7% (sd = 45) when it was off. The other statistically significant difference was at orifice 8: mean percent read range for the 'under' metric was 18.5% (sd = 17.0) when the AWS was 'high' and 38.7% (sd = 27.6) when the AWS was 'low'.

Table 9. PIT testing results from 32-mm PIT tags. Total read range (maximum distance a tag was detected) is presented as a percentage of the full read range, the maximum possible distance a tag could be detected within, over, under, or by an antenna. Kruskal-Wallis (KW) tests assessed statistical differences between high velocity jet (HVJ) categories of on (1.5 m3/s) or off and Auxiliary water supply (AWS) categories of high (8 – 9 m^3/s) or low (3.75 – 4.75 m^3/s).

Antenna	Measure	n	Mean Read Range		KW Test P-Value	
			Percent	Total (cm)	AWS	HVJ
Vee-trap	By	23	44.2	13.3	0.518	0.245
Orifice 24	Under	23	93.5	28.0	0.711	0.563
Weir 24	Over	24	32.9	9.9	0.763	0.350
Orifice 23	Under	24	16.7	5.0	0.361	0.361
Weir 23	Over	24	14.4	4.3	0.218	0.230
Orifice 8	Under	23	28.1	15.5	**0.048**	0.666
Orifice 8	Over	22	19.1	10.5	0.106	0.592
Weir 8	Over	23	20.9	19.8	0.404	**0.001**
West entrance	Under	23	8.1	7.0	0.239	0.238
East entrance	Under	24	0.8	0.7	0.891	**< 0.001**

Detection Efficiency

Efficiency was only evaluated for 23- and 32- mm tags because of the limited data from 12-mm tags. A total of 303 individuals were scanned in the sorting facility by the operator, two of which ascended the fishway twice, making for 305 ascents (n = 3, 127, and 175 for 12-, 23- and 32-mm tags, respectively). Of these 305 ascents, 277 were detected within the fishway and 270 were detected within the time cut-off of 48 hours for inclusion in detection efficiency calculations. Across both tag sizes and all locations, detection efficiency ranged from 6.3% (23-mm tag at Cell 23) to 86.3 % (32-mm tag at Vee-trap). As expected, detection efficiencies were higher for 32-mm tags than 23-mm tags (Table 10). A high percentage of fish successfully ascending the fishway were previously detected at the vee-trap (>80%), but lower fishway cells had lower detection efficiencies (i.e., < 30%). The low detection efficiency of lower cells does limit our understanding of how PIT-tagged fish move through the fishway.

Table 10. Detection efficiencies for each antenna location (i.e., vee-trap or pair of antennas) and for the array overall were calculated as the percentage of PIT-tagged fish scanned by the facility operator that were previously detected at a given location. Detections occurring > 48 hours before being scanned were excluded to account for fish that may have left the fishway undetected.

Tag Size	Total Scanned	Entrance	Cell 8	Cell 23	Cell 24	Vee-Trap	Array
23mm	127	13.4 % n = 17	21.3 % n = 27	6.3 % n = 8	55.1 n = 70	83.5 n = 106	86.6 % n = 110
32mm	175	29.7 % n = 52	30.3 % n = 53	10.3 % n = 18	69.1 n = 121	86.3 n = 151	90.9 % n = 159

1.3.3 Fishway Effectiveness

Fishway effectiveness was assessed through a variety of means. TTE analyses evaluated factors associated with approach to and entry of the fishway using radio detection data from Bull Trout, Mountain Whitefish and Rainbow Trout. Datasets for Arctic Grayling and Burbot were too limited.

There was a large amount of movement data from within the fishway, mostly from PIT-tagged individuals. The low detection efficiency combined with known milling behaviors within the fishway preclude this data from being analyzed within a TTE framework. Instead, we combine radio and PIT detection data from within the fishway to summarize the numbers of fish making it to each area and the number and timing of movements within the fishway. These summaries elucidate where barriers within the fishway may exist. Attraction and passage efficiency were calculated as outlined in the management questions, as was trapping efficiency.

A total of 210 radio-tagged fish and 4,560 PIT-tagged fish were detected on the array during the study period. These numbers decrease when only considering the five target species detected within the study area (i.e., excluding radio detections outside of the approach zone) during the operational period and excluding shutdown periods: 149 radio-tagged fish and 1,470 PIT-tagged fish.

TTE Analyses of Approach and Entry

TTE analyses of radio telemetry data are presented by species. There is a model for each state transition, and two state transitions for each zone (i.e., advance and retreat from that zone). Details are provided to help understand certain observations or terms at first mention but not repeated in subsequent models. Presented figures were selected to portray results most relevant to the objectives of Mon-13. Full comprehensive reports of each model are provided in appendices and referred to as required.

The total number of individuals, occupancies, and transitions for each state change within the final dataset used in TTE analyses (e.g., following removal of data collected during shutdown periods) are shown in Table 11. Completed state transitions were evaluated at the occupancy level (i.e., the occupancy of an individual on the array) while the random effect was evaluated at the level of the individual. The number of transitions (i.e., the number of movements between each state) per individual over time was included as a fixed effect.

An important part of the multivariate model selection process is to understand how covariates interact with each other. A challenging characteristic of this dataset is the heterogeneity encompassed by the individual, including the potential for distinct seasonal behaviours across the operational period. For example, the motivation for a Bull Trout to be upstream of the Project may differ from April to August, when they are known to be migrating to spawning grounds. Differences in activity among individuals were substantial in this dataset; the more active an individual, the more it contributes to the dataset. Activity also varied throughout the operational period. These patterns are revealed when observing the number of transitions recorded by individual, shown below for movement into the approach (Figure 12) and entry zones (Figure 13). While we account for this heterogeneity by including a random effect term, it is an important consideration when interpreting model results.

Table 11. The total number of individuals, occupancies, and transitions for each state change for target species. For each zone we model advance and retreat from that zone. From the fishway zone we only assessed rejection (retreat from fishway) because numbers of fish completing the passage state transition (advance to sorting facility) were so low. Rejection could only be modeled for Bull Trout. A continuous presence on the entire array is an occupancy. Transitions represent the number of movements between each state.

Species	Zone	State Transition	Individuals	Occupancies	Transitions
Bull Trout	Approach Zone	Approach	70	263	2058
		Withdraw	63	197	611
	Entry Zone	Entry	39	133	516
		Departure	37	123	1335
	Fishway	Rejection	27	63	436
Mountain Whitefish	Approach Zone	Approach	12	65	115
		Withdraw	12	49	110
	Entry Zone	Entry	9	26	43
		Departure	9	21	59
	Fishway	Rejection	5	11	18
Rainbow Trout	Approach Zone	Approach	16	52	180
		Withdraw	12	32	83
	Entry Zone	Entry	10	17	27
		Departure	8	14	118
	Fishway	Rejection	6	9	15

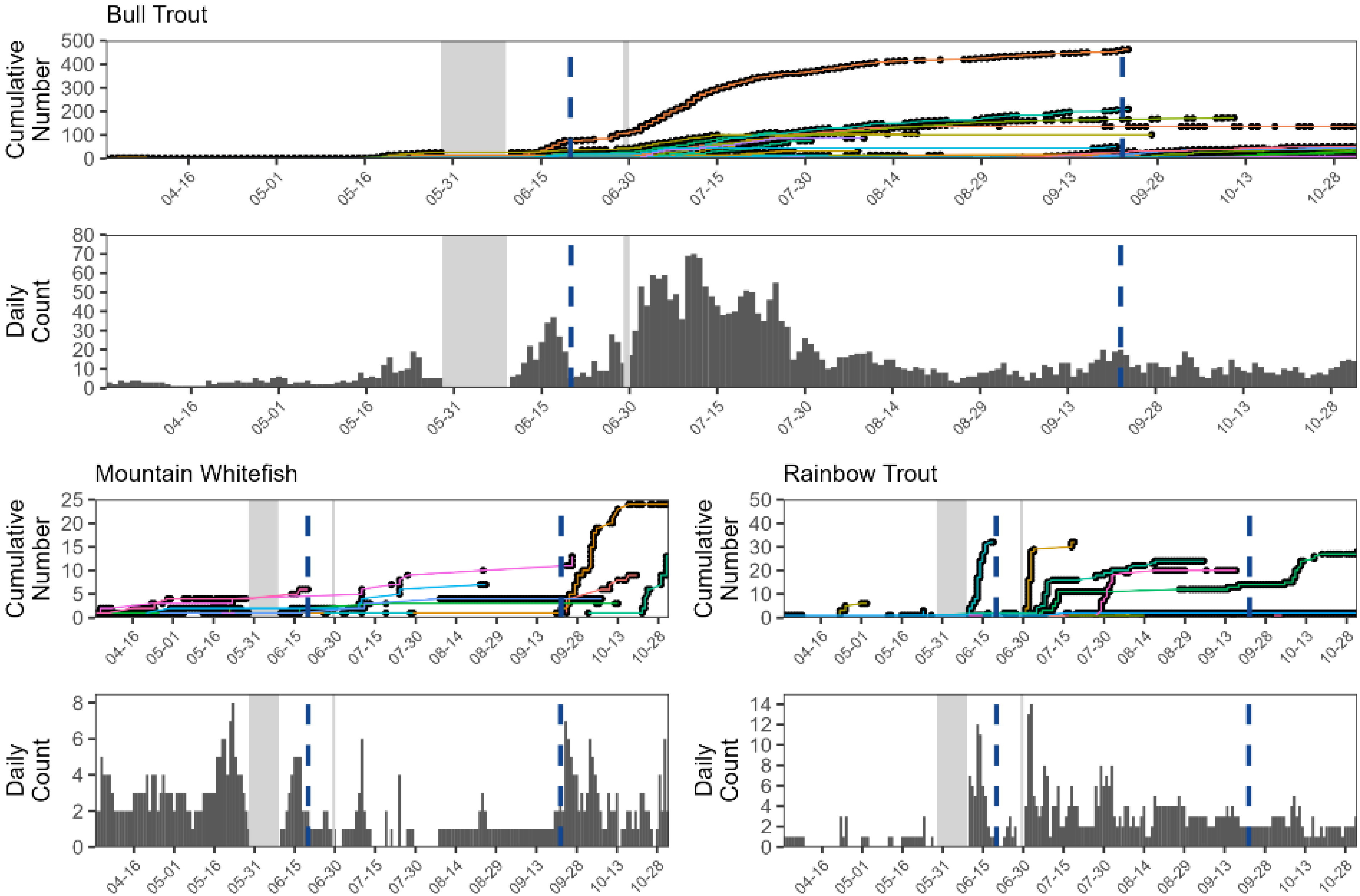

Figure 12. The cumulative number of transitions made by radio-tagged fish into the approach zone (top panel) and daily count of transitions across all individuals into the approach zone (bottom panel) for the duration of the operational period by species. Each transition represents a movement between the outside approach zone and the approach zone. Individual fish are identified by distinct colours. Shutdown periods are shaded grey (data excluded). Blue vertical lines delineate seasons.

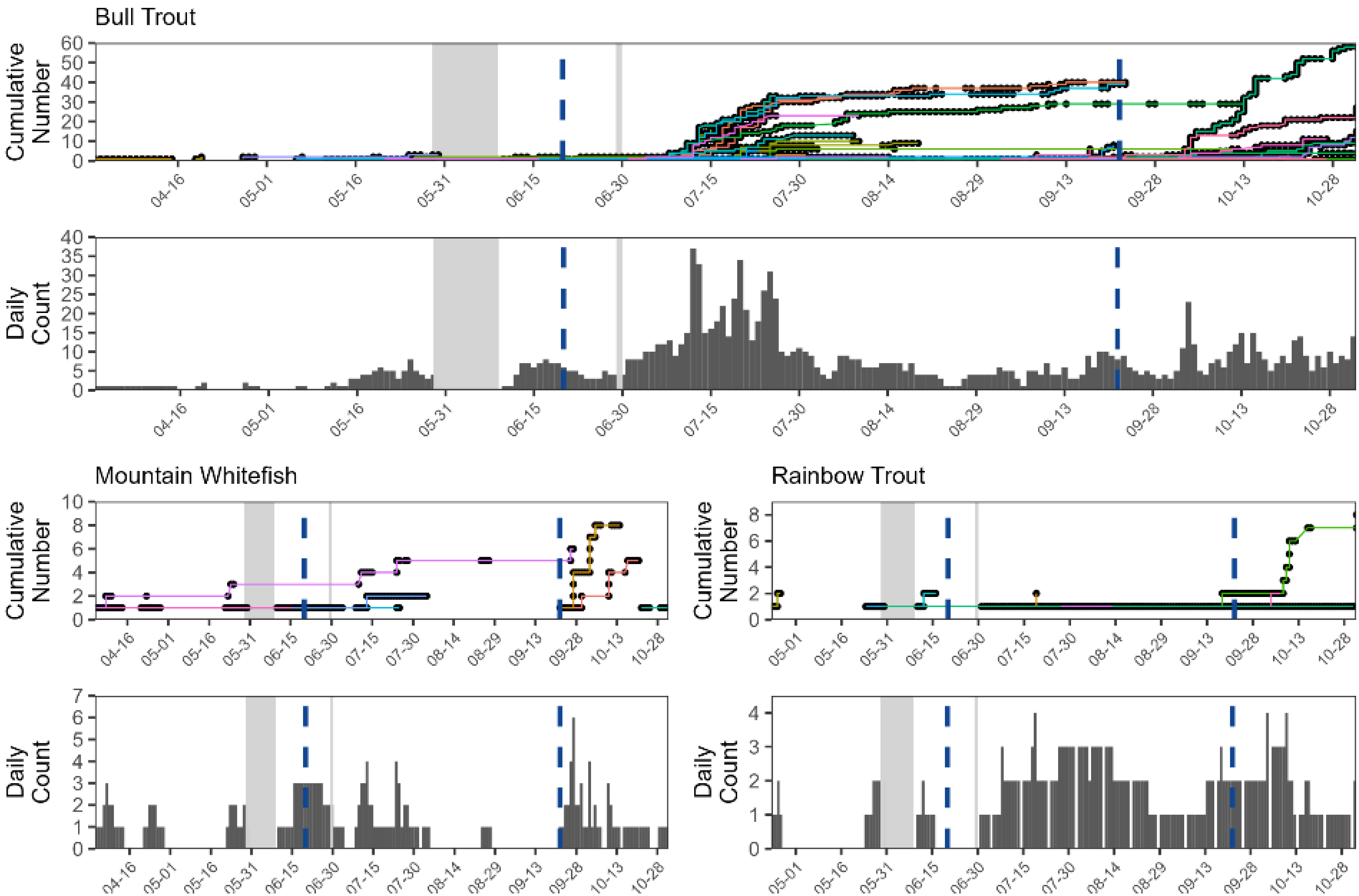

Figure 13. The cumulative number of transitions made by radio-tagged fish into the entry zone (top panel) and daily count of transitions across all individuals into the entry zone (bottom panel) for the duration of the operational period by species. Each transition represents a movement between the approach zone and the entry zone. Individual tagged fish are identified by distinct colours. Shutdown periods are shaded grey; data from these periods was excluded from analyses. Blue vertical lines delineate seasons.

Bull Trout

We were able to fit five models for Bull Trout: approach and withdrawal from the approach zone, entry and departure from the entry zone, and rejection of the fishway.

Approach Zone (Approach/Withdraw)

Models within two ∆AIC of the top model were considered candidates. The top and selected approach model included diel period, season, and river discharge. The second model (∆AIC = 1.08) was not pursued because only one term was added that had a very minimal effect. All terms were statistically significant, including the random effect (variance = 1.5; Table 12). The withdraw model set included six candidate models, all of which included diel period and some combination of attraction flow and river discharge. We retained the top model (diel period and percent attraction flow) as the simplest means to evaluate important variables. All variables except the comparison of the day period relative to all other diel periods were statistically significant in the withdraw model and variance of the random effect was 0.53, considerably lower than in the approach model (Table 12). The process of model selection is explained in Appendix B: Bull Trout Approach Zone Model Selection .

Magnitude of effect for each term is described by the hazard ratio (HR) and associated confidence intervals (CIs), shown in Figure 14. The deviation from 1 in the HR indicates the magnitude of effect as determined by the unit of measure (e.g., to the next unit increase for continuous variable or the next ordered category in categorical variables). Values < 1 indicate a negative effect and those > 1 a positive effect. Of particular interest are variables that both increase advancement and decrease retreat from the approach zone because both conditions will increase overall passage rates for that species.

Diel period was included in both models. In the approach model the HR for day (1.65) means approach rates are 65% faster during this period than others. Dusk and night both have negative effects, with approach rates being 25% and 57% slower than all other time periods, respectively. The effect of the last level, dawn, is inferred based on other levels as having a positive effect ($\beta = 0.648$). Therefore, approach rates were fastest during dawn and daylight hours. There is uncertainty around the effects of diel period in the withdraw model. The dusk period has a strong positive effect with large confidence intervals: approach rates are 42 to 152% faster relative to other periods. The effect of the night period has tighter confidence intervals and indicates slow withdrawal rates. Visualizing these effects shows a consistent effect of both rates (approach and withdraw) being faster during daylight hours and a clear pattern of approach rates decreasing from dawn to night, with more uncertainty in the withdraw model (Figure 15).

River discharge was included in the approach model and percent attraction flow, which incorporates both river discharge and total attraction flow, in the withdraw model. The HR for discharge was 0.984 (Figure 14), which means rates of approach decrease by 1.6% for each 10 m/s^3 increase in discharge. Although this number is small, the biological implications could be large as average daily change in discharge across the season was ~200 m/s^3. The HR for percent attraction flow in the withdraw model is 0.68 (Figure 14) indicating that rates of withdrawal decrease by 32% as the proportion of attraction flow relative to total discharge increases. Visualizing these effects by coercing experienced discharge and percent attraction flow into categories confirms a decrease in approach rates with increasing discharge and shows a drop in approach rates at the highest discharge category (Figure 16). Both models suggest increased passage rates with lower river discharges: approach rates are faster and withdrawal rates are slower when the attraction flow percentage is higher (i.e., lower discharges and/or higher attraction flows).

With respect to seasonal effects, only present in the approach model, the main finding is faster approach rates during the summer months: HR of 1.42 for summer indicates that approach rates are 42% faster in the summer relative to spring and fall. Results also indicate the approach rates are slowest in the fall. Full results and a visual of approach rates stratified across seasons are provided in Appendix B: Bull Trout Approach Zone Model Selection .

Fit of the approach model was assessed as adequate because the assumption of proportional hazards failed for discharge. Additionally, the random effect was strongly correlated with season and to a lesser extent, discharge (Figure 17). These patterns are difficult to interpret but indicate inter-individual differences in rates of approach across seasons. Corroborating this is the high variance held by the random effect. We had no concerns regarding model fit for the withdraw model. Assessments of model fit are further detailed in Appendix B: Bull Trout Approach Zone Model Selection .

Table 12. Coefficient estimates (β) with standard errors (SE), p-values, and hazard ratios (HR) with upper and lower 95% confidence interval (UCI, LCI) of covariates from selected model for approach and withdrawal rates analyzed with Cox time-to-event models. These models represent advance and retreat from the approach zone. The sample size (n) refers to the number of exposure intervals in the model (completed transitions and censors). The number of transitions indicates the number of completed advance of retreat state transitions.

State Transition	Variable		β	SE	p-value	HR	LCI	UCI
Approach Rates	Diel: Day vs. Mean		0.503	0.056	**< 0.001**	1.654	1.483	1.844
	Diel: Dusk vs. Mean		-0.304	0.122	**0.013**	0.738	0.581	0.937
	Diel: Night vs. Mean		-0.847	0.075	**< 0.001**	0.429	0.37	0.496
	Season: Spring vs. Mean		-0.416	0.07	**< 0.001**	0.66	0.575	0.756
	Season: Summer vs. Mean		0.348	0.053	**< 0.001**	1.416	1.276	1.571
	River Discharge		-0.016	0.001	**< 0.001**	0.984	0.982	0.986
	Random Effect	p-value	**0.056**					
		Variance	1.548892					
	Sample size		n = 27115, transitions = 1927					
Withdrawal Rates	Diel: Day vs. Mean		-0.026	0.09	0.774	0.974	0.816	1.163
	Diel: Dusk vs. Mean		0.635	0.145	**< 0.001**	1.887	1.419	2.51
	Diel: Night vs. Mean		-0.295	0.104	**0.005**	0.745	0.607	0.913
	Percent Attraction Flow		-0.386	0.107	**< 0.001**	0.679	0.551	0.838
	Random Effect	p-value	**< 0.001**					
		Variance	0.5309697					
	Sample size		n = 28713, transitions = 593					

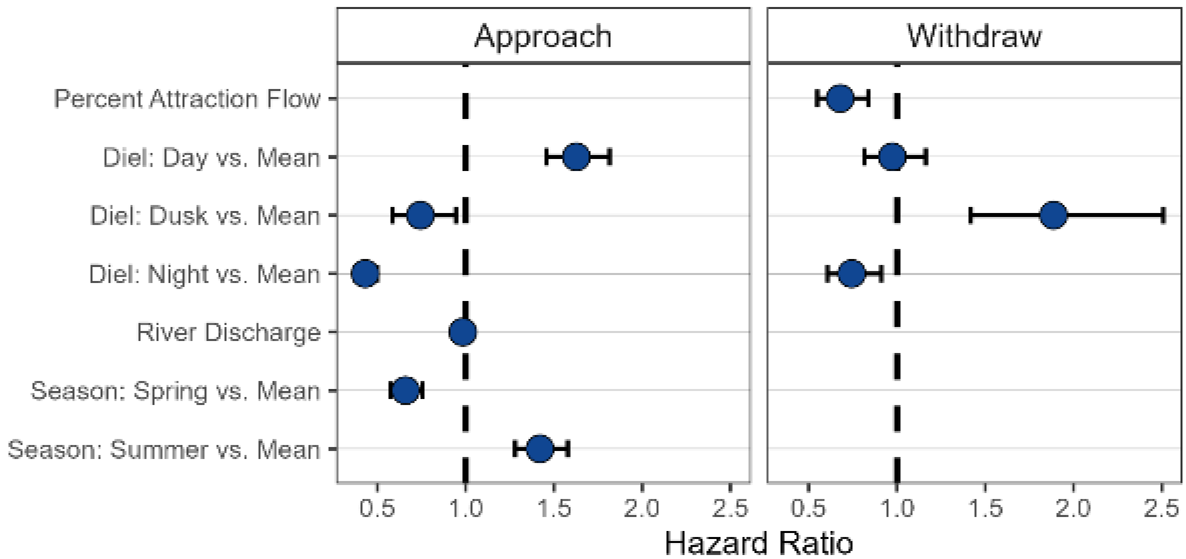

Figure 14. Hazard ratios with confidence intervals from time-to-event models of approach and withdrawal rates, representing advance and retreat from the approach zone, for radio-tagged Bull Trout. Deviation from 1 (indicated by a dashed line) in the hazard ratio indicates the magnitude of effect as determined by the unit of measure.

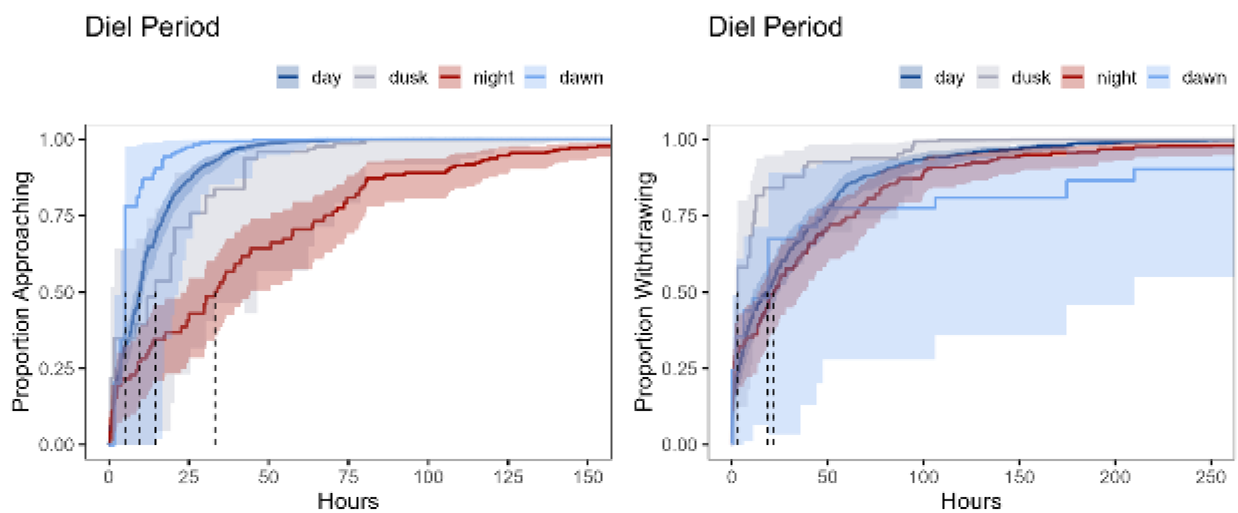

Figure 15. Kaplan-Meyer (KM) curves of rates of approach (left; advance from approach to entry zone) and withdrawal (right; retreat from approach zone) across diel periods for radio-tagged Bull Trout. Dashed vertical lines show the median for each category. KM curves show raw data and, therefore, do not account for the effects of other covariates included in the model.

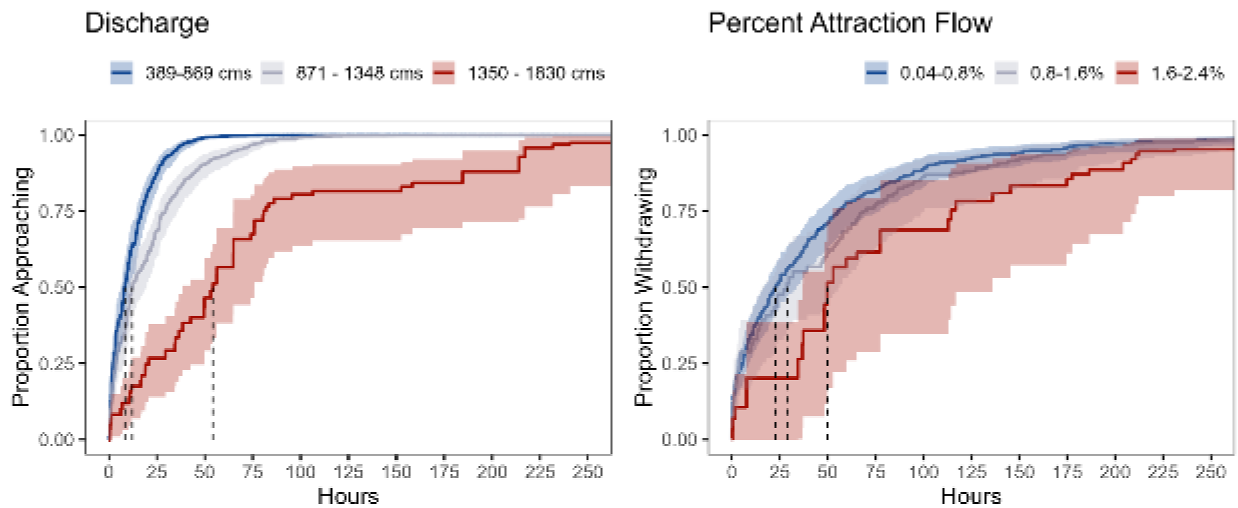

Figure 16. Kaplan-Meyer curves showing the effects of discharge on rates of approach (left; advance from approach to entry zone) and the effects of percent attraction flows on rates of withdrawal (right; retreat from approach zone) for radio-tagged Bull Trout. Both continuous variables have been coerced into three categories evenly distributed across the range of values. Within each percent attraction flow category river discharge ranged from 470 – 1825 m^3/s, 389 - 1213 m^3/s, and 415 - 617 m^3/s (in ascending order). Dashed vertical lines show the median for each category. KM curves show raw data and, therefore, do not account for the effects of other covariates included in the model.

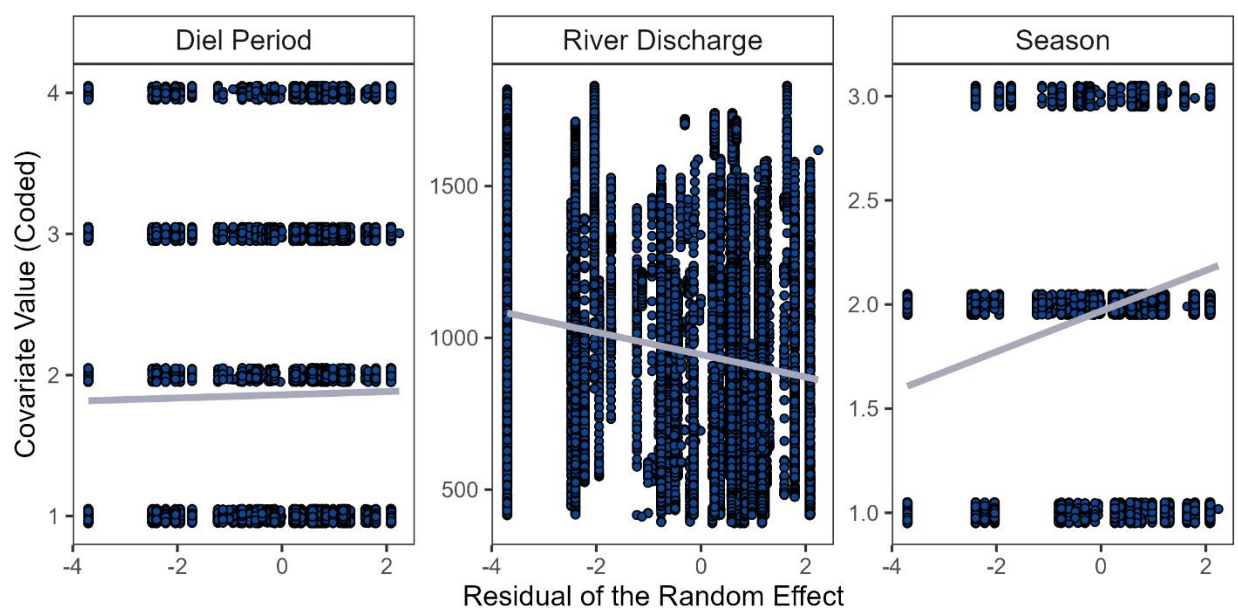

Figure 17 Correlations between the residuals of the random effect, which represents an individual, and each covariate included in the Bull Trout approach rates model. Correlations between the random effect and a covariate indicate variability at the level of the individual. Categorical covariates represented numerically according to order coded within models (first level of day and spring for diel period and season, respectively).

Entry Zone (Entry/Departure)

The top and selected entry model included diel period, day, river discharge and both attraction flow terms (HVJ and AWS); no other model was considered. The season variable had to be removed for entry models to converge; season was also excluded from departure models for consistency. The continuous 'day' variable retains some ability to assess seasonal patterns (linearly). The second competing model for departure rates (ΔAIC of 1.25) included the same terms as the entry model, and was therefore selected for ease of interpretation, justified in Appendix C: Bull Trout Entry Zone Model Selection. Across both models, the only terms without statistical significance were the HVJ attraction flow term in the entry model and river discharge in the departure model (Table 13). The random effect was significant in both models, holding variances of 0.98 (entry) and 0.69 (departure; Table 13).

Several results point to increased entry rates for Bull Trout with higher attraction flows. Advancement from the entry zone was faster with higher AWS flows and retreat was slower. An HR of 1.2 (LCI = 1.14, UCI = 1.28) in the entry model and 0.95 (LCI = 0.91, UCI = 0.98) in the departure model for the AWS term means entry rates increase by 14 to 28% and departure rates decrease by 2.3 to 8.5% for every unit increase in AWS. The effect is clear upon comparing entry between AWS categories (flows of 3.75-4.75 m^3/s versus 8.5 to 8-9 m^3/s), but there is overlap in departure rates (Figure 19). The HVJ attraction flow term also had a negative effect in the departure model, meaning departure rates decrease by 2 to 18% when the HVJ is on. The HVJ effect was not statistically significant in the entry model. Of additional consideration is the statistically significant increase in entry rates at lower river discharges when attraction flows would be more prevalent. The HR of 0.97 for river discharge indicates a 3% decrease in entry rates with every 10 m^3/s increase in discharge.

Both models included a temporal aspect; there was a 3% increase in entry rates and a 0.9% decrease in departure rates with every day of the operational period (see Table 13 for HRs). Diel period was also included in both models, but results reflect the limitations of categorical variables with low sample sizes. While we can conclude entry rates are faster during the day period, the range of confidence intervals is substantial (Figure 18). Results also indicate entry rates increase during dawn and decrease at dusk and night. Confidence intervals were similarly wide in the departure model, with departure rates being fastest during the dusk period and slower at night (Figure 18). Diel effects are not as clear in the departure model given large and overlapping confidence intervals but like the entry model, most data were from the day period. Full results and a visual of entry and departure rates stratified by diel period are provided in Appendix C: Bull Trout Entry Zone Model Selection.

It is important to note that fit of the entry model was poor and the number of completed state transitions was low. No statistically significant variable passed the assumption of proportional hazards, indicative of time-variable effects on the hazard and unaccounted-for interactive effects. The model was presented here in the interest of exploring the dataset but is not statistically sound. However, a clear finding is that departure from the entry zone was frequent and rapid whereas entry into the fishway was slow and infrequent. In the entry model, some exposure durations were > 500 hours (time from first detection in entry zone to detection within the fishway), whereas in the departure model exposure durations were typically < 5 hours (time from first detection in entry zone to retreat out of entry zone).

Table 13. Coefficient estimates (β) with standard errors (SE), p-values, and hazard ratios (HR) with upper and lower 95% confidence interval (UCI, LCI) of covariates from selected model for entry and departure analyzed with Cox time-to-event models. These models represent advance and retreat from the entry zone. The sample size (n) refers to the number of exposure intervals in the model (completed transitions and censors). The number of transitions indicates the number of completed advance of retreat state transitions.

State Transition	Variable		β	SE	p-value	HR	LCI	UCI
Entry Rates	Diel: Day vs. Mean		0.766	0.178	**< 0.001**	2.151	1.517	3.05
	Diel: Dusk vs. Mean		-1.007	0.459	**0.028**	0.365	0.148	0.899
	Diel: Night vs. Mean		-0.671	0.208	**0.001**	0.511	0.34	0.768
	Day of the Year		0.028	0.003	**< 0.001**	1.029	1.023	1.035
	River Discharge		-0.028	0.002	**< 0.001**	0.972	0.968	0.977
	Attraction Flow: AWS		0.189	0.029	**< 0.001**	1.208	1.141	1.28
	Attraction Flow: HVJ		-0.103	0.074	0.165	0.902	0.779	1.043
	Random Effect	p-value	**< 0.001**					
		Variance	0.9784958					
	Sample size		n= 23517, transitions = 394					
Departure Rates	Diel: Day vs. Mean		-0.169	0.081	**0.036**	0.844	0.721	0.989
	Diel: Dusk vs. Mean		0.67	0.151	**< 0.001**	1.953	1.453	2.626
	Diel: Night vs. Mean		-0.444	0.105	**< 0.001**	0.641	0.522	0.788
	Day of the Year		-0.009	0.002	**< 0.001**	0.991	0.988	0.994
	River Discharge		-0.002	0.002	0.219	0.998	0.995	1.001
	Attraction Flow: AWS		-0.056	0.017	**0.001**	0.945	0.915	0.977
	Attraction Flow: HVJ		-0.109	0.046	**0.018**	0.896	0.819	0.982
	Random Effect	p-value	**< 0.001**					
		Variance	0.6925452					
	Sample size		n = 4258, transitions = 1334					

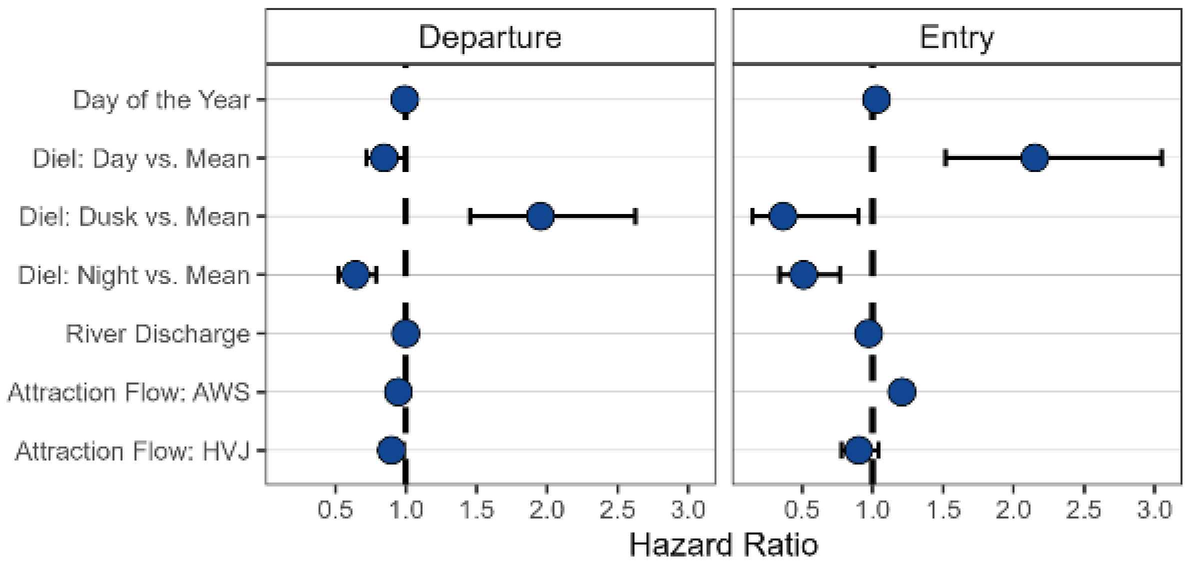

Figure 18. Hazard ratios with confidence intervals from time-to-event models of entry and departure rates, representing advance and retreat from the entry zone, for radio-tagged Bull Trout. Deviation from 1 (indicated by a dashed line) in the hazard ratio indicates the magnitude of effect as determined by the unit of measure.

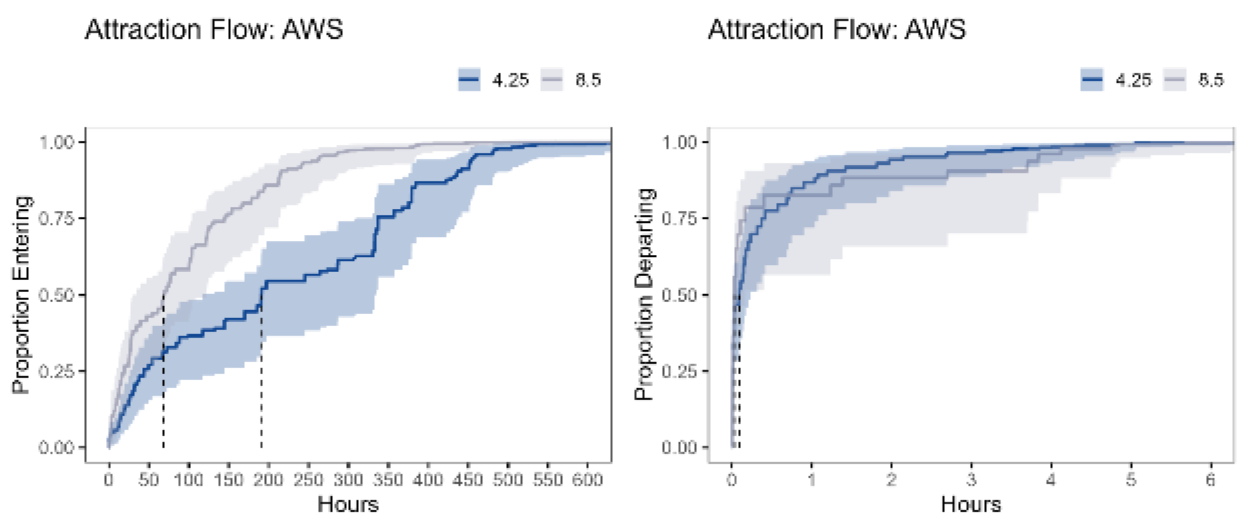

Figure 19. Kaplan-Meyer (KM) curves showing rates of entry (left; advance from entry zone to fishway) and departure (right; retreat from entry zone) across auxiliary water supply (AWS) attraction flow scenarios for radio-tagged Bull Trout. AWS flows had two setpoints: 4.25 and 8.5 m^3/s. Because AWS flows varied considerably, the displayed setpoints represent flows of 3.75-4.75 m^3/s and 8-9 m^3/s. Flows were outside of this range 29% of the time and are still encompassed by modeling. Dashed vertical lines show the median for each category. KM curves show raw data and, therefore, do not account for the effects of other covariates included in the model.

Fishway Rejection

The top rejection model included number of transitions, diel period, river discharge, and the AWS attraction flow. No other model was pursued. All terms but diel periods of day and dusk were statistically significant, and variance of the random effect was 1.3. Model fit was poor given non-normally distributed residuals and that several variables failed to meet the assumption of proportional hazards and/or were correlated with the random effect. The most notable finding is the negative effect of number of transitions (HR = 0.98). While the effect is small, it is potentially biologically meaningful. For every additional transition, rates of rejection decrease by 2%, as would be expected in the event of habituation or learned behaviour. Rejection rates were also slower during the night diel period (HR = 0.61; LCI = 0.43, UCI = 0.87) and with high river discharge (HR = 0.97). Contrary to models from the entry zone, rejection rates were faster at higher AWS attraction flows (HR = 1.16; LCI = 1.09, UCI = 1.24). Model diagnostics and results are provided in Appendix D: Bull Trout Fishway Rejection Model Selection.

Mountain Whitefish

Movement among tagged Mountain Whitefish occurred overwhelmingly during the day and most completed state transitions occurred during the fall. There was insufficient data to evaluate all four diel periods. Instead, day and night were compared in a two-level factor. The categorical season variable also had to be removed in some models.

Approach Zone (Approach/Withdraw)

The top approach model was chosen from a candidate set of five because no additional terms were statistically significant in subsequent models. This model included day, diel period, and river discharge, all of which were statistically significant along with the random effect (variance = 1.2). However, model fit was poor. Residuals of the random effect were bimodal, generally separating those approaching the fishway from those not. Additionally, model diagnostics suggest that interactions of inter-individual variability and time (season) were not encompassed by the model. There were 12 candidate withdraw models (ΔAIC < 2; Appendix E: Mountain Whitefish Approach Zone Model Selection) and no one clear best model. All models included variables of day period, discharge or WSEL, AWS attraction flows, and day of the year. We selected the top model for simplicity, for which model fit was good. Model outputs are in Table 14.

The comparison of night and day had a significant positive effect in both models. The exceptionally high HR in the approach model (3.4) has large confidence intervals, suggesting rates of approach

87 to 524% faster during the day relative to night. While a positive effect is apparent, data limitations and model fit influence interpretations of magnitude because there were very few completed state transitions during the night (Figure 20). Rates of withdrawal are also faster during the day with very large confidence intervals and weak significance (Table 14).

River discharge and day were also significant in the approach model (Table 14). The negative effect of discharge means for each 10 m^3/s increase in discharge, rates of approach decrease by 1.9%. The HR for day of 1.01 indicates that for each subsequent day of the operational period, approach rates increased by 1%.

Table 14. Coefficient estimates (β) with standard errors (SE), p-values, and hazard ratios (HR) with upper and lower 95% confidence interval (UCI, LCI) of covariates from selected model for entry and departure analyzed with Cox time-to-event models. These models represent advance and retreat from the entry zone The sample size (n) refers to the number of exposure intervals in the model (completed transitions and censors). The number of transitions indicates the number of completed advance of retreat state transitions. Statistically significant p-values bolded (α = 0.05).

State Transition	Variable		β	SE	p-value	HR	LCI	UCI
Approach Rates	Day of the Year		0.01	0.004	**0.004**	1.01	1.003	1.017
	Diel: Day vs. Night		1.228	0.307	**< 0.001**	3.416	1.87	6.237
	River Discharge		-0.017	0.004	**0.001**	0.983	0.975	0.992
	Random Effect	p-value	**< 0.001**					
		Variance	1.16388					
	Sample size		n = 8667 transitions = 75					
Withdrawal Rates	Diel: Day vs. Night		0.289	0.142	**0.042**	1.335	1.01	1.764
	River Discharge		-0.006	0.003	0.054	0.994	0.989	1
	Attraction Flow: AWS		-0.092	0.05	0.068	0.912	0.826	1.007
	Random Effect	p-value	0.924					
		Variance	0.0000005					
	Sample size		n = 11373, transitions = 104					

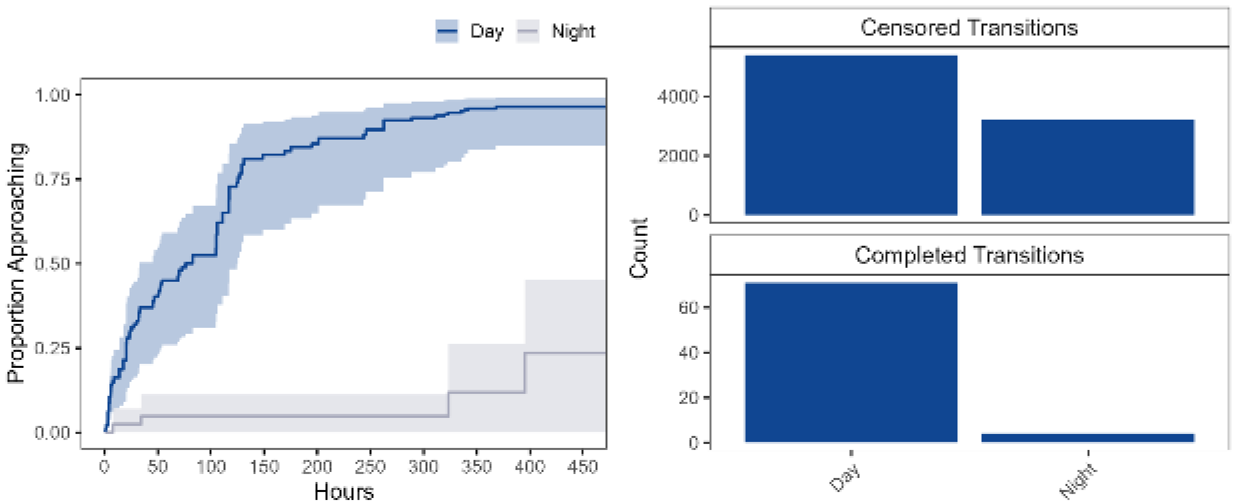

Figure 20. Rates of approach (left; advance from approach to entry zone) across diel period categories of day (dawn and day diel periods combined) and night (dusk and night). The right plot shows count data of number of exposure intervals (completed and censored) included in the time-to-event model. Data are overwhelmingly from the day period.

Entry Zone (Entry/Departure)

Entry models did not converge with categorical variables. We achieved convergence with their removal, but all models had equal weight. The analysis was not pursued further. The departure model set included five models of which the top model included just the number of transitions, which was statistically significant with a positive effect. The random effect was also significant with a variance of 0.3. Model fit was poor, as shown in Appendix F: Mountain Whitefish Entry Zone Model Selection.

Rainbow Trout

The random effect structure of the Rainbow Trout data limited modeling. In the largest dataset (approach) there were 16 individuals characterized by a dichotomy in activity levels (see details in Appendix H: Rainbow Trout Approach Zone Model Selection). Some fish with many occupancies made few approach transitions and others with few occupancies made many approach transitions. This may reflect differences between resident and migratory Rainbow Trout, but data are too limited at this time to assess this. The result was a strong correlation between the number of transitions and random effect (individual). Ultimately the number of transitions term was removed because when included it was highly significant and correlated with the random effect. As in the Mountain Whitefish models, day was compared to night in a two-level factor.

There were three competing approach models (ΔAIC < 2). The top model, which included day period, river discharge, and the HVJ attraction flow term, was selected and model fit was assessed as good. All terms and the random effect were significant (Table 15). There was no one model of good fit in the withdraw model set and no fixed effects held statistical significance. Only the random effect was significant with a variance of 0.49 in the top model (Table 15). The primary finding from the Rainbow Trout approach model is the exceptionally high variance held by the random effect: 2.95 (Table 15). This indicates substantial heterogeneity or clustering not explained by fixed effects. Additionally, fixed effects revealed that approach rates are 48% higher when the HVJ is on, and that Rainbow Trout approach the fishway faster during the day than night. As seen for other species, river discharge had a negative effect.

The top and selected entry model included season and percent attraction flow, of which only season was statistically significant; no other model was considered. There were several candidate models within the departure model set. The top model that was selected included day, river discharge, and the attraction flow term of AWS. Day and the random effect (variance = 0.88) were the only terms to hold statistical significance. Both models indicate increased rates of advance as the operational period progressed. Fit of models was poor due to limited data. Detailed results of all models are provided in Appendix I: Rainbow Trout Entry Zone Model Selection.

The rejection model was not pursued (see Appendix J: Rainbow Trout Fishway Rejection Model Selection).

Table 15. Coefficient estimates (β) with standard errors (SE), p-values, and hazard ratios (HR) with upper and lower 95% confidence interval (UCI, LCI) of covariates from selected model for approach and withdraw analyzed with Cox time-to-event models. These models represent advance and retreat from the approach zone for Rainbow Trout. The sample size (n) refers to the number of exposure intervals in the model (completed transitions and censors). The number of transitions indicates the number of completed advance of retreat state transitions. Statistically significant p-values bolded (α = 0.05).

Variable	Coefficient	SE	p-value	HR	LCI	UCI
Diel: Day vs. Night	0.603	0.153	**<0.001**	1.827	1.353	2.466
River Discharge	-0.016	0.005	**0.001**	0.984	0.974	0.994
Attraction Flow: HVJ	0.389	0.145	**0.007**	1.476	1.111	1.96
Random Effect			**<0.001**			
Call: (Surv(Time1_s, Time2_s, Status)) ~ DayPeriod + MeanQ10 + MedHVJ + frailty(FreqCode)						
n = 8908, transitions = 145						
Variance of random effect = 2.951743						

Movement within Fishway

Numbers Ascending the Fishway

For Bull Trout and Mountain Whitefish there is a clear barrier between the upper fishway (combined detection on Cell 23, 24 and vee-trap) and the sorting facility (Table 16; Figure 21). Of the 120 tagged Bull Trout that arrived at the fishway entrance (i.e., radio- and/or PIT-tagged fish detected in entry zone or upstream), 109 entered the fishway, 92 made it to the upper fishway and two ascended into the sorting facility. Of note is that the 120 in the entry zone is likely a substantial underestimate because PIT-tagged fish are only first detected at the entrances (rather than the broader entry zone), and we know performance of those antennas is poor. Nonetheless, based on these numbers, 84% of Bull Trout made it to the top of the fishway, but 2.2% of those successfully passed the fishway into the sorting facility. The trend is similar for Mountain Whitefish. Of the 1261 that would have passed the entry zone, 1256 entered, 1073 made it as far as the upper fishway and 194 ascended the fishway; 85% of candidates made it to the top of the fishway and 18% of those Mountain Whitefish making it to the upper pools ascended to the sorting facility.

For Rainbow Trout there is more of a consistent drop in presence with upstream location. The exception is from cell 8 to the upper fishway where only one of the fish making it to cell 8 did not ascend as far as the upper fishway. No tagged Rainbow Trout successfully ascended the fishway.

Of the five Arctic Grayling that arrived at the fishway entrance, four reached the upper fishway (80%) and one was trapped (20%). The two Burbot making it to the entry zone entered the fishway but did not go further; efficiency metrics were not calculated for Burbot.

Table 16. Total numbers of tagged target species detected by either PIT antennas or radio fixed stations at distinct sections of the fishway. Note that while every radio-tagged fish also has a PIT tag, PIT counts in this table refer to those that only have a PIT tag. The entry zone includes detections at the outside entrance fixed station; there is no PIT detection in this zone. The entrance includes detection within the entrances (PIT) or within the entrance pool (radio). The upper fishway includes all detections between cells 23 and the vee-trap. The sorting facility represents detection by facility operators (successful passage).

Species	Entry Zone	Entrance		Cell 8		Upper Fishway		Sorting Facility	
	Radio	PIT	Radio	PIT	Radio	PIT	Radio	PIT	Radio
Arctic Grayling	2	3	1	3	1	3	1	1	0
Burbot	0	2	0	0	0	0	0	0	0
Bull Trout	54	66	43	62	33	61	31	0	2
Mountain Whitefish	10	1251	5	1111	4	1069	4	194	0
Rainbow Trout	10	6	7	5	2	4	2	0	0

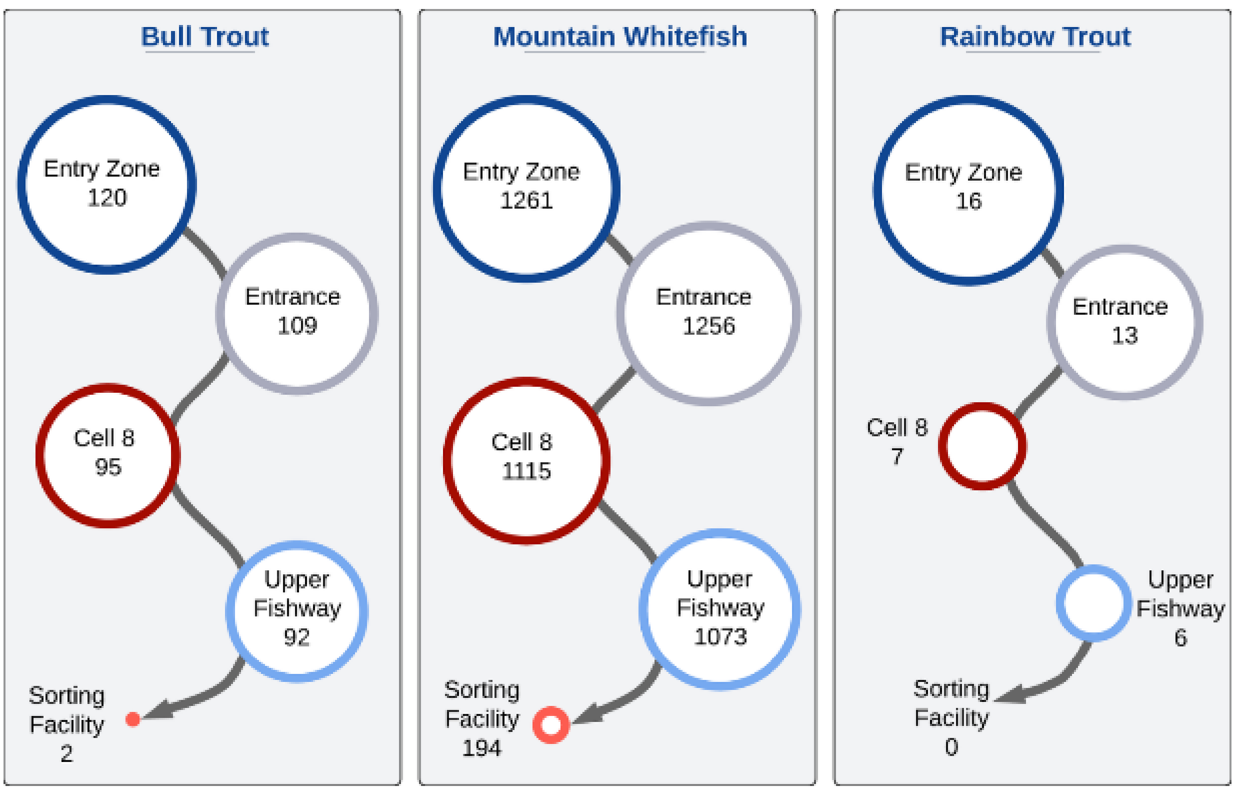

Figure 21. Total combined numbers of Bull Trout, Mountain Whitefish and Rainbow Trout tagged with either PIT or radio tags passing through distinct sections of the fishway. The entry zone includes detections at the outside entrance fixed station; there is no PIT detection in this zone. All other zones include both PIT and radio detection totals. The entrance includes detection within the entrances (PIT) or within the entrance pool (radio). The upper fishway includes the zone between cells 23 and the vee-trap. The sorting facility represents detection by facility operators (successful passage).

Movements within Fishway

Once in the fishway, few fish exhibited directional upstream migrations through the fishway. Numerous upstream and downstream movements were common, and each species had outlier individuals that were exceptionally active (Figure 22). The mean and median number of movements were mostly equal between upstream and downstream directions, which aligns few tagged fish having ascended the fishway. For Bull Trout, the mean and median number of upstream movements were 27.9 and 3, respectively, with a maximum number of 589. Mountain Whitefish were less active with fewer outlier individuals. The mean and median number of upstream movements was 4.5 and 3 with a maximum of 46. Three Arctic Grayling were included in this assessment that made 3, 11, and 42 upstream movements. Fishway ascent times were rapid, with the mean for most fish being approximately one hour (Table 17). Bull Trout showed the most variability, with durations ranging from 6.5 minutes to 13.7 hours (Table 17).

Table 17. Ascent times (minutes) for radio-tagged target species detected in the fishway that made directed upstream movements. Ascent time was calculated as difference between last detection at the entrance of the fishway and first detection at the top of the fishway. Median and interquartile range (IQR) are shown where there is sufficient data to do so.

Species	n	Median ± IQR	Minimum	Maximum
Arctic Grayling	3	46.9	39.9	118
Bull Trout	60	33.1 ± 24.8	6.5	822 (13.7 hrs)
Mountain Whitefish	8	41.6 ± 19.9	27.3	147
Rainbow Trout	2	NA	17.5	86.2

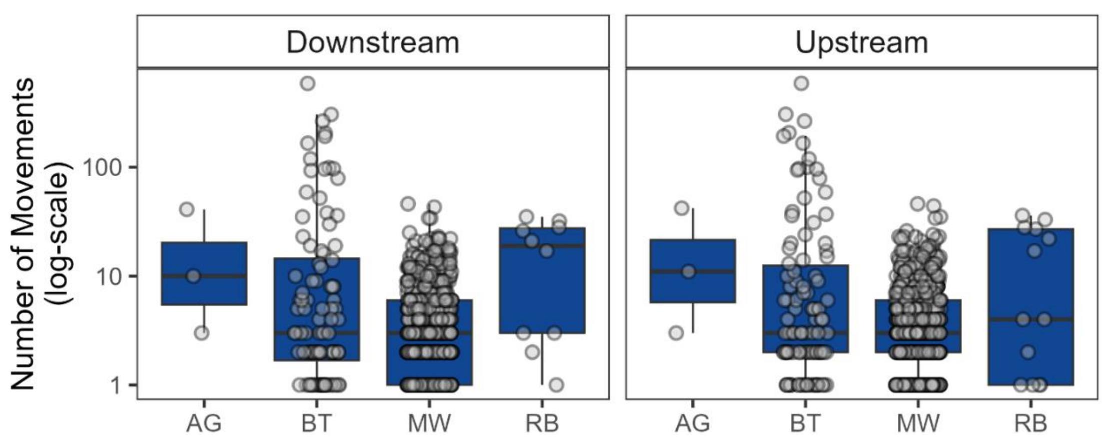

Figure 22. Number of downstream and upstream movements made within the fishway by radio- and/or PIT-tagged Arctic Grayling (AG), Bull Trout (BT), Mountain Whitefish (MW) and Rainbow Trout (RB) during the operational period. The center line of the box represents the median, the box the interquartile range (IQR), and the whiskers the 1.5x IQR, excluding outliers. Points show data from individual fish. Data is shown on a log-scale for better visualization.

Fishway Passage and Efficiency

All five target species were detected within the approach zone during the 2022 operational period (i.e., were candidates for efficiency metrics). For species entering the fishway, attraction efficiency ranged from 18.2% (range: 0 – 41%) for Arctic Grayling to 31.0% (range: 21.3 – 40.8%) for Bull Trout (Table 18). Neither of the two Burbot detected in the approach zone entered the fishway (0% attraction efficiency). Only two radio-tagged Bull Trout ascended the fishway, leading to a passage efficiency of 2.3 % (Table 18). Passage efficiency was 0% for all other species and could not be calculated for Burbot.

The radio telemetry dataset is limited; trapping efficiency also evaluates fishway effectiveness and takes advantage of the larger PIT telemetry dataset. For PIT-tagged species that passed the fishway, trapping efficiency was 2.3% (0 – 5.3%) for Bull Trout, 18.1% (15.8 – 20.4%) for Mountain Whitefish, and 25% (0-67%) for Arctic Grayling (Table 19). None of the six PIT-tagged Rainbow Trout that reached the upper fishway were successfully trapped (0%).

Table 18. Attraction efficiency is the proportion of the total candidate pool that is attracted to and enters the fishway, passage success is the proportion of those fish that successfully pass through the fishway, and passage efficiency is the product of attraction efficiency and passage success. These metrics were evaluated from radio telemetry data for target species. Confidence intervals were calculated using the Wald method for proportions.

Species	Counts			Attraction Efficiency (%)	Passage Success (%)	Passage Efficiency (%)
	Candidates	Entered	Processed			
Bull Trout	87	27	2	31.0 (21.3 – 40.8)	7.41 (0 – 17.2)	2.3
Mountain Whitefish	18	5	0	27.8 (7.1 – 48.5)	0	0
Rainbow Trout	27	6	0	22.2 (6.5 – 37.9)	0	0
Arctic Grayling	11	2	0	18.2 (0 – 41)	0	0
Burbot	2	0	0	0	-	-

Table 19. PIT telemetry data were used to determine trapping efficiency, the proportion of tagged that reached the upper fishway (cell 23, 24 and vee-trap) that were affectively trapped and sorted.. Confidence intervals were calculated using the Wald method for proportions.

Species	Counts		Trapping Efficiency (%)
	Candidates	Processed	
Bull Trout	89	2	2.3 (0 – 5.3)
Mountain Whitefish	1071	194	18.1 (15.8 – 20.4)
Rainbow Trout	6	0	0
Arctic Grayling	4	1	25.0 (0 – 67)
Burbot	0	0	-

1.4 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 informs TUF operations and addresses key uncertainties regarding the attraction flows required to facilitate passage. Resulting data are directly applicable to the management of the TUF, potentially dictating in-season changes to operations, including modifications to the magnitude and timing of supplementary attraction flows.

The TUF began operating in September 2020. Thus, 2022 marks the third year of operations and the second complete, seven-month operational period. The focus of 2021 analyses were to ensure the experimental design and array were appropriate for TTE analyses using a competing risks framework, and to explore environmental factors that may influence passage rates. In 2022 we did the same analyses with further exploration of covariate structure as it relates to fishway effectiveness. Upon completion of the 2023 operational period the dataset will be sufficient to compile all years for a comprehensive analysis.

While there have been challenges with operating the TUF, every year operations more closely align with those outlined in the OPP in terms of time operational, design criteria and attraction flow schedule. In 2020 the TUF was operational for 20 days (Cook et al. 2021). In 2021 operations began as planned on April 1, but there were numerous shutdowns and the fishway was shut down for 11% of the operational period and water surface elevations were above the fishway's design criteria for 61% of the operational period (Moniz et al. 2022). Operations began again on target in 2022 and there were fewer shutdowns; the fishway was shut down for 6% of the operational period. However, water surface elevations above the design criteria continued (59% of operational period) and a pump failure in September that resulted in reduced attraction flows.

Since TUF operations began we have shown that target species can locate, enter, and ascend the fishway to the upper pools. Across all species and zones, competing risk models consistently show fast retreat rates and comparatively slow advance rates, congruent to the presence of an upstream obstacle. Both PIT and radio telemetry indicate a barrier to passage in the upper fishway. We have a better understanding of factors influencing approach and entry given the paucity of passage data. Modeling approach and entry revealed that, among other environmental conditions, river discharge and attraction flow do influence advance and retreat rates in most state transitions. These results are promising because attraction flows and, to a lesser extent, river discharge, can be operationally managed to encourage entry into the fishway. However, operational changes that facilitate increased approach and entry may not increase passage.

The discussion herein is focused on Bull Trout, Rainbow Trout and Mountain Whitefish, the fish for which movement could be evaluated using the competing risks framework. 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, outside of the operational period, spawning in the late winter/early spring (Mainstream 2012; Hatch et al. 2022). Additionally, although Arctic Grayling are known to spawn during the spring in tributaries upstream of the Project (Mainstream 2012), watershed-wide radio telemetry data suggests they make relatively indiscriminate seasonal movements within the Peace River (Hatch et al. 2022). As more data are collected and more fish are tagged through other components of the FAHMFP, sample sizes of target species detected within the Mon-13 study area will increase.

1.4.1 Biological Effectiveness

Biological effectiveness of the TUF was evaluated using TTE analyses to quantify the effects of environmental factors, including supplementary attraction flows, on rates of advance and retreat between distinct spatial zones. Biological effectiveness was additionally assessed by comparing measures of attraction, passage, and trapping efficiency to previous monitoring years and other fish passage systems.

Time-To-Event Analyses

The study is designed such that each species could have a maximum of five state transition models: two for approach, two for entry, and one for rejection of the fishway. Not all could be achieved for all species due to data limitations. We present results from 11 models for three species; low sample sizes precluded these analyses for Arctic Grayling and Burbot. Bull Trout had the most robust dataset, and all models were achieved. Approach zone models had the most data and are, therefore, the most reliable. Models from other zones in many cases had poor fit, diminishing our confidence in the results. The suite of analyses nonetheless elucidates where barriers to passage exist and what factors are associated with passage success.

The variable most often included in selected models was diel period. Most activity occurred during the day for Bull Trout, Mountain Whitefish, and Rainbow Trout, with advance rates being fastest during daylight hours (approach and entry for Bull Trout and Mountain Whitefish, approach for Rainbow Trout). This was especially true for Mountain Whitefish, for which data were overwhelmingly from the day period; rates of withdrawal were also fastest during the day. For Bull Trout, the effect differed slightly in that all retreat rates were slowest during the night period. Together, these findings indicate more activity and faster movement rates during the day. That is, it is not that attraction to the fishway is greater during the day (in such case results would show increase rates of advance and decreased rates of retreat during the day), but that there is more activity during this period. This finding is consistent with 2021 data, but is still 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 et al. 2013; Watson et al. 2019; Naman et al. 2022; Putt et al. 2023). The need for visual cues because of challenging hydraulic conditions, foraging opportunities (Bull Trout), and/or predator avoidance (Mountain Whitefish) near and within the fishway may explain a shift to diurnal movement behaviour (Reebs et al. 1995; Reebs 2002; Keefer et al. 2013).

River discharge was included in most models with a consistent effect of reduced advance rates in all three species with increasing river discharge. For Bull Trout this was the case for both approach and entry. Additionally, there was a negative effect of the percent of attraction flow relative to total river discharge on withdrawal rates. That is, there was less attraction to the fishway (increased withdrawal) when there was less influence of attraction flow. High flows in the Peace River caused water elevations 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 2023), potentially limiting the functionality of the fishway. When Peace River discharge was high, we observed turbulent and non-uniform velocity gradients at the fishway entrance that may have been distracting to fish as they approached and attempted to enter the fishway (Enders et al. 2005; Brown et al. 2006; Liao 2007). It is not uncommon for the Peace River to experience large daily fluctuations in discharge, particularly during periods of hydropeaking. In 2022 hydropeaking occurred in late July and August, when Bull Trout are migrating. We could better understand these effects by incorporating additional hydrological metrics in TTE modelling (e.g., measures of stage change). Additionally, using an acoustic doppler current profiler to measure the velocity fields both within and at the entrance of the fishway at a range of Peace River discharges and attraction flow scenarios may help us better understand the hydraulic conditions encountered by fish approaching, entering, and passing the fishway.

A key objective of this research is to understand how fish respond to attraction flows from the AWS and HVJ. Model results provide good evidence that increased attraction flows do attract Bull Trout towards the fishway. Additionally, our data corroborates that of Moniz et al. (2022) that the AWS is more important for attracting Bull Trout into the fishway compared to the HVJ. Attraction flows were not as important to movement from the approach zone (except percent attraction flow in the withdraw model, as described above) but were prominent in entry zone models, particularly attraction flows from the AWS. Bull Trout entered the fishway faster with elevated AWS attraction flows and departed the entry zone slower with elevated AWS attraction flows and when the HVJ was on. There was also a positive effect of the HVJ in the Rainbow Trout approach model, indicating faster approach rates when the HVJ is on. This adds to the evidence of a preference for more attraction flow for target salmonids (Bull Trout, Rainbow Trout).

Most models also had a seasonal component, either inclusion of the categorical season variable or day of the operational period, a continuous variable. For Bull Trout, approach rates were fastest during the summer, which aligns with watershed-wide telemetry data indicating the Bull Trout complete spawning migrations to areas upstream during the summer months. Additionally, entry rates increased and departure rates decreased throughout the operational period for both Rainbow Trout and Bull Trout. This suggests that these species spent more time in the entry zone as the operational period progressed, potentially attempting passage opportunities. Approach rates also increased for Mountain Whitefish as the operational period progressed, which was expected given that Mountain Whitefish are assumed to be migrating upstream in September and October to spawn upstream of the Project in the late fall and early winter.

The final parameter of interest to discuss, the number of transitions made between each zone, was only included in the rejection model for Bull Trout and the departure model for Mountain Whitefish. We observed rates of rejection decrease among Bull Trout the more often they had been in the fishway and rates of departure increase among Mountain Whitefish the more often they had been in the entry zone. This pattern of number of transitions decreasing retreat rates in Bull Trout and increasing retreat rates in Mountain Whitefish was also observed in 2021, when the effect was even more prominent (Moniz et al., 2022). The authors hypothesized that this pattern was driven by predator-prey interactions. Mountain Whitefish are a common prey item of Bull Trout (McPhail and Baxter 1996; Beauchamp and Van Tassell 2001; Stewart 2002) and Bull Trout have been previously documented to opportunistically feed on concentrated prey downstream of man-made barriers (Furey et al. 2016; Furey and Hinch 2017). A multi-year analysis may further elucidate these patterns and could potentially identify if there is a seasonal component to their reciprocal relationship.

The repeated nature of the data, with many occupancies possible for a given individual that could also make repeated transitions between zones, complicates model structure and interpretation. Additionally, data spanned from April 1 to October 31 and, thus, likely encompassed multiple behavioral states (e.g., feeding versus spawning migrations) for individuals with a continued presence in the study area. 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. Across all models, the most consistent statistically significant variable was the random effect, which in some models held a very high proportion of variance. While the objective of the analyses is to understand factors influencing passage (i.e., fixed effects) so that operational changes can be made to improve passage, this persistent effect of inter-individual variability is an important consideration in the application of results. That is, if a significant effect leads to operational changes, we may not expect this to benefit all individuals across the entire operational period.

It was apparent in some models that interactive effects were present and not accounted for. As we continue to collect radio telemetry data and combine data from multiple years, it may be possible to model interactive effects. This will be particularly informative for understanding the effects of supplementary attraction flows in the context of temporal factors such as season and diel period.

Efficiency Metrics

Overall attraction efficiencies were similar to those observed in 2021, ranging from 0% (Burbot) to 31% (Bull Trout). Improvements from the previous monitoring period include that radio-tagged Arctic Grayling were detected entering the fishway for the first time, and attraction efficiencies were higher for Rainbow Trout (22% in 2022 versus 5% in 2021) and Bull Trout (19% in 2021). However, confidence intervals around these estimates are high and these differences may not be statistically significant.

We exclusively used radio telemetry data to calculate attraction and passage efficiency, and used PIT telemetry to evaluate a new metric, trapping efficiency. Therefore, our estimates of passage efficiency are not comparable to previous years, but they continue to be low. Passage efficiency was 0% for all species but Burbot (could not be assessed) and Bull Trout, for which two passage events led to an estimate of 2.3%. Trapping efficiency is an important metric because it evaluates effectiveness of passage from the last three fishway pools, through the pre-sort holding pool, and into the sorting facility, an area where there is a known barrier. Additionally, by restricting analyses to the upper fishway we can take advantage of the abundant PIT telemetry data while avoiding complications associated with poor performance of the lower antennas, repeated upstream and downstream movements, and multiple fishway entry events that likely go undetected. Trapping efficiencies were low, confirming our assertion that the top of the fishway presents a barrier. Estimates ranged from 0% (Rainbow Trout) to 25% (Arctic Grayling, based on one passage event with a confidence interval of 0 to 67%). Trapping efficiency was 2% for Bull Trout and 18% for Mountain Whitefish.

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), benchmarks that the TUF is far from achieving. However, the predicted efficiencies are high compared to what has been observed at many other fish passage facilities (Roscoe and Hinch 2010; Noonan et al. 2012; Bunt et al. 2016). For example, a review found average upstream passage efficiencies of 61.7% for salmonids and 21.1% for non-salmonids across many fishway types, species, and geographical areas (Noonan et al. 2012). Regardless, direct comparisons of efficiency metrics between fishways will always be difficult given differences in sites, species, fish motivation, and monitoring techniques (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 given the influence of covariates, as done with the TTE analyses herein.

1.4.2 Factors Influencing Fishway Passage

Passage success could not be quantified using the competing risks framework and most entry zone models were data-limited because there were too few passage events. There are several factors that may have influenced the low proportion of tagged fish entering and successfully passing the fishway. Ultimately passage would be better if more fish had entered the fishway. Our TTE models show the fish are quick to leave the vicinity of the fishway: departure rates from the entry zone were exceptionally fast relative to entry rates. The models also suggest that more entry would occur by maximizing attraction flows and reducing river discharge. Doing so may cause more fish to enter the fishway and allow us to better evaluate passage.

Despite data constraints, results indicate that a passage obstruction exists within the fishway. We observed that 83.2% of tagged target species failed to successfully pass the fishway once detected at or upstream of pool 23. Across the five target species, this percentage accounts for 1175 tagged individuals that made it to the top of the fishway, of which 197 were trapped and lifted into the sorting facility. This percentage is a slight (likely not statistically significant) improvement from the estimate of 89.6% from the previous year (Moniz et al. 2022). Data across both years show that fish will travel up and down the fishway multiple times and reside in the uppermost pool for extended periods. These results are supported by visual observations by the facility operator and InStream staff of fish swimming in and out of the pre-sort holding pool past the vee-trap. The additional complication of ending the fishway with a trap, crowder, and lock seems to limit success, which has also been observed in other similar fishways (e.g., a trap and haul fishway at a 62 m dam in Australia; Harris et al. 2019). Consequently, solely attracting a greater number of fish to enter the fishway will be limited in its efficacy. Despite the improvements made to the vee-trap since 2021, more needs to be done to increase one-way, upstream movement into the pre-sort holding pool and prevent fish from escaping the pre-sort holding pool.

Predation both inside and at the entrance of the fishway likely limited successful fish passage for some target species. 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; van der Leeuw and Tidwell 2021), and piscivorous fish (Boulêtreau et al. 2018; Rillahan et al. 2021; Alcott et al. 2021), including opportunistic Bull Trout (Furey et al. 2016, Furey and Hinch

2017). River otters have been repeatedly observed by the facility operator and InStream staff depredating fish inside the fishway since September 2021. It is also likely that Bull Trout predate smaller fish at the entrance and within the fishway, particularly later in the operational period when Bull Trout were no longer migrating upstream to spawn and some Mountain Whitefish still are (Hatch et al. 2023). Like Bull Trout, Walleye are known to be opportunistic feeders (Vigg et al. 1991; McMahon and Bennett 1996). There were 49 individual adult Walleye detected by the radio and/or PIT array inside and at the entrance of the fishway from June to early October. Many Walleye spawn in the Beatton River, a tributary of the Peace River downstream of the Project (Mainstream 2012), and may migrate to the fishway to feed on concentrated prey species post-spawn. Monitoring predation in fishways can be challenging but should be made a priority if we want to understand the potential consequences of limited passage success leading to congregations of fish in the fishway.

Hypothesis-driven TTE modeling comparing rates of movement across state transitions between predator and prey could be informative to understanding these processes. The occurrence of predators inducing behavioural changes in prey through perceived risk, also called non-consumptive effects, is an important determinant of prey behaviour and spatiotemporal habitat use and is commonly evaluated in mammalian research, which may scale to have population and ecosystem level consequences (Whittington et al. 2011; Visscher et al. 2023). A TTE analysis will quantify spatiotemporal movements of predator and prey but cannot confirm predation. Recently, a castable and miniaturized predation event recorder was developed to quantify the predation of juvenile fishes (Demetras et al. 2023). A predation event recorder is a passive, floating, GPS-enabled baited platform utilized to investigate predation rates on a landscape scale (Michel et al. 2020; Nelson et al. 2022). The miniaturized version was successfully tested to estimate mean predation rate, model relationships between predation risk and time and distance to diversion around an agricultural pump station and created heat maps of predation within the study area (Demetras et al. 2023). If we suspect predation continues to be a problem, particularly during operation of the PUF, further quantifying predation to inform mitigation efforts may be prudent.

1.4.3 Conclusions

The TUF has now been operational for two full operational periods, and the biological effectiveness of the fishway continues to be low. A primary objective of monitoring at the TUF is to inform operation of the PUF, currently scheduled to begin in April 2024. Conditions of the PUF will be different: it will be located on river right rather than river left, and turbines will remove energy from the system, potentially making the fishway entrance more attractive. During the construction period all diverted water flows through diversion tunnels and past the TUF, overwhelming the fishway in a way that may not occur during operations. Despite these differences, we intend to maximize our site-specific knowledge of fish passage during this temporary period in preparation for operation of the PUF. Several changes were made to TUF operations in response to a clear obstruction to passage at the top of the fishway (e.g., physical modifications to the vee-trap/finger weir). Given the pace of these modifications and low passage numbers, we were unable to evaluate their effectiveness in this report. However, the common occurrence of fish being detected in the uppermost pools of the fishway but not passing suggests that despite modifications, the trapping mechanism at the pre-sort holding pool is still not functioning effectively.

Our modeling results have consistently shown an effect of individual (i.e., inter-individual variability in movement behaviour) and persistent diurnal movements, with most activity occurring during daylight hours. We additionally present strong evidence that the approach to and entry of the fishway will increase at lower Peace River discharges, and that Bull Trout and Rainbow Trout are attracted to higher attraction flows, particularly from the AWS. Data are still too limited for Arctic Grayling and Burbot, but for Mountain Whitefish, Rainbow Trout, and Bull Trout, we are beginning to understand operational changes that can be made to facilitate passage. Following the 2023 operational period we will have movement data across three consecutive years of fishway operations. Implementing a multi-year analysis will best inform potential changes to the operational strategy of the PUF.

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

2.1 Introduction

Capturing and transporting fish around instream barriers (hereafter ‘trap and haul’) is a method used to mitigate some of the effects of altered migration corridors in rivers (DeHaan and Bernall 2013; Sigourney et al. 2015). Despite being a relatively common method for relocating fish upstream of impassible dams and large reservoirs 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 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 the fish 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 2023). At the TUF, fish that fully ascend the fishway are processed in the sorting facility, sorted into a transport pod, loaded onto a transport truck, 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.

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. 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. Data collected through Mon-14 will be 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 two full operational periods of the TUF (April 1 to October 31, 2021 and 2022) during the construction phase of the Project.

Given that relatively few radio-tagged fish were transported upstream from the TUF in 2021 and 2022, 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, 2023) 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 spawning success or mortality using telemetry data alone, as is the case for Mon-14. For example, telemetry data may confirm that a tagged fish reached its assumed spawning grounds, but that does not necessarily mean that the fish has successfully spawned. Similarly, tag loss or sedentary behaviour in deep or shielded habitat can result in similar detection patterns as inferred mortalities.

In addition to the trap and haul program at the TUF, a supplementary ('contingent') trap and haul program was used in 2021 and 2022 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 (Burgoon and Ford 2022, 2023). Post-release movements of fish transported under the contingent program 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 fish captured at and transported from 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 23). 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; Geraldes and Taylor 2022; Putt et al. 2023). 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).

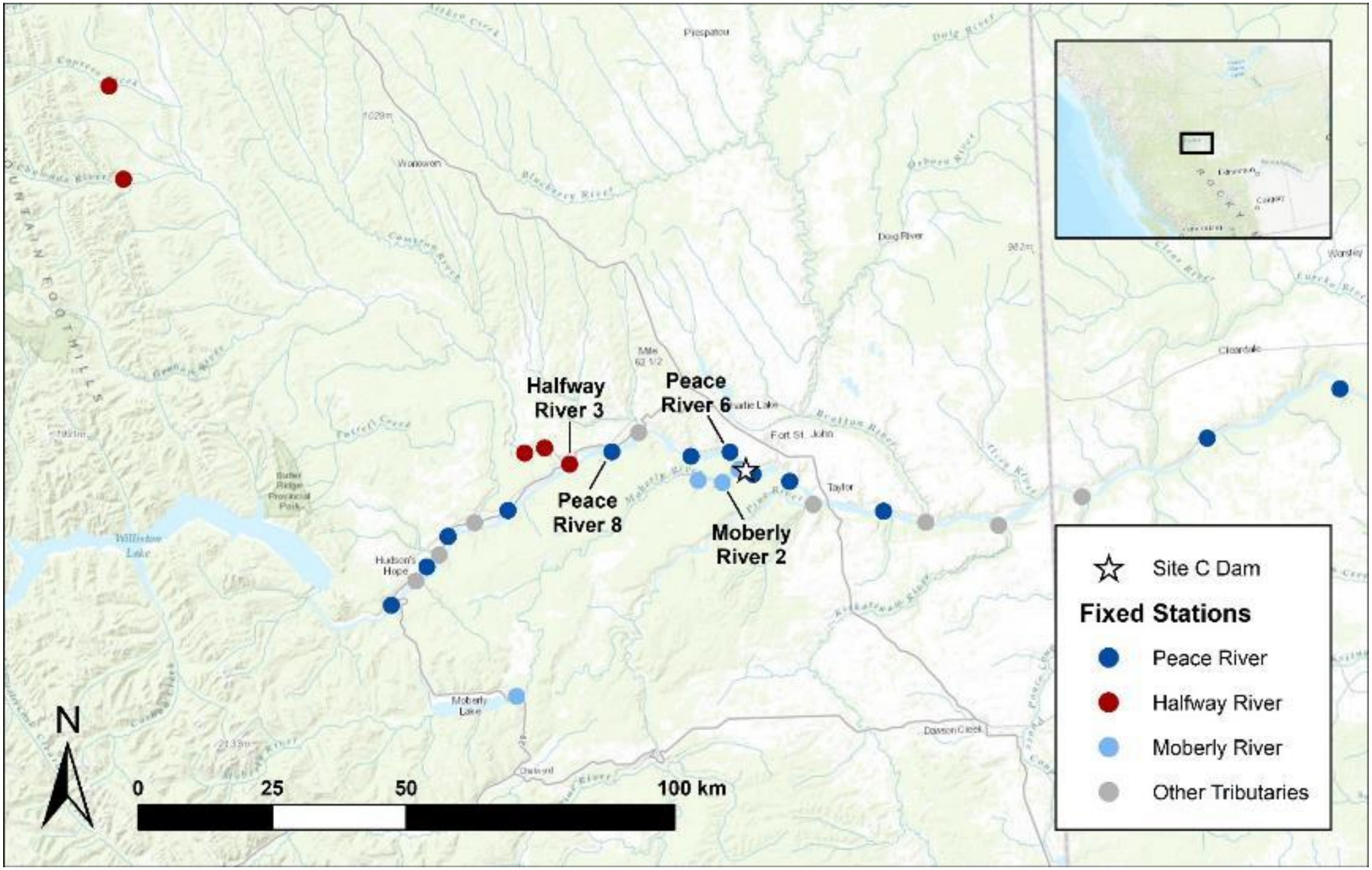

Figure 23 Study area with fixed radio telemetry stations (fixed stations) deployed throughout the Peace River watershed used to detect post-release movements of radio-tagged fish. Fixed stations operating under Mon-13 at or near the temporary upstream fish passage facility are not shown for clarity. Fixed stations used to classify spawning success (detailed 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 in 2021 and 2022 were processed, transported, and released upstream of the Project following the protocols described in the OPP (McMillen Jacobs & Associates and BC Hydro 2022). In 2021, adult target species that were not already radio tagged and met species-specific criteria (Table 20) were assumed to be migrating upstream to spawn and were passed to InStream staff by the facility operator to be processed and implanted with a radio tag before being released upstream (see Moniz et al. (2022) for details). In 2022, however, it was assumed that fish tagged under other components of the FAHMFP would successfully ascend the TUF, so no additional fish were radio tagged under Mon-14.

During the TUF's operational periods in 2021 and 2022, radio-tagged Bull Trout and Mountain Whitefish were released by the facility operator upstream of the Project at one of three release locations (Figure 24). 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 6 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. Had they been captured at the TUF, radio-tagged Arctic Grayling would have been driven 6 km and released at the Moberly River release location approximately 1 km upstream of the Project.

Fish captured at the TUF were transported in one of three 2150-L transport pods hoisted and placed onto a transport truck once per day. Each pod was equipped with a primary and secondary oxygen tank attached to oxygen diffusers. Transport pods 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 pods and when arriving at the release locations. Once at the release location and after ensuring that the difference in water temperature between the transport pod and receiving environment was less than 8°C, the transport pods' 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 20. 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. 2023).

2.4.2 Contingent Trap and Haul

The TUF is designed to operate when the water surface elevation (WSEL) at the tailrace is between 408.4 and 410.5 m. In 2021 and 2022, WSELs exceeded the upper end of the TUF's design criteria 61% and 59% of the operational period, respectively. As a result, BC Hydro commissioned WSP 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 program'). The goal of the contingent trap and haul program was to provide supplemental fish passage to mitigate the potential lack of biological effectiveness of the TUF when WSELs were above design criteria, or when the TUF was not operational. 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 Little and Ford (2022), while Burgoon and Ford (2022, 2023) summarize methods specific to the contingent trap and haul program.

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 between August 1 and October 31 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 (Mainstream 2012), ice and access issues at the intended Moberly River release location prevented fish from being released there in 2021 and 2022, except for a brief period between April 28 and May 4, 2022 when the Moberly River release location was accessible. Instead, Arctic Grayling were primarily released at 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 (Mainstream 2012), were also released at the Peace River release location in April 2021 and 2022 when ice prevented fish from being released in the Halfway River.

Under the contingent trap and haul program, 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 (Burgoon and Ford (2022, 2023).

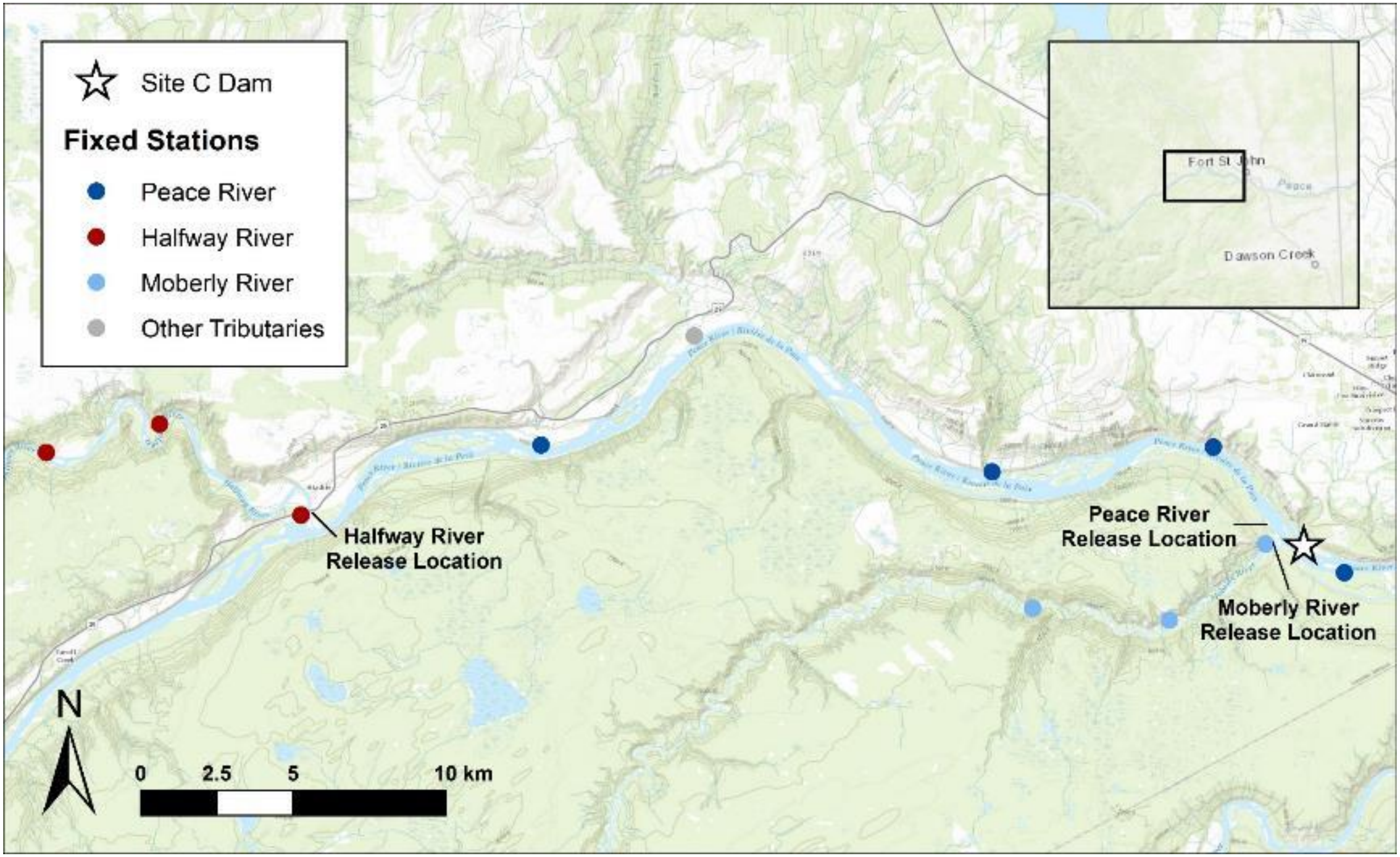

Figure 24 The three locations used to release fish transported from the temporary upstream fish passage facility (TUF) and through the contingent trap and haul program. Nearby fixed radio telemetry stations (fixed stations) are shown for reference. Fixed stations operating under Mon-13 at or near the 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 42 to 46 fixed stations (depending on the year) operating under several components of the FAHMFP (Figure 24) and by mobile tracking surveys (Hatch et al. 2022, 2023). Most of the detection data used for confirming successful 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). Fixed stations operating under Mon-1b, Task 2d were deployed at the entrance of each major tributary of the Peace River from Many Islands, Alberta upstream to Peace Canyon Dam 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. Two fixed stations were also located in Halfway River spawning tributaries (Chowade River and Cypress Creek) to monitor Bull Trout spawning migrations. Finally, three fixed stations were located along modified side channels (or 'offset channels') downstream of the Project beginning in September 2022. The installation and demobilization dates for each fixed station operating under Mon-1b, Task 2d in 2021 and 2022 can be found in Hatch et al. (2022) and Hatch et al. (2023), respectively.

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. (2023).

The Mon-13 fixed station array in and around the TUF (Figure 4) provided data on 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 1.2.2. 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 and 2022.

Mobile tracking surveys were conducted in 2021 and 2022 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, 2023). 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 from its confluence with the Peace River upstream to Moberly Lake. The Moberly River was not surveyed again in 2022. The Halfway River was surveyed by fixed-wing aircraft during peak Bull Trout spawning in September 2021 and 2022. 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. Finally, an SRX800-MD4 Lotek receiver attached to a handheld Yagi antenna was used to opportunistically scan the Peace River and Halfway River release locations from shore in 2022 to confirm whether and for how long radio-tagged fish remained stationary after release.

Radio telemetry data used in this study were collected between April 2021 and January 2023. 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. (2023). This 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 for 2021 and 2022 can be found in Hatch et al. (2022) and Hatch et al. (2023), respectively.

2.4.4 Hydrologic Conditions

Although not used to evaluate the effectiveness of the Project's trap and haul program directly, 2021 and 2022 discharge data from the Halfway River, Moberly River, and Peace River were obtained and summarized to provide additional context to the conditions at the three release locations during the study period. Mean daily discharge data were obtained from the Water Survey of Canada gauges at the Halfway River near Farrell Creek (07FA006), the Moberly River near Fort St. John (07FB008), and the Peace River above Pine River (07FA004). Given that the Peace River release location is upstream of the Moberly River, and the Peace River gauge station is downstream of the Moberly River, the mean daily discharge of the Moberly River was subtracted from the Peace River discharge more accurately estimate conditions at the Peace River release location. Annual hydrographs for both years were then plotted and briefly summarized.

2.4.5 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) from April 1, 2021 to January 2023. No Burbot were transported upstream of the Project during the 2021 or 2022 operational periods. Radio-tagged fish released upstream of the Project were classified as either having been successful or unsuccessful at reaching their assumed spawning grounds. Additional classifications were used for fish that did not successfully reach their spawning grounds. These 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 21. Proportions of each classification were calculated for the four target species using data from fish transported from the TUF and through the contingent trap and haul program. Where possible, proportions of each classification were also calculated separately and compared between programs and release locations. Results from genetic analysis were used to determine if transported Arctic Grayling, Bull Trout, and Rainbow Trout originated upstream or downstream of the Project (Geraldes and Taylor 2022). Genetic results were not available for Mountain Whitefish. Although not used specifically to confirm trap and haul success, detection data from two PIT arrays located in the Chowade River and in Cypress Creek (two tributaries of the Halfway River) operating under other components of the FAHMFP were used to inform migration patterns and timing of radio-tagged fish reaching these tributaries (Putt et al. 2023).

Mountain Whitefish and Rainbow Trout were only released at the Peace River release location and, therefore, no comparisons between release locations could be made for these species. Radio-tagged Arctic Grayling were primarily released at the Peace River release location except for one fish that was released directly into the Moberly River in early May 2022. 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. Although comparisons were made between release locations, results should be interpreted with caution given the uneven sample sizes and differences in timing of releases.

Species-specific criteria were used to determine success in reaching assumed spawning grounds after release (Figure 23;

Table 22). 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.

Relatively specific criteria were used to classify trap and haul success for Arctic Grayling and Bull Trout given our understanding of which tributaries these species spawn in upstream of the Project (

Table 22; Mainstream 2012; Geraldes and Taylor 2022; Hatch et al. 2023; Putt et al. 2023). 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. 2022, 2023), 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 23). A similar classification is used by LGL under Mon-1b, Task 2d (Hatch et al. 2023). 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; Hatch et al. 2023; Putt et al. 2023). Therefore, Bull Trout detected within the Halfway River at or upstream of the expected inundation zone (Figure 23, Halfway River 3 fixed station) were considered to have successfully reached their assumed spawning grounds.

A more generalized spatial extent was used to classify success for Rainbow Trout and Mountain Whitefish (

Table 22). 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 23; Mainstream 2012; Geraldes and Taylor 2022). 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 Peace River release location were considered to have successfully reached their spawning grounds. Additionally, like Arctic Grayling, both Mountain Whitefish and Rainbow Trout detected within the Moberly River at or upstream of the Moberly River 2 fixed station were considered to have successfully reached their spawning grounds. It is worth noting that true spawning success could not be confirmed in this study.

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 at and over both release locations throughout 2021 and 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 by fixed stations or mobile tracking were also assumed to be post-release mortalities. In both cases (i.e., no post-release detections or repeated downstream detections at the same location), 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 (Schmetterling 2003; Reischel and Bjornn 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 without having successfully reached their spawning grounds were not classified as fallback, and instead were classified as having made a downstream movement. All other fish that remained upstream of the Project after release that did not reach their spawning grounds were classified as 'unconfirmed'.

Post-release classifications of movements from the 2021 operational period (see results in Moniz et al. 2022) were updated based on telemetry data collected through January 2023. For example, transported fish that were classified 'unconfirmed' in 2021 could be reclassified as 'success' in 2022 if they migrated to their spawning grounds in 2022. Similarly, transported fish that were classified as assumed mortalities in 2021 could be reclassified in 2022 using updated telemetry data.

Table 21. 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 22. 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	Moberly River 2	5
	Peace River 6	5
Rainbow Trout	Moberly River 2	5
	Peace River 8	31

2.5 Results

2.5.1 Hydrologic Conditions

Discharge in the Peace River was more variable and fluctuated more rapidly in 2021 and 2022 compared to the unregulated natural flow regimes of the Halfway and Moberly Rivers (Figure 25).

Ice-out at the Halfway and Moberly River release locations began in late April to early May of both years, with discharge increasing through May and peaking in June, receding until reaching baseflows in the fall, and then eventually freezing again in the winter. At the Peace River release location, flows remained high in the winter and early spring of both years and then dropped through May and June. In 2021, discharge in the Peace River peaked again in July and then dropped in August and September before increasing again in the winter. In 2022 flows remained low through most of July, but generally increased starting in August and into the winter.

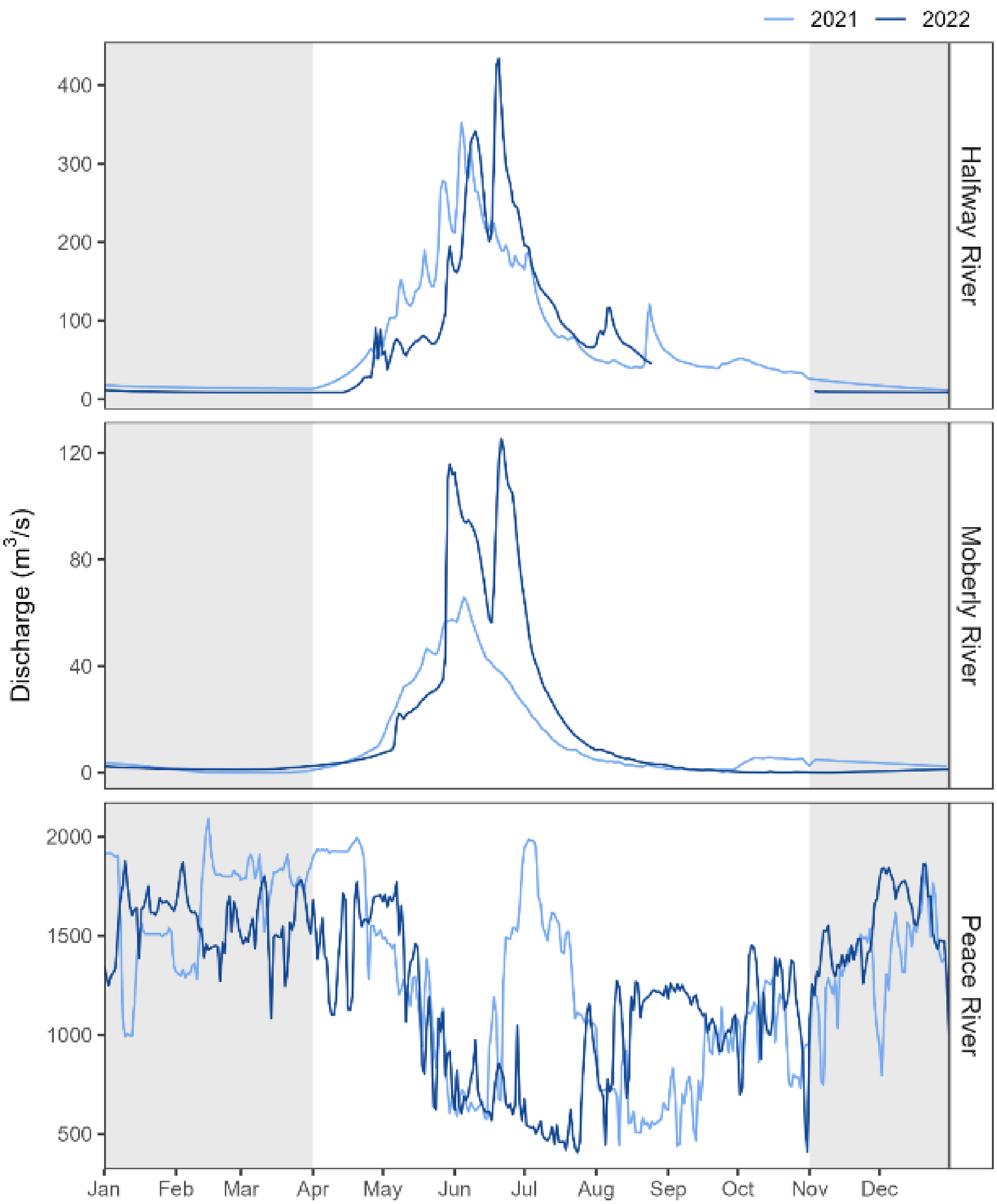

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Figure 25. Discahrge at the Halfway River, Moberly River, and Peace River release locations in 2021 and 2022. Peace River values were estimated by subtracting the mean daily discharge recorded at the Moberly River gauge (07FB008) from the Peace River (07FA004). Data were not available at the Halfway River station (07FA006) from August 26 to November 2, 2022. Grey areas indicate time outside of the temporary upstream fish passage facility's operational period (April 1 to October 31).

2.5.2 Fish Characteristics and Transport Conditions

Fishway Trap and Haul

Seven radio-tagged Bull Trout and six radio-tagged Mountain Whitefish were transported and released upstream of the Project by the facility operator during the 2021 and 2022 operational periods. Three of the seven Bull Trout were radio-tagged at the TUF by InStream in 2021. Two additional Bull Trout were captured at the TUF each year that were previously radio-tagged under other components of the FAHMFP. Of the seven radio-tagged Bull Trout, three were genetically confirmed to have originated upstream of the Project (e.g., the Halfway River; Geraldes and Taylor 2022), while the remaining four were not analyzed for genetics. All six Mountain Whitefish transported and released upstream were radio-tagged at the TUF in 2021. No radio-tagged Mountain Whitefish successfully ascended the fishway in 2022.

The seven Bull Trout transported from the TUF were released in the Halfway River in August 2021 and 2022 during five release events (Table 23). Transport times to the Halfway River release location were between 62 and 93 minutes, and the difference in water temperature between the transport tank and the Halfway River during the five releases did not exceed 1.7 °C. The holding time (time between capture and release) was less than 5.4 hours for five of the seven radio-tagged Bull Trout transported from the TUF. The remaining two had holding times of 19.9 and 20.5 hours, as they were captured and tagged at the TUF and then released the following morning. It should be noted 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). There were one to three radio-tagged and non-radio-tagged Bull Trout transported per release event at the Halfway River release location in 2021 and 2022.

The six radio-tagged Mountain Whitefish were released in the Peace River in September and October 2021 during four release events, with two to 92 fish transported per release event (Table 23). Transport times were between 10 and 15 minutes and the difference in water temperature between the transport tank and the Peace River during the releases never exceeded 0.5 °C. The holding time was 5.3 hours or less for all six radio-tagged Mountain Whitefish.

Table 23. Fish characteristics and release conditions for both trap and haul programs in 2021 and 2022. Fish transported refers to the total number of fish in a transport tank per release event, including non-radio-tagged and non-target species. 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. Lengths and weights are of transported radio-tagged fish only. Ranges in values are provided for each program, species, and release location.

Program	Species	Release Location	Release Events (n)	Fish Transported (n)	Holding Time (h)	Transport Time (min)	Temp. Difference (°C)	Length (mm)	Weight (g)
TUF	Bull Trout	Halfway River	5	1-3	2.0-20.5	62-93	0.4-1.7	580-865	1842-6622
	Mountain Whitefish	Peace River	4	2-92	2.6-5.3	10-15	0.1-0.5	360-430	493-804
Contingent	Arctic Grayling	Peace River	10	2-189	1.3-7.9	14-24	0.0-1.3	295-361	269-577
	Arctic Grayling	Moberly River	1	4	2.2	21	4.3	310	301
	Bull Trout	Peace River	8	1-26	0.8-6.6	13-20	0.1-0.5	425-851	878-8731
	Bull Trout	Halfway River	21	1-13	1.8-8.7	47-77	0.1-8.2	335-910	293-8193
	Mountain Whitefish	Peace River	2	126-136	1.3-2.6	24	0.0-0.2	296-370	345-634
	Rainbow Trout	Peace River	21	1-144	1.5-8.2	10-91	0.0-2.4	299-444	287-910

Contingent Trap and Haul

Four of the five target species were radio-tagged and released upstream of the Project in 2021 and 2022 under the contingent trap and haul program. In total, there were 14 Arctic Grayling, 59 Bull Trout, three Mountain Whitefish, and 27 Rainbow Trout released upstream of the Project, including 16 Bull Trout, two Mountain Whitefish, and one Rainbow Trout that had previously been radio-tagged under the contingent program or other components of the FAHMFP. One Bull Trout was transported upstream from the TUF in 2021 and under the contingent program in 2022, while another five were transported upstream under the contingent program during both years.

One radio-tagged Arctic Grayling was released in the Moberly River in May 2022 under the contingent trap and haul program, while the remainder were released at the Peace River release location between April and July 2021 and 2022. The three radio-tagged Mountain Whitefish transported under the contingent program were released in the Peace River in October 2021. Radio-tagged Rainbow Trout were released in the Peace River between April and July of both years, except for one released in October 2021. Radio-tagged Bull Trout were only released into the Peace River in April 2021 and 2022 before ice-out at the Halfway River release location. Transport times to the Peace River release location under the contingent program were between 10 and 91 minutes and the difference in water temperature between the transport tank and the Peace River never exceeded 2.4 °C (Table 23). There were up to 189 radio-tagged and non-radio-tagged fish transported per release event at the Peace River release location since 2021.

Most Bull Trout releases under the contingent program occurred at the Halfway River release location in late April through May of both years, with five additional releases between June and August. Transport times to the Halfway River release location were between 47 and 77 minutes and the difference in water temperature between the transport tank and the Halfway River was 5.2°C or less among all releases (Table 23), except on July 15, 2021 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 (Burgoon and Ford 2022). There were up to 13 radio-tagged and non-radio-tagged Bull Trout transported per release event at the Halfway River release location in 2021 and 2022.

According to genetic analysis (Geraldes and Taylor 2022), all 14 radio-tagged Arctic Grayling released upstream of the Project in 2021 and 2022 under the contingent trap and haul program were confirmed to have originated in the Moberly River. Of the 59 Bull Trout released under the contingent program, 48 were genetically confirmed to have originated upstream of the Project (e.g., the Halfway River), while the remaining 11 were either not sampled or the results of the genetic analysis were inconclusive. Sixteen of the 27 radio-tagged Rainbow Trout were confirmed to have originated upstream of the Project, while three were confirmed to have originated downstream. The remaining eight were either not sampled or genetic results were inconclusive.

2.5.3 Post-Release Fish Movements

Post-release movements are presented for the four target species captured and transported upstream by both trap and haul programs in 2021 and 2022. 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 26 by species, program, and release location. Detection history plots of each radio-tagged fish released upstream of the Project in 2021 and 2022 can be found in Appendix K: Trap and Haul Detection Histories.

Success to Spawning Grounds

Six of the 14 (43%) radio-tagged Arctic Grayling released were classified as successfully reaching their spawning grounds in the Moberly River. Five fish were detected at the Moberly River 2 fixed station and then again upstream of that during mobile tracking surveys in 2021. The sixth Arctic Grayling was released in 2021, remained in the Peace River upstream of the Project through 2021, and then successfully reach its spawning grounds in spring 2022. None of the Arctic Grayling released in 2022 reached their spawning grounds, including the one released directly into the Moberly River. Three of the six fish that reached their spawning grounds migrated back downstream of the Project in June 2021, presumably after spawning. An additional Arctic Grayling migrated back downstream of the Project in June 2022 after reaching its spawning grounds for a second time after its release in 2021. The two other successful Arctic Grayling remained upstream of the Project.

Forty-two of the 66 (64%) radio-tagged Bull Trout releases were classified as successfully reaching their spawning grounds in the Halfway River. Five of the seven (71%) that were transported from the TUF reached their spawning grounds, with four taking one day or less after release to reach the boundary of the expected inundation zone of the Site C Reservoir. The fifth was missed by the Halfway River 3 fixed station but was then detected by the Chowade River fixed station and PIT antenna 28.4 days after release. Four of the five Bull Trout migrated back downstream of the Project in late September to early October, presumably after spawning. Thirty-seven of the 59 (63%) Bull Trout releases under the contingent program reached their spawning grounds. Twenty-six of the 42 (62%) successful Bull Trout transported from the TUF or under the contingent program migrated back downstream of the Project, presumably after spawning.

Aside from the one Arctic Grayling released in the Moberly River, Bull Trout were the only radio-tagged target species released at more than one location. Fifteen Bull Trout were released at the Peace River release location in April 2021 and 2022 through the contingent program while the Halfway River release location was iced over. Of the 15 released in the Peace River, five (33%) were classified as having successfully reached their spawning grounds. After the Halfway River thawed in late April, Bull Trout were then released at the Halfway River release location. Of the 51 Bull Trout released directly into the Halfway River between late April and early August, 37 (73%) successfully reached their spawning grounds.

Five of the nine (56%) radio-tagged Mountain Whitefish transported in 2021 were classified as successfully reaching their assumed spawning grounds, including one that had previously been classified as a post-release mortality. Three of the five fish were tagged at and transported from the TUF, while the remaining two were tagged and transported through the contingent program. Three of the five migrated back downstream of the Project, presumably after spawning. No radio-tagged Mountain Whitefish were transported upstream of the Project in 2022 under either program.

Fifteen of the 27 (56%) radio-tagged Rainbow Trout were classified as having reached their assumed spawning grounds. Nine of the 15 fish were detected in the Halfway River or one of its tributaries, while another two were detected at the Moberly River 2 and 3 fixed stations. Interestingly, one of the Rainbow Trout that reached the Halfway River (Code 149.400-305) and another that reached the Moberly River (Code 149.400-293) were genetically confirmed to have originated downstream of the Project. The remaining four Rainbow Trout reached the Peace River 8 fixed station located on the Peace River just downstream of the Halfway River and Maurice, Lynx, and Farrell creeks. Four of the 15 successful Rainbow Trout migrated back downstream of the Project, presumably after spawning.

Mortality

Of the 116 releases, ten (9%) were classified as assumed mortalities, including one Arctic Grayling, seven Bull Trout, one Mountain Whitefish, and one Rainbow Trout. The Arctic Grayling

(Code 149.400-216) and Mountain Whitefish (Code 149.360-678) were never detected after release, while the Rainbow Trout (Code 149.400-184) was detected eight different times at the Peace River release location from May to September 2022. The Arctic Grayling and Rainbow Trout were captured and released in July 2021 through the contingent program and made up 7% and 4% of released fish of their species, respectively. The Mountain Whitefish was captured and tagged at the TUF in September 2021 and made up 17% of the six radio-tagged Mountain Whitefish transported upstream from the TUF.

The seven Bull Trout classified as assumed mortalities were released under the contingent trap and haul program at the Peace River and Halfway River release locations between April and May of both years. Four of the seven were recaptures that were originally radio-tagged in 2019 under other components of the FAHMFP (Codes 149.360-134 and 149.360-308) or in 2021 under the contingent program (Codes 149.360-690 and 149.360-717). None of the four were detected after being released upstream. The other three Bull Trout were released at the Halfway River release location and then repeatedly detected downstream in the same general vicinity during at least five separate mobile tracking surveys between September 2021 and September 2022. 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. All seven Bull Trout were PIT-tagged, but none were detected on the PIT arrays located in the Chowade River and in Cypress Creek. These mortalities comprised 11% of the 66 total Bull Trout releases and 12% of the 59 releases under the contingent program. There were no mortalities associated with the seven radio-tagged Bull Trout transported from the TUF.

Fallback

Two 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 two Bull Trout (Codes 149.360-704 and 149.400-146) were first detected downstream of the Project less than 41 hours after being released at the Peace River release location in April and made up 3% of the 59 radio-tagged Bull Trout released through the contingent program. The two Rainbow Trout (Codes 149.360-715 and 149.360-684) were released on May 20 and October 13, 2021, and made up 7% of the 27 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.

All four fish were genetically confirmed to have originated upstream of the Project. 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, six Arctic Grayling, 13 Bull Trout, three Mountain Whitefish, and nine Rainbow Trout migrated back downstream of the Project after 48 hours of being released upstream without having successfully reached their spawning grounds. Five of the six Arctic Grayling migrated back downstream of the Project within 13 days of their release, while the sixth (Code 149.400-314) migrated all the way up to the Peace River 11 fixed station before returning back downstream of the Project in late July, 67 days after release. These six Arctic Grayling made up 43% of the 14 Arctic Grayling releases.

Of the 13 additional Bull Trout that migrated back downstream of the Project after 48 hours of being released without having successfully reached their spawning grounds, seven did so within 16 days of release. 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. These 13 Bull Trout, along with the two that fell back within 48-hours of release made up 23% of the 66 total Bull Trout releases.

Three Mountain Whitefish (Codes 149.360-670, 149.360-673, 149.400-160) migrated back downstream of the Project less than a week after release. 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 releases.

Nine Rainbow Trout migrated back downstream of the Project without having successfully reached their spawning grounds. Eight of the nine made little to no detected upstream movements after release, while the ninth (Code 149.400-195) migrated up to the Peace River 7 fixed station before returning downstream of the Project 24 days after release. Six of the nine Rainbow Trout migrated downstream of the Project within 29 days of release, while the remaining three were detected downstream after 62, 155, and 349 days. These nine Rainbow Trout, along with the two that fell back within 48-hours of release made up 41% of the 27 Rainbow Trout releases.

Unconfirmed

One Arctic Grayling and two Bull 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 149.400-240) was released at the Peace River release location on June 15, 2022, and migrated upstream to the Peace River 7 fixed station where it was last detected in September 2022. One Bull Trout (Code 149.360-706) was released at the Peace River release location on April 23, 2022, was detected again three days later at the Peace River 7 fixed station and has not been detected since. The other Bull Trout (Code 149.400-325) was released in the Halfway River on May 24, 2022, reached the Halfway River 2 fixed station on May 31, and then swam back downstream where it was detected at the Peace River 9 station in early June and has not been detected since.

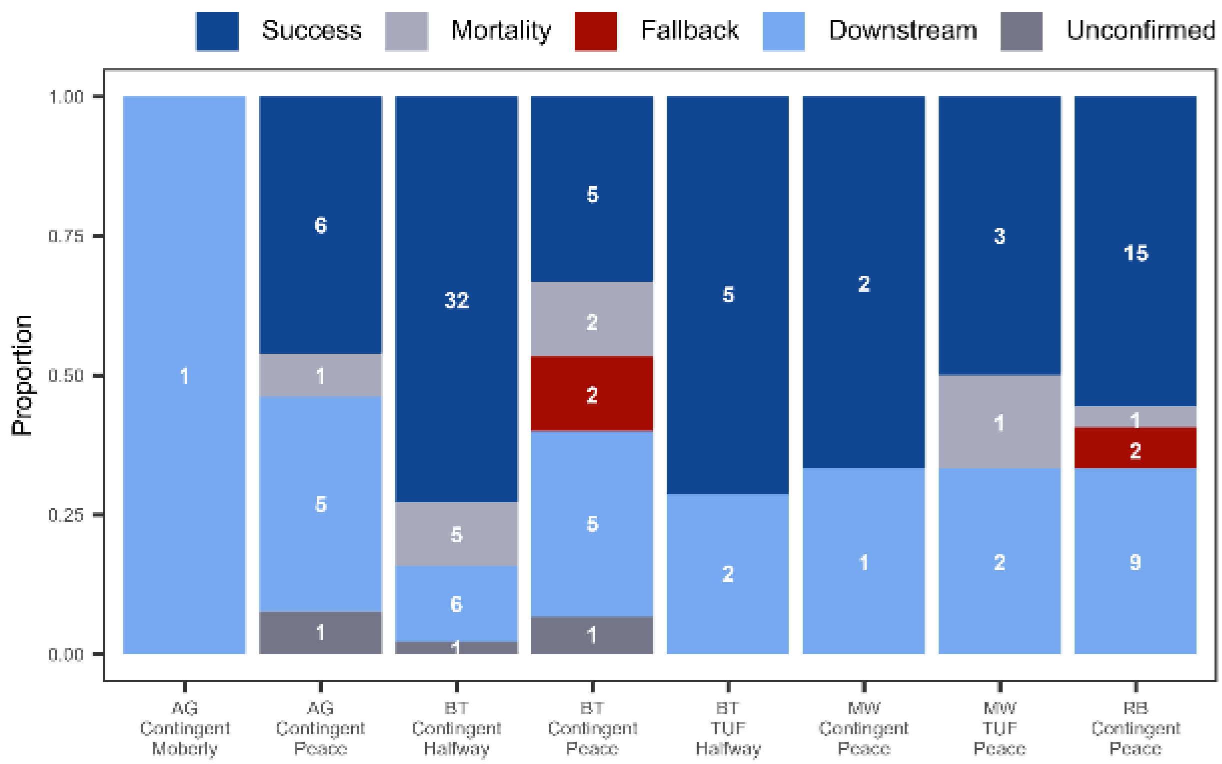

Figure 26 Proportions of movement classifications for radio-tagged Arctic Grayling (AG), Bull Trout (BT), Mountain Whitefish (MW), and Rainbow Trout (RB) transported from the temporary upstream fish passage facility (TUF) or through the contingent trap and haul program and released in either the Peace, Moberly, 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 monitoring program 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. Results 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 Mon-14 during the construction phase of the Project 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 during both years of the study. Although few radio-tagged fish were transported from the TUF during this time, 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 assumed spawning grounds. With such limited data, especially for fish transported from the TUF, results should be interpreted with caution. Future years of monitoring during the operations phase of the Project 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 and 2022 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 classification 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 43% (Arctic Grayling) to 64% (Bull Trout) for both trap and haul programs combined. Proportions were relatively similar between the two programs for Mountain Whitefish given the relatively low sample sizes. For Bull Trout, proportions of success were slightly higher for those transported from the TUF (71%) compared to those transported through the contingent program (63%). However, the proportion of success for Bull Trout released under the contingent program directly into the Halfway River was more similar (73%) to the proportion transported from the TUF, while the proportion released into the Peace River was significantly lower at 33%. It is worth noting that 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 April of both years, while those transported directly to the Halfway River were released closer to their known spawning period (i.e., August and September; Putt et al. 2023). 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. 2022, 2023). 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 significantly lower proportion of success for fish released at the Peace River release site.

Limited access to the Moberly River release location in 2021 and 2022 meant that all but one 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, six out of the 13 (46%) Arctic Grayling released at the Peace River release location reached their assumed spawning grounds. 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 somewhat encouraging, as access to the Moberly River will likely continue to be limited, particularly as the reservoir is filled in future years. It is worth highlighting, however, that all six radio-tagged Arctic Grayling released upstream of the Project in 2022 failed to successfully reach their spawning grounds. This difference in success between years may be explained by differences in the timing of releases and/or differences in water temperature at release sites. For example, the five Arctic Grayling that successfully reached their spawning grounds in 2021 were all released in April and early May when water temperatures at the release site were 2.5 to 4.4°C, whereas the six Arctic Grayling transported in 2022 were released in May and June when water temperatures at release sites were 5.9 to 13.7°C. Arctic Grayling are known to spawn shortly after ice-out when water temperatures reach approximately 4°C (McPhail 2007), and they are consistently observed entering the Moberly River by the end of April, presumably to spawn (Hatch et al. 2021, 2022, 2023). Despite these observations, there are currently too few data to confidently determine which, if any, conditions lead to an increased chance of success for Arctic Grayling released upstream of the Project.

Three fish, including one Arctic Grayling and two Bull Trout that were not classified as successfully reaching their spawning grounds in 2022, 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.

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; Bowerman et al. 2016; DeWeber et al. 2017; Kock et al. 2018, 2021). We classified ten out of the 116 releases (9%) as assumed mortalities. Species-specific proportions of assumed mortality ranged from 4% (Rainbow Trout) to 11% (Bull Trout and Mountain Whitefish). Program- and species-specific proportions of mortality ranged from 0% (Bull Trout) to 17% (Mountain Whitefish) for fish transported from the TUF, and 0% (Mountain Whitefish) to 12% (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, ongoing analysis of the radio-telemetry data collected through various components of the FAHMFP may make classifications of mortality more conclusive over time. This 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 et al. 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 seven assumed mortalities 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. 2023). 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 3% of the 116 post-release movements as fallback, with species-specific proportions ranging from 0% (Arctic Grayling, Mountain Whitefish) to 7% (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, 2018; Kock et al. 2016, 2021). All four 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, 31 of the 116 (27%) releases migrated back downstream of the Project after 48 hours of being released upstream without having successfully reached their spawning grounds. Eighteen of the 31 (58%) fish migrated back downstream of the Project within two weeks of release. An additional 38 fish migrated back downstream of the Project after having successfully reached their assumed spawning grounds. Together, 63% of the 116 releases eventually led to downstream movements past the Project, including 62% of all Bull Trout releases. These movements are worth highlighting, as passage downstream of the Project during the operations phase (i.e., entrainment) has the potential to cause negative effects on these populations through delayed or immediate mortality (Algera et al. 2020). Although not specifically monitored under Mon-14, entrainment rates and survival of all five target species will be monitored during the operations phase of the Project under the Site C Entrainment Monitoring Program (Mon-10).

2.6.2 Conclusions

Mon-14 has collected data on the post-release movements of radio-tagged Arctic Grayling, Bull Trout, Mountain Whitefish, and Rainbow Trout transported upstream of the Project during its construction phase. Promisingly, all four species were confirmed to have successfully reached their assumed spawning grounds after release. However, it was 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 three Mountain Whitefish transported from the TUF. Although not all fish transported upstream of the Project continued their migration after release (H_1), more data will need to be collected during the operations phase of the Project before an attempt is made at addressing either hypothesis or the associated management question pertaining to Mon-14. With the data collected so far, however, it does appear that transporting Bull Trout upstream of the Project in April is less effective than transporting them directly into the Halfway River after it has thawed and may not be worth the potential risks associated with capture, handling, transport, and/or post-release downstream movements (i.e., entrainment). 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 and 2022 suggest that the trap and haul program can successfully pass fish upstream of the Project, ultimately, several years of data need to be collected and analyzed during the operations phase of the Project to fully understand the effectiveness of the program, including the chosen release locations for each of the target species.

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 monitoring programs aim to better understand and optimize fish passage at Site C, from initial approach within the Mon-13 study area to upstream release and movements to spawning grounds.

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.

The TUF has now been operational for two full operational periods. We have established that the experimental design and existing radio and PIT telemetry arrays are appropriate for evaluating the movements of target species as they approached, entered, passed, and were released from the TUF upstream of the Project. Across two years of modeling the environmental factors associated with attraction to and entry of the fishway with TTE analyses, there have been some consistencies in results. For example, it is apparent that attraction flows effectively increase rates of approach to and entry of the fishway for Bull Trout. However, movement patterns also vary among diel period, season, and Peace River discharge, for Bull Trout and other target species. To maximize effectiveness, It is clear that operational strategies will have to vary seasonally or with environmental conditions. This is to be expected given the diversity of species using the fishway, and their unique biological requirements. Operations will have to holistically consider trade-offs and how each species may differentially respond. For example, maximal attraction flows may only be beneficial to Bull Trout during the period of upstream migration (and otherwise may attract them to a fishway only to feed on other target species that do not require high attraction flows).

The need for a seasonally and biologically relevant adaptive management strategy extends to transporting fish as well. For example, we found that transporting Bull Trout upstream of the Project in April is less effective than transporting them directly into the Halfway River after it has thawed. Transporting Bull Trout in the spring may not be worth the potential risks associated with handling, transport, and/or post-release downstream movements (i.e., entrainment), especially when the permanent facility and turbines are operating.

The examples above of how our results can inform operations are focused on Bull Trout because that is the target species for which we have the most data. Our dataset is limited by poor passage through the upper portion of the TUF (i.e., from the upper pools through the vee-trap and crowder, into the sorting facility). Since data collection began, there is ample evidence that fish can reach the uppermost pools of the fishway but that the vee-trap and/or finger weir into the pre-sort holding pool, crowder, and elevator presents a barrier. Improving the effectiveness of the 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 also increasing the sample sizes of radio-tagged fish transported and released upstream of the Project to be monitored under Mon-14.

Our research has also been impacted by shutdown periods of various durations, challenges with fishway pump operations, and water surface elevations often above the fishway's design criteria. To mitigate for the potential lack of biological effectiveness of the TUF during these operational challenges, BC Hydro commissioned WSP to conduct boat electroshocking surveys in the Peace River in the vicinity of the TUF to capture and transport fish upstream of the Project (Burgoon and Ford 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.

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 operational period were used to calculate species-specific attraction and passage efficiencies. While TTE analyses do incorporate seasonal and temporal components, these are not biologically relevant to each species. It would be more informative to evaluate differences in movement rates across species-specific biologically relevant timelines of spawning periods, using the best data available.

It is promising that 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. We have been able to do so with some limitations, and with continued data collection, results will guide operational recommendations for the TUF and the PUF.

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Appendix A: TTE Covariate Selection Process

R Markdown Report

Last Produced 2023-08-02

Model Selection Summary

To determine which variables to include in the final model set we use the Bull Trout Approach and Entry data, the most rich data sets. The steps taken to choose a final covariates are detailed below.

1) A full approach model was run with all covariates and including all data

The result was a random effect that held a very large amount of variance, with residuals that were right skewed and slightly bimodal. Additionally, there was seasonality in activity level (number of transitions, referred to as SubOccupancy in code) and a strong correlation between the random effect and subOccupancy. We separated the data into two models, hypothesizing a bimodality in seasonal differences in activity (e.g., spawning migrations vs. not).

2) Observe if the seasonality effect was affecting model fit

Two models were run: High activity and low. The classification of high and low activity was derived from a histogram of the number of transitions by day; there was a natural distribution of high activity mid-season. The high activity model had the same outcome as the full model. Low activity model didn't converge. Based on this we concluded that seasonal differences in activity were not driving the poor model fit and it was best to retain all data. We then explored individual variables for their effect on model fit.

3) Identify problematic variables

SubOccupancy (E.g., Approach Model)

When models were run separately according to activity level, SubOccupacy was a problem. Model fit only marginally improved when removing SubOccupancy. It was ultimately retained because we are interested in this parameter.

AttFlowRat (E.g., Entry Model)

Originally to evaluate the influence of discharge on how attraction flows are perceived, the proportion of attraction flow to total river discourage was calculated as total attraction flow (AWS+HVJ)/Q. The scale of this variable resulted in extreme coefficients and HRs. To temper the effect, we changed it to a percentage (AWS+HVJ)/Q * 100. We also explored if would be instead better to include an interaction between individual attraction flow parameters and Q. Model fit did improve with the interaction term, but the inclusion of interactive effects substantially increases complexity and difficulties with interpretation. Rather than include interactions in the final model set I decided to keep the percentage attraction flow variable and explore the potential for interactive effects post-hoc if this variable turns out to be important to a given state model.

Discharge

MeanQ is highly significant in almost all models but with HRs close or equal to 1. This makes it really hard to interpret the effect because we are looking at 1cms differences (e.g., a highly significant HR of 0.99 tells us that rate of movement changes 0.1% for each 1 cms. Additionally, the resolution of the discharge data is to the nearest 10. To help better interpret HRs I divided the discharge variable by 10 thereby each unit change in the HR means a discharge change at a resolution of 10 cms.

Temperature

Although known to be important to fish behaviour, temperature was correlated with Q and season (and, accordingly, SubOccupancy, day). However, most of these correlations were did not meet our correlation coefficient threshold of exclusion (only day and temperature had a correlation coefficient > 0.4). Temperature was highly significant with a small effect in almost every model. We are more interested in Q and Season in terms of fishway effectiveness and so decided to remove temperature. Where models were tested with and without the temperature variable it did not affect the outcome but did improve fit.

4) Further simplify model structure

Assess if this is possible while still achieving our goals.

- MedAttFlow was removed. While we are primarily interested in attraction flow, I decided this parameter is not actually important to operations. Operationally, BCH will modify either the HVJ or the AWS. A significant effect of MedAttFlow isn't really meaningful in terms of operational strategies. It was retained as a percentage of total flow.
- Removed temperature (see above)
- Remove WSEL as it is so correlated with discharge.

Candidate Model Set

The set of candidate models included all possible and logical combinations of the following covariates.

```
 [1] "SubOccupancy" "Day"          "DielPeriod"   "Season"       "MeanTemp"
 [6] "MeanQ"        "MeanWSE"      "MedAWS"       "MedHVJ"       "MedAttFlow"
[11] "AttFlowRat"
```

Only logical covariate combinations (i.e., those not retained within the other in some way) and with correlation coefficients < 0.4 were retained. We excluded the following combinations of covariates:

- WSE * temp (highly correlated)
- day * temp (highly correlated)
- MeanQ * MeanWSE * AttFlowRat
- MedAttFlow * MedAWS * AttFlowRat
- SubOccupancy * Day
- Day * season

The number of models resulting is:

```
[1] 247
```

Approach Models V1

All models within the candidate set are run within a for loop according to the call:

coxph(as.formula((Surv(Time1_s,Time2_s, Status)) ~ Covariates + frailty(FreqCode))

where Covariates are those listed within the candidate set of models.

The final model set includes any with a Delta AIC of < 2

Covariates	DeltaAIC	AICw	LogLik
SubOccupancy+DielPeriod+Season+MeanTemp+MeanQ	0.00	0.43	-5048.74
SubOccupancy+DielPeriod+Season+MeanTemp+MeanQ+MedAWS	1.98	0.16	-5048.74
SubOccupancy+DielPeriod+Season+MeanTemp+MeanQ+MedHVJ	1.98	0.16	-5048.74
SubOccupancy+DielPeriod+Season+MeanTemp+MeanQ+MedAttFlow	1.99	0.16	-5048.74

Much like last year, we see a pattern of environmental variables playing an important role, with individual attraction flow variables being added on individually with higher AIC values. I'm confident just using the best model to explore model fit.

The addition of individual parameters on top of five included covariates suggests there might be a correlation problem. This could be due to Q* Temp or SubOccupancy * Season. We are going to continue with diagnostics but may consider further reducing the model set.

Model Approach (coxph vs. coxme)

The above approach uses the coxph() function from the survival package. I also explored coxme::coxme to run the same model. The results of the coxme model (below) are similar, but the random effect holds more variance and variables have higher significance. Results aren't sufficiently different that I feel the need to explore further. Current reading suggests coxme is better for complex models, but we found the diagnostic testing of coxph more straight forward. When we combine data from multiple years, I suggest using coxme, but for this year I think coxph is easier and achieves the same outcome.

```
Cox mixed-effects model fit by maximum likelihood
  Data: BT_Approach_data
  events, n = 1927, 27115 (25 observations deleted due to missingness)
  Iterations= 9 61
                    NULL Integrated    Fitted
Log-likelihood -6547.897  -5143.326 -5047.994

                    Chisq    df p     AIC     BIC
Integrated loglik 2809.14  9.00 0 2791.14 2741.07
 Penalized loglik 2999.81 52.75 0 2894.32 2600.86

Model:  (Surv(Time1_s, Time2_s, Status)) ~ SubOccupancy + DielPeriod +      Season +
MeanQ + MeanTemp + (1 | FreqCode)
Fixed coefficients
                     coef exp(coef)     se(coef)      z           p
SubOccupancy -0.001158662 0.9988420 0.0004259837  -2.72 0.006500000
DielPeriod.L -0.036271074 0.9643788 0.0842462793  -0.43 0.670000000
DielPeriod.Q  1.148664527 3.1539780 0.1032424046  11.13 0.000000000
DielPeriod.C  0.398106383 1.4890024 0.1190182487   3.34 0.000820000
Season.L     -0.427443381 0.6521743 0.0748064459  -5.71 0.000000011
Season.Q     -0.005330282 0.9946839 0.1129956993  -0.05 0.960000000
MeanQ        -0.001516018 0.9984851 0.0001143258 -13.26 0.000000000
MeanTemp      0.109033674 1.1151999 0.0193815051   5.63 0.000000018

Random effects
 Group    Variable  Std Dev  Variance
 FreqCode Intercept 1.596528 2.548901
```


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Diagnostics Process of Select Model

- Model Summary
- Schoenfeld residuals
- Covariate distribution
- Deviance and random effect residuals

```
# Run and summarise best BT model
BT_BestModel <- coxph((Surv(Time1_s,Time2_s, Status))~
                        SubOccupancy+DielPeriod+Season+MeanQ+MeanTemp+
                        frailty(FreqCode),
                      data=BT_Approach_data)

BT_summary <- summary(BT_BestModel)
```

Coefficients and variance of RE of this model are as follows:

```
                    coef se(coef)   se2   Chisq     DF     p
SubOccupancy      -0.001    0.001 0.001   3.863  1.000 0.049
DielPeriod.L      -0.035    0.084 0.084   0.172  1.000 0.678
DielPeriod.Q       1.148    0.103 0.103 123.695  1.000 0.000
DielPeriod.C       0.399    0.119 0.119  11.224  1.000 0.001
Season.L          -0.422    0.077 0.076  29.854  1.000 0.000
Season.Q           0.010    0.118 0.114   0.007  1.000 0.931
MeanQ             -0.002    0.000 0.000 172.513  1.000 0.000
MeanTemp           0.105    0.020 0.020  26.922  1.000 0.000
frailty(FreqCode)     NA       NA    NA 975.030 49.019 0.000

[1] "Variance of random effect= 1.752336   I-likelihood = -5140.9"
```

Schoenfeld Test

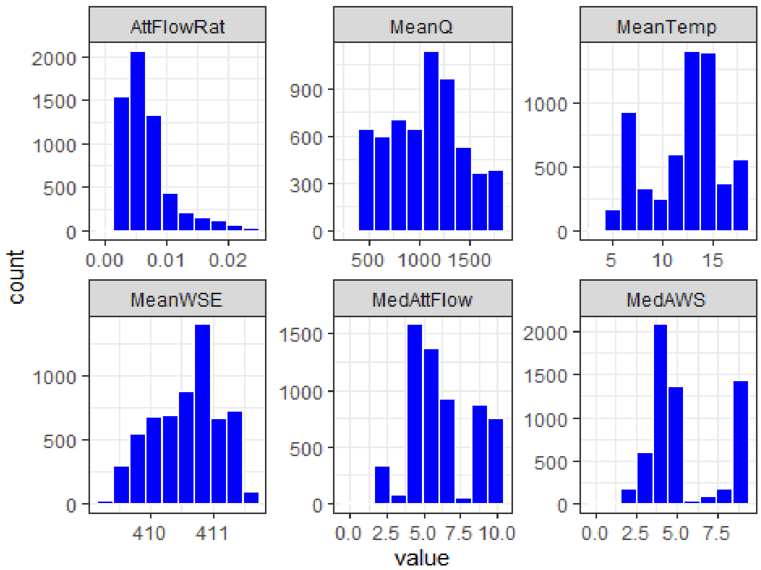
Test assumption of Proportional Hazard, that hazard ratio between two individuals remains constant and proportional over time. Violated if $p < 0.05$

```
               chisq    df       p
SubOccupancy  1.6481  0.92 0.18164
DielPeriod    1.9785  3.00 0.57658
Season        0.9239  1.92 0.61056
MeanQ        11.0174  0.98 0.00087
MeanTemp      0.0491  0.96 0.81038
GLOBAL       16.1020 56.80 1.00000
```

Violated for Q, but no other variable. The distribution of Q could likely be transformed to normal with a log transformation, but it is not dramatic. A log transformation would bring this variable into a normal distribution, but it would be tricky to interpret if we did so. A mixed-effect structure should be able to handle a non-normal distribution.

I looked at distributions of all variables. The distribution of AttFlowRat (not included in this model) is highly left-skewed. I'm more concerned about the distribution of AttFlowRat than Q.

Here are the distribution of covariates:

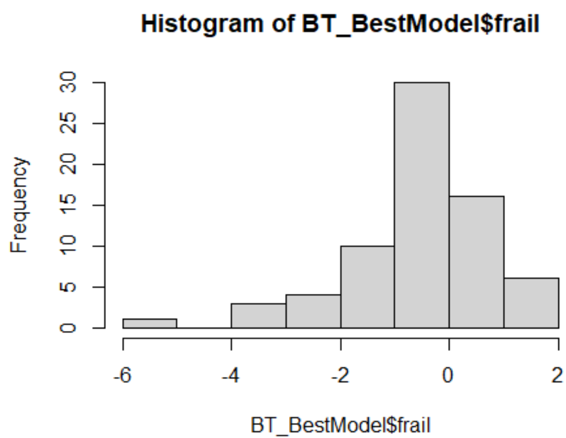


I suspect the violation in the Schoenfeld test for Q is due to clustering of individuals. Next look at random effect.

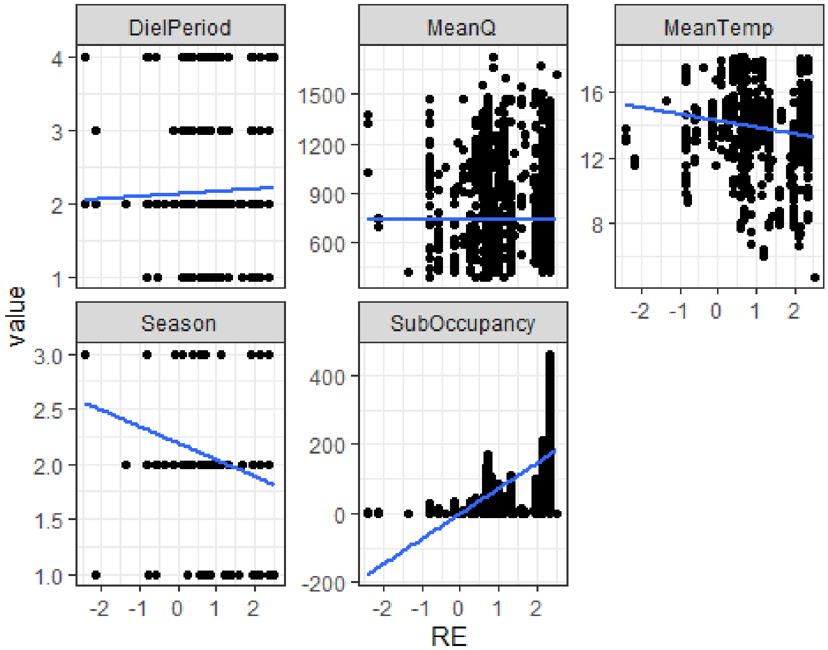
Random Effect and Influence of Individuals

The significance and variance of the random effect are worth investigating further. Our random effect is FishID; differences attributed to the individual are therefore important to the observed variation. The variance is also high (~2), meaning variance not explained by fixed predictors between individuals is substantial. Additionally, like last year the random effect shows a slight bimodal distribution. Intra-individual differences could be masking an effect of covariates of interest (e.g., attraction flows) and the bimodality could be a sign that models achieve a better fit if the data are split.

Looking closer, the bimodality is driven by just one individual with a large negative residual: BT 360714 had nine occupancies and was on the array from March 31 to August 5 but was never detected in the entry zone.



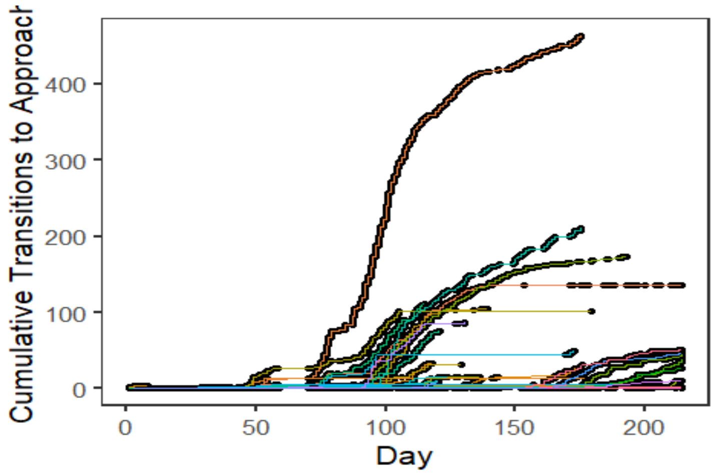
I want to look at the correlation between the random effect and covariates. Unfortunately, I can extract RE from the coxph object, but I can't get associated individual IDs. I can get this from the coxme model so I will use it. Although results are slightly different, the story is the same and it will indicate if there is a problem; it's likely that that problem would exist in the coxph model too.



Q doesn't really seem to be a problem in terms of correlation with random effect, but I have concerns about the correlations with season and SubOccupancy and temperature. A strong correlation suggests variation explained by covariates may be largely explained by the variation in the random effect. I think this shows a seasonality issue and that BT don't behave/approach the fishway in the same way throughout the year. You wouldn't expect a seasonal migrant to behave the same throughout the year. We may need to break up the model by season if we want to tease out the factors that attract BT to the fishway.

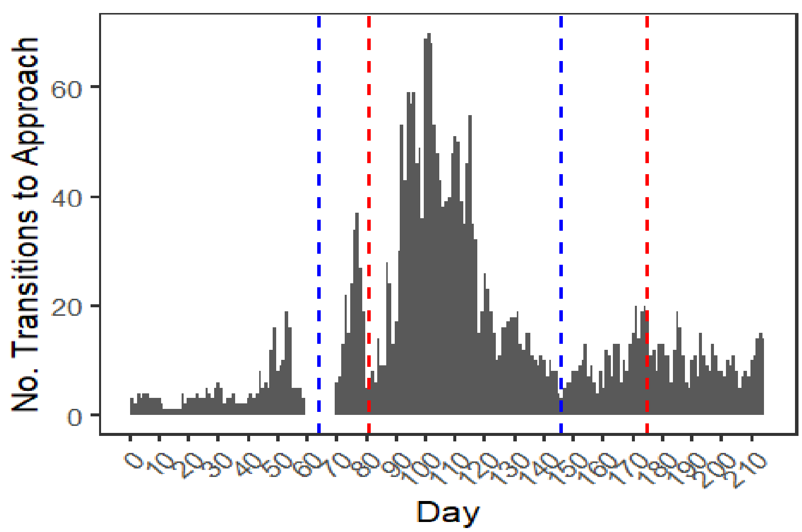
Number of Transitions (SubOccupancy) and Seasonality

This figure shows the number of transitions made by each individual BT. You can see there are more active individuals and less active, which is to be expected. What is more important from this figure is that there appears to be pulses of activity. A large pulse mid-season and smaller one later in the season. Looking at this as a distribution may show why we see such a strong effect of seasonality.



This shows the number of transitions to the approach by day within the operational period. Its obvious to me in this figure that there are three distinct periods of activity that roughly align both with the changing of seasons and biologically meaningful activity: Spring (low activity, feeding), Summer (high activity, spawning migration), fall (low activity, feeding kelting).

Blue lines are those drawn on visually by me to identify biologically relevant time periods. Red are those delineating calendar seasons. To me, it is illogical to use calendar season when we can use our data to better inform time period delineation. To increase power, we could also have two time periods: high activity and low activity. Running these models separately may also resolve the correlation between the random effect and temperature.



Model Revision (V2): Separate models according to activity

As a second revision to modeling we will run models separately according to seasonal "activity". We're not calling this season because we're only running two models rather than three: Between Day 64 and 146 activity is "High", otherwise it is Low. I predict that if we're interested in the factors predicting fishway usage, we need to look at activity phases separately.

Approach Models V2a (High Activity)

Removing the “season” covariate results in the following covariates:

```
 [1] "SubOccupancy" "Day"          "DielPeriod"   "MeanQ"        "MeanTemp"
 [6] "MeanWSE"      "MedAWS"       "MedHVJ"       "MedAttFlow"   "AttFlowRat"
```

The number of models resulting is:

```
[1] 139
```

As with initial model, data is processed with the same loop and equation (not shown) and the final model set includes any with a Delta AIC of < 2.

Covariates	DeltaAIC	AICw	LogLik
SubOccupancy+DielPeriod+MeanQ+MeanTemp	0.00	0.28	-2909.01
SubOccupancy+DielPeriod+MeanQ+MeanTemp+MedAWS	0.09	0.27	-2908.09
SubOccupancy+DielPeriod+MeanQ+MeanTemp+MedAttFlow	0.45	0.23	-2908.26
SubOccupancy+DielPeriod+MeanQ+MeanTemp+MedHVJ	1.95	0.11	-2908.99

The final model set looks very similar to the full model, with an even higher random effect. This is not an improvement.

Summary

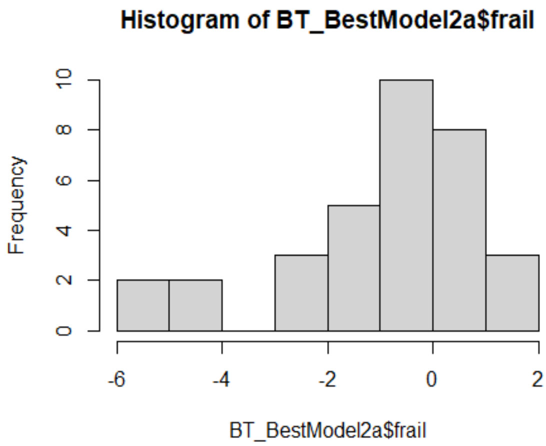
```
# Run and summarise best model
BT_BestModel2a <- coxph((Surv(Time1_s,Time2_s, Status))~
                          SubOccupancy+DielPeriod+MeanQ+MeanTemp+
                          frailty(FreqCode),
                        data=BT_Approach_data2a)
BT_summary2a <- summary(BT_BestModel2a)

#Extract variance of random effect
BT_summary2a$print2

[1] "Variance of random effect= 2.481079   I-likelihood = -2970.2"
```

Schoenfeld Test and Residuals

PH Assumption is not broken in this model for any covariate, which is an improvement to the full model.

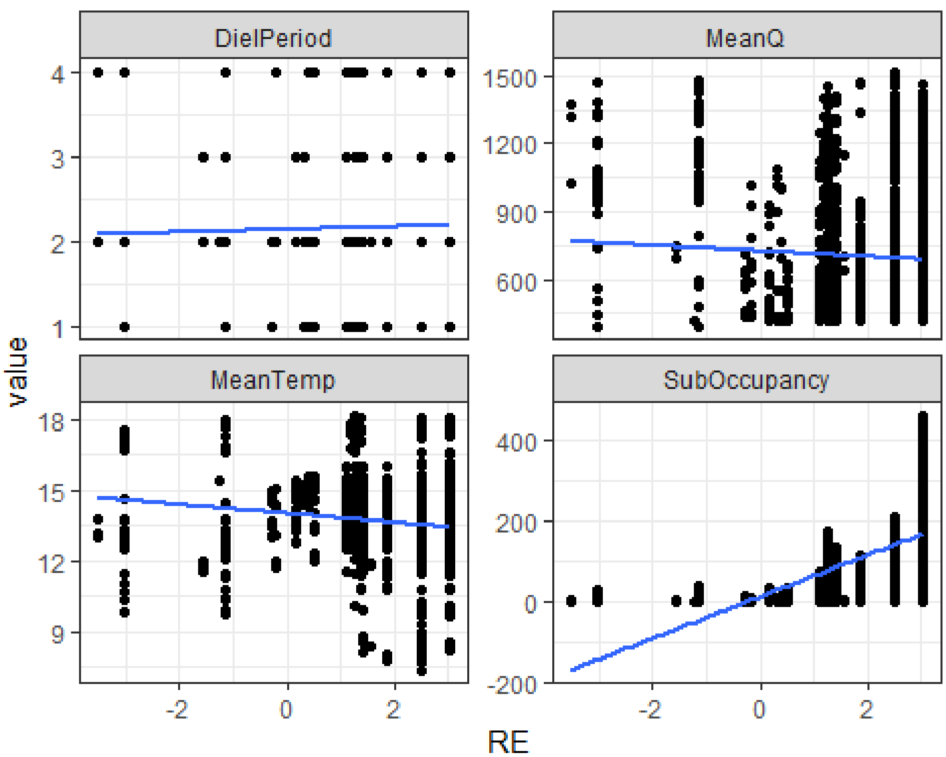
```
             chisq    df    p
SubOccupancy 0.503  0.95 0.46
DielPeriod   1.649  3.00 0.65
MeanQ        0.215  1.00 0.64
MeanTemp     0.185  0.97 0.65
GLOBAL       2.754 34.22 1.00
```

Residuals still aren’t amazing. Showing even more of a bimodality (2 outliers) and a right skew.



Random Effect and Influence of Individuals

SubOccupancy still very correlated with RE. That this still occurs within this dataset limited to the "high activity" period shows that it's unavoidable in our data that the variation explained by SubOccupancy may be largely explained by the variation in the random effect. This is OK and to be expected, as both represent individual "behaviours".



Approach Models V2b (Low Activity)

Here we will look at the “low activity” period between days 0-64 and 146-214. We won’t include “season” but will include covariate, “Period”, indicating if it’s the early or late time period.

As with initial model, data is processed with the same loop and equation (not shown) and the final model set includes any with a Delta AIC of < 2.

```
NULL
```

Covariates	DeltaAIC	AICw	LogLik
SubOccupancy+DielPeriod+Period+MeanQ	0.00	0.13	-1161.69
SubOccupancy+DielPeriod+Period+MeanQ+MedAWS	0.54	0.10	-1161.03
SubOccupancy+DielPeriod+Period+MeanQ+MedHVJ	1.10	0.07	-1161.25
DielPeriod+Period+MeanQ	1.11	0.07	-1162.07
SubOccupancy+DielPeriod+Period+MeanQ+MedAttFlow	1.41	0.06	-1161.44
DielPeriod+Period+MeanQ+MedAWS	1.58	0.06	-1161.41
SubOccupancy+DielPeriod+Period+MeanQ+MeanTemp	1.70	0.05	-1161.58
SubOccupancy+DielPeriod+Period+MeanQ+MedAWS+MedHVJ	1.74	0.05	-1160.65

Similar, except AIC more widely distributed and variables are more diverse. This mix of variables shows me that this model may be data limited.

Summary

```
# Run and summarise best BT model
BT_BestModel2b <- coxph((Surv(Time1_s,Time2_s, Status))~
                          SubOccupancy+DielPeriod+Period+MeanQ+
                          frailty(FreqCode),
                        data=BT_Approach_data2b)

Warning in coxpenal.fit(X, Y, istrat, offset, init = init, control, weights =
weights, : Inner loop failed to coverge for iterations 2
```

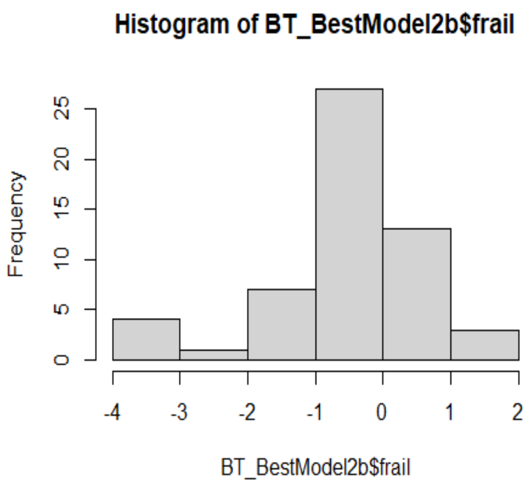
Model not converging, again because of the SubOccupancy variable. The first line shows number of iterations with SubOccupancy and the second without; the model is much improved removing the subOccupancy variable.

```
[1]  7 82

[1]  7 39
```

Schoenfeld Test

```
             chisq    df      p
SubOccupancy  4.98  0.48 0.0089
DielPeriod   12.47  3.00 0.0059
Period        2.04  0.52 0.0685
MeanQ         9.98  0.97 0.0015
GLOBAL       24.44 40.58 0.9788
```

PH Assumption is broken for half of the covariates and residuals are OK but do show data limitations.



Final Model Selection

Ultimately, I've decided to include subOccupancy in the final model but remove temperature. Even though it's SubOccupancy that is the most problematic in terms of correlation with the RE, it is an important behaviour to quantify. Temperature is also slightly correlated with many variables: subOccupancy, day, season, wse, Q. Temperature is not something we're directly interested in and so it was in and model fit is improved when Q and Temp aren't together.

Covariates	DeltaAIC	AICw	LogLik
DielPeriod+Season+MeanQ+MedAWS	0.00	0.19	-2938.12
DielPeriod+Season+MeanQ	0.01	0.19	-2939.08
DielPeriod+Season+MeanQ+MedAttFlow	0.76	0.13	-2938.48
DielPeriod+Season+MeanQ+MedHVJ	1.52	0.09	-2938.85
DielPeriod+Season+MeanQ+MedAWS+MedHVJ	1.56	0.09	-2937.91
SubOccupancy+DielPeriod+Season+MeanQ+MedAWS	1.73	0.08	-2938.04
SubOccupancy+DielPeriod+Season+MeanQ	1.73	0.08	-2938.99

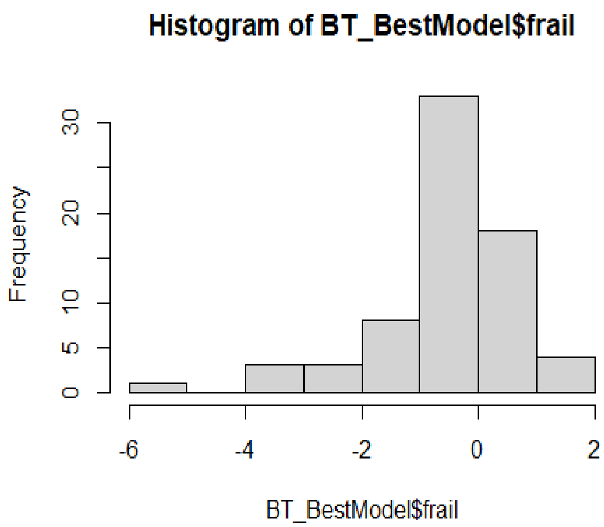
```
# Run and summarise best model
BT_BestModel <- coxph((Surv(Time1_s,Time2_s, Status))~
                        DielPeriod+Season+MeanQ+MedAWS+
                        frailty(FreqCode),
                      data=BT_Approach_data)
BT_summary <- summary(BT_BestModel)
```

Schoenfeld Test and Residuals

The assumption of PH is still violated for Q, but the value is higher (slight improvement). Residuals are similar.

```
              chisq    df      p
DielPeriod  2.31096  3.00 0.5103
Season      0.27913  1.93 0.8578
```

```
MeanQ         8.01790  0.99 0.0045
MedAWS        0.00224  1.00 0.9622
GLOBAL       12.02728 54.68 1.0000
```



Model Interpretation

Significance of coefficients is similar, variance of the RE is reduced with removal of temperature. This is a big improvement because we can learn more about the fixed effects.

```
# Observe coefficients (rounded to 3 decimals for clarity)
round(BT_summary$coefficients, 3)

                     coef se(coef)   se2    Chisq     DF     p
DielPeriod.L       -0.013    0.084 0.084    0.026  1.000 0.873
DielPeriod.Q        1.136    0.103 0.103  121.161  1.000 0.000
DielPeriod.C        0.401    0.119 0.119   11.327  1.000 0.001
Season.L           -0.542    0.061 0.060   79.550  1.000 0.000
Season.Q           -0.073    0.111 0.108    0.431  1.000 0.512
MeanQ              -0.002    0.000 0.000  206.851  1.000 0.000
MedAWS             -0.003    0.012 0.012    0.061  1.000 0.805
frailty(FreqCode)      NA       NA    NA 1297.210 47.766 0.000

#Extract variance of random effect
BT_summary$print2

[1] "Variance of random effect= 1.549084   I-likelihood = -5156.3"
```

Exploring AttFlowRat and Q

Attraction flow rate didn't come up as problematic in the approach models because it wasn't an important variable. It does seem highly important to the entry model though; in preliminary model runs it was highly significant with extreme HRs. We have some convergence issues in the entry model due to diel period data limitations, but if we run the full set anyway the top models are:

Covariates	DeltaAIC	AICw	LogLik
DielPeriod+Season+AttFlowRat	0.00	0.72	-1030.43
SubOccupancy+DielPeriod+Season+AttFlowRat	2.15	0.25	-1031.20
Day+DielPeriod+MeanQ+MedAWS+MedHVJ	7.86	0.01	-1032.96
Day+DielPeriod+MeanQ+MedAWS	7.94	0.01	-1033.98

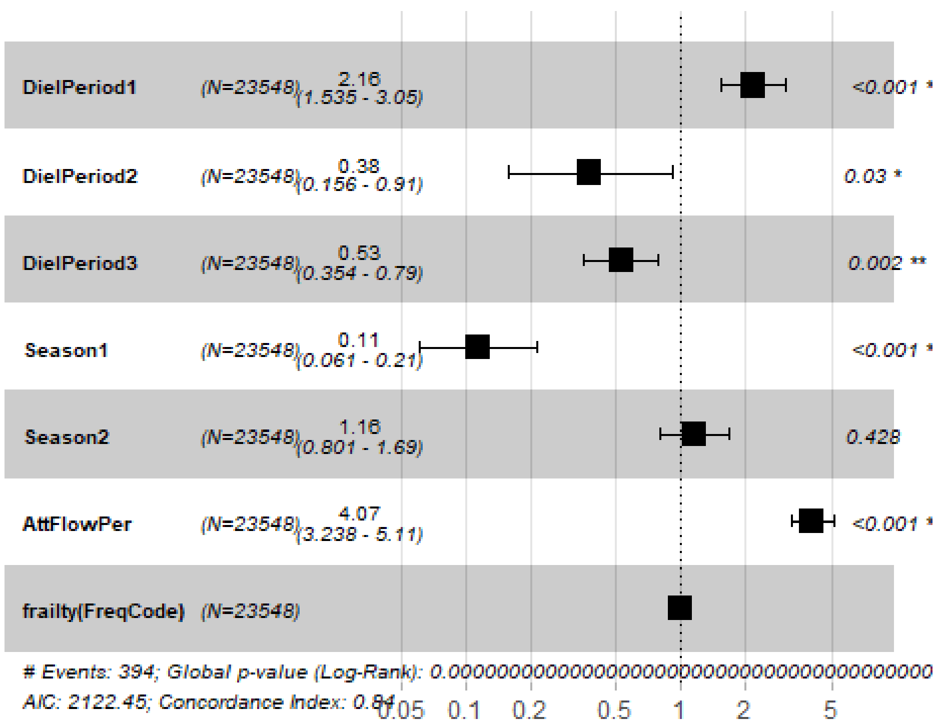
Model Comparisons

A problem with the AttFlowRat variable is that the coefficient (140!) and HR are extremely high, and it is highly significant.

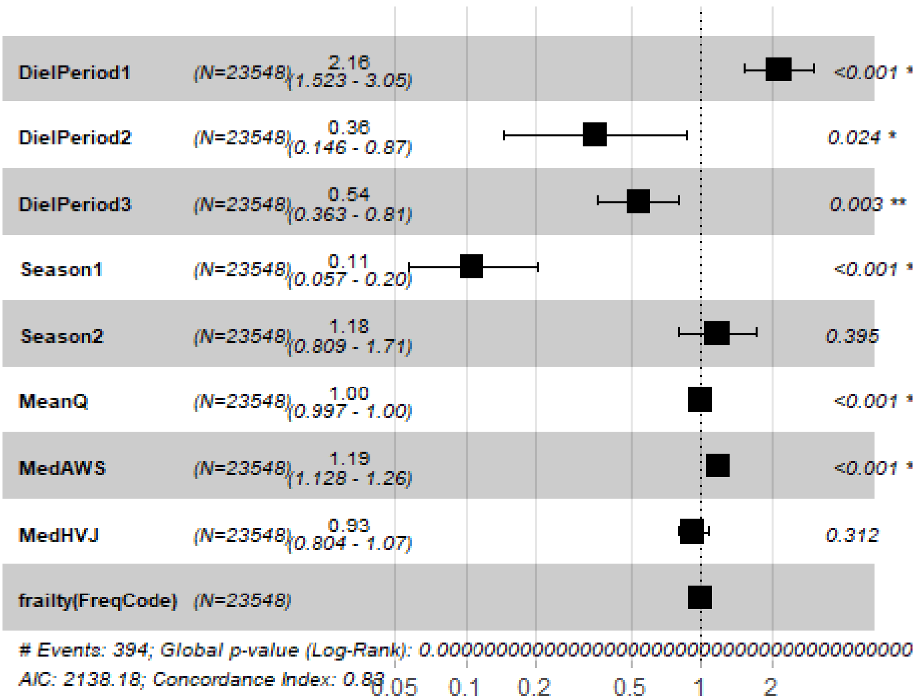
	x
DielPeriod1	0.772
DielPeriod2	-0.974
DielPeriod3	-0.639
Season1	-2.173
Season2	0.150
AttFlowRat	140.292

We will explore the following options to retain this variable while improving model fit:

- View it as a percentage rather than proportion.
  - This improves things a lot.



- Log transform. Going to stick with percentage because HRs are easier to interpret.
  - There is no improvement when log transforming AttFlowPer. Residual distribution identical and PH assumption worse
- If the entire model set is run without AttFlowRat, is Q instead retained?
  - Yes. Along with day, diel period, AWS and HVJ. Perhaps this variable just represents the influence of Q?
  - Here we have very little effect of Q, a positive effect of AWS and a negative effect of HVJ. These results are pretty unclear. Is attraction flow better or not? Maybe interpreting attraction flows as a percentage of discharge is the way to go.



- Include interaction terms of HVJ*Q and AWS*Q
  - DielPeriod+ MeanQ*MedAWS + MedHVJ: Where there is a significant interaction, the ggforest plot only plots the main effects. But you can see that when the interactive effect is accounted for the main effect of AWS is larger than when the interaction effect is not accounted for.
  - DielPeriod+ MeanQ*MedHVJ + MedAWS: Interactive effect is not significant.

	coef	se(coef)	se2	Chisq	DF	p
DielPeriod1	0.775	0.177	0.177	19.167	1.000	0.000
DielPeriod2	-0.996	0.456	0.456	4.773	1.000	0.029
DielPeriod3	-0.648	0.206	0.206	9.900	1.000	0.002
Season1	-2.102	0.322	0.313	42.642	1.000	0.000
Season2	0.173	0.192	0.181	0.815	1.000	0.367
MeanQ	0.000	0.001	0.001	0.356	1.000	0.551
MedAWS	0.502	0.073	0.072	47.354	1.000	0.000
MedHVJ	-0.084	0.074	0.074	1.311	1.000	0.252
frailty(FreqCode)	NA	NA	NA	145.780	24.811	0.000
MeanQ:MedAWS	0.000	0.000	0.000	23.465	1.000	0.000

	coef	se(coef)	se2	Chisq	DF	p
DielPeriod1	0.767	0.177	0.177	18.779	1.000	0.000
DielPeriod2	-1.031	0.456	0.456	5.102	1.000	0.024
DielPeriod3	-0.610	0.206	0.206	8.808	1.000	0.003
Season1	-2.237	0.321	0.312	48.692	1.000	0.000
Season2	0.163	0.191	0.181	0.726	1.000	0.394
MeanQ	-0.002	0.000	0.000	52.424	1.000	0.000
MedHVJ	-0.052	0.196	0.196	0.070	1.000	0.791
MedAWS	0.177	0.029	0.029	37.167	1.000	0.000
frailty(FreqCode)	NA	NA	NA	147.515	24.865	0.000
MeanQ:MedHVJ	0.000	0.000	0.000	0.015	1.000	0.903

- Include interaction term of MedAttFlow*Q

	coef	se(coef)	se2	Chisq	DF	p
DielPeriod1	0.775	0.178	0.178	19.020	1.000	0.000
DielPeriod2	-1.037	0.458	0.458	5.133	1.000	0.023
DielPeriod3	-0.636	0.206	0.206	9.513	1.000	0.002
Season1	-2.087	0.322	0.313	42.077	1.000	0.000
Season2	0.193	0.192	0.181	1.004	1.000	0.316
MeanQ	0.001	0.001	0.001	0.786	1.000	0.375
MedAttFlow	0.453	0.068	0.068	44.366	1.000	0.000
frailty(FreqCode)	NA	NA	NA	145.835	24.805	0.000
MeanQ:MedAttFlow	0.000	0.000	0.000	24.134	1.000	0.000

Variable Selection

The interaction models are the best fit (mod 5 = AWS*Q) followed by the first 2 models which include AttFlowRat and AttFlowPer.

Interactions are hard to incorporate into what is already a very complex model set being applied to a limited dataset. The AttFlowRat is effectively an interaction term held within a single variable but I think the main effects of attraction flows are better represented when the main effects and interaction are included. I think the best way forward is to retain AttFlowPer, but then run the interaction if AttFlowPer is included in the top model to help with the discussion and interpretation of the model.

```
                          df      AIC DeltaAIC  AICw
mod5_QAWSint        33.44386 2115.005    0.000 0.939
mod1_AttFlowRat     30.79499 2122.454    7.449 0.023
mod2_AttFlowPer     30.79499 2122.454    7.449 0.023
mod7_MedAttFlowQInt 32.42967 2123.213    8.208 0.016
mod4_NoAttFlowRat   32.51624 2138.179   23.174 0.000
mod6_QHVJint        33.52673 2140.182   25.177 0.000
mod3_AttFlowPerLog  30.77921 2149.478   34.472 0.000
```

Conclusions and Important Considerations

- SubOccupancy is a difficult variable, but easier to handle with temperature removed.
- Temperature was a problematic variable, being slightly correlated with all temporal variables (season, day, subOccupancy) and environmental variables (Q, WSE)
- Random effect highly significant
- Environmental variables play the biggest role (generally not controllable)
- Season also problematic and highly significant; may not be biologically relevant. Should we consider activity levels?
- Diel period is problematic where data is limited or where movements very diel-dominated (e.g., all movement during the day as with MW), particularly the dusk and dawn time period which inherently encompass less time (and data)

Appendix B: Bull Trout Approach Zone Model Selection

R Markdown Report

Last Produced 2023-08-02

Two models sets are evaluated:

- Approach looks at movement from approach zone into entry zone.
- Departure looks at movement from approach zone to outside approach zone.

Covariates

The same covariates are used for both models. Many covariates were removed from last year for a more targeted analysis:

- Temperature presented a correlation issue in some models with day, WSE and Q, especially when included with SubOccupancy
- Discharge values were divided by 10 (they are recorded in 10 cms increments) for ease of interpretation. That is, so that we can interpret the HR as a unit change being 10 cms rather than 1 cms.
- Although SubOccupancy was repeatedly a problematic variable, it is a variable of interest and so was retained. Efforts were made to simplify the model set in other ways. One change in the coding from last year, that improved model fit was not giving a number to subOccupancies occurring during shutdown periods. The SubOccupancy term is referred to as number of transitions in the report.

Only logical covariate combinations (i.e., those not retained within the other in some way) and with correlation coefficients < 0.4 were retained. This removed combinations of:

- SubOccupancy and Day
- Day and season

Categorical variables diel period and season are ordered sequentially (starting with the period ‘Day’ and season ‘Spring’, respectively) and are included in models as ordered factors. Both terms are ordered continuous factors (i.e., no natural baseline; ‘Day’ always before ’Dusk” but “Day” not necessarily Level 1). Therefore we use sum contrasts (contr.sum()) where each level is compared to the mean of all others.

While MedAWS and MedHVJ are treated as a continuous variable in modelling they are visualized as categorical for easier interpretation whereby:

- ifelse(MedAWS >= 3.75 & MedAWS <= 4.75, “4.25”,
- ifelse(MedAWS >= 8 & MedAWS <= 9, “8.5”

The “Other” category is filtered out and not plotted.

Below are the retained covariates and the resulting number of models in the model set.

```
[1] "SubOccupancy" "Day"          "DielPeriod"   "Season"       "MeanQ10"
[6] "MedAWS"       "MedHVJ"       "AttFlowPer"

[1] 129
```

Approach

It's worth looking at the two top models because we're interested in the subOccupancy variable, but it's clear that environmental parameters have the strongest effect. For now, will just look at the top model.

Covariates	DeltaAIC	AICw	LogLik
DielPeriod+Season+MeanQ10	0.00	0.31	-5067.26
SubOccupancy+DielPeriod+Season+MeanQ10	0.80	0.21	-5066.62
DielPeriod+Season+MeanQ10+MedHVJ	1.90	0.12	-5067.22
DielPeriod+Season+MeanQ10+MedAWS	1.94	0.12	-5067.24

Diel Period, Season, Q

Each diel period and season comparison has significance, meaning all diel periods and seasons differ from each other. Mean Q is also significant, as is the random effect.

The second model was also explored but the SubOccupancy term, the only added term, was far from significant and so the model was not considered further.

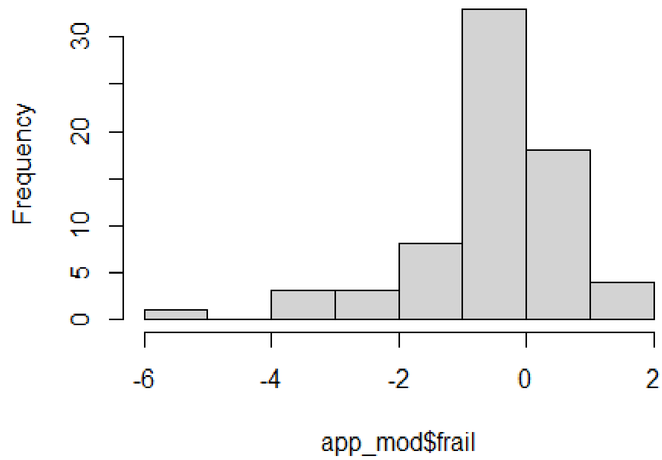
	coef	se(coef)	se2	Chisq	DF	p
DielPeriod1	0.48692	0.05564	0.05563	76.59576	1.00000	0.00000
DielPeriod2	-0.29512	0.12188	0.12187	5.86347	1.00000	0.01546
DielPeriod3	-0.83962	0.07476	0.07475	126.12950	1.00000	0.00000
Season1	-0.41506	0.06988	0.06848	35.27996	1.00000	0.00000
Season2	0.35173	0.05306	0.05208	43.94328	1.00000	0.00000
MeanQ10	-0.01563	0.00108	0.00108	208.30612	1.00000	0.00000
frailty(FreqCode)	NA	NA	NA	1298.07967	47.77607	0.00000

The random effect explains a lot of variance: 1.55

```
[1] "Variance of random effect= 1.54969   I-likelihood = -5156.3"
```

Model Fit

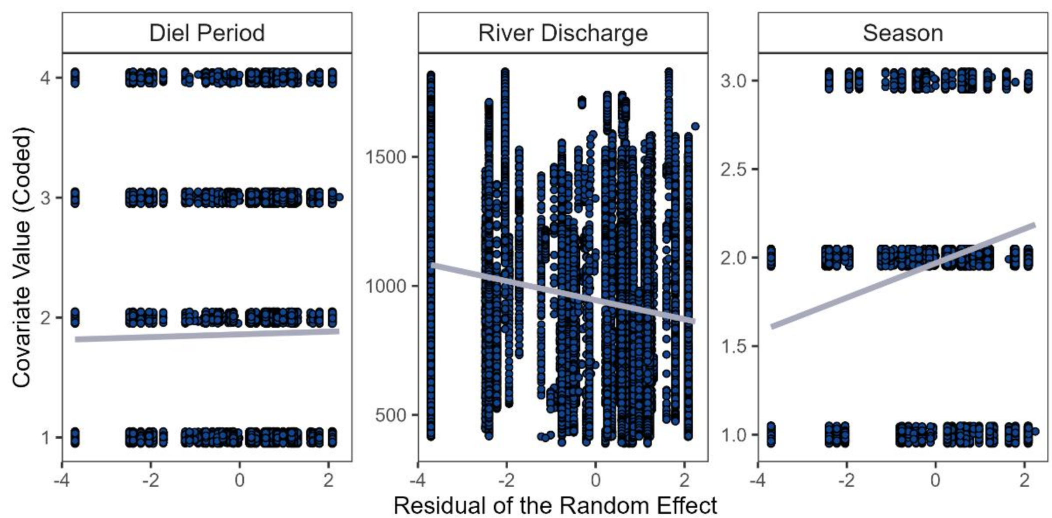
Residuals of the random effect show a slight right skew and one outlier. This is worth noting, but I'm still confident in the results produced. This is to be expected given the nature of the data with few very active individuals. The individual with the large negative residual is 360714 - this BT had nine occupancies and was on the array from March 31 to August 5 but was never detected in the entry zone.



The assumption of proportion hazards fails for Q.

```
             chisq    df      p
DielPeriod   2.317  3.00 0.5091
Season       0.282  1.93 0.8562
MeanQ10      7.997  0.99 0.0046
GLOBAL      11.785 53.69 1.0000
```

Season is correlated with the random effect. There are individual-level differences in behaviour throughout the operational period.



Model Interpretation

Diel period, season and discharge are all highly significant in terms of their effects on approach rate

Season

There was a positive effect of Summer and a negative effect of Spring. The HR of 0.66 for the spring indicates that approach is 34% slower relative to summer and fall. The HR of 1.42 for summer indicates that approach rates are 42% faster in the summer relative to spring and fall. These numbers also tell us the approach rates are even slower in the fall (e.g., fall is more different from summer than spring).

Diel Period

Day has a positive effect meaning approach are the fastest during this time period, 65% faster than other time periods. Dusk and night both have negative effects, with approach rates being 25% and 57% slower than all other time periods, respectively.

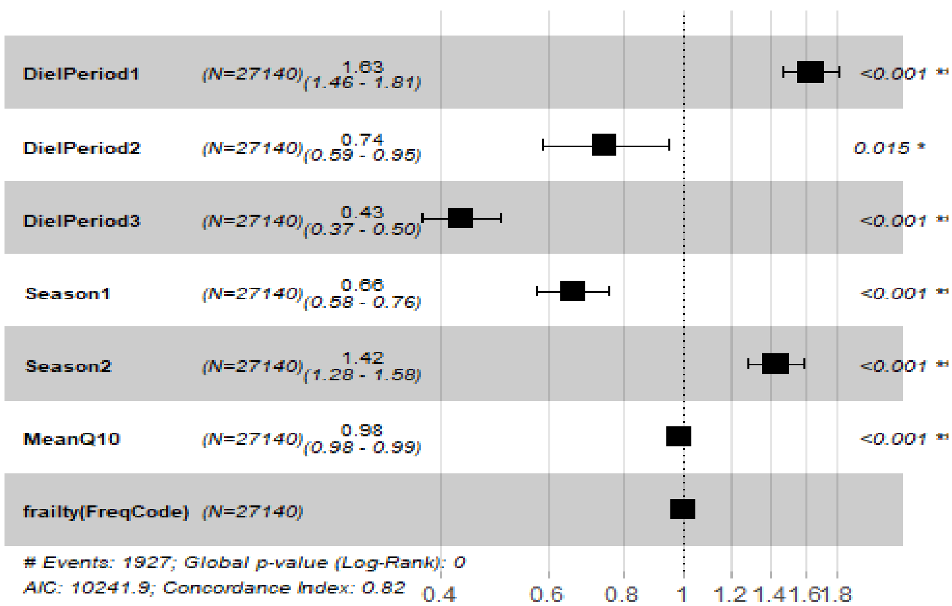
Discharge

The HR for discharge is 0.984 which means for each 10 cms increase in discharge, rates of approach decrease by 1.6%. With average daily change in discharge being 200cms, this could potentially have a large effect.

Summary

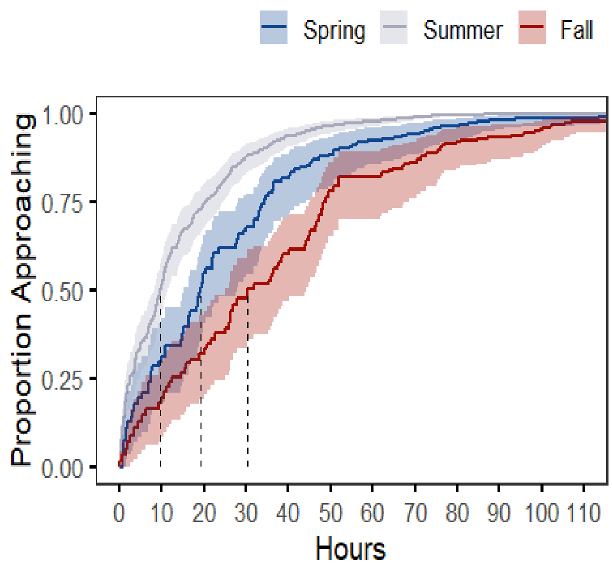
Rates of approach are fastest during the Day and the summer season and are reduced with increasing discharge.

	exp(coef)	exp(-coef)	lower .95	upper .95
DielPeriod1	1.62729	0.61452	1.45918	1.81478
DielPeriod2	0.74444	1.34329	0.58626	0.94531
DielPeriod3	0.43187	2.31549	0.37301	0.50003
Season1	0.66030	1.51446	0.57579	0.75722
Season2	1.42152	0.70347	1.28112	1.57731
MeanQ10	0.98449	1.01575	0.98240	0.98658

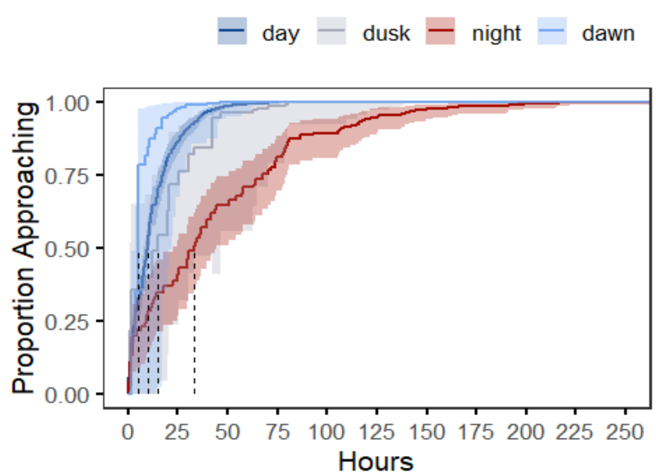


Model Visualization

Visualizing season you can clearly see faster approach rates in the summer followed by spring and fall.

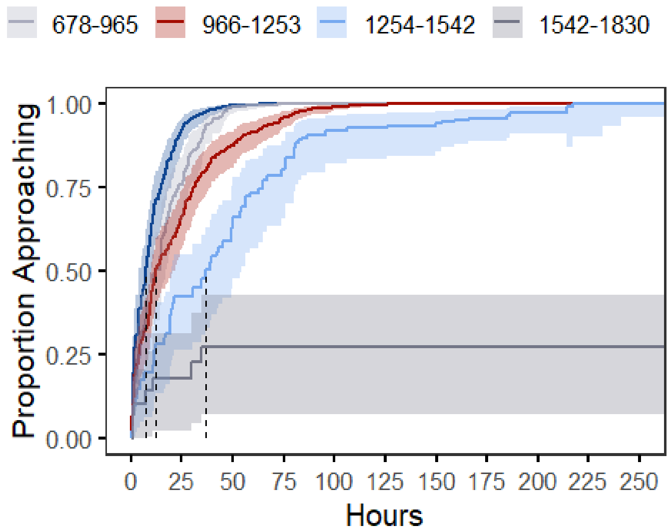


With diel period, you can see slower approach rates at night, with fewer differences between other periods.



I want to observe the effect of discharge to get an idea of linearity, or if potential thresholds might exist. This will inform if maybe we might want to explore spline regressions in the future (e.g., attraction flows are effective at attracting BT to the fishway until X discharge).

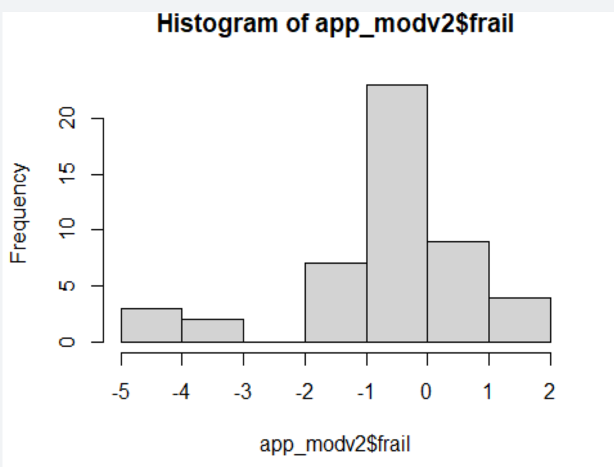
Results very clearly show a linear decrease with Q, and a drop at very high discharges.



Exploring Seasonality

Looking at just summer data, the effect of diel period and Q are consistent. Day is included instead of season. Residual distribution is not improved and shows biomodality. My concern was that this association between season and RE may be masking an effect of attraction flow potentially only present during the spawning migration; this does not appear to be the case.

```
NULL

# A tibble: 6 × 5
  term              estimate std.error statistic   p.value
  <chr>                <dbl>     <dbl>     <dbl>     <dbl>
1 Day                0.00468   0.00177 6.97 8.27e-  3
2 DielPeriod1        0.479     0.0668       51.5   7.21e- 13
3 DielPeriod2       -0.517     0.150        11.8   5.82e-  4
4 DielPeriod3       -0.675     0.0869       60.2   8.43e- 15
5 MeanQ10           -0.0167    0.00153     120.    7.71e- 28
6 frailty(FreqCode) NA         NA         1083.    1.32e-203
```



Withdraw

The withdraw model set included six candidate models (∆AIC < 2). All models included diel period and some combination of attraction flow and river discharge (or in one case, WSE< which is highly correlated with Q). Day and SubOccupancy were each included once, but when these models were explored, these terms were highly non-significant (P > 0.6). We retained the top model as the simplest means to evaluate the effects of diel period, river discharge, and attraction flow.

```
NULL
```

Covariates	DeltaAIC	AICw	LogLik
DielPeriod+AttFlowPer	0.00	0.12	-2166.18
SubOccupancy+DielPeriod+AttFlowPer	0.85	0.08	-2165.63
Day+DielPeriod+AttFlowPer	1.02	0.07	-2166.29
DielPeriod+Season+AttFlowPer	1.28	0.06	-2165.50
DielPeriod+MeanQ10+MedAWS	1.75	0.05	-2166.42
DielPeriod+MeanWSE+MedAWS	1.98	0.05	-2166.44

Model 1: Diel Period, AttFlowPer

The best model included AttFlowPer, the percent of attraction flow to discharge. Because this is essentially an interaction term, I compared AICs of models including AttFlowPer (mod1), MeanQ*MedAWS (mod2) and MeanQ*HVJ (mod3). Model 1, including AttFlowPer is the best fit of the data. Mod4 is the second model resulting from the full model set, which includes suboccupancy. We will be exploring that model as well.

```
                   df      AIC DeltaAIC       AICw
retreat_mod1 44.51380 4421.387 0.000000 0.47829541
retreat_mod4 45.49316 4422.237 0.849974 0.31269914
retreat_mod2 46.15571 4423.238 1.851693 0.18949869
retreat_mod3 46.12222 4427.786 6.398935 0.01950676
```

Diel periods of dusk and night are significant along with AttFlowPer, and the random effect.

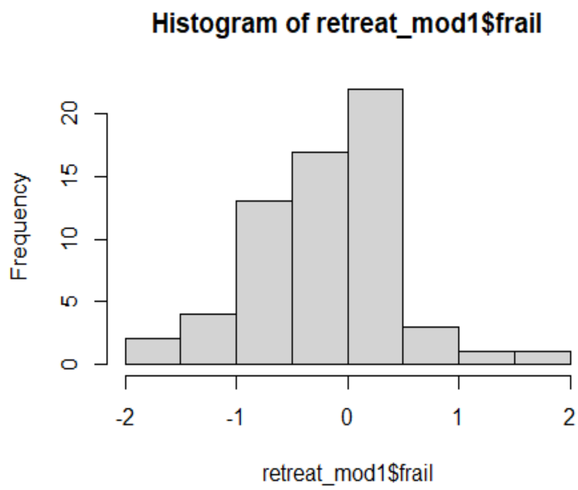
Random effect that holds less variation than the approach model: 0.53

	coef	se(coef)	se2	Chisq	DF	p
DielPeriod1	-0.02587	0.09025	0.09009	0.08217	1.00000	0.77438
DielPeriod2	0.63519	0.14536	0.14513	19.09397	1.00000	0.00001
DielPeriod3	-0.29497	0.10384	0.10370	8.06898	1.00000	0.00450
AttFlowPer	-0.38647	0.10680	0.10518	13.09497	1.00000	0.00030
frailty(FreqCode)	NA	NA	NA	258.57873	40.55381	0.00000

```
[1] "Variance of random effect= 0.5309697   I-likelihood = -2231.8"
```

Model 1 Fit

Residuals look OK.



So does assumption of proportional hazard. See next model for correlations with RE.

```
             chisq    df    p
DielPeriod 4.7961  2.99 0.19
AttFlowPer 0.0449  0.97 0.82
GLOBAL     4.8008 44.51 1.00
```

Model 2: Transitions, Diel Period, AttFlowRat

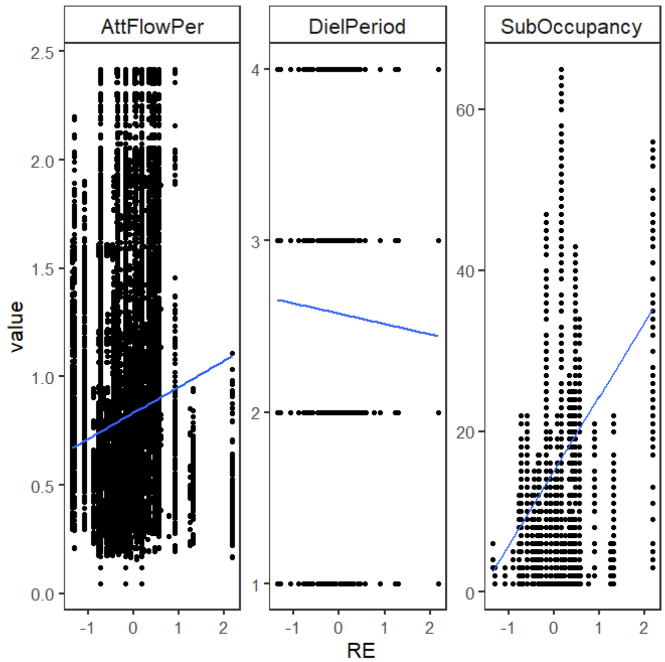
The only difference with this model is the inclusion of SubOccupancy, which is not significant. The variable also does not pass the PH assumption.

	coef	se(coef)	se2	Chisq	DF	p
SubOccupancy	-0.00201	0.00416	0.00400	0.23394	1.00000	0.62862
DielPeriod1	-0.02635	0.09024	0.09009	0.08528	1.00000	0.77027
DielPeriod2	0.63359	0.14537	0.14514	18.99588	1.00000	0.00001
DielPeriod3	-0.29167	0.10404	0.10387	7.85892	1.00000	0.00506
AttFlowPer	-0.39277	0.10773	0.10603	13.29152	1.00000	0.00027
frailty(FreqCode)	NA	NA	NA	257.10370	40.60852	0.00000

```
               chisq    df     p
SubOccupancy  5.4641  0.93 0.017
DielPeriod    4.7823  2.99 0.187
AttFlowPer    0.0495  0.97 0.813
GLOBAL       10.4406 45.49 1.000
```

Strong correlation between SubOccupancy and RE. It is non-significant, fails the PH test and is correlated with the RE. The significant RE suggests between-individual variation contributes to the outcome. Non-significance of SubOccupancy while correlated with the RE may indicate that the random effect is capturing most of the variability associated with that variable; the RE already accounts for the individual-specific effects that the highly correlated variable would capture. We will stick with Model 1.

The other variables (included in mod1) are not correlated with the RE in a concerning way.



Model Interpretation

The dusk and night diel periods and percent attraction flow are all highly significant in terms of their effects on withdraw rate.

Diel Period

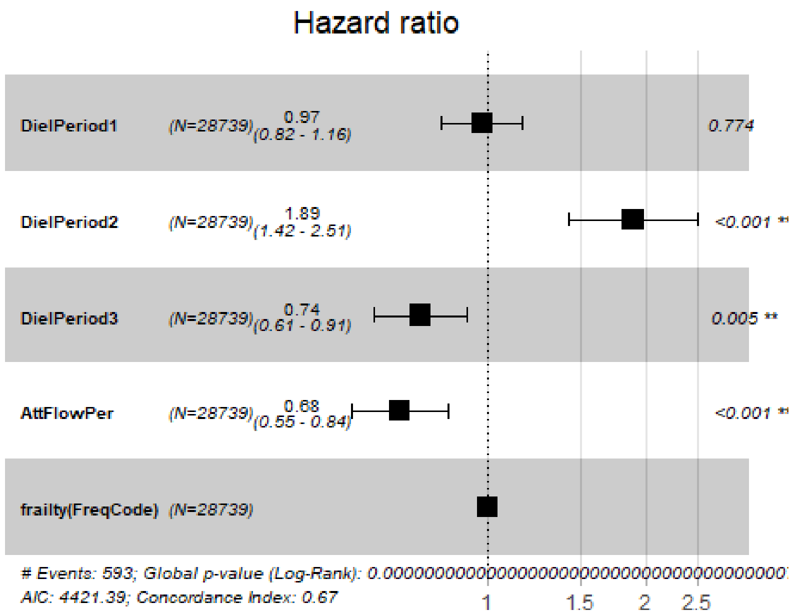
Dusk has a positive effect meaning approach are the fastest during this time period, a very large 89% faster than other time periods. Night has a negative effect, with the withdraw rate being 26% slower than all other time periods.

Attraction Flow Percentage

The HR for AttFlowPer is 0.68 (negative effect); as the proportion of attraction flow relative to total discharge increases, rates of withdraw decrease by 32%. The percentage ranges from near 0 to 2.4, so a 32% decrease is substantial.

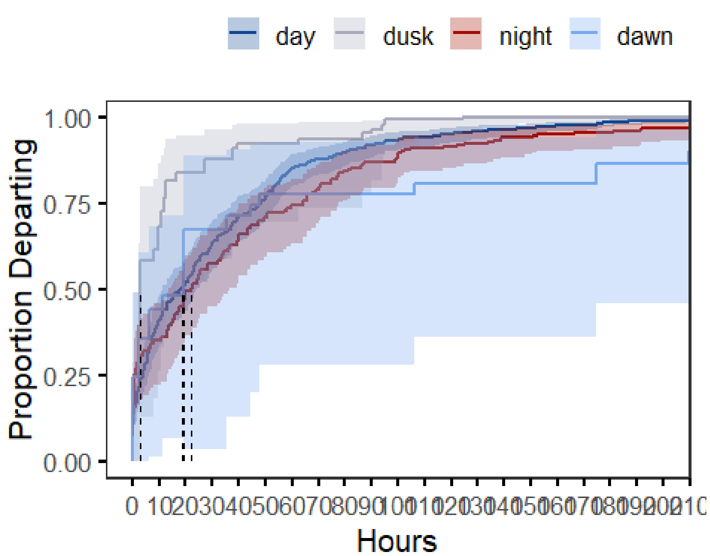
Summary

The diel period effect is confusing. Day isn't significant, withdraw rates are slowest at night and much faster during dusk. I suspect the dusk effect may be due to limited sample size, but it does indicate that this is when BT are leaving the approach zone. The attraction flow percentage result is interesting and suggests if attraction flow isn't strong enough relative to discharge, BT will leave the approach zone.

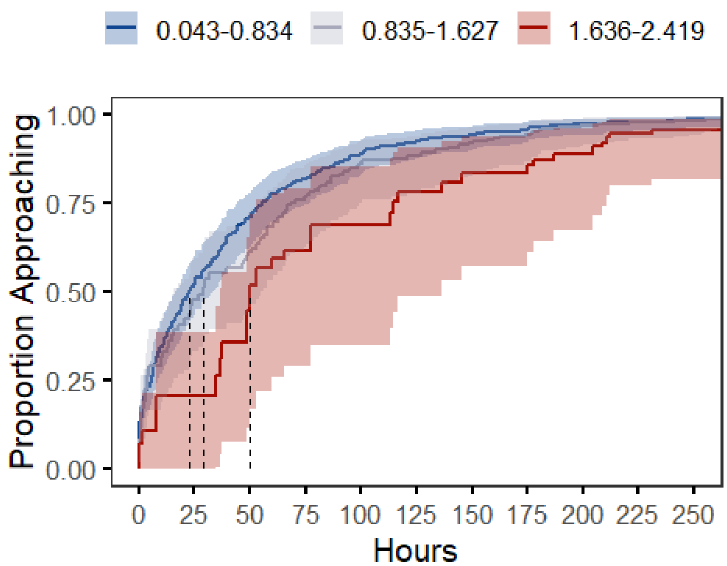


Model Visualization

The diel period results are a little messy and support going to two diel periods (night and day). You do see clear differences between night and day (faster retreat during the day). There also does appear to be rapid retreat during dusk but the dawn period muddles comparisons, likely due to data limitations.



Breaking attraction flow percentage into 3 categories, you can see linearity (faster at higher percentages). There does not seem to be the same 'threshold' effect that we saw with discharge and approach.



Approach/Withdraw Comparison

- Movement into the approach zone is all about the environment and the individual. The random effect holds a lot of variances in the and there are strong effects of season, diel period, and discharge. Bull Trout approach the fishway faster during the day and in the summer and approach rates decrease with increasing discharge.
- Although the random effect is still highly significant in the withdraw model, it holds much less variance. Intra-individual variability is less of a driving factor in movement out of the approach zone.
- The only parameter shared among the models is diel period. Movement into the approach zone is faster as diel periods progress from Dawn to Night (fastest during dawn, slowest at night). For the withdraw model I think the effects of dawn and dusk are clouded by low sample sizes. It's clear when visualizing the data that rates of withdraw are faster during the Day than night, but the day period wasn't actually statistically significant where dawn was (with large confidence intervals). We can conclude though that both movement in and out of the approach zone is faster during dawn and day than at night.
- Discharge played a role in both stat transitions, though in different ways. For approach there was a decrease in approach rates with increases discharge. Visualizing this, you can see approach rates drop dramatically at higher discharges (there are also fewer of these extreme high discharge events). This suggests a threshold effect and may be something we want to explore in the future. In the withdraw model, it's more about the percentage of flow held by attraction flows - as this proportion increases the rate of withdraw decreases. Together these results point to less movement to and more movement out of the approach zone at higher discharges.
- The lack of seasonality in the Retreat model is interesting. It may suggest that many fish approach in the summer and fall, but don't necessarily leave.
- The effect of attraction flows are somewhat convoluted and discharge plays a large role. For example, they do not appear to 'attract' Bull Trout as you would expect attraction flows to do, but under higher attraction flows, relative to Peace River discharge, Bull Trout are less likely to leave the approach zone.

Appendix C: Bull Trout Entry Zone Model Selection

R Markdown Report

Last Produced 2023-08-02

Two model sets are evaluated:

- Entry looks at movement into the fishway from the Entry Zone
- Departure looks at movement out of the Entry zone back into the Approach Zone

Entry

Like with previous models we see an importance of diel period and Q but AWS and HVJ also come up in the top model. Day is also included. The two top models have very similar weights. It is unlikely that HVJ adds much but I'll start with that model.

The Season variable had to be removed due to lack of data. Models would not converge. Instead, the day variable encompasses seasonality.

```
[1] "SubOccupancy" "Day"          "DielPeriod"   "MeanQ10"      "MeanWSE"
[6] "MedAWS"       "MedHVJ"       "AttFlowPer"

[1] 77
```

Covariates	DeltaAIC	AICw	LogLik
Day+DielPeriod+MeanQ10+MedAWS+MedHVJ	0.00	0.48	-1032.96
Day+DielPeriod+MeanQ10+MedAWS	0.08	0.46	-1033.98

Diel Period, Day, Q, AWS, HVJ

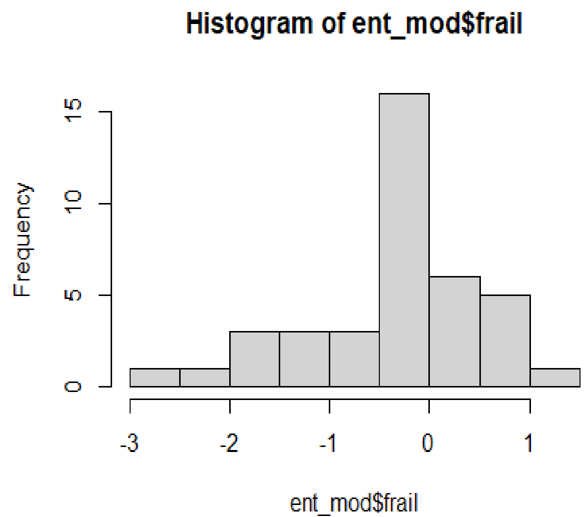
All terms except HVJ are statistically significant including the random effect, which has a variance of 0.98.

	coef	se(coef)	se2	Chisq	DF	p
DielPeriod1	0.76596	0.17824	0.17820	18.46729	1.00000	0.00002
DielPeriod2	-1.00690	0.45949	0.45944	4.80204	1.00000	0.02843
DielPeriod3	-0.67113	0.20796	0.20791	10.41543	1.00000	0.00125
Day	0.02847	0.00282	0.00255	101.81071	1.00000	0.00000
MeanQ10	-0.02790	0.00245	0.00243	129.83960	1.00000	0.00000
MedAWS	0.18935	0.02944	0.02936	41.37108	1.00000	0.00000
MedHVJ	-0.10337	0.07443	0.07438	1.92903	1.00000	0.16486
frailty(FreqCode)	NA	NA	NA	167.54155	25.40167	0.00000

```
[1] "Variance of random effect= 0.9784958   I-likelihood = -1077.1"
```

Model Fit

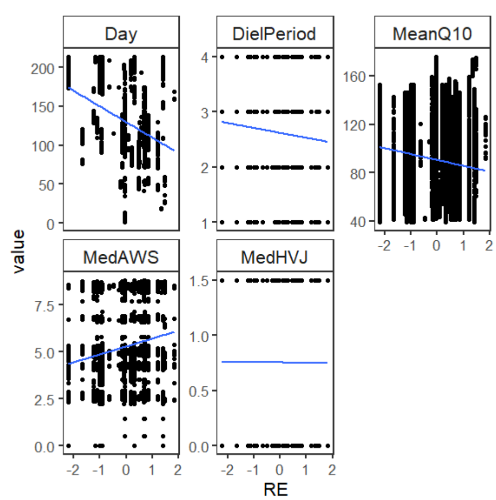
Residuals look pretty good.



No statistically significant variable meets the assumption of proportional hazard; this is a red flag. Their hazard ratios are not constant over time, effects on the outcome change over time, and the random effect does not adequately account for the unobserved heterogeneity in the data.

```
              chisq    df        p
DielPeriod 20.625  3.00  0.00013
Day        12.057  0.82  0.00035
MeanQ10    17.871  0.98 0.000023
MedAWS      4.169  0.99  0.04086
MedHVJ      0.199  1.00  0.65519
GLOBAL     36.782 32.19  0.26462
```

There are correlations with day, but it's not a concern. It isn't that strong and it's to be expected.



Model Interpretation

All terms included in the model have importance, including the HVJ. Even though it's not significant, the negative effect is notable given our interest in attraction flows.

Diel Period

The effects of diel period are dramatic. The HR for the Day period is 2.16, which indicates entry rates are 116% faster during the day (however, consider also the range of 1.52-3.06). Entry rates are 64% slower during the dusk and 50% at night. These numbers indicate faster entry rates during the dawn period, as well.

Day

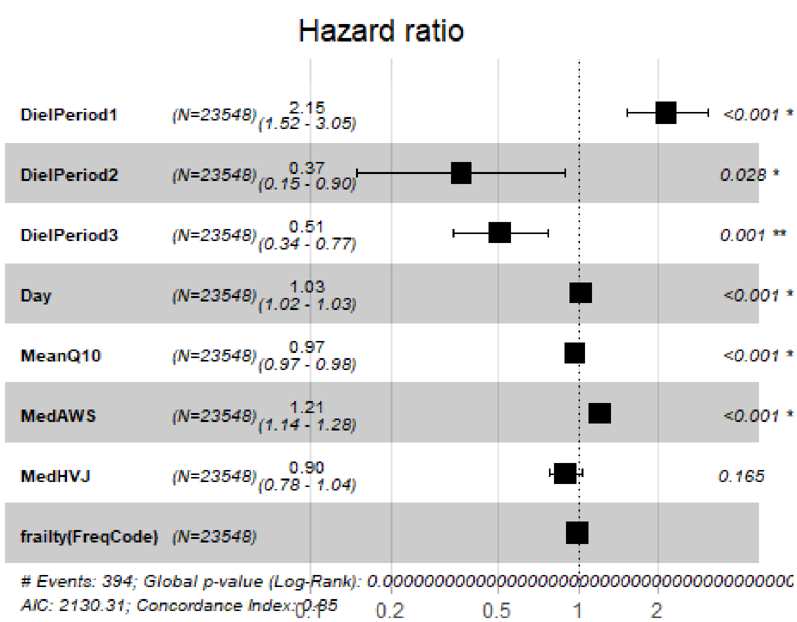
The effect of day is significant and positive. The effect seems small (HR = 1.03) but the error around this is very small and significance high. It indicates a 3% increase in entry rates as the season progresses (summer and fall periods only; so from June 20 onward, ~150 days)

River Discharge

Similar to the day variable, the HR of Q is 0.97 with tight confidence intervals and high significance. The effect is negative, such that every 10 cms decrease in discharge entry rates increase by 3%. Again, this is significant considering the range if discharge values present in this system.

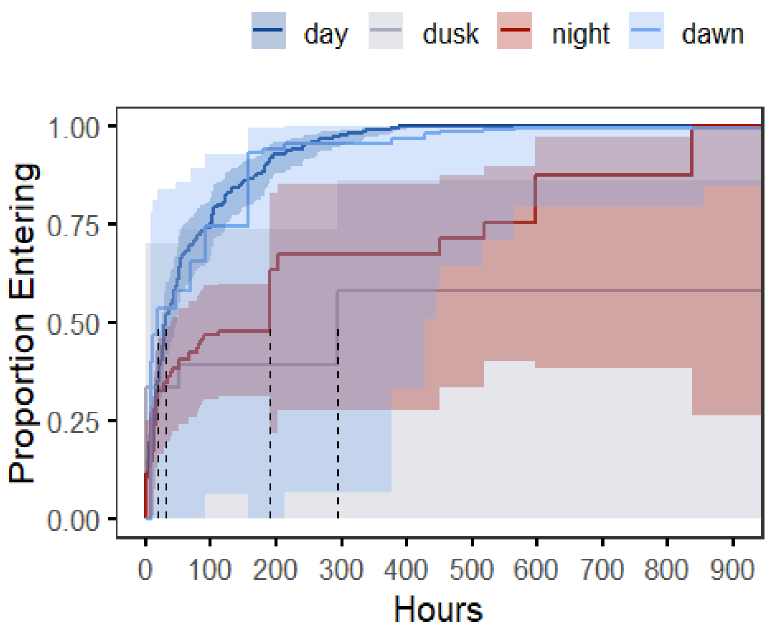
AWS / HVJ

The HR for AWS is 1.2 with confidence intervals of 1.14-1.28; for every unit increase in AWS, entry rates increase by 14-28%. Although not significant, the negative effect of HVJ is noteworthy. A HR of 0.9 suggests a 10% decrease in entry rates for each unit increase. HVJ is either on (0) or off (1.5) so the unit increase is just from 0 to 1.5. These results suggest less entry when the HVJ is on.

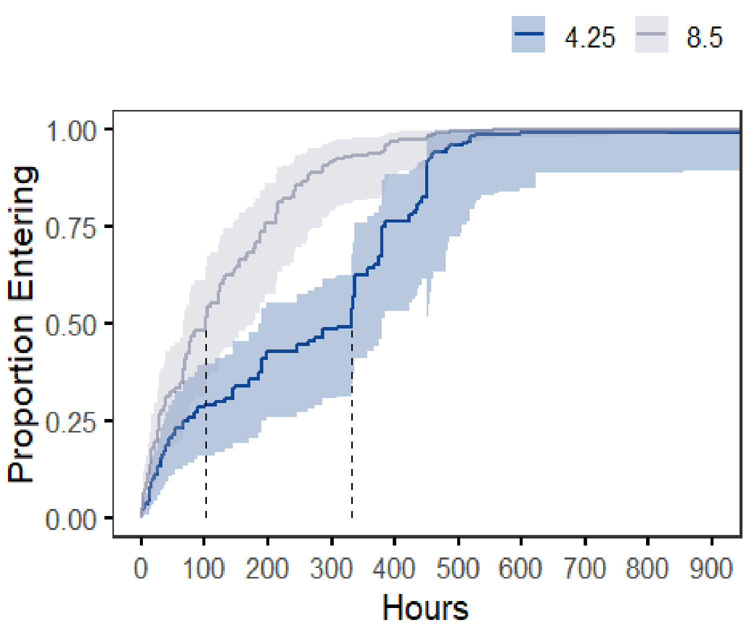


Model Visualization

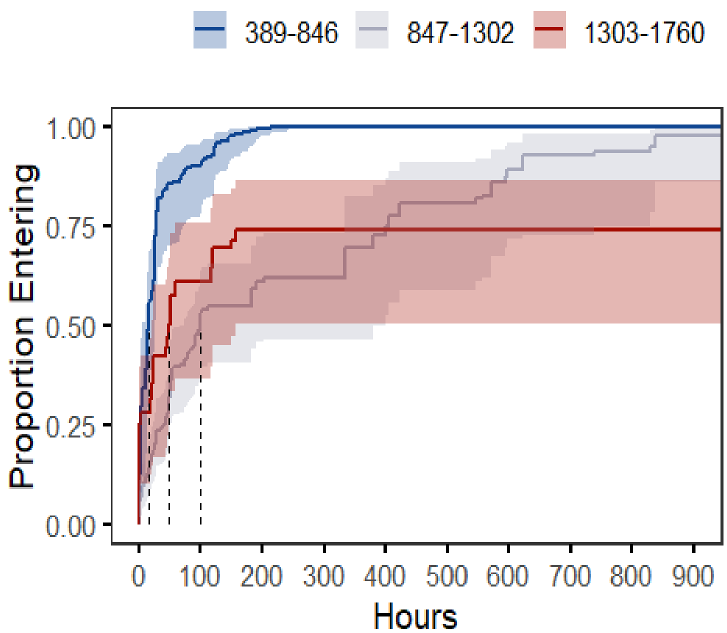
Here we really see the limitations of the dusk and dawn period, and even a natural grouping of dawn and day and dusk and night. Additionally, nearly all of our data is from the daytime period.



Entry rates at the lower AWS attraction flows really lag behind those seen at higher attraction flows.



The effect of discharge is linear. Entry rates are clearly fastest at lower discharges (< 800 cms).



Departure

The top model includes day, diel period and percent attraction flow. However, the model including discharge, AWS and HVJ is also a candidate (Delta AIC <2) and is consistent with the top entry model. I feel comfortable selecting the second model rather than the first because percent attraction flow really just combines the three terms.

Covariates	DeltaAIC	AICw	LogLik
Day+DielPeriod+AttFlowPer	0.00	0.53	-2000.73
Day+DielPeriod+MeanQ10+MedAWS+MedHVJ	1.25	0.28	-1999.75
Day+DielPeriod+MedAWS+MedHVJ	3.71	0.08	-2001.71
Day+DielPeriod+MeanQ10+MedAWS	4.76	0.05	-2002.49
Day+DielPeriod+MeanWSE+MedAWS+MedHVJ	5.84	0.03	-2001.97
Day+DielPeriod+MedAWS	7.05	0.02	-2004.37
Day+DielPeriod+MeanWSE+MedAWS	9.27	0.01	-2004.66

Day+DielPeriod+MeanQ10+MedAWS+MedHVJ

All terms are significant except for discharge. The random effect is also significant with a variance of 0.69.

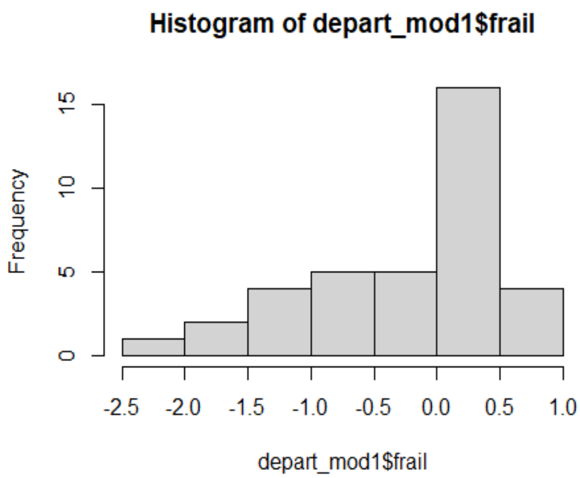
	coef	se(coef)	se2	Chisq	DF	p
Day	-0.00914	0.00162	0.00150	31.77686	1.00000	0.00000
DielPeriod1	-0.16941	0.08069	0.08052	4.40807	1.00000	0.03577
DielPeriod2	0.66959	0.15086	0.15057	19.69909	1.00000	0.00001
DielPeriod3	-0.44417	0.10509	0.10494	17.86341	1.00000	0.00002

	coef	se(coef)	se2	Chisq	DF	p
MeanQ10	-0.00192	0.00156	0.00153	1.51309	1.00000	0.21867
MedAWS	-0.05607	0.01697	0.01695	10.90950	1.00000	0.00096
MedHVJ	-0.10930	0.04638	0.04631	5.55432	1.00000	0.01844
frailty(FreqCode)	NA	NA	NA	429.09207	28.68813	0.00000

```
[1] "Variance of random effect= 0.6925452   I-likelihood = -2058.7"
```

Model Fit

Residuals have a right skew but it's not terrible.

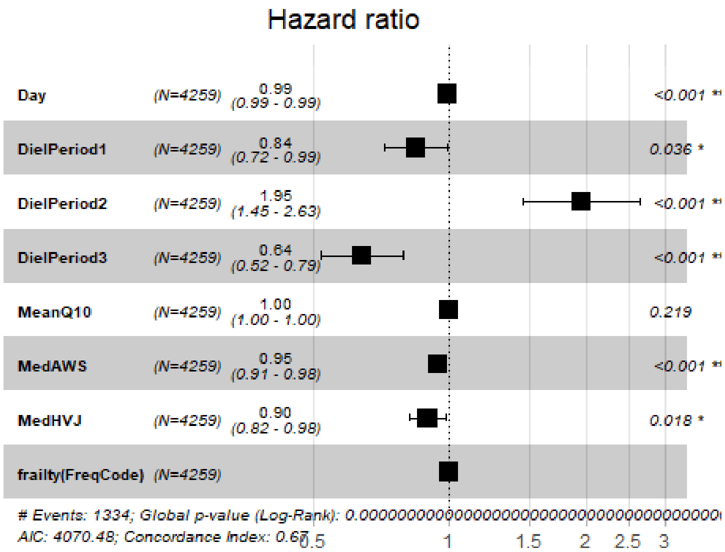


All variables pass the assumption of proportional hazards.

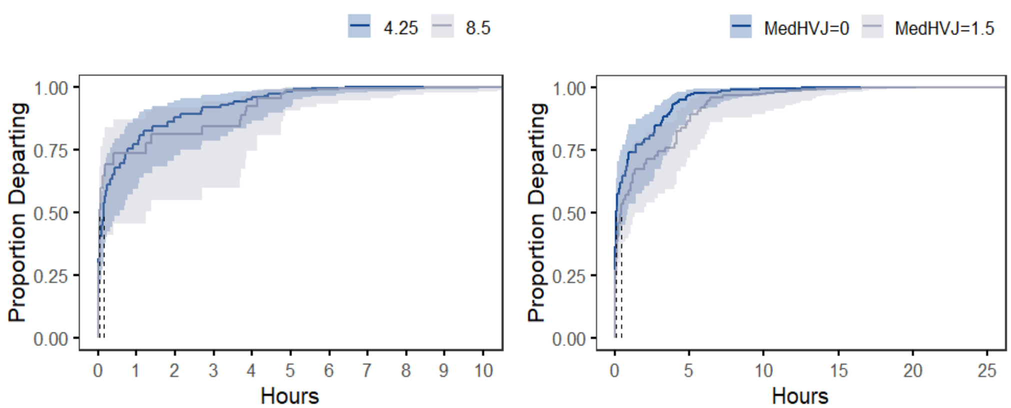
```
             chisq    df     p
Day         0.0727  0.86 0.73
DielPeriod 4.3920  2.99 0.22
MeanQ10     0.1439  0.96 0.69
MedAWS      1.2668  1.00 0.26
MedHVJ      1.5778  1.00 0.21
GLOBAL      6.7122 35.49 1.00
```

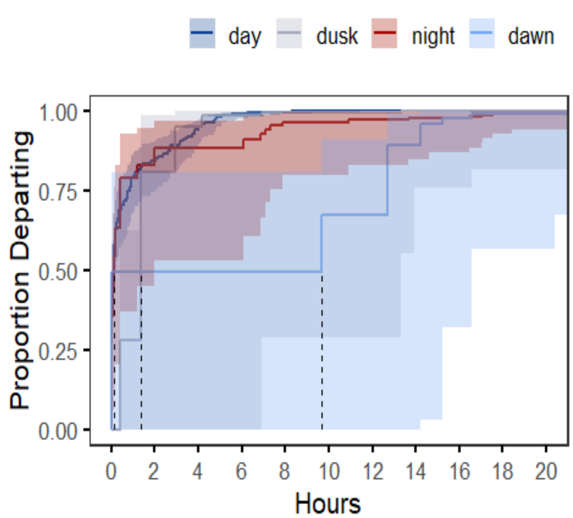
The random effect is correlated with Day. This isn't a concern.

Model Interpretation



Model Visualization





Appendix D: Bull Trout Fishway Rejection Model Selection

R Markdown Report

Last Produced 2023-08-02

Rejection models can't be run with the season variable. Like with the entry model, the Day variable instead encompasses seasonal variability.

The top model will be retained as the best. The weight of the next model (with addition of HVJ) is nearly 2, and we've seen in previous models that when included the HVJ isn't significant, does not improve model fit, and has little effect.

Covariates	DeltaAIC	AICw	LogLik
SubOccupancy+DielPeriod+MeanQ10+MedAWS	0.00	0.65	-778.75
SubOccupancy+DielPeriod+MeanQ10+MedAWS+MedHVJ	1.82	0.26	-778.66

SubOccupancy, Diel Period, Q and AWS

All variables are significant except diel periods of day and dusk. I suspect that we will have very little power to make diel period comparisons. I think the focus on this model should be on the nature of the AWS effect.

The random effect holds a substantial variance: 1.3

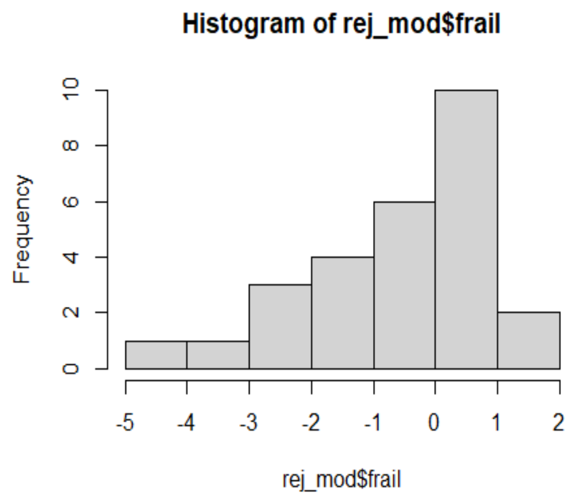
	coef	se(coef)	se2	Chisq	DF	p
SubOccupancy	-0.02029	0.00445	0.00438	20.75306	1.00000	0.00001
DielPeriod1	0.12559	0.14945	0.14935	0.70613	1.00000	0.40073
DielPeriod2	-0.29215	0.33257	0.33242	0.77166	1.00000	0.37970
DielPeriod3	-0.49041	0.18050	0.18038	7.38220	1.00000	0.00659
MeanQ10	-0.02990	0.00259	0.00252	133.37981	1.00000	0.00000
MedAWS	0.15047	0.03265	0.03211	21.23994	1.00000	0.00000
frailty(FreqCode)	NA	NA	NA	322.45855	23.21315	0.00000

```
[1] "Variance of random effect= 1.304316   I-likelihood = -828.9"
```

The second model included HVJ but given the very high p-value of HVJ, this model will not be pursued.

Model Fit

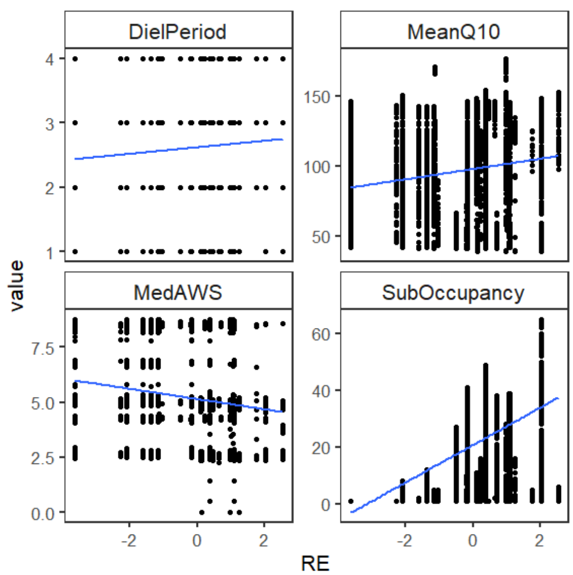
Residuals of the model look pretty good. There is a right skew but no outliers.



Only AWS meets the PH assumption. Not a good sign.

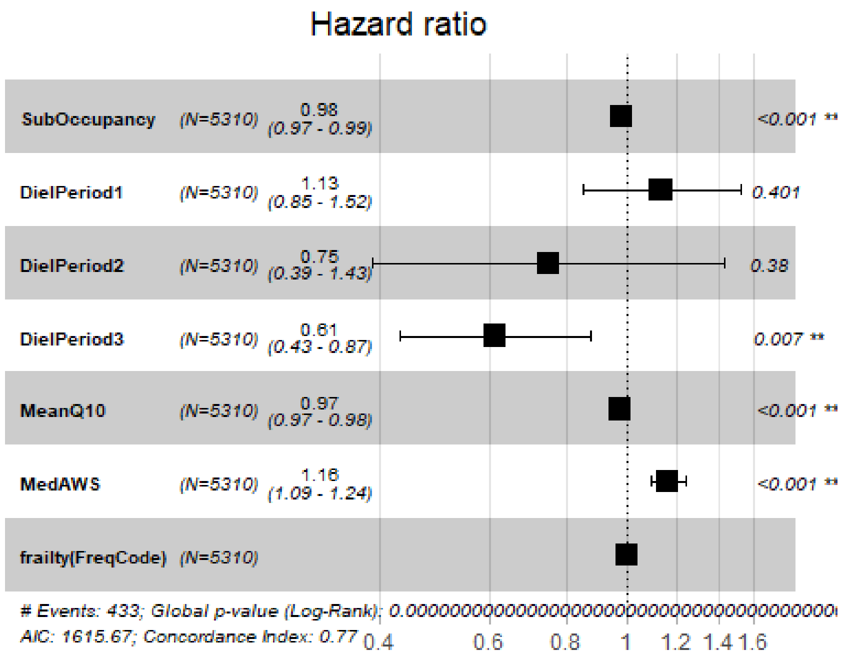
```
               chisq    df        p
SubOccupancy  5.415  0.97   0.0189
DielPeriod   16.084  2.99   0.0011
MeanQ10      18.298  0.95 0.000017
MedAWS        0.728  0.97   0.3816
GLOBAL       27.258 29.09   0.5626
```

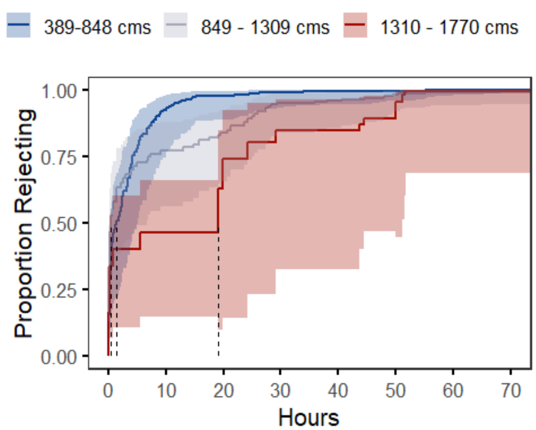
The SubOccupancy variable is really correlated with the random effect, as is AWS and Q.

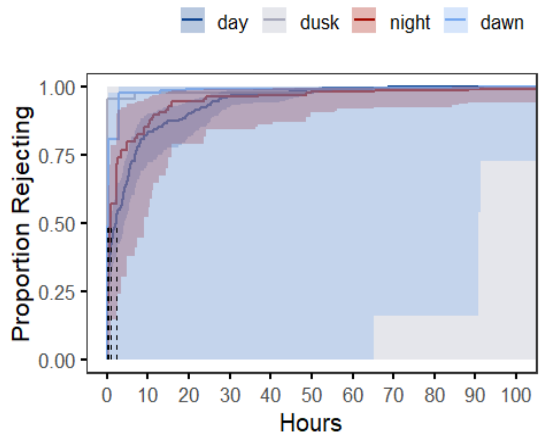


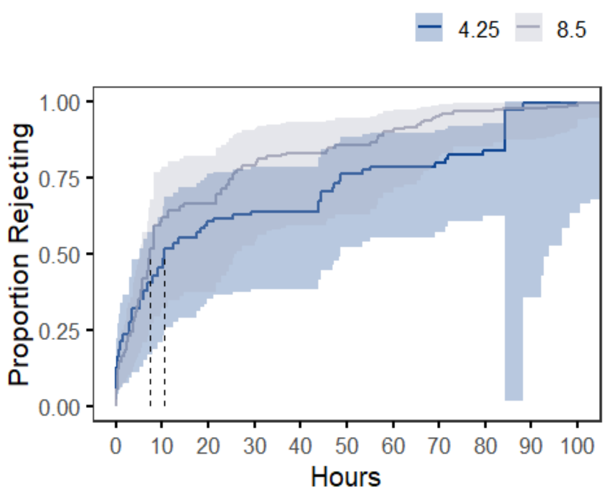
Model Interpretation

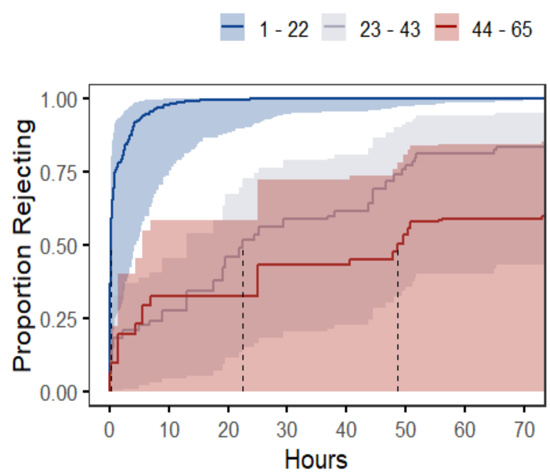
Despite the poor model fit, I'm still interested in the effect of AWS to see if it aligns with what we've seen in all the other models. AWS has a positive effect, which is not what we would expect. Bull Trout reject the fishway faster with higher attraction flows. There is a lot of overlap when just categories of high and low AWS are plotted.The diel period effect is consistent; slow rates of rejection at night.


Hazard ratio
SubOccupancy (N=5310) 0.98 (0.97 - 0.99) <0.001 **
DielPeriod1 (N=5310) 1.13 (0.85 - 1.52) 0.401
DielPeriod2 (N=5310) 0.75 (0.39 - 1.43) 0.38
DielPeriod3 (N=5310) 0.61 (0.43 - 0.87) 0.007 **
MeanQ10 (N=5310) 0.97 (0.97 - 0.98) <0.001 **
MedAWS (N=5310) 1.16 (1.09 - 1.24) <0.001 **
frailty(FreqCode) (N=5310)
# Events: 433; Global p-value (Log-Rank): 0.000000000000000000000000000000000000000
AIC: 1615.67; Concordance Index: 0.77
0.4 0.6 0.8 1 1.2 1.4 1.6


389-848 cms
849 - 1309 cms
1310 - 1770 cms
Proportion Rejecting
Hours


day
dusk
night
dawn
Proportion Rejecting
Hours


4.25
8.5
Proportion Rejecting
Hours


1 - 22
23 - 43
44 - 65
Proportion Rejecting
Hours

Appendix E: Mountain Whitefish Approach Zone Model Selection

R Markdown Report

Last Produced 2023-07-11

Full Model Set

A first attempt at modeling will include all covariates used in the Bull Trout approach models.

```
[1] "SubOccupancy" "Day"          "DayPeriod"    "Season"       "MeanQ10"
[6] "MeanWSE"      "MedAWS"       "MedHVJ"       "AttFlowPer"

[1] 90
```

Movement in and out of Approach Zone

Approach

Model Selection

Models 1, 3, and 5 of our interest, with models 2 and 4 just being simplified versions.

```
NULL
```

Covariates	DeltaAIC	AICw	LogLik
Day+DayPeriod+MeanQ10	0.00	0.21	-153.03
DayPeriod+MeanQ10	0.59	0.16	-153.33
Day+DayPeriod+MeanQ10+MedHVJ	1.12	0.12	-152.61
DayPeriod+MeanQ10+MedAWS	1.21	0.12	-152.80
Day+DayPeriod+MeanQ10+MedAWS	1.29	0.11	-152.76

I ran the models with attraction flow terms, but the additional terms were not significant (far from, with p-values > 0.3). I won't bother looking into them further. We will stick with the top model.

	coef	se(coef)	se2	Chisq	DF	p
Day	0.01027	0.00351	0.00295	8.55595	1.0000	0.00344
DayPeriod1	1.22853	0.30846	0.30822	15.86282	1.0000	0.00007
MeanQ10	-0.01720	0.00449	0.00440	14.67425	1.0000	0.00013
MedHVJ	-0.16622	0.17610	0.17578	0.89093	1.0000	0.34522
frailty(FreqCode)	NA	NA	NA	43.86529	9.0147	0.00000

Day+DayPeriod+MeanQ10

All terms are significant, including the random effect, except some seasons (summer) and diel periods (dusk).

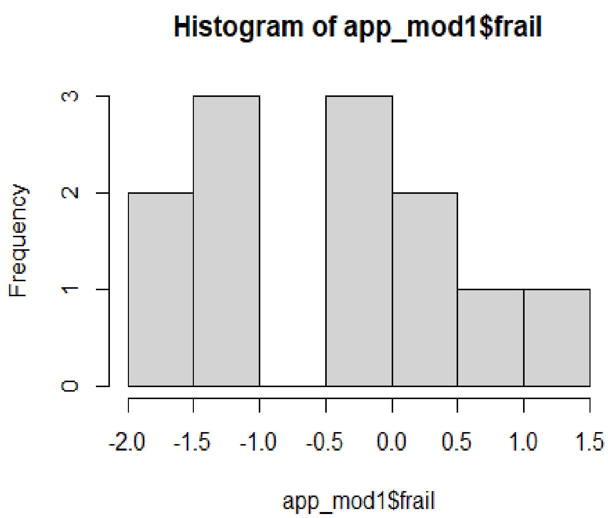
	coef	se(coef)	se2	Chisq	DF	p
Day	0.01013	0.00354	0.00295	8.17399	1.00000	0.00425
DayPeriod1	1.22699	0.30744	0.30721	15.92764	1.00000	0.00007
MeanQ10	-0.01735	0.00449	0.00440	14.96135	1.00000	0.00011
frailty(FreqCode)	NA	NA	NA	43.72322	9.02148	0.00000

Variance of the random effect is high like in BT models: 1.18

```
[1] "Variance of random effect= 1.179799   I-likelihood = -168.4"
```

Model Fit

Distribution of the residuals of the random effect aren't amazing but there is no dramatic skew. Strange to have no peak; I have never seen this.



Day fails the PH assumption, but others are fine.

```
              chisq    df       p
Day        13.22538  0.69 0.00014
DayPeriod   0.00137  1.00 0.97028
MeanQ10     1.08176  0.96 0.28634
GLOBAL     15.82329 11.67 0.18172
```

There is a strong correlation between the RE and Day for successful attempts and correlations with river discharge. Taking all this together, I would classify model fit as poor.

Model Interpretation

There is a lot of significance in this model, but the forest plot shows how much variability and uncertainty there is in the data, particularly within the diel period effects.

Day

The HR for SO is 1.01 indicating that for each subsequent day, approach rates increase by 1%. This linearity is expected for a fall-migrating species that is present within the study area year-round.

Day Period

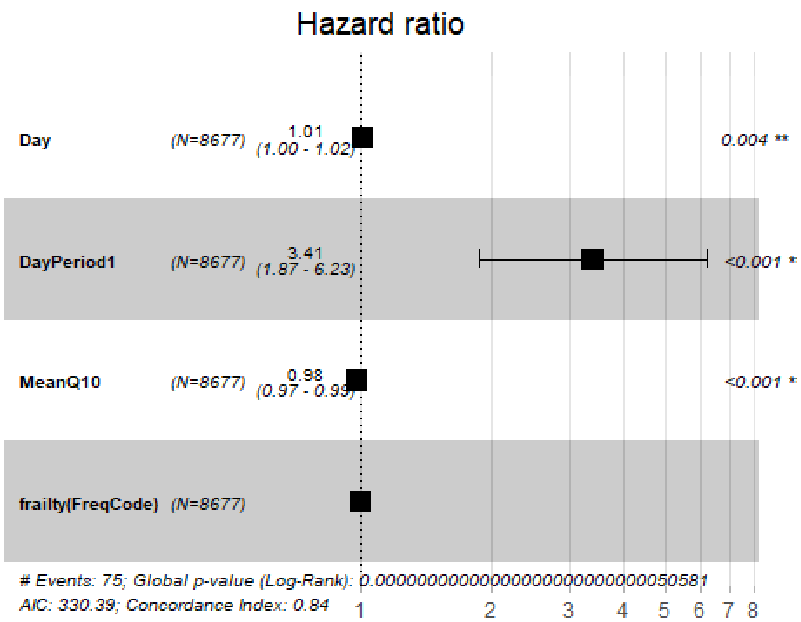
The HR for day vs night is very large, as are their confidence intervals (HR = 3.42; LCI = 1.87; UCI = 6.24). This means that approach rates are 87 - 524% faster during the day!

Discharge

The HR for discharge is 0.981 which means for each 10 cms increase in discharge, rates of approach decrease by 1.9%. With average daily change in discharge being 200cms, this could potentially have a large effect.

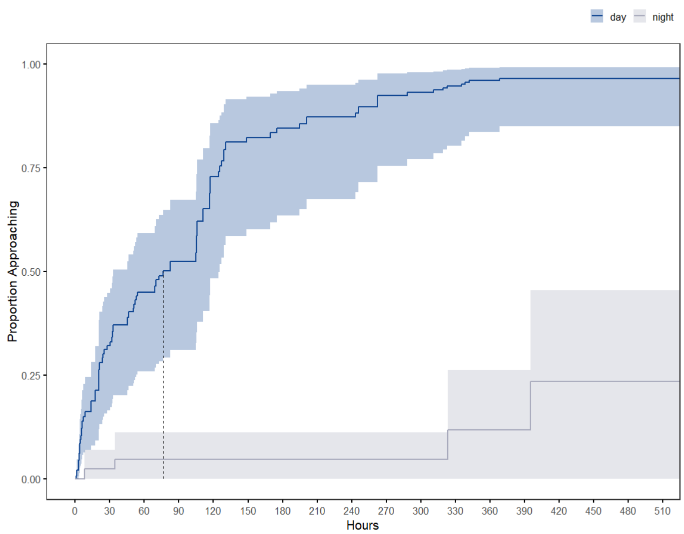
Summary

Rates of approach are dramatically faster during the Day, increase through the operational period, and decrease with increasing discharge.

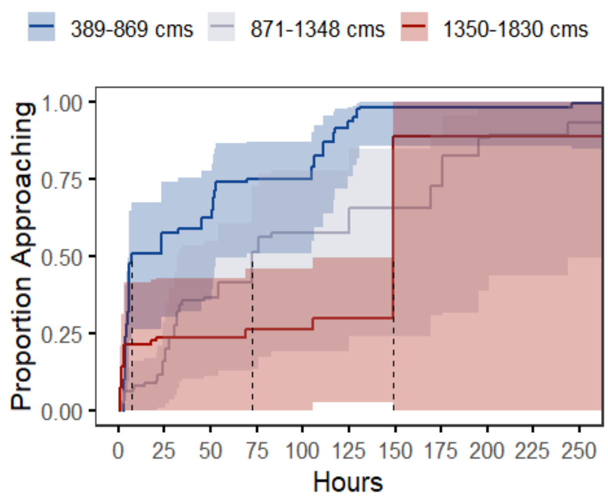


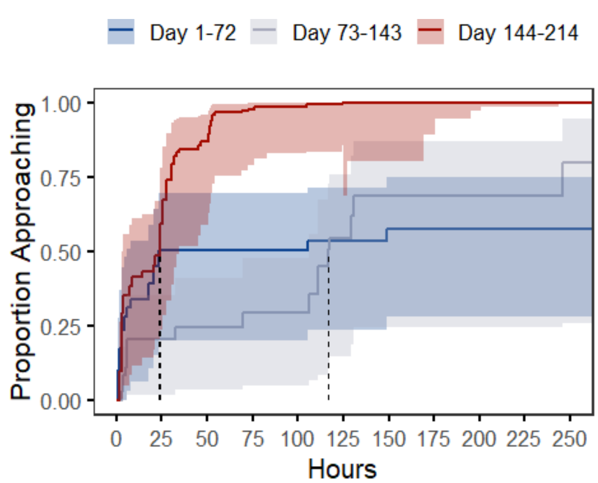
Model Visualization

Not only are approach rates clearly faster during the day, but there is a lack of data from the night period. As is expected with a strong preference for movement during the day.



Looking at discharge we see a similar pattern to the BT data: a drop in approach rates at high discharges (here we're looking at a range of 1350-1830 cms). Splitting up day by category you see a rapid increase in approach rates in the later portion of the operational period.

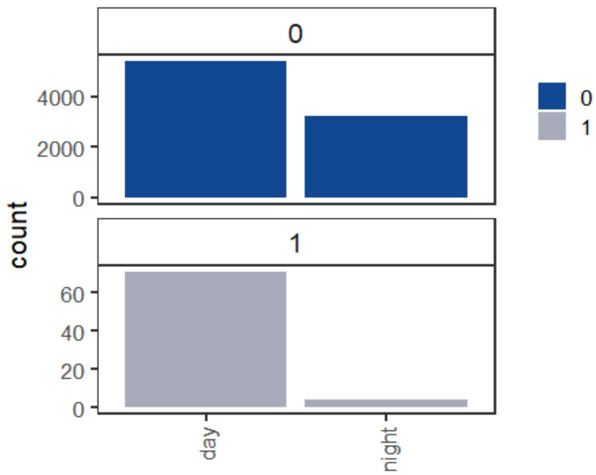




Diel Movements

Not only do MW approach the fishway more slowly at night, almost all movements occur during the day. There were ~100x more unsuccessful events (did not make it to entry zone), but nearly all successful events happened during the day. The next figure shows how MW are also moving during the night (though less so), but that the proportion of successful events is greater during the day.

Interpreting the effect of diel period in the TTE model is tricky because of such lower sample sizes during dawn and dusk periods - either due to lack of movement or because these periods are of a much shorter duration. Observing the raw data it is apparent that MW movement towards the fishway overwhelming occurs during the day.



Withdraw

Model Selection

Even though there are many models with delta AIC < 2, I'm going with the top one. All others are just variations of it (WSE and Q very correlated). The large candidate model set is indicative that the data does not fit our model structures well.

Covariates	DeltaAIC	AICw	LogLik
DayPeriod+MeanQ10+MedAWS	0.00	0.07	-328.60
DayPeriod+MeanWSE+MedAWS	0.63	0.05	-329.43
DayPeriod+MeanQ10	0.83	0.05	-328.58
Day+DayPeriod+MeanQ10	0.98	0.04	-329.63
DayPeriod+MeanWSE	1.26	0.04	-329.01
Day+DayPeriod+MeanQ10+MedAWS	1.34	0.04	-328.79
Day+DayPeriod+MeanWSE	1.44	0.03	-329.87
DayPeriod+MedAWS	1.53	0.03	-328.96
DayPeriod	1.66	0.03	-329.22
DayPeriod+MeanQ10+MedAWS+MedHVJ	1.72	0.03	-328.41
Day+DayPeriod+AttFlowPer	1.89	0.03	-330.07
Day+DayPeriod+MeanWSE+MedAWS	1.97	0.03	-329.11

DayPeriod+MeanQ10+MedAWS

As expected with the model set with no one clear best model, few parameters are significant. The only significance is DayPeriod, but discharge is just barely non-significant.

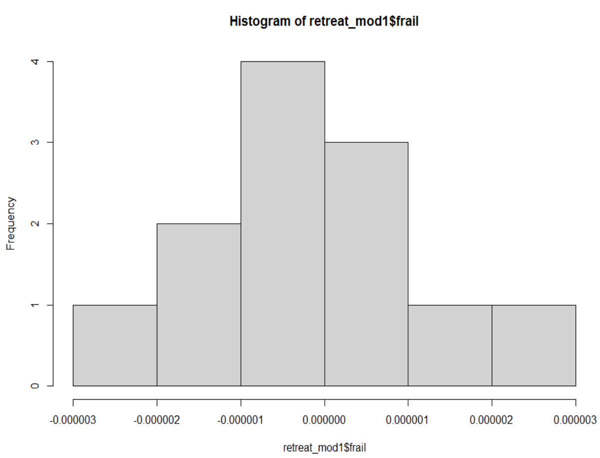
	coef	se(coef)	se2	Chisq	DF	p
DayPeriod1	0.28888	0.14213	0.14213	4.13090	1.00000	0.04211
MeanQ10	-0.00572	0.00296	0.00296	3.72805	1.00000	0.05351
MedAWS	-0.09194	0.05034	0.05034	3.33658	1.00000	0.06776
frailty(FreqCode)	NA	NA	NA	0.00004	0.00004	0.92434

Variance of the random effect is negligible.

```
[1] "Variance of random effect= 0.0000005   I-likelihood = -329.2"
```

Model Fit

Residuals are great and all variables pass the PH assumption. With the RE holding so little variation and the PH not violated I'm not worried about correlations with the RE.




```
          chisq df    p
DayPeriod 0.669  1 0.41
MeanQ10   1.146  1 0.28
MedAWS    0.673  1 0.41
GLOBAL    2.149  3 0.54
```

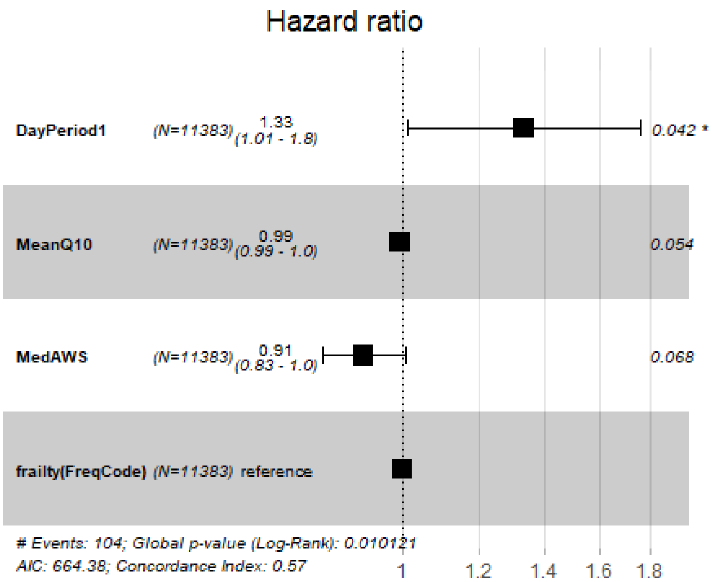
Model Interpretation

Diel Period

We see rates of withdraw are 33% faster during the day (HR = 1.33), but there are large confidence intervals around this. This is the only term of statistical significance.

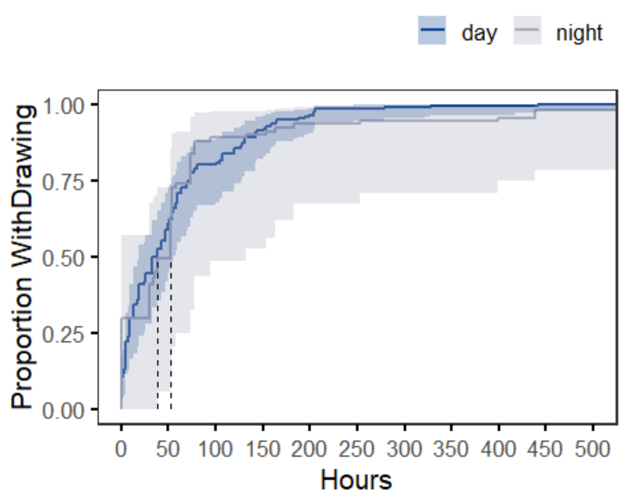
Discharge and Attraction Flow

Even though these terms are non-significant, I want to look in to the magnitude and direction of the effect. They both have a negative effect, so MW have decreased withdraw rates at higher flows. Specifically, with each 10 cms increase in discharge, withdraw rates decrease by 1%. With every unit increase in HVJ, withdraw rates decrease by 9%. Therefore, MW are less likely to withdraw from the approach zone at higher flows.



Model Visualization

The difference between day and night in this dataset could simply be attributed to more data during the day period and tighter confidence intervals, rather than faster rates of withdraw.



Conclusions

The primary take home from the diel effect is that almost all data is from the day period. In terms of flow, MW stay in the approach zone longer (decreased withdraw rates) at higher flows from both river discharge and AWS attraction from the fishway, but this isn't statistically significant.

Appendix F: Mountain Whitefish Entry Zone Model Selection

R Markdown Report

Last Produced 2023-07-11

Movement In and Out of Entry Zone

Have to remove categorical variables because there just were not enough in each category. The entry zone models only include data from day diel period, where we know most data is from. Season was removed. Seasonal variability is encompassed by day.

Entry

DayPeriod	n_success	n_total
day	18	2730
night	1	1605

```
[1] 38
```

Model Selection

All models came up with an equal weight. None of them fit the data. Models were not pursued further.

Departure

Model Selection

I selected the second model given our interest in attraction flow.

```
NULL
```

Covariates	DeltaAIC	AICw	LogLik
SubOccupancy	0.00	0.18	-50.15
SubOccupancy+AttFlowPer	0.97	0.11	-49.71
SubOccupancy+MeanQ10	1.32	0.09	-50.02
SubOccupancy+MeanWSE	1.36	0.09	-50.04
SubOccupancy+MedAWS	1.58	0.08	-49.99

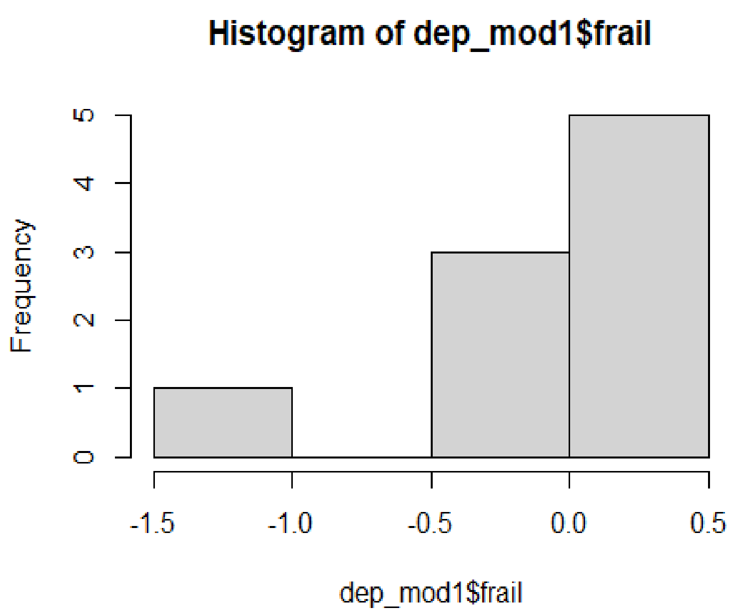
SubOccupancy+AttFlowPer,

Only SubOccupancy term is significant, and the variance of the random effect is 0.33. This is not a very informative model.

```
Call:
coxph(formula = (Surv(Time1_s, Time2_s, Status)) ~ SubOccupancy +
    AttFlowPer + frailty(FreqCode), data = dep_dat)

  n= 168, number of events= 59

                  coef    se(coef) se2     Chisq DF   p
SubOccupancy       0.1854 0.05016  0.04816 13.66 1.00 0.00022
AttFlowPer        -0.1468 0.36592  0.32811  0.16 1.00 0.69000
frailty(FreqCode)                          12.16 3.61 0.01200

             exp(coef) exp(-coef) lower .95 upper .95
SubOccupancy    1.2037     0.8308    1.0910     1.328
AttFlowPer      0.8635     1.1581    0.4215     1.769

Iterations: 7 outer, 49 Newton-Raphson
     Variance of random effect= 0.3331984   I-likelihood = -62.2
Degrees of freedom for terms= 0.9 0.8 3.6
Concordance= 0.713  (se = 0.075 )
Likelihood ratio test= 28.69  on 5.33 df,   p=0.00004
```

Model Fit

Residuals look bad and show the limitations to the data (low sample size). The assumption of PH fails for percent attraction flow.




```
              chisq   df    p
SubOccupancy 0.0247 0.92 0.85
AttFlowPer   3.0529 0.80 0.06
GLOBAL       3.0609 5.33 0.73
```

Appendix G: Mountain Whitefish Fishway Rejection Model Selection

R Markdown Report

Last Produced 2023-07-11

With even less data than the entry model, model fit will be poor.

DielPeriod	n_success	n_total
day	14	716
dusk	0	88
night	1	351
dawn	3	73

Season	n_success	n_total
Spring	2	114
Summer	3	802
Fall	13	312

Covariates	DeltaAIC	AICw	LogLik
MedHVJ	0.00	0.22	-33.91
SubOccupancy+MedHVJ	0.88	0.14	-33.92
MeanWSE+MedHVJ	1.79	0.09	-34.42
MeanQ+MedHVJ	1.81	0.09	-34.52
MedAWS+MedHVJ	1.83	0.09	-35.12

Best Model: HVJ

HVJ is significant and the random effect just barely not significant. Random effect accounts of a variance of 0.47, pretty low compared to other models. Positive effects means MW reject faster when HVJ on.

	coef	se(coef)	se2	Chisq	DF	p
MedHVJ	0.96229	0.45788	0.45342	4.41679	1.00000	0.03559
frailty(FreqCode)	NA	NA	NA	6.58698	2.22841	0.04625

```
[1] "Variance of random effect= 0.4703096   I-likelihood = -37.8"
```

Appendix H: Rainbow Trout Approach Zone Model Selection

R Markdown Report

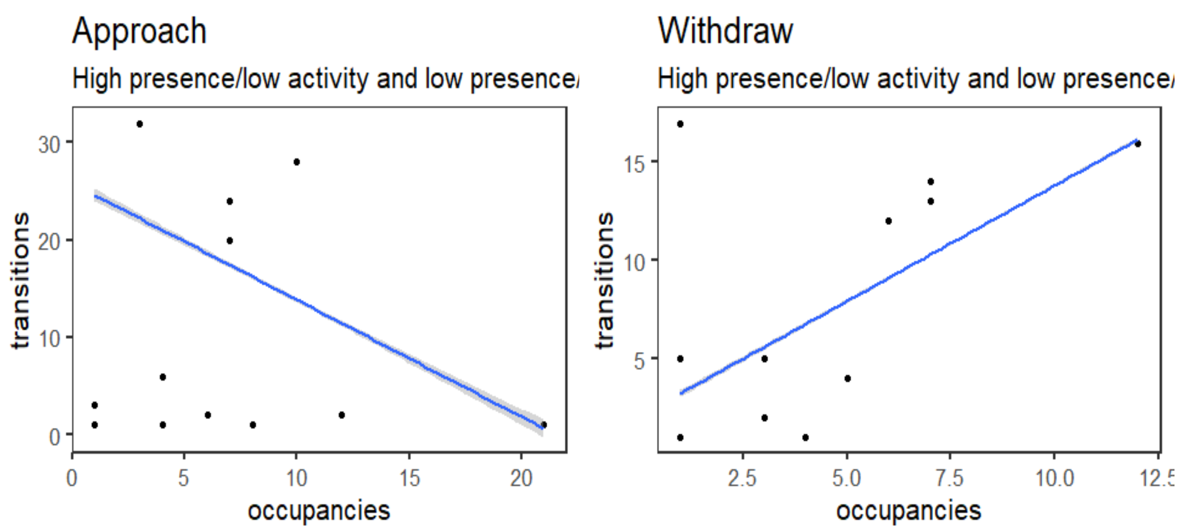
Last Produced 2023-07-11

Model Set

A first attempt at modeling included all covariates used in the Bull Trout approach models. However, SubOccupancy was repeatedly a problematic variable, highly significant and highly correlated with the random effect. The correlation with the RE implies that the covariate has an effect that cannot be fully explained by the fixed effects, and that it is associated with the hazard function in a manner that is specific to the individual.

Here we see why in the approach data: of the 16 individuals in the dataset, we see a pattern of very active and very inactive fish. In the inactive fish category, four individuals each only had one transition during one occupancy. In the high activity group, we either see many transitions (32 for two fish) or many occupancies (21 for one fish). This dichotomy in number of transitions is driving the correlation between subOccupancy and the random effect. As a result, the SubOccupancy variable will be removed.

The effect is opposing between the approach and withdraw datasets, as expected. Some fish are spending a lot of time in the approach zone (many occupancies) but are making few transitions into the entry zone. These same individuals are making transitions out of the approach zone, and out of the study area. This could be indicative of resident behaviour.



```
# A tibble: 16 × 4
   FreqCode     n occupancies transitions
   <fct>    <int>       <dbl>       <dbl>
 1 400131       3           1           1
 2 400301       7           1           1
 3 400303      19           1           1
 4 360366      26           8           1
 5 400558      83           1           1
 6 360719      91           3          32
 7 400306     100           4           1
 8 400111     105          21           1
 9 360722     129           4           6
10 400193     165           3          32
11 400236     219           1           3
12 360591     306           6           2
13 400308     633           7          20
14 400151    1446           7          24
15 400148    2365          10          28
16 400270    3216          12           2
```

In the model set we removed SubOcupancy. Looking at the data, it's clear that we don't have the power to include categorical predictors. There were only two and three successes at dusk and dawn; it is unknown if this is an association between movement of diel period or just because these periods are shorter. Instead of diel period we used the DayPeriod variable, inclusive of just day (day/dawn) and night (night/dusk).

```
[1] "Day"         "DayPeriod"   "Season"      "MeanQ10"     "MeanWSE"    
[6] "MedAWS"      "MedHVJ"      "AttFlowPer" 

[1] 64
```

Movement In and Out of Approach Zone

Approach

Model Selection

We will explore the top three models.

```
NULL
```

Covariates	DeltaAIC	AICw	LogLik
DayPeriod+MeanQ10+MedHVJ	0.00	0.31	-190.69
Day+DayPeriod+MeanQ10+MedHVJ	0.74	0.22	-190.54
DayPeriod+MeanQ10+MedAWS+MedHVJ	1.94	0.12	-190.68

Model Comparison

We explored the top three models, but all additional covariates were non-significant and the random effect higher.

DayPeriod, Q and HVJ

In the top model all covariates were significant.

We did explore the second model as well, but the additional term (Day) was non-significant. The first model is the best fit.

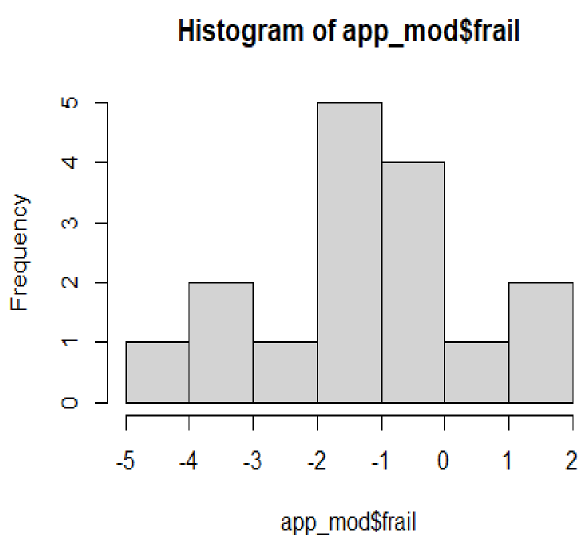
The variance of the RE is 2.9! Exceptionally high. Essentially this tells us that there is substantial unobserved heterogeneity or clustering in the data that is not explained by the fixed effects.

	coef	se(coef)	se2	Chisq	DF	p
DayPeriod1	0.59529	0.15334	0.15330	15.07141	1.00000	0.00010
MeanQ10	-0.01643	0.00505	0.00472	10.58159	1.00000	0.00114
MedHVJ	0.38904	0.14470	0.14456	7.22840	1.00000	0.00718
frailty(FreqCode)	NA	NA	NA	134.38363	13.04396	0.00000

```
[1] "Variance of random effect= 2.949924   I-likelihood = -214.3"
```

Model Fit

The model residuals don't look bad, and all variables pass the assumption of PH. Only very limited correlations with the RE.

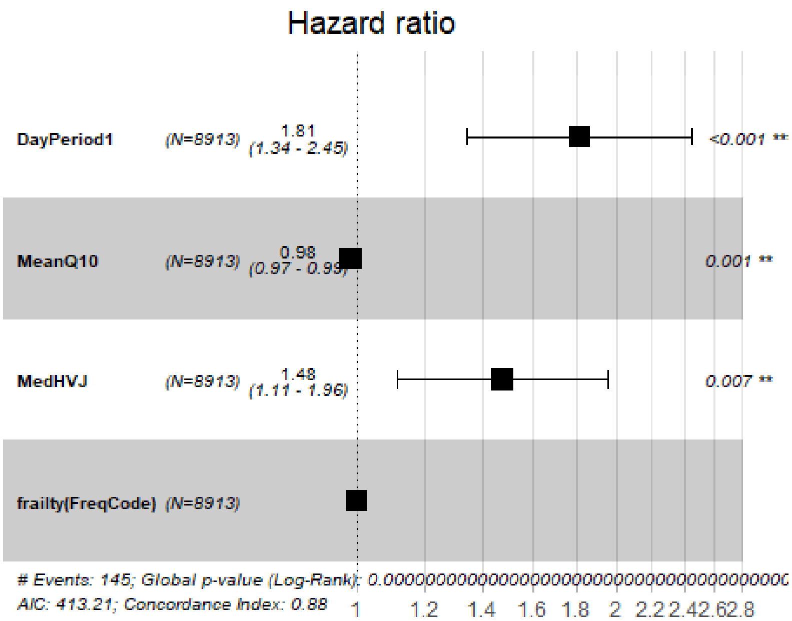



```
          chisq    df    p
DayPeriod 0.192  1.00 0.66
MeanQ10   0.128  0.87 0.67
MedHVJ    2.524  1.00 0.11
GLOBAL    2.967 15.91 1.00
```

Model Interpretation

Day has a strong positive effect meaning approach rates are faster during the day then night (35-147% faster!). Additionally, the positive effect of HVJ suggests rates of approach are 48% higher when the HVJ is on than when it is off.

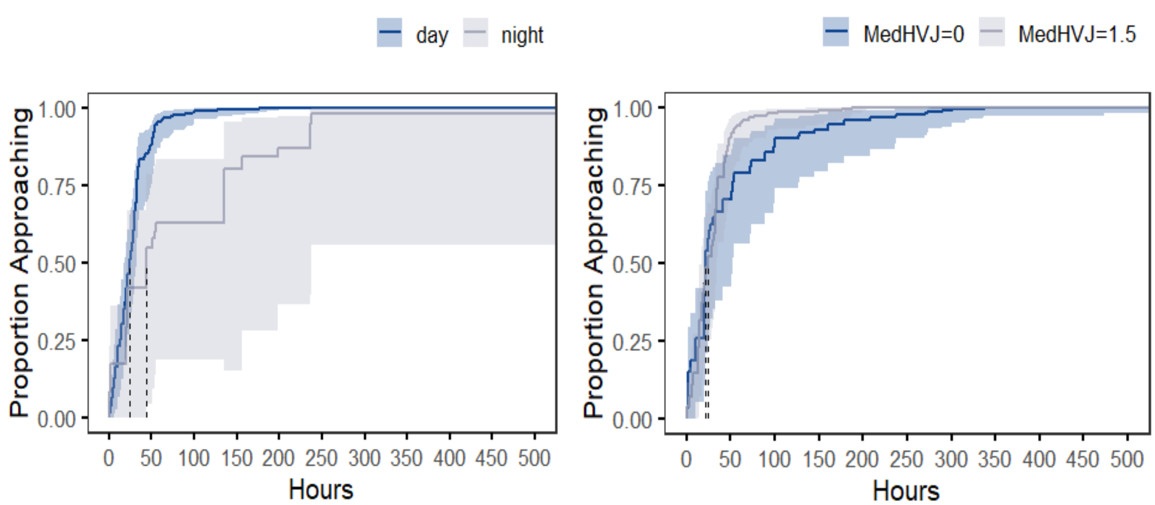
River discharge has a negative effect. The HR of 0.98 indicates that for every 10 cms increase, approach rates decrease by 2%.



Model Visualization

The effect of day period is clear whereby approach rates are faster during the day.

The effect of HVJ is less clear, but still present. Faster approach rates when the HVJ is on, especially as time progresses.



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Withdraw

Model Selection

There are many models within the candidate set. I examined the first, fourth and fifth, none of which had any significant covariates. For simplicity, I will stick with the top model.

```
NULL
```

Covariates	DeltaAIC	AICw	LogLik
Day+MeanQ10	0.00	0.10	-189.64
Day	0.22	0.09	-190.31
Day+MeanWSE	0.74	0.07	-189.96
Day+DayPeriod+MeanQ10	1.08	0.06	-189.12
Day+MeanQ10+MedHVJ	1.47	0.05	-189.35
Day+DayPeriod	1.66	0.04	-189.97
Day+MedHVJ	1.76	0.04	-190.06
Day+DayPeriod+MeanWSE	1.87	0.04	-189.47
Day+MeanQ10+MedAWS	2.00	0.04	-189.67

Day and Discharge

The overall model and the random effect are statistically significant, but the two covariates of day and discharge are not.

Variance held by the random effect is still quite high, 0.49. Along with the statistical significance, this tells us that the main thing driving retreat is the individual.

	coef	se(coef)	se2	Chisq	DF	p
Day	0.0061	0.00467	0.00335	1.70631	1.0000	0.19146
MeanQ10	-0.0071	0.00447	0.00415	2.52508	1.0000	0.11205
frailty(FreqCode)	NA	NA	NA	29.90170	7.3384	0.00013

```
[1] "Variance of random effect= 0.4963823   I-likelihood = -202.9"
```

Comparing Approach and Withdraw

The main take-home when comparing these models is the substantial inter-individual variability. We have a small dataset split between very active and very inactive individuals. The approach data also aligns with other species in that movement is preferred during the day. A new finding is the preference for the HVJ among rainbow trout on approach to the fishway, though there is a lot of variability in this finding.

Appendix I: Rainbow Trout Entry Zone Model Selection

R Markdown Report

Last Produced 2023-07-11

Entry

I will just look at the top model.

```
NULL
```

Covariates	DeltaAIC	AICw	LogLik
Season+AttFlowPer	0.00	0.15	-19.82
Season	1.18	0.08	-21.41
Season+MeanWSE	1.34	0.08	-20.49
Season+MedAWS	1.92	0.06	-20.78

Season and Percent Attraction Flow

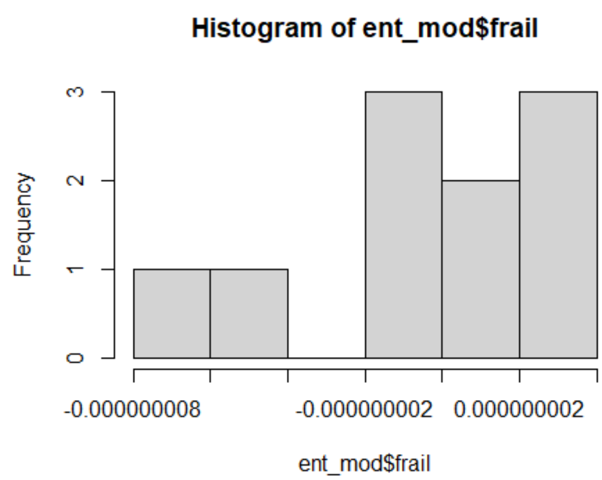
The summer season is the only statistically significant term. The p-value of attraction flow percentage is low enough that we will evaluate this term further (0.07). Interestingly, the random effect is not significant and holds negligible variance. This is interesting as it was so prominent in the approach and withdraw models.

	coef	se(coef)	se2	Chisq	DF	p
Season1	-0.42477	0.56189	0.56189	0.57148	1	0.44967
Season2	-1.16549	0.49497	0.49497	5.54451	1	0.01854
AttFlowPer	1.30282	0.70750	0.70750	3.39087	1	0.06556
frailty(FreqCode)	NA	NA	NA	0.00000	0	0.98910

```
[1] "Variance of random effect= 0.000000005   I-likelihood = -19.8"
```

Model Fit

Residuals do not look good and show the data limitations; the entire dataset is based on 10 individuals. All variables pass the assumption of PH. Correlations with the RE are not explored as it was not important in this model.

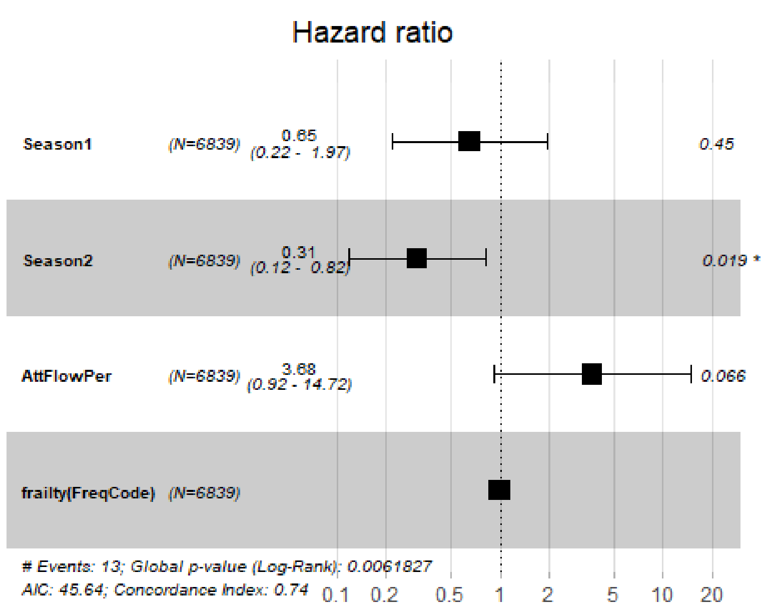



```
            chisq df    p
Season      0.581  2 0.75
AttFlowPer  1.644  1 0.20
GLOBAL      1.646  3 0.65
```

Model Interpretation

HRs show that entry rates are 70% slower during the summer than in other months. This means that entry rates are much higher in the fall.

Despite the statistical non-significance of the percent attraction flow term, I think it is important to discuss. The HR shows a strong positive effect, but a lot of variability; for every unit increase in the percent attraction flow entry rates increase by 268% - note that the range of the LCI passes 1, which means the error expands into the effect being negative.



Departure

Covariates	DeltaAIC	AICw	LogLik
Day+MeanQ10+MedAWS	0.00	0.11	-50.51
Day+MeanQ10	0.38	0.09	-51.79
Day+AttFlowPer	0.84	0.07	-51.60
Day+DayPeriod+MeanQ10	1.17	0.06	-51.26
Day+DayPeriod+MeanQ10+MedAWS	1.49	0.05	-50.34
Season+AttFlowPer	1.80	0.05	-52.48
Day+MeanQ10+MedAWS+MedHVJ	1.88	0.04	-50.60

Day, Discharge and AWS

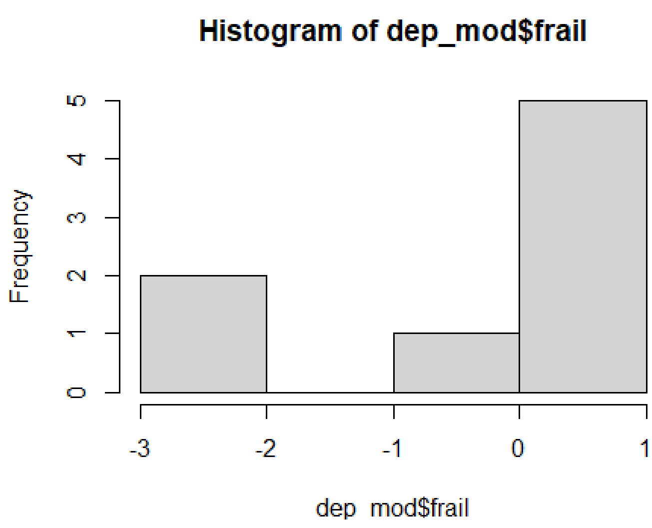
Only day is statistically significant, as is the random effect.

	coef	se(coef)	se2	Chisq	DF	p
Day	-0.02632	0.01135	0.00981	5.37940	1.00000	0.02038
MeanQ10	0.02573	0.01404	0.01326	3.35593	1.00000	0.06696
MedAWS	-0.11232	0.09439	0.09283	1.41601	1.00000	0.23406
frailty(FreqCode)	NA	NA	NA	29.29636	4.26522	0.00001

```
[1] "Variance of random effect= 0.8750365   I-likelihood = -63.9"
```

Model Fit

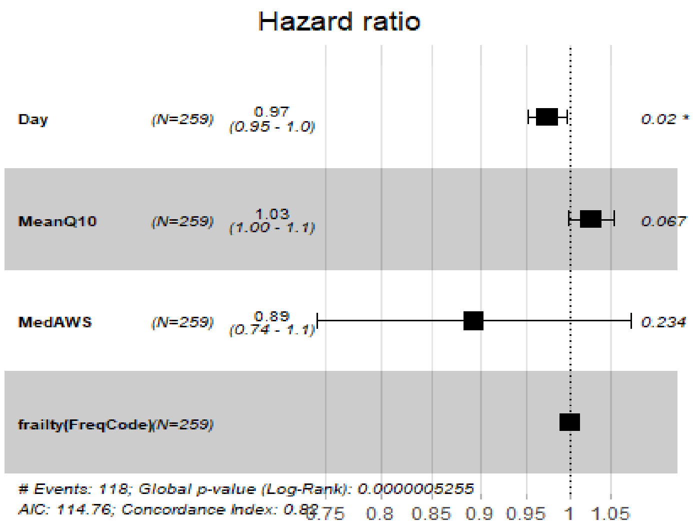
Model residuals are poor. All variables pass the assumption of PH but there is a correlation between the RE and Day, the only significant variable. I think all we're seeing here is the random effect, and that there is more activity among contributing individuals later in the operational period.




```
         chisq   df    p
Day     0.0218 0.75 0.79
MeanQ10 0.0853 0.89 0.73
MedAWS  0.1517 0.97 0.68
GLOBAL  0.2202 6.87 1.00
```

Model Interpretation

We see slower departure rates as the operational period increases: 3% decrease for each subsequent day of the operational period. That is significant and does indicate that with time, rainbow trout are less likely to leave the entry zone. The direction of the non-significant effects of discharge and AWS are notable. Departure rates increase with higher discharges but decrease with increasing AWS. This points to Rainbow Trout staying in the entry zone longer with higher AWS and lower attraction flows.



Comparing Entry and Departure

Both models suffered from limited data, but both retained components of river discharge, attraction flow and time. Although the results contain much uncertainty, they point to rainbow trout staying in the entry zone longer as the operational season progresses, and at lower discharges and higher attraction flows.

Appendix J: Rainbow Trout Fishway Rejection Model Selection

R Markdown Report

Last Produced 2023-07-11

I selected the second model for consistency with movement in and out of the entry zone.

```
NULL
```

Covariates	DeltaAIC	AICw	LogLik
Day	0.00	0.09	-22.77
Day+AttFlowPer	1.43	0.04	-22.49
Day+MeanQ10	1.45	0.04	-22.49
MeanWSE	1.78	0.04	-23.66
Day+DayPeriod	1.87	0.04	-22.70

Model Comparison

The model itself is not statistically significant, neither are either included terms. This is not worth pursuing further but it is interesting that the same terms best fit the data as with the entry and departure models.

```
Call:
coxph(formula = (Surv(Time1_s, Time2_s, Status)) ~ Day + AttFlowPer + 
    frailty(FreqCode), data = rej_dat)

  n= 1700, number of events= 14 
   (5 observations deleted due to missingness)

                  coef      se(coef) se2      Chisq DF p   
Day                0.009004 0.006059 0.006059 2.21  1  0.14
AttFlowPer        -0.134213 0.673637 0.673637 0.04  1  0.84
frailty(FreqCode)                             0.00  0  0.99

           exp(coef) exp(-coef) lower .95 upper .95
Day           1.0090      0.991    0.9971     1.021
AttFlowPer    0.8744      1.144    0.2335     3.274

Iterations: 7 outer, 26 Newton-Raphson
     Variance of random effect= 0.000000005   I-likelihood = -22.5 
Degrees of freedom for terms= 1 1 0 
Concordance= 0.618  (se = 0.097 )
Likelihood ratio test= 2.64  on 2 df,   p=0.3
```

Appendix K: Trap and Haul Detection Histories

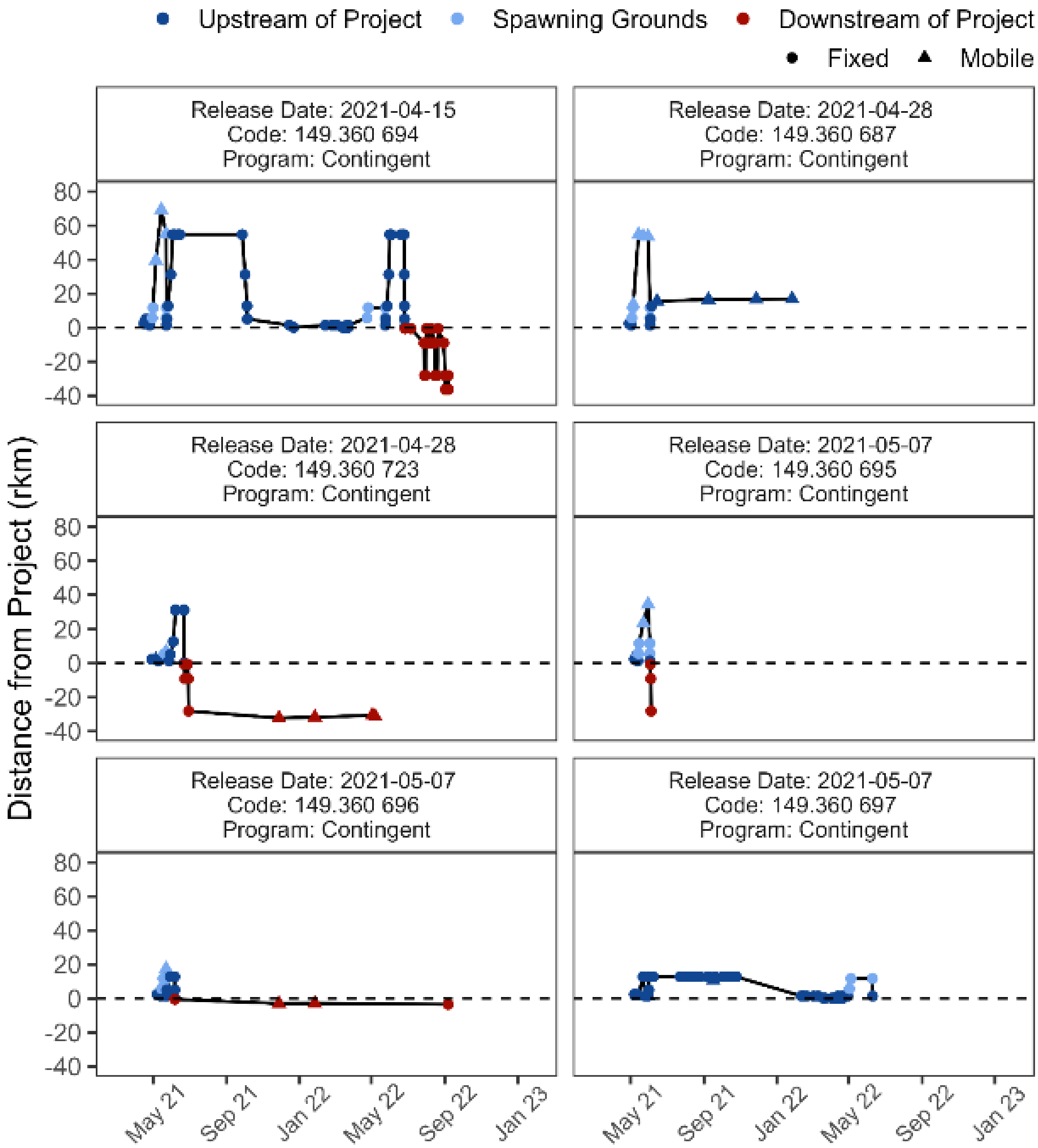


Figure K1 Detection history plots for radio-tagged Arctic Grayling released upstream of the Project. Plots begin at release and include all detections through January 2023. Detections at or upstream of the Moberly River 2 fixed station were considered within spawning grounds. Detections downstream of the Beatton River (~36 rkm downstream of Project) are not shown for clarity.

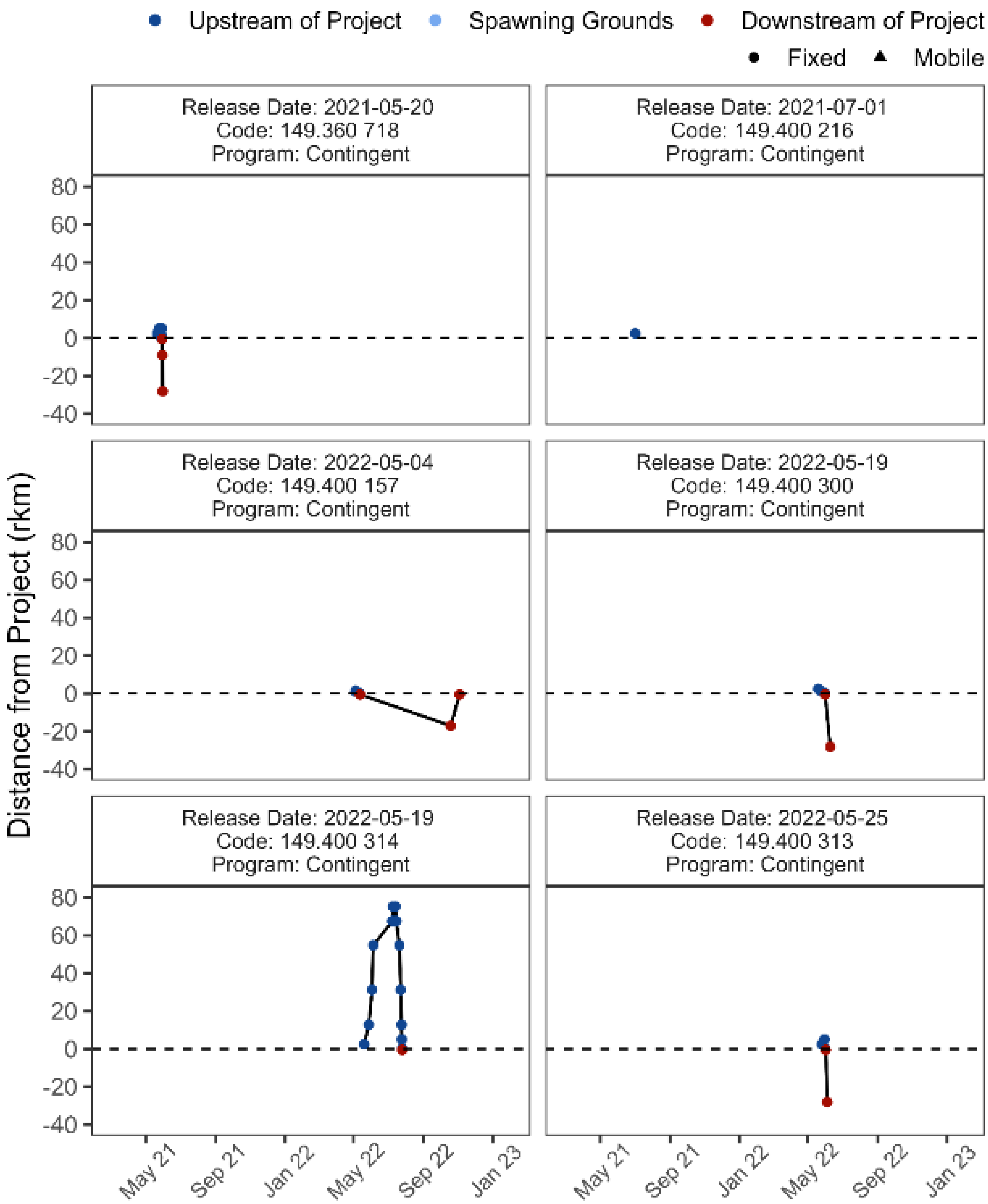


Figure K1 continued.

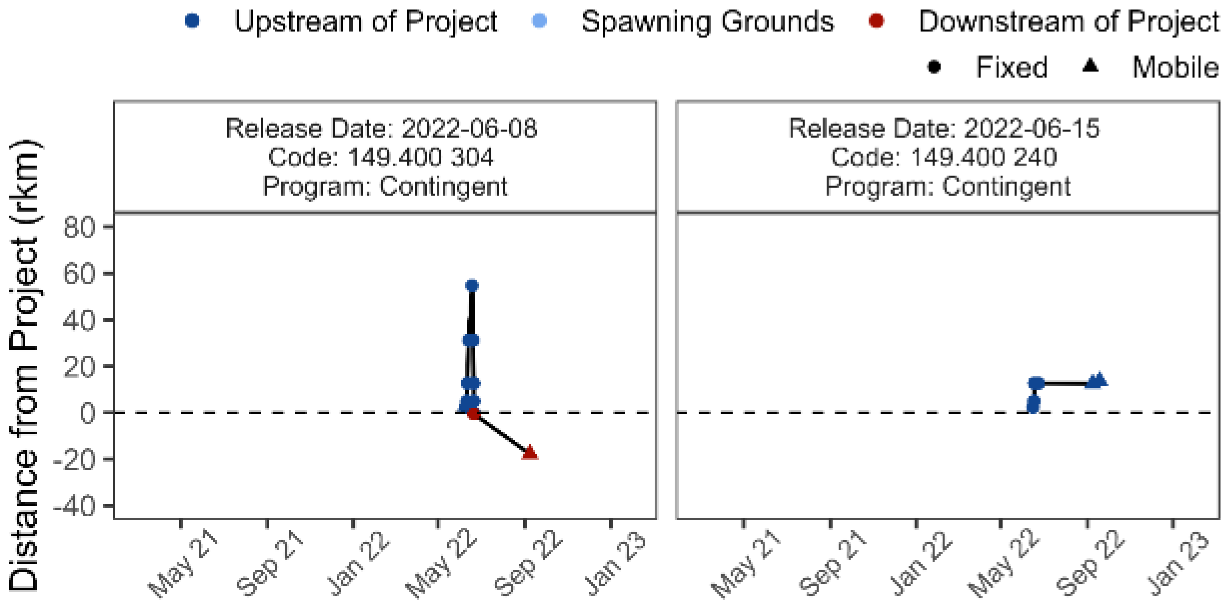


Figure K1 continued.

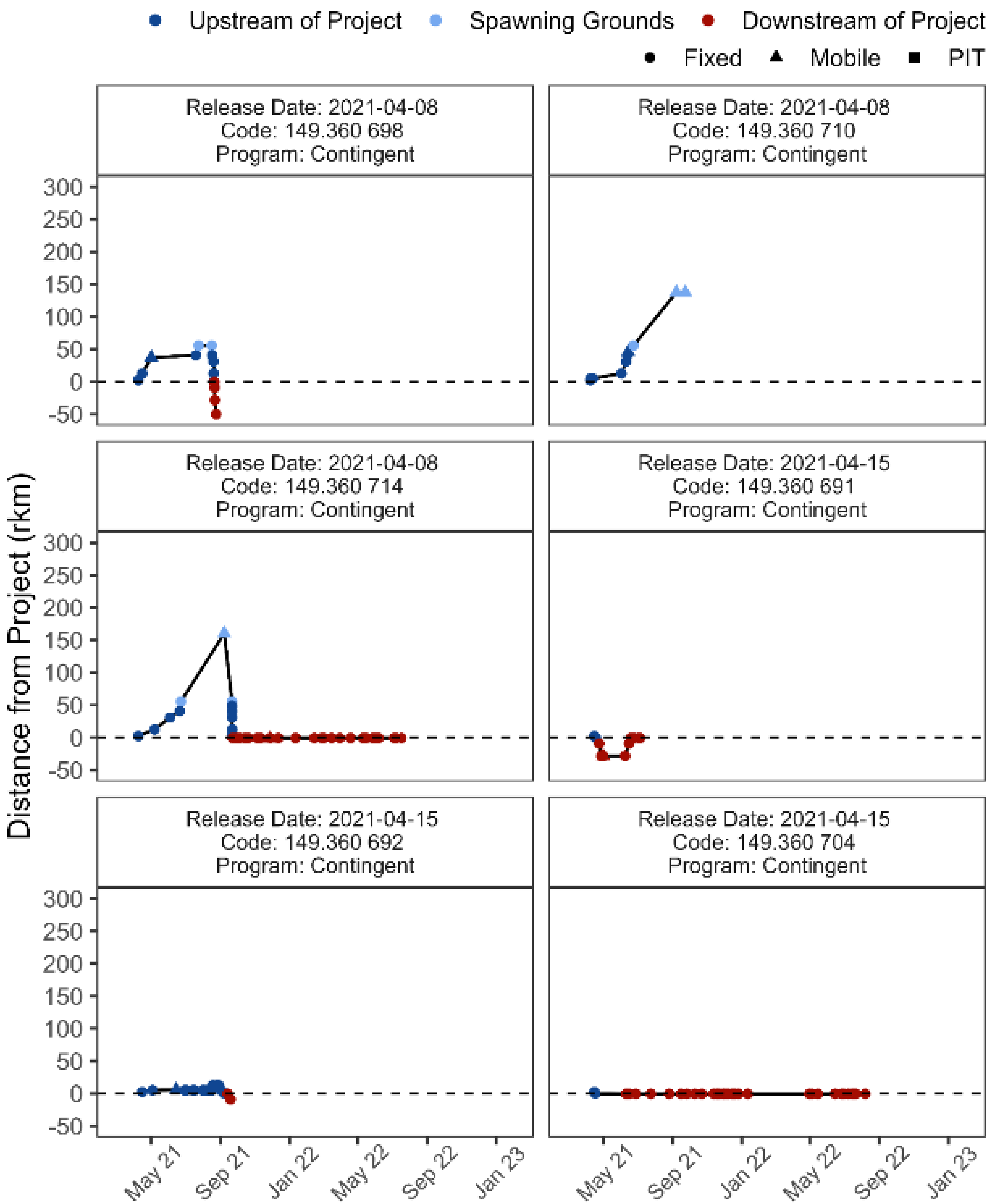


Figure K2 Detection history plots for radio-tagged Bull Trout released upstream of the Project. Plots begin at release and include all detections through January 2023. Detections at or upstream of the Halfway River 3 fixed station were considered within Bull Trout spawning grounds. Detections downstream of the Beatton River (~36 rkm downstream of Project) are not shown for clarity.

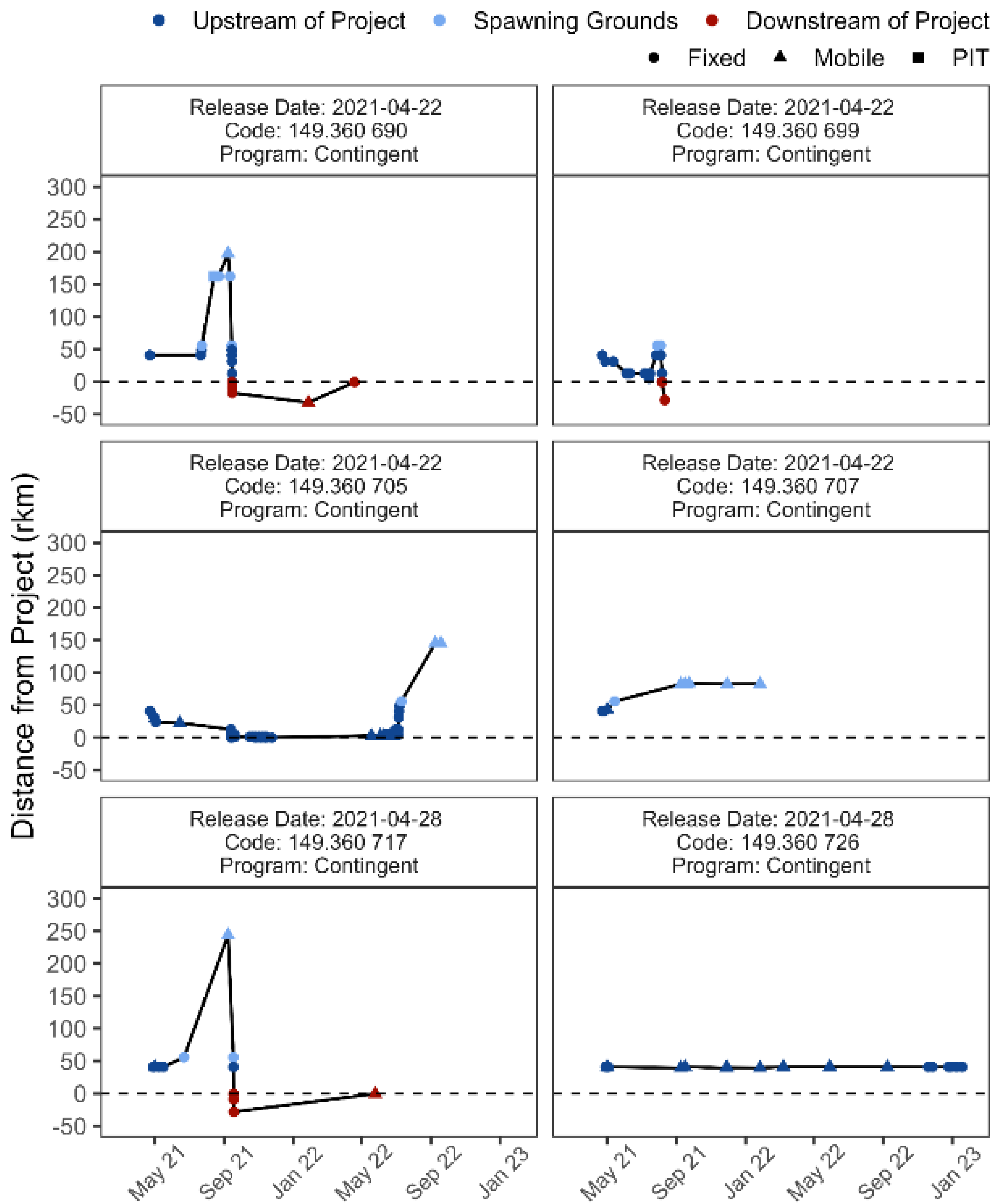


Figure K2 continued.

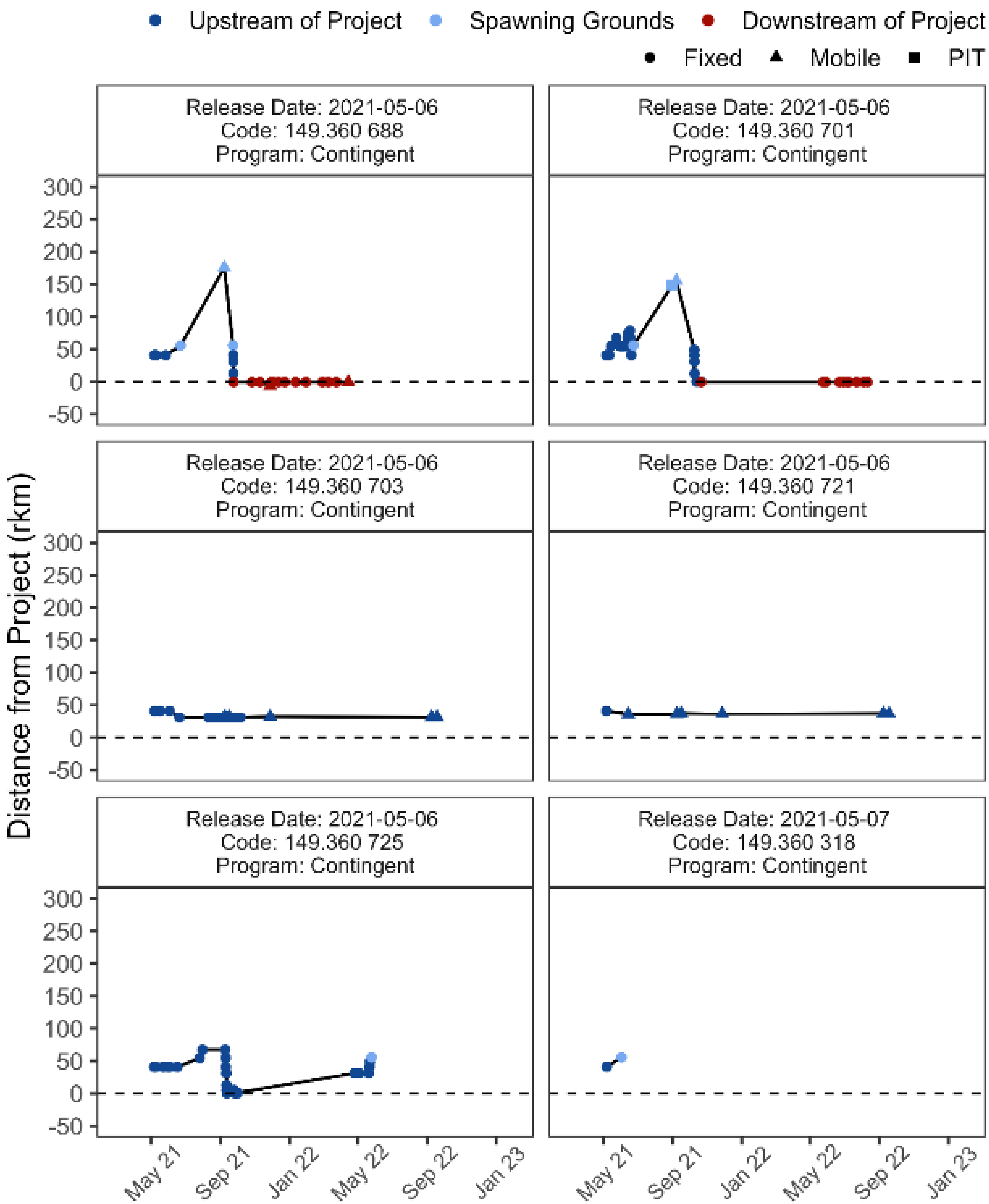


Figure K2 continued.

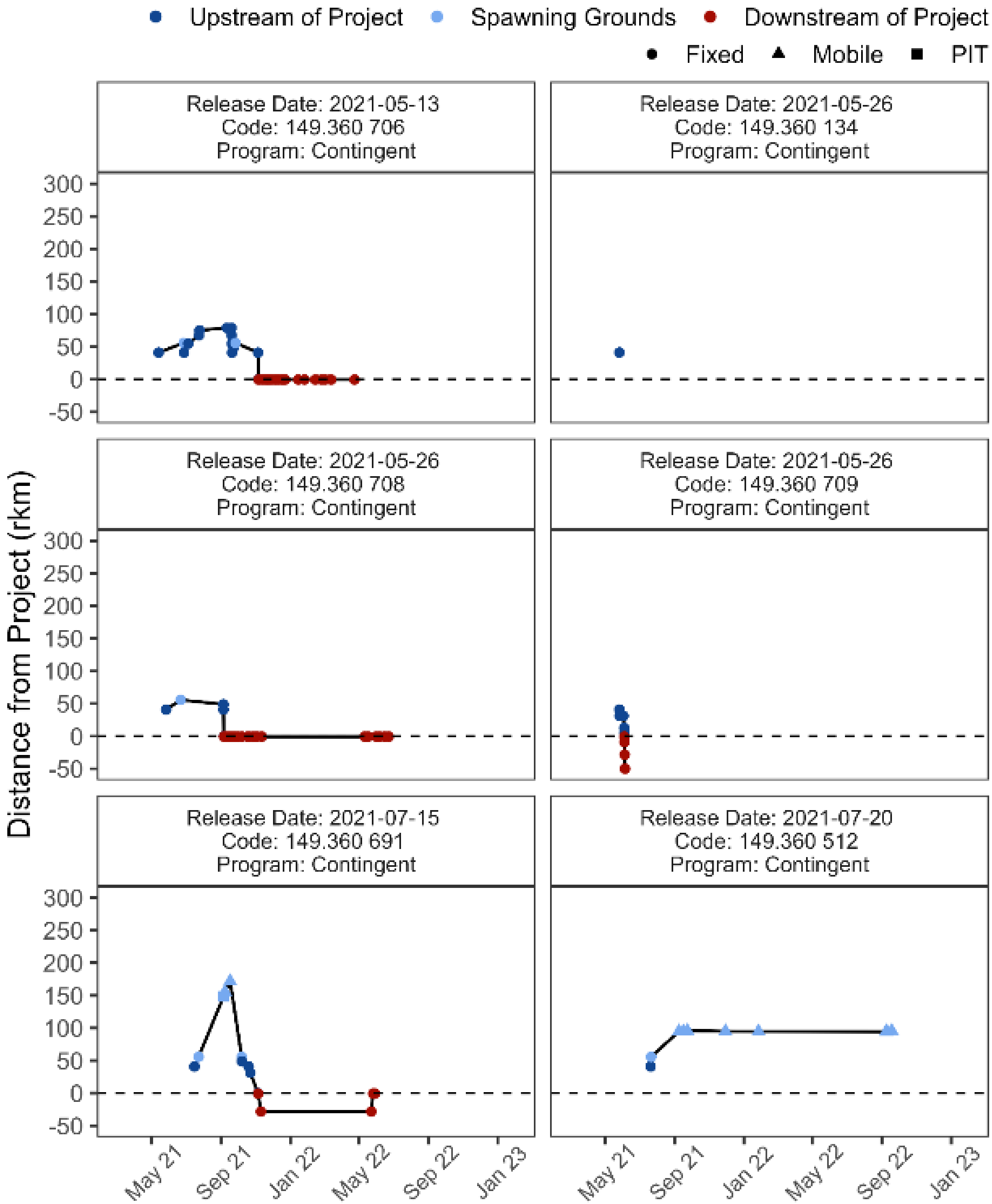


Figure K2 continued.

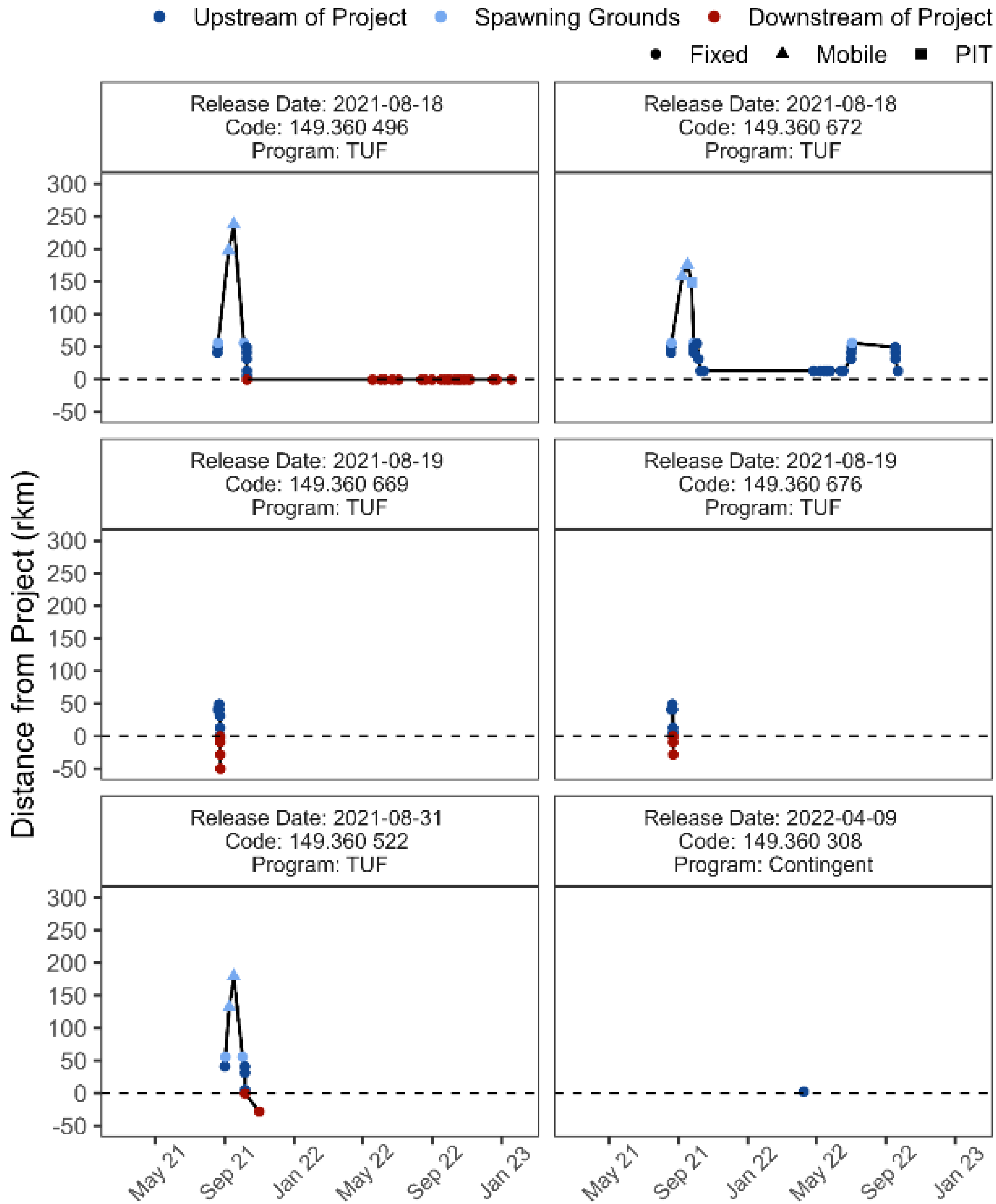


Figure K2 continued.

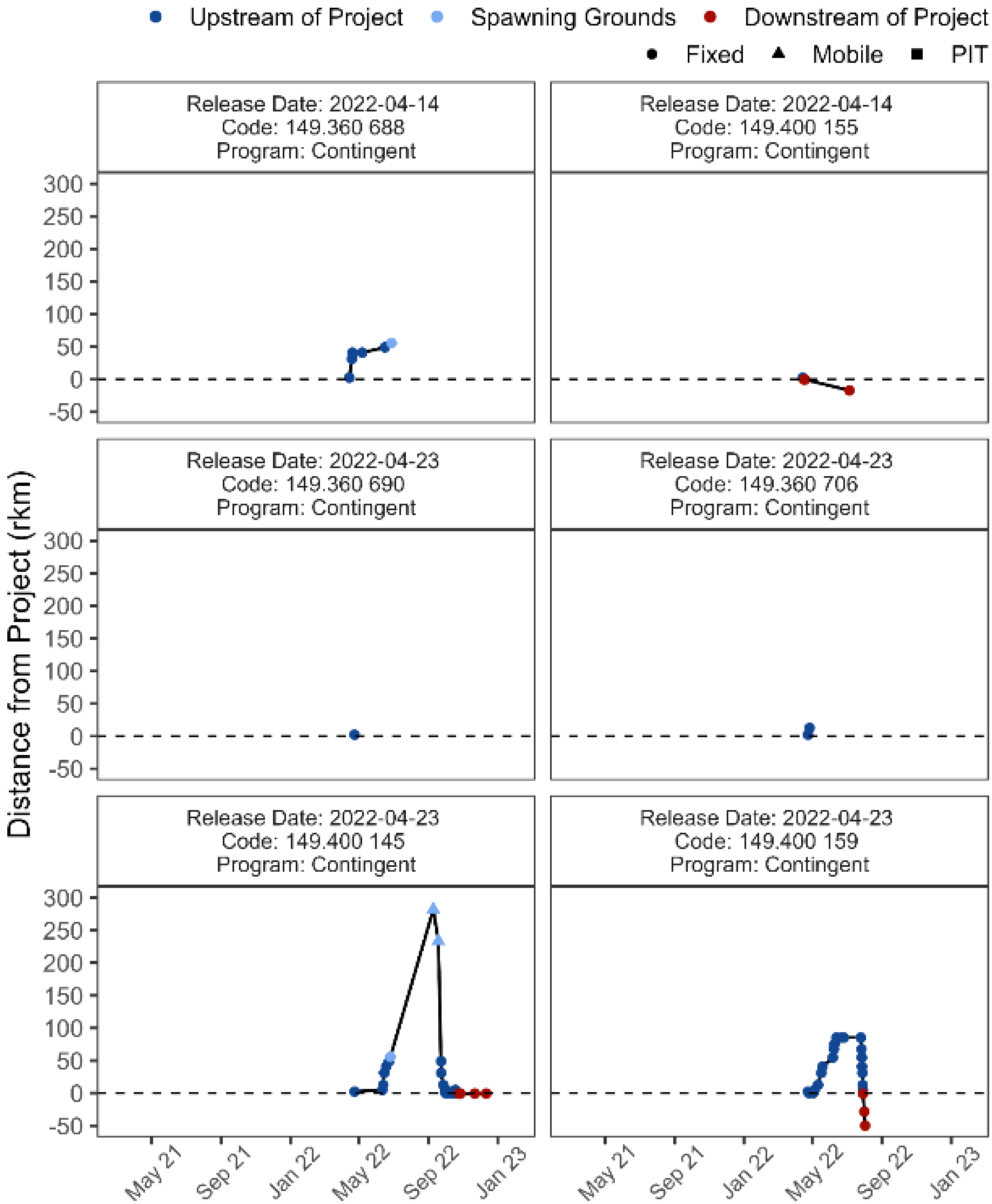


Figure K2 continued.

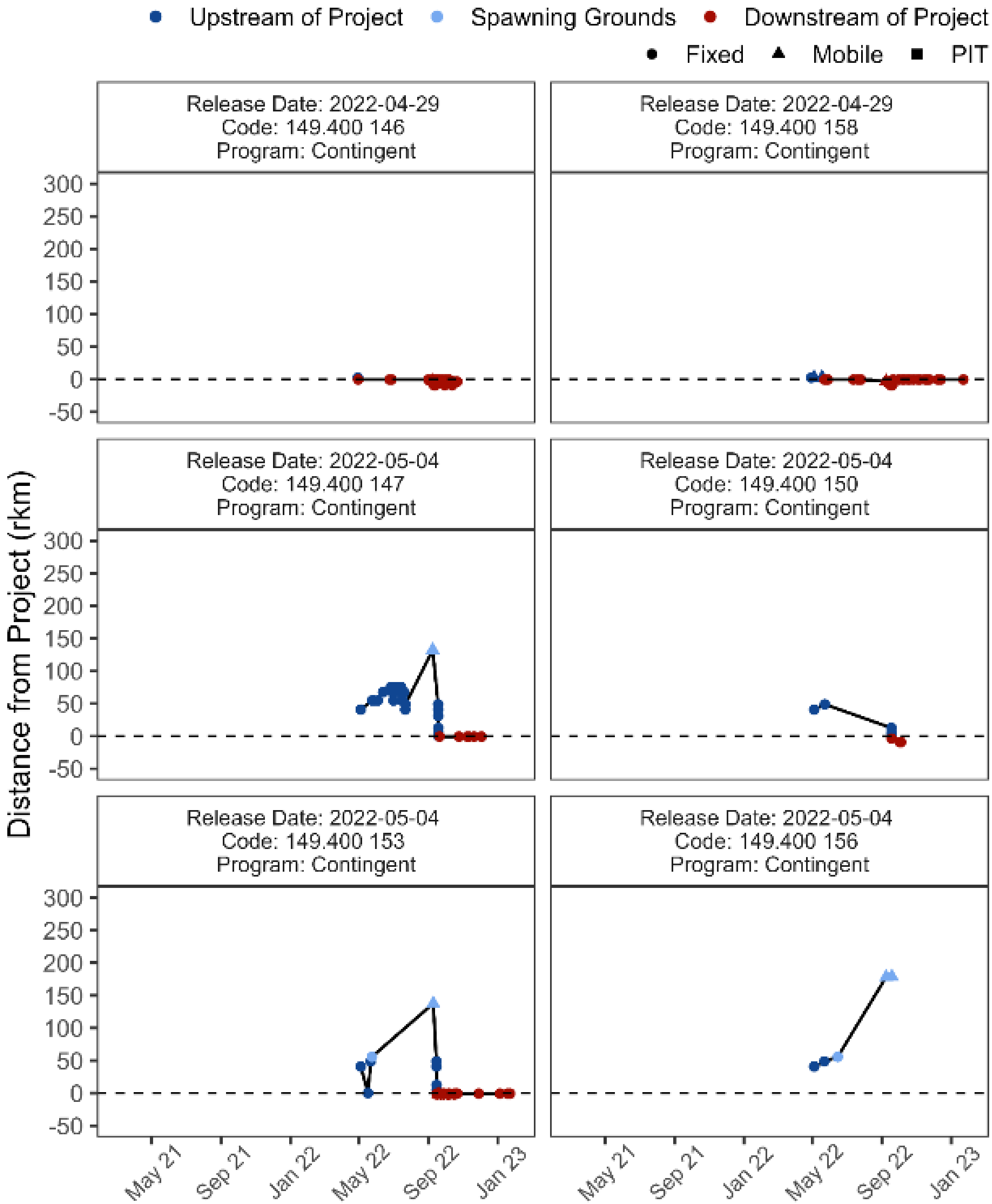


Figure K2 continued.

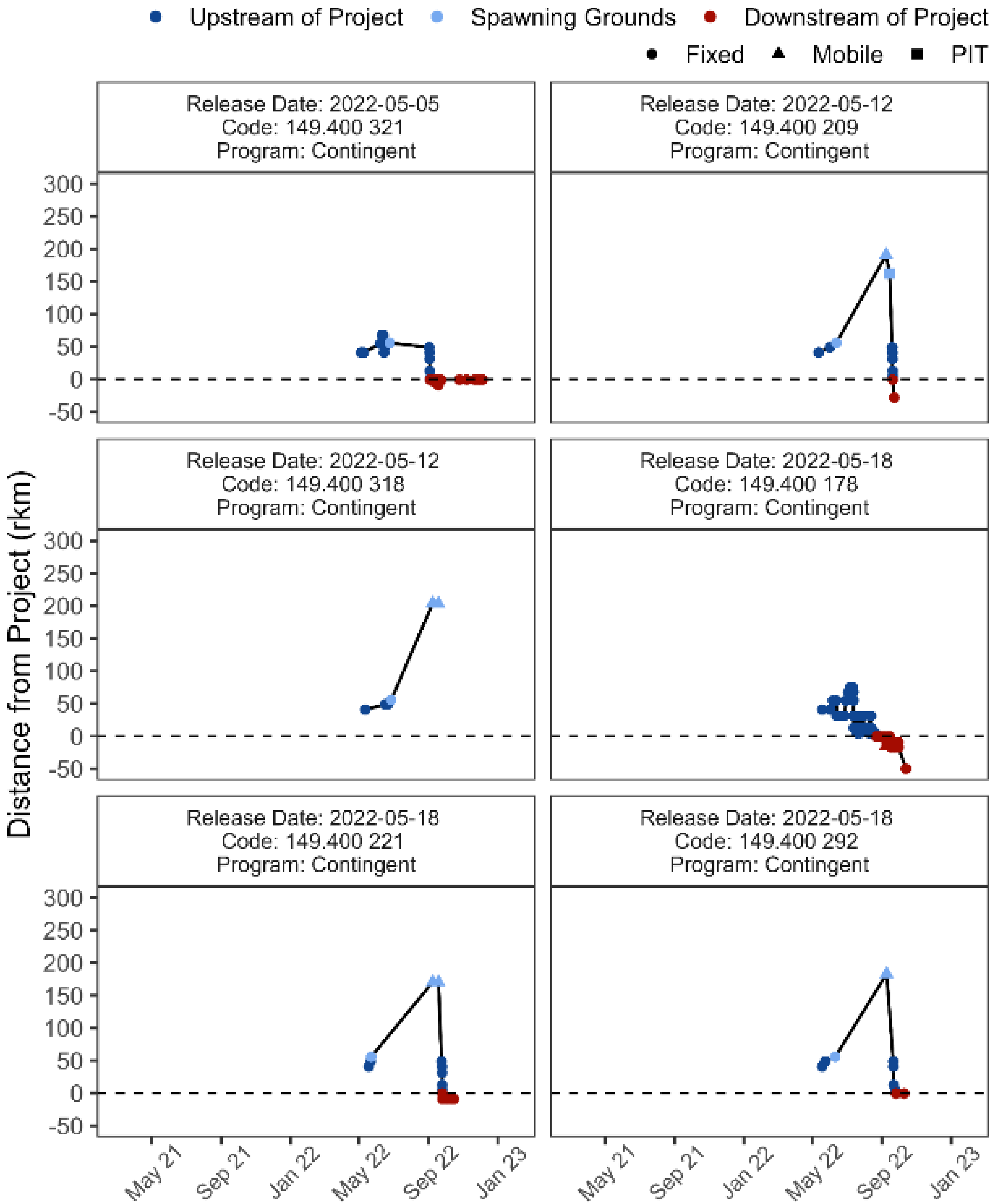


Figure K2 continued.

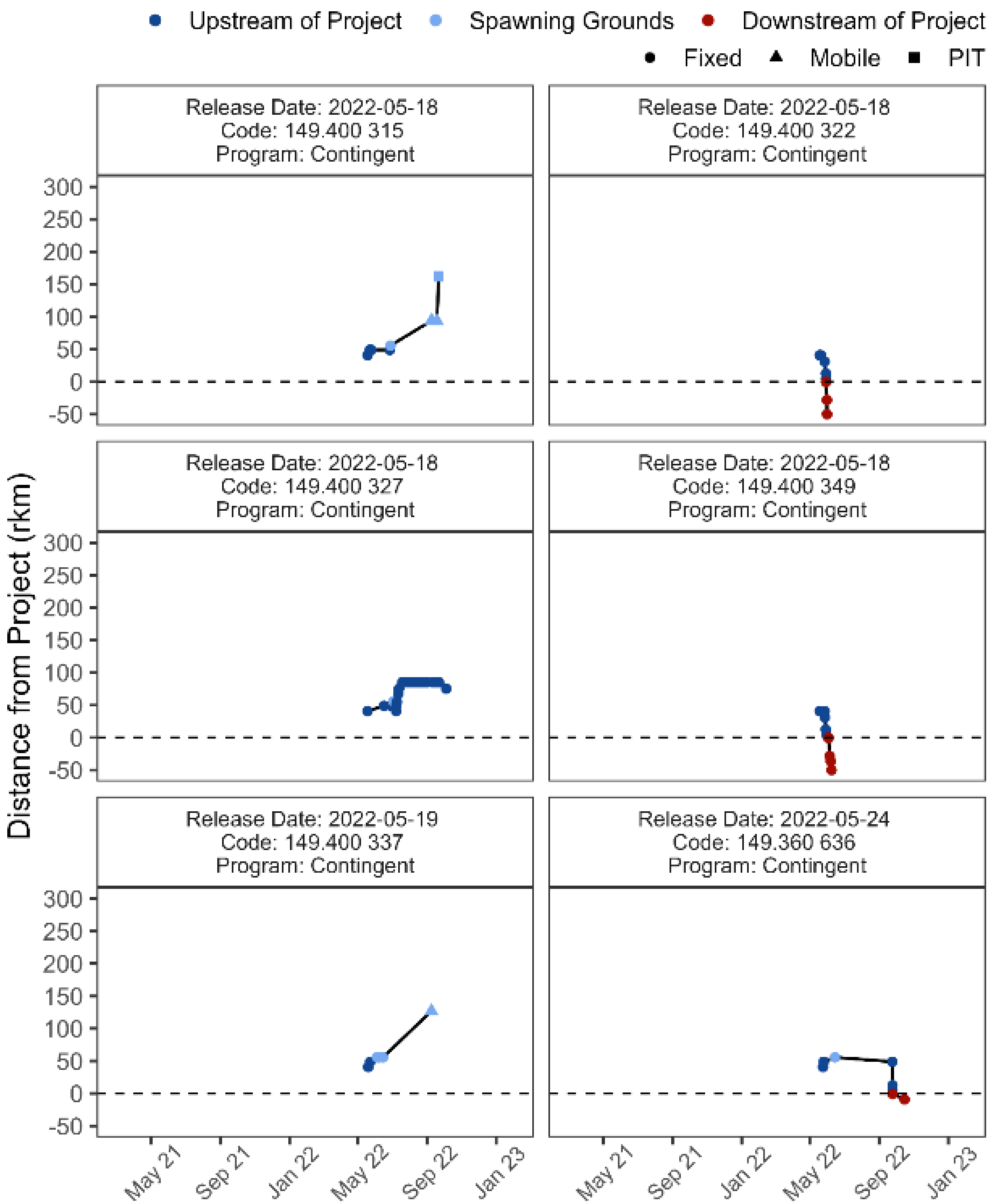


Figure K2 continued.

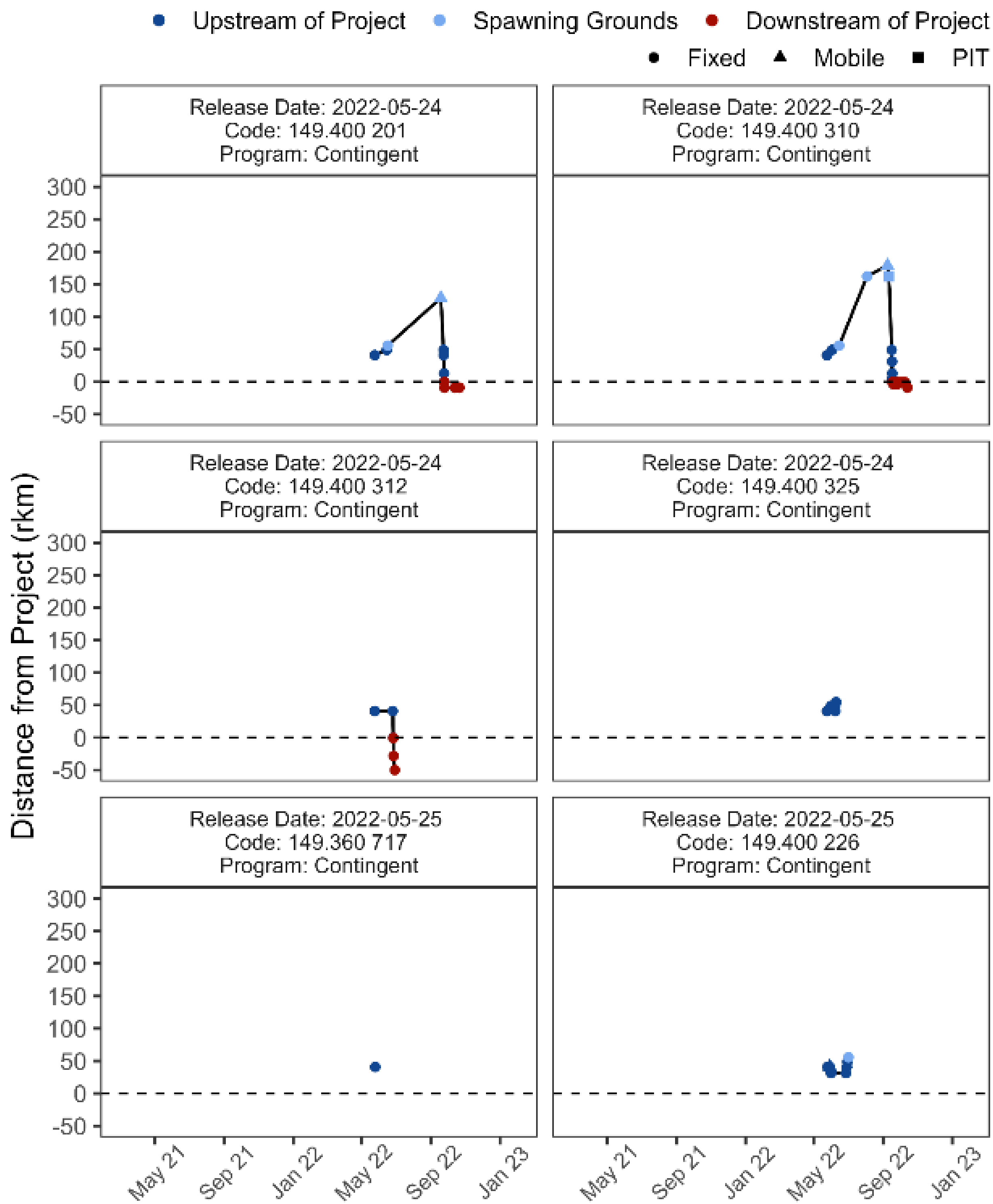


Figure K2 continued.

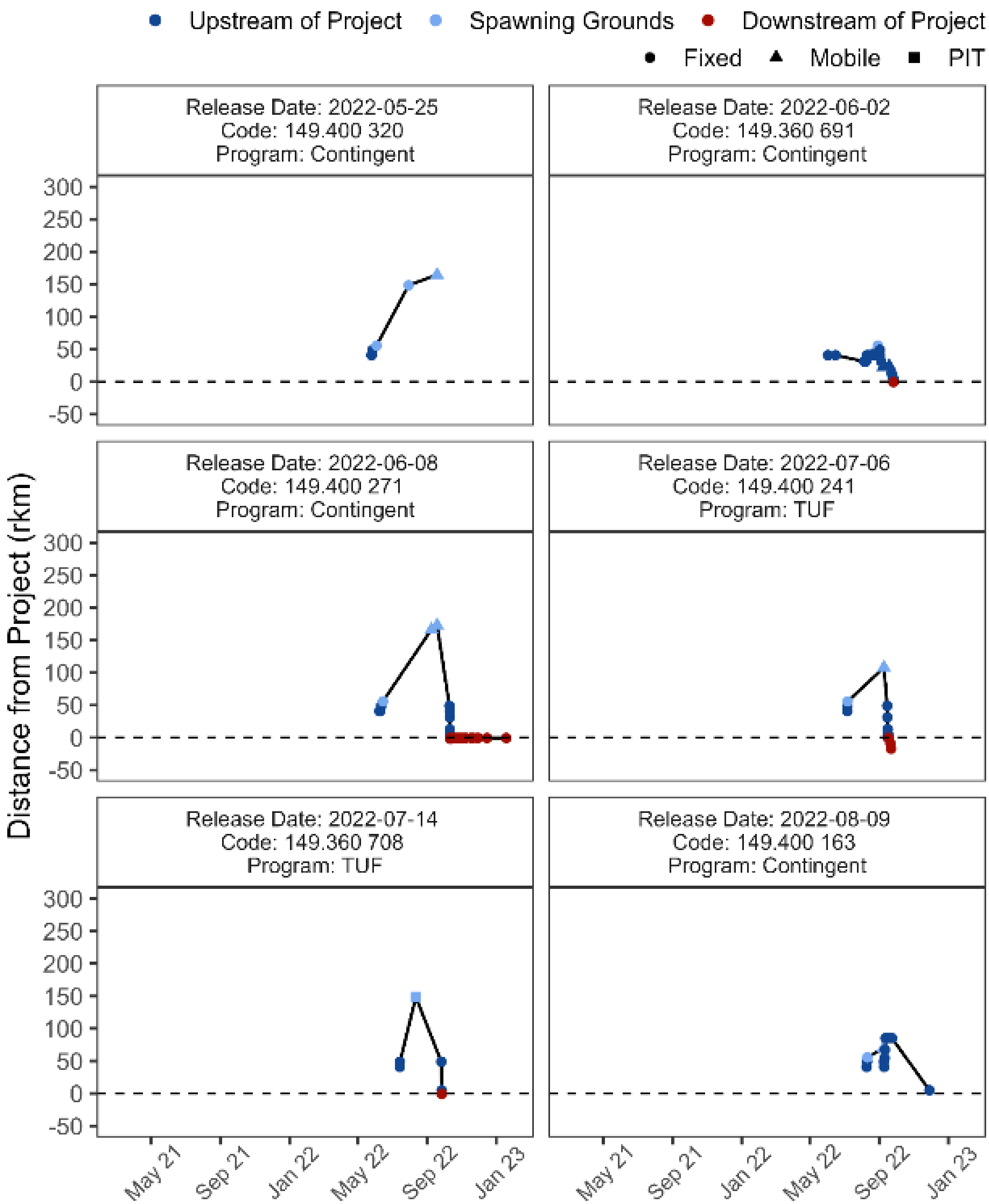


Figure K2 continued.

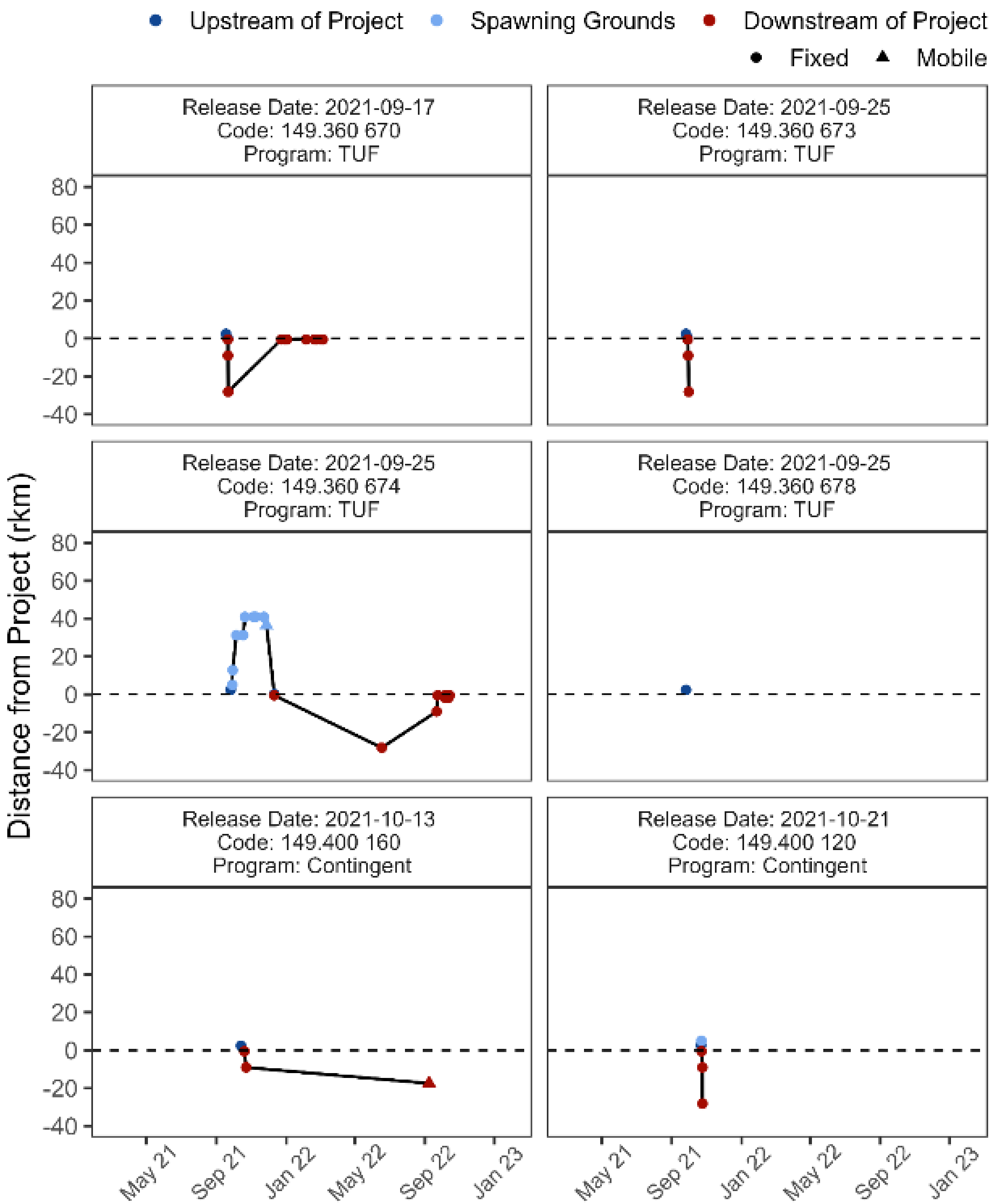


Figure K3 Detection history plots for radio-tagged Mountain Whitefish released upstream of the Project. Plots begin at release and include all detections through January 2023. Detections downstream of the Beatton River (~36 rkm downstream of Project) are not shown for clarity.

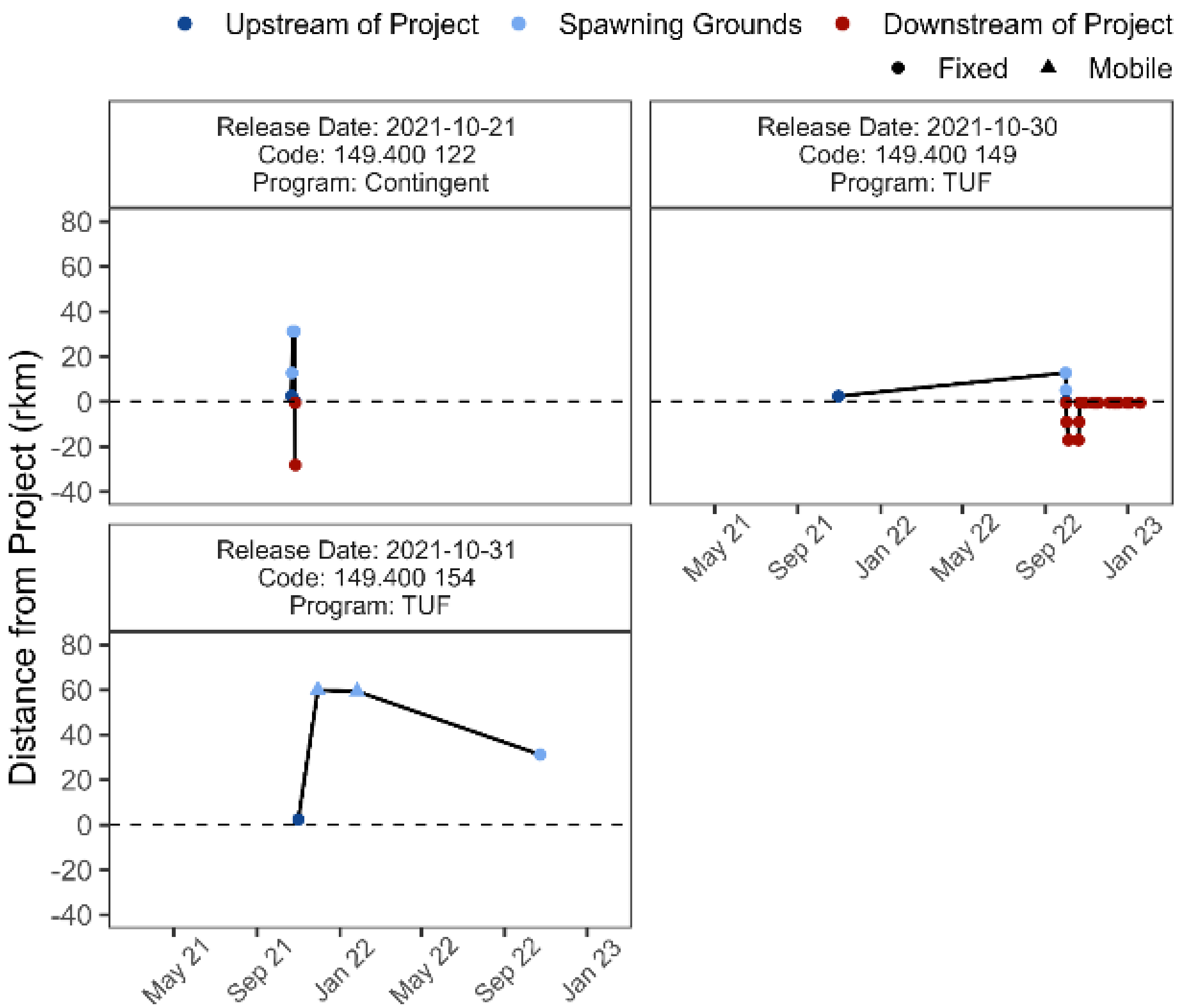


Figure K3 continued.

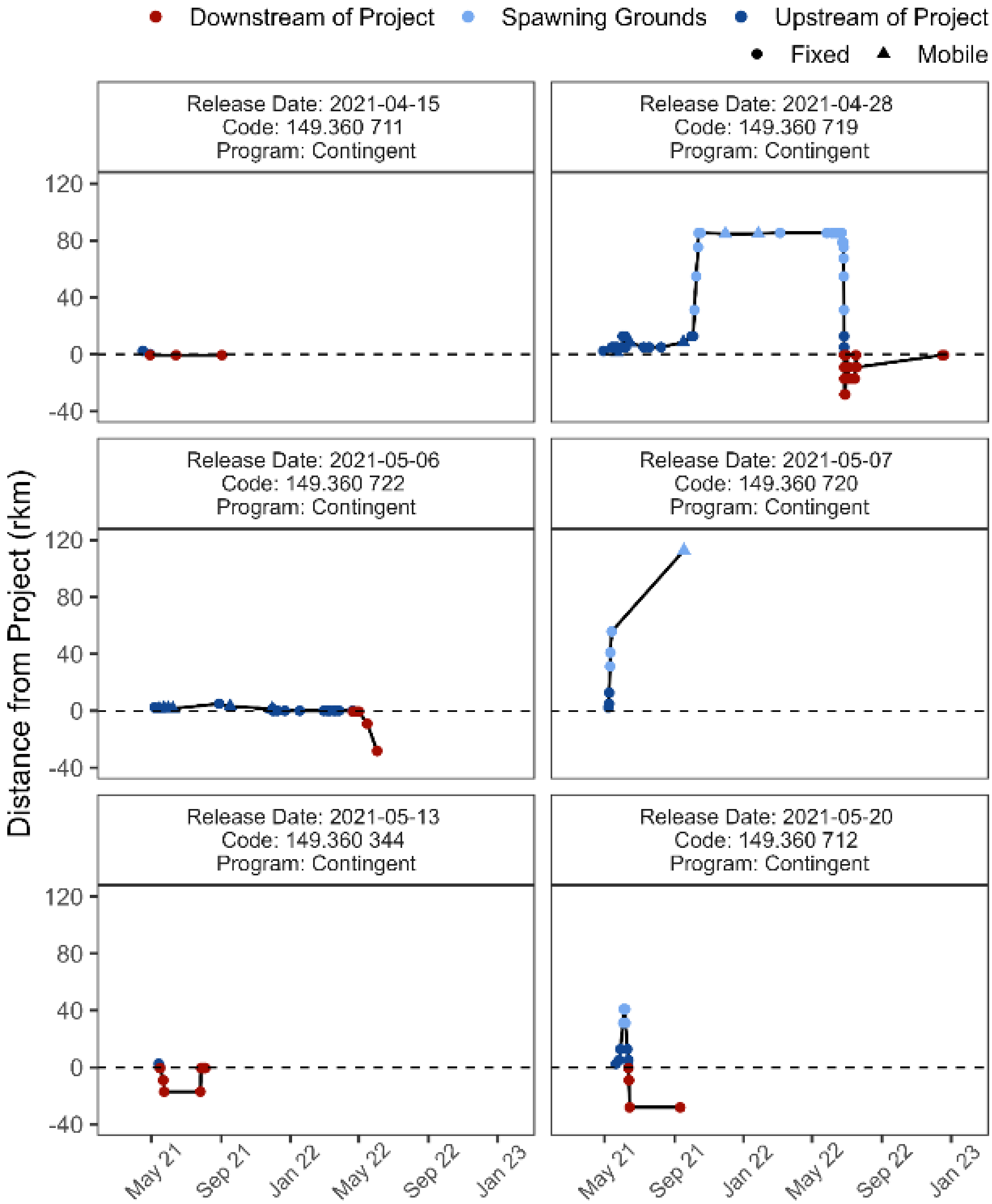


Figure K4 Detection history plots for radio-tagged Rainbow Trout released upstream of the Project. Plots begin at release and include all detections through January 2023. Detections downstream of the Beatton River (~36 rkm downstream of Project) are not shown for clarity.

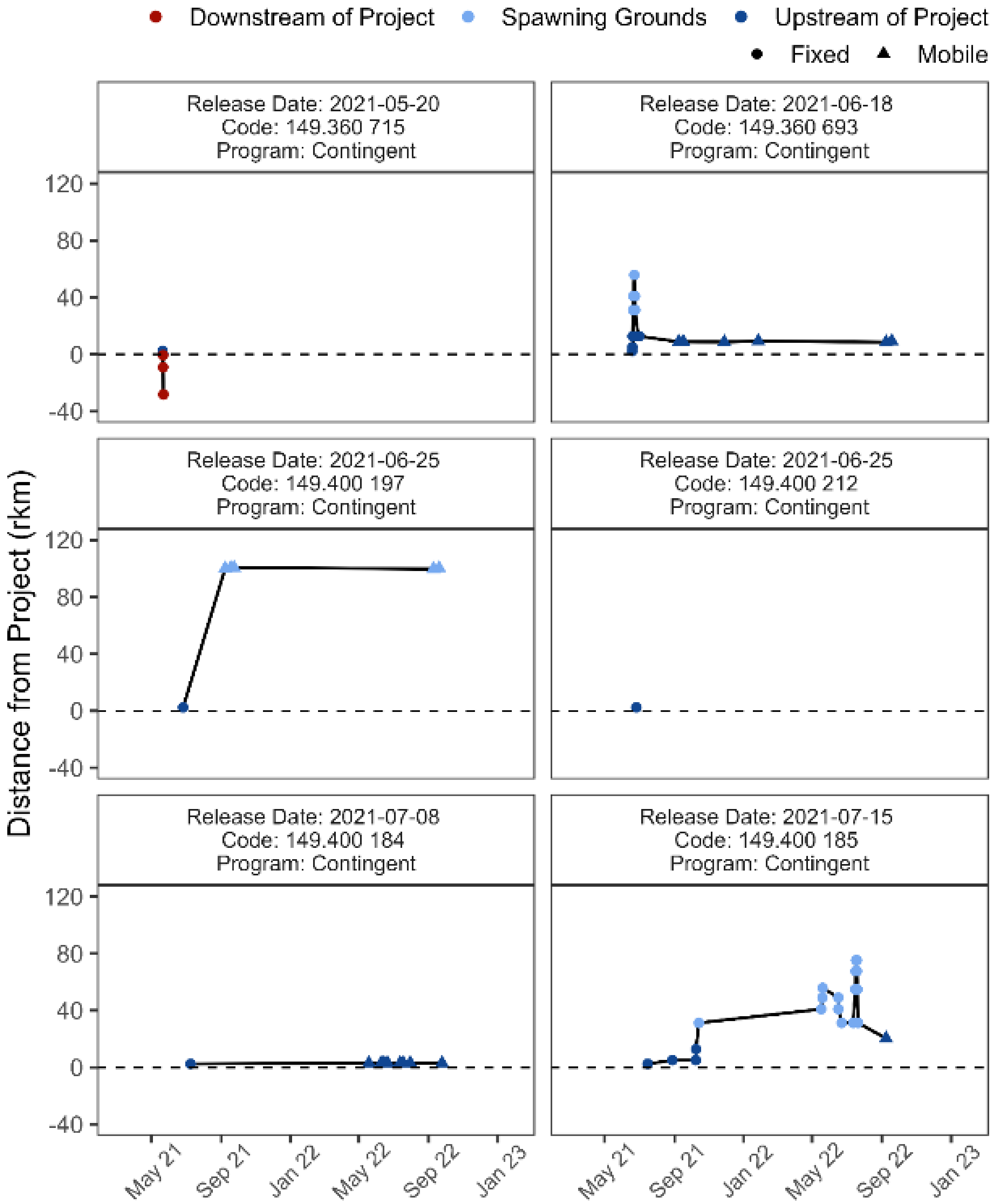


Figure K4 continued.

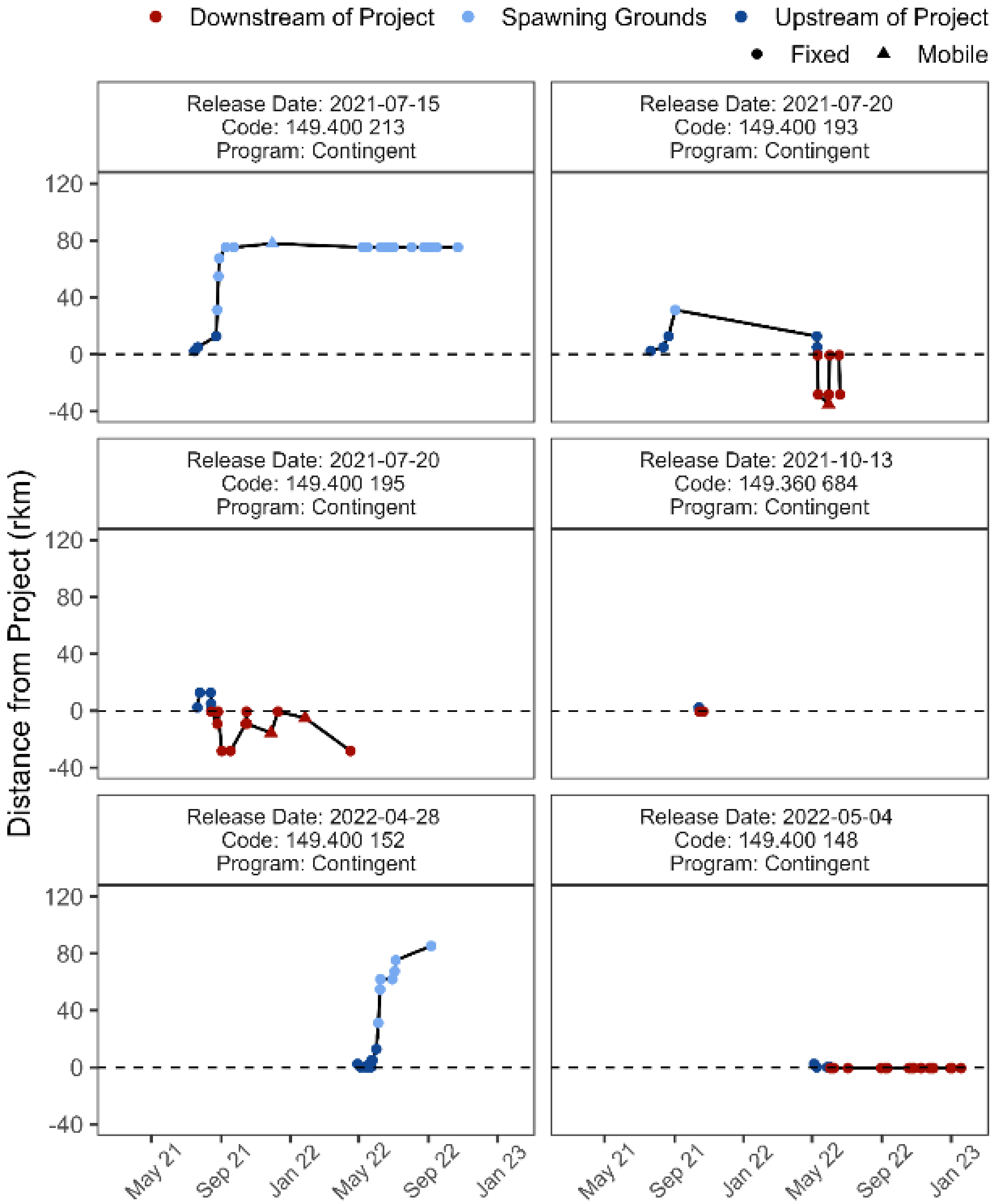


Figure K4 continued.

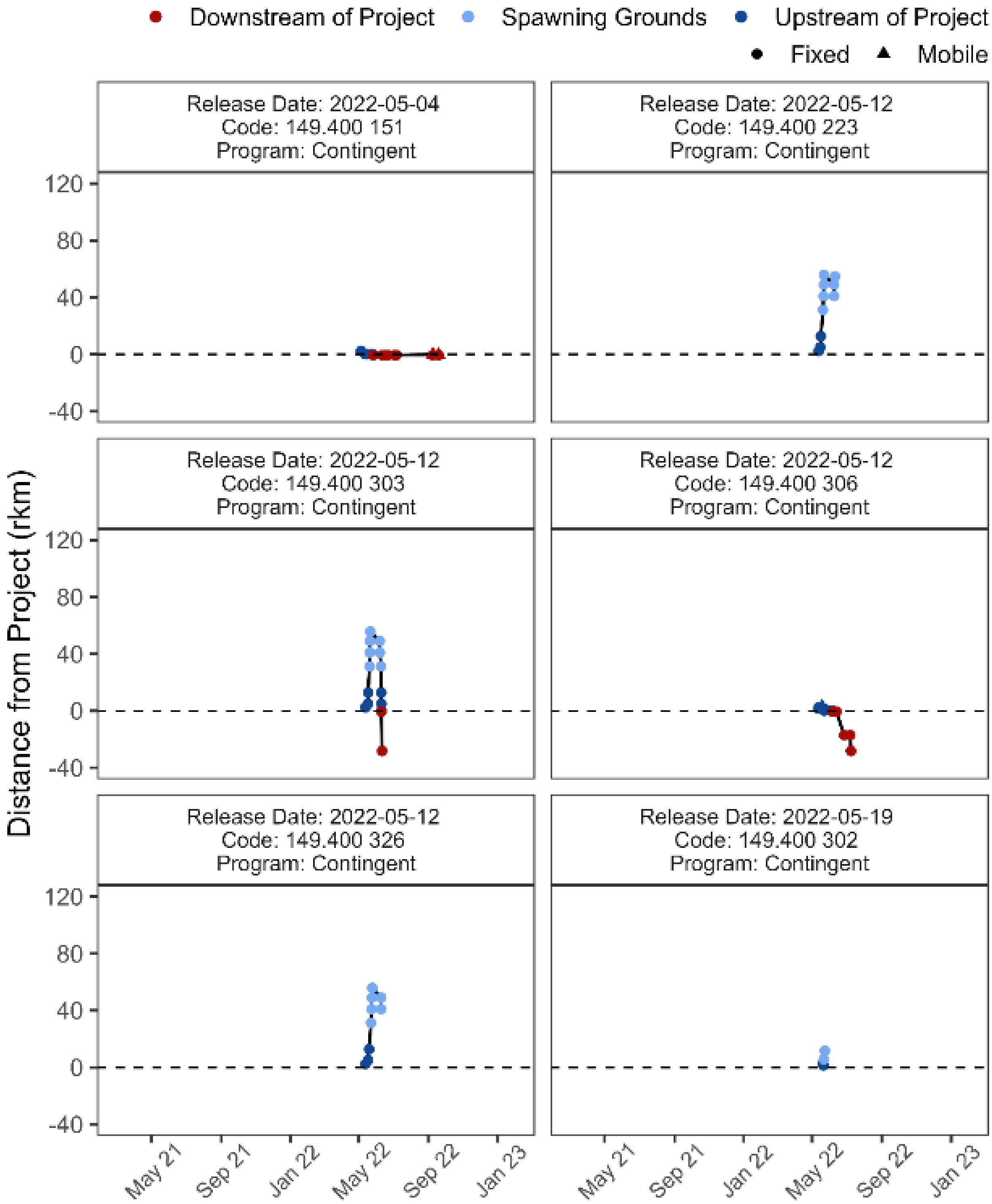


Figure K4 continued.

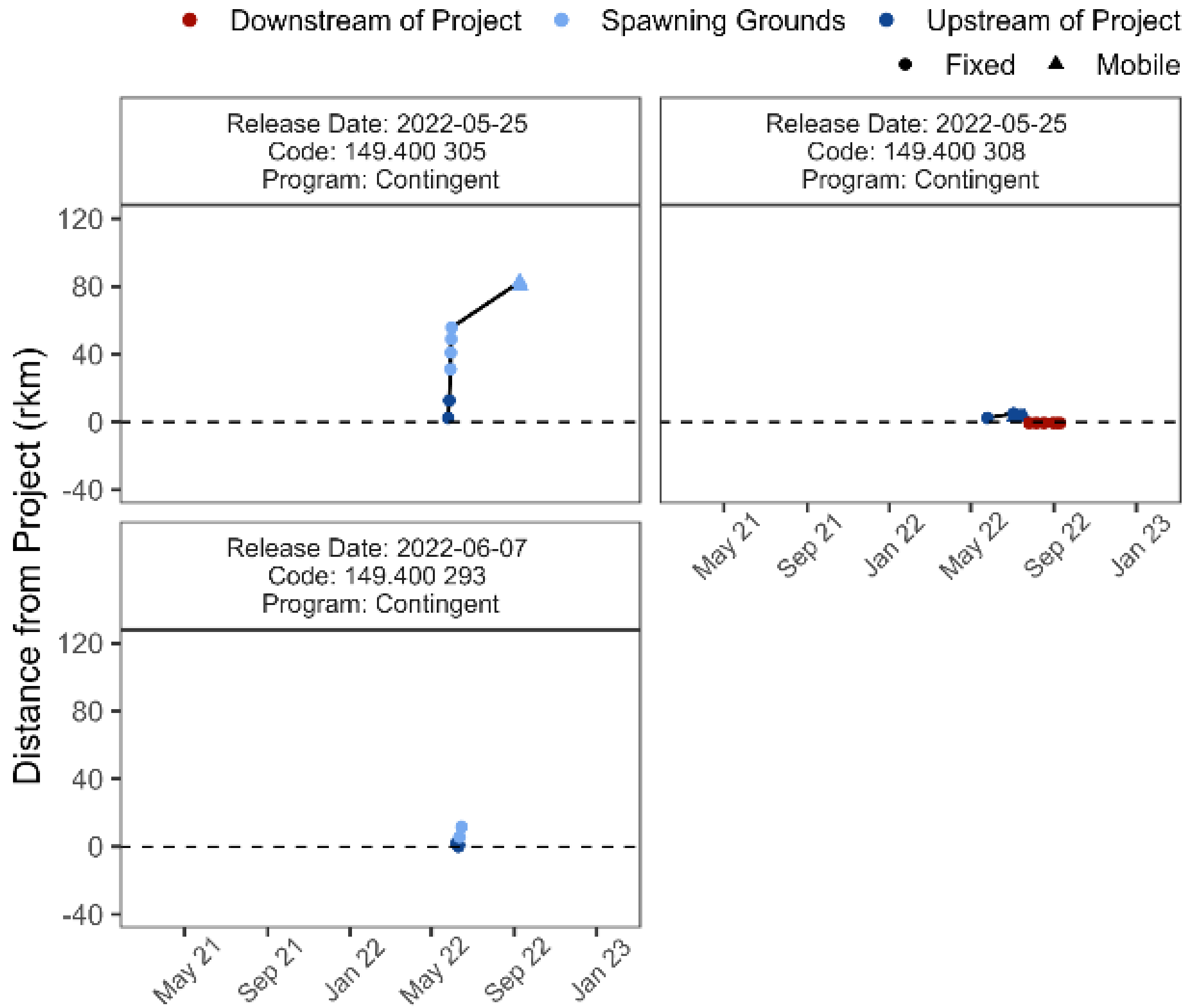


Figure K4 continued.