Site C Clean Energy Project

Site C Reservoir Tributaries Fish Community and Spawning Monitoring Program (Mon-1b)

Task 2a – Peace River Arctic Grayling and Bull Trout Movement Assessment

Task 2d – Site C Fish Movement Assessment

Construction Year 9 (2023)

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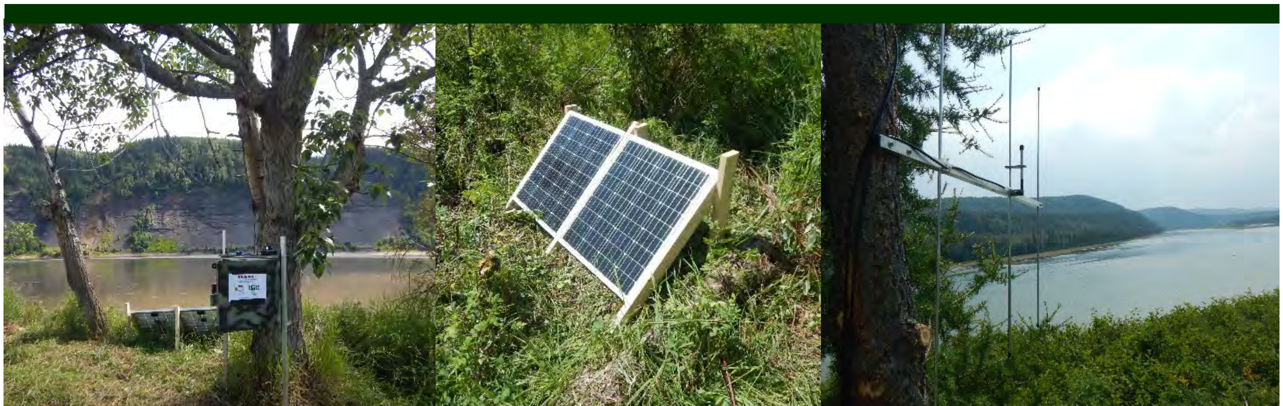
Site C Fish Movement Assessment
(Mon-1b, Tasks 2a and 2d)



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Executive Summary

In accordance with Provincial Environmental Assessment Certificate Condition No. 7[1] and Federal Decision Statement Condition Nos. 8.4.3[2] and 8.4.4[3] for BC Hydro's Site C Clean Energy Project (the Project), BC Hydro has developed the Site C Fisheries and Aquatic Habitat Monitoring and Follow-up Program (FAHMFP[4]). The Site C Reservoir Tributaries Fish Community and Spawning Monitoring Program (Mon-1b) represents one component of the FAHMFP that is designed to monitor the responses, using before and after comparisons, of target Peace River fish populations to the construction and operation of the Project.

This report describes the monitoring data collected during the 2023 field season (1 January 2023 to 31 January 2024) as well as an accompanying analysis that includes all data collected from the ongoing study (1 May 2019 to 31 January 2024). The data collection and analysis are intended to address two components of Mon-1b: the Site C Fish Movement Assessment (Mon-1b, Task 2d) as well as the Peace River Arctic Grayling and Bull Trout Movement Assessment (Mon-1b, Task 2a).

The Site C Fish Movement Assessment (Mon-1b, Task 2d) was implemented to evaluate movement patterns of key indicator species (Arctic Grayling *Thymallus arcticus*, Bull Trout *Salvelinus confluentus*, Burbot *Lota lota*, Mountain Whitefish *Prosopium williamsoni*, Rainbow Trout *Oncorhynchus mykiss*, and Walleye *Sander vitreus*) in the Peace River and its tributaries. To achieve these study objectives, LGL designed, deployed, and maintained a fixed radio telemetry array comprised of 28 to 34 (depending on the study year) fixed-stations along the Peace River and its tributaries. The Peace River Arctic Grayling and Bull Trout Movement Assessment (Mon-1b, Task 2a) was designed to determine the magnitude, direction, and seasonality of Arctic Grayling and Bull Trout movements within the Peace River and its tributaries to help determine the Project's effects on these metrics, and to inform various monitoring programs.

The work was broken into three parts: 1) deployment and maintenance of the fixed-station array, along with the storage and organization of the resulting detection data; 2) fixed wing mobile tracking surveys to augment the data collected by the fixed-station array; and 3) data analysis to characterize the movement patterns of key indicator species.

The array of fixed-stations was designed to encompass the Local Assessment Area from Peace Canyon Dam (river km 20) to Many Islands, Alberta (river km 231). Between these locations, fixed-stations were located at the entrance of every major tributary, with Peace River fixed-stations located approximately halfway between each tributary entrance. In all, 34 fixed-stations collected detection data in 2023. Three of which are operated perennially and have been maintained since their installation in 2019. The remaining 31 fixed-stations are operated seasonally and were re-installed for the 2023 season between 3 March to 7 November 2023. Sites deployed within an area of cellular coverage could be contacted remotely to check or change settings, check functionality, and/or download data. In 2023, all sites were tested for basic operability. Also, range tests performed for 28 of the 34 fixed-stations showed that the distance at which 50% of tag transmissions were properly detected and decoded was on average 435 m from the antennas, though this metric varied among

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[1] The EAC Holder must develop a Fisheries and Aquatic Habitat Monitoring and Follow-up Program to assess the effectiveness of measures to mitigate Project effects on healthy fish populations in the Peace River and tributaries, and, if recommended by a QEP or FLNR, to assess the need to adjust those measures to adequately mitigate the Project's effects.

[2] The plan shall include: an approach to monitor changes to fish and fish habitat baseline conditions in the Local Assessment Area.

[3] The plan shall include: an approach to monitor and evaluate the effectiveness of mitigation or offsetting measures and to verify the accuracy of the predictions made during the environmental assessment on fish and fish habitat.

[4] Site C Fisheries and Aquatic Habitat Monitoring and Follow-up Program available at https://www.sitecproject.com/document-library/environmental-management-plans-and-reports.

fixed-stations from 80 to >750 m. The average fixed-station detection efficiency for both upstream and downstream movements was 91% in 2023 (range = 61% to 100%).

Mobile tracking effort in 2023 focused on Halfway River Bull Trout during peak spawning migrations in September. Two mobile surveys of the Halfway River were conducted by fixed wing aircraft, one taking two-days to complete[5]. Antennas were mounted to the aircraft and connected to telemetry receivers in the cabin for each mobile survey. Unlike in 2020 and 2021, no Moberly River mobile surveys were conducted to track spawning Arctic Grayling in 2022 or 2023. Arctic Grayling spawning behaviour in the Moberly River was instead interpreted using the Moberly River array, comprised of four fixed-stations: Moberly River 1/2/3 and Moberly Lake. Furthermore, no supplemental mobile tracks were conducted during the 2022/2023 winter offseason[6].

The downloaded data from fixed-stations and the post-processed mobile-tracking data files were stored and compiled for inclusion into the Site C Fish Movement Assessment Database. Data were processed to validate the detection records by removing those that were likely false positives and those which resulted from electronic noise. The fixed-station array and mobile tracking efforts collected nearly 18 million valid detection records that passed the filtering criteria between 1 January 2023 and 31 January 2024. Individual fish tracks were processed for the distances and directions moved, and the seasonality of movement patterns.

The Bull Trout spawning analysis identified 22 adult Bull Trout with potential spawning behaviours in the Halfway River and its tributaries during the fall spawning period in 2023. Fourteen Bull Trout were detected in the Chowade River, five in Cypress Creek, two in the Halfway River near Chowade River, and one in Needham Creek.

Potential spawning patterns by Bull Trout in the Halfway River watershed were further analyzed using all available telemetry data collected from 2019 to 2023 to investigate their tendency to return to the same tributary for repeat spawning (i.e., site fidelity) and the occurrence of skip-spawning. Over this period, 16 individual Bull Trout were tracked repeatedly in the upper Halfway River watershed (above Cameron River) across multiple spawning seasons. Of these, 12 individuals (75%) were detected in the same tributary during more than one spawning season, indicating site fidelity. The remaining 4 individuals (25%) were detected in different tributaries, suggesting a lack of site fidelity.

A total of 26 Bull Trout were detected in the upper Halfway River watershed during at least one spawning season and tracked across two or more seasons. Of these, 12 individuals exhibited a potential skip-spawn behavior during at least one spawning season. In total, 14 potential skip-spawning events (24%) were recorded, compared to 44 potential spawning events (76%). Three of the skip-spawning events were based on detections at the Pine River fixed station during the Bull Trout spawning season. However, since these fish were only detected at the mouth of the Pine River, it cannot be conclusively determined that they were spawning there.

Twenty-eight radio-tagged Mountain Whitefish were analyzed to evaluate spawning behaviours (8 released in 2006, 2 released in 2020, and 18 released in 2021). In total, 44 potential spawning events were detected, with the majority occurring in a corridor that extended from the Project to the mouth of the Pine River (n= 31). After river diversion (i.e., in the data collected since October 2020), 10% of Mountain Whitefish were detected upstream of Site C during at least one spawning season, whereas the equivalent proportion from before

[5] Halfway River mobile detection flights were conducted on 7 September, 8 September, and 17 September 2023.

[6] Supplemental mobile surveys during the off-season were conducted during the 2020/2021 and 2021/2022 winters.

diversion (from the historical dataset) was 25%. This difference may be an artefact of low sample sizes and the large variability of individualistic movement patterns exhibited by Mountain Whitefish.

No radio tagged adult Arctic Grayling exhibited spawning behaviour in the Moberly River during the Arctic Grayling spawning period from April to June 2023.

Fish movement patterns through the Site C Project corridor were analyzed before and after river diversion to evaluate potential Project impacts during the construction phase and to complement the Site C Fishway Effectiveness Monitoring Program (Mon-13) at broader temporal and spatial scales. Post-diversion data revealed a 2- to 8-fold increase in the frequency of a specific movement pattern, where study fish approached the Site C area, retreated approximately 9 rkm downstream, and then re-approached. This behavior may suggest exploratory passage, where fish investigate the impoundment, retreat, and later return. A similar pattern, though on a smaller spatial and temporal scale, was reported and modeled in the time-to-event analysis for Mon-13, which was used to evaluate the effectiveness of the temporary upstream passage facility.

Since operations began in 2020, the temporary passage facility has not met the target passage benchmarks, with passage efficiency ranging from 0-4% across all target species. The increased frequency of this movement pattern may reflect a study fish's difficulty in successfully passing through the facility. However, it's important to consider that fish approaching Site C post-diversion may not always be attempting to pass; this behavior could also be related to feeding, as food availability may be higher near the outlet of the diversion tunnels. Although approaching Site C may not always indicate an intent to pass upstream, the increased occurrence of the approach-retreat-reapproach movement pattern suggests a possible shift in behaviors among resident fish below the Project.

The results in this report are drawn from data collected during the initial years of a long-term program, meaning the dataset and interpretations are evolving and will expand as more data is collected. The figures generated to characterize magnitude, seasonality, and direction were created to display the capacity of the telemetry detection system (fixed and mobile) to facilitate the analysis of large-scale monitoring of movement patterns, and to support answering specific management questions. The management questions that are presented herein were carefully curated to be at least partially addressable with the data available at the time of writing. Tagged study fish continue to move and be detected. Construction of the Project continues and the reservoir has yet been filled. Continued operation of the fixed-station array, and continued mobile tracking, will help further address the management questions outlined herein, as well as those that will be addressed in the future.

Table of Contents

List of Figures

List of Tables

List of Appendices

Introduction

In accordance with Provincial Environmental Assessment Certificate Condition No. 7[7] and Federal Decision Statement Condition Nos. 8.4.3[8] and 8.4.4[9] for BC Hydro's Site C Clean Energy Project (the Project), BC Hydro has developed the Site C Fisheries and Aquatic Habitat Monitoring and Follow-up Program (FAHMFP[10]). The Site C Reservoir Tributaries Fish Community and Spawning Monitoring Program (Mon-1b) represents one component of the FAHMFP that is designed to monitor the responses, using before and after comparisons, of target Peace River fish populations to the construction and operation of the Project.

This report addresses two interrelated tasks within the Site C Reservoir Tributaries Fish Community and Spawning Monitoring Program (Mon-1b): the Site C Fish Movement Assessment (Task 2d) as well as the Peace River Arctic Grayling and Bull Trout Movement Assessment (Task 2a). The Site C Fish Movement Assessment was implemented annually between 2019 and 2023 to characterize the magnitude, seasonality, and direction of six key indicator species (Arctic Grayling *Thymallus arcticus*, Bull Trout *Salvelinus confluentus*, Burbot *Lota lota*, Mountain Whitefish *Prosopium williamsoni,* Rainbow Trout *Oncorhynchus mykiss*, and Walleye *Sander vitreus*) in the Peace River and its tributaries; while the Peace River Arctic Grayling and Bull Trout Movement Assessment expanded on those objectives by focusing on Bull Trout and Arctic Grayling movements within known spawning tributaries.

To achieve the study objectives of both tasks, radio telemetry was employed to catalog fish movements throughout the Peace River and its tributaries. More specifically, study fish were implanted with specialized radio transmitters and were detected by either fixed-station or mobile tracking techniques. Fixed-stations benefit from the capability for continuous operation at important locations which, in turn, provides the basis for addressing the objectives of the Site C Fish Movement Assessment. Mobile tracking, on the other hand, primarily serves to address the Peace River Arctic Grayling and Bull Trout Movement Assessment as well as supplement the underlying telemetry dataset.

The fixed radio telemetry array was designed to span the temporal and spatial extent of the FAHMFP. Temporally, collection of radio telemetry data began in July 2019 (Hatch et al. 2020) with the aim to build on baseline studies that were conducted by the BC Ministry of Environment from 1996-1999 (Burrows et al. 2001, AMEC & LGL 2010b), and by AMEC and LGL from 2005-2009 (AMEC & LGL 2008a,b, 2009, 2010a). The intent is to operate the array in Construction Years 5 to 10[11] followed by Operation Years 1-5, 10-11, 15-16, 20-21, 25-26 and 29-30[12]. Spatially, the extent of the array is meant to coincide with the sampling and tagging of target species by the Peace River Large Fish Indexing Survey (Mon-2, Task 2a). The array was designed to cover 200 river kilometres of the Peace River, including the entrances to major tributaries (Maurice Creek, Lynx Creek, Farrell Creek, Halfway River, Cache Creek, Moberly River, Pine River, Beatton River, Kiskatinaw River, and Pouce Coupe River), as well as to provide additional coverage within important tributaries (Halfway River, Moberly River, Chowade River, and Cypress Creek). That said, the array

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[7] The EAC Holder must develop a Fisheries and Aquatic Habitat Monitoring and Follow-up Program to assess the effectiveness of measures to mitigate Project effects on healthy fish populations in the Peace River and tributaries, and, if recommended by a QEP or FLNR, to assess the need to adjust those measures to adequately mitigate the Project's effects.

[8] The plan shall include: an approach to monitor changes to fish and fish habitat baseline conditions in the Local Assessment Area;

[9] The plan shall include: an approach to monitor and evaluate the effectiveness of mitigation or offsetting measures and to verify the accuracy of the predictions made during the environmental assessment on fish and fish habitat.

[10]Site C Fisheries and Aquatic Habitat Monitoring and Follow-up Program available at https://www.sitecproject.com/document-library/environmental-management-plans-and-reports.

[11] 2019 - 2024

[12] 2024-2028, 2034-2035, 2039-2040, 2044-2045, 2049-2050 and 2053-2054, respectively

is designed to be flexible, whereby stations can be added, moved, and/or improved as monitoring progresses or study priorities shift (e.g., the telemetry array monitoring Site C Offset 108R).

The Peace River Arctic Grayling and Bull Trout Movement Assessment (Mon-1b, Task 2a) began in 2020 with mobile tracking surveys conducted from a helicopter or fixed wing aircraft. Mon-1b, Task 2a expanded on the fixed station array's coverage area by venturing farther into recognized spawning tributaries for Arctic Grayling and Bull Trout. The temporal and spatial extent of the tracking surveys cover known migratory periods (April to June for Arctic Grayling; August to September for Bull Trout) and locations (Moberly River for Arctic Grayling, and the Halfway River for Bull Trout). The mobile tracking protocols were modelled after those of the baseline telemetry studies (AMEC & LGL 2008a,b, 2009, 2010a,b), while considering changes to the physical conditions in the study area due to the Project.

Objectives

The objective of the Site C Fish Movement Assessment (Mon-1b, Task 2d) is to collect telemetry data that can characterize the magnitude, direction, and seasonal variability of movements of key indicator species in the Peace River and its tributaries. Data collected by the Site C Fish Movement Assessment is critical to understanding any changes in fish movement that are associated with the construction and operation of the Project. Telemetry data will also be used to supplement other on-going monitoring programs within the FAHMFP. Such information will help address other fisheries management questions and test hypotheses from the different monitoring programs, such as the Site C Reservoir Tributaries Fish Community and Spawning Monitoring Program (Mon-1b), the Peace River Fish Community Monitoring Program (Mon-2), and the Site C Fishway Effectiveness Monitoring Program (Mon-13).

The objective of the Peace River Arctic Grayling and Bull Trout Movement Assessment (Mon-1b, Task 2a) is to perform mobile aerial radio-tracking surveys to determine the magnitude, direction, and seasonality of Arctic Grayling and Bull Trout movements within the Peace River and key spawning tributaries. Data will inform various other components of the FAHMFP but may also be used to inform the operation of the temporary and permanent upstream fish passage facilities, such as the transport and release of these species.

Methods

Study Fish Collection and Tagging

In conjunction with the Peace River Large Fish Indexing Survey (Mon-2, Task 2a) and the Contingent Fish Capture and Transport Program, WSP Global collected, radio-tagged, and released 108 study fish between 14 August and 23 September 2023 (WSP 2023 & 2024). All radio-tagged study fish were collected by boat electroshocking using methods and settings that were consistent with previous study years (WSP 2024). Collected study fish were identified to species, weighed in grams, measured for length (most species measured for fork length, FL, but Burbot were measured for total length, TL) in millimetres, and assigned a life stage (i.e., adult or juvenile[13]) based on their length (Figure 1). Similar to 2019 through 2022, candidate study fish for radio tagging were selected based on the health and vigor of the fish following a post-capture holding period; wherein fish that appeared stressed or unhealthy were excluded from contention (WSP 2024).

[13] Categorizing study fish as an adult or juvenile is based on a fork length (FL) cut-off by species; where above the FL cut-off is an adult and under that is a juvenile. For Bull Trout, 250 mm is the FL cut-off between juvenile and adult while 260 and 300 mm are the cut-offs for Rainbow Trout and Arctic Grayling, respectively (WSP 2024).

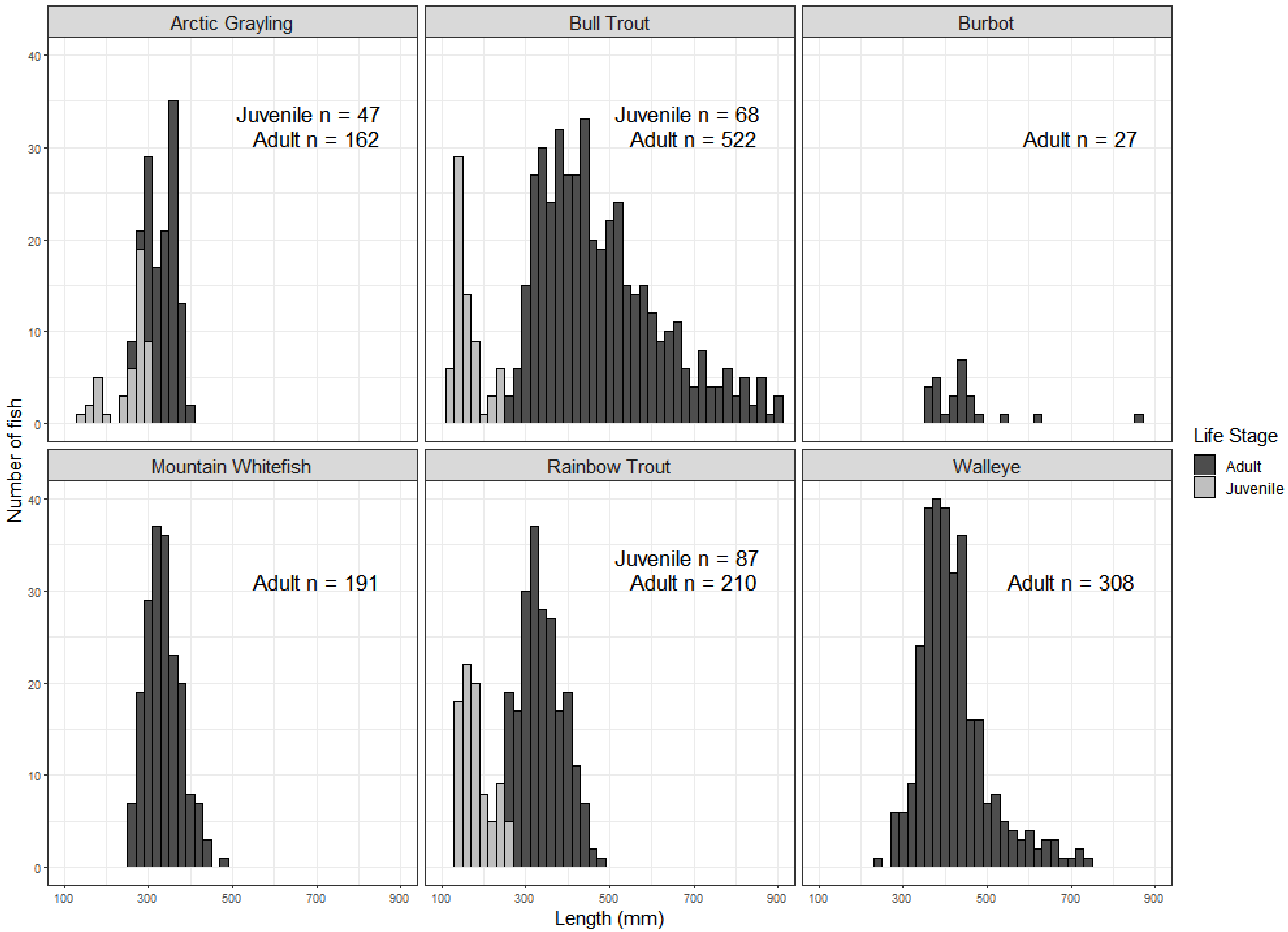

Figure 1. **Histograms of tagged study fish lengths (mm) by species (fork length for most, total length for Burbot) for all study years. Life stage, either juvenile or adult, is denoted by light and dark bars, and sample sizes are specified within each species panel.**

Table 1. Lotek Nano radio tag models are listed along with tag weight (grams in air), average burst interval[14] (seconds), expected battery life (days), and the quantities deployed since 2019, by channel.

Tag model	Tag weight (g)	Avg burst interval (secs)	Expected battery life (days)	Number Deployed 2019 Channel 3	2020 Channel 3	2021 Channel 3	2021 Channel 5	2022 Channel 5	2023 Channel 5
NTF-3-2	0.57	9.5	173	81	91				
NTF-5-2	1.50	9.5	335	12	12				
NTF-6-1	2.50	9.5	493	7	8				
NTF-6-2	4.00	9.5	931	227	168		206	204	108
NFT-6-2_3s	4.00	3.0	359	2					
NFT-6-2_5s	4.00	5.0	565			58			

Acceptable study fish in 2023 were all tagged by surgically inserting a Lotek Nano NTF-6-2 radio tag (Table 1). The maximum allowable tag burden, defined as the ratio between tag weight and the weight of the study fish, was 2.0% for all tagged fish in 2023 (WSP 2024), a standard maximum tag burden for telemetry studies (e.g., Jepsen et al. 2005, Smircich and Kelly 2014). For all 2023 tagged fish, the tag burden ranged between 0.09% and 1.64%, with a mean of 0.68%.

Prior to 2021, all of the radio tags transmitted at a radio frequency of 149.360 MHz (‘Channel 3’). Starting in 2021 and extending into 2023, transmitters of a second frequency (149.400 MHz; or ‘Channel 5’) have been deployed. The technology used by the radio tag manufacturer (Lotek Wireless[15]) to produce individually-recognizable coded tags only allows for 728 unique IDs and after surpassing that number in 2021, a second frequency was required. All study fish in 2023 were radio tagged on Channel 5, and all radio tags were the larger model (Nano NTF-6-2) to prioritize a longer expected battery life for all study fish.

Based on the manufacturer’s expected battery life estimates for each of the tag models deployed (Table 1), the number of fish that are expected to have had active tags were calculated, by date and species, and are presented in Figure 2. Radio tags were activated using a Lotek tag activator, tag operation was verified, and tag codes were validated using a Lotek model SRX800 MD-4 receiver.

Prior to surgery, tags and surgical instruments were disinfected in a 10% Super Germiphene™ solution for 10 minutes before being rinsed with distilled water[16]. Candidate study fish were sedated in an anesthetic bath containing a solution of 50 PPM clove oil and 95% ethanol. Fish were anaesthetized one at a time and closely monitored. The degree of sedation was determined by a fish’s ability to remain vertical in the anesthetic bath as well as by monitoring the gills for slow and consistent movement. Once anaesthetized, the fish was removed from the anesthetic bath, age and DNA samples were taken, the fish was then weighed, measured, PIT-tagged[17] and then placed ventral side up on a sponge-lined tray in preparation for the surgical tag insertion.

[14] Burst interval refers to the interval of time (in seconds) between radio transmissions. This number is averaged because a range is used to avoid an instance where multiple tags are synced to the same interval. For most tags, the burst interval ranged between 9.197 to 9.801 seconds.

[15] Lotek Wireless Nano Tags: https://www.lotek.com/products/freshwater-nanotag-series/

[16] All surgical instruments were sterilized in an autoclave every evening.

[17] Passive integrated transponders or PIT tag.

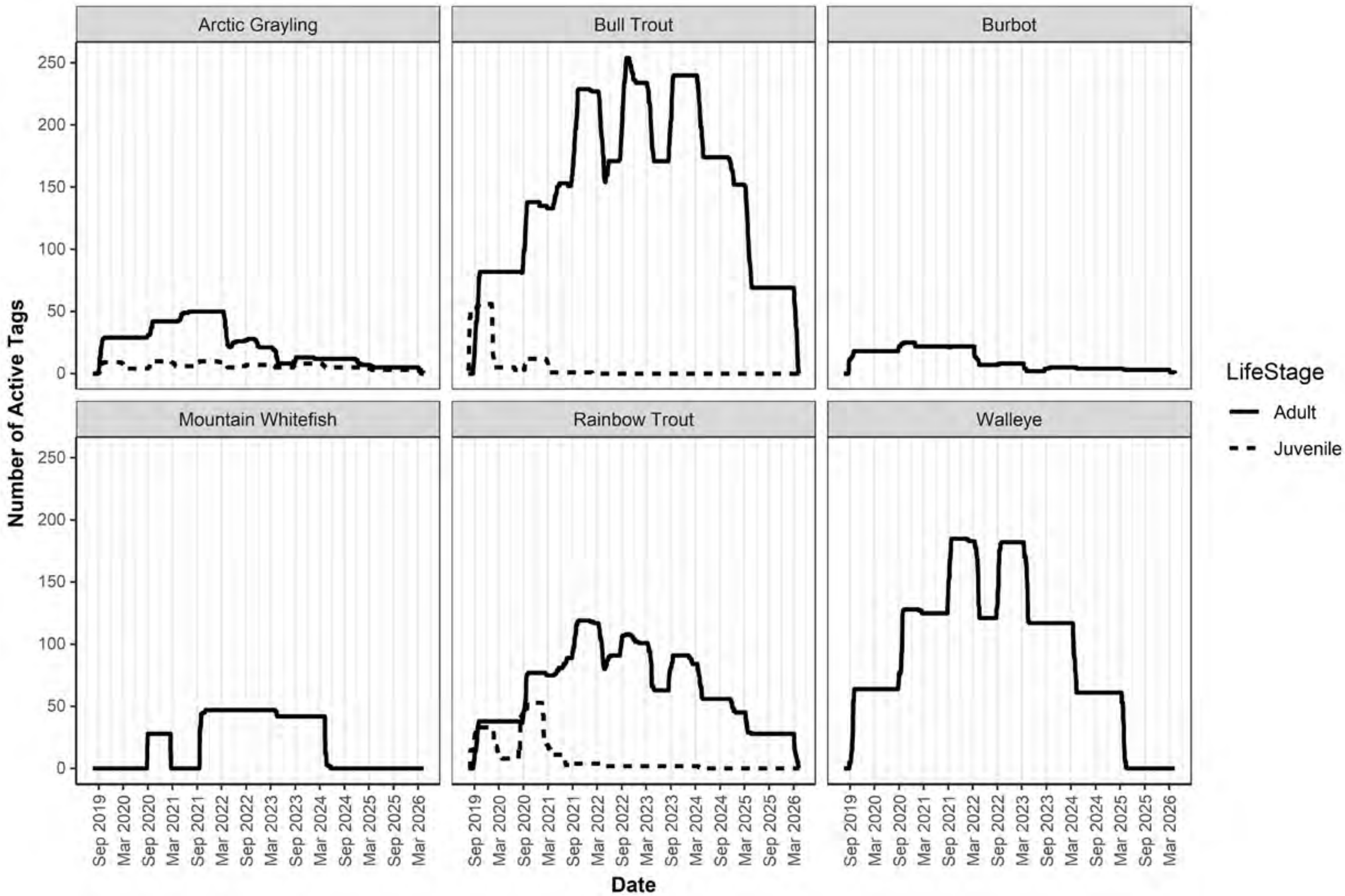

Figure 2. **Estimated numbers of active radio tags, by species and date, from 2019 onward. Values are based on the numbers of tags deployed by date, and the manufacturer's battery life estimates for each of their tag models.**

Surgical procedures followed standard methods (e.g., Liedtke and Wargo-Rub 2012). During surgery, a peristaltic pump water system was used to continuously irrigate the fish's gills with fresh river water. Using a #11 scalpel blade an incision of approximately 1.5 times the radio tag diameter was cut through the abdominal wall in a location that was anterior to the cloacal vent, slightly off the mid-line, and posterior to the liver. Using a stainless-steel cannula, the radio tag was inserted through the incision and directed along the body wall toward the fish's caudal fin. Once inserted, the tag was gently seated, with the tag's antenna protruding outside of the fish's body cavity and positioned along the mid-line of the fish. The cannula was removed, and the incision was stitched with two or three stitches[18]. In general, the handling of fish was minimized wherever possible to reduce any latent tagging effects. Following surgery, the radio-tagged fish was placed in an aerated recovery livewell for a minimum of 10 minutes of monitoring until normal swimming behaviour resumed. Once the tagged fish recovered, the fish was released near the capture location[19].

An overview map of the study area, including the fish release locations in 2023, by Peace River release sections, is displayed in Figure 3. The numbers of radio-tagged fish released each year (since 2019) are listed by species, age class, tag model, and release river/section in Table 2. Histograms showing the size distributions of study fish are displayed for each of the focal species in Figure 1. Detailed spatial distributions of fish releases are shown using a series of maps in Appendix A.

[18] Stitching was by simple surgeon 2-1-1 interrupted stitches using Ethicon Vicryl Plus 5-0 or 4-0 braid sutures depending on the size of the study fish (Ethicon Inc. Somerville, NJ, US).

[19] Fish were released at the approximate halfway point between the upstream and downstream boundaries of the sample site.

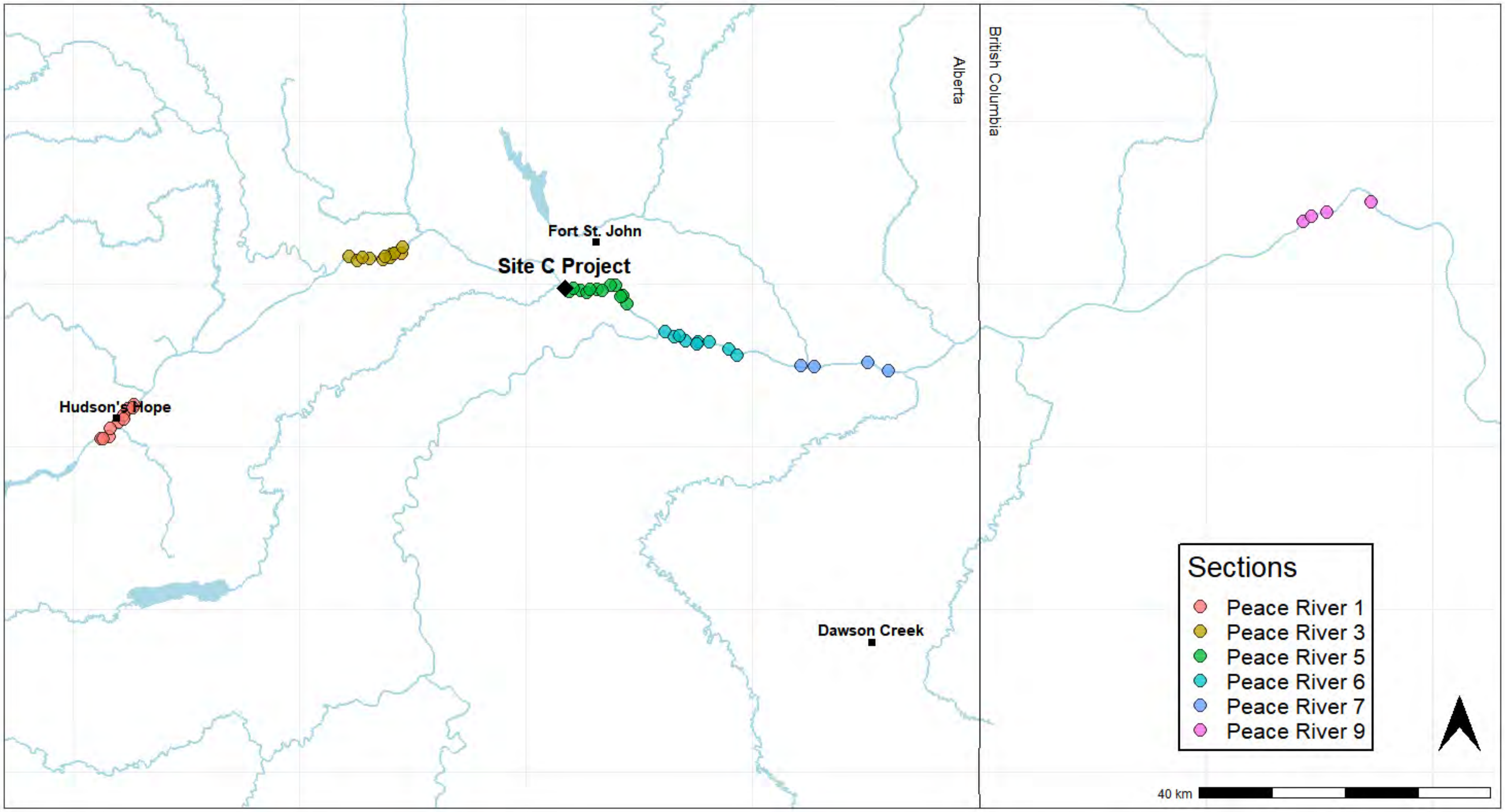

Figure 3. **Map of the Peace River study area showing release locations colored by section for study fish radio-tagged in 2023.**

Table 2. **Radio-tagged study fish from 2019 through 2023 are listed by species, age class, radio tag model, and release location. Study fish released into the Peace River were separated by section (Figure 3). In most cases, study fish released in a tributary location <1 km from the confluence of the Peace River were counted as a Peace River release for the purpose of this table. Additionally, fish released in sub-tributaries are counted under their primary tributary. For example, fish released in the Chowade River, or Cypress Creek are counted as Halfway River fish.**

Year	Species	Age Class	Tag Model	Peace River Section 1	Halfway River Boat Launch	Peace River Section 3	Upstream of Site C	Peace River Section 5	Peace River Section 6	Peace River Section 7	Peace River Section 9	Maurice Creek	Farrell Creek	Halfway River	Pine River	Beatton River	Kiskatinaw River	Total
2019	Arctic Grayling	Adult	NTF-6-2			20		4	4	1								**29**
2019	Arctic Grayling	Juvenile	NTF-6-2						3	2								**5**
2019	Arctic Grayling	Juvenile	NTF-3-2					3	1									**4**
2020	Arctic Grayling	Adult	NTF-6-2			12		1										**13**
2020	Arctic Grayling	Juvenile	NTF-6-2			1												**1**
2020	Arctic Grayling	Juvenile	NTF-6-1			1												**1**
2020	Arctic Grayling	Juvenile	NTF-3-2			2		1	1									**4**
2021	Arctic Grayling	Adult	NTF-6-2				1											**1**
2021	Arctic Grayling	Adult	NFT-6-2_5s				7											**7**
2021	Arctic Grayling	Juvenile	NTF-6-2					1		2								**3**
2021	Arctic Grayling	Juvenile	NFT-6-2_5s					1										**1**
2022	Arctic Grayling	Adult	NTF-6-2			2	5											**7**
2022	Arctic Grayling	Juvenile	NTF-6-2	1			1											**2**
2023	Arctic Grayling	Adult	NTF-6-2			1		3	1									**5**
2023	Arctic Grayling	Juvenile	NTF-6-2					3										**3**
2019	Bull Trout	Adult	NTF-6-2	25		25		13	10	4	1							**78**
2019	Bull Trout	Adult	NFT-6-2_3s	1														**1**
2019	Bull Trout	Adult	NTF-6-1	2					1									**3**
2019	Bull Trout	Juvenile	NTF-5-2					1	2					2				**5**
2019	Bull Trout	Juvenile	NTF-3-2											51				**51**
2020	Bull Trout	Adult	NTF-6-2	12		17		11	6	1	4							**51**
2020	Bull Trout	Adult	NTF-6-1	1				1										**2**
2020	Bull Trout	Adult	NTF-5-2			2												**2**
2020	Bull Trout	Adult	NTF-3-2	2														**2**
2020	Bull Trout	Juvenile	NTF-6-1						1									**1**
2020	Bull Trout	Juvenile	NTF-3-2	4		1		3	2		1							**11**
2021	Bull Trout	Adult	NFT-6-2	12		21	1	17	7	5	1				1		1	**66**
2021	Bull Trout	Adult	NFT-6-2_5s	2	17	5	6	1	1									**32**
2022	Bull Trout	Adult	NFT-6-2	15	18	27	5	16	11	10	3							**105**
2023	Bull Trout	Adult	NFT-6-2	12		25		13	11	5	3							**69**
2019	Burbot	Adult	NTF-6-2			1		1		5	8							**15**
2019	Burbot	Adult	NTF-6-1						3									**3**
2020	Burbot	Adult	NTF-6-2					2		2	2							**6**
2020	Burbot	Adult	NTF-5-2	1														**1**
2021	Burbot	Adult	NFT-6-2														1	**1**
2022	Burbot	Adult	NFT-6-2								1							**1**
2023	Burbot	Adult	NFT-6-2					1		1	1							**3**
2020	Mountain Whitefish	Adult	NTF-3-2					19	5	4								**28**
2021	Mountain Whitefish	Adult	NFT-6-2				3	23	14						2			**42**
2021	Mountain Whitefish	Adult	NFT-6-2_5s				4	1										**5**
2019	Rainbow Trout	Adult	NTF-6-2	17		15		5										**37**
2019	Rainbow Trout	Adult	NFT-6-2_3s	1														**1**
2019	Rainbow Trout	Juvenile	NTF-6-2			2												**2**
2019	Rainbow Trout	Juvenile	NTF-5-2	2		1		1	2									**6**
2019	Rainbow Trout	Juvenile	NTF-3-2	7		2				1			15					**25**
2020	Rainbow Trout	Adult	NTF-6-2	19		16		1										**36**
2020	Rainbow Trout	Adult	NTF-6-1	1				1										**2**
2020	Rainbow Trout	Adult	NTF-3-2	2														**2**
2020	Rainbow Trout	Juvenile	NTF-5-2			1						7	1					**9**
2020	Rainbow Trout	Juvenile	NTF-3-2	9		1			1	1		20	10					**42**
2021	Rainbow Trout	Adult	NFT-6-2	14		8	7	4		1							1	**35**
2021	Rainbow Trout	Juvenile	NFT-6-2	1		1												**2**
2021	Rainbow Trout	Adult	NFT-6-2_5s			1	8											**9**
2022	Rainbow Trout	Adult	NFT-6-2	9		5	11	3										**28**
2023	Rainbow Trout	Adult	NFT-6-2	11		11		6										**28**
2019	Walleye	Adult	NTF-6-2			2		1	11	48								**62**
2019	Walleye	Adult	NTF-6-1					1										**1**
2019	Walleye	Adult	NTF-5-2							1								**1**
2020	Walleye	Adult	NTF-6-2	2		13		8	11	17	10							**61**
2020	Walleye	Adult	NTF-6-1						1		1							**2**
2020	Walleye	Adult	NTF-3-2					2										**2**
2021	Walleye	Adult	NFT-6-2					3	18	17					5	12	1	**56**
2021	Walleye	Adult	NFT-6-2_5s					1	1							2		**4**
2022	Walleye	Adult	NFT-6-2						29	31	1							**61**
Total				**185**	**35**	**242**	**59**	**177**	**158**	**159**	**37**	**27**	**26**	**53**	**8**	**14**	**4**	**1184**

Fixed-Station Telemetry

Radio telemetry fixed-stations were comprised of four basic components: the radio receiving equipment, power system, housing, and remote connectivity equipment. Radio receiving equipment was comprised of 3-element YAGI antennas that receive radio signals, which then pass through a coaxial cable to a Lotek model ASP-8 switcher, and into a model SRX800 or SRX1200 (hereafter SRX) receiver for coding and storage (Figure 4). At most sites, two antennas were deployed (Table 3) with one oriented upstream and the other downstream.

The power system provided continuous energy to the station through two 80-watt solar panels wired to a 10-amp solar controller that maintained two 100 amp-hour deep cycle AGM batteries (Figure 4). The batteries were then connected to the SRX receiver. When the angle of the sun and the hours of daylight were adequate (i.e., generally from April to October), the solar setup provided renewable energy to the receiver. During the remainder of the year, the receiver ran primarily off the two deep cycle batteries which required a battery swap approximately every three weeks during routine maintenance. The solar panels were installed onto

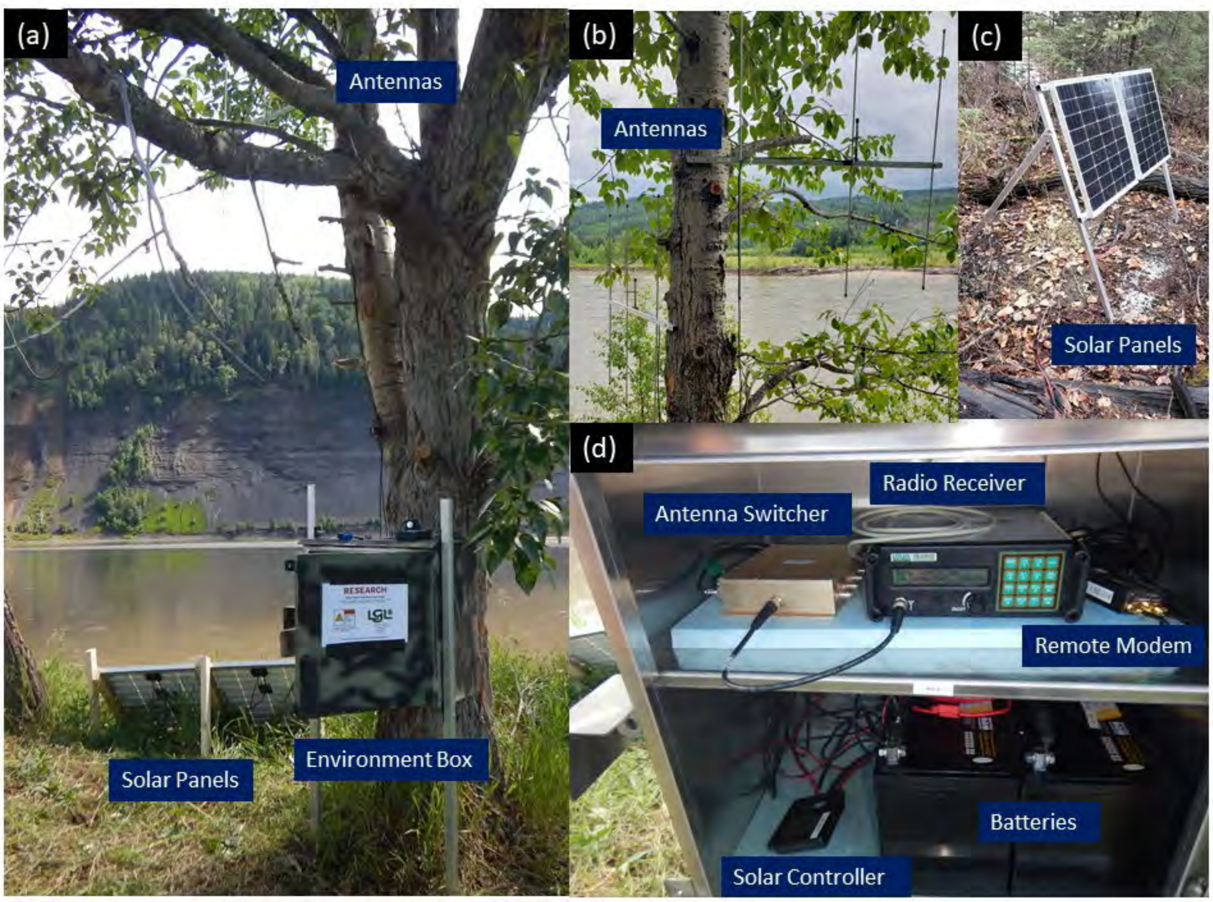

Figure 4. Example of a fixed radio telemetry station. (a) View of the antennas, environment box, and solar panels. (b) Two 3-element YAGI antennas are mounted to a tree. (c) Two 80-watt solar panels mounted to an aluminum stand for deployment during the winter months. (d) View of the inside of an environment box showing the Lotek SRX800 receiver, ASP-8 switcher, LTE remote modem, solar controller, and AGM deep cycle batteries.

either a ground-mounted wood/aluminum stand or mounted onto a tree depending on the solar exposure and logistics of the station location (Figure 4).

The telemetry station electronics were housed in a custom fabricated aluminum environment box that was sealed and locked during the study period (Figure 4). Station locations that had a sufficient cellular signal were wired to a 4G LTE modem that allowed remote data downloads, receiver maintenance, and power observation (Figure 4).

In most circumstances the environment box was lag-bolted to a large tree with the receiver antennas mounted to the same tree approximately 2 to 4 m above the box (Figure 4). In cases where a suitable tree was not available, a stand was constructed for the environment box with the antennas mounted on a mast that was supported by an aluminum tripod (Table 3).

The angle between two antennas was specific to each site but 120° was the standard. Antennas installed at angles greater than 120° risked collecting 'reverse detections' from the non-intended read direction (e.g., upstream antenna reading downstream detections from the backside of the antenna), while an angle less than 120° risked overlapping detection zones and could decrease a fixed-station's detection range.

Stations were programmed to scan two frequencies over each individual antenna. The receivers scanned one channel for 10 seconds per antenna, flip to the other channel for 10 seconds per antenna, and then flip back to repeat the cycle.

Temporal and Spatial Extent of the Array

The spatial extent of the array was designed to encompass the Local Assessment Area (LAA) (Figure 5), from Peace Canyon Dam (river km [RKM][20] 20) to Many Islands, Alberta (RKM 231). Between these locations, stations were located at the entrance of every major tributary with one Peace River station located approximately halfway between each tributary entrance (Table 3, Figure 5). Deviations from this general format included detection gates[21] created at Peace River #1A/Peace River #1B and Kiskatinaw River/Peace River #3. Detection gates were created to increase detection probability through these corridors. Deploying stations on the left and right banks at Many Islands (Peace River #1A/Peace River #1B), for example, should help determine if a radio-tagged study fish has left the LAA. Furthermore, seven fixed-stations were installed within the Moberly River and Halfway River drainage systems (referenced as 'Tributary Upstream' in Table 3 and Figure 5) along with three fixed-stations installed in the 108R Offset Side Channel (referenced as 'Side Channel' in Table 3 and Figure 5).

In 2023, 34 fixed radio telemetry stations were deployed and maintained by LGL Limited in the same locations as the fixed-stations operated in 2022. Four stations located at lower elevations in the future Site C Reservoir (i.e., Peace River 6-8 and Cache Creek) were demobilized early in June 2023 to prepare for reservoir filling[22] (Table 3). Like 2022, three stations were operated within the 108R Side Channel located downstream of the Project for the Site C Offset Effectiveness Monitoring Program[23] (Figure 6). In addition to the 34 LGL receivers, there were twelve fixed-stations operated as part of Mon-13 (Site C Fishway Effectiveness Monitoring Program), whose maintenance was managed by InStream Fisheries Research.

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[20] RKM or river kilometres in the Peace River are calculated as the distance (in kilometres) from the tailrace of WAC Bennet Dam.

[21] A detection gate is comprised of two receivers, one placed on either riverbank, to increase detection probability.

[22] The Site C reservoir was not filled in 2023 and was postponed to 2024. Therefore, these stations were redeployed for the 2024 field season.

[23] Refer to Whelan et al. (2023) for more information on the Site C Offset Effectiveness Monitoring Program.

Table 3. Station names, types, numbers, installation and demobilization dates, and status (as of January 2024). Twelve stations, deployed or maintained as part of Mon-13 (Site C Fishway Effectiveness Monitoring Program), are named with a prefix "INS". *Red* demobilization dates refer to stations left operating with a low-voltage cut-off, where the date value is when the station went dormant for the off-season.

Station Name	Access	Station Type	Station #	Installation Date	Demobilization Date	Modem	Operation	Antenna Count / Location
Peace River 1A	Boat	Peace River	1	12 Jul 2023	5 Nov 2023	No	Seasonal	2 / tree
Peace River 1B	Boat	Peace River	2	16 Apr 2023	5 Nov 2023	No	Seasonal	2 / tree
Peace River 2	Boat	Peace River	3	16 Apr 2023	*5 Nov 2023*	No	Seasonal	2 / tree
Pouce Coupe River	Boat	Tributary Entrance	4	16 Apr 2023	5 Nov 2023	No	Seasonal	2 / tree
Peace River 3	Boat	Peace River	5	16 Apr 2023	6 Nov 2023	No	Seasonal	2 / tree
Kiskatinaw River	Boat	Tributary Entrance	6	16 Apr 2023	6 Nov 2023	No	Seasonal	2 / tree
Beatton River	Boat	Tributary Entrance	7	17 Apr 2023	*6 Nov 2023*	No	Seasonal	2 / tree
Peace River 4	Truck	Peace River	8	28 Jan 2023	*7 Nov 2023*	No	Seasonal	2 / tripod
Pine River	Boat	Tributary Entrance	9	17 Apr 2023	*6 Nov 2023*	No	Seasonal	2 / tree
Peace River 5	Boat	Peace River	10	17 Apr 2023	6 Nov 2023	No	Seasonal	2 / tree
Site C Dam	Truck	Peace River	11	11 Jul 2019	-	Yes	Perennial	2 / tree
South Side Channel	Boat	Side Channel	52	7 Apr 2023	*20 Oct 2023*	Yes	Seasonal	2 / tree
East Side Channel	Boat	Side Channel	51	7 Apr 2023	7 Nov 2023	Yes	Seasonal	2 / tree
West Side Channel	Boat	Side Channel	50	15 Apr 2023	7 Nov 2023	Yes	Seasonal	2 / tree
INS Mainstem 2	Truck	Peace River	33	1 Aug 2020	-	-	Perennial	2
INS Approach Zone A	Truck	Peace River	34	2 Aug 2020	-	-	Perennial	1
INS Approach Zone B	Truck	Peace River	35	3 Aug 2020	-	-	Perennial	1
INS Cofferdam	Truck	Peace River	36	3 Aug 2020	-	-	Perennial	2
INS Diversion Tunnel	Boat	Peace River	37	4 Apr 2021	-	-	Perennial	2 / tree
INS Entrance Aerial	Truck	Peace River	38	15 Sep 2020	-	-	Perennial	1
INS Entrance Dipole	Boat	Peace River	39	29 Mar 2023	6 Nov 2023	-	Seasonal	2 / tree
INS Entrance Pool Dipole	Boat	Peace River	40	29 Mar 2023	6 Nov 2023	-	Seasonal	2 / tree
INS Turning Basin	Boat	Peace River	41	29 Mar 2023	6 Nov 2023	-	Seasonal	2 / tripod
INS Cell 8	Boat	Peace River	42	29 Mar 2023	6 Nov 2023	-	Seasonal	2
INS Vee-Trap	Boat	Peace River	43	29 Mar 2023	6 Nov 2023	-	Seasonal	1
INS Diversion Tunnel Inlet	Boat	Peace River	46	28 Mar 2021	-	-	Perennial	1
Moberly River 1	Truck	Tributary Entrance	12	11 Jul 2019	5 Jun 2023	Yes	Perennial	2 / tree
Moberly River 2	Helicopter	Tributary Upstream	13	4 Mar 2023	30 Sep 2023	No	Seasonal	2 / tree
Moberly River 3	Helicopter	Tributary Upstream	14	4 Mar 2023	30 Sep 2023	No	Seasonal	2 / tree
Moberly Lake	Truck	Tributary Upstream	47	2 Mar 2023	4 Nov 2023	Yes	Seasonal	2 / tree
Peace River 6	Truck	Peace River	15	28 Jan 2023	6 Jun 2023	Yes	Seasonal	2 / tree
Peace River 7	Truck	Peace River	16	18 Apr 2023	2 Oct 2023	Yes	Seasonal	2 / tree
Cache Creek	Truck	Tributary Entrance	17	3 Mar 2023	11 Jun 2023	No	Seasonal	2 / tree
Peace River 8	Truck	Peace River	18	9 Mar 2023	6 Jun 2023	Yes	Seasonal	2 / tripod
Halfway River 1	Truck	Tributary Entrance	19	8 Jul 2019	-	Yes	Perennial	2 / tree
Halfway River 2	Helicopter	Tributary Upstream	20	4 Mar 2023	8 Nov 2023	No	Seasonal	2 / tree
Halfway River 3	Helicopter	Tributary Upstream	21	4 Mar 2023	8 Nov 2023	No	Seasonal	2 / tree
Chowade River	Truck	Tributary Upstream	29	25 Jul 2023	1 Oct 2023	No	Seasonal	2 / tree
Cypress Creek	Truck	Tributary Upstream	30	22 Jul 2023	1 Oct 2023	No	Seasonal	2 / tree
Peace River 9	Truck	Peace River	22	7 Mar 2023	*4 Nov 2023*	Yes	Seasonal	2 / tree
Farrell Creek	Truck	Tributary Entrance	44	7 Mar 2023	4 Nov 2023	Yes	Seasonal	2 / tree
Peace River 10	Truck	Peace River	24	7 Mar 2023	1 Oct 2023	Yes	Seasonal	2 / tree
Lynx Creek	Truck	Tributary Entrance	25	19 Apr 2023	1 Oct 2023	No	Seasonal	2 / tree
Peace River 11	Truck	Peace River	26	5 Mar 2023	*4 Nov 2023*	Yes	Seasonal	2 / tree
Maurice Creek	Truck	Tributary Entrance	31	5 Mar 2023	1 Oct 2023	Yes	Seasonal	2 / tree
Peace Canyon Dam	Truck	Peace River	45	7 Mar 2023	4 Nov 2023	Yes	Seasonal	2 / tree

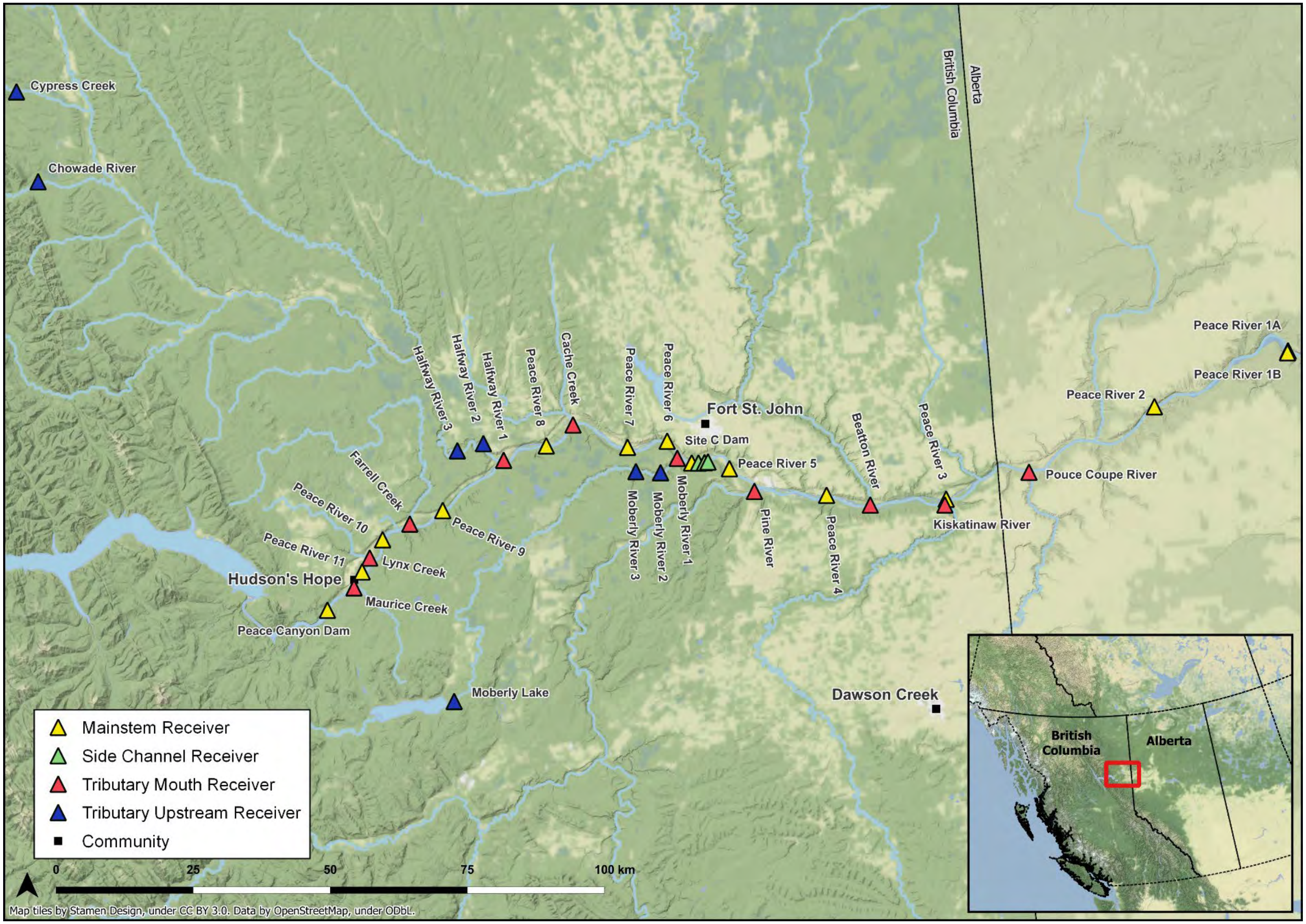

Figure 5. **Locations of the 34 fixed radio telemetry stations operated for the Site C Fish Movement Assessment in 2023. Twelve additional stations that are not shown on this map were deployed or maintained by InStream Fisheries Research as part of Mon-13 (Site C Fishway Effectiveness Monitoring Program, see Figure 6). 'Side Channel Receiver' refers to three receivers that are operated in the 108R Side Channel downstream of Site C.**

Figure 6. **Locations of the three 108R Side Channel receivers deployed in 2023 (yellow triangles). Blue triangles denote the stations installed at Site C Dam. Refer to Whelan et al. (2023) for more information on the Site C Offset Effectiveness Monitoring Program.**

The temporal extent of the array spanned from 3 March to 7 November 2023 for the seasonally operated fixed-stations; with the remaining fixed-stations staying active and operated perennially (Table 3). Redeployment timing of the seasonal fixed-stations varied by site and was dependent on access (e.g., the install of the Chowade River and Cypress Creek stations can be delayed due to snow limited access; Table 3). In 2023, seven stations were left operating past demobilization with a low voltage cut-off (Table 3). During the reduced solar conditions in winter, the setup was designed to disconnect from the system load (SRX and modem) after falling below a threshold voltage (11.1 V) and remain dormant until conditions improved in February or March to repower and reconnect the system at 12.2 V.

Testing

The power system, radio equipment, and remote connection systems were all tested for basic functionality upon deployment. The radio equipment was tested to ensure tag signals were being coded at expected ranges and the antenna angles were correctly oriented. Power systems were tested for capacity and confirmation of power generation. Lastly, each station equipped with a cellular modem was tested by logging on from an off-site computer to confirm remote accessibility.

Beyond basic functionality testing, range testing was conducted for 28 of the 34 fixed-stations operated in 2023. The most common range testing approach was a series of upstream to downstream 'tag drag' drifts from a jet boat. To begin a range test drift, the jet boat was positioned approximately 800 m upstream of the fixed-station, active test tags were deployed, and the boat was powered down to allow a drift with the flow of the river. Each range test drift ended approximately 800 m downstream of the fixed-station, after which, these procedures were repeated. Test tags were programmed to transmit more frequently (every 3 seconds) and deployed at a depth of 1 m for all tests. During each test, the boat had an onboard GPS unit set to high-frequency tracking, which continuously collected spatial and temporal data points as the boat and test tags drifted through the detection area. Other range testing approaches used the same base methodology but without the jet boat and either tracked by foot or a radio-controlled boat in shallow environments.

GPS tracking data were run through GIS scripts to calculate, from moment to moment, the distance of the test tags from the antennas in question. The GPS data were then temporally correlated to detection records and grouped into 50 m bins for analysis and plotting. Detection probabilities were calculated within each 50 m bin as the quotient of the observed quantity of detections divided by the expected quantity. It was necessary to use proportions of expected quantities, rather than success/failure for every individual transmission, because channel and antenna switching receiver functions often meant that not all transmissions were expected to be detected. For each station, the detection probabilities were plotted against the distance from the receiver and fit with a logistic regression curve to graphically display detection range. The fitted logistic equation parameters were used to calculate the distances in which detection probability was at a certain level (e.g., 50%). As is standard practice in acoustic and radio telemetry studies, the distance at 50% detection probability and the steepness of the curve were used to interpret the detection range for each station (Kessel et al. 2014).

Range test data were also used to create detection probability maps for each receiver station. Track data for each range test were split into 30 s periods, and the test tag's location at the temporal midpoint of the period was determined. The observed proportion of detections during the period was calculated as the ratio of the number of detections recorded to the expected quantity. The expected quantity of detections for each tag in each 30 s period was determined based on the tag's pulse rate and the receiver's configuration (i.e., accounting for antenna and channel switching). Kriging was used to interpolate the observed proportion of detections over the area covered by the range test. The proportion of detections were logit transformed prior to fitting. For intervals where the proportion of observed detections was equal to 0 or 1, values were fixed at 0.001 and 0.999 respectively, restricting the transformed data to logit values between -6.9 and 6.9. Variograms for each receiver were fit in R (R Core Team 2023) using autoKrige in the automap package (Hiemstra et al. 2009), which automatically selects the best fit from several variogram models given the data. Predicted rasters were then back-transformed to the probability scale for plotting.

Download and Maintenance

Standard fixed-station maintenance required a monthly on-site visit in which the data were downloaded, notes were recorded about functionality, and the equipment was inspected for damage and/or malfunction. Data were downloaded using SRX800/SRX1200 Host software on a field laptop before being uploaded to the cloud (done later when a Wi-Fi connection was re-established). Field logs were maintained throughout the field season, and key indicators of the systems operational performance were recorded. These indicators included: current voltage, remaining percent battery capacity, solar amp hours collected, and remaining data storage.

Table 4. Fixed-station deployment, maintenance, and demobilization field schedule in 2023.

Start Date	End Date	Work Completed
overwinter	28 February 2023	Winter Maintenance
1 March 2023	10 March 2023	Station Installations 1
14 April 2023	21 April 2023	Station Installations 2
3 June 2023	12 June 2023	Download/Testing/Maintenance 1
10 July 2023	18 July 2023	Download/Testing/Maintenance 2
20 August 2023	25 August 2023	Download/Testing/Maintenance 3
26 September 2023	3 October 2023	Download/Testing/Maintenance 4
3 November 2023	10 November 2023	Station Demobilization 1
11 November 2023	overwinter	Winter Maintenance

There are three situations in which a station needs remote or physical maintenance: equipment malfunction, loss of power, or a full memory bank. The receivers normally record an internal battery voltage check hourly, and a conspicuous loss of these checks from the data would be an indication that the fixed-station was not functional. Moreover, the beacon tag detection records (should be detected six times in the first minute of each hour when scanning one frequency) could be used to evaluate whether the fixed-station was properly scanning and to assess antenna and wiring integrity. The timing when battery check records stopped, or when a beacon tag was no longer being recorded, was used to identify when an outage began. To guarantee that every fixed station was operating and collecting data as expected, field visits occurred cyclically every four to six weeks (Table 4).

Mobile Telemetry

Mobile tracking (Table 5, Appendix D) was employed to expand on the detection coverage provided by the fixed-station array and to meet the core objectives of the Peace River Arctic Grayling and Bull Trout Movement Assessment (Mon-1b, Task 2a). In 2023, mobile surveys were designed to track Bull Trout in the Halfway River watershed in September to identify potential spawning locations and describe the timing of movement immediately prior to and following spawning. The approach was to conduct two multi-day flight surveys[24] centered around peak Bull Trout spawning as per the guidance of the Peace River Bull Trout Spawning Assessment (Mon-1b, Task 2b). Two surveys of the Halfway River and its upper tributaries were conducted in September taking three overflights to complete (Table 5; Appendix D, Figure D1). Mobile surveys were also conducted opportunistically on a variety of dates throughout 2023 (Table 5), either by helicopter in the Moberly River, or by boat in the Peace River mainstem.

Bull Trout mobile tracking flights were conducted by fixed wing aircraft (Table 5). Fixed wing flight speeds and altitude remained consistent across surveys at 100-160 km/h and 150-215 m above the river. A two-element Yagi antenna was mounted on each wing of the aircraft. Shielded coaxial cable (RG-58) was used to connect the antennas to two SRX800-MD receivers in the cabin, where each receiver scanned only one of the two transmitter frequencies (i.e., 149.360 or 149.400 MHz). Specifically, the signal from the port and starboard antennas were merged and the combined feed was split and fed into each of the receivers. A GPS signal was fed directly into the SRX800 receivers (producing georeferenced detection data), and a handheld GPS unit was

[24] Two or more days of flying can sometimes be required to completely cover the areas of interest.

Table 5. Mobile tracking survey dates, locations tracked, and vessels used in 2023.

Date	Task / Areas Covered	Vessel
18 April 2023	Moberly River, adhoc tracking	Helicopter
10 June 2023	Peace River Mainstem, adhoc tracking	Boat
12-13 July 2023	Peace River Mainstem, adhoc tracking	Boat
7 September 2023	Bull Trout tracking in the Halfway, Survey 1, Day 1	Fixed-wing
8 September 2023	Bull Trout tracking in the Halfway, Survey 1, Day 2	Fixed-wing
17 September 2023	Bull Trout tracking in the Halfway, Survey 2	Fixed-wing
27-29 September 2023	Peace River Mainstem, adhoc tracking	Boat
5 November 2023	Peace River Mainstem, adhoc tracking	Boat

run to store a complete track of the survey route. Receiver clocks were synchronized with the GPS units prior to each flight. The approximate position and identity of each detected radio tag (tagged fish) was recorded manually on a datasheet by the field crew, as a backup to the electronic systems. Prior to the first survey, a test tag was used to qualitatively confirm detection range at altitude, and test receiver gain settings.

The SRX800 receivers and GPS units were downloaded after each day, and the data were sent electronically to the office staff for processing. Detections from each day were filtered to remove noise, and erroneous detections from codes that were not associated with active tags. Then, the highest-powered detection of each unique tag was selected, and the timestamp and geographic coordinates of that detection were used to represent that fish's location during the time of the flight survey. Thus, at the end of each flight, each unique tag appeared once in the resulting datafile, on a line containing its ID (frequency, code, species), a timestamp, latitude, longitude, and power reading associated with the highest power detection event, as well as the number of times it was detected during the flight.

The georeferenced data were processed using a Python script in ArcGIS that assigned each detection to a 'mobile tracking zone' (Figure 7) and outputted the name of the river/creek in which the detection was located, and a RKM reading. RKM readings were specific to each river or creek in the study area and were a measure of the distance of the detection location from the river's mouth or confluence to the next order stream (e.g., a detection recorded in the Halfway River at a location 25 RKM its confluence with the Peace River was given a value of 25 RKM). The exception being RKM readings in the Peace River, which were defined as the distance downstream from WAC Bennett Dam (RKM 0). Lastly, the post-processed data were uploaded into the Site C Fish Movement Assessment Database and were processed further (see proceeding section) using R (R Core Team 2023) and Telemetry Manager (English et al. 2012).

When processing mobile telemetry data in general, we did not assume that detections within 0.5 km of the mouth of a tributary were committed to continuing upstream. This is because many of these detections could theoretically be of fish that are actually in the Peace River mainstem yet appear to be within a tributary as a result of the position of the aircraft, the timing of tag transmissions relative to the motion of the aircraft, or, to a lesser extent, the sampling error of the GPS device (which typically had better than 50 m accuracy). As such, the mobile-tracking zones (Figure 7) associated with tributary areas were set to start 0.5 km from their junction with the larger river to which they join.

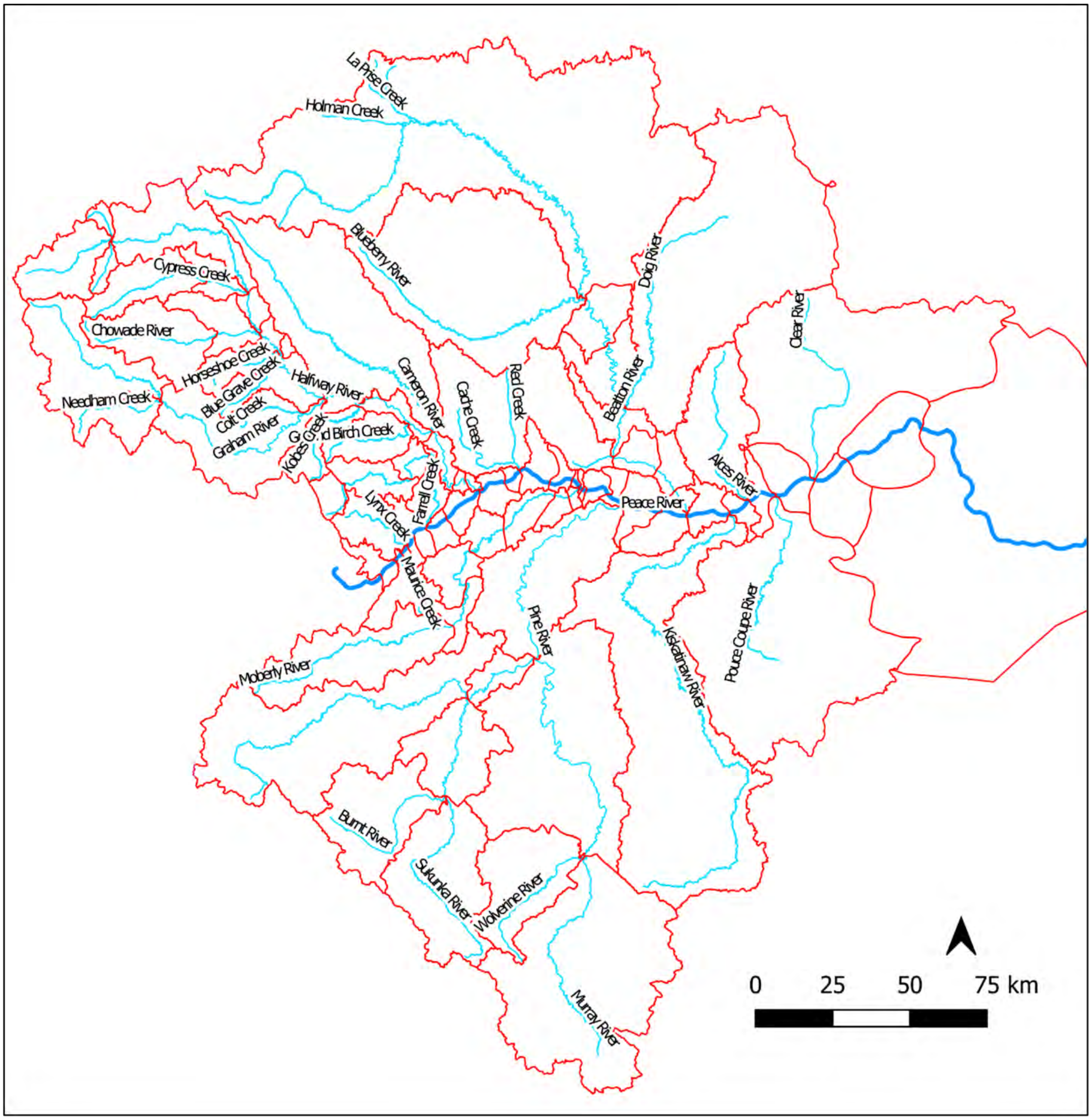

Figure 7. Mobile tracking zones (polygons with red borders) overlain on the Peace River (dark bold blue) and its major tributaries (lighter blue). Zones were defined by watershed boundaries, and the positions of the fixed-station receivers.

Data Management and Processing

The downloaded data files and the post-processed mobile-tracking data files were stored and compiled for inclusion into the Site C Fish Movement Assessment Database. The Site C Fish Movement Assessment Database is a SQL-Server relational database comprised of multiple data tables stored on a local network. Data are retrieved and queried using Microsoft Access (or R, if preferred) as the front-end to the database. All data tables are carefully keyed and organized for easy and comprehensive querying. A visual representation of the database, displaying how each of the tables relate to each other, is provided in Figure C1 (in Appendix C). Table C1 describes each table with text.

A system is in place to accept data requests from other contractors and record the request information into the SQL Server database. To date, there have been 20 requests for data from the Site C Fish Movement Assessment Database; all of which have been fulfilled, and those from 2023 are summarized in Table C2. Metadata about each request include: the request date, fulfillment date, organization name, fulfiller name, requesters name, and requesters contact information (Table C2). Other than formal requests, though, the data have been processed and analyzed by LGL staff both in-season, in response to requests from BC Hydro, and as part of the annual reporting tasks.

Data processing begins with the validation of individual detection records. The SRX800 and SRX1200 models are particularly sensitive radio receivers which benefit from boosted detection ranges at the cost of additional noise and false-positive detections. A false-positive detection occurs when a receiver codes a signal and incorrectly assigns it to a fish from which it did not originate. The filtering process developed for the Site C Fish Movement Assessment includes five steps:

- Removal of duplicate records[25];
- Removal of records that do not match the list of released tag codes and frequencies.
- Removal of detections that *do* match the list of released tag codes, but which occurred prior to the release of the fish or after its removal;
- Pulse rate filtration;
- Detection frequency filtration; and
- Examination of individual detection histories.

Since the Lotek NanoTags were programmed to transmit at a certain pulse rate (e.g., one transmission every 9.8 seconds), we were able to use the expected timing of transmissions to filter out detections that were recorded outside of the expected cycle, an approach used more commonly in acoustic telemetry or JSATS[26] (Beeman and Perry 2012). For example, two detections separated by 5 seconds would be rejected if the tag had a pulse rate of 9.8 seconds. Following this, we applied a detection frequency filter that rejected any detection if it was not part of a set of three or more within a ten-minute window. Random noise events that lead to false-positive detections are more likely to occur as singular events (or events separated by more than 10 minutes), or with timing other than that of the manufacturer's programmed pulse rate.

Another validation step was an examination of detection histories for each individual study fish to locate any 'red-flag' patterns. These patterns can include detection sequences in which a study fish moves between geographically distinct fixed-stations (i.e., >100 m) in a matter of seconds or in situations where a study fish may have avoid detection by too many fixed-stations along a supposed movement route.

[25] Duplicate records occur when a fixed-station's databanks are not cleared after downloading. The next subsequent download will include newly collected detections as well as the detections recorded from the previous cycle(s).

[26] Juvenile Salmon Acoustic Telemetry System, or JSATS, is a high frequency acoustic telemetry approach that can create large quantities of noise and false-positive detection data.

Data Analysis

Specific analytical methods follow in the subsequent sections. In all cases in which statistical analyses occurred, including the calculation of 95% confidence bounds, we assumed an alpha level of 0.05 (Zar 1984).

Detection Efficiency

Detection efficiency is defined as the proportion of study fish detected while passing a fixed-station. This is different from detection probability which is defined as the probability of detecting a radio tag's transmission at a particular distance from an antenna. Detection efficiency is a *post-hoc* metric derived from actual study fish's movements while detection probability is generated during range testing with test tags. Where applicable, both metrics were used in conjunction to evaluate a fixed-station's effectiveness at detecting radio-tagged study fish (Adams et al. 2012, Kessel et al. 2014).

Detection efficiency analyses were conducted for all fixed-stations and separated by movement direction (i.e., upstream or downstream) that had at least one complete and known passage event (i.e., a valid detection upstream and downstream of the analyzed fixed-station). The metric was calculated by dividing the quantity of study fish detected during fixed-station passage by the total quantity of study fish known to have passed that fixed-station. The total quantity of study fish that passed a fixed-station was defined as the count of fish whose sequential detection history showed movement in the direction of interest and detections both upstream and downstream of the analyzed fixed-station. Asymptotic 95% confidence intervals were calculated using the binomial error distribution (Zar 1984).

Spans in which a fixed-station outage was known to have occurred were not included in the detection efficiency analysis. The underlying goal was to estimate the proportion of study fish detected while a fixed-station was actively collecting data.

Detection efficiencies were also calculated *post-hoc* for Halfway River (Bull Trout) mobile tracking efforts (Appendix D, Figure D1). This analysis was updated from iterations in previous study years to focus only on detections that occurred within the Chowade River and Cypress Creek. During the Bull Trout spawning season, there are PIT and fixed-station radio arrays operated on Chowade and Cypress; as such, detections on these arrays were used to identify study fish that were present in these tributaries during the spawning season. The resulting detection efficiency was calculated as a proportion of the possible detection events that were actually detected while mobile tracking over Chowade and Cypress. The objective of this detection efficiency analysis is to be used as a tool for evaluating and interpreting the efficacy of the Halfway River mobile surveys in 2023. This calculation assumes that a possible detection event is in fact possible, and the study fish has not shed (or expelled) the radio tag, nor has the radio tag ceased transmitting (either due to battery failure or excessive damage to the tag antenna).

Magnitude, Seasonality and Direction

The detection data (both mobile and fixed-station) were georeferenced and then processed using a Python script in ArcGIS that assigned each detection to a river kilometer (RKM). Next, the detection data were reorganized into a movement-focused format in which each data row represented a recorded movement, such that the change in time and distance moved between each successive detection could be calculated for each individual study fish. For each movement, the direction was defined by whether it was oriented as upstream or downstream.

One of the core objectives of the Site C Fish Movement Assessment (Mon-1b, Task 2d) is to conduct large scale, region-wide analyses of the telemetry data to determine the magnitude, direction, and seasonal variability of fish movements in the Peace River and its tributaries. To address this objective, figures were produced for each study species that display average monthly movement distances, as well as figures that show monthly tributary entrance and exit behaviours.

Movement distances (in RKM) were categorized, averaged, and then plotted with 95% confidence intervals (Zar 1984)[27]. Mean movement distances were categorized by species, river, direction, and month. Data collected from 2019 through 2023 were included in this analysis to create a region-wide representation of fish movements designed to grow with each successive data collection season until the establishment of the Site C Reservoir. Movements in the Peace River were analyzed and displayed for all six indicator species[28], while movements specific to Peace River tributaries were analysed for Bull Trout, and Arctic Grayling, in the Halfway River, and Moberly River respectively. The tributaries and respective species analyzed were based on known or expected behaviours in those tributaries (i.e., spawning) as well as the availability of detection data from mobile tracking efforts and/or upstream tributary fixed-stations.

For month-scale analyses of movement, each observed displacement event was assigned to a month based on the halfway-point between the timestamps of the two start and end detection events. Since the accuracy of this method declines as the duration between the two detection events increases, a threshold of <45 days between detection events was used to filter movements and hence restrict analysis.

Seasonal fish movements were further explored by analyzing monthly tributary entrance and exit behaviours. Ten fixed-stations were placed at or near tributary entrances (one station per tributary entrance, Table 3). Each tributary entrance fixed-station was equipped with an antenna that was pointed upstream of that tributary along with one antenna that pointed downstream (or into the Peace River). The sequence of detections on each antenna orientation was analyzed to enumerate monthly tributary entrance and exit behaviours by species. For this analysis, three uncontested[29] detections on the upstream antenna meant the study fish was located upstream of that tributary fixed-station, with the opposite true for three uncontested detections on the downstream antenna. Any movement from downstream to upstream was identified as an entrance behaviour while any movement from upstream to downstream was an exit behaviour. Some individual study fish repeatedly entered and exited a tributary within a matter of days, which, if left uncorrected, would skew the resulting count towards species and fixed-stations that were more likely to capture this behavioural pattern. Therefore, to create a visualization that was standardized across species, tributaries, and years, individual study fish were limited to three tributary interactions per month[30]. This approach was independently validated by using upstream detection data (fixed-station and mobile) from the Halfway River and Moberly River to confirm that entry and exit behaviours were identified as expected.

The monthly movement analyses are a means to condense and visualize the available telemetry data with the underlying purpose of displaying large scale movement patterns that can be leveraged to interpret the capacity of the array and monitor fish movement as the Project progresses. This approach helps condense a large amount of movement data into a standardized format for all six indicator species. That said, the approach has some limitations that should be stated. The telemetry system does not possess the capacity for universal and

[27] Categorized monthly movement distances for all six species were normally distributed.

[28] Bull Trout, Arctic Grayling, Walleye, Rainbow Trout, Mountain Whitefish and Burbot.

[29] The fixed-station receiver switches to other available antennas every ten seconds. An uncontested detection string refers to a string of detections recorded on only one antenna within the 10 seconds the receiver scanned that frequency.

[30] Most of the study fish with this behaviour started and ended the analyzed month in the same location, i.e., above or below the tributary, and were assigned two interactions (one exit and entry). However, some of study fish with numerous detections in a single month ended the month in a different location than they began. These fish were assigned three interactions to account for their final location (i.e., entry/exit/entry or exit/entry/exit).

ubiquitous detection. This means that specific and/or granular movements made by study fish have the potential to be overlooked. This includes, but is not limited to, movements that may occur between fixed-stations, outside of the detection array (Figure 5), or movements that occur during the non-operating period between November and March. This can limit biological interpretations when portions of a study area are more thoroughly combed for detectable study fish than others. For example, the detection coverage of the Halfway River is not the same every month of the year. Mobile tracking in the Halfway River is designed to capture Bull Trout spawning behaviour in September (Appendix D, Figure D1) and the Halfway River #2 and Halfway River #3 fixed-stations are not operated from December through February (Table 3).

Spawn Timing and Distribution

In accordance with the underlying objectives of Mon-1b, Task 2a (Peace River Arctic Grayling and Bull Trout Movement Assessment), Bull Trout and Arctic Grayling spawning behaviours were analyzed in 2023. Previous research has identified the Halfway River as the primary spawning tributary for Peace River Bull Trout[31] and the Moberly River as the primary spawning tributary for Peace River Arctic Grayling[32] (Geraldes & Taylor 2022).

Consistent with this understanding, fixed-stations were deployed and operated on the Moberly and Halfway rivers (Figure 5) during each spawning period to capture upstream movements that are indicative of spawning. Additionally, mobile tracking surveys were conducted across the Halfway River drainage during the 2023 Bull Trout spawning period. Mobile tracking surveys to target spawning Arctic Grayling in the Moberly River had been conducted in previous years (Hatch et al. 2020, 2021) but were not conducted in 2023.

Individual Bull Trout and Arctic Grayling detection histories were manually analyzed in conjunction with prior knowledge of spawn timing[33] to identify entry and exit timing, as well as upstream and downstream movements. In 2023, approximate spawn tributaries were identified for individual Halfway River Bull Trout through the additional geospatial information from the Halfway River mobile tracking survey along with PIT and fixed-station detection histories (Table 5).

For Halfway River Bull Trout, it was assumed that a spawning study fish would follow a generalized paradigm in which the individual enters the tributary system, migrates upstream to the desired spawning location, and then resides in this spawning location before migrating back downstream and eventually exiting the tributary. A modification to this paradigm includes any individuals that potentially residualize or die in their spawning tributary either before or after a potential spawning event. In which case, spawning location would be based on the identification of any pre- or post-spawn behaviours along with the application of any prior knowledge of peak spawn timing.

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[31] Genetic analysis of Peace River Bull Trout samples collected between 2016 and 2020 estimated that 94% of individuals originated from the Halfway River and its tributaries whereas 4% originated from the Pine River with the remaining 3% undetermined (Geraldes & Taylor 2022). Furthermore, otolith and fin ray microchemistry analysis of Peace River sampled Bull Trout confirmed this trend with the majority of individuals originating from the Halfway River while the minority originated from the Pine and Moberly rivers (Mainstream Aquatics 2012, TrichAnalytics 2020).

[32] Genetic analysis of Peace River Arctic Grayling samples collected between 2018 and 2020 estimated that 86% of individuals originated from the Moberly River whereas 7% originated from the Pine River, <1% from the Halfway River and the remaining 7% undetermined (Geraldes & Taylor 2022). Otolith and fin ray microchemistry validate this finding, and consistently found that the majority of Arctic Grayling sampled near Site C originate from the Moberly River with lesser proportions originating from the Halfway, Pine, or Beatton rivers (Mainstream Aquatics 2012, TrichAnalytics 2020).

[33] Bull Trout spawn in the fall with spawner activity peaking during the month of September (Putt et al. 2020), while Arctic Grayling spawn in the spring during the months of May and June (Nelson and Paetz 1992, Mainstream Aquatics 2012).

Halfway River Spawning Site Fidelity

Site fidelity for Bull Trout in the Halfway River, defined as the tendency of an individual to return to the same (or similar) spawning location in different years, was analyzed to understand spawning behavior patterns in the Halfway River watershed between 2019 and 2023. To focus the analysis, a subsection of the Halfway River watershed was selected to restrict the study area to locations where Bull Trout spawning could potentially occur. While known spawning sites in the watershed are well documented (Putt et al. 2024), other areas that may be suitable for spawning are less so. For this analysis, we assumed Bull Trout could spawn upstream of the Cameron River confluence (123.8 W, 56.35 N to 122 W, 57.2 N).

This upstream region, referred hereafter as the upper Halfway River, includes both the documented spawning sites as well as the upper most sections of the Halfway River and western tributaries with clear water habitat that could potentially support spawning (Mainstream 2012). Areas downstream of the Cameron River confluence, including the Cameron River itself, were considered unlikely to support Bull Trout spawning due to unsuitable substrate and water quality differences (Mainstream 2012). Potential spawning locations were restricted to detections within this area during the Bull Trout spawning season (August-September). Detection data from mobile radio tracking, fixed-station radio, and PIT tags were all included in this analysis.

Site fidelity was defined as consistent, inter-annual spatial overlap of Bull Trout detections during August and September within the upper Halfway River. Spatial overlaps were determined by applying a 5 km circular buffer around each validated detection of a tagged fish and plotting detections across multiple years. One detection per year was selected to visualize overlaps, and all detections were visually inspected and quality-controlled (QA/QC) to ensure accuracy. Detections with false overlaps (e.g., buffers that overlapped but were not within the same creek/river) were manually corrected. Bull Trout with non-overlapping detections across multiple years were plotted to highlight individuals that potentially exhibited skip-spawning behavior or lacked site fidelity.

It's important to note that the presence of a tag in the Upper Halfway River does not necessarily confirm spawning activity. Additional evidence, such as observations of spawning fish, redds, or habitat characteristics typical of spawning areas, is required to confirm spawning. Therefore, while we present all Bull Trout detections during the spawning season, we refer to those downstream of the Cameron River as locations during the spawning period and those upstream as potential but unconfirmed spawning locations.

Site C River Diversion and Passage Analysis

Fish movement patterns through the Site C Project corridor were analyzed and compared before and after river diversion, which began in October 2020. This analysis aims to interpret the Project's effects during the construction monitoring phase and complement the findings of the Site C Fishway Effectiveness Monitoring Program (Mon-13) reported by InStream Fisheries (Cook et al. 2024). While Mon-13 focuses on the passage facility by modeling and assessing the efficiency of the temporary upstream fishway (TUF) under various environmental conditions during operation, this analysis offers a broader comparison of fish behavior patterns before and after the river diversion.

A successful upstream passage event was defined as a detection of a fish below the Site C Project (via radio or PIT) followed by a detection above it, while a downstream event was characterized by the reverse sequence. Successful upstream and downstream passage events occurring before and after river diversion were recorded for each tracked species and plotted to visualize trends across species.

Additionally, upstream and downstream travel times through the Site C Project corridor were analyzed to assess how transit behaviors have changed following river diversion. To standardize movement distances for this analysis, only two fixed stations were utilized: Peace River 6 and Site C Dam (including stations managed by InStream Fisheries). An upstream movement was defined as a fish transiting from the Site C Dam fixed-station array to Peace River 6, while a downstream movement was the opposite. The time taken for study fish to travel through this section of the river was categorized into 5-day bins, resulting in a histogram that displayed the frequency of movements for each time interval (e.g., 0-5 days, 5-10 days, 10-15 days, and so on). Travel times were calculated exclusively for Bull Trout due to the specific nature of the analyzed corridor between Peace River 6 and Site C, which resulted in insufficient data points for the other tracked species. Only Bull Trout tracking data collected after 2019 were included in this analysis because earlier data primarily relied on mobile detections and did not include these fixed stations.

Finally, during the analysis of passage following diversion, a notable behavioral pattern emerged: some study fish exhibited a tendency to cycle between the Peace River 5 fixed-station (located 9 rkm downstream of the Project, Figure 5) and the Site C Dam array (located directly downstream of the Project, Figure 5). The frequency of this movement pattern was analyzed for tracked study species and compared before and after river diversion.

Results

Data Collection

The fixed-station array and mobile tracking effort collected almost 18 million valid detection records that passed the filtering criteria between 1 January 2023 and 31 January 2024 (Table 6). Starting in January 2023, data collection occurred solely at the three fixed-stations that were operated overwinter (Site C Dam, Moberly River 1, and Halfway River 1), while the remainder of the array[34] was seasonally operated between March and November 2023. Appendix B presents an overview of the relative quantities of validated detections for each fixed-station (Figure B1). Further, the frequency of noise signal detections (Code 999) per fixed-station is displayed in Figure B2, and the frequency of false-positive detections is shown in Figure B3.

The fixed-station array was online 87% of the time between the 2023 installation and demobilization dates (Table 4, Table 7). Excluding optimistic overwinter deployment periods, the array was functional 93% of the main study period (March to November) in 2023. The remaining 7% was the result of typical minor receiver-specific interruptions (Table 7), typically involving low light late winter or early autumn operating conditions. Notable interruptions in 2023 occurred at Peace River 1 A/B (destroyed in a wildfire), Beatton River (battery needed to be replaced), Cache Creek (receiver damaged by lightning strike), Farrell Creek (animal disturbance), Offset 108R South (animal disturbance; memory overload), and at five of the temporary upstream fish passage facility (TUF) sites (download computer was lost).

Table 6. Counts of valid detection records and unique codes (individual study fish) detected at each receiver from 1 Jan 2023 to 31 Jan 2024.[35]

Station Name	Valid Count	Unique Codes	Station Name	Valid Count	Unique Codes
Peace River 1 (1A & 1B)	1,373,657	21	Moberly Lake	0	0
Peace River 2	1,807	25	Peace River 6	1,139	4
Pouce Coupe River	105,709	27	Peace River 7	1,969	9
Peace River 3 (& Kiskatinaw River)	1,335,039	58	Cache Creek	0	0
Beatton River	1,075,876	75	Peace River 8	269,190	20
Peace River 4	2,875,210	94	Halfway River 1	25,824	42
Pine River	38,028	59	Halfway River 2	9,393	31
Peace River 5 (& INS Mainstem 1)	78,633	81	Halfway River 3	11,577	24
South Side Channel	1,294,619	36	Chowade River	305	5
East Side Channel	410	2	Cypress Creek	82	1
West Side Channel	32,396	40	Peace River 9	24,663	32
Site C Dam (all recievers)	6,050,468	104	Farrell Creek	320	1
Diversion Tunnel Inlet	374	1	Peace River 10	309,090	29
Moberly River 1	244	1	Peace River 11	2,975,819	44
Moberly River 2	506	1	Maurice Creek	6,935	5
Moberly River 3	567	1	Peace Canyon Dam	6,934	4

[34] Including all fixed-stations left dormant over winter with a low-voltage cutoff awaiting better solar conditions.

[35] Note that some stations are grouped together to create a detection gate that can detect passing fish from both sides of the river (i.e., Peace River 1 and Peace River 3). Similarly, Site C Dam is a group of overlapping fixed-stations including the single fixed-station operated by LGL Limited as well as the twelve fixed-stations operated by Instream Fisheries Research in 2022.

Table 7. Outage start date, end date, days offline, and notes for all fixed-stations that experienced an outage from 1 Jan 2023 to 31 Jan 2024. Further dissections into outages are displayed in beacon tag detection plots in Appendix B (Figure B4)

Study Year	Station Name	2023 Outage Start	Outage End	2023 Days Offline	Note
2023	Peace River 1A	16 April 2023	12 July 2023	88	Forest Fire
2023	Peace River 1B	16 May 2023	12 July 2023	58	Forest Fire
2023	Peace River 1B	20 October 2023	5 November 2023	17	Low Light Conditions
2023	Peace River 2	1 January 2023	16 April 2023	106	Low Light Conditions (overwinter deployment)
2023	Peace River 2	27 September 2023	5 November 2023	40	Low Light Conditions / Cold weather
2023	Pouce Coupe River	25 October 2023	5 November 2023	12	Low Light Conditions
2023	Kiskatinaw River	27 September 2023	6 November 2023	41	Low Light Conditions / Cold weather
2023	Beatton River	1 January 2023	17 April 2023	107	Low Light Conditions (overwinter deployment)
2023	Beatton River	2 August 2023	28 September 2023	58	Battery needed to be replaced
2023	Beatton River	25 October 2023	6 November 2023	13	Low Light Conditions
2023	Peace River 4	1 January 2023	28 January 2023	28	Low Light Conditions (overwinter deployment)
2023	Peace River 4	3 February 2023	6 February 2023	4	Low Light Conditions (overwinter deployment)
2023	South 108R Side Channel	25 June 2023	14 July 2023	20	Memory was full
2023	South 108R Side Channel	11 August 2023	29 September 2023	50	Animal disturbance
2023	East 108R Side Channel	5 November 2023	7 November 2023	3	Low Light Conditions / Cold weather
2023	INS Mainstem 2	1 January 2023	3 January 2023	3	Not operational
2023	INS Mainstem 2	7 January 2023	7 January 2023	1	Not operational
2023	INS Mainstem 2	10 January 2023	18 January 2023	9	Not operational
2023	INS Approach Zone A	1 January 2023	18 January 2023	18	Not operational
2023	INS Approach Zone B	1 January 2023	22 January 2023	22	Not operational
2023	INS Diversion Tunnel	1 January 2023	18 January 2023	18	Not operational
2023	INS Diversion Tunnel Inlet	1 January 2023	21 January 2023	21	Not operational
2023	INS Entrance Aerial	1 January 2023	18 January 2023	18	Not operational
2023	INS Entrance Dipole ch 3	21 June 2023	5 July 2023	15	Download Computer Lost
2023	INS Entrance Dipole ch5	21 June 2023	5 July 2023	15	Download Computer Lost
2023	INS Turning Basin	28 April 2023	9 May 2023	12	Not operational
2023	INS Turning Basin	21 June 2023	5 July 2023	15	Download Computer Lost
2023	INS Cell 8	21 June 2023	5 July 2023	15	Download Computer Lost
2023	INS Vee-Trap	21 June 2023	5 July 2023	15	Download Computer Lost
2023	Site C Dam	1 January 2023	26 January 2023	26	Low Light Conditions (overwinter deployment)
2023	Moberly River 1	1 January 2023	8 January 2023	8	Low Light Conditions (overwinter deployment)
2023	Moberly River 1	12 January 2023	18 January 2023	7	Low Light Conditions (overwinter deployment)
2023	Moberly River 1	2 February 2023	7 February 2023	6	Low Light Conditions (overwinter deployment)
2023	Moberly River 1	17 February 2023	17 February 2023	1	Low Light Conditions (overwinter deployment)
2023	Moberly River 1	22 February 2023	24 February 2023	3	Low Light Conditions (overwinter deployment)
2023	Moberly River 1	27 February 2023	6 March 2023	8	Low Light Conditions (overwinter deployment)
2023	Peace River 6	1 January 2023	28 January 2023	28	Low Light Conditions (overwinter deployment)
2023	Peace River 6	1 February 2023	7 February 2023	7	Low Light Conditions (overwinter deployment)
2023	Cache Creek	8 March 2023	11 June 2023	96	SRX fried (last year's lightning strike)
2023	Peace River 8	1 January 2023	9 March 2023	68	Low Light Conditions (overwinter deployment)
2023	Halfway River 1	1 January 2023	6 January 2023	6	Low Light Conditions (overwinter deployment)
2023	Halfway River 1	13 January 2023	18 January 2023	6	Low Light Conditions (overwinter deployment)
2023	Halfway River 1	20 January 2023	26 January 2023	7	Low Light Conditions (overwinter deployment)
2023	Halfway River 1	1 February 2023	7 February 2023	7	Low Light Conditions (overwinter deployment)
2023	Halfway River 1	15 February 2023	17 February 2023	3	Low Light Conditions (overwinter deployment)
2023	Halfway River 1	21 February 2023	8 March 2023	16	Low Light Conditions (overwinter deployment)
2023	Halfway River 1	16 September 2023	2 October 2023	17	Vandalism
2023	Peace River 11	1 January 2023	5 March 2023	64	Low Light Conditions (overwinter deployment)
2023	Peace River 11	15 March 2023	19 April 2023	36	Low Light Conditions
2023	Farrell Creek	7 May 2023	11 June 2023	36	Animal disturbance
2023	Farrell Creek	14 September 2023	1 October 2023	18	Low Light Conditions / Cold weather
2023	Peace Canyon Dam	9 July 2023	11 July 2023	3	Battery needed to be replaced
2023	Peace Canyon Dam	24 October 2023	4 November 2023	12	Low Light Conditions / Cold weather

Fixed-Station Range Testing

An objective of Mon-1b, Task 2d is to range test every fixed-station annually to assess and quantitatively evaluate functionality. As such, wherever possible, all fixed-station antennas were tested individually to create detection probability maps (Figure 8) and logistic detection probability curves (Appendix F). Additionally, all stations were also tested for basic range functionality[36] on deployment and were analyzed *post-hoc* to determine detection efficiency.

Among the 34 fixed-stations operating in 2023, 28 were range tested (Table 8). The six that were not range tested in 2023 were Moberly River 1, Peace River 6, Cache Creek, Peace River 8, Halfway River 1 and Halfway River 2. Four of these stations (all except Halfway River 1/2) were demobilized early in 2023 in preparation for reservoir filling; therefore there was not enough time to perform the range test. Halfway River 1 had been vandalized shortly before the range test was scheduled to be conducted and a malfunctioning RC boat at the end of the field season meant Halfway River 2 was not tested in 2023.

Range test detection probability maps were created for each tested station to visualize the expected detection zones (Figure 8). An ideal detection probability map would display a gradient across the tested area that builds from high detection probabilities near the station (80-100%, shown as green) to moderate probabilities (60%-80% as light green, 40-60% as yellow, and 20-40% as orange) all the way to zero detection probability further away from the station (0-20%, shown as red). Most fixed-stations displayed this ideal detection probability map (n=18) including Peace River 1/2/3/5/7/9/10/11, Pouce Coupe River, Kiskatinaw River, Beatton River, Moberly River 3, Chowade River, Cypress Creek, Farrell Creek, Lynx Creek, Maurice Creek, and the 108R West Side Channel.

Three fixed-station range tests produced detection probability maps with sufficient detection area, but which were missing the 'no detection' (red) zones at the edges of the tested area (Figure 8). The stations that made up this category include Peace River 4 as well as the 108R South/East Side Channels. This occurred when most or all of the test was conducted within a positive detection area and that area sufficiently covered the river. These stations are operating within expected parameters.

Non-conforming or 'spotty' detection probability maps resulted from the range tests at Peace Canyon Dam, Pine River, Moberly River 2, and Halfway River 3 stations (Figure 8). The low detection probability areas from the Peace Canyon Dam detection map were likely due to shadowing caused by the Hwy 29 bridge just downstream of the fixed-station, as well as a high noise environment near Peace Canyon Dam. The Moberly River 2 and Halfway River 3 fixed-stations were both operational but performed sub-optimally during the range test for unknown reasons. Both fixed-stations will receive a systemic refresh for the 2024 field season and detection capabilities will be reassessed and confirmed. The Pine River detection map displayed an odd dead area near the station which was either the result of shadowing from a large sub-surface structure or, more likely, a clerical error made during the test that resulted in a disconnect between the detection data and tag position information.

Both Peace River 11 and Beatton River are fixed-station receivers where numerous tagged study fish reside for much of the year. These additional tags in the detection area likely created collisions (i.e., when numerous tags of the same frequency are in the same location, their overlapping transmissions can interfere with a

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[36] Basic range functionality was qualitatively tested by carrying a test tag to ~250 m upstream and downstream of an antenna and then validating detections.

Table 8. Completion of a successful range test by study year (Yes, No, Not Tested or "-").

Fixed-Station	Successful Range Test				
Name	2019	2020	2021	2022	2023
Peace River #1A	Yes	Yes	Yes	Yes	Yes
Peace River #1B	Yes	Yes	Yes	Yes	Yes
Peace River #2	No	Yes	Yes	Yes	Yes
Pouce Coupe River	Yes	Yes	Yes	Yes	Yes
Peace River #3	Yes	Yes	Yes	No	Yes
Kiskatinaw River	Yes	Yes	No	Yes	Yes
Beatton River	No	*Not Tested*	No	No	Yes
Peace River #4	Yes	*Not Tested*	Yes	Yes	Yes
Pine River	Yes	Yes	Yes	*Not Tested*	Yes
Peace River #5	Yes	Yes	Yes	Yes	Yes
South Side Channel	-	-	-	Yes	Yes
East Side Channel	-	-	-	Yes	Yes
West Side Channel	-	-	-	Yes	Yes
Site C Dam	*Not Tested*	*Not Tested*	Yes	Yes	Yes
Moberly River #1	Yes	*Not Tested*	Yes	Yes	*Not Tested*
Moberly River #2	-	*Not Tested*	Yes	Yes	Yes
Moberly River #3	-	*Not Tested*	Yes	Yes	Yes
Moberly Lake	-	-	Yes	No	No
Peace River #6	Yes	Yes	Yes	Yes	*Not Tested*
Peace River #7	Yes	*Not Tested*	Yes	Yes	Yes
Cache Creek	Yes	*Not Tested*	Yes	No	*Not Tested*
Peace River #8	Yes	*Not Tested*	Yes	Yes	*Not Tested*
Halfway River #1	Yes	*Not Tested*	Yes	Yes	*Not Tested*
Halfway River #2	-	*Not Tested*	No	Yes	*Not Tested*
Halfway River #3	-	*Not Tested*	Yes	Yes	Yes
Chowade River	Yes	*Not Tested*	*Not Tested*	Yes	Yes
Cypress Creek	Yes	*Not Tested*	*Not Tested*	No	Yes
Peace River #9	Yes	*Not Tested*	Yes	Yes	Yes
Farrell Creek	Yes	*Not Tested*	Yes	Yes	Yes
Peace River #10	Yes	*Not Tested*	Yes	Yes	Yes
Lynx Creek	Yes	*Not Tested*	-	Yes	Yes
Peace River #11	Yes	*Not Tested*	Yes	Yes	Yes
Maurice Creek	Yes	*Not Tested*	Yes	Yes	Yes
Peace Canyon Dam	No	*Not Tested*	No	Yes	Yes

receiver's ability to decode each of the unique signals), which can result in lower detection probabilities and can create odd detection patterns.

The Moberly Lake fixed-station was the only one in 2023 for which its range test was deemed unsuccessful. This was due to a severed GPS cable that was not discovered until after the range test was conducted. Without the satellite corrections, the internal clock of the receiver was able to drift enough to disrupt the quality of the range test (for which the receiver and GPS clocks need to be synced), but note that the drift was not enough to affect the efficacy of the station during the field season (detections of study fish may have been off by a few minutes).

Lastly, Site C Dam was range tested over a large detection space made of four fixed-station receivers (see part 7 of Figure 8). As displayed, the area immediately downstream of the Project has relatively reduced detection ranges, which is a function of the ambient noise created by the construction activity. Near constant construction activity including, but not limited to, heavy machinery use, electrical powerlines, and radio communication creates interference that is picked up on the receiver as code 999. To maximize functionality in areas such as this, the sensitivity of the receiver must be reduced, which minimizes the interference, but also impacts the effective range.

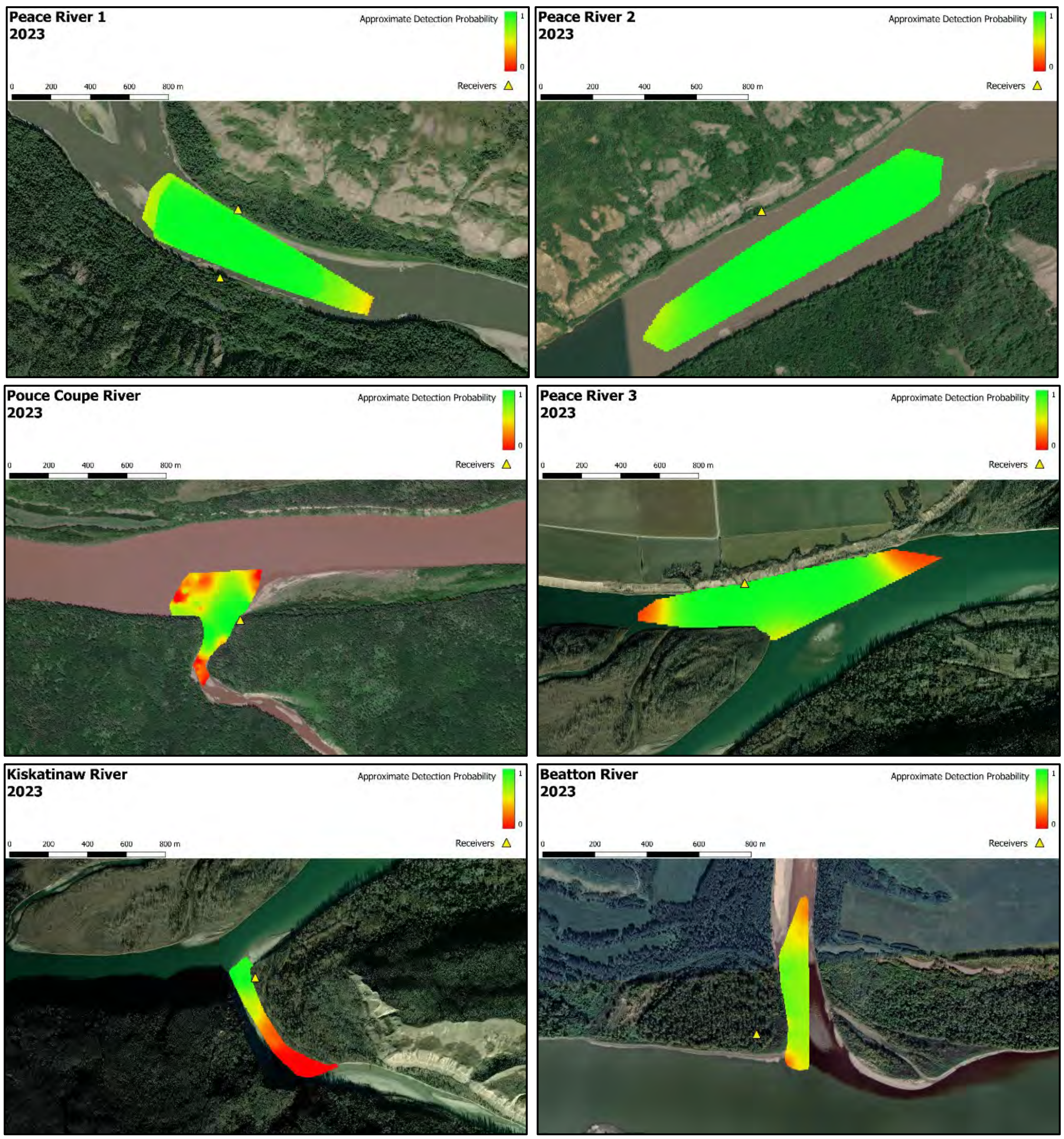

Figure 8. Range test detection probability maps for Peace River and tributary fixed-station receivers. Figure continues on the subsequent 3 pages. (Part 1 of 4)

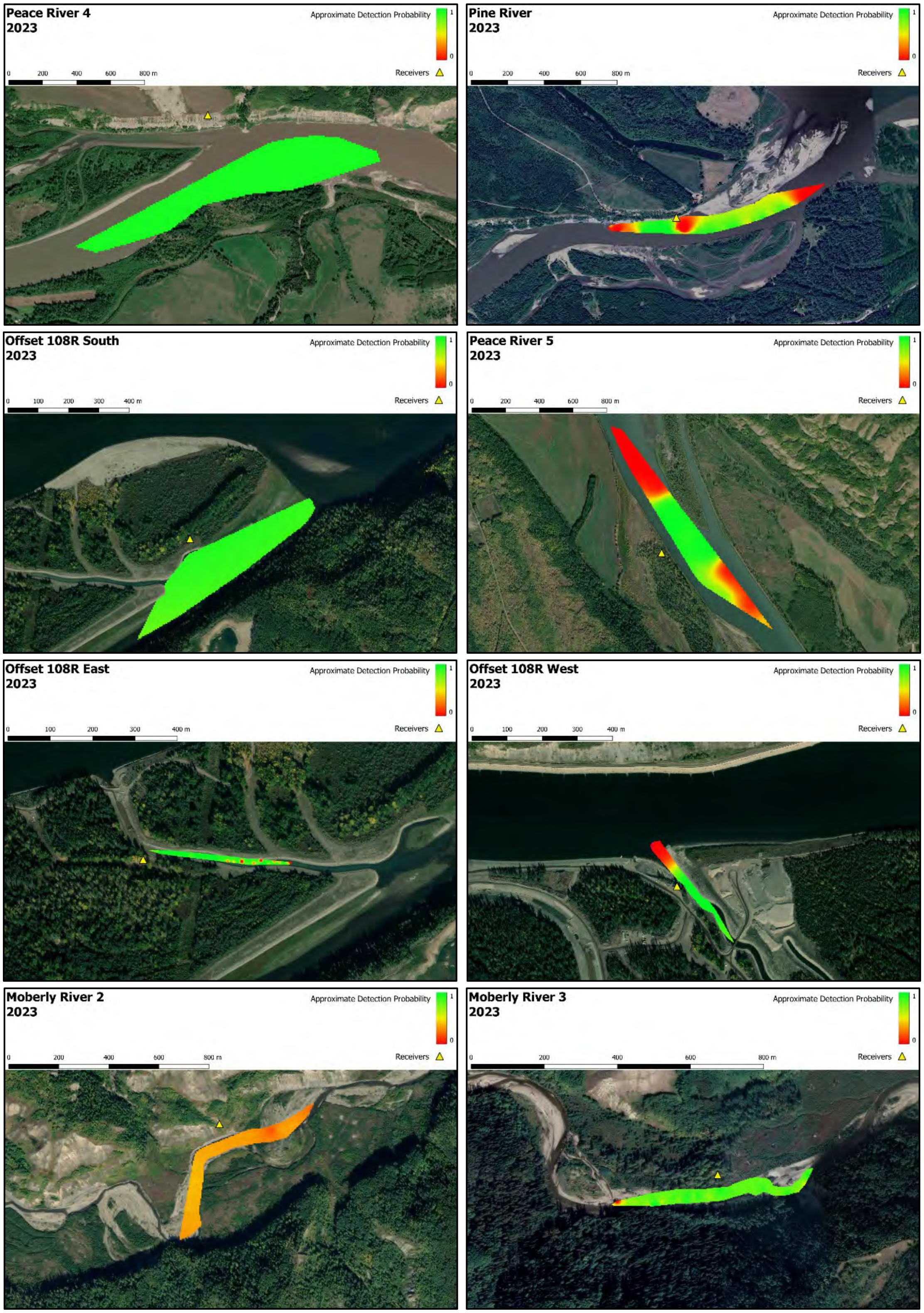

Figure 8 continued (Part 2 of 4).

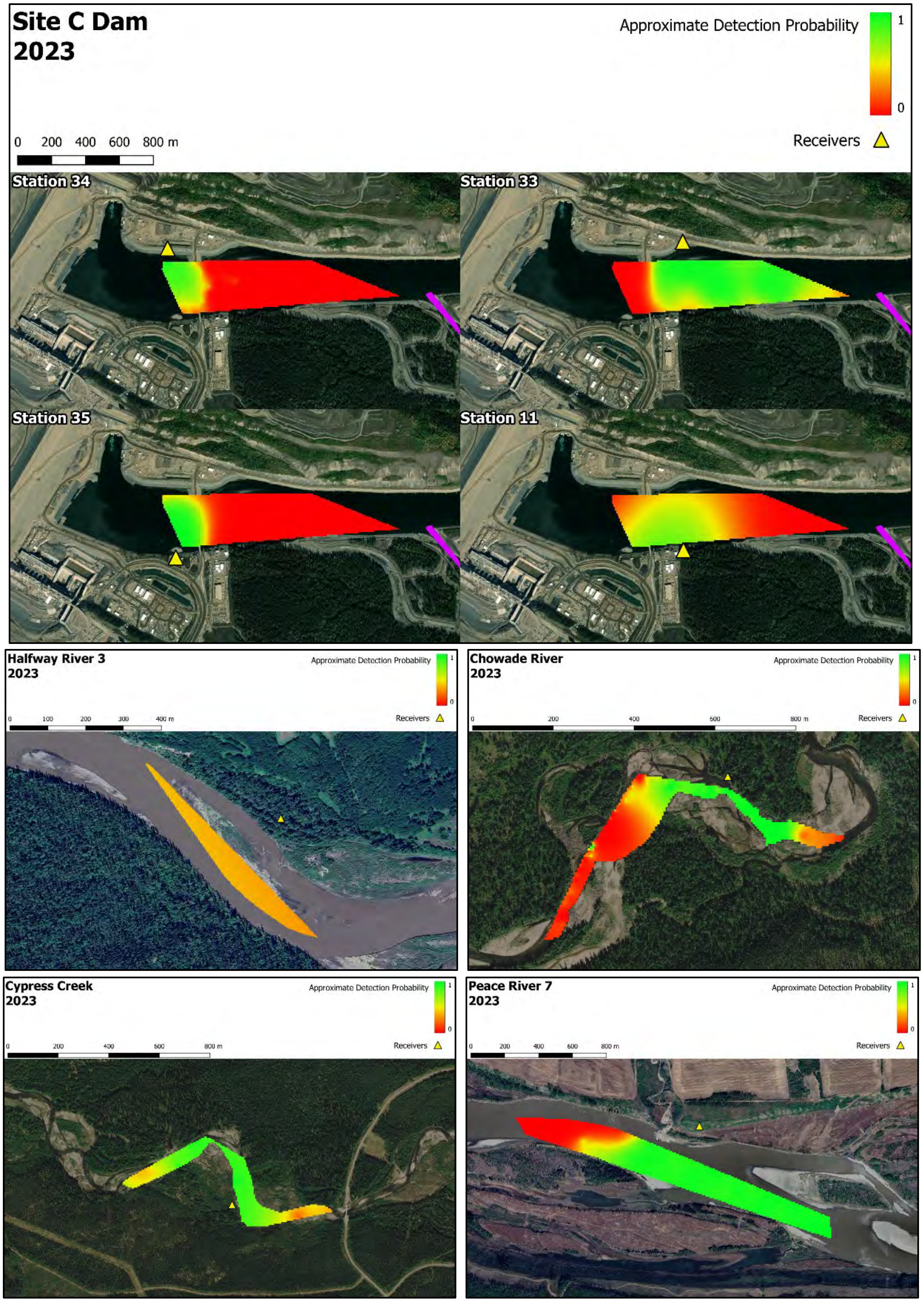

Figure 8 continued (Part 3 of 4).

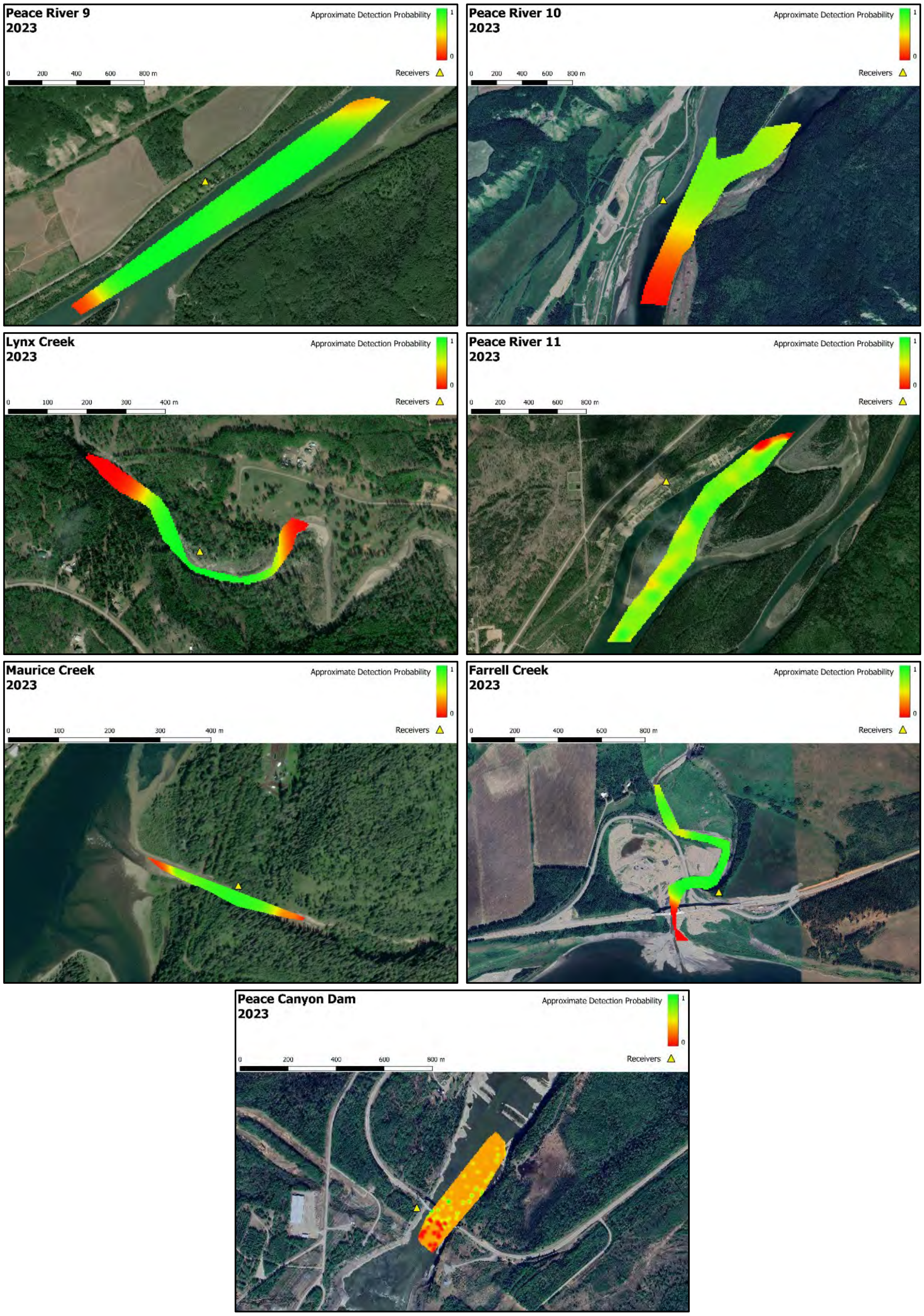

Figure 8 continued (Part 4 of 4).

Table 9. Inflection point (distance at which 50% of transmissions are detected), in metres (with standard errors in brackets) for range tests of specific antennas performed in 2023. See Appendix F. Inflection point estimates that were not statistically significant (“ns”) have been excluded.

Station #	Station Name	Antenna One (DS)	Antenna Two (US)
1	Peace River #1A	647 (47)	586 (168)
2	Peace River #1B	750 (37)	638 (81)
3	Peace River #2	750 (31)	750 (87)
4	Pouce Coupe River	202 (41)	261 (14)
5	Peace River #3	750 (34)	478 (10)
6	Kiskatinaw River	ns	189 (11)
7	Beatton River	ns	382 (37)
8	Peace River #4	750 (137)	750 (85)
9	Pine River	608 (46)	221 (59)
10	Peace River #5	444 (47)	326 (6)
52	South Side Channel	750 (296)	ns
51	East Side Channel	243 (20)	-
50	West Side Channel	206 (45)	94 (12)
11	Site C Dam	280 (18)	147 (10)
13	Moberly River #2	ns	ns
14	Moberly River #3	ns	334 (50)
47	Moberly Lake	ns	80 (29)
16	Peace River #7	564 (55)	563 (109)
21	Halfway River #3	370 (51)	427 (29)
29	Chowade River	251 (94)	432 (32)
30	Cypress Creek	244 (30)	358 (34)
22	Peace River #9	750 (108)	750 (71)
44	Farrell Creek	226 (6)	543 (47)
24	Peace River #10	750 (112)	219 (81)
25	Lynx Creek	220 (5)	186 (4)
26	Peace River #11	735 (31)	750 (124)
31	Maurice Creek	126 (4)	101 (7)
45	Peace Canyon Dam	583 (87)	ns

Similar to previous years, a logistic curve was fit to the detection proportion data from test tag drags, and the parameter values used to estimate the ‘inflection point’, i.e., the distance at which 50% of the signals were detected. For 11 of the antennas, the estimated inflection point was farther away than 750 m (700-750 m was the largest bin included in the logistic regressions), and these are recorded in Table 9 as having their inflection point at “750 m”. In addition, eight of the logistic regressions had inflection point parameter estimates that were not statistically significant and were thus not included in Table 9. For stations with statistically significant estimates, the median inflection point was 427 m (range: 80 to >750 m; Table 9). Range testing logistic curve figures are displayed in Appendix F.

Fixed-Station Detection Efficiency

Detection efficiency[37] was calculated *post-hoc* to compliment detection probability[38] in evaluating and validating the efficacy of the fixed-station array (Adams et al. 2012, Kessel et al. 2014). Detection efficiencies were between 69.5 and 100% (median = 91.1%) for fixed-stations or combinations of fixed-stations in 2023 (Table 10, Figures 9 and 10). The detection efficiency calculation is only possible at fixed-stations with adequate detection coverage both upstream and downstream of the fixed-station to validate movements. Therefore, detection efficiency was not calculated at Peace Canyon Dam or Peace River #1A/1B on the Peace River as well as multiple tributary stations including Maurice Creek, Lynx Creek, Farrell Creek, Chowade River, Cypress Creek, Cache Creek, Pouce Coupe River, or the 108R offset array. Additionally, stations located in the lower portions of the future Site C Reservoir (Peace River 6,7,8) were all demobilized early (June 2023) in preparation for the potential of reservoir filling, therefore these stations logged fewer usable detection strings than in previous study years.

At many of the stations, the detection efficiencies in 2023 were similar to the estimates from previous study years (Figures 9 and 10). Among the 16 fixed-stations analyzed in 2023, Peace River 5 exhibited the lowest detection efficiency for both upstream and downstream orientations (Table 10). Peace River 5 was successfully range tested in 2023 and identified as operating effectively (Figure 8). That said, a decreased detection efficiency has been common at this station since 2021 (Figure 9), which potentially aligns with river diversion which occurred in October 2020. As detailed in the Site C River Diversion Analysis section within this report, there has been a significant increase in repeated movements by radio-tagged Bull Trout cycling between some of the fixed-stations downstream of the Project following river diversion (i.e., Site C Dam, 108R Offset array, Peace River 5, Pine River, and Peace River 4). Many of these movements between these stations are relatively fast and contribute to non-detections by the Peace River 5 fixed-station, which potentially contributes to that lower than expected detection efficiency.

Mobile Tracking Detection Efficiency

Using all available data sources (mobile radio, fixed-station radio and PIT), 22 Bull Trout were detected in Chowade River and Cypress Creek during the 2023 spawning season. Among these fish, 8 were detected during at least one of the two mobile surveys in 2023, while the remaining 14 were detected solely on the fixed-station radio and/or PIT arrays on Chowade and Cypress. However, of the 14 fish that were not detected during the mobile surveys, nine were beyond the expected manufacturer's tag battery failure date when the mobile survey was conducted.

These tags could be presumed dead or potentially failing. Therefore, all Bull Trout whose expected battery failure date preceded the mobile survey dates were removed from this analysis leaving 14 Bull Trout detected in Chowade River and Cypress Creek in 2023. Among these Bull Trout, five were not detected during either mobile flight survey, resulting in a mobile tracking detection efficiency of 64%. Finally, of the five fish not detected during either mobile survey two were detected in the Peace River following the spawning season while the other three were last detected on the Chowade River PIT. Assuming those three fish proceeded downstream to the Peace River following the spawning season (as is the expected behaviour), these three Bull Trout may have shed their tag or the antenna was significantly damaged.

[37] Defined as the proportion of study fish known to have passed a particular fixed-station.

[38] Defined as the probability to detect a test tag's transmission at various distances from a receiver antenna.

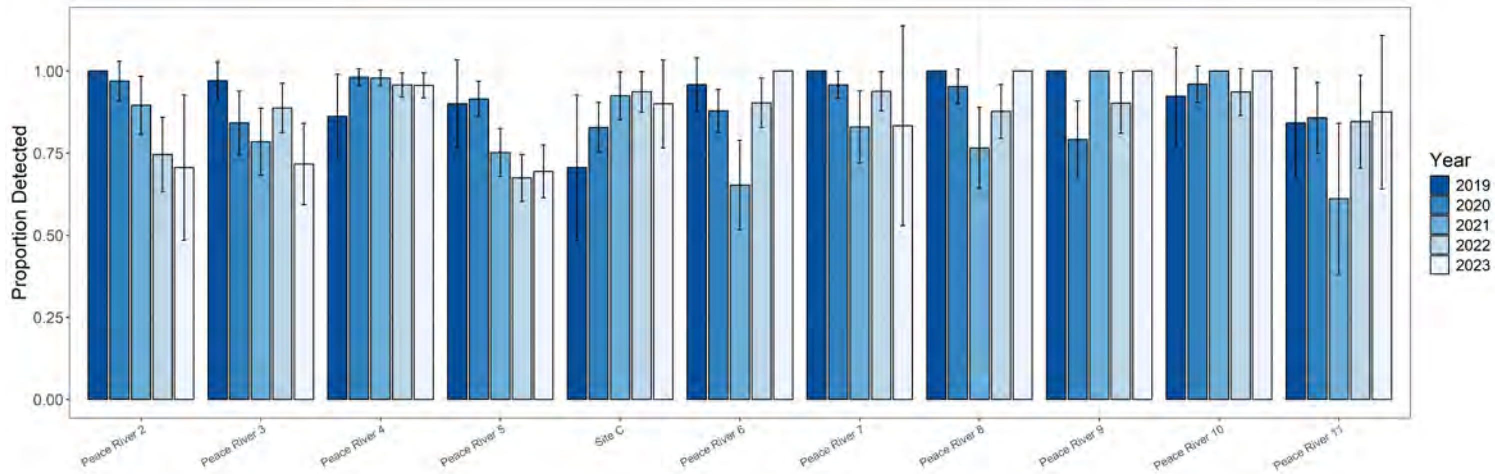

Figure 9. Detection efficiency by fixed-station and year for applicable Peace River fixed-stations. Error bars show the 95% confidence intervals.

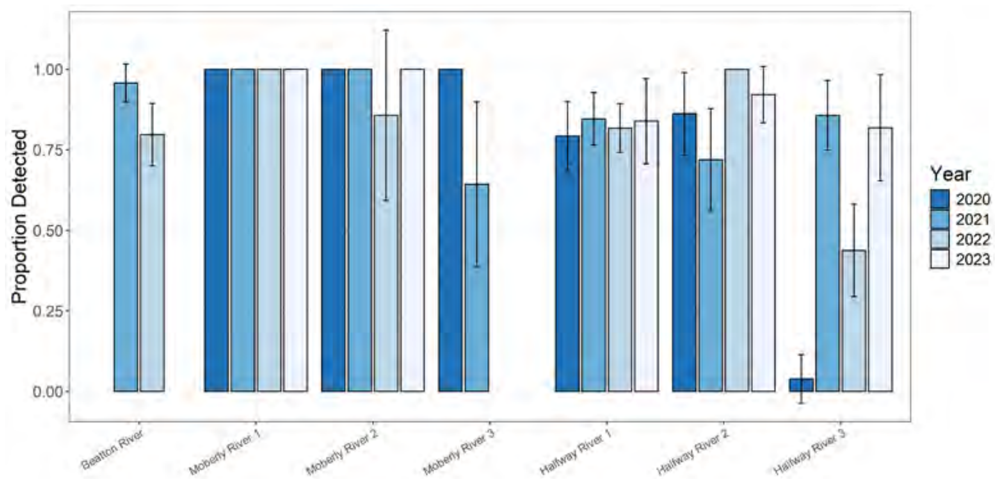

Figure 10. Detection efficiency by fixed-station and year for applicable tributary fixed-stations. Error bars show the 95% confidence intervals

Table 10. Fixed-station detection efficiencies in 2023 for upstream and downstream movement orientations. N = the number of tagged fish known to have moved past the receiver.

		Upstream		Downstream		Both	
Station Name	**River Type**	**Det. Eff.**	**N**	**Det. Eff.**	**N**	**Det. Eff.**	**N**
Peace River 2	Peace River	75.0%	8	66.7%	9	70.6%	17
Peace River 3	Peace River	80.0%	30	60.9%	23	71.7%	53
Peace River 4	Peace River	100.0%	61	90.7%	54	95.7%	115
Peace River 5	Peace River	65.6%	61	72.9%	70	69.5%	131
Site C	Peace River	100.0%	9	81.8%	11	90.0%	20
Peace River 6	Peace River	-	0	100.0%	2	100.0%	2
Peace River 7	Tributary	100.0%	1	80.0%	5	83.3%	6
Peace River 8	Peace River	100.0%	1	100.0%	2	100.0%	3
Peace River 9	Peace River	100.0%	8	100.0%	15	100.0%	23
Peace River 10	Peace River	100.0%	13	100.0%	14	100.0%	27
Peace River 11	Peace River	66.7%	3	100.0%	5	87.5%	8
Moberly River 1	Tributary	100.0%	1	-	0	100.0%	1
Moberly River 2	Tributary	100.0%	1	-	0	100.0%	1
Halfway River 1	Tributary	81.5%	27	100.0%	4	83.9%	31
Halfway River 2	Tributary	92.3%	26	91.7%	12	92.1%	38
Halfway River 3	Peace River	85.7%	14	75.0%	8	81.8%	22

Movement Analysis

Magnitude, Seasonality, and Direction

Region-wide seasonal movement patterns were interpreted from monthly movement distance. Tributary entrance and exit plots (Figures 11 through 16) were created using all applicable telemetry data collected from 2019 through 2023. The tributaries that were included in the analyses varied among the study species depending on the known/expected migratory behaviours, detection coverage, or the presence of notable movements in the dataset.

Arctic Grayling

In 2023, there were fewer movements recorded by Arctic Grayling than in previous study years, with no detections at any of the three Moberly River fixed-stations operated during the year (Figure 11). Peace River Arctic Grayling traditionally use the Moberly River to spawn, entering the river in April/May and exiting from April to June (Figure 11). The lack of Moberly River detections by radio-tagged Arctic Grayling in 2023 was likely an artefact of low sample size, as apposed to a marked decrease in spawning activity. In 2023, 36 Arctic Grayling were expected to possess active radio tags based on manufacturer tag life estimations, yet only 12 were detected, including seven that appeared to be a shed tag or a mortality[39]. Thus, only five Arctic Grayling were tracked in 2023, all of which were released that same year and were last detected downstream of Site C.

Arctic Grayling movement in the Peace River in 2023 was more sporadic than in previous years. There was a tendency towards upstream movement early in the year (from April to July), while downstream movements were more prevalent later in the year (most prominently in August). No error bars are displayed for the 2023 figures as all monthly Arctic Grayling movements had only one sample per travel month and direction.

Bull Trout

Similar to 2019-2022, Bull Trout in 2023 exhibited balanced upstream and downstream movements throughout the Peace River between April and October, with decreased movements recorded through the winter months (Figure 12). A decrease in activity appeared ubiquitous throughout winter months, although much of the array is offline during this period, which decreases the certainty of that generalization.

Primary tributary movements by Bull Trout were recorded in the Halfway River, with entrance behaviours occurring between April and October (with a spike occurring in May), and exit behaviours largely occurring in September and October (Figure 12)[40]. Bull Trout migrating up the Halfway River are only detectable in the upper regions of the Halfway River watershed between July to September due to the logistics of the fixed-stations (sites are only accessible July or later) and mobile tracking schedule (mobile flights occur in September) meaning May and June upstream movements aren't effectively captured in this analysis.

At the Pine River, a secondary spawning river system to the Halfway River (Mainstem Aquatics 2012, Geraldes and Taylor 2022), entry and exit behaviours were primarily in and around the month of September (Figure 12). These movements may be indicative of spawning behaviour, but without additional upstream fixed-stations and/or mobile tracking efforts in the Pine River, the purpose of these Bull Trout movements remains speculative.

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[39] A shed tag refers to a radio tag that has been expelled from a study fish but the individual survived, while a mortality is when that study fish dies. Unfortunately, both instances appear in the telemetry data the same; as stable and repeating detections from single location over a long period. A mortality can be confirmed by recovering the carcass intact while a shed is confirmed by subsequent PIT detections by the same individual.

[40] Note that any study fish transported and released into the Halfway River (i.e., the Halfway River Boat Launch) were removed from this analysis to avoid bias.

Similar to Arctic Grayling and not displayed in Figure 12, Bull Trout exhibited entrance and exit behaviours in lower quantities at numerous other tributaries (e.g., Maurice Creek, Farrell Creek, Moberly River, Beatton River, and Kiskatinaw River) throughout the study period, and for shorter residence times.

Burbot

Similar to 2022, there were relatively few detections of Burbot within the Peace River in 2023, resulting in an unreliable picture of seasonal movement behaviours (Figure 13). The paucity of detections from tagged Burbot could be the result of a sedentary lifestyle (i.e., study fish did not often move past fixed-stations), and/or a preference for deeper water (radio signals attenuate over depth[41]). Moreover, only 30 individuals have been tagged since 2019 and 11 were expected to be active in 2023. The 2023 telemetry data only included nine detection events from six unique individuals, and few detections were associated with any notable movements (Figure 13).

Mountain Whitefish

Mountain Whitefish telemetry in 2023 did not display any notable movement trends, which could be interpreted as residency throughout most of the field season (Figure 14). There were some movements recorded from April to July in 2023, followed by a potential increase in activity in September and October. These higher levels of movement later in the year match what was seen in 2022, although one individual moved greater than 90 river km both upstream in September and downstream in October, partially skewing the mean for both months. Additionally, this pattern seen in the 2019-2022 dataset could be because the majority of tracked Mountain Whitefish were tagged in September and October 2021 which immediately preceded the downstream behaviour displayed in 2019-2021 (Figure 14). Mountain Whitefish tributary entrance and exit behaviours were recorded at the Pine River and Halfway River fixed-stations in September and October (Figure 14).

Rainbow Trout

Rainbow Trout tracked in the Peace River in 2023 had similar levels of downstream movement to those tracked between 2019 and 2022, but with less consistent upstream movement (Figure 15). Tributary use may have corresponded to spawning activity (tributary entrance in April-May and exit behaviour in June-July, Mainstem 2012), and was similar to previous observations, having occurred primarily in the Halfway River, Pine River, Farrell Creek, and Maurice Creek (Figure 15). The two upstream fixed-stations deployed in the Halfway River (i.e., Halfway River 2/3, Figure 5) detected Rainbow Trout movements in May and June, and later in the year in September and October (Figure 15).

Outside those displayed in Figure 15, tributary entrance and exit behaviours by Rainbow Trout were exhibited across numerous tributaries throughout the operational field season, many of which with short duration (<24 hours) residence times.

Walleye

Walleye in the Peace River in 2023 had even levels of upstream and downstream movements between April and September, with downstream movements being observed at noticeably higher levels than their upstream counterparts in March and October (Figure 16). The majority of tributary use by Walleye was focused around the Beatton River, with some summertime activity around the Pine River, Kiskatinaw River, and Pouce Coupe River (Figure 16).

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[41] Although the Peace River is consistently shallow throughout (<4 m in most locations) relatively small changes in depth (~2 m) can significantly downgrade the ability to detect and code radio signals.

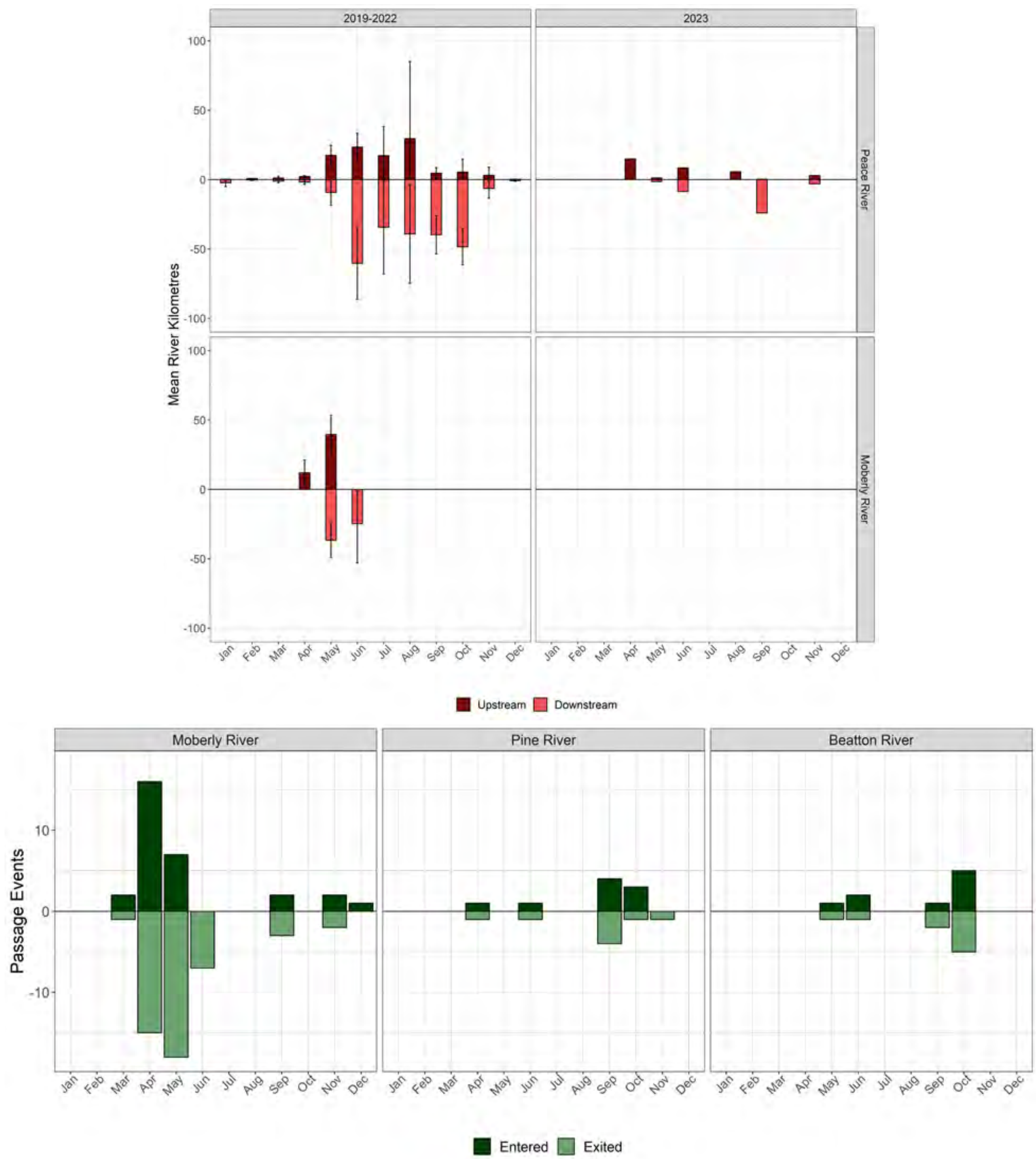

Figure 11. ***Top:*** **Mean movements (in RKM), by month, for Arctic Grayling in the Peace and Moberly rivers, calculated for data collected from 2019 through 2022 and during 2023. Positive values refer to upstream movement, and negative values refer to downstream movement. Error bars show the 95% confidence limits.** ***Bottom:*** **Tributary entrance and exit movements for Arctic Grayling, tallied per individual study fish by month between 2019 and 2023.**

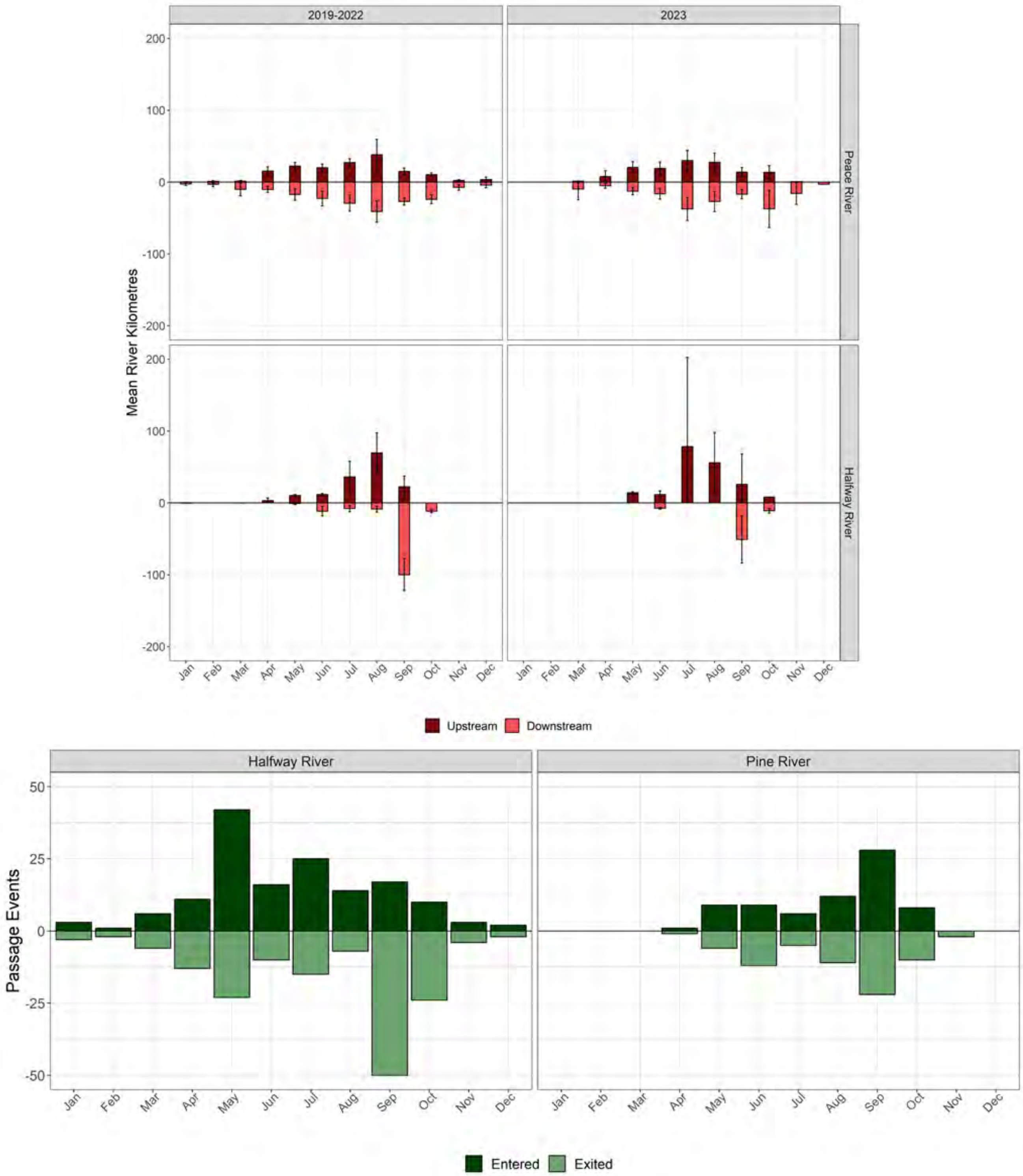

Figure 12. ***Top:*** **Bull Trout mean monthly movements in the Peace and Halfway rivers.** ***Bottom:*** **Monthly tributary entrance/exit movements for Bull Trout. Details as in Figure 11.**

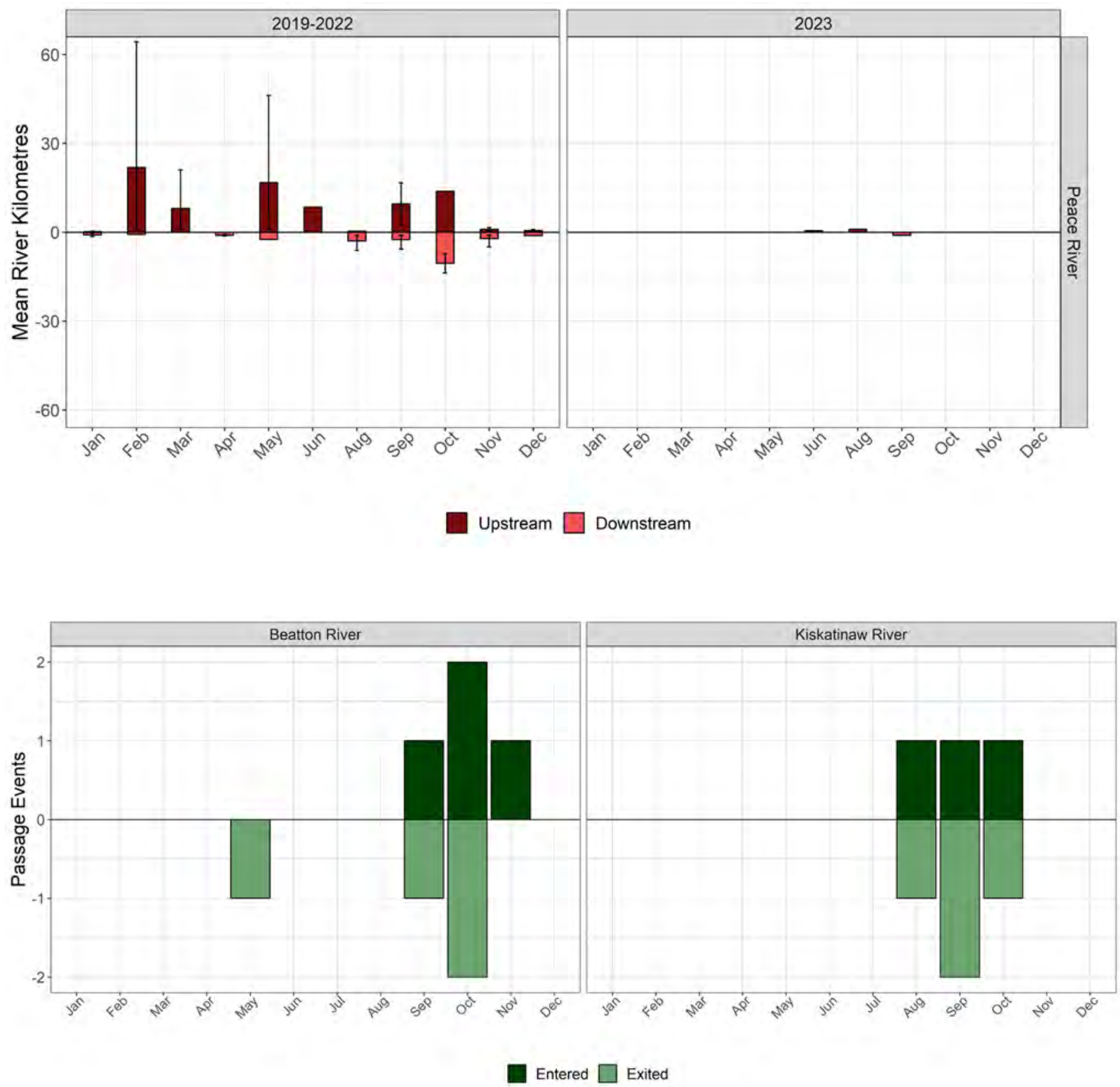

Figure 13. ***Top*: Burbot mean monthly movements in the Peace River. *Bottom:* Monthly tributary entrance/exit movements for Burbot. Details as in Figure 11.**

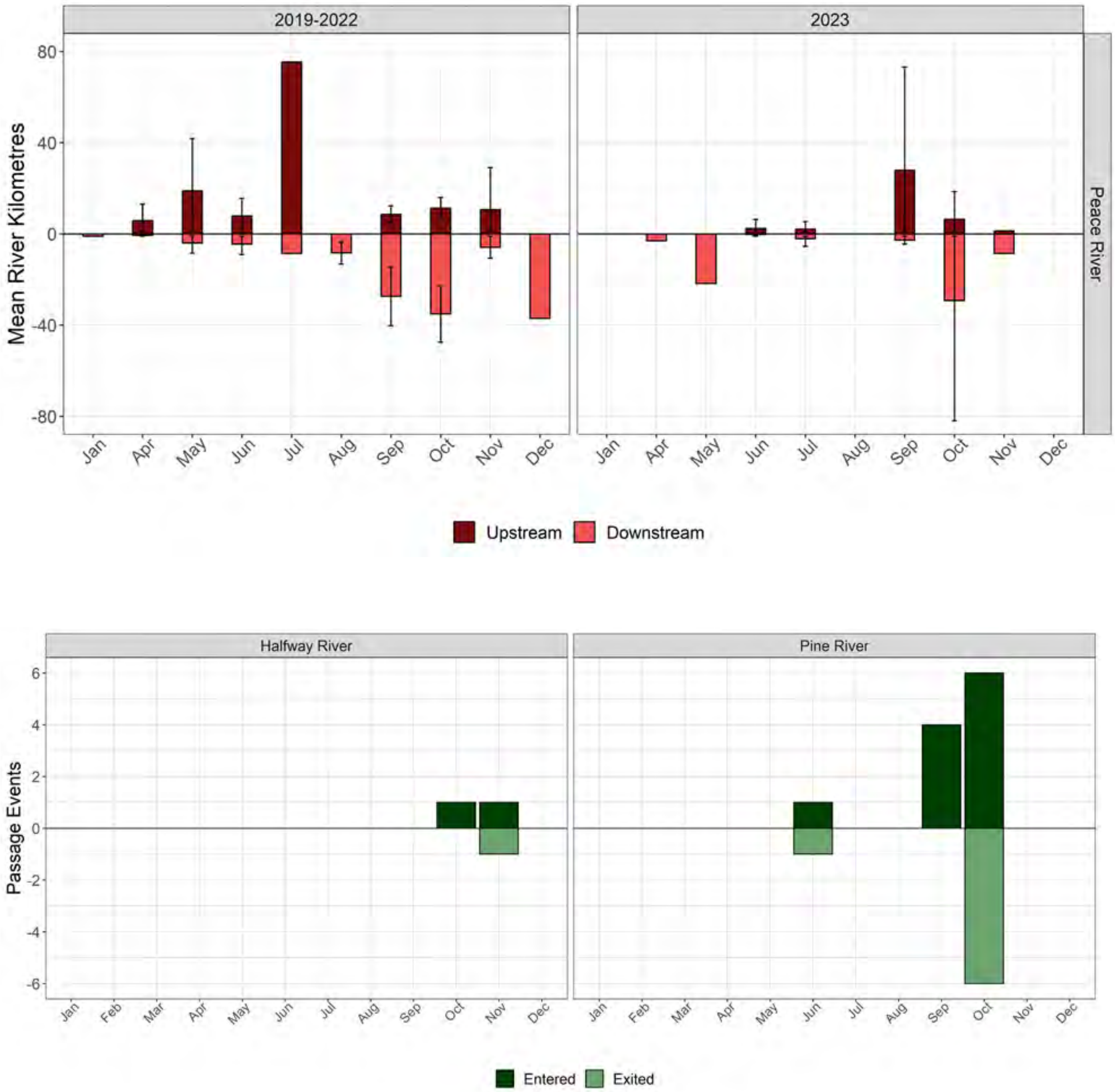

Figure 14. ***Top:*** **Mountain Whitefish mean monthly movements in the Peace River.** ***Bottom:*** **Monthly tributary entrance/exit movements for Mountain Whitefish. Details as in Figure 11.**

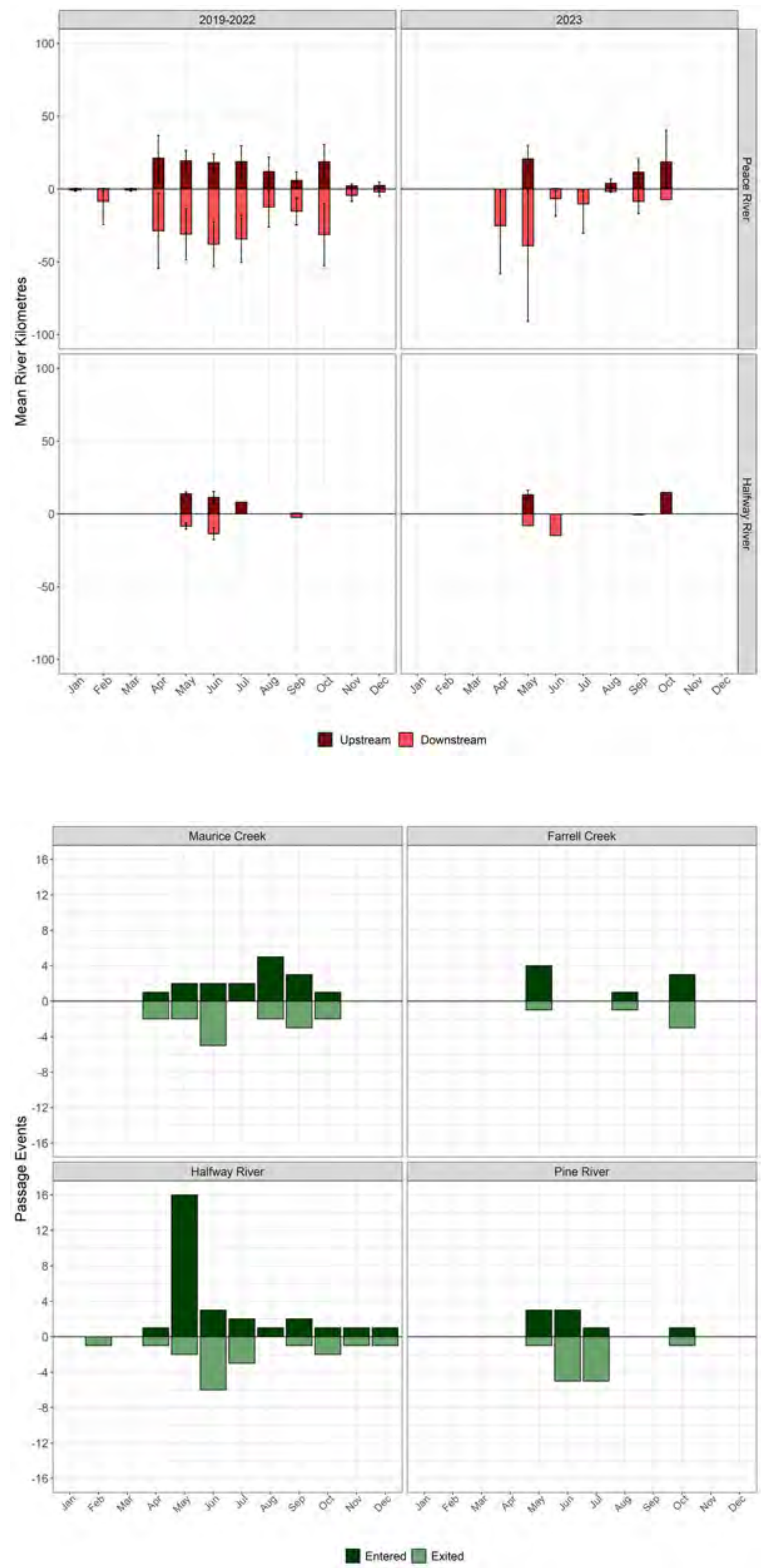

Figure 15. ***Top:*** **Rainbow Trout mean monthly movements in the Peace and Halfway rivers.** ***Bottom:*** **Monthly tributary entrance/exit movements for Rainbow Trout. Details as in Figure 11.**

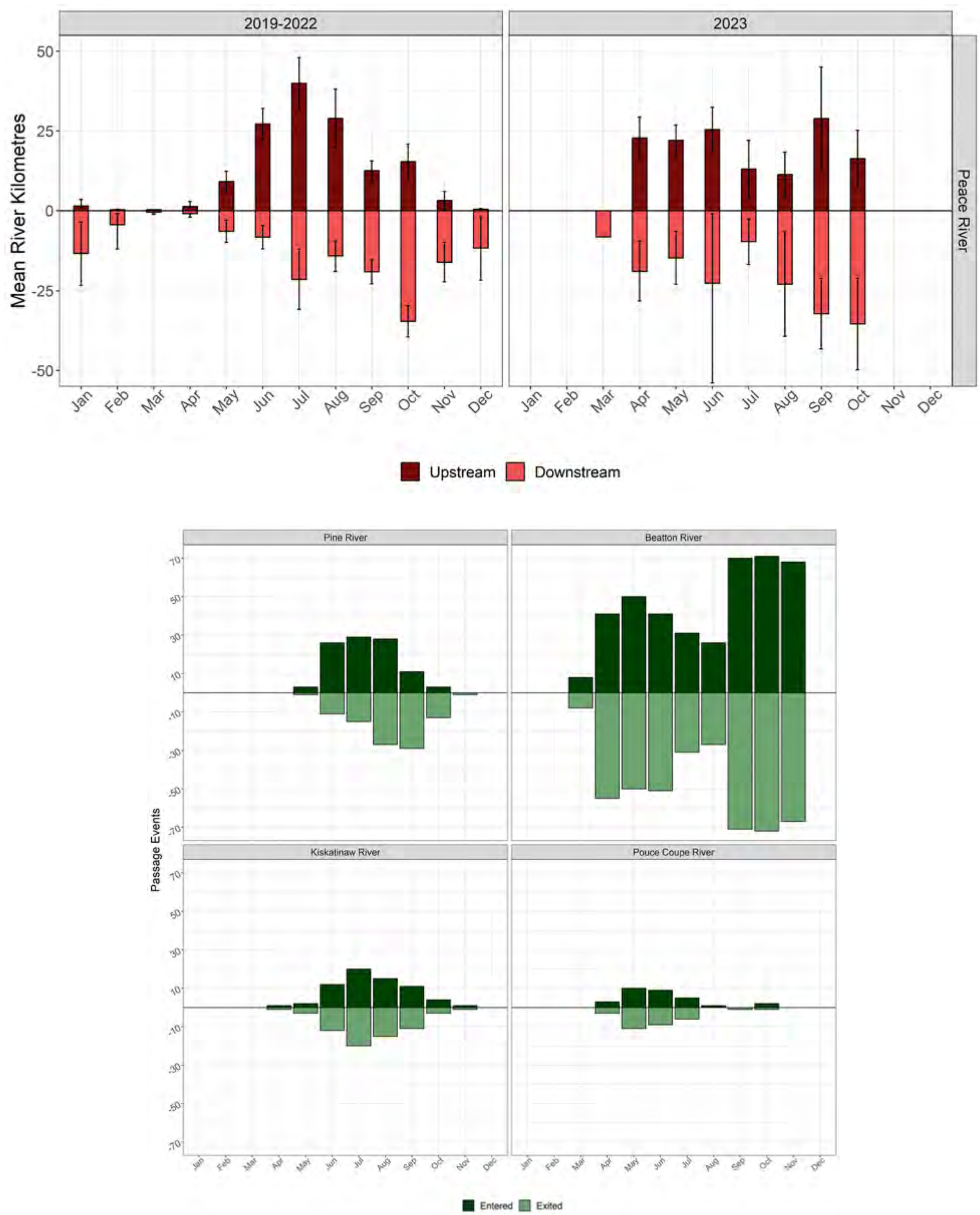

Figure 16. ***Top:*** **Walleye mean monthly movements in the Peace River.** ***Bottom:*** **Monthly tributary entrance/exit movements for Walleye. Details as in Figure 11B.**

Spawn Timing and Distribution

Arctic Grayling

Moberly River mobile tracking did not occur in 2023, which means Moberly River Arctic Grayling peak spawn timing and potential spawner locations were not determined. Furthermore, although the Moberly River fixed-station array was operational in 2023, no potential spawners were detected during the Moberly River Arctic Grayling spawning window.

Mountain Whitefish

Mountain Whitefish typically mature at age 4 and spawn in the fall when water temperatures are between 2-6°C (McPhail 2007, BC Hydro 2015, Boyer 2016) and in the Peace River this occurs sometime between October and November (Mainstream 2010). Since 2020, 75 Mountain Whitefish have been radio tagged for the Site C Fish Movement Assessment: 28 in 2020 and 47 in 2021. Among those, 20 Mountain Whitefish have had at least one valid October detection, possessed a detection history that was not indicative of post-tagging trauma/mortality, and was at least 300 mm in length when tagged. Additionally, 116 Mountain Whitefish were radio-tagged for pre-construction monitoring in 2006; however, only 8 of these were released in the same Peace River section as those released in 2020-2021, had at least one valid October detection, possessed a detection history that was not indicative of post-tagging trauma/mortality, and was at least 300 mm in length when tagged. This totaled 28 Mountain Whitefish that were analyzed as potential spawners (Table 11, Figure 17).

From the present dataset, the majority of spawn-period detections were picked up downstream of the Project (n=13) and near the mouth of the Pine River (n=7). The remaining detections were dispersed throughout the LAA with three upstream of Site C, seven between Site C and the Beatton River, and four from the Beatton River into Alberta. By contrast, the detections from 2006-2007 included one below Site C Dam, three at the Pine River, three upstream of Site C, 3 between Site C and the Beatton River, and one below the Beatton River into Alberta (Table 11, Figure 17).

Table 11. **Spawning season (October-November) detection locations for large Mountain Whitefish (>300 mm FL) that were detected during at least one spawning season, were released within Peace River Section 5 or 6[42], and did not indicate any signs of post tagging mortality/trauma. "Shed or Mortality" refers to tag that was likely expelled from the fish , yet was continued to be detected.**

Tag_id	2006	2007	2021	2022	2023
943	-	-	Halfway River 1	below Site C Dam	nd
1007	-	-	below Site C Dam	Shed or Mortality	Shed or Mortality
1017	-	-	PR - Kiskat to Beatton	Shed or Mortality	Shed or Mortality
1018	-	-	below Site C Dam	nd	nd
1020	-	-	below Site C Dam	Peace River 1	nd
1022	-	-	nd	nd	Pine River
1028	-	-	Pine River	Pine River	nd
1030	-	-	Pine River	Pine River	Pine River
1036	-	-	below Site C Dam	nd	nd
1037	-	-	below Site C Dam	below Site C Dam	Shed or Mortality
1047	-	-	-	Pine River	below Site C Dam
1052	-	-	Peace River 9	nd	Peace River 9
1088	-	-	Peace River 1	nd	nd
1115	-	-	below Site C Dam	below Site C Dam	nd
1128	-	-	below Site C Dam	Shed or Mortality	Shed or Mortality
1133	-	-	Peace River 5	Beatton River	nd
1137	-	-	Pouce Coupe River	Shed or Mortality	Shed or Mortality
1176	-	-	below Site C Dam	Peace River 5	Peace River 5
1237	-	-	below Site C Dam	PR - Pine to PR5	nd
1242	-	-	Peace River 4	Peace River 4	nd
9151	Pine River	Pine River	-	-	-
9159	PR - Halfway to PR9	Shed or Mortality	-	-	-
9167	Pine River	Shed or Mortality	-	-	-
9179	PR - PR5 to STC	PR - Pine to PR5	-	-	-
9202	Moberly River	PR - PR4 to Pine	-	-	-
9204	PR - PR5 to STC	Shed or Mortality	-	-	-
9218	Moberly River	Shed or Mortality	-	-	-
9234	PR - Alces to Kiskat	Shed or Mortality	-	-	-

[42] All Mountain Whitefish tagged since 2019 were captured and released in either Peace River Section 5 or 6. Therefore, for comparison purposes, the Mountain Whitefish selected for analysis from those tagged in 2006 were similarly released in either Peace River Section 5 or 6.

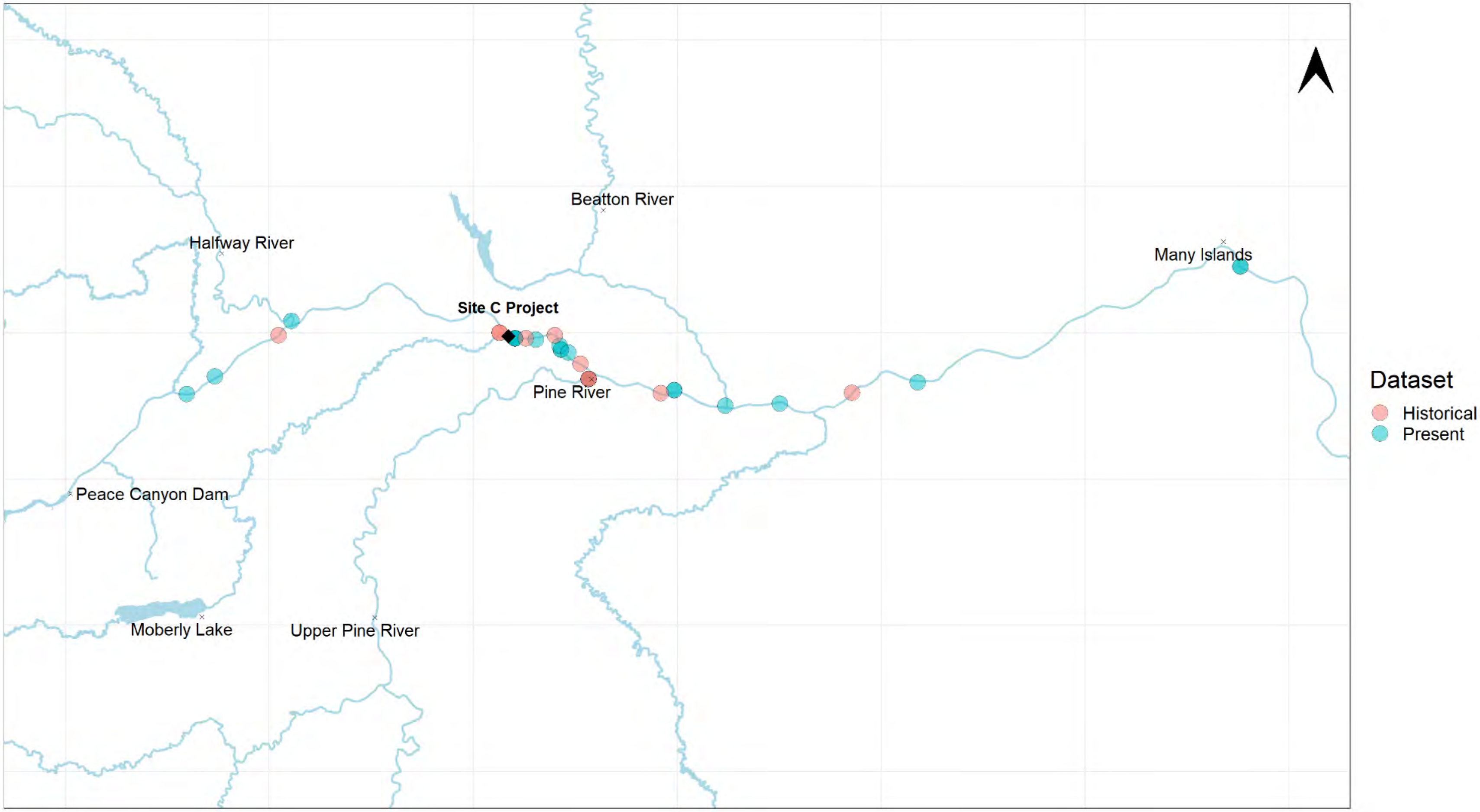

Figure 17. Mapped locations of Mountain Whitefish detected during the October-November spawning season. Color depicted refers to the dataset these results were extracted from Historical in red (tagged in 2006) and Present in blue (tagged in 2020-2021).

Bull Trout

In 2023, a total of 22 adult Bull Trout were detected in the Upper Halfway River, upstream of the Cameron River confluence, by either radio or PIT telemetry (Table 12, Figure 18, E1, and E2). Half (n = 11) were detected by radio *or PIT*[43] (mobile and/or fixed-station) while the other half were solely detected on the PIT array (Table 12).

Eleven of these Bull Trout were detected entering the Halfway River via radio detections from the Halfway River 1 fixed-station (Figure 5). The median date of entry from the Peace River into the Halfway River was 21 May 2023, with a range from 8 April to 31 August 2023. A similarly wide range of entrance dates was reported in previous years, with Bull Trout entering between 26 April and 17 July 2020 (Hatch et al. 2021), between 21 April and 18 September 2021 (Hatch et al. 2022), and between 1 May and 7 September 2022 (Hatch et al. 2023).

In 2023, after detection in the upper Halfway River, 15 Bull Trout have yet to be recorded exiting the system, meaning they have not been detected passing any of the lower Halfway River or Peace River radio stations. For eight of these fish, the 2023 spawning season extended beyond the expected expiration date of their radio tags, as confirmed by their spawning season detections only occurring on the PIT arrays (Table 12).

Of the remaining seven fish, four were detected entering the system, suggesting that they were either harvested, died, or shed/damaged their radio tags during spawning or migration. The final three were not detected entering or exiting the Halfway River; two of these were located through mobile surveys and potentially still have active radio tags, while the third has not been detected on the radio telemetry system since August 31, 2022, which may indicate a shed, damaged, or failed tag.

For the seven Bull Trout detected exiting the Halfway River, the median exit date was 27 September 2023, with a range from 20 September to 18 October 2023. This exit timing was similar to previous years: 2020 (6 September to 7 October), 2021 (20 September to 4 November), and 2022 (9 September to 10 October).

Based on the available detection history for these 22 Bull Trout, spawning potentially occurred in the Chowade River (n = 14), Cypress Creek (n = 5), the Halfway River near the Chowade n = 2), and Needham Creek (n = 1). Of those with sufficient pre-Halfway detection history (n = 11), 64% (n = 7) migrated from upstream of Site C, while the remaining 36% (n = 4) migrated from downstream of Site C and were captured and transported above the dam via the TUF or contingent capture programs[44].

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[43] Note that most of the fish detected via radio (fixed or mobile) methods were also detected on the expected PIT arrays.

[44] This analysis doesn't include fish that were radio tagged and released by the contingent capture program in 2023.

Table 12. Potential spawn locations for Halfway River Bull Trout in August and September 2023 listed by detection type (i.e., mobile radio, fixed station radio, or PIT array). Datetime enter and exit describe when that study fish entered and exited the Halfway River watershed for the 2023 spawning season. "*nd*" refers to no detection. Expired battery (TRUE or FALSE) depicts whether the 2023 spawning season occurred after the suggested manufacturer's battery expiration date (i.e., expiration date). ***Note that a tag can operate beyond it's estimated expiration date (e.g., Tag_ID 758) or underperform by prematurely failing before this date.***

Tag_ID	Detection Type	Location	Datetime Enter	Datetime Exit	Expired Battery	Expiration Date
1004	Radio - Mobile	Cypress Creek	5/20/2023	*nd*	FALSE	4/15/2024
1165	Radio - Mobile	Chowade River	7/5/2023	9/27/2023	FALSE	3/25/2024
1253	Radio - Mobile	Needham Creek	5/21/2023	9/25/2023	FALSE	3/17/2025
1286	Radio - Mobile	Chowade River	5/12/2023	9/25/2023	FALSE	4/24/2025
1421	Radio - Mobile	Halfway River *near* Chowade	*nd*	*nd*	FALSE	5/20/2025
1459	Radio - Mobile	Cypress Creek	5/7/2023	*nd*	FALSE	5/23/2025
1482	Radio - Mobile	Cypress Creek	5/8/2023	9/29/2023	FALSE	5/30/2025
1495	Radio - Mobile	Halfway River *near* Chowade	*nd*	*nd*	FALSE	4/27/2025
758	Radio - Fixed	Chowade River	8/8/2023	9/28/2023	TRUE	3/19/2023
1048	Radio - Fixed	Chowade River	6/9/2023	9/20/2023	FALSE	11/20/2024
1269	Radio - Fixed	Chowade River	6/27/2023	*nd*	FALSE	4/9/2025
422	PIT - Fixed	Chowade River	*nd*	*nd*	TRUE	3/19/2022
568	PIT - Fixed	Chowade River	*nd*	*nd*	TRUE	3/14/2022
635	PIT - Fixed	Chowade River	*nd*	*nd*	TRUE	4/18/2022
747	PIT - Fixed	Chowade River	*nd*	*nd*	TRUE	1/4/2022
840	PIT - Fixed	Chowade River	*nd*	*nd*	TRUE	4/7/2023
880	PIT - Fixed	Cypress Creek	*nd*	*nd*	TRUE	4/11/2023
940	PIT - Fixed	Chowade River	*nd*	*nd*	TRUE	4/23/2023
941	PIT - Fixed	Chowade River	*nd*	*nd*	TRUE	3/6/2023
1160	PIT - Fixed	Chowade River	*nd*	*nd*	FALSE	4/1/2024
1193	PIT - Fixed	Chowade River	4/8/2023	*nd*	FALSE	3/24/2024
1518	PIT - Fixed	Cypress Creek	8/31/2023	10/18/2023	FALSE	5/29/2024

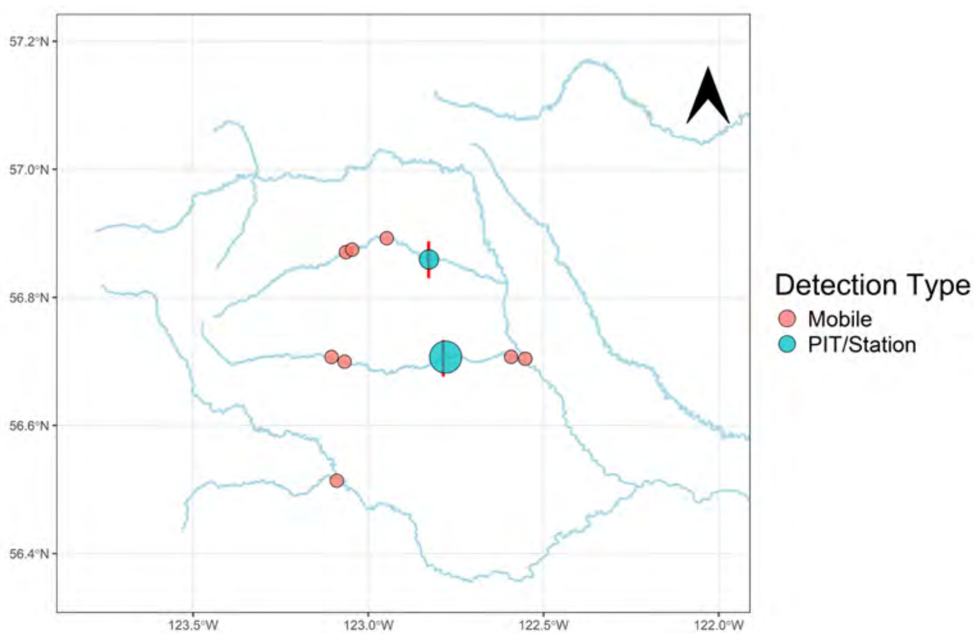

Figure 18. Potential Bull Trout spawning locations in the Halfway River watershed during the 2023 spawning season (August/September). Size of points indicate the number of individual fish detected on the PIT array or radio fixed-stations (PIT/Station). For the Cypress Creek PIT/radio fixed-station there were two individual fish detected in 2023 while Chowade River yielded 12 individuals detected in 2023. All mobile detection points represent one fish.

Halfway River Spawning Site Fidelity

Out of the 324 adult Bull Trout monitored over multiple August-September spawning seasons, 77 were detected within the upper Halfway River during that time frame. This area is defined as the mainstem Halfway River and its tributaries upstream of the Cameron River confluence (see Figure 18). Of these 77 individuals, 26 were tracked across two or more spawning seasons, with 16 specifically detected in the Upper Halfway River during multiple spawning seasons. (Table 13, Figure 19, Figure 20).

Bull Trout determined to have site fidelity were detected in the upper Halfway River within overlapping 5km circular zones during two or more spawning seasons (Figure 19). Among the 16 Bull Trout tracked within the upper Halfway River over two or more spawning seasons, the majority (n = 12) demonstrated site fidelity across study years (Figure 19). The remaining four Bull Trout did not exhibit site fidelity within the upper Halfway River and were detected in different regions of the area during subsequent spawning seasons (Figure 20). Site fidelity was most frequently observed in the Chowade River (n = 9), followed by the mainstem Halfway River (n = 2) and Cypress Creek (n = 1).

In contrast, 12 individual Bull Trout displayed potential skip-spawning behavior at least once (Table 13, Figure 19-20). Among these, 10 exhibited a single potential spawn in the upper Halfway River in addition to one (or more) potential skip-spawns outside of this area (Figure 21). One Bull Trout (Tag_ID 941) showed both site fidelity and a skip-spawn (Figure 19), while another (Tag_ID 1139) recorded two potential skip-spawns along with two detections in different regions of the Upper Halfway River (Figure 20, Table 13).

In total, 14 potential skip-spawn events (24%) were recorded, compared to 44 potential spawning events (76%). Three of the skip-spawn events were based on detections at the Pine River fixed station during the Bull Trout spawning season (Table 13). Although the Pine River is a known spawning site for Peace River Bull Trout (Mainstream 2012), genetic analysis from Geraldes et al. 2022 confirmed that none of these three Bull Trout were of Pine River or mixed origin.

It's important to recognize that these results may not fully represent the entire study area, as detection coverage is uneven. For instance, PIT arrays and fixed radio stations on the Chowade River and Cypress Creek enhance detection capacity in these locations, while the rest of the upper Halfway River relies solely on mobile tracking surveys. Similarly, in the Pine River, only the river mouth is monitored by a fixed station, limiting the ability to detect upstream movements. Lastly, this analysis is based solely on Bull Trout detection histories within known and probable spawning regions; therefore, presence in these areas does not necessarily confirm spawning activity, and absence of detection does not definitively indicate that the individual skip-spawned that year.

Table 13. Spawning season (August-September) detection locations for Bull Trout that were in the Halfway River upstream of the Cameron River confluence during more than one study year. Individual Bull Trout are organized by the 'Site Fidelity' column which divides fish into six categories: site fidelity in Chowade River, in Cypress Creek, in Halfway River, across multiple sites within the Halfway River, across Halfway & Pine Rivers, and outside Upper Halfway River (i.e., fish was detected in a Upper Halfway River during a spawn season/year and then detected outside during another spawn season/year). "*nd*" indicates that the fish was not detected during the spawning season. Dashes indicate that the fish was not being tracked (before release, or after transmitter battery death / recovery). "Rx" is receiver, "*ups*" is upstream, "*dns*" is downstream. *Note that all of these Bull Trout listed in this table were determined to be of Halfway River origin, no mixed ancestry or Pine River origin individuals (Geraldes 2022).*

Tag_ID	Site Fidelity	2020	2021	2022	2023
613	*in Chowade River*	Chowade River	Chowade River	Chowade River	-
635	*in Chowade River*	Chowade River	Chowade River	*nd*	-
747	*in Chowade River*	-	Peace River	Chowade River	Chowade River
758	*in Chowade River*	-	Chowade River	Chowade River	Chowade River
769	*in Chowade River*	-	Chowade River	Chowade River	*nd*
940	*in Chowade River*	-	-	Chowade River	Chowade River
941	*in Chowade River*	-	Chowade River	Halfway River *near* Rx2	Chowade River
1048	*in Chowade River*	-	-	Chowade River	Chowade River
1165	*in Chowade River*	-	-	Chowade River	Chowade River
437	*in Cypress Creek*	Cypress Creek	Cypress Creek	*nd*	*nd*
809	*in Halfway River*	-	Fiddes Creek	Halfway River *near* Fiddes Creek	*nd*
768	*in Halfway River*	-	Halfway River *dns* Graham River	Halfway River *dns* Graham River	*nd*
880	*multiple sites in Halfway River*	-	Chowade River	Cypress Creek	*nd*
898	*multiple sites in Halfway River*	Chowade River	Halfway River *ups* Cypress Creek	*nd*	-
1004	*multiple sites in Halfway River*	-	-	Halfway River *dns* Graham River	Cypress Creek
1139	*multiple sites in Halfway River*	Chowade River	Peace River	Graham River	Pine River
513	*across Halfway & Pine Rivers*	Halfway River *ups* Cypress Creek	Pine River	*nd*	*nd*
1107	*across Halfway & Pine Rivers*	-	-	Cypress Creek	Pine River
476	*outside Halfway River spawning area*	Peace River	Chowade River	*nd*	Peace River
549	*outside Halfway River spawning area*	Halfway River *ups* Cypress Creek	Halfway River *near* Rx2	*nd*	-
568	*outside Halfway River spawning area*	Peace River	Peace River	*nd*	Chowade River
813	*outside Halfway River spawning area*	-	Peace River	Cypress Creek	*nd*
840	*outside Halfway River spawning area*	-	Peace River	*nd*	Chowade River
948	*outside Halfway River spawning area*	Chowade River	*nd*	*nd*	Peace River
1160	*outside Halfway River spawning area*	-	-	Peace River	Chowade River
1193	*outside Halfway River spawning area*	-	-	Peace River	Chowade River

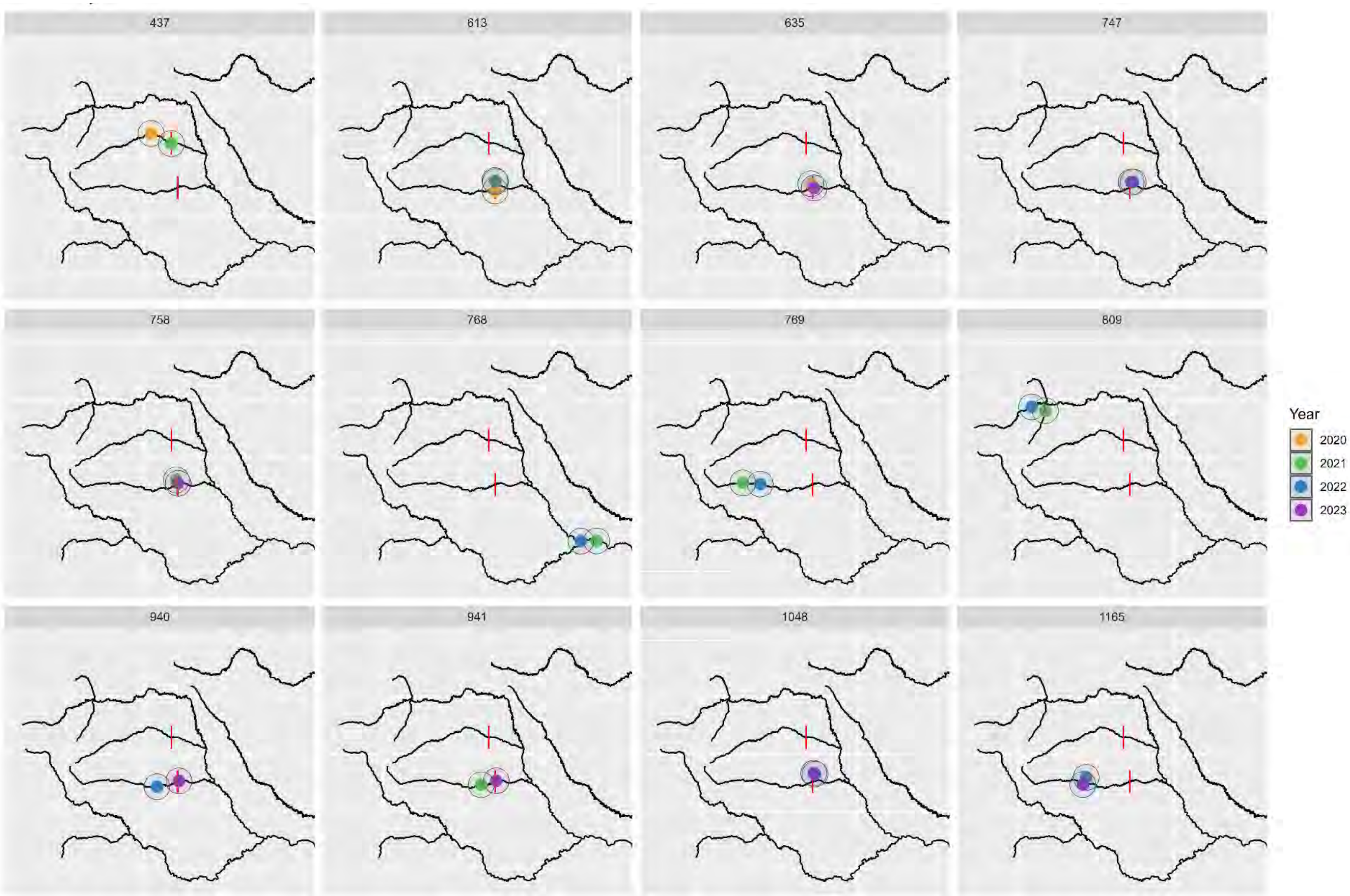

Figure 19. Tagged Bull Trout detections in August and September across years that suggest site fidelity within the Upper Halfway River (i.e., upstream of the Cameron River) based on 5KM buffer. Red lines show PIT and radio fixed radio stations on Chowade and Cypress. Detections outside the Upper Halfway River and outside of the spawning season (Aug/Sep) are not shown.

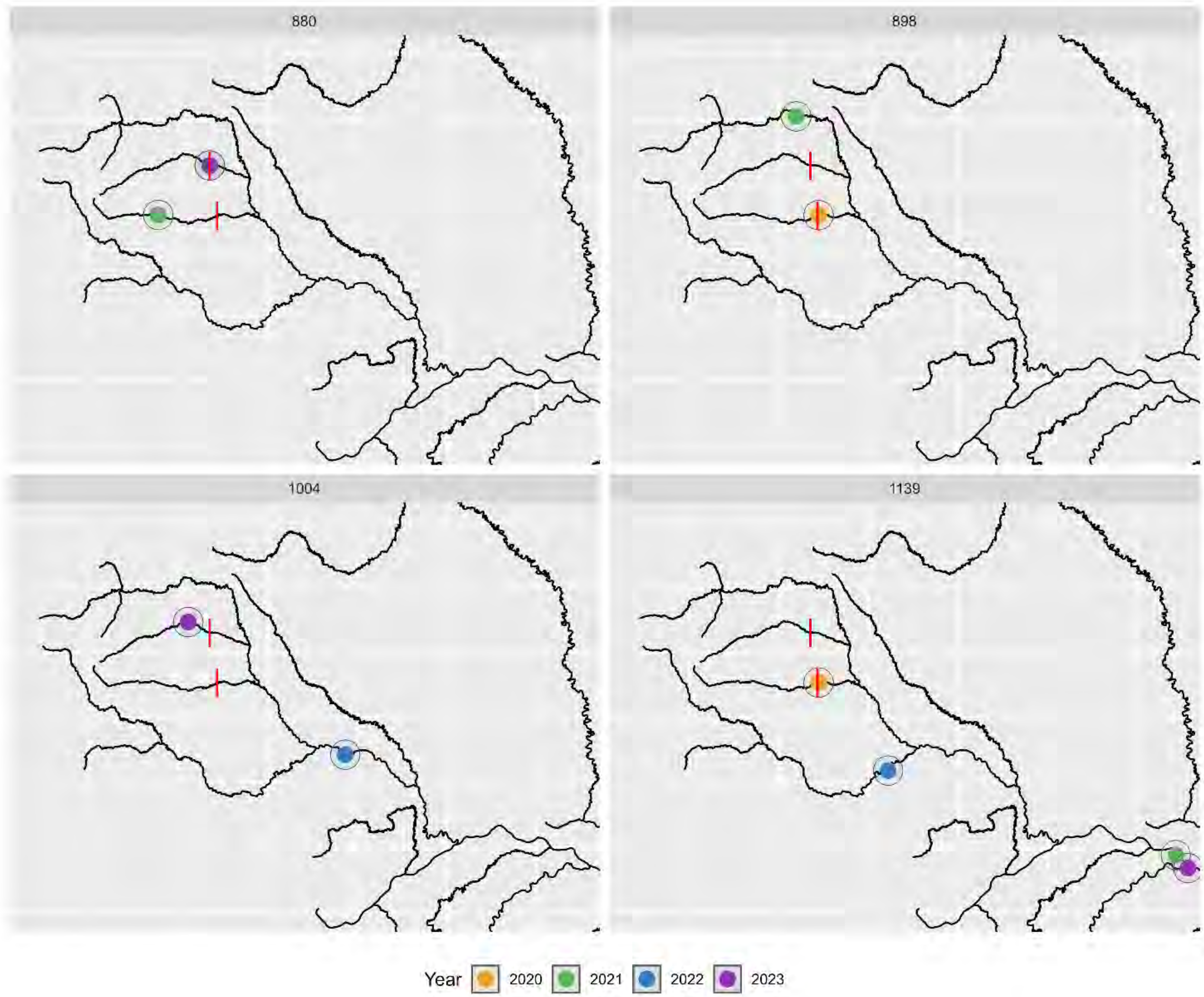

Figure 20. Tagged Bull Trout detections in August and September across years that suggest a lack of site fidelity within the Upper Halfway River (i.e., upstream of the Cameron River) based on 5KM buffer. Red lines show PIT and radio fixed radio stations on Chowade and Cypress. Detections outside of the spawning season (Aug/Sep) are not shown.

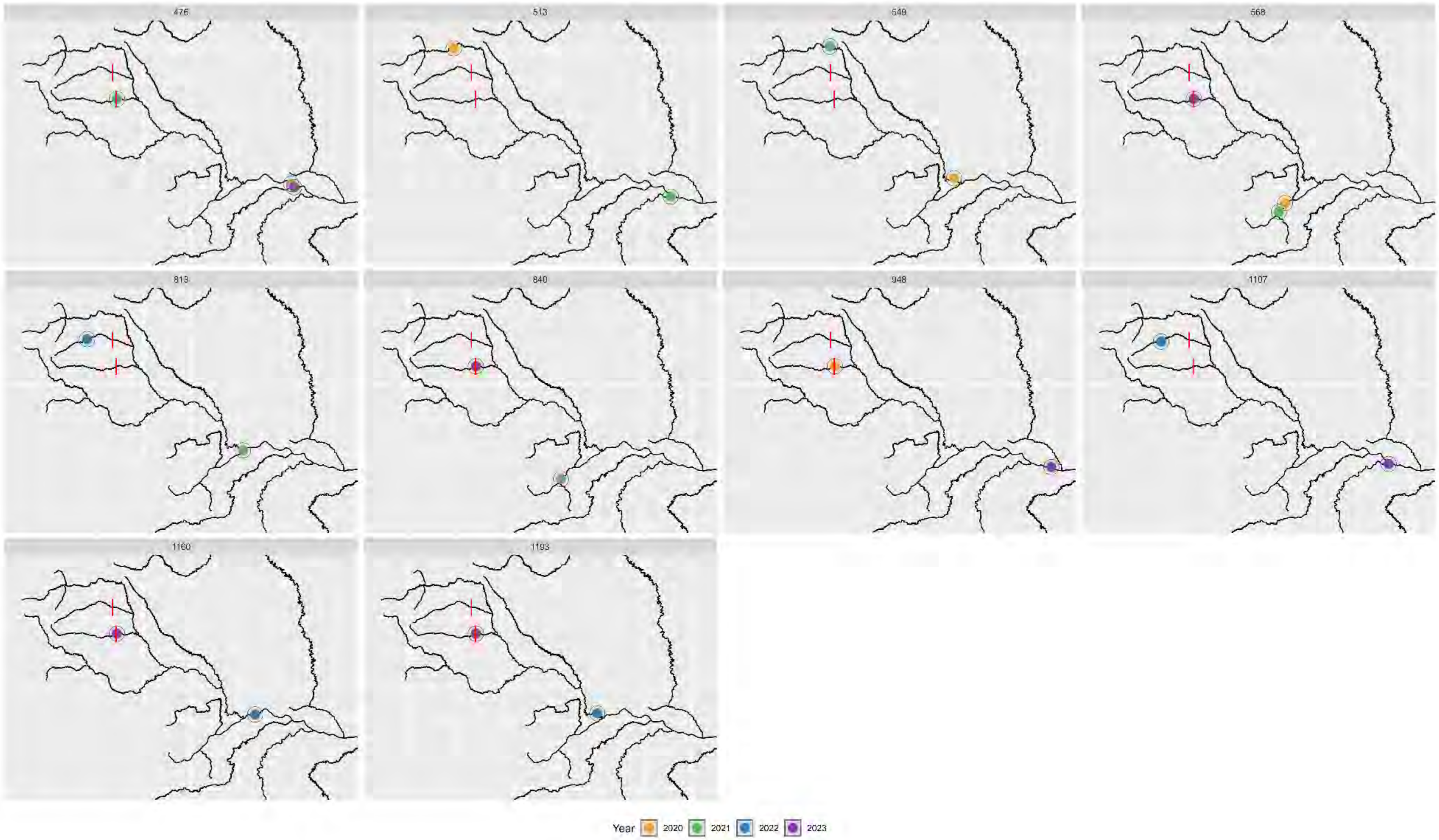

Figure 21. Tagged Bull Trout detections in August and September for individuals with at least one detection within the Upper Halfway River (i.e., upstream of the Cameron River) as well as at least one detection outside of the Upper Halfway River across study years. Red lines show PIT and radio fixed radio stations on Chowade and Cypress. Detections outside of the spawning season (Aug/Sep) are not shown.

Site C River Diversion Analysis

The number of successful passage events through the dam site varied by species before and after river diversion (Figure 22), with the majority being completed by Bull Trout. Upstream movements by radio-tagged Walleye stopped following river diversion, as Walleye captured at the TUF are no longer transported upstream of the Project (BC Hydro 2020). Since diversion, only one radio-tagged Arctic Grayling has been detected passing upstream of Site C; however, it appears this individual shed its radio tag. This conclusion is based on this tag being detected at regular intervals on the same Site C fixed station since 21 August 2023, which suggests the tag is lying on the riverbed outside of the fish or within the remaining carcass. However, the same Arctic Grayling was detected passing through the TUF via PIT detection on 6 October 2023, further indicating a shed radio tag and not a mortality.

Rainbow Trout exhibited similar passage frequencies both before and after the diversion, while only one Burbot was recorded with downstream movement in 2019, followed by subsequent upstream movement in 2020. Likewise, Mountain Whitefish passage events were only recorded after the diversion, due to the limited number of study fish available for tracking before that event.

Following river diversion, it was anticipated that fish behavior would change as species interacted with the Project (BC Hydro 2015). One behavioral pattern analyzed was the tendency for study fish to move upstream towards Site C, then downstream to Peace River 5, before returning upstream to Site C. For all radio-tagged species (except Burbot), the proportional rate of this behavioral pattern increased by 2- to 8-fold when comparing pre- and post-diversion tracking data (Figure 23).

Given the substantial number of Bull Trout passage events recorded both before and after river diversion, and the known use of this corridor (Peace River 6 to Site C Dam, Figure 5) for migration, travel times were calculated specifically for this species (Figure 24). Before river diversion, upstream movements through this corridor varied significantly among individual passage events (range = 0.6 to 267.9 days, median = 13.5 days), with over 50% of events occurring within a few days. After the diversion, upstream movements remained highly variable but were generally longer in duration, with some events taking significantly more time (range = 5.6 to 390.5 days, median = 132.1 days). In contrast, downstream movements by Bull Trout remained dominated by rapid events both before and after the diversion (Figure 24). The primary difference was in the slower movements, where the slowest migrant took 19.4 days before the diversion compared to 282.9 days after.

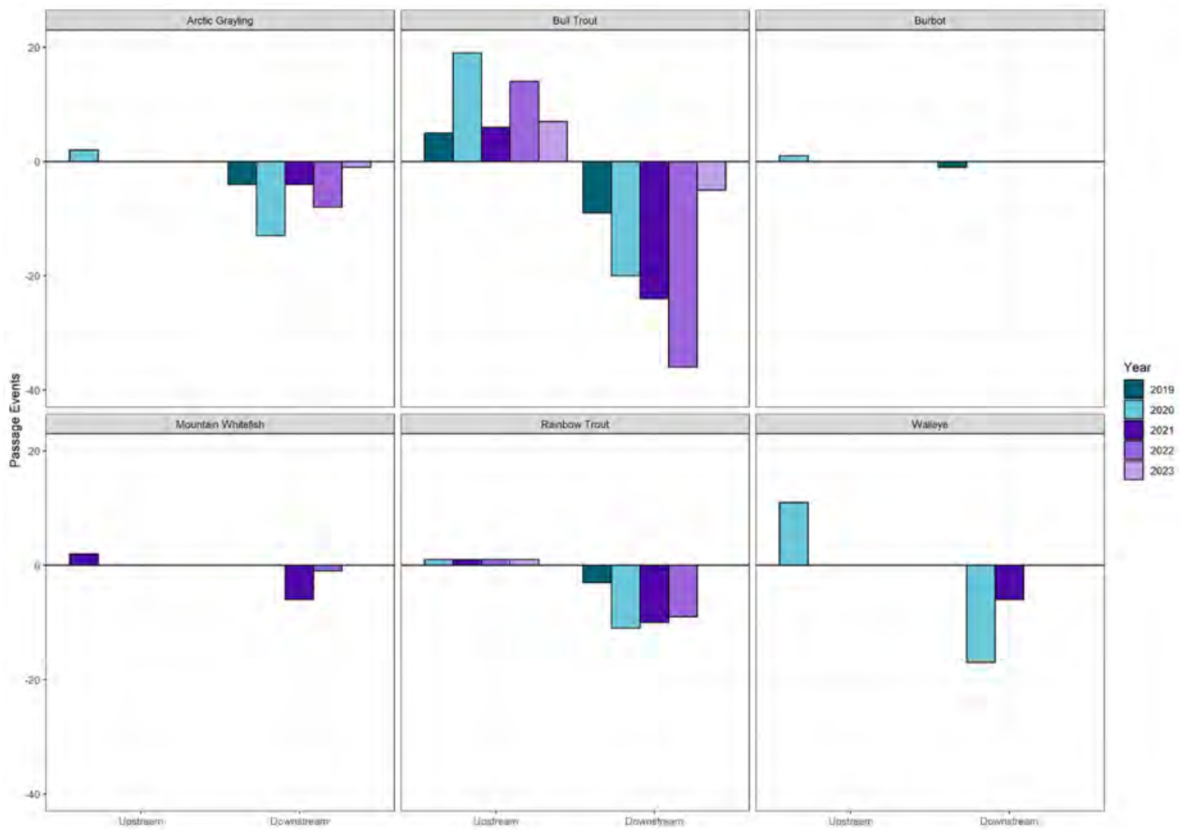

Figure 22. **Quantity of Site C passage events by species and study year from 2019-2023. Before river diversion is depicted in teal (2019-2020) and after river diversion in purple (2021-2023).**

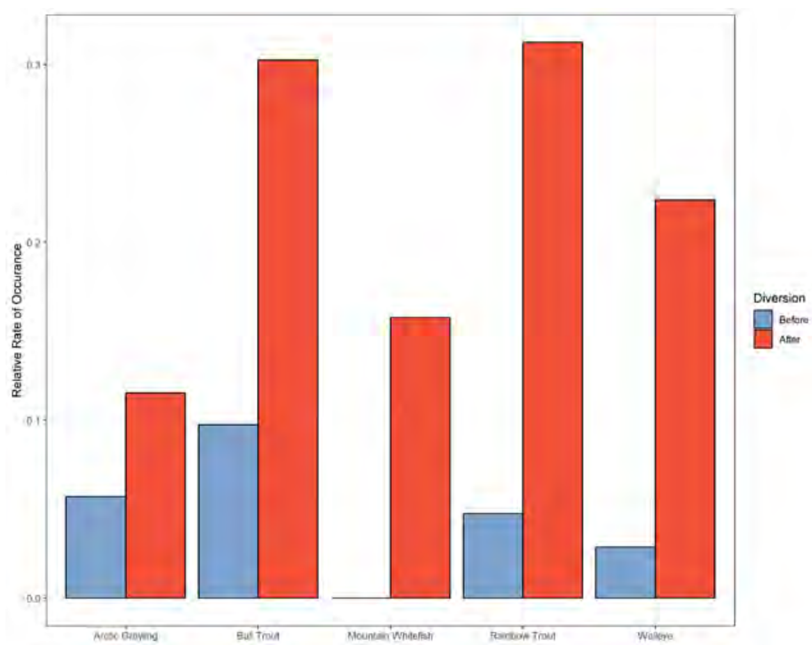

Figure 23. **Relative rate of occurrence for approach-retreat-reapproach behaviours (Site C- Peace River 5 – Site C) by species before and after diversion.**

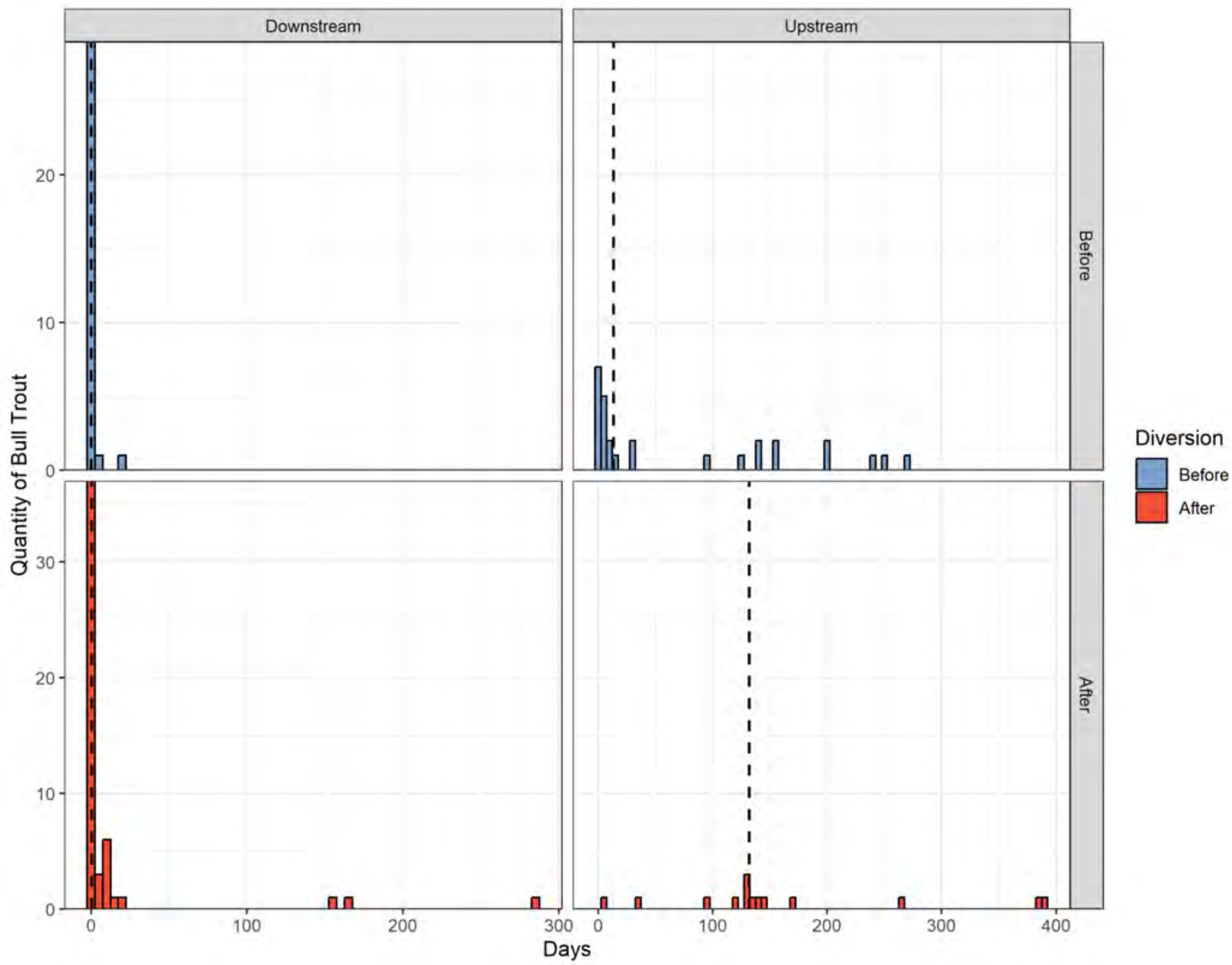

Figure 24. **Histograms of Bull Trout travel times through the Site C Project before and after river diversion in October 2020, separated by movement direction with dotted lines showing the median travel time.**

Discussion

Study Objectives

The objective of the Site C Fish Movement Assessment (Mon-1b, Task 2d) is to collect telemetry data that can determine the magnitude, direction, and seasonal variability of movements from key indicator species in the Peace River and its tributaries. To accomplish this, a fixed radio telemetry array was operated along the Peace River and many of its tributaries in 2023.

The fixed radio telemetry array is intended to operate during the construction[45] and operation[46] of the Project, and will compliment the baseline studies conducted from 1996-1999[47] and 2005-2009[48]. The telemetry data from the 2023 study year contributes to the ever-growing data resource that can be leveraged by BC Hydro to address management questions across various monitoring programs and tasks as the Project transitions from construction to operations.

The telemetry array in 2023 consisted of 34 fixed-stations that collected nearly 18 million valid detections while operating over 93% of the intended study period. Range testing in 2023 yielded a median 50% detection range of 435 m (range: 80 to >750 m)[49] and the median detection efficiency of analyzable fixed-stations was 91% (range: 61-100%). All of these results were within the operational expectations that define a successful collection period. The magnitude, direction, and seasonal variability of movements from key indicator species were summarized and plotted to generalize seasonal movement trends and highlight the capacity of the fixed-station array for more specific analyses.

The objective of the Peace River Arctic Grayling and Bull Trout Movement Assessment (Mon-1b, Task 2a) is to determine the magnitude, direction, and seasonality of Arctic Grayling and Bull Trout movements within the Peace River, Site C Reservoir, and tributaries, to help evaluate the effects that the Project may have on these metrics, and to inform various other monitoring programs. In 2023, Moberly River mobile surveys were not conducted, and the operation of the fixed radio telemetry array (Mon-1b, Task 2d) was the primary contributor to evaluating the timing, direction, and magnitude of Arctic Grayling movements into, within, and out of the Moberly River in May and June.

Bull Trout movements in the Halfway River in August and September 2023 were monitored using the fixed radio telemetry array (Mon-1b, Task 2d) and PIT telemetry array (Mon-1b Task 2b) in conjunction with two multi day fixed wing mobile tracking surveys in September. The telemetry data produced useful information about the timing, direction, and magnitude of Bull Trout movements into, within, and out of the Halfway River watershed in 2023. All the datasets and subsequent analyses added to the growing depth of knowledge for pre-operational Site C Bull Trout and Arctic Grayling behaviours that will be a useful for comparison with data from after reservoir filling.

Management Questions

Since July 2019, there have been 1184 radio-tagged Arctic Grayling (n= 86), Bull Trout (n=479), Burbot (n= 30), Mountain Whitefish (n= 75), Rainbow Trout (n= 264), and Walleye (n= 250) released into the Peace River and its tributaries. From these 1184 radio-tagged study fish, the fixed radio telemetry array and mobile tracking efforts have collected over 75 million valid detections across hundreds of kilometres of the Peace River and its

[45] Construction Years 5 to 10 (2019-2024).

[46] Operation Years 1-5 (2024-2028), 10-11 (2034-2035), 15-16 (2039-2040), 20-21 (2044-2045), 25-26 (2049-2050) and 29-30 (2053-2054).

[47] BC Ministry of Environment from 1996-1999 (Burrows et al. 2001, AMEC & LGL 2010b)

[48] AMEC and LGL from 2005-2009 (AMEC & LGL 2008a, b, 2009, 2010a)

[49] Calculated as the 50% logistic inflection point during the range test analysis.

tributaries. These data build on the telemetry data collected from 1996 to 1999 and 2005 to 2009, and are intended to answer and provide guidance across a myriad of management questions outlined in the FAHMFP[50].

Data collection is ongoing, and some management questions will be better answered at a later date. The questions detailed below were carefully curated as subjects that can be addressed (or at least partially addressed) with the data available at the time of writing this report. Further, information on these questions could assist immediate management decisions and guide ongoing monitoring under the FAHMFP.

Site C River Diversion and Passage Analysis

Fish movement patterns through the Site C Project corridor were analyzed before and after river diversion to assess Project effects during construction and to complement the Site C Fishway Effectiveness Monitoring Program (Cook et al. 2024). Notably, post-diversion data revealed a 2-8 fold increase in the frequency of a particular movement pattern, where a fish approaches the Site C dam array (located just downstream of the Project), retreats downstream to the Peace River 5 station (located 9 rkm downstream of the Project), before re-approaching the Site C dam array. This pattern could potentially be characterized as an exploratory passage behavior, where fish assess passage conditions by advancing and retreating multiple times (Martins et al. 2014).

This finding complements the Mon-13 results while offering insights at a broader spatial and temporal scale. In Mon-13, the approach-retreat-reapproach behavior exhibited by Bull Trout, Mountain Whitefish, and Rainbow Trout was identified as a significant factor in their time-to-event models (referred to as the naïve variable in Cook et al. 2024), albeit at a smaller spatial scale around the passage facility.

Since operations began in 2020, the temporary passage facility has not met the target passage benchmarks, with passage efficiency ranging from 0-4% across all target species. The increased frequency of this movement pattern may reflect a study fish's difficulty in successfully passing through the facility. However, it's important to consider that fish approaching Site C post-diversion may not always be attempting to pass; this behavior could also be related to feeding, as food availability may be higher near the outlet of the diversion tunnels.

Bull Trout migration rates through the Site C corridor of the Peace River were plotted and compared before and after river diversion. As expected, the biggest deviation between Bull Trout migration rates before and after diversion was in the upstream direction. More specifically, there were fewer Bull Trout that quickly migrated upstream of the Project following river diversion. That said, the prevalence of Bull Trout that migrated this corridor very slowly (i.e., > 150 days) was similar before and after diversion.

Species-specific Management Questions

Arctic Grayling

In regard to Arctic Grayling, the management questions revolve around Moberly River spawning behaviours: 1) How many fish moved in/out of the Moberly River, and where in that tributary might spawning be occurring? 2) What proportion of Arctic Grayling in the Moberly River spawn upstream versus downstream of the inundation zone approximated at 12 RKM upstream from the current river mouth? 3) Will Arctic Grayling from the Moberly River move into the Site C Reservoir, or into areas downstream of Site C?

In 2023, no radio-tagged Arctic Grayling were tracked entering the Moberly River during the spawning season, but this was almost certainly a sample size issue (only 5 fish were tracked, and all were downstream of Site C),

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[50] Site C Fisheries and Aquatic Habitat Monitoring and Follow-up Program available at https://www.sitecproject.com/document-library/environmental-management-plans-and-reports.

and is therefore not representative of the use of the Moberly River in 2023 by the untagged population at large. As such, further progress toward addressing the Arctic Grayling management questions was not made using 2023 telemetry data.

All radio tagging is conducted under the Peace River Large Fish Indexing Program (Mon-2, Task 2a), which has reported declines in Arctic Grayling catch rates throughout the Peace River (WSP 2024). These declines have translated into missed tagging quotas for Arctic Grayling: for example, in 2023, only eight Arctic Grayling were radio-tagged despite a quota of 30 fish. In 2024, radio tagging efforts will aim to use the TUF, which successfully passed 89 Arctic Grayling in 2023, therefore serving as an additional resource to meet Arctic Grayling tagging quotas moving forward.

Since river diversion, only one radio-tagged Arctic Grayling has been detected passing upstream of the Site C Project via the TUF or the contingency electrofishing program. However, the detection history suggests that this fish likely shed its radio tag before moving upstream.

Bull Trout

The Bull Trout management questions that were addressed with the inclusion of the 2023 telemetry data were: 1) Are Bull Trout exhibiting skip spawn behaviours? 2) Are Bull Trout that have spawned in the Halfway River returning to the same tributary to spawn in future years?

A total of 26 Bull Trout were detected in the upper Halfway River during at least one spawning season and tracked across two or more spawning seasons. Among these, 12 individuals showed potential skip-spawning behavior at least once. From those individual Bull Trout, a total of 14 potential skip-spawn events (24%) were recorded, compared to 44 potential spawning events in the Halfway River (76%). Three of the potential skip-spawn events were based on detections at the Pine River fixed station during the Bull Trout spawning season. Although the Pine River is a known spawning site for Peace River Bull Trout (Mainstream 2012), genetic analysis (Geraldes et al. 2022) indicated that none of these three Bull Trout were of Pine River or mixed origin (Pine and Halfway). Since these fish were only detected at the mouth of the Pine River, it cannot be conclusively assumed that they were spawning there.

Since 2019, 16 unique Bull Trout have been detected in the upper Halfway River over multiple spawning seasons. Of these, 12 (75%) exhibited site fidelity across study years, while the remaining 4 (25%) were detected in different areas of the upper Halfway River, indicating a lack of site fidelity. However, these findings are based solely on detection histories, meaning they confirm presence in potential spawning grounds during known spawning seasons but do not definitively confirm spawning activity.

Burbot

No Burbot management questions were addressed with the inclusion of the 2023 telemetry data.

Mountain Whitefish

Mountain Whitefish represent the most abundant large fish species sampled in the Peace River (Mainstream Aquatics 2012). As such, Mountain Whitefish population abundance is a valuable indicator for examining interactions between fish capture and environmental covariates (ESSA 2020). Results from the Peace River Large Fish Indexing (Mon-2, Task 2a) have documented declining Mountain Whitefish catch rates since 2018 in all sampling sections within the Peace River (WSP 2024). Reasons for this apparent decline are not known, however since river diversion in October 2020, Mountain Whitefish downstream of the Project have not been able to access upstream sections of the Peace River without the assistance of the TUF or through contingent electroshocking surveys.

The first management question was to ask if an exploratory analysis of the telemetry data could identify any behavioural trends that might help address why Mountain Whitefish catch rates are declining, or if river diversion has affected Mountain Whitefish behaviour. The second management question was an extension from what was provided in Hatch et al. (2022), asking 'where do radio-tagged Mountain Whitefish spawn'?

Meaningful comparisons of Mountain Whitefish movements from before versus after river diversion were not possible, both because of sample size issues and due to variation in release locations. Sample sizes limited the comparisons that could be made using the present dataset, as there were only four fish tagged prior to river diversion that certainly survived the tagging process (28 were tagged in August 2020 prior to diversion, of which 15 were never detected and another 9 were only detected moving in a downstream direction, possibly indicating tagging-induced mortality). By contrast, 32 Mountain Whitefish certainly survived the tagging process after diversion (47 were tagged in September 2021, of which two were never detected and 13 only moved downstream).

Differences in release locations and tracking methods created limitations when comparing the Mountain Whitefish tagged in 2021 after diversion to those tagged in 2006 before diversion. Most of the Mountain Whitefish that were tracked post-diversion were released downstream of Site C (27 of 32), whereas the fish tagged in 2006 were mostly released upstream of where Site C is now located (102 of the 111 fish that certainly survived tagging). As such, comparisons of the counts or proportions of fish moving past Site C would be inappropriate. Moreover, since the detection data from the 2006-2007 studies were largely based on mobile tracking (AMEC and LGL 2008b), measures of travel speed derived from these data are not directly comparable to those estimated from the data generated from the current fixed-station receiver array.

Despite the data limitations, 28 radio-tagged Mountain Whitefish could be analyzed to evaluate individual spawning behaviours (8 released in 2006, 2 released in 2020, and 18 released in 2021). Among these, 44 potential spawning events were detected, with the majority occurring in a corridor that extends downstream of the Project into the mouth of the Pine River (n= 31). In the present data (after river diversion), 10% of Mountain Whitefish were detected upstream of Site C during at least one spawning season, which is in contrast to the 25% from the historical (before diversion) dataset. This difference may be an artefact of low sample sizes and the large variability of individualistic movement patterns exhibited by Mountain Whitefish in this dataset, which has been noted by Boyer (2016), Hook et al. (2016), and Harrison et al. (2019).

Rainbow Trout

No Rainbow Trout management questions were addressed with the inclusion of the 2023 telemetry data.

Walleye

No Walleye management questions were addressed with the inclusion of the 2023 telemetry data.

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Appendices

Appendix A. Spatial Distributions of Fish Releases

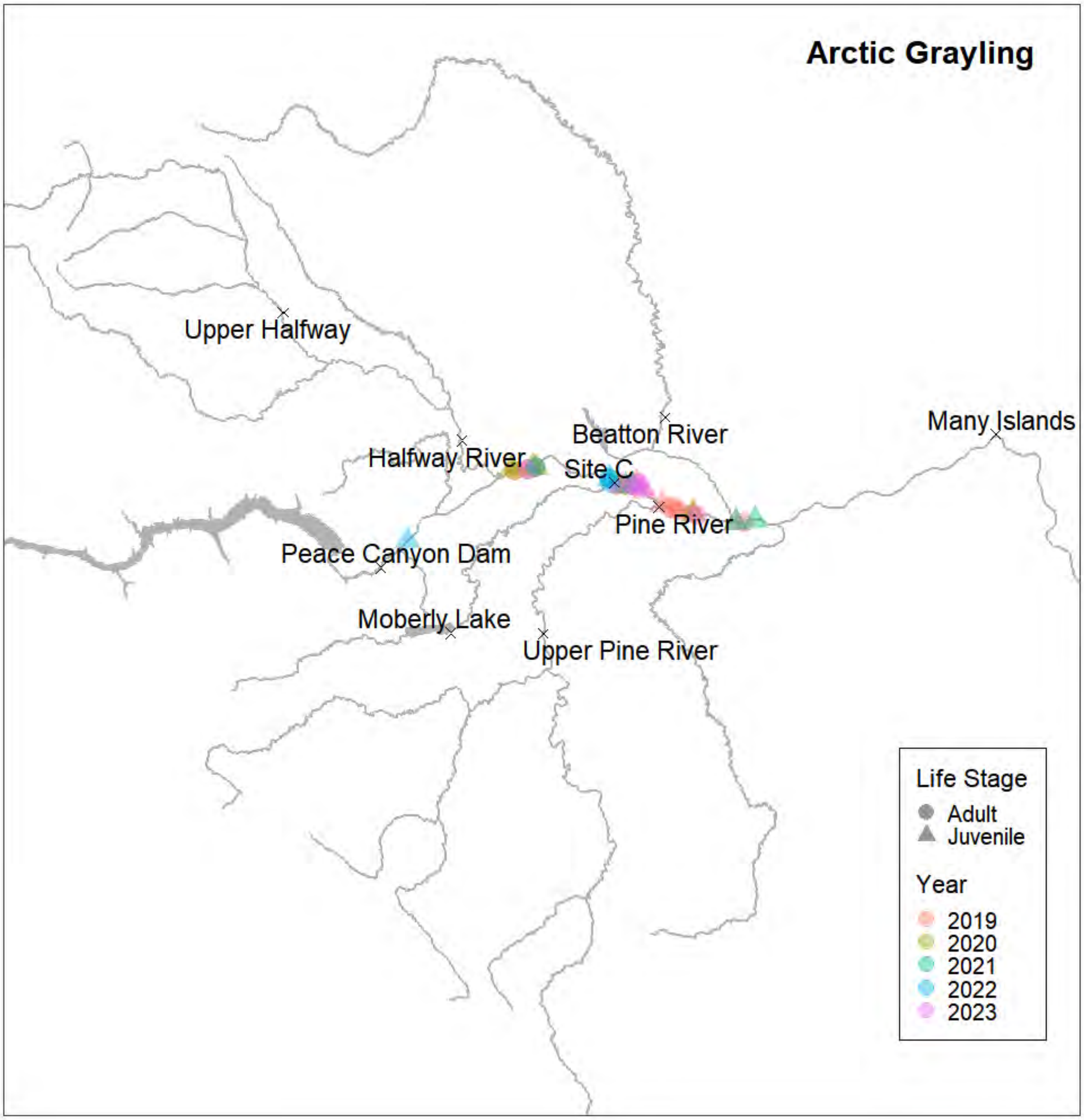


Figure A1. **Arctic Grayling release locations and points of reference (×) from the present dataset (2019 to 2023). Juvenile fish are depicted as triangles, adults depicted as circles. Point colours indicate year of release.**

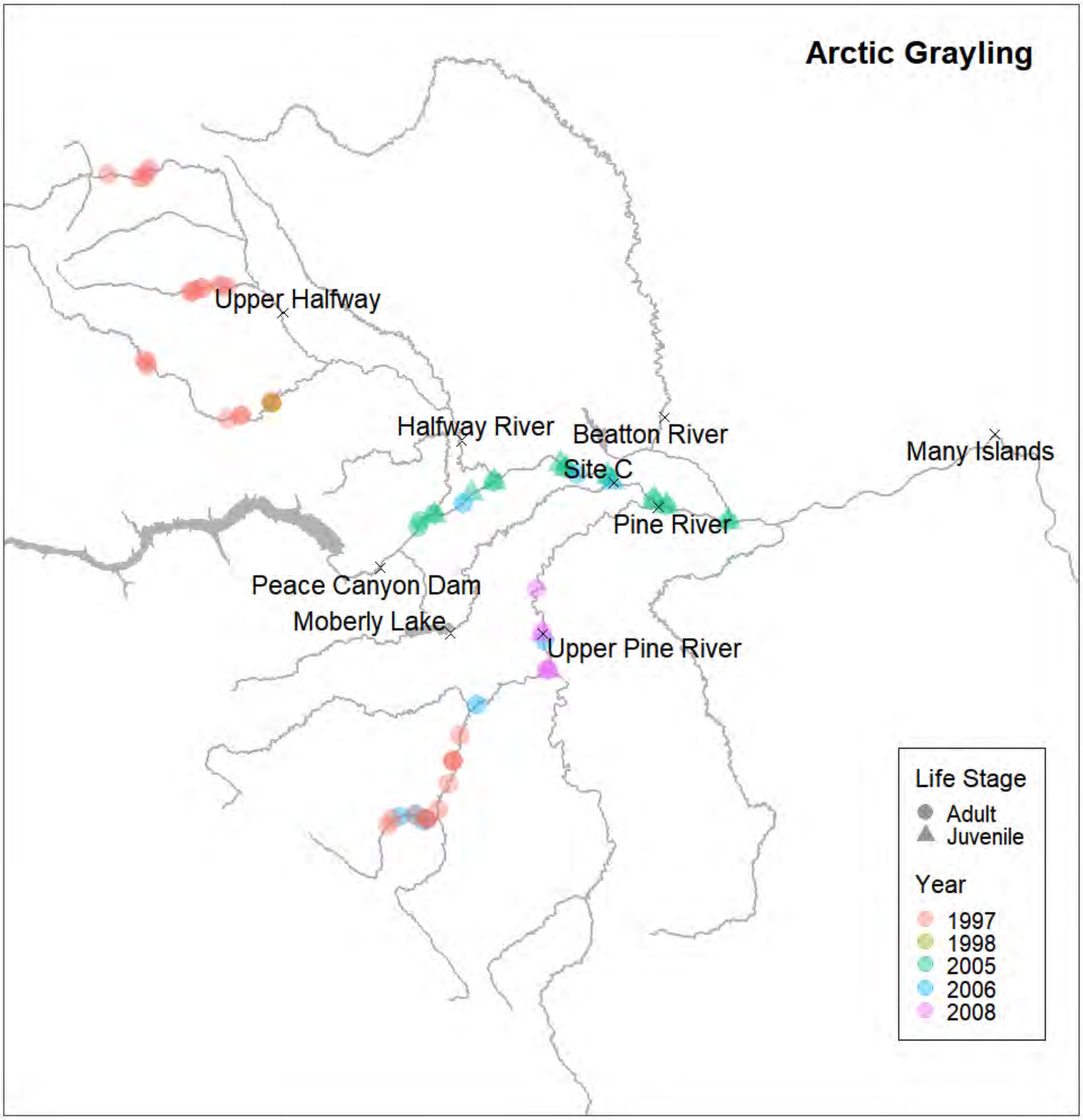


Figure A2. **Arctic Grayling release locations and points of reference (×) from the historical dataset (1996 to 1998 and 2005 to 2008). Juvenile fish are depicted as triangles, adults depicted as circles. Point colours indicate year of release.**

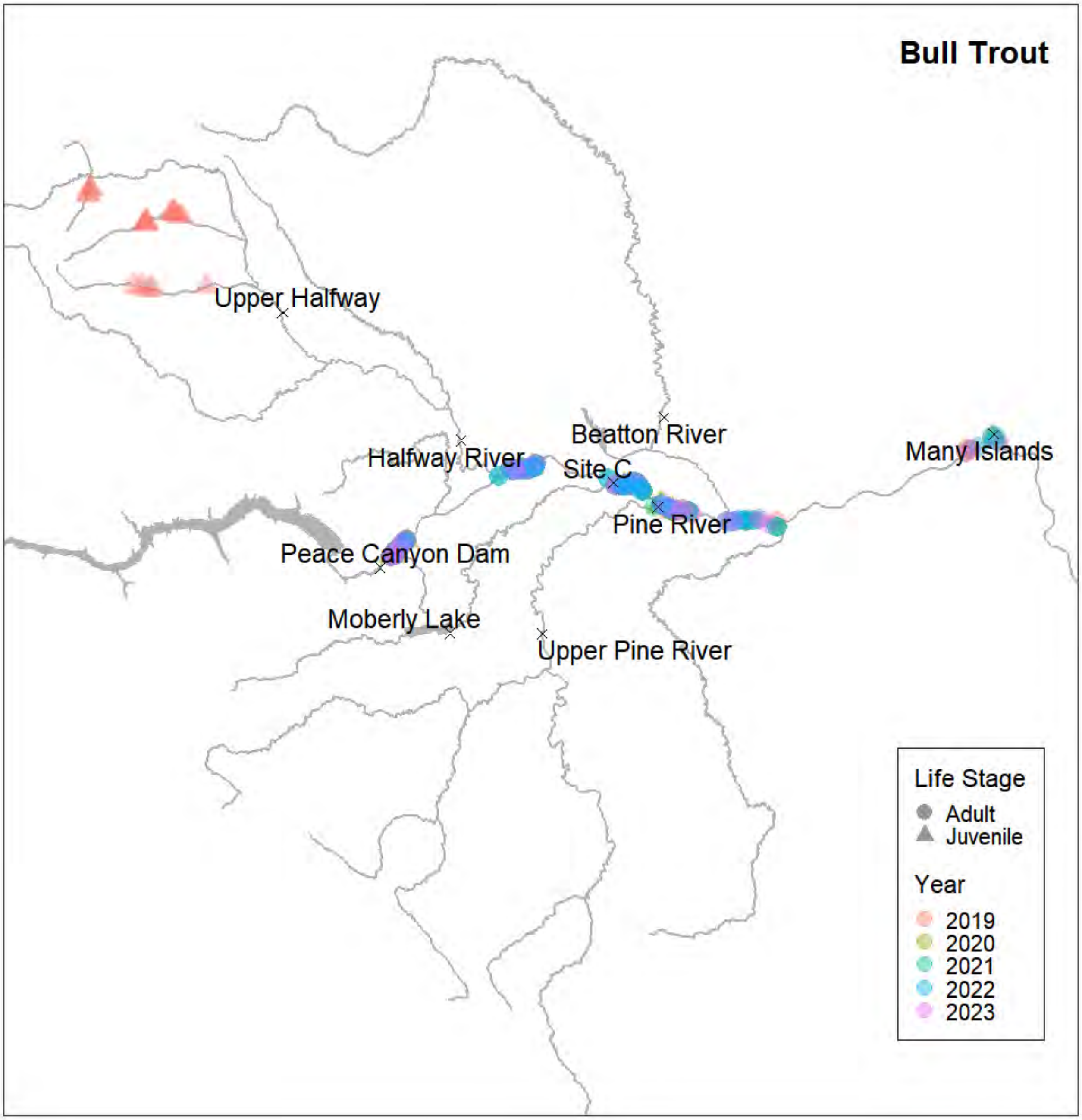


Figure A3. Bull Trout release locations and points of reference (×) from the present dataset (2019 to 2023). Juvenile fish are depicted as triangles, adults depicted as circles. Point colours indicate year of release.

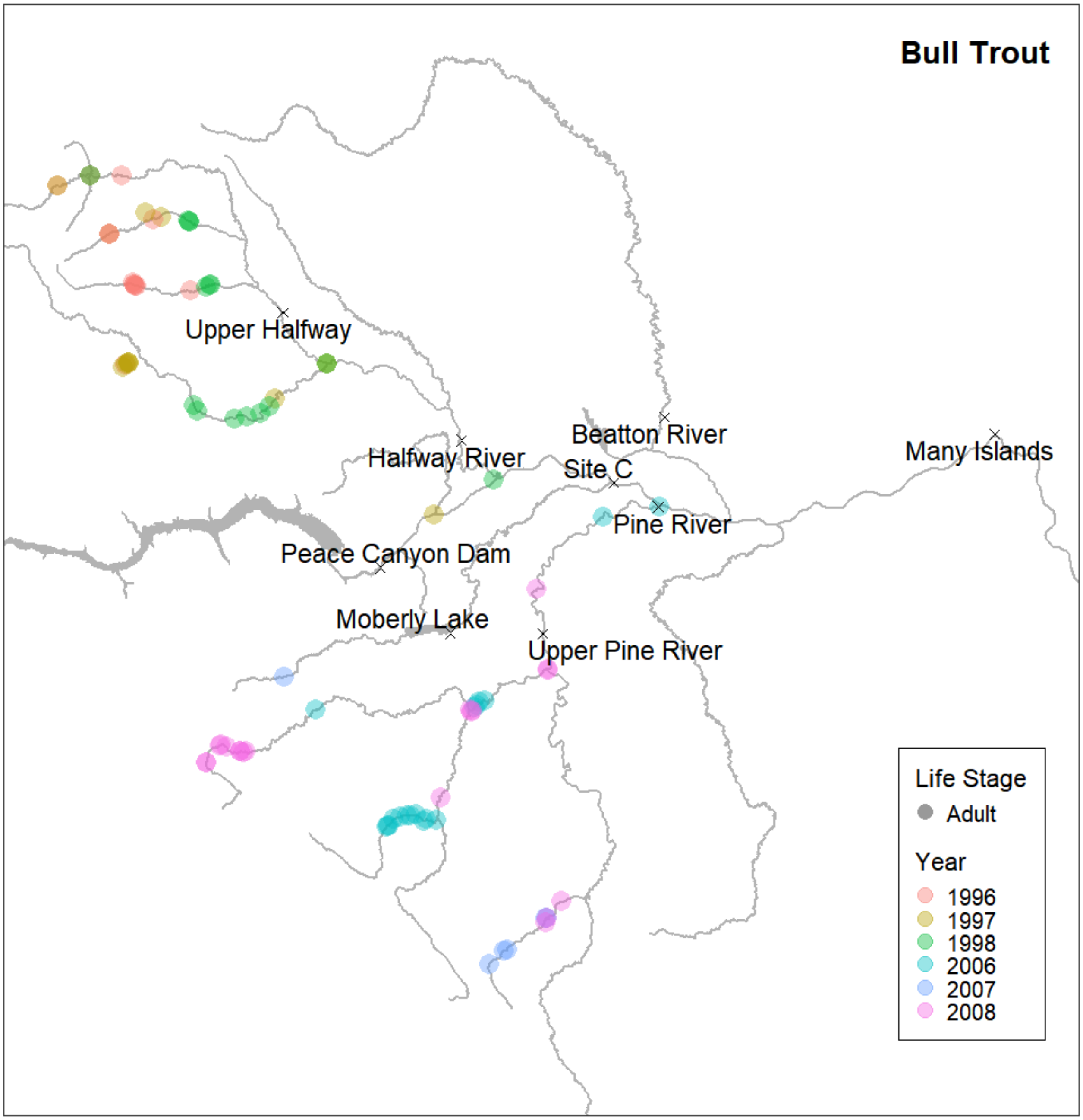


Figure A4. **Bull Trout release locations and points of reference (×) from the historical dataset (1996 to 1998 and 2005 to 2008). Juvenile fish are depicted as triangles, adults depicted as circles. Point colours indicate year of release.**

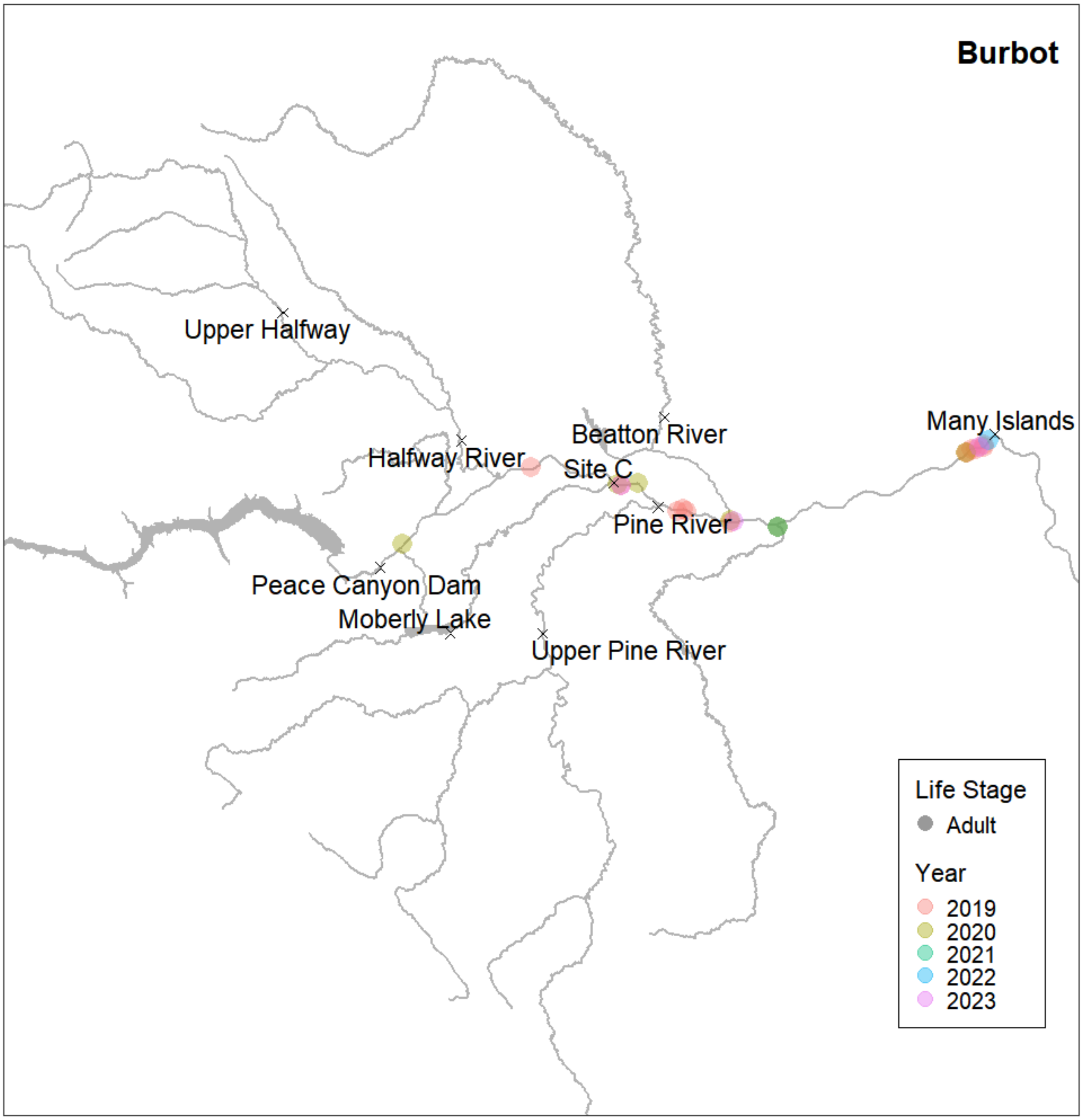


Figure A5. **Burbot release locations and points of reference (×) from the present dataset (2019 to 2023). Juvenile fish are depicted as triangles, adults depicted as circles. Point colours indicate year of release.**

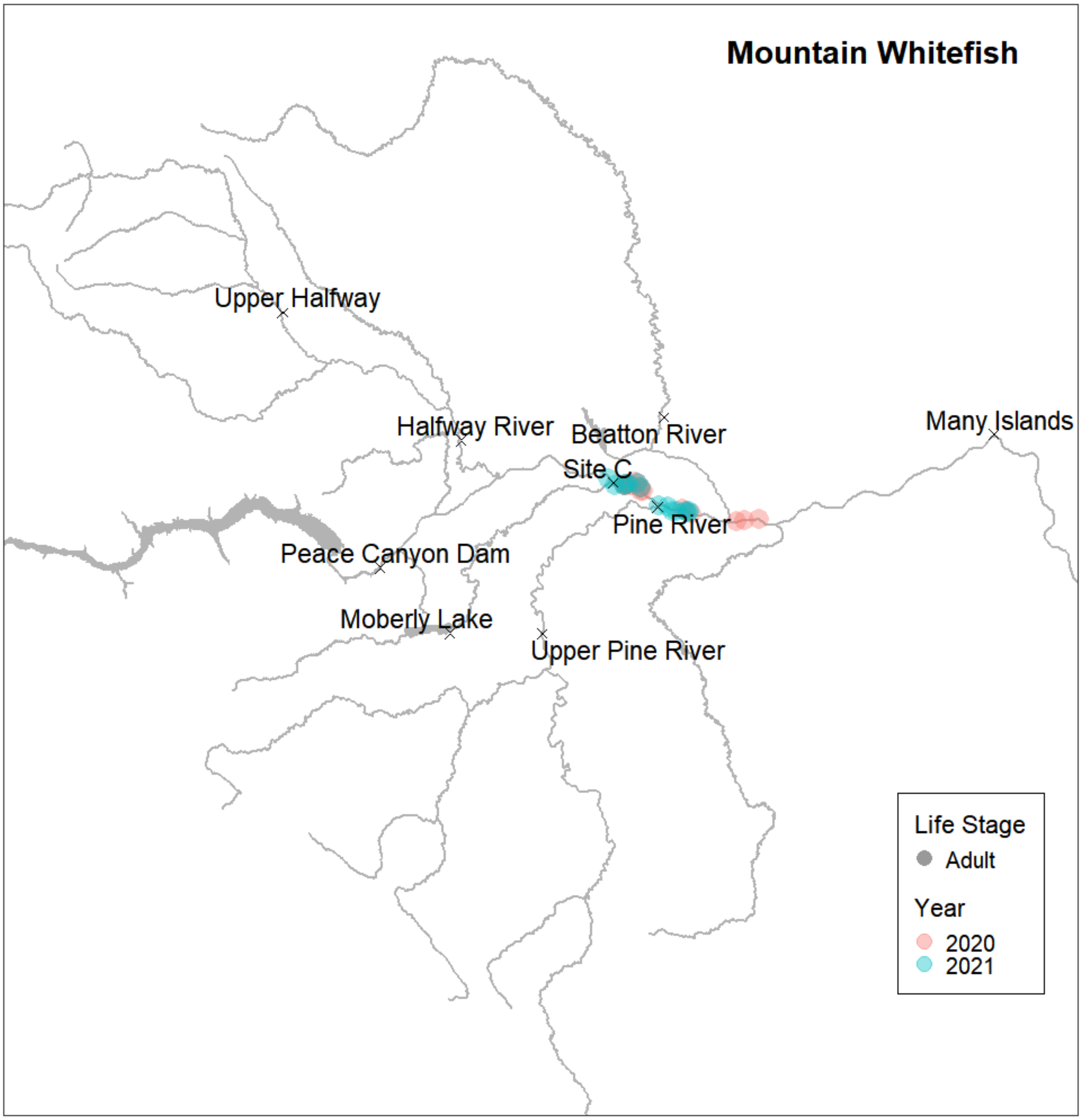


Figure A6. **Mountain Whitefish release locations and points of reference (×) from the present dataset (2019 to 2023). Juvenile fish are depicted as triangles, adults depicted as circles. Point colours indicate year of release.**

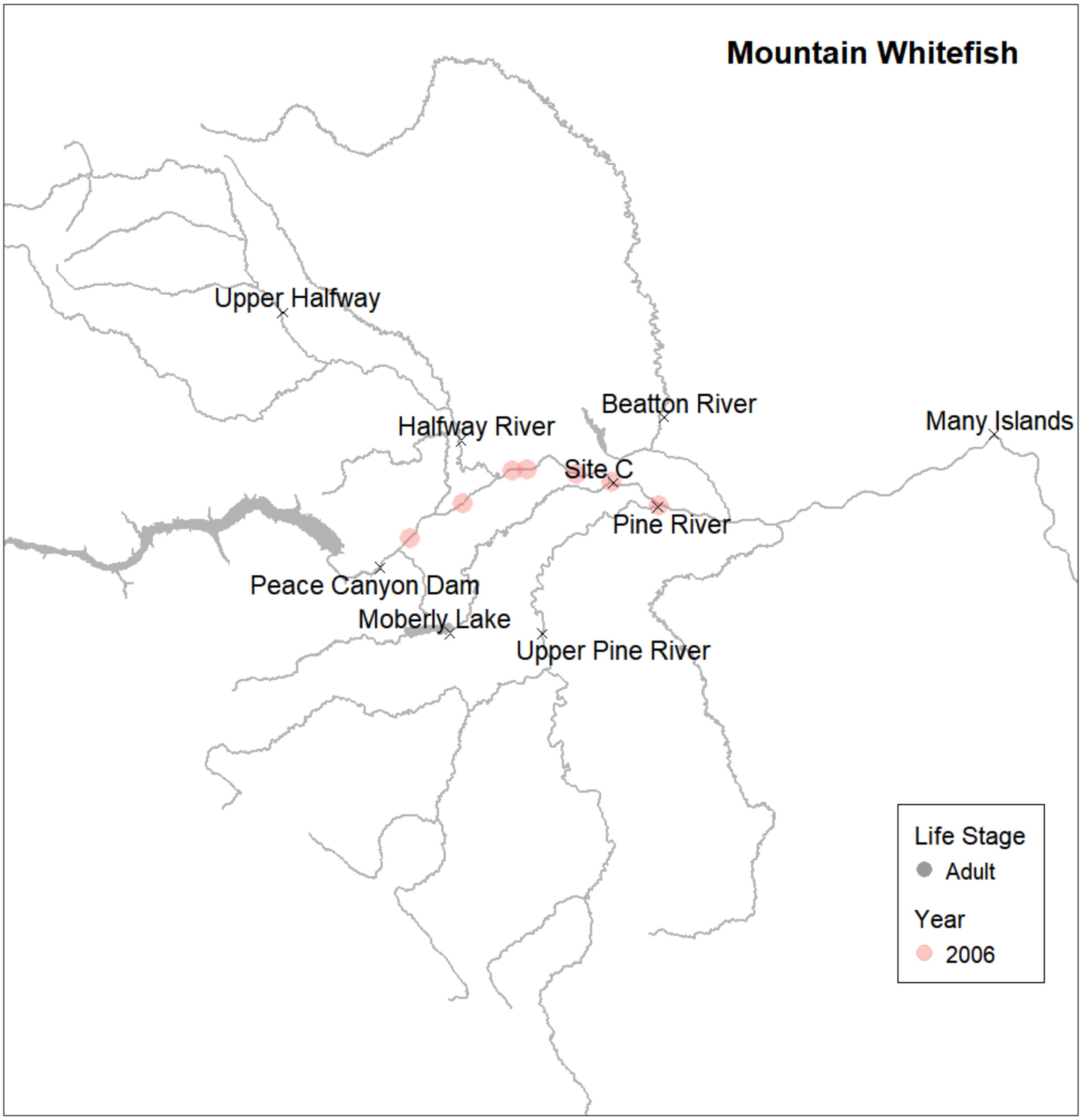


Figure A7. **Mountain Whitefish release locations and points of reference (×) from the historical dataset (1996 to 1998 and 2005 to 2008). Juvenile fish are depicted as triangles, adults depicted as circles. Point colours indicate year of release.**

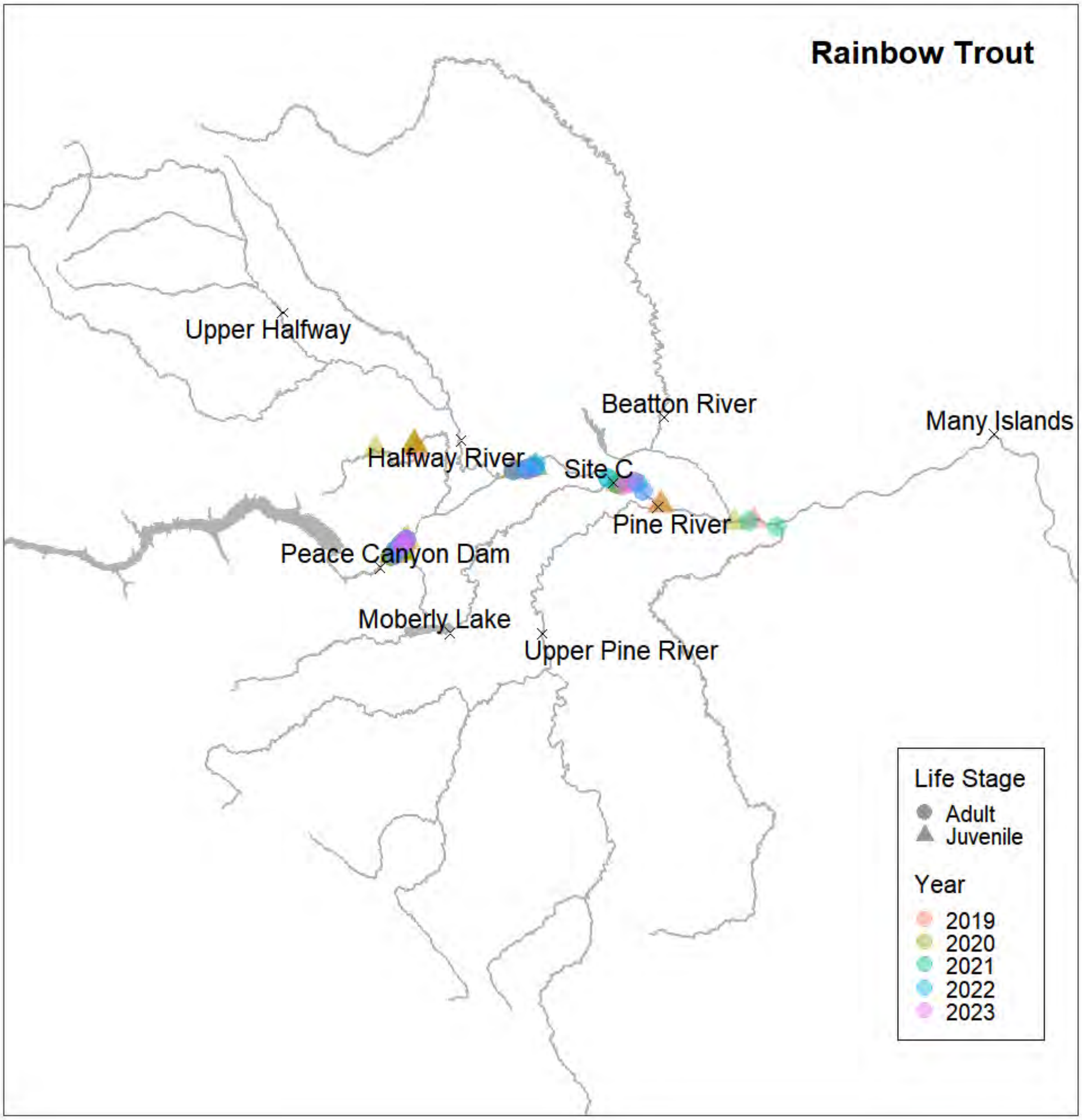


Figure A8. **Rainbow Trout release locations and points of reference (×) from the present dataset (2019 to 2023). Juvenile fish are depicted as triangles, adults depicted as circles. Point colours indicate year of release.**

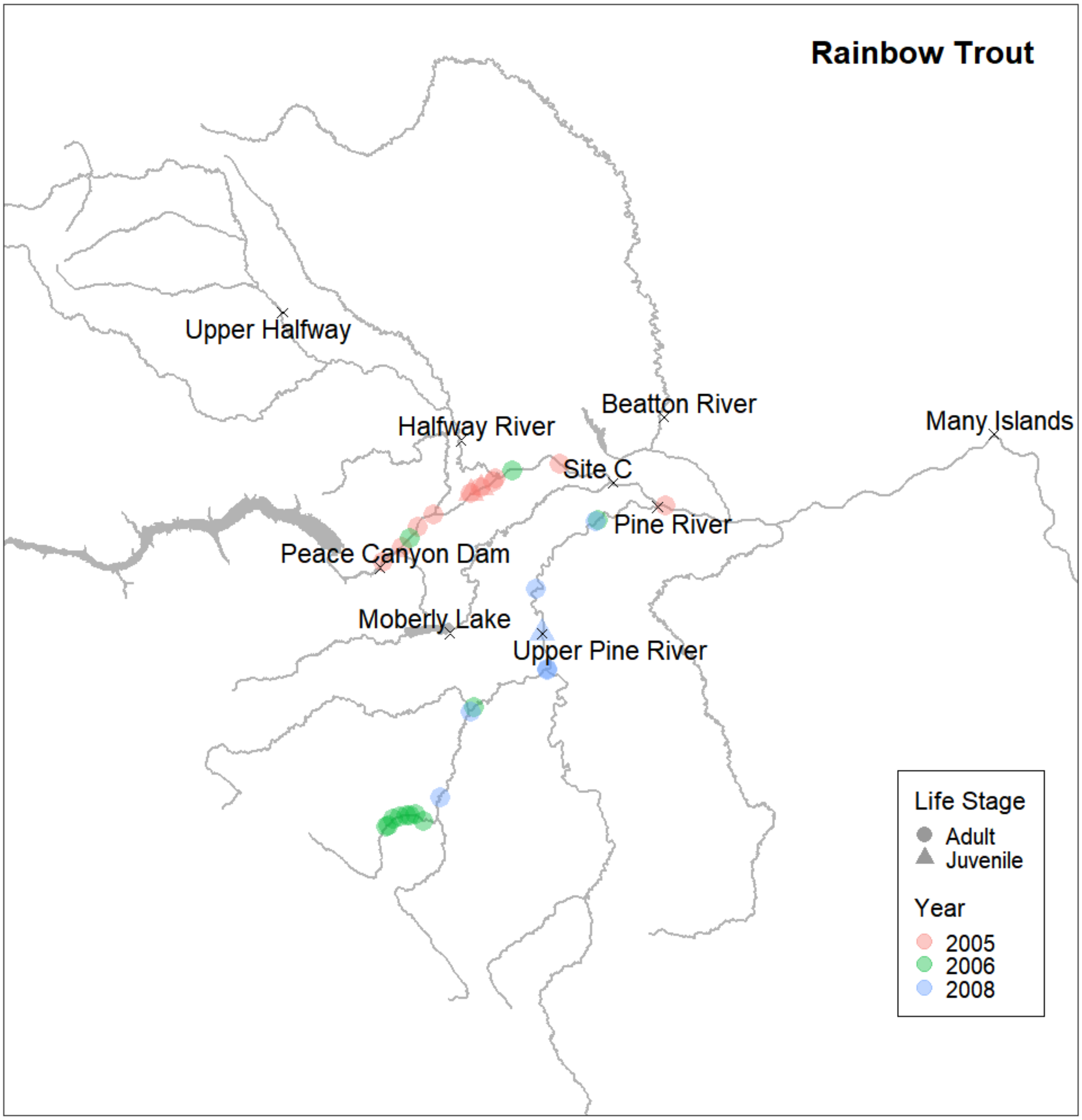


Figure A9. Rainbow Trout release locations and points of reference (×) from the historical dataset (1996 to 1998 and 2005 to 2008). Juvenile fish are depicted as triangles, adults depicted as circles. Point colours indicate year of release.

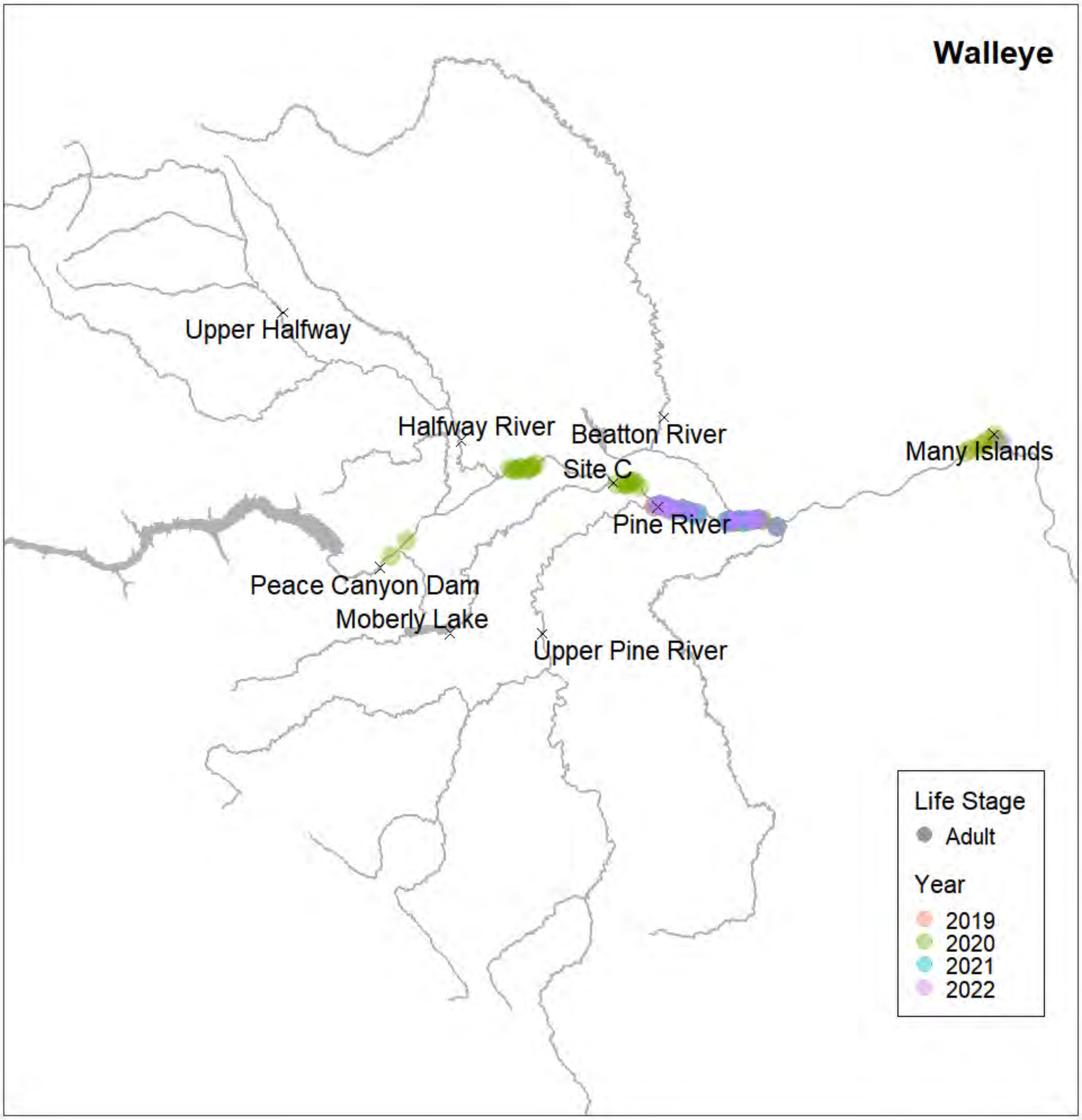


Figure A10. Walleye release locations and points of reference (×) from the present dataset (2019 to 2023). Juvenile fish are depicted as triangles, adults depicted as circles. Point colours indicate year of release.

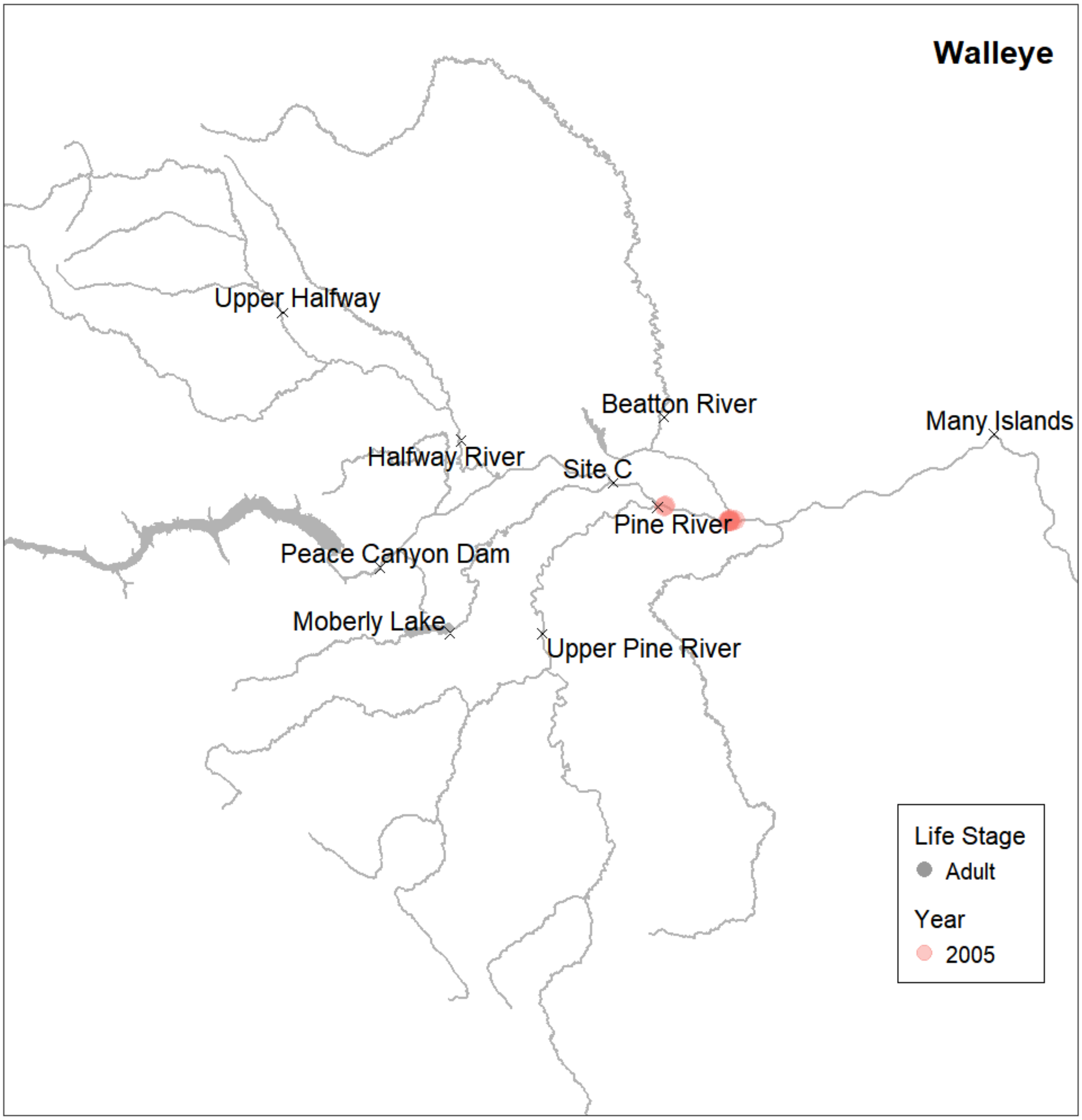


Figure A11. Walleye release locations and points of reference (×) from the historical dataset (1996 to 1998 and 2005 to 2008). Juvenile fish are depicted as triangles, adults depicted as circles. Point colours indicate year of release.

Appendix B. Valid, Noise, False-Positive, and Beacon Detection by Date and Receiver

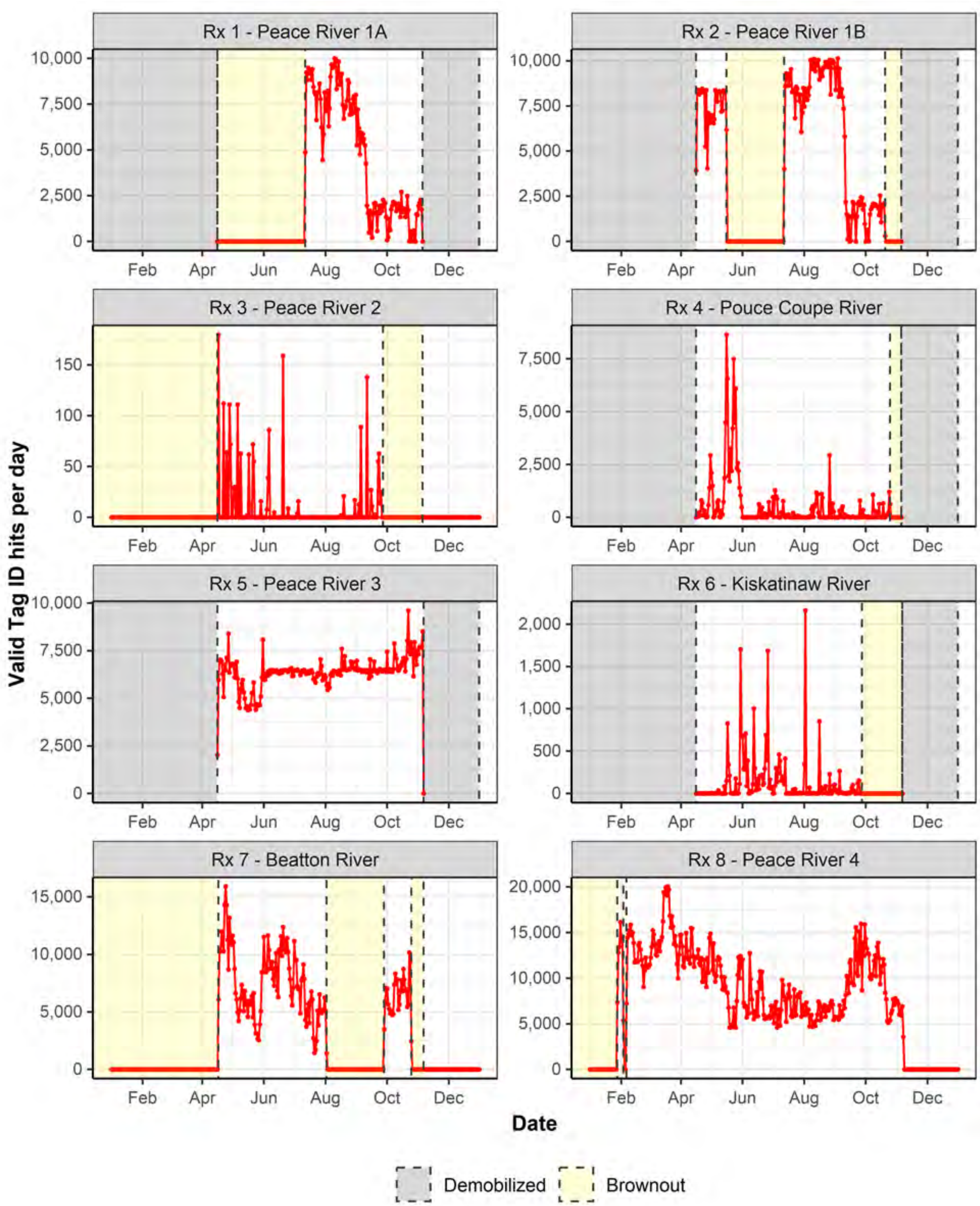


Figure B1. **Validated detection signals by station organized into hits per day in 2023. The spaces highlighted with a yellow or gray rectangle signify periods in which receiver outages had occurred and data collection did not proceed. The figure continues on the five next pages.**

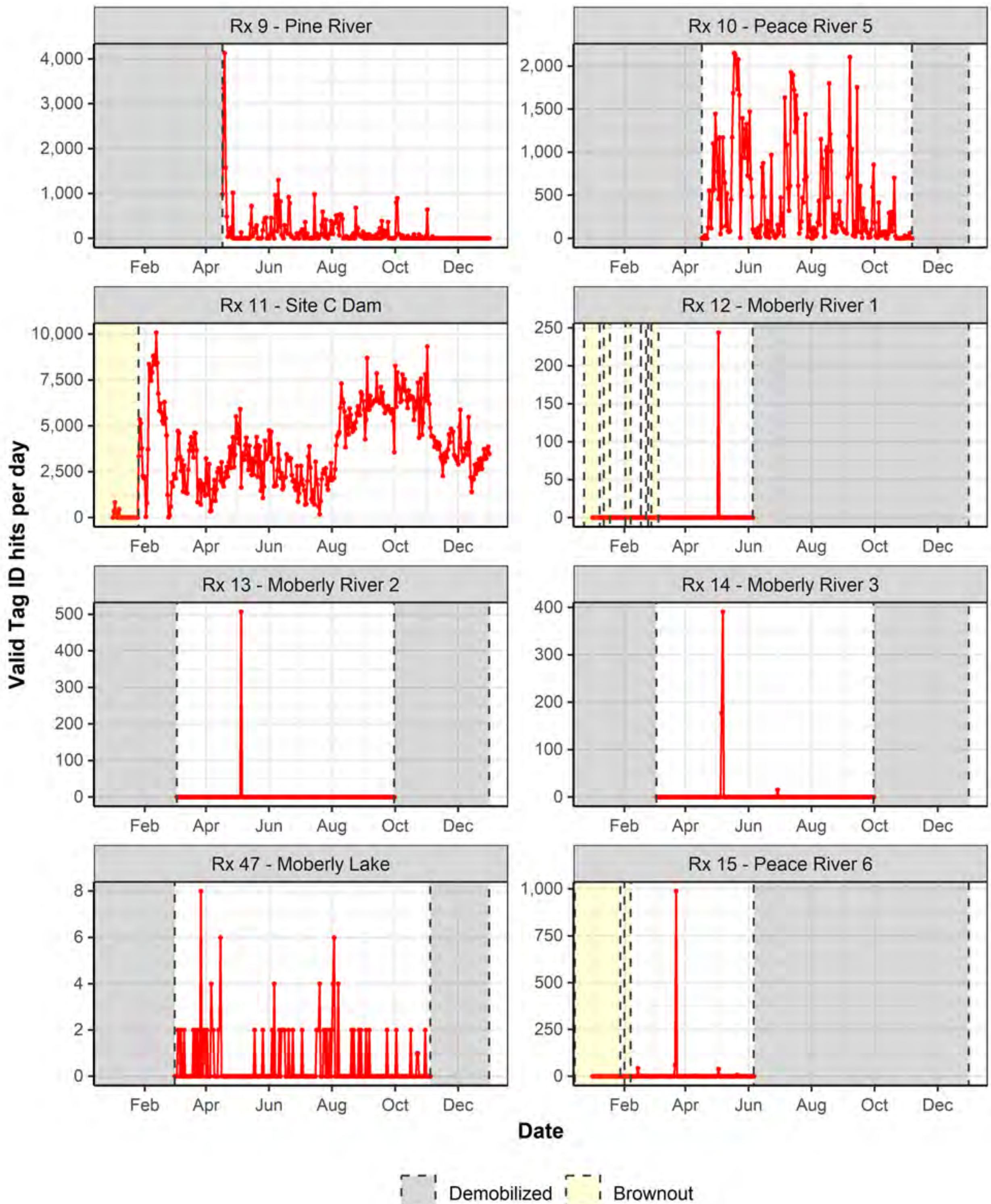


Figure B1 continued (part 2 of 6).

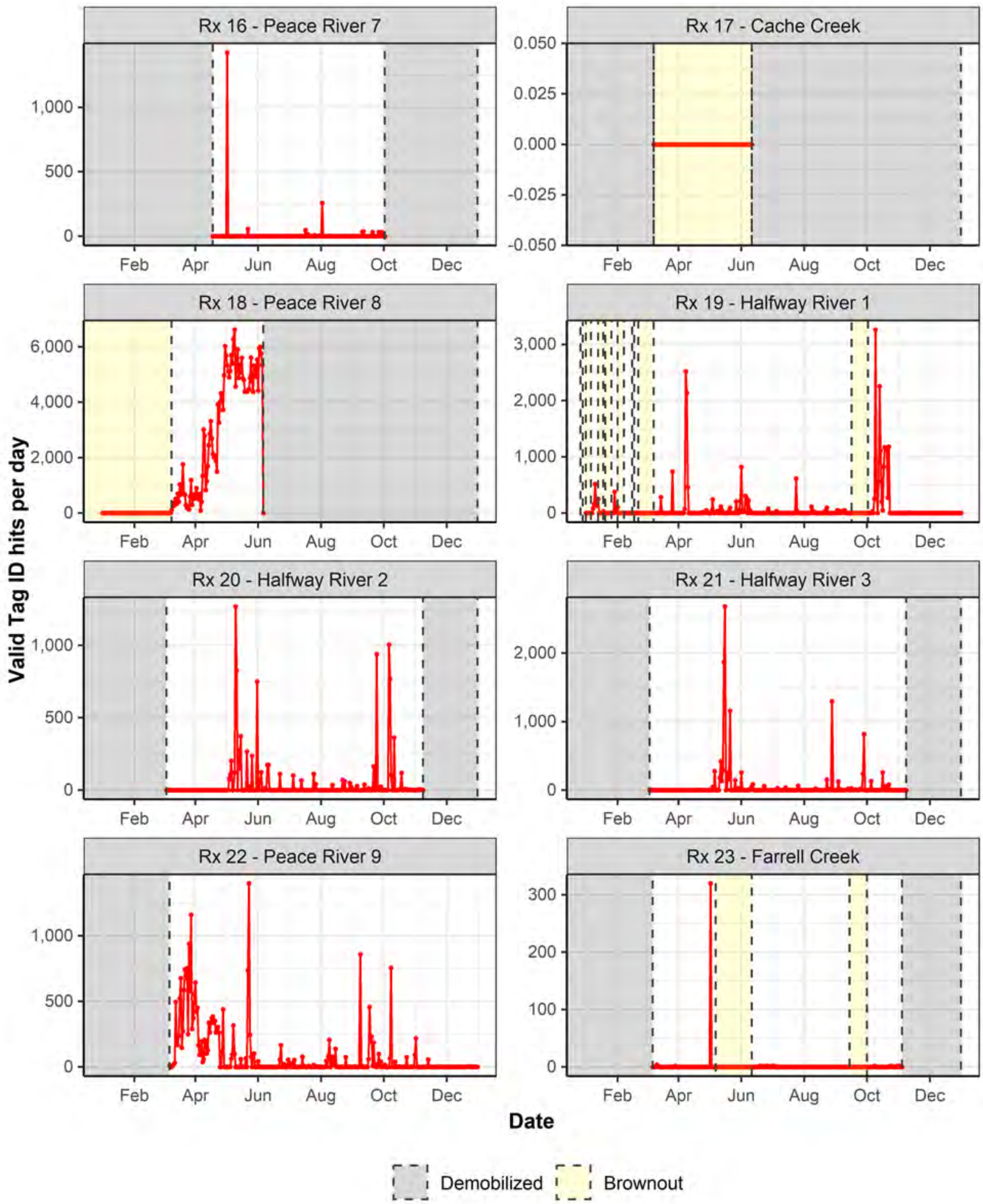


Figure B1 continued (part 3 of 6).

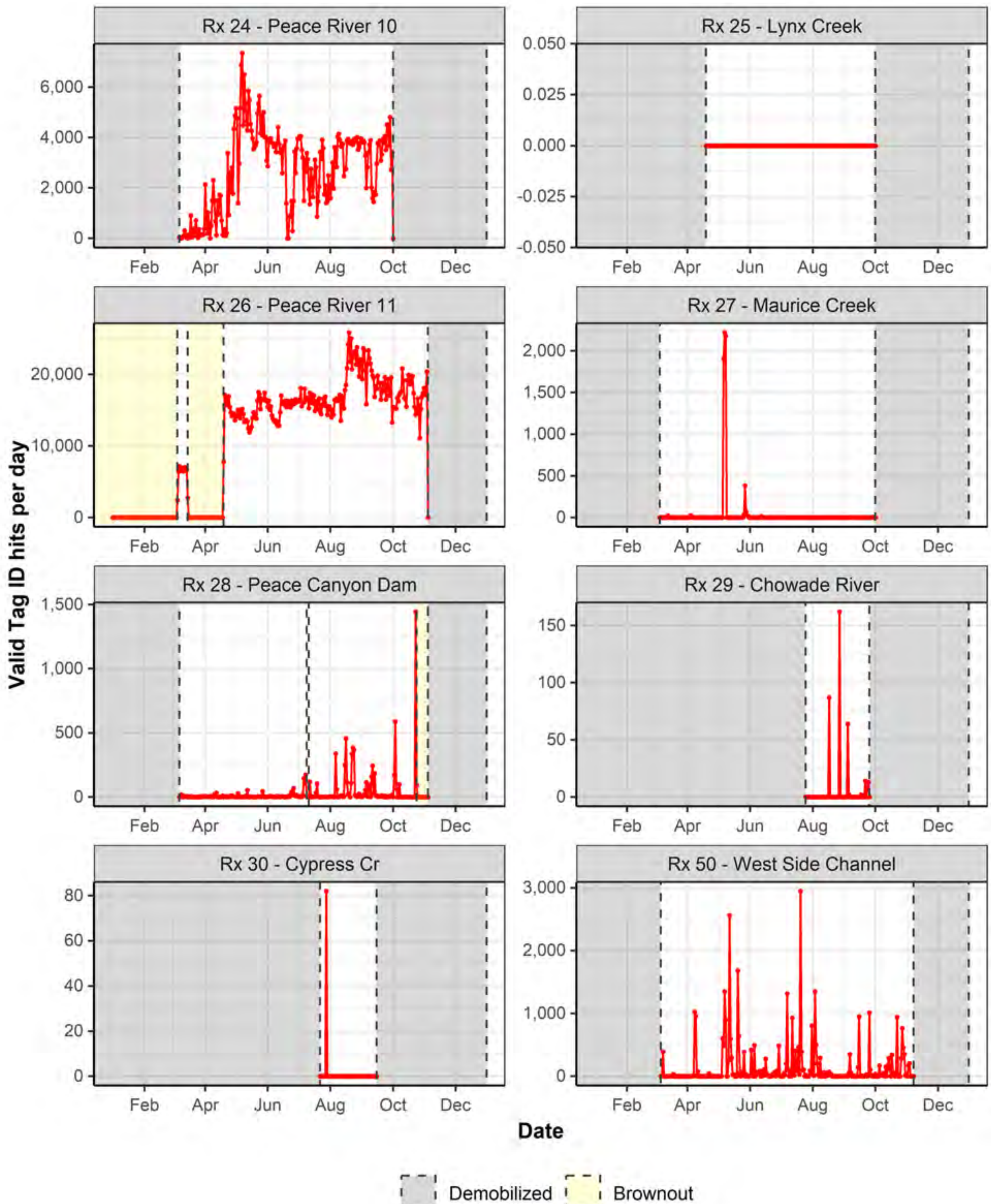


Figure B1 continued (part 4 of 6).

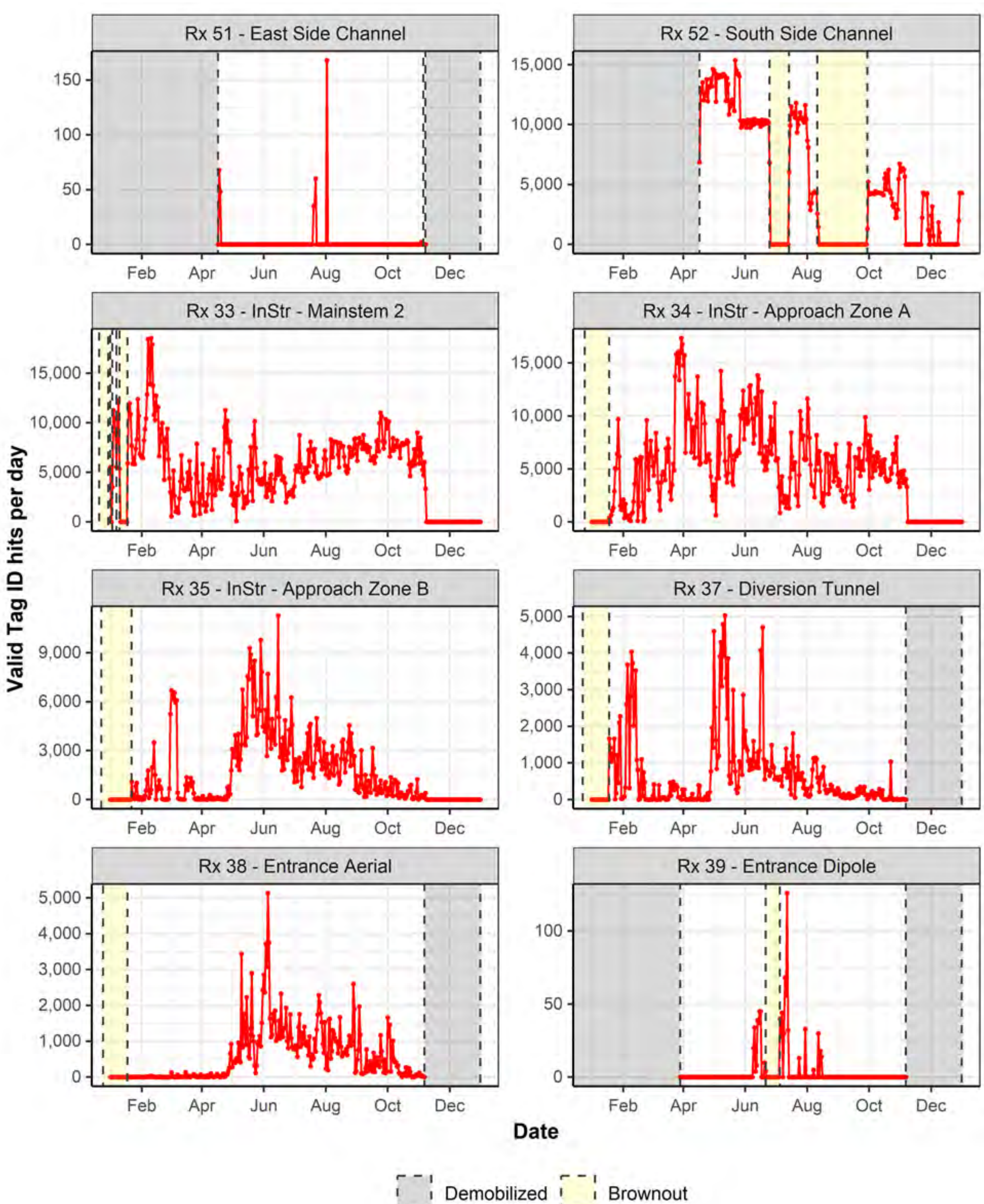


Figure B1 continued (part 5 of 6).

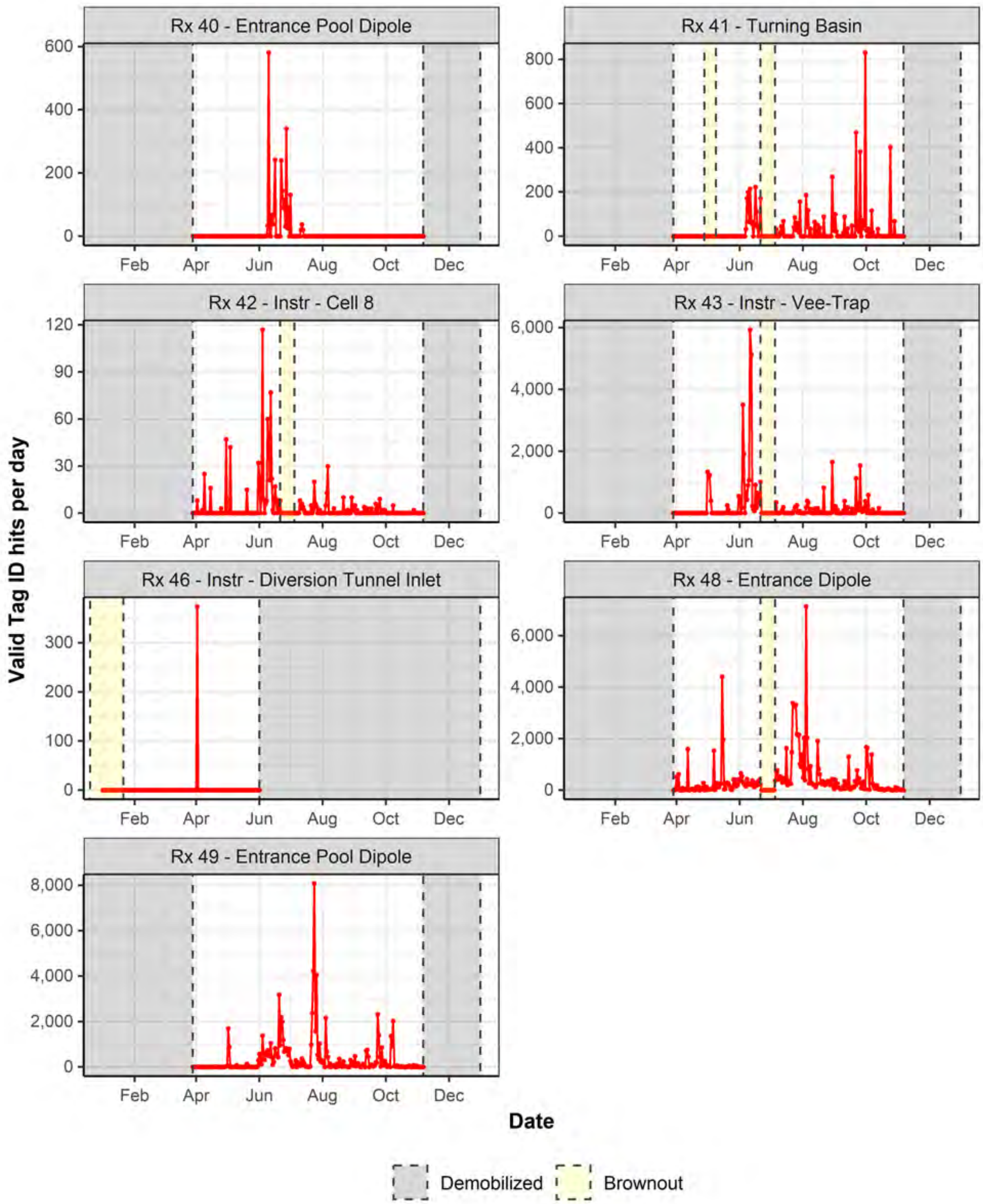


Figure B1 continued (part 6 of 6).

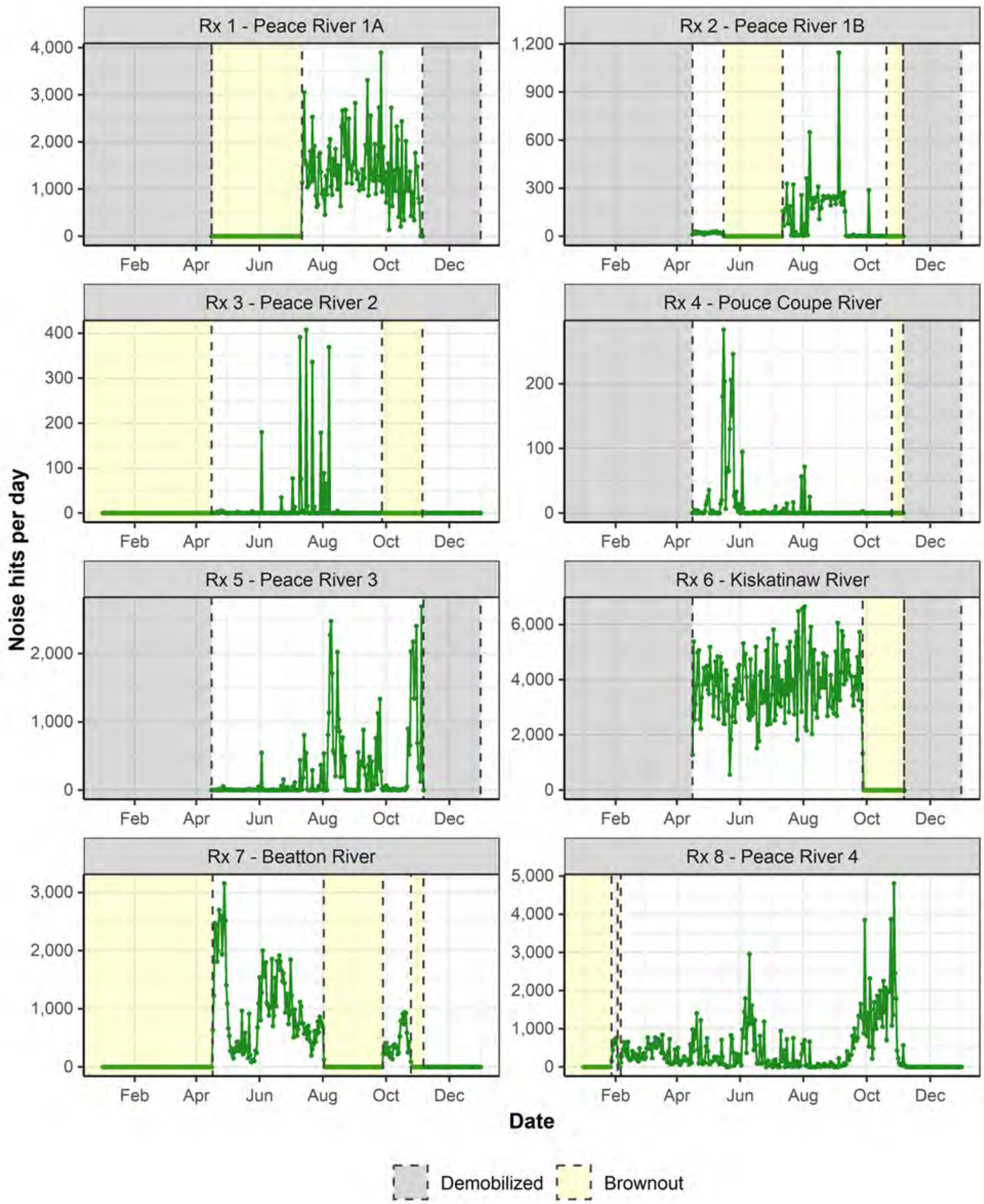


Figure B2. Noise (Code 999) signals by station organized into hits per day in 2023. The spaces highlighted with a yellow or gray rectangle signify periods in which receiver outages had occurred and data collection did not proceed. The figure continues on the five next pages.

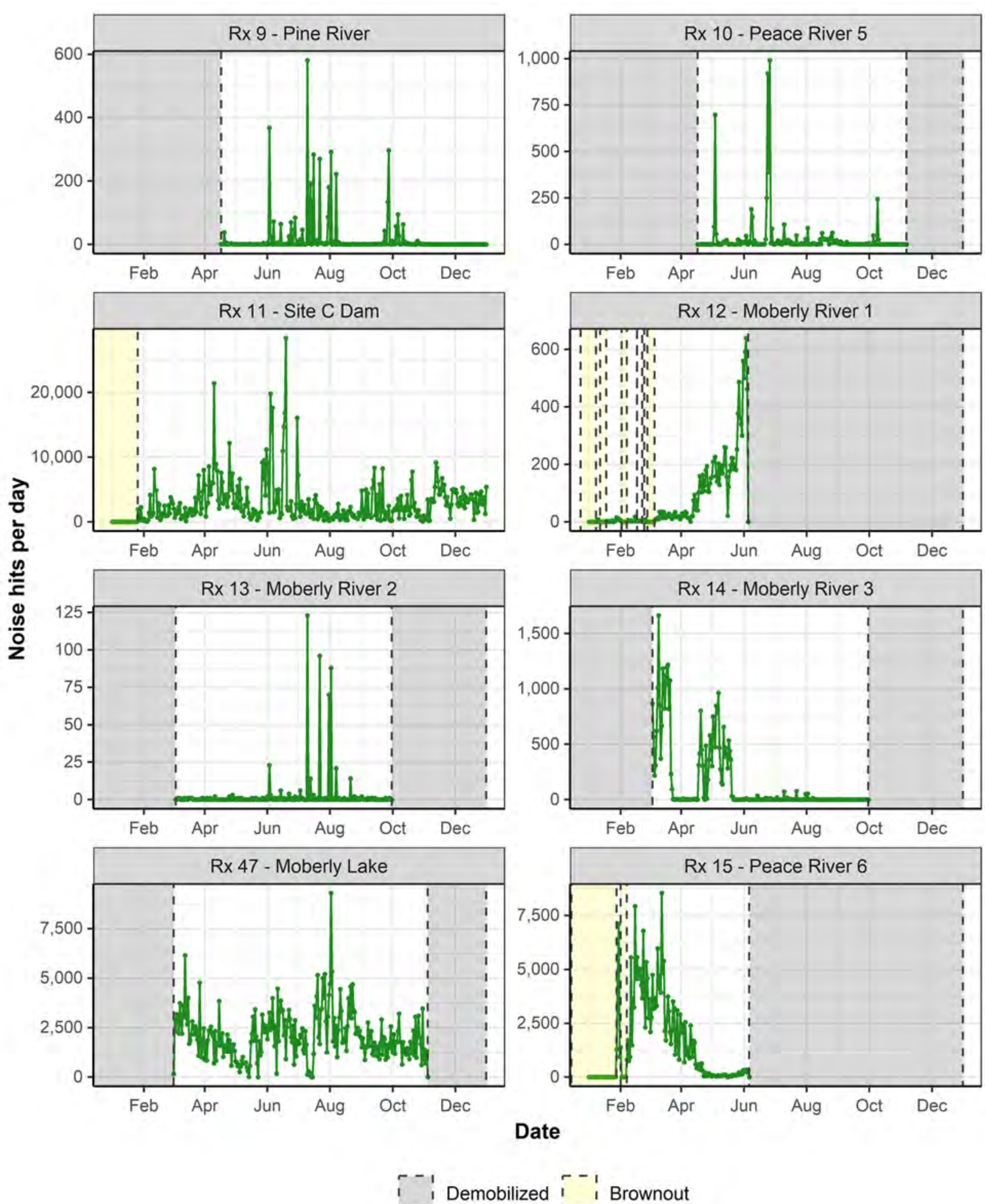
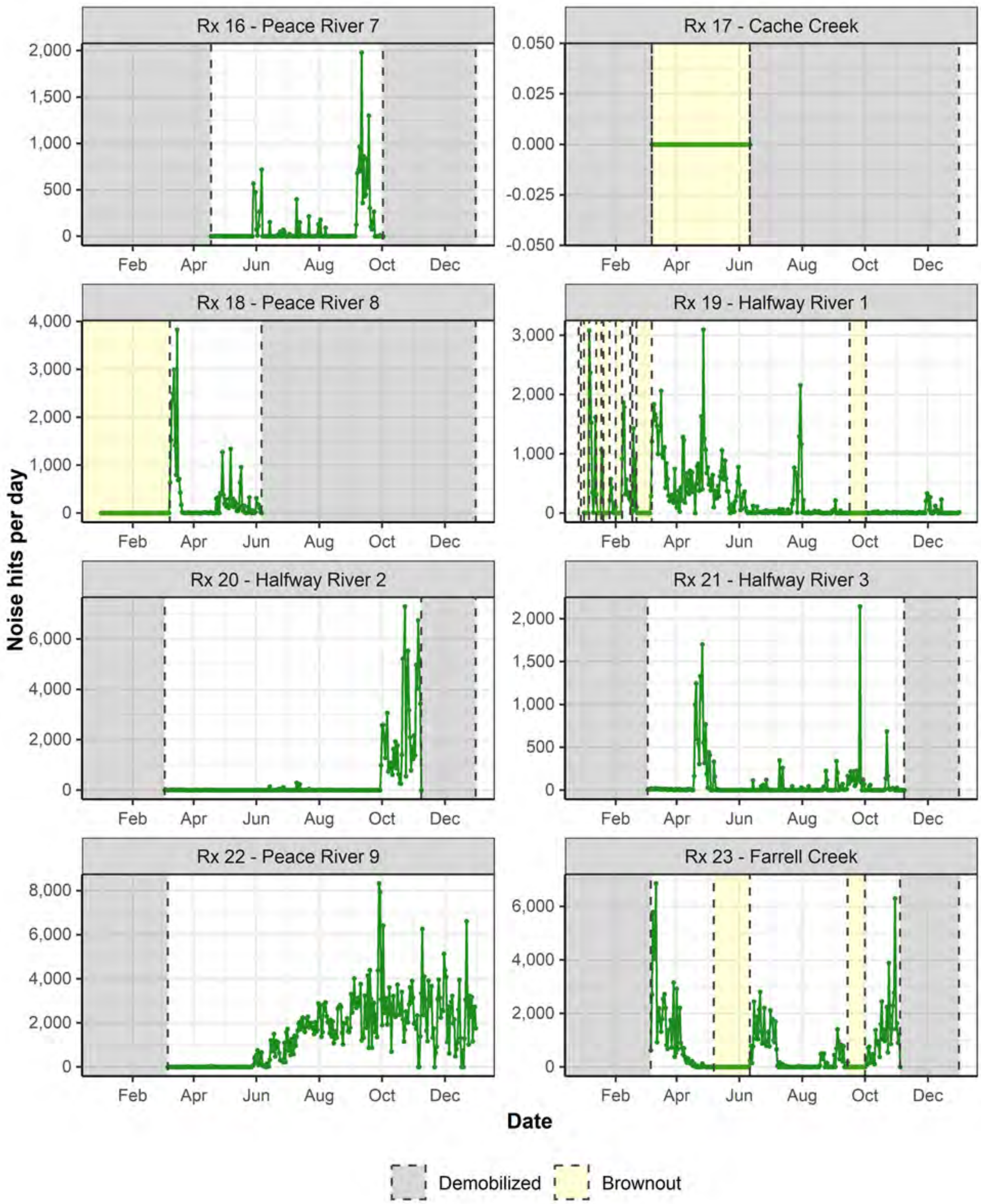


Figure B2 continued (part 2 of 6).



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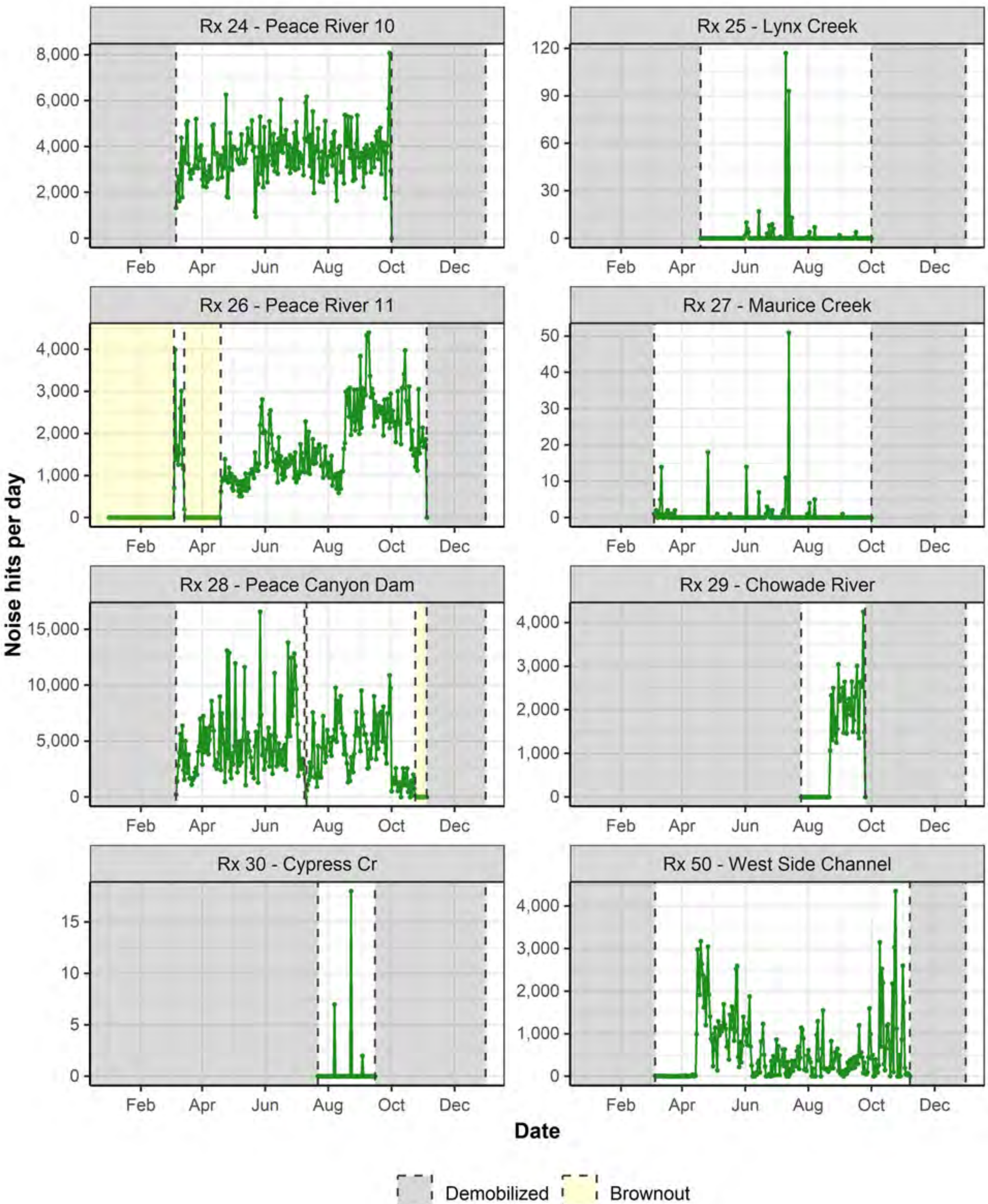

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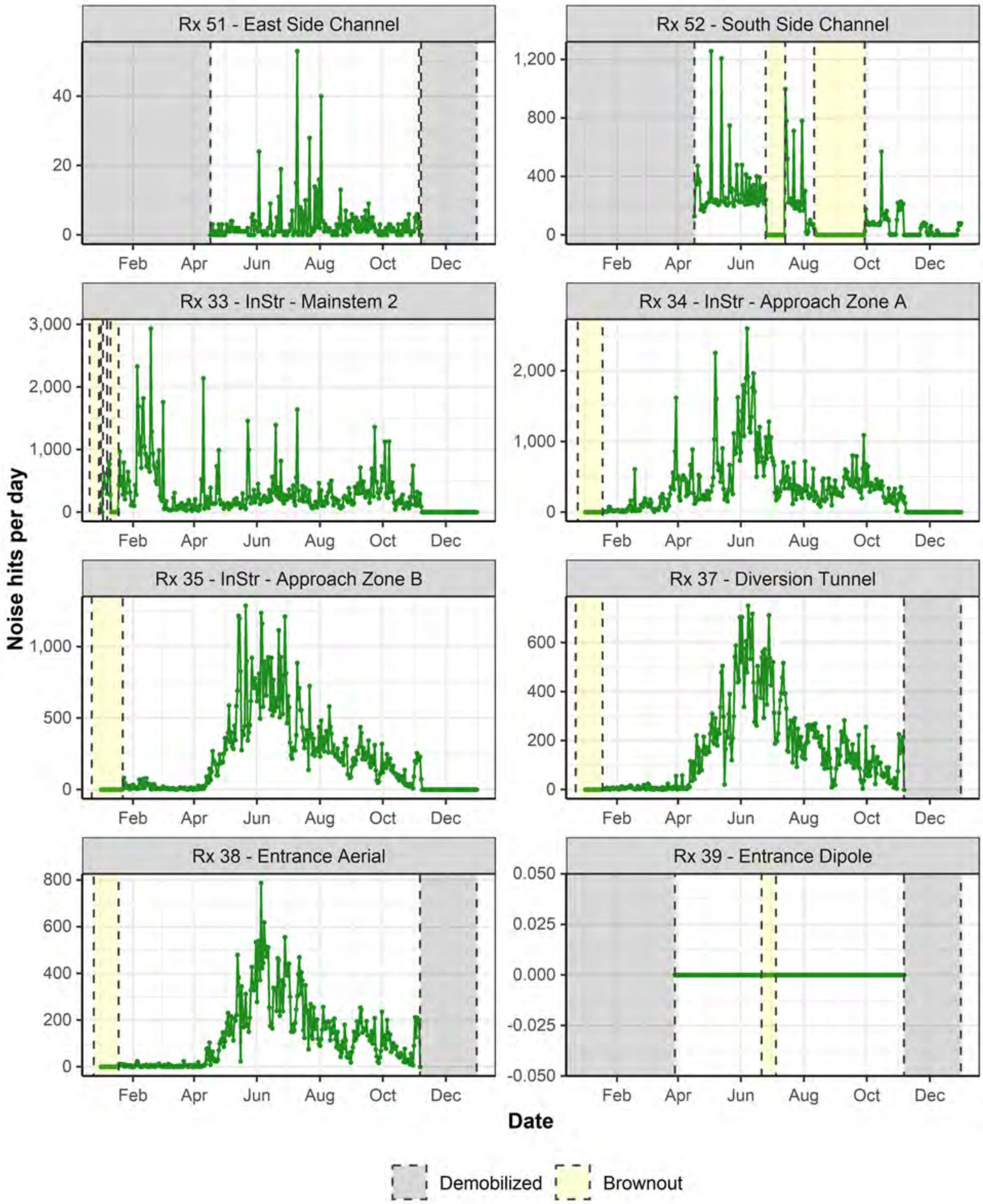


Figure B2 continued (part 5 of 6).

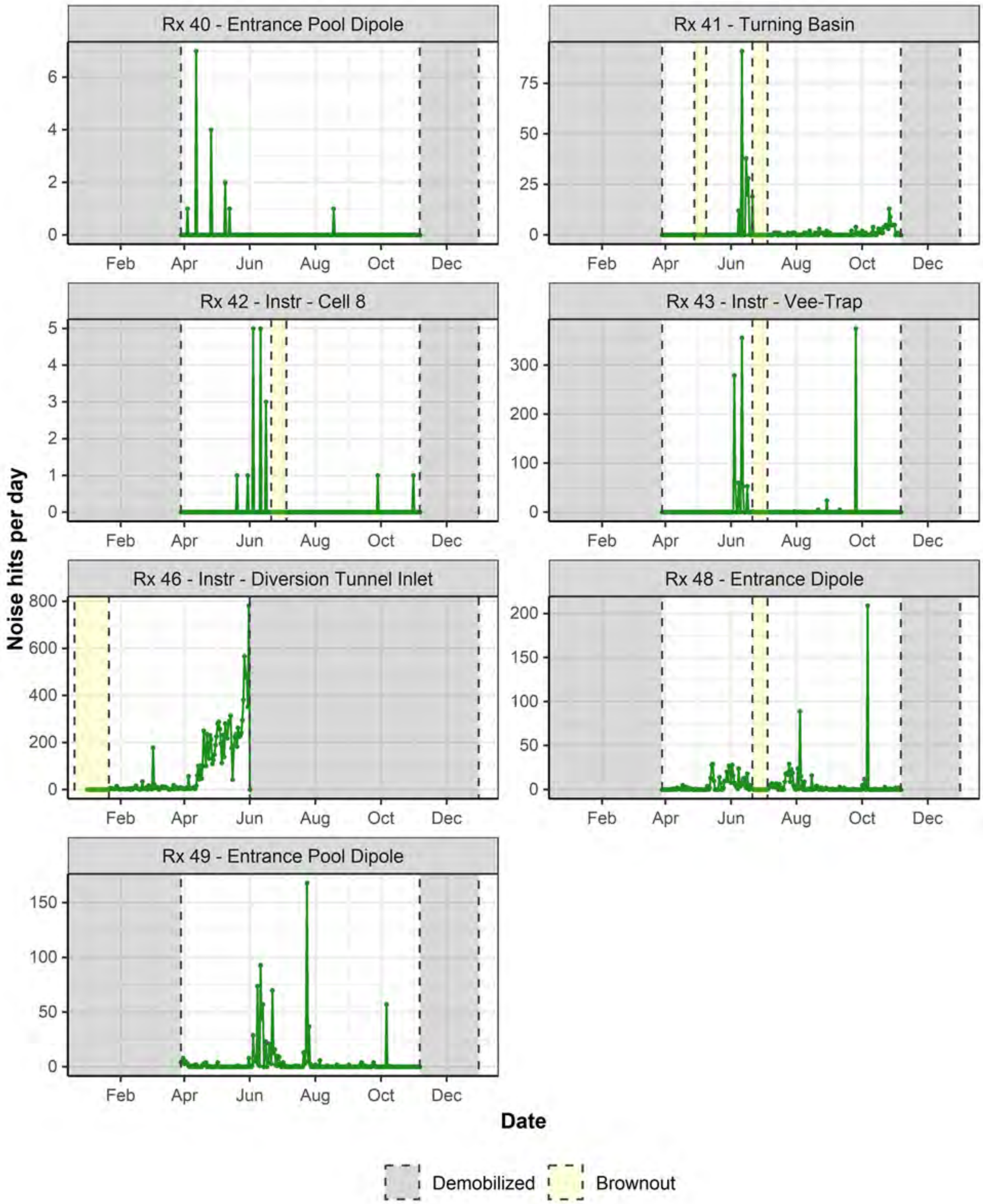


Figure B2 continued (part 6 of 6).

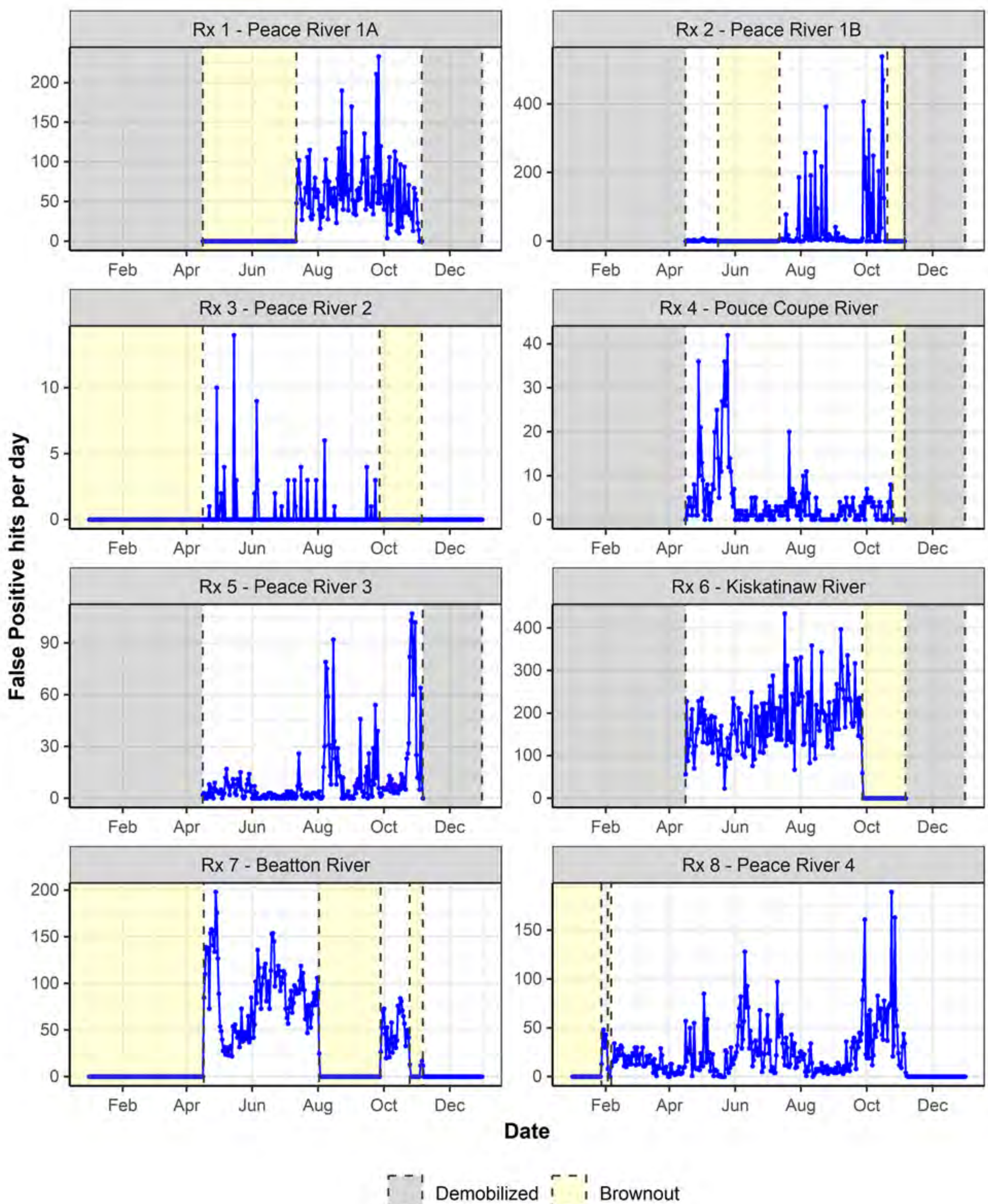


Figure B3. **False positive signals by station organized into hits per day in 2023. The spaces highlighted with a yellow or gray rectangle signify periods in which receiver outages had occurred and data collection did not proceed. The figure continues on the five next pages.**

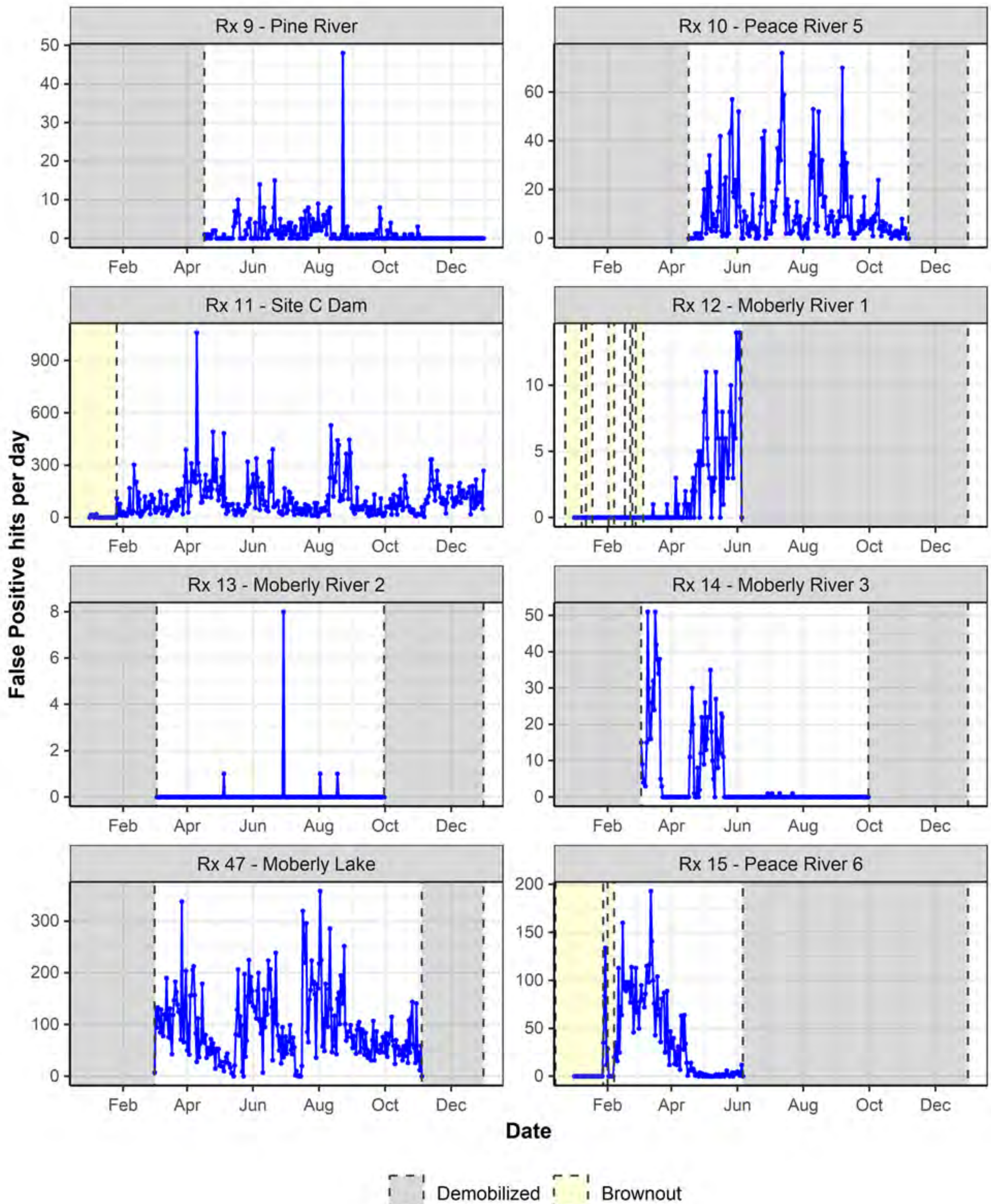


Figure B3 continued (part 2 of 6).

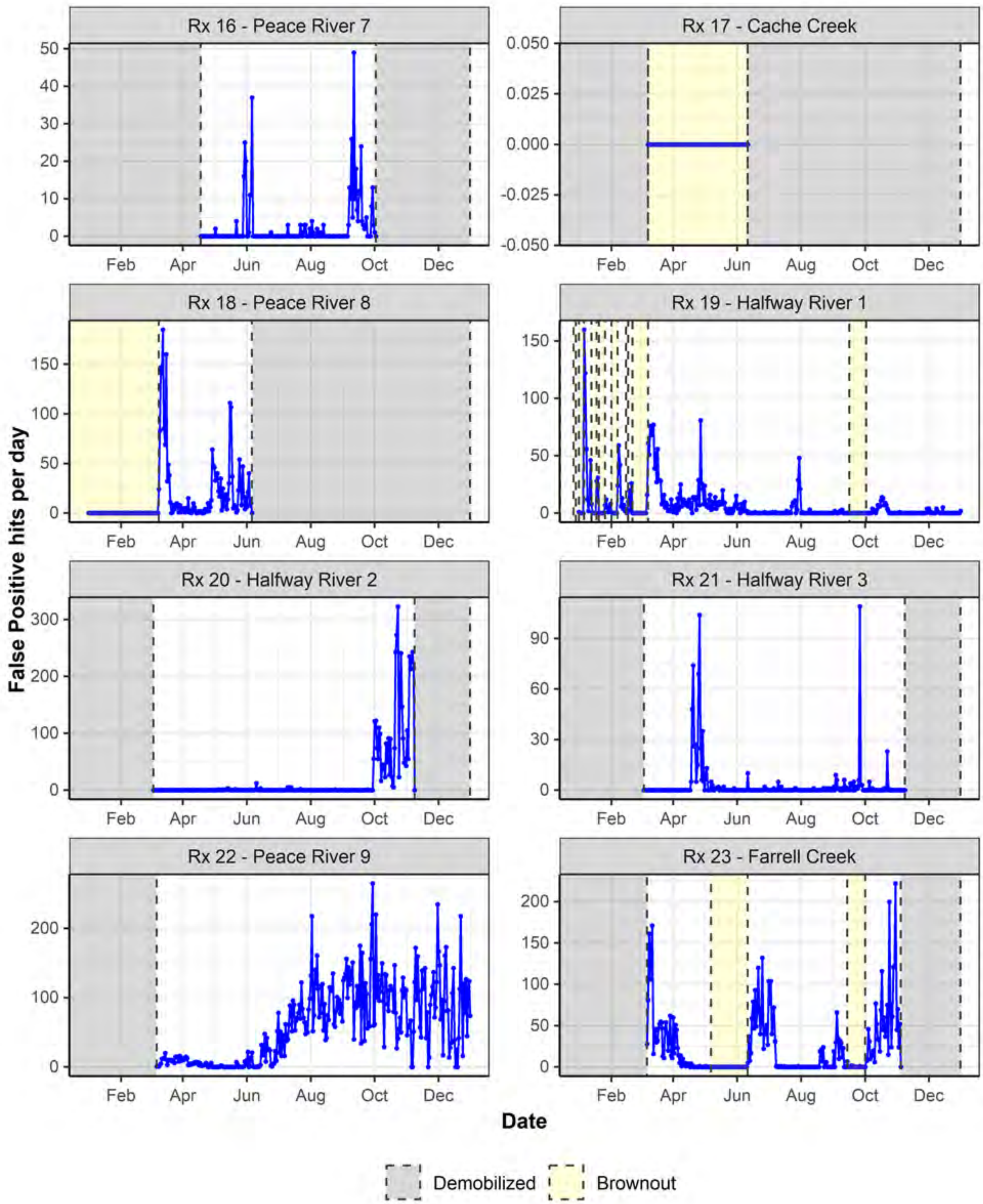


Figure B3 continued (part 3 of 6).

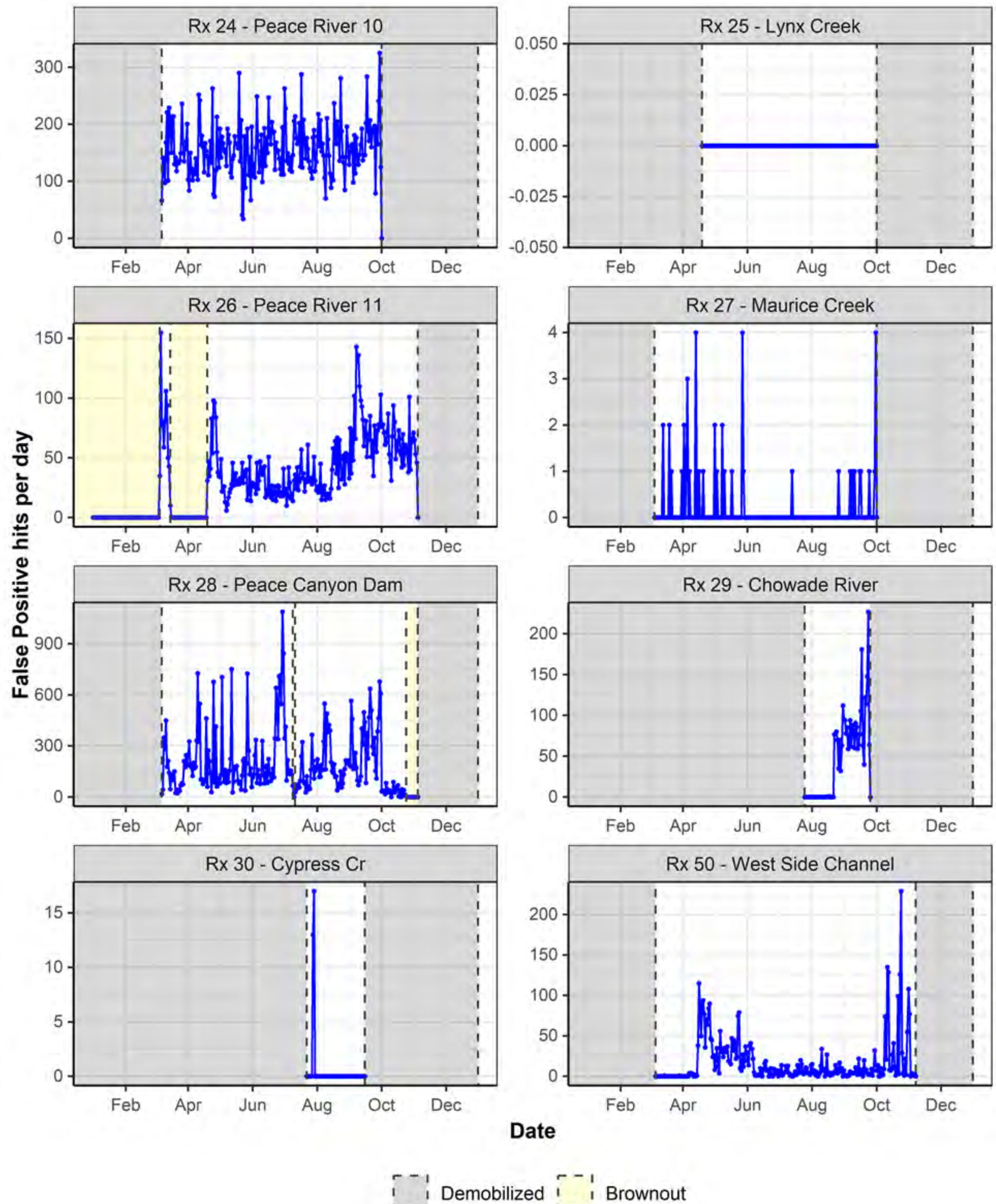


Figure B3 continued (part 4 of 6).

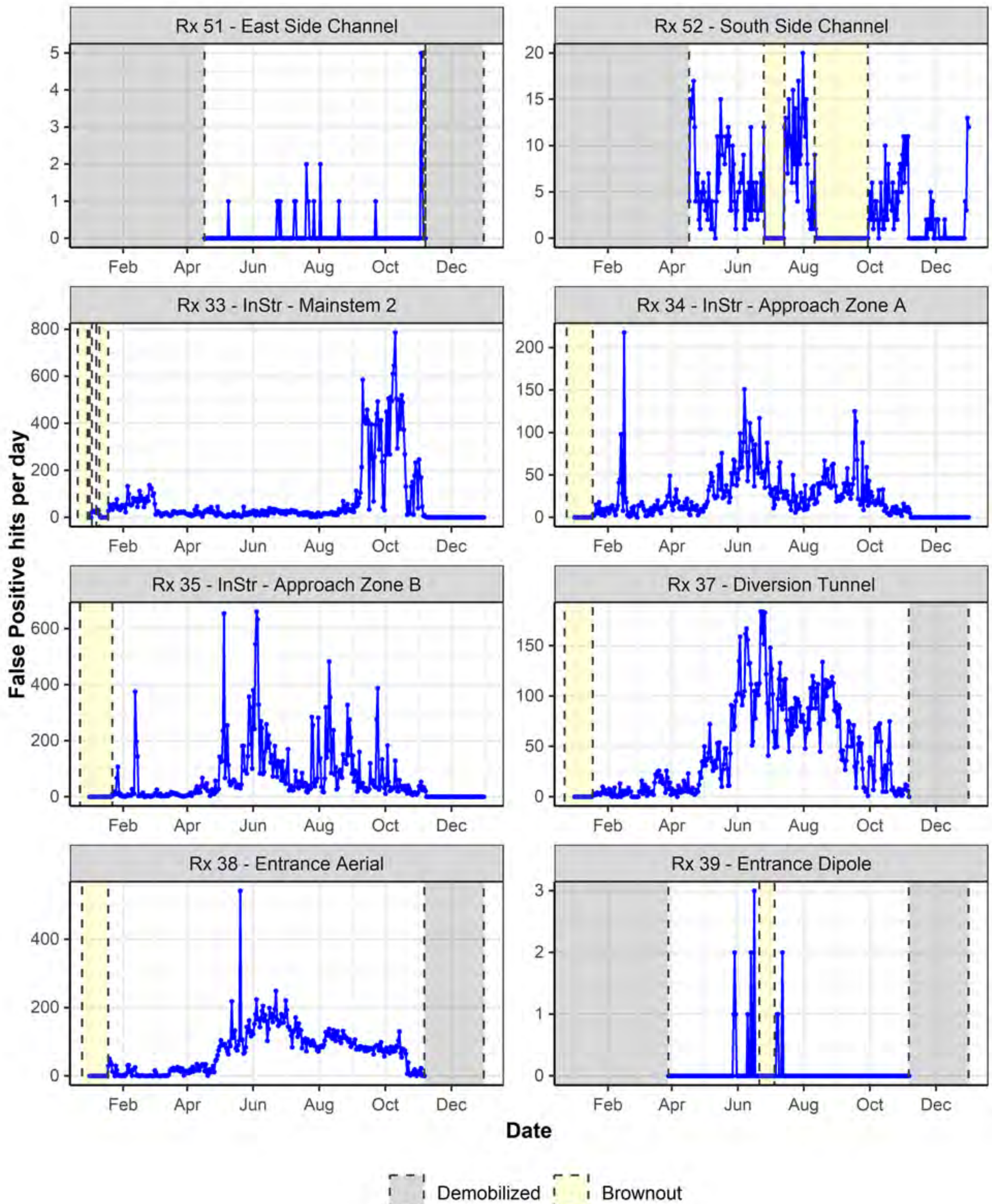


Figure B3 continued (part 5 of 6).

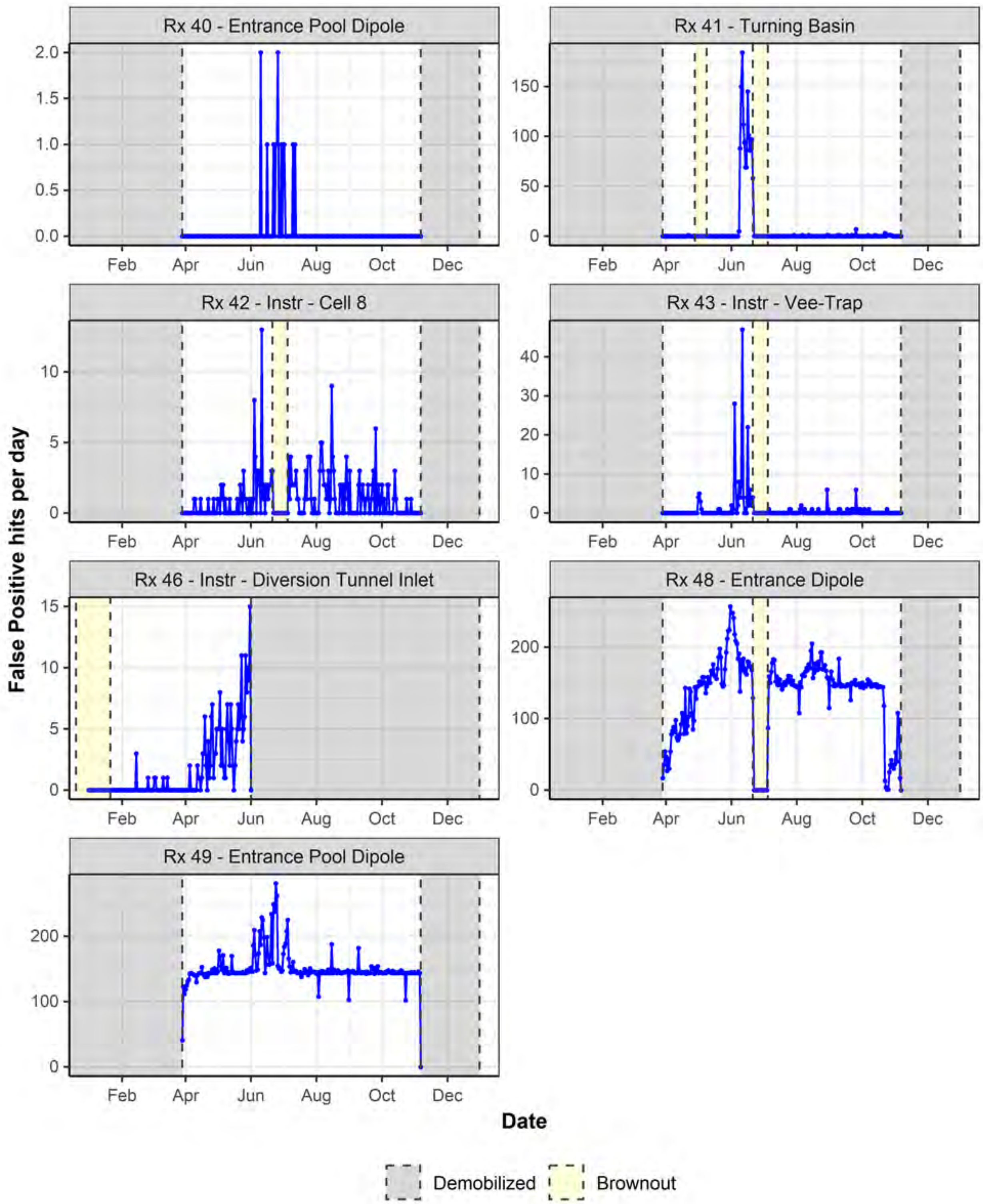


Figure B3 continued (part 6 of 6).

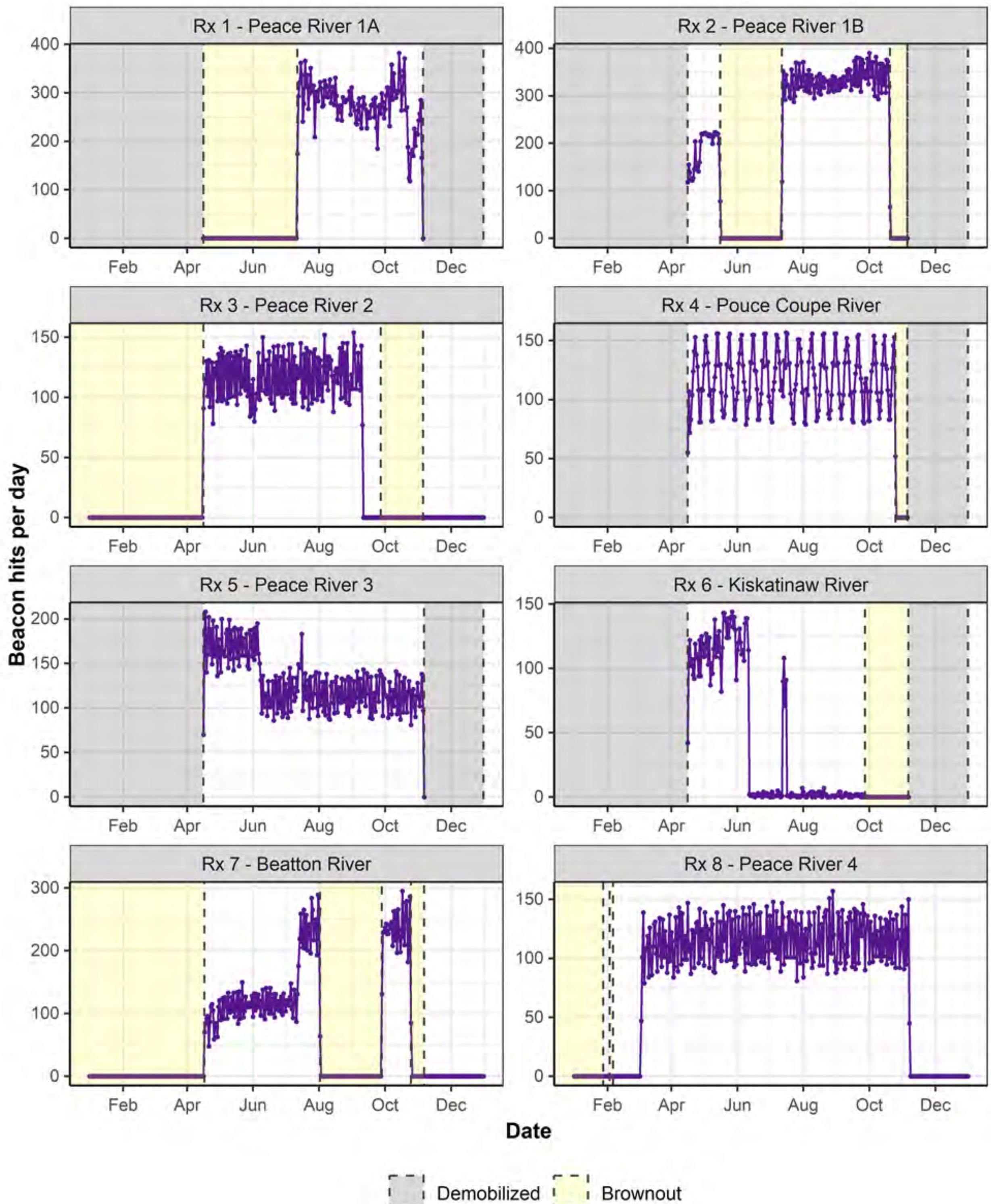


Figure B4. **Beacon tag signals by station organized into hits per day in 2023. The spaces highlighted with a yellow or gray rectangle signify periods in which receiver outages had occurred and data collection did not proceed. The figure continues on the five next pages.**

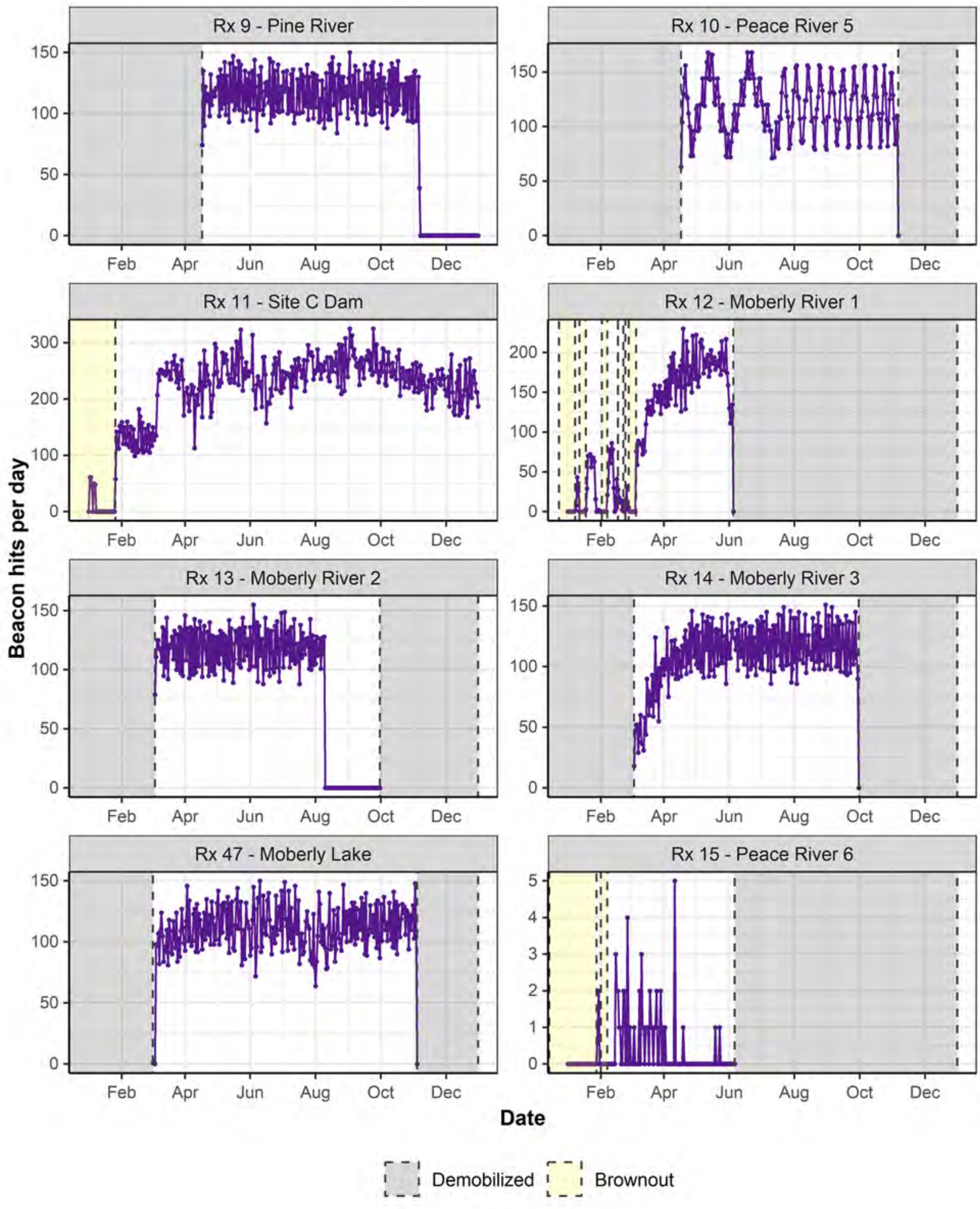


Figure B4 continued (part 2 of 6).

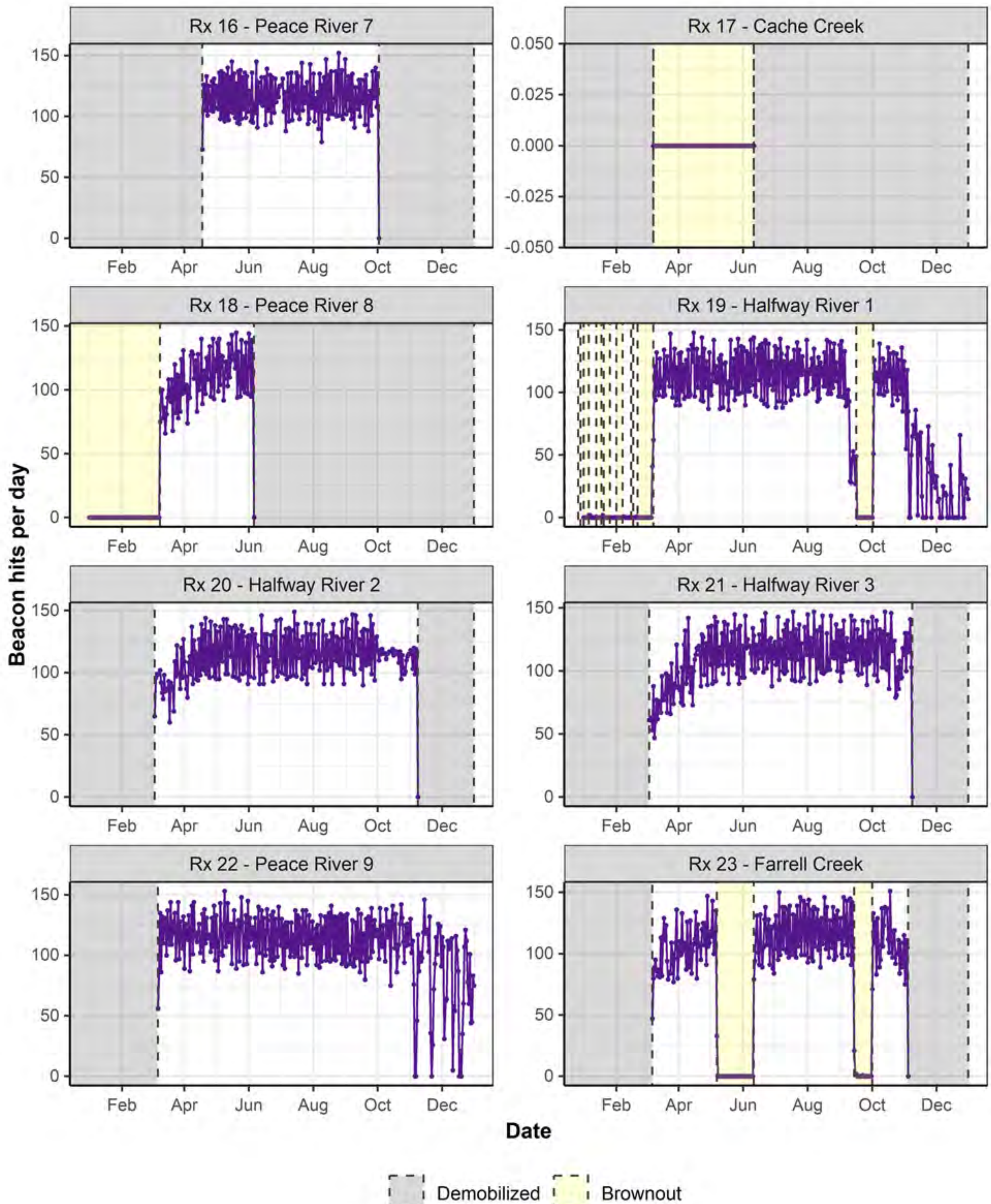


Figure B4 continued (part 3 of 6).

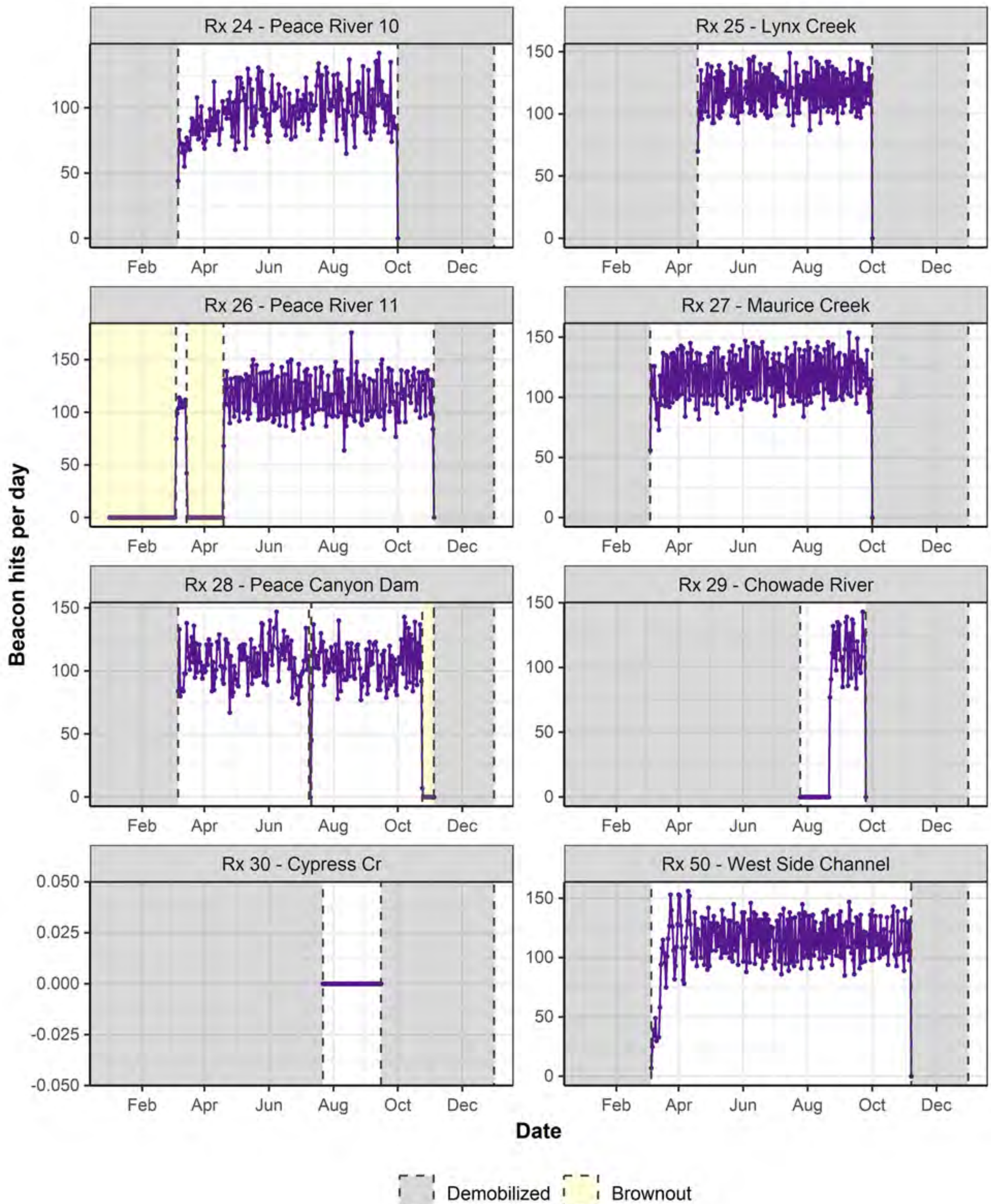


Figure B4 continued (part 4 of 6).

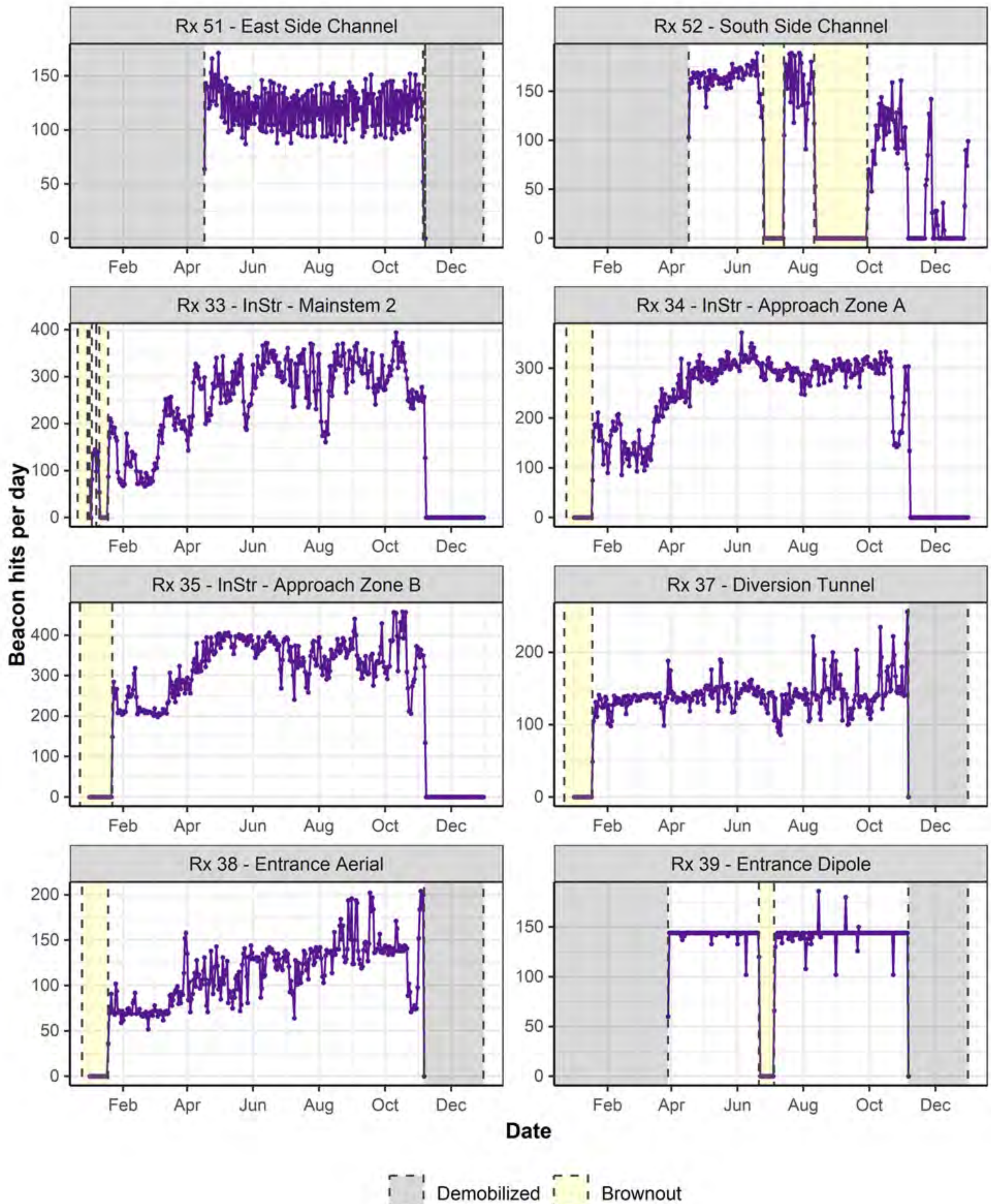


Figure B4 continued (part 5 of 6).

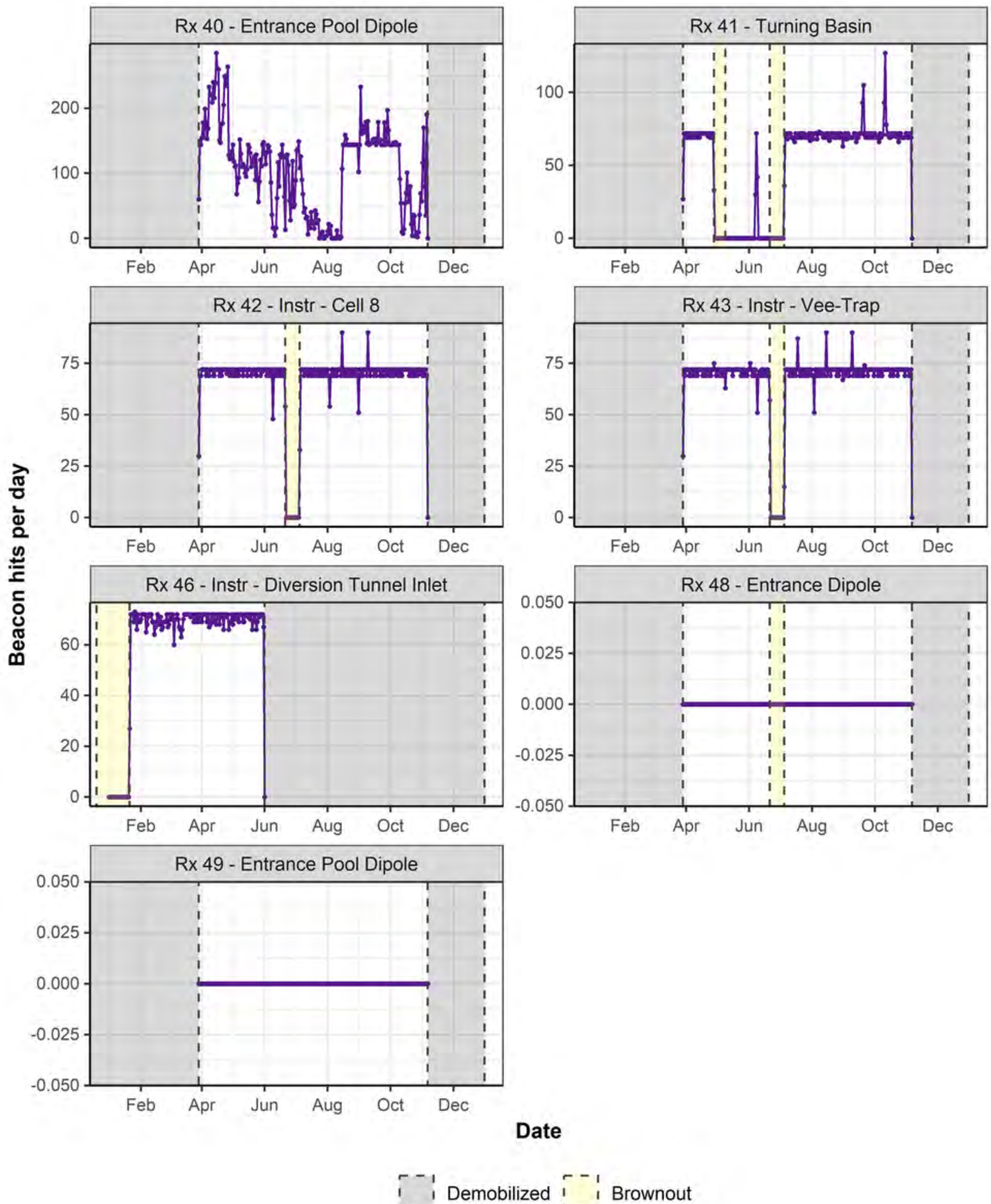


Figure B4 continued (part 6 of 6).

Appendix C. Site C Telemetry Database

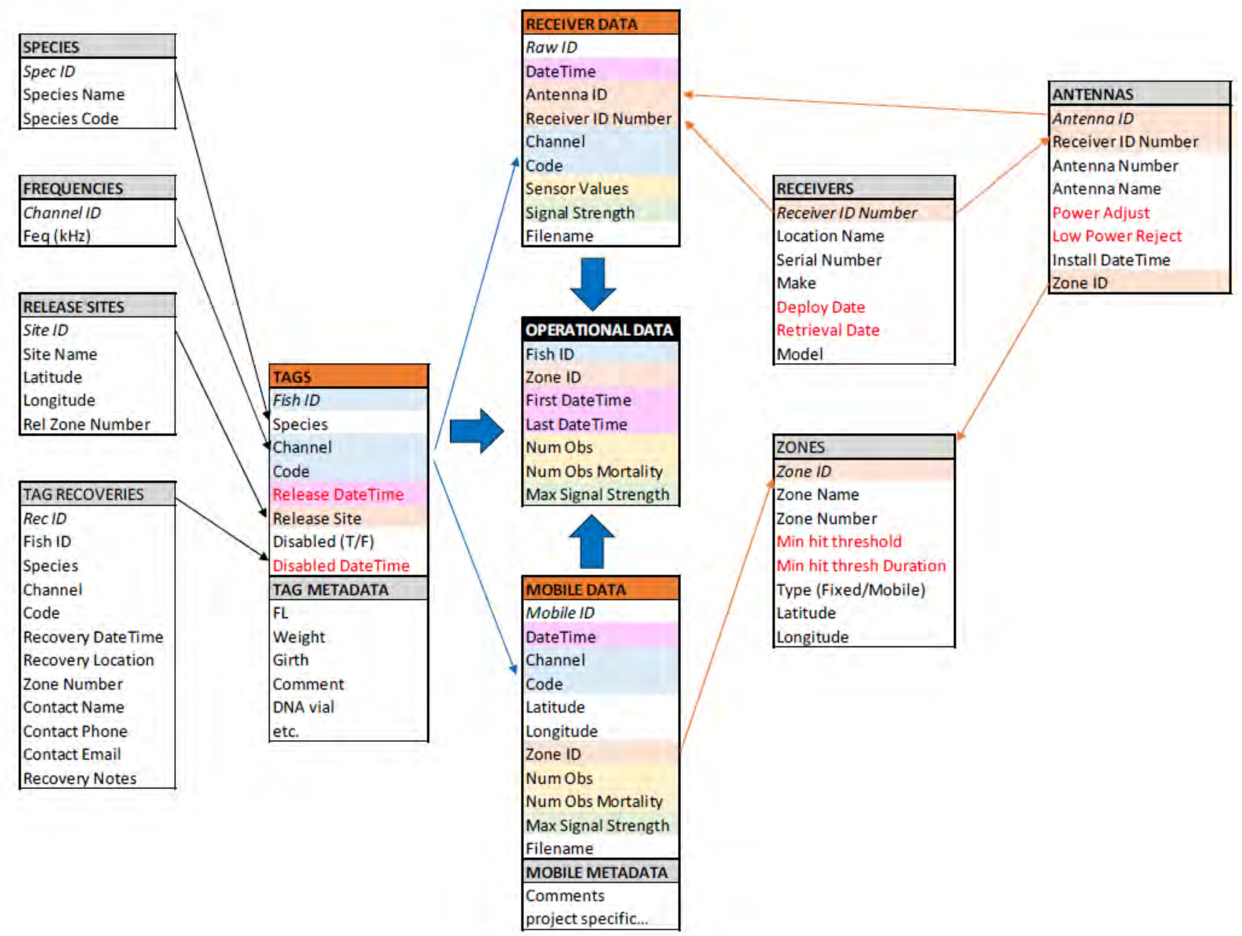


Figure C1. Visual representation of the database, displaying how each of the tables relate to each other.

Table C1. An outline of table names and table contents for the SQL server database.

Table Name	Table Contents	Notes
Species	Key to species codes	
Frequencies	Frequency, channel and code for all tags received	
Release Sites	Release locations	
Tag Recoveries	A detailed account of tags recovered	
Tags	Tagged fish characteristics and release data	
Antennas	Antenna orientation per station	
Receivers	Station locations as well as deploy/demob dates	
Zones	River zones geographically seperated for analysis	
Receiver Data	Processed detection data from fixed receiver sites	
Mobile Data	Processed detection data from mobile telemetry	
Operational Data	All processed detection data and fish attributes for analysis	
DataRequests	Record of data requests	not displayed in Figure C1
DetRadio_FilesImported	Record of SRX800 detection files imported	not displayed in Figure C1
EquipmentFunctionality	List of equipment inventory and status	not displayed in Figure C1
DownTime	Station outages with date ranges and notes	not displayed in Figure C1
StationDeployments	Station deployment locations and notes	not displayed in Figure C1
StationEquipment	Equipment inventory per station	not displayed in Figure C1

Table C2. Details for 2023 data requests from the Site C Fish Movement Database; including request and fulfillment dates along with information about the requester, fulfiller and data delivered.

Date Requested	Date Fufilled	Request Organization	Request Name	Request Contact (Email)	Fufiller Name	Fufiller Contact	Data Description
9-Mar-23	10-May-23	Instream Fisheries	Katrina Cook	Katrina@instream.net	David Robichaud	drobichaud@lgl.com	Full (basinwide) detection histories for 78 tags that has single hits in the Instream dataset.
30-Jun-23	5-Jul-23	BC Hydro	Nich Burnett	nich.burnett@bchydro.com	David Robichaud	drobichaud@lgl.com	Detections of a harvested Rainbow Trout
28-Jun-23	5-Jul-23	WSP	Dustin Ford	dustin.ford@wsp.com	Kyle Hatch	khatch@lgl.com	Whether pre-spawing locations of 2021 and 2022 'active ' Grayling were upstream vs downstream of site C
26-Jul-23	26-Jul-23	WSP	Dustin Ford	dustin.ford@wsp.com	David Robichaud	drobichaud@lgl.com	Detections of another recaptured Rainbow Trout
15-Nov-23	16-Nov-23	Instream Fisheries	Katrina Cook	Katrina@instream.net	David Robichaud	drobichaud@lgl.com	all downloads from Station 11 covering the period from April 1 to October 31

Appendix D. Mobile Tracking Routes

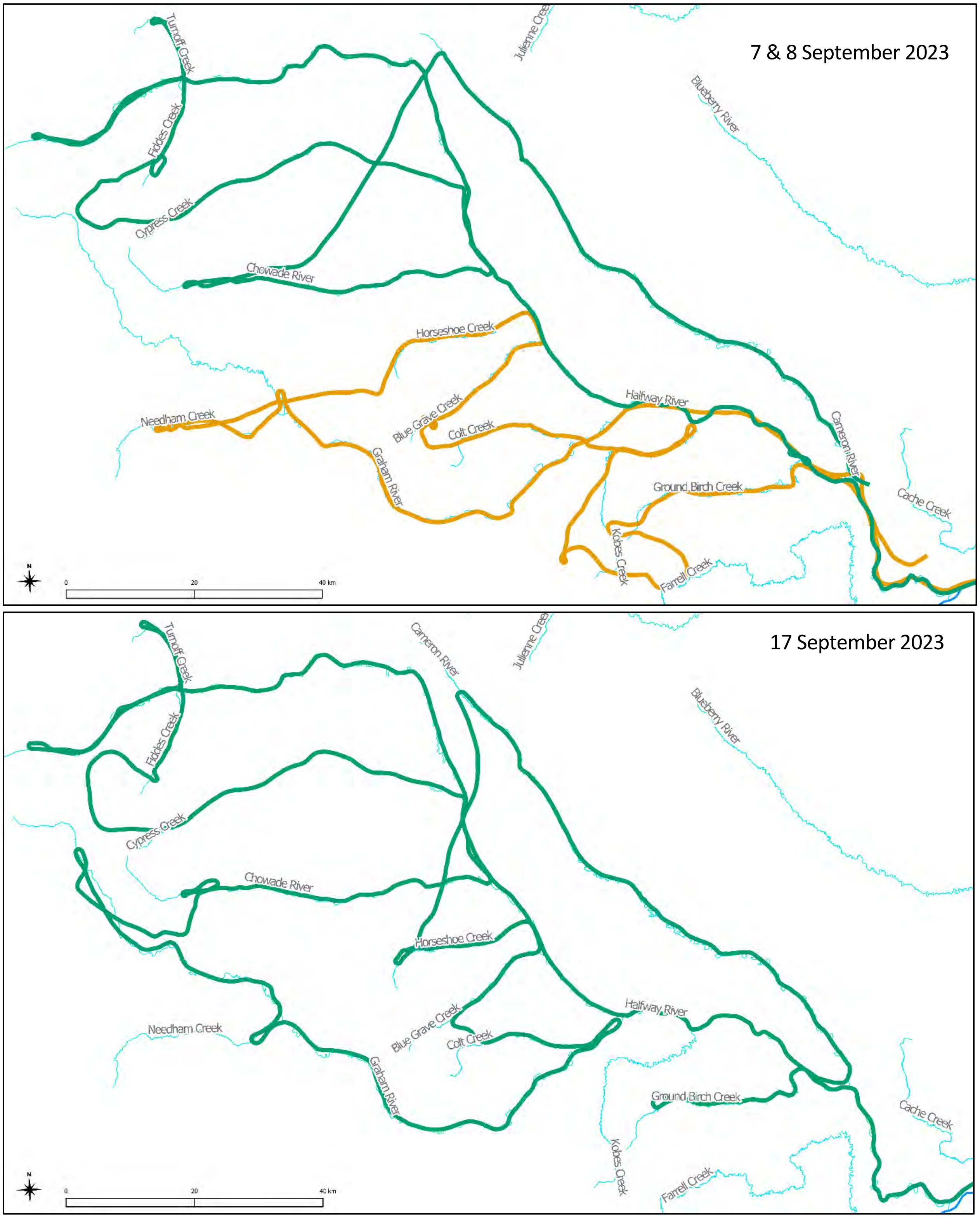


Figure D1. **Tracking routes (early September survey took two flights – shown in orange and green – to complete) for two mobile-telemetry tracking surveys of the Halfway River watershed, September 2023 (see Table 5).**

Appendix E. Additional Tracking Maps

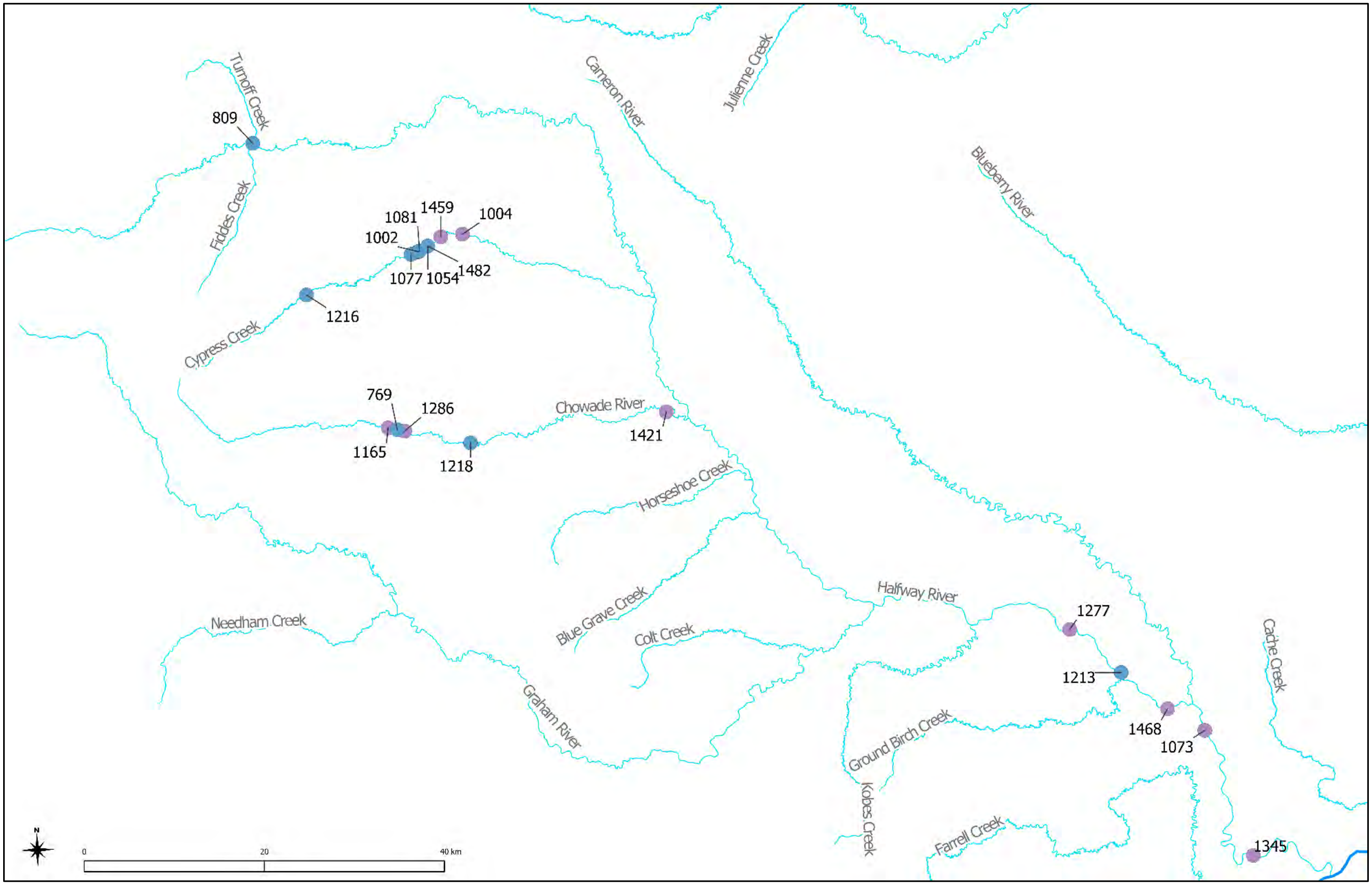


Figure E1. **Bull Trout detection locations, labeled with a unique Tag ID number, during the first of Halfway River mobile tracking surveys, 7 & 8 September 2023. Presumed shed tags (that had not moved since last year) are shown in blue, otherwise purple.**

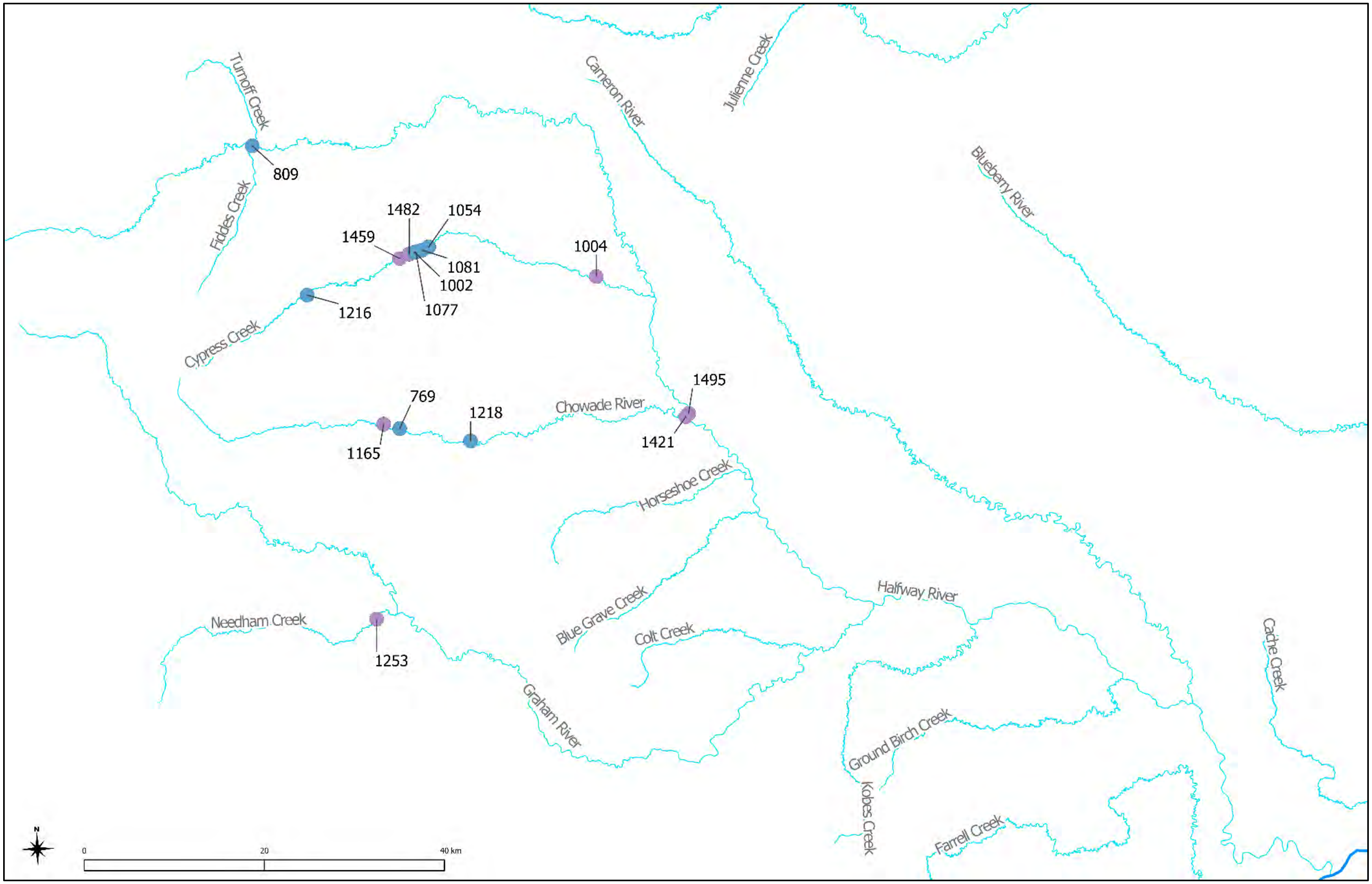


Figure E2. **Bull Trout detection locations, labeled with a unique Tag ID number, during the second of two Halfway River mobile tracking surveys, 17 September 2023. Presumed shed tags (that had not moved since last year) are shown in blue, otherwise, purple.**

Appendix F. Range Test Logistic Figures

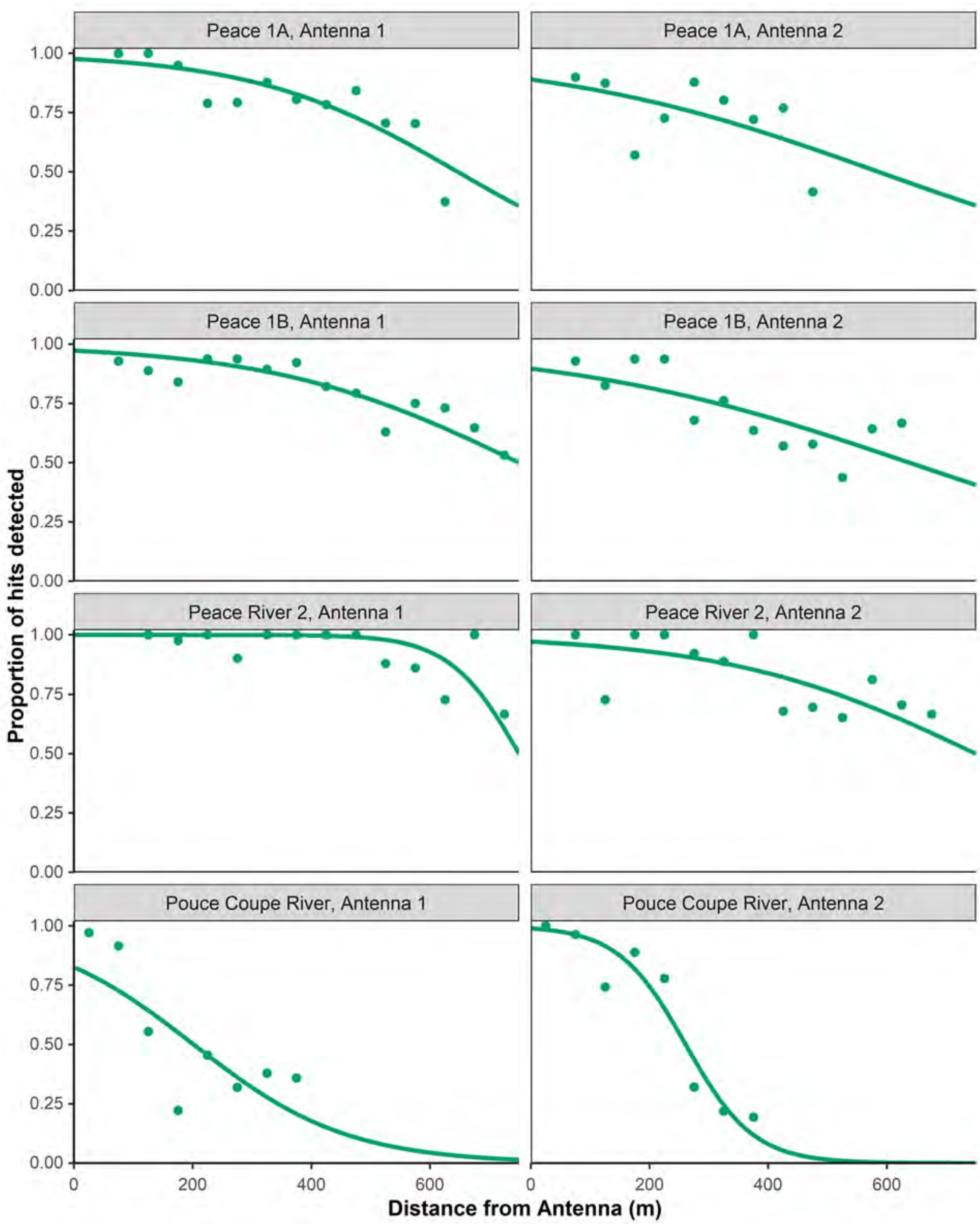


Figure F1. Range test results for specific antennas at fixed stations tested in 2023. Figure continues on following seven pages.

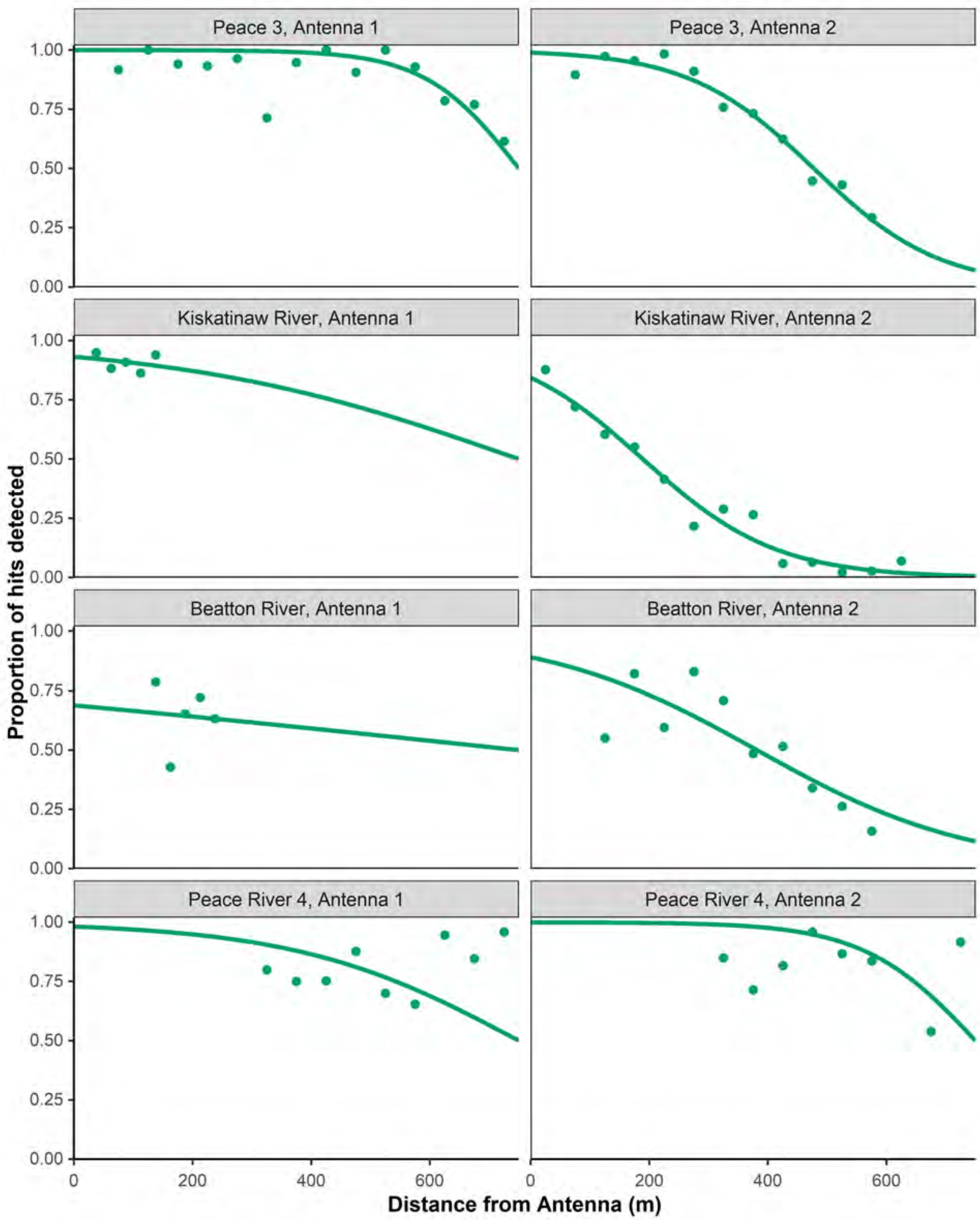
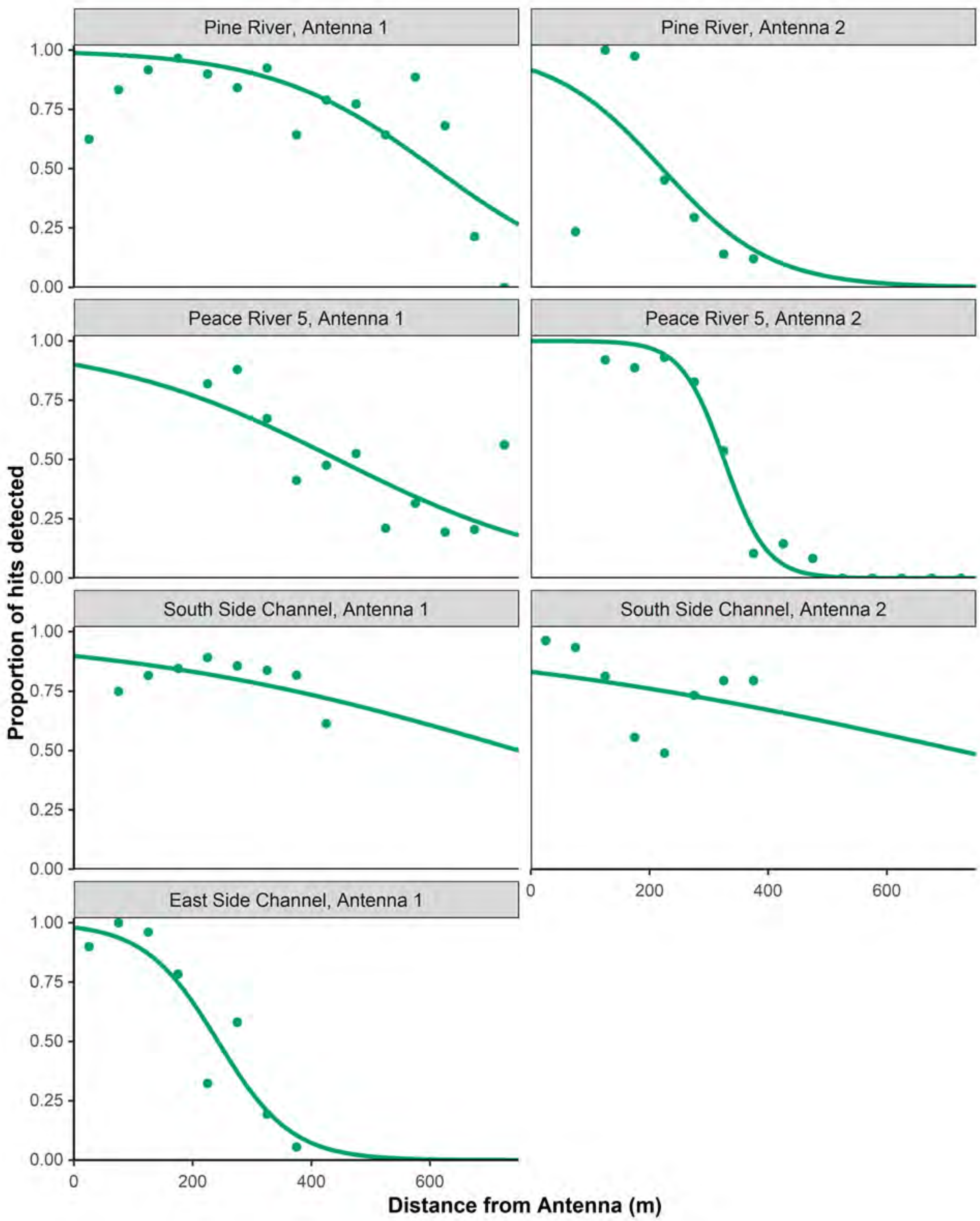


Figure F1 continued (part 2 of 8).



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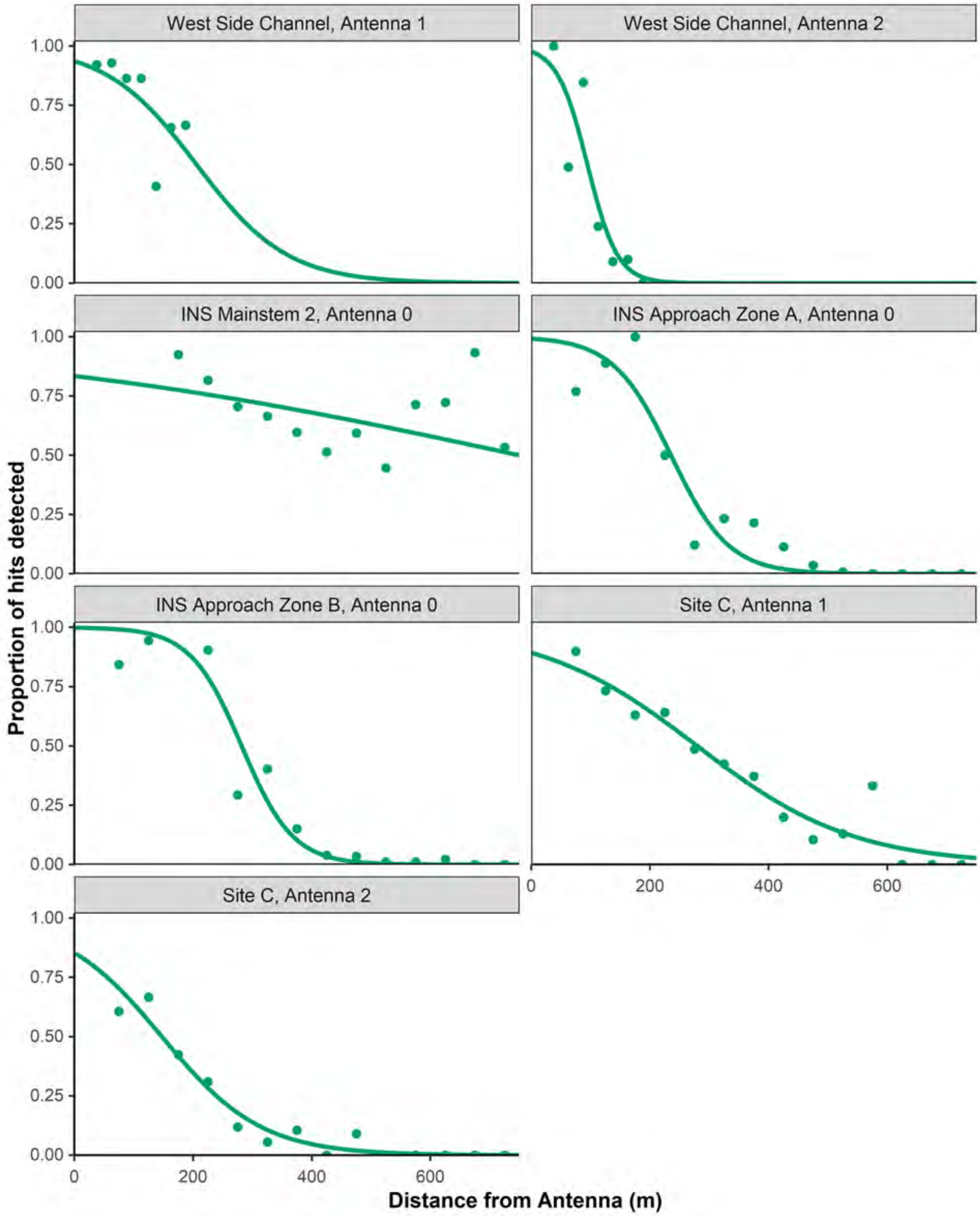

Figure F1 continued (part 4 of 8).

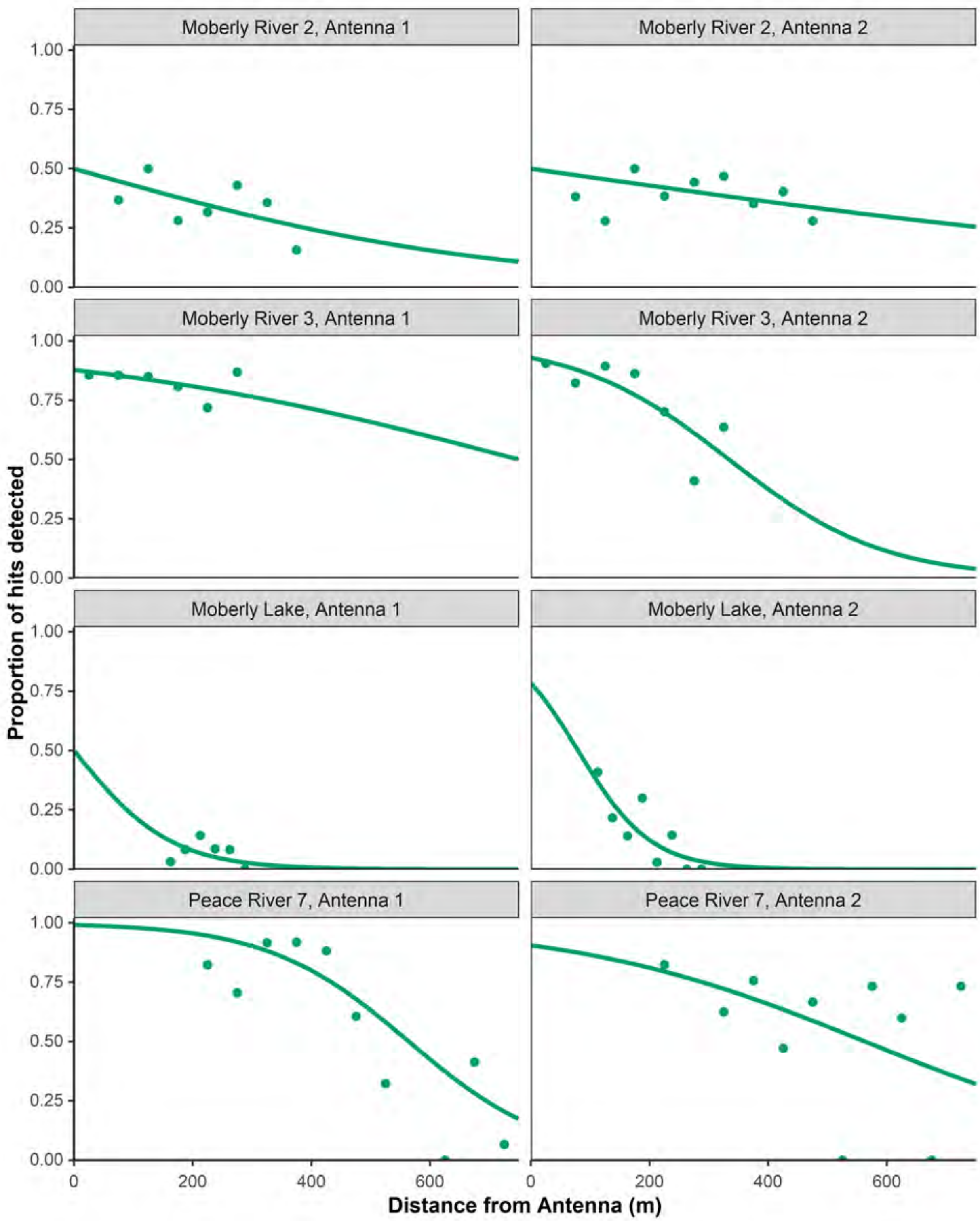

Figure F1 continued (part 5 of 8).

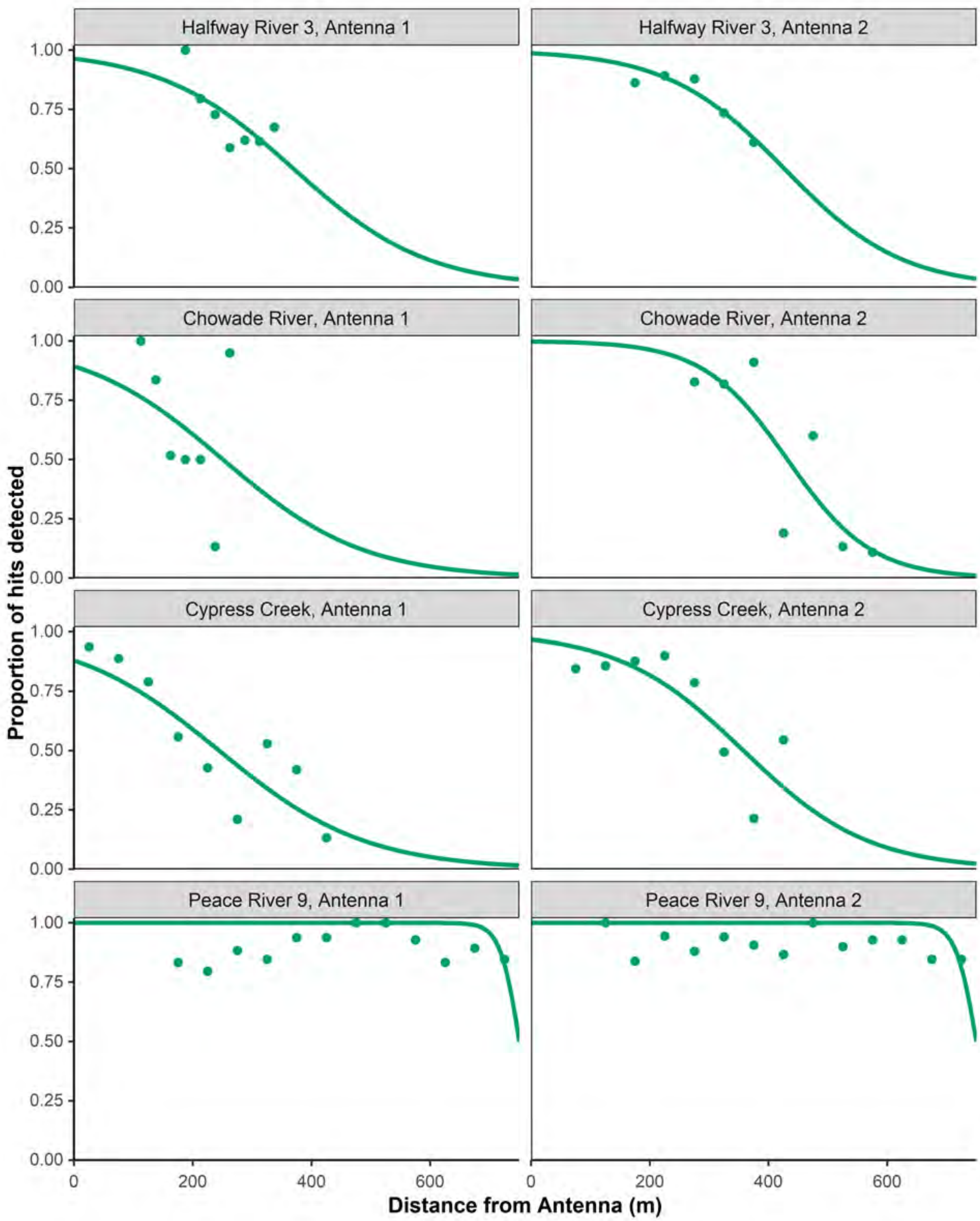

Figure F1 continued (part 6 of 8).

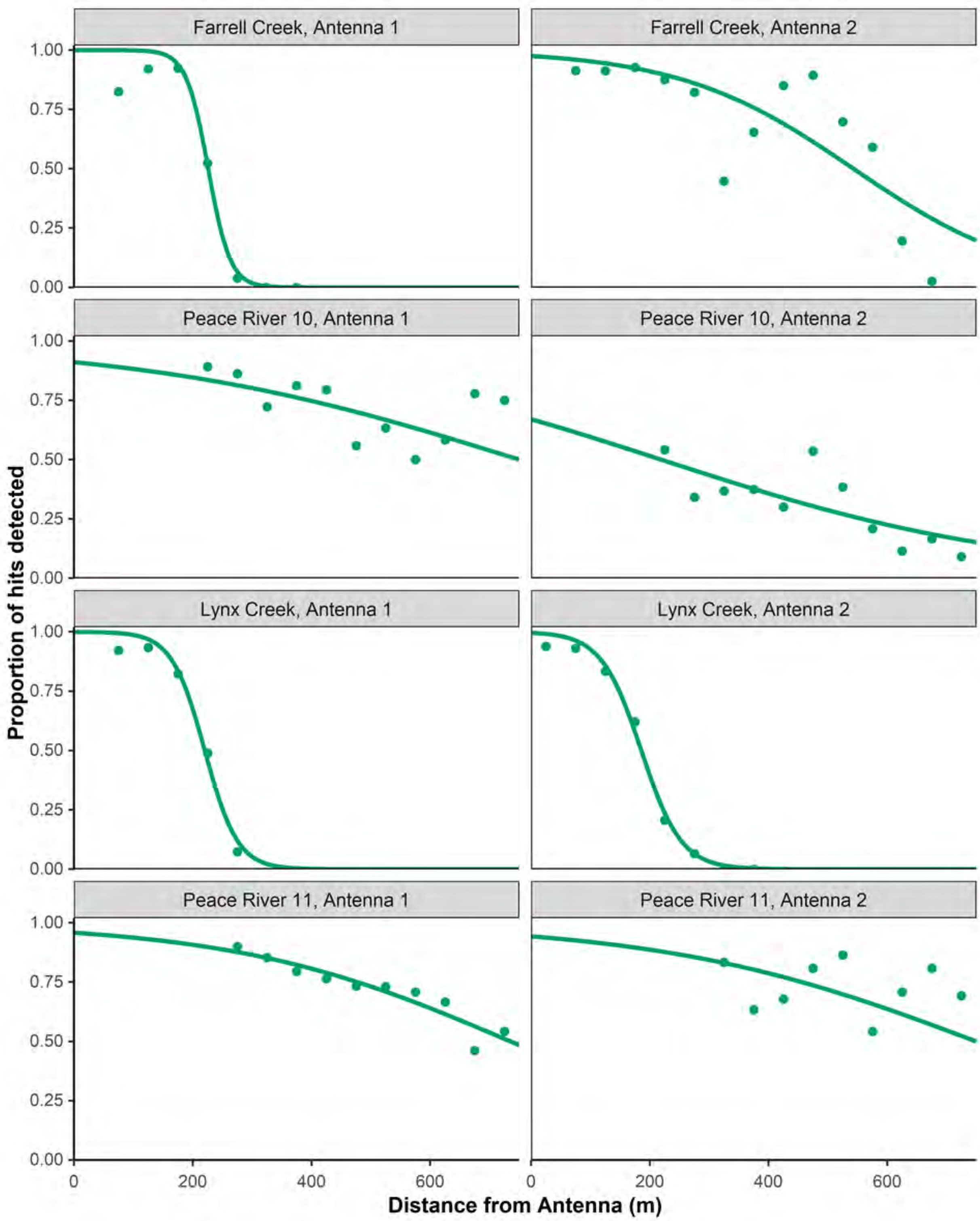

Figure F1 continued (part 7 of 8).

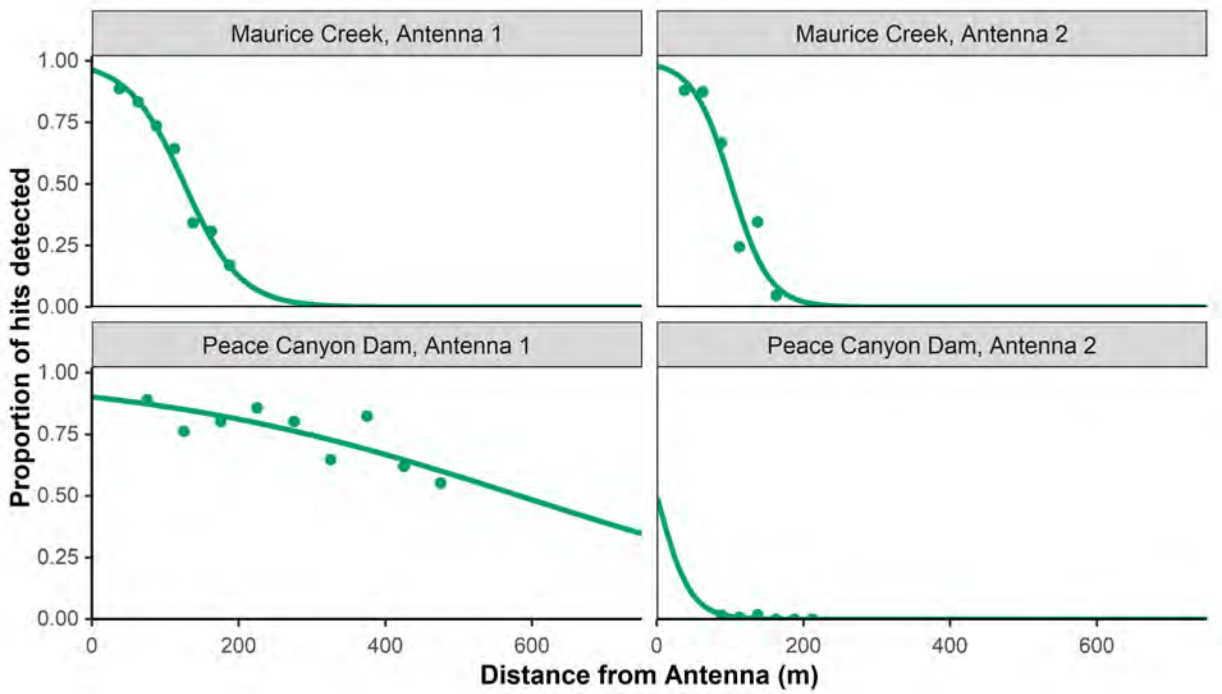

Figure F1 continued (part 8 of 8).