Site C Clean Energy Project

Site C Fishway Effectiveness Monitoring Program (Mon-13)

Construction Year 10 (2024)

Katrina Cook, PhD, RPBio
InStream Fisheries Research Inc.

Dan Scurfield, BSc, RPBio
InStream Fisheries Research Inc.

Daniel Ramos-Espinoza, BSc
InStream Fisheries Research Inc.

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Katrina Cook*, Dan Scurfield, Daniel Ramos-Espinoza

Prepared for:

BC Hydro – Site C Clean Energy Project

333 Dunsmuir St, 13th floor

Vancouver, BC, V6B 5R3

Prepared by:

InStream Fisheries Research

1121A Enterprise Way

Squamish, BC, V8B 0E8

*Corresponding author

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Executive Summary

Hydroelectric dams obstruct riverine connectivity and pose significant challenges for migratory fishes. The Site C Clean Energy Project (the Project) on the Peace River in northeastern British Columbia was in its tenth year of construction during this reporting year (2024). Once the river was diverted to facilitate construction (2020), BC Hydro began operating the temporary upstream fish passage facility (TUF) from April 1 to October 31 annually. The TUF ceased operations on September 15, 2024 and fish passage transitioned to the permanent upstream fish passage facility (PUF). Very little monitoring occurred at the PUF in 2024. The facility was operational for commissioning, but construction continued, and crew access to the facility was limited.

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). The first full year of data collection under Mon-13 occurred in 2021. The movements of five target species (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. The aim of Mon-13 was to evaluate whether the TUF provided effective upstream passage for these target species attempting to migrate upstream during construction of the Project. Effective upstream passage was defined by two hypotheses: (1) target fish species can locate and use the fishway, and (2) attraction and passage efficiencies are at least 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 fish that, after entering the fishway, successfully pass through it and reach the sorting facility. In later years we introduced the concept of trapping efficiency, the proportion of fish that, after reaching the upper fishway (defined as four uppermost pools), successfully reach the sorting facility.

In previous years, a key component of the program was to evaluate the effectiveness of varying attraction flows and other time-varying operational and environmental parameters using multivariate modeling. However, the TUF mostly without attraction flows in 2024 and with frequent shutdowns. We could not assess attraction flows or complete multivariate modeling as done in previous years. Our primary focus shifted to developing efficient systems to query and synthesize information, ensuring reported numbers are as accurate as possible. The current database is extensive – 20,087 PIT-tagged fish have been detected during operational periods since 2021,

with 590 of these also having radio tags. These data provide a baseline against which to compare new data collected from the PUF.

Both the TUF and the PUF consisted of a weir-orifice fishway (the “fishway”) that terminated with a mechanism trapping fish in 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 separated according to release location. Upstream transport was provided by truck. We confirmed through detection of PIT tags that all five target species can locate and enter the TUF fishway and apart from Burbot, ascend to the upper three pools. However, attraction efficiencies calculated from radio telemetry data were low, ranging from 0% (Burbot) to 33% (Bull Trout). 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. Passage efficiencies were very low: the best result was from Bull Trout, which had a passage efficiency of 4%. Passage efficiency estimates were very data limited, derived from a maximum of 12 radio-tagged individuals per species that passed the fishway. The estimate of trapping efficiency pulls from a larger dataset of PIT detection data and confirms the presence of a barrier at the top of the fishway, ranging from 7.3 % for Rainbow Trout to 27.8 % for Arctic Grayling. While informative, these efficiency metrics are an oversimplification of complex movements that are occurring within the study area. For example, a count of tagged fish of each species making it to distinct zones along a downstream to upstream trajectory revealed that attracting fish from the far-field of the study area to the area immediately outside of the fishway entrances also limited the biological effectiveness of the TUF.

Collectively, detection data confirm that barriers to movement through the study area have led to efficiency metrics that were far below the target and poor passage overall. Ultimately data from the TUF provided a learning opportunity prior to operating the PUF. Indeed, 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 on the Peace River in northeast British Columbia. The Project was in its tenth year of construction in 2024. To facilitate construction of the earthfill dam, the Peace River was diverted through two diversion tunnels. In October 2020, BC Hydro began operating a temporary upstream fish passage facility (TUF) once passage was no longer possible through the mainstem. 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. Reservoir filling began in late August 2024, accompanied by preparations to operate the permanent upstream fish passage facility (PUF). Both fish passage facilities included a weir-orifice fishway (the "fishway"). The designs of the two fishways differed in some ways, but they both terminated in a mechanism that trapped fish in a final pool from which they were crowded into a lift and raised into a sorting facility. Fish requiring upstream transport were hauled by truck to their respective sites.

Construction activities associated with the Project have altered the longitudinal habitat connectivity of the Peace River. Longitudinal connectivity in riverine systems is essential to the maintenance and expression of life history diversity among fish populations, particularly migratory fishes seeking upstream areas to reproduce or feed. Hydroelectric dams are well-known for blocking the natural flow of rivers, and their impacts have eliminated migratory 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). This is a key concern in the Peace River, which supports a diverse fish community of 32 species. However, even with well-designed structures, not all fish will pass equally well (Caudill et al. 2007; Bunt et al. 2012; Thiem 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 hydrological conditions that are appropriate for a diversity of fish species with different behaviours is a particularly challenging aspect of operating a fish passage facility. Excessive turbulence or water velocities can deter many sizes and species of fish, have latent or indirect negative impacts, and may lead to exhaustion or require protracted recovery periods, all of which may impede migration (Burnett et al. 2017).

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. Fishway efficiency metrics 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 that, having already entered the fishway, successfully pass through it. 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. A more comprehensive alternative is a time-varying analysis that explores how the environmental conditions experienced by individual fish influence their movement at a given time during their interaction with the fishway, as described by Castro-Santos and Perry (2012).

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. The Site C Fishway Effectiveness Monitoring Program (Mon-13) is a component of the FAHMFP. 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.

A key component of the monitoring program is understanding the effectiveness of attracting fish from the Peace River into the fishway, and the attraction flows required to do so. The facilities were designed such that attraction flows 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 entrances. 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. Mon-13 intended to test various combinations of these two components of attraction flow as they were experimentally manipulated on predetermined schedules. This was achieved from 2020 to 2023 and based on the findings from the multi-year analysis, BC Hydro intended to operate the AWS at 10 m^3/s and not operate the HVJ in 2024. However, the horizontal propeller pumps had an electric fault within the first week of operations in 2024 (BC Hydro 2024a), ceasing operation of the AWS. The HVJ was then turned on, but its operation was terminated in late-May due to low water levels. The result was that there was no attraction flow for the majority of the 2024 operational period.

The Project has been a dynamic study site under active construction. Mon-13 was intended to have an adaptive framework, making changes based on advances in our knowledge, improvements to techniques, and/or limitations due to construction activities and environmental conditions. Since there were no attraction flows in 2024, no new data were available for evaluation or to inform operation of the PUF. Therefore, data collected in 2024 will not be included in our multi-year analyses incorporating time-varying components. Instead, we provide an updated summary of raw numbers of tagged fish detected since 2021. These summaries are guided by the management question and associated hypotheses of Mon-13, which are as follows:

> Does the TUF provide effective upstream passage for migrating Arctic Grayling, Bull Trout, Burbot, Mountain Whitefish, and Rainbow Trout that are attempting to migrate upstream during the construction of the Project?
>
> H_1: Arctic Grayling, Bull Trout, Burbot, Mountain Whitefish, and Rainbow Trout locate and use the fishway.
>
> H_2: Fishway attraction and passage efficiency are as predicted in the Environmental Impact Statement (EIS[1]; attraction efficiency of 80% and passage efficiency of 76%).

In addition to attraction and passage efficiency metrics, we began calculating trapping efficiency in 2022 to better take advantage of available data and understand low passage rates. Trapping

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

efficiency refers to the proportion of fish that, after reaching the upper fishway (defined as the four uppermost pools), successfully reach the sorting facility (are trapped by the facility operator).

2. Methods

2.1 Study Area

The Peace River is 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 2-1). The TUF operated in 2024 from April 1 to September 15. The diversion tunnel outlet closure cofferdam work commenced on September 16 (BC Hydro 2024b). The PUF was first operational on September 16 for commissioning and was included within our study site from that day onward.

Distinct spatial zones along the trajectory of an upstream migration were delineated within the study site and a telemetry tracking system with strategic detection points (hereafter 'array') determined how target fish move between these zones at the TUF. The four zones of the radio and PIT telemetry array included: 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 presumably detect attraction flows and reach the fishway entrance; and 4) the 'fishway' delineated when a tagged fish entered the fishway of the TUF. No telemetry infrastructure was installed within the PUF in 2024 due to the extent of ongoing construction activities at that facility.

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 both the TUF and the PUF (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, allowing fish to move between adjacent pools by either swimming over weirs or along the bottom through submerged orifices. The fishways each had two entrance gates that lead into an entrance pool (Figure 2-3). Each distinct pool (25 at the TUF and 17 at the PUF) had a weir and an orifice. Fish entered the final pool (the "pre-sort holding pool") through a one-way trap. Fish held in the pre-sort holding pool until crowded into a fish lock and raised 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.

In the sorting facility, all fish were processed and sampled by the facility operator. Following sampling, fish were sorted according to release location and trucked to their designated release site.

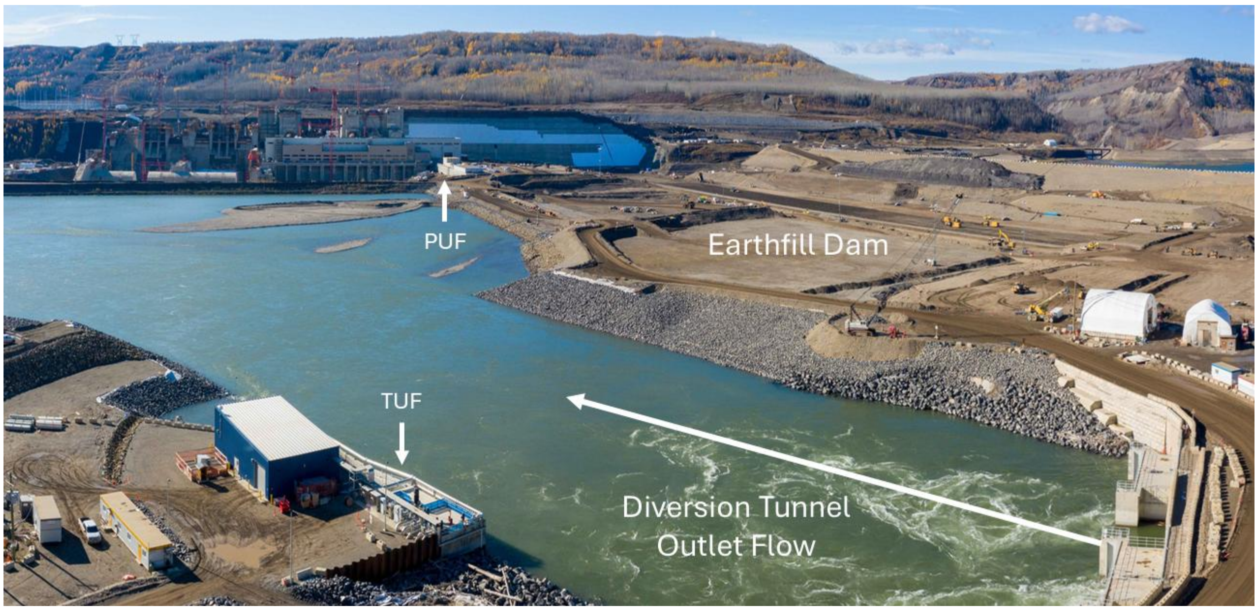

Figure 2-1. Aerial photo of the tailrace area showing the temporary upstream fish passage facility (TUF) and the permanent upstream fish passage facility (PUF) on the Peace River, diverted through two tunnels which do not allow for upstream fish passage. Photo provided by BC Hydro, March 2025.

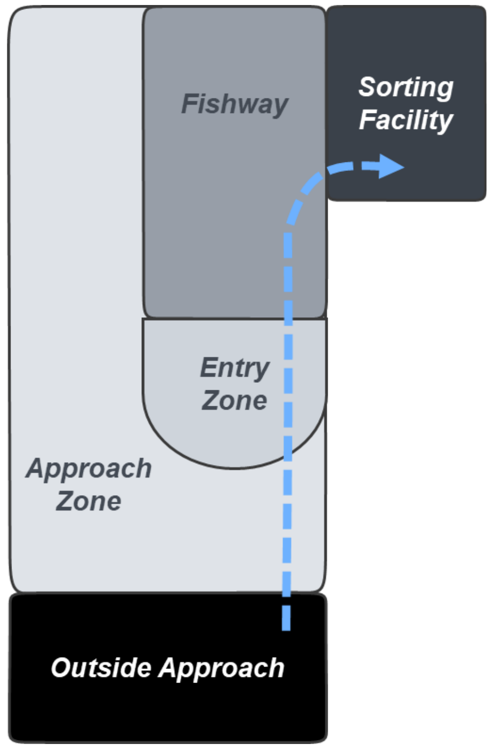

Figure 2-2. Schematic showing the distinct zones across which movement is evaluated as tagged fish approach, enter, and pass the fishway.

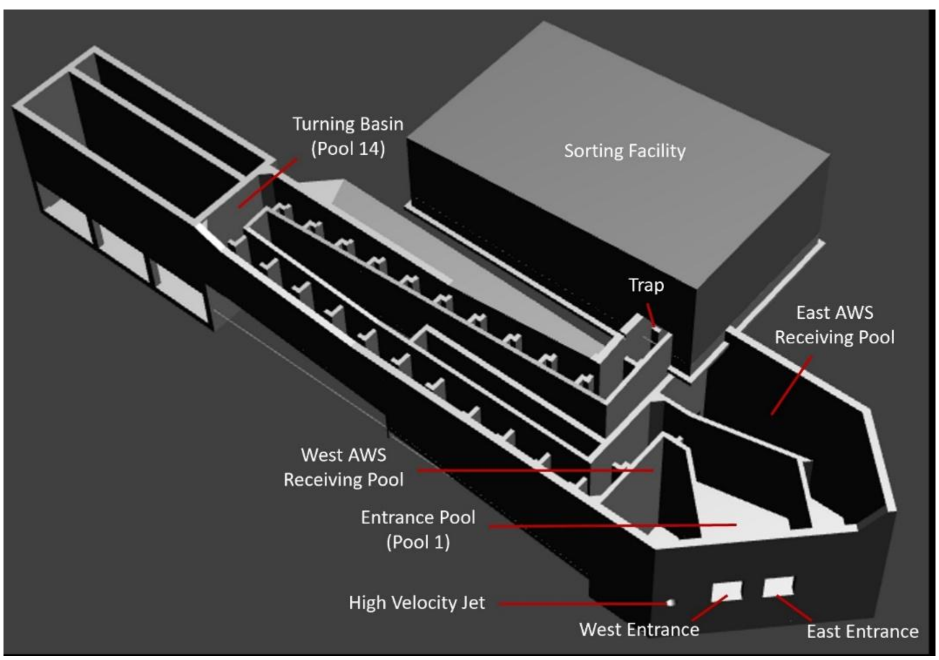

Figure 2-3. A drawing of the temporary upstream fish passage facility (TUF). Upstream migrating fish entered the fishway via one of the two entrance gates and ascended to the sorting facility for transport. Fishway attraction flows were provided by an auxiliary water supply (AWS) that flowed through entrances and a high velocity jet located adjacent to the fishway entrances.

2.2 Fishway Operations and Environmental Conditions

Hydrological conditions thought to influence fish passage were monitored, as in previous years. Attraction flows from the AWS were set to a target of 10 m^3/s starting April 1. The target was not achieved, and AWS flows steadily declined during the first week until pump failure at 6:58 on April 5 (BC Hydro 2024a). The HVJ was turned on at 17:58 on April 9 but could no longer be operated as of May 22 due to low water levels (BC Hydro 2024c). There was no attraction flow from May 22 12:04 onward. Attraction flow data are not presented or discussed further.

Environmental data were collected from a variety of sources. Sensors deployed throughout the TUF were used to monitor flow, water surface elevation at the tailrace of the fishway, and water temperature within the pre-sort holding pool at 1-minute intervals for the duration of the operational period (McMillen 2022). Only water surface elevation data are reported herein (BC Hydro sensors LT_600 and LT_601). 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).

It was common for the TUF to shut down throughout its years of operation, during which no passage occurred. We considered a shutdown as when fishway flows were less than or equal to 0.5 m^3/s for at least five minutes. Note that this is a change from previous years where we used shutdown timing data provided to us by BC Hydro, which we later found to not encompass all the shutdowns that occurred. This recalculation means that there will be differences in counts from previous years' reports. Shutdown intervals, along with reasons (where known) are provided in Appendix A. In 2024 the TUF had 25 distinct shutdown periods, which ranged from six minutes to three days and 16 hours. The fishway was operational for 90.2% of the intended 2024 operational period.

2.3 Telemetry Array

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. Additional radio stations were added during the fall of 2024 to observe movements of tagged fish around the outside of the PUF.

All fixed stations and PIT antennas within the TUF fishway were demobilized after the end of the operational period, while fixed stations outside of the fishway remained in operation.

The radio telemetry array consisted of fixed radio telemetry stations (‘fixed stations’) deployed for monitoring movement around the TUF (n = 11) and the PUF (n = 7) in the tailrace area (Figure 2-4; Appendix B) and within the TUF fishway (Figure 2-5). Each fixed station had an aerial antenna (providing large detection areas, up to hundreds of meters depending on the settings) or a submerged dipole antenna (providing small detection areas of approximately 3-10 m). Fixed stations were programmed to scan between two alternating frequencies every 10 seconds, except for the entrance and entrance pool dipoles at the TUF that each had two receivers scanning a single frequency. A beacon tag (MFT-3B, Lotek Wireless) was installed at or near each fixed station to monitor for temporary outages and emitted a coded signal once every 10 seconds for one minute each hour.

Range testing of fixed stations downstream of the TUF has occurred annually since 2021 in collaboration with WSP Global Inc. (WSP). Testing occurred twice in 2024. The first range test was a boat drift test on August 21, prior to completion of the tunnel outlet cofferdam (i.e., the TUF was still operational). As in previous years, we wanted to ensure that the combined detection range of the paired receivers at the approach and outside approach gates spanned the full river channel width. The second range test occurred following completion of the tunnel outlet cofferdam on October 26, 2024. This second test had two components. The first was an additional assessment of the range of the approach and outside approach gates using a boat drift, as done previously. We also tested the range of the newly deployed tailrace receivers for monitoring movements around the PUF with tag drifts using a remote-controlled vessel. This method was chosen given the proximity of these stations to the tailrace, which is a challenging area to operate a boat.

The PIT telemetry array consisted of nine antennas that were designed and fabricated by InStream Fisheries Research (IFR) to fit key locations of the TUF (Figure 2-5). There were four designs of PIT antennas: pass-through, pass-over, pass-under, and pass-by (Table 2-1). Pass-through antennas were rectangular, detecting PIT-tagged fish 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 antennas. PIT antennas were not tested in 2024. We have established that operational conditions influence antenna performance. Without attraction flows, testing results would not be relevant to the design of PIT antennas for the PUF.

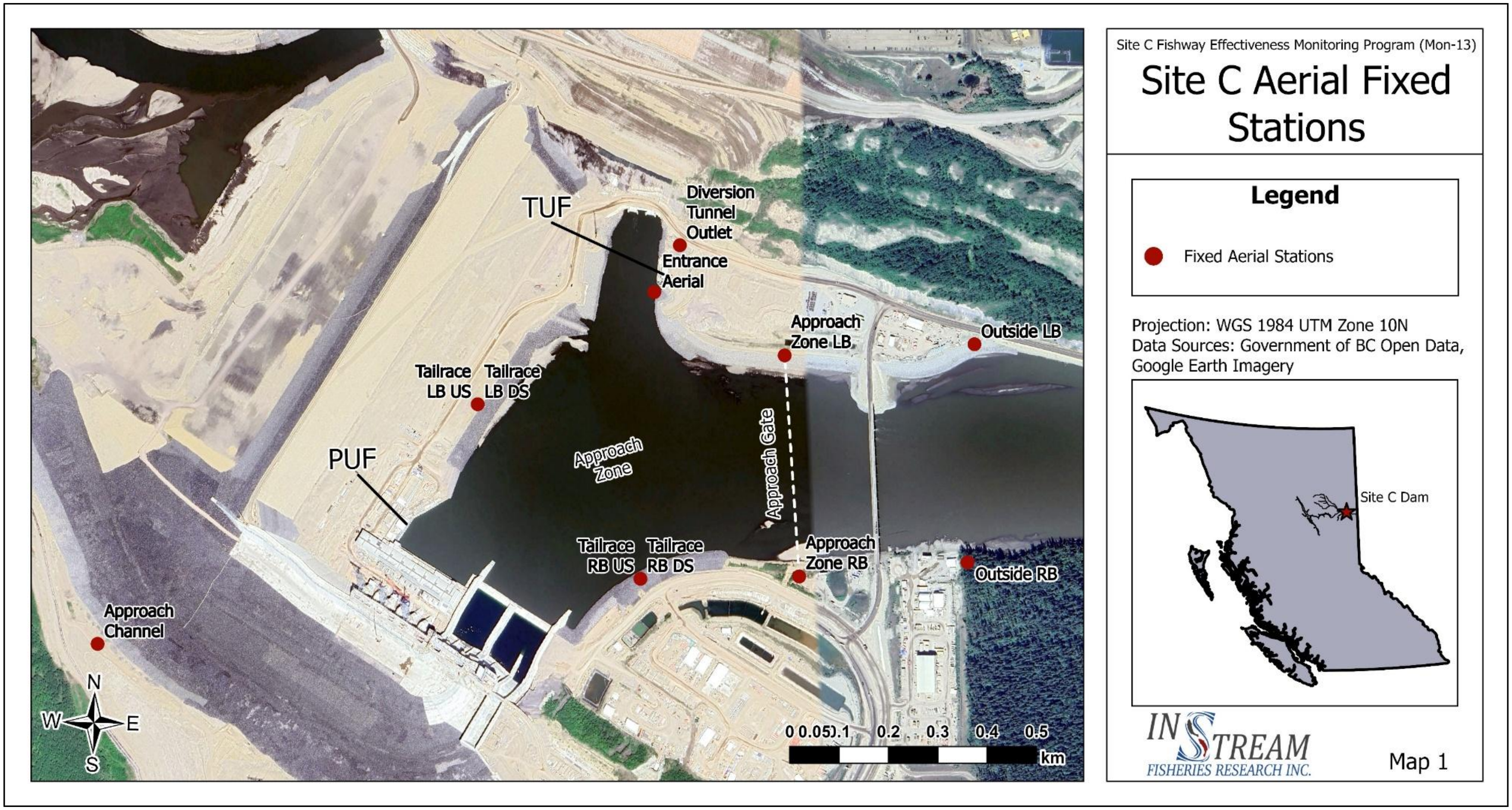

Figure 2-4: The aerial fixed radio telemetry stations deployed along the left bank (LB) and right bank of the mainstem Peace River used to detect radio-tagged fish approaching the temporary upstream facility (TUF) and the Permanent upstream facility (PUF). Radio telemetry stations in the tailrace have antennas pointed upstream (US) and antennas pointed downstream (DS). Images is resulting from two captures dates: June 1, 2024 (left) and May 31 2023 (right).

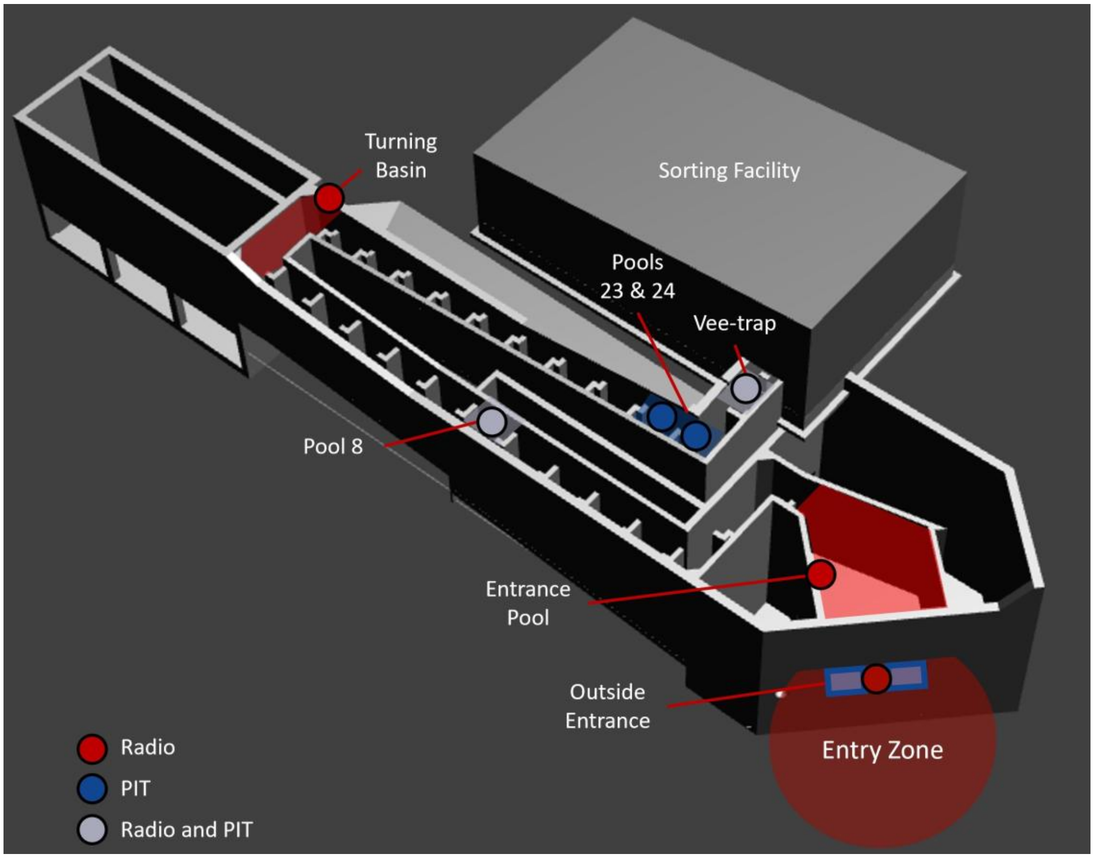

Figure 2-5. Diagram of detection points via dipole fixed radio telemetry stations and passive integrated transponder (PIT) antennas within the temporary upstream fish passage facility. The target detection areas are shaded.

Table 2-1. 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 into pool 9.
Orifice 8	Pass-under / Pass-over	Determined if tagged fish used the orifice into pool 9.
Weir 23 / Weir 24	Pass-over	Determined if tagged fish used the weir into pool 23 / 24.
Orifice 23 / Orifice 24	Pass-under	Determined if tagged fish used the orifice into pool 23 / 24.
Trap	Pass-by	Determined if tagged fish passed into the pre-sort holding pool.

2.4 Data Management and Analyses

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. In 2024, the fishways at the TUF and the PUF were operated by WSP, who collected all metadata from fish that successfully ascended the fishway, scanned fish for existing tags, implanted HDX PIT tags in fish without existing HDX tags, and transported fish to be released upstream. WSP also 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 through other monitoring programs (BC Hydro 2025). IFR 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 IFR, WSP, and LGL, and data compilation efforts were collaborative.

2.4.1 Radio Data Processing

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 base 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 true and false-positive detections for each fixed station, as done in previous years (Table 2-2). 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 true versus a false-positive detection for each record.

Training data comprised both assumed valid detections (i.e., detections of deployed study tags) and known false-positive detections (i.e., spurious detections from tags not present 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 true positives. In subsequent iterations, detections were classified as true 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 true that are known to be false positives. The set of predictor variables that minimized the false positive rate was used for the final iterative classification process. When the false positive rate was the same for multiple sets of predictor variables, the set that was most conservative (i.e., removed the most potential false positives) during the initial classification was used. Filtered datasets for all 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, rather than from nearby areas outside it. 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. Finally, radio-tagged fish that only had a single detection on the 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 parties.

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 January 1, 2025. Detections of 116 tag codes that could not be identified but showed valid detection histories (i.e., multiple detection points in a logical progression) were classified as 'species unknown'.

Once false positives were removed, an interval analysis was used to remove overlapping detections between receivers. 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). All detection data collected during the operational period (including those collected during shutdown periods) were used to establish station-specific intervals. Intervals (in seconds) selected for each location were as follows: 2000 (outside RB and LB), 1600 (approach RB and LB), 430 (entry zone), 210 (entrance pool), 240 (pool 8), 120 (turning basin), 270 (trap).

Table 2-2. 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 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

2.4.2 Detection Data Summaries

Radio telemetry data were summarized to detail the presence of target species through the five distinct zones within study area (i.e., outside approach, approach, entry, the fishway and the sorting facility) and make comparisons to previous years. For each target species, we calculated the total number of each species detected within each zone during the operational period. Fish scanned by the facility operator that were transported but afterwards detected on the array were considered new individuals. Categorizing the fishway into linear zones – outside approach, approach zone, 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.

Efficiency metrics were also calculated, as a comparison to previous years. 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. 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 and radio telemetry data combined were used to determine trapping 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 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).

3. Results

3.1 Environmental Conditions

Hydrological conditions were represented by discharge in the Peace River and water surface elevation at the tailrace. The hydrograph has had unique characteristics every year of monitoring (Figure 3-1). In 2024, flows were relatively low from the start of the operational period through to the end of June, apart from an increase to 1300 m^3/s in early May across a period of three days. The early part of the operational periods has typically seen high flows. The summer showed a lot of variability, as in previous years. A peak of 1810 m^3/s was achieved on August 28 at 03:45. On this day flows were also reduced to 528 m^3/s by 10:15 to allow closure of a diversion tunnel to facilitate reservoir filling. The low for the operational period was 398 m^3/s on October 3.

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 a water surface elevation 410.5 m. The fishway was operating out of specification when 410.5 m was exceeded, which occurred for a total of 7 days in 2024 (Figure 3-2). Water elevations more often exceeded 410.5 m in previous years (i.e., the maximum was 122 days [57% of operational period] in 2022; Cook et al. 2023)

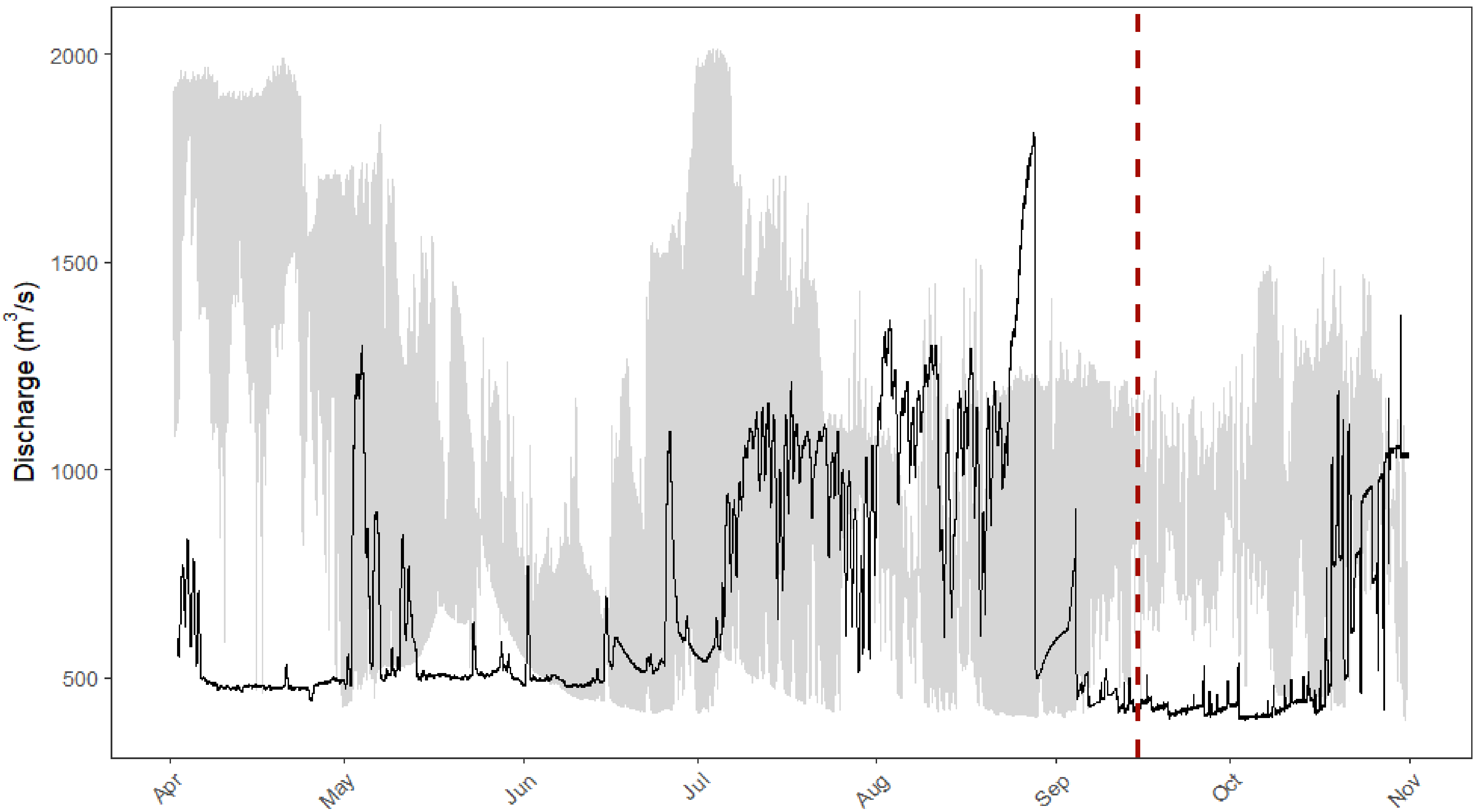

Figure 3-1. Peace River discharge measured at the Water Survey of Canada gauge at Peace River above Pine River (07FA004) in 2024 (black). The range of discharge values between 2021 and 2023 is shown in grey. The red vertical dashed line indicates when operations ceased at the temporary upstream fish passage facility in 2024.

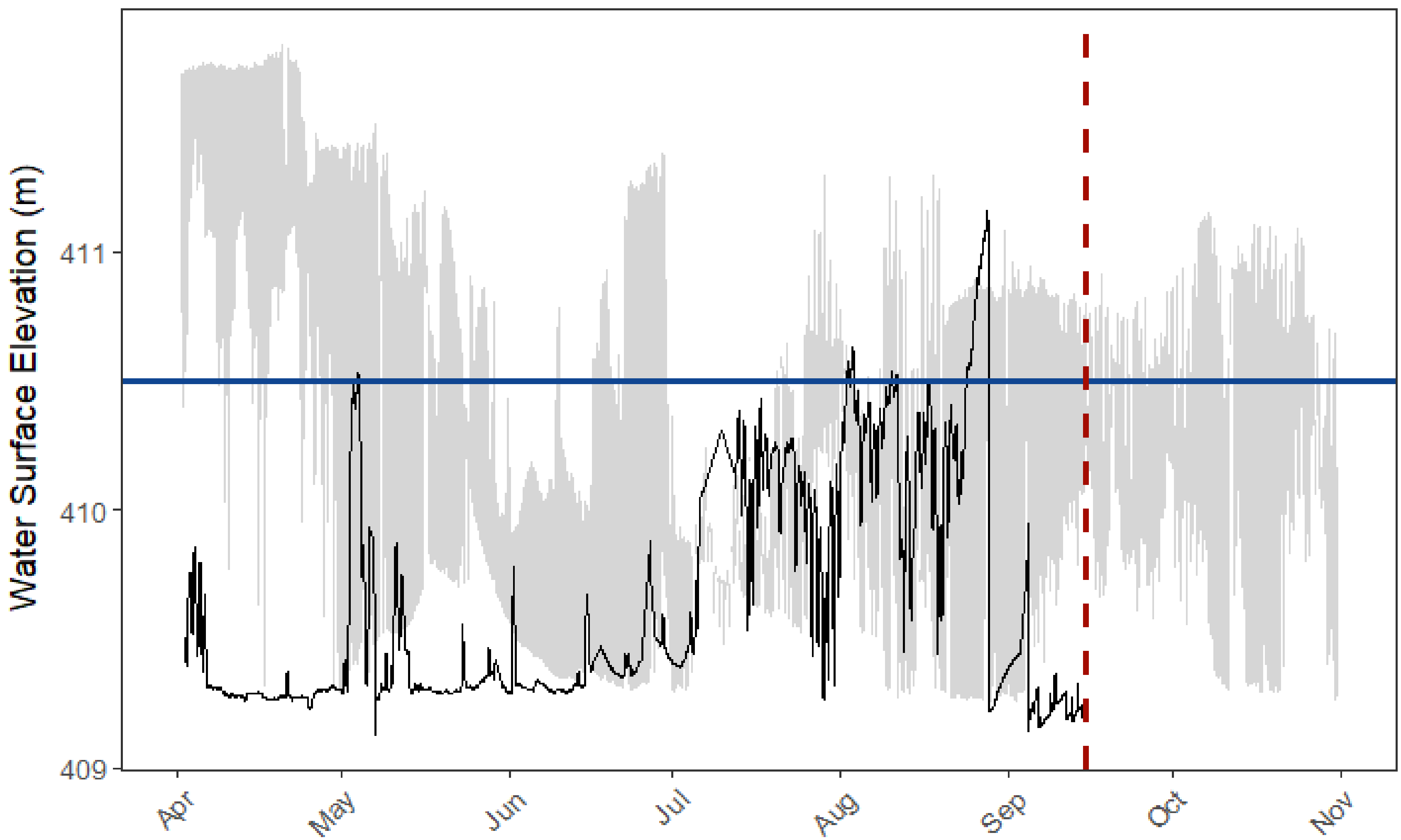

Figure 3-2. Water surface elevation (WSE) at the tailrace of the fishway during the operational period of the TUF in 2024 (black) and the range from 2021 to 2023 (grey). The blue horizontal line indicates the upper limit of WSE of the design criteria of the fishway, 410.5 m The red vertical dashed line indicates when operations ceased at the temporary upstream fish passage facility in 2024. Data provided by BC Hydro sensors LT_600 and LT_601. Data was collected at 1-minute intervals. Hourly averages are plotted.

3.2 Array Performance

Two range tests of the aerial stations in the tailrace were completed in 2024, in August and October. Results from the approach zone and outside approach zone were similar between tests. Detection range overlapped by approximately 150 to 200 m at both paired stations (Figure 3-3). Four tailrace stations were added in September 2024 in two locations to monitor movements around the PUF. Each station included an upstream and downstream antenna, each with their own receiver, on both the left and right banks of the river. The stations with the downstream-pointed antennas had detection ranges of approximately 200 to 300 m, with approximately 50 m overlapping. Results from the stations with the upstream-pointed antennas were comparatively poor, but the test was limited due to the inability to effectively range test those areas during spillway release. More testing is needed to understand the range of the stations with the upstream-pointed antennas.

The array did experience data outages in 2024. Data were lost between 2024-06-24 18:00 and 2024-07-16 13:00 from both receivers in the entrance pool and between 2024-04-25 11:00 and 2024-05-23 07:00 from the entrance aerial stations due to user error. Aside from these outages, the performance of the array was excellent, as determined by evaluating the continuity of detections. A beacon tag should be detected every hour, and tagged fish are highly concentrated throughout the study area. We assumed a station was not recording data if it failed to record a detection within an hourly interval. The maximum duration a station did not record a detection outside of known outages was three hours and four of our ten stations had no outages throughout the entire operational period (Table 3-1).

Performance of the PIT array was not assessed in 2024 due to the lack of attraction flows but extensive testing occurred in previous years (Cook et al. 2024).

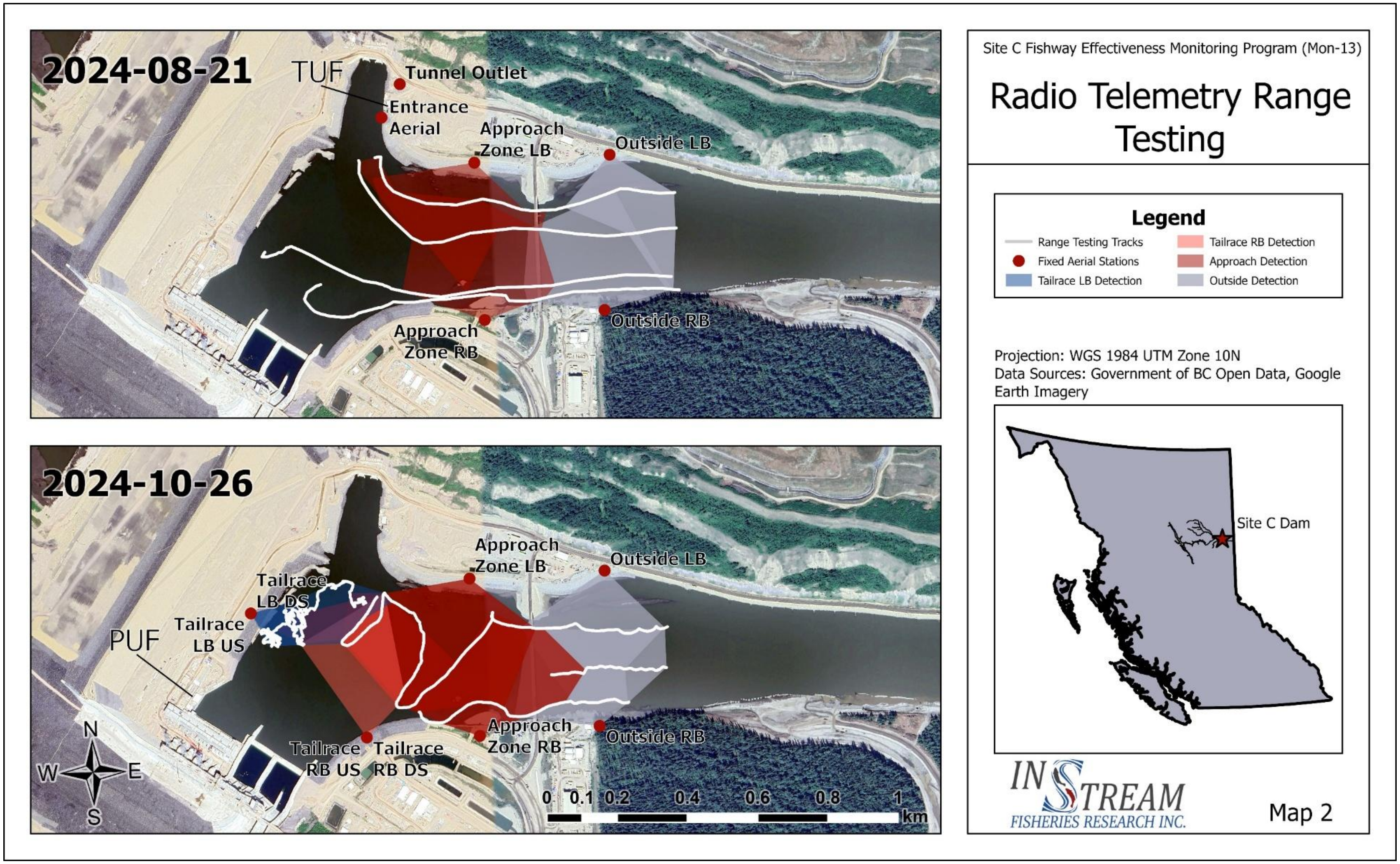

Figure 3-3: Approximate detection ranges of the paired outside approach (grey), approach (red), tailrace right bank (RB), and tailrace left bank (LB) of aerial fixed stations on August 21 and October 26, 2024. GPS tracks of the boat drift tests are shown as white lines. The tunnel outlet and entrance aerial antenna, as well as the fuil extent of the upstream (US) tailrace LB and Tailrace RB US were not range tested due to restricted access. The tunnel outlet and entrance aerial station were decommissioned September 2024, and all four tailrace aerial fixed stations were installed September 11-15, 2024.

Table 3-1. Outage durations are presented as the total hours and the maximum continuous duration that a receiver did not detect beacon or valid fish tags. Beacon tags transmitted every hour at each fixed radio telemetry station.

Station	Outage Durations (hrs)		Station	Outage Durations (hrs)	
	Total	Maximum		Total	Maximum
Outside LB	0	NA	Outside entrance 1	0	NA
Approach LB	0	NA	Entrance pool 1	526	526
Approach RB	0	NA	Turning basin	2	2
Tunnel outlet	4	3	Pool 8	5	1
Entrance aerial	670	668	Trap	2	1

3.3 Fish Movement Summaries

There were 20,087 PIT-tagged fish (with 590 individuals also having radio tags) detected during operational periods since 2021. These counts include only 23 Burbot, which were, therefore, excluded from most detection data summaries. Species ID was unknown for 3,595 PIT-tagged fish. Our species identification process has changed from previous years (Appendix C); this has led to greater confidence in species assignments, but also more individuals of unknown species. When only considering the five target species detected outside of shutdown periods, 6,595 PIT-tagged fish were detected with 437 individuals also having radio tags.

Seasonal variation in the presence of target species was apparent (Figure 3-4). The abundance of Arctic Grayling peaked in the study area in early June and in the fishway in late April / early May. Bull Trout abundance was normally distributed in the approach zone, peaking in late June. The pattern was different in the fishway, with consistently high abundance between mid-June and early July. Mountain Whitefish showed a bimodal distribution in both the approach zone and fishway, with abundance in the approach zone peaking in mid-May to mid-June and in October. Modes were not as defined in the fishway. Rainbow Trout had a more consistent presence in the study area outside of April, with higher numbers occurring between late-May and mid-August. It is also apparent (Figure 3-4) that proportionally few fish detected within the fishway successfully ascended into the sorting facility (discussed further in Fishway Effectiveness).

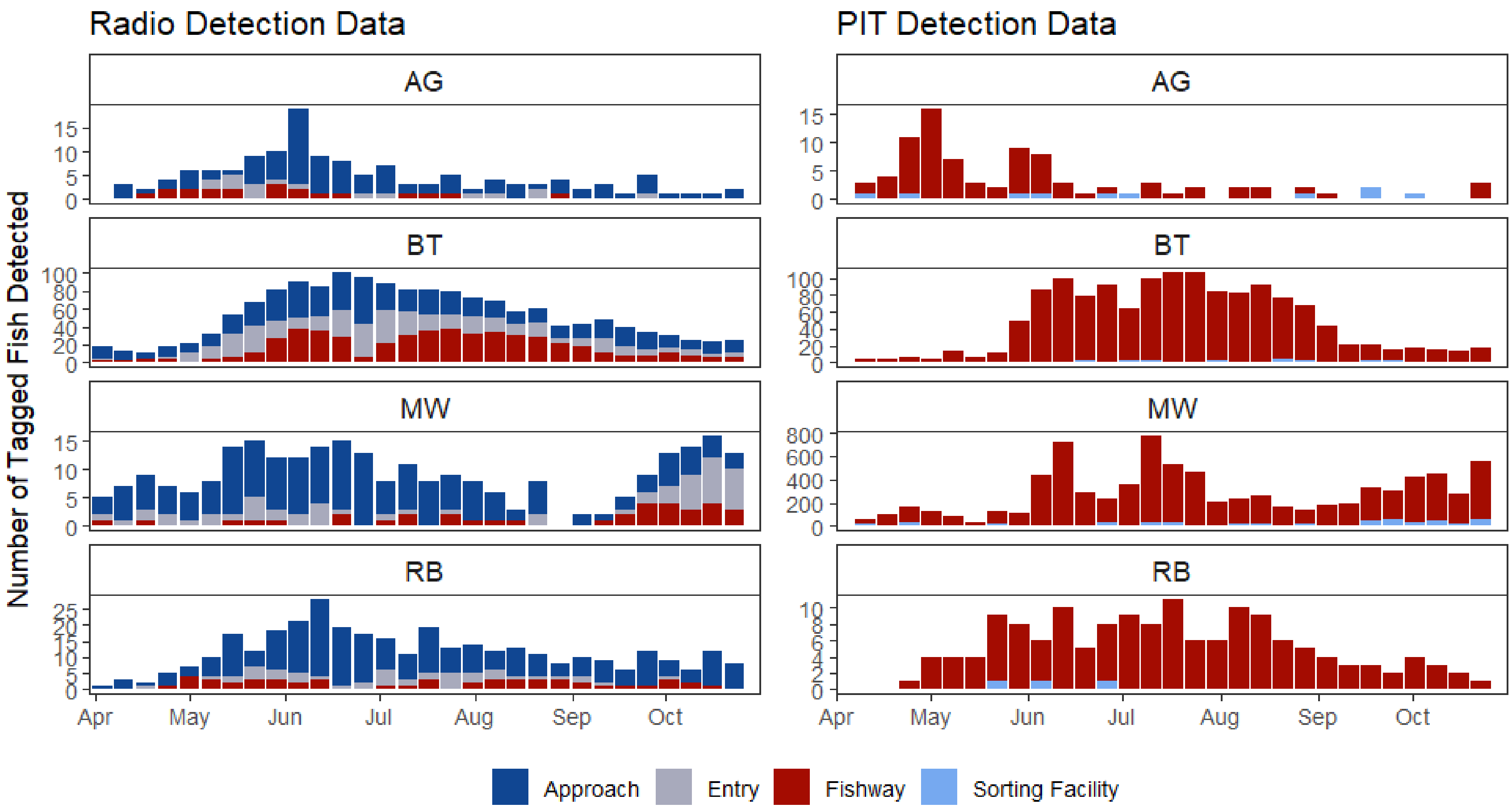

Figure 3-4 Numbers of target fish detected by week of the TUF operational period (April 1 to October 31) across all years, coloured according to the uppermost zone of detection in that week. Data collected from areas covered by the radio area (i.e., all zones except the sorting facility) are presented separately from data collected from areas covered by both radio and PIT telemetry (i.e., within the fishway and the sorting facility) because of discrepancies in the quantity of data. Many more fish are PIT-tagged, but no PIT-tagged fish can be detected outside of the fishway. Burbot data are not presented due to low sample sizes.

3.4 Fishway Effectiveness

Fishway effectiveness of the TUF was previously evaluated through time-to-event analyses, a comprehensive method that incorporates time-varying covariates. Given a lack of attraction flows in 2024, we evaluated fishway effectiveness by summarizing the numbers of tagged fish making it to various detection points along the array from the approach zone through to the sorting facility. We also calculated metrics of attraction, passage, and trapping efficiency for consistency with previous years. This analysis has been updated from previous years given a new protocol for matching tag codes with species identification metadata (Appendix C). Data is presented for all operational periods since 2021 combined, excluding shut down periods. Raw data by year is provided in Appendices D (numbers within each zone) and E (efficiency metrics).

We tallied the numbers of tagged fish reaching key zones across the entire study area (radio data only) and within the fishway during operational periods, excluding shutdowns. We assessed the five target species, and a group that represents all other species. This “other” group includes Longnose Sucker (n = 5483), fish of unknown species (n = 3584), Largescale Sucker (n = 2802), White Sucker (n = 378), Walleye (n = 203), non-speciated suckers (n = 167), Northern Pike (n = 7), Northern Pikeminnow (n = 7) , Lake Trout (n = 7), Lake Whitefish (n = 3) and, Kokane (n = 2). Tallies assumed a detection at an upstream zone meant an individual passed all downstream zones (e.g., if a tagged fish was scanned in the sorting facility, we know it passed all downstream detection locations even if it was not recorded on those antennas). These data highlight locations along a presumed upstream trajectory where a noticeable drop in the number of fish detected occurred, suggesting a passage impediment or barrier. However, this visualization ignores milling behaviors and assumes detected fish were attempting to pass through the facility. Nonetheless, there was evidence to suggest a barrier between the upper fishway and the sorting facility was present for all groups. This was indicated by the numbers of fish detected (Figure 3-5), holding behaviours in the upper pools (data not shown), and by observations of fish movements by IFR and fishway operators. Outside of the fishway, a decline was apparent between the approach zone and the entry zone across all groups (Figure 3-5).

All five target fish species have been detected within the approach zone using radio telemetry and were candidates for efficiency metrics. For species entering the fishway, attraction efficiency ranged from 15.1% for Arctic Grayling to 34.5% Bull Trout (Table 3-2). No Burbot entered the fishway (0% attraction efficiency). Passage efficiency was 3.3% for radio-tagged Bull Trout (n = 12), 3.8% for Arctic Grayling (n = 2), 0.9% for Rainbow (n = 1), and 0% for Mountain Whitefish

(Table 3-2). Passage efficiency could not be calculated for Burbot. These estimates of attraction and passage efficiency are limited because they rely entirely on radio-telemetry detections. We took advantage of the larger PIT-detection dataset to estimate trapping efficiency. This metric evaluated the effectiveness of upstream passage from the upper fishway to the sorting facility. Trapping efficiency was lowest for Rainbow Trout at 7.3% and highest for Arctic Grayling at 27.8% (Table 3-3).

Table 3-2. Summary of radio telemetry data used to determine attraction efficiency, passage success, and passage efficiency for target species from 2021 to 2024. Attraction efficiency is the proportion of total candidates that were attracted to and entered the fishway, passage success is the proportion of those that passed into the sorting facility, and passage efficiency is the product of the two. Confidence intervals (in brackets) derived using the Wilson Score method.

Species	Counts			Attraction Efficiency (%)	Passage Success (%)	Passage Efficiency (%)
	Candidates	Entered	Passed			
Bull Trout	359	124	12	34.5 (29.8 – 39.6)	9.7 (5.6 – 16.2)	3.3
Mountain Whitefish	72	18	0	25.0 (16.4 – 36.1)	0	0
Rainbow Trout	115	20	1	17.4 (11.5 – 25.3)	5.0 (0.9 – 23.6)	0.9
Arctic Grayling	53	8	2	15.1 (7.9 – 27.1)	25.0 (7.1 – 59.1)	3.8
Burbot	21	0	0	0 (0 – 15.5)	-	-

Table 3-3. Summary of PIT telemetry data used to determine trapping efficiency, the proportion of tagged target fish species that reached the upper fishway that were effectively trapped from 2021 to 2024. Confidence intervals (in brackets) were calculated using the Wilson Score method.

Species	Counts		Trapping Efficiency (%)
	Candidates	Passed	
Bull Trout	287	26	9.1 (6.3 - 12.9)
Mountain Whitefish	3423	521	15.2 (14.1 - 16.5)
Rainbow Trout	41	3	7.3 (2.5 - 19.4)
Arctic Grayling	36	10	27.8 (15.8 - 44)
Burbot	0	0	-

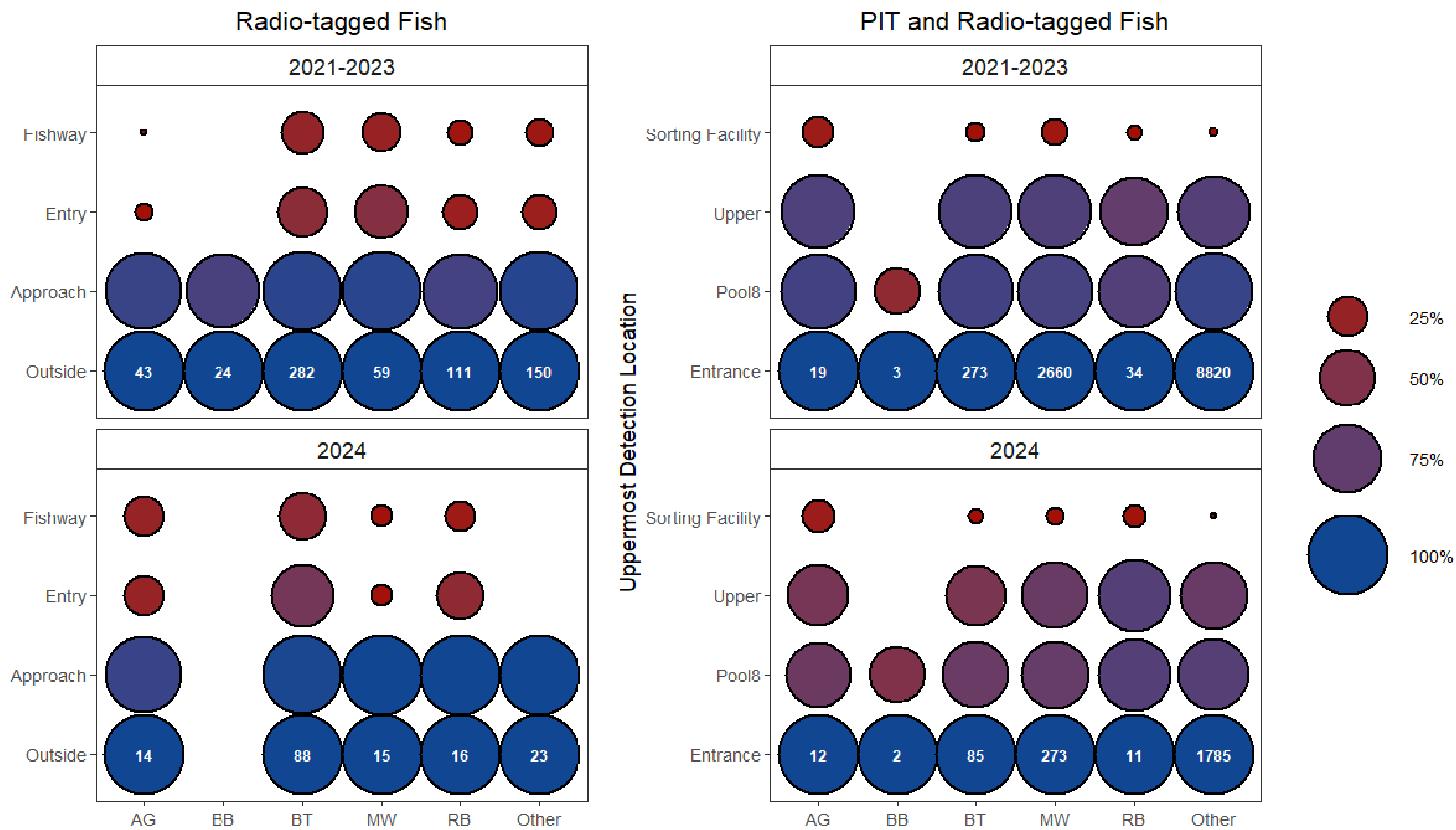

Figure 3-5 The number of tagged fish reaching key zones within the fishway (both PIT and radio data; left panels) and across the entire study area (radio data only; right panels) during operational periods since 2021, excluding shutdown periods. Numbers are shown for target species (Arctic Grayling, AG; Burbot, BB; Bull Trout, BT; Mountain Whitefish, MW; Rainbow Trout, RB) and all other species grouped (other'). The lower-most location in all cases is 100% because all fish detected upstream would have passed that point. All other points are sized and coloured on a scale as the percentage of the total shown on the bottom row in each panel. A substantial change in the size or colour at successive zones denotes a decrease in the number of fish detected and may be indicative of a barrier.

4. Discussion

The objective of Mon-13 was to evaluate the biological effectiveness of the TUF for the upstream passage of migrating Arctic Grayling, Bull Trout, Burbot, Mountain Whitefish, and Rainbow Trout. We have worked towards this objective since 2020, with the focus of analyses and reporting evolving each year. In earlier years, we ensured the experimental design and telemetry array were appropriate for our planned analyses (2020/2021), on executing models and identifying important covariates (2022), and on synthesizing data into a multi-year modeling approach to inform fishway operations (2023). The 2024 reporting year marked a transition from construction to permanent operations. The TUF operated without attraction flows for most of the 2024 operational period and had to be regularly shutdown. As a result, our primary focus shifted to developing efficient systems to query and synthesize information, ensuring reported numbers were as accurate as possible. The current database is extensive and provides a baseline for which to compare new data collected from the PUF. The data management systems we established will carry over to monitoring the PUF.

The TUF provided critical learning opportunities ahead of operating the PUF. All sources of information (i.e., PIT and radio telemetry, visual observations) suggest a barrier to passage existed between the upper pools of the fishway and the sorting facility of the TUF. Where passage efficiency could be quantified, values were far below target levels. As a result of this poor performance, the pre-sort holding pool, trapping mechanism, and crowder were redesigned at the PUF to improve passage into the sorting facility. A further challenge at the TUF was the poor performance of the PIT antennas - particularly in the lower fishway. Ultimately this meant that we had low confidence in our detection data. Additionally, PIT codes and fish metadata collected at the sorting facility prior to 2024 contained frequent errors. Species were often misidentified, and passage timing data often conflicted with detection histories, limiting the extent of analyses available for PIT data. Accordingly, data management systems at the sorting facility were overhauled in 2024. Improvements were also made to the PIT array. Antennas deployed in the upper fishway in 2022 performed substantially better than the original designs (unfortunately the lower fishway was inaccessible). With additional research we have further improved the design and performance of antennas for the PUF and have developed a thorough field-testing procedure to ensure maximum performance. A major improvement with the new design is that antennas are mounted on frames that can be removed in-season for repair and modifications or relocated to any pool in the PUF.

Efficiency metrics calculated from the TUF should provide a broad comparison of the biological effectiveness of the two facilities once more data has been collected from the PUF. Overall attraction efficiencies were low for the TUF (ranged from 0% for Burbot to 34.5% for Bull Trout), and passage efficiencies were even lower (ranged from 0% for Mountain Whitefish to 3.8% for Arctic Grayling). Trapping efficiency is more informative than passage efficiency because it focuses on there upper fishway, an area where passage is limited, and it incorporates PIT data, thereby leveraging a larger dataset. Trapping efficiencies ranged from 7.3 % (Rainbow Trout) to 27.8 % (Arctic Grayling). Neither passage nor trapping efficiency could be calculated for Burbot. Results indicated that a barrier exists within the upper fishway. The design of a trap, crowder, and lock at the end of the fishway is challenging because it is difficult to create one that is effective for multiple species (e.g. also seen in Harris et al. 2019).

Efficiency metrics are a simplistic means to estimate effectiveness – fish passage is a dynamic process inherently not fixed in time; a single measure of efficiency does not allow flexibility in evaluating how fish move between zones. Following the EIS provided for the Project and the references cited therein (BC Hydro 2012), we defined attraction efficiency as the proportion of tagged fish that were attracted to and entered the fishway. However, it is also of value to assess the proportion of fish that are attracted to the entry zone, an aspect not captured in our reported efficiency metrics. Assessing counts of fish within each zone – the approach zone, entry zone, fishway, and sorting facility – suggests that, in addition to the barrier between the fishway and the sorting facility, a barrier also exists between the approach zone and the entry zone. Across all target species and years, 789 radio-tagged fish were detected in the approach zone, 278 in the entry zone (35% of candidates) and 194 in the fishway (70% of those making it to the entry zone). These data indicate that attracting fish from the far-field was likely a greater limitation to the biological effectiveness of the TUF than attracting fish from the near-field entry zone into the fishway.

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 was 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). While the goal should be to improve efficiency metrics at the PUF, data from the TUF may be useful for establishing more realistic efficiency targets.

The biological effectiveness of the TUF was low throughout its operation, which likely concentrated fish within the fishway, particularly at the top. 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 2022), and piscivorous fish (Boulêtreau et al. 2018; Alcott et al. 2021; Rillahan 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).

Future analyses and fishway operations should consider biologically relevant variability in behaviour (e.g., accounting for active migration periods versus resident behaviours) and seasonal variability in presence. Previous modeling has indicated these factors are very important for predicting rates of movement between zones (Cook et al. 2024) and count data indicates that all species show seasonality in their abundance in the study area. 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 prey for piscivorous fish. 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. For example, Bull Trout may prefer higher velocity attraction flows that may detract other species. Elevating attraction flows during the Bull Trout spawning migration period may increase effectiveness, but maintaining these flows through the entire operational period may reduce effectiveness for other species (e.g., for Mountain Whitefish in the fall). However, we caution that seasonal analyses of this data have not be conducted. Operations will have to holistically and explicitly consider trade-offs and how each species may differentially respond.

Conditions at the PUF will be different: the facility is located on river right rather than river left, and the 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. We also expect that as a permanent facility, the PUF will not be impacted by shutdown periods like those experienced at the TUF or other operational challenges (e.g., pump failures, water surface elevations above design criteria). The TUF database provides a baseline for comparison with the PUF, where we will continue to evaluate effectiveness with multivariate modeling that reflects the dynamic nature of fish passage problems. We now have a much better understanding of species-specific spatial and temporal movement patterns in the dam tailrace than we did prior to operating the TUF, a well-defined strategy for data analysis, and benchmarks for comparing future data.

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Appendix A: Fishway Shutdowns and Modifications

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

Shutdown Start	Shutdown End	Duration	Reason
2021-04-20 12:01	2021-04-20 12:06	5 mins	Unknown
2021-04-20 13:17	2021-04-21 06:27	17.16 hrs	Water surface elevations on April 20 exceeded operating range, causing automatic pump shutdowns and drained the fishway.
2021-06-11 17:42	2021-06-16 13:01	4.8 days	The operator observed sheen on the water surface in the receiving pool and shut down the facility to analyze water samples.
2021-06-29 11:02	2021-07-25 10:02	25.95 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.
2021-07-25 20:44	2021-07-25 21:21	37 mins	Unknown
2021-07-26 06:00	2021-07-26 06:57	57 mins	Power outage.
2021-08-13 16:49	2021-08-13 17:09	20 mins	Unknown
2021-09-08 09:28	2021-09-09 16:12	1.27 days	Maintenance: install analog cards and replace brass bushing on the fish lock.
2021-09-11 08:11	2021-09-16 14:03	5.23 days	Maintenance: install analog cards and replace brass bushing on the fish lock.
2021-10-07 13:57	2021-10-07 17:35	3.63 hrs	Flows turned off to clean sand from fish lock and flush sprayers in pre-sort holding pool.
2021-10-31 15:34	2021-10-31 15:40	6 mins	Unknown
2022-04-08 14:30	2022-04-08 14:41	11 mins	Unknown
2022-04-19 04:57	2022-04-19 05:55	58 mins	Unknown
2022-05-29 14:41	2022-05-29 15:02	21 mins	Unknown
2022-05-29 15:04	2022-06-09 08:24	10.72 days	Increased local inflows caused sediment to clog water intake screens and the differential between the diversion tunnel outlet and wet well exceeded criteria.
2022-06-12 13:54	2022-06-12 14:02	8 mins	Unknown
2022-06-12 15:02	2022-06-12 16:11	1.15 hrs	Unknown
2022-06-29 10:00	2022-06-30 15:39	1.14 days	Continued sediment build-up.

Shutdown Start	Shutdown End	Duration	Reason
2022-07-03 19:14	2022-07-03 19:23	9 mins	Unknown
2022-07-03 19:25	2022-07-04 08:52	13.45 hrs	Unknown
2022-08-01 15:53	2022-08-02 07:55	16.03 hrs	Unknown
2022-08-02 13:18	2022-08-02 13:41	23 mins	Unknown
2022-08-11 14:23	2022-08-11 14:37	14 mins	Unknown
2022-08-25 14:18	2022-08-25 14:27	9 mins	Unknown
2022-08-30 23:21	2022-08-30 23:27	6 mins	Unknown
2022-09-04 15:04	2022-09-04 15:25	21 mins	Unknown
2022-09-14 08:55	2022-09-14 09:07	12 mins	Unknown
2022-09-15 13:49	2022-09-15 14:20	31 mins	Unknown
2023-04-01 11:30	2023-04-01 11:36	6 mins	Unknown
2023-04-17 14:53	2023-04-17 15:15	22 mins	Unknown
2023-04-17 15:28	2023-04-17 15:51	23 mins	Unknown
2023-05-03 14:49	2023-05-03 15:17	28 mins	Unknown
2023-05-08 07:46	2023-05-08 14:48	7.02 hrs	Power lines were installed at the diversion tunnel outlet
2023-05-10 14:32	2023-05-10 14:52	20 mins	Unknown
2023-05-10 14:58	2023-05-10 15:09	11 mins	Unknown
2023-05-16 09:00	2023-05-17 06:30	21.5 hrs	Site on evacuation alert due to a nearby wildfire
2023-05-21 15:15	2023-05-21 16:02	47 mins	Unknown
2023-05-24 13:19	2023-05-24 13:58	39 mins	Unknown
2023-05-28 11:22	2023-05-28 14:25	3.05 hrs	Unknown
2023-05-31 11:33	2023-05-31 11:44	11 mins	Unknown
2023-05-31 11:46	2023-05-31 13:52	2.28 hrs	Unknown
2023-07-04 12:15	2023-07-04 14:32	2.28 hrs	Unknown

Shutdown Start	Shutdown End	Duration	Reason
2023-07-12 15:01	2023-07-12 16:12	1.18 hrs	Unknown
2023-07-19 13:25	2023-07-19 15:51	2.43 hrs	Unknown
2023-07-25 13:27	2023-07-25 15:28	2.01 hrs	Unknown
2023-08-02 14:11	2023-08-02 15:36	1.42 hrs	Unknown
2023-08-08 15:09	2023-08-08 15:41	32 mins	Unknown
2023-08-10 09:29	2023-08-10 09:45	16 mins	Unknown
2023-08-10 10:03	2023-08-10 17:43	7.66 hrs	Unknown
2023-08-10 17:45	2023-08-11 03:26	9.68 hrs	Unknown
2023-08-11 03:28	2023-08-11 09:07	5.65 hrs	Unknown
2023-08-11 09:09	2023-08-11 10:43	1.57 hrs	Unknown
2023-08-11 10:45	2023-08-11 11:17	32 mins	Unknown
2023-08-11 11:19	2023-08-11 11:27	8 mins	Unknown
2023-08-11 11:29	2023-08-11 13:01	1.53 hrs	Unknown
2023-08-20 13:44	2023-08-21 06:47	17.05 hrs	Unknown
2023-08-27 14:26	2023-08-28 12:32	22.10 hrs	Unknown
2023-09-04 07:58	2023-09-05 07:29	23.52 hrs	Unknown
2023-09-19 13:44	2023-09-20 11:39	21.92 hrs	Unknown
2023-10-11 14:16	2023-10-12 07:00	16.73 hrs	Unknown
2023-10-23 14:08	2023-10-24 07:04	16.73 hrs	Unknown
2024-04-02 11:33	2024-04-02 12:13	40 mins	Unknown
2024-04-05 07:23	2024-04-05 07:30	7 mins	Unknown
2024-04-15 10:13	2024-04-15 13:53	3.67 hrs	Shutdown to remove the horizontal propeller pumps and perform detailed inspection
2024-05-04 09:34	2024-05-04 14:19	4.75 hrs	Facility shutdown for 5 hours to re-establish water levels in the wet well
2024-05-06 09:41	2024-05-06 16:44	7.05 hrs	Facility shutdown for 7 hours to re-establish water levels in the wet well

Shutdown Start	Shutdown End	Duration	Reason
2024-05-09 09:26	2024-05-09 15:25	5.98 hrs	Facility shutdown for 6 hours to re-establish water levels in the wet well
2024-05-17 13:55	2024-05-18 17:58	1.17 days	Facility shutdown for 28 hours to re-establish water levels in the wet well
2024-05-29 09:29	2024-05-30 14:38	1.2 days	Facility shutdown for 29 hours to re-establish water levels in the wet well
2024-06-03 09:12	2024-06-05 05:49	1.85 days	Facility shutdown for 45 hours to re-establish water levels in the wet well
2024-06-09 11:25	2024-06-09 17:41	6.27 hrs	Facility shutdown for 6 hours to re-establish water levels in the wet well
2024-06-14 10:26	2024-06-14 17:17	6.85 hrs	Facility shutdown for 7 hours to re-establish water levels in the wet well
2024-06-16 09:29	2024-06-17 16:24	1.28 days	Facility shutdown for 31 hours to re-establish water levels in the wet well
2024-06-20 13:38	2024-06-20 22:03	8.42 hrs	Facility shutdown for 8 hours to re-establish water levels in the wet well
2024-06-24 14:13	2024-06-24 14:32	19 mins	Unknown
2024-06-25 10:50	2024-06-26 19:25	1.35 days	Facility shutdown for 30 hours to re-establish water levels in the wet well
2024-07-02 14:56	2024-07-02 15:36	40 mins	Unknown
2024-07-06 09:36	2024-07-06 09:46	10 mins	Unknown
2024-07-06 10:48	2024-07-10 03:05	3.67 days	Gear on the fish lock gate valve was stripped and had to be replaced
2024-07-10 03:07	2024-07-12 14:58	2.48 days	Gear on the fish lock gate valve was stripped and had to be replaced
2024-07-23 00:42	2024-07-23 09:11	8.48 hrs	Brown out to the facility power supply
2024-07-23 09:36	2024-07-23 13:17	3.68 hrs	Brown out to the facility power supply
2024-07-23 14:36	2024-07-23 14:42	6 mins	Unknown
2024-07-24 15:38	2024-07-25 08:59	17.35 hrs	Brown out to the facility power supply
2024-08-19 13:46	2024-08-19 14:07	21 mins	Malfunction - Fishway supply pump shut off during a crowd. Operator reset the facility wet system, which restarted the fishway supply pump
2024-08-23 13:47	2024-08-23 13:58	11 mins	Malfunction - Fishway supply pump shut off during a crowd. Operator reset the facility wet system, which restarted the fishway supply pump

Appendix B: Fixed Radio Telemetry Stations

Table B10. 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.

Spatial Zone	Fixed Station Name	No.	Type	Date installed	Date Deactivated	Purpose
Outside approach	Outside LB	33	Aerial	2020-08-01	Active	The combined detection range defined the outside approach zone, which confirmed when fish left the array.
	Outside RB	11	Aerial	Unknown (LGL Operated)	Active	
Approach zone	Approach Gate LB	34	Aerial	2020-08-02	Active	The combined detection range formed the approach zone gate, which delineated the approach zone from the outside approach.
	Approach Gate RB	35	Aerial	2020-08-03	Active	
	Tunnel outlet	37	Aerial	2024-03-28	2024-09-10	Determined if fish were approaching the diversion tunnel outlet prior to or instead of the TUF fishway.
	PUF tailrace RB-DS	54	Aerial	2024-09-11	Active	Determined the location of fish on RB or LB of the area downstream of the PUF. Antennas scanned both upstream (US) and downstream (DS) on both banks.
	PUF tailrace RB-US	55	Aerial	2024-09-11	Active	
	PUF tailrace LB-DS	56	Aerial	2024-09-12	Active	
	PUF tailrace LB-US	57	Aerial	2024-09-15	Active	
	PUF roughness element DS	58	Aerial	2024-09-27	Active	Determined if fish were approaching the PUF via the roughness elements leading into the PUF entrances.
	PUF roughness element US	59	Aerial	2024-10-17	Active	
	TUF entrance aerial	38	Aerial	2024-03-28	2024-10-15	Determined if fish were nearing the fishway entrance.
PUF/TUF entry zone	PUF outside entrance	60	Dipole	2024-09-27	Active	Defined the entry zone of the PUF.
	TUF outside entrance	39/48	Dipole	2024-03-28	2024-09-22	Defined the entry zone of the TUF.
TUF fishway	TUF entrance pool	40/49	Dipole	2024-03-28	2024-09-15	Confirmed fishway entry.
	TUF pool 8	42	Dipole	2024-03-28	2024-09-22	Determined if fish reached pool 8
	TUF turning basin	41	Dipole	2024-03-28	2024-09-15	Determined if fish reached the turning basin.
	TUF trap	43	Dipole	2024-03-28	2024-09-22	Determined if fish reached pool 25

Appendix C: Species Identification Procedure

Metadata, which includes relevant data of species identification, fish size, and a time stamp, among many other pieces of information, comes from a variety of sources: (1) In-river radio and PIT tag deployment data (WSP); (2) In-river encounter of tagged fish (WSP); (3) Processing of fish in the fishway sorting facilities at the TUF and the PUF (Palmer Environmental 2020-2023; WSP 2024). There were several problems within these datasets, listed below with solutions. We expect troubleshooting to continue as more data is collected.

Problem 1: Species ID data from the TUF was unreliable in 2023

- Species listed as unknown if the only data available for a tag is from the TUF in 2023
- If species identification from all other sources is different from that collected from the TUF in 2023 but consistent with each other, retain species identification from other sources

Problem 2: Inconsistencies in sucker identification across all datasets

- If any combination of CSU, WSU, and LSU are used inconsistently within a tag code, recode as an unidentified sucker (“SU”).

Problem 3: Conflicting species IDs that don't align with predation events and don't have any other rationale, not considering data collected from the TUF in 2023

- Change species identification to unknown.

Problem 4: Suspected and known predation situations. These are reviewed case-by-case

- If a predation event is known or suspected, the tag(s) of the depredated fish is/are listed as inactive at the time of last encounter as the prey species. The tag(s) of the depredated fish become(s) active at the first time of encounter of the predator. Species is listed unknown between the last encounter as the prey and first encounter of the predator because we have no knowledge of when the predation occurred.
- Predation is confirmed in the following ways:
    - Field notes from WSP’s tagging and fish encounter databases
    - Assumed through biologically relevant changes in size and species (e.g., small Mountain Whitefish to large Bull Trout or Northern Pike).

We expect many instances of tag-to-tag predation for that we are not able to account for.

Appendix D: Numbers of Fish Passing each Zone

Table D1. Counts of radio and pit-tagged fish detected within each distinct zone by year.

Species	Radio tag data only				PIT and radio tag data			
	Outside	Approach	Entry	Fishway	Entrance	Pool 8	Upper	TUF Sorting Facility
2021								
AG	22	21	0	0	2	2	2	1
BB	13	12	0	0	1	1	0	0
BT	93	86	26	20	40	36	29	3
MW	25	24	15	9	712	603	541	50
Other	58	58	12	8	1793	1624	1361	58
RB	41	39	6	3	4	3	3	0
2022								
AG	13	11	2	1	2	2	2	0
BB	4	2	0	0	2	0	0	0
BT	93	90	40	28	107	94	90	2
MW	19	18	10	5	989	881	847	128
Other	42	42	14	11	2750	2545	2121	81
RB	36	31	12	7	14	9	8	0
2023								
AG	8	8	3	3	15	13	12	2
BB	7	7	0	0	0	0	0	0
BT	96	96	51	40	126	114	113	15
MW	15	15	3	2	959	850	844	128
Other	50	46	9	7	4277	4042	3747	260
RB	34	29	8	7	16	16	14	2
2024								
AG	14	13	4	4	12	8	7	2
BB	2	1	0	0	0	0	0	0
BT	88	87	55	34	85	59	47	5
MW	15	15	2	2	273	194	190	18
Other	23	23	0	0	1785	1439	1254	76
RB	16	16	6	3	11	9	9	1

Appendix E: Yearly Efficiency Metrics

Table E1. 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	86	20	2	23.3 (15.6 – 33.2)	10 (2.8 – 30.1)	2.33
Mountain Whitefish	24	9	0	37.5 (21.2 – 57.3)	0	0
Rainbow Trout	39	3	0	7.7 (2.7 – 20.3)	0	0
Arctic Grayling	21	0	0	0	-	-
Burbot	12	0	0	0	-	-
2022						
Bull Trout	90	28	2	31.1 (22.5 – 41.3)	7.1 (2.0 – 22.6)	2.21
Mountain Whitefish	18	5	0	27.8 (12.5 – 50.9)	0	0
Rainbow Trout	31	7	0	22.6 (11.4 – 39.8)	0	0
Arctic Grayling	11	1	0	9.1 (1.6 – 37.7)	0	0
Burbot	2	0	0	0	-	-
2023						
Bull Trout	96	42	7	43.8 (34.3 – 53.7)	16.7 (8.3 – 30.6)	7.31
Mountain Whitefish	15	2	0	13.3 (3.7 – 37.9)	0	0
Rainbow Trout	29	7	1	24.1 (12.2 – 42.1)	14.3 (2.6 – 51.3)	3.45
Arctic Grayling	8	3	1	37.5 (13.7 – 69.4)	33.3 (6.1 – 79.2)	12.49
Burbot	7	0	0	0	-	-
2024						
Bull Trout	87	34	1	39.1 (29.5 – 49.6)	2.9 (0.5 – 14.9)	1.13
Mountain Whitefish	15	2	0	13.3 (3.7 – 37.9)	0	0
Rainbow Trout	16	3	0	18.8 (6.6 – 43.0)	0	0
Arctic Grayling	13	4	1	30.8 (12.7 – 57.6)	25.0 (4.6 – 69.9)	7.7
Burbot	0	0	0	-	-	-

Table E2. 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	29	3	10.3 (3.6 - 26.4)
Mountain Whitefish	545	45	8.3 (6.2 - 10.9)
Rainbow Trout	3	0	0
Arctic Grayling	2	1	50 (9.5 - 90.5)
Burbot	0	0	-
2022			
Bull Trout	92	2	2.2 (0.6 - 7.6)
Mountain Whitefish	1053	182	17.3 (15.1 - 19.7)
Rainbow Trout	8	0	0
Arctic Grayling	3	0	0
Burbot	0	0	-
2023			
Bull Trout	118	16	13.6 (8.5 - 20.9)
Mountain Whitefish	1430	227	15.9 (14.1 - 17.9)
Rainbow Trout	18	2	11.1 (3.1 - 32.8)
Arctic Grayling	22	6	27.3 (13.2 - 48.2)
Burbot	0	0	-
2024			
Bull Trout	48	5	10.4 (4.5 - 22.2)
Mountain Whitefish	395	67	17 (13.6 - 21)
Rainbow Trout	12	1	8.3 (1.5 - 35.4)
Arctic Grayling	9	3	33.3 (12.1 - 64.6)
Burbot	0	0	-