Site C Clean Energy Project

Site C Fishway Effectiveness Monitoring Program (Mon-13)

Construction Year 9 (2023)

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Executive Summary

Hydroelectric dams, such as that currently under construction at 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 operated the temporary upstream fish passage facility (TUF) annually from April 1 to October 31. The TUF consisted of a weir-orifice fishway (the “fishway”) that terminated in a trapping mechanism to a final pool (the “pre-sort holding pool”), from which fish were crowded and elevated into a sorting facility. Fish were sampled in the sorting facility, tagged, and sorted according to release location. Upstream transport was provided by truck. To facilitate use of the fishway, attraction flows were provided by an auxiliary water supply (AWS) flowing through two entrance gates, which was supplemented by a high velocity jet (HVJ) located adjacent to the fishway entrances. These two components of attraction flow were manipulated on a predetermined schedule to understand how to best facilitate attraction and passage among species.

Here we report findings from the Site C Fishway Effectiveness Monitoring Program (Mon-13), a component of the Site C Fisheries and Aquatic Habitat Monitoring and Follow-Up Program (FAHMFP). Implementation of Mon-13 began in 2020, and the first full year of data collection was 2021. Under this monitor, 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 downstream of the Project. Mon-13 aimed to address a management question related to whether the TUF provided effective upstream passage for target species attempting to migrate upstream during construction of the Project. Effective upstream passage was defined by two hypotheses stating that target fish species can locate and use the fishway, and that passage and attraction efficiencies are 80% and 76%, respectively. Attraction efficiency is the proportion of a given fish species that successfully approach and enter the fishway, whereas passage efficiency is the proportion of those entering the fishway that pass in completion. An additional key component of the program was understanding the effectiveness of attracting fish from the Peace River into the fishway, and the attraction flows required to do so. We present a synthesis of all data collected between 2021 and 2023.

Each year had unique challenges and there was substantial inter-annual variability in local environmental conditions. According to the raw numbers of time operational, time within design

criteria specification, and fish passed, 2023 was the most successful year to date. However, 2023 had distinct operational challenges not seen in other years including a common failure to reach the highest setpoints of attraction flows and more frequent shutdowns. Since April of 2021, 17,323 PIT-tagged fish have been detected on the array during operations, of which 439 also had radio tags. These numbers decreased when only considering the five target species detected outside of shutdown periods since 2021, the bounds for inclusion in our analyses: 3,085 PIT-tagged fish, 350 also with radio tags. We confirmed that all five target species can locate and enter the fishway and apart from Burbot, ascend to the upper three pools. A striking result that was consistent across species and years was the presence of a barrier between the upper pools of the fishway and the sorting facility, which required being captured by the crowder and lock at the upstream end of the pre-sort holding pool. Of the 28,512 that were detected entering the fishway, 43% of these were detected in the upper pools but only 7% of those known to make it to the upper pools ascended the fishway in completion (n = 895).

The simplest means of evaluating fishway effectiveness is with the metrics of attraction, passage, and trapping efficiency. Trapping efficiency was added to our analyses in 2022 in response to the barrier at the top of the fishway. Trapping efficiency refers to the proportion of fish reaching the upper fishway (defined as four uppermost pools) that pass through in completion to ascend into the sorting facility. Attraction efficiencies ranged from 0% (Burbot) to 33% (Bull Trout). Passage efficiencies, which were based on passage success estimates with very low sample sizes, ranged from 0% (Arctic Grayling) to 4% (Bull Trout) and could not be calculated for Burbot. For trapping efficiency, the best results were from Bull Trout and Mountain Whitefish, species for which sample sizes resulted in narrower confidence intervals. Of the fish that make it to the upper fishway, 9-14% of Bull Trout and 12-15% of Mountain Whitefish were trapped. Trapping efficiencies were 5% for Rainbow Trout and 21% for Arctic Grayling, with large confidence intervals. Unfortunately, the modifications made to the top of the fishway to improve trapping efficiency did not apparently lead to improved effectiveness – that is, trapping efficiency did not increase across years. Results confirmed that the top of the fishway was a barrier to the upstream movements of fish.

A more comprehensive means to assess fishway effectiveness is through time-to-event (TTE) modeling, which incorporates the time-varying operational and environmental factors that influence fishway use. Four models representing distinct state transitions (i.e., a movement between distinct spatial zones) were attempted for each species (but could not always be executed due to data limitations) consisting of an advance and retreat model for both approach to and entry of the fishway. Detection data were most abundant and reliable from Bull Trout and

Mountain Whitefish. As a result, models for these two species are the most informative and are a focal point of the report. River discharge or water surface elevations were included in most models with a consistent effect of reduced rates of advance to, and increased rates of retreat from the fishway as the amount of water increased in all three species with sufficient data to model these relationships (Bull Trout, Mountain Whitefish, and Rainbow Trout). The effect of river discharge was generally linear, with rates of approach towards the fishway gradually decreasing as flows increased; for every 100 m^3/s increase in flows, approach rates decreased by 13% (Bull Trout) to 17% (Rainbow Trout). These species are less likely to approach the fishway at high water levels. In terms of fishway entry, water surface elevation was more important than river discharge for Bull Trout, the only species will sufficient data to produce informative entry models. There was a decrease in entry rates at the highest elevations, which aligned with when the fishway would have been outside of design criteria.

A key objective of this research is to understand how fish respond to attraction flows. We have good evidence that increased attraction flows from the AWS effectively attract fish into the fishway. For Bull Trout, fishway entry was faster and retreat from the entry zone slower with higher AWS attraction flows and percentage of AWS attraction flows to river discharge, respectively. Findings were similar for Rainbow Trout (faster entry with higher percent total attraction flow to river discharge) and Mountain Whitefish (slower departure at higher attraction flows), though the relationships were not as clear. Two conclusions can be drawn from these collective results. For one, in no instance was the HVJ associated with advance or retreat rates, and it was rare for total attraction flow metrics (HVJ + AWS) to be included in models. We can conclude that the HVJ contributes little to no attraction to the fishway. Additionally, AWS attraction flows on the higher end of the range observed tend to be preferred among all species. However, because of pump failures in 2022 and 2023 and the use of the HVJ in 2021 and 2022, study fish had relatively less exposure to the maximum AWS attraction flows.

Consistent across most species, models, and years was the inclusion of fishway experience and diel period. Experience was described by the binary "naïve" variable, which indicated if an individual fish had previously made a given movement (e.g., between the entry zone and fishway). The naïve variable appeared in all selected models for Bull Trout and Mountain Whitefish and the selected Rainbow Trout approach models. It is expected that the direction of effect for variables that increase advancement towards the fishway will be opposing between advance and retreat models for a given zone. However, the effect of the naïve variable was unanimously positive. In all cases non-naïve tagged fish made faster movements in both the upstream and downstream direction (advance and retreat). A positive effect in both directions combined with low fishway passage rates indicates that experience is not associated with increased advance to the fishway but increased activity and faster movements in general. Fish are not learning how to pass the fishway. Similarly, the diel period variable, a two-level categorical variable of “day” or “night” was present as a negative effect in nearly all models, though it was not always statistically significant. A negative effect indicates slower rates of rates of upstream and downstream movement during nighttime hours. This was most apparent among Mountain Whitefish, for which nearly all movement occurred at much faster rates during daylight hours. The consistent inclusion of both experience and diel period across species may be related to ecological relationships that are models are not accounting for such as predation and/or feeding opportunities the fishway may be providing. The seven-month operational period of the TUF extends across varying seasonal activities for target species (e.g., spawning migrations, feeding, kelting) . It is likely that the fishway was used for more than just upstream migration. For example, the fishway could have also served as a reliable source of food. Accordingly, we discuss further analytical methods to consider, including multi-species models.

Our modeling approach identified attraction flows and other hydrological conditions that may facilitate better approach and entry among target species, particularly Bull Trout. These factors can be operationally managed to encourage entry into the fishway during migratory periods. However, we can conclude that the TUF did not provide effective upstream passage. While all target fish species can locate and use the fishway, efficiency metrics were far below the target, and the barrier at the top of the fishway resulted in poor passage overall. Data from the TUF provided a learning opportunity prior to operating the permanent upstream fish passage facility (PUF) once construction of the Project is complete, currently scheduled for the summer of 2024. Our results have informed the design and planned operations of the PUF and do provide optimism for improved fish passage at this facility.

Acknowledgements

We acknowledge this research is being conducted on the traditional territory of Treaty 8 First Nations of Dunne Zaa, Cree and Tse'khene cultural descent. The Site C Fishway Effectiveness Monitoring Program is funded by BC Hydro's Site C Clean Energy Project. We would like to thank Brent Mossop and Nich Burnett at BC Hydro for administering this project. All InStream Fisheries Research staff provided essential field and logistical support throughout the planning and execution of this monitor, most notably LJ Wilson, Cole Martin, Luke Irwin, and Jordan Bastin. Staff from LGL Limited and WSP Global Inc. have been invaluable collaborators. The assistance and continued support from Jason Smith, Kyle Hatch, and Dave Robichaud from LGL Limited, and Dustin Ford and Demitria Burgoon from WSP Global Inc. are greatly appreciated. We also thank the West Moberly First Nation, especially Kayla Brown for their contributions. Support provided by Ted Castro-Santos from the United States Geological Survey was instrumental to experimental design and analyses.

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1. Introduction

The Site C Clean Energy Project (the “Project”) is a third dam and hydroelectric generating station currently under construction on the Peace River in northeast British Columbia. To facilitate construction, BC Hydro began diverting the Peace River through diversion tunnels and, in October of 2020, began operation of the temporary upstream fish passage facility (TUF). The purpose of the TUF was to provide upstream fish passage from April 1 through October 31 during each year of the river diversion phase of the Project until reservoir filling occurs (currently planned for the fall of 2024). The TUF includes a weir-orifice fishway (the “fishway”) that terminates in a trapping mechanism to a final pool, where fish were elevated into a sorting facility. Once sorted according to release location, fish species to be transported upstream were hauled by truck to various locations. The TUF will be decommissioned once BC Hydro begins operating the permanent upstream fish passage facility (PUF).

One of the major consequences of large river obstructions is the altering of longitudinal habitat connectivity that is essential to the maintenance and expression of life history diversity among fish populations (Cooke et al. 2012). This is particularly true for migratory fishes seeking upstream areas to reproduce or feed. Hydroelectric dams are well-known for blocking the natural flow of rivers and pose considerable challenges for migratory fishes. The impacts of dams to the life cycles of fishes has eliminated species from river basins across the globe (Beamish and Northcote 1989; Nehlsen et al. 1991). Consequently, there has been extensive effort to create or improve passage for migratory fishes at barriers, especially at dams (Fuentes-Pérez et al. 2016; Burnett et al. 2017; Baumgartner et al. 2018). One of the biggest challenges is developing design concepts and structures that will effectively pass a broad range of species (Thiem et al. 2012; Silva et al. 2018; Birnie-Gauvin et al. 2019). Even within well-designed structures, not all fish will pass equally well (Caudill et al. 2007; Thiem et al. 2012; Bunt et al. 2012).

To be effective, fishways must attract fish to the entrance, enable fish to enter and swim upstream, and achieve both with minimal energy expenditure. Migrating fish are naturally drawn to areas of higher flow, which is a key determining factor in locating a fishway. Supplemental flows are generally required to attract fish to fishway entrances. Maintaining attraction flows that are appropriate for a diversity of fish species with different behaviours is a particularly challenging aspect of operating a fish passage facility. High flows consisting of excessive turbulence or water velocities can pose a challenge for many sizes and species of fish, can result in latent or indirect negative effects, and may cause migratory delays (Bunt et al. 2012; Burnett et al. 2014). 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 migratory period to understand how potential effects may differ among species present at a given time (Cooke and Hinch 2013).

The biological effectiveness of a fishway refers to how well the structure achieves its intended purpose of enabling fish to successfully navigate past an obstacle, in this case the Project. Fishway efficiency metrics (e.g., attraction and passage efficiency) are often seen as a benchmark of biological effectiveness. Attraction efficiency is the proportion of a given fish species that successfully approach and enter the fishway, whereas passage efficiency is the proportion of those entering the fishway that pass in completion. While efficiency metrics 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 and fails to inform factors that may influence fishway effectiveness. Therefore, we used 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.

Approach to a fishway, entry of the fishway, and successful passage can all be considered distinct state transitions experienced by individual fish (Castro-Santos and Perry 2012; Silva et al. 2018). 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 fish 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). The rate of each state transition is also influenced by time-varying environmental factors. Competing risk TTE survival analyses provides a framework to integrate these temporal components into assessments of opposing rates of movement across distinct spatial zones. Under this framework, factors that increase advance rates and/or decrease retreat rates between any two states will increase the biological effectiveness of a fishway.

1.1 Objectives and Management Questions

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 No’s. 8.4.3 and 8.4.4 for the Project. The Site C

Fishway Effectiveness Monitoring Program (Mon-13) is a component of the FAHMFP that began in 2020, the first year of TUF operations, and aims to inform the design and operation of the PUF.

A key component of the program is understanding the effectiveness of attracting fish from the Peace River into the fishway, and the attraction flows required to do so. Attraction flows at the TUF were provided by an auxiliary water supply (AWS) that flowed into the entrance pool and through the two entrance gates, and a high velocity jet (HVJ) that provided additional flow adjacent to the fishway entrance. Flows provided by the AWS could be programmed to various magnitudes up to 10 m^3/s and the HVJ could either be on (up to 1.5 m^3/s) or off. Combinations of these two components of attraction flow were experimentally manipulated on predetermined schedules throughout the monitoring program to better understand how differing attraction flows may be used to improve passage rates for target species. Radio and passive integrated transponder (PIT) telemetry were used to monitor the movements of five target fish 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, anglers, and local provincial management objectives.

The Project is a dynamic study site under active construction. Mon-13 has and will continue to be conducted within an adaptive framework – 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.

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 the 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%).

Through previous years of monitoring, we have learned that while all five target fish species can locate and use the fishway (H_1), passage rates are low (Cook et al. 2021; Moniz et al. 2022). Therefore, a new efficiency metric was added in 2022 that more accurately reflects the data available: trapping efficiency. Trapping efficiency refers to the proportion of fish reaching the upper fishway (defined as the four uppermost pools) that pass through in completion to ascend into the sorting facility.

The focus of this report is a multi-year synthesis analysis of H_2 and understanding factors associated with movements of fish within the fishway through TTE analyses.

2. Methods

2.1 Study Area

The Project is located within the Peace River, approximately 10 km southwest of Fort St. John, British Columbia. Originating in the Rocky Mountains, the Peace River is approximately 2,000 km long and flows to the northeast through northern Alberta, joining the Athabasca River in the Peace-Athabasca Delta. The study area is a small reach of the mainstem Peace River, including all riverine habitat approximately 1.5 river km downstream of the Project up to and including the TUF (Figure 1).

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 was divided into four zones to support a multi-state competing risk framework: 1) the 'outside approach', delineated when tagged fish left the study area; 2) the 'approach zone' delineated when tagged fish entered the study area and became candidates for fish passage; 3) the 'entry zone' delineated when tagged fish could

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

presumably detect attraction flows and reach the fishway entrance; and 4) the ‘fishway’ delineated when a tagged fish entered the fishway.

Considering the species assemblage expected to require upstream passage, a Half Ice Harbor weir-orifice fishway with a 1(V):10(H) slope coupled with trap and haul was selected as the most suitable design for the TUF (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. The fishway had two entrance gates, referred to as the west entrance and east entrance, that lead into an entrance pool (Figure 2). The HVJ is adjacent to the west entrance. There were 25 distinct pools, each with a weir and an orifice. Pool 14 was a turning basin, where ascending fish must make two 90-degree turns to continue upstream. The final pool (Pool 25) has a one-way trap on the upstream end that leads fish into a final pool (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). Fish held in the pre-sort holding pool until they were ascended via lift into the sorting facility by the facility operator. The lock was typically operated in the morning and the afternoon of each day, but this depended on the number of fish in the fishway and other operational constraints. An important consequence of this design feature is that passage from the pre-sort holding pool into the sorting facility was not volitional but occurred at distinct intervals at the discretion of the facility operator.

All fish that were crowded and lifted into the sorting facility were processed and sampled by the facility operator. Following sampling, fish were sorted according to release location and trucked to specific release locations.

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

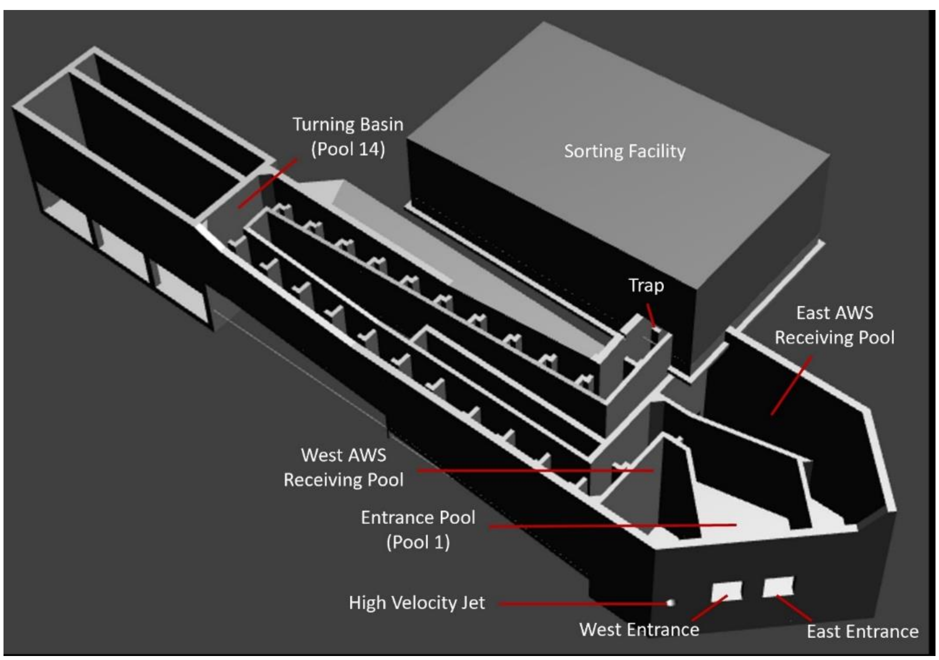

Figure 2. A drawing of the temporary upstream fish passage facility (TUF). Upstream migrating fish entered the fishway via one of the two entrance gates and ascended to the sorting facility for transport. Fishway attraction flows were provided by an auxiliary water supply (AWS) that flowed into receiving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

2.2 Fishway Operations and Environmental Conditions

Operational and environmental factors thought to facilitate or limit fish passage were monitored. During the 2023 operational period (April 1 to October 31, 2023) the auxiliary water supply (AWS) was experimentally manipulated to provide four distinct attraction flow scenarios (Table 1). This is different from previous years when attraction flows came from both the AWS and the high velocity jet (HVJ) which each varied to provide four distinct scenarios (Table 1). The HVJ was discontinued in 2023 because results suggested that the HVJ did not improve the ability of fish to approach and enter the facility and interfered with the functionality of PIT antennas. While this is a notable operational change, the schedule was designed such that total flow amounts remained consistent among years (i.e., the sum of the AWS and HVJ in 2021 and 2022 equaled the total AWS flow in 2023). Attraction flows changed three times daily in each scenario – at 00:00, 08:00, and 16:00 (Table 1). Some variability around the target AWS setpoint is expected because operation of the fishway must be changed continually according to environmental conditions (e.g., water surface elevations, river discharge, opening of entrance gates) to maintain AWS flows. Conversely, the HVJ is either on or off and is a consistent flow.

Hydrology within the study area also differed considerably among years due to upstream river operations and construction activities, particularly within the diversion tunnel outlet. The years of 2021 and 2022 were characterized by high river discharge and in preparation for reservoir filling in 2023, the operation of facilities upstream of the Project kept relatively low water levels. Also in preparation for reservoir filling, one of the two diversion tunnels was closed on June 15, 2023 to install orifice rings that reduced its diameter. Once the orifice rings were installed, the tunnel was reopened on October 14, 2023. The changes to river hydrology at the fishway because of these construction activities were dramatic, inevitably impacting how fish interacted with and moved through the area.

Environmental data were collected from a variety of sources. Sensors deployed throughout the TUF were used to collect flow, water surface elevation at the tailrace of the fishway (BC Hydro sensors LT_600 and LT_601), and water temperature within the pre-sort holding pool (BC Hydro 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). Sunrise and sunset times used to define diel periods were obtained using the 'suncalc' package in R (Thieurmel and Elmarhraoui 2022).

The TUF has been shut down for several reasons, most often because water levels exceeded the operational criteria. In 2023 there were seven shutdowns. While numerous, each of these shutdown periods were of shorter duration than in previous years. In 2023 the fishway was operational for 97% of the intended operational period, compared to 94% and 81% in 2022 and 2021, respectively. All data collected during shutdown periods were removed from datasets used in analyses.

Other changes to the fishway since operations began included physical modifications to the trapping mechanism at the top of the fishway and the addition of lights. The original trapping mechanism was a vee-trap, that was modified in August of 2021. In 2022 the vee-trap was replaced with a finger weir trap, that was also subsequently modified several times. Appendix A: Fishway Shutdowns and Modifications Fishway Operations includes details and timing of shut down periods and other operational changes. These changes may impact results but would be difficult to control for in our analytical approach (i.e., represent irreversible changes with no ability for systematic testing).

The TUF began operating on October 1, 2020. However, we do not include data from the first year of operations in our data summaries or analyses. A 10-day shutdown period was required in 2020 due to cold temperatures and, thus, the 2020 operational period was only 20 days during a time when few fish species are actively migrating upstream (except Mountain Whitefish). There were also fewer tagged fish at large within the watershed. Collectively this means that data from 2020 is very limited; a better understanding of fishway effectiveness is provided by only including data from April 2021 onwards.

Table 1. The schedule for attraction flows (m^3/s) within the temporary upstream fish passage facility for a single, four-day cycle. Attraction flows were provided from the auxiliary water supply (AWS) only in 2023, and by both the AWS and high velocity jet (HVJ) in 2021 and 2022. 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	08:00	16:00	0:00	08:00	16:00	0:00	08:00	16:00	0:00	08:00	16:00
2023	AWS	4.25	5.75	8.5	10	4.25	5.75	8.5	10	4.25	5.75	8.5	10
	HVJ	0	0	0	0	0	0	0	0	0	0	0	0
2021/ 2022	AWS	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	0	1.5	0	1.5	0	1.5	0	1.5	0	1.5	0	1.5

2.3 Telemetry Array Design

The radio telemetry array recorded tagged fish approaching and entering the fishway, and both radio and PIT technologies recorded movements within the fishway. Successful passage was confirmed by the facility operator that scanned all fish for PIT tags. All PIT and radio tags were deployed within the TUF and the watershed at large by other groups who are sampling and tagging fish as part of other components of the FAHMFP.

The radio telemetry array consisted of 11 fixed radio telemetry stations (hereafter ‘fixed stations’;

Table 2) deployed within the study area on the Peace River (Figure 3) and within the TUF (Figure 4). Each fixed station had either one or two 3-element Yagi aerial antennas (providing large detection areas, up to hundreds of meters depending on the settings), or either one or two submerged dipole antennas (providing small detection areas of approximately 3-10 m) for a specific defined area of interest. Fixed stations were programmed to scan between two alternating frequencies every 10 seconds, except for the entrance and entrance pool dipoles that each had two receivers scanning a single frequency. The PIT telemetry array consisted of nine antennas that were designed and fabricated by InStream Fisheries Research (

Table 3). There were four designs of PIT antennas: pass-through, pass-over, pass-under, and pass-by. Pass-through antennas were rectangular, detecting PIT-tagged on all four sides as they swam through. The other designs were one-sided, detecting PIT-tagged fish as they swam over, under, or beside the antenna. PIT antennas were custom built to fit key locations of the TUF and paired with submerged dipole antennas (Figure 4).

All fixed stations within the fishway were demobilized after the end of the operational period and deployed by April 1 of every year. Fixed stations outside of the fishway were operated outside of the fishway operational period. Additional details of fixed stations and PIT antennas including their construction, power requirements, and changes to the array through the four years of monitoring are further detailed in previous reports (Moniz et al. 2022; Cook et al. 2023).

Table 2. 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	Purpose
Outside LB	Outside approach	SRX800-MD4	Aerial	The combined detection range of these two fixed stations defined the outside approach, which determined when fish left and/or re-entered the array.
Outside RB	Outside approach	SRX800-MD4	Aerial	
Approach LB	Approach zone	SRX800-MD4	Aerial	The combined detection range of these two fixed stations formed the approach zone gate, which delineated 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	
Tunnel outlet	Approach zone	SRX800-MD4	Aerial	Determined if fish were approaching the diversion tunnel outlet prior to or instead of the fishway entrance.
Entrance aerial	Approach zone	SRX800-MD4	Aerial	Determined if fish were nearing the fishway entrance.
Outside entrance	Entry zone	SRX1200-MD2	Dipole	Defined the entry zone.
Entrance pool	Fishway	SRX1200-MD2	Dipole	Determined if tagged fish entered the fishway.
Pool 8	Fishway	SRX1200-MD2	Dipole	Determined if fish reached pool 8 of the fishway.
Turning basin	Fishway	SRX1200-D2	Dipole	Determined if fish reached the turning basin (pool 14) of the fishway.
Trap	Fishway	SRX1200-D2	Dipole	Determined if fish reached pool 25 of the fishway.

Table 3. The purpose and type of passive integrated transponder (PIT) antennas deployed at key locations throughout the temporary upstream fish passage facility.

Antenna Name	Type	Purpose
West entrance	Pass-through	These antennas framed each entrance of the fishway and determined if tagged fish were near (< 1m) the fishway entrances.
East entrance	Pass-through	
Weir 8	Pass-through	Determined if tagged fish used the weir going into pool 9.
Orifice 8	Pass-under / Pass-over	Determined if tagged fish used the orifice going into pool 9.
Weir 23	Pass-over	Determined if tagged fish used the weir going into pool 23.
Orifice 23	Pass-under	Determined if tagged fish used the orifice going into pool 23.
Weir 24	Pass-over	Determined if tagged fish used the weir going into pool 24.
Orifice 24	Pass-under	Determined if tagged fish used the orifice going into pool 24.
Trap	Pass-by	Determined if tagged fish passed into the pre-sort holding pool.

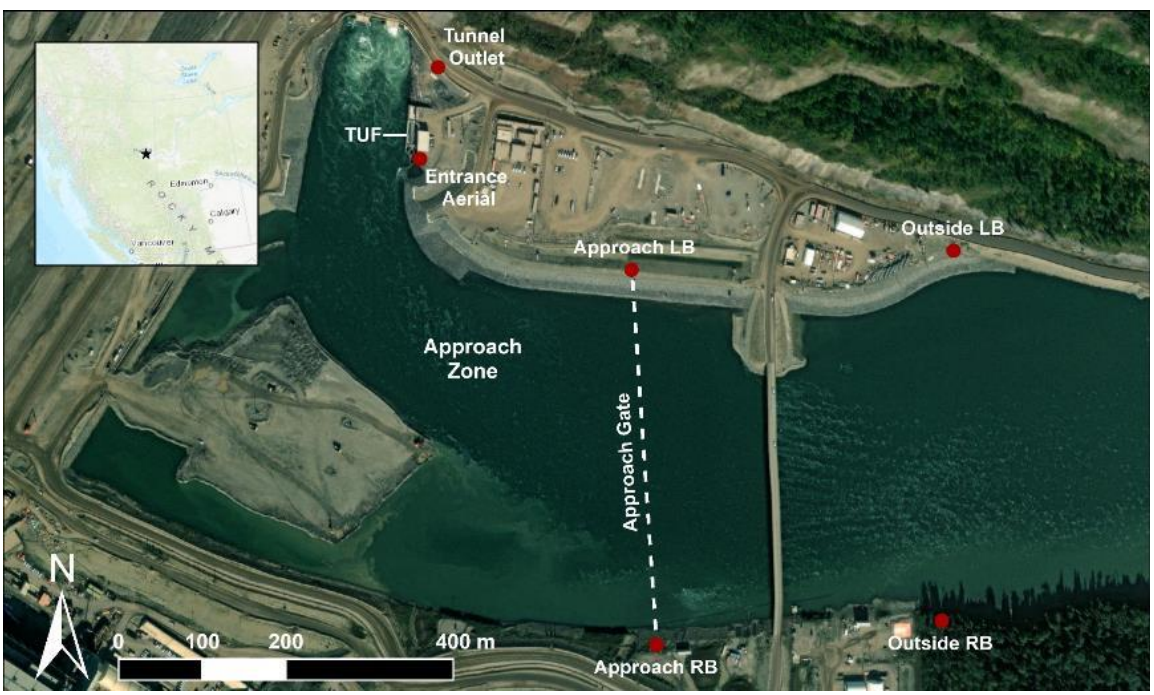

Figure 3. The six aerial fixed radio telemetry stations deployed along the left bank (LB) and right bank (RB) of the mainstem Peace River and used to detect radio-tagged fish approaching the temporary upstream fish passage facility.

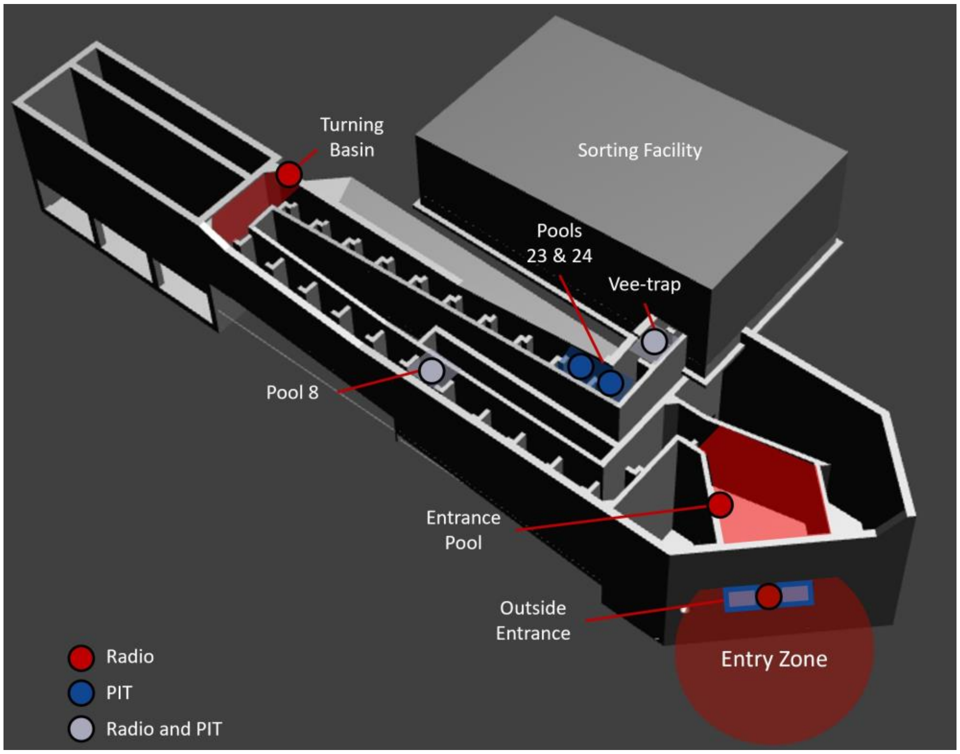

Figure 4. Diagram of detection points via dipole fixed radio telemetry stations and passive integrated transponder (PIT) antennas within the temporary upstream fish passage facility. The target detection areas are shaded.

2.4 Testing Array Performance

2.4.1 Fixed Radio Telemetry Stations

Range testing of fixed stations downstream of the TUF has occurred annually since 2021 in collaboration with WSP Global Inc. (WSP). The four approach and outside approach LB and RB fixed stations were tested by drifting test tags via jet boat (see detailed method in Hatch et al. 2023). To test the dipole antennas within the fishway, 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) only; settings have remained identical since. The tunnel outlet and entrance aerial fixed stations have not been tested because boat access was not permitted within the diversion tunnel outlet due to hazardous conditions.

Additionally, a beacon tag (MFT-3B, Lotek Wireless) was installed at or near each fixed station to monitor for 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).

2.4.2 PIT Antennas

PIT antennas underwent extensive testing prior to installation, immediately following installation, and approximately weekly throughout each annual operational period. Given our interest in how attraction flows influence fish passage success, the original intent of testing was to understand how fishway operations impacted PIT antenna performance. We determined that the HVJ severely impacted the performance of the PIT antennas, particularly at pool 8 (Cook et al. 2021; Moniz et al. 2022), which factored into the decision to cease operation of the HVJ. Testing was performed using 12-, 14-, 23-, and 32-mm HDX PIT tags, and we established that antenna performance improved with increasing tag size. Testing continued in 2023 with 32-mm tags only with the objective to understand how antenna performance differed among antenna designs, locations, and years, which informed antenna design for the PUF.

To test the PIT antennas within the fishway, a test tag housed within a section of PVC pipe (to maintain proper tag orientation) was affixed to a 5-m aluminum rod and used to measure the maximum distance from each antenna the tag could be detected (read range). Read range was measured according to the design of the antenna (e.g., directly above ‘pass-over’ antennas, directly below ‘pass-under’ antennas) and calculated as a percentage of the full read range for that antenna (Table 4). Here, full read range is defined as the maximum possible distance from an antenna that 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, full read range was set at 30 cm. This distance reasonably covered the area above the antenna where fish would be expected to pass over and allowed for 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, Kruskal-Wallis tests were used to assess statistical differences among years for each antenna.

Table 4. 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
Trap	Side edge outward horizontally towards opposite end of trap	30

2.5 Telemetry Download and Data Management

All telemetry stations were downloaded approximately every two weeks during the operational period. Raw radio telemetry download files were transferred monthly to LGL Limited (LGL) to be included in the Site C Fish Movement Assessment Radio Telemetry Database and to BC Hydro, providing further backup. Various parties 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 TUF between 2020 and 2023 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. 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 Fisheries Research managed all fixed stations described in Section 2.3, except for the outside RB fixed station, which was managed by LGL. Distinct databases were maintained by Palmer, InStream, WSP, and LGL, and data compilation efforts were collaborative (Figure 5).

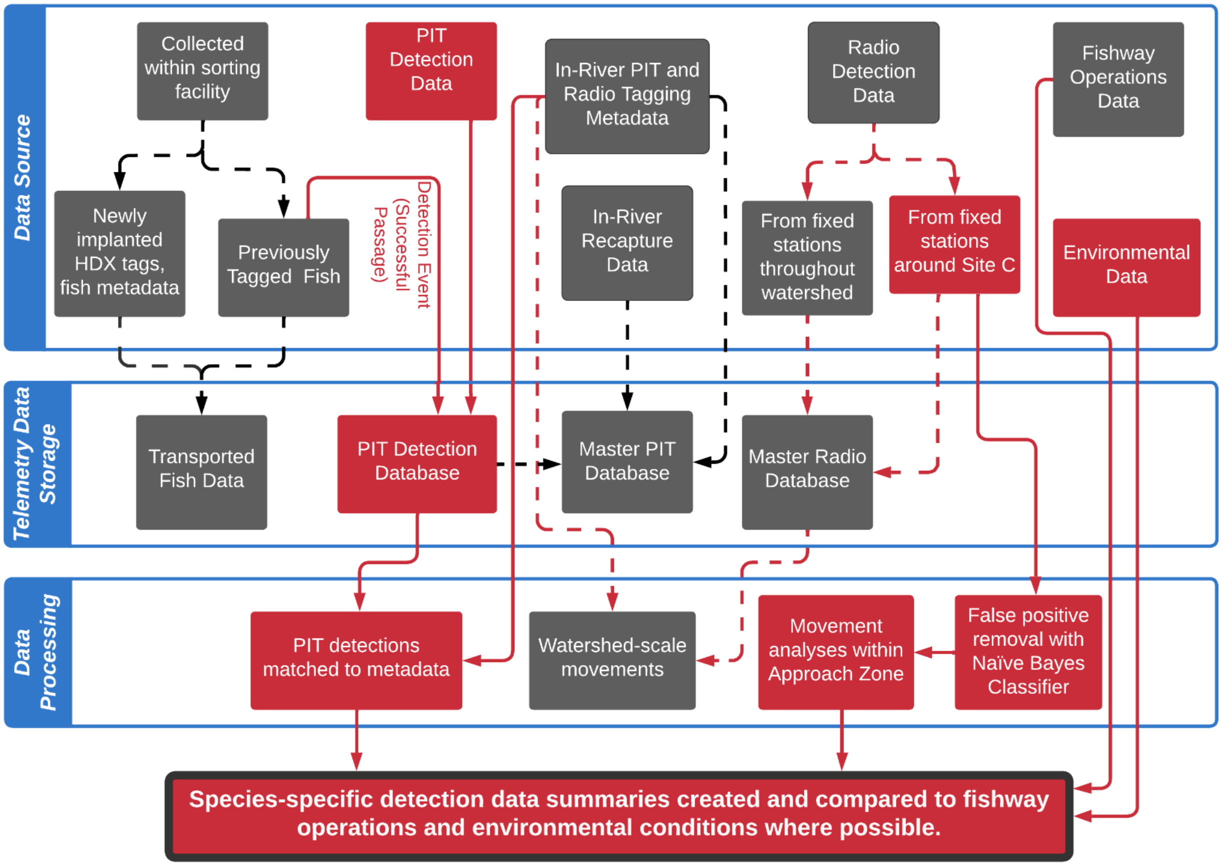

Figure 5. The process of data collection, storage, and processing within the Site C Fisheries and Aquatic Habitat Monitoring and Follow-up Program (for components relevant to the data in this report). Red boxes represent data held by InStream Fisheries Research Inc. (InStream), while grey boxes represent data held by other collaborating consultants. Red arrows indicate data processes conducted for Mon-13, solid arrows indicate those conducted by InStream, and dashed arrows indicate those conducted by other consultants.

2.6 Telemetry Data Processing

2.6.1 Data Filtering

Radio telemetry data from the six aerial fixed stations were filtered using Movement Analysis Software for Telemetry (MAST), an open-source algorithm that provides a transparent and repeatable method for false-positive identification and removal in radio telemetry detection data (Nebiolo and Castro-Santos 2022). The framework is comprised of a supervised learning algorithm based that uses a naïve bayes classifier to identify and remove false-positive detections using training data. 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 5). 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 remaining data. 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 MAST 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 had very few false-positive detections, too few to use the MSAT method. Dipole data had to be manually filtered. To do this, all detections of tags known not to be in the watershed, noise detections (i.e., 999 codes), and single detections at given station not detected elsewhere were removed. Filtered datasets for all 11 fixed stations were then combined into a single dataset.

Additional filtering on the combined dataset was undertaken to ensure that all detections from within the fishway were from tagged fish within the fishway and not nearby, outside of the fishway. Through this process we ensured that detection histories were logical. The entrance pool fixed station detected some tagged fish known to be in pool 25 near the trap fixed station; therefore, detections at this station that came directly before or after a detection at the 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.

All PIT detection data collected from all antennas since 2021 were collated and filtered to remove all test and false positive ‘ghost’ tags. The remaining dataset was cross-referenced with WSP’s master database, which includes all known PIT tags deployed within the watershed by all agencies. While we have completed this process annually, we chose to re-search tag codes detected in previous years because WSP’s database is constantly updated as new information is received. The search was conducted on November 29, 2023. Detections of 39 tag codes that could not be identified were removed from the final dataset and were not included in analyses.

Table 5. 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

2.6.2 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 behaviour (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 (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.

2.7 Analyses

2.7.1 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.

For each state transition and species, we evaluated how environmental factors, including supplementary attraction flows, influenced competing rates of advancement and retreat from the approach zone (approach and withdraw), as well as advancement and retreat from the entry zone (entry and departure; Figure 6). Competing models could not be built for the final zone of 'fishway' due to a lack of successful passage events into the sorting facility. Additionally, fish were considered to have successfully passed the fishway once they were crowded into the fish lock and processed by the facility operator and cannot continuously pass between the fishway and the sorting facility at volition. Once fish enter the pre-sort holding pool of the TUF they must hold until they are ascended via lift into the sorting facility at discrete periods (see description in section 2.1), which would encompassing multiple hourly and sub-hourly sets of time-varying covariates (exposure intervals).

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 into 1-hour 'exposure intervals', where a mean value for each covariate was calculated and assigned to each hour of the day. During changes in daily diel periods (e.g., day to night), intervals were divided into two sub-hourly intervals. Therefore, there were a minimum of 26 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 if it became inactive.

State transition rates were calculated for each tagged fish, as follows:

- Approach (advance from approach zone to entry zone): Duration from start of candidacy to first detection at the entry zone.
- Withdraw (retreat from approach zone): Duration between first and last detection within approach zone before retreating into outside approach zone.
- Entry (advance from entry zone into fishway): Duration from first detection at the entry zone to first detection within the fishway (i.e., at the entrance pool fixed station). If a fish was missed by this first station, it was excluded because exact entry timing, and conditions at time of entry, were unknown. All movements within the candidacy zone between first detection at the entry zone to first detection within the fishway were included. That is, a fish could leave the entry zone and enter the approach zone multiple times prior to fishway entry.
- Departure (retreat from entry zone): Duration between first and last detection within entry zone before retreating into the approach zone.

A single fish could transition between the same two zones more than once during a given occupancy on the array. The number of transitions for each movement type was assigned a sequential number for each individual within each year.

To account for the statistical dependence among repeated movements from the same fish, state 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 transition rates (Goerig and Castro-Santos 2017). Eleven explanatory variables were considered as fixed effects in candidate models (

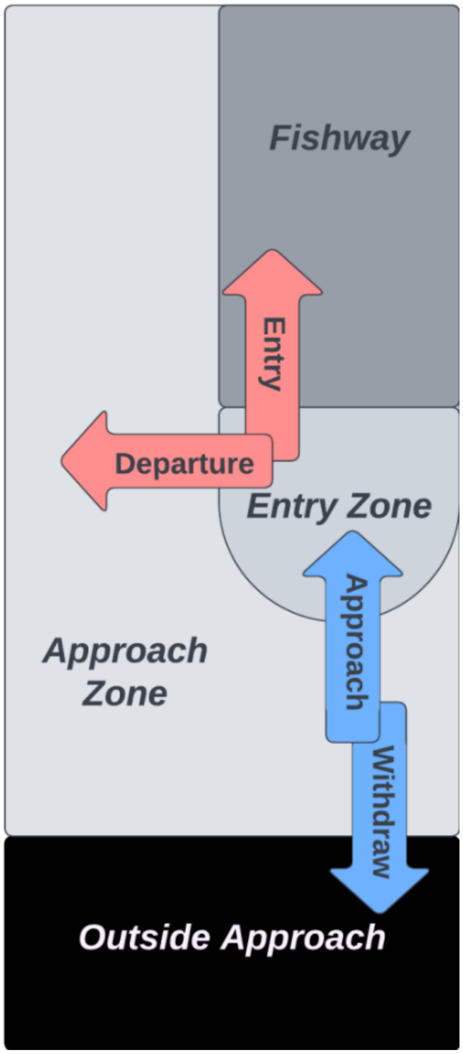

Figure 6. Schematic of competing risks framework for time-to-event analyses. Each spatial zone represents the transitional states between which tagged fish can move. Tagged fish become candidates for the analysis once in the approach zone. Paired state transition models are colored accordingly. Figure adapted from Alcott et al. (2021).

Table 6). Water temperature was collected but not included as a predictor of fish movement in analyses because it was correlated with many other covariates of direct interest.

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 used in analyses has varied from year to year as more data is collected.

To identify important covariates, a suite of candidate models consisting of all combinations of fixed effects was built for each fish species and state transition (sample size permitting) while ensuring no model contained correlated variables ($r > 0.4$) or variables with logical linkages (e.g., AWS attraction flows and total attraction flows). Models were 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. A categorical year effect (2021, 2022 or 2023) was mandatory in all models. This resulted in a maximum of 132 candidate models.

Candidate models were selected by minimizing the Akaike's information criterion (AIC) while maximizing consistency between competing state transitions (e.g., approach and withdraw, entry and departure). 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. Model diagnostics of selected models were evaluated by several means. Schoenfeld residuals were examined to confirm that effects were consistent over time (assumption of proportional hazard; Hosmer and Lemeshow 1999). The distributions of random effects were evaluated visually for normality and the variance of the random effect was considered.

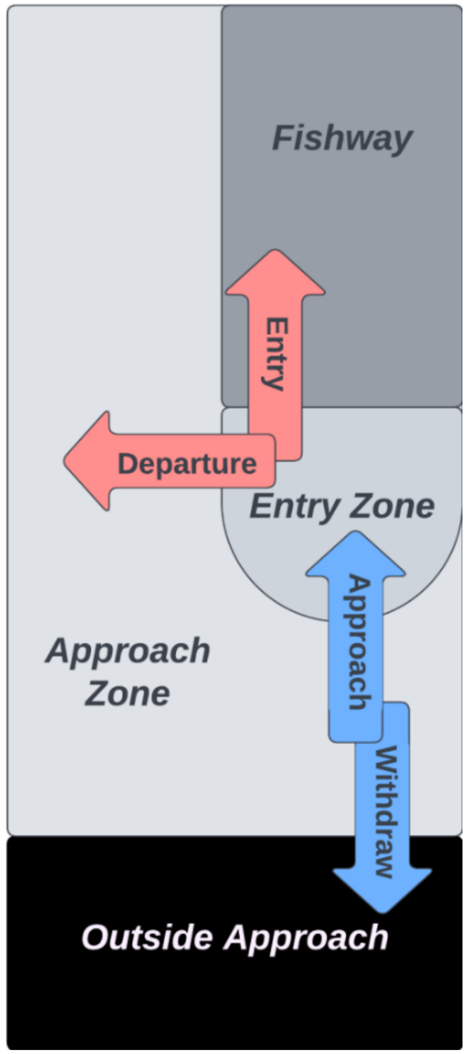

Figure 6. Schematic of competing risks framework for time-to-event analyses. Each spatial zone represents the transitional states between which tagged fish can move. Tagged fish become candidates for the analysis once in the approach zone. Paired state transition models are colored accordingly. Figure adapted from Alcott et al. (2021).

Table 6. All possible explanatory variables used in Cox regression models to evaluate time-to-event behaviour in a multi-state competing risk framework.

	Factor	Description
Activity	Transitions	The cumulative number of advance or retreat transitions per individual (including those observed during shutdown periods) within a given operational year. This number increased each time an individual left the zone of interest and then returned (e.g., a fish approached the entry zone, departed, and then entered again). This variable is log-transformed to reduce the influence of outliers.
	Naïve	A binary coding of number of transitions to represent if the fish has made the movement once (naïve) or more than once (non-naïve) during a given operational year.
Temporal Variation	Season	Three-level ordered categorical variable, including spring, summer, and fall. Spring ran from the beginning of the operational period (April 1) to June 19, summer from June 20 to September 21, and fall from September 22 to the end of the operational period (October 31). Linear and quadratic contrasts are tested. The linear contrast tests for a linear increase or decrease in state transition rates across seasons. The quadratic contrast tests for a curvature in the response.
	Diel Period	Categorical variable of 'day' or 'night'. Daily transition times between periods were obtained using the 'suncalc' package in R (Thieurmel and Elmarhraoui 2022). Night was defined as any time when the sun is below the horizon (sunset, when sun disappears below the horizon to sunrise, when top edge of the sun appears on the horizon).
Attraction Flow Terms	AWS	Median hourly AWS discharge. Values recorded at the TUF.
	Total Attraction Flow	Median hourly combined attraction flow (AWS + HVJ)
	Percent Attraction Flow	Median hourly combined attraction flow (AWS + HVJ) divided by the mean hourly Peace River discharge expressed as a percentage.
	Percent AWS Flow	Median hourly AWS divided by the mean hourly Peace River discharge expressed as 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).
Year	A mandatory categorical variable in every model (2021, 2022, 2023).	

2.7.2 Fish Movement Summaries

The known low detection efficiency of PIT antennas and substantial milling behaviour of fish within the fishway precluded our ability to analyze PIT detection data in a way that accounted for individual directional movements, as done with radio detection data. With performance of the entrance antennas being particularly poor, we had little confidence in determining when an occupancy on the PIT array ended and when a new one began. Instead, radio and PIT data from within the fishway were combined across all years and raw numbers of tagged fish summarized. If a fish was scanned by the facility operator, it was considered a new individual if it re-entered (i.e., was transported, returned downstream of the Project, and re-entered the fishway). Categorizing the fishway into linear zones – entry zone, entrance pool, pool 8, upper fishway (pool 23, 24 and trap), and sorting facility – we calculated the number of fish known to make it to each point. If a tagged fish was first detected in the upper fishway we know it went undetected at some point at all downstream locations. Visualizing these summaries may reveal barriers in the fishway.

2.7.3 Efficiency Metrics

Fishway efficiency metrics were obtained from radio detection data for each species. Attraction efficiency was calculated as 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. PIT telemetry data were used to determine trap efficiency, the proportion of tagged fish that reached the upper fishway (pool 23, 24 and trap) that were scanned in the sorting facility. This metric evaluates effectiveness of the upper fishway\.

The Wilson Score Interval was used to quantify uncertainty in all proportional estimates. The Wilson method applies a transformation to the normal approximation formula, to accommodate for the loss of coverage typical of other confidence intervals. The Wilson Score interval adjusts for small sample sizes and extreme proportions by modifying the standard binomial confidence interval formula. It centers the interval around a weighted mean of the observed proportion and the expected proportion, incorporating the critical value to account for the confidence level (0.95).

A Yate's continuity correction was applied, which results in more accurate confidence bounds, particularly when the sample size is small or the proportion is near 0 or 1.

All analyses were performed in R Studio version 4.3.0 and statistical significance was evaluated at a p-value of 0.05.

3. Results

The results provided herein focus on the data identified as being important to the movement of tagged target fish species through exploratory analyses conducted annually since 2020. More detailed data for each year can be found in annual reports for 2020 (Cook et al. 2021), 2021 (Moniz et al. 2022), and 2022 (Cook et al. 2023).

3.1 Fishway Operations and Environmental Conditions

3.1.1 Attraction Flows

Attraction flows from the AWS varied around targets due to operational or environmental constraints. In 2023, AWS attraction flows were scheduled to alternate between 10 m^3/s, 8.5 m^3/s, 5.75 m^3/s, and 4.25 m^3/s. However, the highest flow target was often not achieved. Attraction flows of 10 ± 0.5 m^3/s were only met for 9.5% of the operational period, whereas these flows were scheduled for a quarter of the time. When the HVJ was in use (2021 and 2022), it either provided 1.5 m^3/s of flow with no variability or was off. Overall, the magnitude of total attraction flow (AWS + HVJ) was reduced in each year: mean (± standard deviation) by operational year was 6.84 ± 2.41 m^3/s (2021), 6.17 ± 2.24 m^3/s (2022), and 5.94 ± 2.32 m^3/s (2023). Attraction flow by source (HVJ or AWS) and year are provided in Appendix B: Attraction Flows by Year.

Attraction flows from the AWS (Figure 7) provided the best multi-year comparison, as the AWS produced a greater magnitude of flow (up to 10 m^3/s vs. 1.5 m^3/s for the HVJ) directly from the entrance gates (the HVJ is to the side) in all years. A few notable patterns emerged. Attraction flows seemed to best follow target operations in April and were most variable in June. Additionally, pumps often failed to reach maximum attraction flows, particularly in 2023. The exception was in early April, September, and early October, when maximum flows were regularly met in all years. Flows dropped considerably after mid-October in 2023. A similar pattern emerged in 2022 after September 28 when pumps 1 and 2 were shut down.

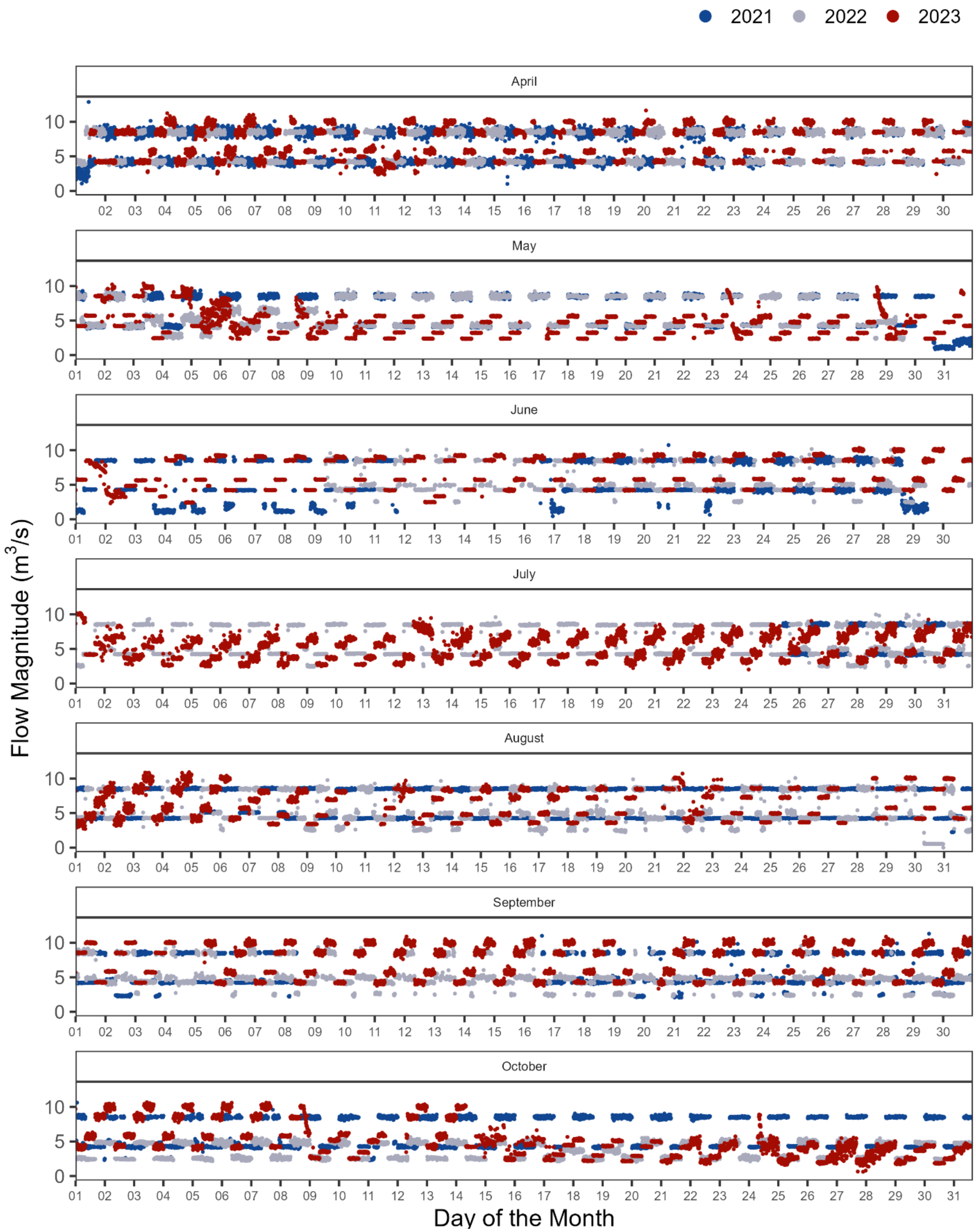

Figure 7. Attraction flows from the auxiliary water supply recorded every 10 minutes from the temporary upstream fish passage facility during the operational period in 2021 (blue), 2022 (grey), and 2023 (red). Only data from when the fishway was operational is shown (i.e., shutdown periods are excluded). Data provided by BC Hydro.

3.1.2 Hydrology

Overall, the first two full years of monitoring (2021 and 2022) had similar hydrological conditions with high discharge and high variability. While the 2023 hydrograph was characterized by lower discharge and less variability.

Hydrological conditions, represented by discharge in the Peace River and water surface elevation at the tailrace, were variable within and among years. Like previous years, April 2023 exhibited high flows (> 1500 m^3/s) with a maximum discharge within the range of previous years (1900 m^3/s; Table 7). However, unlike previous years, subsequent discharge increases were smaller in 2023 and discharge was lower overall (Figure 8). For example, in 2021, maximum flows occurred in July during a period of sustained high discharge that persisted through much of the month (and a resulted in a lengthy shut down period). While in 2022, there was no summer peak, but discharge of 1000-1500 m^3/s occurred throughout late summer and fall. Conversely, in 2023, discharge remained below 1000 m^3/s for much of the operational period after the peak in April. These patterns were also reflected in water surface elevations, which are correlated with discharge. The upper limit of the design criteria of the fishway is 410.5 m, a level that was exceeded for 104 days in 2021, 125 days in 2022, and 24 days in 2023 (Table 7). A cautious approach was taken to operating the fishway in 2021 (the first full season of operations) and it was often shut down due to high flows. The fishway was shut down less frequently in 2022, despite water surface elevations often being outside of the design criteria. While in 2023, water levels were nearly a meter lower than prior years and the fishway was most often operated within the design criteria.

Rapid fluctuations in river discharge were common across all years (Table 7). The maximum daily change in discharge was 836 m^3/s to 909 m^3/s among years. The greatest variability was in August in 2021 and 2022, and in April 2023. Overall, the mean daily change in discharge was approximately 200 m^3/s in 2021 and 2022, and 141 m^3/s in 2023. The magnitude of discharge variability was not considered in our analyses, but values highlight the dynamic nature of the environment and importance of considering instantaneous conditions during movements of interest.

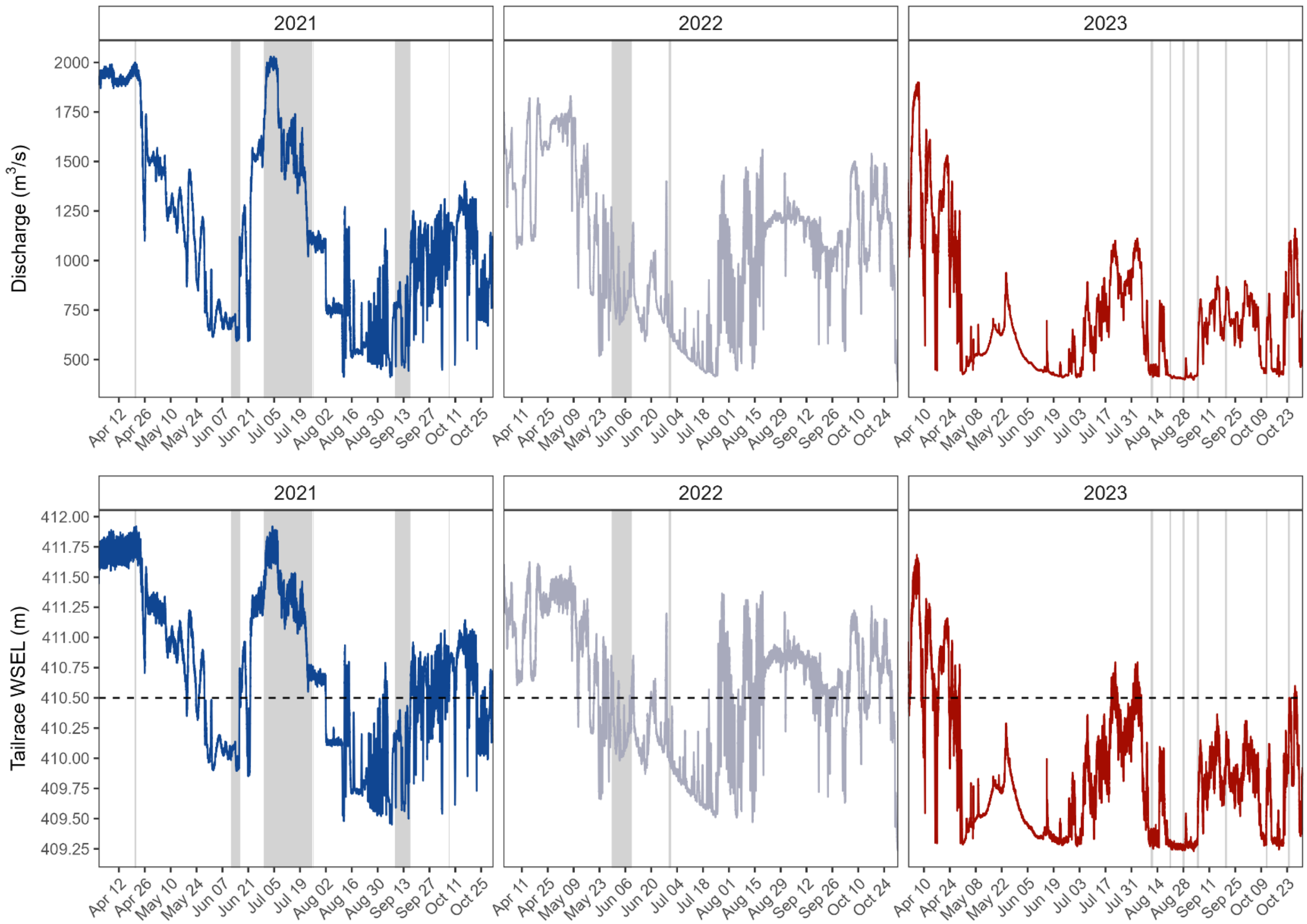

Figure 8. Peace River discharge measured at the Water Survey of Canada gauge at Peace River above Pine River (07FA004) in 2021 (blue), 2022 (grey), and 2023 (red). Water surface elevation (WSEL) was calculated as the mean water level recorded between sensors LT-600 and LT-601 located in the tailrace of the temporary upstream fish passage facility (data provided by BC Hydro). The horizontal dashed lined on the bottom panels indicates the upper limit of the design criteria of the fishway (410.5 m). Grey shaded areas indicate shutdown periods.

Table 7. Annual summary statistics of hydrological conditons at the temporary upstream fish passage facility. Water surface elevation data provided by BC Hydro. Days above criteria refers to the number of days above 410.5 m, the upper limit of the design criteria of the fishway (the operational period between April 1 and October 31 consists of 213 days). Peace River discharge was measured at the Water Survey of Canada gauge at Peace River above Pine River (07FA004).

Year	Water Surface Elevation (m)				River Discharge (m^3/s)				
	Avg.	Min.	Max.	Days above criteria	Min.	Max.	Avg.	Max. Daily Change (mm-dd)	Avg. Daily Change
2021	410.7	409.5	411.9	104	411	2030	1156	856 (08-12)	212
2022	410.6	409.2	411.6	125	389	1830	1066	909 (08-19)	235
2023	409.8	409.2	411.7	24	398	1900	710	836 (04-11)	141

3.1.3 Interannual Variability

We conducted exploratory assessments of interannual variability among environmental and operational data to better understand data structure prior to completing the larger multi-year multivariate analyses. Given the amount of data, statistical tests revealed high significance ($p < 0.5$) of all main effects (Figure 9) and post hoc comparisons (data not shown). River discharge and water surface elevations were greater in 2021 and 2022 relative to 2023. Total attraction flows (AWS + HVJ) significantly decreased with each subsequent year. This can be explained by pump failures in 2022 and by the lack of HVJ flows in 2023. However, given the lower river discharge in 2023, the percentage of attraction flow to river discharge was highest in 2023. Attraction flows from the AWS were greatest in 2023, followed by 2021 and 2022.

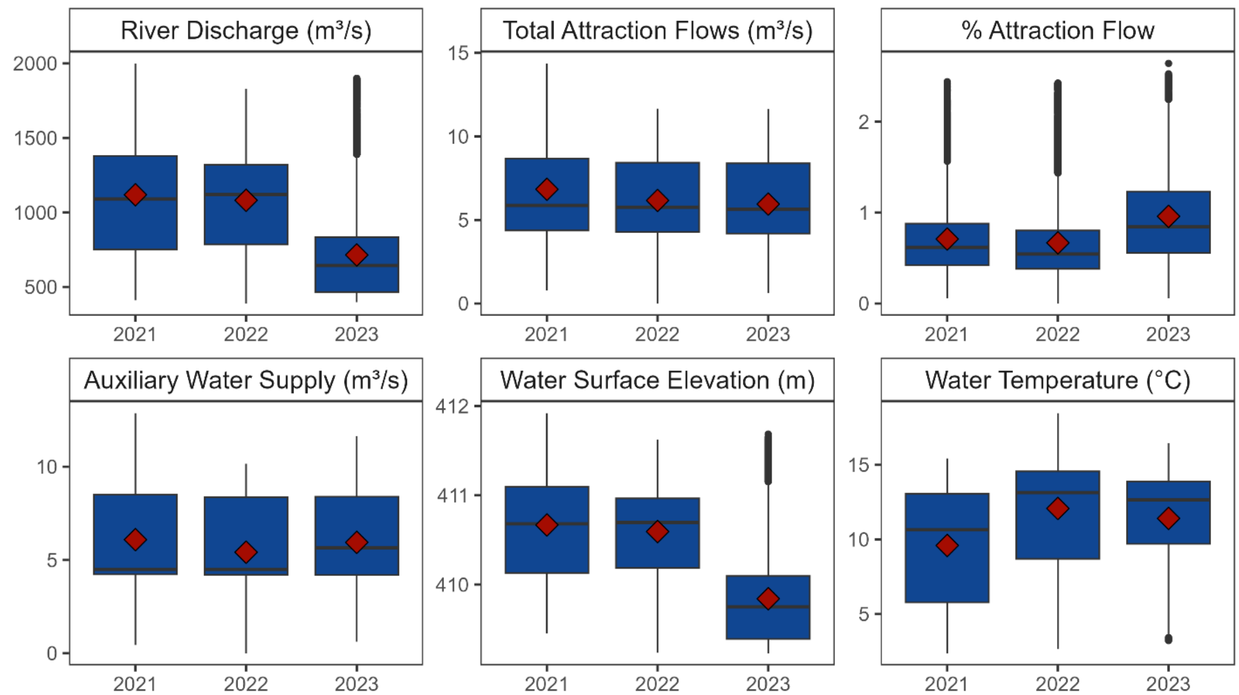

Figure 9. Distributions of key operational and environmental parameters by operating year at the temporary upstream fish passage facility. Total attraction flows represent the combined flow from the auxilliary water supply and supplementary high velocity jet. Total attraction flow as a percentage of Peace River dischange is also shown. Boxes show interquartile range and median. Whiskers extend to 1.5x the interquartile range and points show outliers. The red diamond shows the mean. River discharge data from Water Survey of Canada gauge 07FA004. All other data provided by BC Hydro.

3.2 Telemetry Array Performance

3.2.1 Fixed Radio Stations

The detection range of fixed stations downstream of the fishway (i.e., outside approach and approach zone) was assessed in all three years using boat drifts. The objective of testing was to ensure that the combined detection range of paired receivers at each location spanned the full river channel width (Figure 10). Results were similar in 2021 and 2023, indicating an overlapping detection range of approximately 150 to 200 m at the two sets of paired stations. Results differed in 2022; the approach zone stations overlapped by approximately 50 m and the outside approach stations did not overlap at all. The reason for this discrepancy is unknown. Note that test tags were deployed 1 m below the water surface during testing, and so results are not directly comparable to radio-tagged fish that presumably would have been located deeper in the water column.

There were no outages of concern during the 2021 or 2022 operational periods, but there were periods of data loss in 2023. Data from June 21 to July 7 from four stations (outside entrance, pool 8, turning basin, and trap) was lost. Additionally, there was a known outage due to user error at the turning basin station between April 28 and June 7. The data loss combined with the outage at the turning basin meant this station did not reliably contribute to the dataset in 2023. However, the turning basin is not a defined distinct spatial zone for which we evaluate passage.

The continuity of beacon tag detections provides a fine scale understanding of performance for fixed stations. A beacon tag should be detected every hour. If a station fails to detect the beacon tag (or a fish tag) in each hour we can assume that the station was not recording data. This is different from the data outages described above where we know that the station was not operational and/or data was lost. Assessing these short duration outages provided a more robust understanding of array performance. We do not know why receivers may have experienced these short duration outages, but they could occur, for example, during a download or a period of high noise when a receiver could not effectively process detections. Detailed performance metrics from beacon tag detections are only available for 2022 and 2023. In 2021, performance was assessed by visually confirming continuous detection of beacon tags (Moniz et al. 2022). For data from 2022 and 2023, we summed the duration of hourly intervals that a beacon or fish tag was not detected. In 2023, beacon tags were detected at each station every day of the operational period except during known outages. The maximum duration a station did not detect a beacon tag outside of known outages was seven hours (Table 8). Across 2022 and 2023 combined, the proportion of the total operational time that stations were not detecting tags (i.e., no beacon or fish tags detected) was low, ranging from 0.3 to 1.7% at stations without known outages, and 3.6 to 10.6% at stations with known outages.

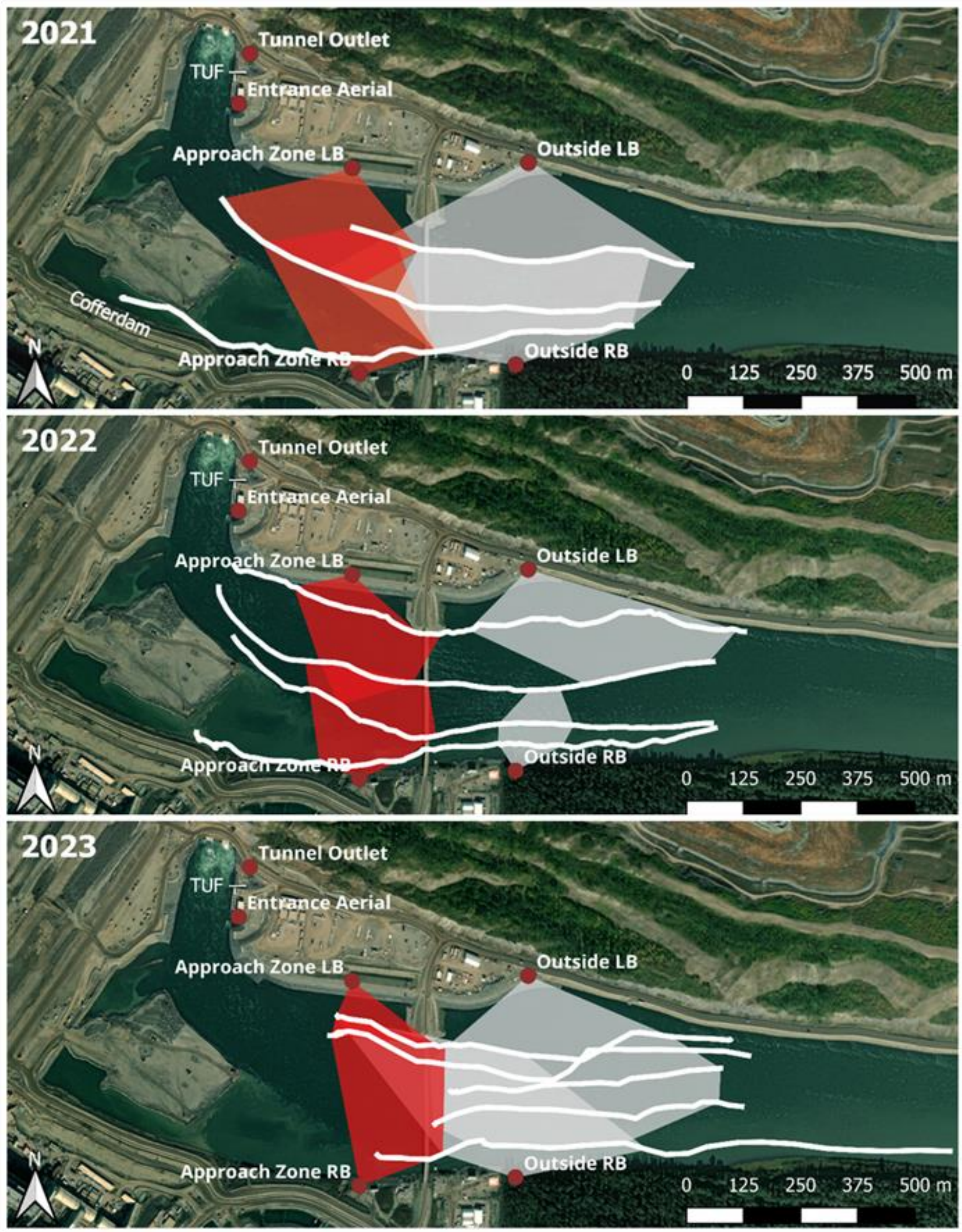

Figure 10. Approximate detection ranges of the paired approach (red) and outside approach (grey) fixed stations in 2021, 2022 and 2023 on the left bank (LB) and right bank (RB). GPS tracks of the boat drift tests used for range testing are shown as white lines. The tunnel outlet and entrance aerial have not been range tested due to restricted access within the diversion tunnel outlet area. The RB cofferdam station was removed prior to the 2022 operational period.

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)				Total % Operational Period (2022 and 2023)
	2022		2023		
	Total	Maximum	Total	Maximum	
Outside LB	158	7	13	4	1.7
Approach LB	132	2	3	3	1.3
Approach RB	126	2	25	6	1.5
Tunnel outlet	106	1	0	0	1.0
Entrance aerial	143	1	0	0	1.4
Outside entrance [1]	12	7	353	328 [2]	3.6
Entrance pool [1]	11	7	22	6	0.3
Turning basin	122	2	965	962 [2, 3]	10.6
Pool 8	73	7	346	329 [2]	4.1
Trap	102	7	354	335 [2]	4.5

[1] Outside entrance and entrance pool both have two receivers, one per frequency. Beacon tags were deployed to share between the two sites, one on each frequency, one at each site. However, sites did not detect the other site's beacon reliably. Therefore, outages are only estimates for one frequency at each site (149.360 at outside entrance and 149.400 at entrance pool)

[2] Stations were functioning, but data lost from computer prior to upload between 2023-06-21 and 2023-07-05

[3] Outage at station 41 between 2023-04-28 11:00:00 and 2023-06-07 13:00:00

3.2.2 PIT Antennas

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 controls for variation in antenna size. The highest mean percent read range in 2023 was 71.7% at the Orifice 24 antenna. Other antennas were lower, ranging from 46.2% (trap) to 1.7% (east entrance; Figure 11 and Appendix C: PIT Antenna Testing Results). Mean total read range (the raw value recorded during testing) ranged from 1.5 cm (east entrance) to 21.5 cm (orifice 24; Appendix C: PIT Antenna Testing Results).

Statistical analyses revealed some differences among years in percent read range (Figure 11). Notably, in 2023, percent read range significantly increased at the trap, weir 24, and orifice 23 antennas ($p < 0.001$, $p = 0.028$, $p = 0.023$, respectively) and decreased at the east entrance antenna ($p = 0.009$), where performance has been challenging throughout the study (full results in Appendix C: PIT Antenna Testing Results). A contributing factor in the decision to turn off the HVJ in 2023 was that PIT antenna testing results clearly indicated that antenna performance at pool 8 was negatively affected when the HVJ was on. Given that performance did not increase at pool 8 in 2023 despite the HVJ not operating suggests read range was likely affected by factors unrelated to fishway operations. For example, there were wiring complications at these antennas that prevented tuning. Unlike other antennas that we have been able to remove and modify, the pool 8 PIT antennas have been permanently deployed since September of 2020; as such, decreased performance was expected.

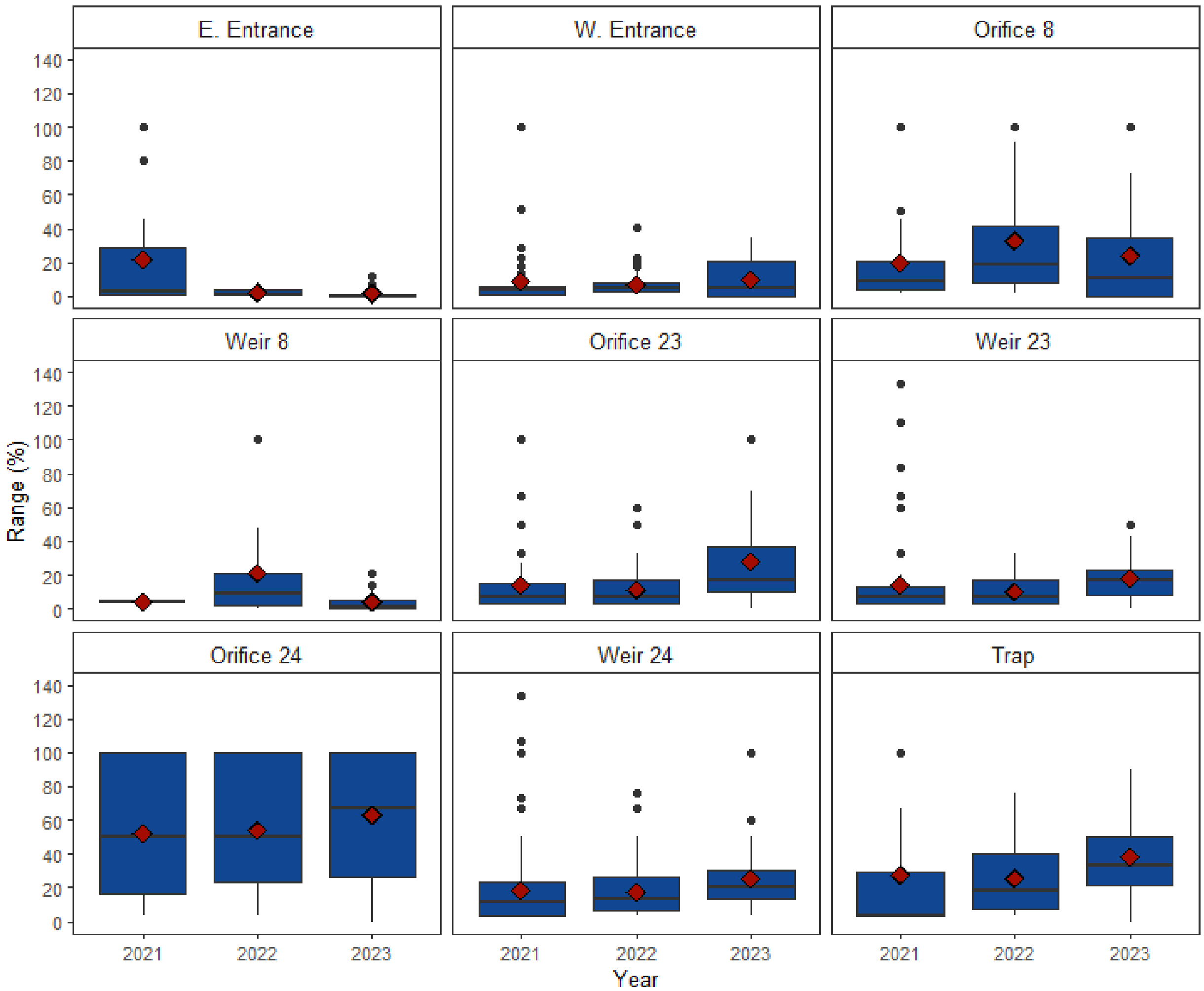

Figure 11. PIT antenna test results using 32-mm HDX PIT tags, 2021 to 2023. Total read range (maximum distance a tag was detected) is presented as a percentage of the full read range (maximum possible distance a tag could be detected within, over, under, or by an antenna).

3.3 Fishway Effectiveness

We evaluated fishway effectiveness two ways. First, we used time-to-event (TTE) analyses of radio detection data from all years to evaluate factors associated with upstream and downstream movements within the approach and entry zones of the TUF for four of five target fish species (note, the dataset for Burbot was too limited to complete the analysis). Second, we summarized the numbers of PIT- and radio-tagged fish making it to various detection points within the fishway, including fully passing the fishway (i.e., scanned in the sorting facility). Despite the large amount of data collected from within the fishway, mostly from PIT-tagged individuals, the low detection efficiency of the PIT antennas combined with known milling behaviours within the fishway precluded these data from being analyzed within a TTE framework.

Overall, a total of 17,323 PIT-tagged fish (with 439 individuals also having radio tags) have been detected on the telemetry array during operations. When only considering the five target species detected outside of shutdown periods since 2021 (the bounds for inclusion in our analyses), these numbers decrease to 3,085 PIT-tagged fish with 350 individuals also having radio tags.

3.3.1 Modeling of Fishway Approach and Entry

We produced a model for each of the two state transitions for each zone (i.e., advance and retreat from both the approach zone and entry zone) for each target fish species using radio detection data. Details are provided to help interpret models and understand terms at first mention but are not repeated for subsequent models. Not all results are presented visually; figures were selected to portray the most relevant results. The total number of individuals, occupancies, and transitions for each state change within each model are shown in Table 9. 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) made by each individual within a given operational year was included as a fixed effect. Bull Trout had the most robust dataset and, consequently, the most informative models. Therefore, results focused on this species.

We observed variability in activity within each species, including the potential for distinct seasonal behaviours across the operational period. Seasonal variation in activity was expected, especially among migratory species like Bull Trout. The distribution of the daily count of approach movements (i.e., number of advance transitions between the approach and entry zones) across the operational period showed this seasonal heterogeneity for each species (Figure 12). Pulses of increased movement were apparent, potentially during migratory periods, but most target species were present within the study area for most of the operational period. This suggests that the study area was not just used for directional migration.

Inter- and intra-individual heterogeneity in activity was also apparent. The cumulative number of advance transitions (i.e., between the approach and entry zones and entry zone and fishway) revealed that some individuals made continuous and repeated advance transitions whereas others made relatively few movements during certain time periods (Figure 13 for Bull Trout;

Appendix D: Heterogeneity in Activity (MW, RB, AG) for all other species). The most active individual Bull Trout made 485 movements between the approach zone and entry zone! This is compared to a median of 25 transitions for the tagged population. While we accounted for this heterogeneity by including individual as a random effect term, it created challenges when interpreting model results because active fish inherently contributed more to models.

Final model selection occurred through AIC-guided multi-model inference. Details of the model selection approach, including presentation of all candidate model sets, are provided in the appendices by species. An important part of the multivariate model selection process is to understand the distribution of covariates and how they interact with each other. These data are provided for selected models in the appendices with additional model diagnostics. See Appendices E through L.

Table 9. The total number of individuals, occupancies, and transitions for each state for target fish species. A continuous presence on the array is an occupancy; an individual could have multiple occupancies. Successes reveal the number of occupants that completed a given transition. Transitions represent the number of movements between each state. Total transitions represent the total across all occupancies and years (i.e., the total number of times that movement was made during the study period). Maximum, mean and median values of transitions are for a given occupant.

Species	Movement	Individuals	Occupancies	Successes	Transitions			
					Total	Max.	Median	Mean
Arctic Grayling	Approach	17	50	12	222	37	1	3.21
	Withdraw	5	10	10	50	12	3	5.35
	Entry	4	11	4	39	6	2	2.54
	Departure	4	10	10	84	16	12	9.34
Burbot	Withdraw	1	10	10	80	14	7	8.33
Bull Trout	Approach	137	660	380	30388	485	25	59.34
	Withdraw	85	411	411	5996	71	8	11.47
	Entry	85	383	192	6841	179	31	35.78
	Departure	82	343	343	14587	330	43	53.2
Mountain Whitefish	Approach	26	167	74	1279	45	2	7.07
	Withdraw	19	91	91	671	25	5	6.26
	Entry	18	73	28	277	24	1	2.82
	Departure	18	63	63	576	28	10	9.99
Rainbow Trout	Approach	41	107	32	1086	141	2	10.13
	Withdraw	18	45	45	226	16	7	5.66
	Entry	18	31	13	122	22	1	2.22
	Departure	14	24	24	362	73	12	13.54

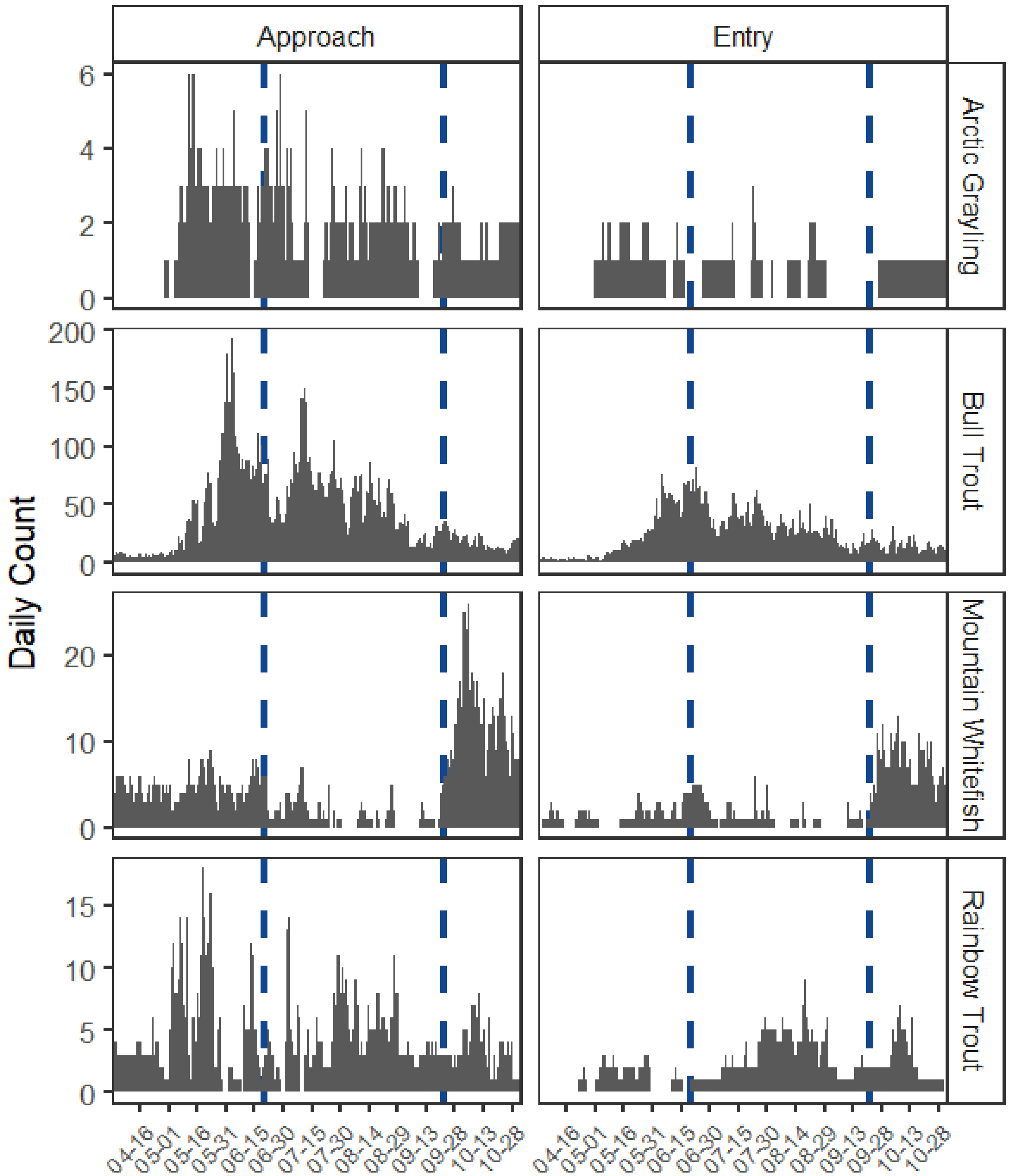

Figure 12. Daily count of upstream movements made from the approach zone to the entry zone of the temporary fishway among radio-tagged target species (excluding Burbot due to data limitations). Distributions reveal season variations in movements. Vertical dashed lines delineate seasons of spring, summer and fall. Note differences in y-axis values among species.

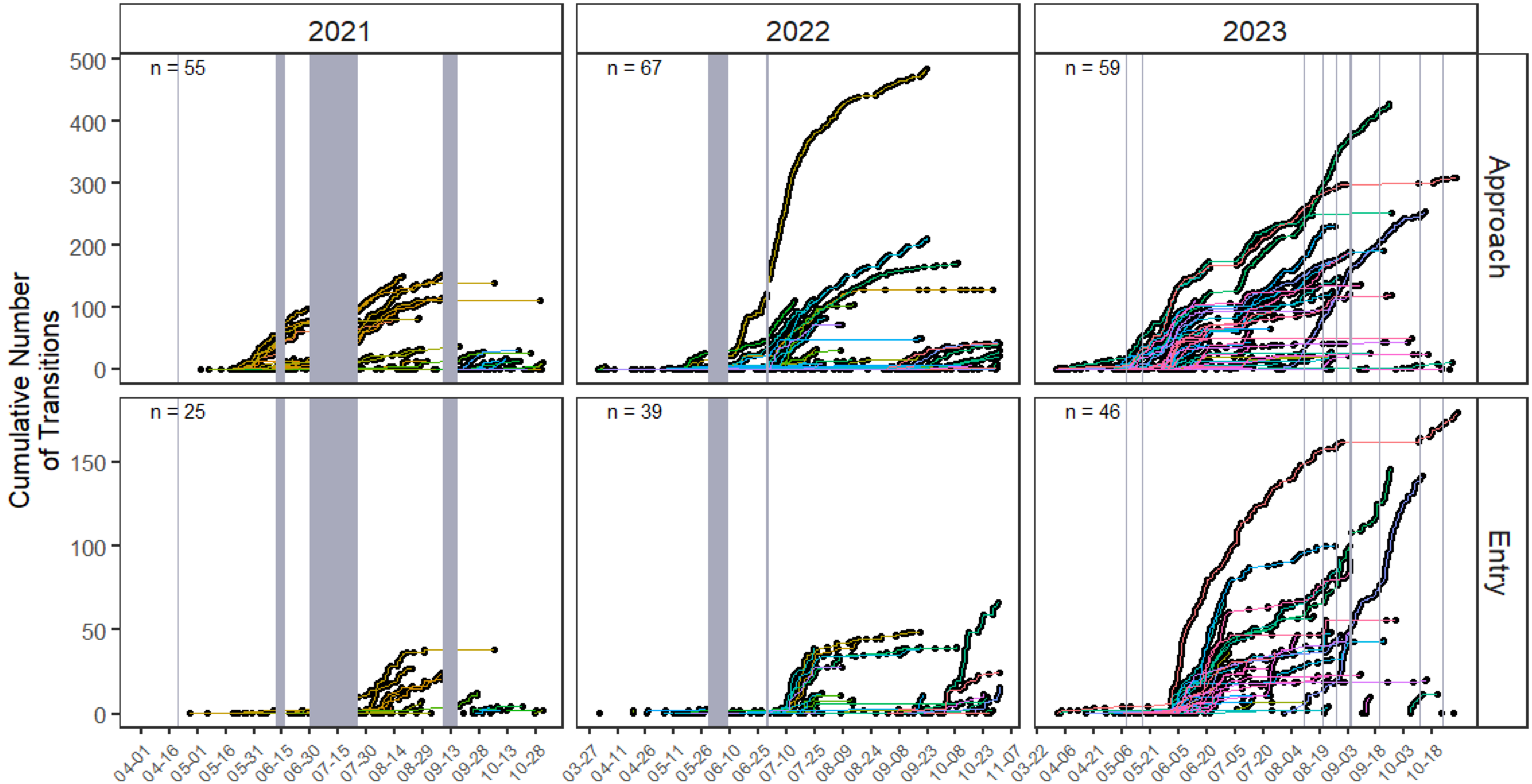

Figure 13. Cumulative number of advance transitions made by radio-tagged Bull Trout into the approach and entry zones of the temporary fishway for the duration of the operational period in each year. Each transition represents a movement between the outside approach zone and the approach zone, or from the approach zone into the entry zone. Individual fish are identified by colour. Shutdown periods are shaded grey (data excluded).

Bull Trout: Approach Zone (Approach/Withdraw)

Selected approach and withdraw models included the statistically significant terms of naïve (i.e., binary expression of if the fish had made the movement before), the linear expression of the season variable, and river discharge (Table 10). Diel period and AWS attraction flows were statistically significant in the approach model only (Table 10).

Magnitude of effect for each term is described by the β coefficient, z-value, p-value, and hazard ratio. Among statistically significant terms ($p < 0.5$), we relied on the z-value and hazard ratio to interpret the magnitude of effect. The z-value indicates the magnitude of effect of each predictor relative to all others in the model (centered around 0). The hazard ratio and its confidence intervals quantify the relationship in terms of a one-unit change in the predictor, thus allowing for a practical interpretation of each effect. One-unit change is the next unit increase for continuous variables or the next ordered category in categorical variables. The hazard ratio is centered around 1; values < 1 indicate a negative effect and those > 1 a positive effect.

Of particular interest were variables that both increased advancement and decreased retreat from a spatial zone (in this case, the approach zone), which would be assumed to also increase overall passage probability. Effects are described in order of importance to both state transitions out of the approach zone, followed by those only important to one state transition. Absolute z-values were higher in the approach model than in the withdraw model, indicating effects of covariates on movement rates were greater in the approach model. Variance of the random effect was 0.68 and 0.48 for approach and withdraw models, respectively. The only statistically significant year comparison was 2023 to 2021 in the approach model.

Table 10. Outputs from selected approach and withdraw Cox time-to-event models showing coefficient estimates (β) with standard errors (SE), z-values, p-values, and hazard ratios (HR) with upper and lower 95% confidence interval (UCI, LCI). These models represent advance and retreat from the approach zone. Events refers to the number of completed state transitions (n) relative to the total number of observations in the dataset. Iterations refers to the number of fitting iterations it took to converge during each phase, which informs the model fitting process. The variance of the random effect (RE) indicates the variability explained by differences between individuals.

Variable	State Transition: Approach							State Transition: Withdraw						
	β	SE	Z	P	HR	LCI	UCI	β	SE	Z	P	HR	LCI	UCI
Naïve vs. Non-naïve	1.65	0.11	14.58	< 0.0001	5.20	4.16	6.48	0.47	0.12	3.84	< 0.001	1.60	1.26	2.02
Diel Period: Day vs. Night	-0.85	0.03	-25.03	< 0.0001	0.43	0.40	0.46	-0.03	0.06	-0.53	0.59	0.97	0.86	1.09
Season (Linear)	-0.30	0.05	-5.57	< 0.0001	0.74	0.67	0.82	0.22	0.10	2.28	0.022	1.24	1.03	1.5
Season (Quadratic)	-0.06	0.03	-1.67	0.095	0.94	0.88	1.01	0.01	0.06	0.10	0.92	1.01	0.89	1.13
River Discharge	-0.14	0.01	-21.68	< 0.0001	0.87	0.86	0.88	0.09	0.01	7.98	< 0.0001	1.09	1.07	1.11
AWS Attraction Flows	-0.03	0.01	-5.57	< 0.0001	0.97	0.96	0.98							
Year: 2022 vs. 2021	0.06	0.08	0.74	0.46	1.06	0.90	1.24	0.04	0.13	0.27	0.79	1.04	0.80	1.34
Year: 2023 vs. 2021	-0.32	0.09	-3.37	< 0.001	0.73	0.61	0.88	-0.26	0.16	-1.61	0.11	0.77	0.56	1.06
Events	n = 6427, 75455							n = 1474, 58258						
Iterations	11, 84							14, 76						
RE Variance	0.6800727							0.4813049						

River Discharge

Both approach and withdraw models suggested fishway approach rates increased with lower river discharges. River discharge was highly significant in both models with high z-values. The effect was negative in the approach model and positive in the withdraw model. When coercing the continuous river discharge variable into categories rounded to the nearest 100 m^3/s, there was a clear and linear separation among groups. Despite data limitations among the highest values of river discharge, there was a nearly sequential decrease in approach rates with each increasing bin of river discharge (Figure 14). Data limitations among the highest values could reflect difficulties associated with advance movements under higher flows, or because the river was simply at these discharges for less time. The effect was not as clear in the withdraw model as in the approach model, as would be expected by the comparatively smaller z-value. Faster rates of withdraw occurred at the highest river discharges, but there was otherwise a lot of overlap among bins (data not shown).

Hazard ratios provide the most practical means to understand effects. Hazard ratios of 0.87 (LCI = 0.86, UCI = 0.88) for approach and 1.09 (LCI = 1.07, UCI = 1.11) for withdraw indicate that within the range of river discharge values observed to date, with every 100 m^3/s increase in discharge, rates of advance movement out of the approach zone decreased by 12.8% and rates of retreat increased by 9%.

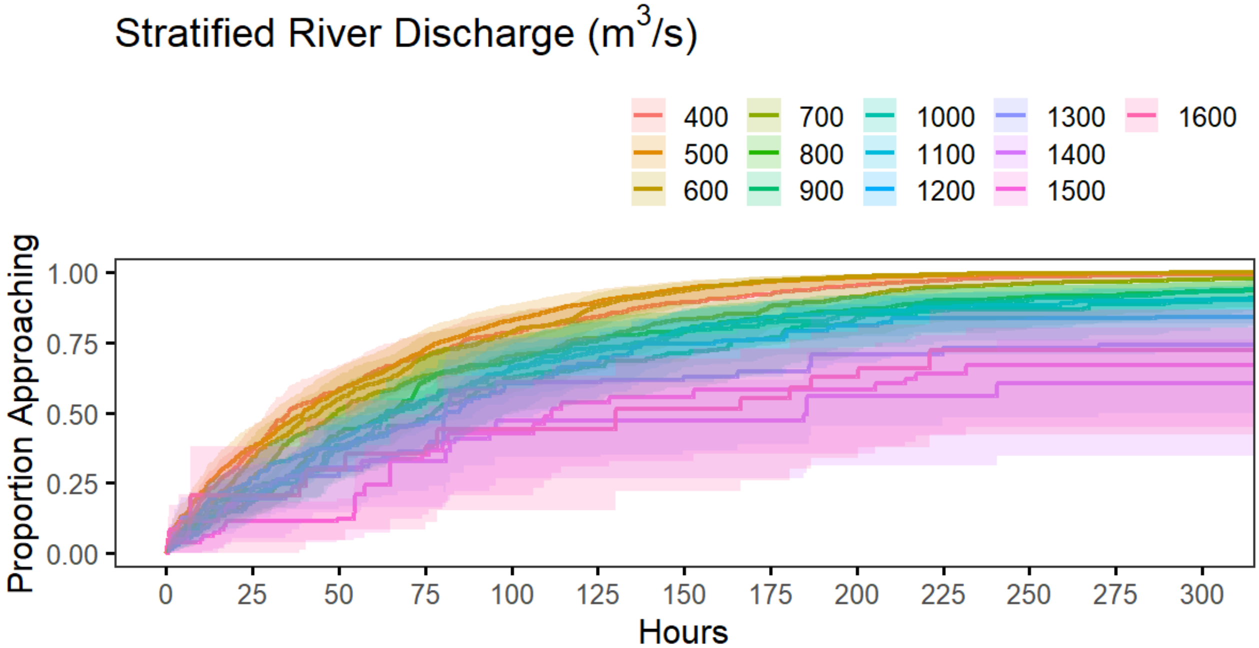

Figure 14. Survival curves from a Cox proportional hazard model showing the effects of river discharge on rates of approach for radio-tagged Bull Trout. The model was run with all selected covariates including the river discharge variable rounded to the nearest 100 and stratified according to these categories. These survival curves have been simplified for visualization and do not incorporate the random effect of individual-level variation. The two highest categories of river discharge (1700 and 1800 m^3/s) were removed for visualization (not from model results) due to data limitations resulting in extreme confidence intervals.

Experience (Naïve)

We expected that the direction of effect for variables that increased advancement towards the fishway would be opposing between advance and retreat models, as seen with river discharge. However, the effect of fishway experience (variable: naïve) was positive in both models. Non-naïve fish made faster advance and retreat movements than naïve fish. This suggests that experience may not be associated with increased advance to the fishway but rather increased activity (i.e., more movements) and faster movements in general. Visualizing the modeled effect exemplifies the difference in approach rates with previous experience: 50% of advance state transitions occurred within approximately 5 hours for non-naïve fish relative to nearly 80 hours for naïve fish (Figure 15). The effect was less pronounced in the withdraw model (50% of state transitions occur within around 10 hours for both groups), but faster withdraw rates were apparent among non-naïve fish overall (Figure 15). The hazard ratios were large, especially in the approach model. The hazard ratio of 5.2 (LCI = 4.16, UCI = 6.48) for approach rates and 1.6 (LCI = 1.26, UCI = 2.02) for withdraw rates indicated that there was a 420% increase in approach rates and a 60% increase in withdraw rates among non-naïve fish relative to naïve fish. The hazard ratios were larger than other terms in the model because only two categories are being compared. The z-values gave a better idea of magnitude of effect relative to other terms. Z-values indicated that while experience was important (z-value = 14.58 and 3.84 for approach and withdraw, respectively), it was not as important as discharge in both models (z-value = -21.68 and 7.89 for approach and withdraw, respectively) and diel period in the approach model (z-value = -25.03).

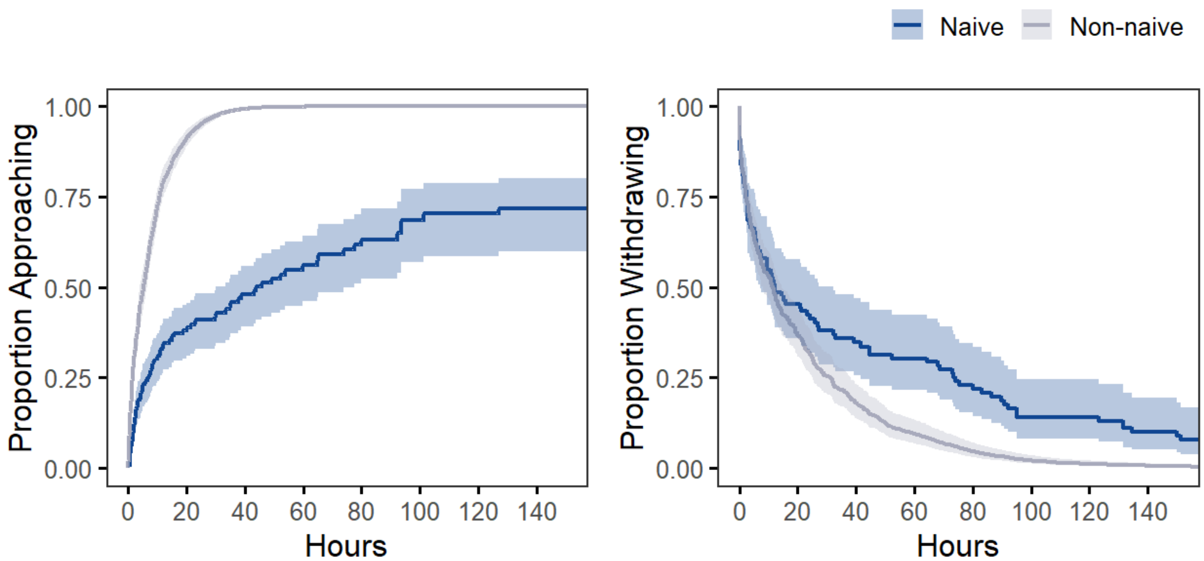

Figure 15. Survival curves from a Cox proportional hazard model showing the effects of previous experience with the given movement on rates of approach (left; advance from approach to entry zone) and rates of withdraw (right; retreat from approach zone) for radio-tagged Bull Trout. Experience is expressed as naïve (the individual has never made the movement before during the operational period of a given year) or non-naïve (the individual has made the movement before during the operational period of a given year). Dashed vertical lines show the median time for each category. These survival curves have been simplified for visualization and do not incorporate the random effect of individual-level variation.

Season

In both approach and withdraw models only the linear season effect was significant; the quadratic effect was not. The linear effect assumes a straight-line relationship between rates of movement and season, ordered chronologically from spring to fall. The quadratic effect tests a non-linear relationship. The negative linear effect was stronger in the approach model than the positive linear effect in the withdraw model. Approach rates were fastest in the spring, followed by summer and fall, while the opposite was observed for the withdraw model (data not shown).

Evaluating the number of transitions is also informative (Figure 16). There were considerably more approach than withdraw transitions, with most occurring in the summer, followed by spring and fall. This result aligned with our biological expectations (Bull Trout initiate spawning migrations in the summer). Taken together, results indicated that while approach rates were fastest in the spring, most approach events occurred in the summer at a slower rate than in the spring. This highlights the importance of both the spring and summer seasons for Bull Trout.

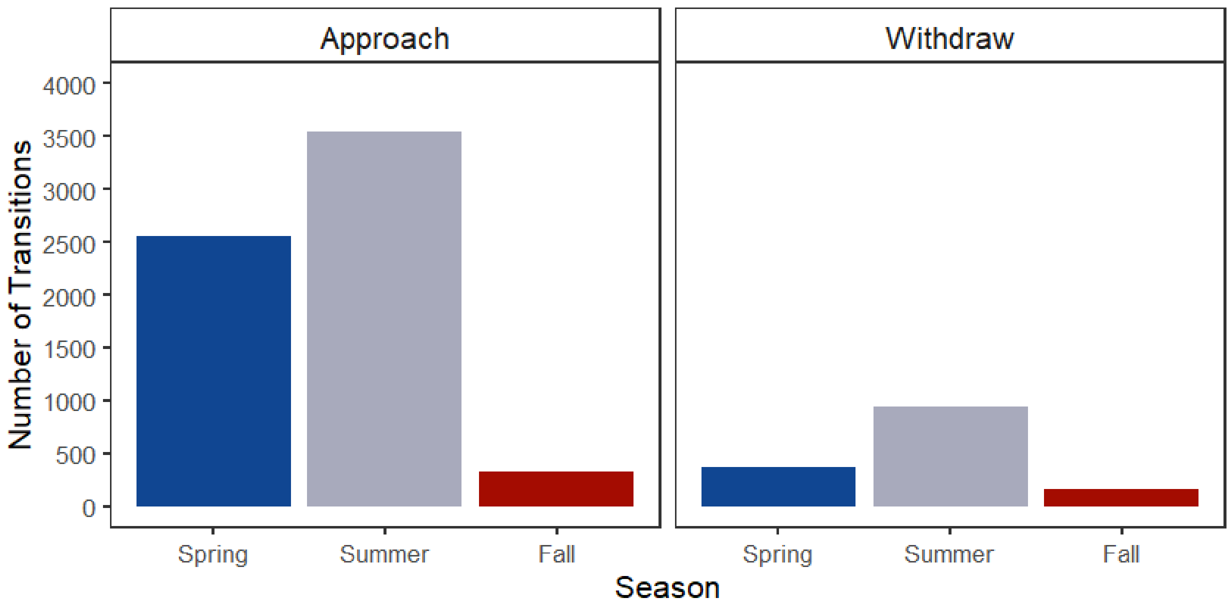

Figure 16. Number of approach (advance from approach to entry zone) and withdraw (retreat from approach zone) transitions made in each season for radio-tagged Bull Trout. These data do not reflect the rate of movements but the frequency of events.

Diel Period

The effect of diel period, which was only significant in the approach model, indicated upstream movement was faster during the day. The magnitude of effect was exceptional, having the highest z-value of all terms (-25.03) and high statistical significance (< 0.0001). A hazard ratio of 0.43 (LCI = 0.40, UCI = 0.46) indicates that rates of approach were 57% slower during the night than day (Figure 17). There were also approximately 4.5 times more transitions during the day than night. Bull Trout were clearly attracted to the entry zone during the day; approach movements were both faster and more frequent. The lack of effect in the withdraw model was noteworthy. Activity was not greater overall during the day (no significant negative effect), nor was the opposing movement apparent (no rejection of the approach zone at night, as would be indicated by a significant positive effect).

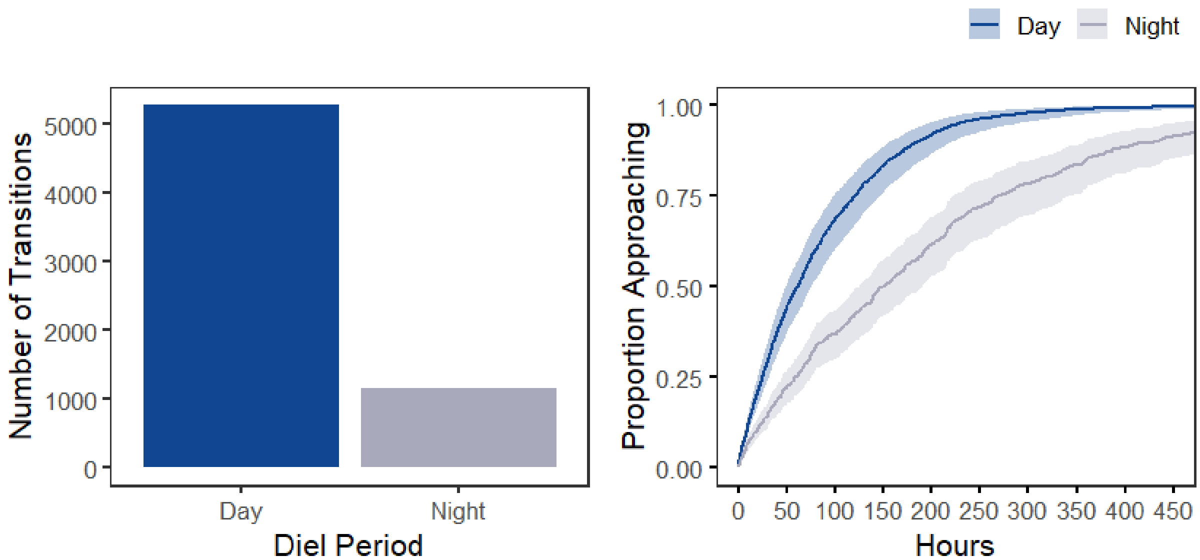

Figure 17. The effect of diel period on approach movements (advance from approach to entry zone) among radio-tagged Bull Trout from a Cox proportional hazard model is shown both in terms of frequency (number of transitions; left) and rate of movement (right). A greater number of transitions indicates that more movement occurred during that time and the survival curve shows the duration of each event. These survival curves have been simplified for visualization and do not incorporate the random effect of individual-level variation.

Attraction Flow

The negative effect of AWS attraction flows on approach rates had the lowest absolute z-value of all statistically significant variables (-3.37). Approach rates to the entry zone were faster at lower attraction flows. The hazard ratio of 0.97 (LCI = 0.96, UCI = 0.98) indicated that for each unit (1 m^3/s) increase in AWS flows, approach rates decreased by 3%. When data were binned according to AWS target for visualization, the two lowest flow targets had the fastest approach rates and the two highest flow targets had slower approach rates (though there was a lot of variability in the results; Figure 18). This finding was contrary to modelling exercises from previous years where approach was faster at higher attraction flows.

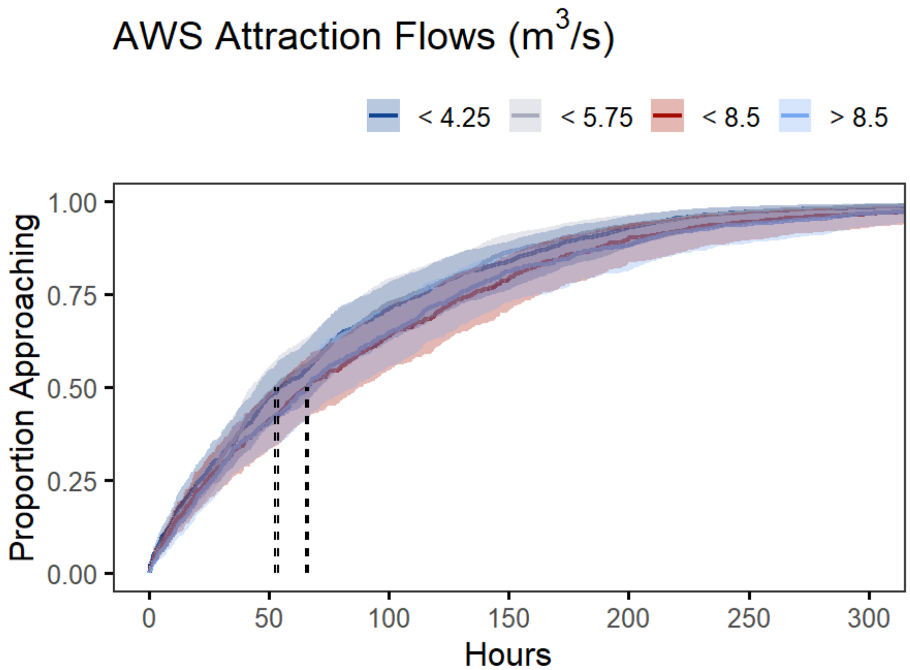

Figure 18. Survival curves from a Cox proportional hazard model showing the effects of auxiliary water supply (AWS) attraction flows on rates of approach (advance from approach to entry zone) for radio-tagged Bull Trout. Attraction flows were included in models as a continuous variable but were coerced into bins according to the four categories of operational targets for visualization. The curves result from a model run stratified by these categories, inclusive of all other covariates of the select model. Dashed vertical lines show the median time for each category. These survival curves have been simplified for visualization and do not incorporate the random effect of individual-level variation.

Bull Trout: Entry Zone (Entry/Departure)

We assessed movement from the entry zone in both directions: advance movements into the fishway (entry) and retreat movements out of the entry zone (departure). Entry represents the rate of advance into the fishway from the candidacy zone (i.e., approach zone and entry zone) and departure represents the rate of retreat from the entry zone into the candidacy zone. In setting up the dataset for modeling, each occupancy began with first detection in the entry zone for that occupant. For rates of entry into the fishway, the event duration for each occupant continued until fishway entry, which may have included movements into the approach zone. Conversely, event durations for rates of departure ended at last detection within the entry zone. Therefore, the larger spatial and temporal scale encompassed by entry events meant that durations were longer and not directly comparable to departure events. This problem was not apparent in the approach zone models because there was no further downstream zone once fish retreated from the approach zone.

Hydrological parameters featured strongly in selected entry zone models. Water surface elevation and AWS attraction flows, included in the entry model, and AWS attraction flow as a percentage of river discharge, included in the departure model, were all statistically significant with high magnitude of effect (high z-values and low p-values). The inclusion of these variables suggests that both river hydrology and AWS attraction flows were important for movement in and out of the entry zone, but that the nature of the relationship differed between state transitions. Additional terms with statistical significance in both selected models included naïve, diel period, and both the linear and quadratic expressions of season (Table 11). Variance of the random effect was 0.52 and 0.45 for entry and departure models, respectively. The only statistically significant comparison year comparison was 2022 to 2021 in the entry model.

Table 11. Outputs from selected approach and withdraw Cox time-to-event models showing coefficient estimates (β) with standard errors (SE), z-values, p-values, and hazard ratios (HR) with upper and lower 95% confidence interval (UCI, LCI). These models represent advance and retreat from the approach zone. Events refers to the number of completed state transitions (n) relative to the total number of observations in the dataset. Iterations refers to the number of fitting iterations it took to converge during each phase, which informs the model fitting process. The variance of the random effect (RE) indicates the variability explained by differences between individuals.

Variable	State Transition: Entry							State Transition: Departure						
	β	SE	Z	P	HR	LCI	UCI	β	SE	Z	P	HR	LCI	UCI
Naïve vs. Non-naïve	2.09	0.13	16.14	< 0.0001	8.11	6.29	10.45	0.31	0.13	2.31	0.02	1.37	1.05	1.78
Diel Period: Day vs. Night	-0.65	0.06	-11.24	< 0.0001	0.52	0.46	0.58	-0.62	0.05	-11.47	< 0.0001	0.54	0.48	0.60
Season (Linear)	0.34	0.09	3.99	< 0.0001	1.40	1.19	1.66	-0.22	0.09	-2.51	0.01	0.81	0.68	0.95
Season (Quadratic)	0.21	0.06	3.75	< 0.001	1.23	1.10	1.37	0.29	0.06	5.09	< 0.0001	1.33	1.19	1.48
Water Surface Elevation	-1.13	0.07	-15.71	< 0.0001	0.32	0.28	0.37							
AWS Attraction Flows	0.18	0.01	16.18	< 0.0001	1.20	1.17	1.22							
% AWS to River Discharge								-0.27	0.04	-6.06	< 0.0001	0.77	0.70	0.83
Year: 2022 vs. 2021	0.58	0.18	3.15	0.002	1.79	1.25	2.57	-0.21	0.12	-1.74	0.08	0.81	0.64	1.03
Year: 2023 vs. 2021	-0.14	0.20	-0.68	0.5	0.87	0.59	1.29	-0.26	0.14	-1.83	0.07	0.77	0.59	1.02
Events	n = 1973, 79803							n = 2905, 24411						
Iterations	17, 125							20, 106						
RE Variance	0.5249509							0.4483585						

Hydrology: Water Surface Elevation, Discharge, Attraction Flow

Several results pointed to increased entry rates for Bull Trout with higher attraction flows and reduced river discharge or water surface elevations. The entry model clearly indicated that entry rates were faster with higher AWS attraction flows and low water surface elevations; for both variables the relationship appeared linear (Figure 19). Along with the naïve variable (discussed later), these variables had the highest z-values (16.18 and -15.71, respectively; Table 10). The hazard ratio for AWS attraction flows was 1.2, meaning a 20% increase in entry rates for every unit (1 m^3/s) increase in AWS flows. Results were similarly clear for water surface elevations: the hazard ratio of 0.32 indicated a 68% decrease in entry rates with every unit (1 m) increase in elevation. Note that while a 68% decrease seems exceptional, water surface elevations ranged by a total of 2.5 m across the three study years (Table 7). In that context, a one-meter increase is substantial.

Results from the departure model supported that Bull Trout preferred higher attraction flows and lower water levels for entry. Departure rates were slower (i.e., more time in entry zone) with a higher percentage of attraction flow to river discharge. The hazard ratio of 0.77 (LCI = 0.70, UCI = 0.83) indicated a 23% decrease in departure rates with every percentage increase in attraction flow relative to river discharge. However, there was considerable variability in this estimate with decreases ranging from 17 to 30%, as per confidence interval estimates. Additionally, visualization of the trend revealed approximate linearity until the highest percentages. It is possible that a quadratic effect may exist that we do not have the power to identify with the current modeling approach. That is, when the percentage of attraction flow to river discharge was within the highest values observed (e.g., > 2%), departure rates may have increased (Figure 19).

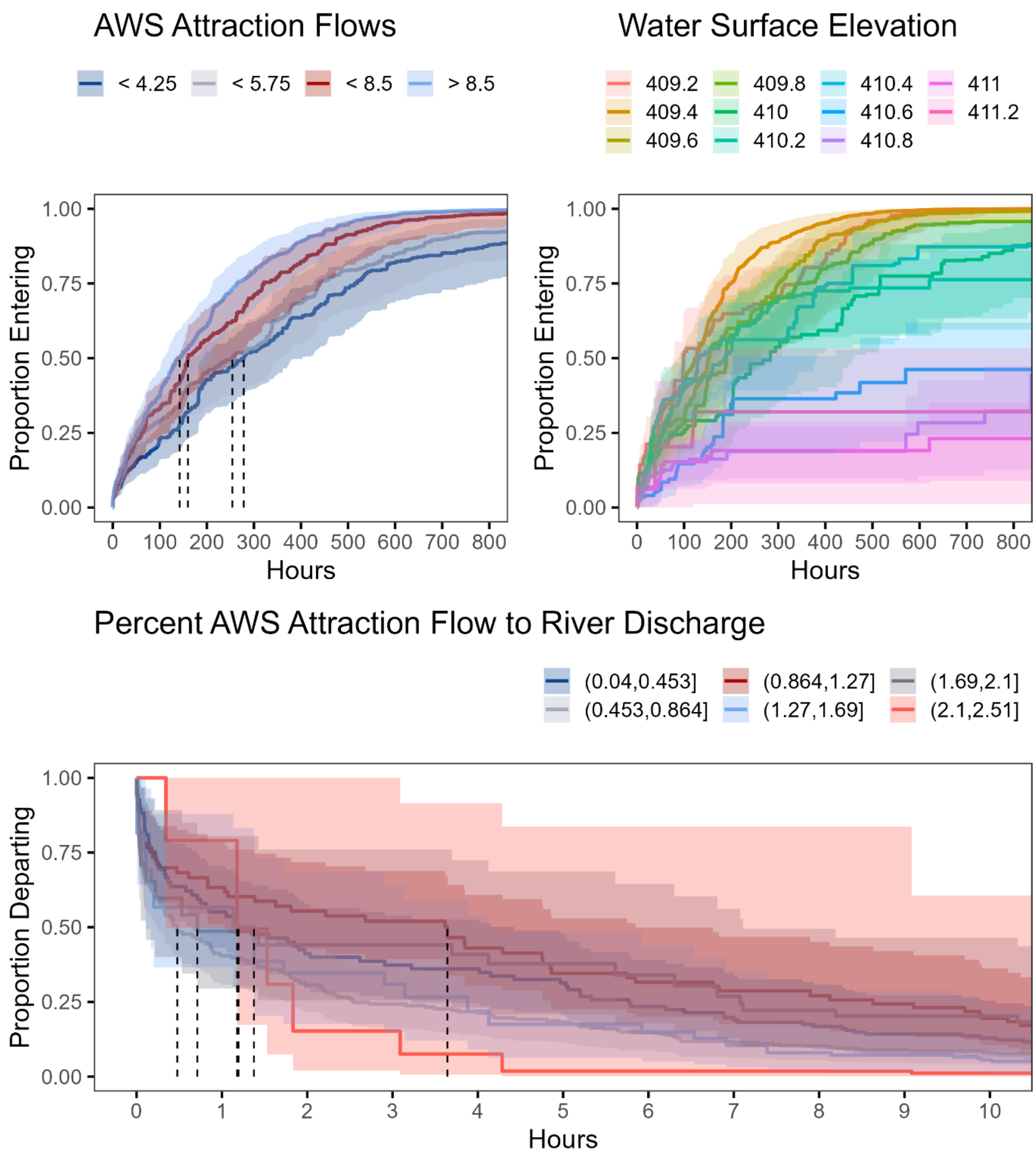

Figure 19. Survival curves from a Cox proportional hazard model showing the effects of hydrological parameters on rates of entry (top; advance from entry zone to fishway) and departure (bottom; retreat from entry zone) among radio-tagged Bull Trout. River discharge and attraction flows were important to both rates, but effects manifested differently. The entry model had effects of auxiliary water supply (AWS) attraction flows (top right) and water surface elevation (top left). The departure model had an effect of AWS attraction flows as a percentage of total river discharge (bottom). Variables were categorized for visualization according to AWS targets, rounded to the nearest 0.2 m for water surface elevation, or into six even bins for AWS flow as a percentage of river discharge. Survival curves have been simplified for visualization and do not incorporate the random effect of individual-level variation. Additionally, the largest categories within the water surface elevation have been removed from the figure (not from modeling) due to lack of data.

Experience (Naïve)

As with the approach zone models, the effect of experience was positive in both the fishway entry and departure models. Non-naïve fish made faster advance and retreat movements than naïve fish, supporting the idea of increased activity and faster movements during daylight hours in general. The hazard ratio for the naïve variable in the entry model was larger than in the approach model: a value 8.1 (LCI = 6.3, UCI = 10.5) suggests rates of entry were 711% faster among non-naïve fish relative to naïve fish. The magnitude of effect was also high, emphasizing the importance of this term to the entry model (Table 11). The effect was less pronounced in the departure model; a hazard ratio of 1.37 indicated that departure rates were 37% slower among non-naïve fish (Table 11).

Season

Both the linear and quadratic expression of the season term were statistically significant in both models, but there was less support for the quadratic term (Table 11). It was visually apparent that entry rates increased and departure rates decreased as the seasons progressed from spring to fall (linear; Figure 20). Rates of movement in the spring and summer were also more similar to each other than to those from the fall period (quadratic). These results differ from the approach zone models that found advance towards the entry zone was fastest in the spring. In terms of number of transitions, most entry and departure events occurred in the summer, as seen for the approach model. The difference in seasonal patterns between the approach and entry models is difficult to interpret but may indicate that Bull Trout used the approach and entry zones differently through the operational period.

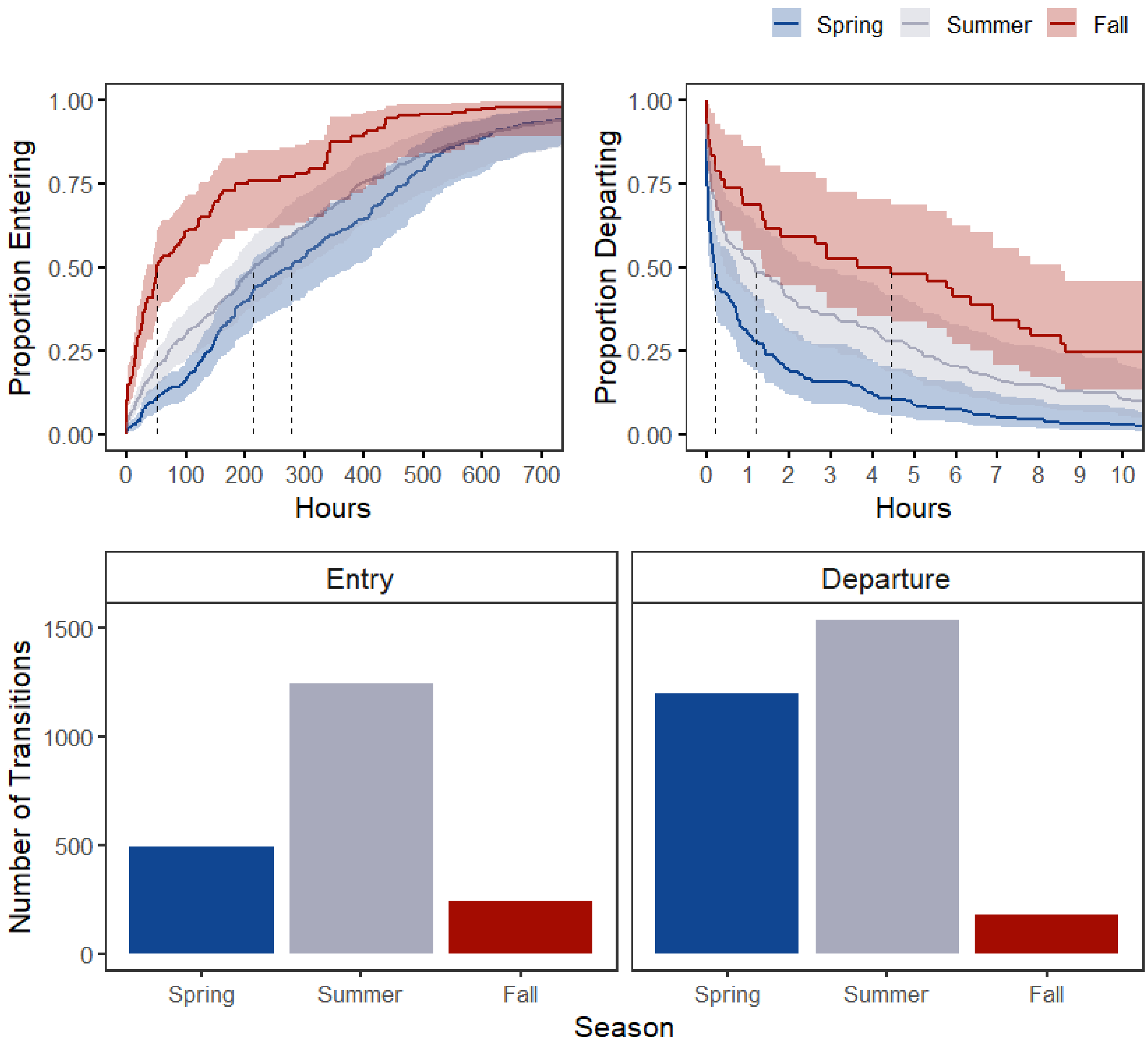

Figure 20. Survival curves from Cox proportional hazard models showing seasonal differences in rates of entry (top left; advance from entry zone to fishway) and rates of departure (top right; retreat from entry zone to approach zone) for radio-tagged Bull Trout. Dashed vertical lines show the median time for each category. Survival curves have been simplified for visualization and do not incorporate the random effect of individual-level variation. Bottom panels show the number of entry and departure transitions; a higher value indicates more movement (i.e., successful transitions) occurred during that time.

Diel Period

The diel period term was statistically significant with a negative effect in both the entry and departure models, with a similar magnitude of effect (Table 11). Both entry and departure rates were faster and the number of transitions greater during the day than during the night (Figure 21).

This indicates both the speed and frequency of movements out of the entry zone are increased during the day.

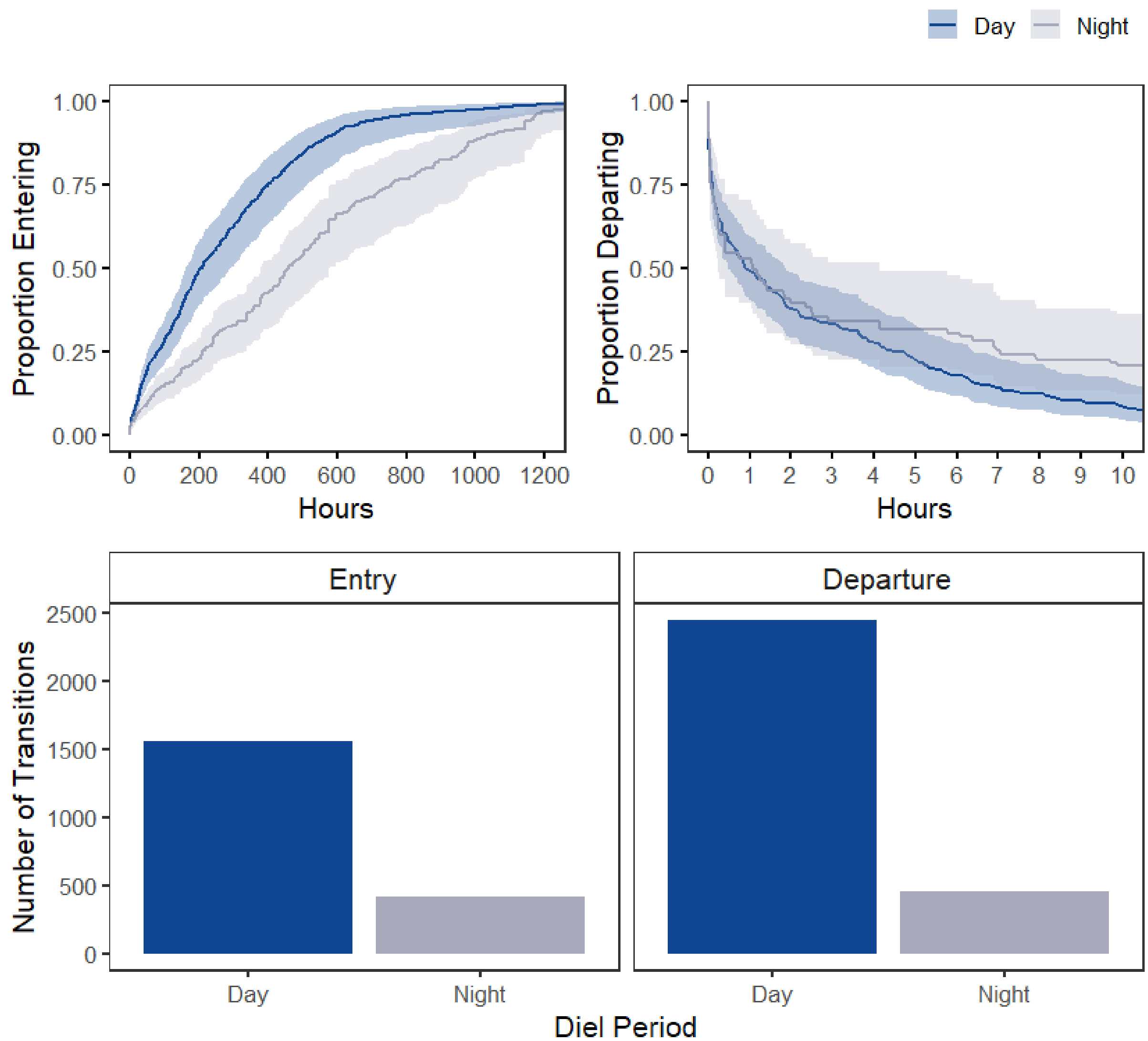

Figure 21. Survival curves from Cox proportional hazard models showing differences in rates of entry (top left; advance from entry zone to fishway) and rates of departure (top right; retreat from entry zone to approach zone) between day and nighttime periods for radio-tagged Bull Trout. Survival curves have been simplified for visualization and do not incorporate the random effect of individual-level variation. Bottom panels show the number of entry and departure transitions; a higher value indicates more movement (i.e., successful transitions) occurred during that time.

Mountain Whitefish

The Mountain Whitefish dataset was more limited than that for Bull Trout with only 18 to 26 individuals per state transition across all three study years. The entry model was particularly data-limited and model diagnostics revealed poor fit (Appendix H: Diagnostics of Selected Mountain Whitefish Models). Selected models were generally simpler than those for Bull Trout models with fewer statistically significant effects. We, therefore, opted to describe the terms of importance for all four Mountain Whitefish models (i.e., approach/withdraw and entry/departure) collectively.

Generally, temporal factors of season and diel period were most important across all models. Additionally, non-naïve fish had faster transition rates than naïve fish (data not shown). Hydrological variables appeared in approach and departure models but not in the entry and withdraw models. Model outputs from the approach zone are presented in Table 12 and outputs from the entry zone are in Table 13.

Table 12. Outputs from selected approach and withdraw Cox time-to-event models showing coefficient estimates (β) with standard errors (SE), z-values, p-values, and hazard ratios (HR) with upper and lower 95% confidence interval (UCI, LCI). These models represent advance and retreat from the approach zone among radio-tagged Mountain Whitefish. Events refers to the number of completed state transitions (n) relative to the total number of observations in the dataset. Iterations refers to the number of fitting iterations it took to converge during each phase, which informs the model fitting process. The variance of the random effect (RE) indicates the variability explained by differences between individuals.

Variable	State Transition: Approach							State Transition: Withdraw						
	β	SE	Z	P	HR	LCI	UCI	β	SE	Z	P	HR	LCI	UCI
Naïve vs. Non-naïve	**0.84**	**0.24**	**3.52**	**< 0.001**	**2.31**	**1.45**	**3.69**	0.26	0.25	1.06	0.29	1.30	0.80	2.11
Diel Period: Day vs. Night	**-2.19**	**0.21**	**-10.24**	**< 0.0001**	**0.11**	**0.07**	**0.16**	-0.25	0.19	-1.34	0.18	0.78	0.54	1.12
Season (Linear)	**1.56**	**0.17**	**9.12**	**< 0.0001**	**4.74**	**3.39**	**6.62**	0.30	0.17	1.77	0.08	1.35	0.97	1.87
Season (Quadratic)	0.05	0.17	0.29	0.77	1.05	0.75	1.47	**-0.45**	**0.16**	**-2.85**	**0.004**	**0.64**	**0.47**	**0.87**
River Discharge	**-0.15**	**0.02**	**-6.06**	**< 0.0001**	**0.86**	**0.82**	**0.90**							
Year: 2022 vs. 2021	**-0.48**	**0.18**	**-2.61**	**0.009**	**0.62**	**0.43**	**0.89**	0.11	0.22	0.49	0.62	1.11	0.73	1.70
Year: 2023 vs. 2021	-0.48	0.25	-1.90	0.058	0.62	0.37	1.02	-0.49	0.32	-1.52	0.13	0.61	0.33	1.15
Events	n = 377, 14999							n = 198, 9520						
Iterations	3, 25							12, 63						
RE Variance	0.1599061							0.05066147						

Table 13. Outputs from selected entry and departure Cox time-to-event models showing coefficient estimates (β) with standard errors (SE), z-values, p-values, and hazard ratios (HR) with upper and lower 95% confidence interval (UCI, LCI). These models represent advance and retreat from the entry zone among radio-tagged Mountain Whitefish. Events refers to the number of completed state transitions (n) relative to the total number of observations in the dataset. Iterations refers to the number of fitting iterations it took to converge during each phase, which informs the model fitting process. The variance of the random effect (RE) indicates the variability explained by differences between individuals.

Variable	State Transition: Entry							State Transition: Departure						
	β	SE	Z	P	HR	LCI	UCI	β	SE	Z	P	HR	LCI	UCI
Naïve vs. Non-naïve								0.67	0.30	2.24	0.025	1.96	1.09	3.53
Diel Period: Day vs. Night	-1.41	0.44	-3.20	0.001	0.24	0.10	0.58	-1.69	0.33	-5.16	< 0.0001	0.18	0.10	0.35
Season (Linear)	2.122	0.52	4.07	< 0.0001	8.35	3.01	23.20	-1.37	0.26	-5.35	< 0.0001	0.25	0.15	0.42
Season (Quadratic)	-0.10	0.37	-0.26	0.79	0.91	0.44	1.88	0.58	0.25	2.36	0.018	1.79	1.10	2.89
Water Surface Elevation								-0.72	0.21	-3.37	< 0.001	0.48	0.32	0.74
AWS Attraction Flows								-0.14	0.04	-3.33	< 0.001	0.87	0.79	0.94
Year: 2022 vs. 2021	1.77	0.39	4.49	< 0.0001	5.88	2.71	12.75	-1.08	0.25	-4.32	< 0.0001	0.34	0.21	0.55
Year: 2023 vs. 2021	3.12	0.39	8.04	< 0.0001	22.71	10.6	48.63	-1.11	0.28	-3.99	< 0.0001	0.34	0.19	0.57
Events	n = 68, 10387							n = 199, 1424						
Iterations	10, 72							5, 32						
RE Variance	0.01587323							0.00008135451						

Temporal Factors: Season, Diel Period

Season was statistically significant in all four models. The linear season term had a high magnitude of effect in both advance models (approach and entry). The quadratic term was statistically significant in the withdraw model. Both the linear and quadratic terms were statistically significant in the departure model (the linear term had a higher magnitude of effect). Results indicated that approach and entry was much faster during the fall period (Figure 22). A hazard ratio of 4.74 (UCI = 3.39, LCI = 6.62) in the approach model and 8.35 (UCI = 3.01, LCI = 23.19) suggested approach and fishway entry rates increased by 374% and 735%, respectively, from spring to summer and from summer to fall. The number of approach and entry transitions were also much higher during the fall (Figure 22). Visually, the lack of data from the spring and summer periods, particularly from the entry and departure models, was evident. While Mountain Whitefish were present in the study area throughout the operational period, they primarily entered the fishway during the fall. Seasonality in the retreat models (withdraw and departure) had a much lower magnitude of effect and directionality of the effect varied (data not shown).

A negative effect of diel period was present in all models, and statistically significant in all but the withdraw model (Table 12, Table 13). As seen with Bull Trout, Mountain Whitefish moved faster and made more movements during the day, and this was especially the case for upstream movements (Figure 23).

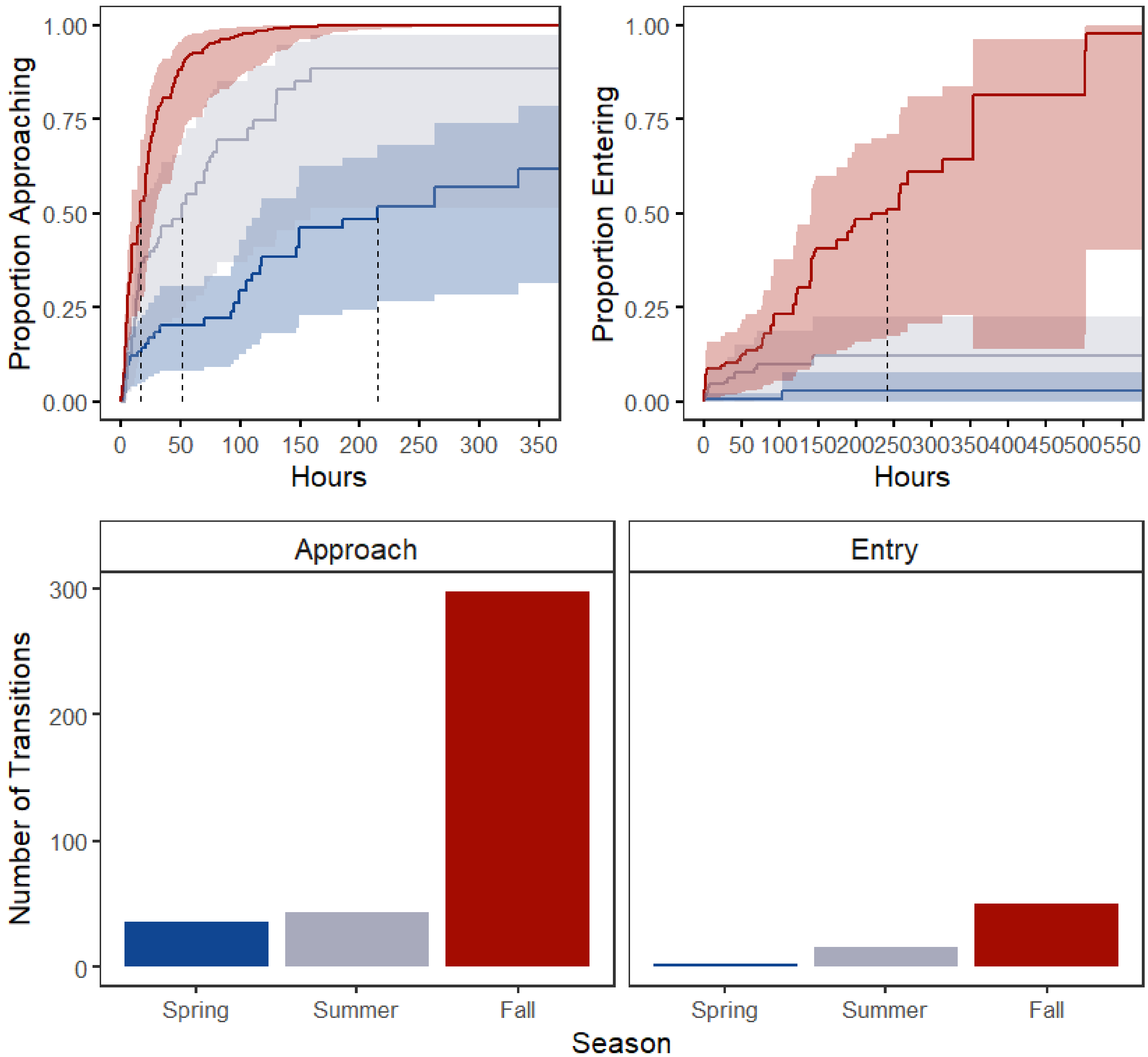

Figure 22. Survival curves from Cox proportional hazard models showing seasonal differences in rates of approach (top left; advance from approach to entry zone) and entry (top right; advance from entry zone to fishway) for radio-tagged Mountain Whitefish. Dashed vertical lines show the median time for each category, where it was reached. Survival curves have been simplified for visualization and do not incorporate the random effect of individual-level variation. Bottom panels show the number of entry and departure transitions; a higher value indicates more movement (i.e., successful transitions) occurred during that time.

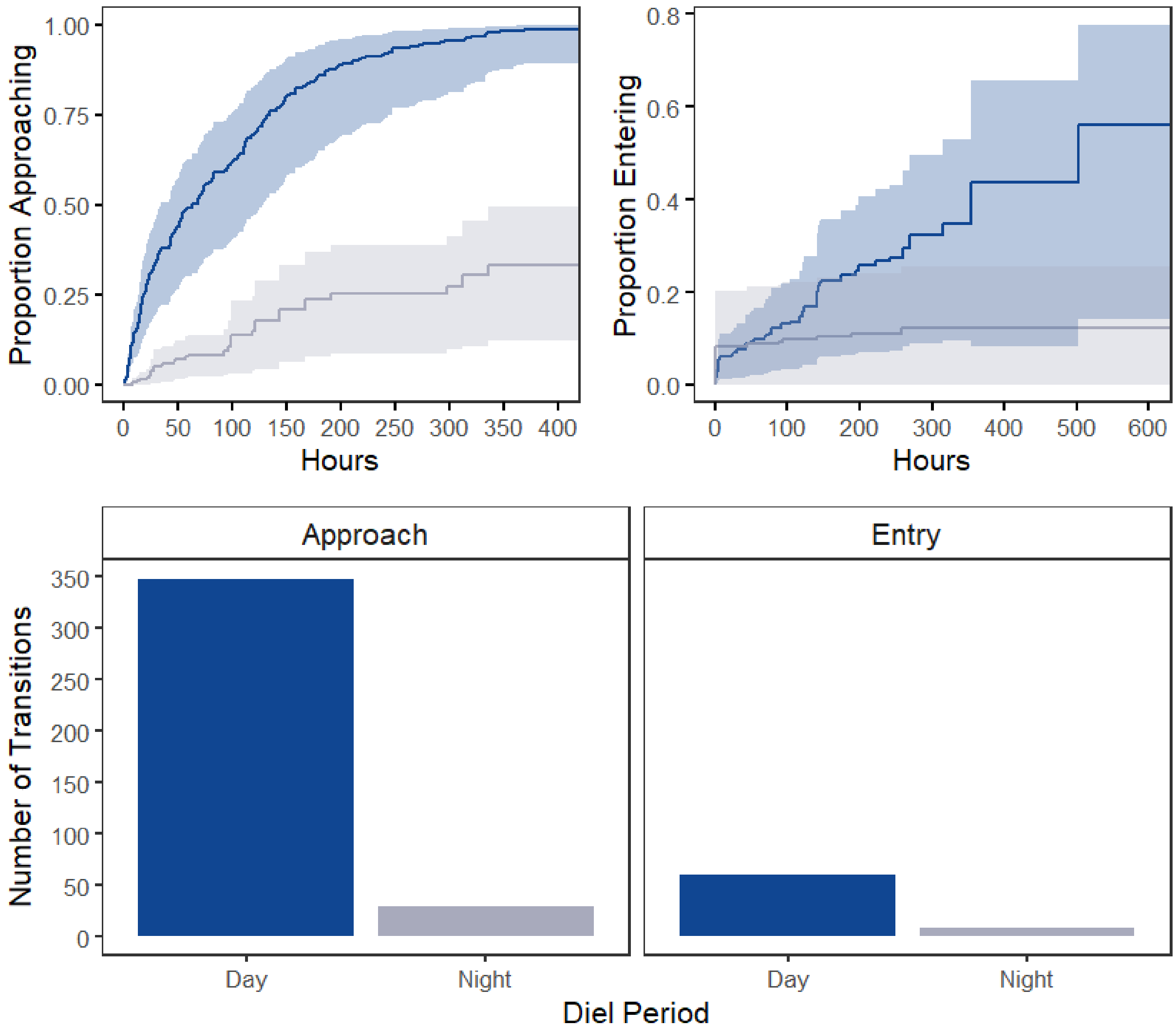

Figure 23. Survival curves from Cox proportional hazard models showing differences in rates of approach (top left; advance from approach to entry zone) and entry (top right; advance from entry zone to fishway) among diel periods for radio-tagged Mountain Whitefish. Survival curves have been simplified for visualization and do not incorporate the random effect of individual-level variation. Bottom panels show the number of entry and departure transitions; a higher value indicates more movement (i.e., successful transitions) occurred during that time.

Hydrology: Water Surface Elevation, Discharge, Attraction Flows

The effect of river discharge on approach rates was negative. As with Bull Trout, approach rates decreased with increasing river discharge. A hazard ratio of 0.86 (LCI = 0.82, UCI = 0.90) indicated a 14% decrease in approach rates with every 100 m^3/s increase in river discharge. Data limitations precluded visualizing this effect binned by 100 m^3/s categories as done for Bull Trout;

instead, we binned data into six evenly distributed categories. A linear effect in binned data was apparent (Figure 24).

Hydrological parameters were also important in the departure model but not in the entry model, potentially because of the increased spatial and temporal scale of the entry database. Both water surface elevation and AWS attraction flows had significant negative effects on rates of departure. This could be interpreted as Mountain Whitefish preferring higher water surface elevations and higher attraction flows (slower departure rates equates to more time in the entry zone); however, there was substantial uncertainty, and results should be interpreted cautiously. Data were not shown because large confidence intervals precluded effective visualization. Uncertainty was best described by the hazard ratios. A hazard ratio of 0.49 with confidence intervals of 0.32 and 0.74 for water surface elevation indicated that rates of departure decreased by 26% to 68% for every meter of elevation increase. For AWS attraction flows, a hazard ratio of 0.87 (LCI = 0.80, UCI = 0.94) meant departure rates decreased by 6% to 20% for every 1 m^3/s increase in attraction flows.

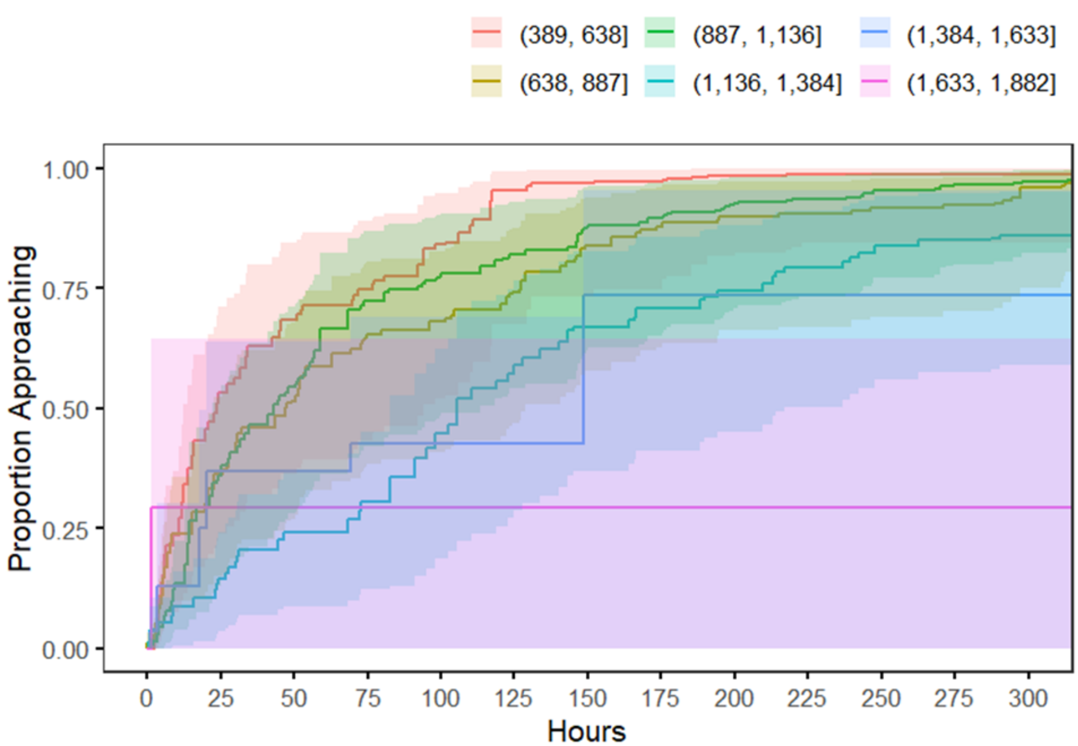

Figure 24. Survival curves from a Cox proportional hazard model showing the effects of river discharge on rates of approach for radio-tagged Mountain Whitefish. The model was run with all selected covariates including the river discharge variable stratified into six even categories for visualization. These survival curves have been simplified for visualization and do not incorporate the random effect of individual-level variation.

Rainbow Trout

The Rainbow Trout dataset had 14 to 41 individuals per state transition across all three study years. There was a dichotomy in activity, where some individuals made many transitions (contributed a lot of data) and other individuals made very few transitions (contributed little data). The resulting bimodal distribution presented challenges to fitting models, and combined with low sample sizes, meant that the random effect of individual fish was highly influential. The most striking and consistent finding across all Rainbow Trout models was the high variance explained by the random effect (Table 14, Table 15). Within each state transition, the median number of transitions was less than ten (Table 9). Most individuals made fewer than 30 transitions, but a small number of individuals made substantially more transitions in the approach and departure models (Figure 25). Accordingly, variance of the random effect in these models was 3.7 (approach) and 2.7 (departure). This finding suggested that inter-individual differences played a substantial role in the observed results. Further, where the naïve variable was included (approach and withdraw models), it held high statistical significance – which aligned with the finding of the individual being important. Like in other models, non-naïve fish consistently moved faster than naïve fish.

Despite model limitations, there were significant effects of river discharge and AWS attraction flows. Approach rates decreased by 17% with every 100 m^3/s increase in river discharge (Hazard Ratio = 0.83, LCI = 0.77, UCI = 0.88). As in the approach model for Bull Trout, there was a negative effect of AWS attraction flows. The hazard ratio was 0.94 (LCI = 0.89, UCI = 0.99) representing a 6% decrease in approach rates for every 1 m^3/s increase in AWS attraction flows. In contrast, the effect of total attraction flows as a percentage of river discharge was positive in the fishway entry model: as the percentage of attraction flow to river discharge increased, entry rates also increased. Given inconsistencies in the direction of effect in the approach and entry models and the lack of hydrological parameters in the withdraw and departure models, relationships between hydrological conditions and movements of Rainbow Trout were inconclusive.

Seasonality was apparent in the entry zone models. The linear expression of the season term had a positive effect in the entry model and a negative effect in the departure model. Entry rates were rapid in the fall and departure rates were slow. Collectively this indicated greater fishway entry among Rainbow Trout during the fall (data not shown).

A statistically significant negative effect of diel period in the approach and departure models suggested that Rainbow Trout moved between the approach and entry zones faster during the day in both directions (data not shown).

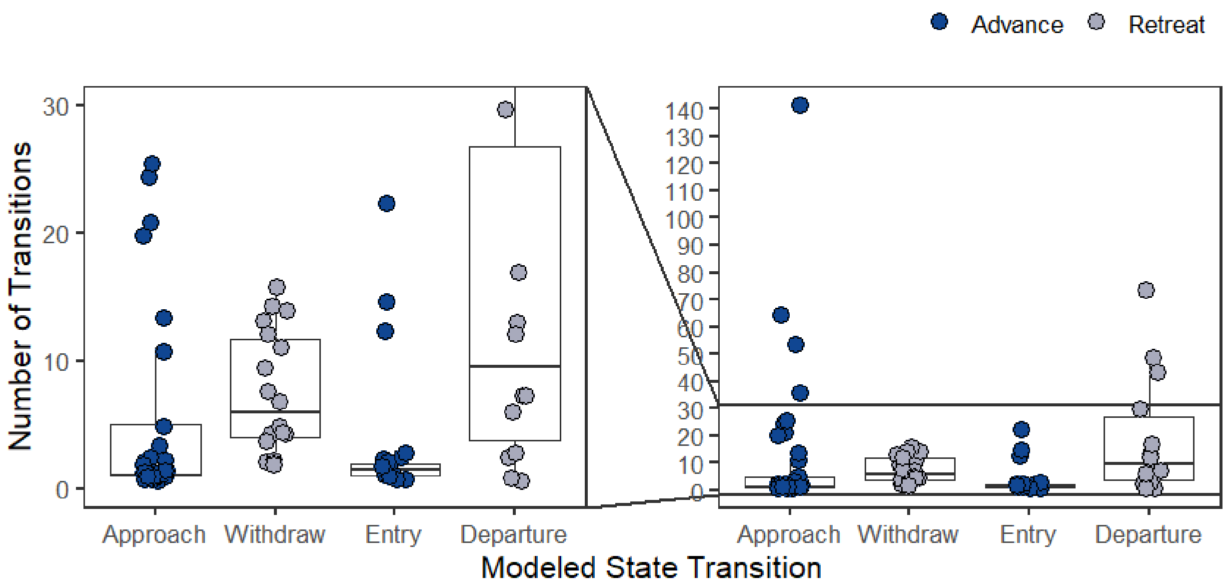

Figure 25. Number of transitions (i.e., a distinct movement between zones) made by each individual radio-tagged Rainbow Trout included in a time-to-event analysis evaluating rates of advance and retreat movements between the approach zone, entry zone and fishway. Each point represents an individual. The left panel is a zoomed in image of the right to better show the distributions.

Table 14. Outputs from selected approach and withdraw Cox time-to-event models showing coefficient estimates (β) with standard errors (SE), z-values, p-values, and hazard ratios (HR) with upper and lower 95% confidence interval (UCI, LCI). These models represent advance and retreat from the approach zone among radio-tagged Rainbow Trout. Events refers to the number of completed state transitions (n) relative to the total number of observations in the dataset. Iterations refers to the number of fitting iterations it took to converge during each phase, which informs the model fitting process. The variance of the random effect (RE) indicates the variability explained by differences between individuals.

Variable	State Transition: Approach							State Transition: Withdraw						
	β	SE	Z	P	HR	LCI	UCI	β	SE	Z	P	HR	LCI	UCI
Naïve vs. Non-naïve	2.40	0.38	6.37	< 0.0001	11.05	5.27	23.16	0.67	0.29	2.30	0.02	1.96	1.10	3.48
Diel Period: Day vs. Night	-0.99	0.14	-6.97	< 0.0001	0.37	0.28	0.49							
Season (Linear)	0.61	0.33	1.86	0.06	0.61	0.97	3.50							
Season (Quadratic)	0.42	0.26	1.61	0.11	0.42	0.91	2.56							
River Discharge	-0.19	0.03	-5.84	< 0.0001	0.82	0.77	0.88							
AWS Attraction Flows	-0.06	0.03	-2.29	0.02	0.94	0.89	0.99							
% AWS to River Discharge								-0.43	0.29	-1.49	0.14	0.65	0.36	1.15
Year: 2022 vs. 2021	-1.18	0.84	-1.41	0.16	0.31	0.06	1.58	-0.38	0.59	-0.65	0.52	0.68	0.21	2.17
Year: 2023 vs. 2021	0.20	0.89	0.22	0.82	1.22	0.21	6.98	-0.61	0.66	-0.92	0.36	0.54	0.15	2.00
Events	n = 393, 12731							n = 126, 6759						
Iterations	7, 49							14, 74						
RE Variance	3.685883							0.9234061						

Table 15. Outputs from selected entry and departure Cox time-to-event models showing coefficient estimates (β) with standard errors (SE), z-values, p-values, and hazard ratios (HR) with upper and lower 95% confidence interval (UCI, LCI). These models represent advance and retreat from the entry zone among radio-tagged Rainbow Trout. Events refers to the number of completed state transitions (n) relative to the total number of observations in the dataset. Iterations refers to the number of fitting iterations it took to converge during each phase, which informs the model fitting process. The variance of the random effect (RE) indicates the variability explained by differences between individuals.

Variable	State Transition: Entry							State Transition: Departure						
	β	SE	Z	P	HR	LCI	UCI	β	SE	Z	P	HR	LCI	UCI
Diel Period: Day vs. Night	-0.52	0.47	-1.11	0.26	0.59	0.24	1.48	-0.62	0.27	-2.31	0.02	0.54	0.31	0.91
Season (Linear)	1.49	0.61	2.46	0.01	4.45	1.36	14.64	-1.65	0.68	-2.44	0.01	0.19	0.05	0.72
Season (Quadratic)	0.96	0.57	1.70	0.09	2.61	0.86	7.92	0.64	0.48	1.33	0.18	1.89	0.74	4.87
% Total Attraction Flows to River Discharge	0.84	2.32	2.13	0.03	2.32	1.07	5.05							
Year: 2022 vs. 2021	-1.26	0.28	-1.35	0.18	0.28	0.04	1.78	0.02	1.10	0.02	0.98	1.02	0.12	8.81
Year: 2023 vs. 2021	-1.04	0.35	-0.85	0.39	0.35	0.03	3.87	0.98	1.28	077	0.44	2.66	0.22	32.65
Events	n = 52, 9264							n = 196, 3010						
Iterations	5, 30							9, 50						
RE Variance	1.103235							2.724660						

Arctic Grayling

The dataset for Arctic Grayling was very limited. No Arctic Grayling made it to the entry zone in 2021 and only two Arctic Grayling made it to the entry zone in each of 2022 and 2023. Candidate model sets for all state transitions were large (indicating no one model was a good fit to the data), model residuals were poor, and results were based on few individuals. This was an improvement from previous years of single-year datasets where we could not obtain model convergence at all. While models did converge for all four state transitions, we cannot reach meaningful conclusions. Results are not considered further. All candidate model sets and selected model outputs and diagnostics are included in Appendix K: Arctic Grayling Candidate Model Sets.

3.3.2 Movements within Fishway

Numbers Ascending

A barrier to upstream fish movement between the upper fishway and the sorting facility was evident (Four Burbot entered the fishway over the study period, but none ascended beyond pool 8 of the fishway.

Table 16; Figure 26). Of the 742 tagged Bull Trout that arrived at the fishway entrance (i.e., radio- and/or PIT-tagged fish detected in entry zone or upstream), 630 entered the fishway, 256 ascended to the upper fishway, and 21 made it into the sorting facility. Of note, is that the 742 fish detected in the entry zone is likely an underestimate because PIT-tagged fish were only first detected at the entrances (rather than the broader entry zone), and performance of those PIT antennas was poor. Nonetheless, based on these numbers, while 41% of Bull Trout that entered the fishway made it to the upper pools of the fishway, only 8.2% of those successfully passed to the sorting facility. The trend was similar for Mountain Whitefish. Of the 6693 fish that would have passed the entry zone, 6665 entered the fishway, 3333 (50%) ascended to the upper fishway, and 403 (12%) made it to the sorting facility. Of the 53 Arctic Grayling that arrived at the fishway entrance, 26 (49%) reached the upper fishway and three (12%) made it to the sorting facility. Of the 95 Rainbow Trout that arrived at the fishway entrance, 28 (29%) reached the upper fishway and two (2%) reached the sorting facility. Four Burbot entered the fishway over the study period, but none ascended beyond pool 8 of the fishway.

Table 16. Total numbers of tagged fish (target species) detected by either PIT antennas or radio fixed stations at various detection points within the temporary upstream fish passage facility during each full year of operations. The entry zone only includes detections at the outside entrance fixed station; there is no PIT detection point in this zone. The entrance includes detection at the entrances (PIT) or within the entrance pool (radio). The upper fishway includes all detections between pool 23 and the trap. The sorting facility represents a scan by facility operators (successful passage).

Year	Species	Entry Zone	Entrance Pool	Pool 8	Upper Fishway	Sorting Facility
2021	Arctic Grayling	4	4	4	3	1
	Burbot	2	2	1	0	0
	Bull Trout	95	70	53	31	3
	Mountain Whitefish	1072	1057	877	603	58
	Rainbow Trout	14	8	6	4	0
2022	Arctic Grayling	10	8	6	4	0
	Burbot	2	2	0	0	0
	Bull Trout	272	233	170	93	2
	Mountain Whitefish	2498	2488	1852	1223	186
	Rainbow Trout	32	22	11	6	0
2023	Arctic Grayling	39	37	29	19	2
	Burbot	0	0	0	0	0
	Bull Trout	375	327	217	132	16
	Mountain Whitefish	3123	3120	2052	1507	159
	Rainbow Trout	48	42	29	18	2

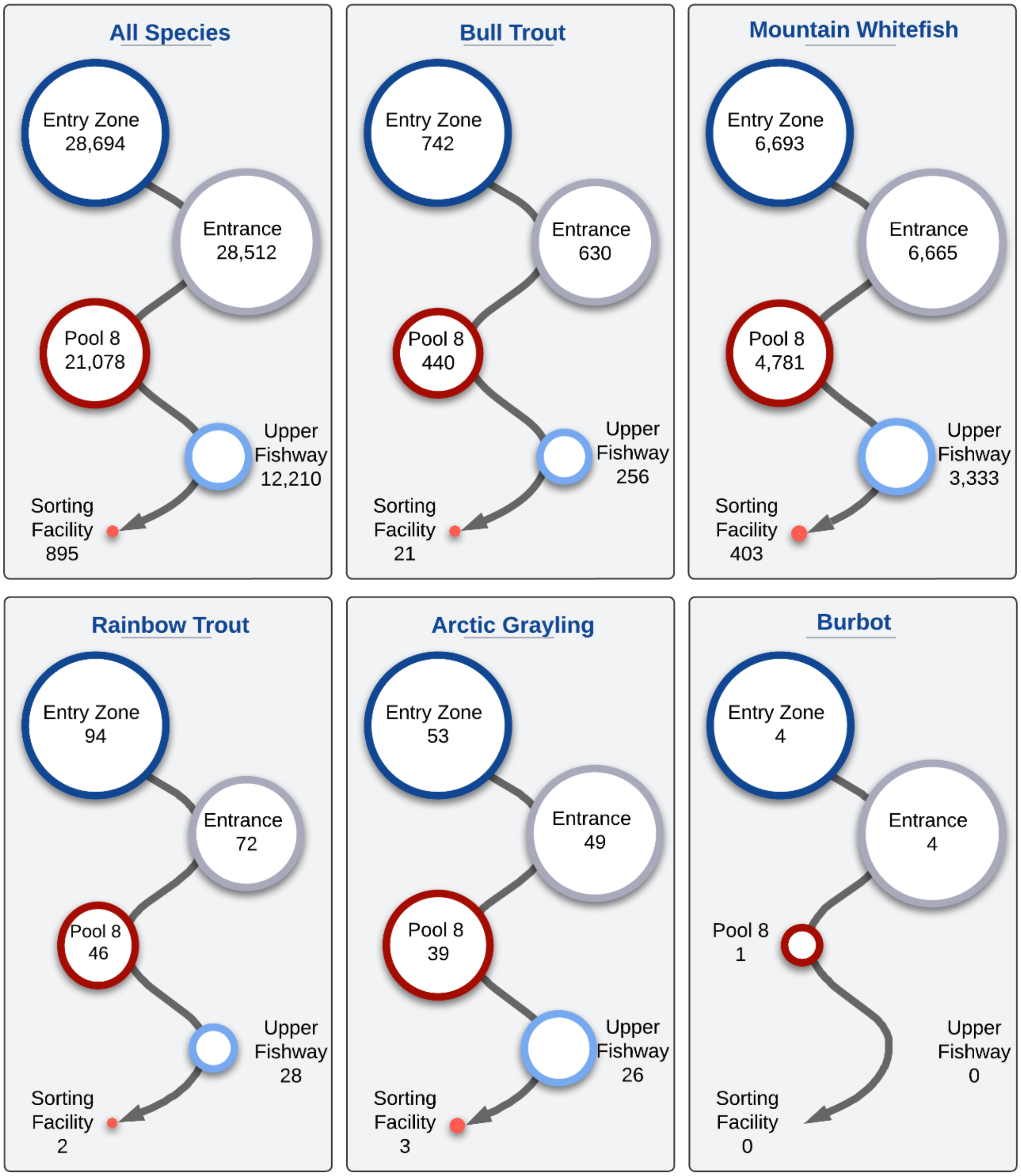

Figure 26. Total numbers of tagged (radio and PIT) fish detected within the temporary upstream fish passage facility, 2021-2023. The first panel shows all fish species combined (not just target species) and subsequent panels show numbers for each target species. For all but the most upstream (sorting facility), numbers detected within each zone account for all upstream detections not accounted for by the stations in that zone (i.e., detections of fish that passed the zone but were missed). The entry zone includes detections at the outside entrance fixed radio station. Given that there is no PIT detection in this zone, numbers from the entry zone number are biased low. All other zones have both PIT antennas and fixed radio stations. The entrance includes detections within the entrances (PIT) or within the entrance pool (radio). The upper fishway includes pools 23 & 24 and the trap. The sorting facility represents scan by facility operators (successful passage).

Efficiency Metrics

All five target fish species have been detected within the approach zone using radio telemetry and were candidates for efficiency metrics. For most species entering the fishway, attraction efficiency ranged from 17.6% (range: 0.9 – 22.0%) for Arctic Grayling to 32.8% (range: 27.1 – 38.7%) for Bull Trout (Table 17). Of the twenty-two Burbot detected in the approach zone, none entered the fishway (0% attraction efficiency). For passage efficiency, eleven radio-tagged Bull Trout fully ascended the fishway to the sorting facility resulting in a passage efficiency of 4.1% (Table 17). Only one radio-tagged Mountain Whitefish and one radio-tagged Rainbow Trout fully ascended the fishway (passage efficiencies of 3.0% and 1.0%, respectively). Passage efficiency was 0% for radio-tagged Arctic Grayling and could not be calculated for Burbot.

Taking advantage of the larger PIT telemetry dataset, the trapping efficiency metric evaluated effectiveness of upstream passage from the upper fishway to the sorting facility, which was a known barrier. Trapping efficiency was lowest for Rainbow Trout at 5.1 % and highest for Arctic Grayling 20.8% (Table 18). Trapping efficiency could not be calculated for Burbot. We are particularly interested in how trapping efficiency has changed across years because of the modifications that have been made to the upper fishway since operations began (see Appendix A: Fishway Shutdowns and Modifications). A visualization of these data does not reveal notable improvements to trapping efficiency over time (Figure 27).

Further details on all efficiency metrics are in Appendix L: Yearly Efficiency Metrics.

Table 17. Summary of radio telemetry data for target fish species used to determine attraction efficiency, passage success, and passage efficiency (2021-2023 combined). Attraction efficiency is the proportion of total candidates that were attracted to and then entered the fishway, passage success is the proportion of those fish that successfully passed through the fishway into the sorting facility, and passage efficiency is the product of attraction efficiency and passage success. Confidence intervals (shown in brackets) were calculated using the Wilson Score method for proportions.

Species	Counts			Attraction Efficiency (%)	Passage Success (%)	Passage Efficiency (%)
	Candidates	Entered	Passed			
Bull Trout	252	83	11	32.8 (27.2 – 39.2)	12.8 (7.1 – 22.9)	4.1
Mountain Whitefish	54	15	1	27.1 (16.9 – 41.9)	11.1 (0.3 – 34.0)	3.0
Rainbow Trout	90	16	1	18.4 (10.8 – 27.6)	5.6 (0.3 – 32.3)	1.0
Arctic Grayling	35	4	0	17.6 (3.7 – 27.7)	0	0
Burbot	22	0	0	0	-	-

Table 18. Summary of PIT telemetry data for target fish species used to determine trapping efficiency, the proportion of tagged fish that reached the upper fishway (pool 23, 24 and trap) that were effectively trapped and thus reached the sorting facility (2021-2023 combined). Confidence intervals (shown in brackets) were calculated using the Wilson Score method for proportions.

Species	Counts		Trapping Efficiency (%)
	Candidates	Passed	
Bull Trout	231	21	9.1 (5.8 – 13.7)
Mountain Whitefish	2960	402	13.3 (12.4 – 14.9)
Rainbow Trout	21	2	5.1 (1.7 – 31.8)
Arctic Grayling	22	3	20.8 (3.6 – 36.0)
Burbot	0	0	-

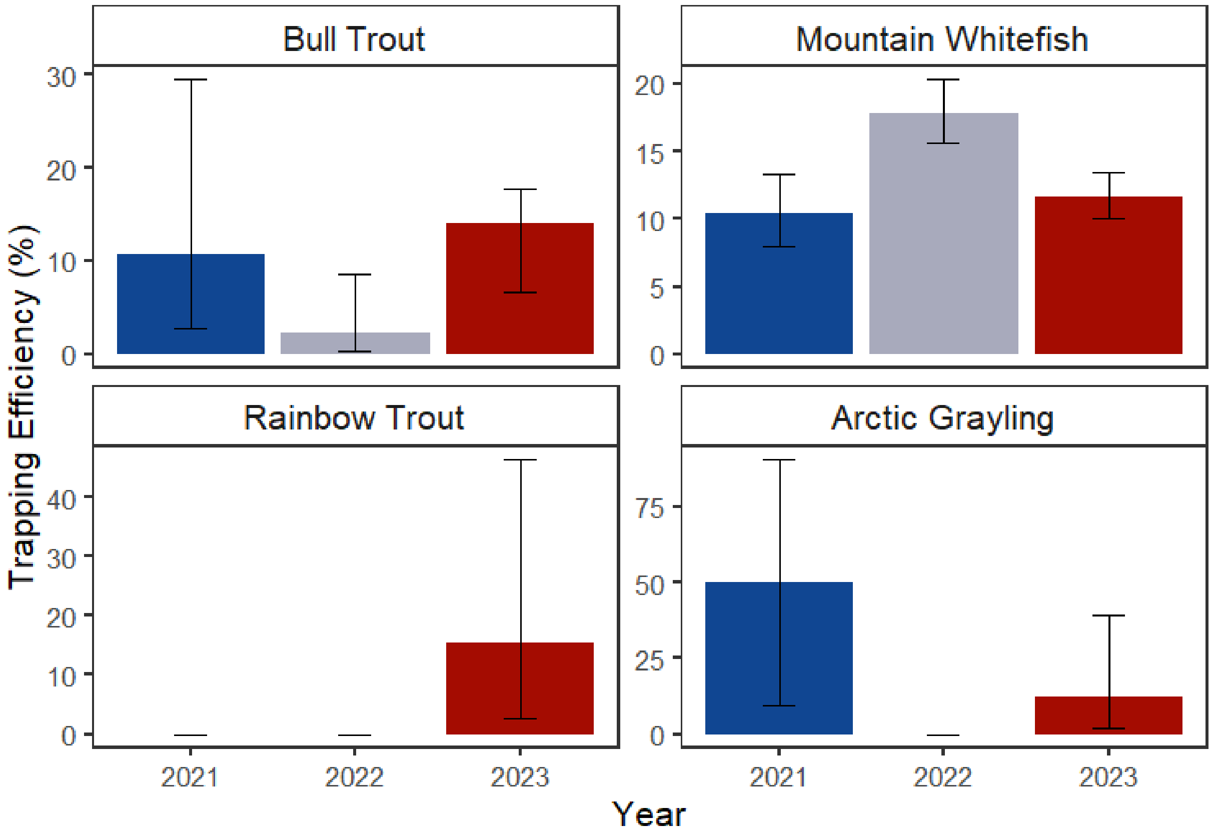

Figure 27. PIT telemetry data were used to determine trapping efficiency, the proportion of tagged that reached the upper fishway (Pools 23, 24 and trap) that were affectively trapped. Confidence intervals were calculated using the Wilson Score method for proportions. Note differences in y-axis values among the panels.

4. Discussion

The objective of Mon-13 was to evaluate the biological effectiveness of the temporary upstream fish passage facility (TUF) for the upstream passage of migrating Arctic Grayling, Bull Trout, Burbot, Mountain Whitefish, and Rainbow Trout. Results were meant to inform future fishway operations and address key uncertainties regarding the attraction flows required to facilitate passage.

The TUF began operating in October 2020, and so 2023 marks the fourth year of operations and the third complete, seven-month operational period. The focus of analyses has changed across each reporting period. The fishway was operational for less than a month in the first year (2020) and only exploratory summaries were completed. In the second year (2021), the focus was on ensuring the experimental design and telemetry array were appropriate for a competing risk TTE analysis. Upon successfully executing the planned models, in 2022, we further explored interpretations of each model and the structure of covariates related to fishway effectiveness. In this third, full year of operations (2023), the dataset was sufficiently robust to complete a multi-year, multi-variate analysis.

The TUF provided an opportunity to learn about fishway operations and fish passage in the area prior to operating the permanent upstream fish passage facility (PUF) once Project construction is complete. While there have been operational challenges that have limited abilities to meet the outlined fish passage goals, every year has seen improvements. According to the raw numbers of time operational, time within design criteria specifications, and fish passed, 2023 was the most successful year. To briefly highlight differences, in 2021 the fishway was operational 81% of the operational period, was run outside of design criteria for 104 days, and the facility operator handled 2,457 fish. In 2023, these metrics improved to 97% in terms of time operational, 24 days outside of the design criteria, and 12,727 fish. Despite these apparent successes, 2023 had distinct operational challenges not seen in other years. Although more fish passed, trapping efficiency did not improve (i.e., there were simply more fish in the fishway). Additionally, the attraction flow schedule was more demanding on the pumps. The highest attraction flow scenario was rarely met and ultimately the pumps failed. The result was lower total attraction flows in 2023 relative to previous years. The frequency of shutdowns was also higher. In 2023, there were seven brief shutdowns recorded, and there may have been others that we do not have a record of. This higher frequency of shutdowns in 2023 has implications in terms of how fish use the system because regardless of shutdown duration, the fishway is dewatered and fish are pushed out following a shutdown event. A further change in 2023 relative to previous years is that as the system prepared for reservoir filling, river discharge was much lower, which would have had a substantial impact on how fish interact with the fishway and surrounding area.

Even with these inconsistencies in operations and environmental conditions across years, the resulting large dataset has the benefit of being robust to such variability. Our analytical approach can incorporate this variability and use it to better understand the factors that may increase the success of fish passage. Following three full years of operations, we can confidently conclude that target fish species can locate, enter, and ascend the fishway to the upper pools. Additionally, we have a good understanding of factors influencing approach and entry for Bull Trout and Mountain Whitefish, the target species with an adequate sample size of radio-tagged individuals detected within the study array. Further, all sources of information (i.e., PIT and radio telemetry, visual observations) indicate that a barrier to passage exists between the upper pools of the fishway and the sorting facility. Not only is this a problem for achieving fish passage targets and has ecological consequences, but this failure to advance through the fishway lead to milling behaviours that are difficult to quantify and created a general lack of passage data. These challenges combined with unfortunately low detection efficiency of the PIT antennas, particularly in the lower fishway, means that we still have a poor understanding of the factors influencing movements through the fishway and successful fishway passage, despite an abundance of detection data from within the fishway.

The discussion herein has greater focus on Bull Trout and Mountain Whitefish, the fish for which movement could be reliably evaluated using the competing risks framework. For other target species, sample sizes were low, and analyses were generally uninformative. There were some results for Rainbow Trout, but the fit of models was poor. Data was so limited for Arctic Grayling that resulting models were unreliable. Arctic Grayling are known to spawn during the spring in tributaries upstream of the Project (i.e., Moberly River; Mainstream 2012), but watershed-wide radio telemetry data suggests they make relatively indiscriminate seasonal movements within the Peace River (Hatch et al. 2022). That is, we may not expect a large migration of Arctic Grayling through the fishway prior to spawning. For Burbot, sample sizes were too low to do any analyses. This lack of data was not surprising. There are relatively fewer tagged individuals within the watershed and Burbot are known to be most active and spawn in the winter, outside of the operational period (Mainstream 2012; Hatch et al. 2022).

4.1 Efficiency Metrics and Passage

Efficiency metrics are provided to meet the requirements of the management questions and to provide a simple index of fishway performance. Attraction and passage efficiency were calculated using the radio detection data only (due to limitations in the PIT array of the lower fishway). We leveraged the ample PIT detection database to calculate trapping efficiency, a metric that evaluates effectiveness of passage from the last three fishway pools, through the pre-sort holding pool, and into the sorting facility - the area with a known barrier.

Attraction efficiencies ranged from 0% (Burbot) to 33% (Bull Trout). Passage efficiencies, which were based on passage success estimates with very low sample sizes, ranged from 0% (Arctic Grayling) to 4% (Bull Trout) and could not be calculated for Burbot. For trapping efficiency, the best results were from Bull Trout and Mountain Whitefish, species for which sample sizes resulted in narrower confidence intervals. Of the fish that make it to the upper fishway, 9-14% of Bull Trout and 12-15% of Mountain Whitefish were trapped. Trapping efficiencies were 5% for Rainbow Trout and 21% for Arctic Grayling, with large confidence intervals. Unfortunately, the modifications made to the top of the fishway since 2020 to improve trapping efficiency did not apparently lead to improved effectiveness. Results confirmed that the top of the fishway was a barrier to the upstream movement of fish across all three years.

Results clearly indicated that a passage obstruction exists within the upper fishway. Considering all tagged fish of all species detected since the start of operations in 2021 (n = 28,512), 43% made it to the upper fishway (n = 12,210) and 3% (n = 895) passed. This also meant that 93% of tagged species making it to the top of the fishway failed to pass. Exploratory analyses of the detection data showed that fish will travel up and down the fishway multiple times and reside in the uppermost pool for extended periods (weeks to months). There have also been visual observations by the facility operator and staff from InStream Fisheries Research of fish swimming in and out of the pre-sort holding pool past the trapping mechanism. The design of ending the fishway with a trap, crowder, and lock seems to limit passage success, which has also been observed in other similar fishways (e.g., a trap and haul facility at a 62 m dam in Australia; Harris et al. 2019).

The EIS predicted that attraction and passage efficiencies of 80% and 76%, respectively, would be met or exceeded for all five target species (BC Hydro 2012). The TUF is far from achieving these benchmarks. However, the efficiencies predicted in the EIS were 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 mean 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). The TUF also underperformed relative to these literature values.

4.2 Factors Associated with Fish Movement

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. The modeling of factors associated with rates of advance and retreat across spatial zones of the fishway and downstream areas provides a more comprehensive assessment of biological effectiveness. Therefore, we also evaluated biological effectiveness of the TUF with TTE analyses to quantify the effects of environmental factors, including supplementary attraction flows, on rates of advance and retreat between distinct spatial zones. We produced four state transition models for each species: an advance and retreat model for both approach and entry. Not all models had sufficient data to reach conclusions. Models of detection data from Bull Trout or from the approach zone had the most data and are, therefore, the most reliable. Despite the data limitations, the suite of analyses provides a better understanding of the environmental conditions associated with increased advance towards the fishway. However, an important consideration in interpreting these model results is that we were not able to model passage success due to lack of data. Therefore, so long as the barrier at the top of the fishway exists, attracting more fish from the approach and entry zone will be limited in its efficacy in terms of improving passage.

4.2.1 Hydrology

River discharge or water surface elevations were included in most models with a consistent effect of reduced rates of advance and increased rates of retreat in all three species as the amount of water increased. For Bull Trout, this was the case for both approach and entry. For Mountain Whitefish and Rainbow Trout, a preference for lower river discharge was only apparent in the approach model. The effect of river discharge was generally linear, with rates of advance gradually decreasing as flows increased. The range of discharge observed in the Peace River across the three years of study was large, from 389 to 2030 m^3/s. Modeling revealed that for every 100 m^3/s increase in river discharge, approach rates decreased by 13% (Bull Trout), 14% (Mountain Whitefish), and 17% (Rainbow Trout). This finding, consistent across species, highlights the importance of river discharge with fish being less likely to approach and enter the fishway at high water levels. Indeed, we observed turbulent and non-uniform velocity gradients at the fishway entrance when river discharge was high that may have dissuaded fish from approaching the fishway (Enders et al. 2005; Brown et al. 2006; Liao 2007).

The Bull Trout data allowed for a more nuanced understanding of the relationships between fish movement and hydrology, including AWS attraction flows, water surface elevation, and AWS attraction flows as a percent of river discharge. For example, it was water surface elevation, not river discharge, that best explained variation in fishway entry rates. Additionally, the relationship was not as linear as observed with river discharge and rates of approach. Rates of entry decreased considerably when elevations exceeded 410.2 m. High discharge in the Peace River caused water elevations at the tailrace of the fishway to exceed the design criteria of 410.5 m for much of 2021, 2022, and the first few weeks of 2023. 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. The decrease in entry rates at elevations greater than 410.2 m is indicative of the importance of maintaining water surface elevations within the fishway design criteria. Additionally, for the design criteria of the permanent facility to consider natural variation in Peace River discharge conditions as well as potential shifts in conditions with climate change.

A key objective of this study was to understand how fish respond to attraction flows from the AWS and HVJ. We have good evidence that increased attraction flows from the AWS attracted fish into the fishway. For Bull Trout, entry of the fishway was faster and/or retreat from the entry zone was slower with higher AWS attraction flows and/or a higher percentage of AWS attraction flows relative to river discharge. Findings were similar for Rainbow Trout (faster entry with higher percent total attraction flow relative to river discharge) and Mountain Whitefish (slower departure at higher attraction flows), though the relationships were not as clear for these species. The same trend was apparent but not statistically significant in the Arctic Grayling entry model, which was extremely data limited. Two conclusions can be drawn from these collective results. One, in no instance was the HVJ associated with advance or retreat rates, and it was rare for total attraction flow metrics (HVJ + AWS) to be included in models. Thus, we can conclude that for the species mentioned above, the HVJ contributed little to no attraction to the fishway. Second, AWS attraction flows on the higher end of the range observed tended to be preferred among all fish species. However, because of pump failures in 2022 and 2023 and the use of the HVJ in 2021 and 2022, fish had relatively less exposure to the maximum AWS attraction flows (the TUF can provide up to 10 m^3/s).

That the selected Bull Trout entry model included water surface elevation and AWS attraction flows and the departure model included of AWS attraction flows as a percentage of river discharge highlights the strength of our modeling approach with sufficient sample size. A successful event occurred in the entry model when a tagged fish entered the fishway (i.e., detected on entrance pool dipole). It is logical that this movement would be more dependent on the exact water elevations in the tailrace at the fishway entrance rather than Peace River discharge recorded 6 km downstream. It is also logical that the decision to move downstream would be concurrently dependent on a combination of what is happening in the fishway (attraction flows) and in the river as a whole (river discharge) at the time of the movement. Expectedly, because the influence of attraction flows would have been reduced in the approach zone compared to the entry zone, attraction flows were not as important to movement from the approach zone as from the entry zone.

There were some contradictory findings among models for which we do not have an explanation. In the Bull Trout approach model, rates of approach were faster at lower attraction flows, which is a direct contradiction with both entry zone models that indicated faster entry rates and slower departure rates at higher AWS attraction flows. While we expected differences in the magnitude of effects between spatial zones, a difference in the direction of effect was not expected. Another conflicting finding was the negative effect of water surface elevation on rates of departure among Mountain Whitefish, suggesting that Mountain Whitefish spent more time in the entry zone at higher water elevations. However, there were no hydrological parameters in the selected entry model. In both cases, the magnitude of effect was low and variation high; our confidence in these results was low. While we've noted these results for transparency regarding uncertainties, we do not believe them to be important to the overall study outcomes.

4.2.2 Season

Most models also had a seasonal component. The only exception were those models likely too data limited to detect the effect (Rainbow Trout withdraw model and Arctic Grayling models). The operational period extends through three seasons during which we expected the biological activities of a given species and/or individual to change. The inclusion of a temporal component in top models is not surprising. Patterns in rates of movements and in the frequency of movement events among seasons can help us understand how motivation to use the fishway may change throughout the operational period.

The Bull Trout models exemplified how use of the study area varies seasonally. Rates of entry were fastest in the fall, rates of approach were fastest in the spring, and all movements (i.e., advance and retreat movements from both zones) were more frequent in the summer. In their current form, our model results cannot provide explanation for this seasonal variation, but we can theorize based on biological knowledge and findings from other species. Watershed-wide telemetry data indicates that Bull Trout complete upstream spawning migrations mainly during summer months for spawning in the fall (September), which could explain the increased frequency of movements (Hatch et al. 2023; Putt et al. 2024). Faster entry in the fall could have been occurring among Bull Trout that failed to ascend the fishway during their normal spawning migration window. Alternatively, looking to Mountain Whitefish, rates of approach and entry were overwhelmingly fastest during the fall. This finding was dramatic; movements in the spring and summer were few and much slower than in the fall (e.g., by hundreds of percentiles). 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. Bull Trout can be voracious predators known to opportunistically feed on concentrated prey downstream of man-made barriers (Furey et al. 2016; Furey and Hinch 2017) and Mountain Whitefish are a common prey item of Bull Trout (McPhail and Baxter 1996; Beauchamp and Van Tassell 2001; Stewart 2002). It is likely that poor passage is creating a concentrated source of prey for Bull Trout during the fall migratory period for Mountain Whitefish. This may explain the increase rate of entry movements observed among Bull Trout, and the lack of this pattern in the approach models.

The seasonal differences do not directly inform fishway operations. Instead, they provide context for consideration when interpreting the more tangible results such as attraction flow and water elevations. The challenge will be to ensure the recommendations produced by our analyses are biologically relevant. That is, if the fishway is being operated to enhance passage for Bull Trout, results from their known migration period will have more value than those from when Bull Trout may be using the fishway as a source of food. Understanding seasonal variation will assist with ensuring the biological relevancy of our recommendations.

4.2.3 Experience

The experience parameter, expressed as either the number of times a movement was made (number of transitions) or as if the movement was novel or not (naïve), produced interesting results. The original intent of including the experience variable was to evaluate if fish were developing learned behaviour of how to approach and enter the fishway. Where number of transitions was included in the selected model, it was removed because of strong correlations with the random effect skewed results. We were able to reduce this unwanted outcome by using the naive variable instead.

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. While these inter-individual differences are an important component of the dataset, another reason for choosing the naïve variable over the number of transitions was that detailed interpretation of inter-individual variation was beyond the scope of the management questions of this monitor. By including the naïve variable, we accounted for the effect but simplified the modelling to focus on those effects of primary interest (i.e., attraction flows, river discharge, and seasonal variation in these relationships). It is worth noting that under an expanded scope, the dataset holds great potential to explore divergent behavioural patterns including interactions among species. The persistent effect of inter-individual variability suggests factors that enhance fishway entry, for example, may not benefit all individuals of a species across the entire operational period. Understanding these relationships will be important to fishway operations.

The naïve variable appeared in all selected models for Bull Trout and Mountain Whitefish and the selected Rainbow Trout approach models. It is expected that the direction of effect for variables that increase advancement towards the fishway will be opposing between advance and retreat models for a given zone. However, the effect of the naïve variable was unanimously positive. In all cases, tagged fish made faster movements in both the upstream and downstream direction (advance and retreat) when they had completed the movement previously (i.e., were non-naïve). The magnitude of effect also tended to be large, and larger in advance models than in retreat models. A positive effect in both directions for fish experience combined with low fishway passage rates indicates that experience was not associated with increased advance towards the fishway, but increased activity and faster movements in general. Fish are not learning how to successfully pass the fishway. Perhaps the rapid movements observed among non-naïve fish represented different behavioural types (i.e., fast vs. slow life histories; Nakayama et al. 2017), different attempted uses of the fishway (e.g., passage vs. predation), or different behavioural states (e.g., migratory vs. non-migratory).

Previous modeling encompassing single-year datasets included the number of transitions and results differed. In 2021 and 2022, rates of retreat decreased among Bull Trout, but increased among Mountain Whitefish with increasing number of transitions (Moniz et al. 2022; Cook et al. 2023). It was hypothesized that this pattern was driven by predator-prey interactions. We caution that these previous models had greater uncertainty attributed to their smaller sample size and tended to have high variance around the random effect; a single individual could be highly influential to model results. The more fulsome multi-year analysis presented in this report did not detect this opposing pattern between Mountain Whitefish and Bull Trout.

4.2.4 Diel Period

A finding that has been consistent across species, models, and years was the inclusion of diel period as an explanatory variable. Diel period was present as a negative effect in nearly all models, though it was not always statistically significant. A negative effect indicates slower rates of movement during nighttime hours. As with the experience variable, a consistent direction of effect across opposing state transitions indicates more activity and faster movement rates during the day, rather than greater attraction to the fishway during the day. Within approach models for Bull Trout, Mountain Whitefish, and Rainbow Trout, the magnitude of effect of the diel period variable was substantial and highly statistically significant but this was not true in the withdraw models. For Bull Trout and Mountain Whitefish, diel period also held a high magnitude of effect and high statistical significance in the entry and departure models. This pattern was detectable for Rainbow Trout as well, but the model lacked statistical power. The number of approach, entry, and departure transitions during the day was also greater for Bull Trout and Mountain Whitefish, with differences being dramatic for Mountain Whitefish. Nearly all movement among Mountain Whitefish occurred during daylight hours. These results suggest faster and more frequent approach during the day, and greater overall activity in the entry zone (entry into fishway and departure into approach zone). The pattern of more activity during the day has been observed since operations began. Still, this result is surprising given that both Bull Trout and Rainbow Trout have typically been observed to be most active during dawn, dusk, or at night (Downs et al. 2006; Barnett et al. 2013; Watson et al. 2019; Naman et al. 2022; Putt et al. 2023). The mechanisms of this pattern likely differ seasonally and among species. It is worth noting that in previous analyses we did evaluate four diel periods (dawn, day, dusk, night) but the shorter durations of the dawn and dusk periods limited the power of models and, in all cases, dawn grouped with day and dusk with night. We simplified the diel period variable to increase the power to detect effects of primary interest (e.g., hydrology, attraction flows) but ultimately these factors are related. The need for visual cues due to challenging hydraulic conditions, foraging opportunities, and/or predator avoidance may explain a shift to diurnal movement (Reebs et al. 1995; Reebs 2002; Keefer et al. 2013).

4.3 Conclusions

The biological effectiveness of the TUF continued to be low after three full operational periods – most likely driven by the design of the upper fishway resulting in poor trapping efficiency. A primary objective of monitoring was to inform operation of the PUF, currently scheduled to begin in 2024. Conditions at 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 water flowed through diversion tunnels and past the TUF, overwhelming the fishway in a manner that may not occur at the PUF. Additionally, several modifications were made to the design of the upper pools and trapping mechanism at the PUF. We also expect that has a permanent facility, the PUF will not be impacted by shutdown periods like experienced at the TUF or other operational challenges (e.g., pump operations, water surface elevations above design criteria). As the Project transitions away from construction and into operation, the expectation is that the frequency of these disturbances will decrease.

Our modeling results have consistently shown effects of hydrology, diurnal movement, seasonal variation, and an effect of the individual. There was strong evidence that AWS attraction flows provided better attraction than the HVJ. Specifically for Bull Trout, fishway entry rates increased linearly with AWS attraction flows. To determine optimal attraction flows, we would ideally see a quadratic effect where rates of advancement decreased after a certain magnitude of attraction flow. Therefore, we strongly recommend testing fishway attraction flows to the maximum that the fishway pumps can accommodate. Model results also clearly showed that advancement to the fishway increased at lower Peace River discharges and/or water surface elevations. Further, the Bull Trout model highlighted the importance of the fishway operating within the design criteria. Though data were still too limited for Arctic Grayling and Burbot, we are beginning to understand operational changes that can be made to facilitate passage for Mountain Whitefish, Rainbow Trout, and Bull Trout.

The multi-year analysis approach adopted in this report was an improvement over the prior approach of single-year analyses. The expanded dataset meant the influence of the random effect of individual fish was lower, allowing a better understanding of the fixed effects of interest. Still, our current modeling approach can be considered exploratory, and it was apparent that unaccounted for interactive effects were present. If there is interest in moving towards predictive models developed from hypothesis-testing, our results highlight the importance of multivariate and interaction effects of hydrology, time, and individual.

A challenge within the dataset has and will continue to be distinguishing inter-individual variability in behaviour. For example, differentiating fish that are actively migrating upstream (potentially to spawn) from resident fish and/or those using the area for feeding. The seasonal components incorporated within our models are not necessarily 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. While we still do not fully understand all interacting relationships, we know that operational strategies should reflect seasonal and environmental variability to maximize biological effectiveness. This is to be expected given the diversity of species using the fishway, and their unique biological requirements. Operations will have to holistically and explicitly consider trade-offs and how each species may differentially respond. For example, maximal attraction flows may only be beneficial to Bull Trout during their period of upstream migration (and otherwise may attract them to a fishway only to predate on other target species that do not require high attraction flows).

The level of predation within the fishway and the potential lasting impacts of poor passage on the overall ecological health of the watershed are concerning. The sheer magnitude of detection data from within the fishway is indicative of the number of fish present. Low passage success will concentrate fish and lead to milling behaviours within the fishway – patterns we have observed. The consequences of this include migratory delay, increased energy expenditure, and increased predation (McLaughlin et al. 2013). Predation of concentrated prey near 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 were regularly observed depredating fish inside the fishway and it is likely that Bull Trout are preying upon smaller fish at the entrance of and within the fishway, particularly later in the operational period when Bull Trout are no longer migrating upstream to spawn but Mountain Whitefish are (Hatch et al. 2023). Indeed, we suspect this is the underlying mechanism in the seasonal variability observed in Bull Trout models.

Hypothesis-driven TTE modeling comparing rates of movements of predator and prey species across state transitions could help understand the potential consequences of fish congregating in the fishway because of poor passage. 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 that is commonly evaluated in mammalian research (Whittington et al. 2011; Visscher et al. 2023). We may also see model outcomes change as both predators and prey adjust their behaviour over time at the Project. The current TTE analysis will quantify spatiotemporal movements of predator and prey but cannot confirm predation. If suspected predation continues to be a concern, particularly during operation of the PUF, quantifying predation to inform mitigation efforts may be prudent.

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. Additionally, our data only informs associations with approach and entry because of the data limitations resulting from so few fish successfully passing the fishway. Improving the effectiveness of the trap (i.e., increased one-way, upstream movement into the pre-sort holding pool) would greatly enhance our understanding of movement through this system by potentially allowing for modeling factors associated with advance and retreat movements from a third spatial zone, the fishway.

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Appendix A: Fishway Shutdowns and Modifications

Table A1. Modifications made 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. Information provided by BC Hydro, through internal monthly reports.

Date	Modification
August-October 2021	Several minor adjustments made to improve passage and increase trapping efficiency, including the installation of an overhead light system with programmable timers at the upstream end of the pre-sort holding pool to mimic daylight or attract fish at night. Additionally, sprayers were used to create surface disturbance in the pre-sort holding pool, a hose was aimed at the trap opening, Pump 9 was kept running at all times to increase flow, and the trap gate was closed at 04:00 to prevent fish from moving downstream at dawn.
March 2022	Panels added to side arms of the trap to concentrate the flow cue through the upstream half of the trap.
June 8 2022	Installed a finger weir in the 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 2022	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 2022	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 2022	Finger weir raised again to 5 cm below the water surface.
October 14-31 2022	Pre-sort holding pool lights alternated on or off at night from October 14 to 31.
April 2023	Discontinued operation of the high velocity jet because 2022 monitoring data showed it did not help fish approach/enter the facility and it interfered with monitoring equipment.

Table A2. Summary of operational shutdowns (2020-2023). Information provided by BC Hydro, through internal monthly reports.

Year	Shutdown	Shutdown Start	Shutdown End	Duration	Reason
2020	1	2020-10-20 14:20	2020-10-30 12:50	9.93 days	Operational constraints regarding cold weather forced TUF to be put on standby.
2021	1	2021-04-20 13:15	2021-04-21 06:30	17.25 hrs	Water surface elevations on April 20 exceeded operating range, causing automatic pump shutdowns and drained the fishway.
	2	2021-06-11 18:05	2021-06-16 12:51	4.78 days	The operator observed sheen on the water surface in the receiving pool and shut down the facility to analyze water samples.
	3	2021-06-29 11:23	2021-07-25 10:03	25.94 days	The operator observed a sheen on water surface and shut down the facility. The operator removed and inspected horizontal pumps, which broke the seal on the pumps. New o-rings needed to be sourced and installed prior to start up.
	4	2021-07-26 06:00	2021-07-26 06:57	0.95 hrs	Power outage.
	5	2021-09-08 09:26	2021-09-16 14:04	8.19 days	Maintenance: install analog cards and replace brass bushing on the fish lock.
	6	2021-10-07 13:56	2021-10-07 17:37	3.68 hrs	Flows turned off to clean sand from fish lock and flush sprayers in pre-sort holding pool.
2022	1	2022-05-29 14:41	2022-06-09 08:30	10.74 days	Increased local inflows caused sediment to clog water intake screens and the differential between the diversion tunnel outlet and wet well exceeded criteria.
	2	2022-06-29 09:57	2022-06-30 15:41	29.73 hrs	Continued sediment build-up.
2023	1	2023-05-08 07:50	2023-05-08 14:40	6.83 hrs	Power lines were installed at the diversion tunnel outlet*.
	2	2023-05-16 09:00	2023-05-17 06:30	21.5 hrs	Site on evacuation alert due to a nearby wildfire*.
	3	2023-08-10 10:02	2023-08-11 13:02	27.0 hrs	Flows held low and passed solely through one diversion tunnel to support construction activities, which resulted in unique hydraulics and debris build-up on the pump screen intakes. This caused the water level differential between the diversion tunnel outlet and the pump wet well to exceed 4 meters, which increases risk of damage to mechanical equipment. Facility shut down multiple times to clean the screen intakes and 'reset' the wet well.
	4	2023-08-20 13:43	2023-08-21 06:48	17.08 hrs	
	5	2023-08-27 14:25	2023-08-28 12:33	22.13 hrs	
	6	2023-09-04 07:58	2023-09-05 07:29	23.52 hrs	
	7	2023-09-19 13:43	2023-09-20 11:39	21.93 hrs	
	8	2023-10-11 14:10	2023-10-12 07:00	16.83 hrs	
	9	2023-10-23 14:00	2023-10-24 07:04	17.07 hrs	

*Referred to a standby period because a sort was conducted. Considered equal to a shutdown because fishway flows ceases.

Appendix B: Attraction Flows by Year

The figures below show fishway attraction flows during each operational year. Attraction flows were provided from an auxiliary water supply (AWS) and a high velocity jet (HVJ). AWS flows were set to 4.25 or 8.5 m^3/s in 2021 and 2022 and the HVJ alternated between on (1.5 m^3/s) or off. In 2023 AWS flows were set to 4.25, 5.75, 8.5, or 10 m^3/s and the HVJ was not used. Shutdown periods are greyed. Data provided by BC Hydro.

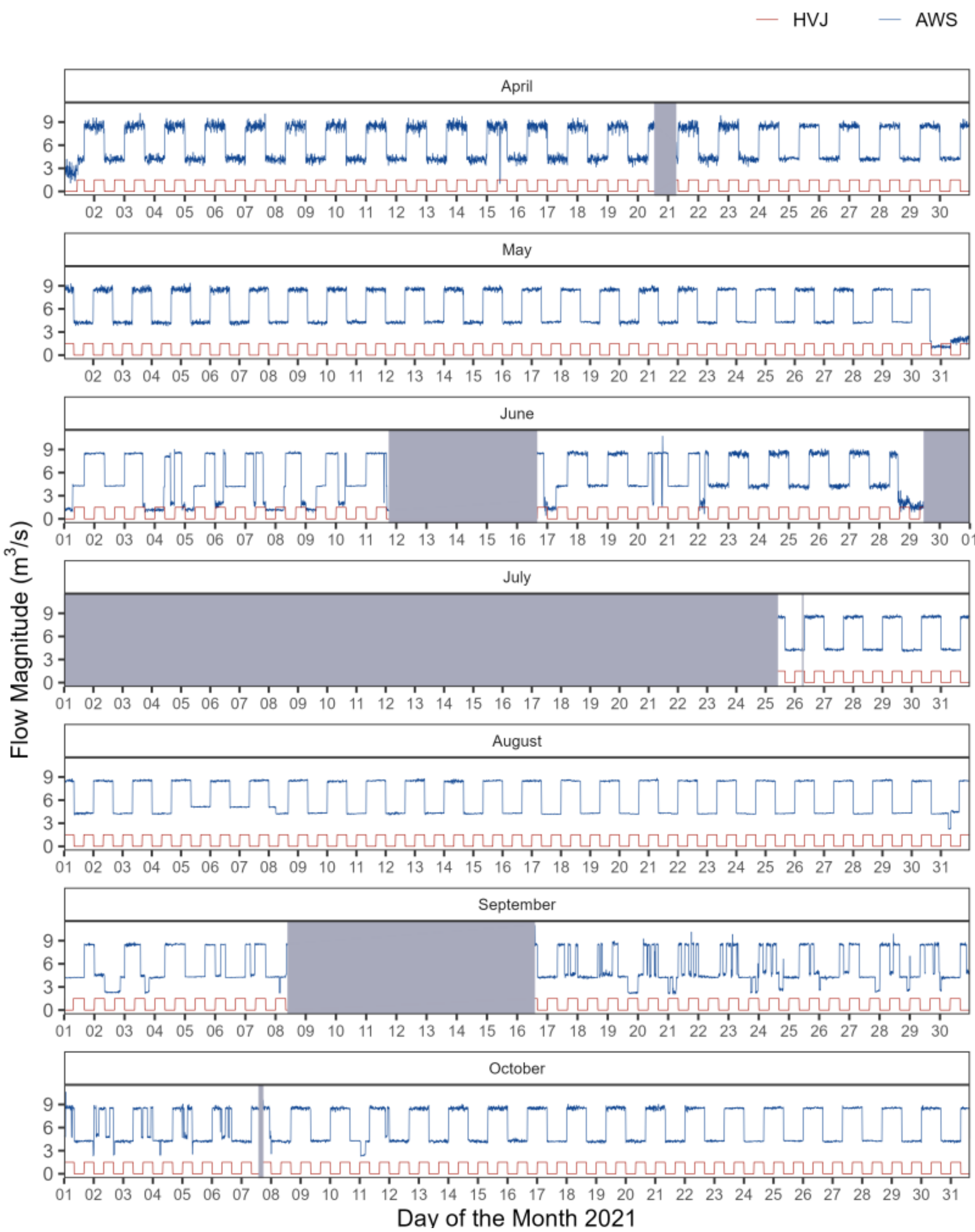

Figure B1. Fishway attraction flows in 2021.

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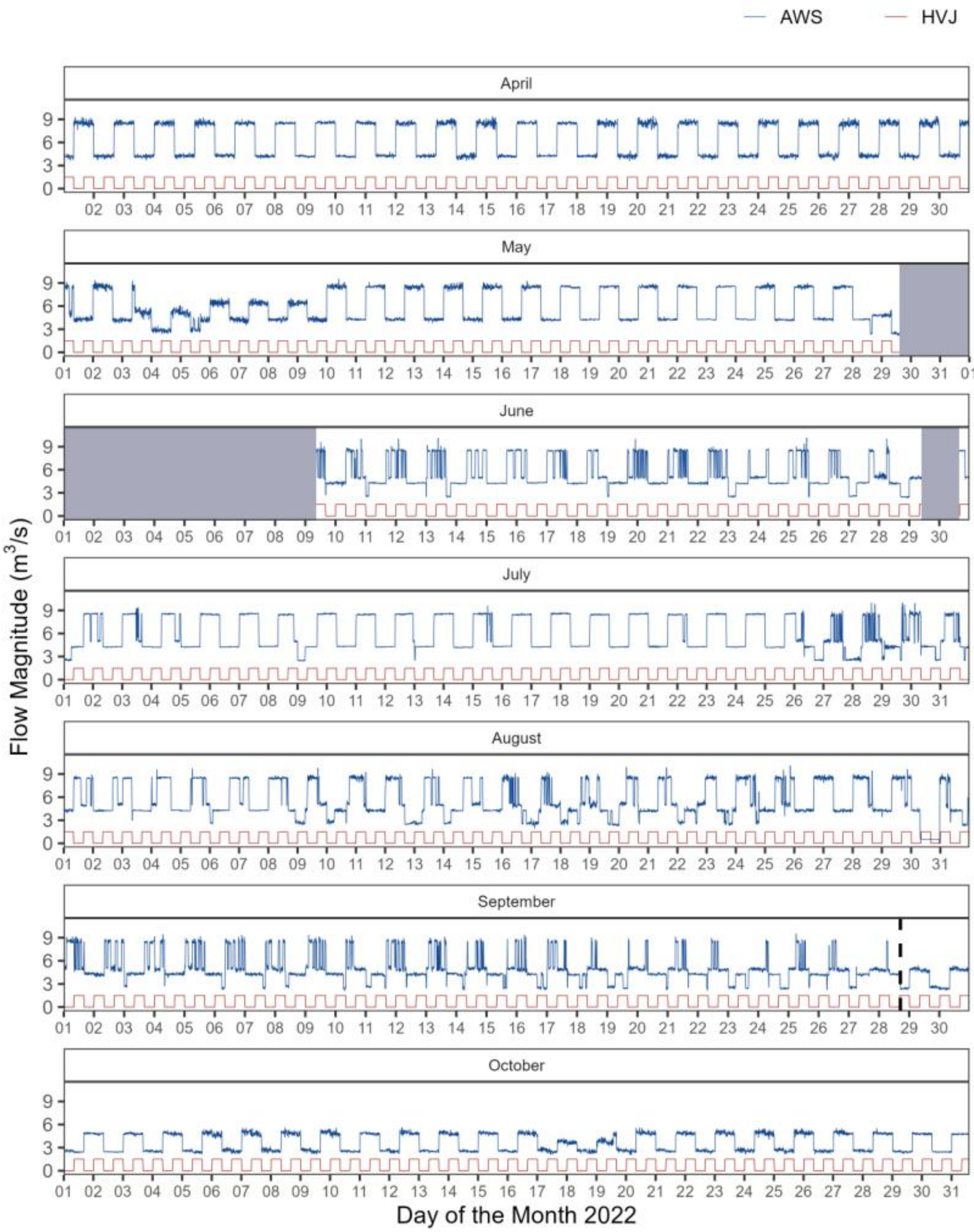

Figure B2. Fishway attraction flows in 2022.

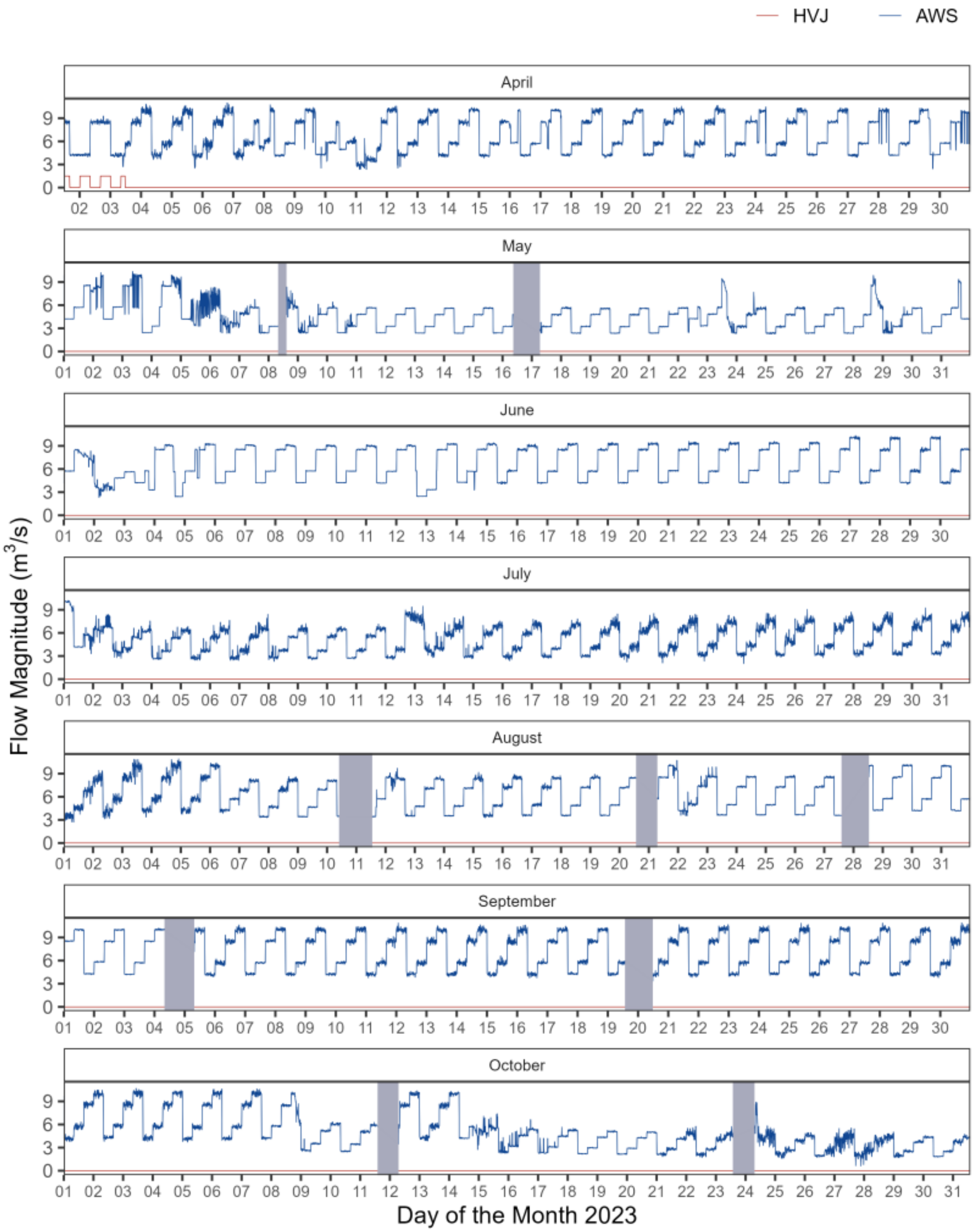

Figure B3. Fishway attraction flows in 2023.

Appendix C: PIT Antenna Testing Results

Table C1. Results of PIT antenna testing. P-values of Kruskall Wallis (KW) tests comparing % read range across years are bolded when significant. A statistical test was only completed when the measure was consistent across all three years (NA stated if not test was conducted).

Antenna	Year	Measure	Tag Size (mm)	Read Range (cm)		% Read Range		Count	KW P-value
				Mean	SD	Mean	SD		
East Entrance	2021	under	32	12.5	28.2	14.4	32.4	14	0.009
	2022	under	32	2.1	1.7	2.5	1.9	15	
	2023	under	32	1.5	2.5	1.7	2.9	26	
West Entrance	2021	under	32	10.9	17.7	12.5	20.3	22	0.94
	2022	under	32	8.8	7.5	10.1	8.6	30	
	2023	under	32	9.7	9.9	11.2	11.4	25	
Weir 8	2021	over	32	4.0	NA	4.2	NA	3	NA
	2021	under	32	51.0	46.2	53.7	48.6	18	0.013
	2022	over	32	35.0	41.2	36.8	43.3	20	
	2023	over	32	4.4	5.6	4.7	5.9	21	
Orifice 8	2021	over	32	8.4	9.4	15.2	17.0	28	NA
	2021	under	32	14.1	13.4	25.6	24.4	31	NA
	2022	over	32	15.4	14.2	27.9	25.8	27	0.055
	2022	under	32	22.2	16.5	40.4	30.0	31	
	2023	under	32	16.0	17.1	29.1	31.0	22	
Weir 23	2021	over	32	5.8	8.2	19.3	27.3	6	NA
	2021	under	32	3.5	1.6	11.7	5.5	33	0.057
	2022	over	32	4.8	2.2	16.1	7.4	31	
	2023	over	32	6.4	3.8	21.4	12.6	21	

Antenna	Year	Measure	Tag Size (mm)	Read Range (cm)		% Read Range		Count	KW P-value
				Mean	SD	Mean	SD		
Orifice 23	2021	over	32	4.2	3.3	14.0	10.9	5	NA
	2021	under	32	5.5	7.0	18.2	23.2	31	0.023
	2022	under	32	5.7	3.9	19.0	13.1	30	
	2023	under	32	9.3	7.7	31.1	25.8	21	
Weir 24	2021	over	32	28.4	5.5	94.7	18.3	5	NA
	2021	under	32	27.0	6.6	90.1	22.1	34	0.028
	2022	under	32	26.8	7.3	89.2	24.5	32	
	2023	under	32	21.5	10.8	71.7	35.9	22	
Orifice 24	2021	over	32	28.4	5.5	94.7	94.7	5	NA
	2021	under	32	27.0	6.6	90.1	90.1	34	0.067
	2022	under	32	26.8	7.3	89.2	89.2	32	
	2023	under	32	21.5	10.8	71.7	71.7	22	
Trap	2021	by	32	4.6	9.0	15.3	30.1	19	< 0.001
	2022	by	32	12.8	4.9	42.6	16.2	33	
	2023	by	32	13.9	5.8	46.2	19.4	21	

Appendix D: Heterogeneity in Activity (MW, RB, AG)

The figures below show the cumulative number of advance transitions made by radio-tagged Mountain Whitefish, Rainbow Trout, and Arctic Grayling. Each figure shows transitions into the approach (top panels) and entry (bottom panels) zones for the duration of the operational period in each year. Each transition represents a movement between the outside approach zone and the approach zone or from the approach zone into the entry zone. Individual fish are identified by distinct colours.

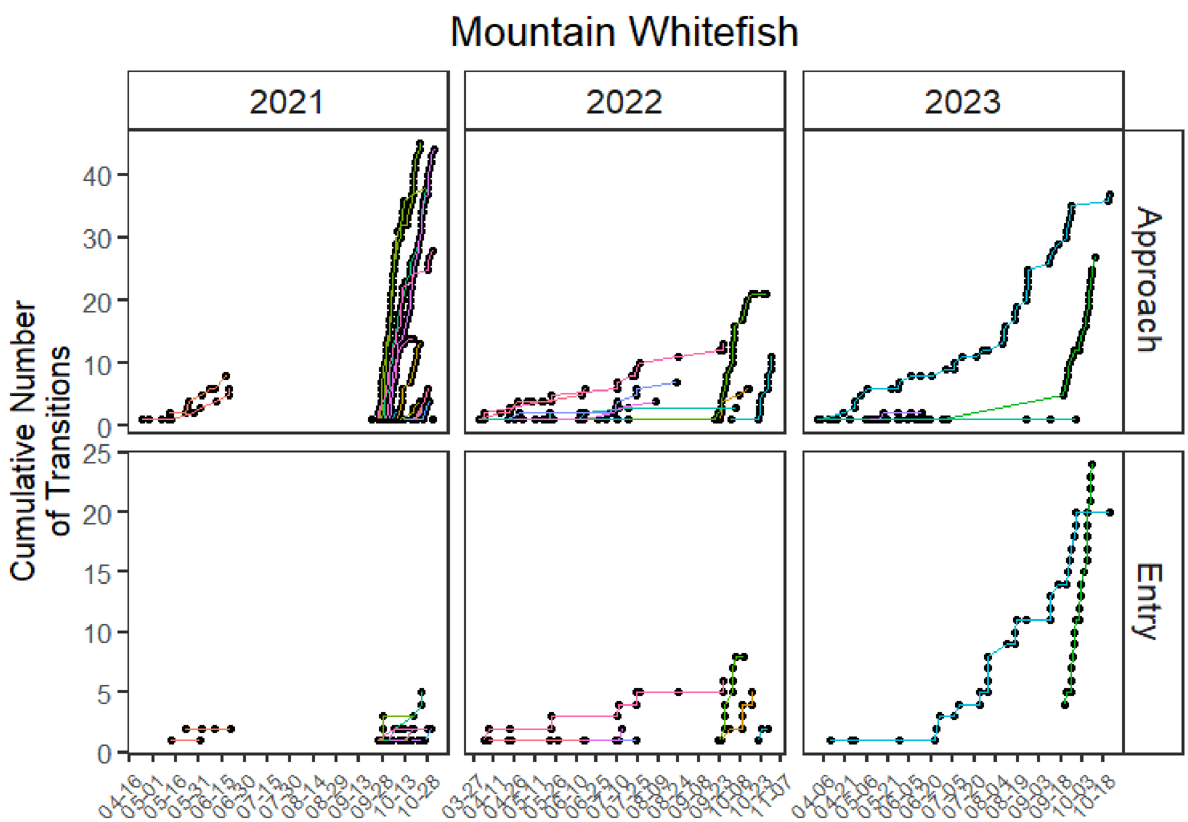

Figure D1. The cumulative number of advance transitions made by radio-tagged Mountain Whitefish.

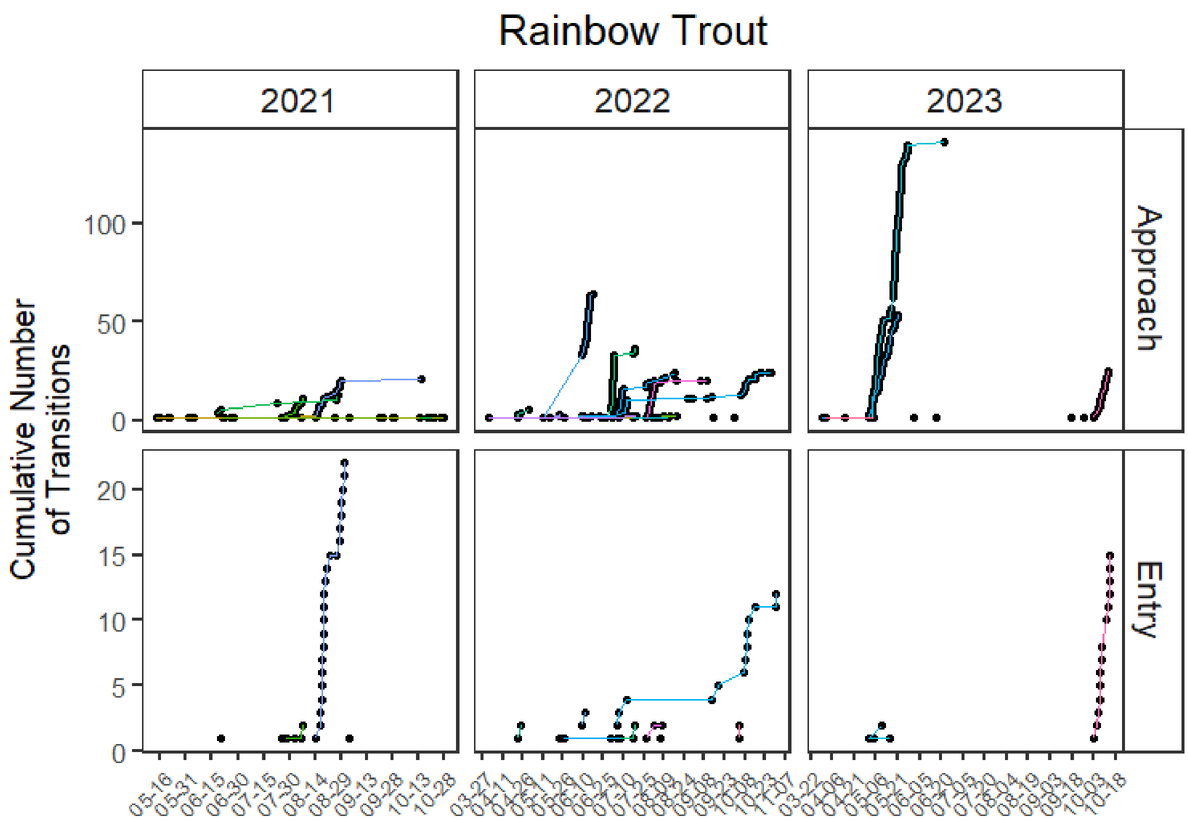

Figure D2. The cumulative number of advance transitions made by radio-tagged Rainbow Trout.

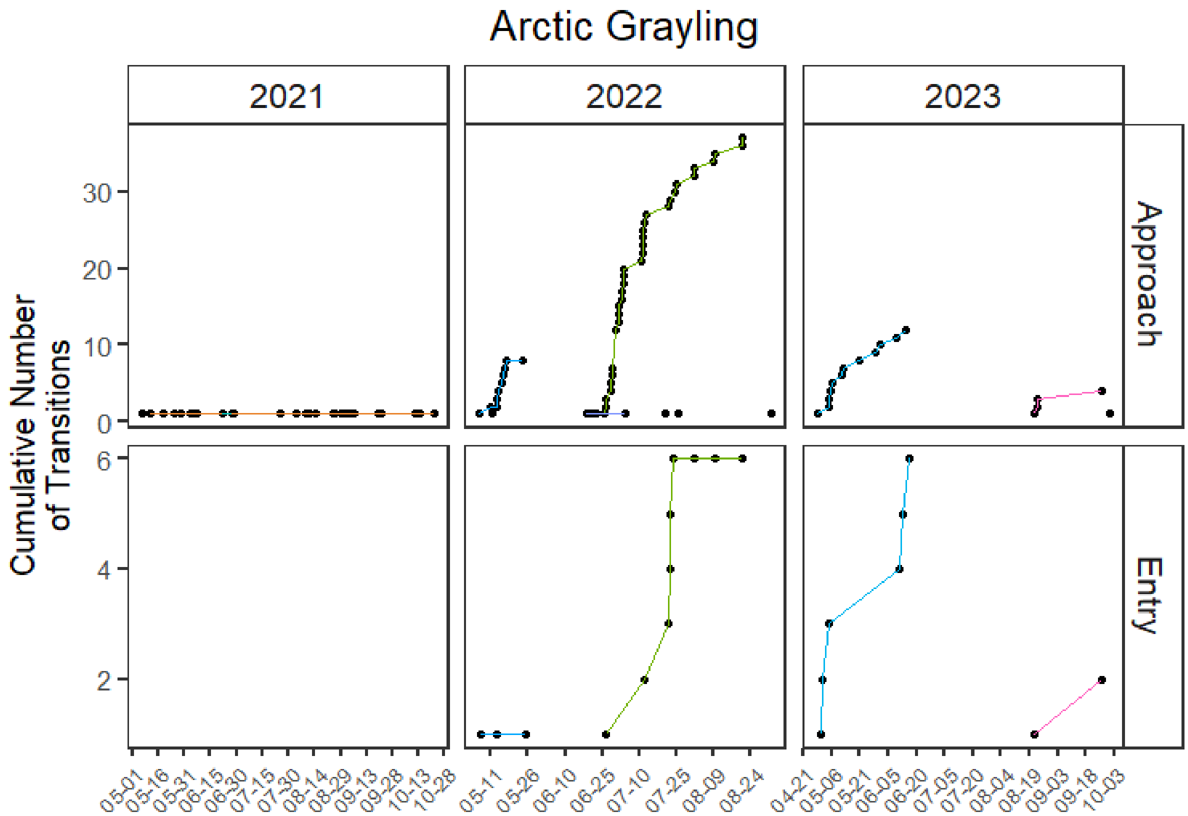

Figure D3. The cumulative number of advance transitions made by radio-tagged Arctic Grayling.

Appendix E: Bull Trout Candidate Model Sets

Approach: No model was within two ΔAIC of the top model within the initial model set (included variables of transitions, diel period, season, river discharge, and AWS attraction flows). We replaced number of transitions with the binary-coded naïve variable for better comparison with the withdraw model and for ease of interpretation. The included terms were the same.

Withdraw: There were three candidate models, all including combinations of naïve, season, river discharge, diel period and total attraction flow (Table E1). We selected the second model (ΔAIC = 1.80) to minimize the ΔAIC value while maximizing comparability with the approach rate model.

Entry: No model was within two ΔAIC of the top model (included variables of naive, diel period, season, water surface elevation, and AWS attraction flows).

Departure: The initial model set included two models that included transitions, season, diel period and percentage of AWS or total attraction flows to river discharge. Model fit was poor. Repeating the model selection process with the naïve variable produced similar results and two candidate models (Table D2). We selected the first to minimize the ΔAIC value and maximize comparability with the entry model (i.e., evaluate AWS rather that total attraction flows).

Table E1. Withdraw candidate model set

Covariates	DeltaAIC	AICw	LogLik
Naïve + Season + MeanQ + Year	0.00	0.28	-6087.35
Naive + DielPeriod + Season + MeanQ + Year	1.80	0.12	-6087.27
Naive + Season + MeanQ + MedAttFlow + Year	1.94	0.11	-6087.35

Table D2. Departure candidate model set

Model set	Covariates	DeltaAIC	AICw	LogLik
Initial run	Transitions + DielPeriod + Season + AWSPer + Year	0.00	0.50	-8808.53
	Transitions + DielPeriod + Season + AttFlowPer + Year	0.44	0.40	-8808.73
Final	Naïve + DielPeriod + Season + AWSPer + Year	0.00	0.59	-8832.68
	Naïve + DielPeriod + Season + AttFlowPer + Year	1.14	0.33	-8833.24

Appendix F: Diagnostics of Selected Bull Trout Models

Approach Zone Models

Approach

Distributions of the continuous variables included in the selected Bull Trout approach model (Figure F1) show:

- A left skew of discharge data. This could likely be corrected with a log transformation, but that will make model results harder to interpret.
- A tri-modal distribution of AWS attraction flows. This is not a concern as it reflects the setpoints. You can really see the lack of exposure to higher AWS attraction flows.

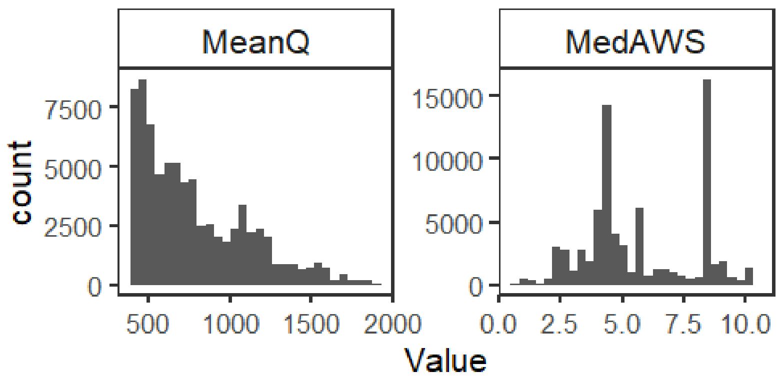

Figure F1. Distributions of continuous variables included in the Bull Trout approach model.

There are some concerning correlations among covariates (Figure F2):

- There is a negative correlation between year and river discharge. We know that river discharge was much lower in 2023 than in other years, especially within the Bull Trout migratory period, and this is reflected here. There isn't much that can be done about this other than collect more data or analyze high flow years (2021, 2022) separately from low flow years (2023). I suspect our data set is big enough to be robust to this effect.
- Negative correlation between Naïve (0)/ Non-naïve (1) and reflects that at lower discharge there are more non-naïve movements (more movement in general). Again, expected.

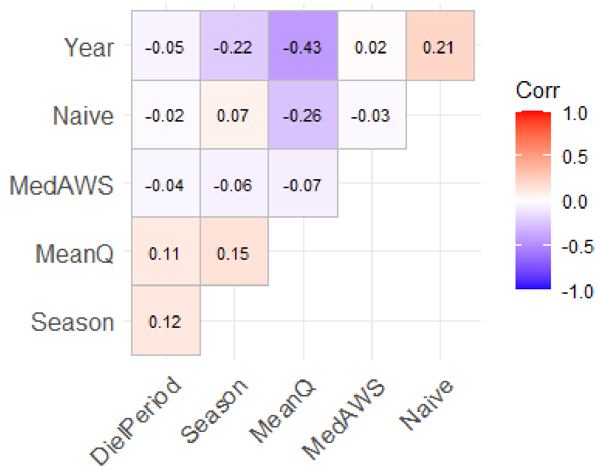

Figure F2. Correlations among selected covariates included in the Bull Trout approach model.

Seasonal variation (Figure F3) shows that river discharge was highest in the fall. This is unexpected. The correlation between season (ordered, spring, summer, fall) and discharge is negative meaning flows decrease with season (this is also reflected in the hydrograph). The higher values of Q in the fall in this dataset means that Bull Trout are making approach movements in the fall at discharges that they wouldn't make in the spring or summer (more motivation in the fall). The drop in attraction flows in the fall is unfortunately likely due to pump failures in both 2022 and 2023.

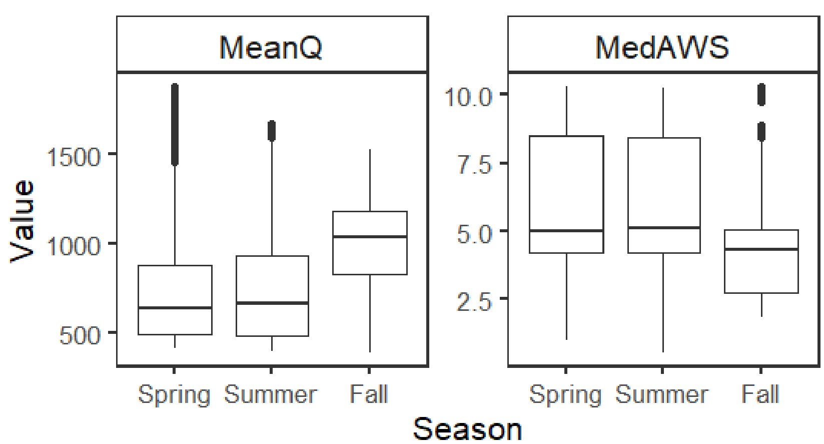

Figure F3. Seasonal differences among continuous variables included in the Bull Trout approach model.

Ultimately the residuals of the model are not textbook, but not of concern (Figure F3). If we wanted to use this model for making predictions the first thing to do would be to log-transform river discharge.

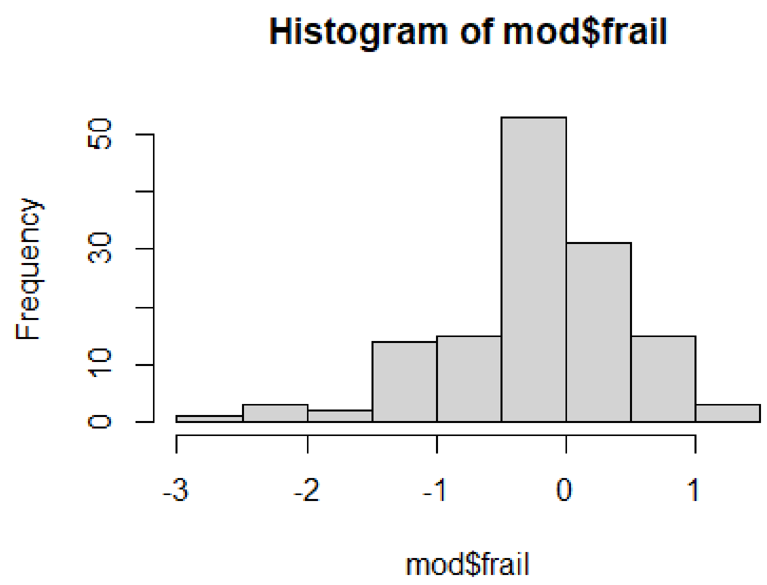

Figure F4. Residuals of the frailty term included in the Bull Trout approach model

Both naïve and year fail the proportional hazards test (Table F1). The naïve term has an extremely low p-value. The significance of the year term in the proportional hazard tests reflects the unavoidable year-specific differences; these might be smoothed out by log-transforming the discharge variable. Removing the naïve variable may also produce better results, but this is an important component of the dataset and that may increase the influence of the random effect. These are simply considerations in case we wanted to do more with the model results. I don't feel that these shortcomings influence the big-picture results as interpreted in the report.

Looking at correlations with the random effect (Figure F5) confirms the suspicion that the naïve variable influenced. A good next step would be to assess how the random effect and model interpretations change when removing this variable.

Table F1. Cox proportional hazards for the Bull Trout approach model

	chisq	df	p
Naive	54.928	0.95	1.1E-13
DielPeriod	0.999	1	0.318
Season	0.797	1.97	0.663
MeanQ	2.95	1	0.085
MedAWS	0.106	1	0.744
Year	7.43	1.88	0.022
GLOBAL	70.619	95.5	0.974

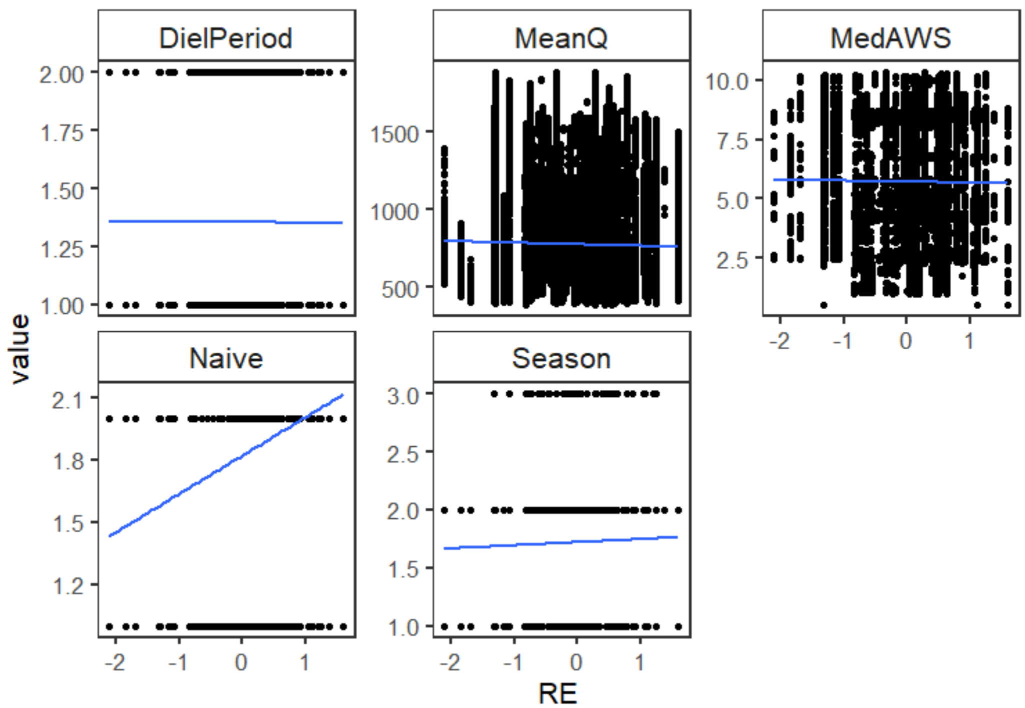

Figure F5. Correlations with random effect in the Bull Trout approach model

Withdraw

The withdraw model has many similar concerns as the approach model. Attractions flow weren't included in the selected model but, otherwise, river discharge is similarly left skewed (Figure F6) and, negatively correlated with year (Figure F7), and elevated in the fall (Figure F8).

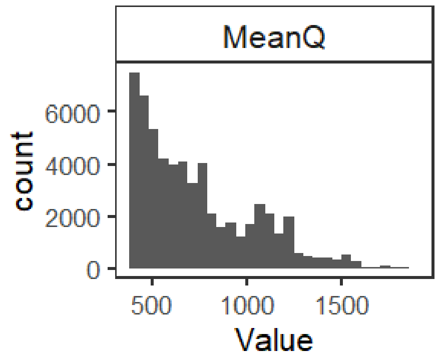

Figure F6. Distributions of continuous variables included in the Bull Trout withdraw model.

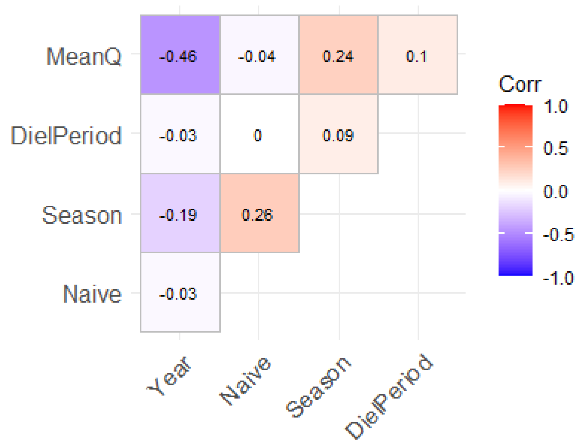

Figure F7. Correlations among selected covariates included in the Bull Trout withdraw model.

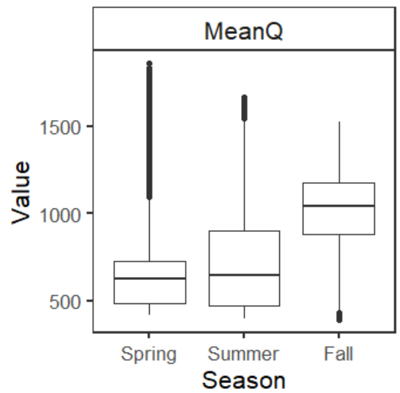

Figure F8. Seasonal differences among continuous variables included in the Bull Trout withdraw model.

Despite the inconsistencies in the discharge variable, residuals of the frailty term from the withdraw model do look better than from the approach model.

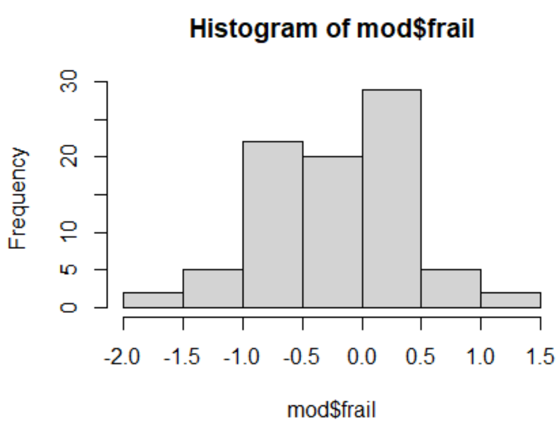

Figure F9. Model residuals of Bull Trout withdraw model.

Assessing results of the cox proportional hazard test shows additional differences from the approach model (Table F2). Here several variables failed: naïve, season, and discharge, but none as dramatically as the naïve variable in the approach model. These variables (including diel period) are also all slightly correlated with the random effect (Figure F10). I'm not sure what could be done to improve this other than log-transforming discharge (unlikely to make a big difference) and collect more data. Ultimately, I think the really divergent hydrological variables across years is the culprit.

Table F2. Cox proportional hazards for the Bull Trout withdraw model.

	chisq	df	p
Naive	10.97	0.96	0.00085
DielPeriod	1.34	1	0.2462
Season	8.46	1.85	0.01227
MeanQ	5.27	0.98	0.02087
Year	2.07	1.59	0.26883
GLOBAL	28.52	71.57	1

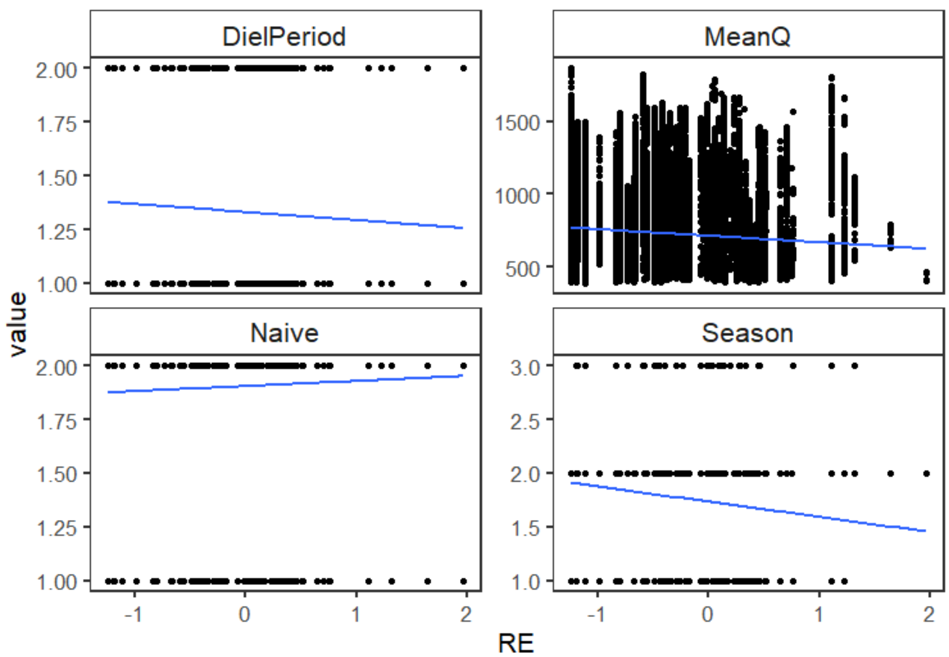

Figure F10. Correlations with random effect in the Bull Trout withdraw model.

Entry Zone Models

Entry

A few interesting things from distributions (Figure F11) are that, 1) WSE values are not as skewed as discharge (potentially a lack of movement at the very high WSE values) and the AWS shows a strong tri-modal distribution despite flows above 7 being relatively rare. Shows a real preference for high AWS.

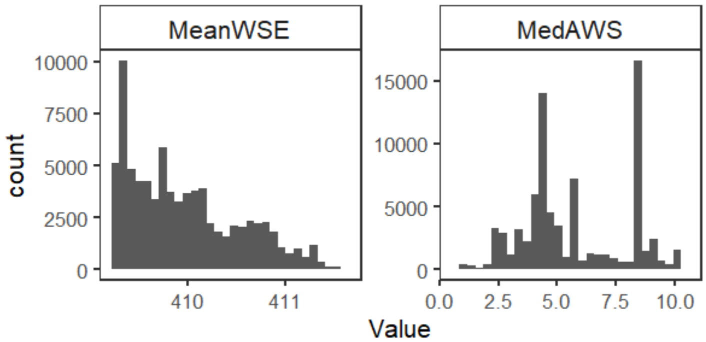

Figure F11. Distributions of continuous variables included in the Bull Trout entry model.

Many correlations among included covariates, notably naïve * season * WSE (Figure F12). This might be an argument to split this model up among biologically relevant time periods.

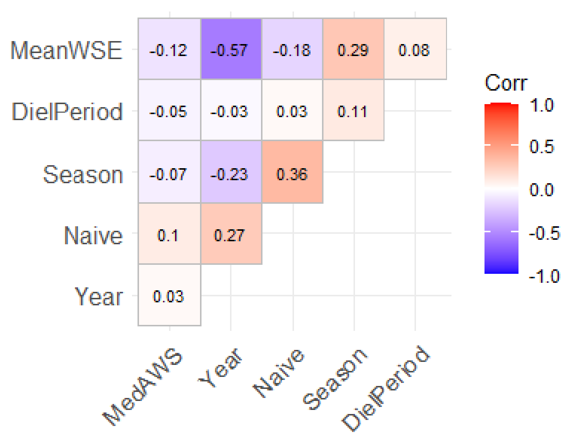

Figure F12. Correlations among selected covariates included in the Bull Trout entry model.

Like in the approach model, season differences (Figure F13) show that the higher values of WSE in the fall in this dataset means that Bull Trout are making approach movements in the fall at water levels that they wouldn't make in the spring or summer (more motivation in the fall). The drop in attraction flows in the fall is unfortunately likely due to pump failures in both 2022 and 2023.

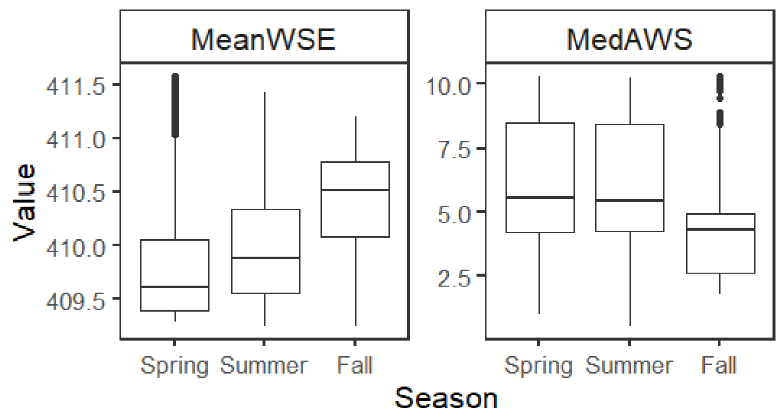

Figure F13. Seasonal differences among continuous variables included in the Bull Trout entry model.

Despite all the correlations of concern in covariates, model residuals look great (Figure F14)! However, season, WSE, AWS, and year all fail the assumption of proportional hazards (Table F3). I'm not sure how important this is.

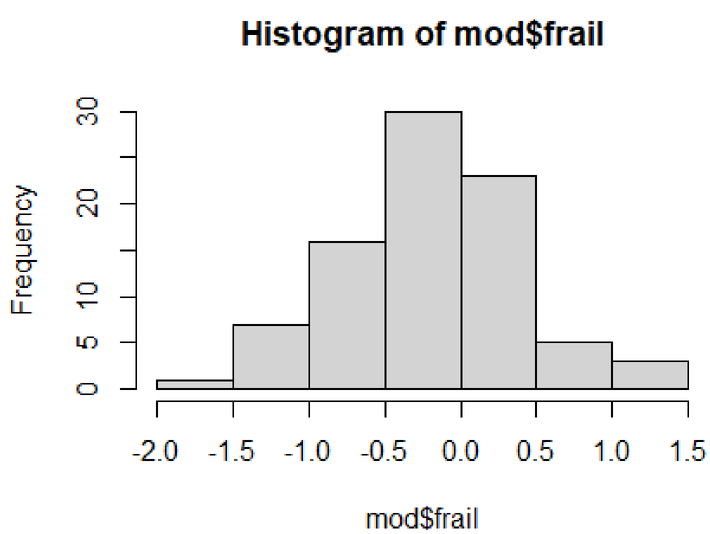

Figure F14. Model residuals of Bull Trout entry model.

Table F3. Cox proportional hazards for the Bull Trout entry model.

	chisq	df	p
Naive	0.703	0.97	0.39
DielPeriod	0.031	1	0.86
Season	24.137	1.9	0.00000491608
MeanWSE	42.01	0.99	0.0000000000880
MedAWS	5.588	1	0.018
Year	5.715	1.61	0.038
GLOBAL	65.995	65.45	0.458

Correlations with the random effect also reflect an influence of season and as with other models, the naïve variable.

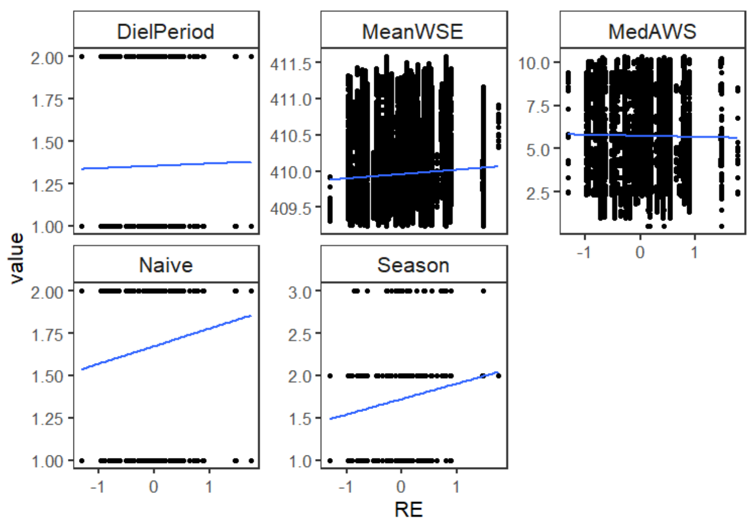

Figure F15. Correlations with random effect in the Bull Trout entry model.

Departure

The inclusion of percent AWS attraction flow of river discharge instead of raw AWS attraction flows does provide a better distribution (Figure F16) and isn't as correlated with year (Figure F17;

lower discharge but higher AWS in 2023). Year and season are correlated but the significance of this, given they're two categorical variables, is hard to interpret.

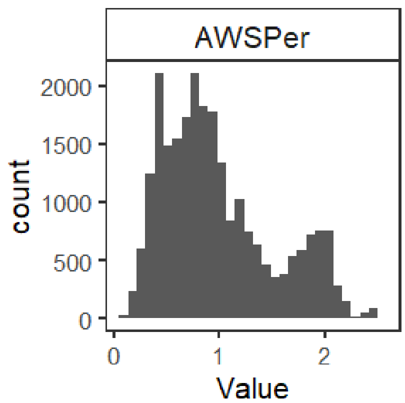

Figure F16. Distributions of continuous variables included in the Bull Trout departure model.

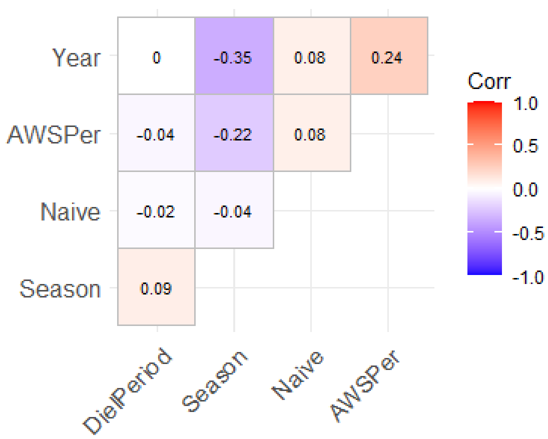

Figure F17. Correlations among selected covariates included in the Bull Trout departure model.

I'm happy with model residuals (Figure F18), but diel period and season fail the assumption of proportional hazard (Table F4) and are also slight correlated with the random effect (Figure F19).

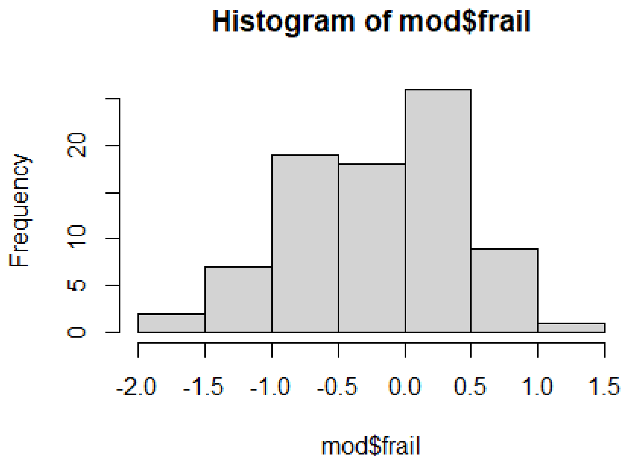

Figure F18. Model residuals of Bull Trout departure model.

Table F4. Cox proportional hazards for the Bull Trout departure model.

	chisq	df	p
Naive	2.69748	0.96	0.09572
DielPeriod	12.60428	1	0.00038
Season	6.89232000000	1.9	0.02881
AWSPer	0.0030400000000	0.99	0.95489
Year	0.79905	1.66	0.58258
GLOBAL	22.21242	71.46	1

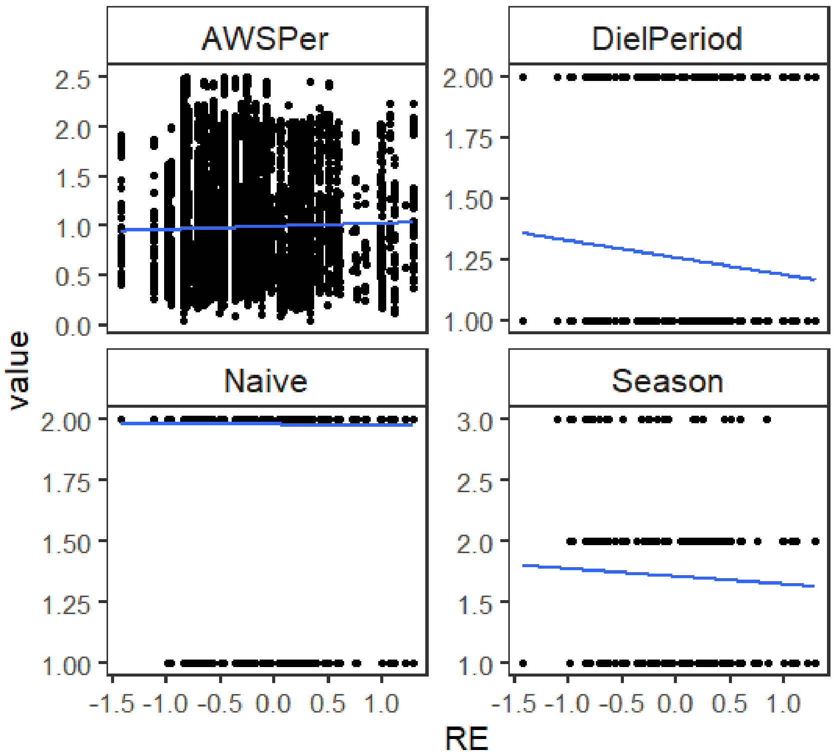

Figure F19. Correlations with random effect in the Bull Trout departure model.

Appendix G: Mountain Whitefish Candidate Model Sets

Approach: The model set included three candidate models. The second was explored given our interest in attraction flows but the high p-value (0.43) and low z-value (-0.78) of the AWS attraction flows led us to select the top model.

Withdraw: There were 16 candidate models; the data do not clearly support one single model over the others. To minimize AIC values while maximizing comparability to the approach model we chose the forth model (∆AIC = 0.77).

Entry: There were nine candidate models. The second was explored given our interest in attraction flows but the high p-value (0.3) and low z-value (1.04) led us to select the top model.

Departure: No model was within two ∆AIC of the top model.

Table G1. Approach candidate model set

Covariates	DeltaAIC	AICw	LogLik
Naive + DielPeriod + Season + MeanQ + Year	0.00	0.39	-1032.21
Naive + DielPeriod + Season + MeanQ + MedAWS + Year	1.47	0.19	-1032.10
Naive + DielPeriod + Season + MeanQ + MedAttFlow + Year	1.58	0.18	-1032.14

Table G2. Withdraw candidate model set

Covariates	DeltaAIC	AICw	LogLik
Season + Year	0.00	0.05	-632.66
DielPeriod + Season + Year	0.31	0.04	-631.86
Naive + Season + Year	0.57	0.04	-631.85
Naive + DielPeriod + Season + Year	0.77	0.03	-630.99
Season + MedAWS + Year	1.29	0.03	-632.23
Season + MeanWSE + Year	1.42	0.02	-633.25
DielPeriod + Season + MedAWS + Year	1.53	0.02	-631.37
Transitions + Season + Year	1.59	0.02	-632.65
Season + MedAttFlow + Year	1.72	0.02	-632.51
Naive + Season + MedAWS + Year	1.79	0.02	-631.40
Season + MeanQ + Year	1.79	0.02	-633.35
Transitions + DielPeriod + Season + Year	1.83	0.02	-631.82
DielPeriod + Season + MeanWSE + Year	1.91	0.02	-632.49
Naive + DielPeriod + Season + MedAWS + Year	1.92	0.02	-630.49
Season + AWSPer + Year	1.93	0.02	-632.64
DielPeriod + Season + MedAttFlow + Year	2.00	0.02	-631.68

Table G3. Entry candidate model set

Covariates	DeltaAIC	AICw	LogLik
DielPeriod+Season+Year	0.00	0.11	-172.68
DielPeriod+Season+MedAWS+Year	0.93	0.07	-172.14
DielPeriod+Season+MeanWSE+Year	1.12	0.06	-172.24
DielPeriod+Season+MedAttFlow+Year	1.55	0.05	-172.45

DielPeriod+Season+AWSPer+Year	1.61	0.05	-172.48
Naive+DielPeriod+Season+Year	1.65	0.05	-172.50
Transitions+DielPeriod+Season+Year	1.78	0.04	-172.57
DielPeriod+Season+MeanQ+Year	1.83	0.04	-172.59
DielPeriod+Season+AttFlowPer+Year	1.89	0.04	-172.62

Appendix H: Diagnostics of Selected Mountain Whitefish Models

Approach Zone Models

Approach

Interestingly, the distribution of river discharge is much more uniform for mountain whitefish approach than bull trout approach (Figure H1). The correlation between season and year is a concern (Figure H2). There were a lot of more MW tagged and detected in 2023 than in previous years, which may be driving that pattern, and the naïve*season correlation. If there is enough data to do so, model fit may be improved by only assessing their fall migratory period and removing the season variable (the only to fail the assumption of proportional hazards; Table H1). Residuals of the random effect (Figure H3) are OK but not amazing.

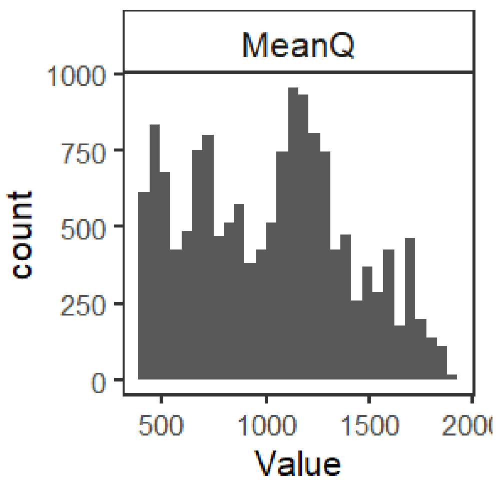

Figure H1. Distributions of continuous variables included in the Mountain Whitefish approach model.

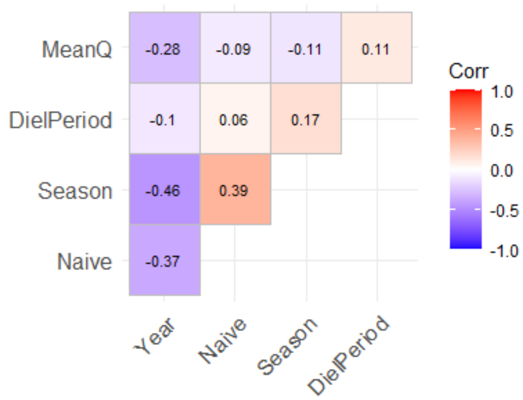

Figure H2. Correlations among selected covariates included in the Mountain Whitefish approach model.

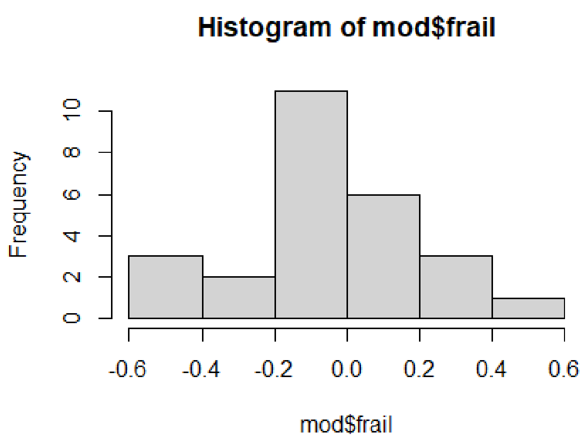

Figure H3. Model residuals of Mountain Whitefish approach model.

Table H1. Cox proportional hazards for the Mountain Whitefish approach model.

	chisq	df	p
Naive	2.5656	0.91	0.097
DielPeriod	0.0571	1	0.811
Season	7.1463	1.8	0.023
MeanQ	0.0376	0.97	0.838
Year	4.1318	1.71	0.097
GLOBAL	17.4526	16.61	0.398

Withdraw

I'm less concerned about diagnostics of the withdraw model because it was generally uninformative and fit wasn't great (Figure H4).

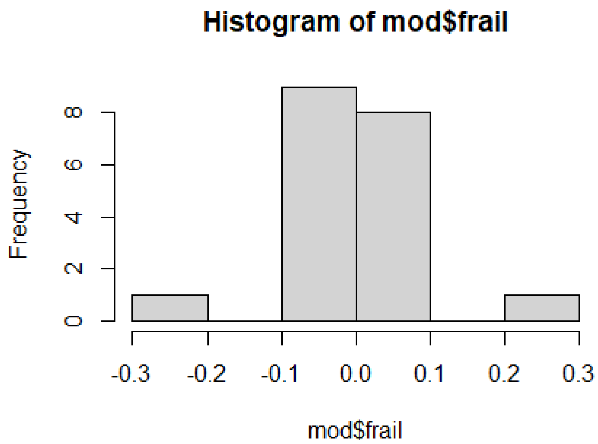

Figure H4. Model residuals of Mountain Whitefish withdraw model.

Entry Zone Models

Entry

The entry model was likewise not very informative and data limited. Residuals are poor (Figure H3).

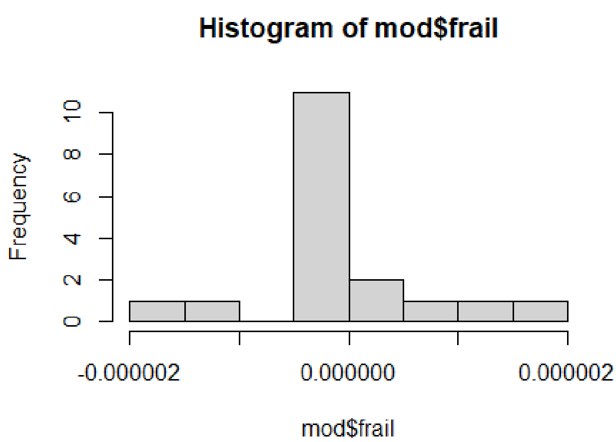

Figure H3. Model residuals of Mountain Whitefish entry model.

Departure

The departure and approach models were the most informative. Here we have high correlations among WSE*Year*Season (Figure H4). Potentially resolved with just looking at data in the fall? The data limitations from the spring and fall period are apparent when looking at seasonal differences (Figure H5). The residuals are skewed (Figure H6) and some variables fail the assumption of proportional hazards. This model could certainly be improved.

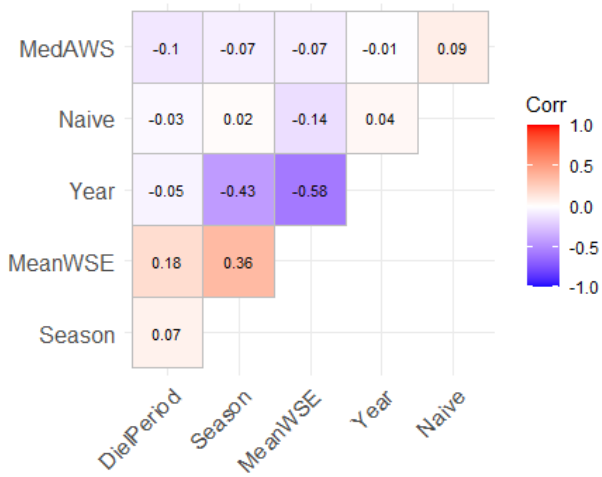

Figure H4. Correlations among selected covariates included in the Mountain Whitefish departure model.

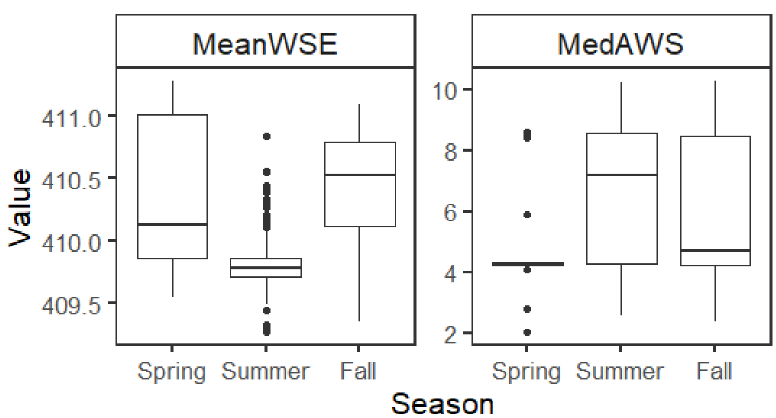

Figure H5. Seasonal differences among continuous variables included in the Mountain Whitefish departure model.

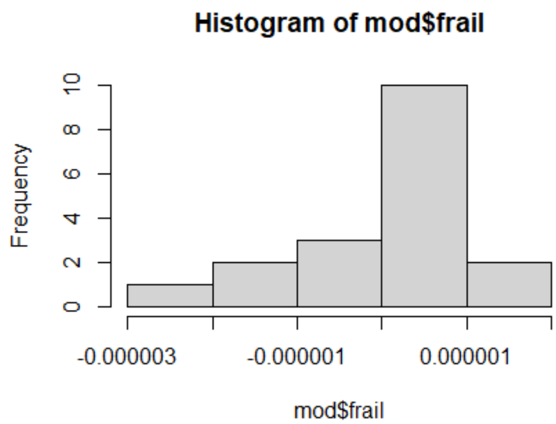

Figure H15. Model residuals of Mountain Whitefish departure model.

Table H2. Cox proportional hazards for the Mountain Whitefish departure model.

	chisq	df	p
Naive	0.69808	1	0.4034
DielPeriod	10.43076	1	0.0012
Season	0.11715	2	0.9431
MeanWSE	0.00276	1	0.9581
MedAWS	4.23278	1	0.0397
Year	0.62835	2	0.7304
GLOBAL	16.16441	8	0.0401

Appendix I: Rainbow Trout Candidate Model Sets

Approach: No model was within two ∆AIC of the top model during the initial run (naive, diel period, season, river discharge and AWS attraction flows).

Withdraw: All top models in the initial round included the number of transitions, but model fit was really poor and the candidate model set really large (data not shown). We repeated the process with the naïve variable. The candidate model set was still really large, indicating that the data do not clearly support a single model. Only the naïve variable was statistically significant.

Entry/Departure: Six (entry) and nine (departure) models were candidates. We selected the top model in both cases but little exploration was done because the top model had minimal statistical significance; we expect the top models to be the best that can be done with poor data.

Table I1. Withdraw candidate model set.

Covariates	DeltaAIC	AICw	LogLik
Naive+AWSPer+Year	0.00	0.04	-259.61
Naive+AttFlowPer+Year	0.02	0.04	-259.63
Naive+DielPeriod+AWSPer+Year	0.23	0.03	-258.72
Naive+DielPeriod+AttFlowPer+Year	0.27	0.03	-258.76
Naive+Season+AttFlowPer+Year	0.32	0.03	-258.65
Naive+Season+AWSPer+Year	0.33	0.03	-258.65
Naive+DielPeriod+Year	0.45	0.03	-259.86
Naive+DielPeriod+Season+AWSPer+Year	0.50	0.03	-257.75
Naive+DielPeriod+Season+AttFlowPer+Year	0.52	0.03	-257.76
Naive+Season+MeanQ+Year	0.70	0.03	-259.01
Naive+MeanQ+Year	0.78	0.03	-260.20
Naive+DielPeriod+Season+Year	0.79	0.03	-258.92
Naive+DielPeriod+Season+MeanQ+Year	0.82	0.03	-258.06
Naive+Year	0.82	0.02	-261.06

Covariates	DeltaAIC	AICw	LogLik
Naive+DielPeriod+MeanQ+Year	0.91	0.02	-259.24
Naive+DielPeriod+Season+MeanWSE+Year	1.06	0.02	-258.19
Naive+DielPeriod+MeanWSE+Year	1.08	0.02	-259.34
Naive+MeanWSE+Year	1.09	0.02	-260.37
Naive+Season+MeanWSE+Year	1.11	0.02	-259.23
Naive+Season+Year	1.24	0.02	-260.14
Naive+MeanQ+MedAWS+Year	1.42	0.02	-259.42
Naive+Season+MeanQ+MedAWS+Year	1.53	0.02	-258.35
Naive+DielPeriod+MedAWS+Year	1.60	0.02	-259.38
Naive+MedAWS+Year	1.66	0.02	-260.40
Naive+MeanWSE+MedAWS+Year	1.72	0.02	-259.58
Naive+MeanQ+MedAttFlow+Year	1.82	0.01	-259.64
Naive+Season+MeanQ+MedAttFlow+Year	1.88	0.01	-258.54
Naive+DielPeriod+MeanQ+MedAWS+Year	1.88	0.01	-258.65
Naive+DielPeriod+MedAttFlow+Year	1.91	0.01	-259.55
Naive+Season+MeanWSE+MedAWS+Year	1.91	0.01	-258.55
Naive+DielPeriod+Season+MeanQ+MedAWS+Year	1.95	0.01	-257.58

Table I2: Entry candidate model set

Covariates	DeltaAIC	AICw	LogLik
Season+AttFlowPer+Year	0.00	0.07	-75.96
DielPeriod+Season+AttFlowPer+Year	0.68	0.05	-75.28
Season+AWSPer+Year	0.98	0.04	-76.36
DielPeriod+Season+AWSPer+Year	1.59	0.03	-75.65

Season+MeanWSE+MedAttFlow+Year	1.74	0.03	-76.21
Season+MedAttFlow+Year	1.97	0.03	-76.46

Table I3: Departure candidate model set

Covariates	DeltaAIC	AICw	LogLik
DielPeriod+Season+Year	0.00	0.09	-216.69
DielPeriod+Year	1.00	0.05	-218.04
DielPeriod+Season+AWSPer+Year	1.42	0.04	-216.43
DielPeriod+Season+MeanQ+Year	1.70	0.04	-216.64
DielPeriod+Season+AttFlowPer+Year	1.81	0.04	-216.62
DielPeriod+Season+MeanWSE+Year	1.83	0.04	-216.69
Transitions+DielPeriod+Season+Year	1.91	0.03	-216.69
DielPeriod+Season+MedAttFlow+Year	1.92	0.03	-216.66
DielPeriod+Season+MedAWS+Year	1.96	0.03	-216.68

Appendix J: Diagnostics of Selected Rainbow Trout Models

Approach Zone Models

Approach

I believe the main factor influencing these models is the heterogeneity in activity, and not only that there were some active and some less active individuals, but when an individual did have a lot of transitions they occurred very rapidly (i.e., all in one season; see plot in

Appendix D: Heterogeneity in Activity (MW, RB, AG). This is likely driving the correlations observed between covariates (Figure J1) and with the random effect (Figure J2). However, model residuals still looked OK, especially considering the data limitations we're working with (Figure J3).

The naïve variable had an exceptionally low p-value result from the test of proportional hazards and was highly correlated with the random effect. This was expected given the structure of the data. I did run the model selection process without the naïve or transitions variables, but that increased the variance around the random effect to >8! The effect of the naïve term is taking some of the variance explained by the individual. I thought it was best explained by both the fixed and random effect than by having an extremely large random effect. Model conclusions do not change from having the naïve variable included or not.

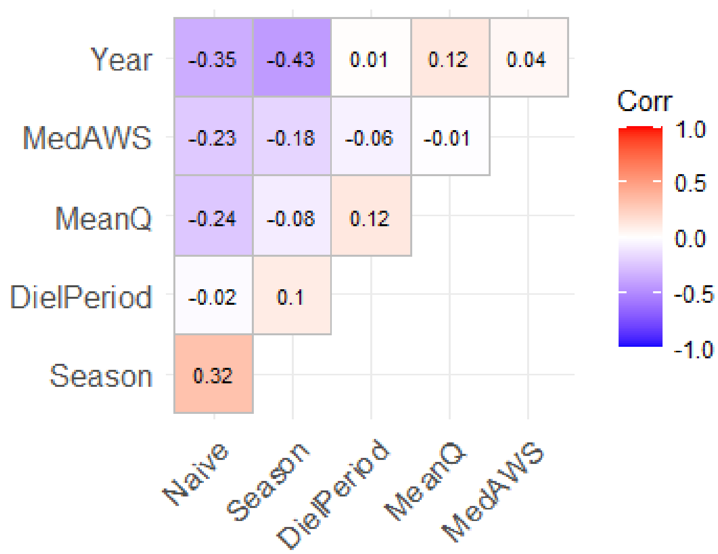

Figure J1. Correlations among selected covariates included in the Rainbow Trout approach model.

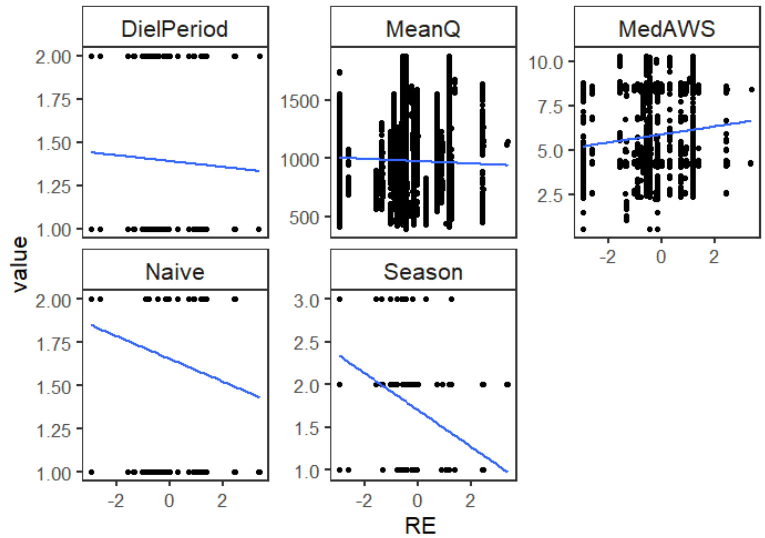

Figure J2. Correlations with random effect in the Rainbow Trout approach model.

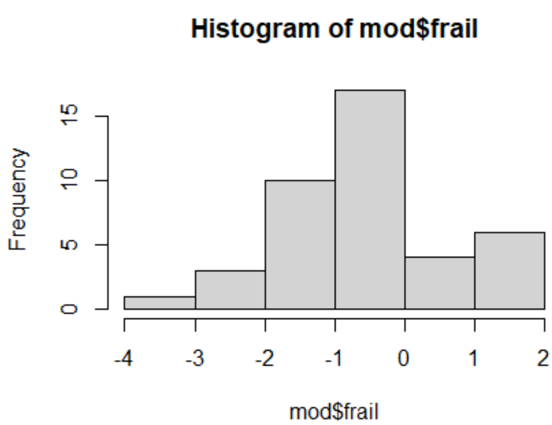

Figure J3. Model residuals of Rainbow Trout approach model.

Table J1. Cox proportional hazards for the Rainbow Trout approach model.

	chisq	df	p
Naive	22.5812	0.86	1.4E-06
DielPeriod	0.1788	0.98	0.6644
Season	0.0352	0.76	0.7593

MeanQ	1.9155	0.89	0.1449
MedAWS	8.1146	0.93	0.0039
Year	0.2057	-0.12	NaN
GLOBAL	31.0393	27.33	0.2845

Withdraw

The withdraw model was very simple and had minimal significance – only the naïve variable held statistical significance in the direction previously observed in all other models. Residuals looked OK (Figure J4), and the year term only moderately failed the test of proportional hazards (Table J2). No concerns.

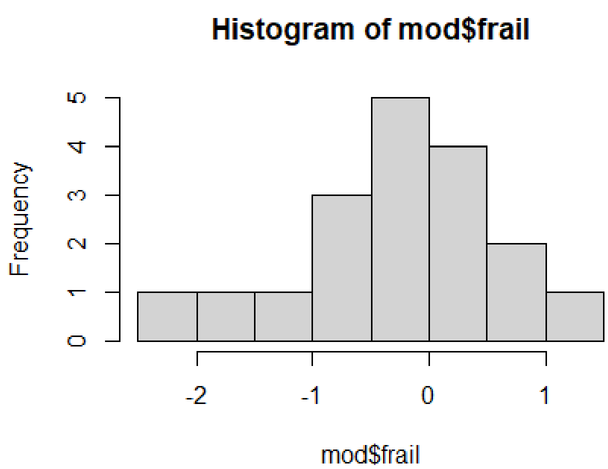

Figure J4. Model residuals of Rainbow Trout withdraw model.

Table J2. Cox proportional hazards for the Rainbow Trout withdraw model.

	chisq	df	p
Naive	0.338	0.94	0.535
AWSPer	0.655	0.91	0.384
Year	3.237	0.29	0.015
GLOBAL	5.852	13.69	0.965

Entry Zone Models

Entry

The entry model had adequate residual distribution (Figure J5) and only the year term failed the test of proportional hazards (Table J3). No concerns.

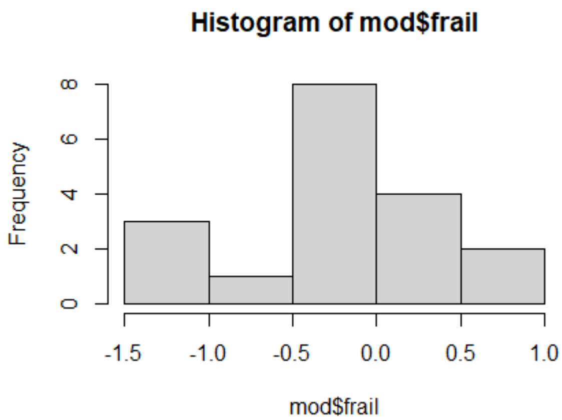

Figure J5. Model residuals of Rainbow Trout entry model.

Table J3. Cox proportional hazards for the Rainbow Trout entry model.

	chisq	df	p
DielPeriod	0.138	1	0.7085
Season	0.22	0.55	0.41101
AttFlowPer	1.88	0.95	0.15903
Year	8.642	0.43	0.00087
GLOBAL	11.903	8.34	0.17584

Departure

The departure model was data limited and the season variable was correlated with the random effect (Figure J6). Data limitations were apparent in the residual distribution. The random effect was also high (2.7). This model is not very informative.

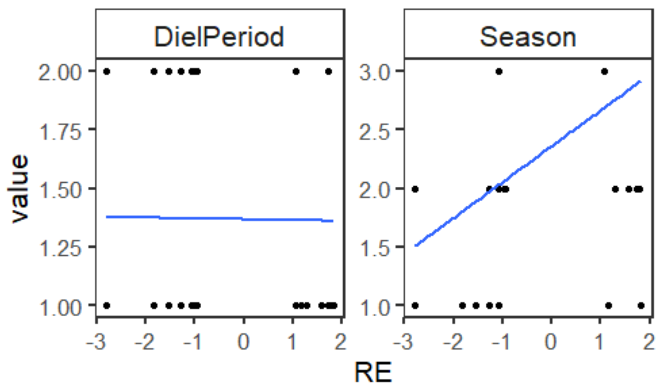

Figure J6. Correlations with random effect in the Rainbow Trout departure model.

Appendix K: Arctic Grayling Candidate Model Sets

Candidate model sets for all Arctic Grayling models were large, ranging from nine models (departure) to over 20 (approach; Tables K1-4). Ultimately, we can conclude that the Arctic Grayling dataset is too limited. Successful events ranged from 10 (entry) to 59 (approach), much lower than needed for this level of complexity (model outputs in Tabel K5).

Table K1. Approach candidate model set

Covariates	DeltaAIC	AICw	LogLik
AWSPer	0.00	0.03	-59.85
DielPeriod+AWSPer	0.04	0.03	-58.81
AWSPer+Naive	0.33	0.03	-60.19
DielPeriod+AWSPer+Naive	0.40	0.03	-59.21
Season+AWSPer	0.44	0.03	-58.41
AttFlowPer	0.46	0.03	-60.02
DielPeriod+AttFlowPer	0.57	0.02	-59.02
Naive+AttFlowPer	0.78	0.02	-60.38
Season+AttFlowPer	0.91	0.02	-58.59
DielPeriod+Naive+AttFlowPer	0.92	0.02	-59.45
DielPeriod	1.15	0.02	-60.33
DielPeriod+Season+AWSPer	1.24	0.02	-57.81
Season+AWSPer+Naive	1.42	0.02	-58.92
MedAWS	1.56	0.01	-60.56
DielPeriod+MedAWS	1.63	0.01	-59.51
MedAttFlow	1.67	0.01	-60.57
Season	1.69	0.01	-60.07
DielPeriod+MedAttFlow	1.74	0.01	-59.52

Covariates	DeltaAIC	AICw	LogLik
DielPeriod+Season+AttFlowPer	1.78	0.01	-58.03
Season+Naive+AttFlowPer	1.88	0.01	-59.10
Naive+MedAWS	1.93	0.01	-60.91
DielPeriod+Naive	1.98	0.01	-60.88
AWSPer+Transitions	1.98	0.01	-59.93
Naive+MedAttFlow	1.99	0.01	-60.91

Table K2. Withdraw candidate model set

Covariates	DeltaAIC	AICw	LogLik
MedAWS+Year	0.00	0.05	-21.24
MedAttFlow+Year	0.30	0.04	-21.39
Year	0.37	0.04	-22.43
DielPeriod+MedAWS+Year	1.62	0.02	-21.05
Naive+MedAWS+Year	1.67	0.02	-21.08
DielPeriod+MedAttFlow+Year	1.80	0.02	-21.14
AWSPer+Year	1.87	0.02	-22.18
Transitions+MedAWS+Year	1.87	0.02	-21.18
AttFlowPer+Year	1.89	0.02	-22.19
Naive+MedAttFlow+Year	1.90	0.02	-21.19
Season+MedAWS+Year	1.91	0.02	-21.20
MeanWSE+MedAWS+Year	1.93	0.02	-21.20
Naive+Year	1.95	0.02	-22.22
MeanQ+MedAWS+Year	1.98	0.02	-21.23

Table K3. Entry candidate model set

Covariates	DeltaAIC	AICw	LogLik
MeanQ+Year	0.00	0.06	-5.78
Naive+MeanQ+Year	0.05	0.06	-4.75
Transitions+MeanQ+Year	0.41	0.05	-4.95
DielPeriod+MeanQ+Year	0.53	0.04	-4.99
MeanWSE+Year	0.99	0.04	-6.26
Naive+MeanWSE+Year	1.16	0.03	-5.30
Season+MeanQ+Year	1.28	0.03	-4.96
DielPeriod+MeanWSE+Year	1.40	0.03	-5.42
Season+Naive+MeanQ+Year	1.61	0.03	-4.13
Season+Transitions+MeanQ+Year	1.80	0.02	-4.22
DielPeriod+Season+MeanQ+Year	1.88	0.02	-4.26

Table K4. Departure candidate model set

Covariates	DeltaAIC	AICw	LogLik
Naive+Year	0.00	0.08	-14.60
Naive+MeanQ+Year	0.78	0.06	-14.02
Naive+MeanWSE+Year	1.12	0.05	-14.17
Season+Naive+Year	1.19	0.05	-14.13
DielPeriod+Naive+Year	1.38	0.04	-14.29
Naive+AttFlowPer+Year	1.61	0.04	-14.40
AWSPer+Naive+Year	1.67	0.04	-14.44
Naive+MedAttFlow+Year	1.81	0.03	-14.51
Naive+MedAWS+Year	1.84	0.03	-14.52

Table K5. Outputs from selected Cox time-to-event models showing coefficient estimates (β) with standard errors (SE), z-values, p-values, and hazard ratios (HR) with upper and lower 95% confidence interval (UCI, LCI). These models represent advance and retreat from the approach and entry zones among radio-tagged Arctic Grayling. Events refers to the number of completed state transitions (n) relative to the total number of observations in the dataset. Iterations refers to the number of fitting iterations it took to converge during each phase, which informs the model fitting process. The variance of the random effect (RE) indicates the variability explained by differences between individuals.

Variable	**State Transition: Approach**					**State Transition: Withdraw**				
	β	SE	Z	P	HR	β	SE	Z	P	HR
AWS Attraction Flows						-0.23	0.16	-1.45	0.15	0.79
% AWS to River Discharge	0.78	0.42	1.85	0.06	2.17					
Year: 2022 vs. 2021						-1.63	0.88	-1.87	0.06	0.19
Year: 2023 vs. 2021						-2.81	1.16	-2.42	0.02	0.06
Events	n = 59, 7384					n = 19, 1407				
Iterations	18, 96					2, 12				
RE Variance	9.052726					0.0003993654				
Variable	State Transition: Entry					State Transition: Departure				
	β	SE	Z	P	HR	β	SE	Z	P	HR
Naïve vs. Non-naïve	-1.25	1.49	-0.84	0.40	0.29	2.19	0.91	2.33	0.02	8.40
River Discharge	-1.96	1.18	-1.66	0.10	0.14	-0.09	0.17	-0.55	0.58	0.91
Year: 2023 vs. 2021	-0.38	2.83	-0.14	0.89	0.68	-2.20	3.15	-0.70	0.49	0.11
Events	n = 10, 3074					n = 30, 679				
Iterations	13, 122					16, 85				
RE Variance	3.160195					7.343136				

Appendix L: Yearly Efficiency Metrics

Table M1. 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 fish species. Confidence intervals were calculated using the Wilson Score method for proportions.

Species	Counts			Attraction Efficiency (%)	Passage Success (%)	Passage Efficiency (%)
	Candidates	Entered	Passed			
2021						
Bull Trout	81	16	2	19.75 (12.0 – 30.4)	12.50 (2.2 – 39.6)	2.47
Mountain Whitefish	23	7	0	30.43 (14.1 – 53.0)	0	0
Rainbow Trout	35	4	0	11.43 (3.7 – 27.7)	0	0
Arctic Grayling	18	0	0	0	-	-
Burbot	11	0	0	0	-	-
2022						
Bull Trout	87	27	2	31.03 (22.8 – 42.0)	7.41 (1.3 – 25.8)	2.30
Mountain Whitefish	17	5	0	29.41 (11.4 – 56.0)	0	0
Rainbow Trout	29	6	0	20.69 (8.7 – 40.3)	0	0
Arctic Grayling	10	1	0	10.00 (0.5 – 45.9)	0	0
Burbot	2	0	0	0	-	-
2023	indicators of statistical tests results?					
Bull Trout	84	40	7	47.62 (36.7 – 58.7)	17.50 (7.9 – 33.4)	8.33
Mountain Whitefish	14	3	1	21.43 (5.7 – 51.2)	33.33 (1.8 – 87.5)	7.14
Rainbow Trout	26	6	1	23.08 (9.8 – 44.1)	16.67 (0.1 – 63.5)	3.85
Arctic Grayling	7	3	0	42.86 (11.8 – 79.8)	0	0
Burbot	9	0	0	0	-	-

Table M2. PIT telemetry data were used to determine trapping efficiency, the proportion of tagged fish that reached the upper fishway (Pools 23, 24 and trap) that were effectively trapped and thus reached the sorting facility. Confidence intervals were calculated using the Wilson Score method for proportions.

Species	Counts		Trapping Efficiency (%)
	Candidates	Passed	
2021			
Bull Trout	28	3	10.71 (2.8 – 29.4)
Mountain Whitefish	560	58	10.36 (8.0 – 13.3)
Rainbow Trout	2	0	0
Arctic Grayling	2	1	50.00 (9.5 – 90.5)
Burbot	0	0	-
2022			
Bull Trout	89	2	2.25 (0.4 – 8.6)
Mountain Whitefish	1044	186	17.82 (15.6 – 20.3)
Rainbow Trout	6	0	0
Arctic Grayling	4	0	0
Burbot	0	0	-
2023			
Bull Trout	114	16	14.04 (6.7 – 17.7)
Mountain Whitefish	1356	158	11.65 (10.0 – 13.5)
Rainbow Trout	13	2	15.38 (2.7 – 46.3)
Arctic Grayling	16	2	12.50 (2.2 – 39.5)
Burbot	0	0	-