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 7 (2021)

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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 2021 field season (1 January 2021 to 31 January 2022) as well as an accompanying analysis that includes all of data collected from the ongoing study (1 May 2019 to 31 January 2022). 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, Bull Trout, Burbot, Rainbow Trout, and Walleye) in the Peace River and its tributaries. To achieve these study objectives, LGL designed, deployed, and maintained a fixed radio telemetry array comprised of 30 fixed-stations per study year 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) mobile tracking surveys (via helicopter and fixed wing) to augment the data collected by the fixed-station array; and 3) data analysis to begin characterizing the movement patterns of key indicator species.

An array of fixed-stations was designed to encompass the Local Assessment Area from Peace Canyon Dam (RKM 20) to Many Islands, Alberta (RKM 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, 30 fixed-stations collected detection data in 2021. Three of which are operated perennially and have been maintained since their installation in 2019. The remaining 27 fixed-stations are operated seasonally and were re-installed for the 2021 season between 9 March and 1 Aug 2021. Sites deployed within an area of cellular coverage could be contacted remotely to check or change settings, check functionality, and/or download data. All sites were tested for operability, and beacon tags were deployed to assess functionality. Twenty eight fixed-stations were range tested and on average 50%

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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.

of transmissions were detected and properly decoded when tags were 245 m away; this metric varied among fixed-stations from 78 to 474 m. Furthermore, the average fixed-station detection efficiency for both upstream and downstream movements was 87.5% in 2021 (range = 61.1 to 100%).

The primary mobile tracking efforts surveyed key migratory periods for Arctic Grayling and Bull Trout, monitoring fish located in the Moberly and Halfway rivers, respectively. Six Moberly River overflights were conducted in May and June 2021[5] by helicopter and two multi-day surveys of the Halfway River watershed were conducted during peak Bull Trout spawning in September 2021[6] by fixed wing aircraft. Antennas were mounted to the aircraft and connected to telemetry receivers in the cabin for each mobile survey. Additionally, five fixed wing watershed-wide mobile tracks were conducted between 27 November 2021 and 27 January 2022 to supplement data while much of the fixed-station array was demobilized and offline during the winter months.

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. 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 over 15 million valid detection records that passed the filtering criteria between 1 January 2021 and 31 January 2022. Individual fish tracks were processed for the distances and directions moved, and the seasonality of movement patterns.

Preliminary spawning results identified 26 adult and active[7] Bull Trout with spawning behaviours in the upper Halfway River and its tributaries during the fall spawning period in 2021. Additionally, six adult and active Arctic Grayling exhibited potential spawning behaviour in the Moberly River during the Arctic Grayling spawning period from April to June 2021. Of these, five moved upstream beyond the inundation zone at RKM 12. All but one[8] of the spawning Arctic Grayling entered the Moberly River from the Peace River and exited back into the Peace River after spawning.

Mountain Whitefish tagging continued in 2021 (n= 47) between 17 September and 31 October 2021 with the objective of characterizing seasonal movement patterns, with a specific interest in fall behaviour as Mountain Whitefish prepare to spawn. Nearly half (n =20) of the Mountain Whitefish tagged in fall 2021 recorded notable downstream behaviours following release, likely impacts related to handling. Mountain Whitefish fall behaviours recorded in 2006 and 2007 (n= 116) were non-migratory which further supports the possibility of handling impacts affecting the Mountain Whitefish tagged in 2021.

To help interpret wintertime Burbot behaviours, mobile surveys were conducted along the Peace River from November 2021 to January 2022, during which 14 wintertime movements were recorded from 10 Burbot. The majority (10 of 14) of these Burbot behaviours were categorized as non-migratory, wherein the individuals did not move significantly during the winter. Of the remaining four, only one Burbot movement was confirmed to have occurred in late fall or winter, wherein the individual migrated 78 RKM downstream from the Beatton River to Many Islands, Alberta in November or December. The remaining

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[5] Moberly River mobile detection flights were conducted on 5 May, 14 May, 22 May, 30 May, 7 June, and 14 June 2021

[6] Halfway River mobile detection flights were conducted on 7 September, 8 September, 16 September, 17 September, and 23 September 2021.

[7] Active refers to a radio-tagged study fish that is not a mortality and possesses a tag that has not yet expired. In terms of spawning, an active study fish is an individual that was tagged before the spawning period began, was detected following release, and was detected during and/or after the spawning period.

[8] This individual has been detected in the same Moberly River location from May 2021 into January 2022 and is presumed a mortality or shed tag.

three Burbot logged relatively long distance movements[9] over long spans of time without intervening detections, which could imply the individual migrated when the array was not in operation (i.e., winter), however without additional resolution that cannot be confirmed.

All of the results presented in this report are preliminary. The figures generated to characterize magnitude, seasonality and direction were created to display the capacity of the telemetry detection system (fixed and mobile), 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. Continued operation of the fixed-station array, and continued mobile tracking, including winter tracking, will help further report on the management questions addressed herein as well as those that will be addressed in the future.

[9] One Burbot migrated within the Peace River upstream of Site C while the other two migrated in the Peace River below Site C.

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Introduction

In accordance with Provincial Environmental Assessment Certificate Condition No. 7[10] and Federal Decision Statement Condition Nos. 8.4.3[11] and 8.4.4[12] 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[13]). 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 in 2019 to characterize the magnitude, seasonality, and direction of six key indicator species (Arctic Grayling *Thymallus arcticus*, Bull Trout *Salvelinus confluentus*, Burbot *Lota lota*, 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 migratory 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 a capability of 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 station 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[14] followed by Operation Years 1-4, 10-11, 15-16, 20-21, 25-26 and 29-30[15]. 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

[10] 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.

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

[12] 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.

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

[14] 2019 - 2024

[15] 2024-2028, 2034-2035, 2039-2040, 2044-2045, 2049-2050 and 2053-2054, respectively

River, Chowade River, and Cypress Creek). That said, the array is designed to be flexible, whereby stations can be added, moved, and/or improved as monitoring progresses or study priorities shift.

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 further 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 migratory 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[16], Golder Associates collected, radio-tagged, and released 264 study fish between April and October 2021. All radio-tagged study fish were collected by boat electroshocking using methods and settings that were consistent with previous study years (Golder Associates 2022). Collected study fish were identified to species, weighed in grams, measured for fork length (FL, in mm) and assigned a life stage (i.e., adult or juvenile[17]) based on their length (Figure 1). Similar to 2019 and 2020, 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 (Golder Associates 2022).

Acceptable study fish in 2021 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 2021 (Golder Associates 2022), which is a standard that has been consistently referenced in telemetry literature (Jepsen et al. 2005, Smircich and Kelly 2014). For all 2021 tagged fish, the tag burden ranged between 0.06% to 1.89% with a mean of 0.80%.

Prior to 2021, all of the radio tags transmitted at a radio frequency of 149.360 MHz ('Channel 3'). Starting in 2021, transmitters of a second frequency (149.400 MHz; or 'Channel 5') were deployed. The technology used by the radio tag manufacturer (Lotek Wireless[18]) to produce individually-recognizable coded tags only allows for 728 unique IDs. The number of radio-tagged fish released in the Peace River area to date has surpassed that number, thus the need for a second frequency. This has implications for array design and detection efficiencies. Additionally, all 2021 study fish were radio tagged with the larger Nano NTF-6-2 radio tag to prioritize a longer expected battery life for all study fish.

Table 1. Lotek Nano radio tag models are listed along with tag weight (grams in air), average burst interval[19] (seconds), expected battery life (days), and the quantities deployed since 2019, by channel.

				Number Deployed			
				2019	2020	2021	
Tag model	Tag weight (grams)	Avg burst interval (secs)	Expected battery life (days)	Channel 3	Channel 3	Channel 3	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	229	168		206
NFT-6-2_5s	4.00	5.0	565			58	

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16 D. Burgoon and D. Ford, technical memorandum, 28 February 2022. Golder Associates Reference No. 20136470-017-TM-Rev0-3000.

17 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 (Golder Associates 2022).

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

19 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 9.799 seconds.

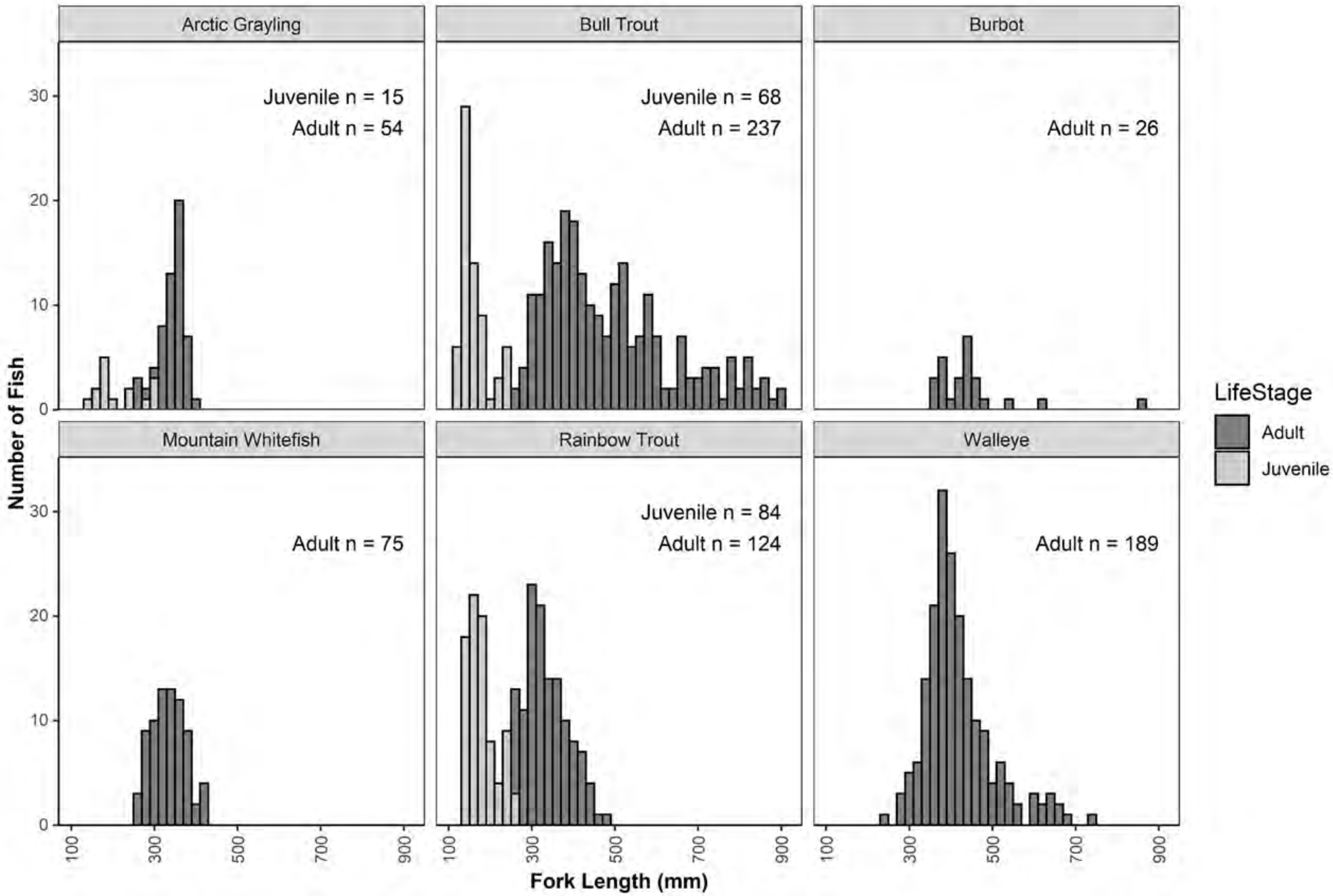

Figure 1. **Histograms of tagged study fish fork length (mm) by species. Life stage, either juvenile or adult, is denoted by light and dark bars and sample sizes are specified within each species window.**

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 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[20]. 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 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 [21] and then placed ventral side up on a sponge-lined tray in preparation for the surgical tag insertion.

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[22]. 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[23]. The exception to this standard was 17 radio tagged Bull Trout that were released at the Halfway River Boat Launch following capture by electrofishing downstream of Site C (n = 14) or while passing the Temporary Upstream Fishway (or TUF, n = 3). Those captured downstream of Site C were collected as part of the Contingent Fish Capture and Transport Program (Golder Associates 2022). In addition to the three Bull Trout captured at the TUF there were also six Mountain Whitefish captured at the TUF before being tagged and then released upstream of Site C.

In total, there were 45 radio tagged study fish that were captured as part of the Contingent Fish Capture and Transport Program. Of which, 31 were collected below Site C and then released into the Site C Forebay, just upstream of Site C. This effort captured and radio-tagged individuals of four different species: Bull Trout (n = 7), Arctic Grayling (n = 8), Rainbow Trout (n = 15), and Mountain Whitefish (n = 1)[24].

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

[21] Passive integrated transponders or PIT tag.

[22] 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)

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

[24] Additional details on the Contingent Fish Capture and Transport Program from 2021 are detailed in this technical memorandum: D. Burgoon and D. Ford, technical memorandum, 28 February 2022. Golder Associates Reference No. 20136470-017-TM-Rev0-3000.

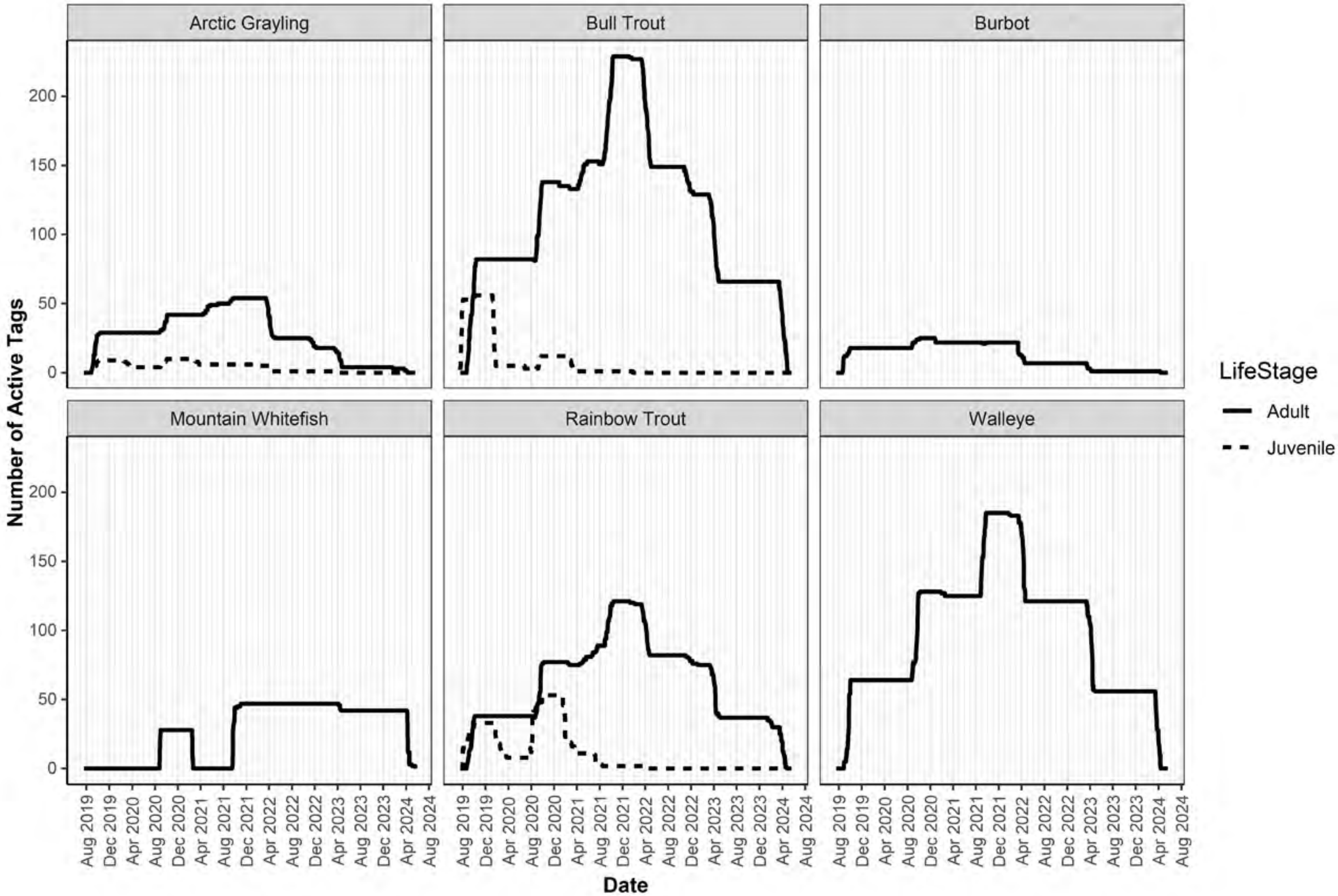

Figure 2. **Estimated numbers of active radio tags, by species and date, from 2019 onward. Values are based on the numbers of tags deployed by date, and the manufacturer's battery life estimates for each of their tag models.**

An overview map of the study area, including the Peace River release sections, and density of fish released in 2021 are displayed in Figure 3. The numbers of radio-tagged fish released each year (i.e., in 2019, 2020, or 2021) 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.

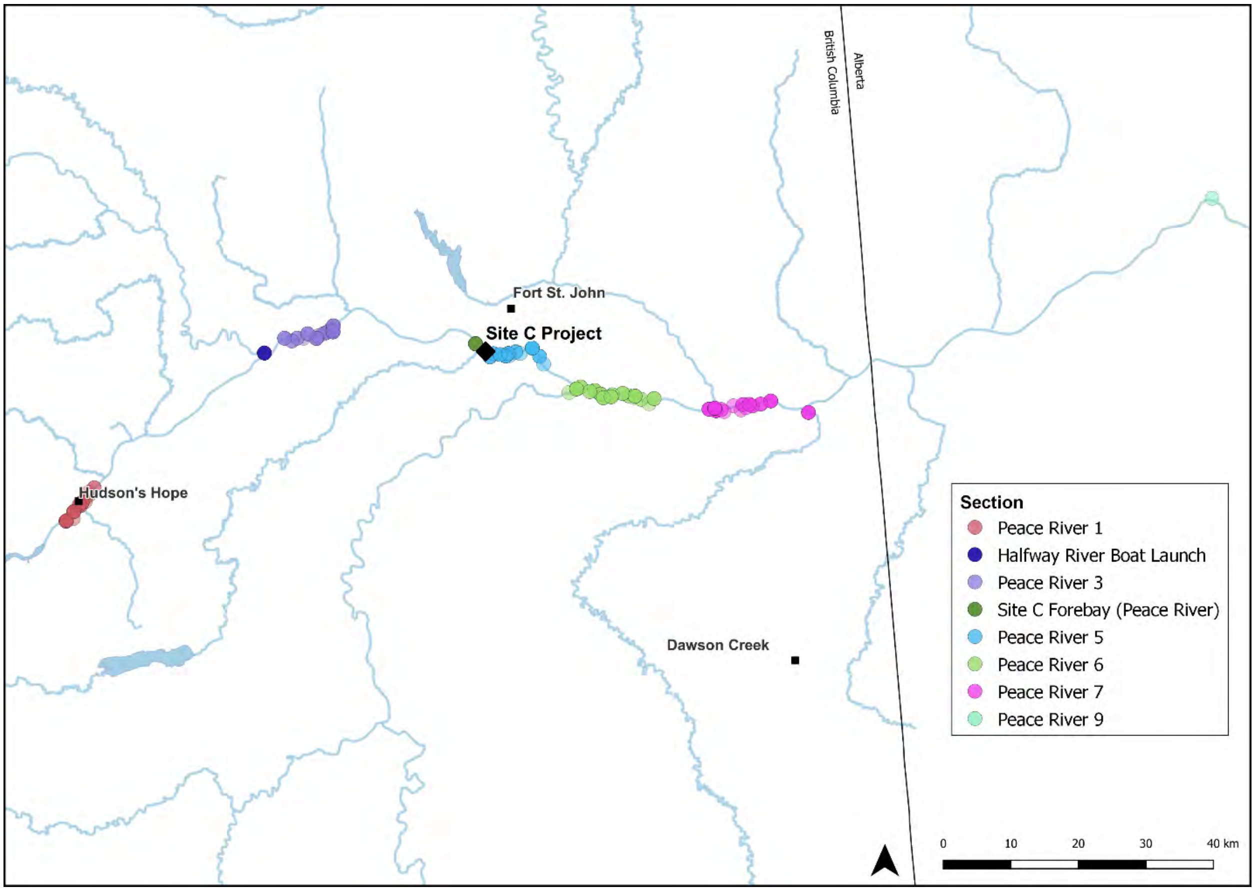

Figure 3. Map of the Peace River study area showing release locations of radio-tagged study fish in 2021.

Table 2. Radio-tagged study fish from 2019 through 2021 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 less than 1 RKM 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	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 Boat Launch	Halfway River	Pine River	Beatton River	Kiskatinaw River	Total
2019	Arctic Grayling	Adult	NTF-6-2	0	20	0	4	4	1	0	0	0	0	0	0	0	0	**29**
2019	Arctic Grayling	Juvenile	NTF-6-2	0	0	0	0	3	2	0	0	0	0	0	0	0	0	**5**
2019	Arctic Grayling	Juvenile	NTF-3-2	0	0	0	3	1	0	0	0	0	0	0	0	0	0	**4**
2020	Arctic Grayling	Adult	NTF-6-2	0	12	0	1	0	0	0	0	0	0	0	0	0	0	**13**
2020	Arctic Grayling	Juvenile	NTF-6-2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	**1**
2020	Arctic Grayling	Juvenile	NTF-6-1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	**1**
2020	Arctic Grayling	Juvenile	NTF-3-2	0	2	0	1	1	0	0	0	0	0	0	0	0	0	**4**
2021	Arctic Grayling	Adult	NTF-6-2	0	0	1	1	0	2	0	0	0	0	0	0	0	0	**4**
2021	Arctic Grayling	Adult	NFT-6-2_5s	0	0	7	1	0	0	0	0	0	0	0	0	0	0	**8**
2019	Bull Trout	Adult	NTF-6-2	26	25	0	13	10	4	1	0	0	0	0	0	0	0	**79**
2019	Bull Trout	Adult	NTF-6-1	2	0	0	0	1	0	0	0	0	0	0	0	0	0	**3**
2019	Bull Trout	Juvenile	NTF-5-2	0	0	0	1	2	0	0	0	0	0	2	0	0	0	**5**
2019	Bull Trout	Juvenile	NTF-3-2	0	0	0	0	0	0	0	0	0	0	51	0	0	0	**51**
2020	Bull Trout	Adult	NTF-6-2	12	17	0	11	6	1	4	0	0	0	0	0	0	0	**51**
2020	Bull Trout	Adult	NTF-6-1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	**2**
2020	Bull Trout	Adult	NTF-5-2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	**2**
2020	Bull Trout	Adult	NTF-3-2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	**2**
2020	Bull Trout	Juvenile	NTF-6-1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	**1**
2020	Bull Trout	Juvenile	NTF-3-2	4	1	0	3	2	0	1	0	0	0	0	0	0	0	**11**
2021	Bull Trout	Adult	NFT-6-2	12	21	1	17	7	5	1	0	0	0	0	1	0	1	**66**
2021	Bull Trout	Adult	NFT-6-2_5s	2	5	6	1	1	0	0	0	0	17	0	0	0	0	**32**
2019	Burbot	Adult	NTF-6-2	0	1	0	1	0	5	8	0	0	0	0	0	0	0	**15**
2019	Burbot	Adult	NTF-6-1	0	0	0	0	3	0	0	0	0	0	0	0	0	0	**3**
2020	Burbot	Adult	NTF-6-2	0	0	0	2	0	2	2	0	0	0	0	0	0	0	**6**
2020	Burbot	Adult	NTF-5-2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	**1**
2021	Burbot	Adult	NFT-6-2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	**1**
2020	Mountain Whitefish	Adult	NTF-3-2	0	0	0	19	5	4	0	0	0	0	0	0	0	0	**28**
2021	Mountain Whitefish	Adult	NFT-6-2	0	0	3	23	14	0	0	0	0	0	0	2	0	0	**42**
2021	Mountain Whitefish	Adult	NFT-6-2_5s	0	0	4	1	0	0	0	0	0	0	0	0	0	0	**5**
2019	Rainbow Trout	Adult	NTF-6-2	18	15	0	5	0	0	0	0	0	0	0	0	0	0	**38**
2019	Rainbow Trout	Juvenile	NTF-6-2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	**2**
2019	Rainbow Trout	Juvenile	NTF-5-2	2	1	0	1	2	0	0	0	0	0	0	0	0	0	**6**
2019	Rainbow Trout	Juvenile	NTF-3-2	7	2	0	0	0	1	0	0	15	0	0	0	0	0	**25**
2020	Rainbow Trout	Adult	NTF-6-2	19	16	0	1	0	0	0	0	0	0	0	0	0	0	**36**
2020	Rainbow Trout	Adult	NTF-6-1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	**2**
2020	Rainbow Trout	Adult	NTF-3-2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	**2**
2020	Rainbow Trout	Juvenile	NTF-5-2	0	1	0	0	0	0	0	7	1	0	0	0	0	0	**9**
2020	Rainbow Trout	Juvenile	NTF-3-2	9	1	0	0	1	1	0	20	10	0	0	0	0	0	**42**
2021	Rainbow Trout	Adult	NFT-6-2	15	9	7	4	0	1	0	0	0	0	0	0	0	1	**37**
2021	Rainbow Trout	Adult	NFT-6-2_5s	0	1	8	0	0	0	0	0	0	0	0	0	0	0	**9**
2019	Walleye	Adult	NTF-6-2	0	2	0	1	11	48	0	0	0	0	0	0	0	0	**62**
2019	Walleye	Adult	NTF-6-1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	**1**
2019	Walleye	Adult	NTF-5-2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	**1**
2020	Walleye	Adult	NTF-6-2	2	13	0	8	11	17	10	0	0	0	0	0	0	0	**61**
2020	Walleye	Adult	NTF-6-1	0	0	0	0	1	0	1	0	0	0	0	0	0	0	**2**
2020	Walleye	Adult	NTF-3-2	0	0	0	2	0	0	0	0	0	0	0	0	0	0	**2**
2021	Walleye	Adult	NFT-6-2	0	0	0	3	18	17	0	0	0	0	0	5	12	1	**56**
2021	Walleye	Adult	NFT-6-2_5s	0	0	0	1	1	0	0	0	0	0	0	0	2	0	**4**
Total				**137**	**171**	**37**	**132**	**106**	**112**	**28**	**27**	**26**	**17**	**53**	**8**	**14**	**4**	**872**

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 two or three, three-element YAGI antennas that receive radio signals, which then pass through a coaxial cable to a Lotek ASP-8 switcher, and into the SRX800 MD-4 receiver for coding and storage (Figure 4). Two antennas were the standard with one oriented upstream and the other downstream. A third antenna was added if the station was situated at the confluence of a tributary, where the first two antennas pointed up and down the Peace River and the third antenna pointed up the tributary.

The power system provided continuous power 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 SRX800 receiver. When the angle of the sun and the hours of

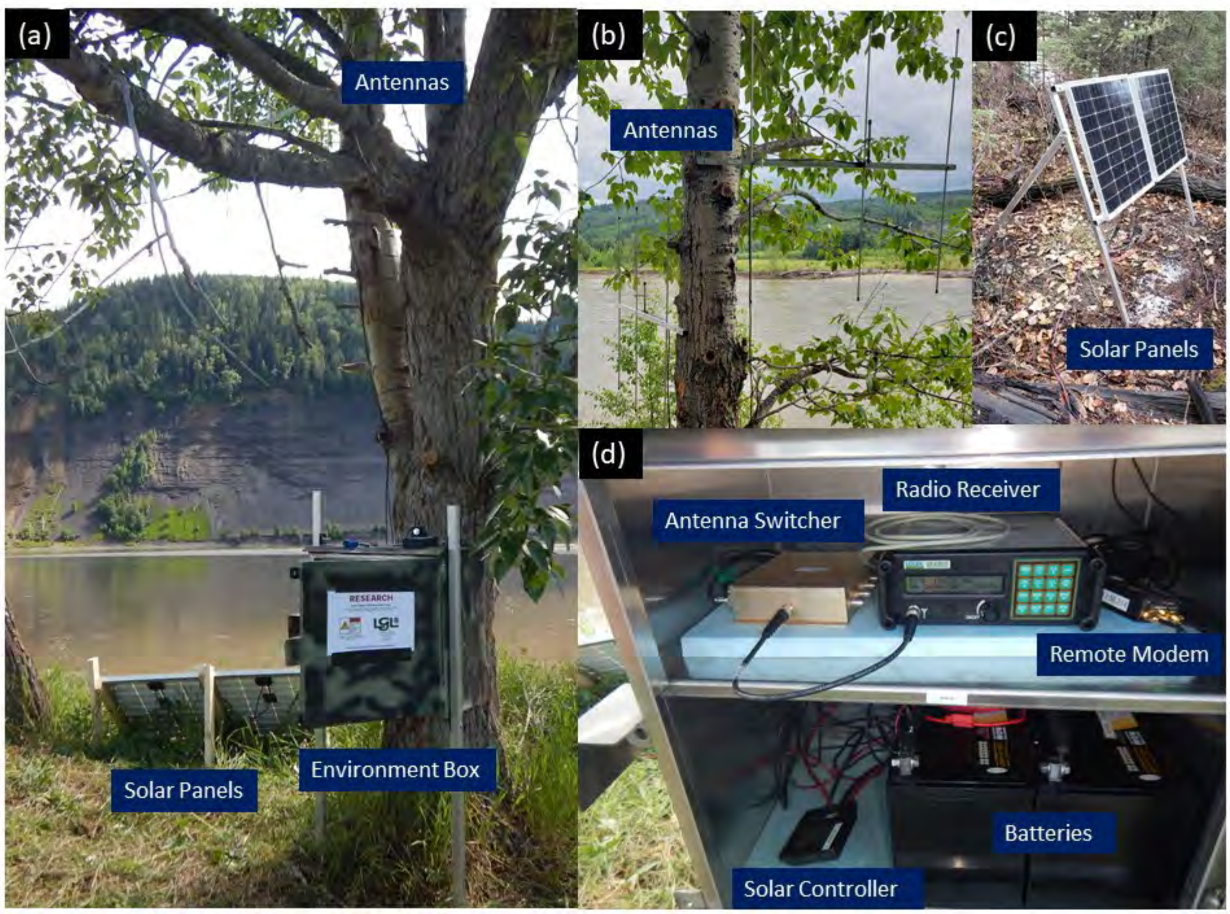

Figure 4. Example of a fixed radio telemetry station. (a) View of the antennas, environment box, and solar panels. (b) Two, three-element YAGI antennas are mounted to a tree. (c) Two, 80-watt solar panels mounted to an aluminum stand for deployment during the winter months. (d) View of the inside of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

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 a ground-mounted wood stand for setups operating spring to fall, and an aluminum stand for stations operating in the winter[25] (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.

All stations had a beacon tag positioned on a nearby tree for outage analyses. Beacon tags emitted a coded radio signal once every ten seconds for the first minute of every hour, followed by 59 minutes of radio silence before repeating the sequence. This programming design ensured that beacon tag transmissions did not congest the radio bandwidth around the fixed-station. At individual fixed-stations, observed beacon tag detections were analyzed against expected beacon tag detections to identify when fixed-station outages occurred (i.e., when data collection was impacted).

Starting in late July (Table 3), stations were programmed to scan two frequencies, whereas they had previously only scanned one. The receivers now scan 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 (RKM[26] 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[27] 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. Additional stations were placed in tributaries upstream of the Peace River (Table 3, Figure 5).

[25] The aluminum solar stand lifts the panels higher to avoid snow accumulation and creates a more vertical orientation to compensate for the position of the sun in winter.

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

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

Table 3. **Station names, types, numbers, installation and demobilization dates, and status (as of January 2022). Ten stations, deployed or maintained as part of Mon-13 (Site C Fishway Effectiveness Monitoring Program), are named with a prefix "INS".**

Station Name	Access	Station Type	Station #	Installation Date	Second Freq Added	Demobilization Date	Modem	Operation	Count / Location
Peace River 1A	Boat	Peace River	1	8 Apr 2021	23 Jul 2021	25 Oct 2021	No	Seasonal	2 / tree
Peace River 1B	Boat	Peace River	2	8 Apr 2021	23 Jul 2021	3 Oct 2021	No	Seasonal	2 / tree
Peace River 2	Boat	Peace River	3	8 Apr 2021	23 Jul 2021	25 Oct 2021	No	Seasonal	2 / tree
Pouce Coupe River	Boat	Tributary Entrance	4	9 Apr 2021	23 Jul 2021	3 Oct 2021	No	Seasonal	3 / tree
Peace River 3	Boat	Peace River	5	9 Apr 2021	23 Jul 2021	25 Oct 2021	No	Seasonal	2 / tree
Kiskatinaw River	Boat	Tributary Entrance	6	9 Apr 2021	23 Jul 2021	25 Oct 2021	No	Seasonal	3 / tree
Beatton River	Boat	Tributary Entrance	7	11 Mar 2021	23 Jul 2021	3 Oct 2021	No	Seasonal	3 / tree
Peace River 4	Truck	Peace River	8	14 Mar 2021	21 Jul 2021	30 Dec 2021	No	Seasonal	2 / tripod
Pine River	Boat	Tributary Entrance	9	28 Apr 2021	23 Jul 2021	3 Oct 2021	No	Seasonal	2 / tree
Peace River 5	Boat	Peace River	10	11 Mar 2021	23 Jul 2021	25 Oct 2021	No	Seasonal	2 / tree
Site C Dam	Truck	Peace River	11	11 Jul 2019	21 Jul 2021	-	No	Perennial	2 / tree
INS Mainstem 2	Truck	Peace River	33	1 Aug 2020	19 Jul 2021	-	-	Perennial	2
INS Approach Zone A	Truck	Peace River	34	2 Aug 2020	19 Jul 2021	-	-	Perennial	1
INS Approach Zone B	Truck	Peace River	35	3 Aug 2020	19 Jul 2021	-	-	Perennial	1
INS Cofferdam	Truck	Peace River	36	3 Aug 2020	19 Jul 2021	-	-	Perennial	2
INS Diversion Tunnel	Boat	Peace River	37	4 Apr 2021	19 Jul 2021	-	-	Perennial	2 / tree
INS Entrance Aerial	Truck	Peace River	38	15 Sep 2020	19 Jul 2021	-	-	Perennial	1
INS Entrance Dipole 1	Boat	Peace River	39	25 Mar 2021	19 Jul 2021	1 Nov 2021	-	Seasonal	2 / tree
INS Entrance Pool Dipole 1	Boat	Peace River	40	28 Mar 2021	19 Jul 2021	1 Nov 2021	-	Seasonal	2 / tree
INS Turning Basin	Boat	Peace River	41	28 Mar 2021	19 Jul 2021	1 Nov 2021	-	Seasonal	2 / tripod
INS Cell 8	Boat	Peace River	42	27 Mar 2021	19 Jul 2021	1 Nov 2021	-	Seasonal	2
INS Vee-Trap	Boat	Peace River	43	28 Mar 2021	19 Jul 2021	1 Nov 2021	-	Seasonal	1
INS Diversion Tunnel Inlet	Boat	Peace River	46	28 Mar 2021	19 Jul 2021	-	-	Perennial	1
Moberly River 1	Truck	Tributary Entrance	12	11 Jul 2019	21 Jul 2021	-	No	Perennial	2 / tree
Moberly River 2	Helicopter	Tributary Upstream	13	11 Apr 2021	22 Jul 2021	1 Oct 2021	No	Seasonal	2 / tree
Moberly River 3	Helicopter	Tributary Upstream	14	12 Mar 2021	22 Jul 2021	27 Oct 2021	No	Seasonal	2 / tree
Moberly Lake	Truck	Tributary Upstream	47	7 Apr 2021	21 Jul 2021	30 Sep 2021	No	Seasonal	2 / tree
Peace River 6	Truck	Peace River	15	10 Mar 2021	21 Jul 2021	25 Oct 2021	No	Seasonal	2 / tree
Peace River 7	Truck	Peace River	16	10 Apr 2021	24 Jul 2021	25 Oct 2021	No	Seasonal	2 / tree
Cache Creek	Truck	Tributary Entrance	17	10 Mar 2021	22 Jul 2021	28 Sep 2021	No	Seasonal	2 / tree
Peace River 8	Truck	Peace River	18	10 Mar 2021	22 Jul 2021	26 Oct 2021	No	Seasonal	2 / tripod
Halfway River 1	Truck	Tributary Entrance	19	8 Jul 2019	22 Jul 2021	-	Yes	Perennial	2 / tree
Halfway River 2	Helicopter	Tributary Upstream	20	22 Jul 2021	22 Jul 2021	27 Oct 2021	No	Seasonal	2 / tree
Halfway River 3	Helicopter	Tributary Upstream	21	12 Mar 2021	22 Jul 2021	27 Oct 2021	No	Seasonal	2 / tree
Chowade River	Truck	Tributary Upstream	29	1 Aug 2021	1 Aug 2021	5 Oct 2021	No	Seasonal	3 / tree
Cypress Creek	Truck	Tributary Upstream	30	30 Jul 2021	30 Jul 2021	6 Oct 2021	No	Seasonal	2 / tree
Peace River 9	Truck	Peace River	22	10 Mar 2021	21 Jul 2021	26 Oct 2021	No	Seasonal	2 / tree
Farrell Creek	Truck	Tributary Entrance	44	9 Mar 2021	21 Jul 2021	28 Sep 2021	No	Seasonal	1
Peace River 10	Truck	Peace River	24	11 Mar 2021	21 Jul 2021	29 Sep 2021	No	Seasonal	2 / tree
Peace River 11	Truck	Peace River	26	11 Mar 2021	21 Jul 2021	26 Oct 2021	No	Seasonal	2 / tree
Maurice Creek	Truck	Tributary Entrance	31	13 Mar 2021	21 Jul 2021	29 Sep 2021	No	Seasonal	2 / tree
Peace Canyon Dam	Truck	Peace River	45	13 Mar 2021	21 Jul 2021	26 Oct 2021	No	Seasonal	2

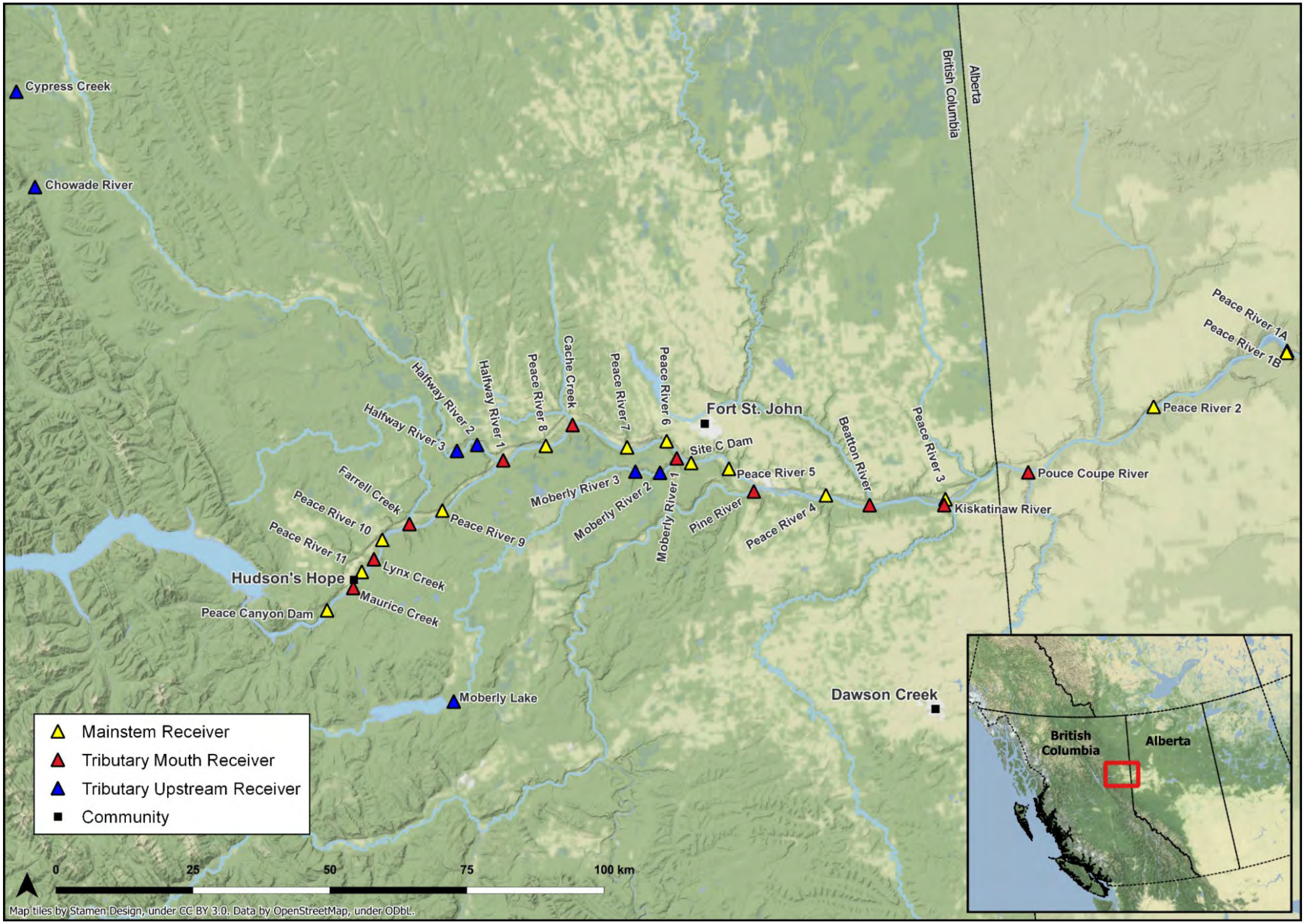

Figure 5. **Locations of the 30 fixed radio telemetry stations operated for the Site C Fish Movement Assessment in 2021. Twelve additional stations that are not shown on this map were deployed or maintained by InStream Fisheries Research as part of Mon-13 (Site C Fishway Effectiveness Monitoring Program).**

Among the 30 fixed radio telemetry stations deployed in 2020 (Hatch et al. 2021), 29 were similarly deployed and operated in 2021 (Table 3). The differences being that the new Moberly Lake fixed-station was operated in 2021 while the Lynx Creek station was not[28]. In addition, 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.

The temporal extent of the array spanned from 9 March to 27 October 2021 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, depending on access (e.g., the install of the Chowade River and Cypress Creek stations were delayed because snow limited access; Table 3).

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 logged into using an off-site computer to confirm remote accessibility.

Beyond basic functionality testing, range testing was conducted for all 30 fixed-stations operated in 2021. 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 meters 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 meters downstream of the fixed-station, after which, these procedures were repeated. The test tags consisted of a Lotek NanoTag Model NTF-3-2 (hereafter the 'low power' tag) and a Lotek NanoTag Model NTF-6-2 (hereafter the 'high power' tag)[29] deployed to a depth of 1 meter for all tests. Test tags were identical to study tags in all respects, except that they were programmed to transmit more frequently (every 3 seconds). 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. 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 (Figure 6).

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[28] Due to ongoing bridge construction and a lack of available receivers, Lynx Creek was not operated in 2021. Lynx was re-installed for the 2022 field season on 28 April 2022.

[29] The Nano NTF-3-2 was the smallest of the radio tags implanted in 2019/2020 and therefore represents the low power tag, while the Nano NTF-6-2 was the largest, representing the high power tag. These differing tag sizes are designed to possess near-equivalent power and range ratings (per Lotek Wireless) , however the range test was utilized to validate that hypothesis.

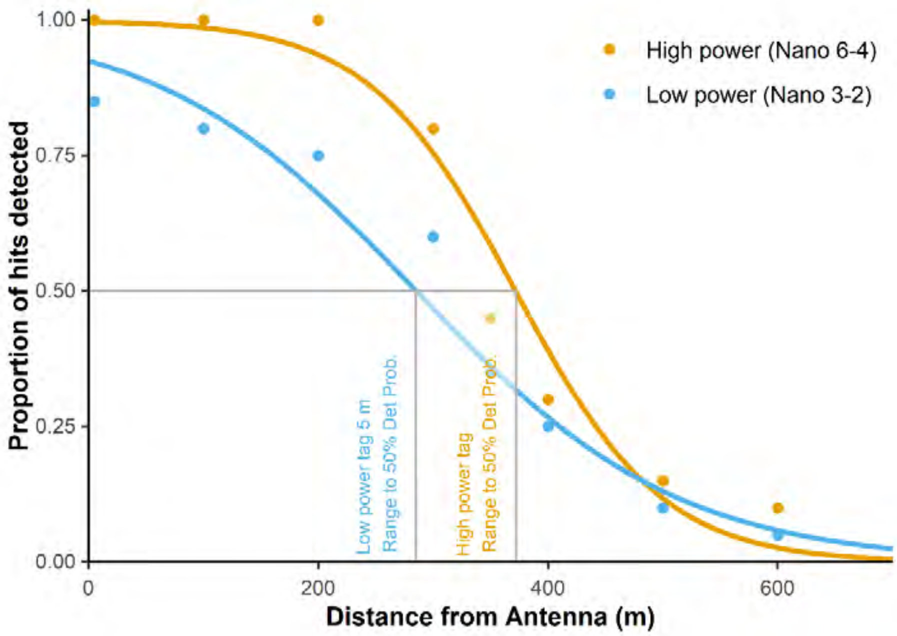

Figure 6. **Example of a detection probability curve generated from sample range test data[30]. Note that this figure includes detection probability results that were within 50m of the antenna; when in actual testing this was rarely feasible given the fixed-station was frequently installed between 50 and 200m from the nearest 1m of testable water.**

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 detection probability at these mentioned values as well as the shape of the curve were used to interpret the detection range for each station (Kessel et al. 2014).

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 Host software on a field laptop before being uploaded to the cloud 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.

There were three situations in which a station needed 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

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[30] Distance was calculated as a test tag's absolute distance (in m) from the receiver antenna at a given point in time. That distance was then grouped into 50 m bins and plotted as the max value within that bin. I.e., a test tag detected at 32 m from the antenna was binned into 0-50m for the proportion analysis and that value was plotted at 50m.

Table 4. Fixed-station deployment, maintenance, and demobilization field schedule in 2021.

Start Date	End Date	Work Completed
overwinter	8 March 2021	Winter Maintenance
9 March 2021	14 March 2021	Station Installations 1
7 April 2021	12 April 2021	Station Installations 2
28 April 2021	5 May 2021	Download/Testing/Maintenance 1
27 May 2021	31 May 2021	Download/Testing/Maintenance 2
14 June 2021	18 June 2021	Download/Testing/Maintenance 3
21 July 2021	24 July 2021	Download/Testing/Maintenance 4
13 August 2021	17 August 2021	Download/Testing/Maintenance 5
28 September 2021	3 October 2021	Station Demobilization 1
25 October 2021	27 October 2021	Station Demobilization 2
28 October 2021	overwinter	Winter Maintenance

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 three to four 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. The primary mobile surveys covered known migratory periods of interest for Arctic Grayling and Bull Trout. These surveys focused on locating likely spawning locations in the Moberly, and Halfway rivers, respectively, and evaluate (where applicable) if spawning occurred upstream of the future reservoir inundation zone. Mobile surveys were also conducted for spring spawning Walleye in the Beatton River as part of the Walleye Spawning and Rearing Use Survey (Mon-2, Task2e) and are reported separately in Smith et al. (2022).

The Moberly and Halfway aerial surveys were designed to meet the core objectives of the Peace River Arctic Grayling and Bull Trout Movement Assessment (Mon-1b, Task 2a) by tracking Arctic Grayling in the Moberly River from May to June and Bull Trout in the Halfway River from August to September to identify probable spawning locations and the timing of movement immediately prior to and following spawning. The remaining mobile surveys were conducted to provide wintertime detection data when the majority of the fixed-station array is demobilized or were conducted opportunistically when crews travelled through the study area for other reasons.

Six Moberly River overflights were conducted from May to mid-June 2021, targeting spawning Arctic Grayling (Appendix D, Figure D1). The first Moberly River survey occurred on 5 May 2021, earlier than in 2020, such that the movements of fish migrating into the Moberly River could be tracked. The last Moberly River overflight occurred on 14 June 2021, and no follow-up surveys were conducted as all of the radio-tagged study fish that looked like they were going to exit the Moberly River had already done so.

Table 5. Mobile tracking survey dates, locations tracked, and vessels used from March 2021 through January 2022.

Date	Task / Areas Covered	Vessel
4 March 2021	Winter tracking, watershed-wide, (prior year) Survey 4, Day 1	Fixed-wing
7 March 2021	Winter tracking, watershed-wide, (prior year) Survey 4, Day 2	Fixed-wing
1 May 2021	Opportunisitic tracking in the Lower Halfway	Helicopter
5 May 2021	Arctic Grayling tracking in the Moberly, Survey 1	Helicopter
14 May 2021	Arctic Grayling tracking in the Moberly, Survey 2	Helicopter
22 May 2021	Arctic Grayling tracking in the Moberly, Survey 3	Helicopter
30 May 2021	Arctic Grayling tracking in the Moberly, Survey 4	Helicopter
7 June 2021	Arctic Grayling tracking in the Moberly, Survey 5	Helicopter
14 June 2021	Arctic Grayling tracking in the Moberly, Survey 6; opportunisitc tracking in Lower Halfway	Helicopter
7 September 2021	Bull Trout tracking in the Halfway, Survey 1, Day 1	Fixed-wing
8 September 2021	Bull Trout tracking in the Halfway, Survey 1, Day 2	Fixed-wing
16 September 2021	Bull Trout tracking in the Halfway, Survey 2, Day 1	Fixed-wing
17 September 2021	Bull Trout tracking in the Halfway, Survey 2, Day 2	Fixed-wing
23 September 2021	Bull Trout tracking in the Halfway, Survey 2, Day 3	Fixed-wing
27 November 2021	Winter tracking, watershed-wide, Survey 1, Day 1	Fixed-wing
29 November 2021	Winter tracking, watershed-wide, Survey 1, Day 2	Fixed-wing
1 December 2021	Winter tracking, watershed-wide, Survey 1, Day 3	Fixed-wing
26 January 2022	Winter tracking, watershed-wide, Survey 2, Day 1	Fixed-wing
27 January 2022	Winter tracking, watershed-wide, Survey 2, Day 2	Fixed-wing

Two surveys of the Halfway River and its upper tributaries were conducted in September taking five overflights to complete (Appendix D, Figure D2), targeting spawning Bull Trout. The approach was to conduct two multi-day flight surveys[31] centered around peak Bull Trout spawning as per the guidance of the Peace River Bull Trout Spawning Assessment (Mon-1b, Task 2b).

Wintertime fixed wing watershed-wide mobile surveys (Appendix D, Figures D4 and D5) were conducted from November 2020 to March 2021 (four surveys in winter 2020-21), and from November 2021 to January 2022 (two surveys in winter 2021-22). The approach was to conduct each survey over several days[32] to supplement detection data while the majority of the fixed station array was offline. Additionally, these surveys were designed to help address management questions centered around late fall or wintertime movements (e.g., for Mountain Whitefish). Results from November 2020 to January 2021 (Surveys 1-3 from 2020-21) are further described in a previous report (Hatch et al. 2021).

In general, mobile surveys were not designed to track zones that were already covered by the fixed-station array, however while in transit to the targeted tributaries, aircraft-based 'opportunistic' mobile tracking was conducted along the Peace River and in the lower Halfway River to supplement the fixed-station array (Appendix D, Figure D1).

Mobile tracking flights were conducted by helicopter for Walleye and Arctic Grayling surveys, and by fixed wing for Bull Trout (Table 5). Fixed wing flight speeds and altitude remained consistent across surveys at 100-160 km/h and 150-215 m above the river. Helicopter flight speed and altitude were dependent on radio activity. The helicopter slowed or changed altitude when groups of tags were detected or when more accurate geolocation was required. Two-element antennas were mounted on the exterior of each

[31] Two or more days of flying was required to completely cover the areas of interest.

[32] Two or more days of flying was required to completely cover the areas of interest.

aircraft. For helicopter work, an H antenna was on mounted on the nose (Figure 7). For fixed-wing aircrafts, a two-element Yagi antenna was mounted on each wing. In either case, shielded coaxial cable (RG-58) was used to connect the antennas to one or two SRX800-MD receivers in the cabin. In 2020, all radio transmitters were on a single frequency, so only a single receiver was required, but an additional receiver was added for the later 2021 surveys to accommodate for transmitters released on the second frequency. When multiple receivers were used, 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 geo-referenced detection data), and a handheld GPS unit was 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.

Figure 7. Twin-engine helicopter equipped with a single H-antenna mounted on the nose for conducting mobile-tracking surveys.

Regardless of the mobile tracking method (helicopter or fixed wing), 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, a latitude and longitude, the number of times it was detected during the flight, and the maximum power reading recorded for that tag.

The geo-referenced data were run through ArcGIS using a Python script that assigned each detection to a 'mobile tracking zone' (Figure 8) and output 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 at 25 RKM upstream the Halfway River from the confluence to the Peace River was given a value of 25 RKM). The exception being RKM readings in the Peace River, 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 2021) 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 the lowest detections could theoretically be of fish that are truly 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 the sampling error of the GPS device. As such, the mobile-tracking zones (Figure 8) associated with tributary areas were set to start 0.5 km from their junction with the larger river to which they join.

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 six requests for data from the Site C Fish Movement Assessment Database; all of which have been fulfilled and 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 receiver is a particularly sensitive radio receiver which benefits from a boosted detection range 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[33];
- Removal of records that do not match the list of released tag codes and frequencies.

[33] 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).

- 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.

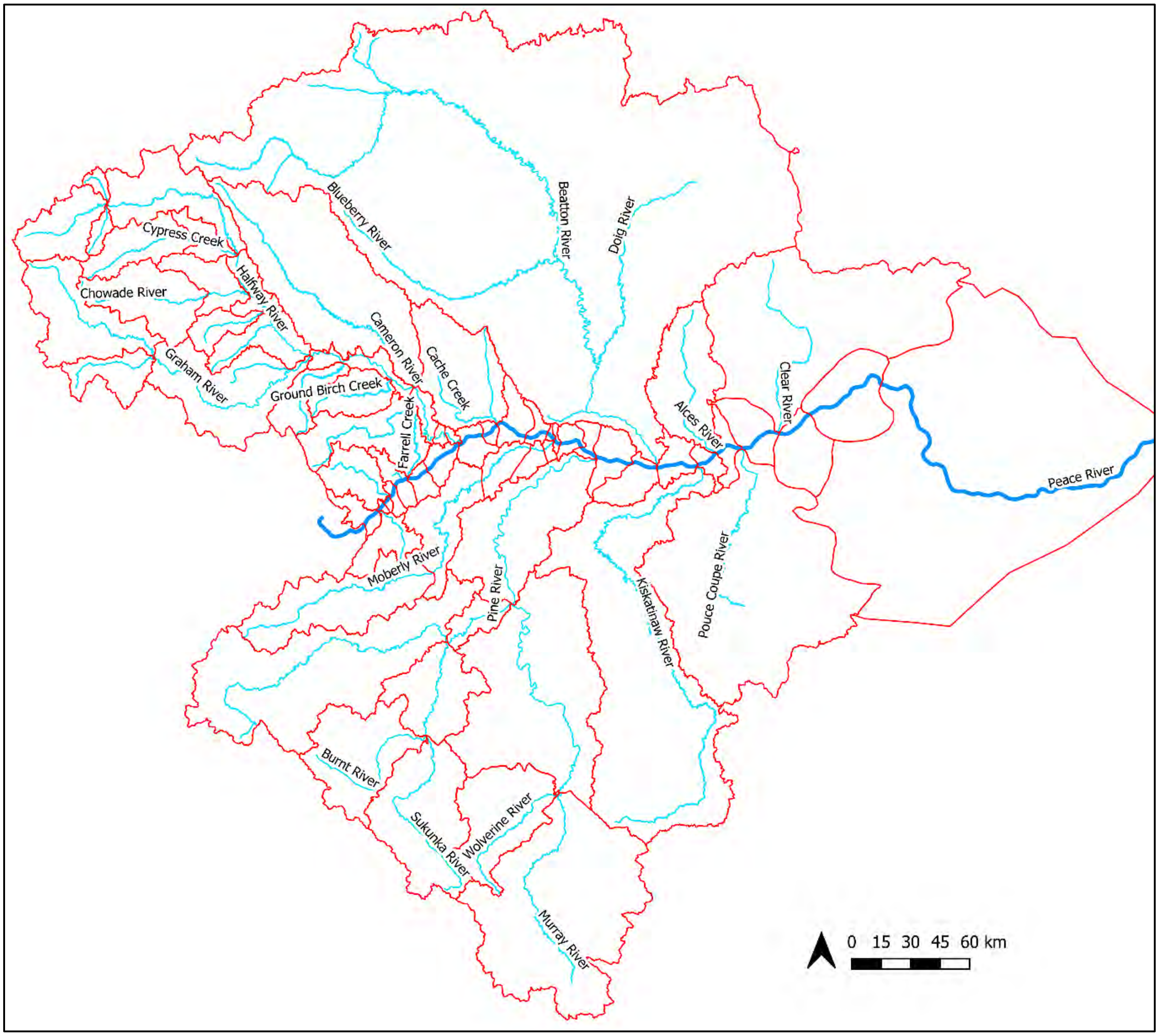

Figure 8.Mobile tracking zones (polygons with red borders) overlain on the Peace River (dark bold blue) and its major tributaries (lighter blue). Zones were defined by watershed boundaries, and the positions of the fixed-station receivers.

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[34] (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 been missed by too many fixed-stations along a supposed movement route.

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 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) and Moberly River (Arctic Grayling) mobile tracking efforts (Appendix D, Figures D1 & D2). Prior detection records at fixed-stations were used to determine where study fish were assumed to be located during each mobile track (Appendix D). If a fish was assumed present during a particular mobile track this was referred to as possible

[34] 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.

detection event[35]. The resulting detection efficiency was calculated as a proportion of the possible detection events that were detected during that track. This calculation assumes that a possible detection event is in fact possible, and the study fish has not exited the spatial expanse of the mobile tracking route without our knowledge.

Magnitude, Seasonality and Direction

The detection data (both mobile and fixed-station) were geo-referenced 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.

Among 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)[36]. Mean movement distances were categorized by species, river, direction, and month. Data collected from 2019 through 2021 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[37], while movements specific to Peace River tributaries were analysed for Bull Trout, Arctic Grayling and Walleye for movements in the Halfway River, Moberly River and Beatton 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 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.

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 (or two) antennas 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[38] detections on the

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[35] The term detection event is used due to the possibility of a single study fish being detectable across multiple mobile tracking flights.

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

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

[38] 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.

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(s). 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[39]. 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 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 D2) and the Halfway River #2 and Halfway River #3 fixed-stations are not operated from December through February (Table 3).

Spawn Timing and Distribution

Spawn timing and distribution were estimated for Bull Trout and Arctic Grayling in accordance with the underlying objectives of Mon-1b, Task 2a (Peace River Arctic Grayling and Bull Trout Movement Assessment).

Detection histories for Bull Trout and Arctic Grayling were manually analyzed to identify an assumed spawn location for all 2021 spawning study fish. Fixed-station placement locations (Figure 5), mobile tracking efforts (Table 5), as well as the resulting analysis relied on previous research to identify the Halfway River as the primary spawning tributary for Peace River Bull Trout[40] and the Moberly River for

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[39] 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).

[40] Genetic analysis of Peace River Bull Trout estimated that 92% of individuals originated from the Halfway River and its tributaries whereas 4% originated from the Pine River with the remaining 4% undetermined (Geraldes & Taylor 2020). 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 originating from the Pine and Moberly rivers (Mainstream Aquatics 2012, TrichAnalytics 2020)

Peace River Arctic Grayling[41] (Mainstream Aquatics 2012). Furthermore, prior research on peak spawn timing was used to evaluate probable spawning locations[42].

In cooperation with this base knowledge, mobile tracking efforts were prioritized to cover the Halfway and Moberly rivers during the respective Bull Trout and Arctic Grayling spawning periods. Additionally, fixed-stations were deployed and operated on the Moberly and Halfway rivers (Figure 5) during each spawning period. Individual Bull Trout and Arctic Grayling detection histories were manually analyzed to identify entry and exit timing, upstream and downstream movements, as well as an approximate spawn location. 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.

Results

Data Collection

The fixed-station array and mobile tracking effort collected over 15 million valid detection records that passed the filtering criteria between 1 January 2021 and 31 January 2022 (Table 6). Starting in January 2021, 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 was seasonally operated between March and November 2021. 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 97.8% of the time between the intended 2021 installation and demobilization dates for each respective receiver (Table 4, Table 7). The remaining 2.2% was the result of minor receiver-specific interruptions (Table 7), with a large share of 2021 outage days coming from a spell of very cold weather that was present from late December 2021 into January 2022. Significantly cold weather conditions negatively affect the operation of the battery systems which effectively render the system unable to maintain any power draw for more than 24 hours regardless of charge capacity. Other notable outages were the result of a landslide on Halfway River 2 that claimed that fixed-station following installation[43] as well as the receiver (and all accompanying electronics) at the Cache Creek station getting fried by what was presumed to be a lightening strike.

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[41] Otolith and fin ray microchemistry analyses have 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).

[42] 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).

[43] The Halfway River 2 fixed-station was buried by the landslide on approximately 14 June 2021. No attempt was made to recover the equipment or data due to safety concerns. The replacement station was installed on 22 July 2021 approximately 1 RKM downstream from the original installation.

Table 6. **Counts of valid detection records and unique codes (individual study fish) detected at each receiver from 1 Jan 2021 to 31 Jan 2022.**[44]

Station Name	Valid Count	Unique Codes
Peace River 1 (1A & 1B)	2,988	39
Peace River 2	16,626	49
Pouce Coupe River	264,432	27
Peace River 3 (& Kiskatinaw River)	545,813	74
Beatton River	1,315,740	87
Peace River 4	1,533,117	132
Pine River	72,720	43
Peace River 5 (& INS Mainstem 1)	158,215	109
Site C Dam (all recievers)	6,883,536	123
Moberly River 1	116,838	14
Moberly River 2	24,550	4
Moberly River 3	5,300	6
Peace River 6	151,376	36
Peace River 7	2,009,629	43
Cache Creek	513	2
Peace River 8	662,166	64
Halfway River 1	339,294	53
Halfway River 2	5,091	20
Halfway River 3	14,376	36
Chowade River	0	0
Cypress Creek	678	2
Peace River 9	325,768	27
Farrell Creek	2,103	3
Peace River 10	230,811	32
Peace River 11	862,843	44
Maurice Creek	296,907	10
Peace Canyon Dam	21,092	3
Moberly Lake	0	0

[44] 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 2021.

Table 7. Outage start date, end date, days offline, and notes for all fixed-stations that experienced an outage from 1 Jan 2021 to 31 Jan 2022. Further dissections into outages are displayed in beacon tag detection plots in Appendix B (Figure B4)

Study Year	Station Name	Outage Start	Outage End	Days Offline	Note
2021	Peace River #10	17 March 2021	6 April 2021	20	Rx not installed correctly
2021	Halfway River #2	1 May 2021	14 June 2021	45	Landslide
2021	Moberly Lake	30 July 2021	15 August 2021	16	Low light conditions
2021	Cache Creek	17 August 2021	28 September 2021	42	Rx fried by massive surge
2021	INS Diversion Tunnel	19 August 2021	26 August 2021	7	Rx not functioning properly
2021	Site C Dam	13 September 2021	2 October 2021	20	Tree fell and blocked solar
2021	Moberly Lake	20 September 2021	29 September 2021	10	Low light conditions
2021	Peace River #1B	24 September 2021	3 October 2021	10	Low light conditions
2021	INS Approach Zone B	13 October 2021	21 October 2021	8	Rx not functioning properly
2021	Site C Dam	19 November 2021	21 November 2021	2	Low light conditions
2021	Halfway River #1	16 December 2021	21 December 2021	5	Cold weather
2021	Site C Dam	19 December 2021	22 December 2021	3	Cold weather
2021	Halfway River #1	24 December 2021	12 January 2022	19	Cold weather
2021	Moberly River #1	28 December 2021	12 January 2022	14	Cold weather
2021	Site C Dam	29 December 2021	13 January 2022	15	Cold weather
2021	INS Approach Zone B	2 January 2022	13 January 2022	11	Cold weather
2021	INS Mainstem 2	3 January 2022	11 January 2022	6	Cold weather
2021	INS Entrance Aerial	4 January 2022	11 January 2022	7	Cold weather
2021	INS Approach Zone A	5 January 2022	11 January 2022	5	Cold weather
2021	INS Diversion Tunnel	6 January 2022	11 January 2022	5	Cold weather
2021	INS Diversion Tunnel Inlet	7 January 2022	11 January 2022	4	Cold weather

Fixed-Station Range Testing

An objective of Mon-1b, Task 2d is to annually range test every fixed-station to assess and quantitively evaluate functionality. As such, wherever possible, all fixed-station antennas were tested individually using both the smallest study tag model (the low power tag) as well as the largest tag model (the high power tag)[45]. In addition to the formalized range testing described below, all stations were also tested for basic range functionality[46] on deployment and were analyzed *post-hoc* to determine detection efficiency.

The formal range testing analysis is based on a procedure that fits a logistic curve to a plot of detection proportion data from test tag drags (Y axis) against distance of the tag from the antenna (X axis). Ideally the fitted curves would show high detection probability in the areas near the antennas and show lowering detection probabilities farther away. Once the curve is fitted, the parameter values are used to estimate the distance at which 50% of the signals are detected. However, this standard procedure is hampered in this study because there could be no near-antenna data collection in many cases. All antennas are at least 15 m from the river, and many are located 100 m or more from wetted areas that are >1 m deep (Table 8). The impossibility of collecting data within 50m of a fixed-station has the consequence of affecting the underlying shape of the logistic curve and the resulting range test statistics (Figure 9). Furthermore, the

[45] The low power tag refers to the Lotek NanoTag Model NTF 3-2 while the high power tag refers to the Lotek NanoTag Model NTF 6-2. According to the manufacturer, Lotek Wireless (https://www.lotek.com/products/freshwater-nanotag-series/).

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

range tests do not account for the orientation of the antenna, noise events during the test, or objects in the environment that shadow detections, all of which have the potential to flatten the prediction curve and create unexpected test results.

Among the 30 fixed-stations operating in 2021, 28 were range tested, with Chowade River and Cypress Creek being only the two not tested. Most tests resulted in a typical detection probability curve (i.e., followed the expected logistic regression shape, similar to Figure 6) as a function of distance from the receiver. Yet, as observed in previous years, some fixed-stations (e.g., Peace River 9, 10 and 11, among others) exhibited relatively flat trends. Most of the time, flattened curves result when tagged fish are present during the range test, affecting the normal detectability of the receiver at unpredictable ranges.

There were four fixed-stations where conducted range tests were not considered successful (Halfway River 2, Peace Canyon Dam, and Kiskatinaw and Beatton rivers; Table 8). A failed test was identified when the data lacked the ability to fit a logistic curve and evaluate a usable inflection point at both antennas. Regardless, the lack of a reliable inflection point does not immediately indicate antenna malfunction as these tests still yielded expected detections at reasonable ranges (Figure 9).

The range test at Halfway River 2 likely failed due to physical shadowing in front of the antennas. Following a landslide that claimed the original deployment of Halfway River 2 (discovered June 2021), the replacement was deployed on a cutbank that likely shadowed and hampered the antenna's detection range. As of 23 April 2022, the Halfway River 2 fixed-station has been re-deployed with a modified antenna setup that has corrected the detection deficiency per a successful range test following installation.

Peace Canyon Dam is installed on the right bank cliff wall, 33 m upstream from the Hudson's Hope Suspension Bridge. In this location, there are likely numerous factors contributing to the failed test; including near receiver shadowing from the cliff wall, shadowing from the suspension bridge as well as the lower gain settings required to combat the noisy Peace Canyon Dam substation located 680 m upstream. Adjustments to the antenna's location, updated gain settings along with fine tuned testing will proceed in the 2022 field season to improve this fixed-station's detectability moving forward.

Kiskatinaw River and Beatton River stations are both placed >100 m from suitable testing waters and were not sufficiently tested at the depth of ranges required to propagate the logistic curve and inflection point. On top of this, the Beatton River fixed-station is placed at the confluence of the Beatton River and Peace River which is a popular holding location for numerous tagged Walleye, thereby creating a congested radio environment that significantly hampers range testing efforts.

A paired t-test was used to compare the detection range (i.e., the distance where detection probability was 50%) between the high and low power tags, using data from the 30 antennas where both tag types were tested successfully (Table 9). While the high power tag averaged 248 m and the low power tag averaged 230 m, the variability among antennas was enough such that these averages were not statistically significant ($t = 1.23$, $P = 0.23$). Furthermore, per Lotek Wireless, both tag sizes (and powers, respectively) are expected to yield similar range results; therefore, the definition of a 'high' and 'low' power is a hypothesis that has yet to be validated by the available data. As such, range testing methods in 2022 and beyond will incorporate only the Nano NTF-6-2 tag to increase the quantity of data collected and significantly decrease the likelihood of a failed test.

Table 8. Completion of a successful range test by study year (Yes, No, Not Tested or NA/-) as well as the approximate minimum distance from the fixed-station antennas to the range test area (i.e., the river or creek).

Fixed-Station Name	Successful Range Test 2019	2020	2021	Minimum Distance from Antenna to Testing Area (m)
Peace River #1A	Yes	Yes	Yes	75
Peace River #1B	Yes	Yes	Yes	75
Peace River #2	No	Yes	Yes	50
Pouce Coupe River	Yes	Yes	Yes	250
Peace River #3	Yes	Yes	Yes	50
Kiskatinaw River	Yes	Yes	No	175
Beatton River	No	*Not Tested*	No	200
Peace River #4	Yes	*Not Tested*	Yes	250
Pine River	Yes	Yes	Yes	75
Peace River #5	Yes	Yes	Yes	125
Site C Dam	*Not Tested*	*Not Tested*	Yes	75
Moberly River #1	Yes	*Not Tested*	Yes	175
Moberly River #2	-	*Not Tested*	Yes	75
Moberly River #3	-	*Not Tested*	Yes	50
Moberly Lake	-	-	Yes	15
Peace River #6	Yes	Yes	Yes	75
Peace River #7	Yes	*Not Tested*	Yes	150
Cache Creek	Yes	*Not Tested*	Yes	25
Peace River #8	Yes	*Not Tested*	Yes	75
Halfway River #1	Yes	*Not Tested*	Yes	50
Halfway River #2	-	*Not Tested*	No	100
Halfway River #3	-	*Not Tested*	Yes	75
Peace River #9	Yes	*Not Tested*	Yes	125
Farrell Creek	Yes	*Not Tested*	Yes	75
Peace River #10	Yes	*Not Tested*	Yes	75
Lynx Creek	Yes	*Not Tested*	-	50
Peace River #11	Yes	*Not Tested*	Yes	250
Maurice Creek	Yes	*Not Tested*	Yes	50
Peace Canyon Dam	No	*Not Tested*	No	100
Chowade River	Yes	*Not Tested*	*Not Tested*	50
Cypress Creek	Yes	*Not Tested*	*Not Tested*	50

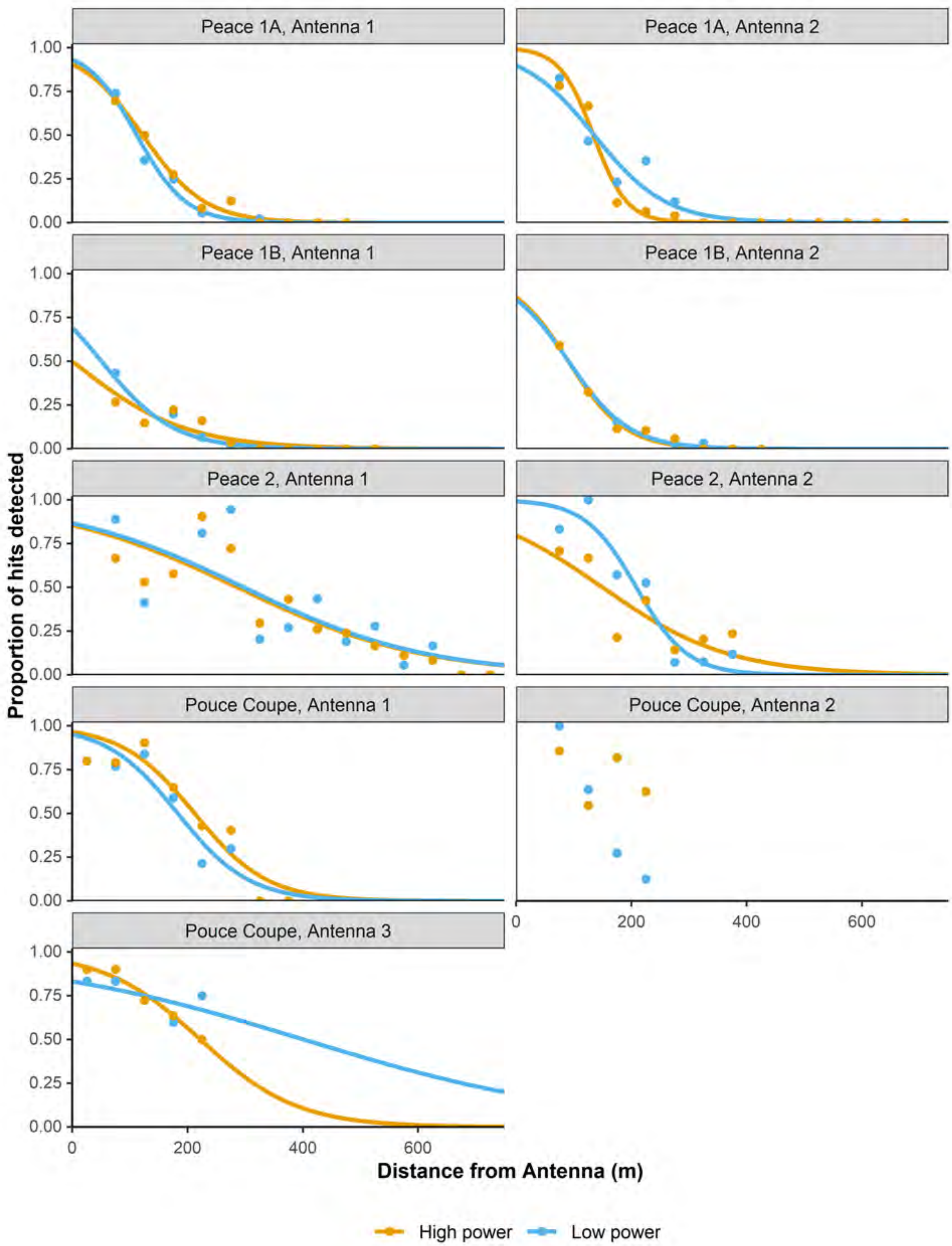

Figure 9. **Range test results for specific antennas at fixed-stations tested in 2021. Figure continues on following five pages.**

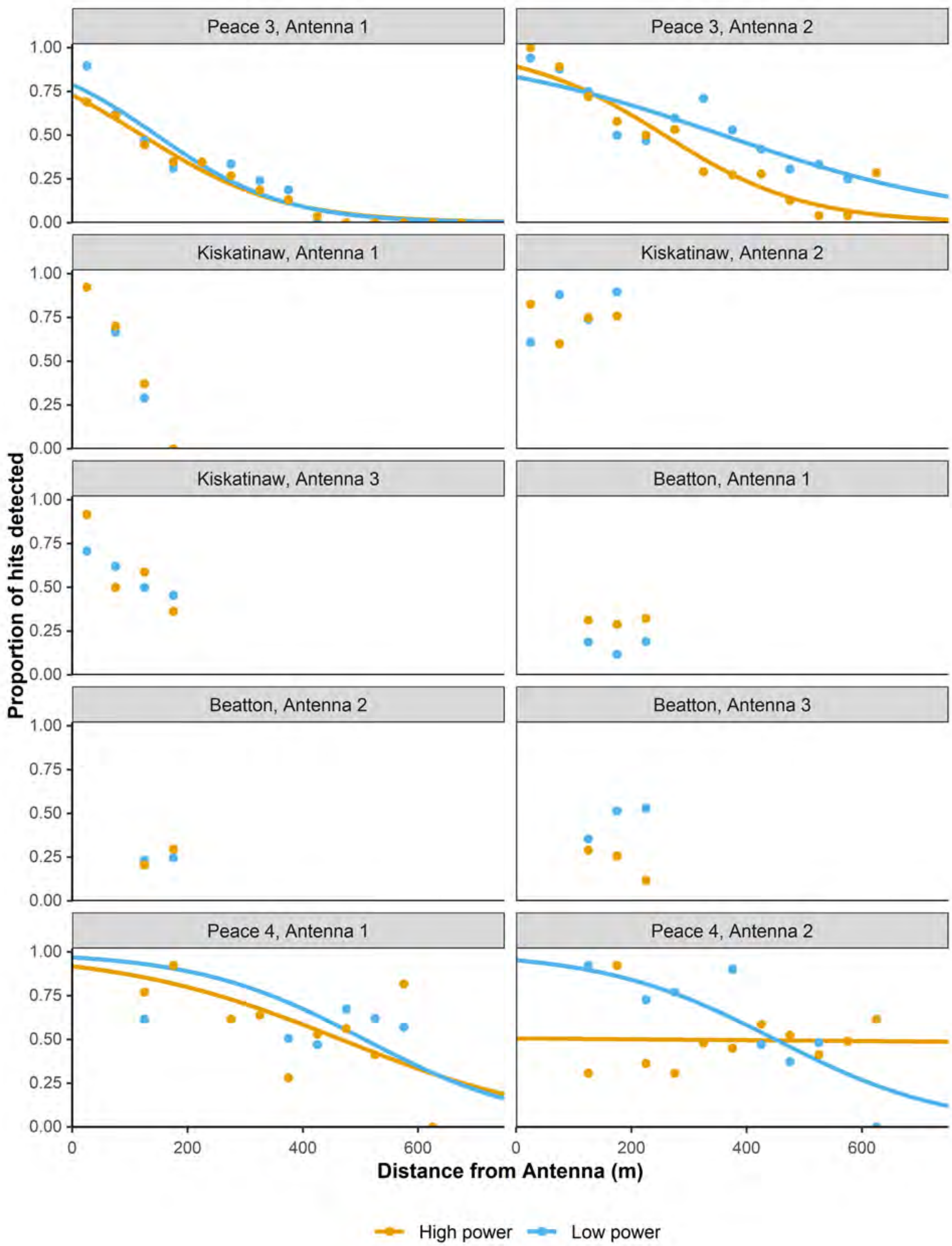

Figure 9 continued (page 2 of 6).

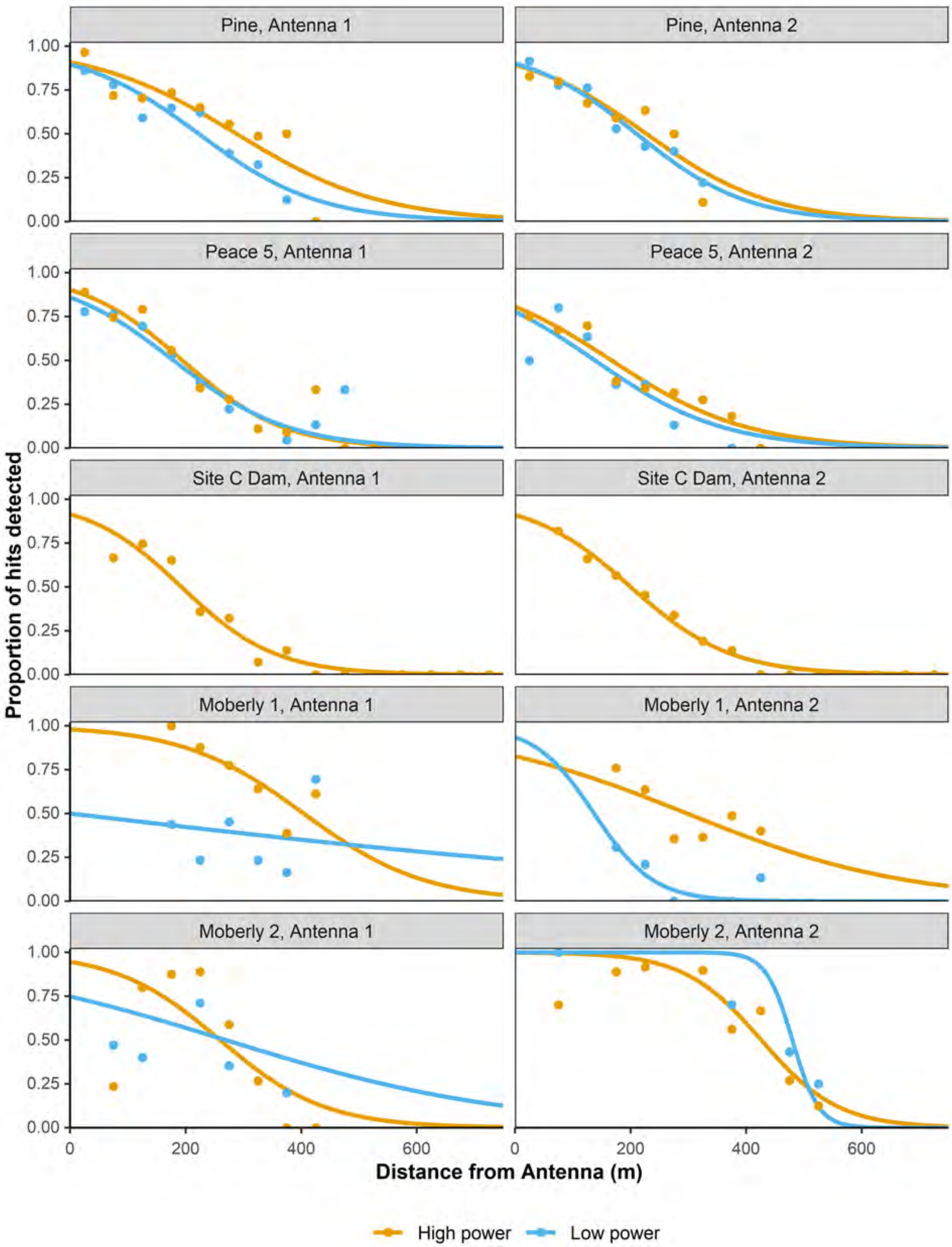

Figure 9 continued (page 3 of 6).

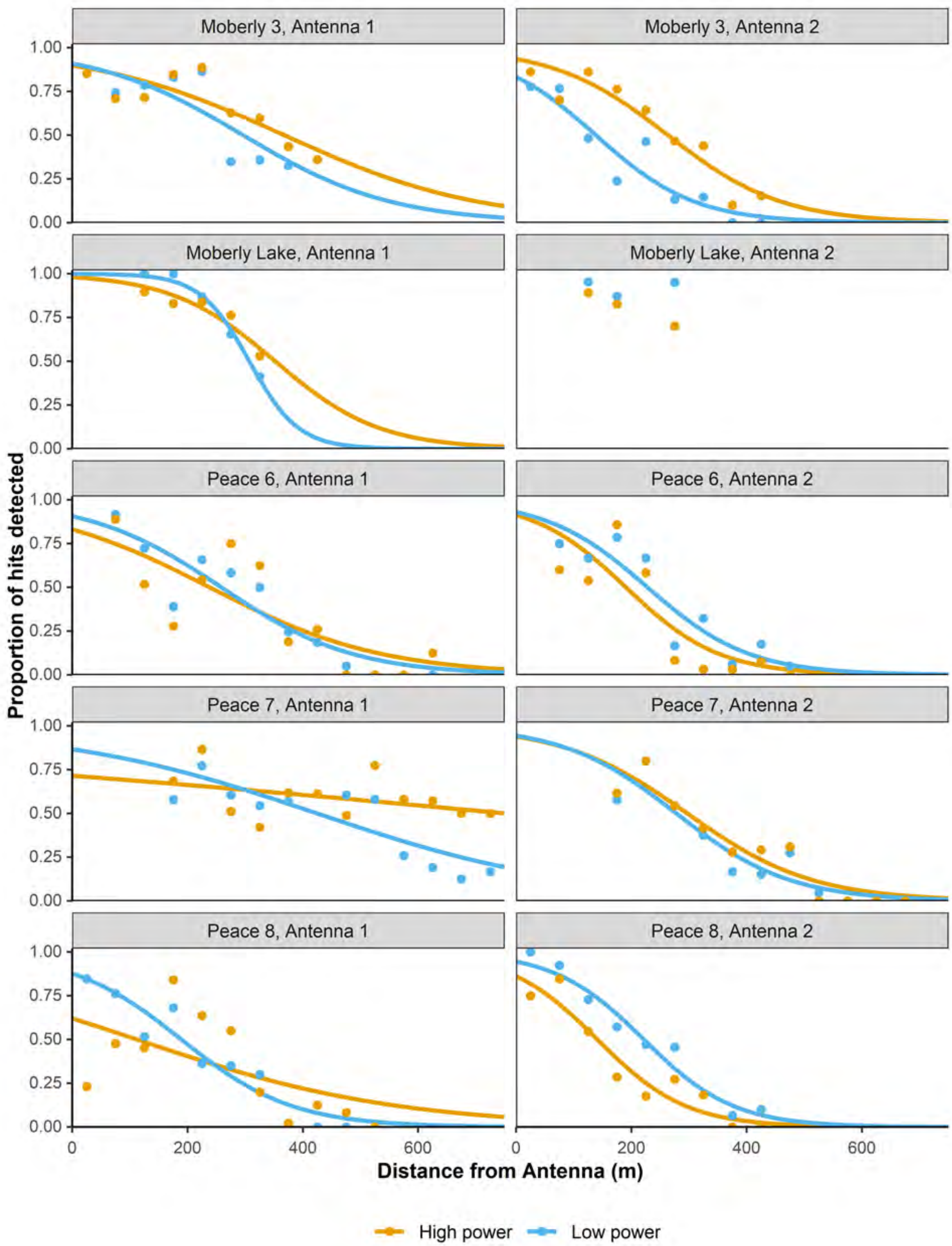

Figure 9 continued (page 4 of 6).

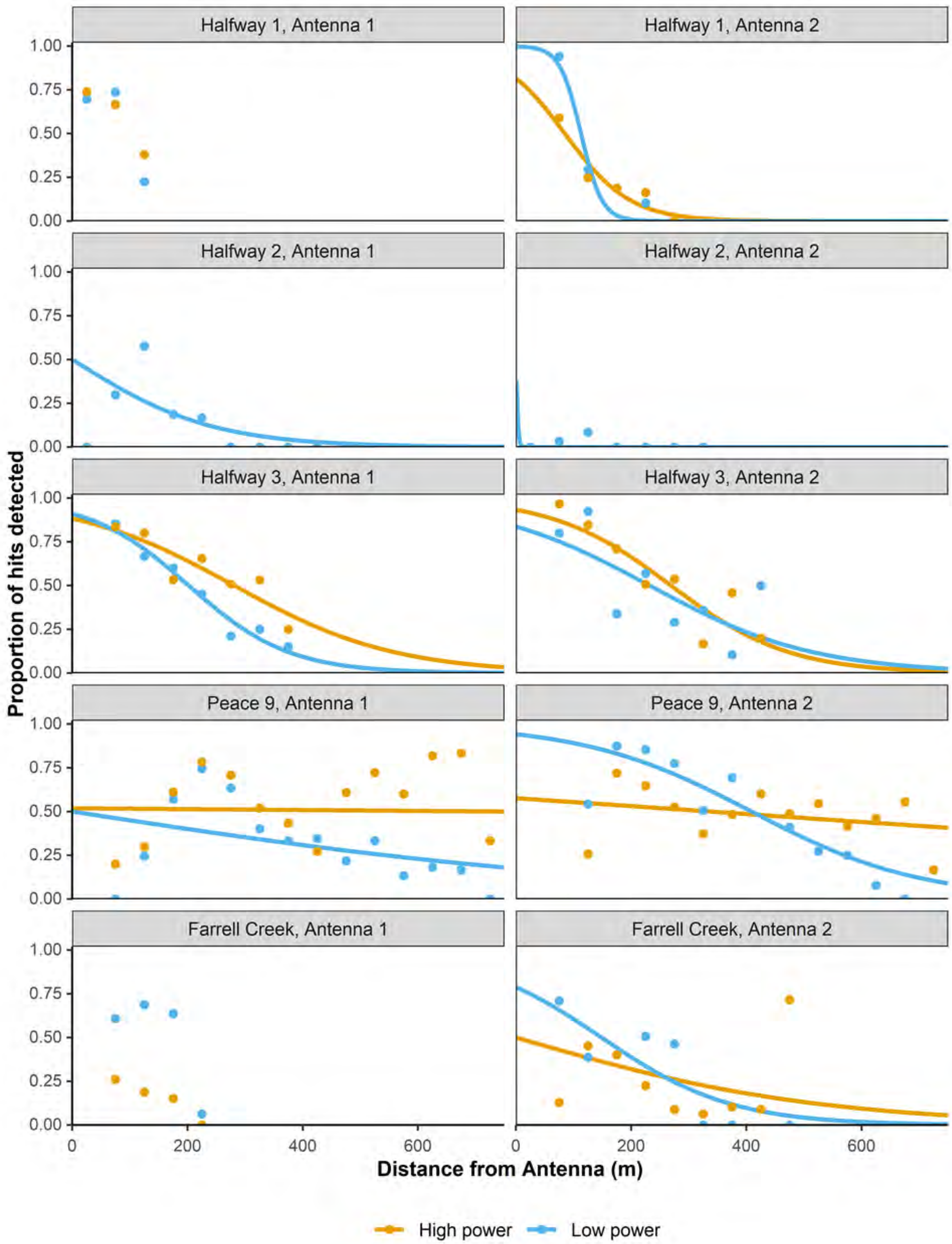

Figure 9 continued (page 5 of 6).

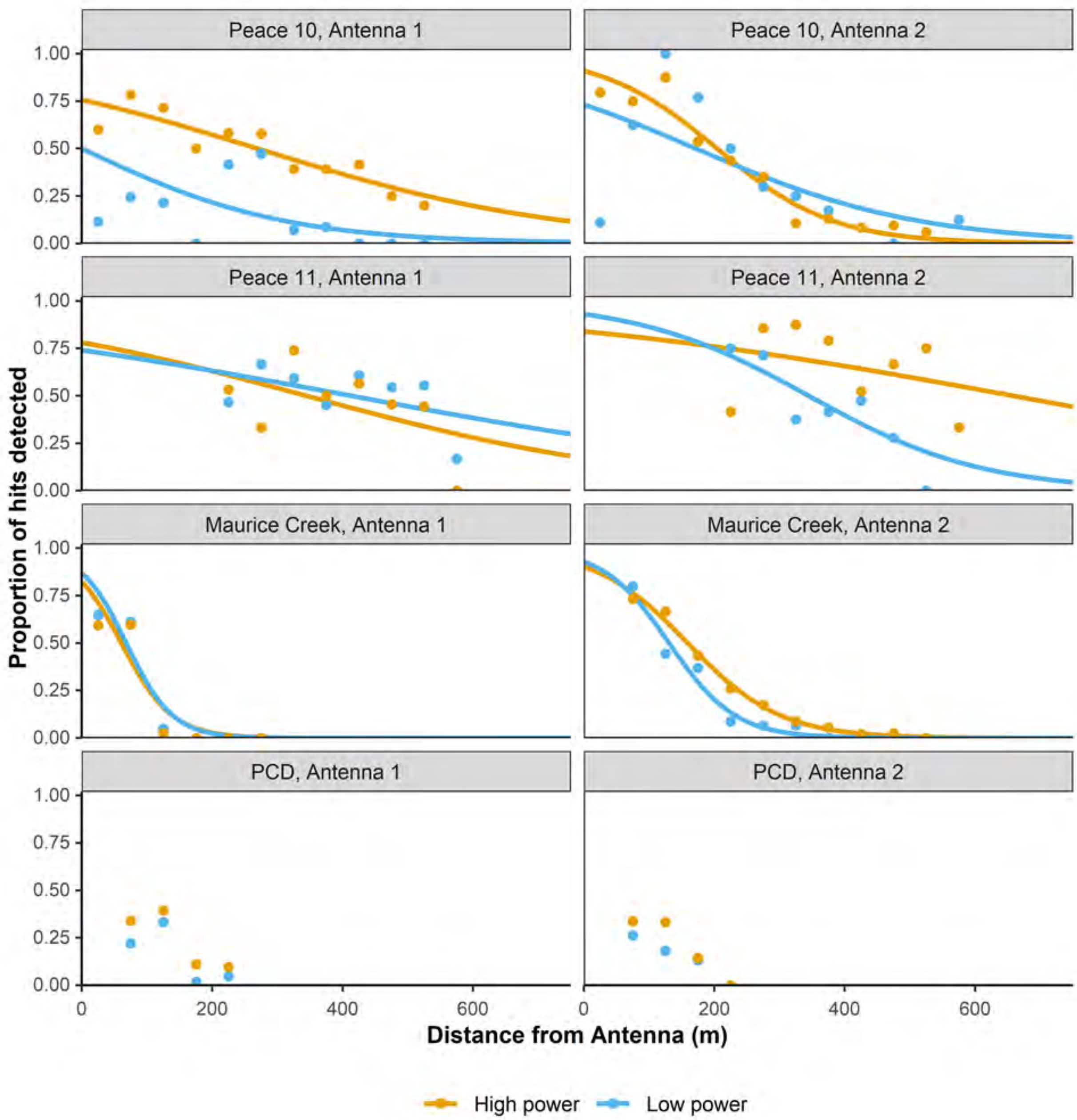

Figure 9 continued (page 6 of 6).

Table 9. Inflection point (distance at which 50% of transmissions are detected), in metres (with standard errors in brackets) for high (model 6-2) and low (model 3-2) power Lotek nano tags, for range tests of specific antennas performed in 2021. See Figure 9. Inflection point estimates that were not statistically significant have been excluded.

		Antenna One (DS)		Antenna Two (US)		Antenna Three (Trib)	
Station #	**Station Name**	**High Power**	**Low Power**	**High Power**	**Low Power**	**High Power**	**Low Power**
1	Peace River #1A	122 (5)	112 (5)	134 (5)	135 (11)		
2	Peace River #1B	-	51 (14)	91 (4)	91 (3)		
3	Peace River #2	286 (34)	297 (46)	150 (32)	209 (14)		
4	Pouce Coupe River	212 (17)	183 (16)	-	-	222 (10)	
5	Peace River #3	121 (9)	146 (16)	257 (20)	359 (32)		-
6	Kiskatinaw River	-	-	-	-	-	-
7	Beatton River	-	-	-	-	-	-
8	Peace River #4	466 (72)	507 (62)	-	450 (39)		
9	Pine River	288 (29)	223 (16)	227 (23)	211 (10)		
10	Peace River #5	194 (17)	179 (19)	167 (16)	138 (28)		
11	Site C Dam	193 (11)	-	200 (5)	-		
12	Moberly River #1	404 (38)	-	298 (41)	137 (32)		
13	Moberly River #2	260 (55)	-	426 (23)	480 (16)		
14	Moberly River #3	368 (38)	296 (30)	263 (18)	138 (18)		
47	Moberly Lake	352 (24)	307 (4)	-	-		
15	Peace River #6	238 (47)	258 (24)	191 (29)	228 (21)		
16	Peace River #7	750 (241)	425 (37)	297 (19)	278 (20)		
18	Peace River #8	-	189 (16)	141 (16)	221 (11)		
19	Halfway River #1	-	-	85 (14)	113 (9)		
20	Halfway River #2	-	-	-	-		
21	Halfway River #3	281 (25)	202 (10)	269 (24)	232 (49)		
22	Peace River #9	-	-	-	409 (30)		
44	Farrell Creek	-	-	0 (260)	149 (34)		
24	Peace River #10	269 (26)	-	204 (12)	172 (69)		
26	Peace River #11	345 (86)	413 (83)	-	345 (34)		
31	Maurice Creek	61 (15)	68 (13)	159 (4)	131 (6)		
45	Peace Canyon Dam	-	-	-	-		

Fixed-Station Detection Efficiency

Detection efficiency[47] was calculated *post-hoc* to compliment detection probability[48] in evaluating and validating the fixed-station array (Adams et al. 2012, Kessel et al. 2014). Detection efficiencies were between 61.1 and 100% for fixed-stations or combinations of fixed-stations in 2021 (Table 10, Figures 10 and 11). 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, Cache Creek, Beatton River, or the Pouce Coupe River.

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

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

Table 10. Fixed-station detection efficiencies in 2021 for upstream and downstream movement orientations.

		Upstream		Downstream		Both	
Station Name	**River Type**	**Det. Eff.**	**N**	**Det. Eff.**	**N**	**Det. Eff.**	**N**
Peace River 2	Peace River	100.0%	19	100.0%	21	100.0%	40
Peace River 3	Peace River	88.9%	27	71.8%	39	78.8%	66
Peace River 4	Peace River	97.9%	48	94.2%	86	95.5%	134
Peace River 5	Peace River	71.7%	53	81.7%	71	77.4%	124
Site C	Peace River	100.0%	3	100.0%	34	100.0%	37
Peace River 6	Peace River	78.9%	19	56.0%	25	65.9%	44
Peace River 7	Tributary	100.0%	14	79.3%	29	86.0%	43
Peace River 8	Peace River	86.7%	15	72.4%	29	77.3%	44
Peace River 9	Peace River	100.0%	15	100.0%	15	100.0%	30
Peace River 10	Peace River	100.0%	10	100.0%	14	100.0%	24
Peace River 11	Peace River	87.5%	8	40.0%	10	61.1%	18
Moberly River 1	Tributary	100.0%	8	100.0%	5	100.0%	13
Moberly River 2	Tributary	100.0%	6	100.0%	5	100.0%	11
Moberly River 3	Tributary	100.0%	5	100.0%	4	100.0%	9
Halfway River 1	Tributary	90.0%	30	89.3%	28	89.7%	58
Halfway River 2	Tributary	75.0%	12	61.1%	118	66.7%	30
Halfway River 3	Peace River	94.4%	18	61.5%	13	80.6%	31
Beatton River	Tributary	96.7%	30	94.4%	18	95.8%	48

At many of the stations, the detection efficiencies in 2021 were lower than in previous years (Figure 10). Among the 18 fixed-stations analyzed in 2021, three exhibited combined (upstream/downstream) detection efficiencies that were below 75% (i.e., Peace River 11, Peace River 6, and Halfway River 2, Table 10). As described above (see 'Fixed-Station Range Testing'), Halfway River 2 was re-installed with a sub-optimal setup that hindered its detection capabilities and has since been rectified for the 2022 season. One factor that likely impacted detection efficiencies in 2021 was the addition of a second radio tag frequency into the study system. Additionally, at Peace River 6 and Peace River 11, the drop in detection efficiency was influenced by fish behaviour and directional flow as the downstream detection efficiency was notably lower than the upstream efficiency at both stations. The resulting p-value from a Pearson's chi-squared test to compare upstream and downstream detection efficiencies was significant at Peace River 11 ($p = 0.008$) but not significant at Peace River 6 ($p = 0.112$). Regardless, gain and antenna orientation adjustments were made in preparation for the 2022 field season to better optimize the under-performing receivers per their respective environments.

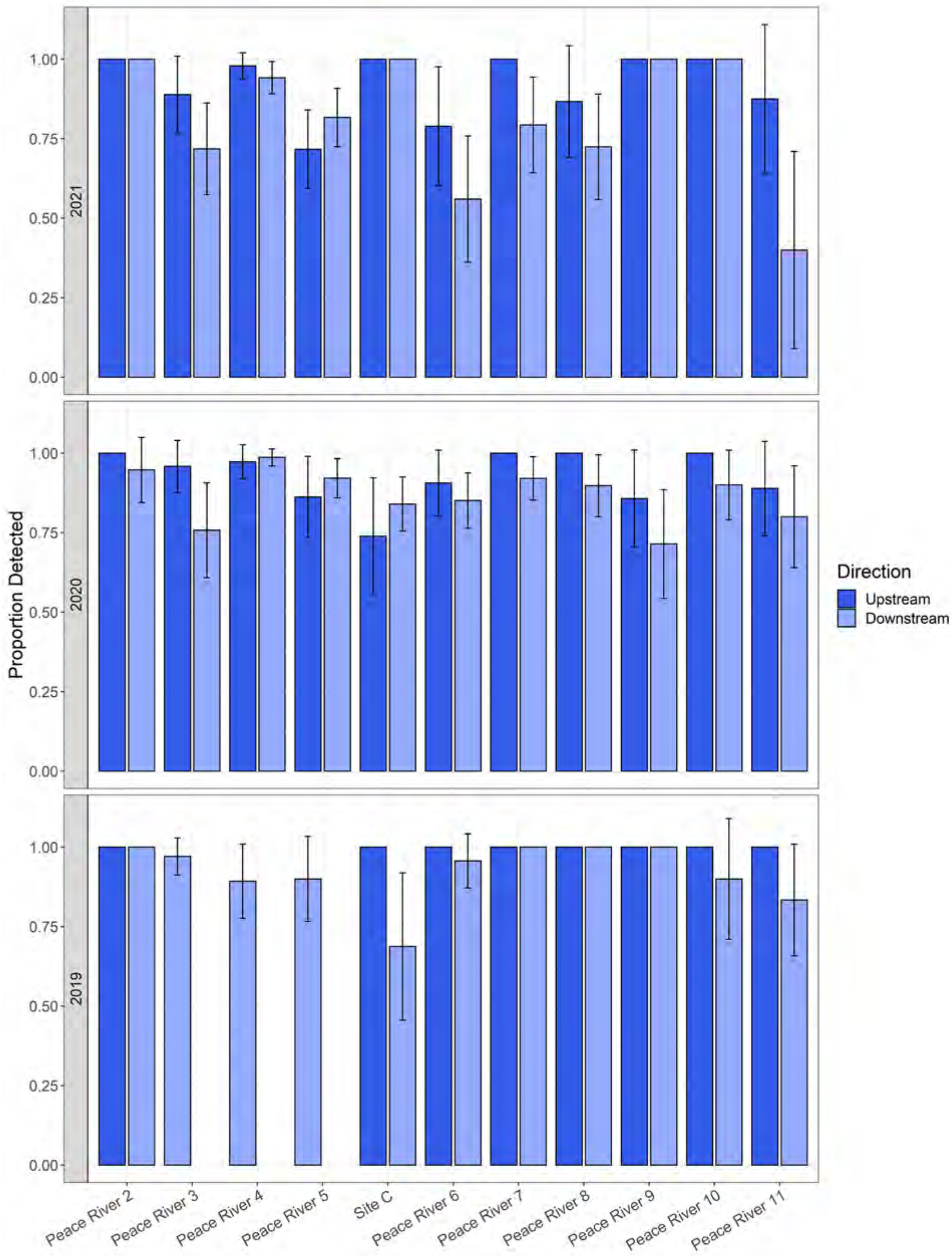

Figure 10. **Detection efficiency by fixed-station and year for applicable Peace River fixed-stations. Error bars show the 95% confidence intervals.**

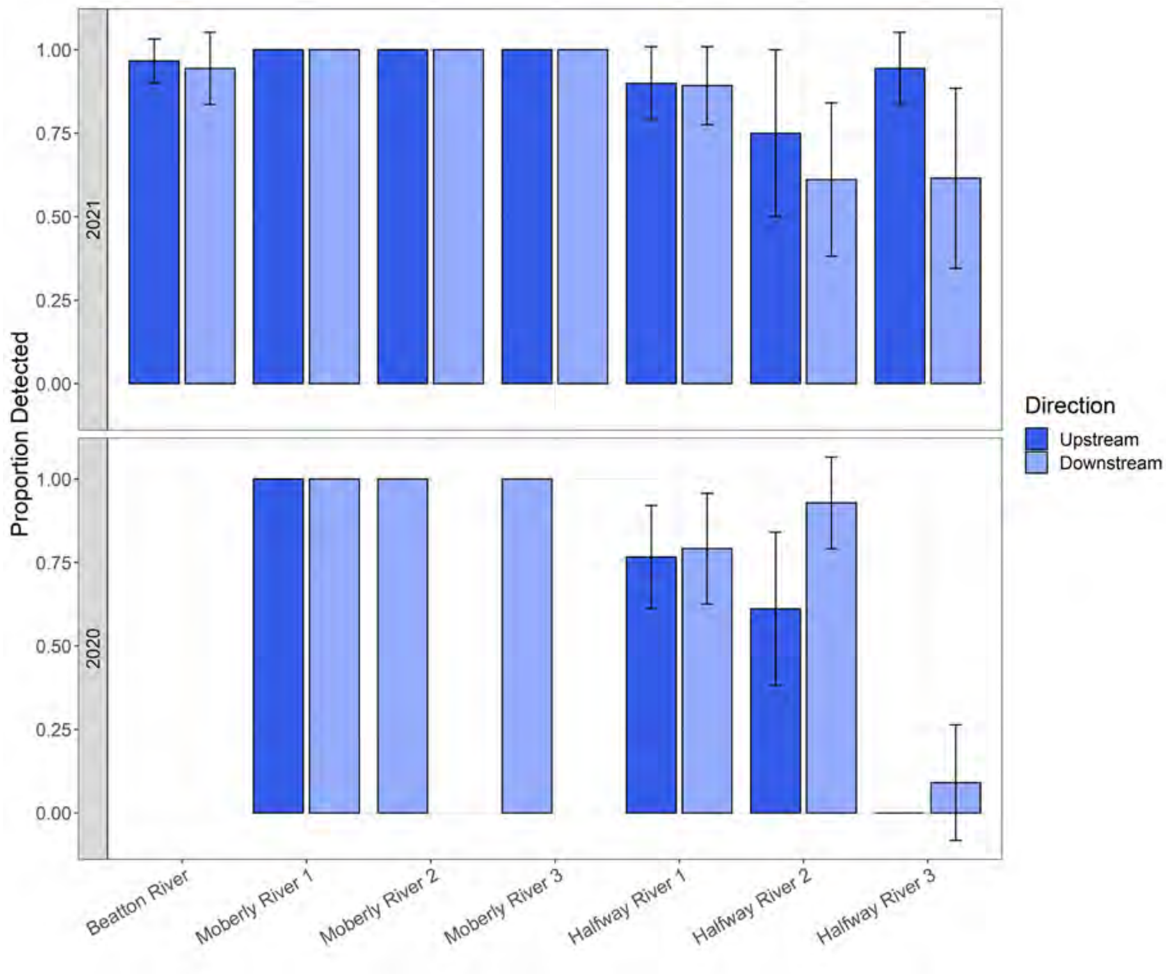

Figure 11. Detection efficiency by fixed-station year for applicable tributary fixed-stations. Error bars show the 95% confidence intervals.

Mobile Tracking Detection Efficiency

Mobile tracking flights in the Moberly River in 2021 (Figure E1) were successful. Using prior detection records there was a total of 20 possible detection events in the Moberly River during the six mobile tracking flights (Appendix D, Figure D1). In this context, a detection event refers to a study fish assumed to be located within the bounds of a mobile tracking route[49]. Of the possible 20 detection events in the Moberly River, 18 were detected which yielded a 90% detection efficiency. Three of the six Arctic Grayling tracked within the Moberly River were already present in the Moberly River during the first flight and entered the system before 5 May 2021. One tag remained within the Moberly River after our last mobile tracking flight, likely a mortality or shed tag, as its signal was still present in the same location as of January 2022. Following departure from the Moberly River, three of the five Arctic Grayling traveled downstream of Site C in the Peace River, and two traveled in the Peace River upstream of Site C.

[49] Note that it's possible for a single study fish to be a distinct detection event for all six mobile tracks if that fish was assumed present during each of the mobile tracks (Appendix D, Figure D1).

The Halfway River overflights yielded a detection efficiency of 83% (Table 12, Figures E2 and E3), having detected 40 of a possible 48 detection events across the two mobile tracking surveys (Appendix D, Figure D2). None of the 28 radio-tagged Bull Trout that travelled up the Halfway River beyond the Halfway #1 fixed-station in September 2021 were missed by both mobile surveys.

Table 11. Locations of radio-tagged Arctic Grayling detections during six Moberly River mobile tracking flights in 2021. Entrance and exit dates (movement past the Moberly #1 fixed-station) are shown for each fish, along with the Peace River locations visited after departing the tributary. Mobile tracking dates for which a given fish was not present in the Moberly River are grayed-out. "Br" = Moberly Bridge; "Lk" = mouth of Moberly Lake; "M3", "M2", and "M1" are the three Moberly fixed-station receivers.

Tag	Enter Date (M1)	5 May	14 May	22 May	30 May	7 Jun	14 Jun	Exit Date (M1)	Moved to
630	21 Apr	missed	missed	Br to M3	Br to M3	Br to M3	Br to M3	stayed	n/a
956	2 May	Br to M3	Lk to Br	Lk to Br	Lk to Br		Outside	2 Jun	Peace Above C
963	26 Apr	Br to M3	Lk to Br	Lk to Br				23 May	Peace Above C
964	13 May		M3 to M2	Br to M3	Br to M3			2 Jun	Peace Below C
965	14 May		M2 to M1	Br to M3				22 May	Peace Below C
992	11 May	Outside	M2 to M1	M3 to M2				27 May	Peace Below C

Table 12. **Locations of radio-tagged Bull Trout detections during two Halfway River mobile tracking surveys (each survey taking 2-3 days of flying to complete) in 2021. Tributary detections shaded yellow. Among-survey movements indicated in center column. Entrance and exit date (movements past the Halfway #1 fixed-station) are shown for each fish. If the detection is missed at Halfway River #1 than approximate dates are inferred from the fish's detection history and are shown in brackets. "H3", "H2", and "H1" are the three Halfway fixed-station receivers**

Tag	Enter	7 & 8 Sept Survey	Movement	16-17 & 23 September Survey	Exit
538	22 Jun 2020	Halfway between Cypress & Fiddes, rkm 221	None	Halfway between Cypress & Fiddes, rkm 220	Did Not
549	1 May 2021	missed	-	Halfway between Cypress & Fiddes, rkm 191	Did Not
613	12 May 2021	Chowade River, rkm 44	Downstream	missed	< 24 Sept 2021
731	18 Aug 2021	missed	-	Halfway between H3 & Cameron, rkm 41	Did Not
756	25 Jul 2021	Graham River, rkm 1	None	Graham River, rkm 1	Did Not
758	27 Jul 2021	Chowade River, rkm 22	Upstream	Chowade River, rkm 33	27 Sep 2021
768	12 Aug 2021	Halfway between Cameron & Graham, rkm 83	None	Halfway between Cameron & Graham, rkm 83	14 Oct 2021
769	15 Jul 2021	Chowade River, rkm 61	Upstream	Chowade River, rkm 66	28 Sep 2021
798	20 Jul 2021	Halfway between Cameron & Graham, rkm 55	None	Halfway between Cameron & Graham, rkm 56	Did Not
807	24 Aug 2021	Halfway between H3 & Cameron, rkm 25	Downstream	Peace River, rkm 85	12 Sep 2021
809	14 May 2021	Fiddes Creek, rkm 5	None	Fiddes Creek, rkm 7	4 Oct 2021
811	31 Aug 2021	Halfway between Graham& Chowade, rkm 92	Upstream	Halfway between Chowade & Cypress, rkm 140	5 Oct 2021
813	16 Sep 2021		-	Halfway between H1 & H2, rkm 3	8 Oct 2021
880	1 May 2021	Chowade River, rkm 51	-		16 Sep 2021
898	18 Aug 2021	Halfway between Cypress & Fiddes, rkm 158	Upstream	Halfway between Cypress & Fiddes, rkm 198	9 Oct 2021
915	21 Apr 2021	Cypress Creek, rkm 26	Upstream	Cypress Creek, rkm 39	27 Sep 2021
941	18 Aug 2021	Chowade River, rkm 31	Upstream	Chowade River, rkm 49	27 Sep 2021
957	6 May 2021	Chowade River, rkm 49	-	missed	23 Sep 2021
959	22 Apr 2021	Cypress Creek, rkm 54	-		14 Sep 2021
960	15 Jul 2021	Chowade River, rkm 30	Upstream	Chowade River, rkm 46	19 Oct 2021
970	19 Jun 2021	Chowade River, rkm 29	-	missed	9 Oct 2021
975	19 Sep 2021		-		4 Nov 2021
976	22 Apr 2021	Halfway between H3 & Cameron, rkm 43	None	Halfway between H3 & Cameron, rkm 43	Did Not
979	< 7 Sept 2021	Graham River, rkm 48	None	Graham River, rkm 48	Did Not
983	20 Jun 2021	Chowade River, rkm 34	-	missed	21 Sep 2021
986	8 May 2021	Turnoff Creek, rkm 3	-	missed	17 Sep 2021
995	< 16 Sept 2021	Peace River, rkm 67	Upstream	Halfway between H1 & H2, rkm 1	> 16 Sept 2021
1161	18 Sep 2021		-	missed	29 Sep 2021

Movement Analysis

Magnitude, Seasonality, and Direction

Region-wide seasonal movement patterns were interpreted from monthly movement distance. Tributary entrance and exit figures were created using all applicable telemetry data collected from 2019 through 2021 (Figures 12 through 17). The tributaries analyzed varied among the study species, and were based on their known/expected migratory behaviours, detection coverage, or the presence of notable movements in the dataset.

Arctic Grayling

As expected, Arctic Grayling are using the Moberly River in April, May, and June to spawn (Figure 12A). More specifically, Arctic Grayling are largely entering the Moberly River in April/May and exiting in May/June (Figure 12B). Although a few Arctic Grayling entrance and exit behaviours were recorded at other tributary stations (e.g., Maurice Creek, Beatton River, Pine River) these behaviours were significantly less frequent and yielded associated residence times that were less than 24 hours, therefore these movements were not further analyzed. In the Peace River, on the other hand, Arctic Grayling have poorly-defined behaviours, with downstream movements in September and October as well as both upstream and downstream behaviour in May and June, presumably in preparation for spawning. Many of the movements were accompanied with high standard errors due mainly to small sample sizes per month analyzed (e.g., Peace River in August was n = 4).

Bull Trout

Bull Trout exhibited generally balanced upstream and downstream movements throughout the Peace River in April through October, with decreased movements recorded through the winter months (Figure 13A). Some tagged Bull Trout appear more likely to move downstream in September and October before winter, with counterpart upstream movements in April and May. A decrease in activity appears 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 September with a small spike occurring in May and exit behaviours largely occurring in September and October (Figure 13B)[50]. Following entrance into the Halfway River, Bull Trout are proceeding upstream in July, August, and September with downstream behaviours largely occurring in September and October, following spawning. Entrance and exit behaviours were also analyzed and displayed for the Pine River (Figure 13B), which is recognized as a secondary spawning river system to the Halfway River (Mainstem Aquatics 2012, Geraldes and Taylor 2020). Study Bull Trout exhibited entrance and exit behaviours in the Pine River primarily in and around the month of September which may be indicative of spawning behaviour. However, without additional upstream fixed-stations and/or mobile tracking efforts in the Pine River these behaviours can not be validated.

Similar to Arctic Grayling, 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 residences, which is indicative of non-significant movement behaviours.

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[50] 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 from these activities.

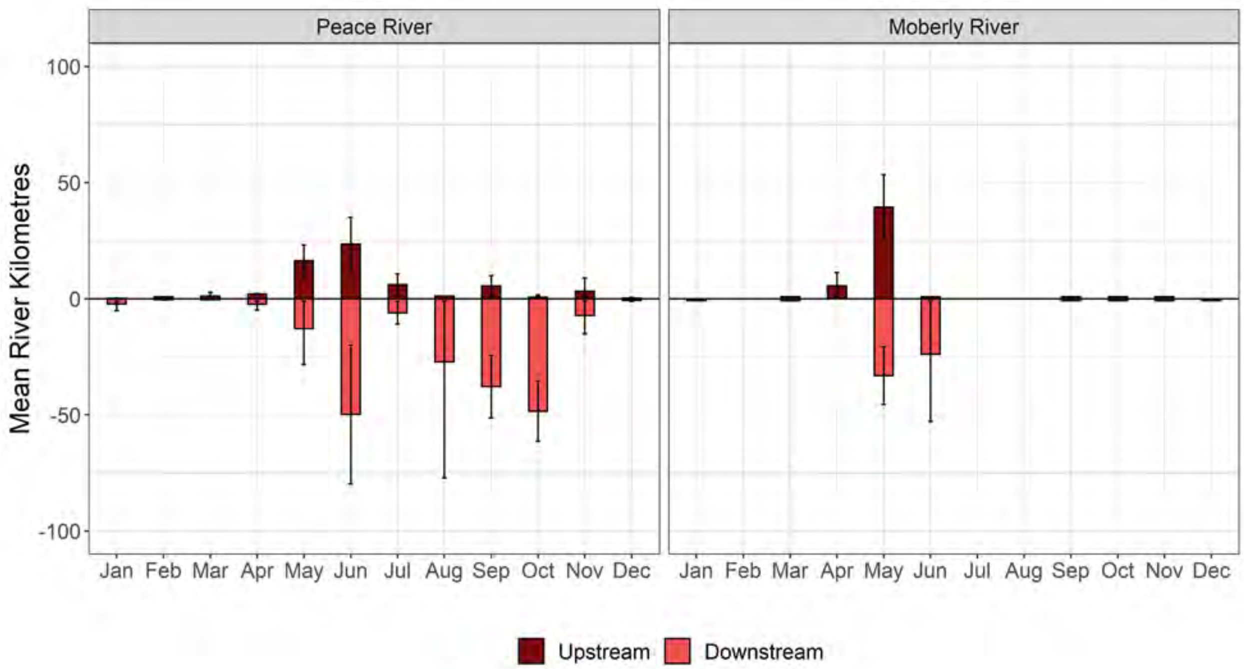

Figure 12A. Mean movements (in RKM), by month, for Arctic Grayling in the Peace River and Moberly River, calculated from all data collected 2019 through 2021. Positive values refer to upstream movement, and negative values refer to downstream movement. Error bars show the 95% confidence limits. Continues A-F

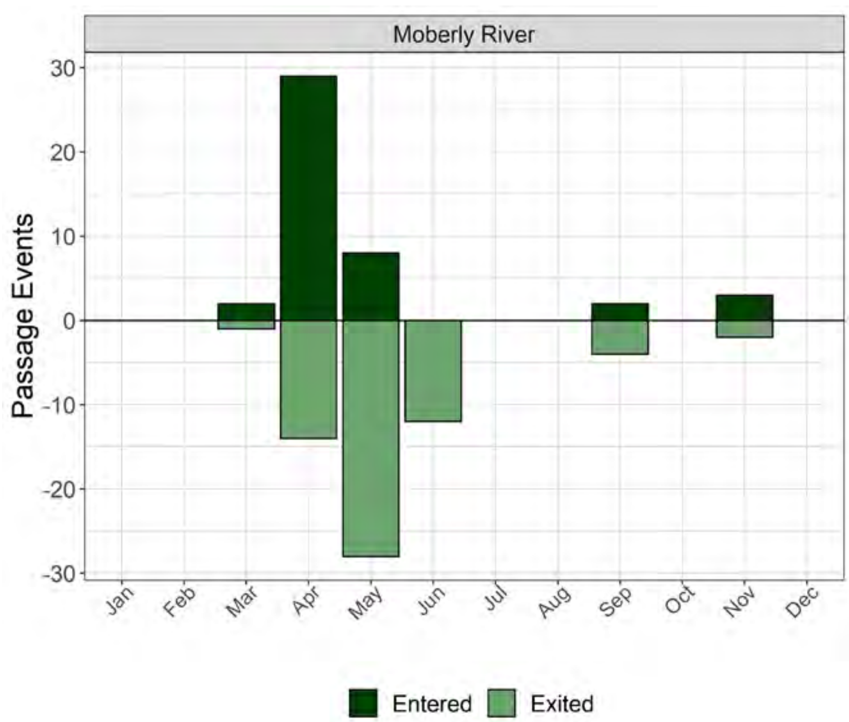

Figure 12B. Tributary entrance and exit movements for Arctic Grayling, tallied per individual study fish by month.

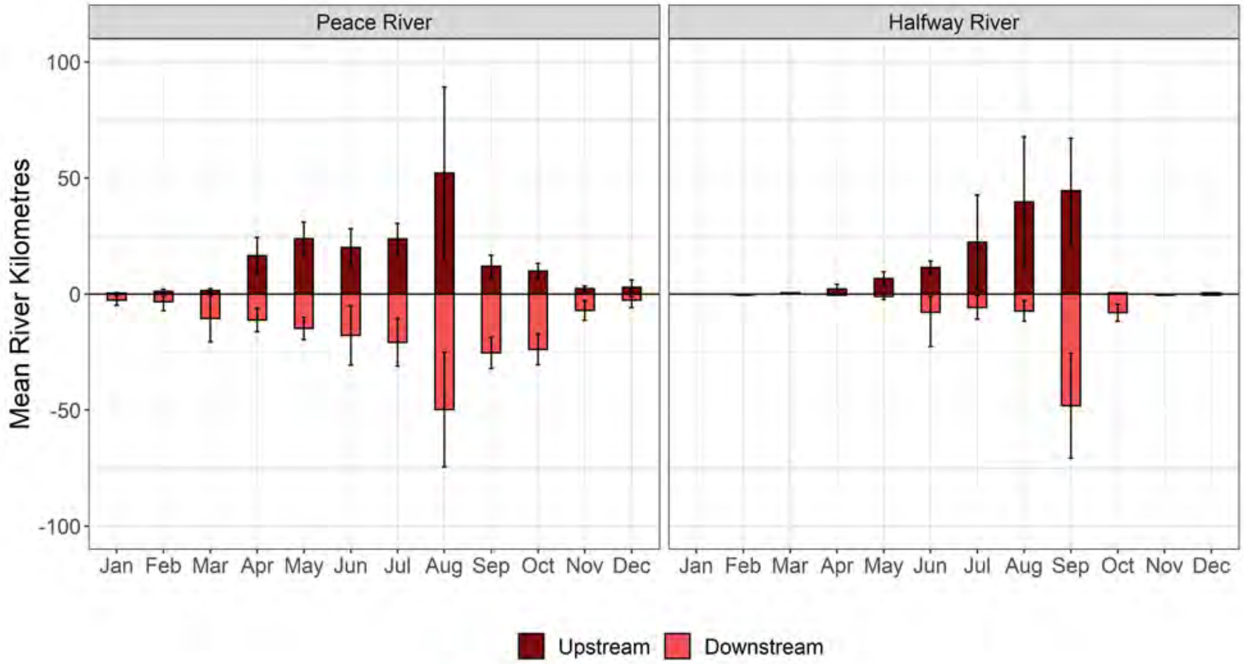

Figure 13A. Bull Trout mean monthly movements. Details as in Figure 12A.

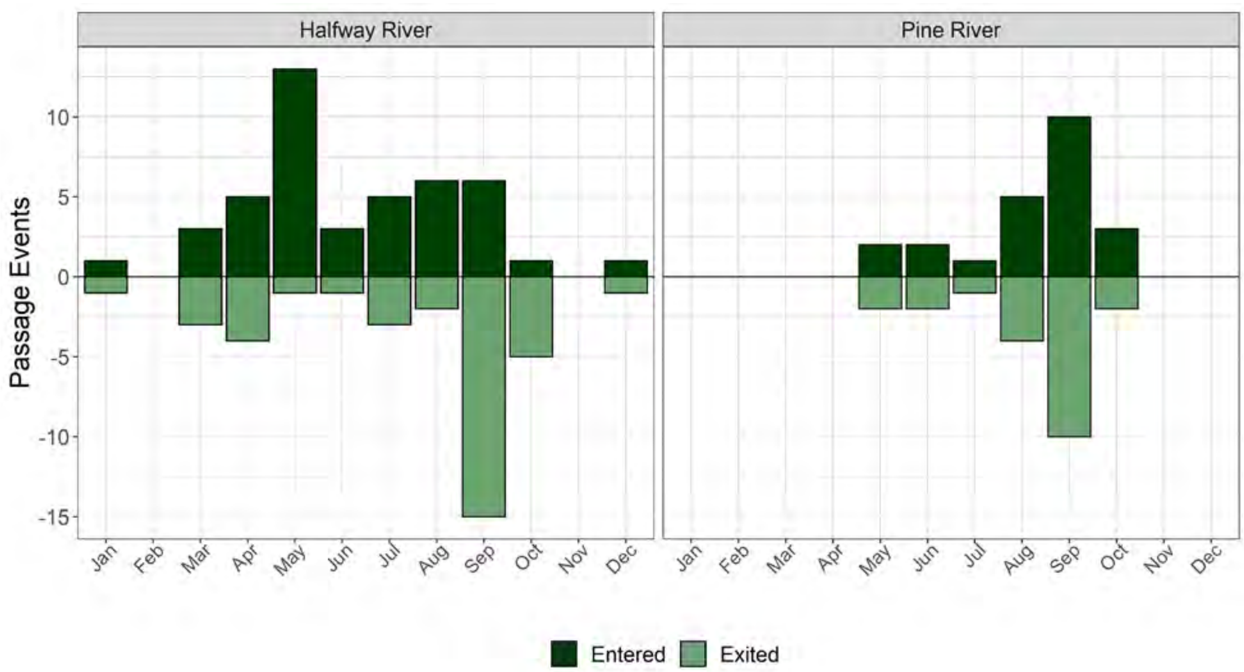

Figure 13B. Monthly tributary entrance/exit movements for Bull Trout. Details as in Figure 12B.

Burbot

Burbot tracks were hampered by relatively few detections that could not provide a reliable picture of seasonal movement behaviours (Figure 14). Fewer detections by Burbot could be the result of a sedentary lifestyle (i.e., study fish did not move past fixed-stations often), and/or a preference for deeper water (radio signals attenuate over depth[51]). All of which being further exacerbated by the relatively low sample size (n=26).

Three tagged Burbot were detected during the winter tracking that occurred from November 2021 to January 2022 (Table 5). Two of the three were detected in the same location before and during the mobile tracking, indicating a lack of movement. The third Burbot entered the Pouce Coupe River in April 2021 and was subsequently detected 22.7 RKM upstream in the Pouce Coupe on 1 December 2021 (Appendix E, Figure E5).

Small numbers of Burbot were also recorded entering and exiting the Beatton and Kiskatinaw rivers in August through October 2021. The Pouce Coupe River entrance behaviour, described above, was not captured by the tributary entrance/exit analysis due to a faulty antenna cable that was discovered and replaced in August 2021.

Mountain Whitefish

In September and October of 2021, 47 Mountain Whitefish were radio-tagged with 40 released downstream of Site C and (n=7)[52] released upstream of Site C (Figure A6). Of these, 42 were successfully detected following release, with the majority of movements being in the downstream direction in September and October (Figure 15A). Additionally, the general upstream movements displayed from April through July were recorded from four Mountain Whitefish tagged in 2020 with a Nano NTF-3-2 that surpassed their expected battery failure dates (expected mid-February 2021) and nevertheless recorded activity during the 2021 field season.

Mountain Whitefish tributary entrance and exit behaviours were recorded at the Pine River and Halfway River fixed-stations in September and October. All but one individual (from the Pine River) exited the respective tributary in the same month as the entrance behaviour (Figure 15B).

Fall 2021 mobile tracking locations were plotted (Figure E4) and individuals were detected scattered along the Peace River except for one individual detected 12.1 RKM upstream the Beatton River on 27 January 2022.

Rainbow Trout

Rainbow Trout tracked from 2019 through 2021 had relatively indiscriminate seasonal movements in the Peace River without an easily discernable pattern (Figure 16A). Likewise, tributary entrance and exit behaviours by Rainbow Trout were exhibited across numerous tributaries throughout the operational field season (Figure 16B). Tributary use that may correspond with spawning activity (tributary entrance in April-May and exit behaviour in June-July, July-August; Mainstem 2012), was observed in Farrell Creek, Halfway River, and Maurice Creek (Figure 16B).

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

[52] Of the seven Mountain Whitefish released upstream of Site C, one individual was collected as part of the Contingent Fish Capture and Transport Program with the remaining six captured in the Temporary Upstream Fishway.

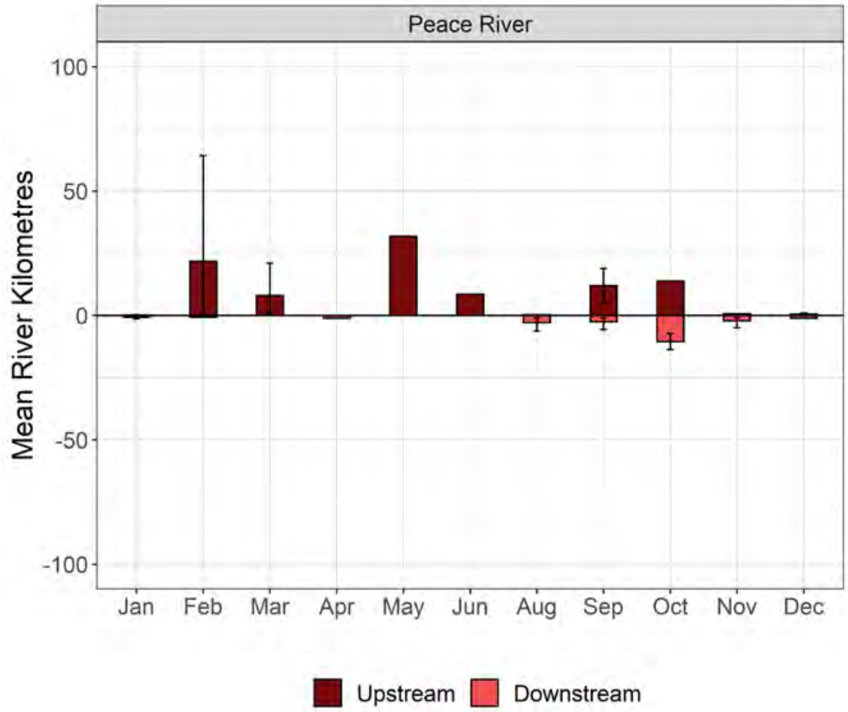

Figure 14A. Burbot mean monthly movements. Note the non-standard Y-axis scale. Details as in Figure 12A.

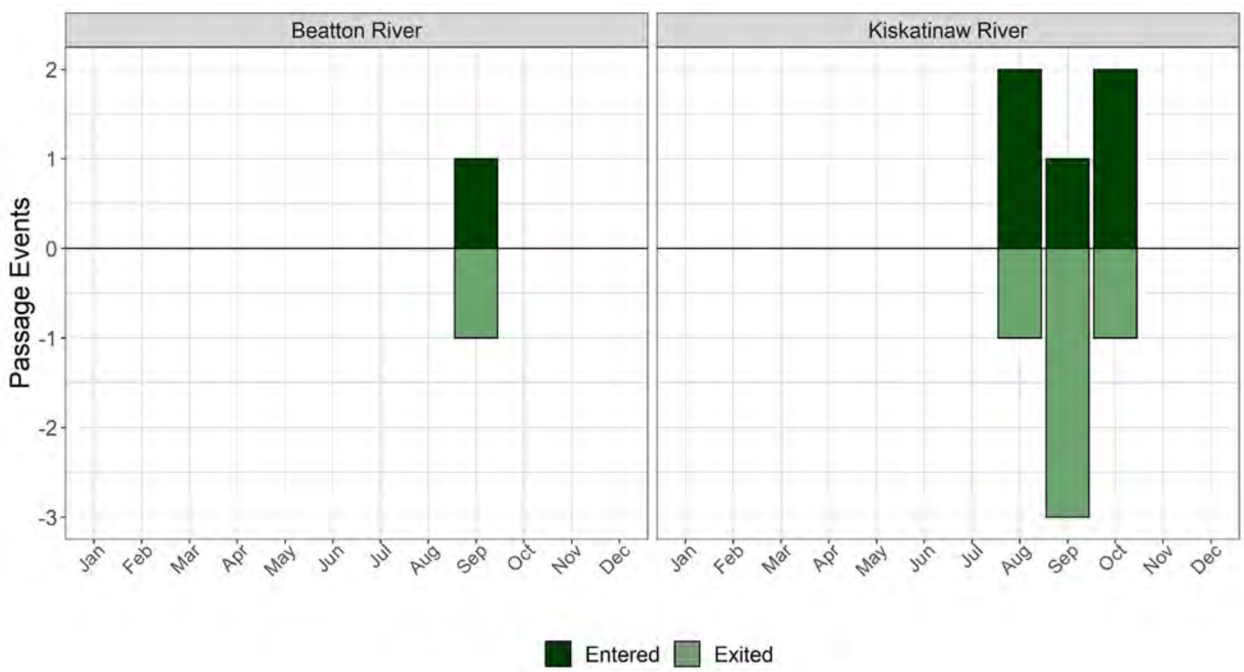

Figure 14B. Monthly tributary entrance/exit movements for Burbot. Details as in Figure 12B.

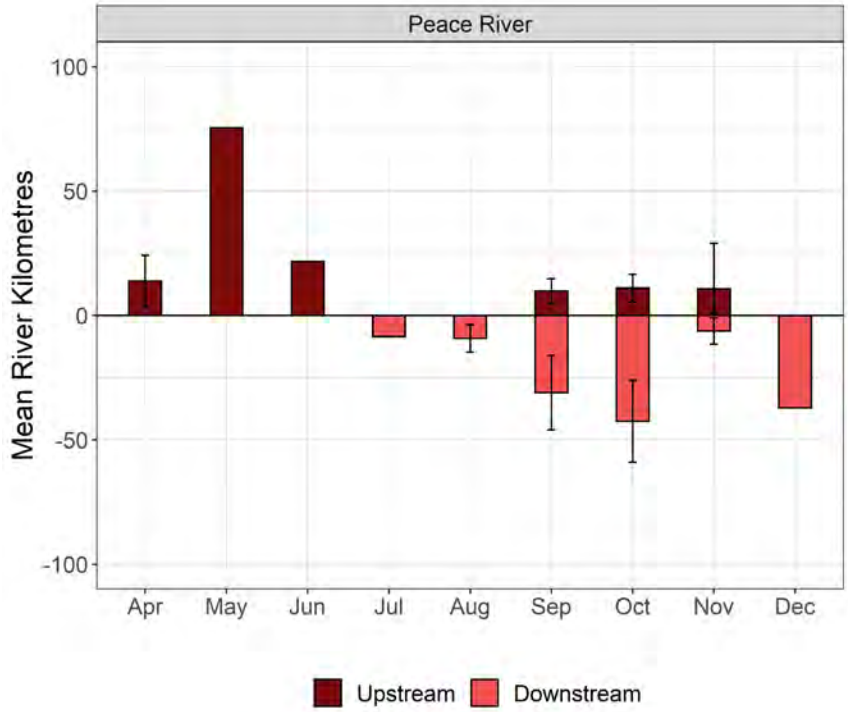

Figure 15A. Mountain Whitefish mean monthly movements. Additional details as in Figure 12A.

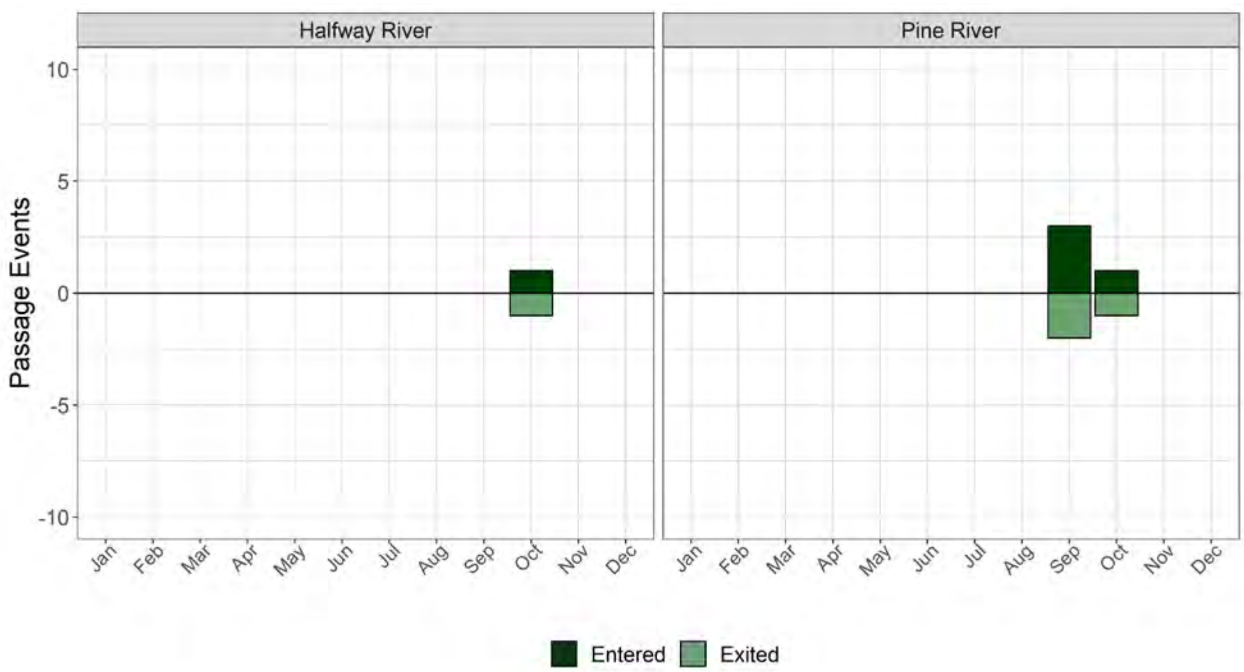

Figure 15B. Monthly tributary entrance/exit movements for Mountain Whitefish. Details as in Figure 12B.

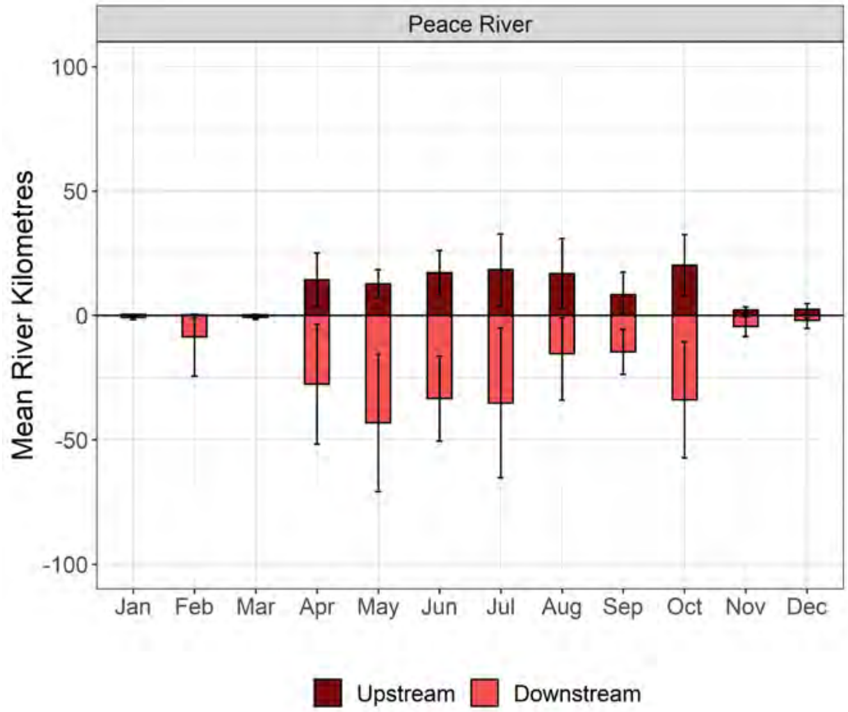

Figure 16A. Rainbow Trout mean monthly movements. Details as in Figure 12A.

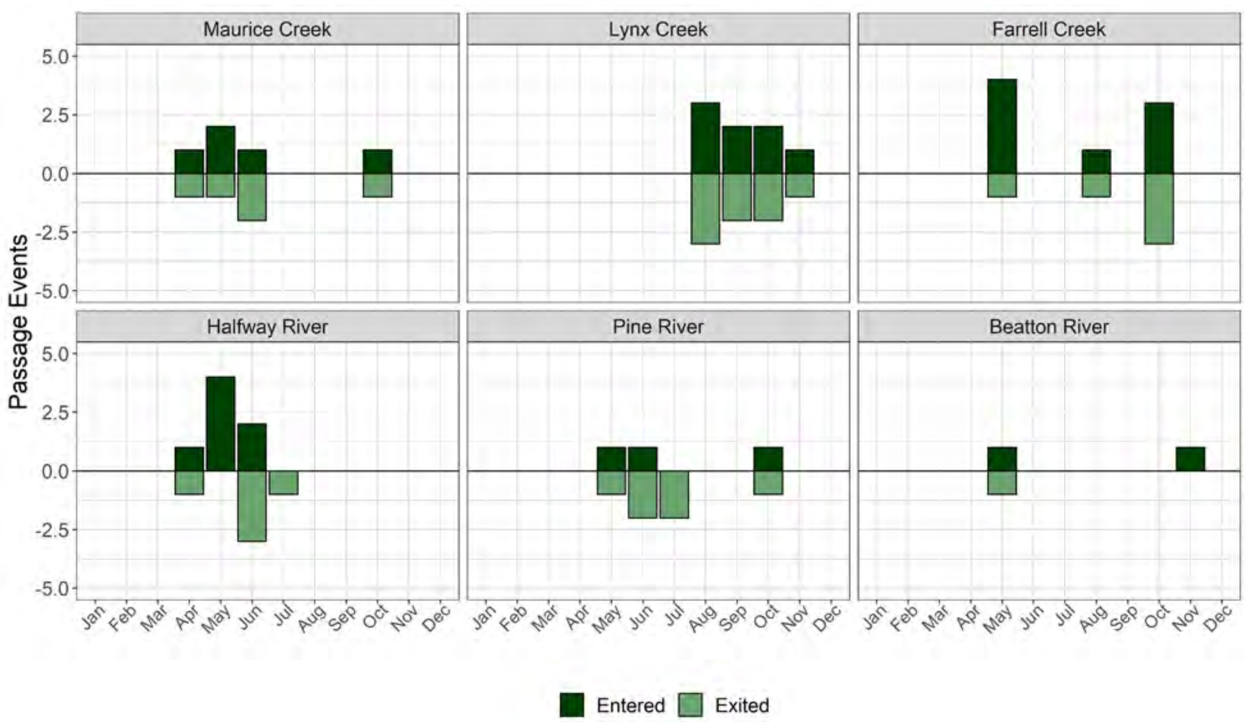

Figure 16B. Monthly tributary entrance/exit movements for Rainbow Trout. Details as in Figure 12B.

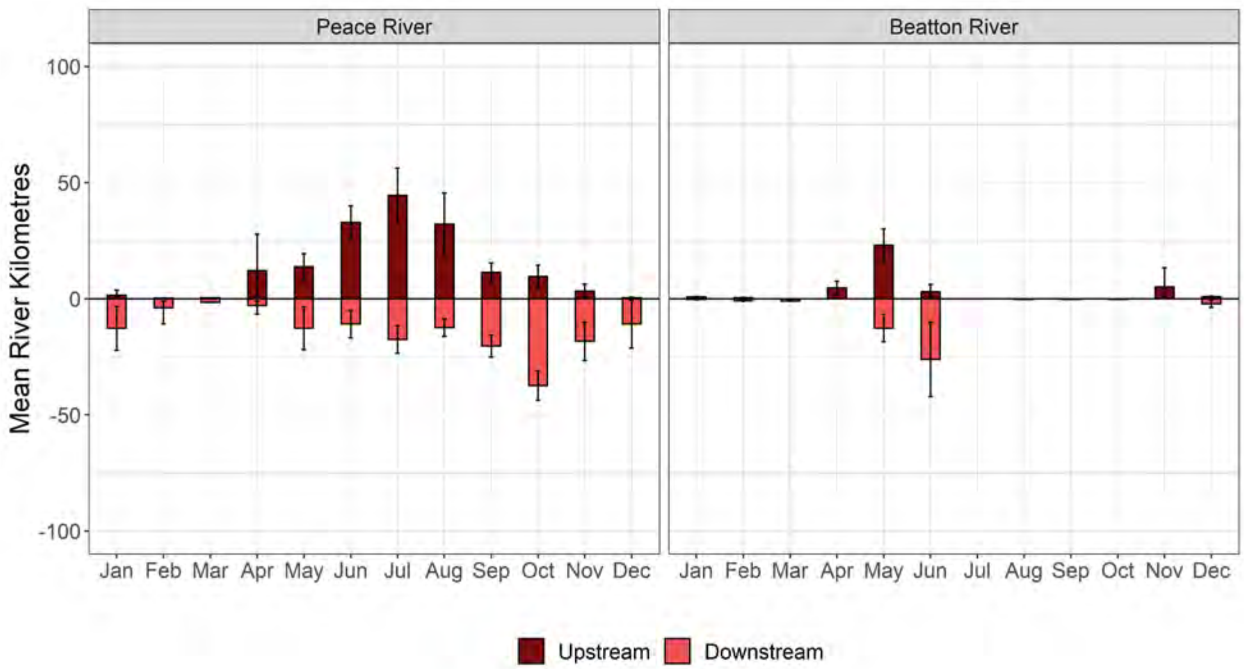

Figure 17A. Walleye mean monthly movements. Details as in Figure 12A.

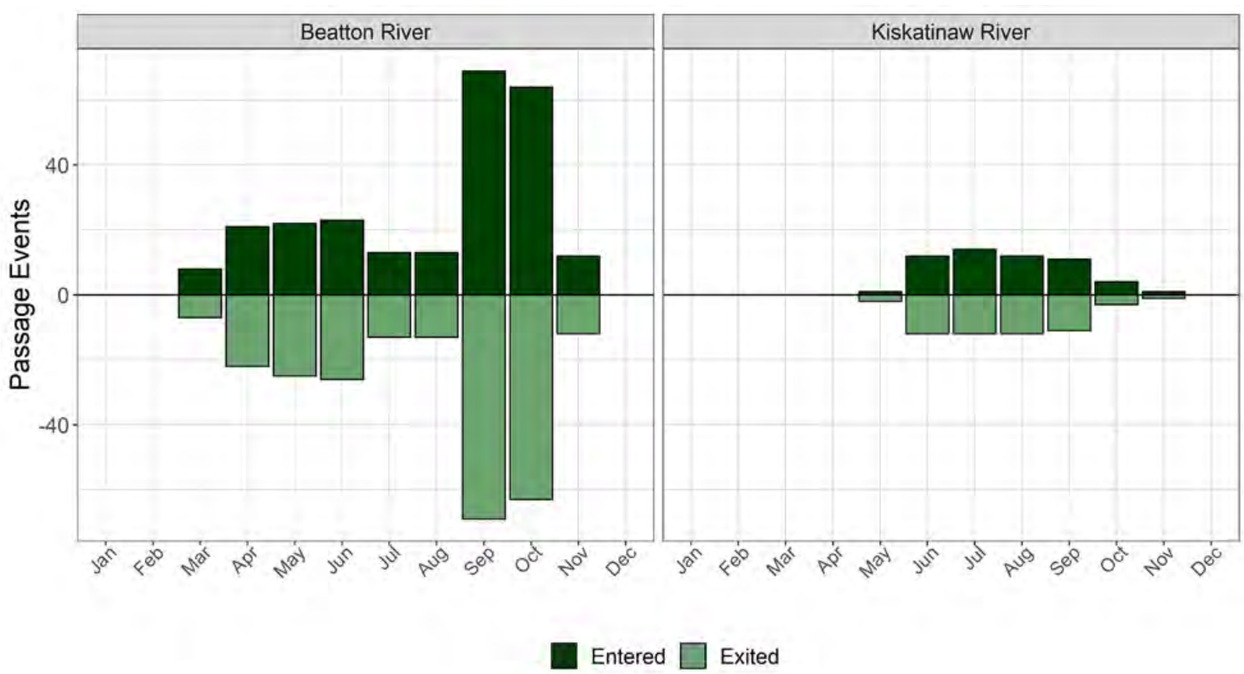

Figure 17B. Monthly tributary entrance/exit movements for Walleye. Details as in Figure 12B.

Walleye

Walleye movements in the Peace River were largely upstream from May to August followed by downstream movements from September to October (Figure 17A). In the Beatton River, Walleye were recorded moving upstream in May and downstream in June which is indicative of springtime spawning behaviours (Mainstream 2012, Smith et al. 2022). It is noteworthy, however, that upstream telemetry in the Beatton River was limited to April/May mobile surveys (Table 5), which means additional granularity through-out the year was not possible.

The majority of tributary use by Walleye was focused around the Beatton River with some summertime behaviour in the Kiskatinaw River (Figure 17B). Peace River movements correspond with Beatton River tributary activity wherein numerous Walleye migrate upstream and away from the Beatton River in April through August before returning downstream to the Beatton in September and October in preparation for winter and the following spring spawn (Figure 17). However, Beatton River monthly entrance and exit activity may not be indicative of migrations further upstream as the majority of spawners do not initiate upstream movements (defined as a movement >1.5 RKM upstream) until at least April (Smith et al. 2022).

Spawn Timing and Distribution

Arctic Grayling

The 2021 Arctic Grayling spawning evaluation identified six individual Arctic Grayling that exhibited probable spawning behaviours during the 2021 spawning period from late April to early June (Figures 12, 18, and E1). This represented 23.1% of the 26 Arctic Grayling adults that were still actively being tracked during the spawning period. In 2020, 14 individual Arctic Grayling were tracked with spawning behaviours in the Moberly River (Figure 18). One Arctic Grayling appeared to spawn in the Moberly River in 2020 and 2021.

The median date an Arctic Grayling entered the Moberly River was 7 May 2021 (range = 21 April 2021 to 14 May 2021) and the median exit was 27 May 2021 (range = 22 May 2021 to 2 June 2021, Table 11). However, it should be noted that five of the six Arctic Grayling that spawned in 2021 were captured downstream of Site C by the Contingent Fish Capture and Transport program and released upstream of Site C (near the Moberly River confluence) between 28 April and 7 May 2021 which may have altered normal entrance timing. Spawning behaviours in 2021 appeared to peak in the Moberly River between 22 May to 30 May 2021 with 50.0% of Arctic Grayling appearing to spawn between RKM 30 and 80 (Figure 18, Figure E1).

Arctic Grayling spawn timing in 2021 appeared to occur slightly earlier than what was reported in 2020 (Hatch et al. 2021). In 2020 the median entrance date for Arctic Grayling was 23 April 2020 (range = 18 March 2020 to 29 April 2020), with a median exit date of 25 May 2021 (range = 16 May 2020 to 16 June 2020). In 2020, Arctic Grayling peak spawning in the Moberly River was estimated to have occurred between 15 May and 20 May 2020.

Of the Arctic Grayling that entered the Moberly River during the spawning period, only one (Tag 992) remained within the 12 RKM inundation zone; detected at 6.2 RKM upstream by mobile tracking on 22 May 2021. The remaining five Artic Grayling all presumably spawned above the future inundation zone. The average Arctic Grayling migrated up the Moberly River 32.3 RKM (range = 6.2 – 68.8 RKM) to spawn before heading back downstream and exiting the system.

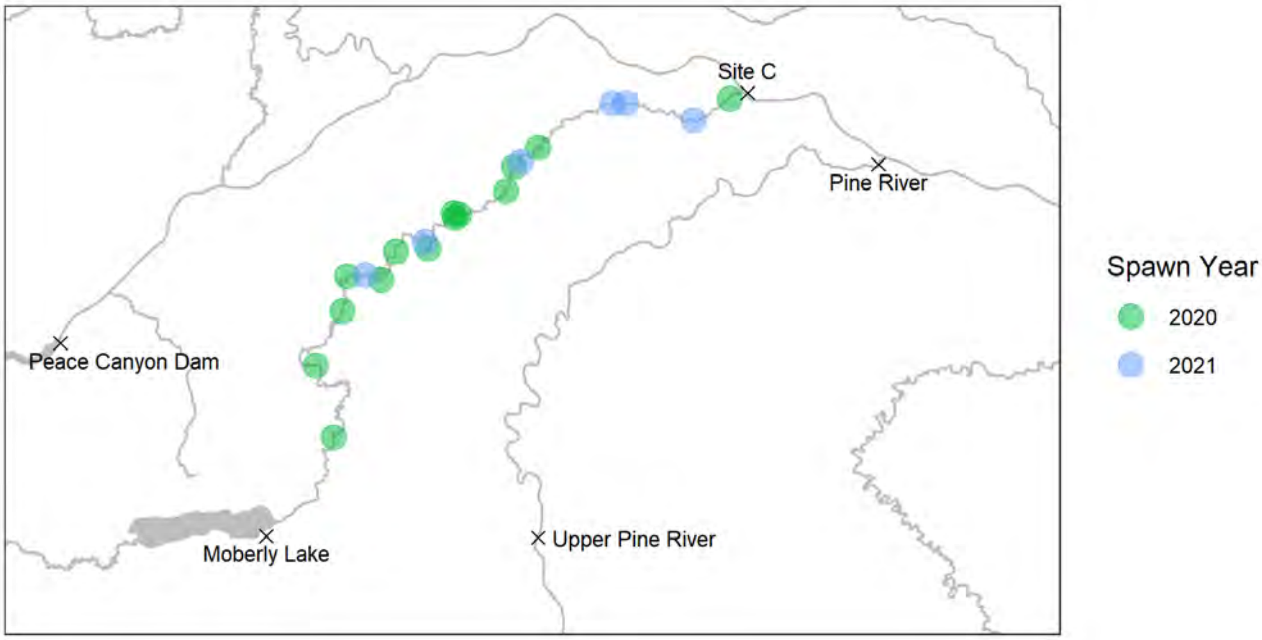

Figure 18. **Probable Arctic Grayling spawning locations in the Moberly River and its tributaries are shown with colours indicating spawn year. Figure continues in section B below.**

Of the six Arctic Grayling that entered the Moberly River from the Peace River, five returned to the Peace River following spawning. One Arctic Grayling (Tag 630) remained within the Moberly River after our last mobile tracking flight (Figure E1), likely a mortality or shed tag, as its signal was still present in the same location as of January 2022.

Bull Trout

In 2021, a total of 26 adult Bull Trout exhibited spawning behaviours in the Halfway River and its tributaries (Figures 19, E2, and E3). Of the 26 Bull Trout that exhibited spawning behaviours in 2021, 11 were released directly into the Halfway River (i.e., the Halfway River Boat Launch) between 22 April and 31 August 2021 which likely affected normal entrance behaviours[53]. Therefore, these fish were culled when calculating Bull Trout entrance timing into the Halfway River.

The median Bull Trout entered the Halfway River on 15 July 2021 (range = 21 April to 18 September 2021) and exited on 27 September 2021 (range = 20 September to 4 November 2021; Table 12). The wide range in Bull Trout entrance timing from 2021 was also reported in 2020 with Bull Trout entering between 26 April and 17 July 2020 (Hatch et al. 2021). Furthermore, exit timing was also similar to the 2020 results: ranging between 6 September and 7 October 2020.

[53] Among these 11 Butt Trout, six were captured downstream of Site C, radio-tagged and released into the Halfway River between 22 April and 13 May 2021. One was captured in the TUF on 18 August 2021, radio-tagged and then released into the Halfway River. Two were captured in the TUF and re-released into the Halfway River in August 2021 while the remaining two were captured downstream of Site C by contingent electrofishing and re-released into the Halfway River in July 2021.

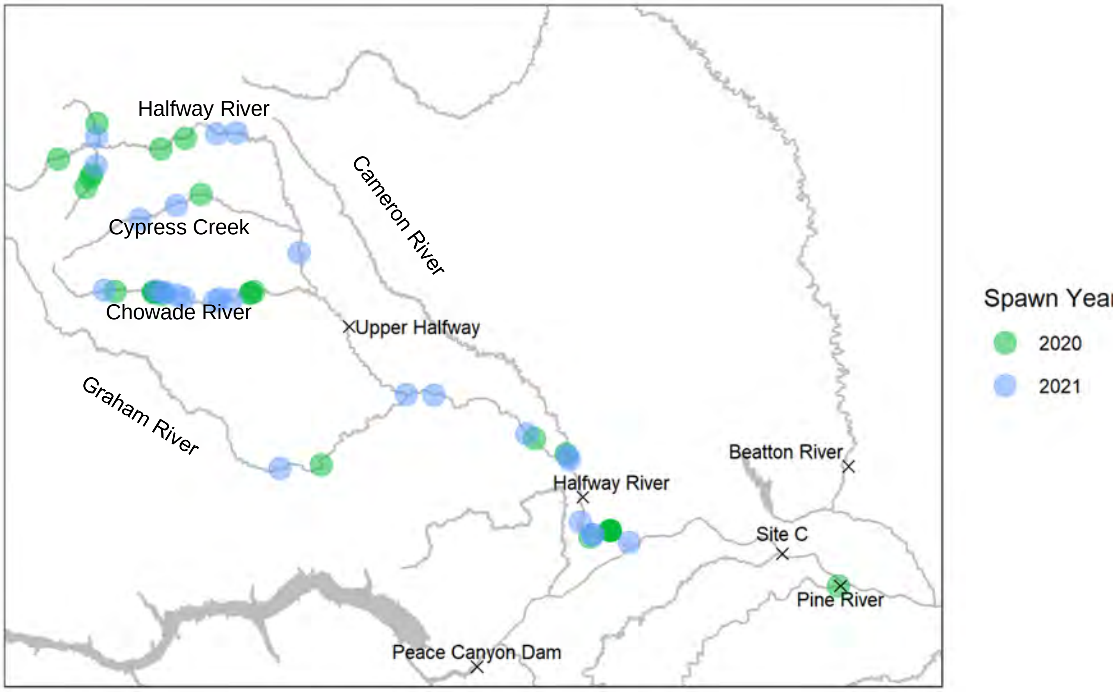

Figure 19. Probable Bull Trout spawning locations in the Halfway River and its tributaries are shown with colours indicating spawn year.

After entering the Halfway River in 2021, five Bull Trout have not yet been recorded exiting the system and are either continuing to reside in the Halfway River, are a mortality or shed their radio tags during spawning or migration. Only one of the Halfway River spawning Bull Trout was recorded spawning in both 2020 and 2021 in the Chowade River.

According to the movement patterns of these 26 Bull Trout, peak spawning in the Halfway River presumably occurred sometime around 16 September 2021. Nine Bull Trout were identified to have spawned in the Chowade River, five in the upper Halfway River (upstream of the Cameron River), one in Fiddes Creek, one in the Graham River, one in Turnoff Creek, two in Cypress Creek and six in the lower Halfway River, downstream of the Cameron River[54] (Figure 19).

Four of the Bull Trout that spawned in the Halfway River migrated from downstream of Site C, and were therefore captured and transported to the Halfway River Boat Launch. These Bull Trout were captured at Site C between 15 July and 31 August 2021.

In 2021, two radio tagged Bull Trout were determined to have been within the Pine River during September spawning which is another tributary where Peace River Bull Trout spawn (Mainstream Aquatics 2012, Geraldes and Taylor 2020).

[54] It's possible some of these individuals did indeed migrate upstream but were not effectively tracked in the upper reaches.

Discussion

Study Objectives

The objective of 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 2021. An additional radio tag frequency was added to the detection system in 2021 which, expectedly decreased the detection efficiency at numerous fixed-stations[55]. The decrease in detection efficiency, however, was not substantial with the average fixed-station yielding an 87.5% detection efficiency in 2021 (for both upstream and downstream movement orientations) which is a minor decrease from the 2020-2021 average of 91.1% (range = 83.3% to 98.3%, Hatch et al. 2021).

The magnitude, direction, and seasonal variability of movements from key indicator species were displayed and inferred individually to generalize seasonal movement trends and highlight the capacity of the fixed-station array. This analysis served to display large-scale movements from each of the six indicator species and allow for region-wide monitoring of fish movement.

The fixed radio telemetry array is intended to operate during numerous phases of the Project, including construction[56] and operation[57], and will compliment the baseline studies conducted from 1996-1999[58] and 2005-2009[59]. The contribution of telemetry data from the 2021 study year adds to the ever-growing resource of telemetry data 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 objective of 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 the Project may have on these metrics, and to inform various monitoring programs. In 2021, six mobile surveys were conducted, which, in conjunction with the operation of the fixed radio telemetry array (Mon-1b, Task 2d), contributed to the understanding of the timing, direction, and magnitude of Arctic Grayling movements into, within, and out of the Moberly River in May and June. The Bull Trout movements in the Halfway River in August and September 2021 were monitored using the fixed radio telemetry array (Mon-1b, Task 2d) in conjunction with two (2-3 day) 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 2021. Both datasets and all analyses added to the growing depth of knowledge for pre-operational Site C Bull Trout and Arctic Grayling behaviours that will become a useful comparative tool for when the reservoir is filled.

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[55] Fixed-receivers need to scan over each frequency separately, which means the addition of a new frequency translates to less time scanning per individual frequency.

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

[57] Operation Years 1-4 (2024-2028), 10-11 (2034-2035), 15-16 (2039-2040), 20-21 (2044-2045), 25-26 (2049-2050) and 29-30 (2053-2054).

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

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

Management Questions

Since July 2019, there have been 872 radio-tagged Arctic Grayling (n=69), Bull Trout (n=305), Burbot (n=26), Mountain Whitefish (n=75), Rainbow Trout (n=208), and Walleye (n=189) released into the Peace River and its tributaries. From these 872 radio-tagged study fish, the fixed radio telemetry array and mobile tracking efforts have collected over 37 million valid detections across hundreds of kilometers of the Peace River and its tributaries. These data build on the telemetry data collected from 1996 to 1999 and 2005 to 2009 and are intended to answer or provide guidance across a myriad of management questions outlined in the FAHMFP[60].

Data collection, however, 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.

Arctic Grayling

Three questions were addressed about Arctic Grayling and are a continuation to the answers originally provided in Hatch et al. (2021) with the addition of data collected in 2021: 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?

To answer these questions, there were 45 adult Arctic Grayling available for analysis (n= 29 from 2019, n= 13 from 2020, n= 3 from 2021). The remaining nine Arctic Grayling that were tagged in 2021 were released later than May spawning and were therefore removed from this analysis. No juvenile Arctic Grayling were used for this analysis.

In 2021, 6 Arctic Grayling were detected moving into the Moberly River from the Peace River before peak spawning in May 2020/2021. This represented 13.3% of the 45 tagged Arctic Grayling and 23.1% of the Arctic Grayling adults that were released and confirmed active on or after May 2021 (n= 26). This is a reduction from 2020 wherein 14 radio-tagged Arctic Grayling showed Moberly River spawning behaviours, which represented 48.3% of the tags available and 70.0% of the tags confirmed active in May 2020. In 2020 and 2021, 90.0% of Moberly River spawning Arctic Grayling (i.e., 18 of 20) spawned above the 12 RKM inundation zone. The average Arctic Grayling spawned at RKM 32.3 in 2021 (range = 6.2 to 68.8) and at 54.8 in 2020 (range = 1.5 to 108.9).

The 20 Moberly River spawning behaviours were recorded by 19 individual Arctic Grayling (i.e., one Arctic Grayling presumably spawned in the Moberly River both years). Outside of spawning, nine of these Arctic Grayling (47.4%) inhabited the reaches of the Peace River that are upstream of Site C (RKM 106), while seven (36.8%) primarily inhabited Peace River reaches downstream of Site C. The remaining three (15.8%) Arctic Grayling used areas both upstream and downstream of Site C during non-spawning portions of the year (range = 75 to 215 RKM).

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

Bull Trout

No Bull Trout management questions were addressed with the inclusion of the 2021 telemetry data.

Burbot

The question asked about Burbot was to describe their November through February (i.e., winter) movements. This is a continuation to the answer provided in Hatch et al. (2021).

In total, 26 Burbot have been radio-tagged in 2019 (n=18), 2020 (n=7), and 2021 (n=1). Potential winter movement behaviours were isolated for Burbot with detections during, before, and/or after two winter spans from November 2019 to March 2020 and November 2020 to March 2021. There were 14 behaviours tracked during or around winter from 10 Burbot.

The majority of Burbot behaviours during winter months (71.4%, or 10 of 14) were categorized as non-migratory, as the individual did not move significantly during or through the winter months. Of the four potential winter movements, only one was confirmed to have occurred during winter wherein the Burbot migrated 78 RKM downstream from the Beatton River to Peace River 1 between 31 October 2020 and 19 December 2020. Another Burbot was recorded migrating 32 RKM downstream from Peace River 8 to Site C, sometime between 3 November 2019 and 13 May 2020. The remaining two Burbot migrated 76 RKM upstream and 116 RKM downstream over long undetected periods between 24 August 2019 to 16 October 2020 and 18 October 2019 to 19 December 2020, respectively. Although these three migrations could have occurred anytime between the date spans, i.e., not during winter, it might be assumed that these fish would have been detected by the fixed radio telemetry array had the individual migrated during the operational season from March to November. However, this cannot be confirmed without the required resolution. No additional Burbot were detected during or through winter months.

Mountain Whitefish

Two interrelated questions were asked about Mountain Whitefish and are an extension from what was provided in Hatch et al. (2021): 1) In the fall, are Mountain Whitefish milling or migrating? 2) Where might they be spawning?

To answer these questions, there were 47 Mountain Whitefish tagged in 2021, and 28 tagged in 2020. The 28 Mountain Whitefish tagged in August 2020 were all tagged with a Lotek Nano 3-2 radio-tag, which is the smallest radio tag we use and as such has a short 185-day battery life. After incorporating battery failure estimates, all 28 Mountain Whitefish from 2020 were expected to have expired before the 2021 monitoring. Regardless, five Mountain Whitefish from 2020 were detected into the 2021 season. All 47 Mountain Whitefish tagged in 2021 were tagged with the bigger and longer lasting Nano NTF-6-2 tag to extend the tracking period. Additionally, 116 Mountain Whitefish were tagged and released in 2006 (AMEC and LGL 2008a).

All 47 Mountain Whitefish tagged in 2021 were tagged in the fall between 17 September and 31 October 2021. Of these fish, 42.6% (n= 20) were tracked in the same general location during the proceeding fall months following release, while another 42.6% (n= 20) were tracked moving appreciably downstream during that same period. Only 4.3% (n=2) logged an upstream movement during fall 2021, with the remaining 10.5% (n= 5) not being tracked following release. The 20 Mountain Whitefish that did not move appreciably all stayed near their original tag and release location, between the Pine River (RKM 122) and Site C (RKM 107). Nine of the 20 Mountain Whitefish with downstream movements in fall 2021 migrated into the Alberta region of the detection array (>168 RKM) while the other 11 stayed between Peace River 4 and the border to Alberta (134 to 168 RKM).

Downstream movements immediately following release are indicative of tagging and handling effects, which is particularly likely given Mountain Whitefish are known to be prone to these effects (Taylor et al. 2011). This is likely a major factor in the prevalence of downstream movements, given the movement occurred shortly after release, and Mountain Whitefish fall movement patterns were non-migratory in 2006 and 2007 (Hatch et al. 2021). The average Mountain Whitefish moved 17.9 RKM downstream (sd = 32.7) in October and November 2021, which is in contrast to an average of 6.4 RKM downstream (sd = 27.1)[61] in 2006 and 1.7 RKM downstream (sd = 7.8) in 2007.

There were three Mountain Whitefish that entered and exited the Pine River from the Peace River in September 2021, along with a similar behaviour from a Mountain Whitefish in October 2020. Furthermore, the pattern of entering the Pine River from the Peace River in late September or October was repeated eight times by five individuals in the 2006 and 2007 data. Additionally, one Mountain Whitefish entered the Halfway River from the Peace River in late October 2021, a pattern that was repeated 14 other times by 12 individuals in the 2006 and 2007 data. These movement patterns are generally corroborated by baseline genetics that inferred Peace River Mountain Whitefish to have genetics that originated from the Pine River (Taylor et al. 2014).

The 47 Mountain Whitefish tagged in 2021 were all tagged with the Lotek Nano NTF-6-2 tag which has an estimated 931-day battery life. Therefore, further analysis in proceeding study years will increasingly refine this analysis as potential tagging and handling effects dissipate and behaviours from tagged Mountain Whitefish return to baseline.

Rainbow Trout

No Rainbow Trout management questions were addressed with the inclusion of the 2021 telemetry data.

Walleye

No Walleye management questions were addressed with the inclusion of the 2021 telemetry data.

[61] Tagging occurred between 21 June 2006 and 27 June 2006, giving these Mountain Whitefish more time to recover than their 2021 counterparts.

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Appendices

Appendix A. Spatial Distributions of Fish Releases

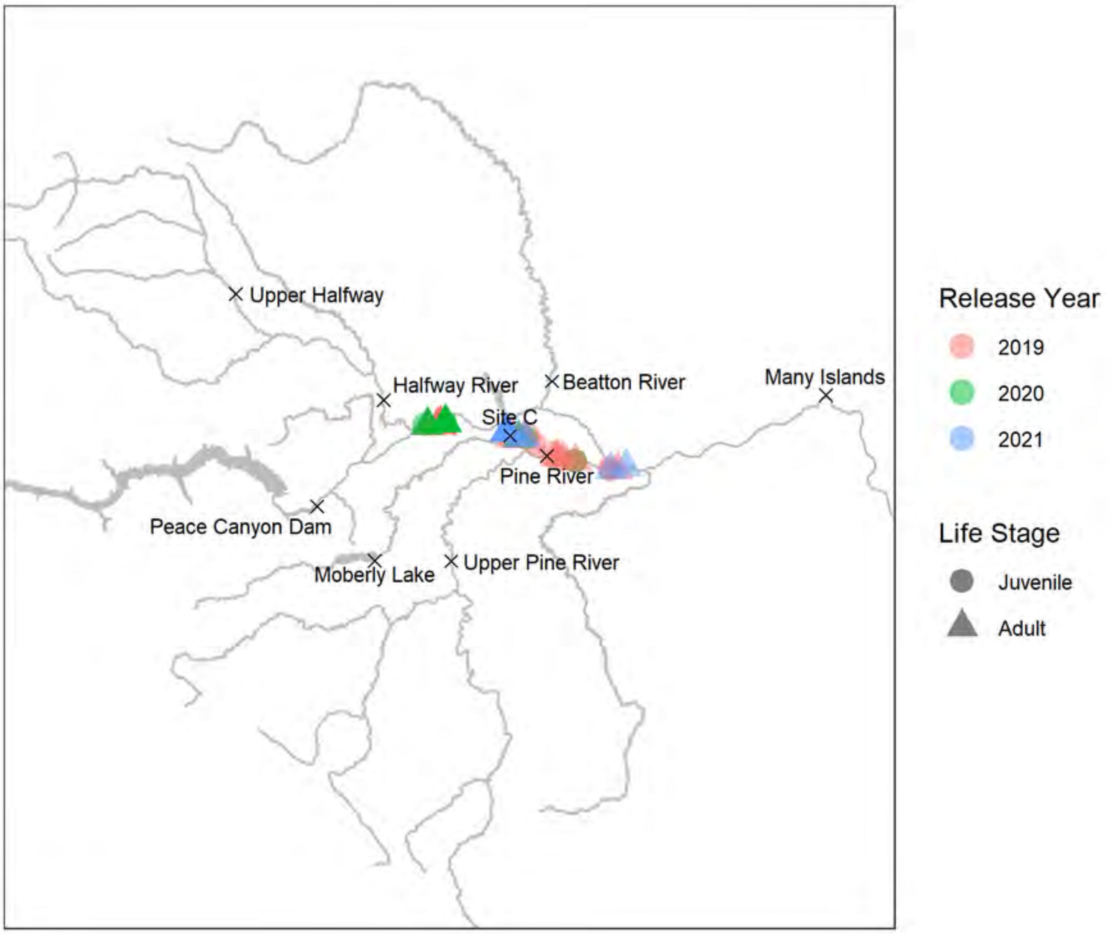


Figure A1. **Arctic Grayling release locations and points of reference (×) from the present dataset (2019 to 2021). Juvenile fish are depicted as circles, adults depicted as triangles. Point colours indicate year of release.**

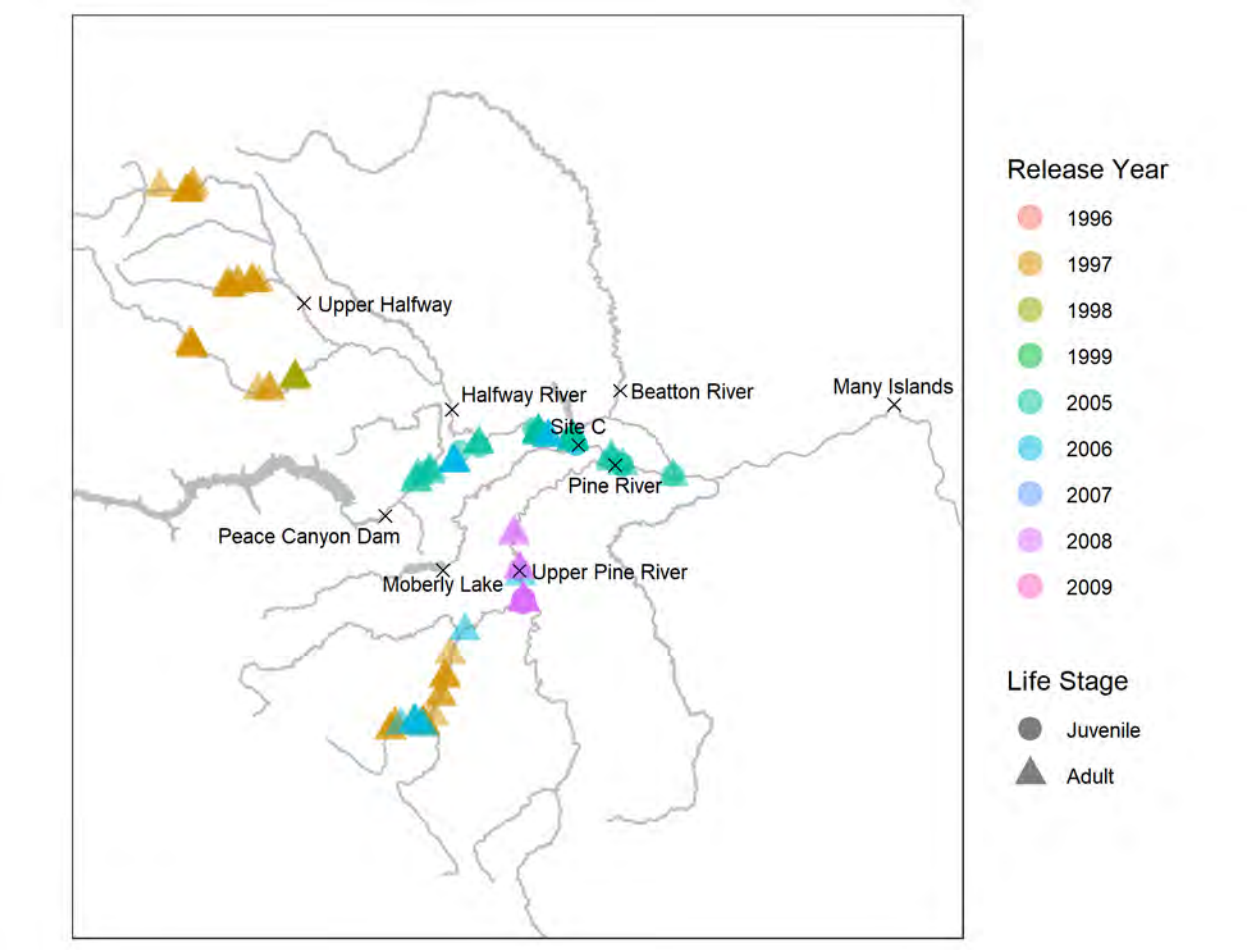


Figure A2. **Arctic Grayling release locations and points of reference (×) from the historical dataset (1996 to 1998 and 2005 to 2008). Juvenile fish are depicted as circles, adults depicted as triangles. Point colours indicate year of release.**

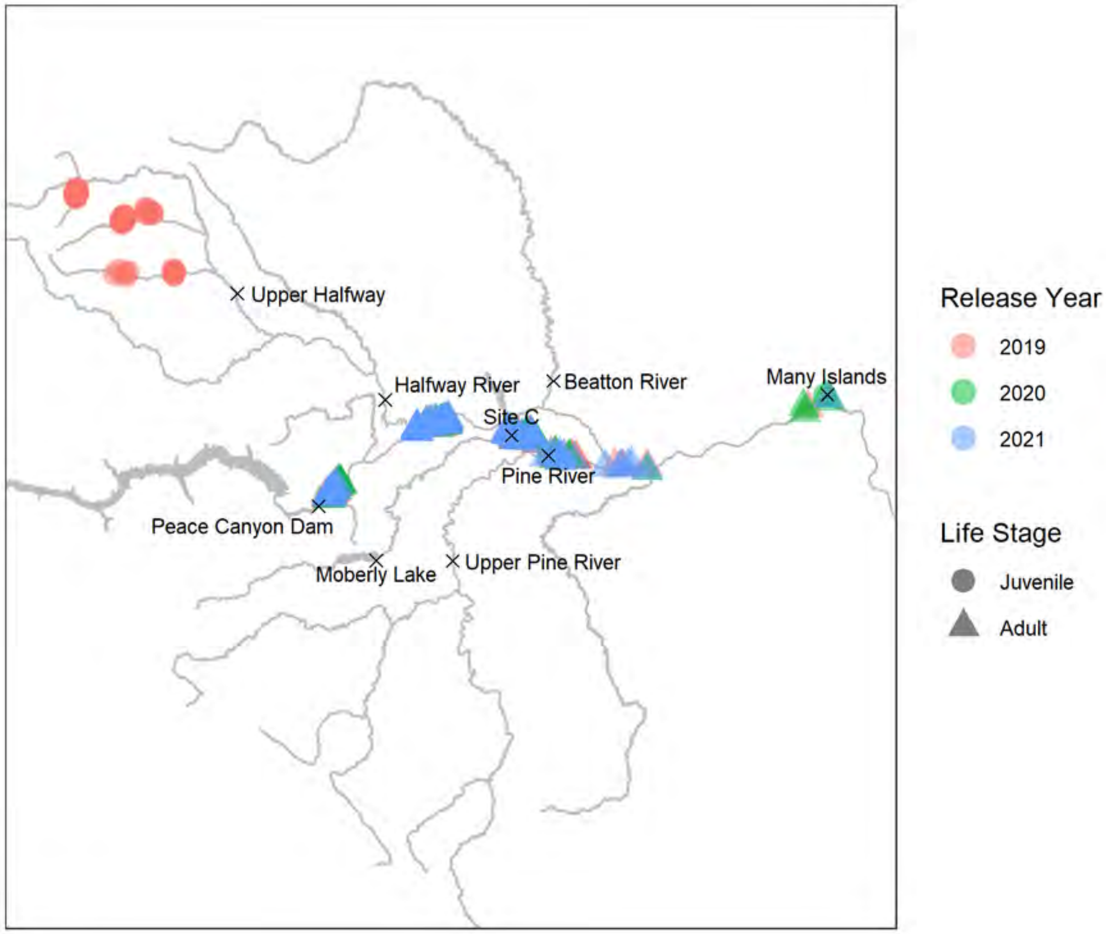


Figure A3. Bull Trout release locations and points of reference (×) from the present dataset (2019 to 2021). Juvenile fish are depicted as circles, adults depicted as triangles. Point colours indicate year of release.

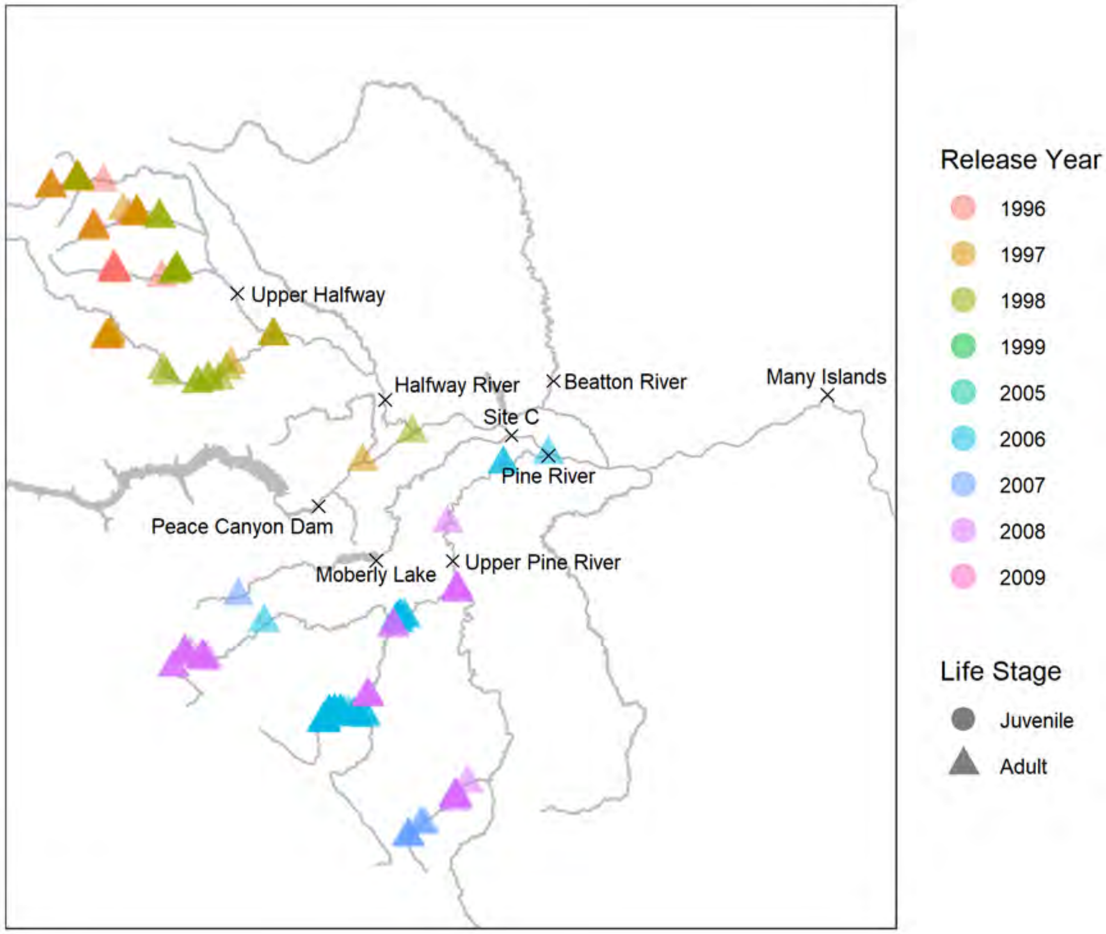


Figure A4. Bull Trout release locations and points of reference (×) from the historical dataset (1996 to 1998 and 2005 to 2008). Juvenile fish are depicted as circles, adults depicted as triangles. Point colours indicate year of release.

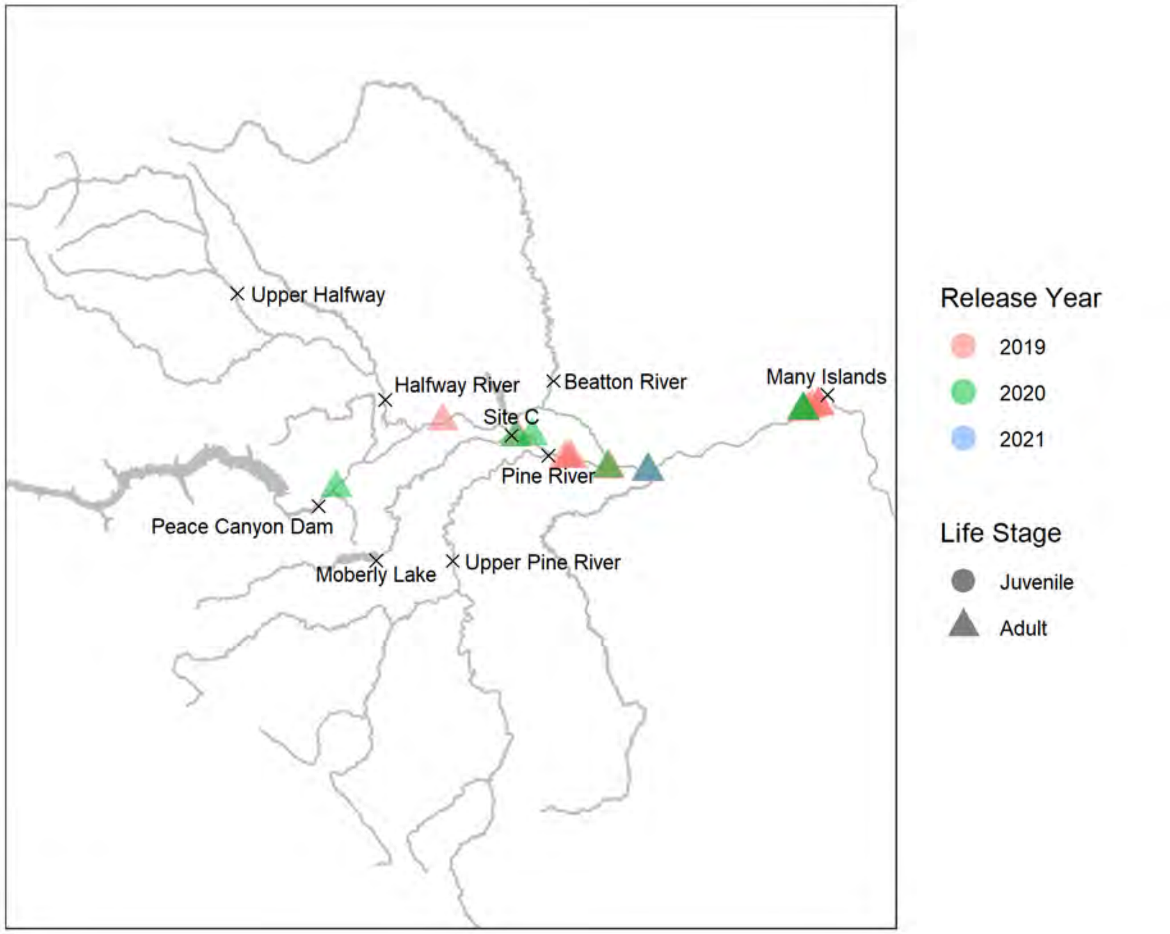


Figure A5. **Burbot release locations and points of reference (×) from the present dataset (2019 to 2021). Juvenile fish are depicted as circles, adults depicted as triangles. Point colours indicate year of release.**

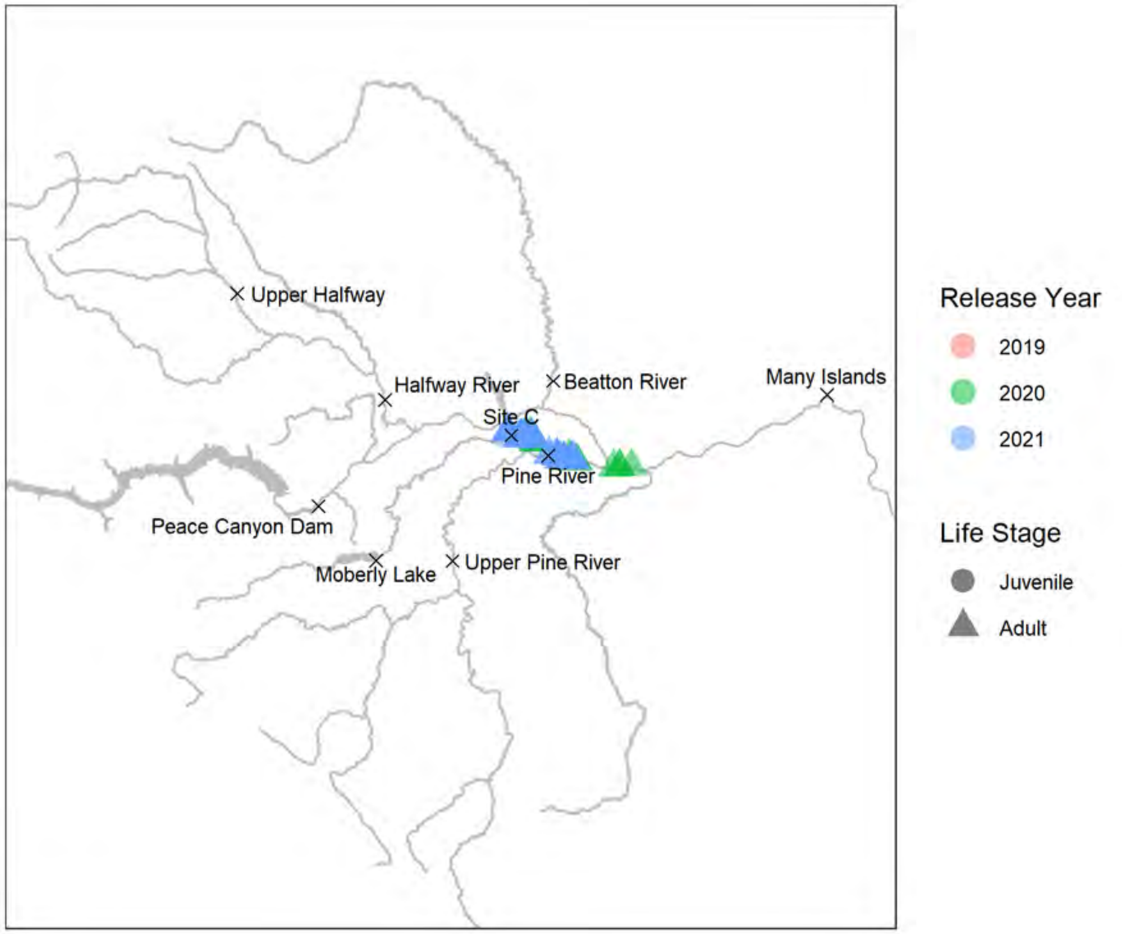


Figure A6. Mountain Whitefish release locations and points of reference (×) from the present dataset (2019 to 2021). Juvenile fish are depicted as circles, adults depicted as triangles. Point colours indicate year of release.

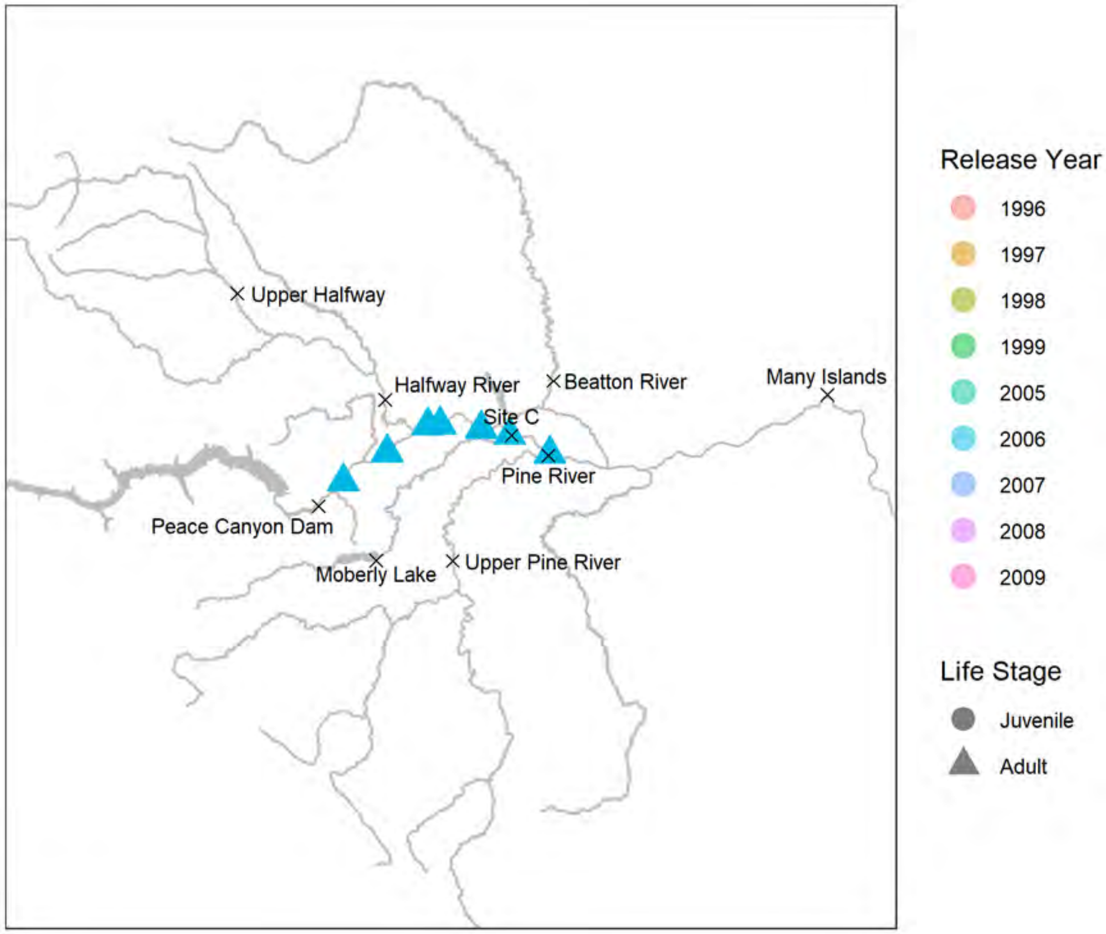


Figure A7. Mountain Whitefish release locations and points of reference (×) from the historical dataset (1996 to 1998 and 2005 to 2008). Juvenile fish are depicted as circles, adults depicted as triangles. Point colours indicate year of release.

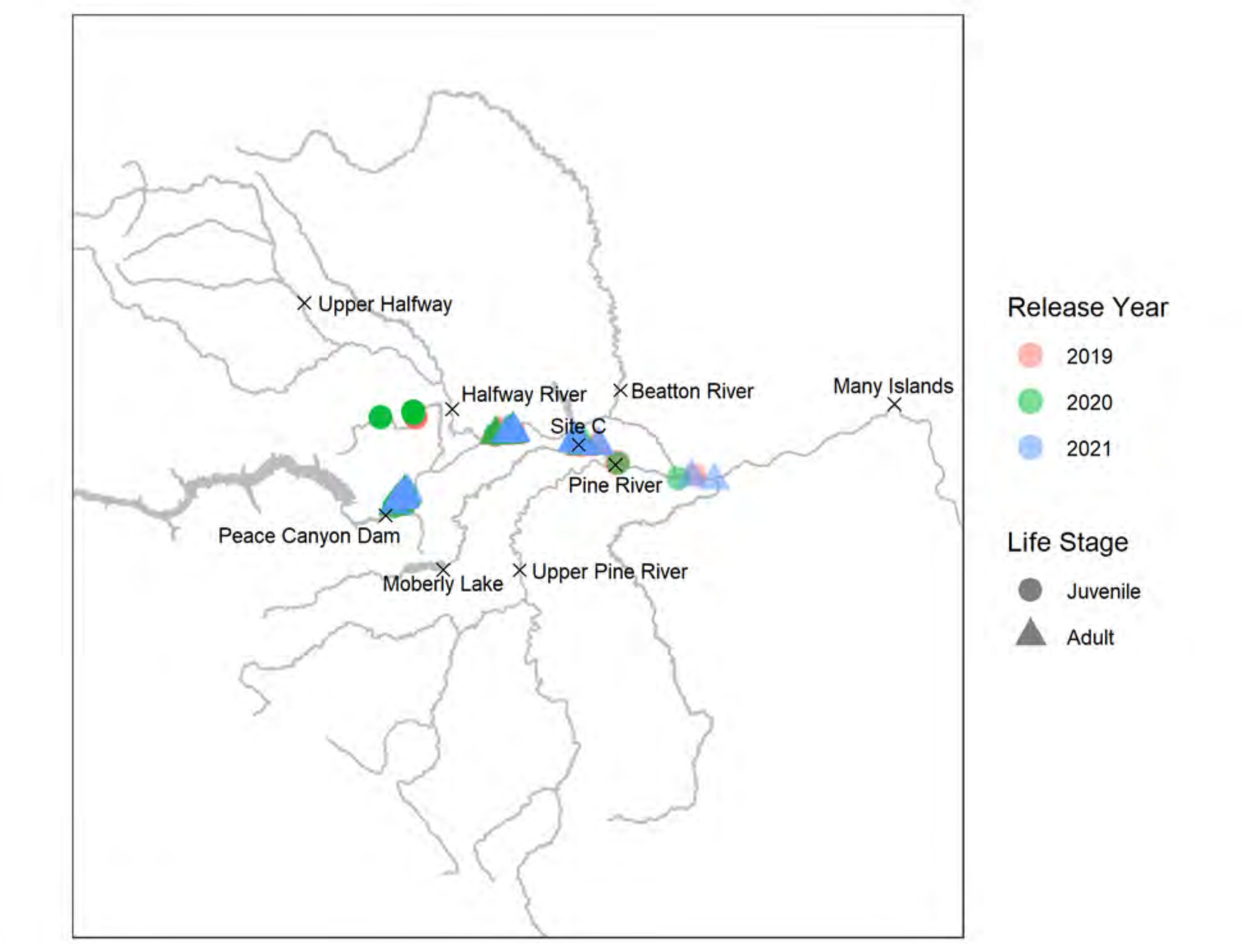


Figure A8. **Rainbow Trout release locations and points of reference (×) from the present dataset (2019 to 2021). Juvenile fish are depicted as circles, adults depicted as triangles. Point colours indicate year of release.**

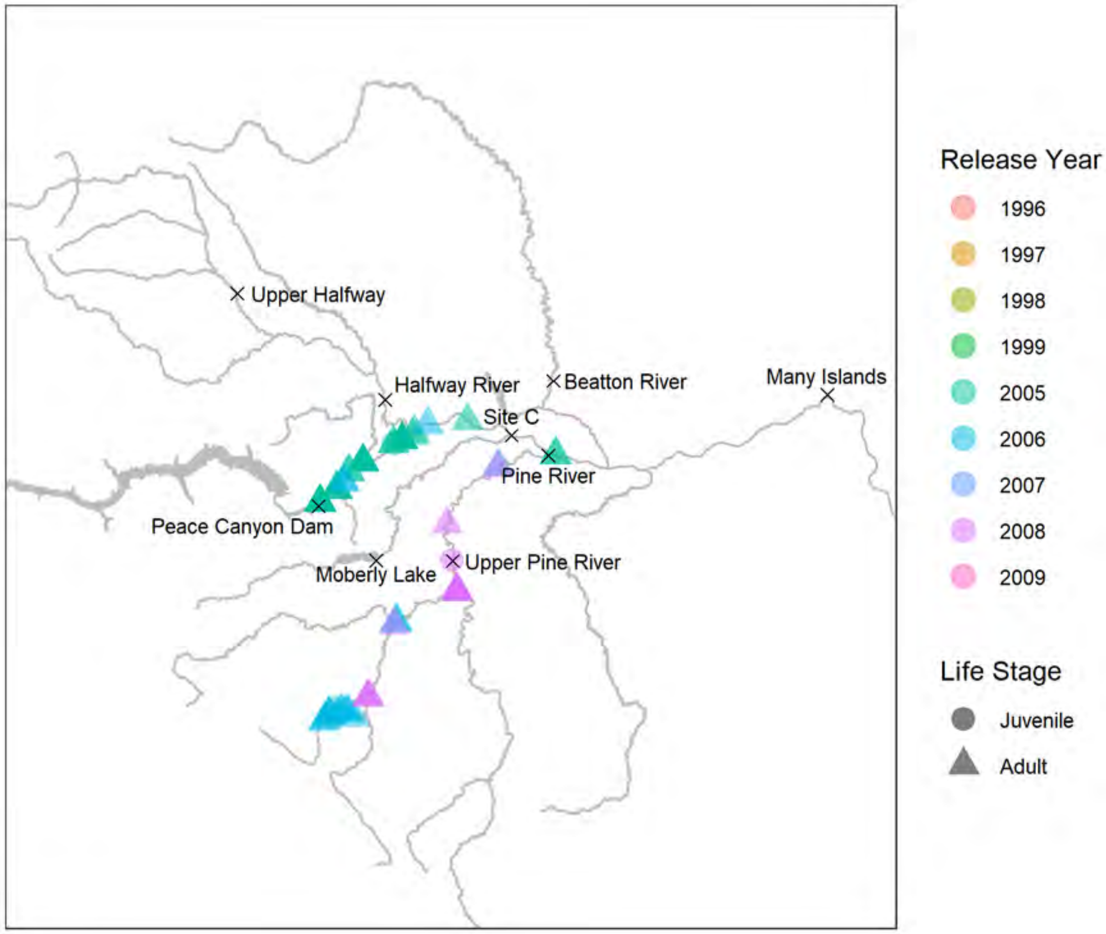


Figure A9. **Rainbow Trout release locations and points of reference (×) from the historical dataset (1996 to 1998 and 2005 to 2008). Juvenile fish are depicted as circles, adults depicted as triangles. Point colours indicate year of release.**

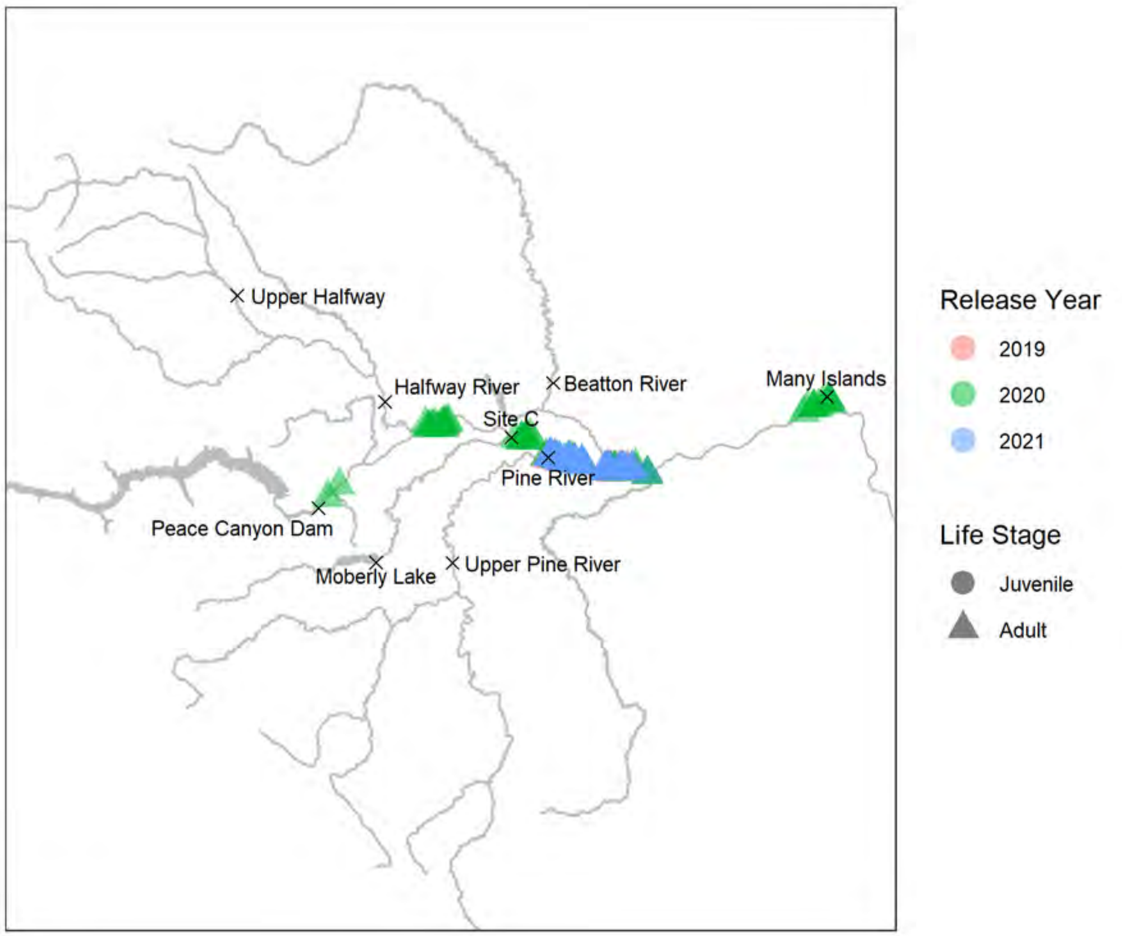


Figure A10. Walleye release locations and points of reference (×) from the present dataset (2019 to 2021). Juvenile fish are depicted as circles, adults depicted as triangles. Point colours indicate year of release.

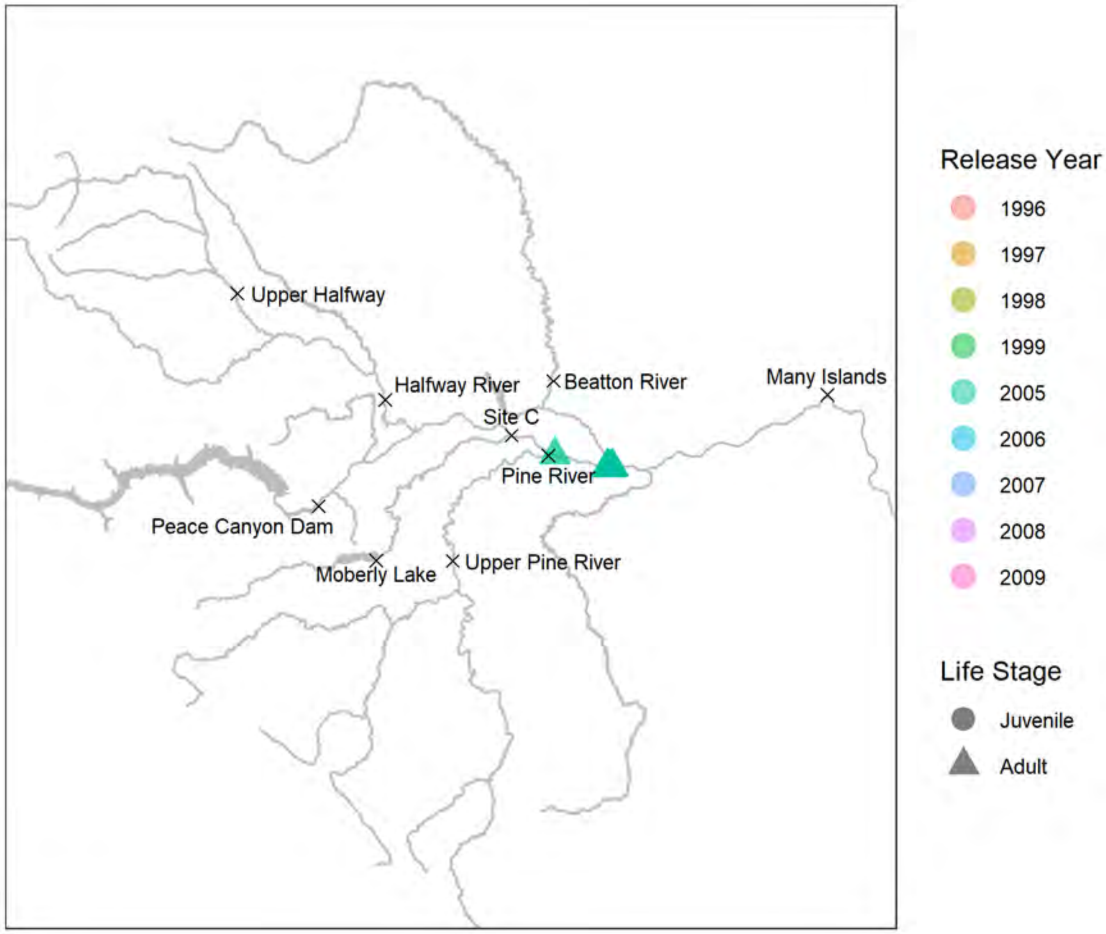


Figure A11. Walleye release locations and points of reference (×) from the historical dataset (1996 to 1998 and 2005 to 2008). Juvenile fish are depicted as circles, adults depicted as triangles. Point colours indicate year of release.

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

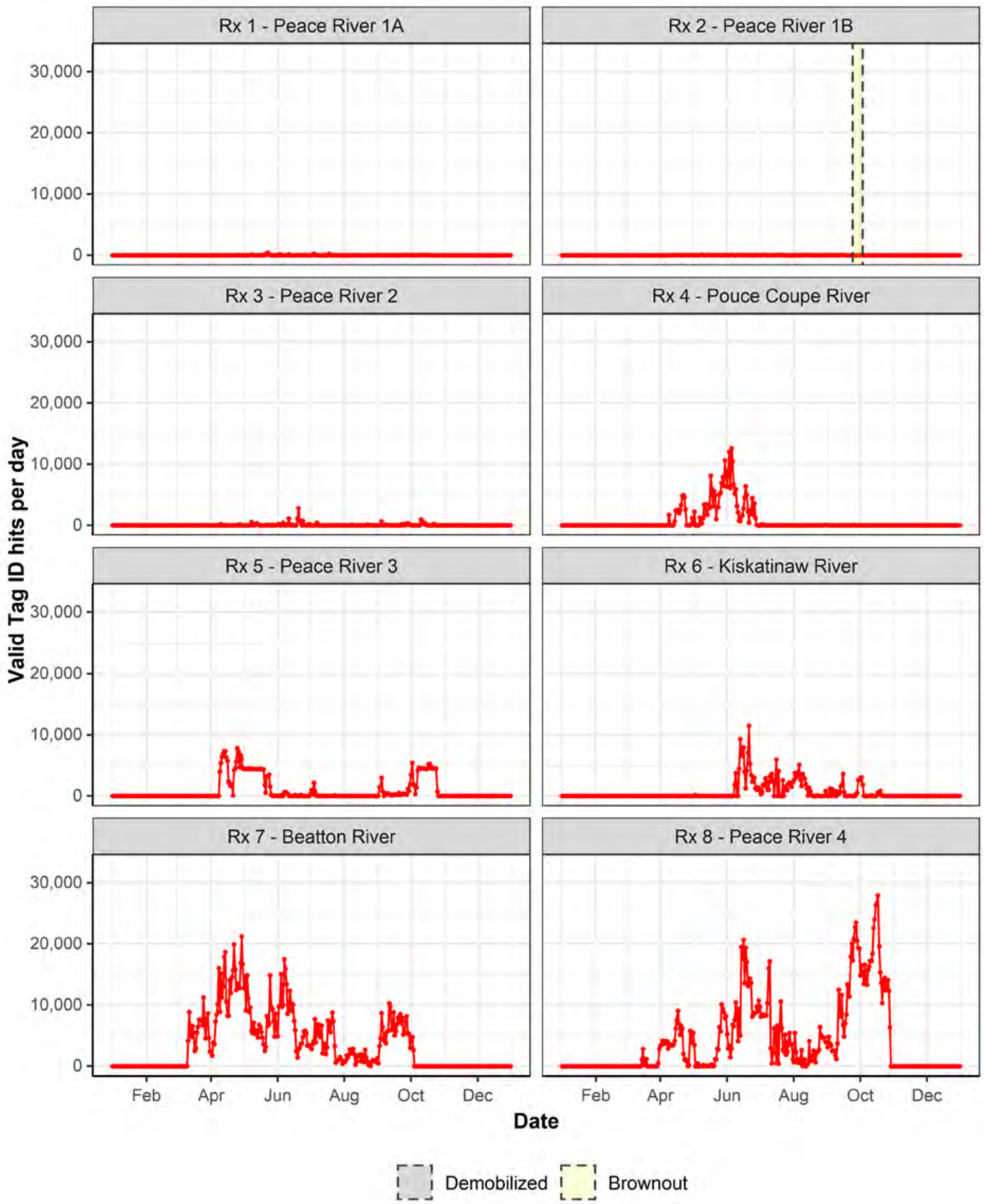


Figure B1. **Validated detection signals by station organized into hits per day in 2021. The spaces highlighted with a yellow or gray rectangle signify periods in which receiver outages had occurred and data collection did not proceed. The figure continues on the five next pages.**

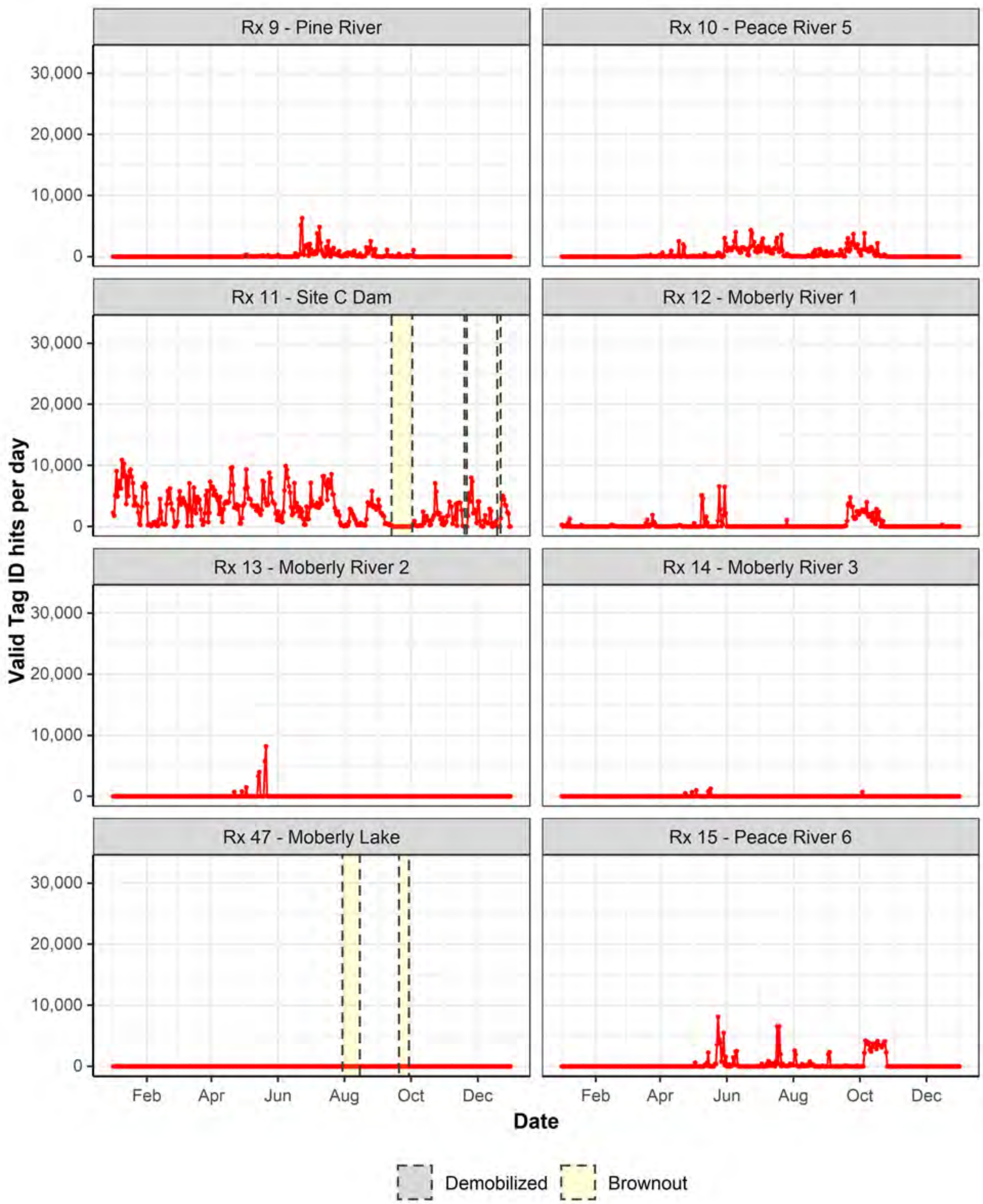
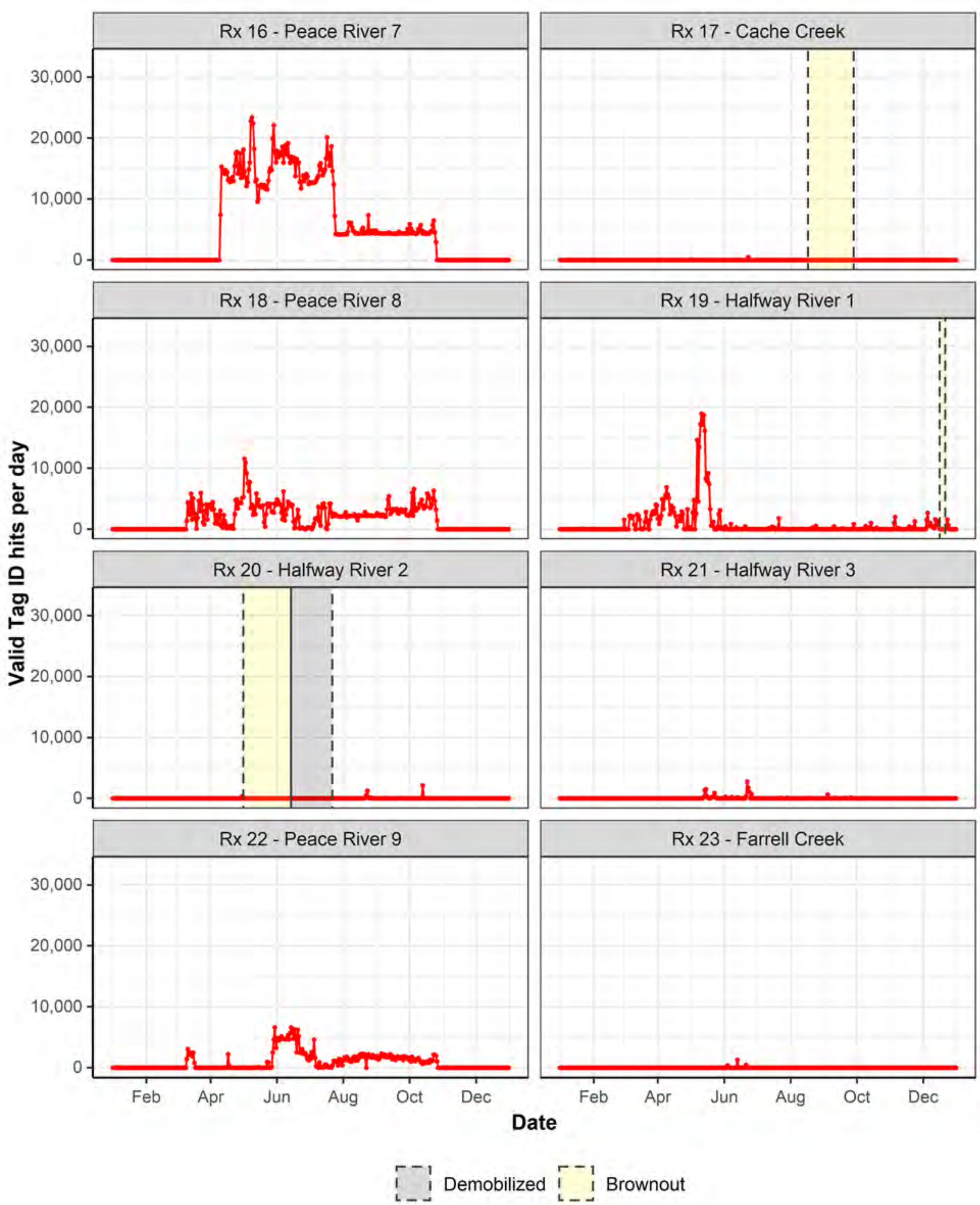


Figure B1 continued (part 2 of 6).



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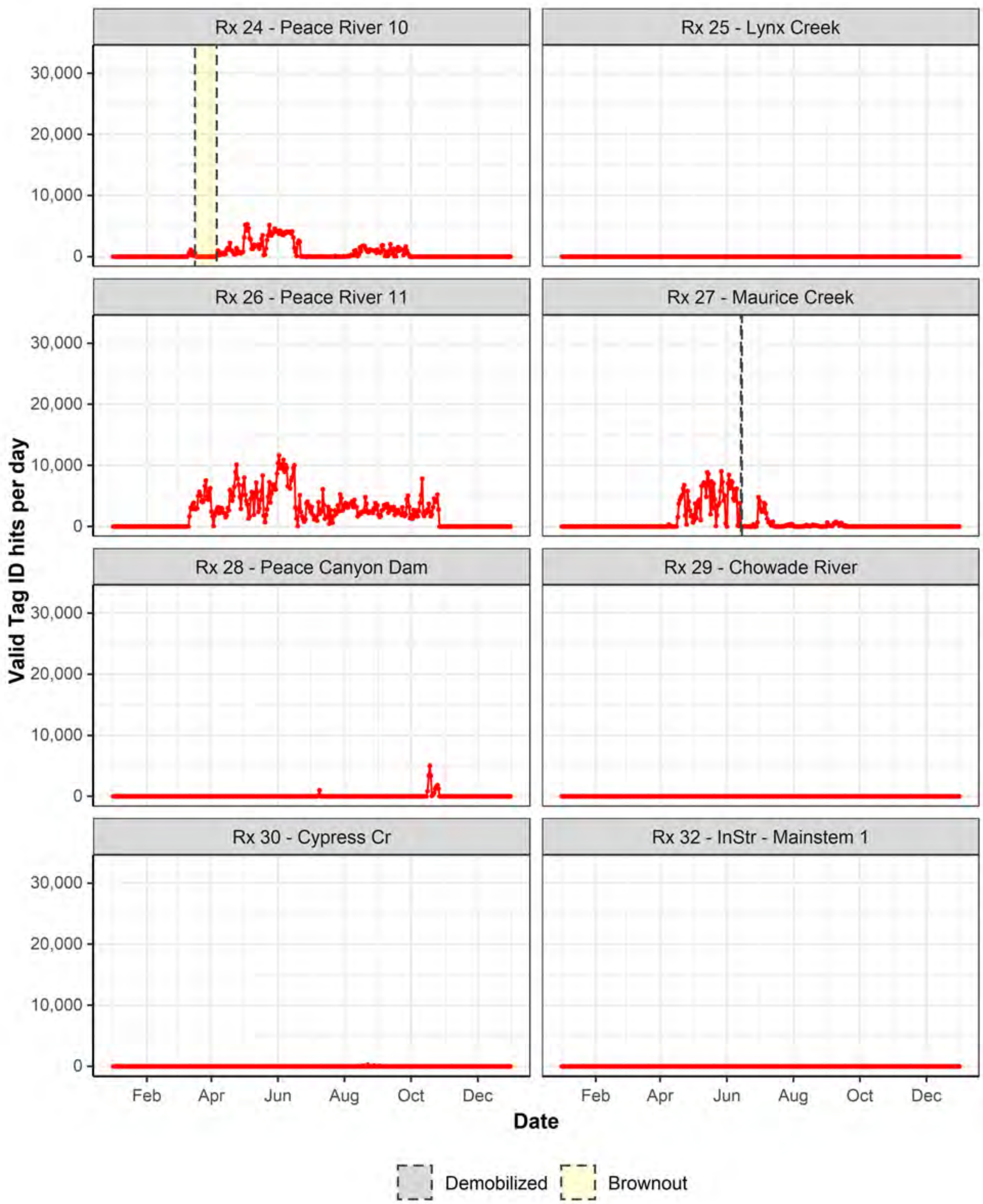

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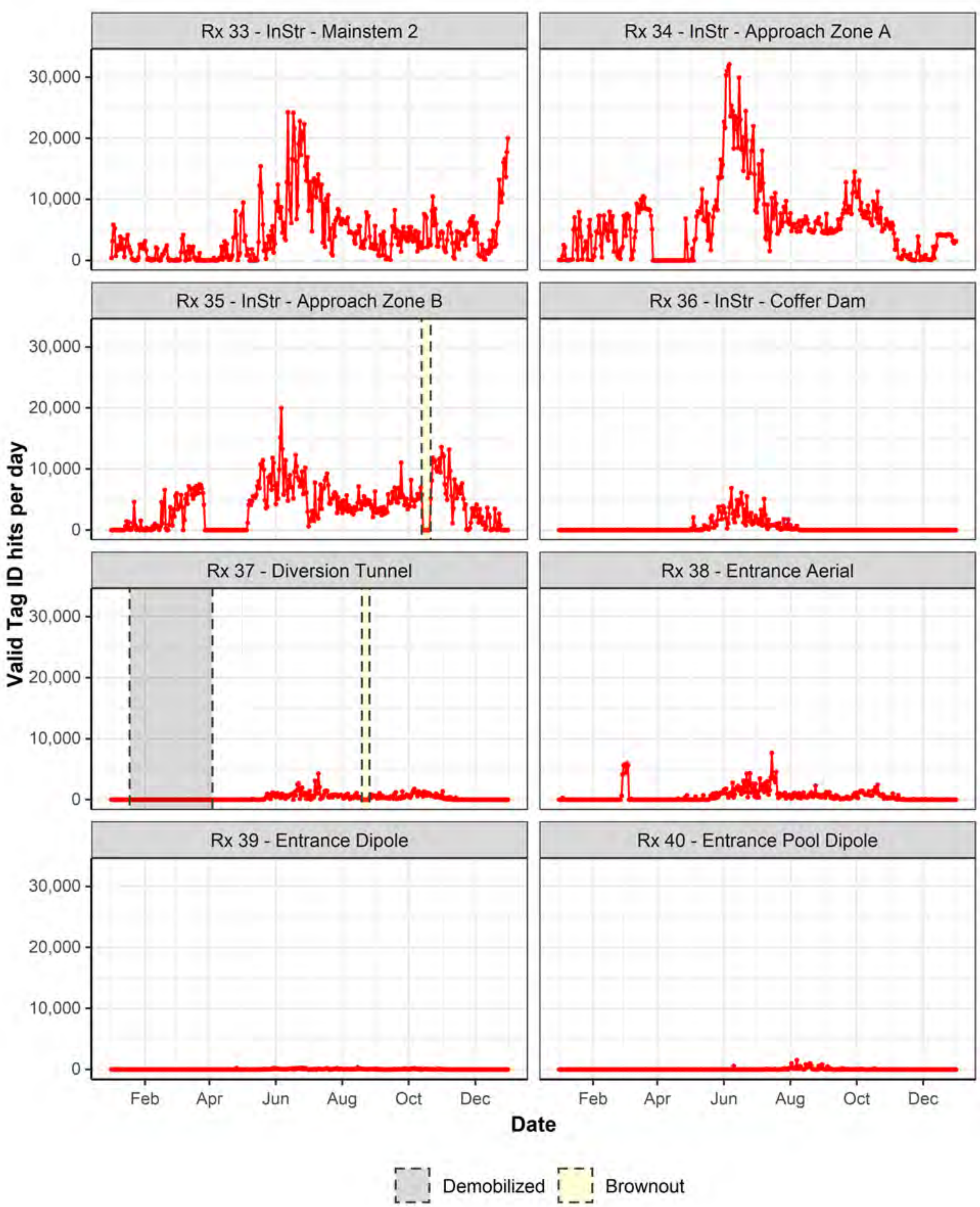

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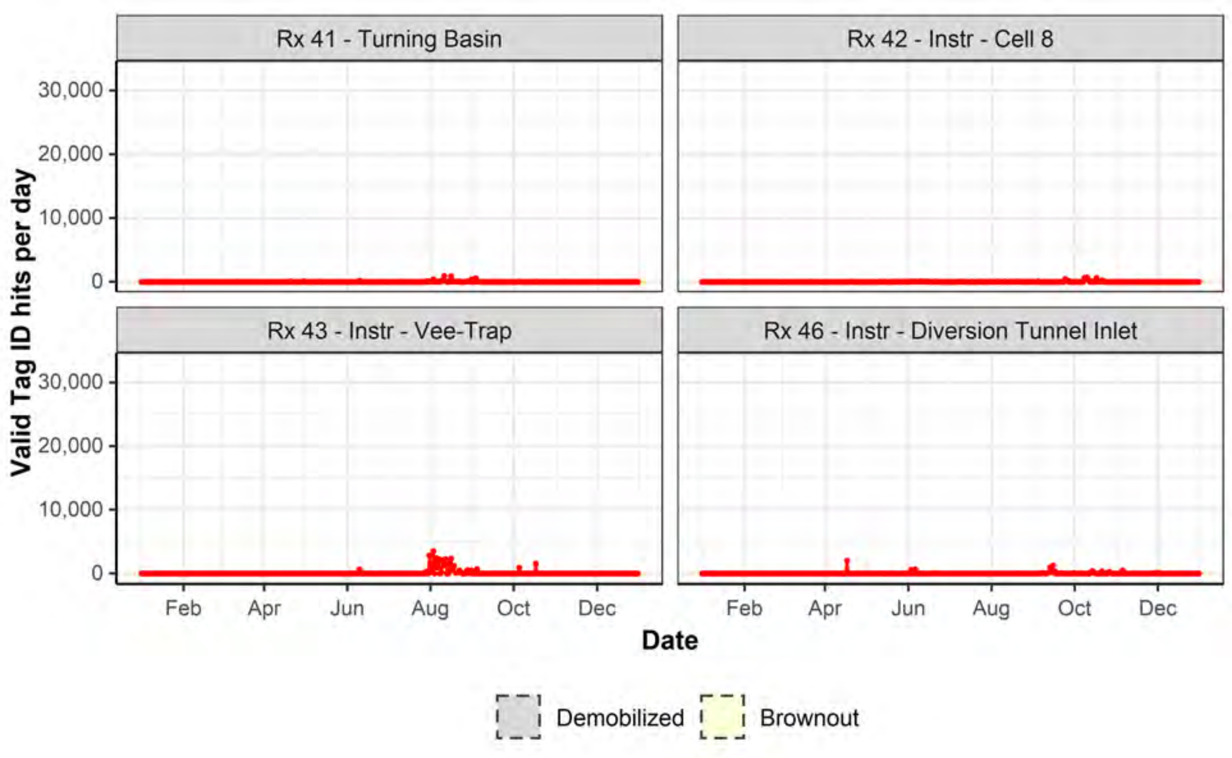

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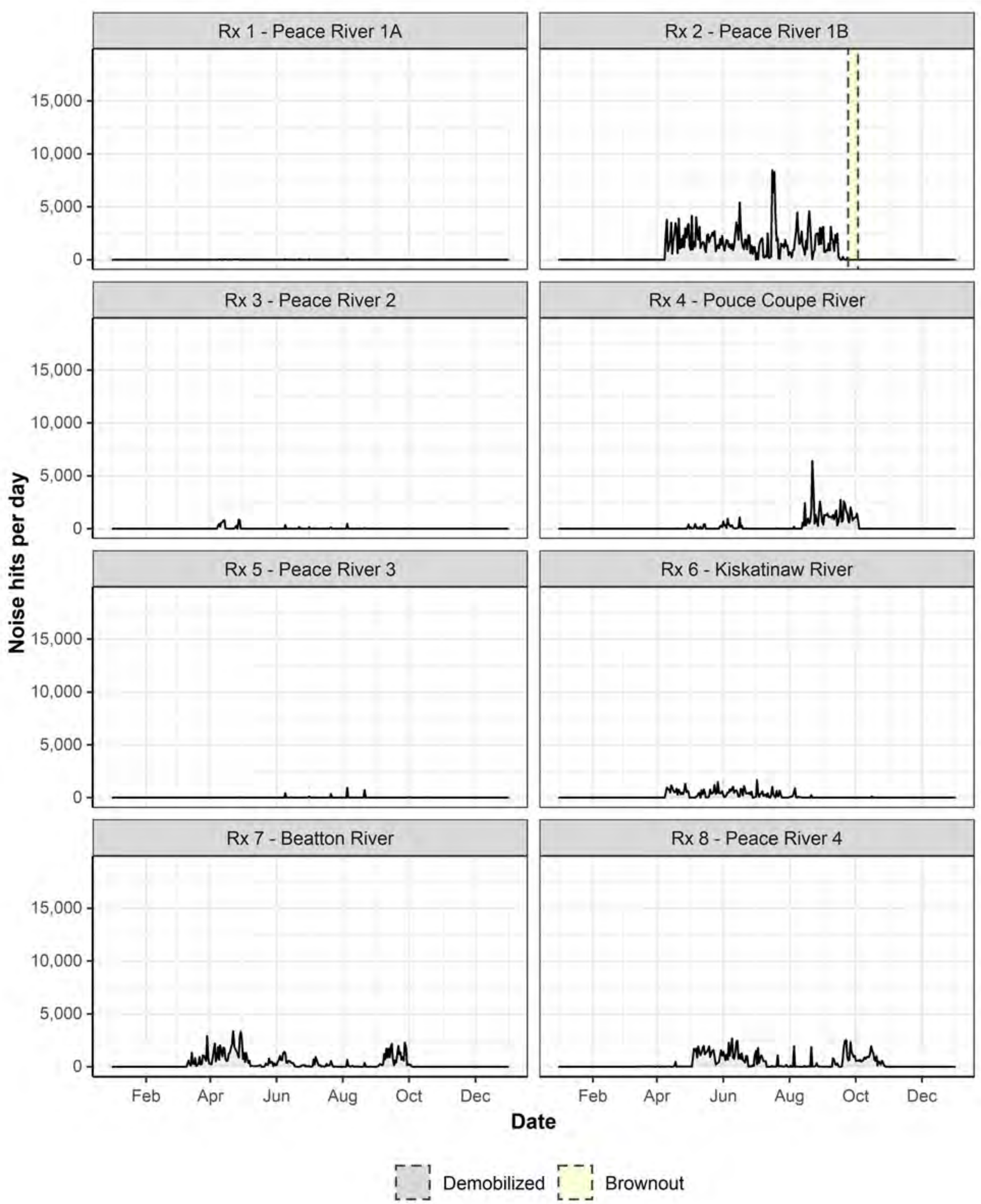
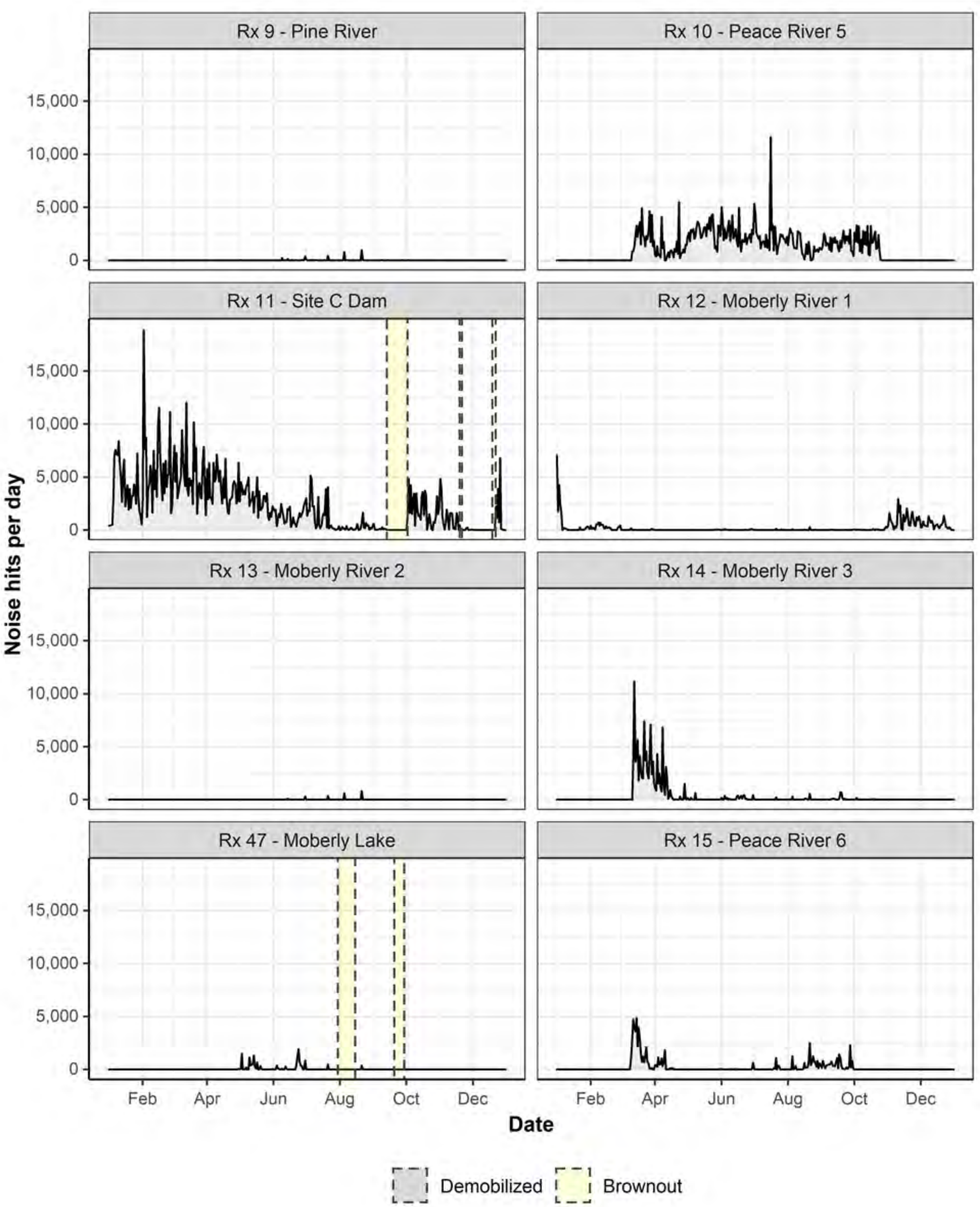


Figure B2. **Noise (Code 999) signals by station organized into hits per day in 2021. The spaces highlighted with a yellow or gray rectangle signify periods in which receiver outages had occurred and data collection did not proceed. The figure continues on the five next pages.**



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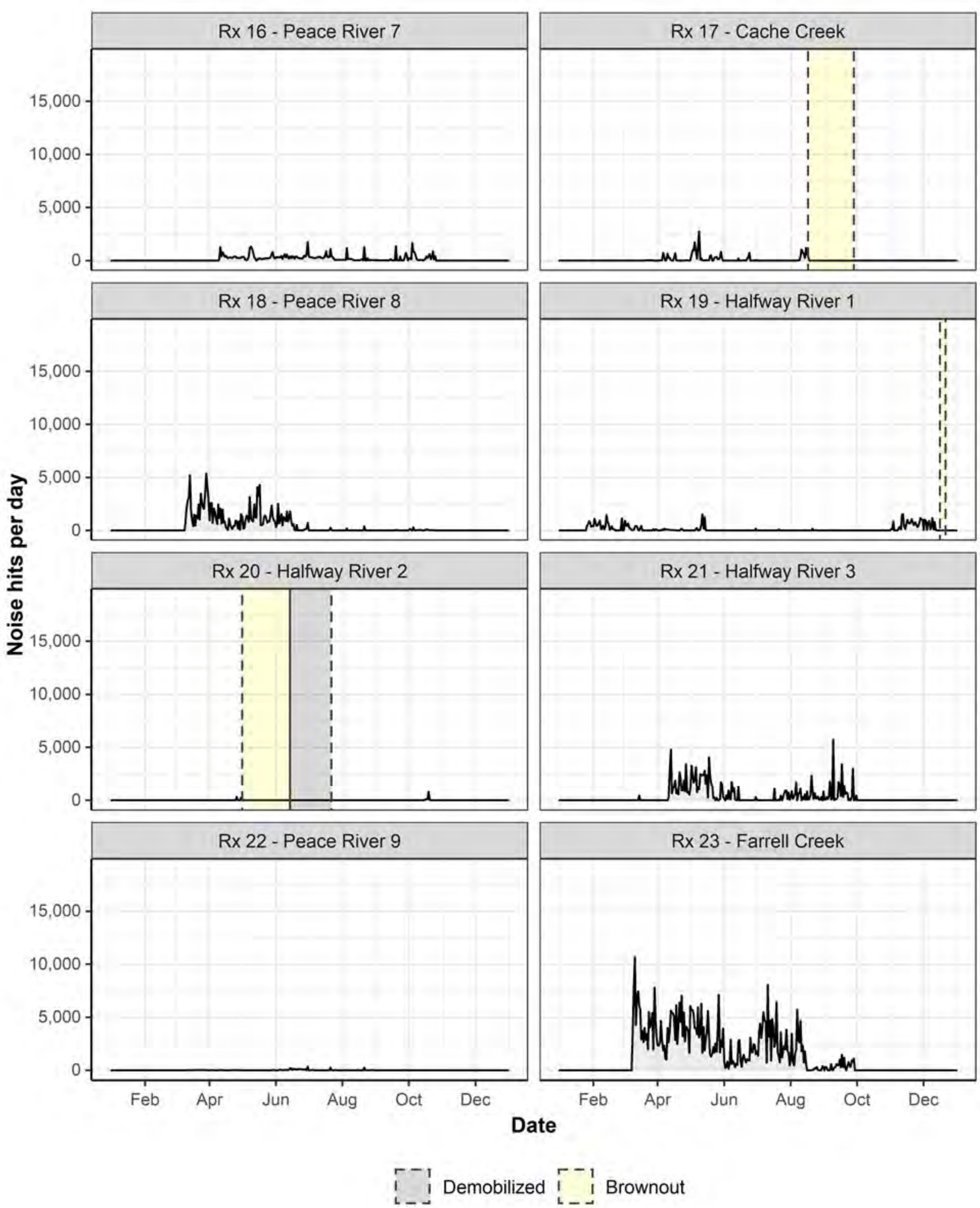

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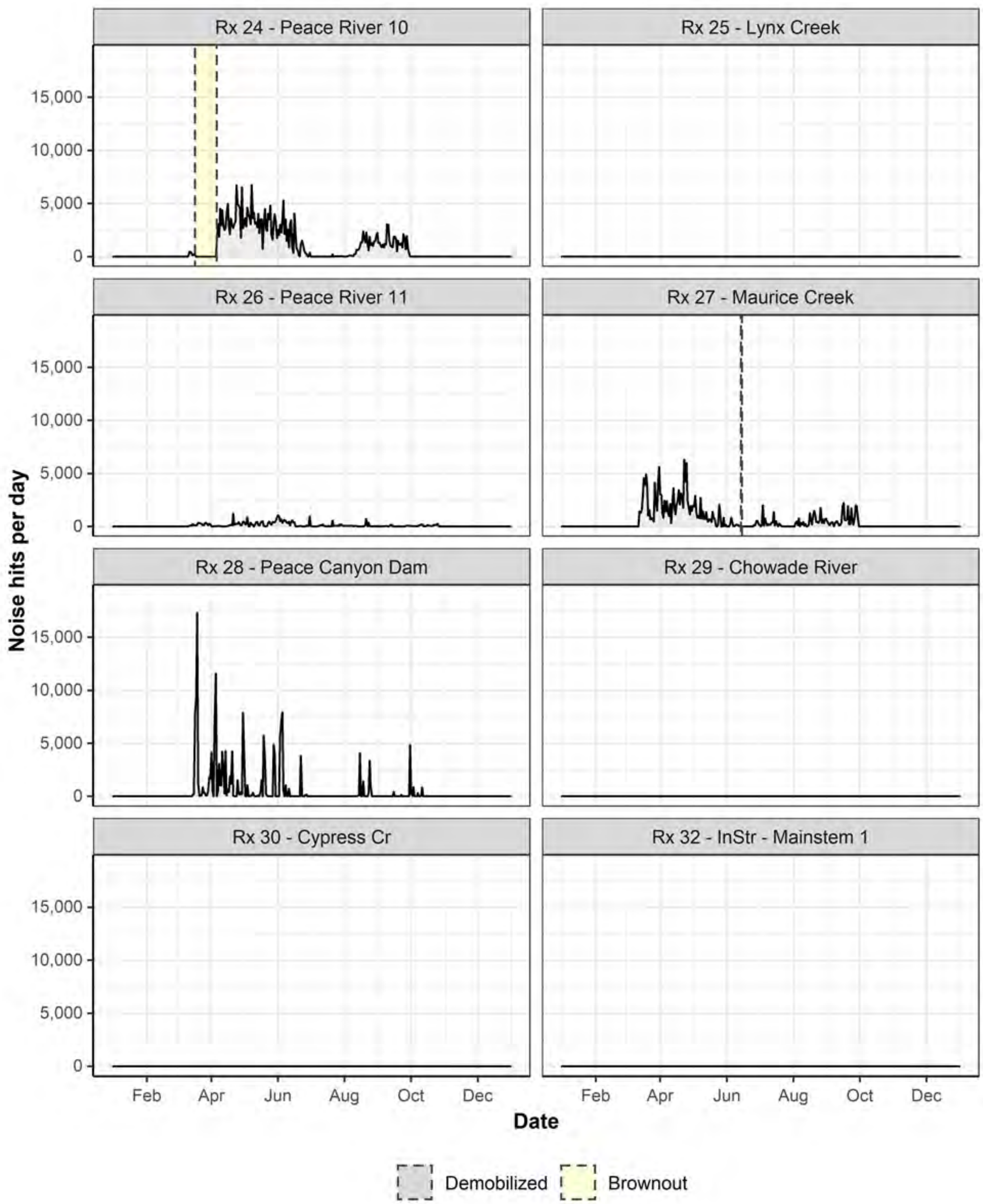

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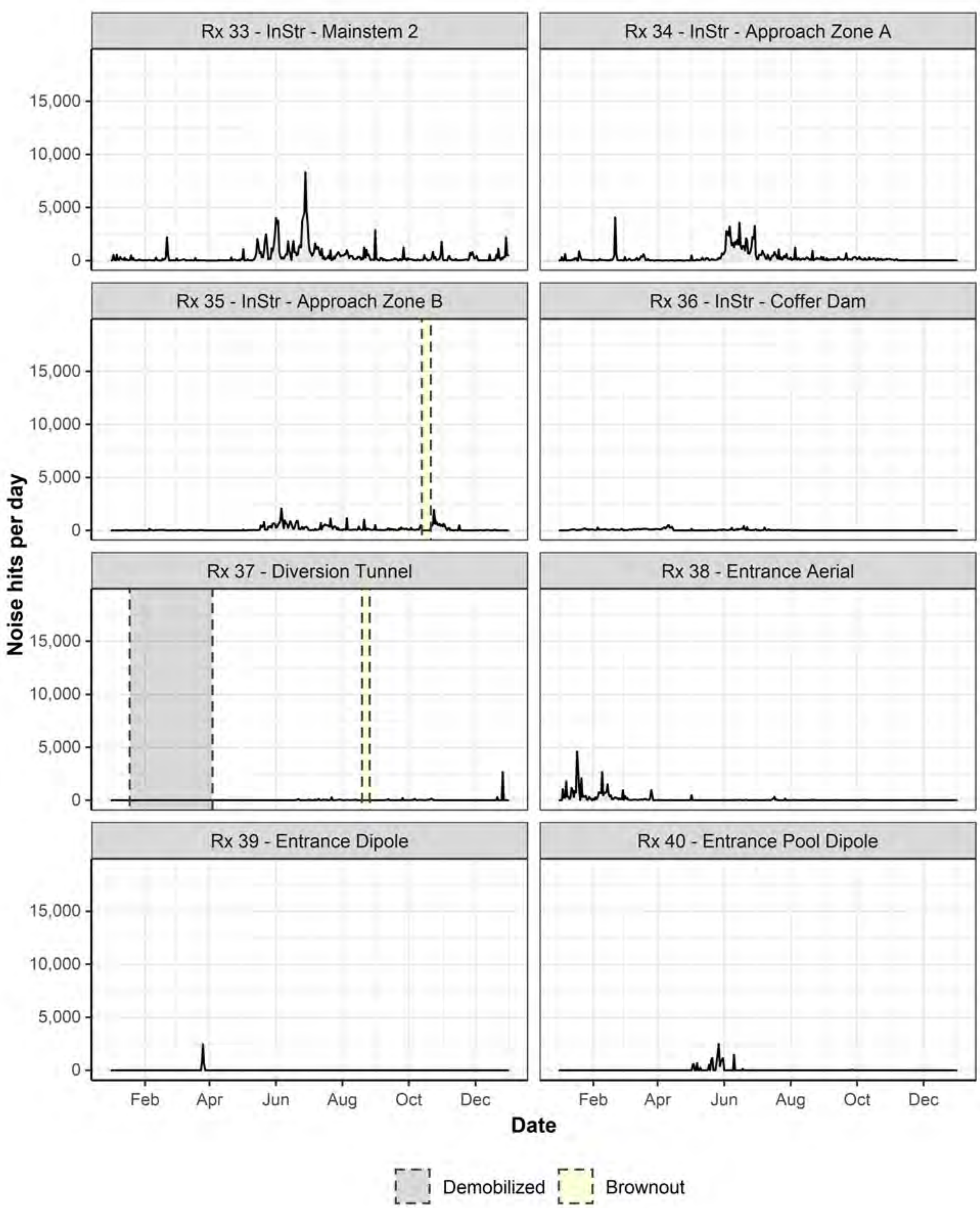
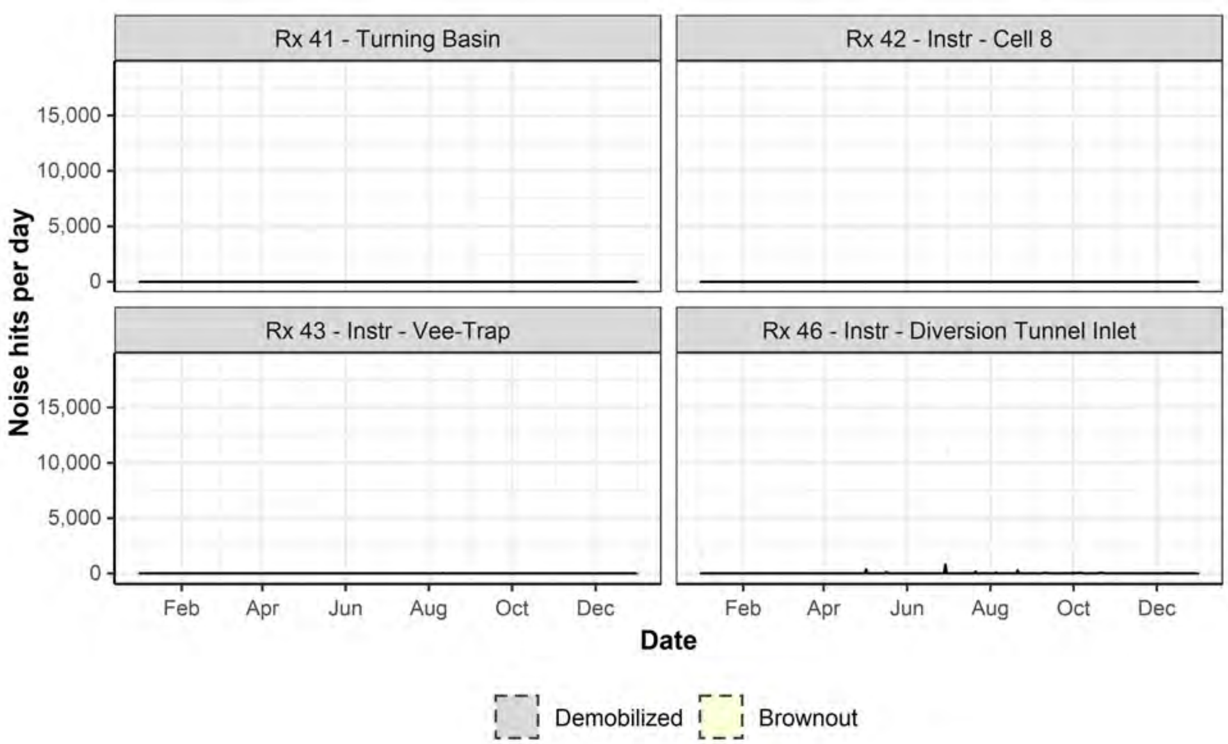


Figure B2 continued (part 5 of 6).



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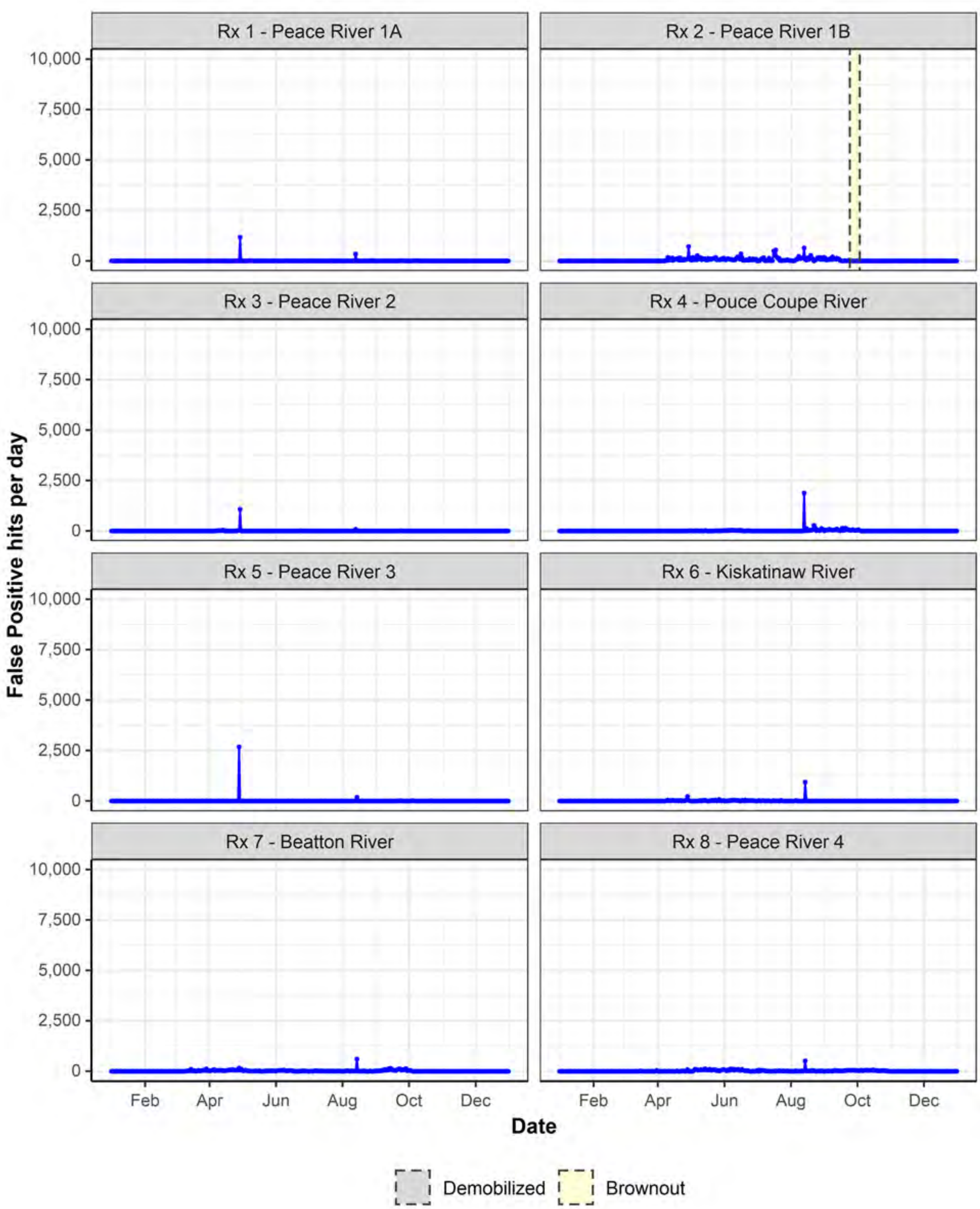
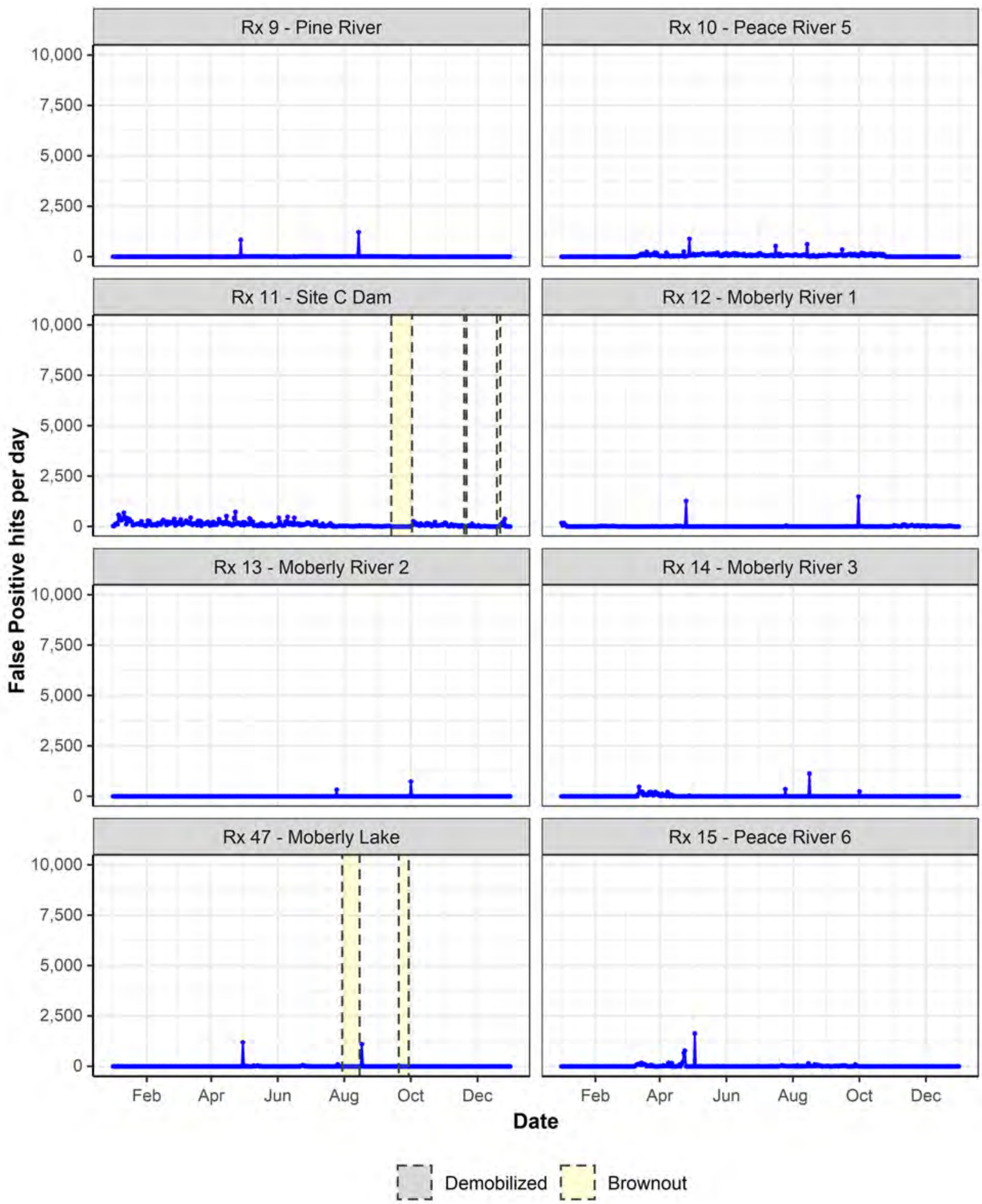


Figure B3. **False positive signals by station organized into hits per day in 2021. The spaces highlighted with a yellow or gray rectangle signify periods in which receiver outages had occurred and data collection did not proceed. The figure continues on the five next pages.**



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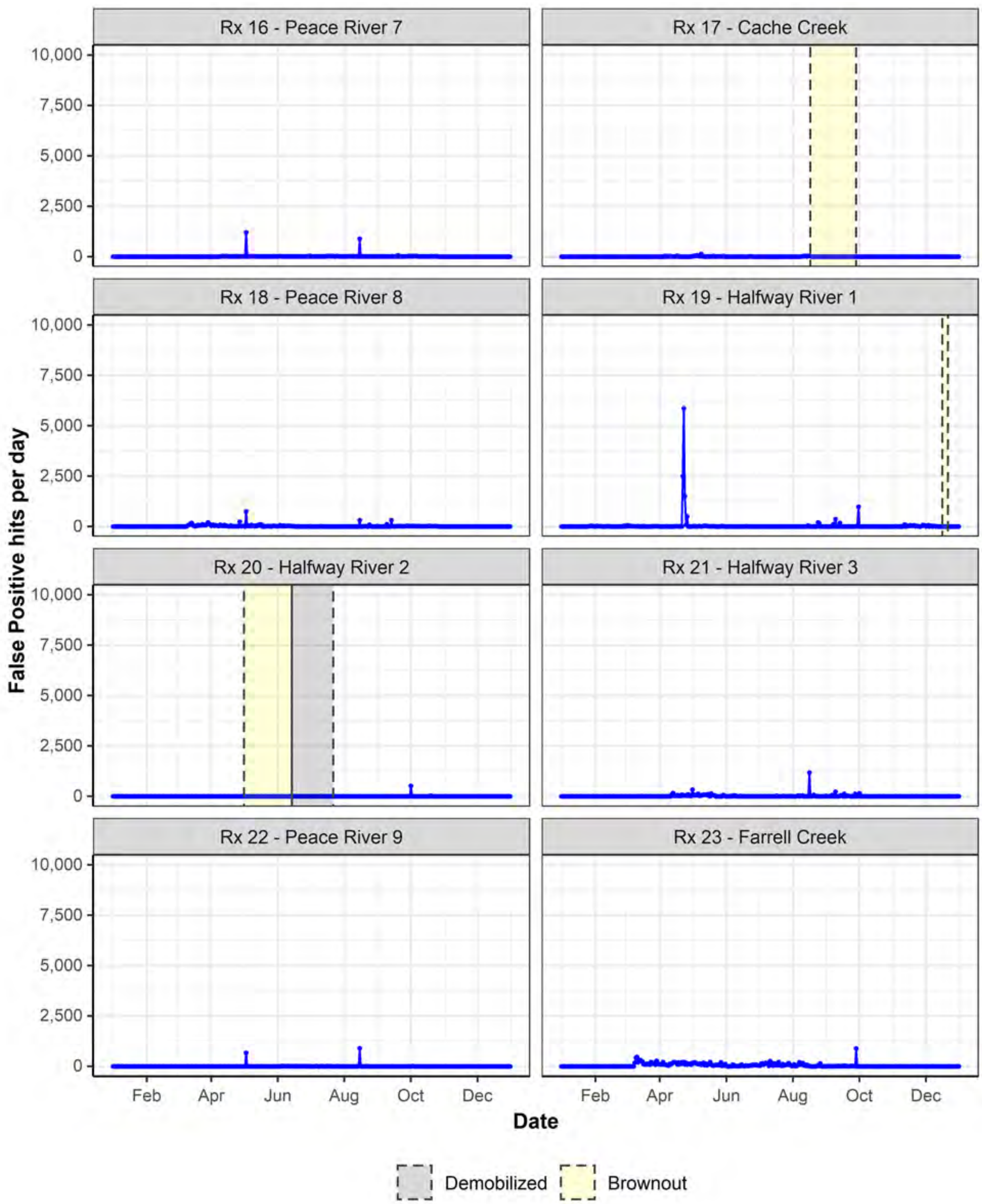

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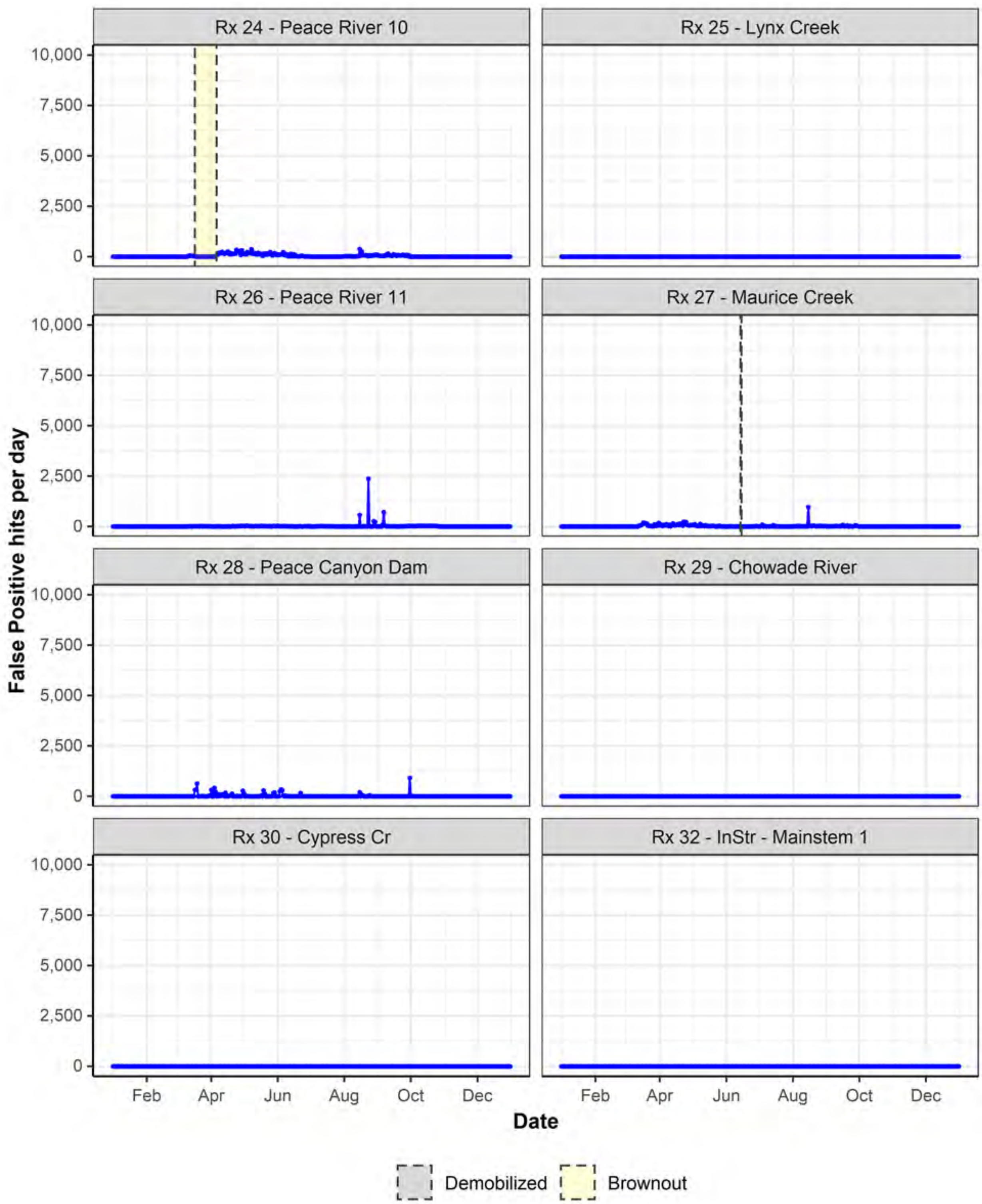

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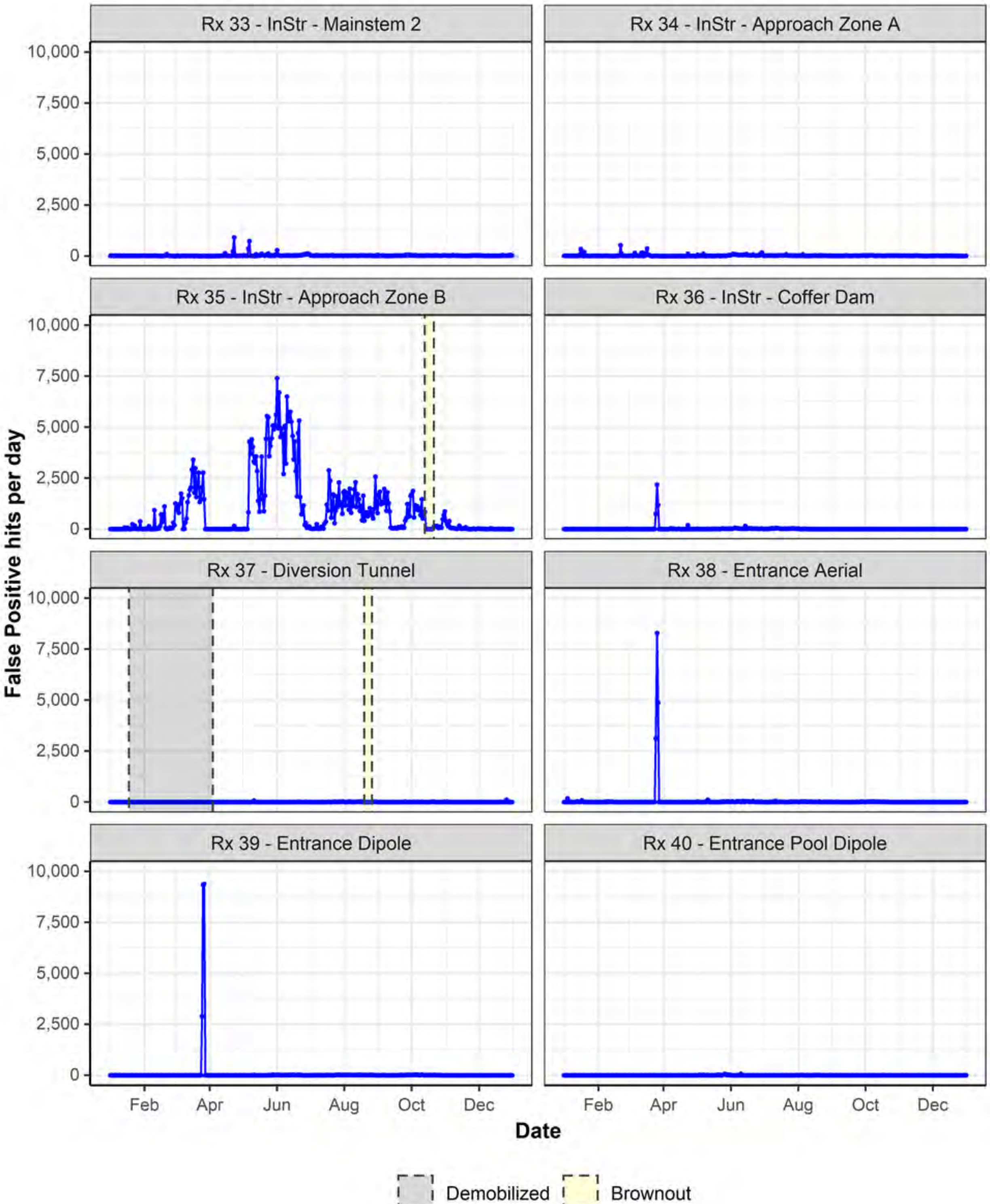

Figure B3 continued (part 5 of 6).

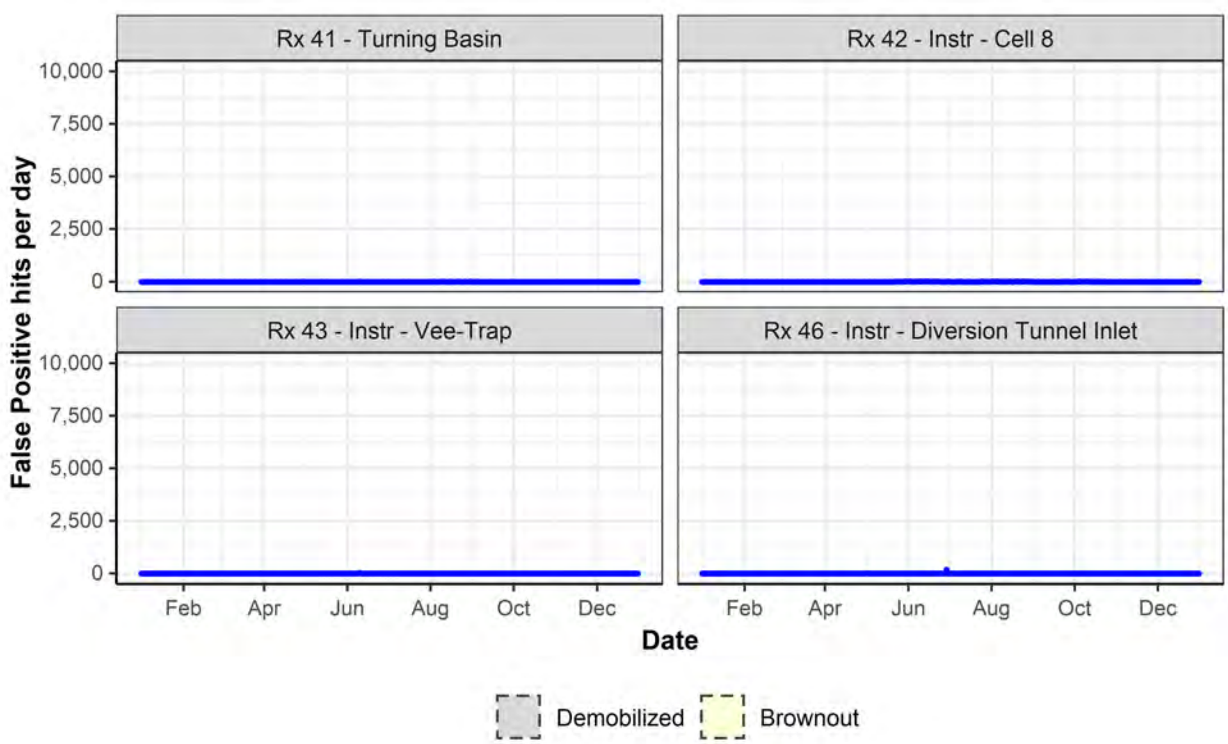

Figure B3 continued (part 6 of 6).

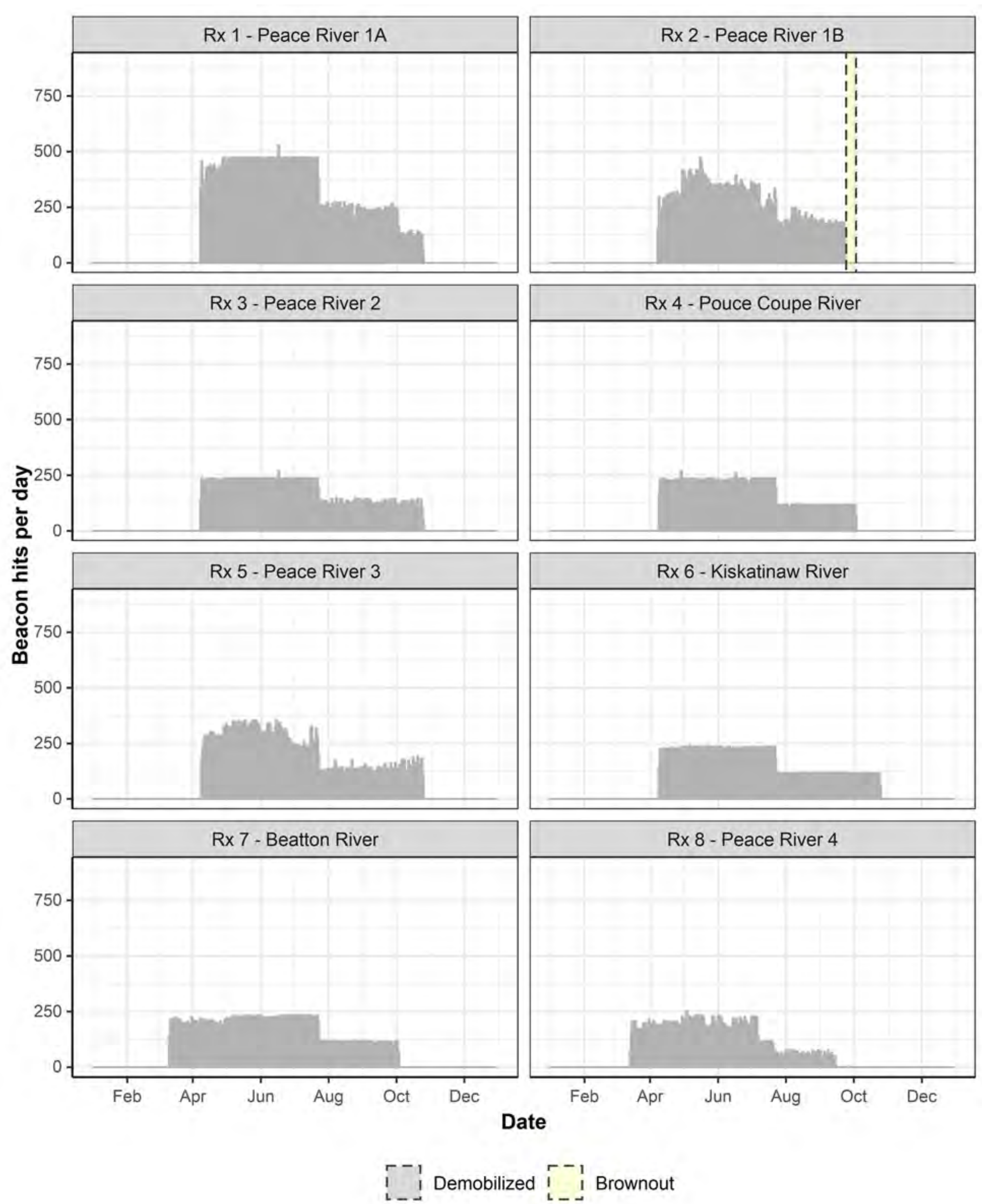

Figure B4. Beacon tag signals by station organized into hits per day in 2021. The spaces highlighted with a yellow or gray rectangle signify periods in which receiver outages had occurred and data collection did not proceed. The figure continues on the five next pages.

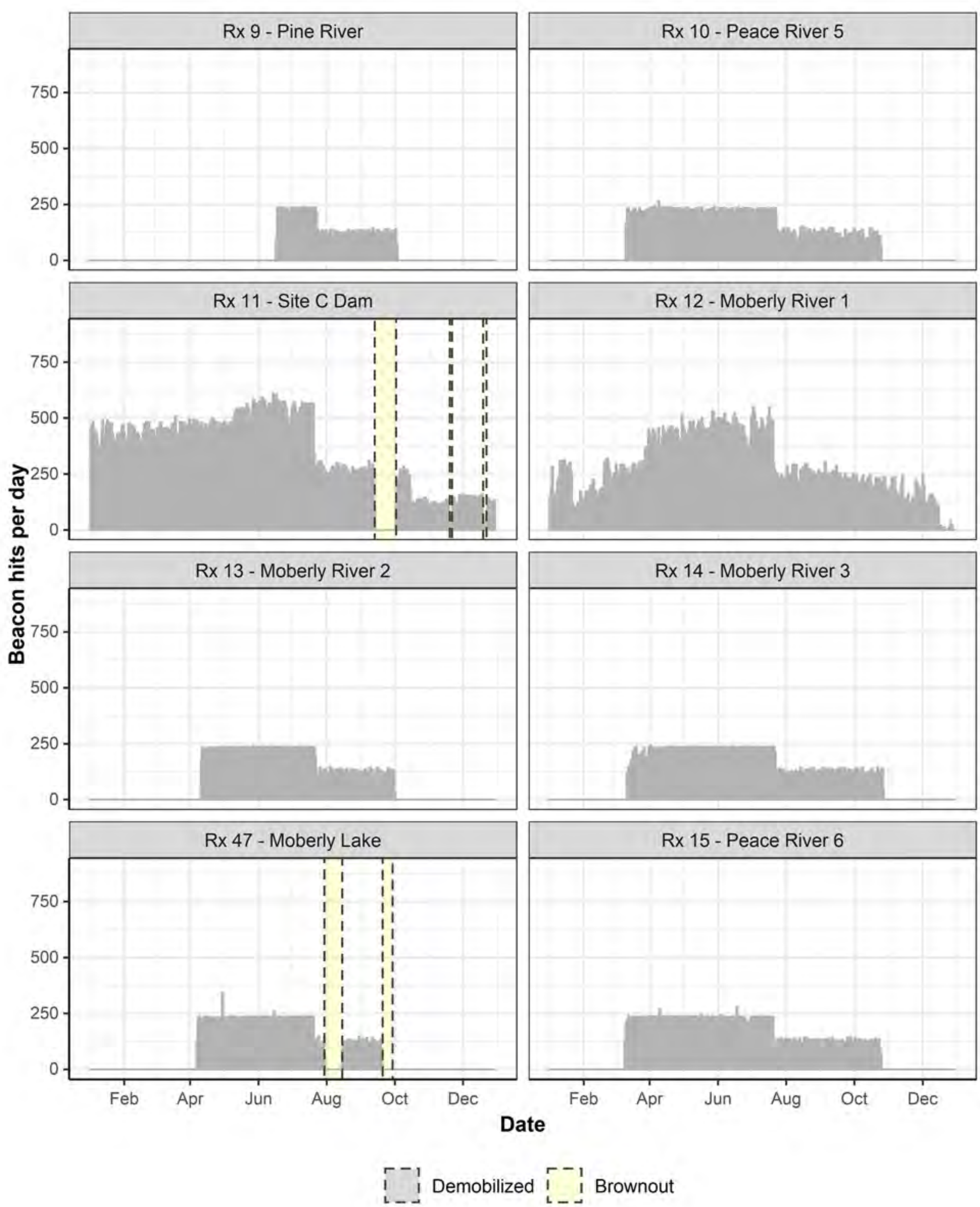

Figure B4 continued (part 2 of 6).

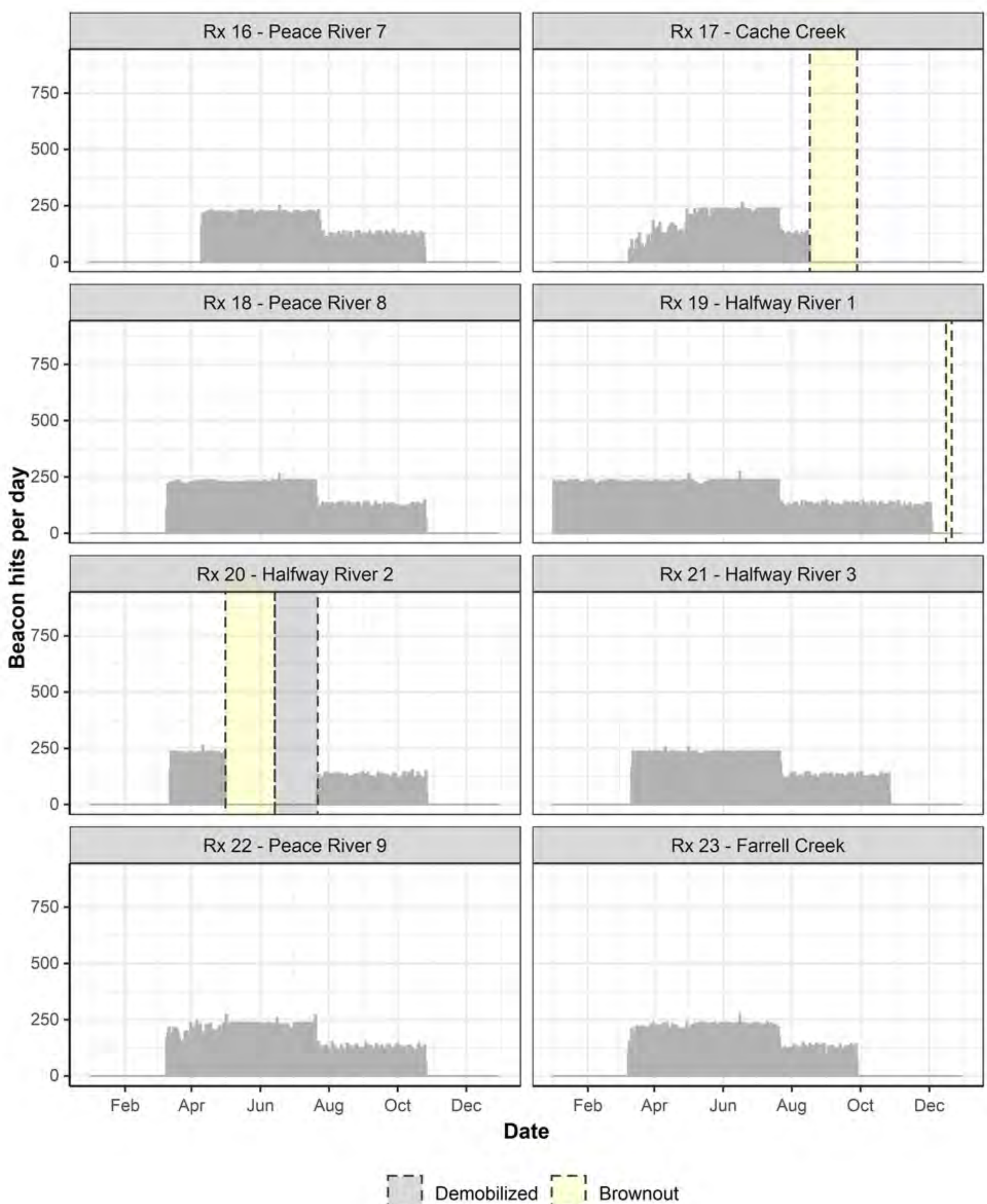

Figure B4 continued (part 3 of 6).

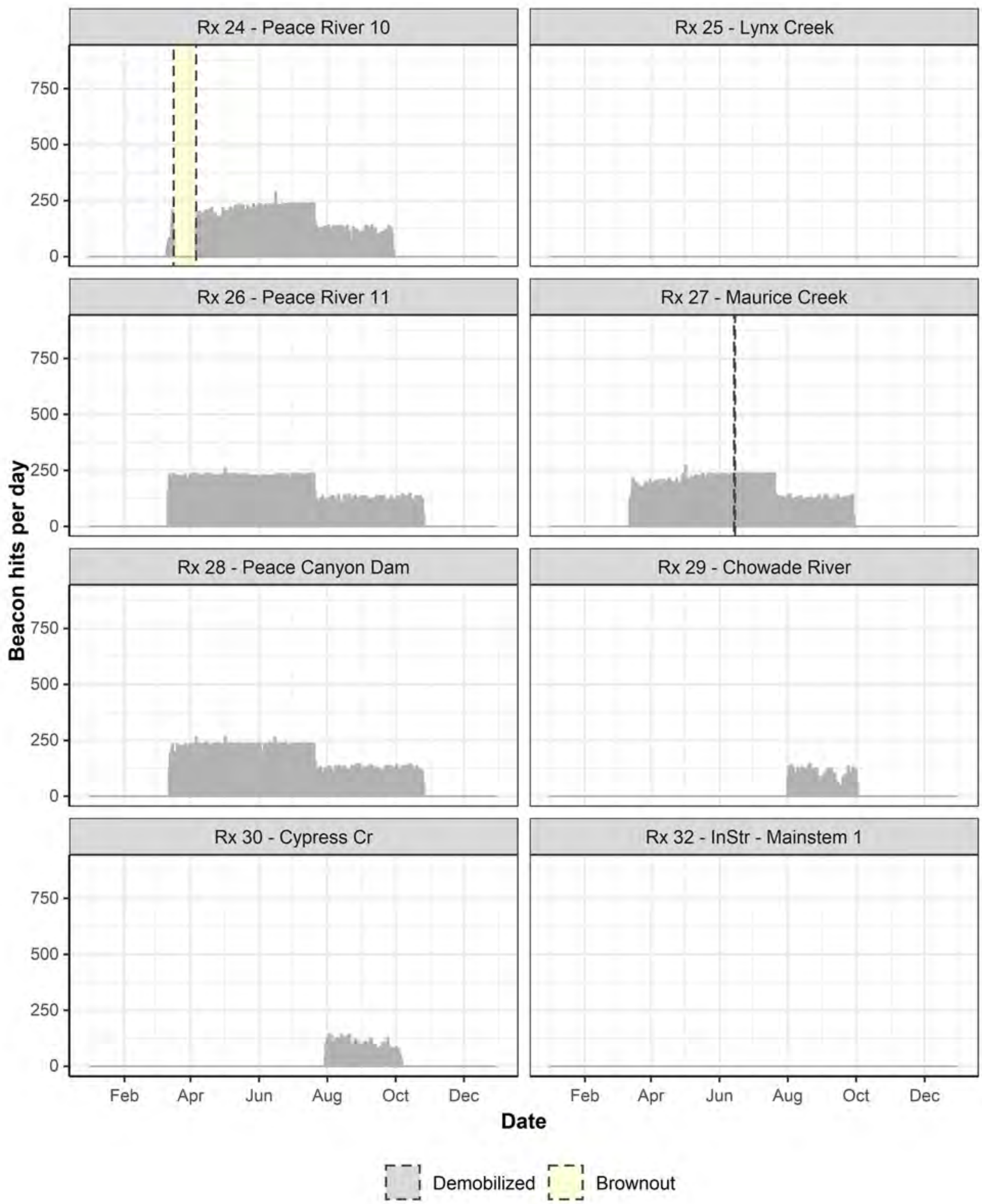

Figure B4 continued (part 4 of 6).

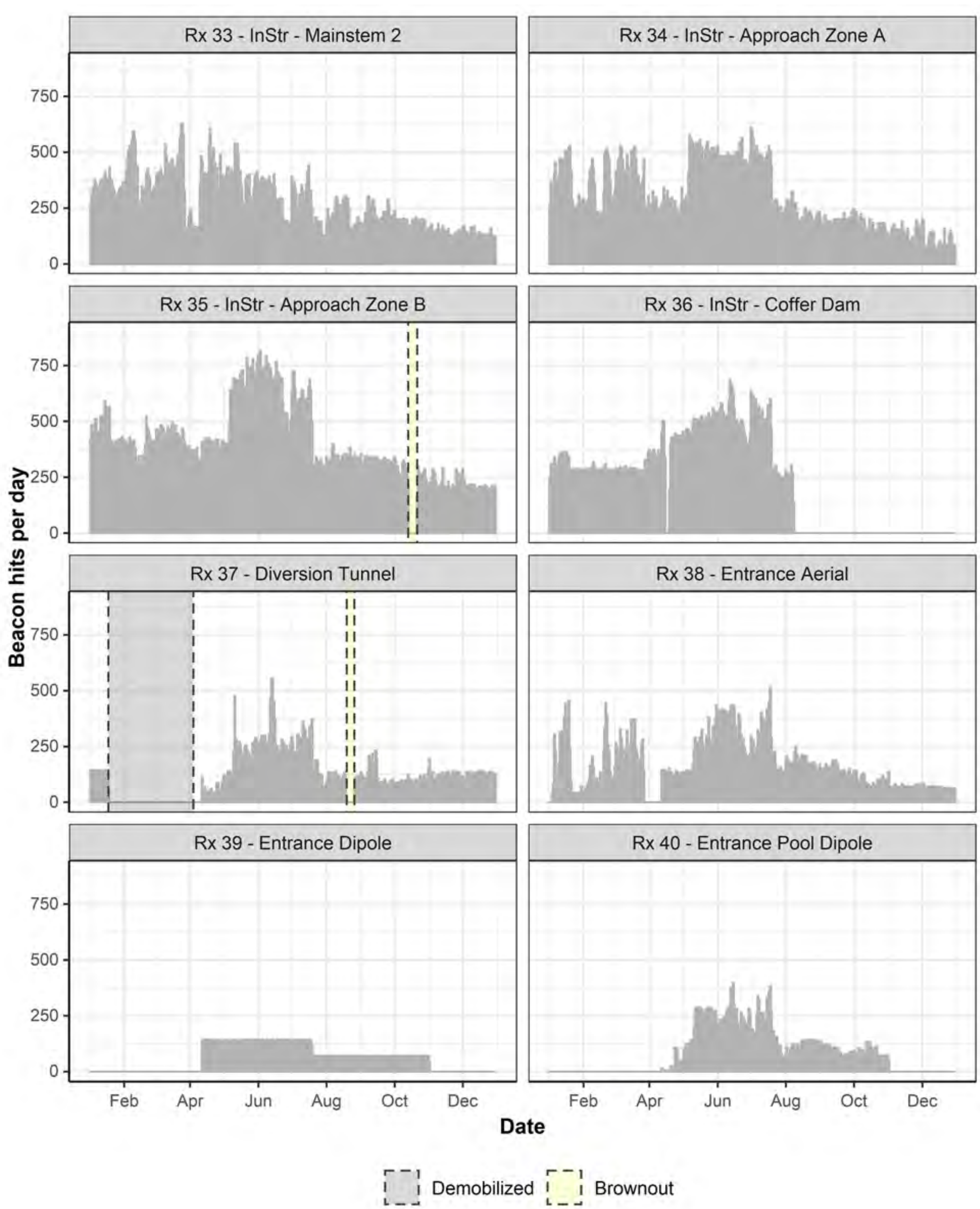

Figure B4 continued (part 5 of 6).

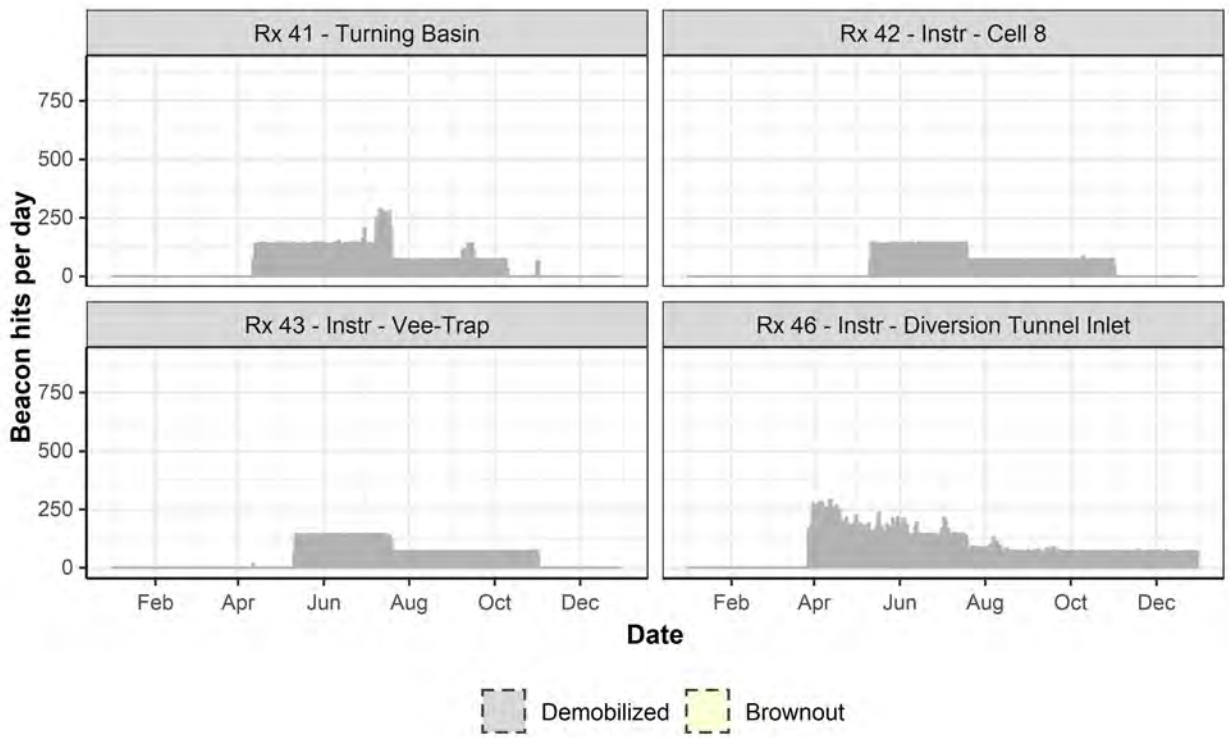

Figure B4 continued (part 6 of 6).

Appendix C. Site C Telemetry Database

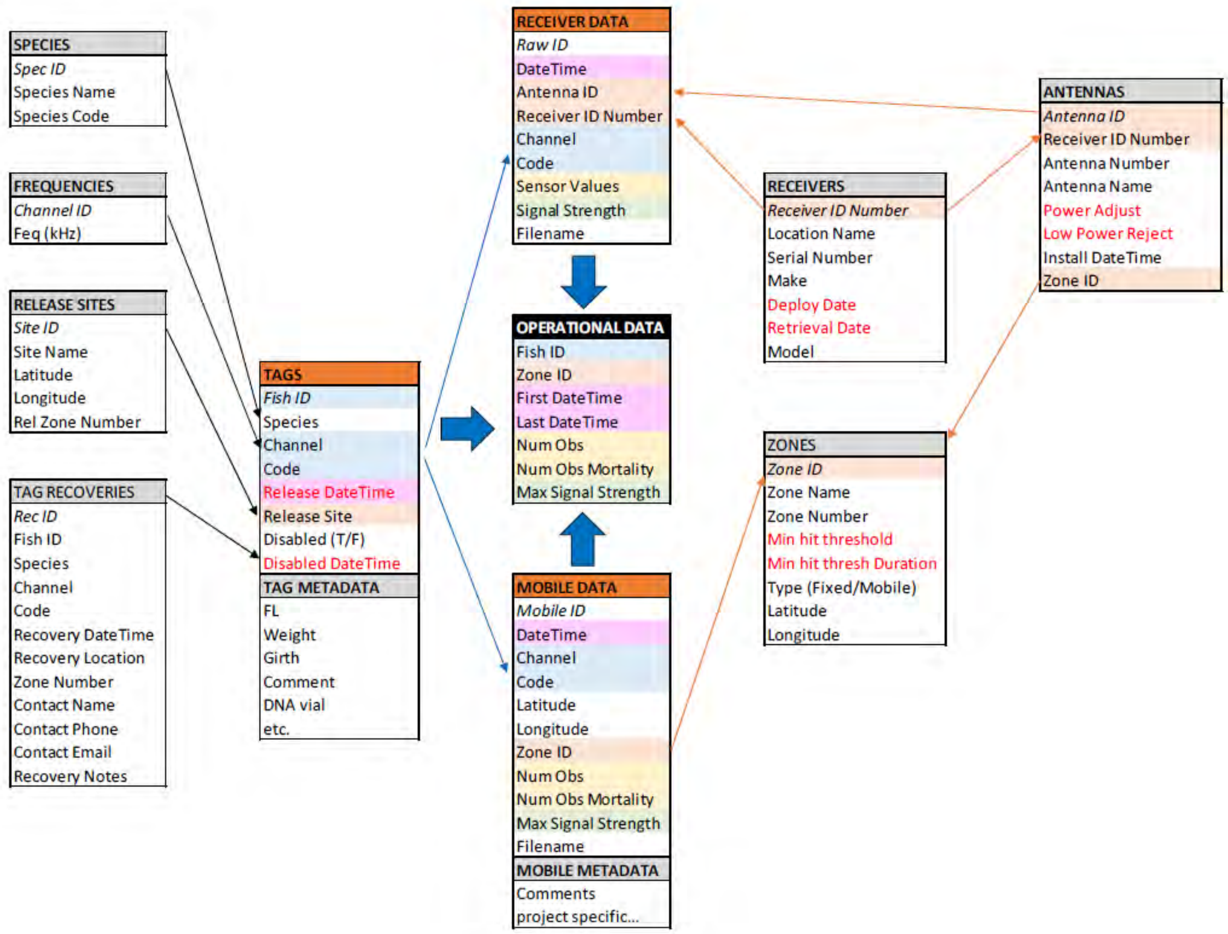

Figure C1. **Visual representation of the database, displaying how each of the tables relate to each other.**

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 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
22-Feb-21	23-Feb-21	BC Hydro	Nich Burnett	nich.burnett@bchydro.com	David Robichaud	drobichaud@lgl.com	Processed (filtered) complete detection history data for Tag 419
19-Jul-21	20-Jul-21	BC Hydro	Nich Burnett	nich.burnett@bchydro.com	David Robichaud	drobichaud@lgl.com	Summary showing when radio tagged MW moved upstream past the dam site in the historic data set
28-Oct-21	28-Oct-21	Instream Fisheries	Pete Moniz	pete@instream.net	David Robichaud	drobichaud@lgl.com	Unfiltered (raw downloads) from Receiver 32
1-Aug-21	22-Dec-21	BC Hydro	Nich Burnett	nich.burnett@bchydro.com	Kyle Hatch	khatch@lgl.com	2020 Site C Fish Movement Database for BC Hydro Storage (i.e., Data Deliverables). All Database tables in .csv format, accompanying R scripts as well as table definitions and table joins for reference.
21-Jan-22	23-Jan-22	BC Hydro	Nich Burnett	nich.burnett@bchydro.com	David Robichaud	drobichaud@lgl.com	Processed (filtered) complete detection history data for Billy the Bull Trout (Tag 898)
25-Jan-22	6-Feb-22	Instream Fisheries	Pete Moniz	pete@instream.net	David Robichaud	drobichaud@lgl.com	Processed (filtered) complete detection history data for fish that were transported above the dam

Appendix D. Mobile Tracking Routes

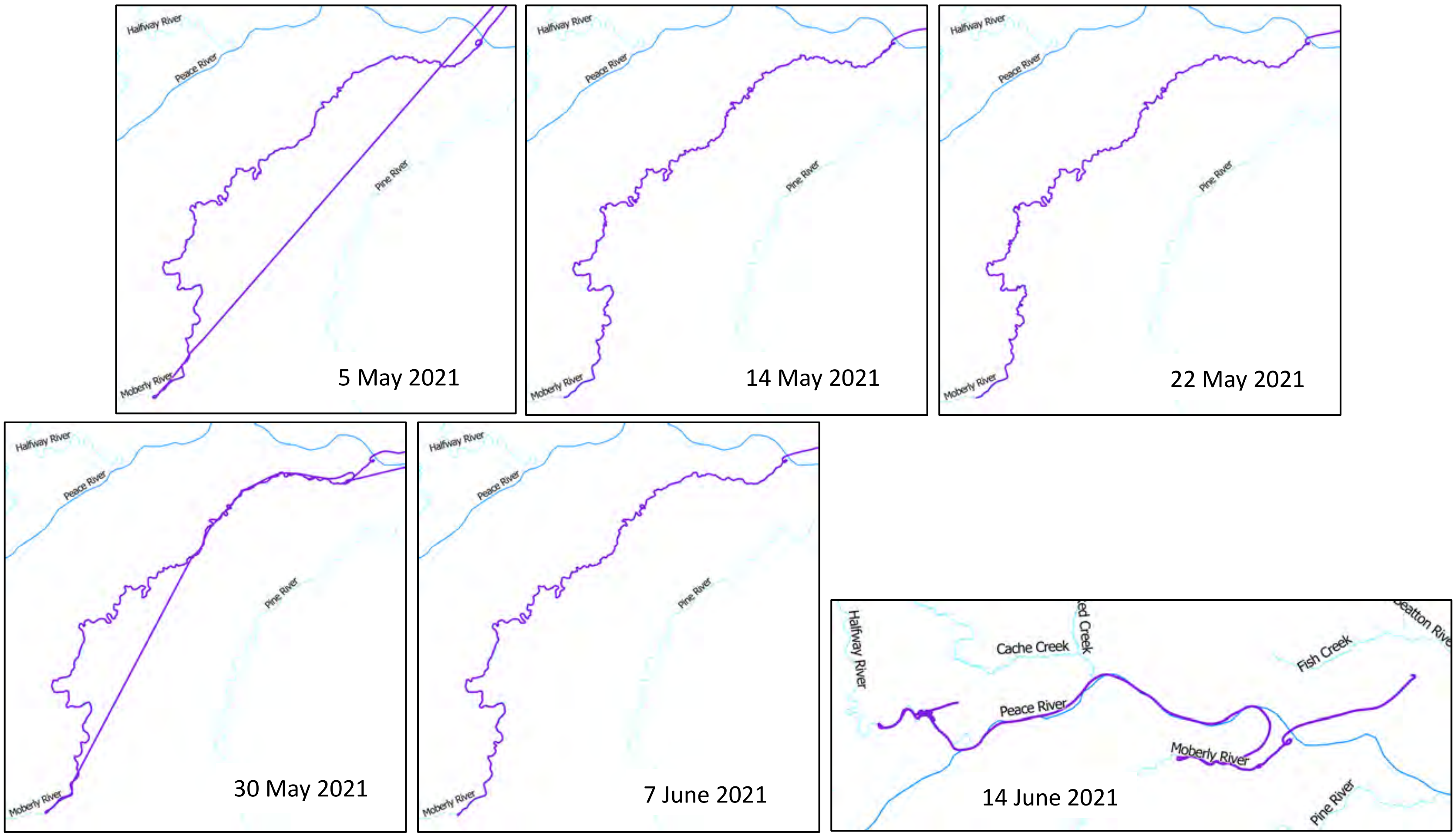

Figure D1. Tracking route (purple) for six mobile-telemetry tracking flights of the Moberly River, May-June 2021 (see Table 5).

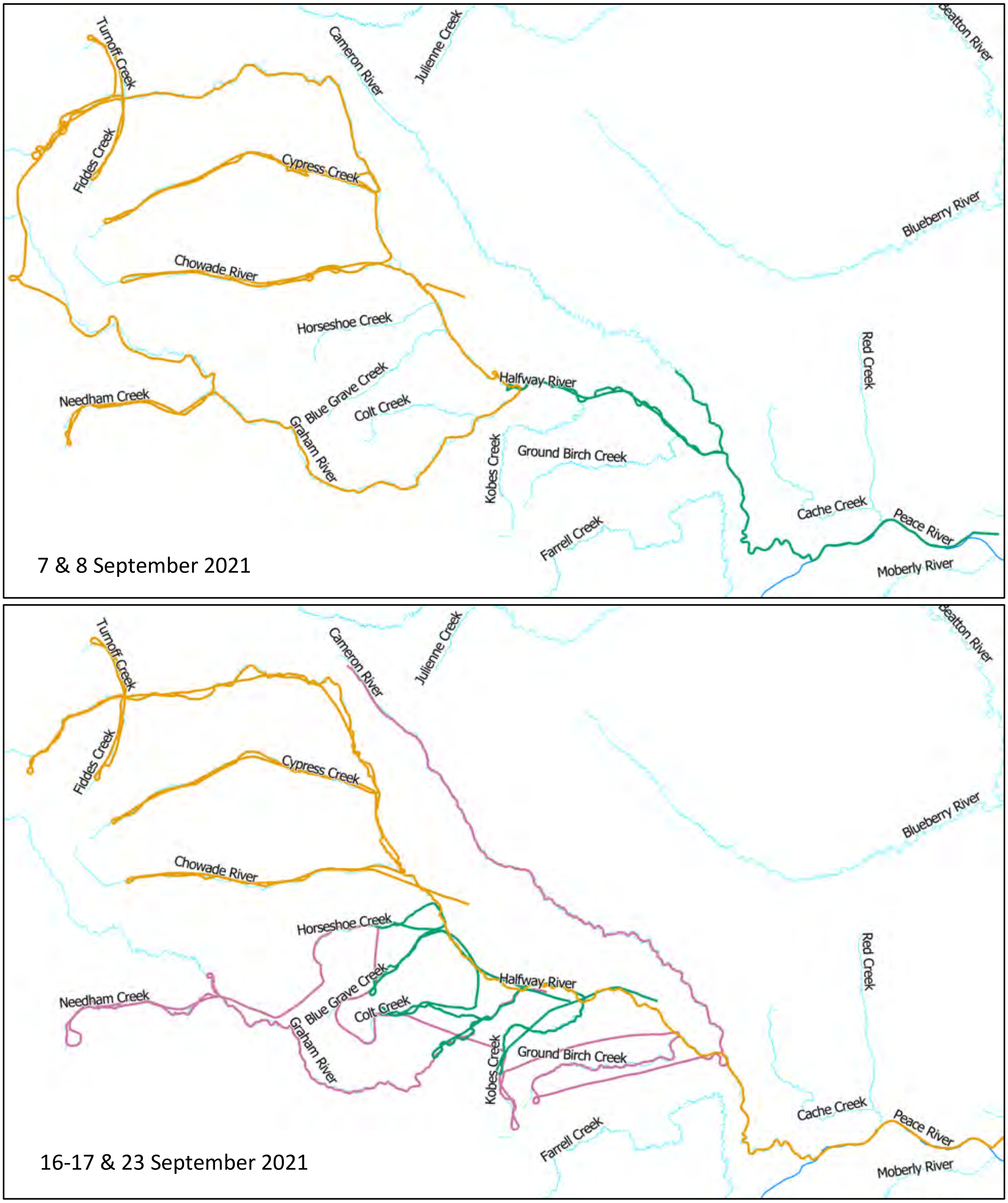

Figure D2. Tracking routes (surveys took two or three flights – shown in orange, green, and magenta – to complete) for two mobile-telemetry tracking surveys of the Halfway River, September 2021 (see Table 5). Some overland flight segments have been removed for figure clarity.

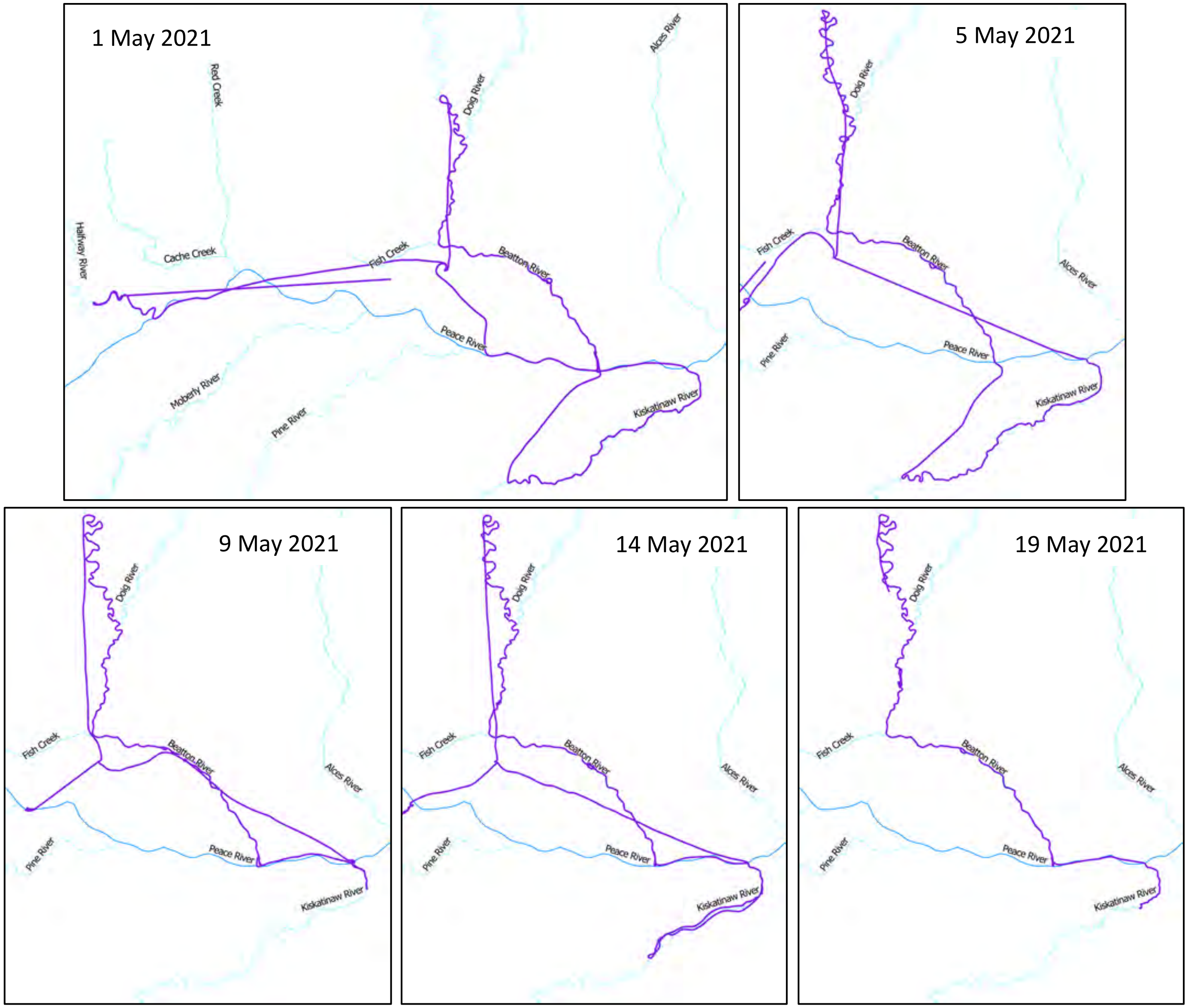

Figure D3. **Tracking route (purple) for ten mobile-telemetry tracking flights of the Beatton and Kiskatinaw rivers, May-June 2021 (see Table 5). Continued overleaf. A detailed Walleye spawning analysis is detailed in a separate report (Smith et al. 2022) to address the objectives of the Walleye Spawning and Rearing Use Survey (Mon-2 Task 2e).**

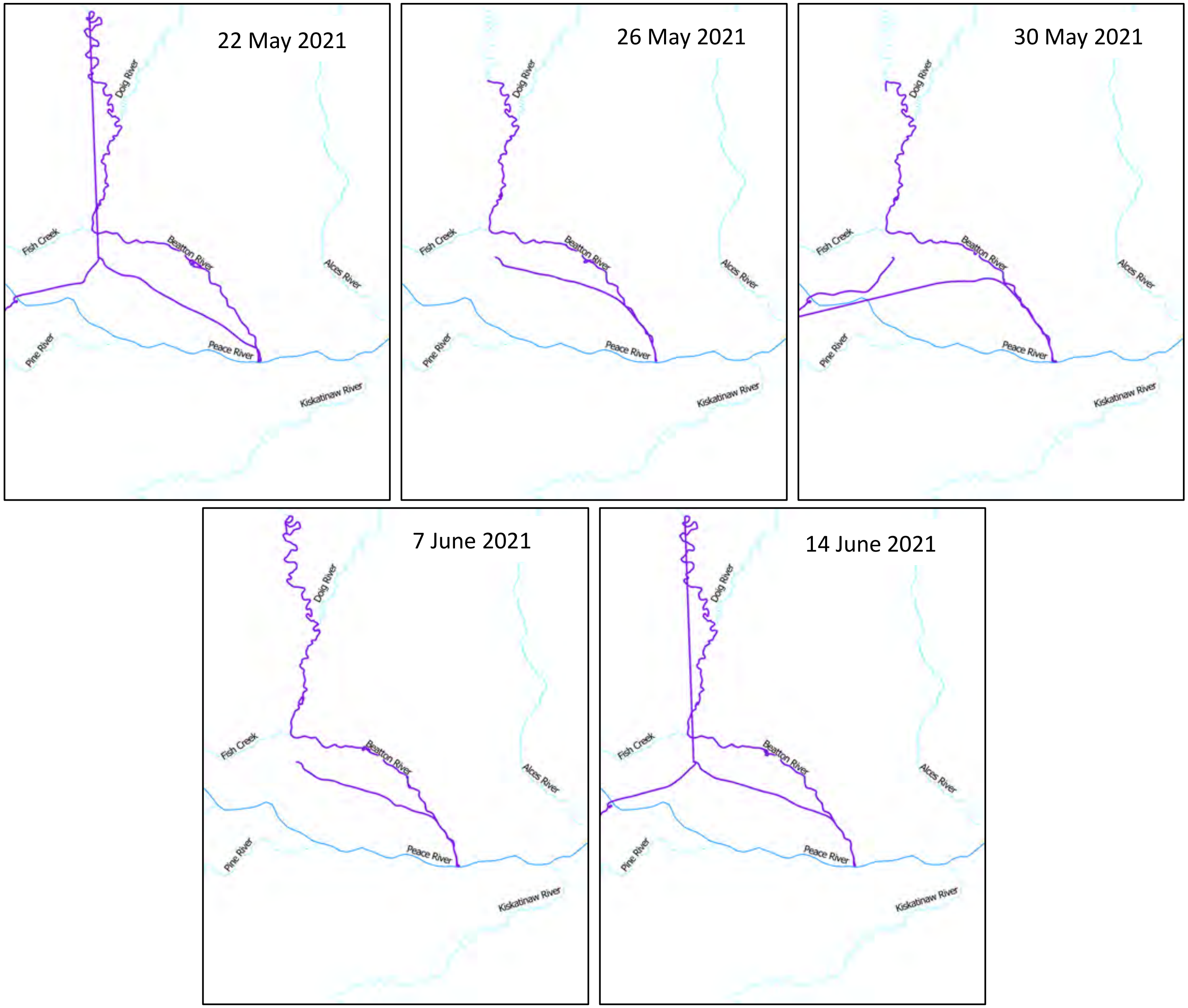

Figure D3 continued (page 2 of 2).

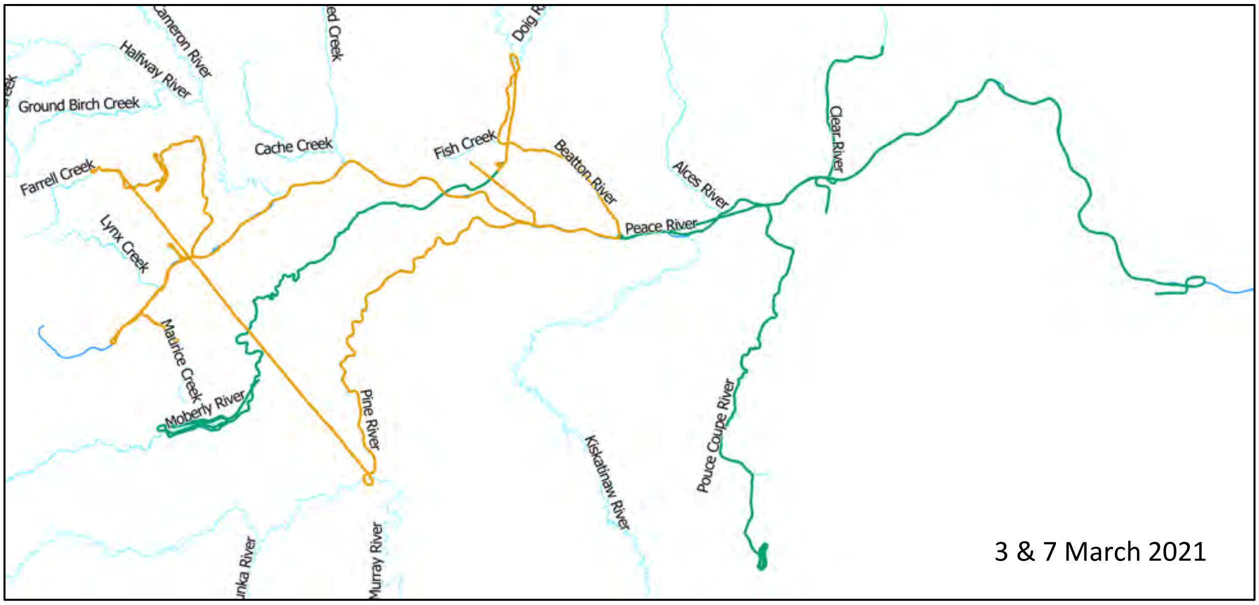

Figure D4. **Tracking routes (survey took two flights – shown in orange and green – to complete) for a fourth wintertime fixed wing mobile-telemetry tracking survey (see Table 5) conducted in the winter of 2020-2021. Routes for previous three wintertime flights are in Hatch et al. (2021). Some overland flight segments have been removed for figure clarity.**

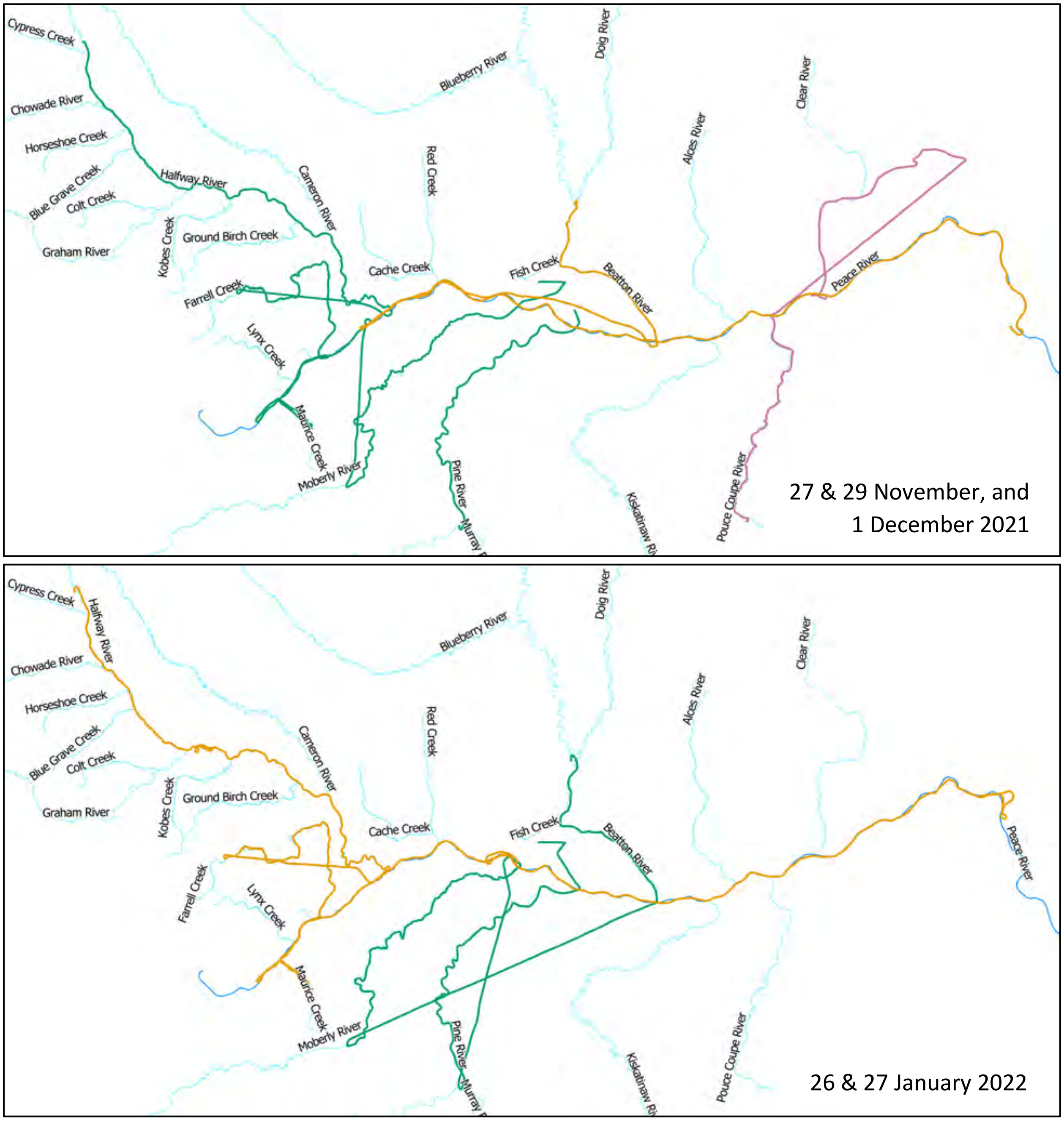

Figure D5. **Tracking routes (surveys took two or three flights – shown in orange, green, and magenta – to complete) for two wintertime fixed wing mobile-telemetry tracking surveys (see Table 5) conducted in the winter of 2021-2022. Some overland flight segments have been removed for figure clarity.**

Appendix E. Additional Tracking Maps

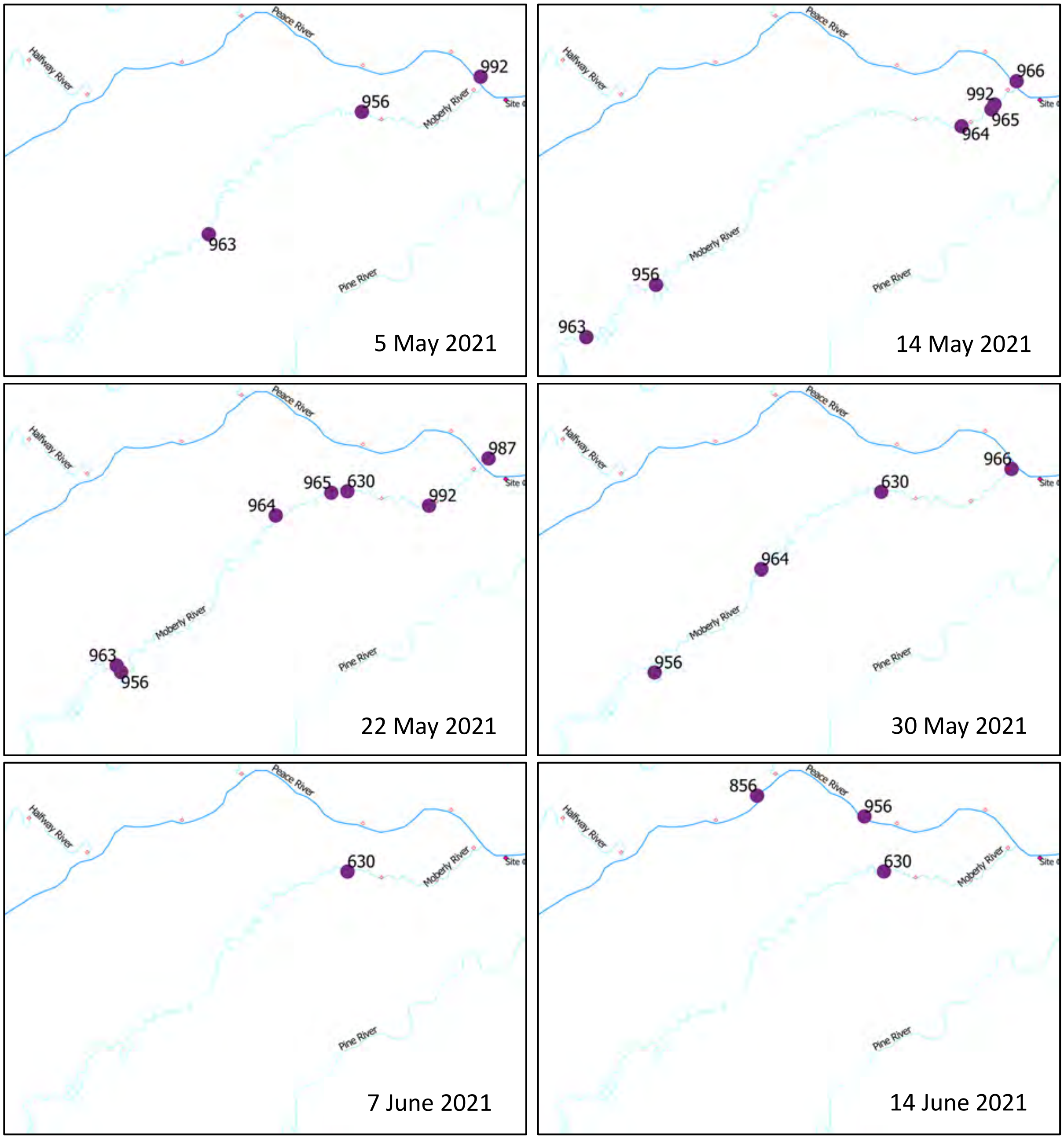

Figure E1. Locations of Arctic Grayling detections in the Moberly River (purple dots) during six spawning-season mobile tracking surveys. Fixed-station receivers shown as diamonds.

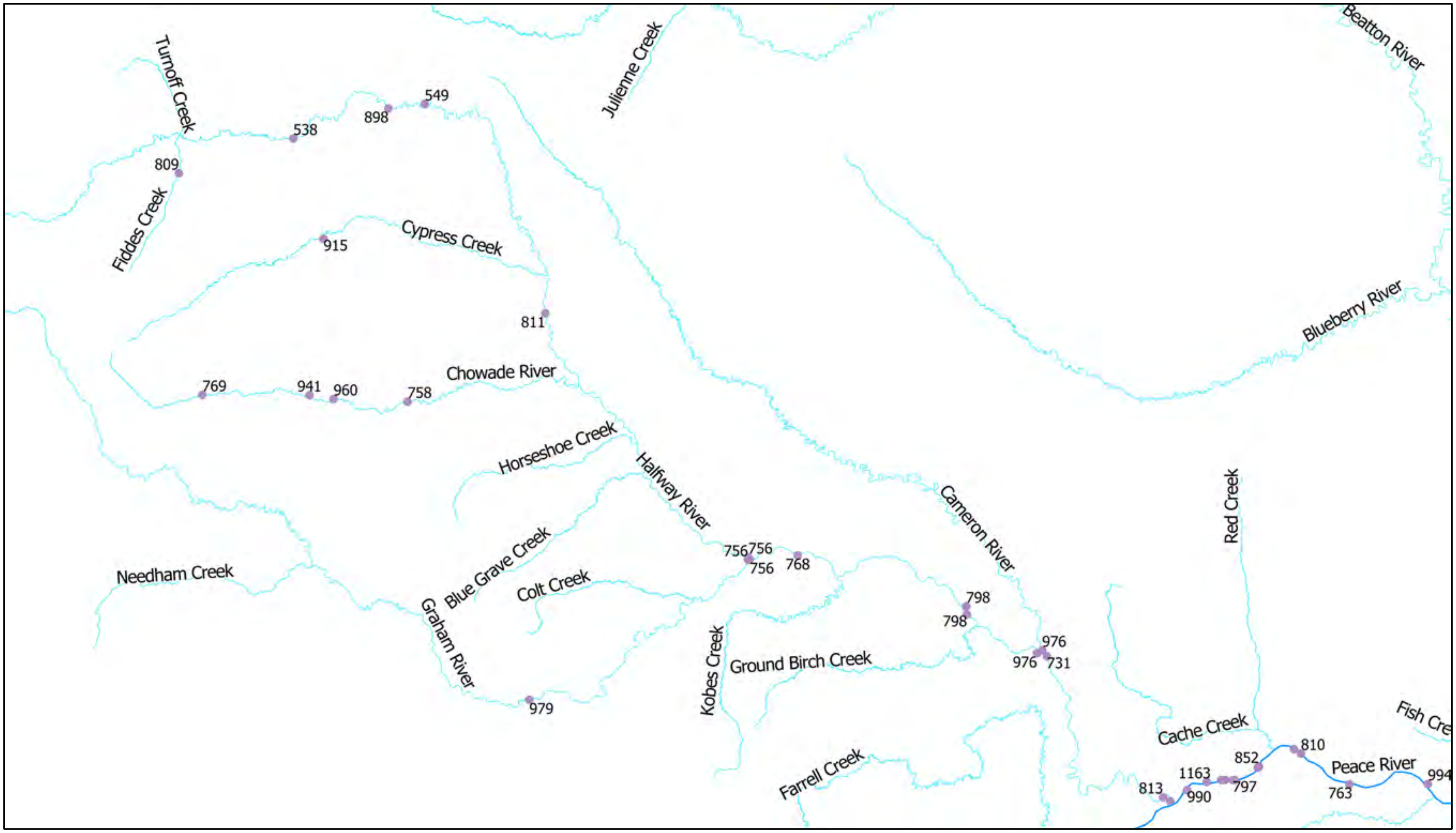

Figure E2. **Bull Trout detection locations, labeled with a unique Tag ID number, during the first of Halfway River mobile tracking surveys, 7 & 8 September 2021. Duplicates refer to study fish detected on multiple flight dates.**

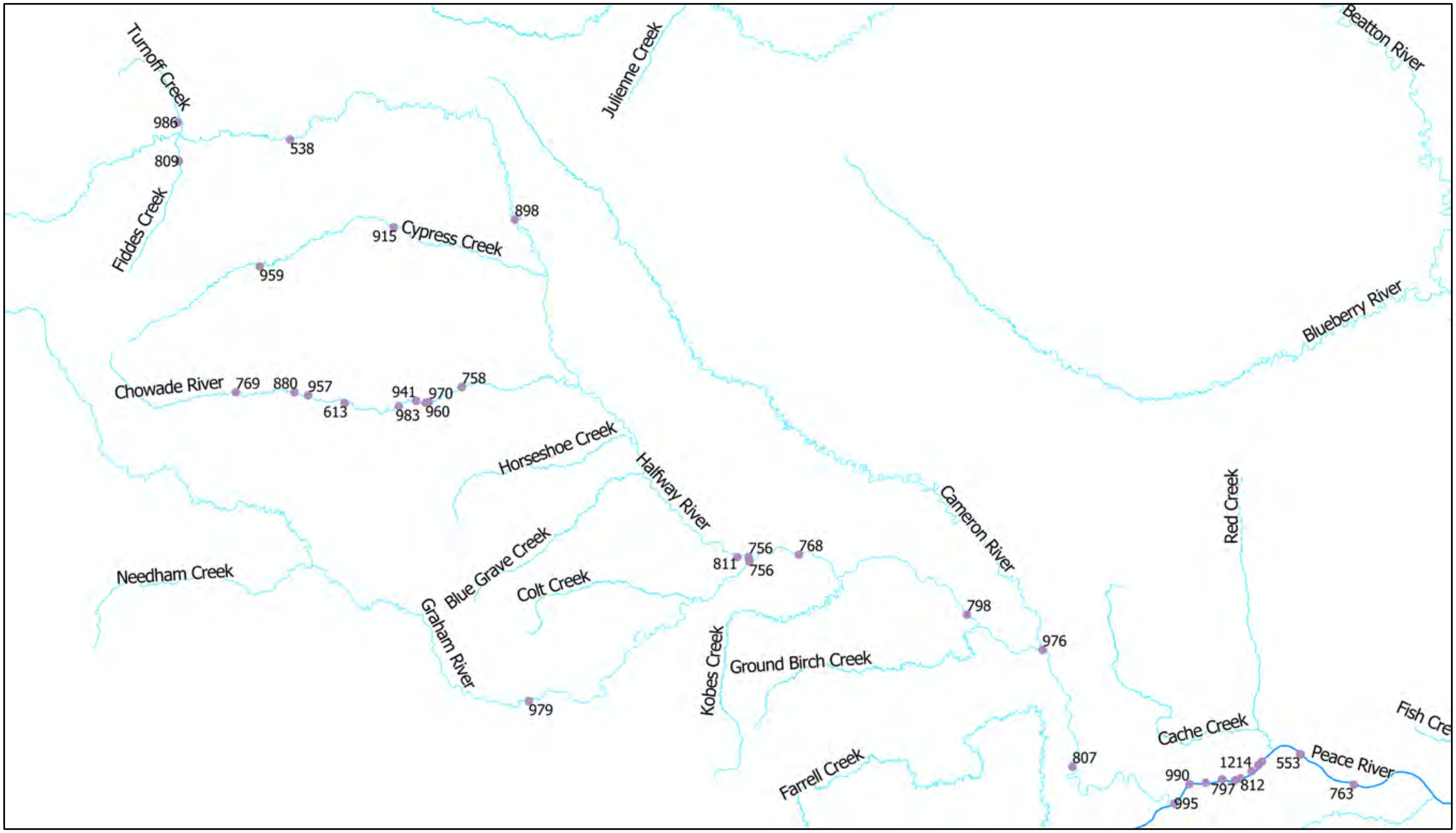

Figure E3. **Bull Trout detection locations, labeled with a unique Tag ID number, during the second of two Halfway River mobile tracking surveys, 16-17 & 23 September 2021. Duplicates refer to study fish detected on multiple flight dates.**

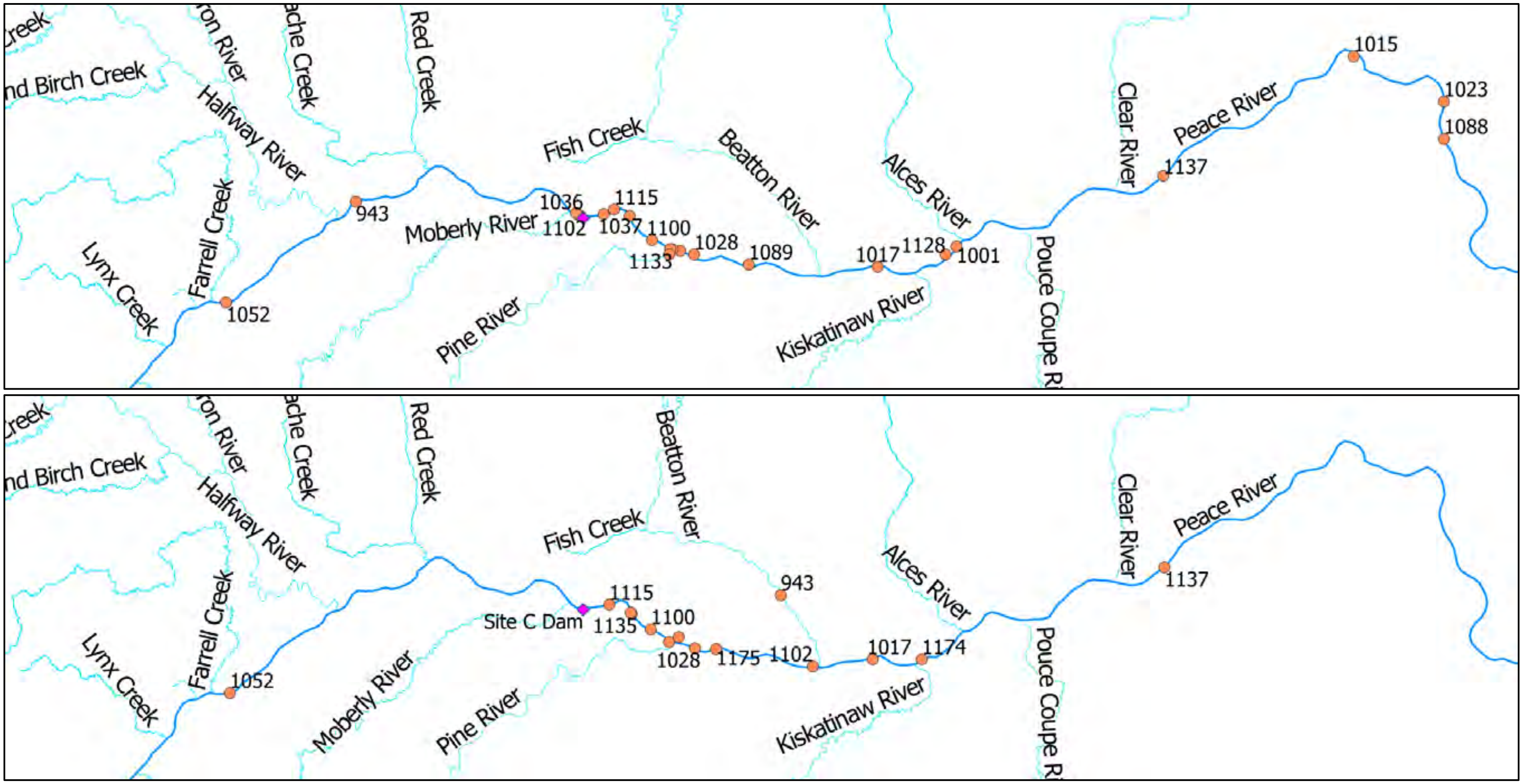

Figure E4. **Mountain Whitefish during two winter mobile telemetry in late November/early December 2021 (upper panel) and late January 2022 (lower panel).**

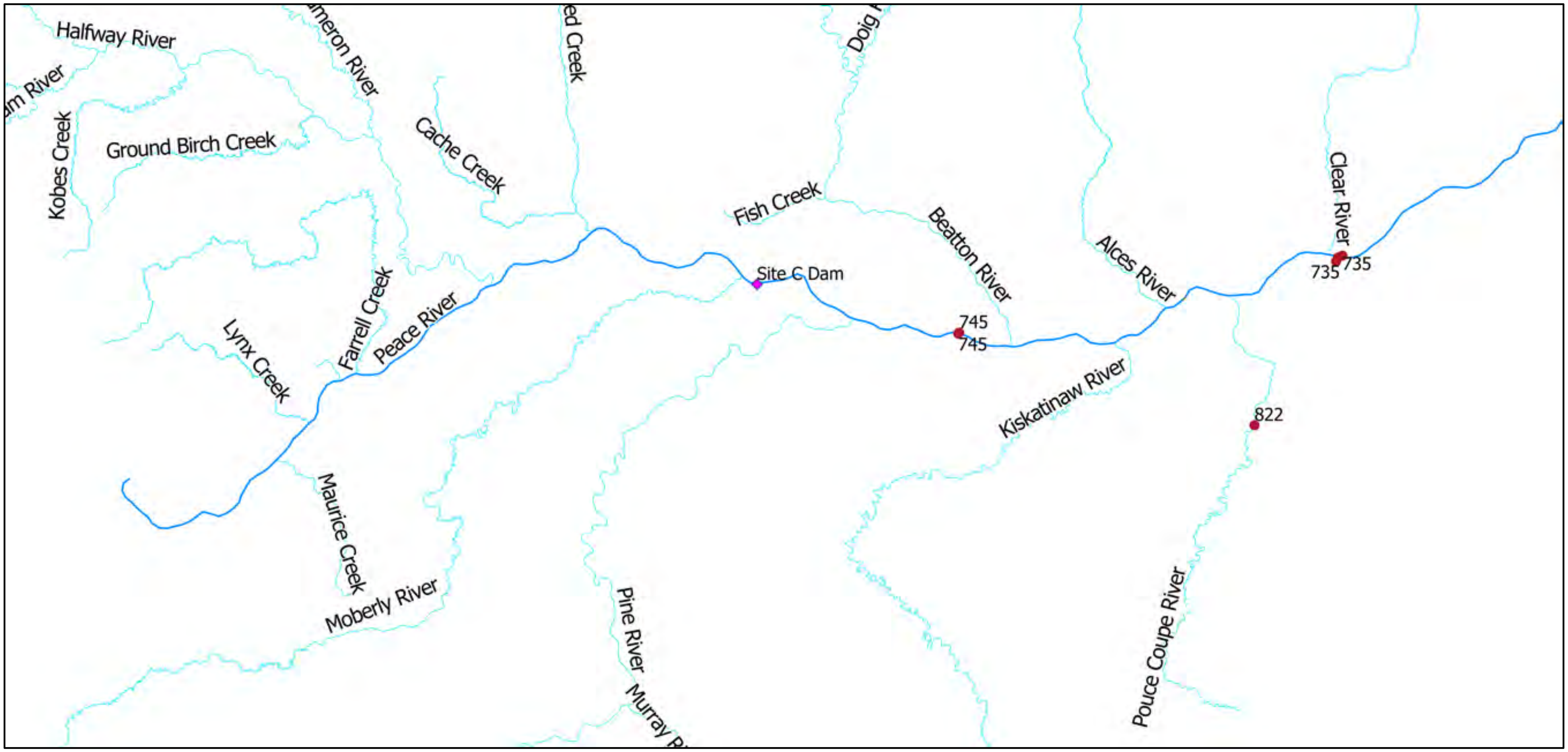

Figure E5. Burbot locations during two winter mobile telemetry in late November/early December 2021 and late January 2022. Duplicates refer to study fish detected on multiple flight dates.