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 6 (2020)

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9 December 2021

Agreement Numbers 12273 and 14200

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

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Acknowledgements

The Site C Fish Movement Assessment is funded by the BC Hydro Site C Clean Energy Project. We would like to thank Nich Burnett and Brent Mossop from BC Hydro as well as the BC Hydro Natural Resource Specialists that helped this project succeed; Justin Krilow, Hugh Delorey, Peter Frost, Brian Purvis, and Jacqueline Pizzey, among others. Thanks specifically to Ted Santos -Castro and Nich Burnett who provided valuable comments on a previous draft of this report. Thank you also to 4 Evergreen Resources for their important contributions. Thanks also to Golder Associates, specifically Demitria Burgoon and Dustin Ford for support. Finally, thank you to Jason Smith, Shane Johnson, Cam McCulloch, Karl English, Lucia Ferreira, Anita Blakley, Naira Johnston, Steven Roias, Julio Novoa, Yury Bychkov, Ian Beveridge, Riley Waytes, and Steve Crawford from LGL Limited for their significant contributions.

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 2020 field season (1 January 2020 to 31 January 2021) as well as an accompanying analysis that includes data collected during the present (1 May 2019 to 31 January 2021) and historical programs (1996 to 1996 & 2005 to 2009). 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 effect 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 2020, five of which were installed in 2019 and have been operating since; the remaining 25 were re-deployed between 17 April and 20 May 2020. 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. A subset of stations were range tested and on average

[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.

50% of transmissions were detected and properly decoded when tags were 215 m away; this metric varied between fixed-stations from 57 to 650 m. Furthermore, average detection efficiencies were calculated for applicable fixed-stations, ranging from 83.3% to 98.3% for all but one fixed-station.

The primary mobile tracking effort surveyed key migratory periods for Arctic Grayling and Bull Trout, monitoring fish located in the Moberly and Halfway rivers, respectively. Five Moberly River overflights were conducted in May and June 2020[5] by helicopter and two 2-day surveys of the Halfway River watershed were conducted during peak Bull Trout spawning in September 2020[6] by fixed wing aircraft. Antennas were mounted to the aircraft and connected to telemetry receivers in the cabin for each mobile survey. Two boat-based tracks of the Peace River were conducted opportunistically, and three additional fixed wing watershed-wide mobile tracks were conducted between 20 November 2020 and 30 January 2021 to supplement data while much of the fixed-station array was demobilized and offline.

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 ~14 million valid detection records that passed the filtering criteria between 1 January 2020 and 31 January 2021. Individual fish tracks were processed for the distances and directions moved, and the seasonality of movement patterns.

Preliminary results showed that passage at Site C varied by species and month but was largely in the upstream direction from March through May (spring) and in the downstream direction from September through November (fall). From June through August (summer), some upstream passage continued, while downstream passage began to increase. After the river was diverted (3 October 2020), there continued to be downstream passage through the diversion tunnels on the dam site. The 37 fish that used the diversion tunnels to pass downstream included five Arctic Grayling, nine Bull Trout, five Rainbow Trout, and 18 Walleye. With respect to upstream passage, fish must now enter the temporary upstream fish passage facility (hereafter temporary facility) located at the diversion tunnel outlet. Data collected prior to river diversion suggested that upstream movements past Site C were rare from November through February (winter) with only one Arctic Grayling and one Bull Trout passing upstream during the 2019/2020 winter and one Mountain Whitefish passing upstream during winter 2006/2007. Upstream passage at Site C becomes relatively more common in March and April for Arctic Grayling and Bull Trout.

Preliminary spawning results identified 27 adult and active[7] Bull Trout with spawning behaviours in the upper Halfway River and its tributaries during the fall spawning period in 2020. The location of four active Bull Trout could not be categorized during fall spawning due to incomplete detection histories. The remaining active Bull Trout (n= 42) resided in the Peace River during the 2020 spawning period. Conversely, 14 adult and active Arctic Grayling exhibited potential spawning behaviour in the Moberly River during the Arctic Grayling spawning period from April-June 2020. Of which, 11 moved upstream

[5] Moberly River mobile detection flights were conducted on 15 May, 20 May, 28 May, 5 June, and 17 June 2020

[6] Halfway River mobile detection flights were conducted on 4 September, 6 September, 11 September, and 15 September 2020.

[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.

beyond the inundation zone at RKM 12. All the spawning Arctic Grayling entered the Moberly River from the Peace River and exited back into the Peace River after spawning.

In 2019, a total of 53 juvenile Bull Trout were tagged in the upper Halfway River and its tributaries to explore movement patterns and timing into the Peace River. However, only four (7.5%) of these juvenile Bull Trout were detected following release and all of which were detected within days at the Chowade River station which was only 0.5 RKM from the release location. All 53 tags have since expired and the only underlying result is that a fall outmigration was not supported by this data. At this time, we cannot reliably assess the proportion that moved out into the Peace River.

Mountain Whitefish were tagged in 2020 (n= 28) with the objective of identifying and categorizing seasonal movement patterns, with a specific interest in fall behaviour as Mountain Whitefish prepare to spawn. Only 12 (42.9%) of these Mountain Whitefish were detected following release and the primary movement behaviour was in the downstream direction, which could imply mortality or handling effects (LGL & AMEC 2008a). All 28 Mountain Whitefish tags have since expired and, in general, these data were not suitable for further interpretation.

The historical dataset, on the other hand, had a more robust sample of Mountain Whitefish released in 2006 (n= 116) which allowed for further analysis. The primary observed behaviour by Mountain Whitefish was nonmigratory or resident. Nonmigratory behaviours were consistent across all months except for upticks in downstream Peace River and upstream tributary movements occurring primarily in July. Beyond that, there did not appear to be any marked movements in preparation for spawning in the fall.

Winter mobile surveys were conducted along the Peace River from November 2020 to January 2021. Among the species targeted was adult Burbot with the objective of interpreting winter behaviours. In total, 25 Burbot were radio-tagged and released in 2019 (n= 18) and 2020 (n= 7). From these, 10 Burbot were detected at least once during the winter mobile surveys. Burbot movements were minimal during the winter mobile surveys alone, however expanding the analysis to include the fixed-station array highlighted 4 individual Burbot that moved at least 11.8 RKM downstream the Peace River between September and January. No Burbot were tagged during the historical period.

All 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 large-scale monitoring of movement patterns and support answering specific management questions. Management questions were carefully curated to be addressable or at least partially addressable with the data available at the time of writing this report. 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 addressed in the future.

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Introduction

In accordance with Provincial Environmental Assessment Certificate Condition No. 7[8] and Federal Decision Statement Condition Nos. 8.4.3[9] and 8.4.4[10] 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[11]). 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, Bull Trout, Burbot, Rainbow Trout and Walleye) 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 through-out 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 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[12] followed by Operation Years 1-4, 10-11, 15-16, 20-21, 25-26 and 29-30[13]. Spatially, the extent of the array is meant to coincide with the sampling and tagging of target species by the Peace River Large Fish Indexing Survey (Mon-2, Task 2a). The array was designed to cover 200 river kilometres of the Peace River, including the entrances to major tributaries (Maurice Creek, Lynx Creek, Farrell Creek, Halfway River, Cache Creek, Moberly River, Pine River, Beatton River, Kiskatinaw River, and Pouce Coupe River), as well as to provide additional coverage within important tributaries (Halfway River, Moberly River, Chowade River, and Cypress Creek). That said, the array is designed to be flexible, whereby stations can be added, moved, and/or improved as monitoring progresses or study priorities shift.

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[8] 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.

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

[10] 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.

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

[12] 2019 - 2024

[13] 2024-2028, 2034-2035, 2039-2040, 2044-2045, 2049-2050 and 2053-2054, respectively

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-June for Arctic Grayling; August-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 categorize 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 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), Golder Associates collected, radio-tagged and released 279 study fish between July and October 2020. All radio-tagged study fish were collected by boat electroshocking using methods and settings that were consistent with previous study years (Golder Associates Ltd. 2020). Collected study fish were identified to species, weighed in grams, measured for fork length (FL, in mm) and assigned an age class (i.e., adult or juvenile[14]) based on their length (Figure 3). Similar to 2019, 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 Ltd. 2020).

Acceptable study fish were tagged by surgically inserting a Lotek Nano radio tag, however the specific tag model employed was dependant on tag burden, which is defined as the ratio between tag weight and the weight of the study fish (Table 1). The maximum allowable tag burden for all tagged fish in 2020 was 2.0% which is a standard that has been consistently referenced in telemetry literature (Jepsen et al. 2005, Smircich and Kelly 2014, Golder Associates Ltd. 2020). For all 2020 tagged fish, the tag burden ranged between 0.06% to 1.89% with a mean of 0.80%. Based on the manufacturer's (Lotek Wireless[15]) 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[16]. Candidate study fish were sedated in an anesthetic bath containing 50 PPM clove oil and 95% ETOH alcohol. 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[17] tagged and then placed ventral side up on a sponge-lined tray in preparation for the surgical tag insertion.

During surgery, a gravity fed, or 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. Lastly, the cannula was removed, and the incision was stitched with two or three stitches[18]. In general, the handling of fish was minimized wherever possible to reduce any latent tagging effects.

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[14] 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 Ltd. 2020).

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

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

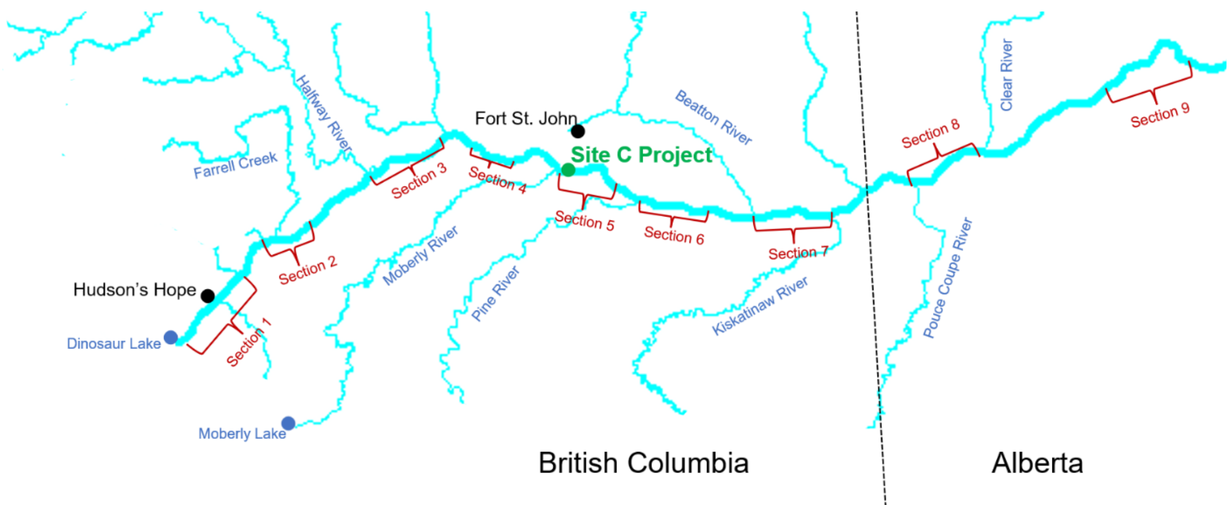
[17] Passive integrated transponders or PIT tag.

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

Following surgery, the radio-tagged fish was placed in an aerated recovery bucket for a minimum of 10 minutes of monitoring until normal swimming behaviour resumed. Once the tagged fish recovered, the fish was released near the capture location[19]. All radio-tagged fish released in 2019 and 2020 are listed by species, age class, tag model and release river/section in Table 2. A simplified map of the study area including the Peace River release sections are displayed in Figure 1 and histograms of study fish size distributions by species is displayed in Figure 3. Last, detailed spatial distributions of releases are displayed in a series of maps in Appendix A.

Table 1. Lotek Nano radio tag models are listed along with tag weight (grams in air), average burst rate[20] (seconds), expected battery life (days) as well the quantity of each model deployed in 2019 and 2020.

Tag model	Tag weight (grams)	Avg burst interval (secs)	Expected battery life (days)	Qty deployed (2020)	Qty deployed (2019)
NTF-3-2	0.57	9.5	185	91	81
NTF-5-2	1.50	9.5	357	12	12
NTF-6-1	2.50	9.5	525	8	7
NTF-6-2	4.00	9.5	992	168	229



[19] Peace River fish were released at the approximate halfway point between the upstream and downstream boundaries of the sample site while tributary fish were released in a suitable location near the sample section that also provided suitable habitat cover for the recovering study fish.

[20] 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. The 2020 burst interval ranged between 9.197 to 9.799 seconds.

Table 2. **Radio-tagged study fish from 2019 and 2020 are listed by species, age class, radio tag model and release location. Study fish released into the Peace River were separated by section (Figure 1) while all study fish released in a tributary location less than 1 RKM from the confluence of the Peace River are 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	Peace River Section 5	Peace River Section 6	Peace River Section 7	Peace River Section 9	Maurice Creek	Farrell Creek	Halfway River	Total
2019	Arctic Grayling	Adult	NTF-6-2	0	20	4	4	1	0	0	0	0	**29**
2019	Arctic Grayling	Juvenile	NTF-6-2	0	0	0	3	2	0	0	0	0	**5**
2019	Arctic Grayling	Juvenile	NTF-3-2	0	0	3	1	0	0	0	0	0	**4**
2020	Arctic Grayling	Adult	NTF-6-2	0	12	1	0	0	0	0	0	0	**13**
2020	Arctic Grayling	Juvenile	NTF-6-2	0	1	0	0	0	0	0	0	0	**1**
2020	Arctic Grayling	Juvenile	NTF-6-1	0	1	0	0	0	0	0	0	0	**1**
2020	Arctic Grayling	Juvenile	NTF-3-2	0	2	1	1	0	0	0	0	0	**4**
2019	Bull Trout	Adult	NTF-6-2	26	25	13	10	4	1	0	0	0	**79**
2019	Bull Trout	Adult	NTF-6-1	2	0	0	1	0	0	0	0	0	**3**
2019	Bull Trout	Juvenile	NTF-5-2	0	0	1	2	0	0	0	0	2	**5**
2019	Bull Trout	Juvenile	NTF-3-2	0	0	0	0	0	0	0	0	51	**51**
2020	Bull Trout	Adult	NTF-6-2	12	17	11	6	1	4	0	0	0	**51**
2020	Bull Trout	Adult	NTF-6-1	1	0	1	0	0	0	0	0	0	**2**
2020	Bull Trout	Adult	NTF-5-2	0	2	0	0	0	0	0	0	0	**2**
2020	Bull Trout	Adult	NTF-3-2	2	0	0	0	0	0	0	0	0	**2**
2020	Bull Trout	Juvenile	NTF-6-1	0	0	0	1	0	0	0	0	0	**1**
2020	Bull Trout	Juvenile	NTF-3-2	4	1	3	2	0	1	0	0	0	**11**
2019	Burbot	Adult	NTF-6-2	0	1	1	0	5	8	0	0	0	**15**
2019	Burbot	Adult	NTF-6-1	0	0	0	3	0	0	0	0	0	**3**
2020	Burbot	Adult	NTF-6-2	0	0	2	0	2	2	0	0	0	**6**
2020	Burbot	Adult	NTF-5-2	1	0	0	0	0	0	0	0	0	**1**
2020	Mountain Whitefish	Adult	NTF-3-2	0	0	19	5	4	0	0	0	0	**28**
2019	Rainbow Trout	Adult	NTF-6-2	18	15	5	0	0	0	0	0	0	**38**
2019	Rainbow Trout	Juvenile	NTF-6-2	0	2	0	0	0	0	0	0	0	**2**
2019	Rainbow Trout	Juvenile	NTF-5-2	2	1	1	2	0	0	0	0	0	**6**
2019	Rainbow Trout	Juvenile	NTF-3-2	7	2	0	0	1	0	0	15	0	**25**
2020	Rainbow Trout	Adult	NTF-6-2	19	16	1	0	0	0	0	0	0	**36**
2020	Rainbow Trout	Adult	NTF-6-1	1	0	1	0	0	0	0	0	0	**2**
2020	Rainbow Trout	Adult	NTF-3-2	2	0	0	0	0	0	0	0	0	**2**
2020	Rainbow Trout	Juvenile	NTF-5-2	0	1	0	0	0	0	7	1	0	**9**
2020	Rainbow Trout	Juvenile	NTF-3-2	9	1	0	1	1	0	20	10	0	**42**
2019	Walleye	Adult	NTF-6-2	0	2	1	11	48	0	0	0	0	**62**
2019	Walleye	Adult	NTF-6-1	0	0	1	0	0	0	0	0	0	**1**
2019	Walleye	Adult	NTF-5-2	0	0	0	0	1	0	0	0	0	**1**
2020	Walleye	Adult	NTF-6-2	2	13	8	11	17	10	0	0	0	**61**
2020	Walleye	Adult	NTF-6-1	0	0	0	1	0	1	0	0	0	**2**
2020	Walleye	Adult	NTF-3-2	0	0	2	0	0	0	0	0	0	**2**
Total				**108**	**135**	**80**	**65**	**87**	**27**	**27**	**26**	**53**	**608**

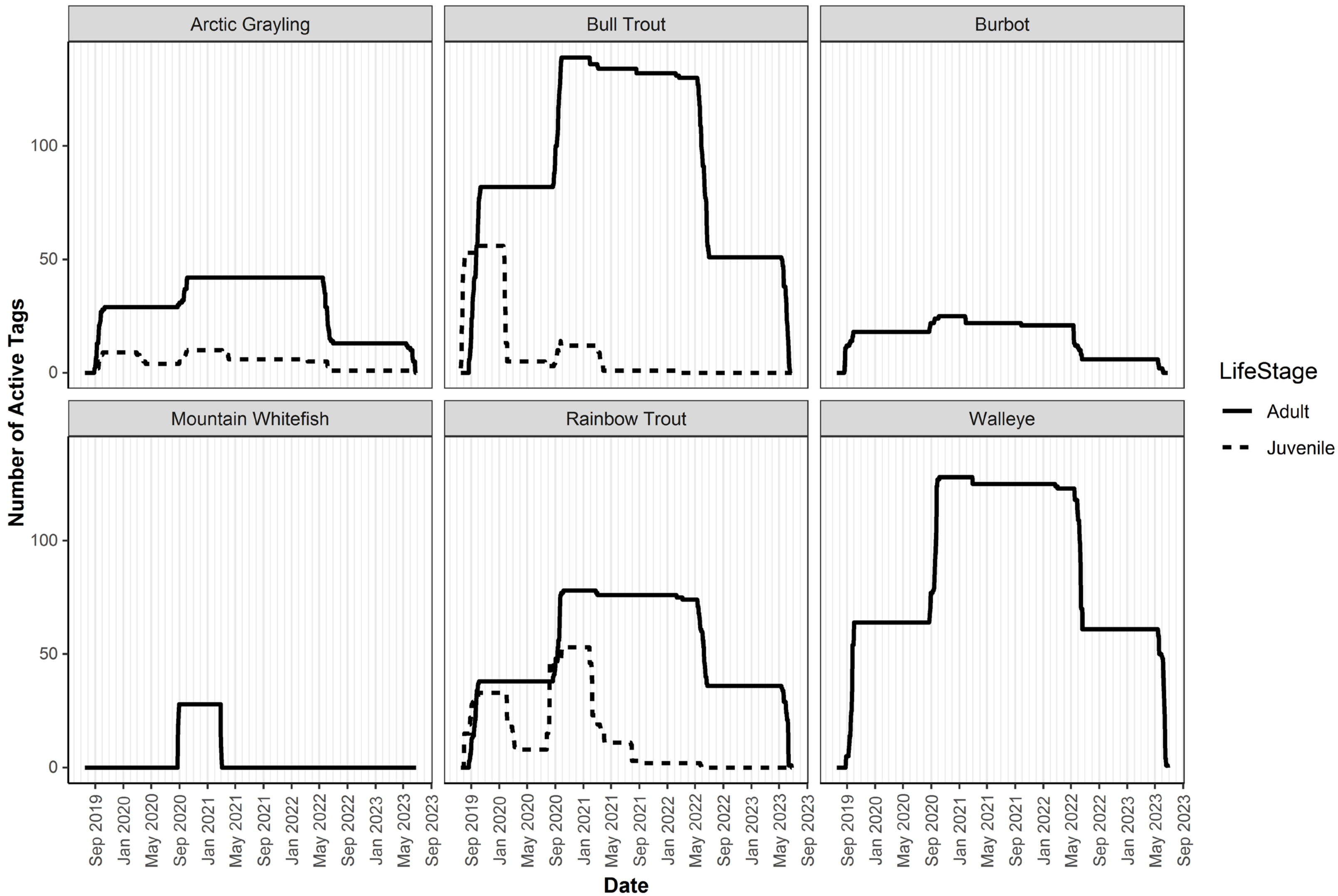


Figure 2. Estimated numbers of active radio tags, by species and date, from 2019 onward. Values are based on the numbers of tags deployed by date, and the manufacturer's battery life estimates for each of their tag models.

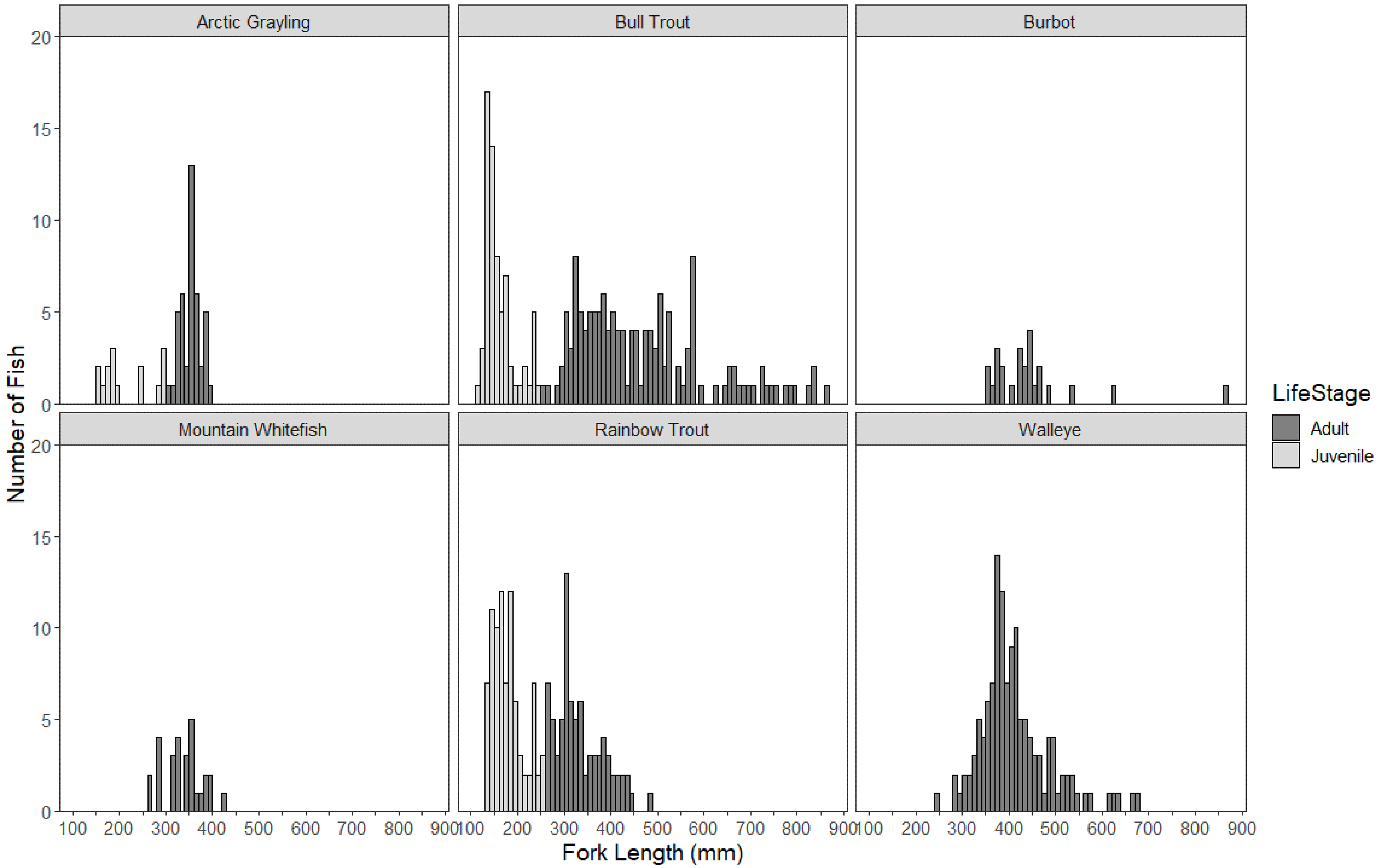


Figure 3. **Histograms of tagged study fish fork length (mm) by species. Life stage, either juvenile or adult, is denoted by light and dark bars.**

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 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 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 2-4 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.

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[21] (Figure 4).

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).

[21] 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.

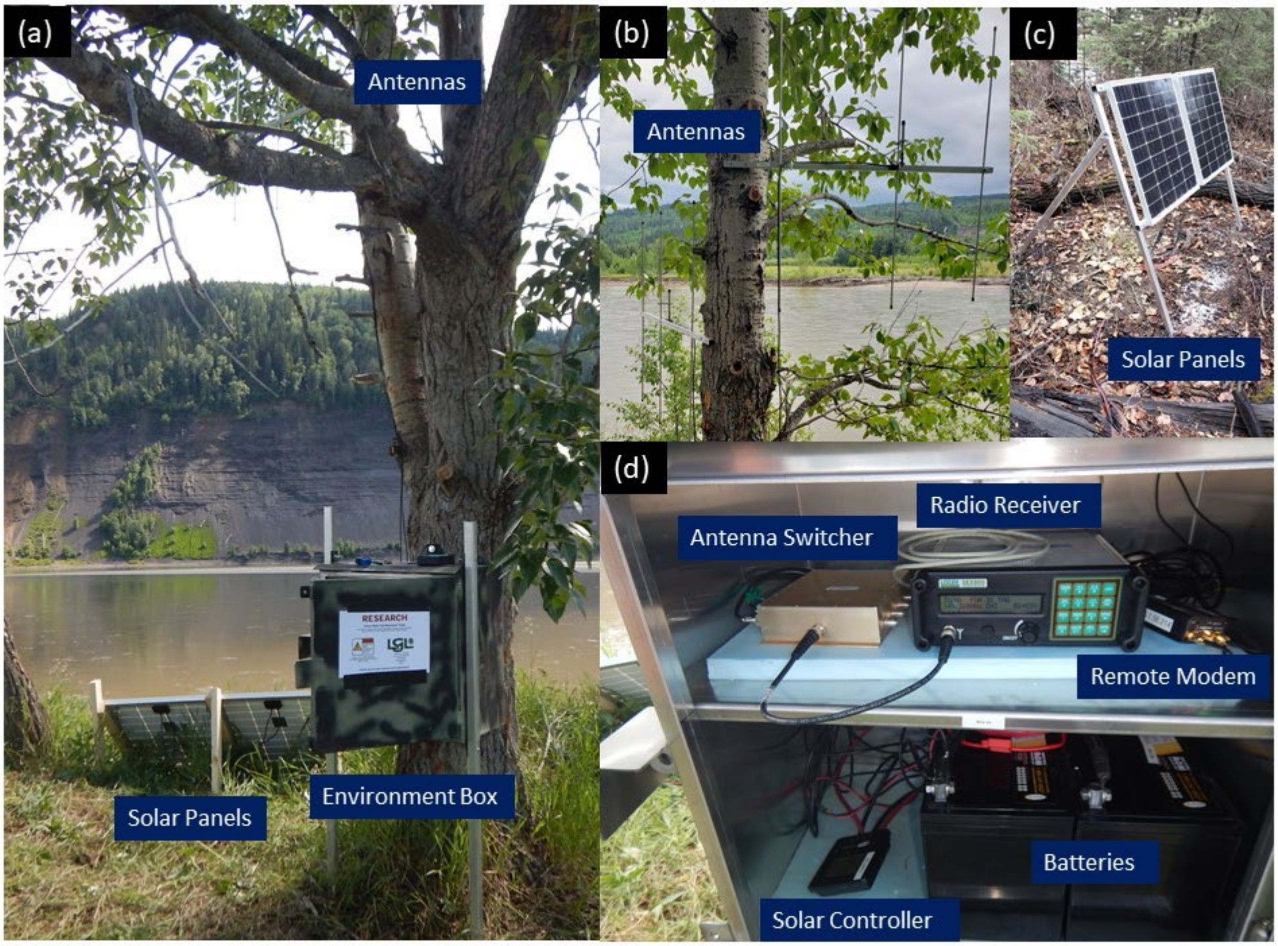


Figure 4. **Example of a fixed radio telemetry station. (a) View of the antennas, environment box, and solar panels. (b) Two, three-element YAGI antennas are mounted to a tree. (c) Two, 80-watt solar panels mounted to an aluminum stand for deployment during the winter months. (d) View of the inside of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

Table 3. Station names, types, numbers, installation and demobilization dates, and status (as of January 2021). 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	Demobilization Date	Modem	Status	Antenna Count / Location
Peace River #1A	Boat	Peace River	1	16 May 2020	7 November 2020	no	Inactive - Stored	2 / tree
Peace River #1B	Boat	Peace River	2	16 May 2020	7 November 2020	no	Inactive - Stored	2 / tree
Peace River #2	Boat	Peace River	3	16 May 2020	7 November 2020	no	Inactive - Stored	2 / tree
Peace River #3	Boat	Peace River	5	17 May 2020	8 November 2020	no	Inactive - Stored	2 / tree
Peace River #4	Truck	Peace River	8	19 May 2020	8 November 2020	no	Inactive - Stored	2 / tripod
Peace River #5	Boat	Peace River	10	18 May 2020	8 November 2020	no	Inactive - Stored	2 / tree
INS Mainstem 1	Truck	Peace River	32	9 August 2020	8 November 2020	yes	Inactive - Stored	2 / tripod
Site C Dam	Truck	Peace River	11	11 July 2019	-	yes	Active	2 / tree
INS Mainstem 2	Truck	Peace River	33	1 August 2020	-	yes	Active	2
INS Approach Zone A	Truck	Peace River	34	2 August 2020	-	yes	Active	1
INS Approach Zone B	Truck	Peace River	35	3 August 2020	-	yes	Active	1
INS Cofferdam	Truck	Peace River	36	3 August 2020	-	yes	Active	2
INS Diversion Tunnel	Truck	Peace River	37	14 September 2020	18 January 2021	yes	Inactive - Stored	1
INS Entrance Aerial	Truck	Peace River	38	15 September 2020	-	yes	Active	1
INS Entrance Dipole	Truck	Peace River	39	13 September 2020	9 November 2020	yes	Inactive - Stored	1 / dipole
INS Entrance Pool Dipole	Truck	Peace River	40	13 September 2020	1 November 2020	yes	Inactive - Stored	1 / dipole
INS Turning Basin	Truck	Peace River	41	23 October 2020	1 November 2020	yes	Inactive - Stored	1
Peace River #6	Boat	Peace River	15	18 May 2020	9 November 2020	yes	Inactive - Stored	2 / tree
Peace River #7	Truck	Peace River	16	14 May 2020	10 November 2020	yes	Inactive - Stored	2 / tripod
Peace River #8	Truck	Peace River	18	14 May 2020	6 November 2020	yes	Inactive - Stored	2 / tree
Peace River #9	Truck	Peace River	22	17 April 2020	6 November 2020	yes	Inactive - Stored	2 / tree
Peace River #10	Truck	Peace River	24	18 April 2020	5 November 2020	yes	Inactive - Stored	2 / tree
Peace River #11	Truck	Peace River	26	19 April 2020	6 November 2020	yes	Inactive - Stored	2 / tree
Peace Canyon Dam	Truck	Peace River	28	1 May 2020	6 November 2020	yes	Inactive - Stored	2 / tree
Pouce Coupe River	Boat	Tributary Entrance	4	16 May 2020	7 November 2020	no	Inactive - Stored	3 / tree
Kiskatinaw River	Boat	Tributary Entrance	6	17 May 2020	8 November 2020	no	Inactive - Stored	3 / tree
Beatton River	Boat	Tributary Entrance	7	17 May 2020	9 November 2020	no	Inactive - Stored	3 / tree
Pine River	Boat	Tributary Entrance	9	18 May 2020	-	no	Not Retreived	2 / tree
Moberly River #1	Truck	Tributary Entrance	12	11 July 2019	-	yes	Active	2 / tree
Cache Creek	Truck	Tributary Entrance	17	17 April 2020	6 November 2020	yes	Inactive - Stored	2 / tree
Halfway River #1	Truck	Tributary Entrance	19	8 July 2019	-	yes	Active	2 / tree
Farrell Creek	Truck	Tributary Entrance	23	21 April 2020	15 October 2020	yes	Inactive - Stored	3 / tree
Lynx Creek	Truck	Tributary Entrance	25	18 April 2020	5 November 2020	yes	Inactive - Stored	2 / tree
Maurice Creek	Truck	Tributary Entrance	31	19 April 2020	5 November 2020	yes	Inactive - Stored	2 / tree
Moberly River #2	Helicopter	Tributary Upstream	13	13 May 2020	11 November 2020	no	Inactive - Stored	2 / tree
Moberly River #3	Helicopter	Tributary Upstream	14	15 May 2020	11 November 2020	no	Inactive - Stored	2 / tree
Halfway River #2	Helicopter	Tributary Upstream	20	20 May 2020	10 November 2020	no	Inactive - Stored	2 / tree
Halfway River #3	Helicopter	Tributary Upstream	21	15 May 2020	11 November 2020	no	Inactive - Stored	2 / tree
Chowade River	Truck	Tributary Upstream	29	31 July 2019	30 September 2020	no	Active	2 / tree
Cypress Creek	Truck	Tributary Upstream	30	30 July 2019	2 October 2020	no	Active	2 / tree

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 20) to Many Islands, Alberta (RKM[22] 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[23] created at Peace River #1A/Peace River #1B and Kistkatinaw 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 2, Figure 5).

All 26 of the fixed radio telemetry stations deployed in 2019 (Hatch et al. 2020) were again deployed and operated in 2020 (Table 3). In addition, there were four new fixed-stations deployed in 2020 via helicopter; Moberly River #2 and 3 and Halfway River #2 and 3. In addition, there were ten fixed-stations deployed as part of Mon-13 (Site C Fishway Effectiveness Monitoring Program), whose deployment and operation was managed by InStream Fisheries Research.

The temporal extent of the array spanned from April to November 2020 for the majority of the fixed-stations; with some of the most accessible fixed-stations remaining active throughout the remainder of the year. Redeployment of the array began on 17 April 2020, which was later than originally planned due to travel and work restrictions that were imposed due to the COVID-19 pandemic. The last fixed-station was deployed on 20 May 2020 (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.

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

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

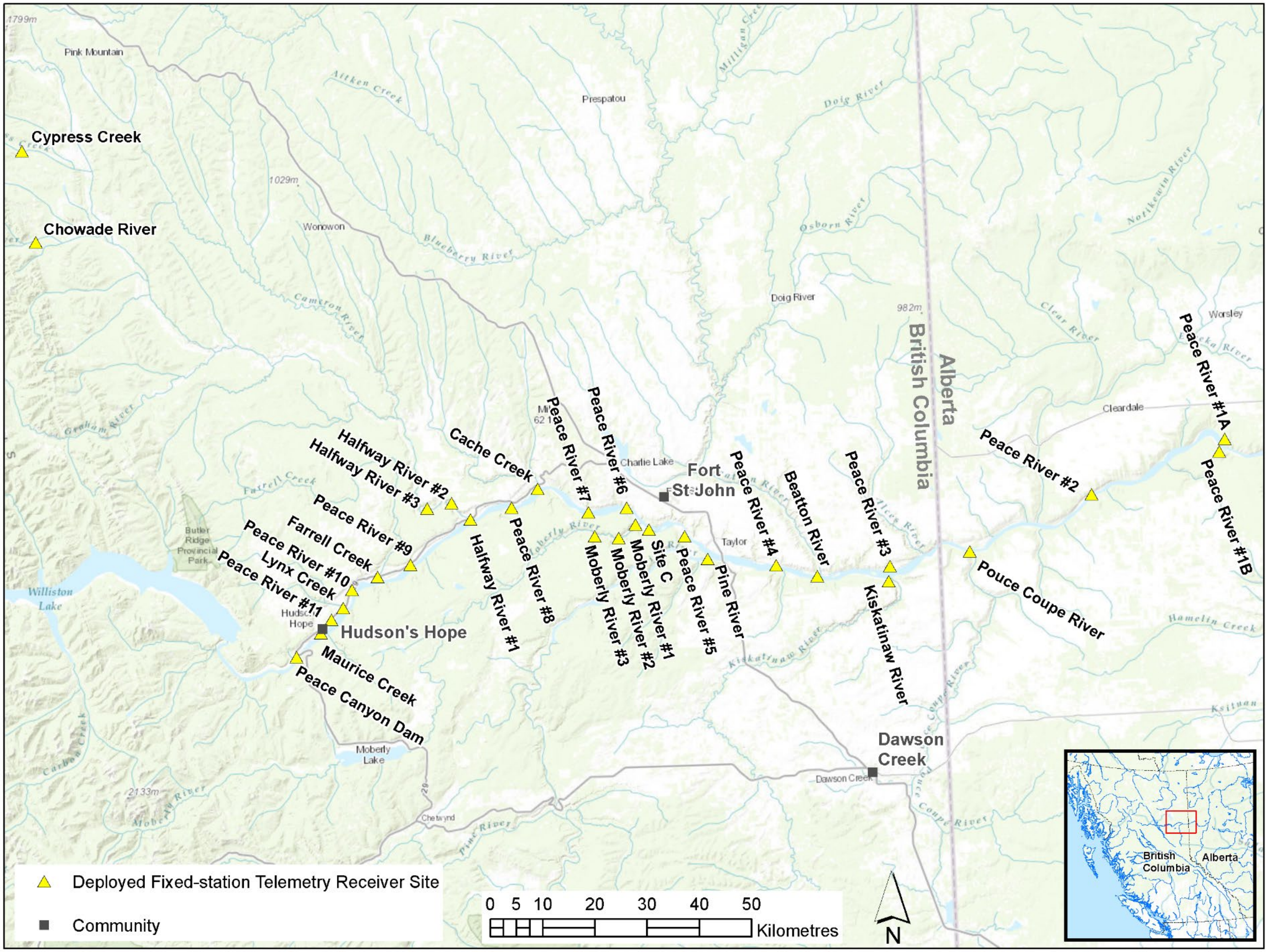


Figure 5. **Location of 30 fixed radio telemetry stations deployed for the Site C Fish Movement Assessment in 2020. Ten other stations, deployed or maintained as part of Mon-13 (Site C Fishway Effectiveness Monitoring Program), are not shown on this map.**

Beyond basic functionality testing, some of the fixed-stations were range tested. 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)[24] 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 then 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).

The fitted logistic equation parameters were used to calculate the distances in which detection probability was 95%, 50% and 5%. 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).

Table 4. Fixed-station deployment, maintenance, and demobilization field schedule in 2020.

Start Date	End Date	Work Completed
overwinter	15 April 2020	Winter Maintenance
16 April 2020	21 April 2020	Station Installations 1
13 May 2020	20 May 2020	Station Installations 2
9 June 2020	17 June 2020	Download/Testing/Maintenance 1
8 July 2020	17 July 2020	Download/Testing/Maintenance 2
4 August 2020	13 August 2020	Download/Testing/Maintenance 3
9 September 2020	18 September 2020	Download/Testing/Maintenance 4
13 October 2020	19 October 2020	Download/Testing/Maintenance 5
5 November 2020	11 November 2020	Station Demobilization
12 November 2020	overwinter	Winter Maintenance

[24] 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.

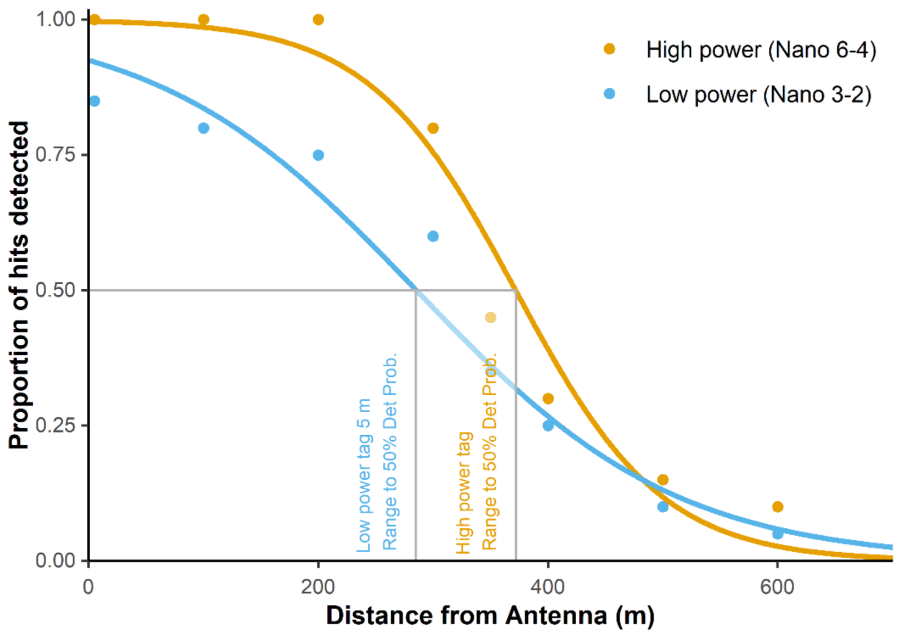


Figure 6. Example of a detection probability curve generated from sample range test data[25]. Note that this figure includes detection probability results that were within 50m of the antenna; when in actual testing this was rarely feasible given the fixed-station was frequently installed between 50 and 200m from the nearest 1m of testable water.

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 times in the first minute of each hour) 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.

[25] 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.

Mobile Telemetry

Mobile tracking 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, upstream of the reservoir inundation zone (measured at 12 RKM upstream the Moberly River). These 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 (Table 5, Appendix D).

Five Moberly River overflights were conducted from May to June 2020 targeting spawning Arctic Grayling (Appendix D, Figure D1). The first Moberly River survey occurred later than intended (15 May 2020) due to logistic concerns stemmed from the COVID-19 pandemic. The last Moberly River overflight occurred on 17 June 2020 and no follow-up surveys were conducted as all the radio-tagged study fish had since exited the Moberly River. Four overflights covering the Halfway River and its upper tributaries were conducted in September 2020 targeting spawning Bull Trout (Appendix D, Figure D2). The approach was two, 2-day flights (i.e., two days of flying are required to cover the areas of interest) centered around peak Bull Trout spawning as per the guidance of the Peace River Bull Trout Spawning Assessment (Mon-1b, Task 2b).

Mobile tracking flights were conducted by helicopter for Arctic Grayling 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. Alternatively, 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 2-element Yagi antennas were mounted to each aircraft and shielded coaxial cable (RG-58) was used to connect the antennas to one or two SRX800-MD receivers in the cabin. Receivers were programmed to scan a single frequency (all radio transmitters for this study were on a single frequency in 2020). When multiple receivers were used, the signal from the port antenna was fed into one receiver, and the signal from the starboard antenna was fed into the other receiver. 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. The 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.

Three fixed wing watershed-wide mobile tracks (Appendix D, Figure D4) were conducted from November 2020 to January 2021 (i.e., winter) to supplement data while most of the fixed station array was offline. Antenna and receiver set ups were specific for fixed wing tracking, but were similar to that described for helicopters, above.

The 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, helicopter-based 'opportunistic' mobile tracking was conducted along the Peace River to supplement the fixed-station array (Appendix D, Figure D1 and Figure D2). Likewise, two boat-based supplemental mobile tracking surveys were conducted along the Peace

River in October 2020 while transiting the Peace River for routine fixed-station maintenance (Appendix D, Figure D3).

Table 5. Mobile tracking survey dates, locations tracked, and vessels used in 2020 and January 2021.

Date	Task / Areas Covered	Vessel
15 May 2020	Weekly Arctic Grayling tracking in the Moberly, Survey 1	Helicopter
20 May 2020	Weekly Arctic Grayling tracking in the Moberly, Survey 2	Helicopter
28 May 2020	Weekly Arctic Grayling tracking in the Moberly, Survey 3	Helicopter
5 June 2020	Weekly Arctic Grayling tracking in the Moberly, Survey 4	Helicopter
17 June 2020	Weekly Arctic Grayling tracking in the Moberly, Survey 5	Helicopter
4 September 2020	Bull Trout tracking in the Halfway, Survey 1, Day 1	Fixed-wing
6 September 2020	Bull Trout tracking in the Halfway, Survey 1, Day 2	Fixed-wing
11 September 2020	Bull Trout tracking in the Halfway, Survey 2, Day 1	Fixed-wing
15 September 2020	Bull Trout tracking in the Halfway, Survey 2, Day 2	Fixed-wing
14 October 2020	Opportunistic boat-track of the Peace River mainstem, Part 1	Boat
16 October 2020	Opportunistic boat-track of the Peace River mainstem, Part 2	Boat
20 November 2020	Winter tracking, watershed-wide, Survey 1, Day 1	Fixed-wing
24 November 2020	Winter tracking, watershed-wide, Survey 1, Day 2	Fixed-wing
19 December 2020	Winter tracking, watershed-wide, Survey 2, Day 1	Fixed-wing
21 December 2020	Winter tracking, watershed-wide, Survey 2, Day 2	Fixed-wing
29 January 2021	Winter tracking, watershed-wide, Survey 3, Day 1	Fixed-wing
30 January 2021	Winter tracking, watershed-wide, Survey 3, Day 2	Fixed-wing

Regardless of the mobile tracking method (helicopter, fixed wing or boat), the SRX800 receivers and GPS units were downloaded after each survey, and the data were sent electronically to the office staff for processing. The detections from each flight were filtered to remove noise, and 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 as representative of the fish's location during the flight. 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 a GIS script that assigned each detection to a 'mobile tracking zone' (Figure 7) 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 Bennet 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 and Telemetry Manager (English et al. 2012).

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, no requests have been submitted for any of the telemetry data from the Site C Fish Movement Assessment Database. Metadata about each request includes: the request date, fulfillment date, organization name, fulfiller name, requesters name, and requesters contact information. 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 this annual report.

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[26];
- Removal of records that do not match the list of released tag codes and frequencies;
- Removal of detections that *do* match the list of released tag codes, but which occurred prior to the release of the fish;
- Pulse rate filtration;
- Detection frequency filtration; and
- Examination of individual detection histories.

Since the Lotek NanoTags were programmed to transmit at a certain pulse rate (e.g., one transmission every 9.8 seconds), we were able to use the expected timing of transmissions to filter out detections that were recorded outside of the expected cycle, an approach used more commonly in acoustic telemetry or JSATS[27] (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 during 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., >100m) 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.

[26] 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).

[27] 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.

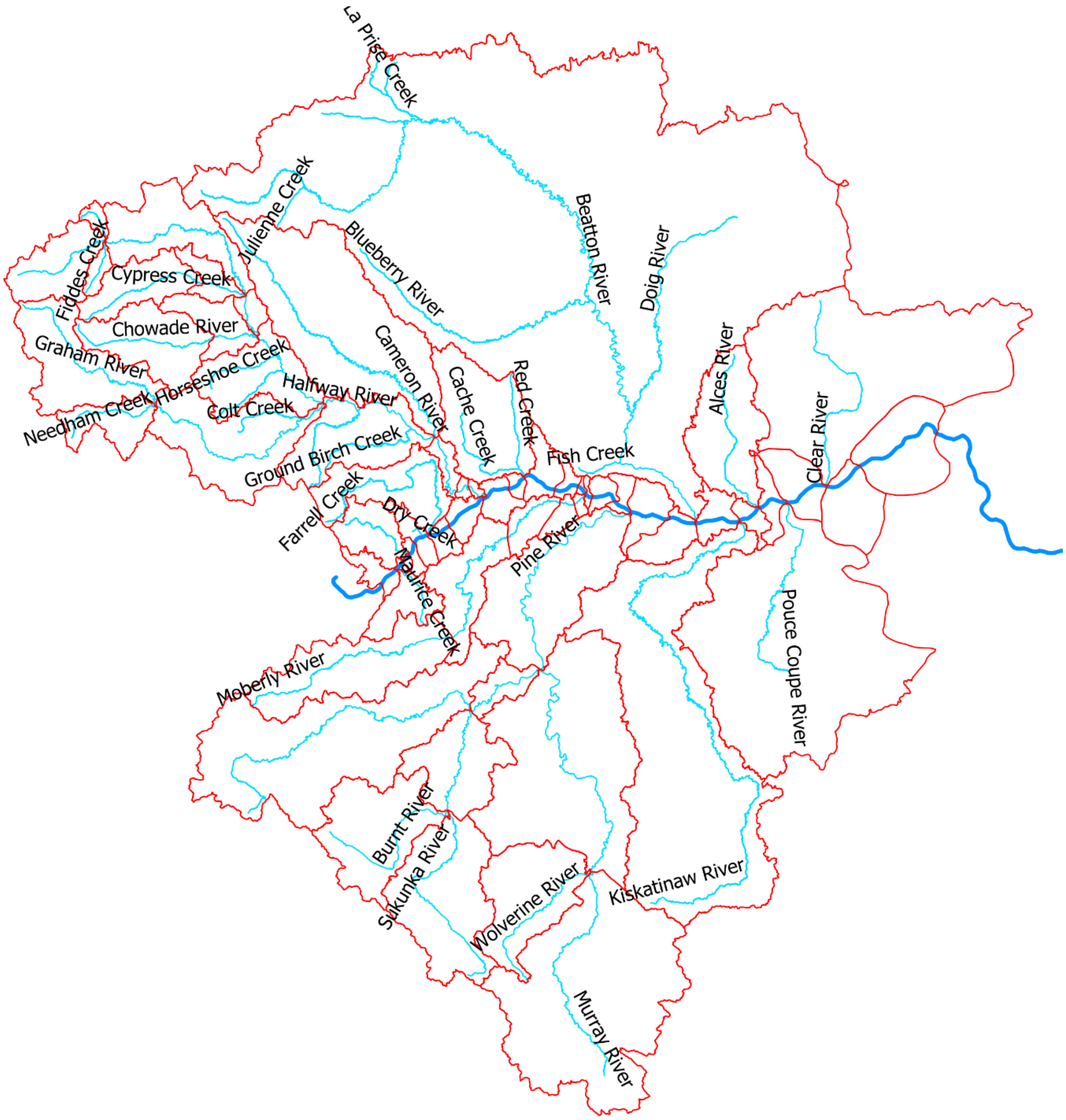


Figure 7. **Mobile tracking zones (polygons with red borders) overlain on the Peace River (dark bold blue) and its major tributaries (lighter blue). Zones were defined by watershed boundaries, and the positions of the fixed-station receivers.**

Data 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 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. Lastly, 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 (Table 7). 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, Figure D1 & Figure D2). Prior detection records at fixed-stations were utilized 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 detection event[28]. 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 hasn't 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 run through a GIS script that assigned each detection a river kilometer (RKM) reading. Next, the detection data were reorganized into a movement-focused format in which each data row represented a recorded movement and defined the change in time and space between each successive detections for each individual study fish.

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

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

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/exit behaviours.

Movement distances (in RKM) were categorized, averaged, and then plotted with 95% confidence intervals (Zar 1984)[29]. Mean movement distances were categorized by species, river type, direction, month, and study period. River type is broad and binary category defined by where the movement occurred, i.e., in the Peace River or in a tributary. Direction, another binary category, is defined by the direction of the movement, whether upstream or downstream.

The month in which a movement occurred was estimated as the median timestamp between two detection events. Given the fact that the month estimation loses accuracy as the span between the two detection events increases, a threshold of <45 days between the two detection events was used to filter movements. Study period refers to whether the data collected was from the present (construction phase, 2019 - 2021) or historical study period (pre-construction phase, 1999-2009). This analysis was separated by study period due to differences in Site C construction activity as well as critical differences in study design that affect the resulting interpretations.

Study fish behaviours 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 tributary entrance and exit behaviours per species per month.

For this analysis, three uncontested[30] detections on the upstream antenna meant the study fish was located upstream of that tributary fixed-station, with the opposite true for three uncontested detections on the downstream antenna(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 and tributaries, individual study fish were limited to three tributary interactions per month[31]. Lastly, 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 being identified as expected.

Tributary entrance and exit figures were accompanied with tributary residence time calculations in days, where applicable. Residence times were calculated for individual fixed-stations during particular time blocks to better understand seasonal behaviours at tributary entrances. Residence times were calculated

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

[30] 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.

[31] 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 awarded 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 awarded three interactions to account for their final location (i.e., entry/exit/entry or exit/entry/exit)

for individual study fish; where during a particular time block (i.e., March through June) the entry datetime is subtracted from the exit datetime to get a residence time in days. Note that at some fixed-stations an entry and an exit weren't recorded for the same study fish; in which case residence times could not be calculated.

In general, 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 Site C Project progresses. This approach helps condense a large sum 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 isn't the same every month of the year. Mobile tracking in the Halfway River is designed to capture Bull Trout spawning behaviour between September and October (Appendix D, Figure D2) and the Halfway River #2 and Halfway River #3 fixed-stations aren't operated from December through February (Table 3).

Site C Behaviour

Using the sequential detection records, we were able to determine which fish passed Site C in 2020. Any sequential position histories that showed detections of a fish downstream of Site C, followed by positions upstream of Site C, an 'upstream passage event' was tallied ('downstream passage events' were tallied similarly). The timing of the passage event was set to be equal to the last recorded detection on the fixed-station at Site C (when the fish was detected upon passage), or was interpolated from the timestamps of the upstream and downstream detections (for fish whose passage was not detected). Fish that approached Site C from upstream areas, but immediately returned back upstream (without being detected downstream of Site C) were not considered to have passed Site C (similarly for fish approaching from downstream). The passage events were tallied for each species, by month, and by movement direction.

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 (The 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 2020 spawning individuals. 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[32] and the Moberly River for Peace River Arctic Grayling[33] (Mainstream 2021). Furthermore, prior research on peak spawn timing was utilized for evaluating probable spawning locations[34].

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 the spawning period and beyond.

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 spawn location and resides in this spawning location before migrating back downstream and eventually exiting the tributary. A modification to this paradigm includes any individuals that potentially residualized in their spawning tributary either before or after a potential spawning event. In which case, spawn location was based on the identification of any pre- or post-spawn behaviors along with the application of any prior knowledge of peak spawn timing.

[32] 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 Ltd. 2012, TrichAnalytics 2020)

[33] 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 and Beatton rivers (Mainstream 2012, TrichAnalytics 2020).

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

Results

Data Collection

The fixed-station array and mobile tracking effort collected over 14 million valid detection records that passed the filtering criteria between 1 January 2020 and 31 January 2021 (Table 6). Starting in January 2020, data collection solely occurred at the five fixed-stations that were operated overwinter (Site C, Moberly River #1, Halfway River #1, Cypress Creek, and Chowade River). The rest of the array was operational throughout the remainder of the year. Following November 2020, the array was reduced to three fixed-stations (Site C, Moberly River #1, Halfway River #1). 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 96% of the time between 17 April 2020 to 11 November 2020 with the remaining 4% resulting from minor receiver-specific interruptions (Table 7). Most outages were from low light conditions in the fall or winter, which meant the solar panels could not collect enough power to maintain the charge of the battery bank. Vandalism at Peace River #8 resulted in some data loss in late October to early November. Some data losses were incurred in April 2020 when deployment at four fixed-stations had incorrect solar installations. The most peculiar outage was at Halfway River #3, where the fixed-station was deployed in mid-May, and then high water prevented the station from being checked in June or July. When the fixed-station was finally serviced for the first time in August, the SRX appeared to be fully charged and functional, but no data had been recorded to the memory banks. A new receiver was swapped in, and the questionable receiver was serviced by Lotek.

Mitigating for fixed-station outages is a priority as the telemetry system operates in support of numerous Mon-1b Tasks; including but not limited to Task 2a and Task 2d. Outages from low-light conditions after October require pre-emptive and more frequent maintenance visits, especially in higher risk locations with low solar exposure. Data loss from incorrect wiring and solar installation are mitigated with the addition of more expansive QA/QC measures from installation crews to ensure the setup will operate as intended. Finally, SRX failure like that at Halfway River #3 can be mitigated with expedited range test analysis.

Table 6. Counts of valid detection records and unique codes (individual study fish) detected at each receiver from 1 Jan 2020 to 31 Jan 2021.[35]

Station #	Station Name	Valid Count	Unique Codes
1 & 2	Peace River 1A & 1B	24,261	38
3	Peace River 2	18,901	41
4	Pouce Coupe River	141,550	22
5 & 6	Kiskatinaw River & Peace River 3	434,977	66
7	Beatton River	1,162,412	74
8	Peace River 4	2,080,699	109
9	Pine River	38,456	36
10 & 32	Peace River 5 & INS Mainstem 1	334,338	99
11 & 33-41	Site C Dam	3,676,339	108
12	Moberly River 1	173,363	30
13	Moberly River 2	9,371	13
14	Moberly River 3	1,018	13
15	Peace River 6	109,117	70
16	Peace River 7	1,892,534	84
17	Cache Creek	38,899	5
18	Peace River 8	827,505	83
19	Halfway River 1	16,759	42
20	Halfway River 2	4,485	29
21	Halfway River 3	93	2
29	Chowade River	4,106	9
30	Cypress Creek	87	1
22	Peace River 9	59,055	36
23	Farrell Creek	335,058	33
24	Peace River 10	122,301	44
25	Lynx Creek	1,547	1
26	Peace River 11	2,391,715	61
27/31	Maurice Creek	54,339	40
28	Peace Canyon Dam	2,257	7

Table 7. Outage start date, end date, days offline, and notes for all fixed-stations that experienced an outage from 1 Jan 2020 to 31 Jan 2021. Further dissections into outages are displayed in beacon tag detection plots in Appendix B (Figure B4)

Station Name	Outage Start	Outage End	Days Offline	Note
Site C	17 January 2020	19 January 2020	2	Low Light Conditions
Halfway River #1	7 February 2020	18 April 2020	71	SRX improperly wired
Cache Creek	5 May 2020	7 May 2020	2	Incorrect Solar Install
Peace River #9	6 May 2020	14 May 2020	8	Incorrect Solar Install
Peace River #10	7 May 2020	14 May 2020	7	Incorrect Solar Install
Lynx Creek	7 May 2020	14 May 2020	7	Incorrect Solar Install
Halfway River #3	15 May 2020	10 August 2020	88	SRX Failure
Maurice Creek	10 October 2020	14 October 2020	4	Low Light Conditions
Halfway River #3	14 October 2020	17 October 2020	4	Low Light Conditions
Peace River #8	22 October 2020	6 November 2020	16	Vandalism
Peace River #7	2 November 2020	10 November 2020	8	Low Light Conditions

[35] Note that some stations are grouped together to create a detection gate that can detect passing fish from both sides of the river (Station #'s 1&2, 5&6, 10&32). Similarly, Site C Dam is a group of overlapping fixed-stations including the single fixed-station operated by LGL Limited (#11) as well as the nine fixed-stations operated by Instream Fisheries Research (#'s 33-41). A slash with two station names denotes a fixed-station that was moved between study years (i.e. Maurice Creek, #27 in 2019 and #31 in 2020).

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. Each fixed-station antenna is tested individually using both the smallest tag in the study (the low power tag) as well as the largest tag in the study (the high power tag)[36]. Due to constraints that stemmed from the COVID-19 pandemic, only nine of the 30 fixed-stations deployed in 2020 were range tested. The remaining fixed-stations that were not range tested in 2020 were tested in 2019 while in an identical configuration (Hatch et al. 2020). Additionally, all 2020 stations were tested for basic range functionality[37] on deployment and were analyzed *post-hoc* to determine detection efficiency. All nine range tested fixed-stations were located downstream of Site C (Figure 8).

Every fixed-station is at least 15m from the river or creek with many located 100m or more from testable areas that are >1m deep (Table 8). This limited the range test analysis near the fixed-station which affected the underlying shape of the logistic curve and the resulting range test statistics (Figure 8). Furthermore, the range tests do not account for the orientation of the antenna, noise events during the test or from objects in the environment that can shadow detections. All of which have the potential to flatten the prediction curve and create unexpected test results.

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 2019, some fixed-stations (e.g., Peace River #3) exhibited flat trends. The range tests at Pouce Coupe Antenna 1 and 2 were conducted too far (>200m) from the respective antennas to fit a typical detection probability curve (Table 8). Also, the model fits did not produce reliable inflection point estimates for Peace River #5 Antenna 1, or for the low power tag tested at Peace River #6 Antenna 2. The lack of a reliable inflection point doesn't immediately indicate antenna malfunction as both tests still yielded expected detections at distances >400m (Figure 8). The unexpected detection probability curve is more likely due to the influence of an unaccounted variable during the test; such as, noise events or environmental shadowing.

Antennas in which detection range was calculated at 50% detection probability for both high and low power tags (Table 9) were isolated for comparative analysis. Using the range tested fixed-stations (n = 9), the high power tag averaged 195 m (± 57.54 m) and the low power tag averaged 273 m (± 54.89 m). Although the low power tags recorded a higher mean range, the overlapping spread from the 95% confidence intervals indicates that these averages are not statistically different (Zar 1984). 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 not yet been validated or refuted by the available data.

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[36] 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/).

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

Table 8. **Completion of a successful range test by study year (Yes, No or NA) as well as the approximate minimum distance from the fixed-station antennas to the range test area.**

Fixed-Station Name	Successful Range Test 2019	2020	Minimum Distance from Antenna to Testing Area (m)
Peace River #1A	Yes	Yes	75
Peace River #1B	Yes	Yes	75
Peace River #2	No	Yes	50
Pouce Coupe River	Yes	Yes	250
Peace River #3	Yes	Yes	50
Kiskatinaw River	Yes	Yes	175
Beatton River	No	No	200
Peace River #4	Yes	No	250
Pine River	Yes	Yes	75
Peace River #5	Yes	Yes	125
Site C Dam	No	No	75
Moberly River #1	Yes	No	175
Moberly River #2	*NA*	No	75
Moberly River #3	*NA*	No	50
Peace River #6	Yes	Yes	75
Peace River #7	Yes	No	150
Cache Creek	Yes	No	25
Peace River #8	Yes	No	75
Halfway River #1	Yes	No	50
Halfway River #2	*NA*	No	100
Halfway River #3	*NA*	No	75
Peace River #9	Yes	No	125
Farrell Creek	Yes	No	75
Peace River #10	Yes	No	75
Lynx Creek	Yes	No	50
Peace River #11	Yes	No	250
Maurice Creek	Yes	No	50
Peace Canyon Dam	No	No	100
Chowade River	Yes	No	50
Cypress Creek	Yes	No	50

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 2020. See Figure 8.**

Station #	Station Name	Antenna	High Power Tag	Low Power Tag
1	Peace River #1A	1	122 (36)	-
1	Peace River #1A	2	57 (8)	-
2	Peace River #1B	1	100 (28)	-
2	Peace River #1B	2	92 (11)	-
3	Peace River #2	1	270 (69)	-
3	Peace River #2	2	205 (32)	-
4	Pouce Coupe River	1	222 (6)	150 (48)
4	Pouce Coupe River	2	-	-
5	Peace River #3	1	227 (69)	431 (77)
5	Peace River #3	2	342 (29)	650 (127)
6	Kiskatinaw River	1	138 (6)	156 (14)
6	Kiskatinaw River	2	70 (116)	205 (83)
9	Pine River	1	129 (12)	186 (10)
9	Pine River	2	142 (10)	203 (17)
10	Peace River #5	1	-	-
10	Peace River #5	2	177 (21)	212 (15)
15	Peace River #6	1	306 (9)	261 (21)
15	Peace River #6	2	312 (7)	-

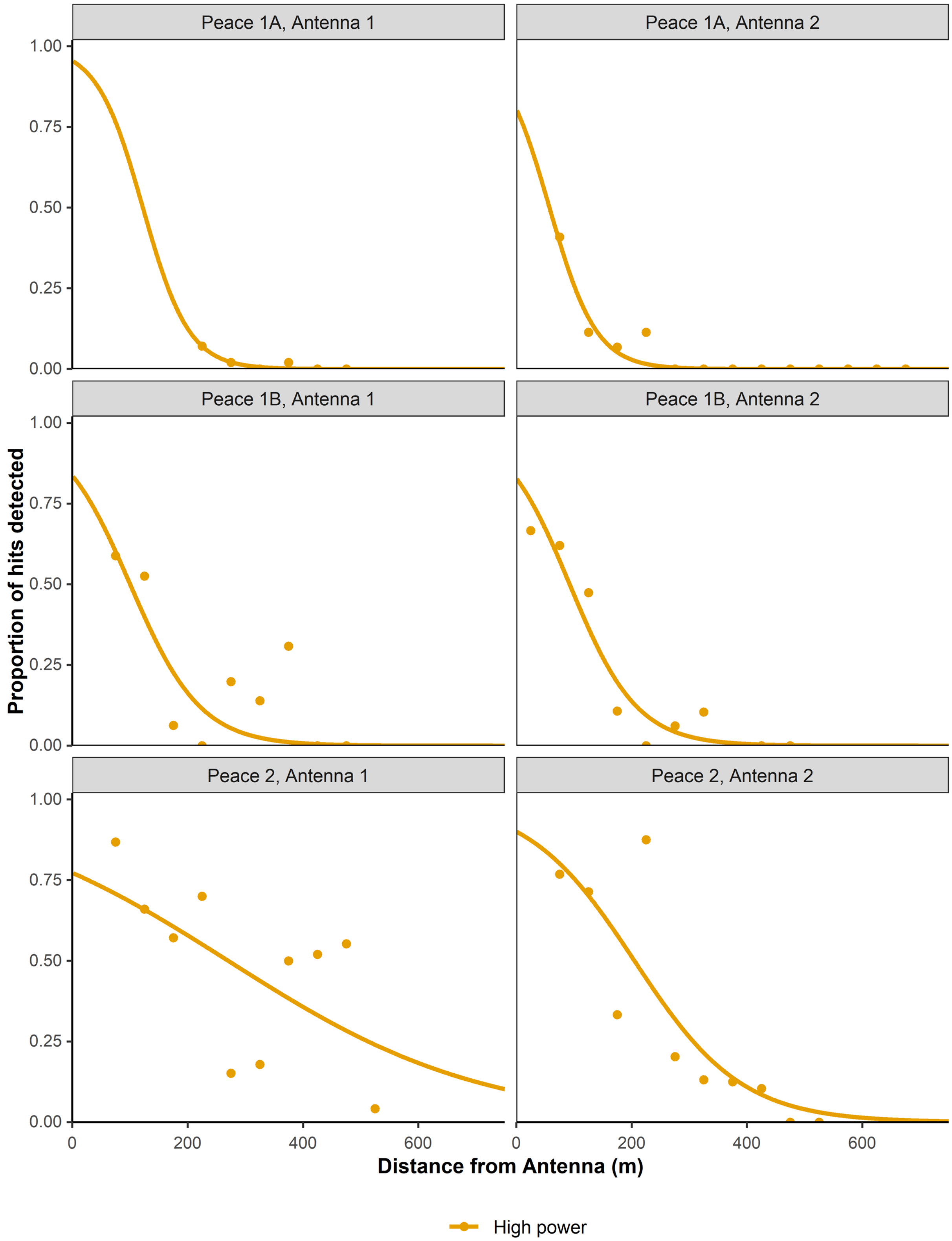

Figure 8. **Range test results for specific antennas at fixed-stations tested in 2020. Figure continues on following two pages.**

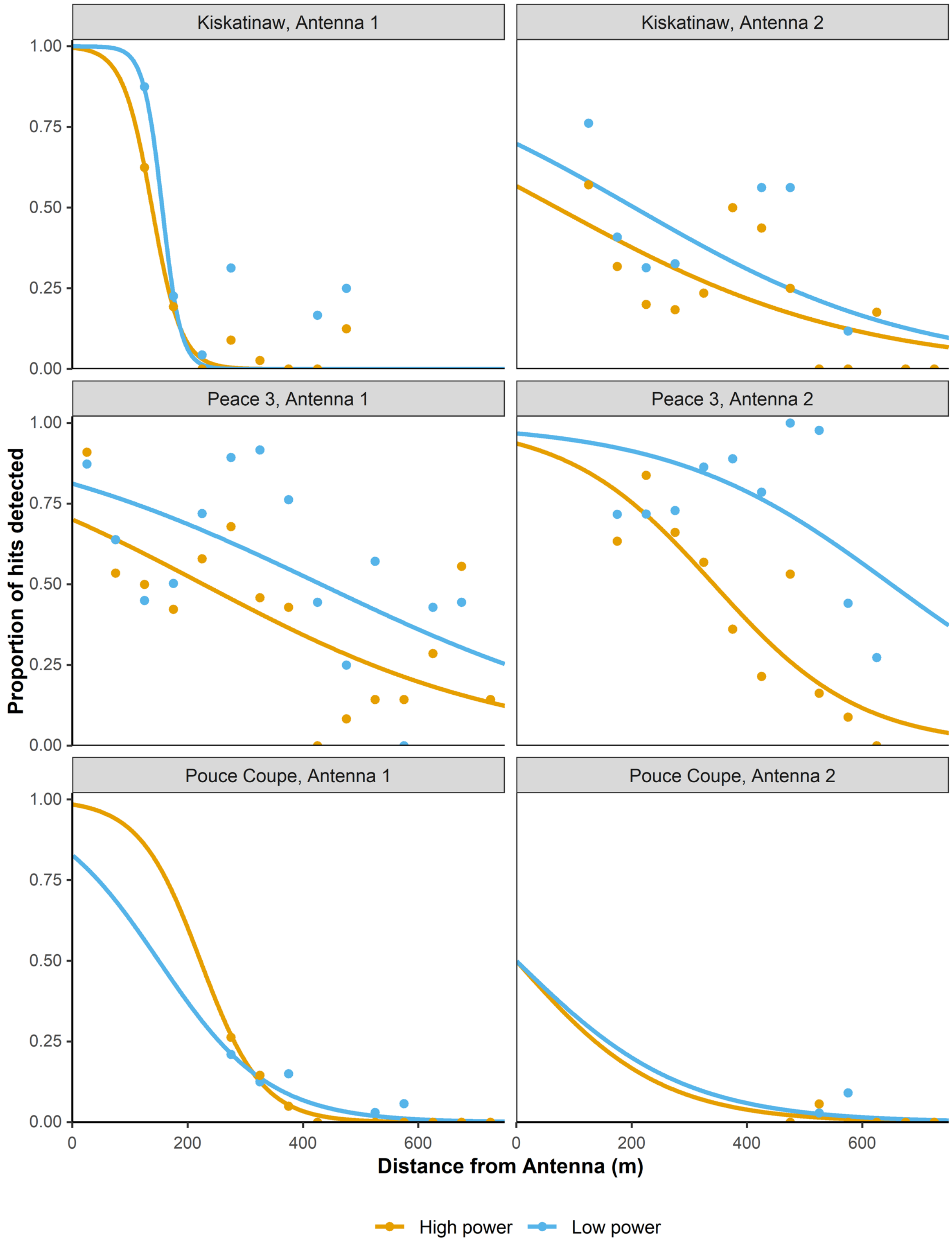

Figure 8 continued (page 2 of 3).

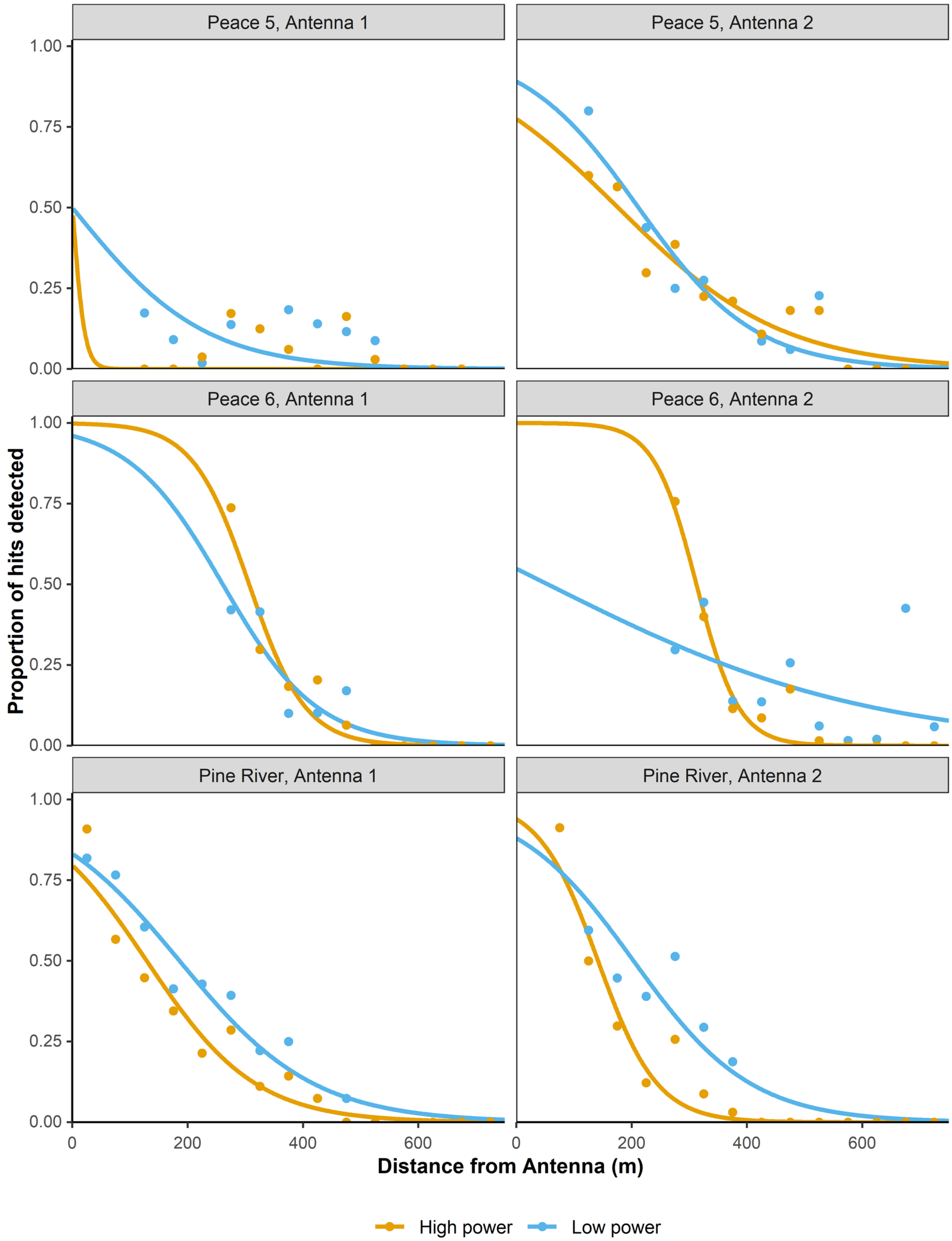

Figure 8 continued (page 3 of 3).

Fixed-Station Detection Efficiency

Detection efficiency[38] was calculated *post-hoc* to compliment detection probability[39] in evaluating and validating the fixed-station array (Adams et al. 2012, Kessel et al. 2014). Detection efficiencies were between 83.3% and 98.3% for the majority of fixed-stations or combinations of fixed-stations (Figure 9).

The primary exception was Halfway River #3, which yielded a 2020 detection efficiency of 6.4% (Figure 9). The Halfway River #3 fixed-station was not operating effectively from mid-May until mid-August due to a malfunctioning SRX-800 receiver. The malfunctioning receiver was replaced in mid-August and began recording operational battery checks and beacon tag detections which implied functionality through-out the remainder of the season. However, when detections at Halfway River #3 were analyzed using the complete detection history of passing study fish (i.e., the detection efficiency analysis) it became apparent this fixed-station was not operating optimally throughout 2020.

Detection efficiency at the Site C fixed-station decreased over the spring and summer of 2020 (Figure 10). The issue was not equipment related; noise increased as construction continued, and detection power decreased as the river was diverted away from the antenna locations. In addition, collisions probably increased as more fish milled downstream of the construction area, and as numbers of additional tagged fish were released into the system, in particular near Site C. Site C detection efficiencies began to rise again in July 2021 following the aforementioned decline (Figure 10). This rise was due to the deployment of additional fixed-stations that were pooled and analyzed together, thereby increasing the detection efficiency in lieu of the changing landscape (Figure 10). These additional receivers were deployed as part of the Site C Fishway Effectiveness Monitoring Program (Mon-13).

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

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

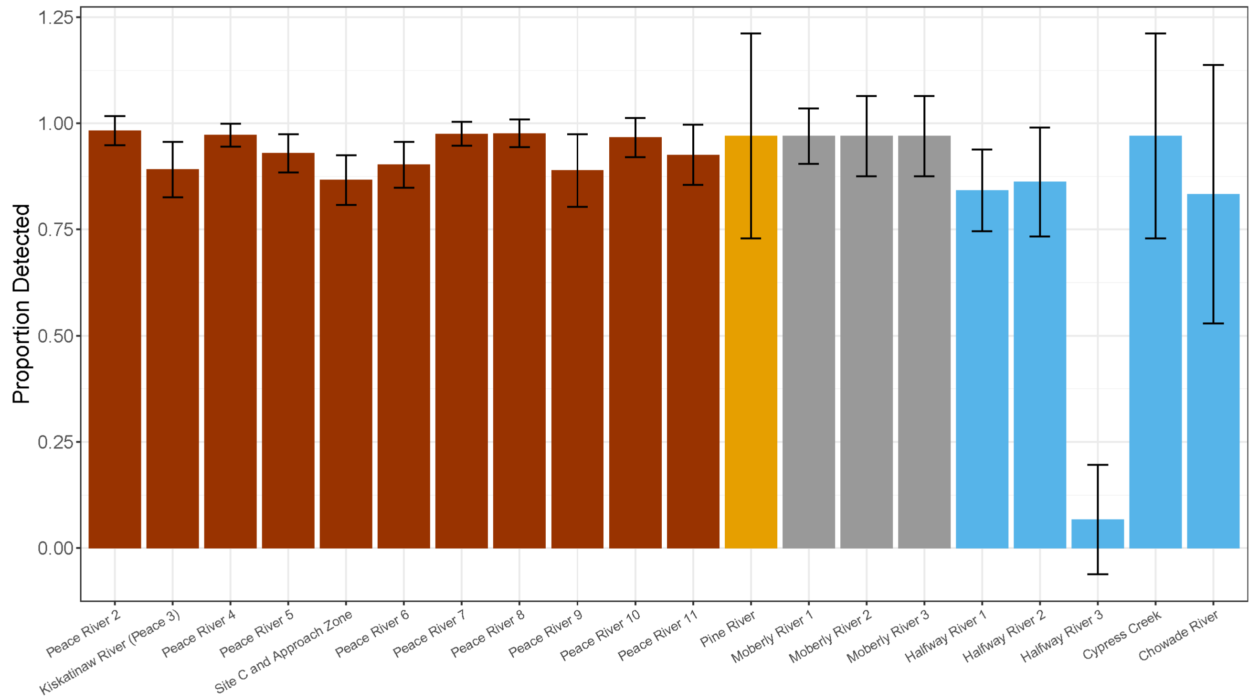

Figure 9. **Detection efficiency by fixed-station for 2019 and 2020. Error bars show the 95% confidence intervals.**

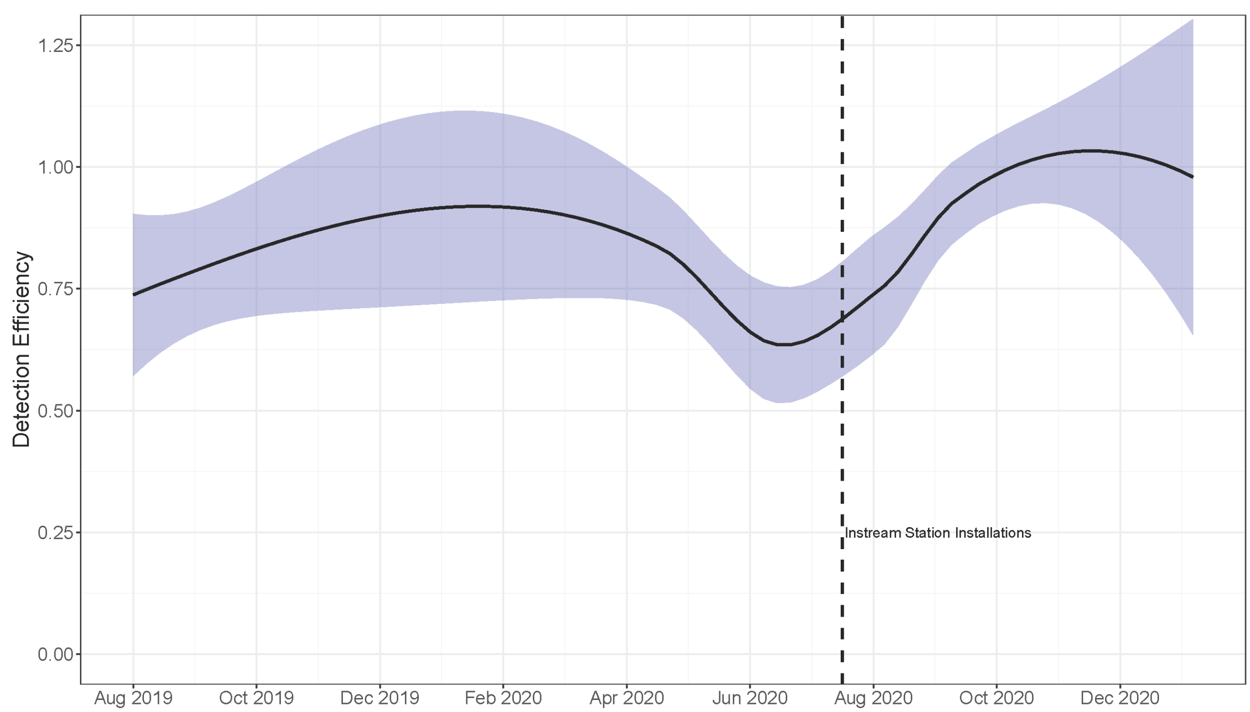

Figure 10. **Detection efficiency at Site C over time. Detection efficiency was smoothed using a 30-day detection efficiency average along with 95% CI intervals calculated from a binomial distribution.**

Mobile Tracking Detection Efficiency

Mobile tracking flights in the Moberly River were very successful (Figure E1). Using prior detection records there was a total of 33 possible detection events in the Moberly River during the five 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[40]. Of the possible 33 detection events in the Moberly River, 31 were detected which yielded a 94% detection efficiency (Table 9). All of the Arctic Grayling tracked within the Moberly River (n= 14) were already present in the Moberly River during the first flight. Following departure from the Moberly River, 50% of Arctic Grayling traveled upstream of Site C in the Peace River (Table 9) while 43% traveled downstream of Site C with one individual (7%) deemed unknown after not being detected following an exit detection at Moberly River #1.

The Halfway River overflights yielded a 69% detection efficiency (Table 10, Figure E2 and Figure E3), having detected 31 of a possible 45 detection events across the four mobile tracking efforts (Appendix D, Figure D2). Of the 22 radio-tagged Bull Trout that travelled at least as far up the Halfway River as the Halfway #3 fixed-station 2020, three were missed by both mobile surveys. Two were detected on the Chowade River receiver without accompanying mobile tracking detections and one was detected on Halfway River #1, #2, and #3 without mobile detections.

Table 10. Locations of radio-tagged Arctic Grayling detections during five Moberly River mobile tracking flights in 2020. 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)	15 May	20 May	28 May	5 Jun	17 Jun	Exit Date (M1)	Moved to
426	10 Apr	Br to M3					16 May	Peace Above C
433	3 Apr	Br to M3	Br to M3	Br to M3			4 Jun	Peace Below C
434	10 Apr	Lk to Br	Lk to Br	Lk to Br			3 Jun	Peace Below C
455	16 Apr	Lk to Br	Lk to Br				26 May	Peace Above C
501	29 Apr	Br to M3	Br to M3	Br to M3	Br to M3		11 Jun	Peace Below C
511	15 Apr	Lk to Br	Lk to Br				25 May	Peace Below C
545	26 Mar	Lk to Br	Lk to Br				26 May	Peace Above C
571	22 Apr	Lk to Br					20 May	Peace Below C
591	16 Apr	Lk to Br	Lk to Br	Br to M3			28 May	Peace Below C
594	18 Mar	M2 to M1	missed	M2 to M1	M2 to M1		15 Jun	Unknown
604	18 Apr	Lk to Br	Lk to Br				24 May	Peace Above C
630	27 Apr	Lk to Br					16 May	Peace Above C
631	11 Apr	Lk to Br					16 May	Peace Above C
657	27 Apr	Lk to Br	Lk to Br	missed	Lk to Br		16 Jun	Peace Above C

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

Table 11. Locations of radio-tagged Bull Trout detections during two Halfway River mobile tracking surveys (each survey taking 2 days to flying to complete) in 2020. 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	4 & 6 Sept Survey	Movement	11 & 15 September Survey	Exit
428	3 Jun 2020	Chowade River	None	Chowade River	Did not
429	1 Jun 2020	missed	-	Chowade River	Did not
437	28 Apr 2020	Cypress Creek	-	missed	20 Sep 2020
444	17 Jul 2020	Chowade River	None	Chowade River	Did not
445	27 May 2020	Halfway River between Cameron and Graham	None	Halfway River between Cameron and Graham	Did not
490	(> Jul 6)	Fiddes Creek	Downstream	Cypress to Fiddes	13 Sep 2020
513	13 May 2020	Cypress to Fiddes	-	missed	10 Sep 2020
528	27 Jun 2020	Halfway River between H2 and H3	None	Halfway River between H3 and Cameron	Did not
538	22 Jun 2020	Cypress to Fiddes	None	Cypress to Fiddes	Did not
540	(11-16 Aug)	Halfway River between Cameron and Graham	None	Halfway River between Cameron and Graham	7 Oct 2020
613	3 May 2020	missed	-	missed (Chowade River)	27 Sep 2020
615	(Jul)	missed	-	Above Fiddes	27 Sep 2020
616	17 Jul 2020	missed	-	Chowade River	23 Sep 2020
634	26 Apr 2020	missed	-	Chowade River	(> 11 Sep)
635	1 May 2020	missed	-	Chowade River	23 Sep 2020
636	5 May 2020	missed	-	Fiddes Creek	(19-21 Sep)
637	13 May 2020	Turnoff Creek	Downstream	Cypress to Fiddes (9/11) Graham to Chowade (9/15)	17 Sep 2020
638	11 May 2020	Fiddes Creek	None	Fiddes Creek	21 Sep 2020
646	27 May 2020	Graham River	None	Graham River	Did not
648	(18-20 Jul)	Chowade River	None	Chowade River	23 Sep 2020
649	20 Jun 2020	missed	-	missed	6 Sep 2020
654	(> 22 Jun)	missed (Chowade River)	-	missed (Chowade River)	3 Oct 2020

Movement Analysis

Magnitude, Seasonality and Direction

Region-wide seasonal movement patterns were interpreted from monthly movement distance and tributary entrance and exit figures, which are presented below by species (Figure 11A through Figure 11F and Figure 12A to Figure 12E[41]).

Arctic Grayling

Notable tributary movements from Arctic Grayling tracked during the present study period (2019–2021) occurred primarily within the Moberly River in April, May and June (Figure 11A and Figure 12A). Directional tributary movements observed during the historical study period (1999-2009) were more protracted, which was likely the result of differences in study design (Figure 11A). In particular, study fish were captured from different populations between the study periods with historical Arctic Grayling being captured from the Halfway and Pine rivers and the present from the Peace River.

Movements in the Peace River were largely downstream in August through November for present period Arctic Grayling (Figure 11A). In the historical period, a similar movement pattern appeared but within the tributaries, which is also likely due to differences in capture location.

Peak Arctic Grayling (present period) entry and exit activity coincided with spawning from April through June at the Moberly River (Figure 12A). Outside of the spring spawning period, there was less significant activity recorded in the Beatton, Kiskatinaw and Pine rivers from September through November (Figure 12A). This is further supported by tributary residence times, where from April to June Arctic Grayling (n = 14)[42] resided in the Moberly River tributary a median of 31.2 days (range= 11.4 - 62.2 days), while from September to November Arctic Grayling (n = 9) resided in the Beatton, Kiskatinaw and Pine Rivers for a median of 0.8 days (range= 0.1 - 7.5 days).

Bull Trout

Present period Bull Trout displayed notable movements in the Halfway River that were upstream in August and downstream in September (Figure 11B). Similar tributary movements were observed in the historical study period, although the patterns were relatively protracted and more distributed, i.e., upstream in May through July and downstream in September through November (Figure 11B). Movements in the Peace River during the present period were largely bi-directional from April through August with a downstream tendency from September through December. During the historical, there was a notable peak in Peace River movement magnitude that occurred in September and was primarily upstream (Figure 11B).

Across all months, Bull Trout exhibited more entrance and exit behaviours at the Halfway River than any other tributary which coincides with known spawning behaviours (Mainstream 2012). However, individual Bull Trout showed a diverse range of activity in multiple other Peace River tributaries spanning numerous months (Figure 12B). Across all months, Bull Trout tributary residence was significantly longer in the Halfway River (median = 101.3 days, range= 0.1 - 147.9, n = 12) and the Pine River (median = 82.9 days, range = 0.1 - 363.0, n = 7) when compared to the Beatton River, Kiskatinaw River, Maurice Creek, Lynx Creek, Farrell Creek and Cache Creek (median = 0.1 days, range = 0.1 - 35.2, n = 30).

[41] Mountain Whitefish tributary activity was not plotted due to insufficient data in 2020.

[42] In this context n refers to the number of individuals that entered and exited the tributary during the analyzed span of time.

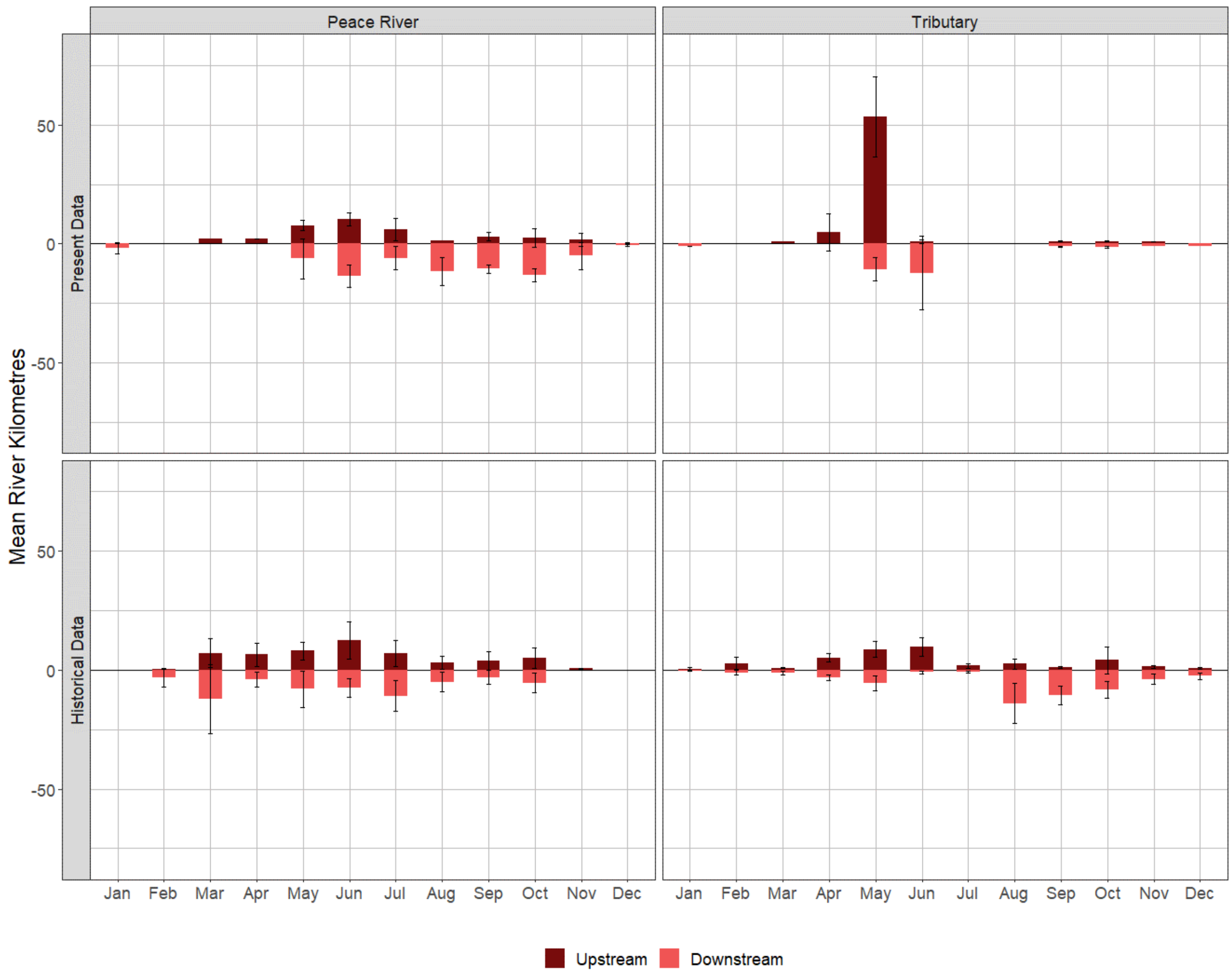

Figure 11A. Mean movements (in RKM) are separated by month for Arctic Grayling in the Peace River and in tributary areas, calculated from the present and historical study periods. Positive values refer to upstream movement and negative values refer to downstream movement. Error bars show the 95% confidence limits. Figure continues in sections B to F, below.

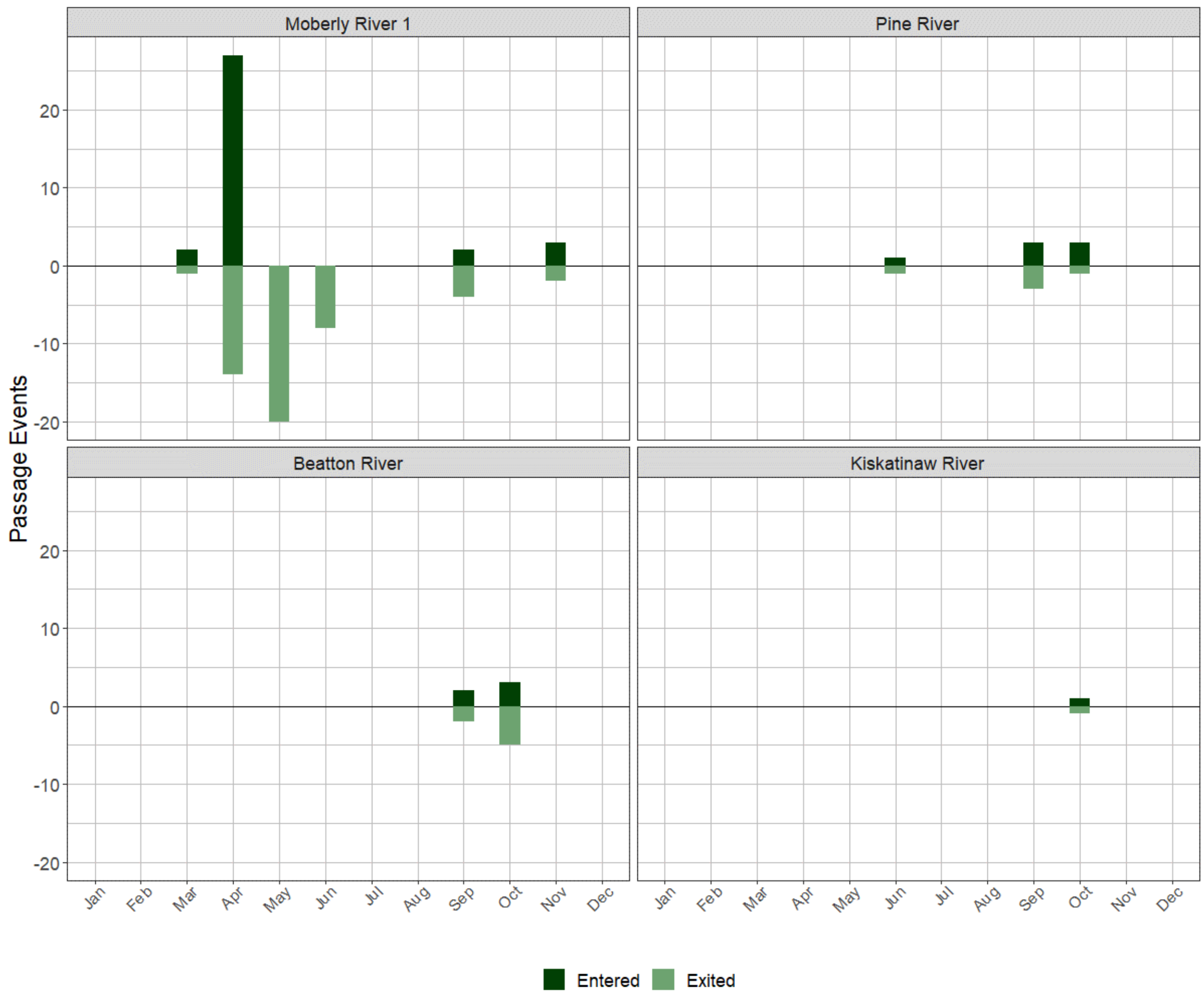

Figure 12A. **Tributary entrance and exit movements for Arctic Grayling were tallied per individual study fish by month. Figure only includes the present data. Figure continues in sections B to E, below.**

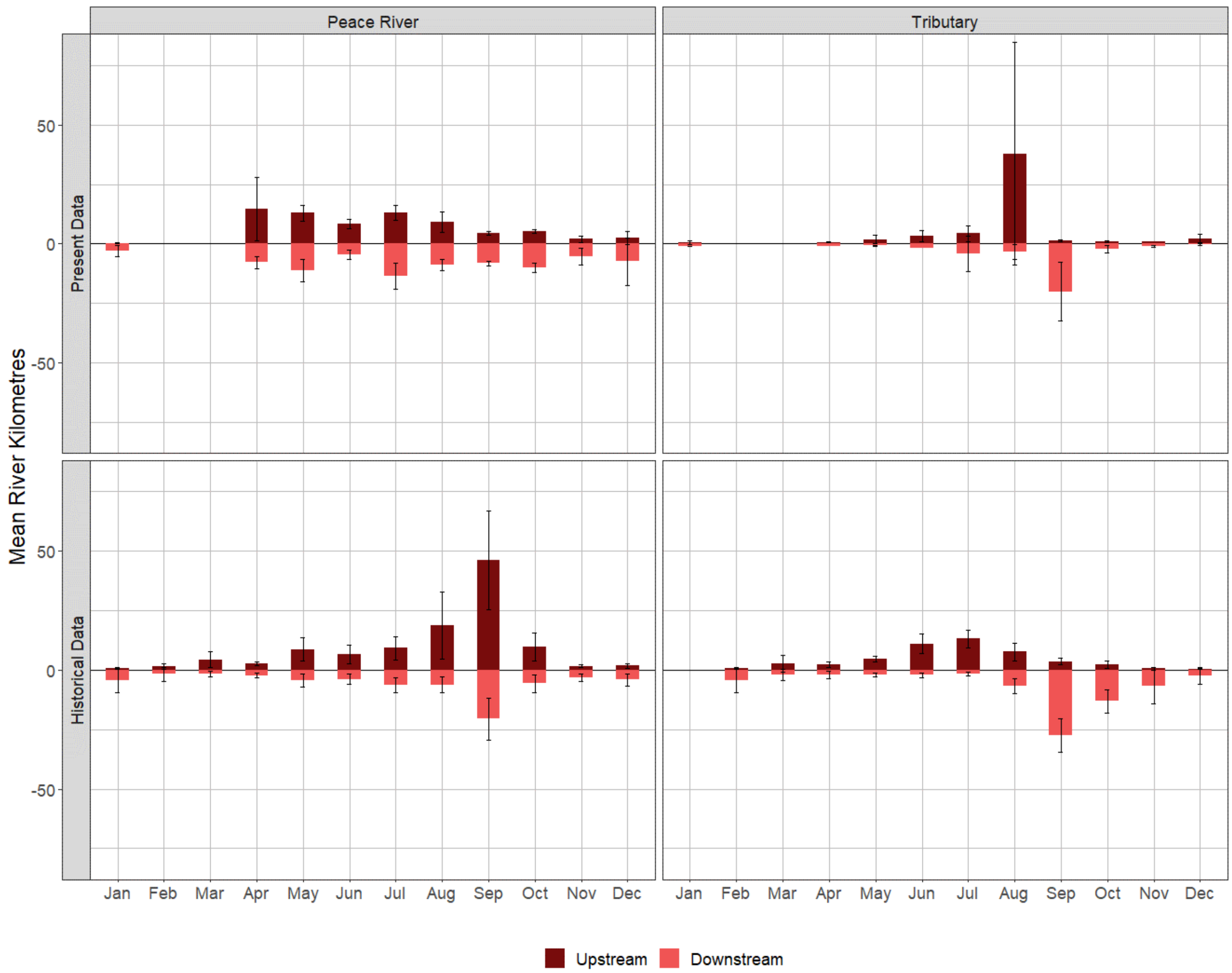

Figure 11B. Bull Trout mean monthly movements. Details as in Figure 11 Error! Reference source not found.**A.**

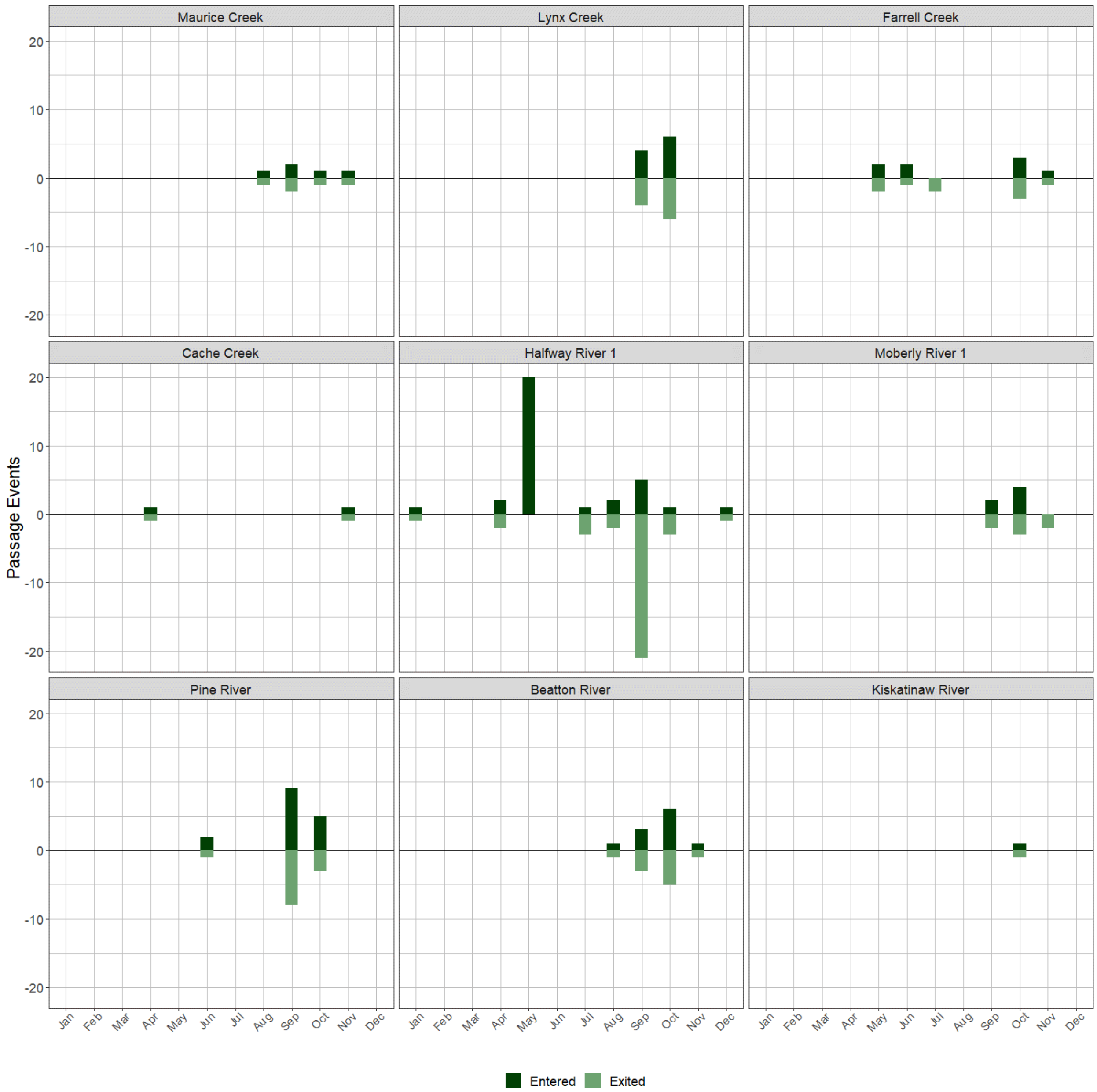

Figure 12B. Monthly tributary entrance/exit movements for Bull Trout. Details as in Figure 12A.

Burbot

Burbot tracks were hampered by relatively few detections that couldn't provide a reliable picture of seasonal movement behaviours (Figure 11C, Figure 12C). 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[43]). All of which was further exacerbated by less fish tagged (n=25).

Some Burbot (n=10) were tracked during winter mobile tracking efforts between 20 November 2020 and 31 January 2021, during which 10 Burbot were detected. Analyzing solely the winter mobile tracking data, Burbot were distributed widely throughout the study area with no specific movement pattern emerging (Figure E4). However, after expanding the analysis to include detections on the fixed-station array, potential downstream oriented movement behaviours emerged on 4 of these Burbot.

Two Burbot recorded moderate downstream movements in the Alberta section of the Peace River fixed-station array, i.e., between Pouce Coupe River and Peace River #1. One Burbot moved 13.9 RKM downstream sometime between 12 October and 20 November 2020. While the second moved 11.8 RKM downstream between 27 August 2020 and 29 January 2021. Unfortunately, a pinpointed datetime of the second movement wasn't available as the movement occurred between two fixed-stations (Peace River #2 and Peace River #1) and this individual eluded five of the six fixed wing winter mobile flights (Table 5).

Two additional Burbot recorded significant downstream movements within the same, Alberta, section of Peace River fixed-station array. One moved 77.4 RKM downstream from the Beatton River to below Peace River #2 (Figure 5) sometime between 31 October 2020 and 19 December 2020. The second moved 116.2 RKM downstream from the Kiskatinaw River to downstream of Peace River #1 (Figure 5) sometime between 27 August 2019 and 19 December 2020. Though that is a long 16-month span, performing this movement while the fixed-station array was operational (April to November) would have required passing the Pouce Coupe, Peace River #2 and Peace River #1 without detection, which is possible but unlikely. Furthermore, the terminal fixed-station (Peace River #1) was configured as a gate with two adjacent fixed-stations on each bank to provide considerable detection overlap. Therefore, it's more feasible that this movement occurred when the fixed-station array was not operational, i.e., during the 2019/2020 or 2020/2021 winter; between 4 November 2019 and 16 May 2020 or 7 November 2020 and 19 December 2020, respectively.

[43] 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.

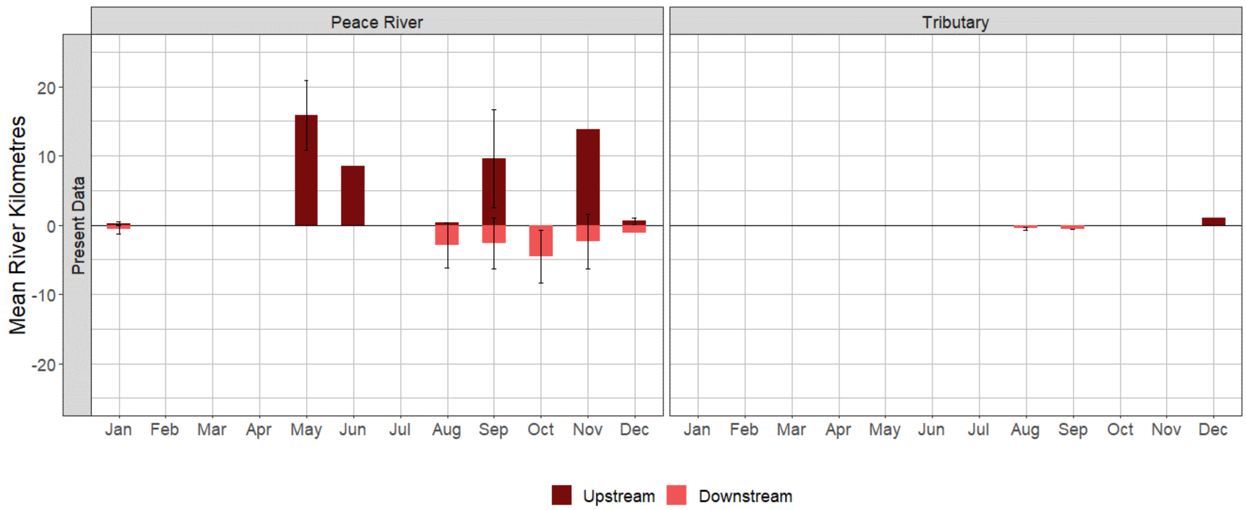

Figure 11C. Burbot mean monthly movements. Note the non-standard Y-axis scale. Details as in Figure 11A.

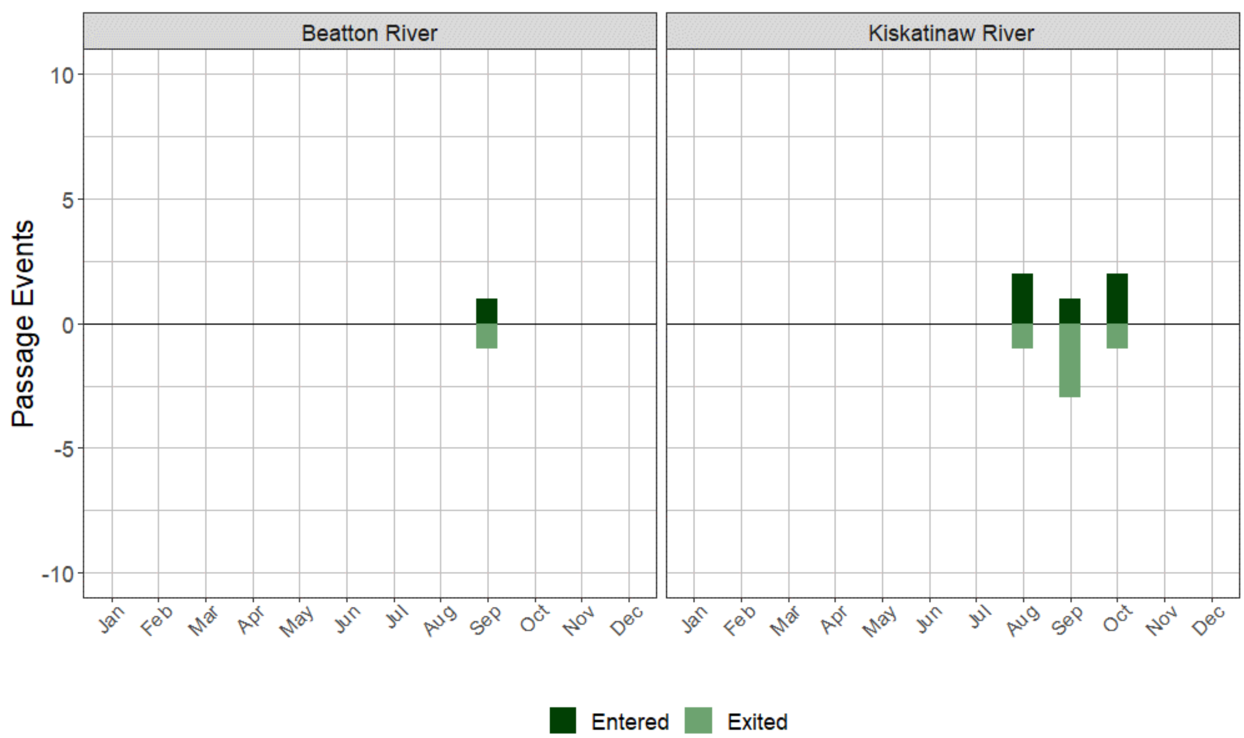

Figure 12C. Monthly tributary entrance/exit movements for Burbot. Details as in Figure 12A

Mountain Whitefish

In 2020, there were 28 Mountain Whitefish that were radio-tagged and released downstream of Site C (Figure A6). Only 12 were detected before every tag battery expired (Figure 2). Following release, all but one of the movements detected was in a downstream direction (Figure 11D). Tributary entrance and exit activity figures weren't generated for Mountain Whitefish due to insufficient available data.

In the historical study period, 116 Mountain Whitefish were tagged in 2006 and all of which were detected for >30 days following release. Similar to 2020, the release locations were all in the Peace River, although the 2006 fish were released at more upstream locations (Figure A7). Most fish remained in the Peace River, although there was some movement into tributaries (Figure 11D). The historical study period recorded 108 winter movements (i.e., "winter movements" were inferred when the last fall detection was distant from the first spring detection), of which 71% (n= 77) were of a distance that was shorter than 5 RKM, despite a few (n= 7) having been longer than 50 RKM.

Across all months, movement distances by Mountain Whitefish were muted, although more movements were noted in June, July and August (Figure 11D). Outside of that, no marked movements in preparation for fall spawning were detected. Fall tracking locations were plotted (Figure E3) and individuals were detected scattered along the Peace River as well as in or around the Halfway, Pine and Beatton rivers. On average, Mountain Whitefish traveled only 3.1 RKM per month which is generally nonmigratory.

Rainbow Trout

Rainbow Trout tributary use that may correspond with spawn timing (upstream movements in May-June, downstream in July-August, Mainstem 2012) was observed during the historical study period but wasn't recorded in the present (Figure 11E). This pattern is likely the result of dissimilar release locations as well as different telemetry data collection methods between each period. In the historical study period half of the tagged Rainbow Trout (n = 28) were released and mobile tracked in the Pine River tributary (Figure A9). In contrast, present period Rainbow Trout (n = 78) were all tagged in the Peace River (Figure A8) and tracked primarily through the fixed-station array. The present study design has limited detection capability within tributaries[44], which may have resulted in unaccounted for Rainbow Trout movements.

Rainbow Trout appear more active in the Peace River during the present study period than the historical (Figure 11E). Although, these differences could be the result of differences in study design. In the present period, it appears Rainbow Trout generally ranged upstream of Site C, near their respective release sites. (Figure 11E, Figure A8).

In the present study period, Rainbow Trout exhibited more entrance and exit behaviours from tributaries upstream of Site C (i.e., Maurice Creek, Lynx Creek, Farrell Creek and Halfway River, Figure 12E). Rainbow Trout spawn in Peace River tributaries in April - May (Mainstream 2012), however tributary entrance and exit behaviours were not isolated to those months alone. Across all months, Rainbow Trout tributary residence was most significant in Maurice Creek (median = 9.1 days, range = 0.2-15.5, n = 5) and the Halfway River (median = 55.9 days, range = NA, n = 1), albeit this was skewed by a long residence from one individual Rainbow Trout. In Farrell and Lynx creeks tributary residence by Rainbow Trout was much shorter (median = 0.1 days, range = 0.0-23.8, n = 10)[45].

[44] Upstream detection capacity in tributaries is considered limited in the present period due to the reliance on detection at specific fixed stations. For a study fish to be detected with an upstream movement in the Moberly or Halfway River they need to pass one of the two upstream fixed station arrays or be mobile tracked during the limited periods of mobile tracking effort. This is different from the methods used during the historical period where mobile tracking was the primary method of telemetry data collection.

[45] Note that Pine River and Beatton River residence times were not calculated because a complete residence cycle by a single individual wasn't available in the data, i.e., an entrance as well as an exit behavior recorded by an individual.

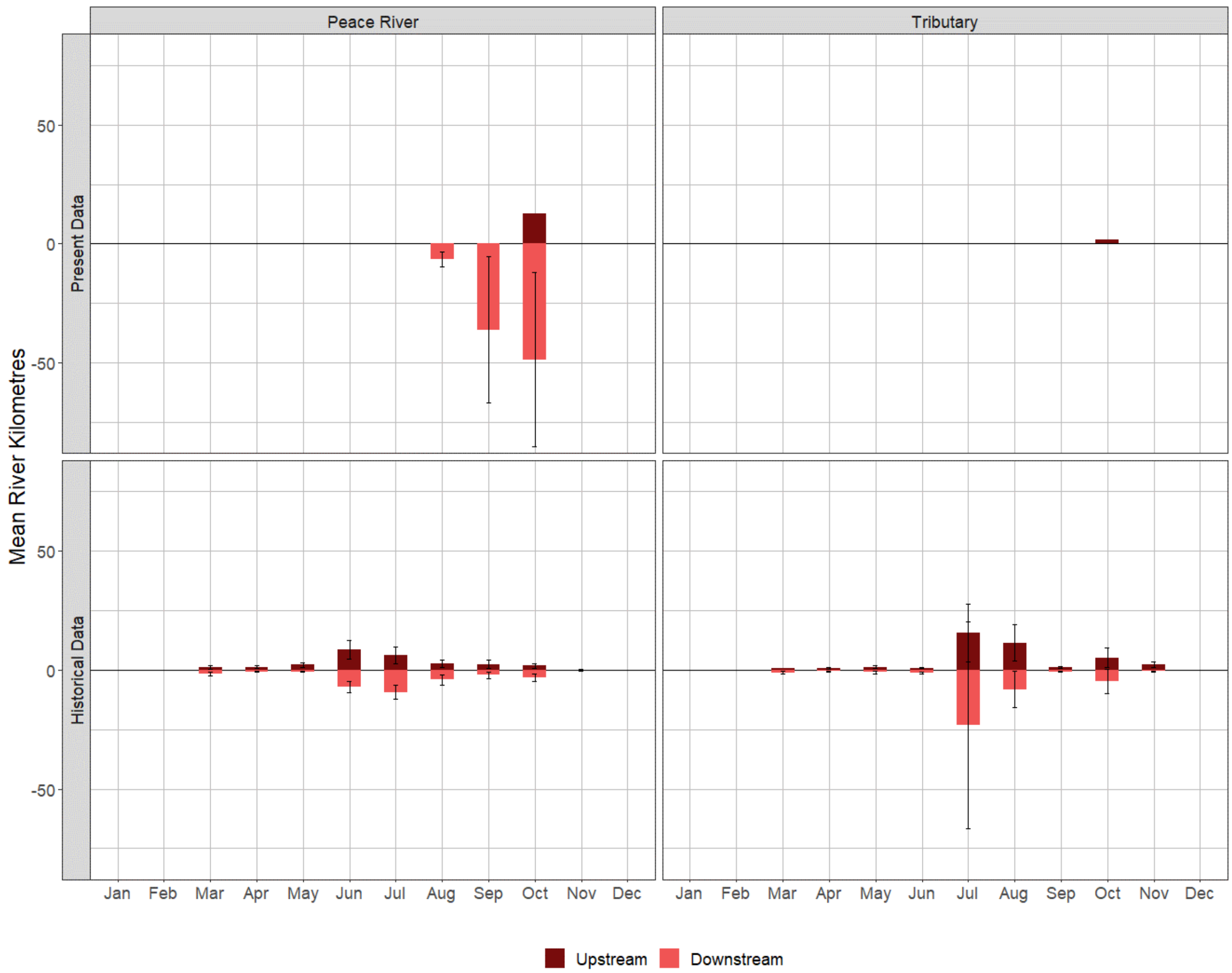

Figure 11D. Mountain Whitefish mean monthly movements. Additional details as in Figure 11A.

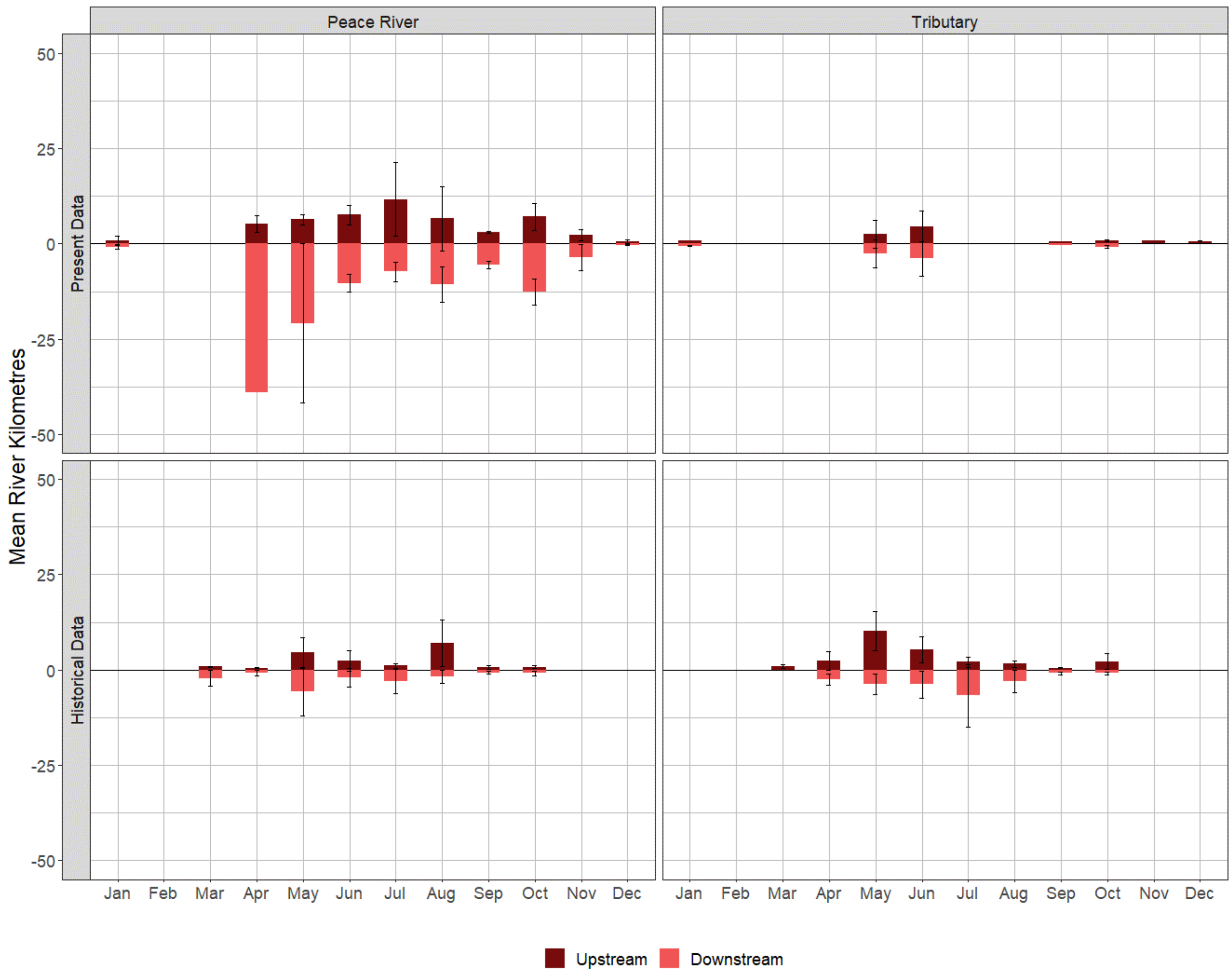

Figure 11E. Rainbow Trout mean monthly movements. Details as in Figure 11A.

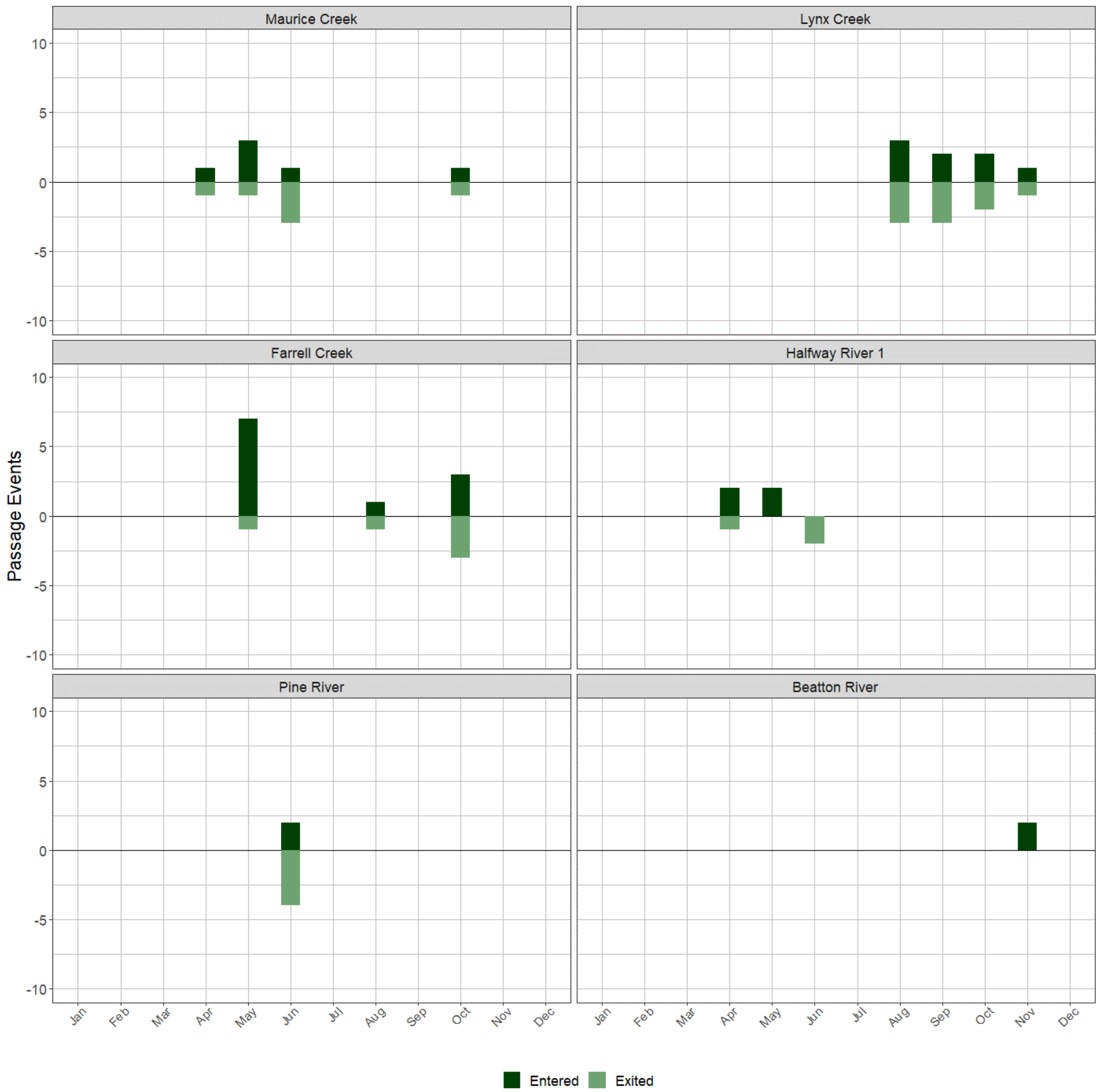

Figure 12D. Monthly tributary entrance/exit movements for Rainbow Trout. Details as in Figure 12A

Walleye

Walleye movements in tributaries during the historical period followed a trend that supports fall spawning behaviour with upstream movements in March-April followed by downstream movements in June-July (Figure 12E). The present study period didn't capture the same trends largely due to limited detection capacity within the Beatton River; a tributary that is known to be important for Peace River Walleye (Mainstem 2012, Figure 12E). Starting March 2021 Beatton River Walleye mobile tracking surveys will be conducted to capture these movements.

Walleye from the present study period were more active in the Peace River from May to August with a tendency for upstream movements (Figure 11F). Conversely, present period Walleye were generally less active from September to January with a downstream tendency (Figure 11F). In the historical study period, Peace River movements were generally more muted with less seasonal trends. Present period Walleye capture and release locations (n = 65) were more distributed across the Peace River than in the historical which could affect seasonal movement trends (Figure A10 and Figure A11).

As expected, Walleye tributary entrance and exit behaviours was focused at the Beatton River fixed-station and was generally more frequent downstream of Site C, i.e., the Pine, Beatton, and Kiskatinaw rivers (Figure 12E). Entrance and exit behaviours at the Beatton River fixed-station peaked in September-October. As mentioned, a majority of Peace River Walleye are expected to spawn in the Beatton River in March-May (Mainstream 2012); a period that wasn't captured by the Beatton River fixed-station which wasn't operational until 18 May 2020.

From March through July, Walleye tributary residence was longest in the Pine River (median = 78.0, Range = 1.4 – 123.2, n = 11) followed by the Kiskatinaw River (median = 1.3, Range = 0.0 – 7.5, n = 11) and the Beatton River (median = 0.2, Range = 0.0 – 18.5, n = 12). Similarly, from August through November Walleye tributary residence was longest in the Pine River (median = 10.2, Range = 0.7 – 58.1, n = 9) and the Beatton River (median = 4.6, Range = 0.0 – 366.5, n = 11), followed by the Kiskatinaw River (median = 0.6, Range = 0.0 – 3.3, n = 13). Walleye are known use the Pine River along with other Peace River tributaries for feeding during warmer water conditions (i.e., June through September), which is corroborated by entry and exit patterns on Figure 12E and accompanying residence times.

Site C Behaviour

Passage at Site C varied by species and month (Figure 13). From December-February, passage activity was muted and largely in the downstream direction. Upstream passage events were more common from April-June during both study periods for Arctic Grayling, Bull Trout, and Walleye. From June-August, upstream and downstream passage activity generally decreased and appeared balanced for most species and both study periods. Lastly from September-November Site C passage was largely in the downstream direction. In the present period, no Mountain Whitefish passed Site C in either direction which was likely the result of the release locations (Appendix A) and low sample size (n= 28).

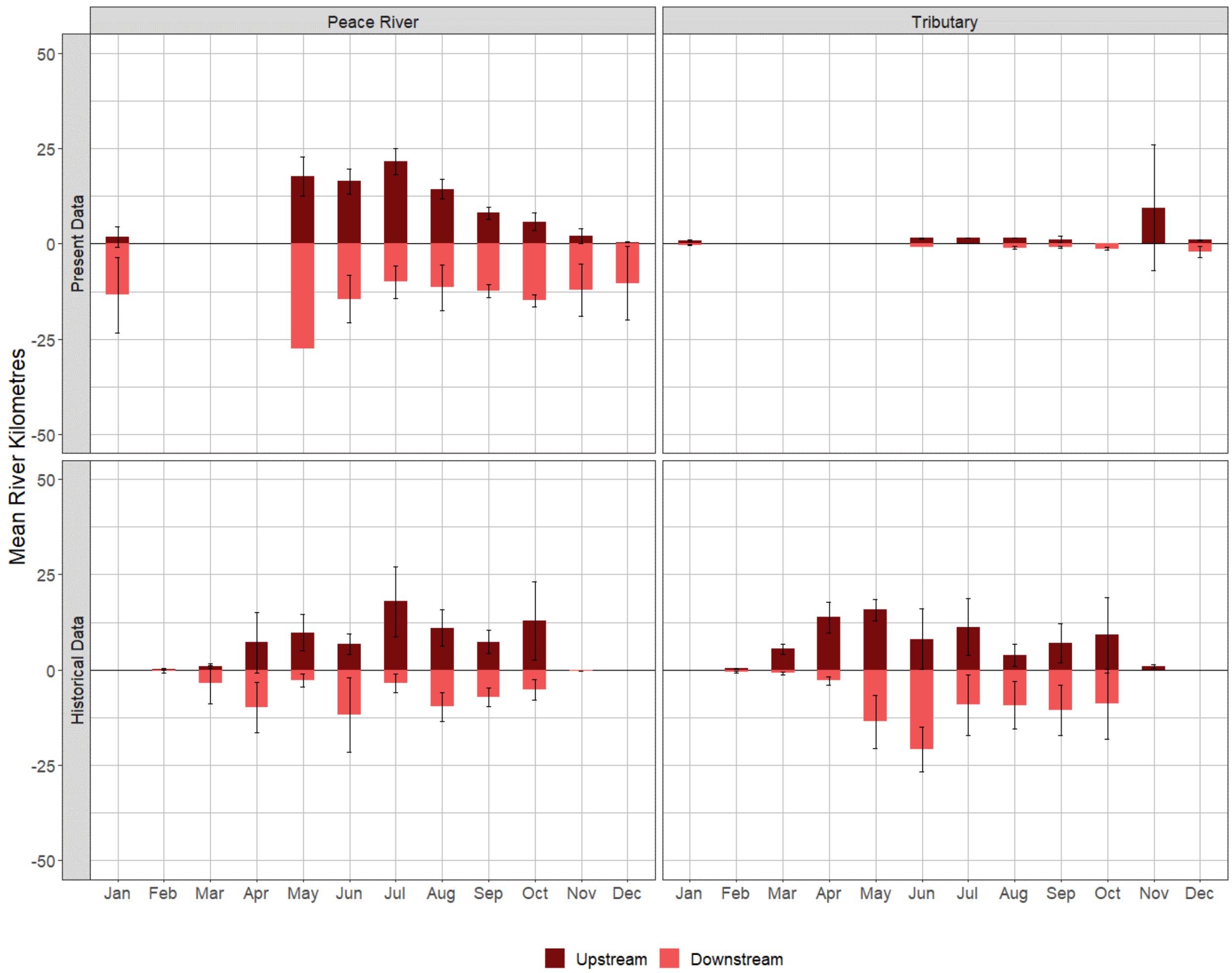

Figure 11F. Walleye mean monthly movements. Details as in Figure 11A.

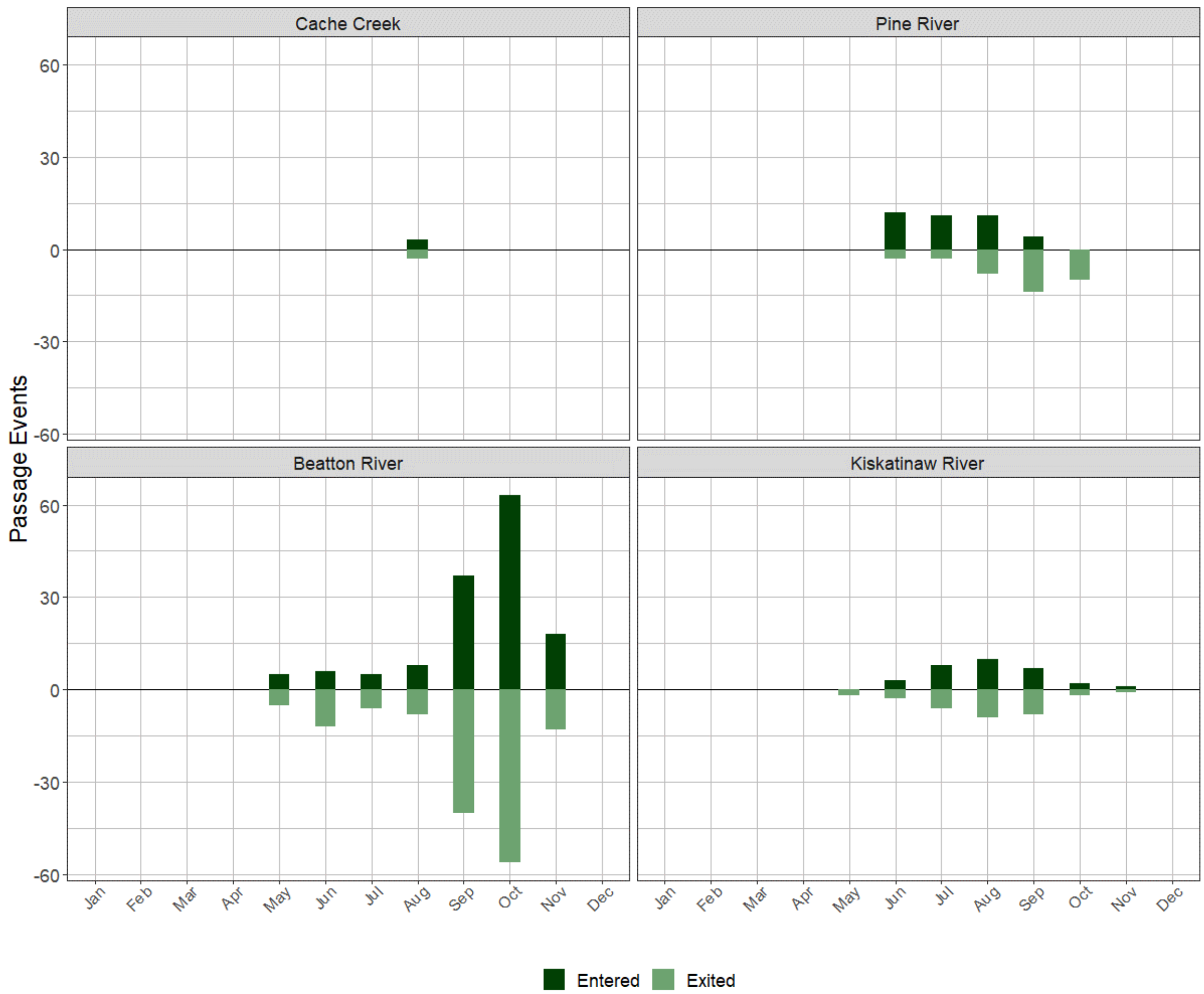

Figure 12E. Monthly tributary entrance/exit movements for Walleye. Details as in Figure 12A

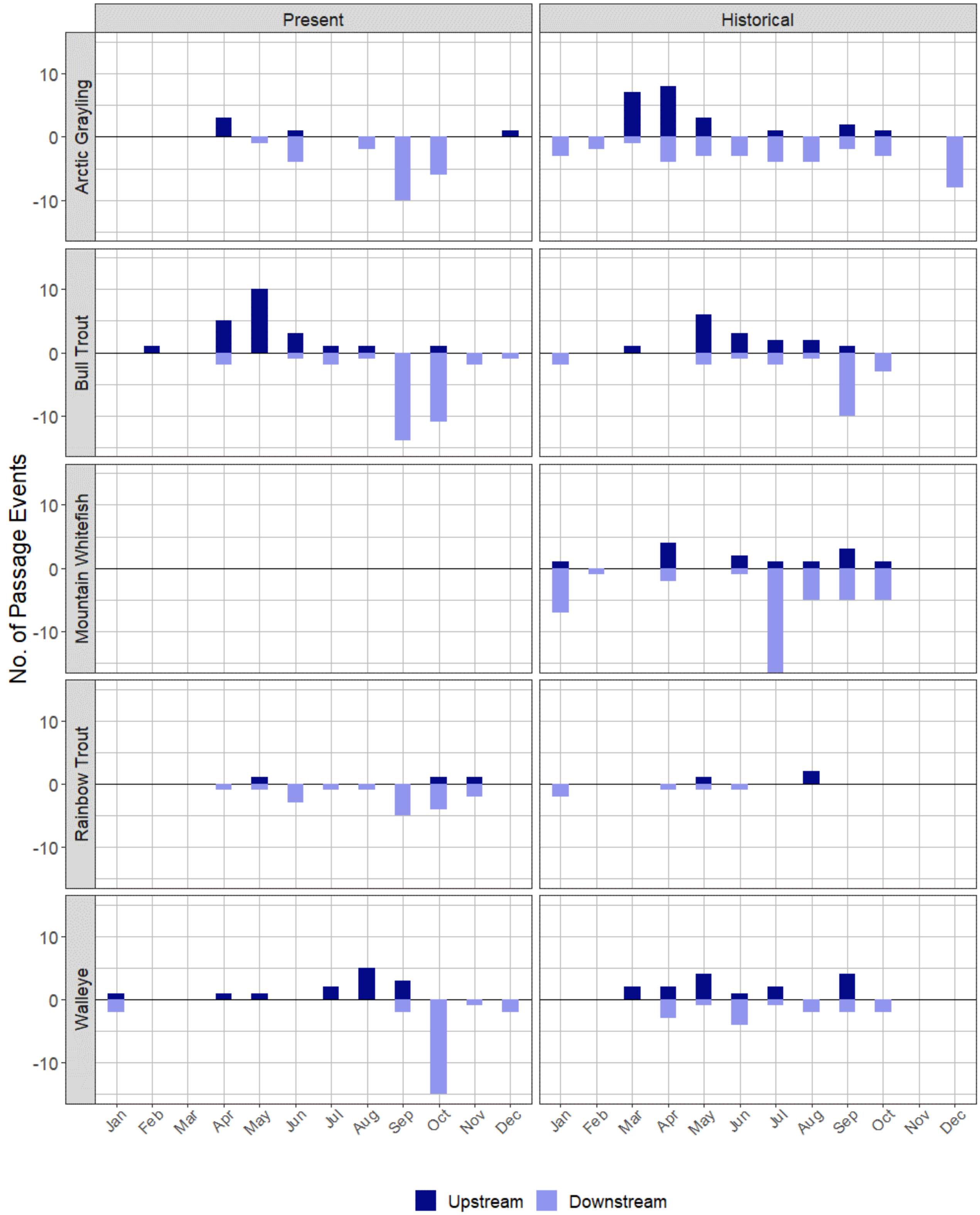

Figure 13. **Counts of adult study fish that passed Site C, by species, month, direction (dark = upstream; light = downstream), and data period. Negative values on Y axis denote counts of fish that moved downstream past Site C.**

Spawn Timing and Distribution

The Arctic Grayling spawning evaluation identified 14 individual Arctic Grayling that exhibited probable spawning behaviours during the 2020 spawning period from late April to early June (Figure 14A, Figure E1). This represented 70.0% of the 20 Arctic Grayling adults that were still actively being tracked during the spawning period. All of the identified spawning behaviours occurred in the Moberly River with a mean distance traveled upstream of 45.8 RKM (range = 1 - 109 RKM). Only one Arctic Grayling that entered and exited the Moberly River during spawning remained within the 12 RKM inundation zone; detected at only 1.5 RKM upstream by mobile tracking on 15 May 2021. The remaining 13 Arctic Grayling recorded in the Moberly River during spawning (92.8%) were all detected at least once at an upstream location that was above the predicted inundation zone.

All 14 Arctic Grayling entered the Moberly River from the Peace River and returned to the Peace River following spawning. The median date an Arctic Grayling entered the Moberly River was 23 April 2020 (range: 18 March 2020 to 29 April 2020) and the median exit was 25 May 2021 (range: 16 May 2020 to 16 June 2020, Figure 12A). Spawning behaviours appeared to peak in the Moberly River sometime around 15 May to 20 May 2020 with 71.4% of Arctic Grayling appearing to spawn between RKM 30 and 80 (Figure 14A, Figure E1).

There were six adult Arctic Grayling that either did not spawn in 2020 or spawned in areas without sufficient detection coverage. One of these individuals was confirmed to have resided in the Peace River during the spawning period, while the remaining five were last detected in the lower reaches of the Peace River fixed-station array between Peace River #4 (134 RKM) and downstream of Peace River #1A/1B (231 RKM). These five individuals exhibited prolonged periods without detection wherein a precise location during the spawning period could not be isolated.

In the historical study period, Arctic Grayling spawning was detected in the Moberly, Pine, and Halfway rivers. However, only 31.3% of adult Arctic Grayling from the historical period were captured and released in the Peace River (as compared to 100% in the present study period) while the remaining 68.7% were sourced from the Pine and Halfway rivers. Of those released into the Pine and Halfway rivers, 90.1% were never detected within the Peace River and were therefore considered residents. Mobile surveys of the Moberly River in spring were only conducted in 2006 and 2007, with the 2007 effort being more temporally expansive. In 2007, seven Arctic Grayling were tracked spawning in the Moberly River with one spawning in 2006 (Figure 14A). These eight spawners traveled a mean distance of 39.8 RKM up the Moberly River (range; 11 to 91 RKM), with seven of the eight (87.5%) spawning upstream of the predicted inundation zone.

In total 73 adult Bull Trout were active and analyzed during the spawning period in September 2020. Of these Bull Trout, 27 (37.0%) exhibited spawning behaviors in the Halfway River and its tributaries (Figure 14B, Figure E2 and Figure E3). Alternatively, the majority of individuals (n= 42, 57.5%) remained in the Peace River during spawning in 2020 and were presumed to have not spawned. This behaviour could be due to numerous factors which includes the individual being a sub-adult or potentially skip spawning behaviour. Sub-adult could be likely as the median fork length of those that remained in the Peace River was smaller at 426.5 mm (range = 301 – 835, n = 42) compared to 577.6 mm (range = 341 – 830, n = 27) for those with Halfway River spawning behaviours. The remaining four Bull Trout had incomplete detection histories wherein a precise location during the spawning period was not able to be determined. Of which, three Bull Trout (4.1%) were detected either entering, exiting or within the Pine River during the spawning period which is another tributary where Peace River Bull Trout spawn (Mainstream 2012, Geraldes 2020).

In 2020, Bull Trout entered the Halfway River between 26 April and 17 July (median: 5 May 2020) and exited between 6 September and 7 October (median: 21 September 2020, Figure 12B).

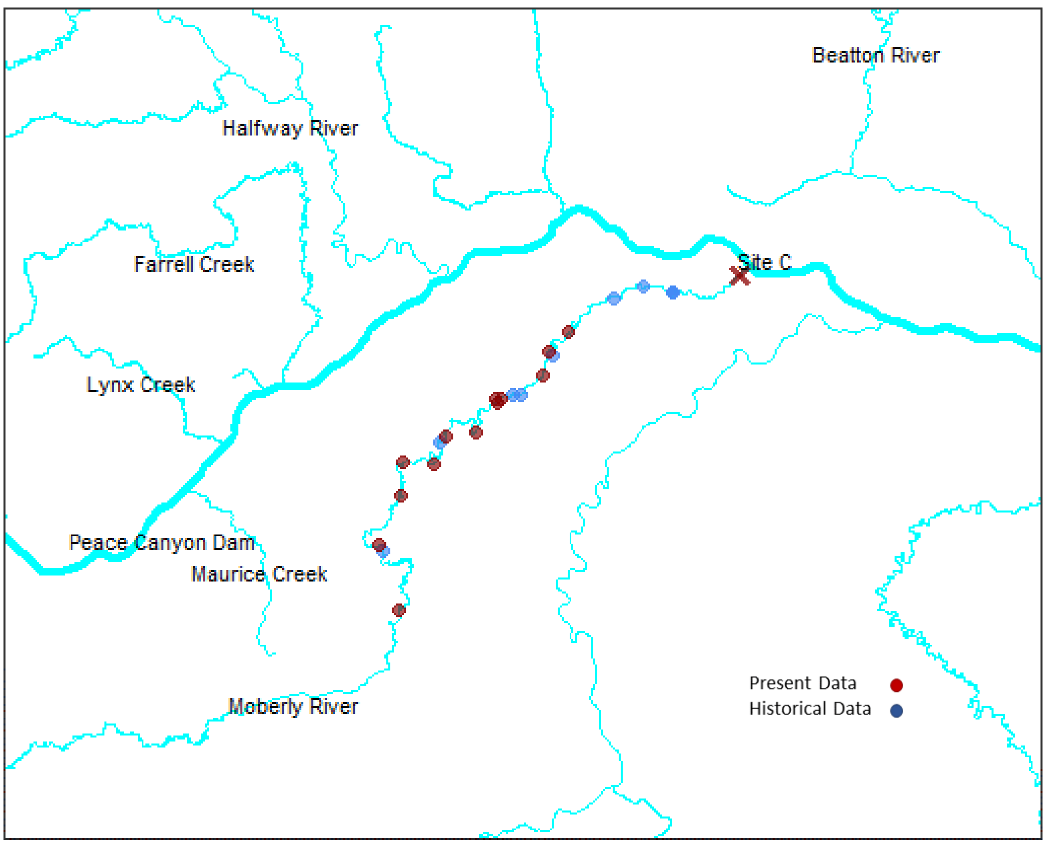

Figure 14A. Probable Arctic Grayling spawning locations in the Moberly River and its tributaries are shown with red circles for the present data and blue circles for the historical data. A red X identifies an individual that entered and exited the Moberly River during spawning but was not detected further upstream. Figure continues in section B below.

Of the 27 Bull Trout with spawning behaviours recorded in the Halfway River and its tributaries, 21 had probable spawn locations that were either pinpointed by mobile tracking efforts or detected at either the Chowade River or Cypress Creek fixed-station. Nine Bull Trout (42.8%) were presumed to have spawned in the Chowade River, six (28.5%) in the Upper Halfway River, three (14.3%) in Fiddes Creek, one (4.8%) in the Graham River, one (4.8%) in Turnoff Creek and one (4.8%) in Cypress Creek. The remaining six Bull Trout were tracked entering and/or exiting the Halfway River during the spawning period and migrated upstream of Halfway River #2 fixed-station but were not validated by detections further upstream.

In the historical study period, most of the adult Bull Trout were captured and released in either the Halfway River system (n = 73, 40.3%) or the Pine River system (n = 105, 58.0%). Only three (1.7%) adult Bull Trout were captured and released into the Peace River. This contrasts the present data in which all of the adult Bull Trout were captured and released into the Peace River.

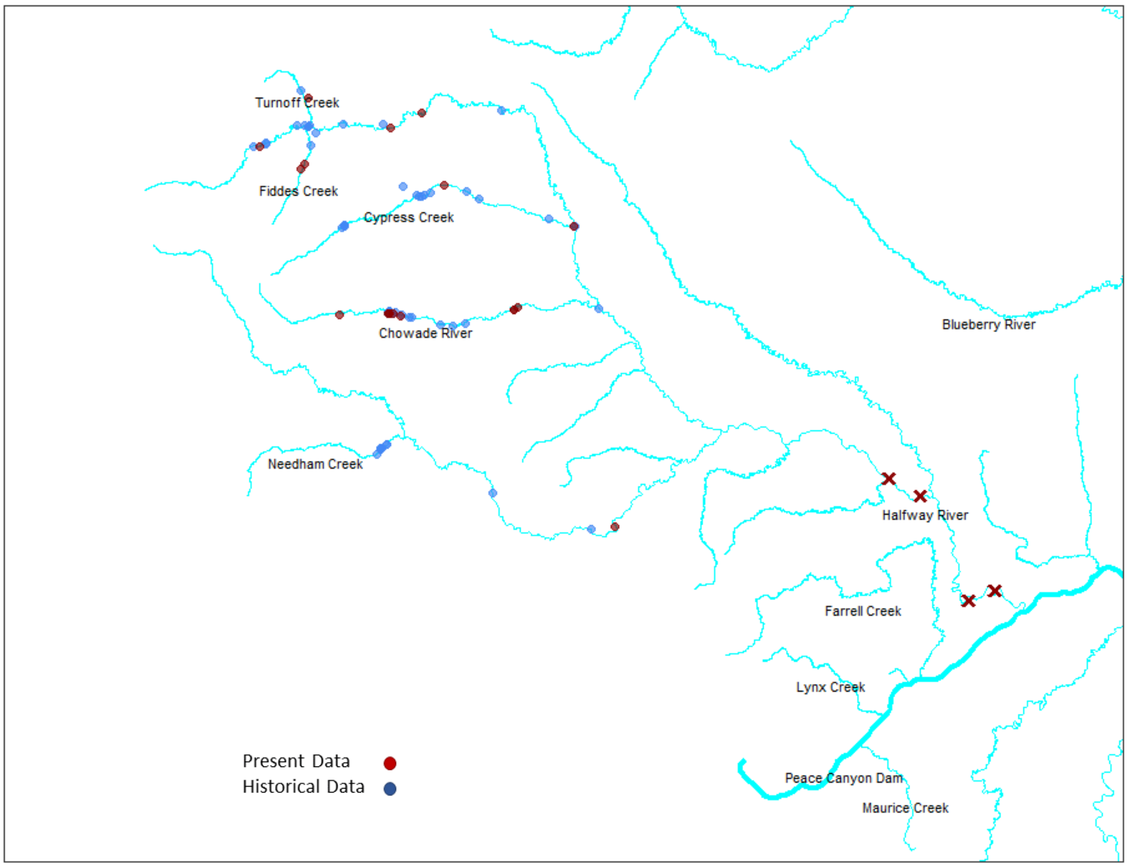

Figure 14B. Probable Bull Trout spawning locations in the Halfway River and its tributaries are shown with red circles for the present data and blue circles for the historical data. A red X identifies an individual that entered and exited the Halfway River during spawning but was not detected and validated

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-station radio telemetry array was operated along the Peace River and many of it's tributaries in 2020. The fixed-station array was online 96% of the time and was deemed effective at detecting tagged fish in 2020, with the primary indicator being detection efficiencies ranging from 83.3% to 98.3% for all but one fixed-station.

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 from BC Hydro managers.

The fixed-station array is intended to operate during numerous phases of the Site C project, including construction[46] and operation[47], and will compliment the baseline studies conducted from 1996-1999[48] and 2005-2009[49]. The contribution of telemetry data from the 2020 study year adds to the on-growing resource of telemetry data that can be leveraged by BC Hydro to address management questions across various monitoring programs and tasks as the Site C Project progresses.

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 2020, five mobile surveys were conducted, which, in conjunction with the operation of the fixed-station receiver array (Mon-1b, Task 2d), generated an 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 2020 were monitored using the fixed-station array (Mon-1b, Task 2d) in conjunction with two 2-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 2020.

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

[47] 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).

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

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

Management Questions

Since July 2019, there have been 608 radio-tagged Arctic Grayling (n=57), Bull Trout (n=207), Burbot (n=25), Mountain Whitefish (n=28), Rainbow Trout (n=162) and Walleye (n=129) released into the Peace River and its tributaries. From these 608 radio-tagged study fish, the fixed-station array and mobile tracking efforts have collected over 21 million valid detections across hundreds of kilometers of the Peace River and its tributaries. This data builds on the telemetry data collected from 1996 to 1999 and 2005 to 2009 and is intended to answer or provide guidance across a myriad of management questions outlined in the FAHMFP[50].

Datum 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.

Arctic Grayling

Three questions were asked about Arctic Grayling. 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 29 adult Arctic Grayling tagged and released in 2019. All of the Arctic Grayling that were tagged in 2020 (n=19) were released between August and October 2020; i.e., after the 2020 Arctic Grayling Spawning period in May. No juvenile Arctic Grayling were used for this analysis.

In 2020, 14 Arctic Grayling were detected in or moving into the Moberly River from the Peace River before peak spawning in May 2020. This represented 48.3% of the 29 Arctic Grayling tagged in 2019 and 70.0% of the Arctic Grayling adults that were released and confirmed active in May 2020 (n= 20). Of these 14 fish, two had been detected at the mouth of the Moberly River on and off since 2019, whereas the remaining 12 made directed movements into the Moberly River between 18 March and 29 April. One of the 14 fish remained within 2 RKM of the Moberly mouth during the spawning period, whereas the other 13 fish (92.9%) moved upstream and beyond the extent of the inundation zone, with 71.4% appearing to spawn between RKM 30 and 80 around 15 May and 20 May 2020. All 14 fish exited the Moberly River between 16 May and 16 June. One Arctic Grayling (7.2%) was detected departing the Moberly River but has not been detected since, which could be one of many possible eventualities including predation, mortality following spawning or sedentary behavior in a deep or shielded habitat that has prevented subsequent detection. The remaining Arctic Grayling distributed throughout the Peace River following spawning, both upstream (50.0%) and downstream (42.8%) of Site C.

Historical data were not particularly informative in addressing the three questions described above as 68.7% of study fish were tagged in the upper Halfway and Pine watersheds. That said, eight Arctic Grayling were identified as potential Moberly River spawners in 2006 and 2007 with 81.9% spawning between RKM 20 and 90 around 10 May and 26 May.

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

Bull Trout

Two questions were asked about Bull Trout. 1) Where have the radio-tagged juvenile Bull Trout been detected thus far? 2) What proportion of juvenile Bull Trout migrate from the tributaries of the Halfway River to the Peace River? To answer these questions, there were 207 fish tagged (138 released in 2019, and 69 released in 2020), of which 68 were juveniles. In the historical data, there were no juveniles tagged in the Halfway watershed.

The majority (92.5%) of the 53 juvenile Bull Trout tagged in Chowade River (n = 12), Cypress Creek (n = 26) and Fiddes Creek (n =15) were never detected following release. The four that were detected were all released near the Chowade River fixed-station with detections recorded shortly after release. None of the juvenile Bull Trout released into the Chowade River or Cypress Creek were detected on the respective PIT arrays operated during certain months of the year in these tributaries by InStream Fisheries Research (Putt et al. 2020). Either the fish died post-release, the fish remained in the tributaries, or the fish departed the tributaries after their tag battery had expired (on or around Feb 2020)[51]. We have no empirical evidence to say which eventuality occurred, however given the quantity of fish tagged (n= 53) and the limited battery life (185 days), an exit following battery failure is a probable scenario. The only definite result is that a fall outmigration was not supported by the data. At this time, we cannot reliably assess the proportion that moved into the Peace River.

In addition to the 53 individuals detailed above, there were 15 juvenile Bull Trout that were tagged in the Peace River, of which five (33.3%) were never detected. The remaining ten (66.6%) all stayed within the Peace River, having moved between 0.3 and 48.5 RKM (average 14.9 RKM) to date. The detected juvenile Bull Trout (n=10) as well as those undetected (n=5) were a similar fork length with a median length of 222.5 mm (range=137-243 mm) and 218.0 mm (range= 156-231 mm), respectively.

Burbot

The question asked about Burbot was to describe their November through January (i.e., winter) movements. In total, 25 Burbot were radio-tagged with 18 tagged in 2019 (3 of which have expired as of 1 February 2021), and 7 in 2020. From these, 10 Burbot were detected at least once by winter mobile flights conducted between 20 November 2020 and 30 January 2021. No Burbot were tagged during the historical study period.

Analyzing solely the winter mobile tracking data, Burbot were distributed widely throughout the study area with no specific movement pattern emerging. None of the fish detected on multiple mobile surveys had moved appreciably. However, after expanding the analysis to include detections on the fixed-station array, potential downstream oriented movement behaviours emerged on 4 individuals. Two Burbot recorded moderate (11.8-13.9 RKM) downstream movements in the Peace River along with two others performing more significant movements in the same direction (77.4 – 116.2 RKM).

All four of these movements, however, lacked a precise datetime with three occurring sometime between September 2020 and January 2021 and one movement potentially occurring sometime between November 2019 and May 2020 or November 2020 and December 2020. The remaining tracked Burbot didn't record any additional movements that can be inferred to have occurred between October and March even after expanding the analysis.

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[51] These Juvenile Bull Trout were tagged with a Lotek Nano 3-2 which per Lotek Wireless has an estimated battery life of 185 days. Therefore, every juvenile Bull Trout tagged in theses tributaries were set to expire on or before February 2021.

Ultimately, there were not enough Burbot movements detected to make any widespread inferences about Burbot behaviour in winter. This could be due to numerous factors including a sedentary lifestyle (i.e., study fish did not move past fixed-stations often), a preference for deeper water (radio signals attenuate over depth[52]), or an individual exiting the fixed-station array without detection. As the quantity of tagged Burbot increases and the detection data expands, Burbot movement patterns are expected to become clearer in future study years.

No Burbot were detected moving upstream in the Peace River to pass Site C, or upstream into the Moberly River from 1 Nov 2019 to 30 Mar 2020.

Mountain Whitefish

Two interrelated questions were asked about Mountain Whitefish. 1) In the fall, are Mountain Whitefish milling or migrating? 2) Where might they be spawning? To answer these questions, there were 28 adult fish tagged between 25 Aug and 30 Aug 2020, of which 12 were detected following release.

All 12 Mountain Whitefish detected in 2020 documented an initial downstream movement that immediately followed release (<5 days), after which 8 were never detected again. Following the initial downstream movement, two Mountain Whitefish held at Peace River #4 until the completion of the field season in October 2020 while one Mountain Whitefish recorded a 12.9 RKM upstream movement from Peace River #4 to the Pine River fixed-station in October 2020. The last Mountain Whitefish detected in 2020 moved 5 RKM downstream within the first few days following release, then held for 45 days at Peace River #4 before migrating another 97.2 RKM downstream and exiting the fixed-station array.

No Mountain Whitefish were detected passing Site C or entering the Moberly River in 2020.

Downstream movements immediately following release are indicative of tag and handling effects, which is particularly likely given Mountain Whitefish are known to be prone to these effects (Taylor et al. 2011). These potential handling effects along with limited sample size make it difficult to make substantive inferences about Mountain Whitefish movement patterns in the Peace River using the present data alone.

However, there were 116 adult Mountain Whitefish that were tracked in the historical study period (all of which were released in late June 2006). Detections of these historical fish, except during a monthlong period after tagging (thought to be representative of a recovery period), were analyzed to help address the questions for Mountain Whitefish. All 116 tagged Mountain Whitefish were detected on multiple and repeated occasions following release. Nonmigratory (or milling) behaviours were the primary behaviours observed with the average Mountain Whitefish traveling only 3.1 RKM per month. Nonmigratory behaviours were consistent across all months except for upticks in movement occurring in June and July. Beyond that, there did not appear to be any marked movements in preparation for spawning in the fall. Tracking that occurred during the Mountain Whitefish spawning period (October through November) showed fish to be distributed throughout the Peace River and its tributaries. Individuals were also tracked within the Halfway, Pine, and Beatton river watersheds.

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[52] 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. This could be exacerbated further during moderate speed, moderate altitude mobile tracking.

In 2020, Mountain Whitefish were tagged with a Lotek Nano 3-2 radio-tag, the smallest of the tags available, to potentially decrease the likelihood of known tagging-related trauma that can occur in this species (AMEC & LGL 2008a). Due to the small size, these tags have a short 185-day battery life which means all 28 Mountain Whitefish will have expired before the fixed-station array is deployed for monitoring in 2021[53]. However, the smaller tag didn't appear to reduce the prevalence of tag and handling effects, indicative by the immediate downstream movements observed. Given the successful post-tagging survival of the historical fish, it stands to reason that Peace River Mountain Whitefish *can indeed* survive the radio tagging process (e.g., tagging in other river systems, Taylor et al. 2011), despite concerns to the contrary. Tags used in 2006 weighed 10 g in air (AMEC & LGL 2008a), as compared to the 0.57 g tags used in 2020.

Upstream movements at the dam site from Nov 2019 to Mar 2020

The final question addressed whether there were appreciable upstream movements recorded at Site C between November 1, 2019 and April 1, 2020, which represents a period in time in which the temporary facility will not be operating (only operated between April 1 and October 31 each year). To answer this question, the complete 2019/2020 dataset was used including 441 adults of various species that were radio-tagged before the river was diverted in October of 2020 (232 of which were released downstream of Site C). Juvenile analysis was not pursued, as only 26 of 167 individuals (15.6%) were released downstream of Site C. The historical data could potentially contribute 512 adults tagged of various species; however historical analysis was hampered by a lack of wintertime tracking that could not provide much precision to isolate when passage may have occurred.

In total, there were 41 upstream movements recorded in the present study period with the majority occurring in spring (n=21, 51.2%) followed by summer (n=12, 29.3%) and fall (n=6, 14.6%). Winter upstream passage was rare with only two events (4.4%) from the 2019/2020 winter. The first was an Arctic Grayling that was detected near the Site C fixed-station on 12 December 2019 before being re-detected on 16 April 2020 at Moberly River #1 while migrating upstream to spawn. The second was a Bull Trout detected on Peace River #4 (28 RKM downstream of Site C) on 29 October 2019 before re-detection on 18 May 2020 at Peace River #7 (13 RKM upstream of Site C). Unfortunately, this Bull Trout avoided detection at the Site C fixed-station while traveling upstream past the dam site.

During the historical study period, there were a total of 60 upstream movements in which a study fish passed the future Site C Project area. passage events recorded, of which the majority occurred in spring (n=33, 55.0%), followed by summer (n=16, 26.7%) and fall (n=10, 16.7%). Similarly, winter upstream passage was rare with only one recorded event representing 1.7% of all upstream passage events recorded in the historical data. The sole individual was an adult Mountain Whitefish detected 18 RKM downstream of Site C on 22 October 2006, followed by a re-detection 19 RKM upstream of Site C on 26 March 2007.

In general, upstream movements past Site C during the winter were rare and represented only 3.0% of all upstream movements recorded in both the present and historical data. This scarcity is compounded by the fact that passage during the winter could not be confirmed for all three fish, and its possible that these movements may have occurred in the preceding fall or spring.

[53] Not including Site C, Halfway River #1 or Moberly River #1 which operate all year round.

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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 and 2020). Released adults are depicted in red and juveniles in blue. Map was produced in ggmap (Kahle and Wickham 2013).**

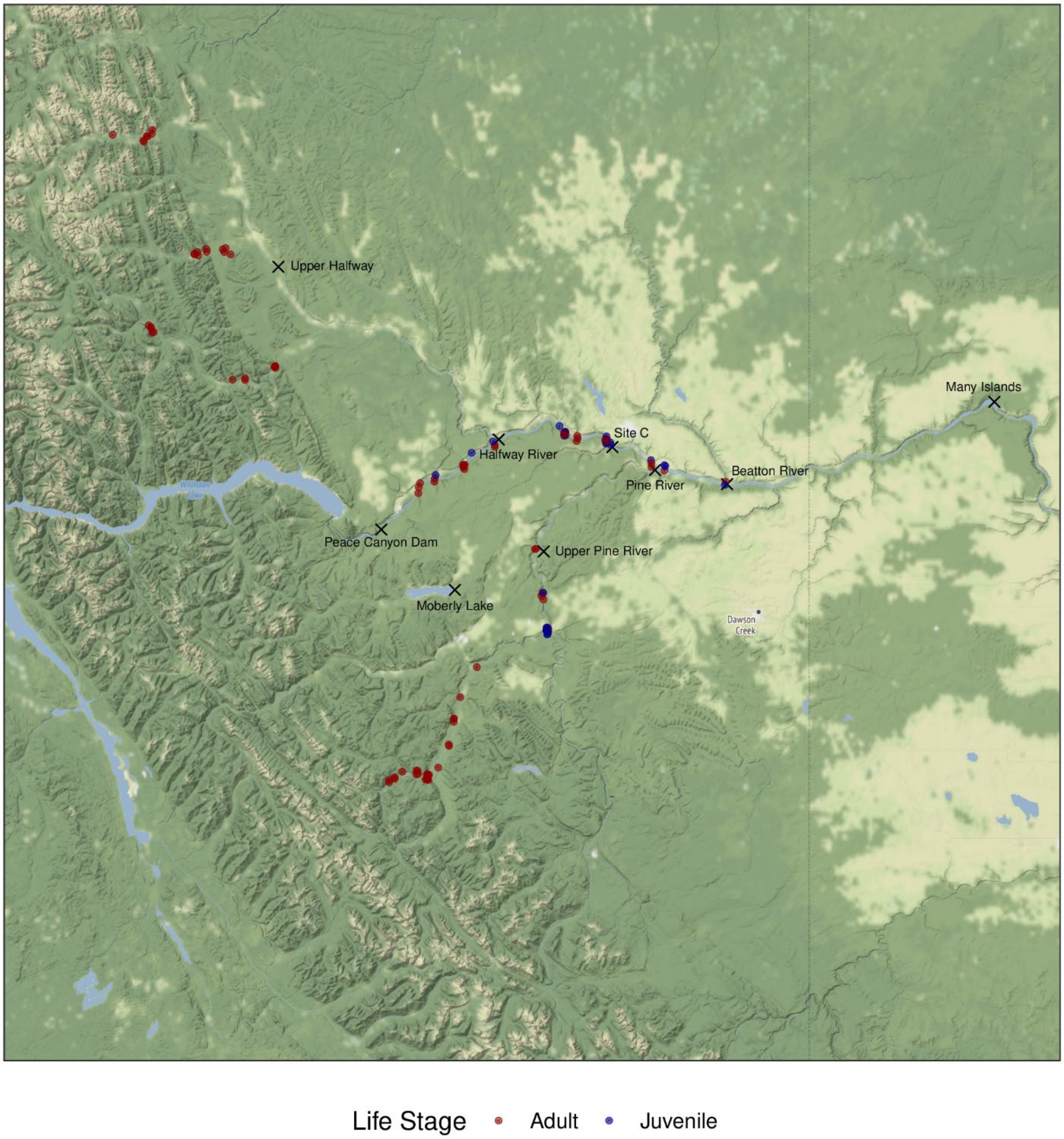


Figure A2. Arctic Grayling release locations (●) and points of reference (×) from the historical dataset (1996 to 1998 and 2005 to 2008). Released adults are depicted in red and juveniles in blue. Map was produced in ggmap (Kahle and Wickham 2013).

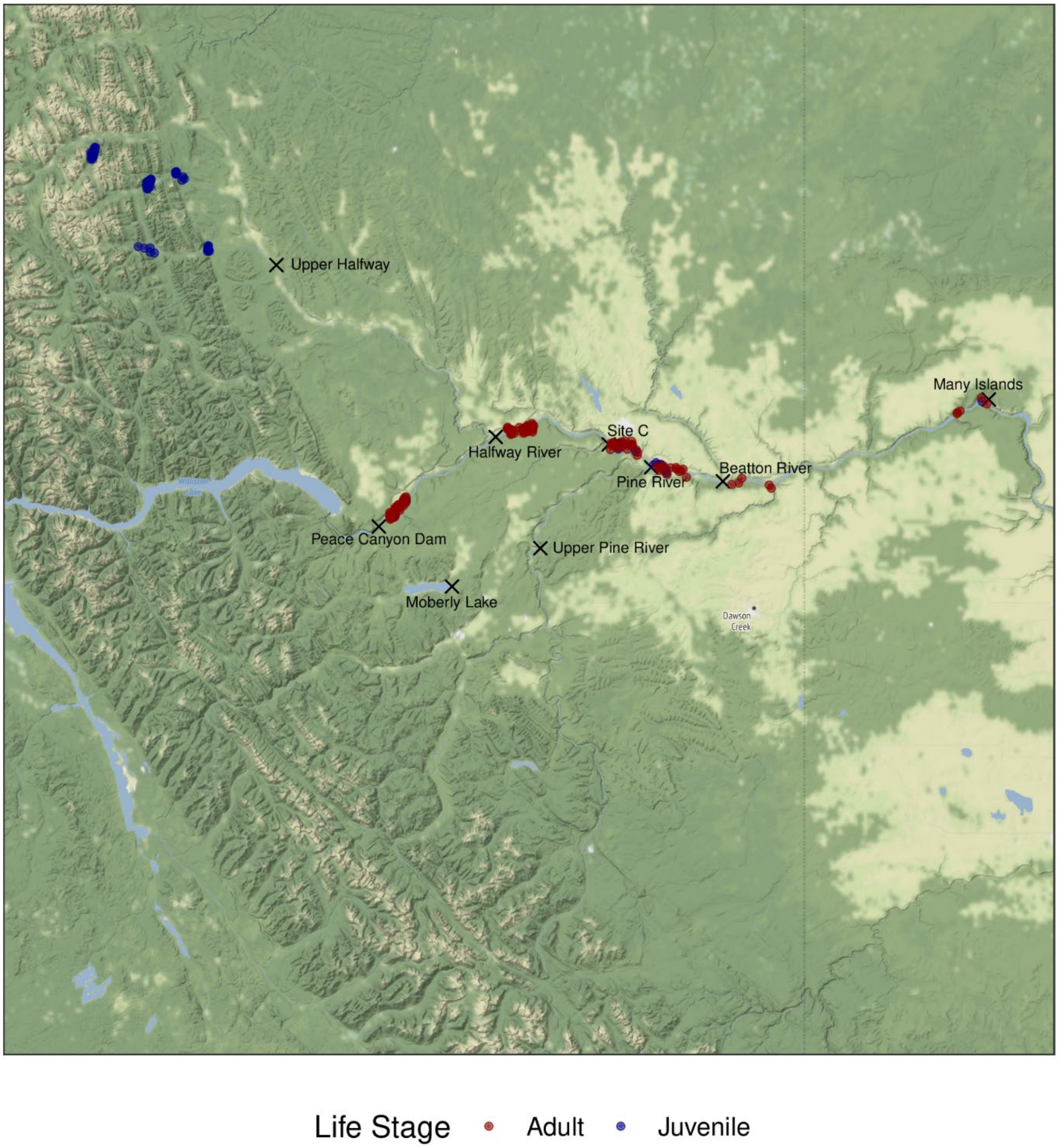


Figure A3. **Bull Trout release locations (●) and points of reference (×) from the present dataset (2019 and 2020). Released adults are depicted in red and juveniles in blue. Map was produced in ggmap (Kahle and Wickham 2013).**

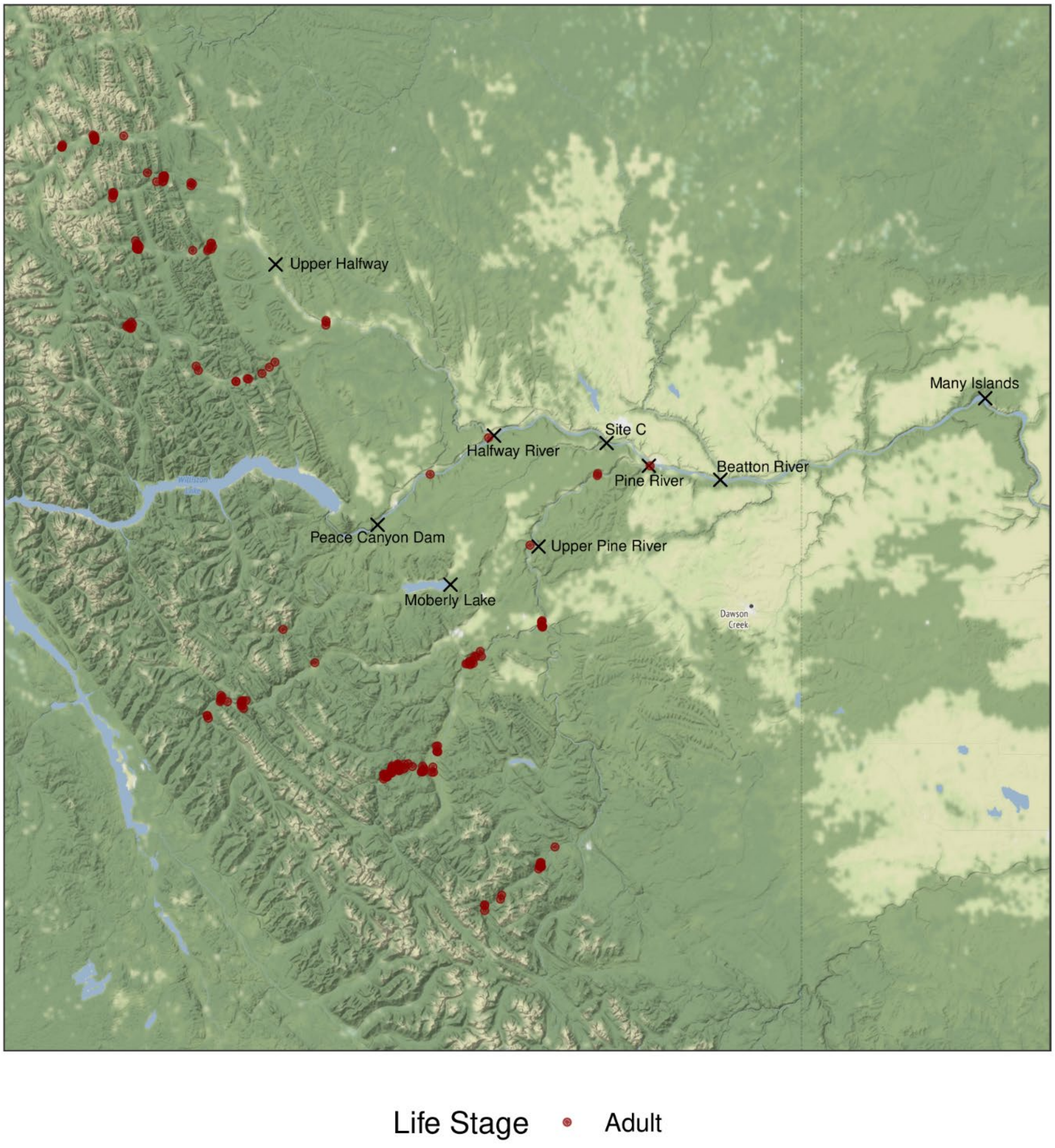


Figure A4. **Bull Trout release locations (●) and points of reference (×) from the historical dataset (1996 to 1998 and 2005 to 2008). Released adults are depicted in red and juveniles in blue. Map was produced in ggmap (Kahle and Wickham 2013).**

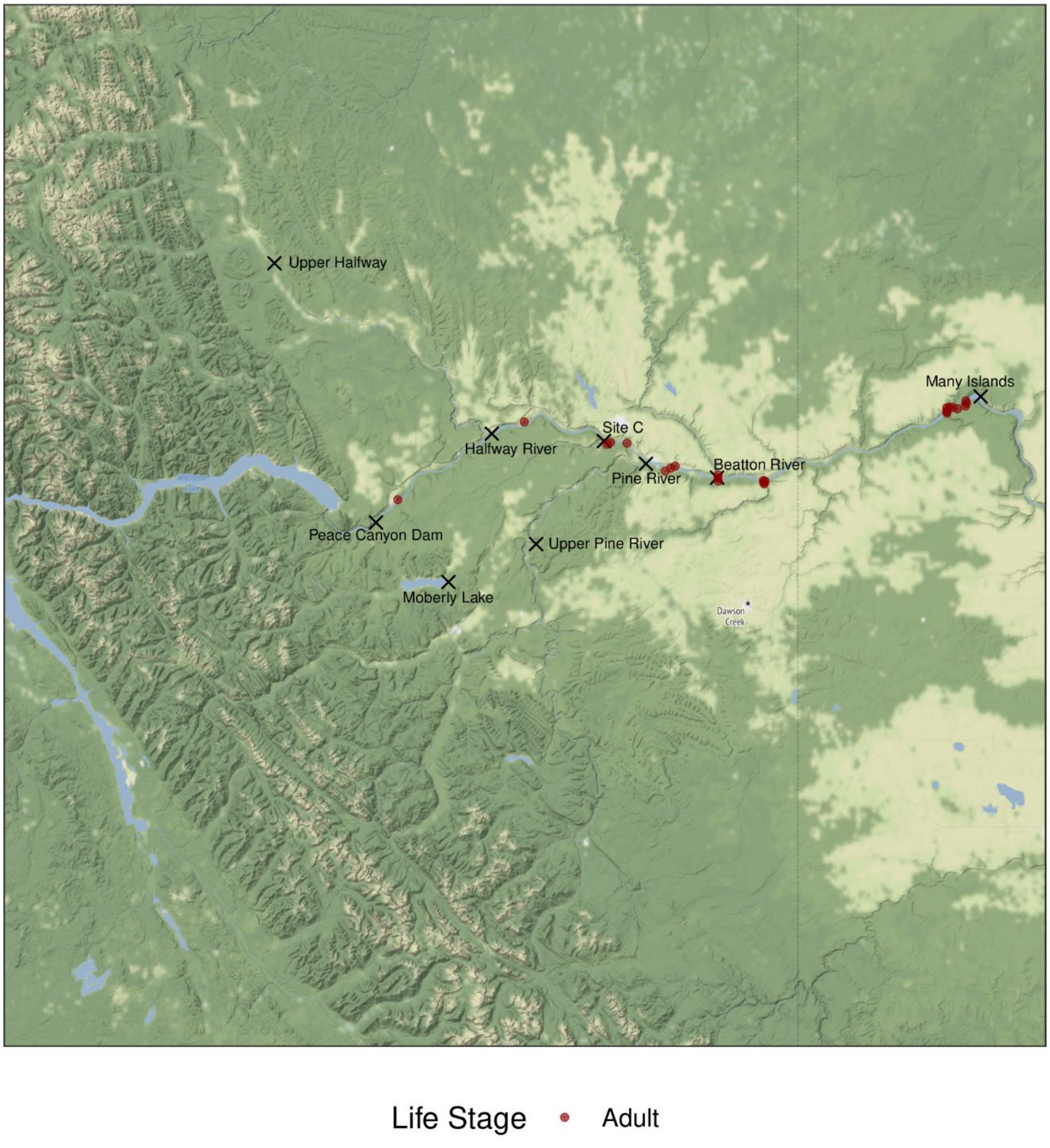


Figure A5. **Burbot release locations (●) and points of reference (×) from the present dataset (2019 and 2020). Released adults are depicted in red and juveniles in blue. Map was produced in ggmap (Kahle and Wickham 2013).**

Figure A6. Mountain Whitefish release locations (●) and points of reference (×) from the present dataset (2019 and 2020). Released adults are depicted in red and juveniles in blue. Map was produced in ggmap (Kahle and Wickham 2013).

Figure A7. Mountain Whitefish release locations (●) and points of reference (×) from the historical dataset (1996 to 1998 and 2005 to 2008). Released adults are depicted in red and juveniles in blue. Map was produced in ggmap (Kahle and Wickham 2013).

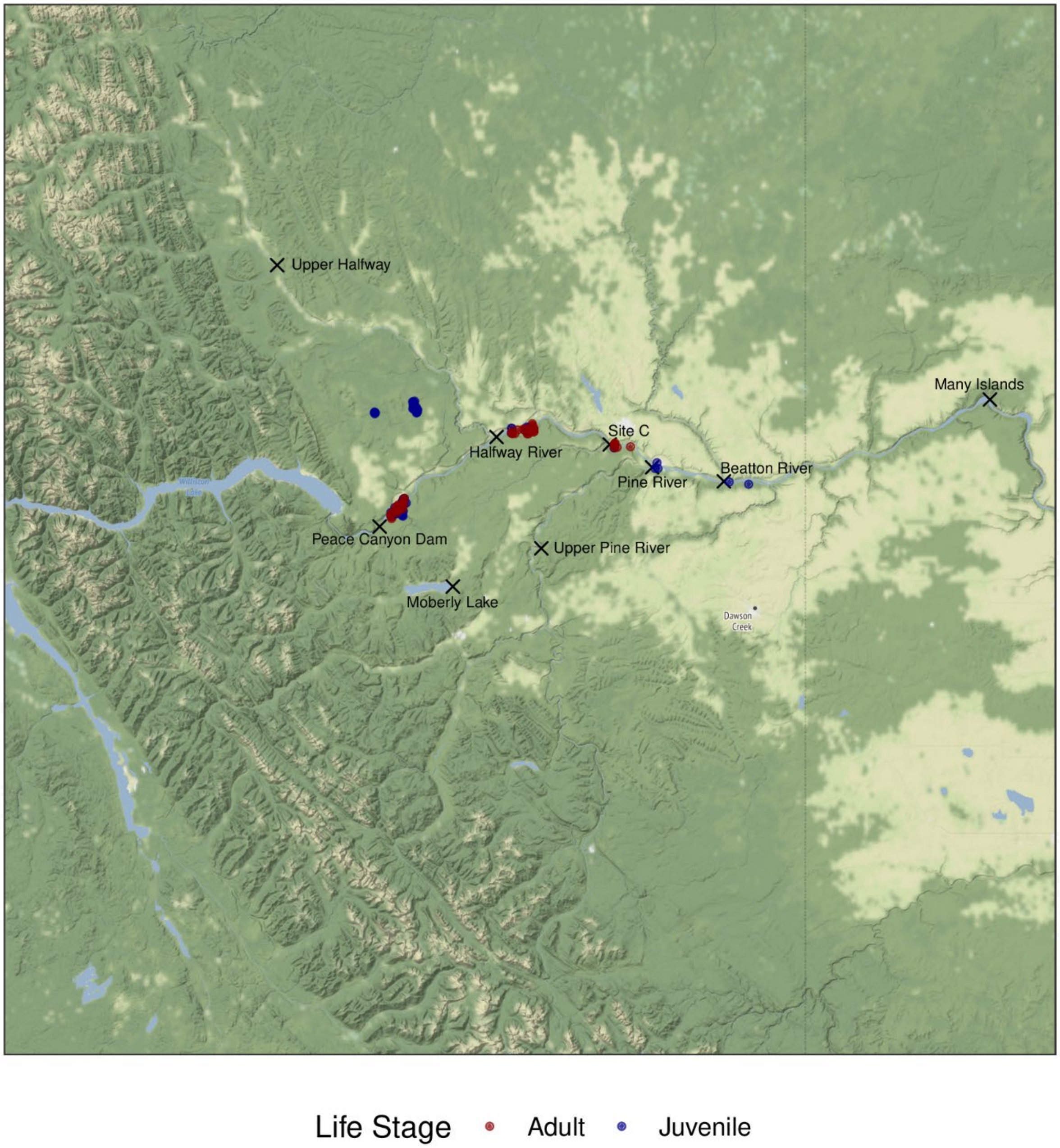


Figure A8. **Rainbow Trout release locations (●) and points of reference (×) from the present dataset (2019 and 2020). Released adults are depicted in red and juveniles in blue. Map was produced in ggmap (Kahle and Wickham 2013).**

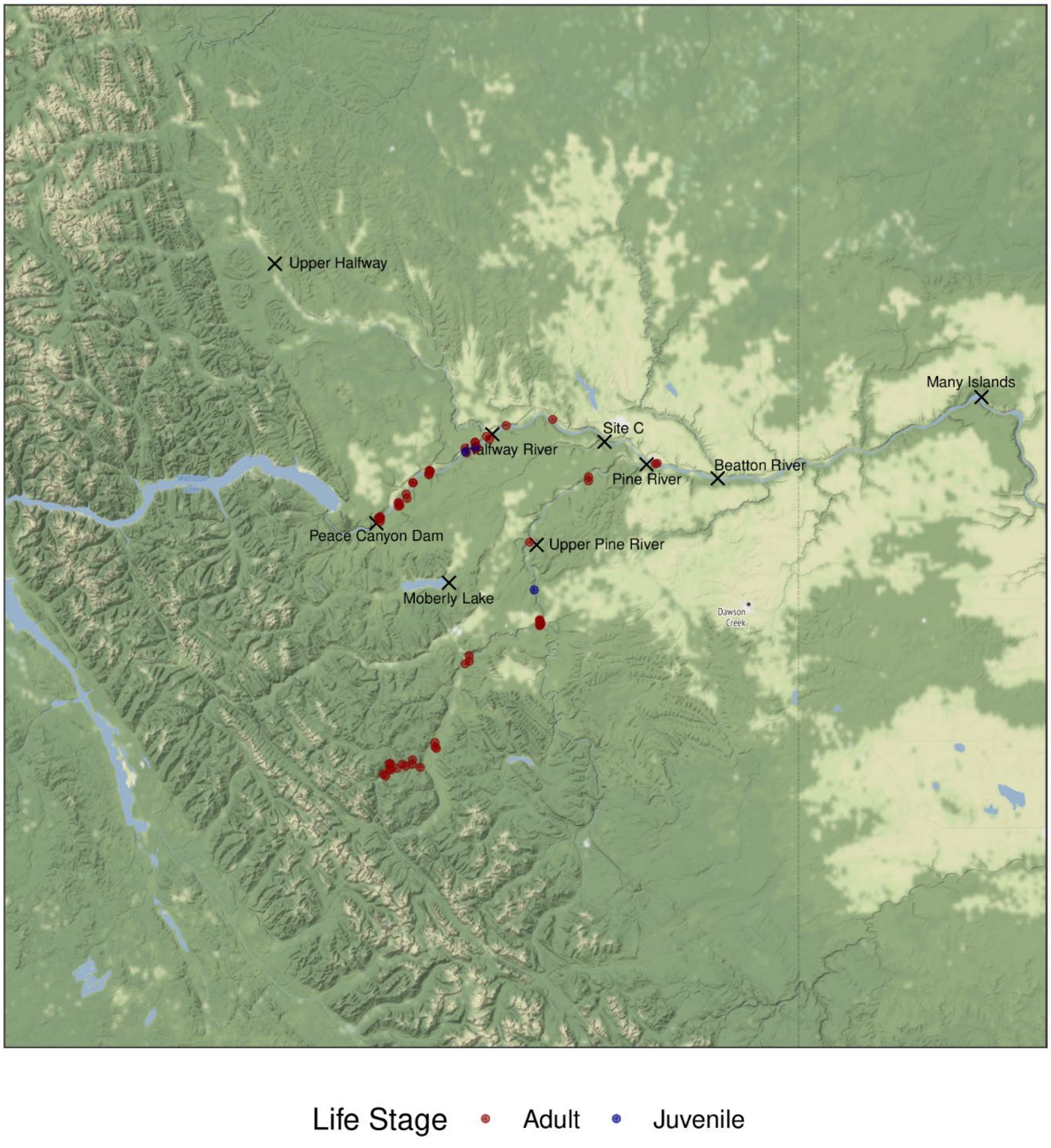


Figure A9. **Rainbow Trout release locations (●) and points of reference (×) from the historical dataset (1996 to 1998 and 2005 to 2008). Released adults are depicted in red and juveniles in blue. Map was produced in ggmap (Kahle and Wickham 2013).**

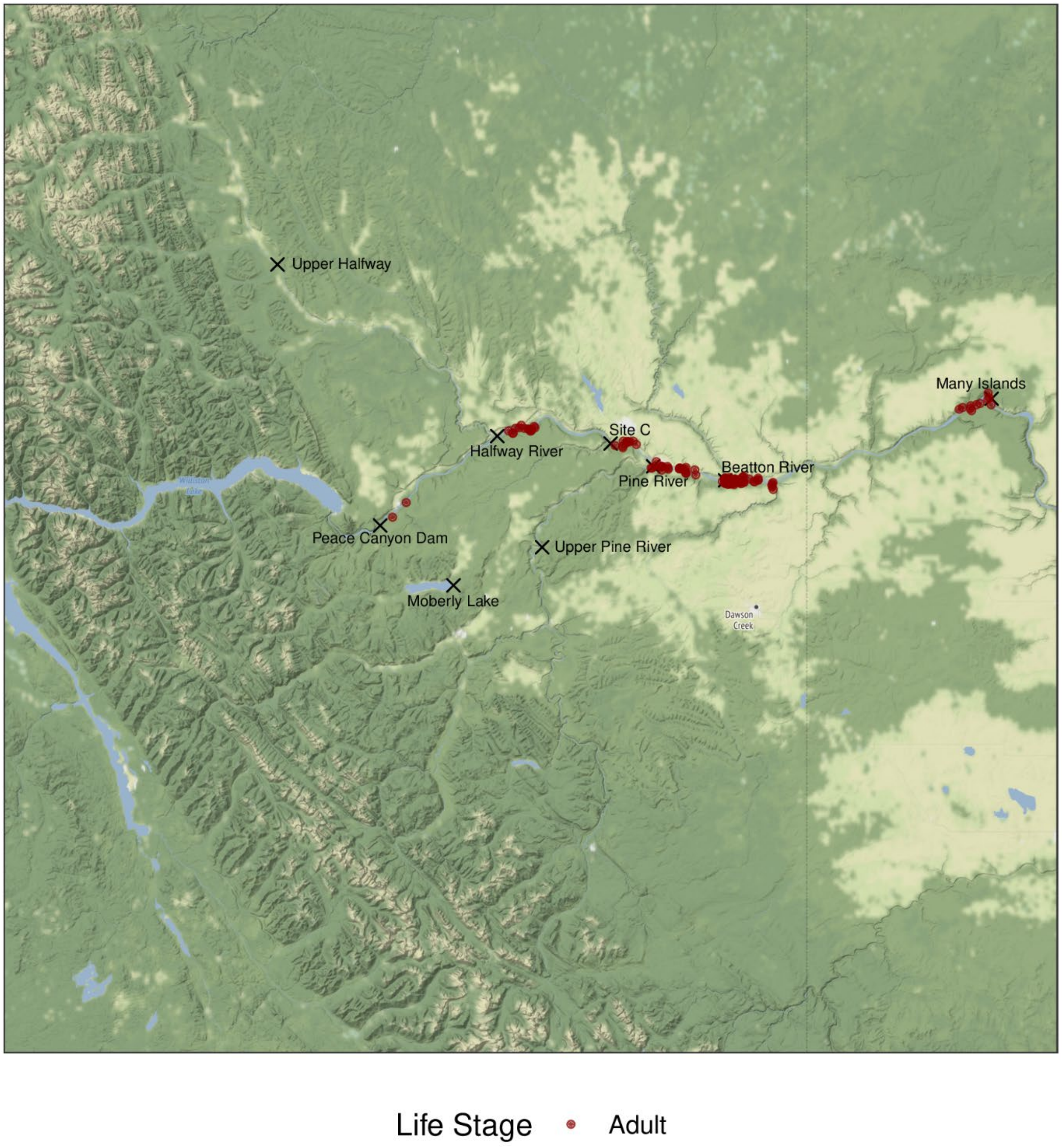


Figure A10. **Walleye release locations (●) and points of reference (×) from the present dataset (2019 and 2020). Released adults are depicted in red and juveniles in blue. Map was produced in ggmap (Kahle and Wickham 2013).**

Figure A11. Walleye release locations (●) and points of reference (×) from the historical dataset (1996 to 1998 and 2005 to 2008). Released adults are depicted in red and juveniles in blue. Map was produced in ggmap (Kahle and Wickham 2013).

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

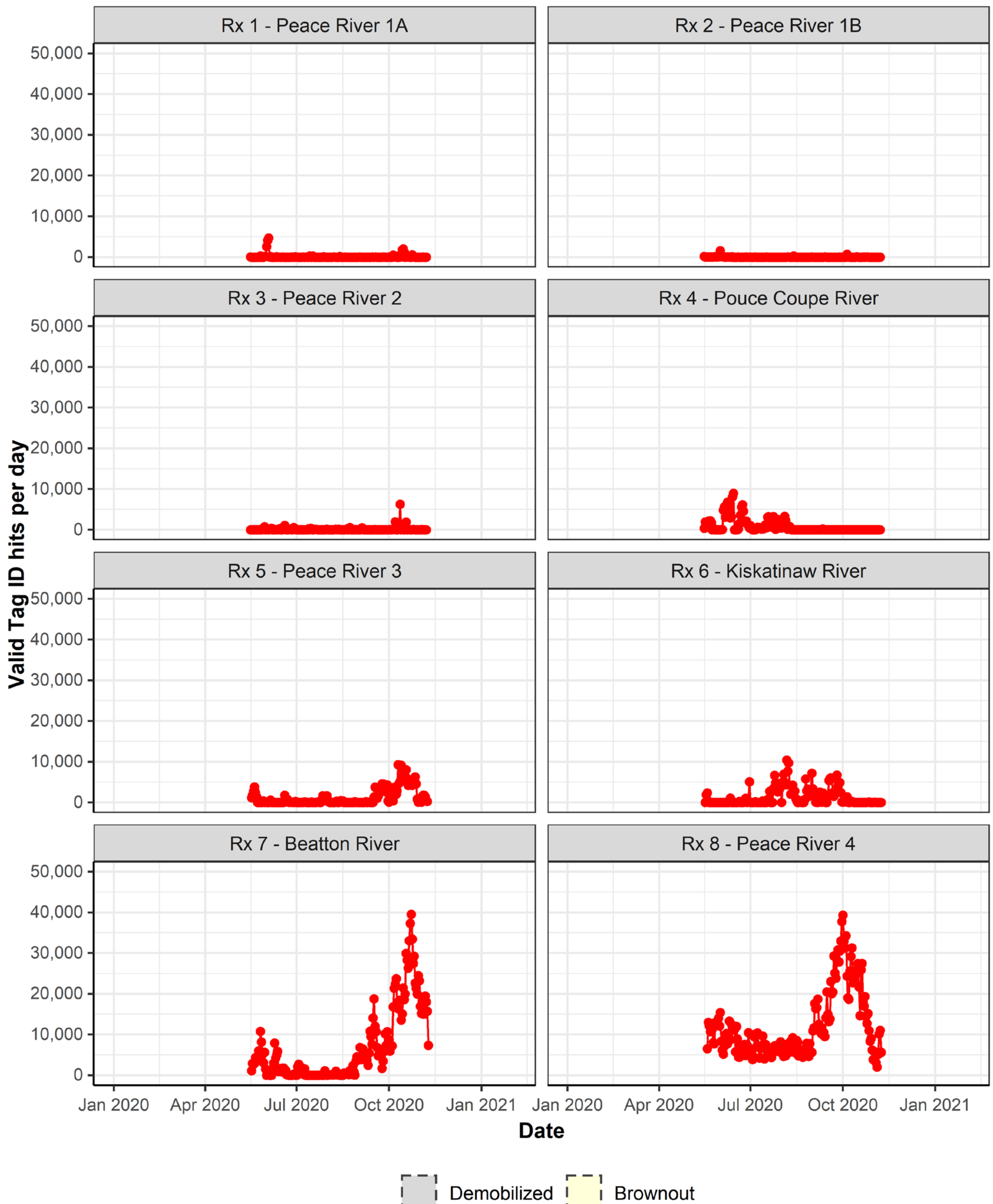


Figure B1. **Validated detection signals by station organized into hits per day in 2020. The spaces highlighted with a yellow or gray rectangle signify periods in which receiver outages had occurred and data collection did not proceed. The figure continues on the four next pages.**

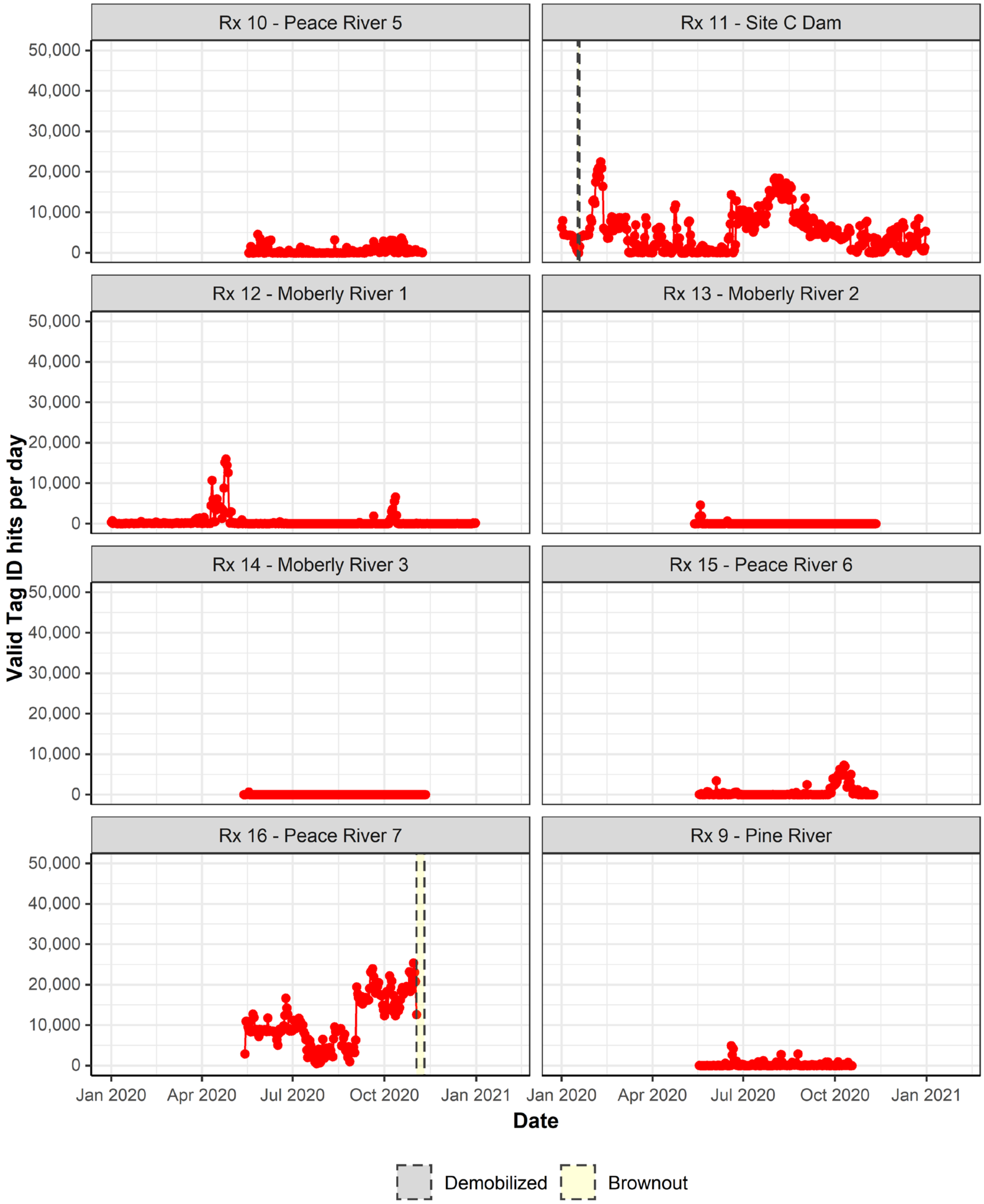


Figure B1 continued (part 2 of 5).

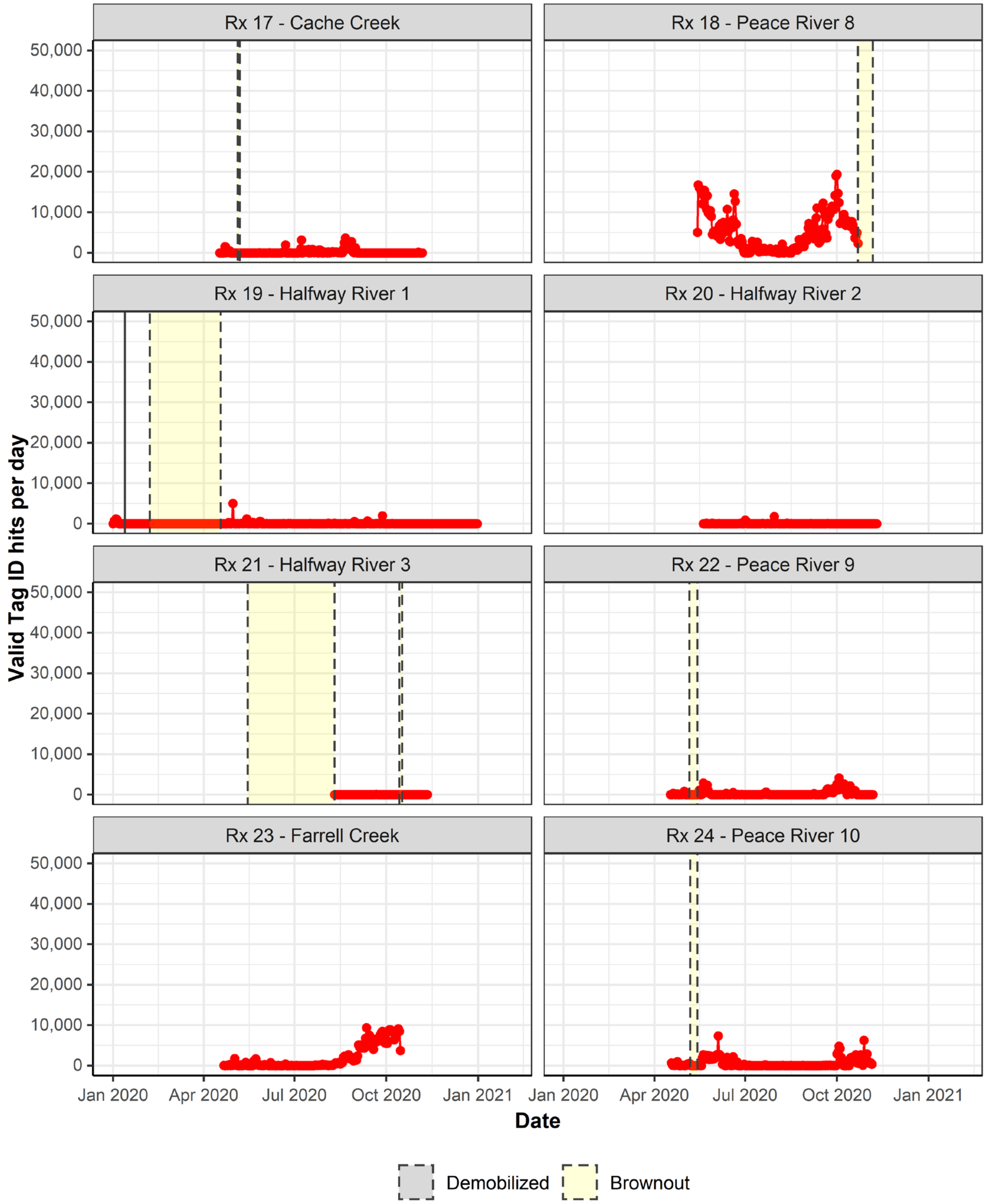


Figure B1 continued (part 3 of 5).

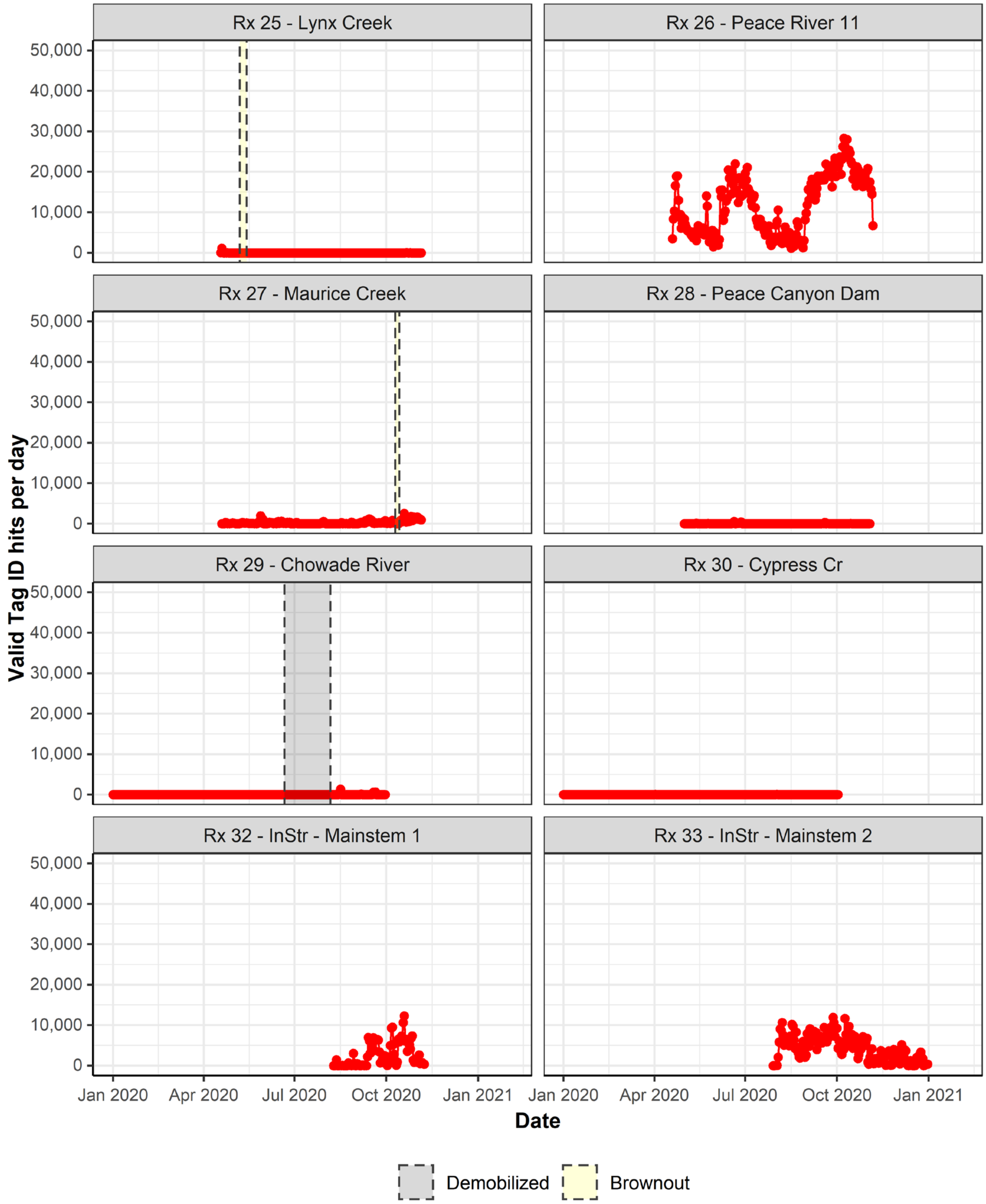


Figure B1 continued (part 4 of 5).

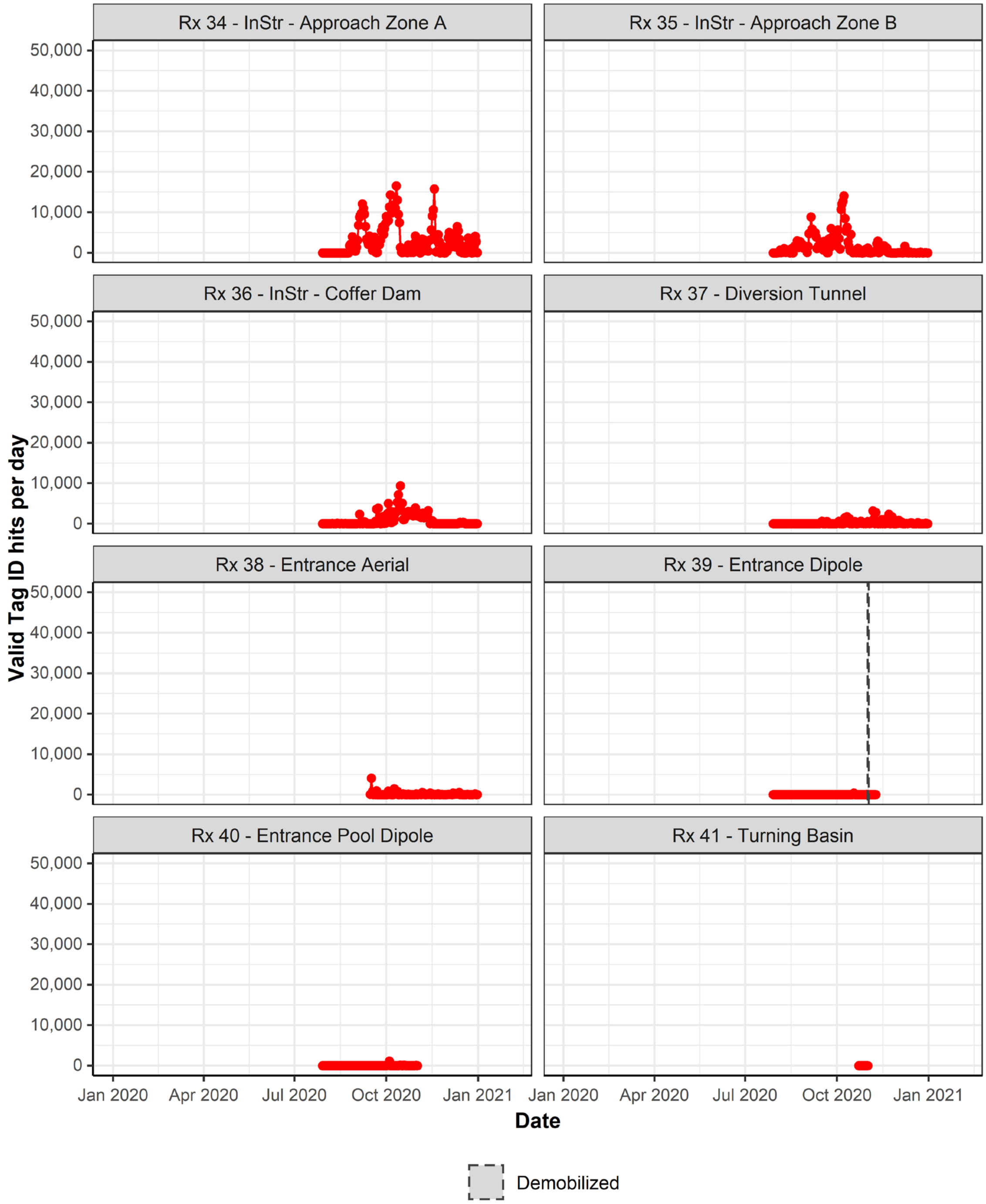


Figure B1 continued (part 5 of 5).

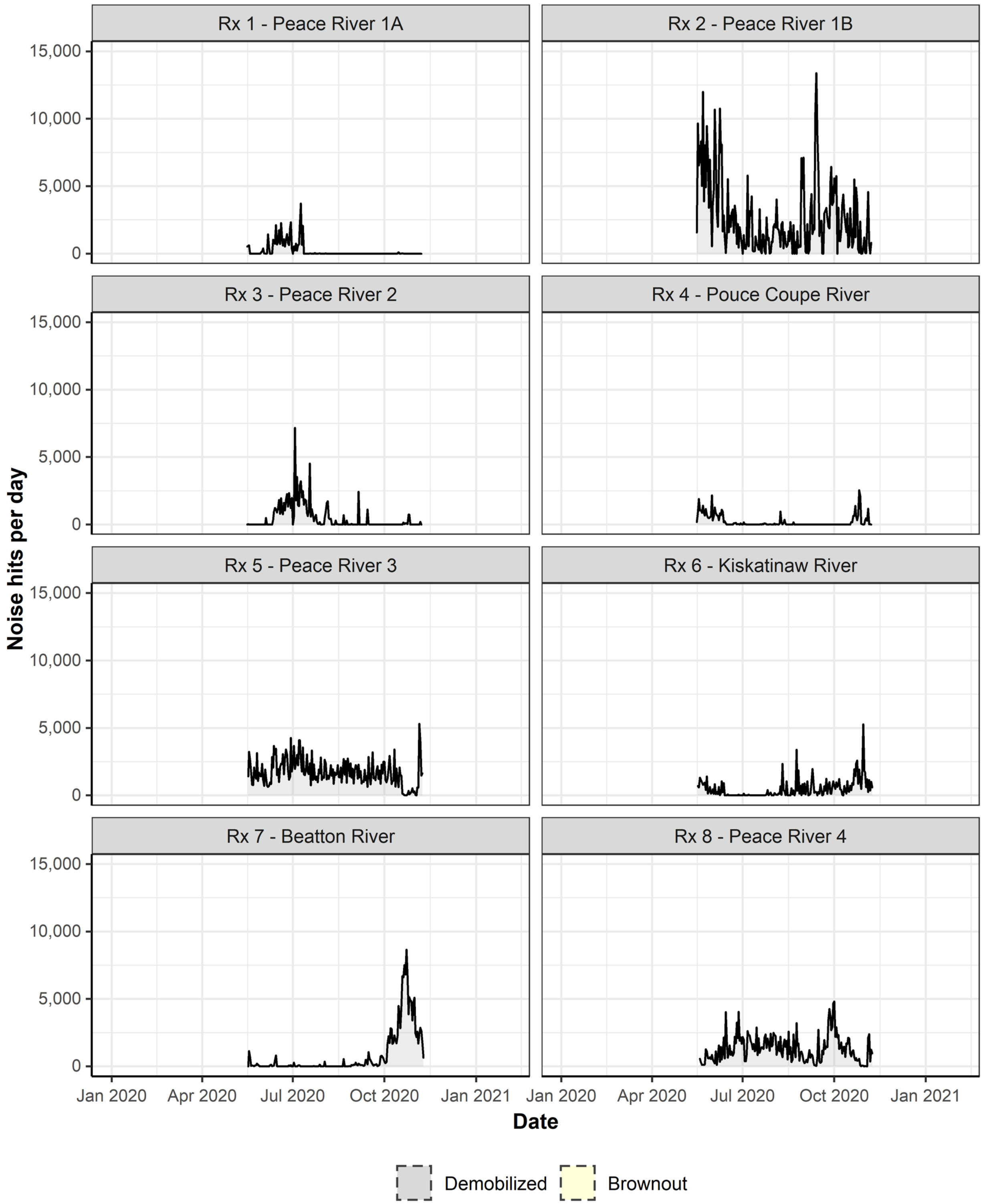


Figure B2. **Noise (Code 999) signals by station organized into hits per day in 2020. The spaces highlighted with a yellow or gray rectangle signify periods in which receiver outages had occurred and data collection did not proceed. The figure continues on the four next pages.**

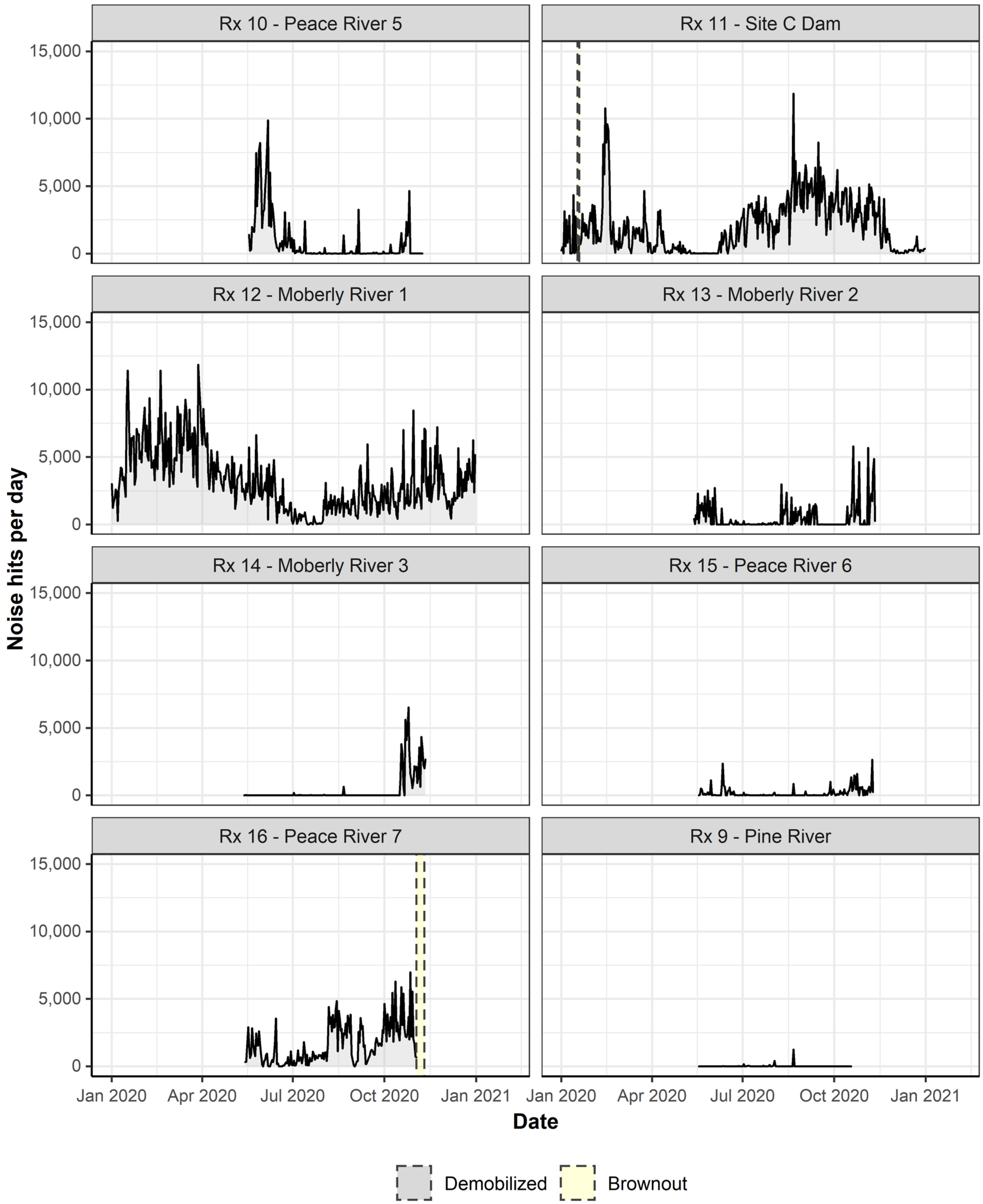


Figure B2 continued (part 2 of 5).

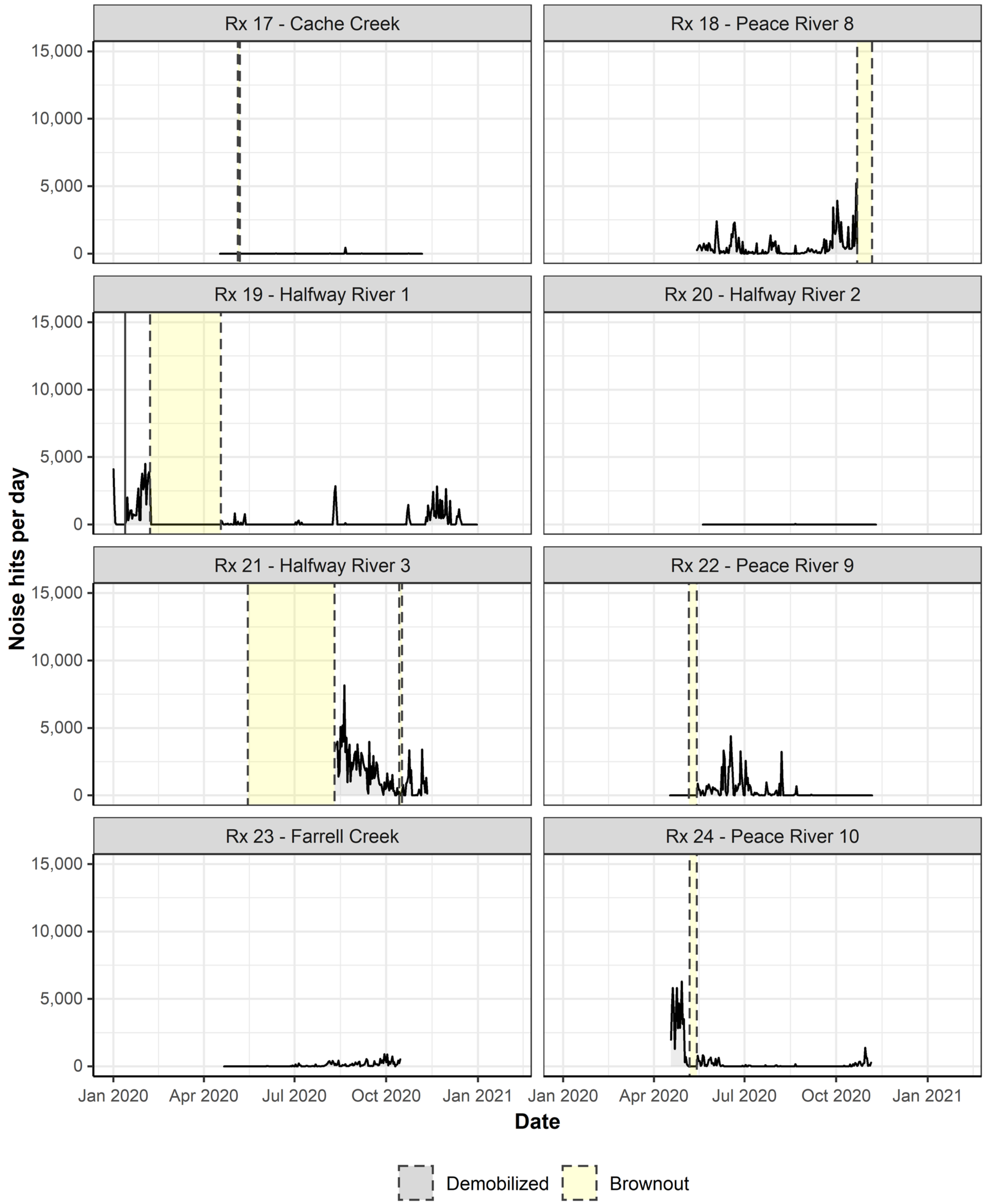


Figure B2 continued (part 3 of 5).

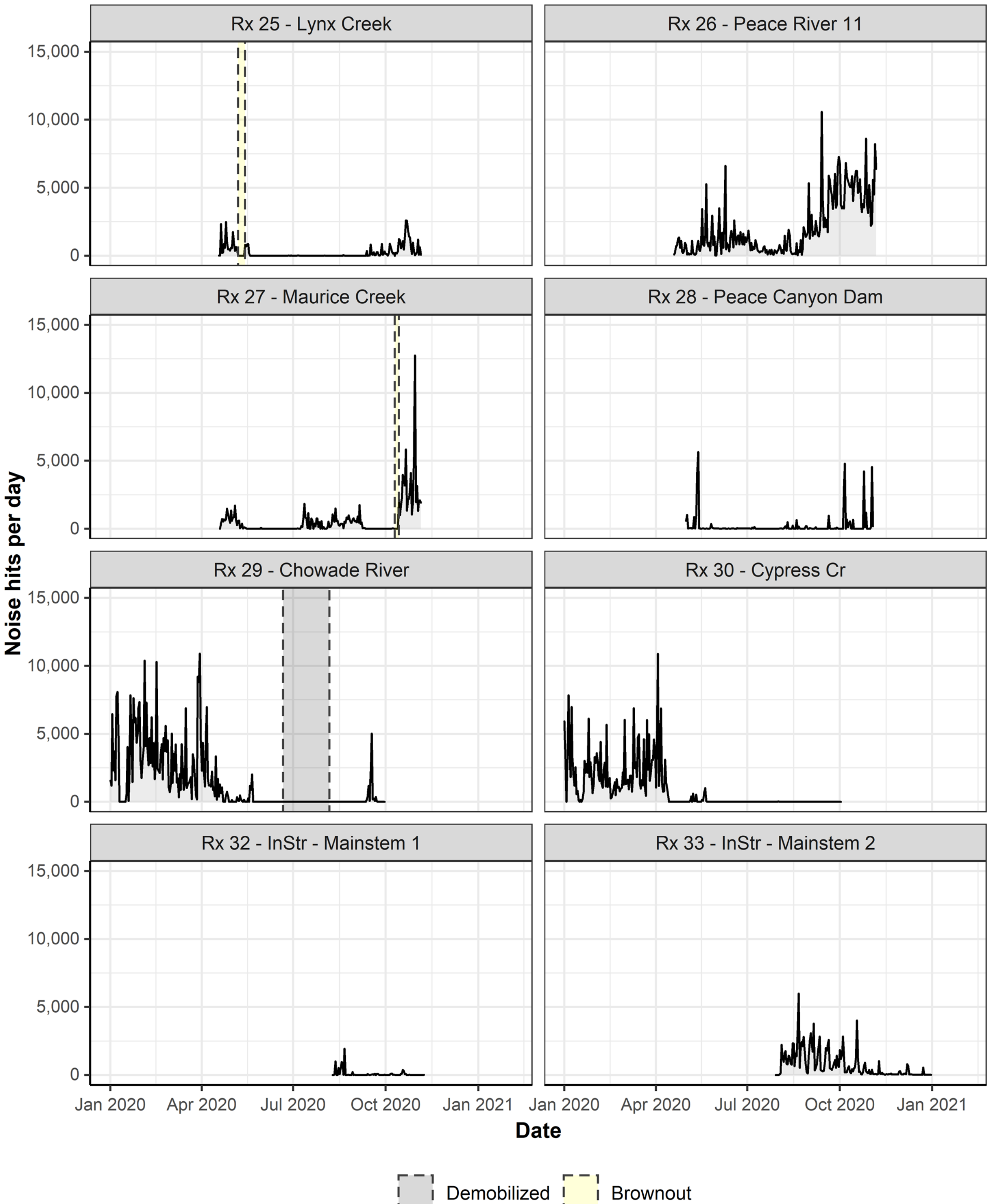
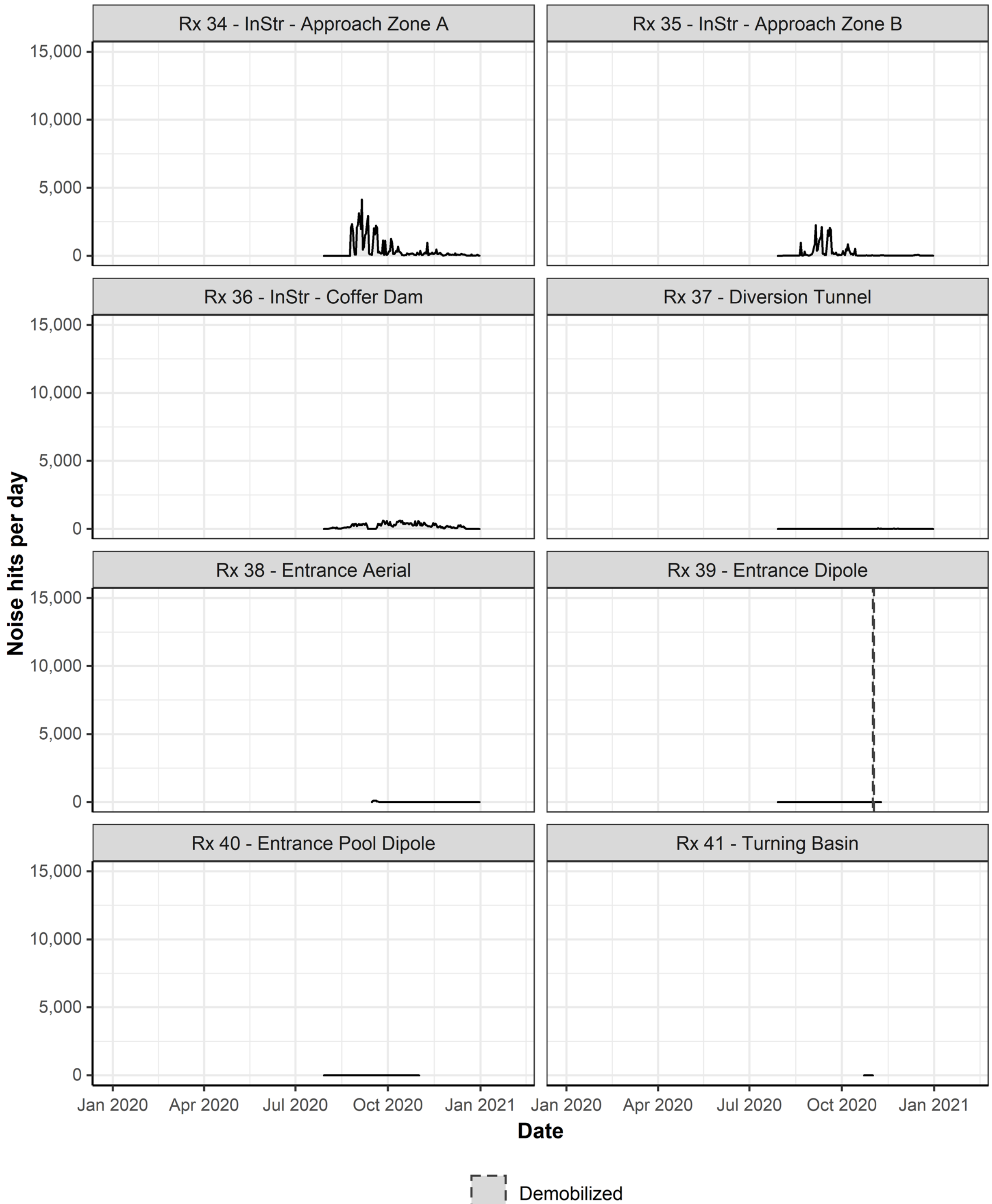


Figure B2 continued (part 4 of 5).



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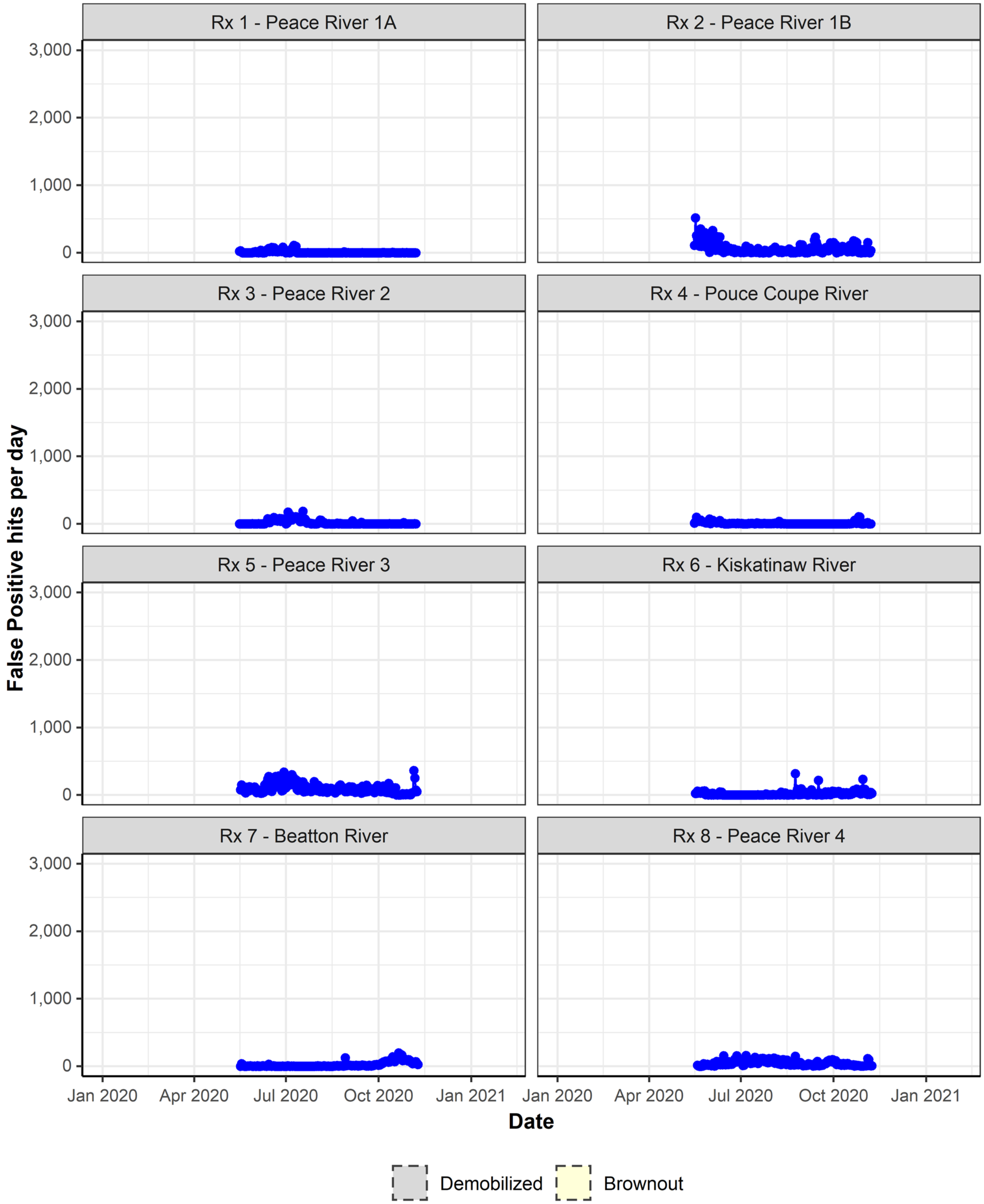


Figure B3. **False positive signals by station organized into hits per day in 2020. The spaces highlighted with a yellow or gray rectangle signify periods in which receiver outages had occurred and data collection did not proceed. The figure continues on the four next pages.**

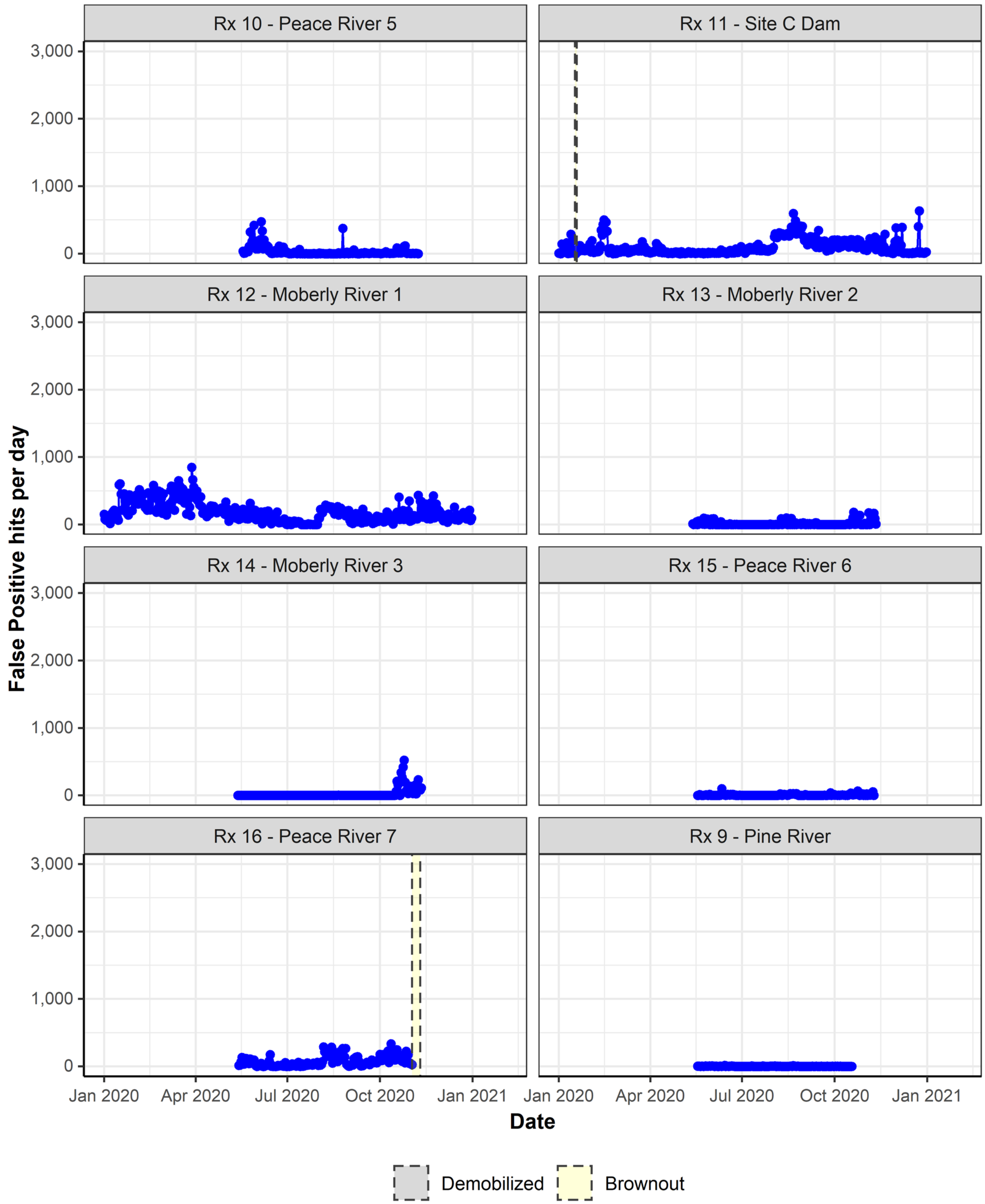


Figure B3 continued (part 2 of 5).

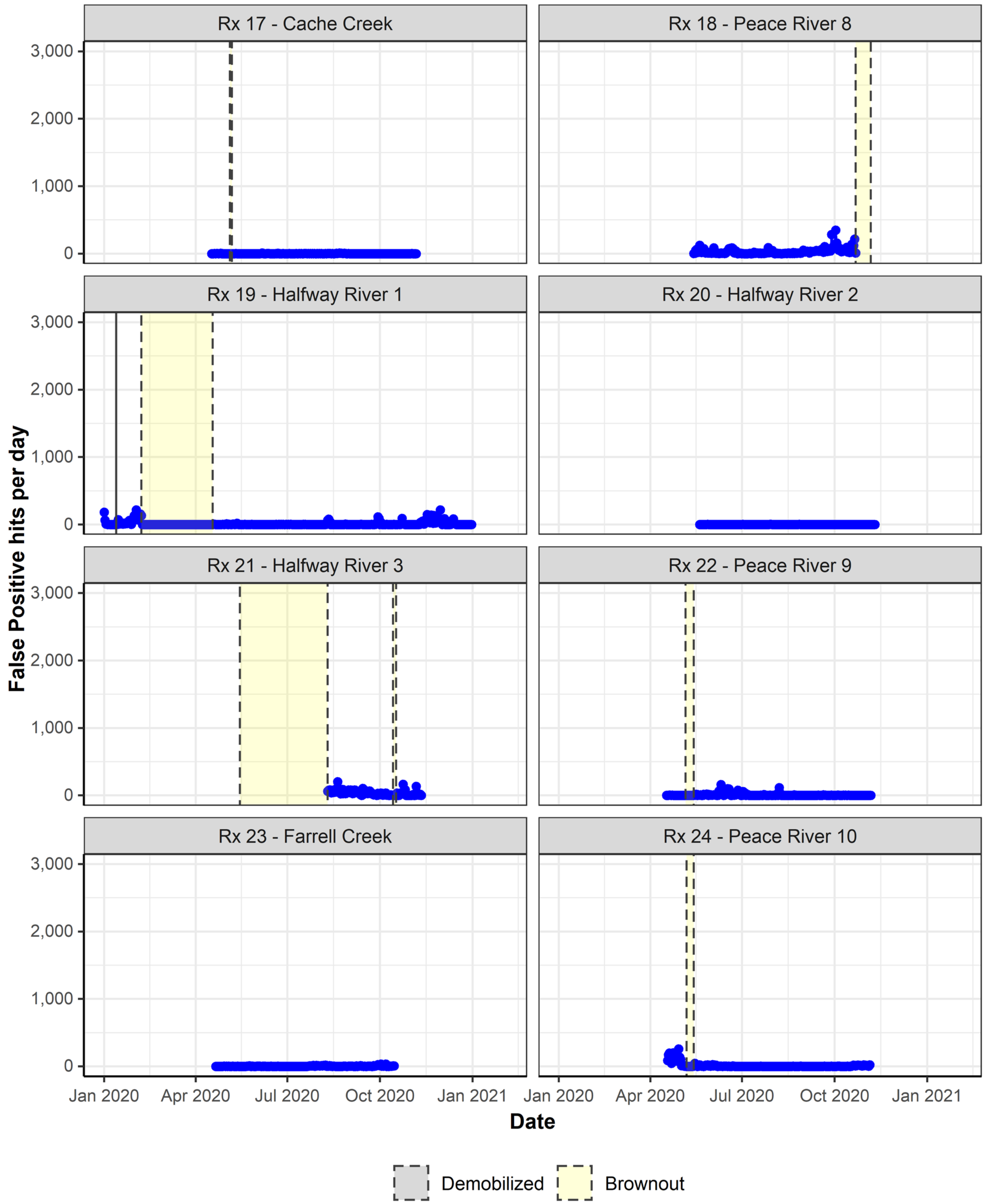


Figure B3 continued (part 3 of 5).

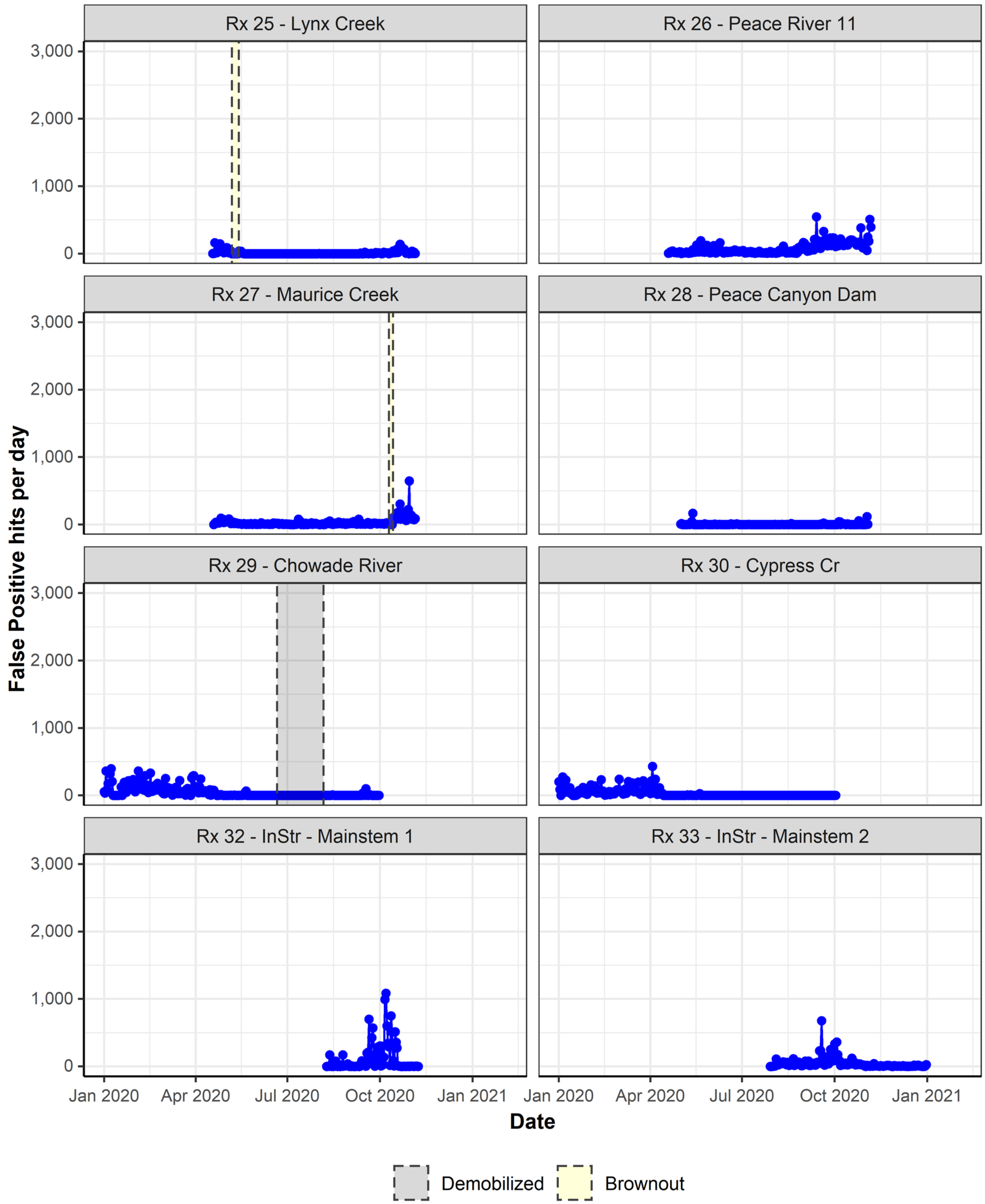


Figure B3 continued (part 4 of 5).

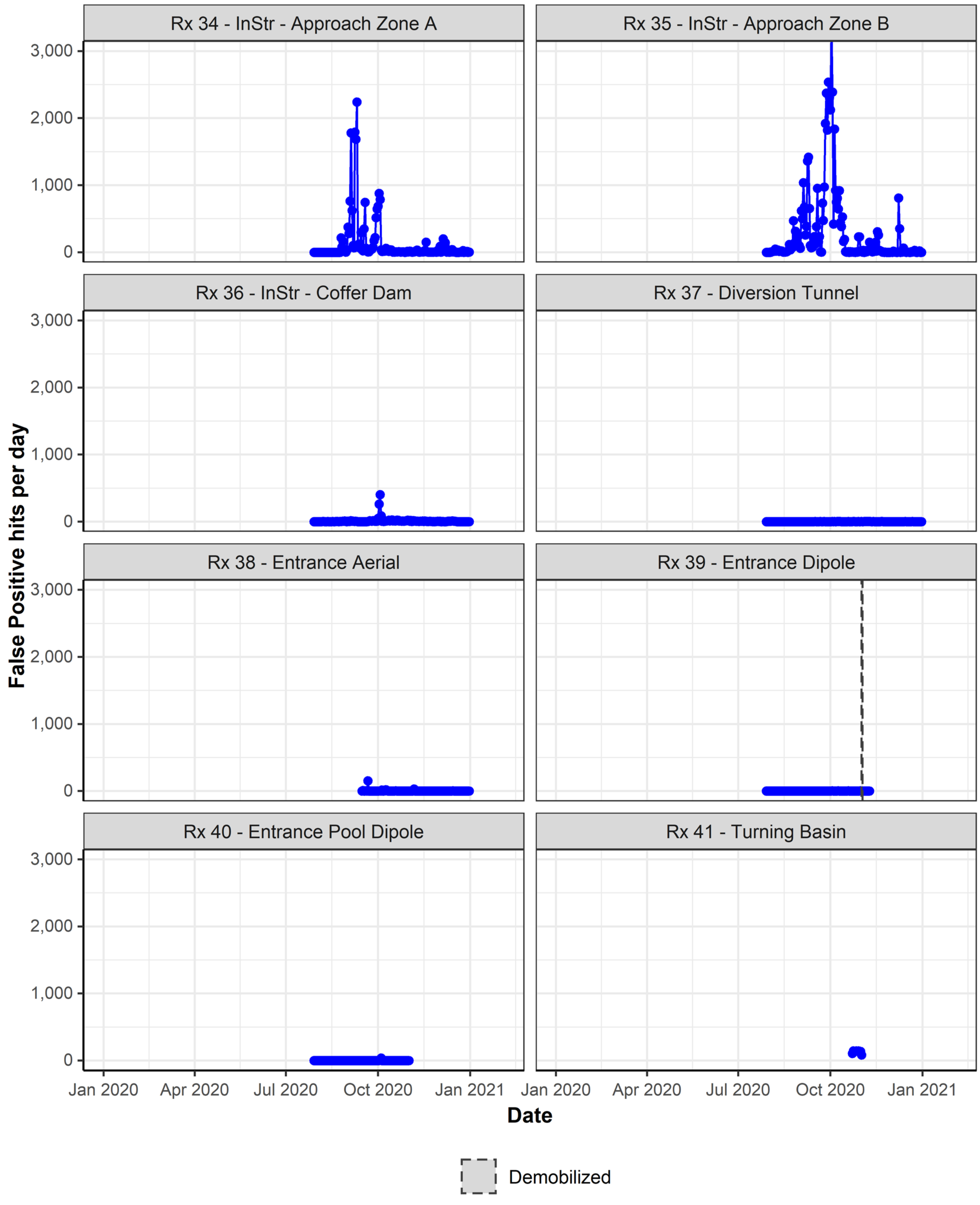


Figure B3 continued (part 5 of 5).

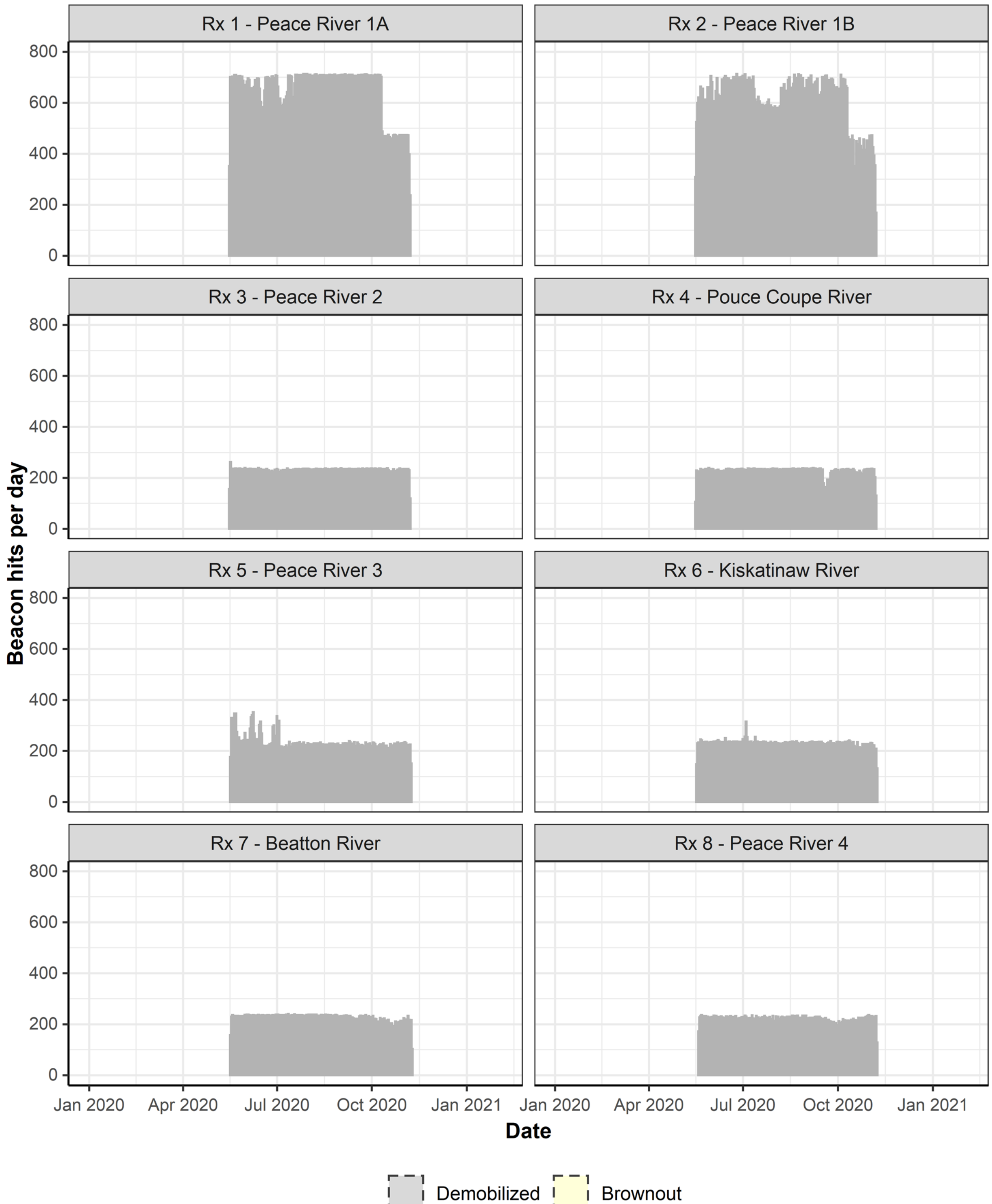


Figure B4. Beacon tag signals by station organized into hits per day in 2020. The spaces highlighted with a yellow or gray rectangle signify periods in which receiver outages had occurred and data collection did not proceed. The figure continues on the four next pages.

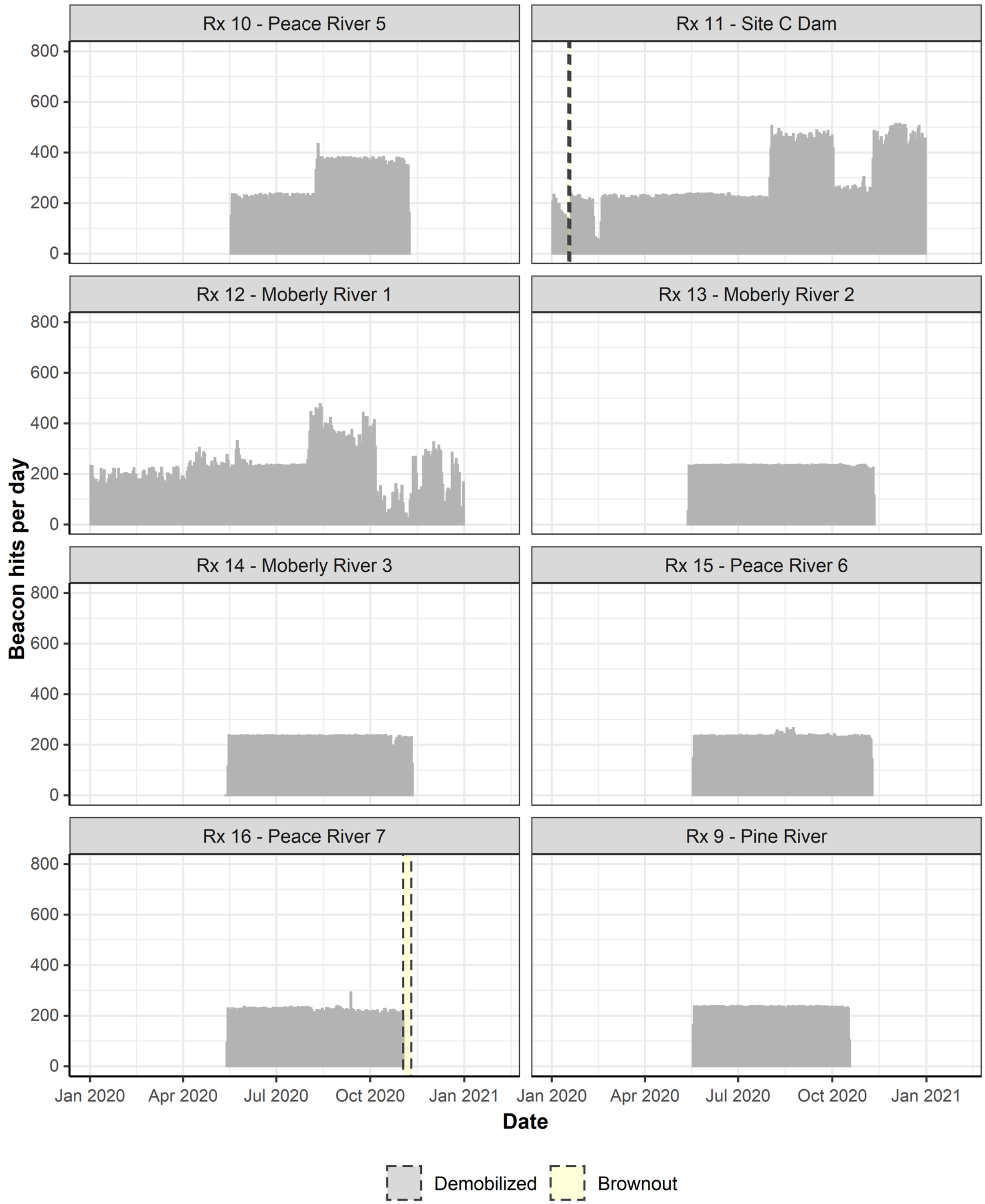
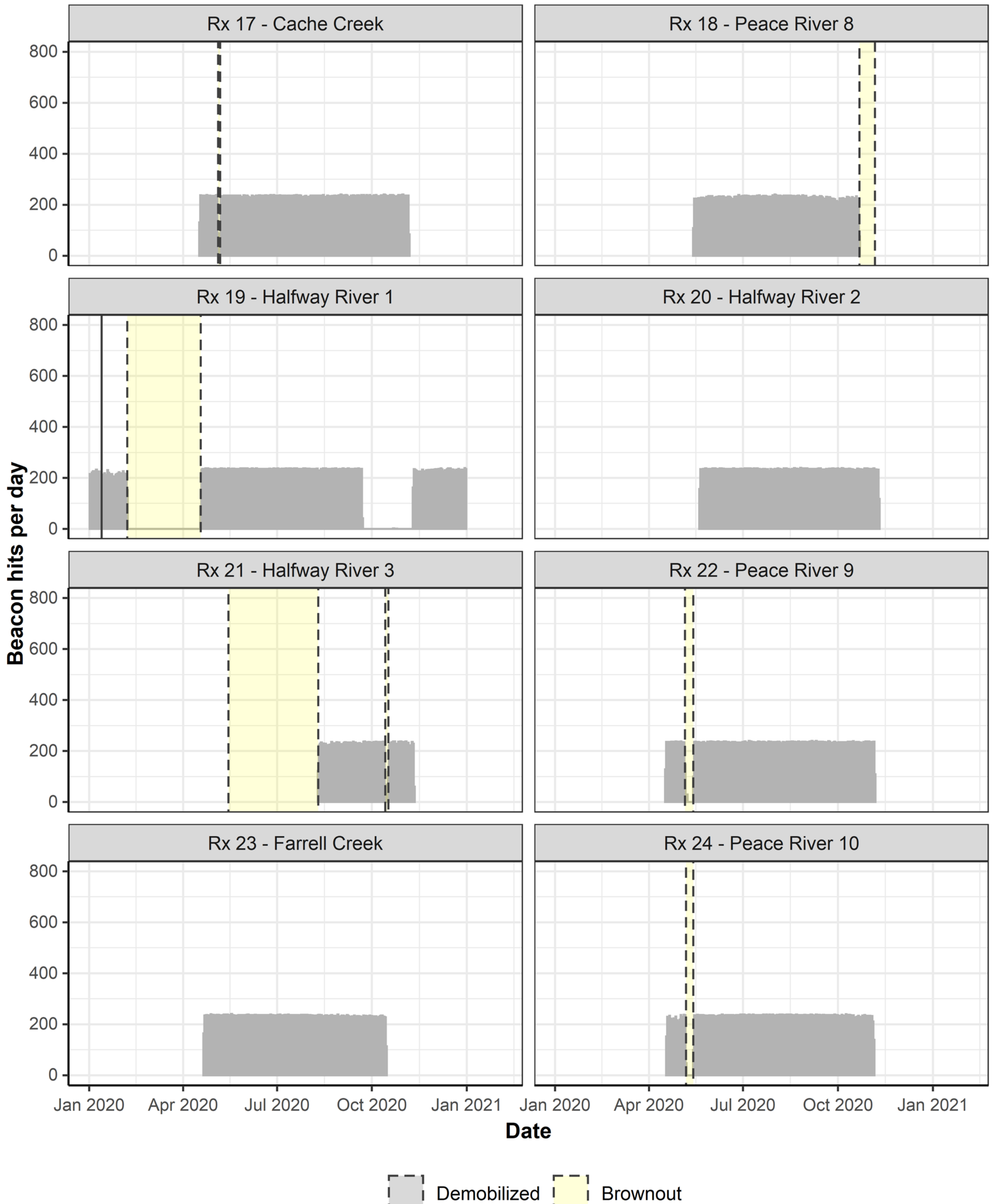


Figure B4 continued (part 2 of 5).



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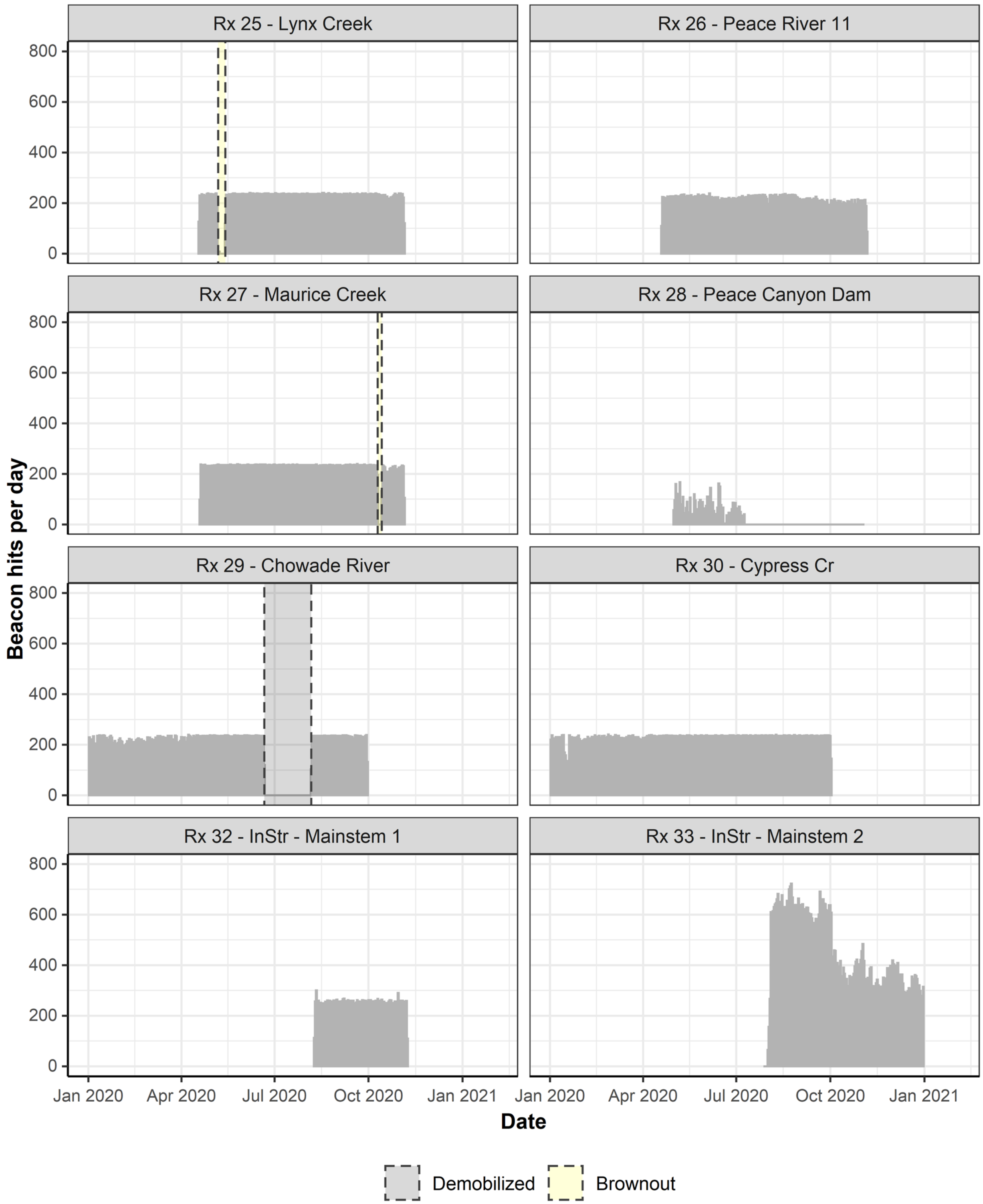

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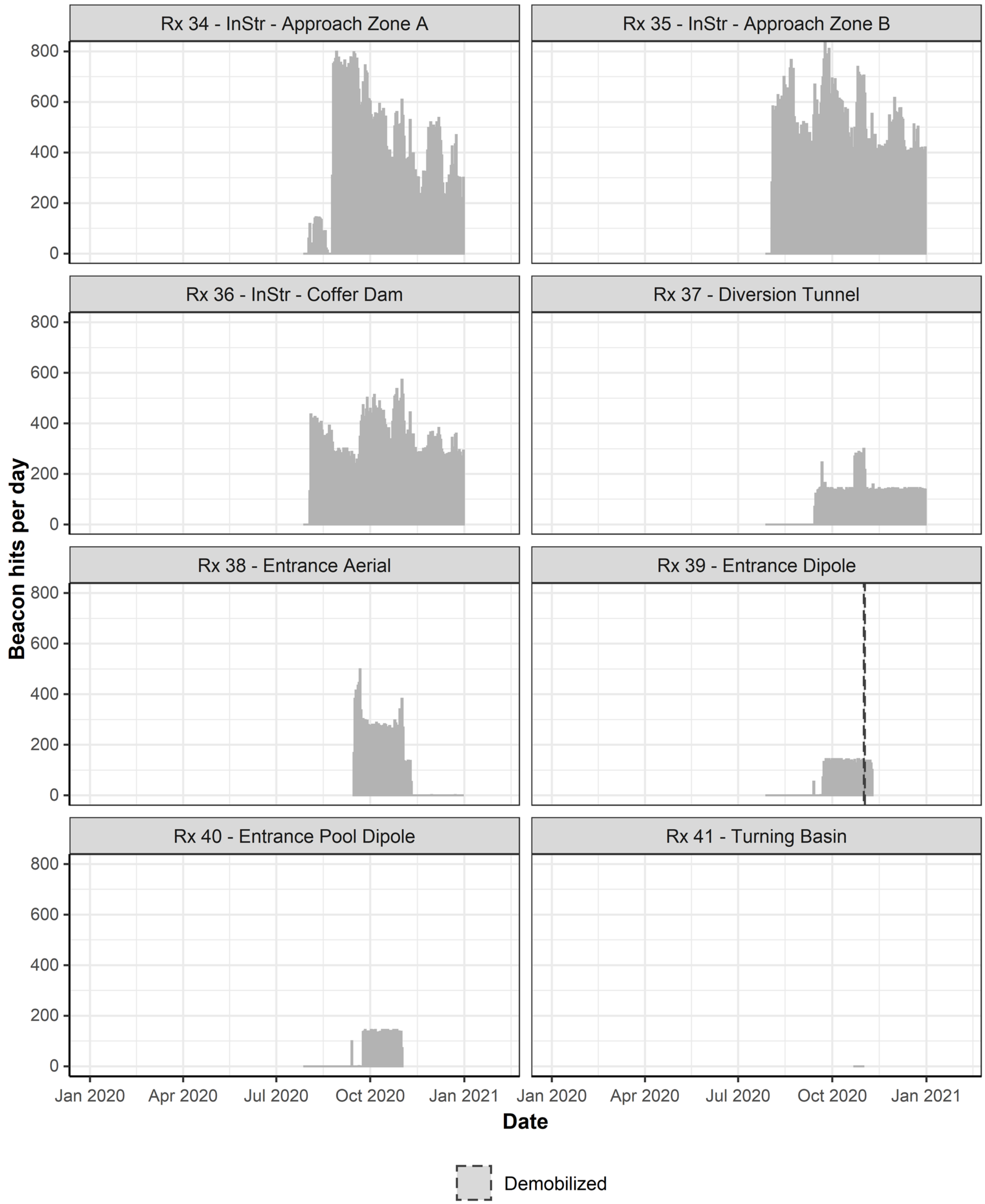


Figure B4 continued (part 5 of 5).

Appendix C. Database Structure

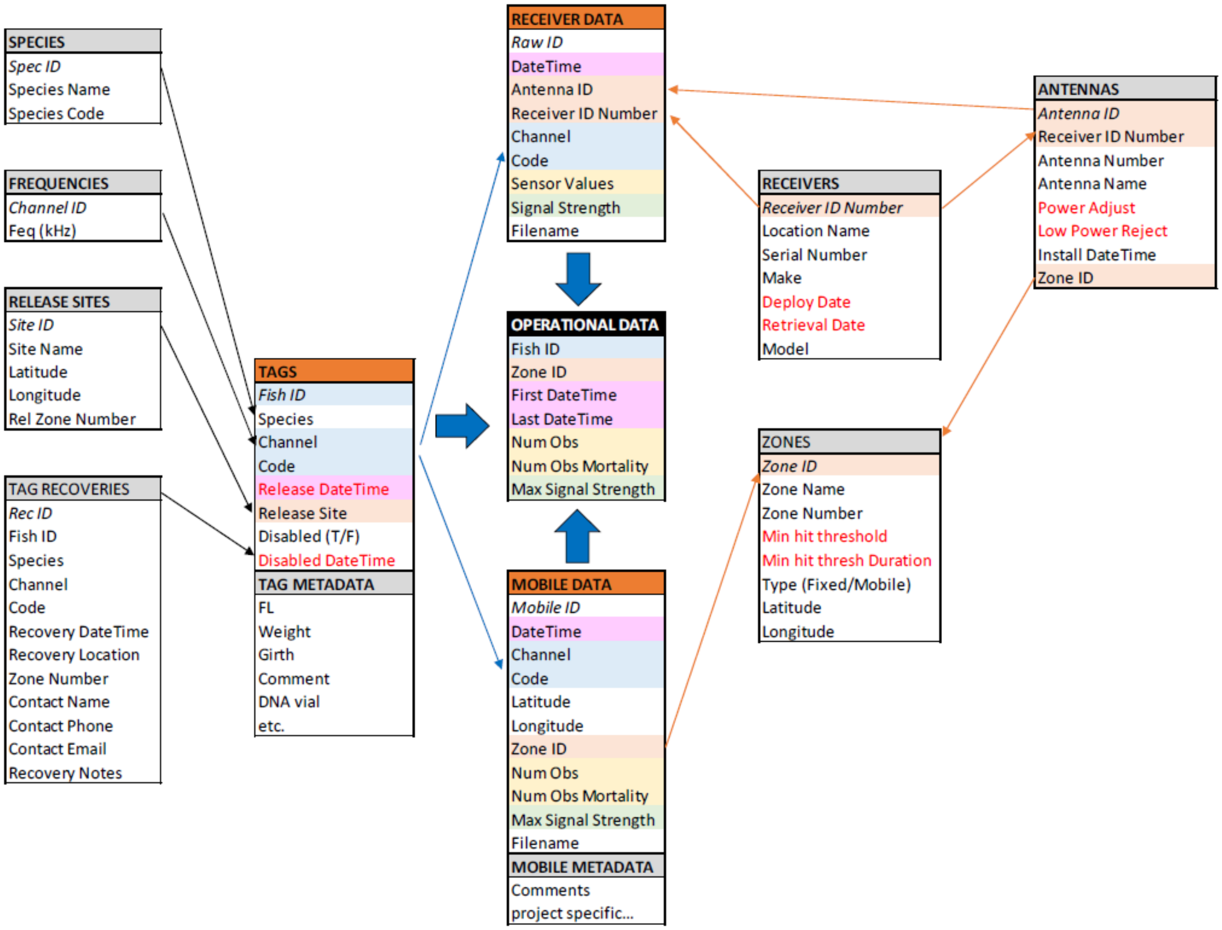


Figure C1. Visual representation of the database, displaying how each of the tables relate to each other.

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

Appendix D. Mobile Tracking Routes

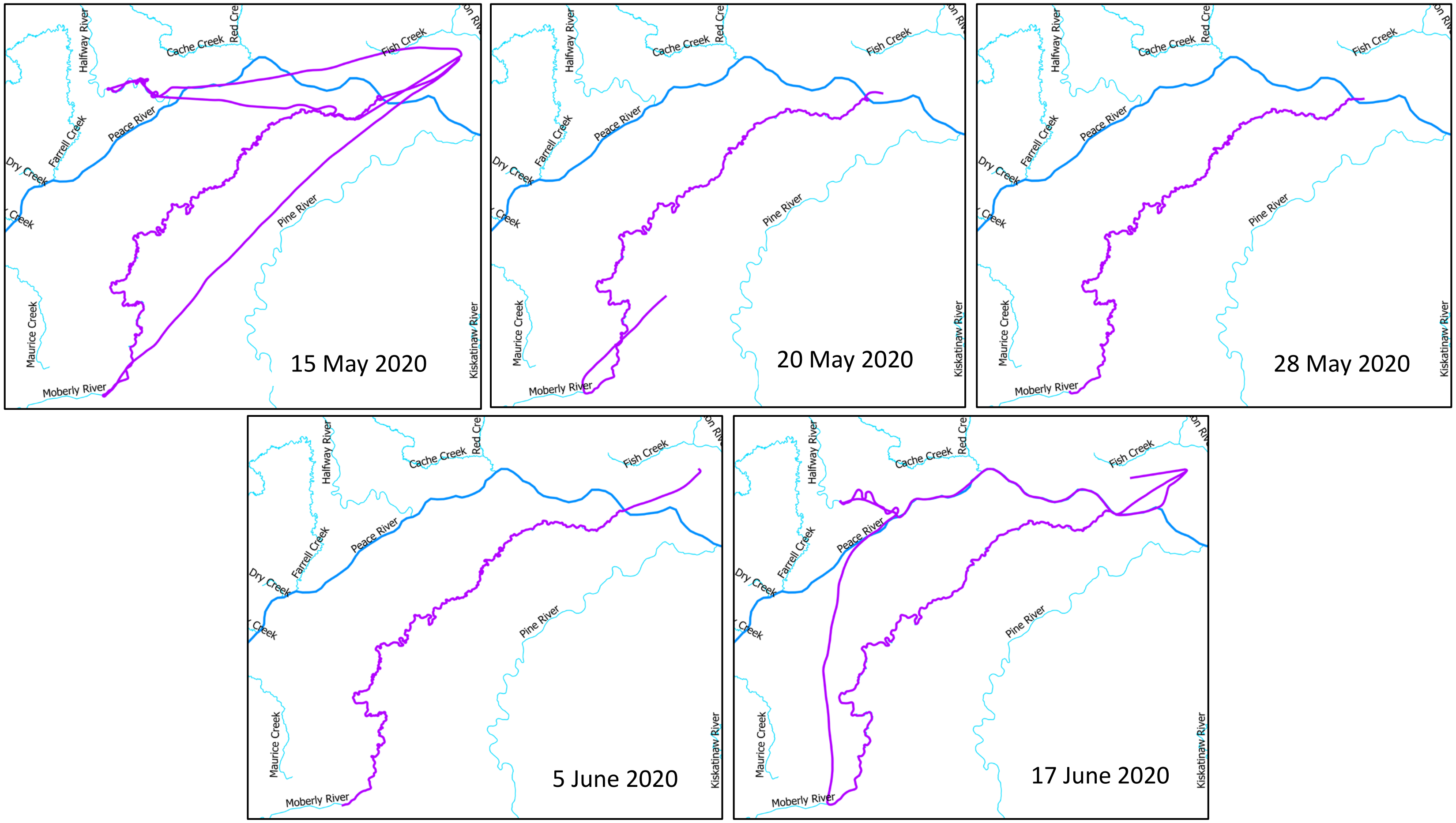


**Figure D1.	Tracking route (purple) for five mobile-telemetry tracking flights of the Moberly River, May-June 2020 (see Table 5).**

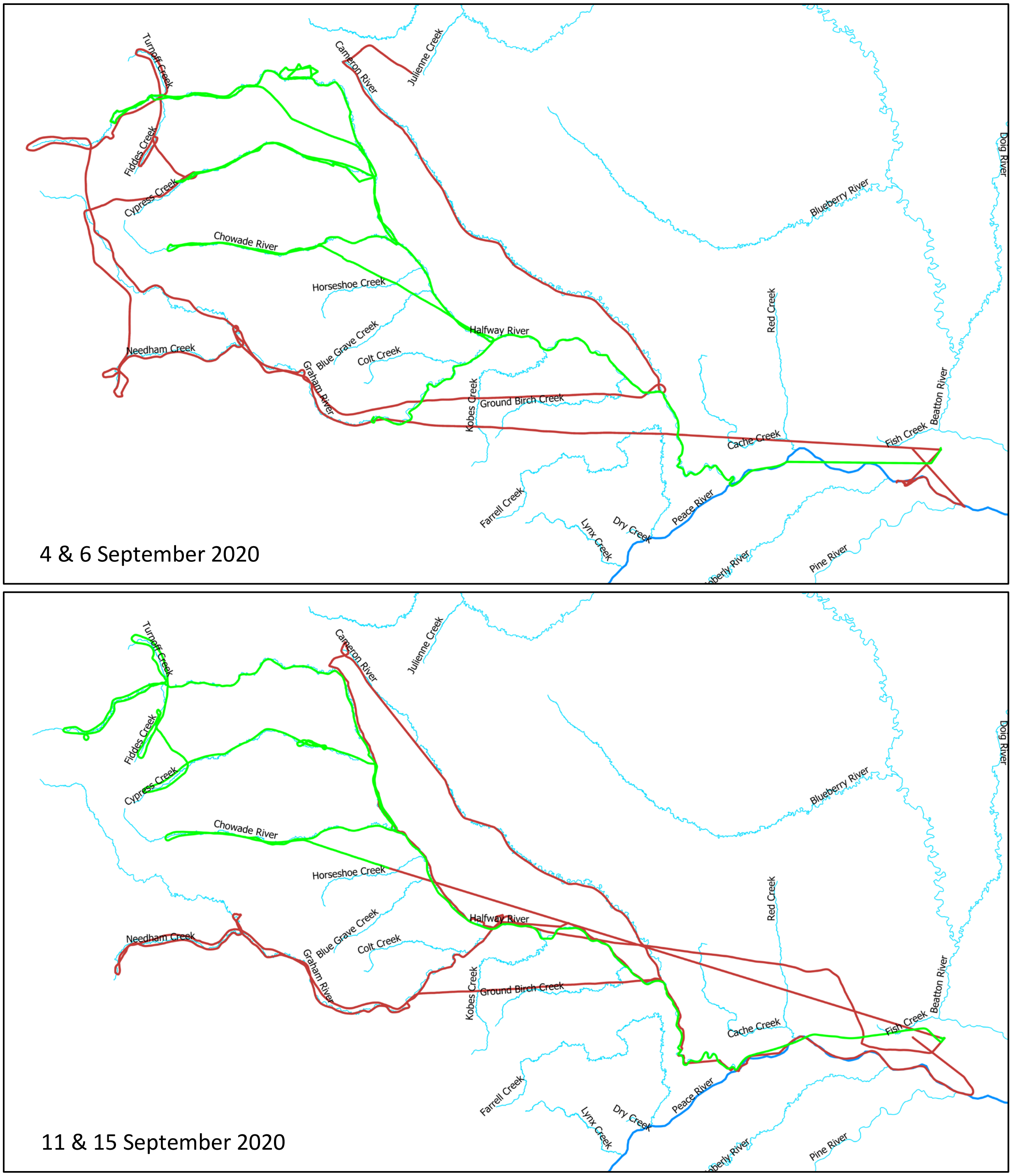


Figure D2. Tracking routes (surveys took two flights, shown in green and red, to complete) for two mobile-telemetry tracking surveys of the Halfway River, September 2020 (see Table 5).

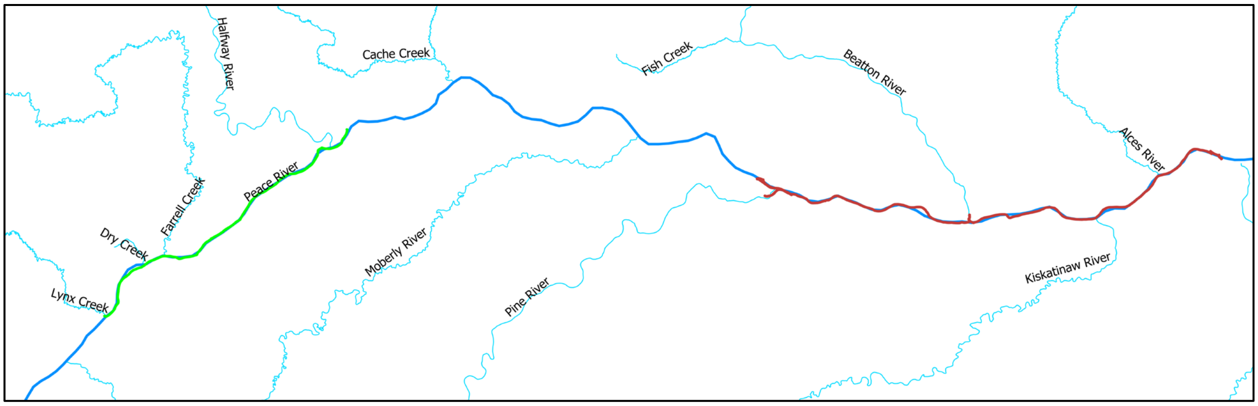


Figure D3. **Tracking routes (14 October in green; 16 October in red) of an opportunistic boat-based mobile survey of the Peace River (see Table 5).**

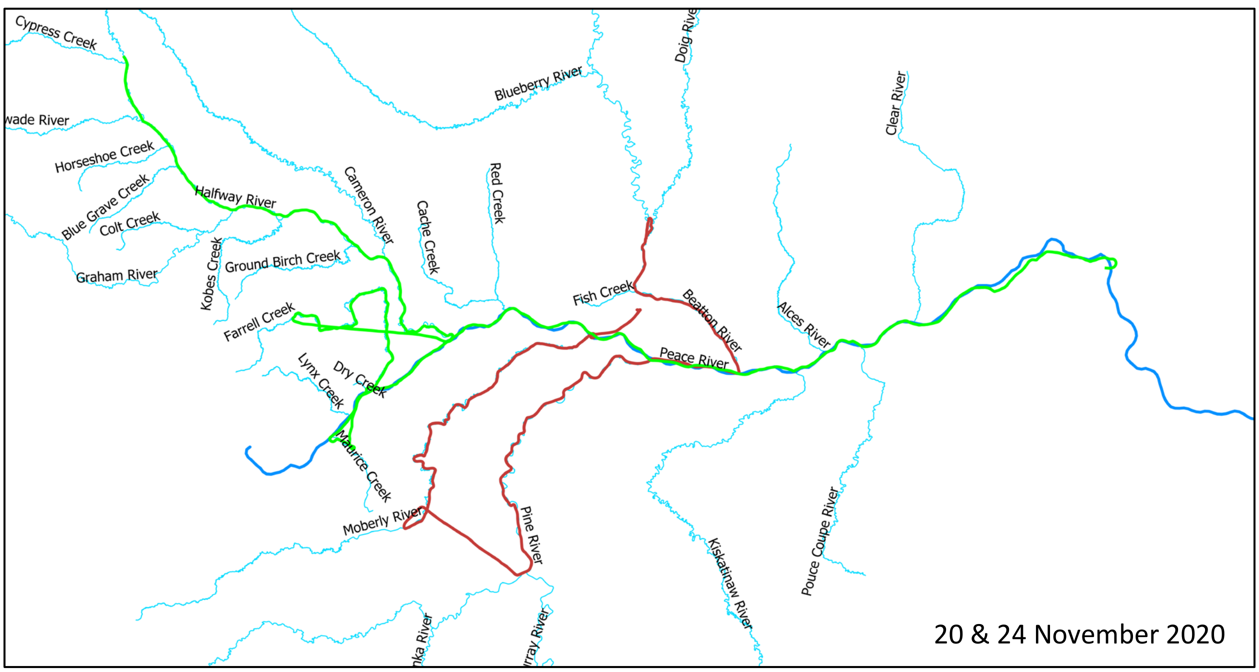
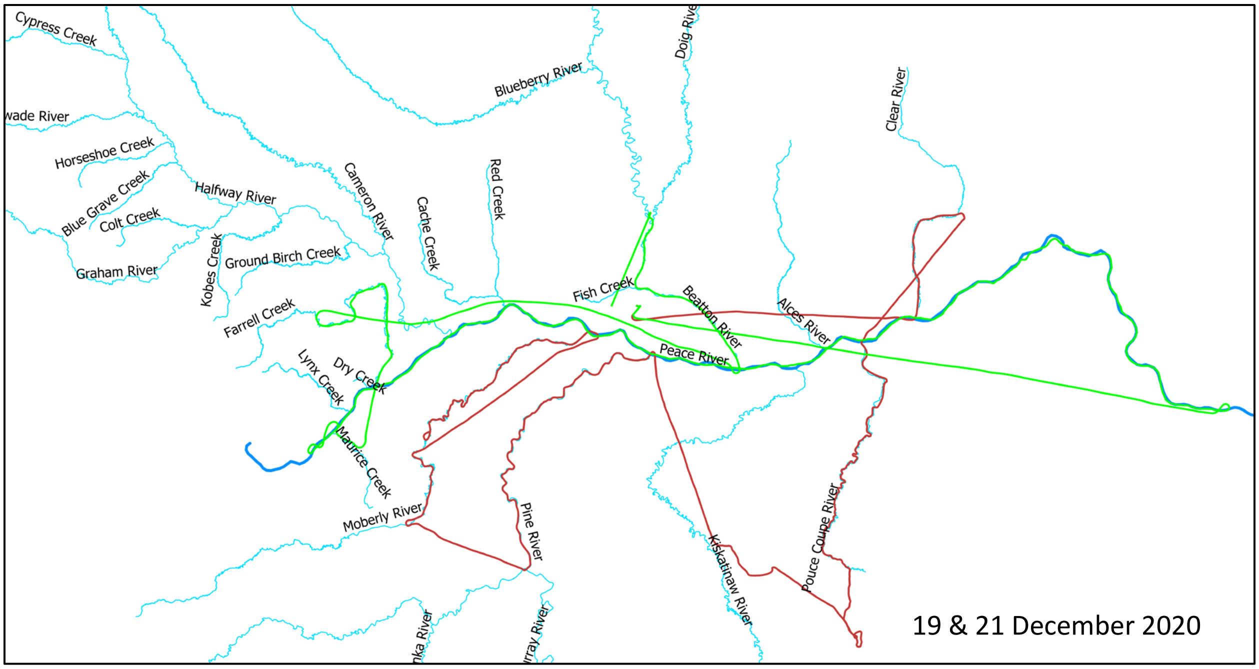


Figure D4. **Tracking routes (surveys took two flights, shown in green and red, to complete) for three wintertime fixed wing mobile-telemetry tracking surveys (see Table 5). Figure continued below.**



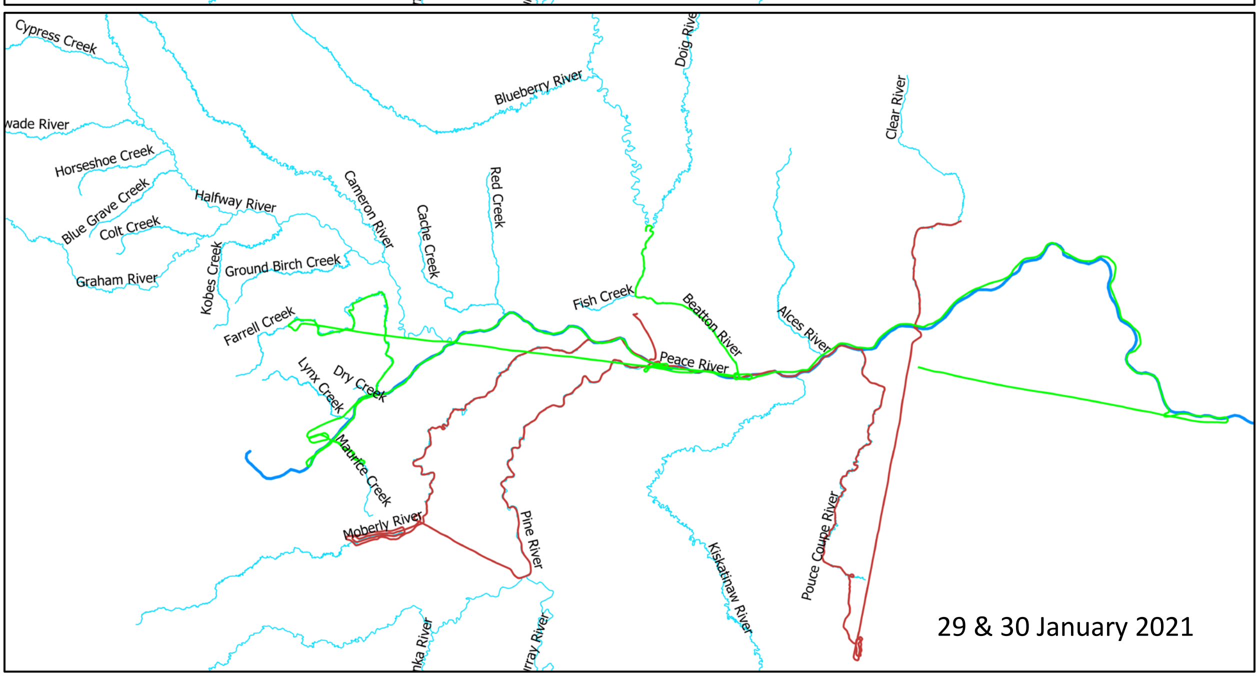


Figure D4 continued.

Appendix E. Additional Tracking Maps

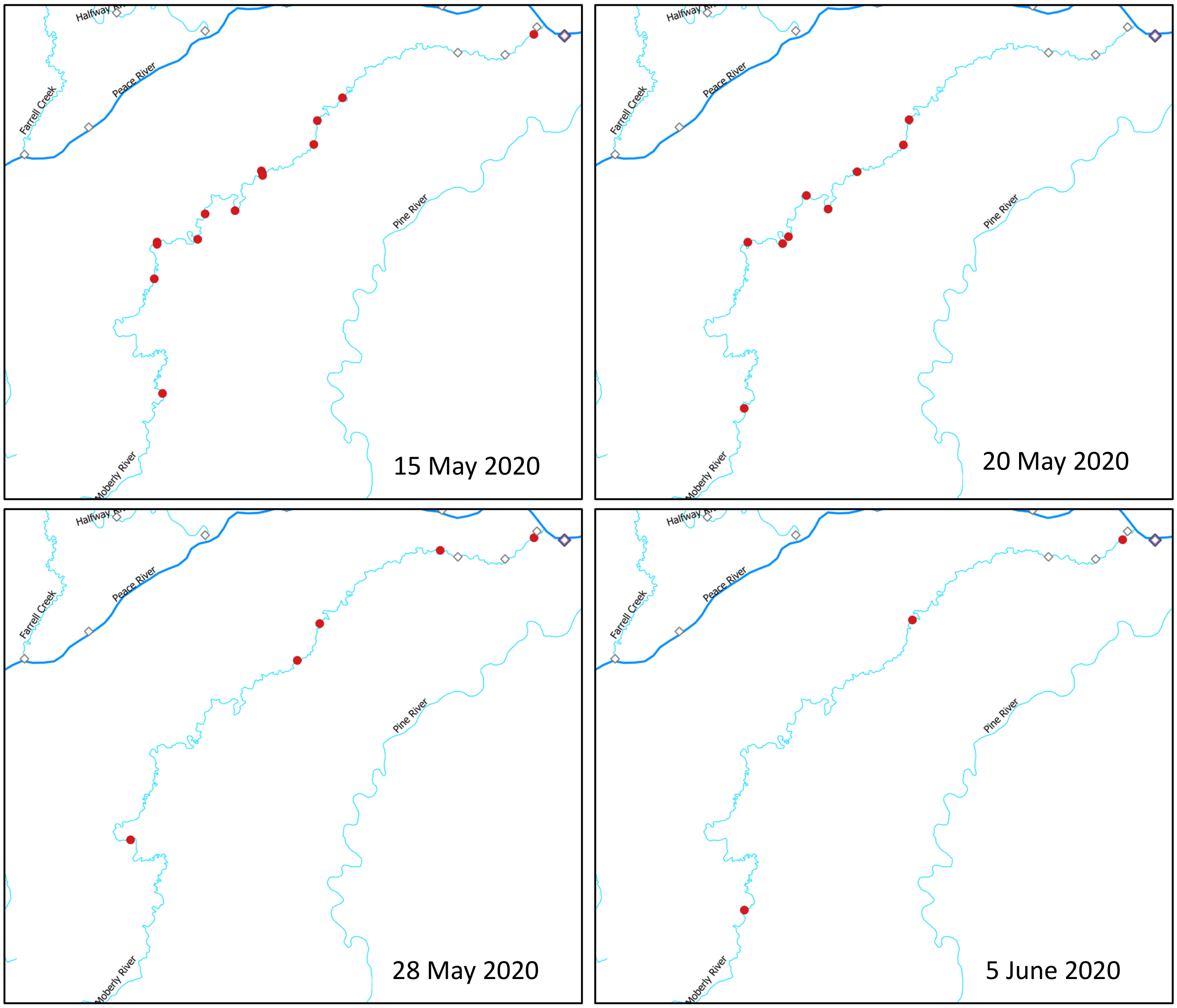


Figure E1. Locations of Arctic Grayling detections in the Moberly River (red dots) during four spawning-season mobile tracking surveys. None were detected during the fifth survey (17 June 2020). Fixed-station receivers shown as white diamonds.

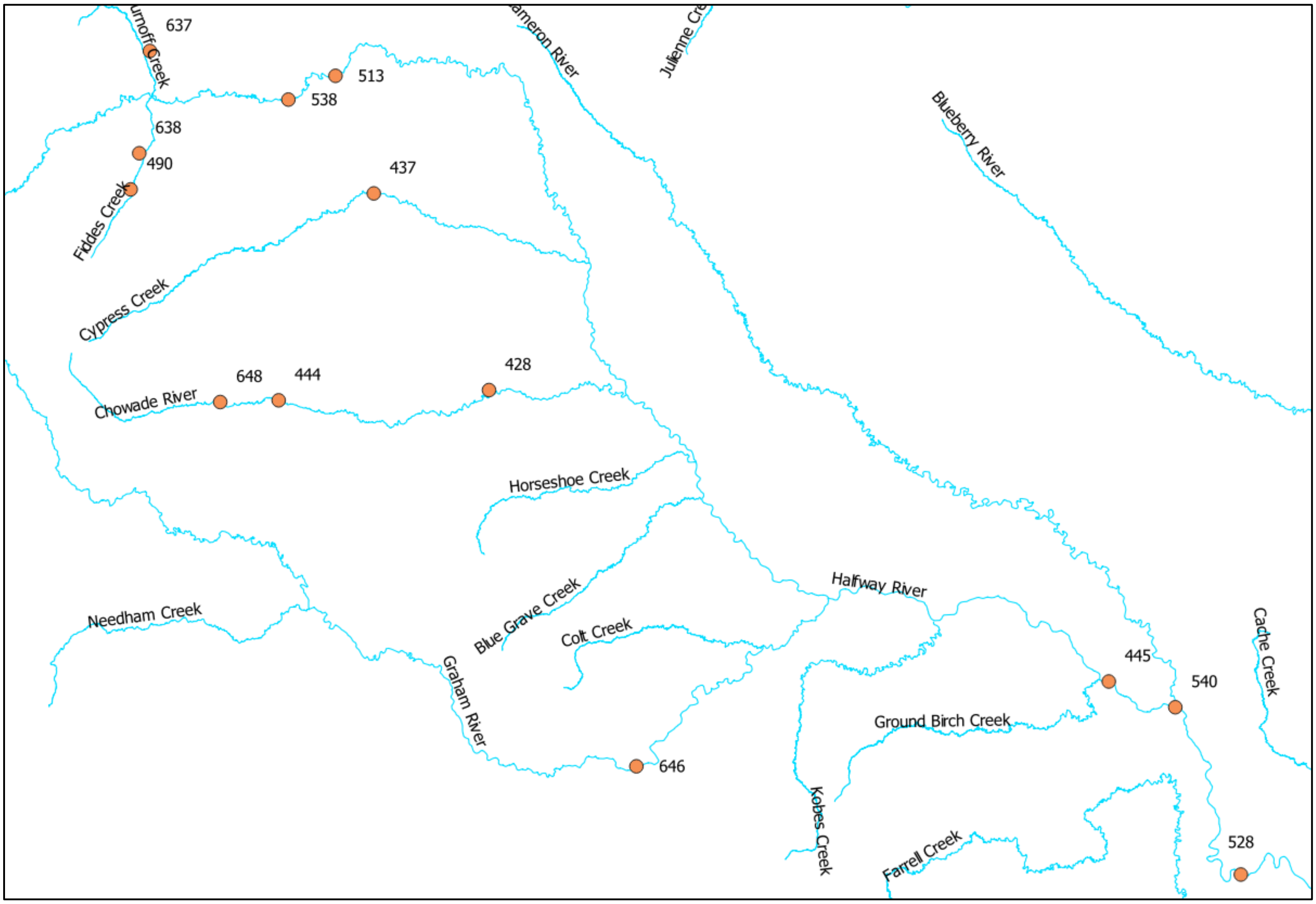


Figure E2. **Bull Trout detection locations, labeled with a unique Tag ID number, during the first of Halfway River mobile tracking surveys, 4 & 6 September 2020.**

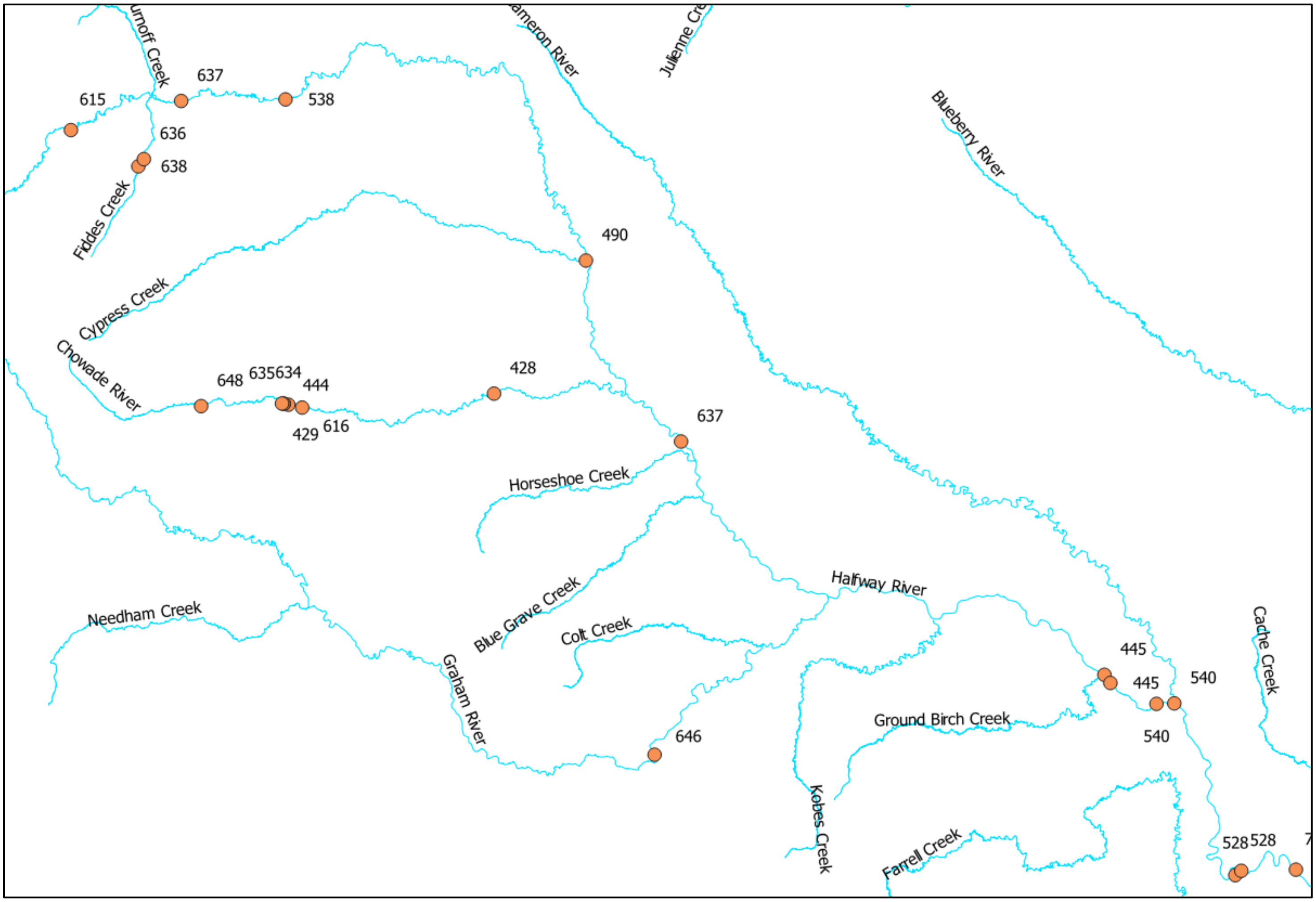


Figure E3. **Bull Trout detection locations, labeled with a unique Tag ID number, during the second of two Halfway River mobile tracking surveys, 11 & 15 September 2020. Duplicates refer to study fish detected on both 11 & 15 September.**

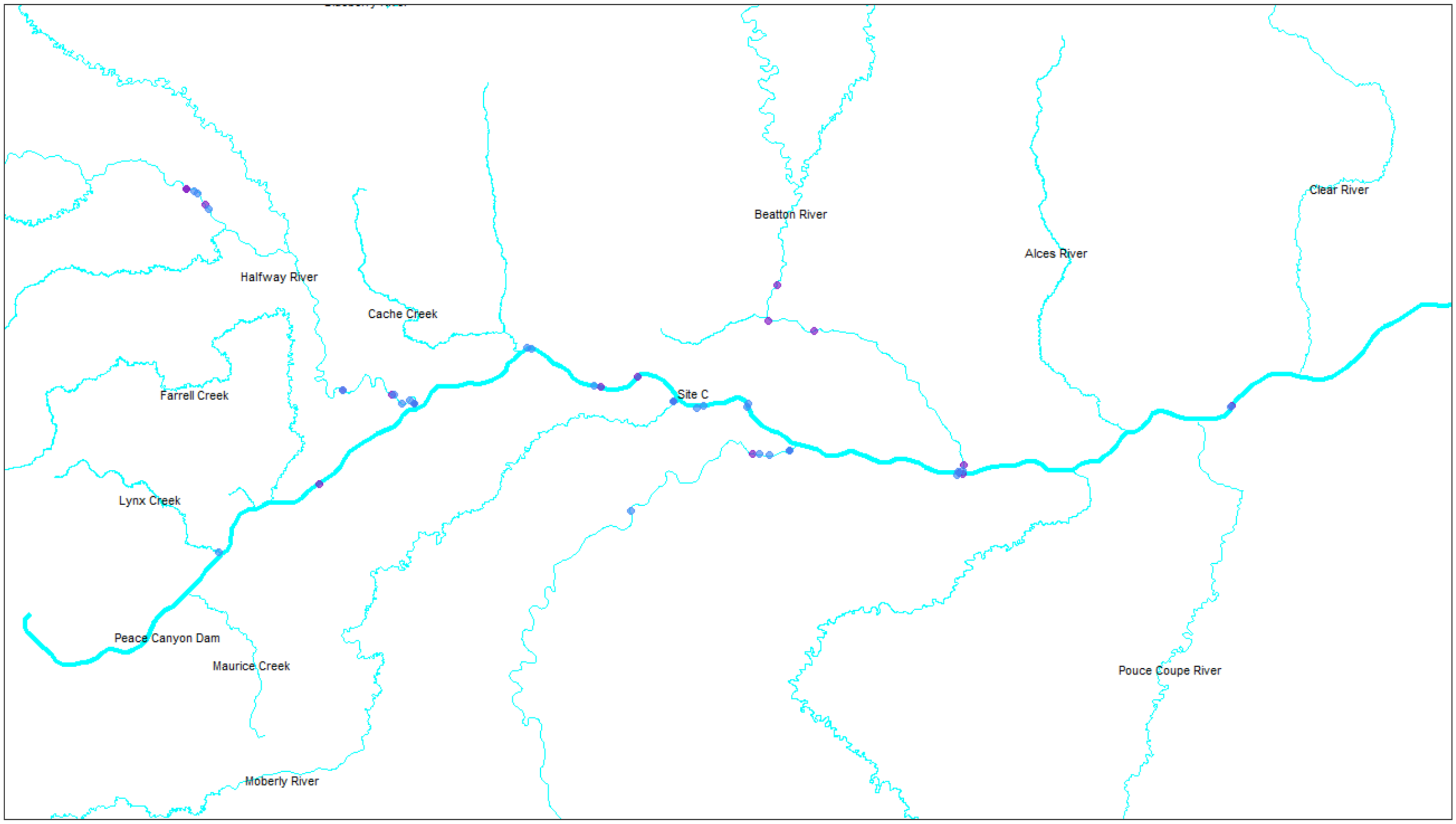


Figure E3. Mountain Whitefish tracked locations in October 2006 (purple) and October 2007 (blue). One detection is displayed per individual per year.

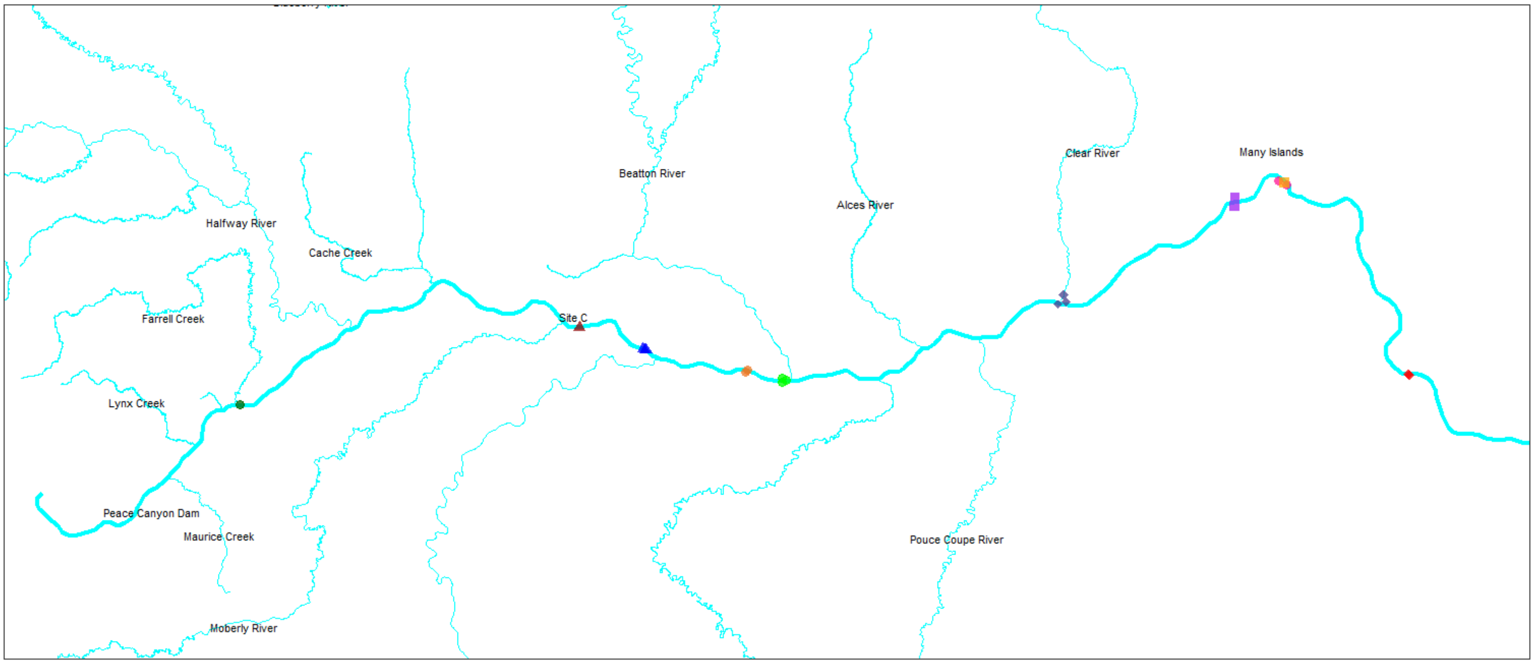


Figure E4. Burbot locations during winter mobile telemetry in November 2020 to January 2021. Individual Burbot are differentiated by color and shape.