Detection of PIT-Tagged Juvenile Salmonids Migrating in the Columbia River Estuary, 2022

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Executive Summary

In 2022, we continued a multi-year study in the Columbia River estuary to detect juvenile Pacific salmon *Oncorhynchus* spp. marked with passive integrated transponder (PIT) tags. Fish were detected using a surface pair trawl with a matrix of rectangular antennas fitted into the cod end. The matrix was configured with three parallel antennas in front and three in the rear, totaling six individual antennas.

This configuration relied on trawl net wings to guide fish toward the cod end of the trawl, where they would come within detection range of the antennas. Entrained fish were able to exit the trawl safely through the antenna array, without capture or handling. We deployed the trawl next to the Columbia River navigation channel between river kilometers (rkm) 66 and 84 and sampled for a total of 638 h.

During this period, the matrix system detected 9,838 PIT-tagged fish, of which 13% were wild, 84% were of hatchery origin, and 3% were of unknown rear type. Species composition of detected fish was 43% spring/summer Chinook, 2% fall Chinook, 43% steelhead, 5% sockeye, 4% coho, less than 1% cutthroat trout, and 3% unknown.

To coincide with arrival in the estuary of spring-migrating juvenile salmon and steelhead, sampling began on 29 March with a single daytime shift operating 3-5 d/week. As numbers of juvenile migrants increased, we intensified the sample effort with two daily shifts: one operating 7 d/week during daylight and a second operating 6 d/week during darkness. Intensive sampling continued from 1 May through 13 June. During intensive sampling, the trawl was deployed for an average of 12.5 h/d, which was considerably more than the 6.7 h/d average in 2021 (only a single shift sampled in 2021). We ended sampling on 13 June after most spring migrants had passed.

During the intensive sample period, average hourly detections of hatchery yearling Chinook were significantly higher during darkness than daylight hours (10.5 vs. 3.9 fish/h; P <0.001). Similarly, average hourly detections of wild yearling Chinook were significantly different between darkness and daylight hours (1.0 vs 0.5 fish/h; P = 0.006). For hatchery steelhead, hourly detection rates were significantly higher during daylight than darkness hours (7.7 vs. 2.6 fish/h; P <0.001). Similarly, for wild steelhead, there was a significant difference between daylight and darkness hours (1.8 vs. 0.5 fish/h; P < 0.001).

We detected 1.2% of the yearling Chinook and 3.0% of the steelhead transported and released below Bonneville Dam. These rates were much higher than those for transported fish in 2021, when we detected 0.3% of the yearling Chinook and 1.1% of the steelhead. Additionally, we detected 1.4% of the yearling Chinook and 2.4% of the steelhead detected at Bonneville. These proportions were also greater than those for in-river migrants in 2021, when we detected 0.5% of the yearling Chinook and 2.2% of the steelhead detected at Bonneville Dam.

In 2022, we were unable to sample with the flexible antenna array during the spring migration season; however, we continued technical development of the system once trawl sampling was complete. Like the trawl, this system is towed behind two vessels to detect passing juvenile salmon, but unlike the trawl, the flexible system does not require use of a net to guide fish to within reading range of the antennas.

Replacing the pair trawl with an array of flexible cable antennas would improve our primary sampling method by eliminating the use of a net. This would prevent incidental sampling impact on salmonids listed under the U.S. Endangered Species Act. A flexible antenna system would also simplify logistics, increase sample efficiency, and reduce the cost of sampling PIT-tagged fish in the estuary.

For tests conducted in 2022, the flexible antenna array was configured with eight to twelve 6.1- by 2.4-m rectangular cable antennas configured horizontally to sample from the surface to a depth of approximately 2.5 m. Testing was conducted from late August through the end of October 2022 to evaluate deployment using new aluminum reader capsules, alternative antenna orientations, and new system configurations.

In 2022, as in previous study years, we examined PIT-tag detection data to evaluate potential factors related to detection probability and to compare passage performance metrics among fish groups by species, rear type (hatchery or wild), and migration history (transported vs. in-river).

For yearling Chinook salmon detected with the trawl, we found a significant effect for date-squared ($P = 0.031$), but no significant effect for migration history ($P = 0.148$). There was no significant interaction between migration history and arrival date ($P = 0.810$ or date-squared ($P = 0.972$). On average, we detected approximately 0.7% of transported and in-river migrants early in the season. This percentage increased to 1.4% during peak migration and then decreased to 0.6% by the end of the season.

For steelhead detected with the trawl, we found a significant effect of date-squared ($P = 0.010$), and migration history ($P = 0.042$). There was no significant interaction between migration history and arrival date ($P = 0.366$) or date-squared

($P = 0.734$). On average, we detected transported vs. in-river migrant steelhead at respective rates of about 1.3 vs. 0.9% in the early season. These percentages increased to about 3.9 vs. 2.8% at peak migration and decreased to roughly 2.0 vs. 1.5% by the end of the spring migration season.

Over the years, we have observed an inverse relationship between river flow and detection rates in the trawl. Mean flow volume at Bonneville Dam during the intensive sample season of 2022 was 31% higher than during similar dates in 2021 (8,410 vs. 6,423 m^3/s), and 2% lower than the 20-year average for 2000-2020 (8,260 m^3/s). Daily river flows were below average at the beginning of the sample season, but were significantly higher than average toward the end. Flows were characterized by an abnormally cool spring followed by a large and late spring freshet, which peaked in mid-June.

Of all juvenile salmonids detected by the trawl in 2022, 14% had been transported, while 11% had been detected passing Bonneville Dam. The remaining 75% had neither been transported nor detected at Bonneville Dam, although at least 96% of our total detections originated upstream from Bonneville Dam.

Mean migration rate to the estuary (rkm 75) was significantly faster for yearling Chinook salmon detected at Bonneville Dam than for those released from barges just below the dam (90 vs. 73 km/d, $P < 0.001$). Similar differences were observed for subyearling Chinook salmon (100 vs. 56 km/d).

Mean migration rate for steelhead was also significantly different for in-river migrants (102 km/d) vs. transported fish (97 km/d; $P = 0.005$). Sockeye detections showed a similar trend as well (103 vs. 98 km/d; n = 3 paired groups). Overall, migration rates to the sample reach were faster for both in-river and transported fish in 2022 than in 2021 across all species. This was likely a function of higher flow volumes in 2022.

Detections of subyearling Chinook salmon have decreased in recent years, commensurate with reduced tagging effort for these fish. In 2022, we detected 137 subyearling fall Chinook, with the majority of detections occurring from late May through the end of the sampling period. Of these 137 fish, 119 originated from the Snake River Basin (73 in-river migrants and 46 transported). The remaining 18 were in-river migrants from Columbia River stocks, with 5 subyearlings released above McNary Dam, and 13 released between McNary and Bonneville Dam.

Of the 442 sockeye detected, 88% were from the Snake River and 12% were from the upper Columbia River above McNary Dam, with <1% originating from the middle Columbia River between McNary and Bonneville Dam. Rear types of detected sockeye were 82% hatchery, 16% wild, and 2% unknown origin. Migration histories of detected sockeye were 90% in-river migrant and 10% transported.

In 2022, as in previous years, detection data from the estuary were essential for estimates of survival probability to the tailrace of Bonneville Dam, the last dam encountered by migrating juvenile salmonids. Detections from the estuary trawl have provided data for estimates of survival through the hydrosystem since 1998. These estimates are critical to research and management programs for endangered salmonids in the Snake and Columbia River Basin and in other basins of the Pacific Northwest.

For the past several years, annual releases of PIT-tagged fish in the Columbia River Basin have totaled nearly 2 million. Detections of these fish as they pass through the estuary continue to increase our understanding of behavior and survival during the critical smolt transition period.

Contents

Introduction

In 2022, we continued a multi-year study in the Columbia River estuary to collect data on migrating juvenile Pacific salmon *Oncorhynchus* spp. implanted with passive integrated transponder (PIT) tags (Ledgerwood et al. 2004; Holcombe et al. 2022). This study began in 1995 and has continued annually except in 1997 and 2020, with sampling conducted in the estuary near Jones Beach, approximately 75 river kilometers (rkm) upstream from the mouth of the Columbia River. We use data from estuary detections to estimate survival and downstream migration timing of these fish.

As in previous years, we used a large surface pair trawl to guide fish through an array of PIT antennas mounted in the open cod end. Target fish were PIT-tagged juveniles with records in the *Columbia Basin PIT Tag Information System* (PTAGIS), a regional database that stores and disseminates information on PIT-tagged fish (PSMFC 1996-2022). These fish were tagged by other researchers for various research projects at natal streams, hatcheries, collection facilities at dams, and other upstream locations.

When PIT-tagged fish are entrained in the trawl, they must pass through the antennas to exit. Upon detection, the tag code, GPS position, and date and time are electronically recorded. Over 1.5 million Snake and Columbia River juvenile salmonids were PIT-tagged and released prior to or during the spring 2022 migration season, based on records in PTAGIS (PSMFC 1996-2022). A proportion of these fish were detected at dams equipped with PIT-tag monitoring systems (Prentice et al. 1990a,b). These systems automatically upload detection information to the PTAGIS database.

We uploaded trawl detection records to PTAGIS and downloaded information on the fish we detected. To evaluate migration performance metrics between Bonneville Dam and the estuary, we used data on each individual fish. These data included species, run, tagging/release time and location, and date/time of detection at interrogation sites downstream from release. Since 1998, trawl detection data have been used for annual survival estimates of yearling Chinook salmon *O. tshawytscha*, steelhead *O. mykiss*, and sockeye salmon *O. nerka* from points of release to Bonneville Dam. Estuary detections are necessary for complete estimates of survival through the entire hydrosystem (Widener et al. 2021).

In 2022, 78,219 PIT-tagged fish were transported from dams on the Snake River and released below Bonneville, and over 65,402 PIT-tagged in-river migrants were detected at Bonneville Dam. Seasonal trends in estuary detection data continue to provide insight into the relationship between juvenile migration performance and smolt-to-adult return ratios (Marsh et al. 2008, 2012).

Matrix Antenna Trawl System

Methods

Study Area

Trawl sampling was conducted in the upper Columbia River estuary between Eagle Cliff (rkm 84) and the west end of Puget Island (rkm 66; Figure 1). This freshwater reach is characterized by frequent ship traffic, occasional severe weather, and river currents often exceeding 1.1 m/s. Tides in this area are semi-diurnal, with about 7 h of ebb and 4.5 h of flood tide, and with a range in surface elevation of about 1.9 m. During the spring freshet (April-June), little or no flow reversal occurs in this reach during flood tide, especially in years of medium-to-high river flow. The trawl was deployed adjacent to a 200-m-wide navigation channel, which is maintained at a depth of 14 m.

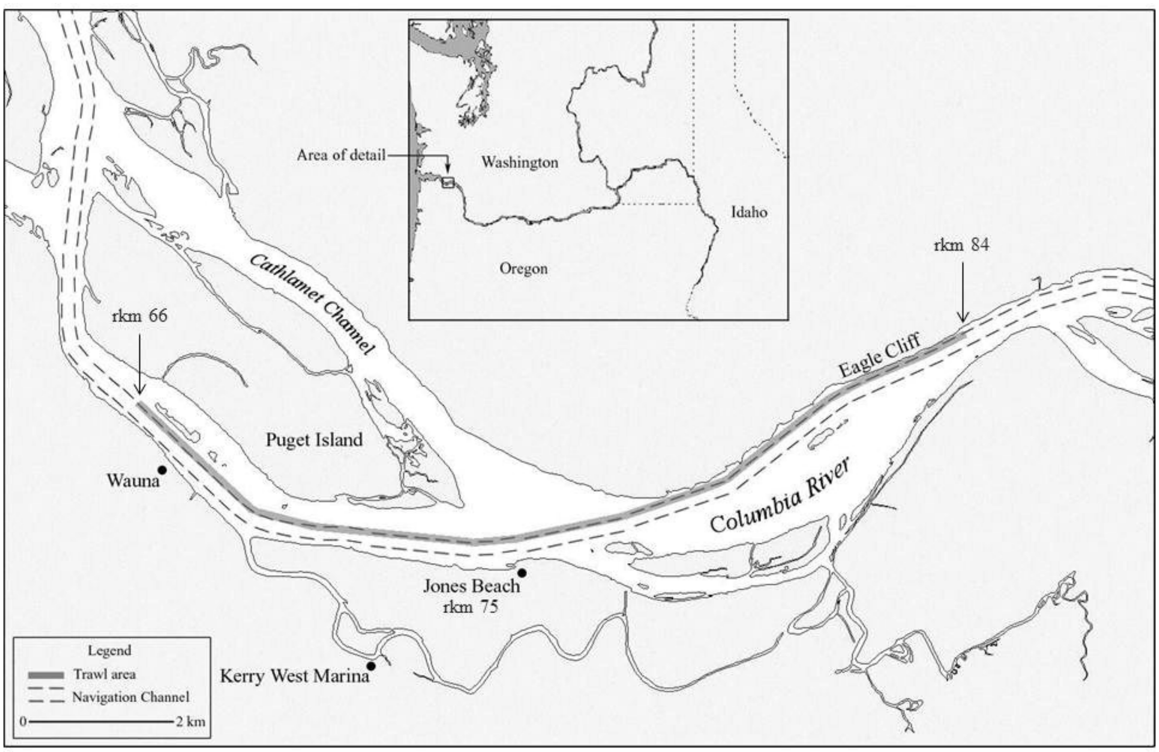

Figure 1. Trawl sampling area adjacent to the navigation channel in the upper Columbia River estuary between rkm 66 and 84, 2022.

Study Fish

We continued to focus detection efforts on large release groups of PIT-tagged fish detected at Bonneville Dam or transported and released just downstream from the dam. All of these fish migrate through the tidal freshwater reach of the estuary, with the vast majority passing from late April through late June.

Release dates and locations of fish detected with the trawl were retrieved from the PTAGIS database (PSMFC 1996-2022). Specific groups of tagged fish targeted for detection included over 201,177 fish released for a comparative survival study, 78,219 fish diverted to barges for NMFS transportation studies, and smaller groups released for other studies.

Migrating juvenile fish released annually in the upper Snake River traverse eight dams and reservoirs or are transported from one of three collector dams to reach the Bonneville Dam tailrace. Transported fish avoid passage of up to seven dams and reservoirs and a freshwater migration of approximately 461 km from the tailrace of Lower Granite to the tailrace of Bonneville Dam (Marsh et al. 2005; 2008; 2010; 2012).

In 2022, detection numbers in the pair trawl were sufficient for analyses of timing and survival for yearling Chinook salmon and steelhead. Trawl detections of sockeye and subyearling Chinook salmon were fewer, limiting analysis. We also detected PIT-tagged coho salmon *O. kisutch* and a small number of coastal cutthroat trout *O. clarkii*.

Sample Period

Spring sampling began on 29 March and continued through the migration period to 13 June. Our sample effort varied commensurate with fish availability in the estuary. Early in the migration season, we sampled 4-5 d/week with a single shift, for an average daily sample effort of 5 h/d. Sample effort was defined as full deployment of the trawl net. During peak spring migration (1 May through 13 June), we sampled with two daily shifts, covering both daylight and darkness periods, for an average daily sample effort of 12.5 h/d.

During the two-shift period, day shifts began before dawn and continued for 8-11 h, while night shifts began in early evening and continued through most of the night or until relieved by the day crew. Sampling was nearly continuous throughout the two-shift period, with refueling, maintenance, and crew changes occurring outside sampling hours, generally between 1400 and 1900 PDT.

Trawl System Design

Antenna Configuration—Configuration of the matrix antenna was similar to the design used since 2013 (Figure 2). Keeping the same dimensions, we replaced the PVC antenna matrix with a new antenna of high-density polyethylene HDPE. New exciter cables were fabricated with wet mate connectors (HydroVolt, AK Industries, Rancho Dominguez, CA)[1] and cut to lengths of 21 m, after determining this length provided maximum antenna current.

A fish-passage corridor was formed using one front and one rear antenna array, each consisting of three parallel antennas, for a total of six antennas. Inside dimensions of individual antennas measured 0.75 by 2.8 m. A 1.5-m length of net mesh connected front and rear arrays, and the overall fish-passage opening was 2.6 by 3.0 m. The matrix antenna array was attached to the open cod end of the trawl and suspended by buoys at a depth of 0.6 m.

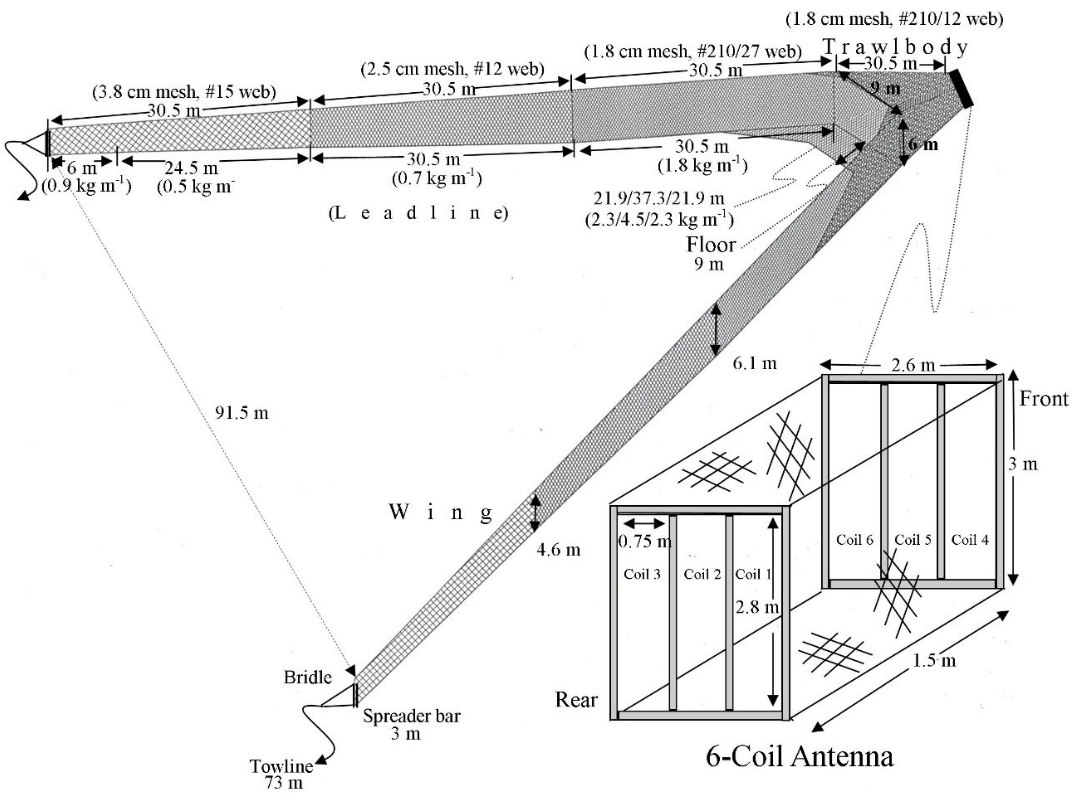

Figure 2. Basic design of the surface pair trawl used with the matrix antenna system to sample juvenile salmonids in the Columbia River estuary (rkm 75), 2022.

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[1] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

This design allowed fish collected in the trawl to exit through the antenna while remaining in the river. Both the front and rear antenna arrays were positively buoyant in water and required 114 kg of lead weight to create neutral buoyancy in the water column (total weight of front and rear components was 456 kg in air).

Trawl net—Basic configuration of the pair trawl net has changed little through the years, despite considerable changes to the detection apparatus (Ledgerwood et al. 2004). On each trawl wing, the upstream end was shackled to a 3-m-long spreader bar and the downstream end attached to the 30.5-m-long trawl body, which was open at the cod end for attachment of the matrix antenna array. The trawl mouth opening was 9 m wide by 6 m tall with a 6.3-m floor extending forward from the mouth (Figure 2). Sample depth was about 5.0 m due to curvature in the trawl body sidewalls under tow.

We towed the pair trawl with 73-m-long lines to prevent turbulence on the net from the tow vessels. After deploying the trawl and antenna, one tow line was passed to the adjacent tow vessel. Both vessels then towed the net upstream facing into the current, maintaining a distance of about 91.5 m between the distal ends of the trawl wings. Even though volitional passage through the trawl and antenna occurred while towing with the wings extended, we continued to bring the wings of the trawl together every 17 minutes to flush debris out of the system. The majority of fish were detected during these 7-minute net-flushing periods.

Electronic components and data transmission—For the matrix trawl detection system, we used essentially the same electronic components and procedures as in 2006-2021. In 2022, we again used a single FS1001M multiplexing transceiver, which is capable of simultaneously powering the detection fields while recording and transmitting detection data from all six antennas. Electronic components for the trawl system were contained in a watertight box (0.8 × 0.5 × 0.3 m) mounted on a 2.4- by 1.5-m pontoon raft tethered behind the antenna.

Data were transmitted from each antenna coil to specific transceiver ports via armored cable. A DC power source was used for the transceiver and antenna. Data were stored temporarily in the transceiver buffer and transmitted wirelessly in real time to a computer on board a tow vessel. During the season, we monitored status reports generated by the transceiver in real time to confirm performance, and we tested each antenna coil periodically using a PIT tag attached to a telescoping pole.

For each fish detected on our antennas, the date and time of detection, tag code, coil identification number, and GPS position were recorded automatically using the computer software program MiniMon, version 1.7.0 (PSMFC 2002). We maintained written logs for each sampling cruise, noting the time and duration of net deployment, net retrieval, approximate location, and any incidence of impinged fish.

Detection data files were uploaded weekly to PTAGIS using standard methods described in the document, *PTAGIS Data Specification* (PSMFC 1996-2022). The specification document, PTAGIS operating software, and user manuals are available from the PTAGIS website operated by Pacific States Marine Fisheries Commission (PSMFC 1996-2022). Matrix trawl detections were designated in the PTAGIS database with site code TWX (towed array-experimental).

Pre-season tests of detection efficiency—As in previous years, we used PIT tags attached to a test tape to evaluate performance of the matrix antenna system (Ledgerwood et al. 2005; Morris et al. 2013). For these tests, we positioned a 2.5-cm-diameter PVC pipe through the center of both the front and rear antenna arrays, extending at least 0.5 m beyond reading range at both ends. We deployed the entire matrix behind an anchored tow vessel without the trawl, and tethered it to a work skiff downstream.

We conducted tests independently on port, middle, and starboard antennas. We attached PIT tags to a vinyl-coated tape measure, with tags spaced at intervals of 30, 60, and 90 cm, and at orientations of 45 or 90 degrees relative to the tape edge. The tape was passed back and forth through the pipe and retrieved by a second vessel. We evaluated detection efficiency based on the proportion of tags detected during a single pass of the tape.

Estimated detection efficiencies from these tests were positively correlated with spacing between test tags, regardless of tag orientation (45 vs. 90 degrees). Of the 1,512 test tags passed through the matrix antenna, those spaced at 30-cm intervals were detected at rates less than 6 and 0% when oriented at 45 or 90 degrees, respectively. With spacing between tags increased to 60 cm, respective detection efficiency increased to 90% and 94% for tags oriented at 45 and 90 degrees. For test tags spaced 90 cm apart, detection efficiency was 100% for tags oriented at 45 or 90 degrees. Results in 2022 were similar to those in previous years and showed the matrix antenna was performing as expected.

Results and Discussion

Factors Affecting Detection Rate

Flow volumes—Through years of sampling, we have observed an inverse relationship between river flow volume and trawl detection rate. Higher flow volume has been consistently associated with lower detection rates of fish previously detected at Bonneville Dam (these fish provide an approximate index of estuary detection efficiency with the trawl).

A variety of factors contribute to the relationship between higher river flows and lower detection rates. First, higher flows carry fish downstream faster. This decreases the amount of time that a given fish is present in the sample reach and available for detection. Second, higher flows allow migrants to expand across a larger cross-sectional area of water. For fish present in the estuary during sampling, we expect that increased spatial dispersion of the passing population would decrease the likelihood of an individual fish entering the trawl.

Higher flows also decrease actual sample time in three ways. First, they increase the transit time required for vessels to return to the upstream end of the sample reach, where the trawl is initially deployed. Second, they decrease the period during which the trawl is deployed by speeding transit to the downstream end of the sample reach, where the trawl must be retrieved. Finally, higher flows typically yield more debris accumulation in the trawl net, reducing sample time due to debris removal.

During the 2022 intensive sampling period of 1 May-13 June, mean river flow volume at Bonneville Dam was 31% higher than similar dates in 2021 (8,410 vs. 6,423 m^3/s; Figure 3). Flows in 2022 were 2% higher than the 20-year average for 2000-2020 (m^3/s). In general, the 2022 season was characterized by below-average flows during the first part of the sampling season with above-average flows into June.

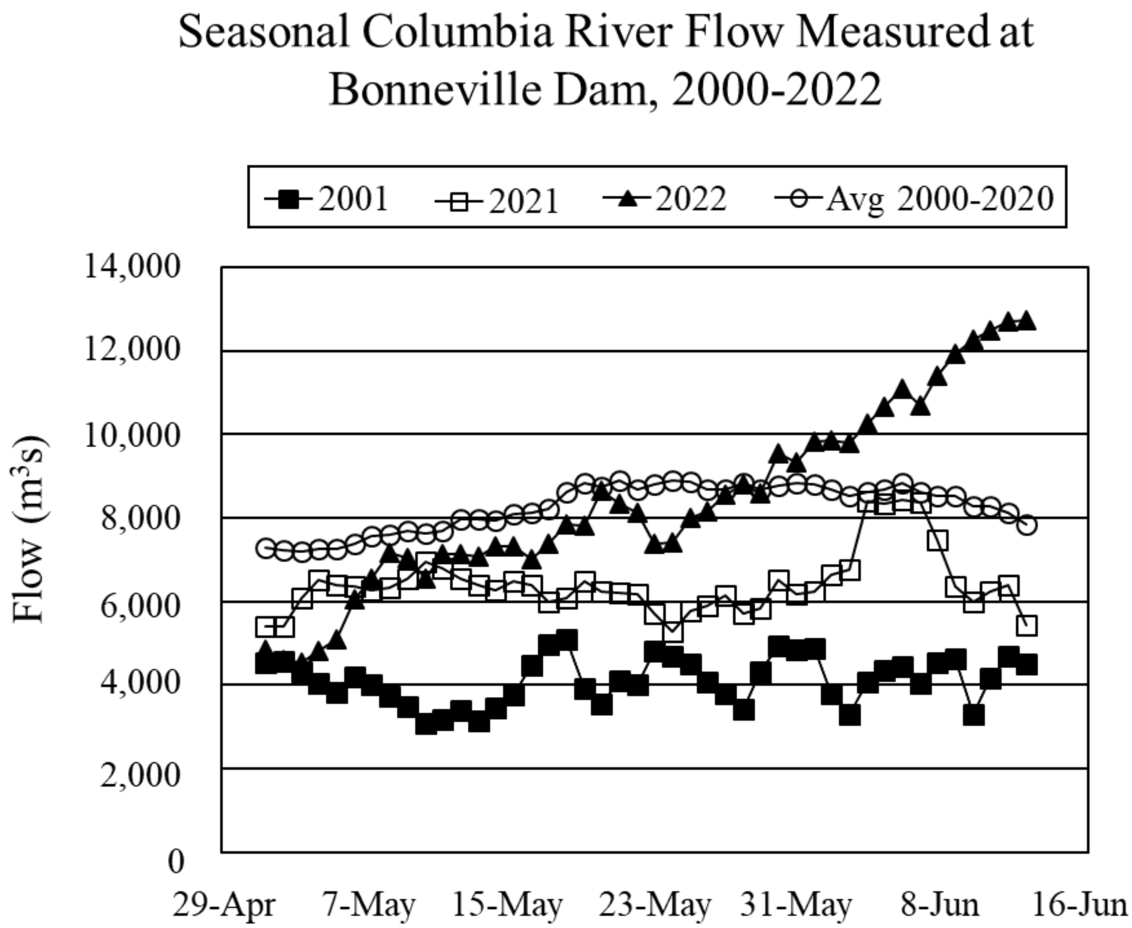

Figure 3. Columbia River flows (m^3/s) at Bonneville Dam during the intensive sample period in 2022 and similar dates in 2021, compared to the average flow from 2000 to 2020. Drought-year flows for 2001 are shown for comparison.

Presence of tagged fish in the sample reach—We estimated that intensive sampling in 2022 coincided with arrival time in the estuary for 99% of the yearling Chinook salmon and 98% of the steelhead passing Bonneville Dam (tagged and non-tagged). These estimates were similar to those made in 2021 for in-river migrants, when 98% of yearling Chinook salmon and 99% of steelhead were estimated to be present in the estuary during sampling.

Our intensive sample period also coincided with arrival in the estuary for 96% of the yearling Chinook salmon transported for NMFS studies. This estimate was slightly lower in 2022 than in 2021, when more than 99% of transported study fish were estimated to be in the estuary during intensive sampling. For transported steelhead, nearly 94% were estimated to be in the estuary during intensive sampling in 2022; this was slightly below the roughly 100% estimated to be present in 2021.

After the intensive sampling period, the majority of fish detected at Bonneville Dam were subyearling Chinook, although yearling Chinook, coho, sockeye, and steelhead were also detected. Fish transportation from upstream dams continued until the end of June (Scott St. John, USACE, Walla Walla Dist., personal communication).

Since 2013, tagging effort for subyearling Chinook has been reduced considerably; however, these fish comprised 66% of the detections at Bonneville Dam after intensive sampling ended in 2022 and 79% of the detections at Bonneville Dam after intensive sampling in 2021. Release dates and totals for tagged subyearling Chinook were much lower in 2022 than in 2021 (160,879 and 222,061, respectively).

Detection Rates

We sampled with the matrix trawl system for 638 h during 2022 and detected 9,838 PIT-tagged fish. In contrast, we sampled for 487 h during 2021 and detected 5,112 fish (Figure 4). Our reduced sample time in 2021 was due to COVID-19 restrictions and inhibited our ability to detect numbers of fish similar to those in previous years. Thus, our detection rate was higher in 2022 compared to 2021 (15 vs. 11 fish/h, respectively).

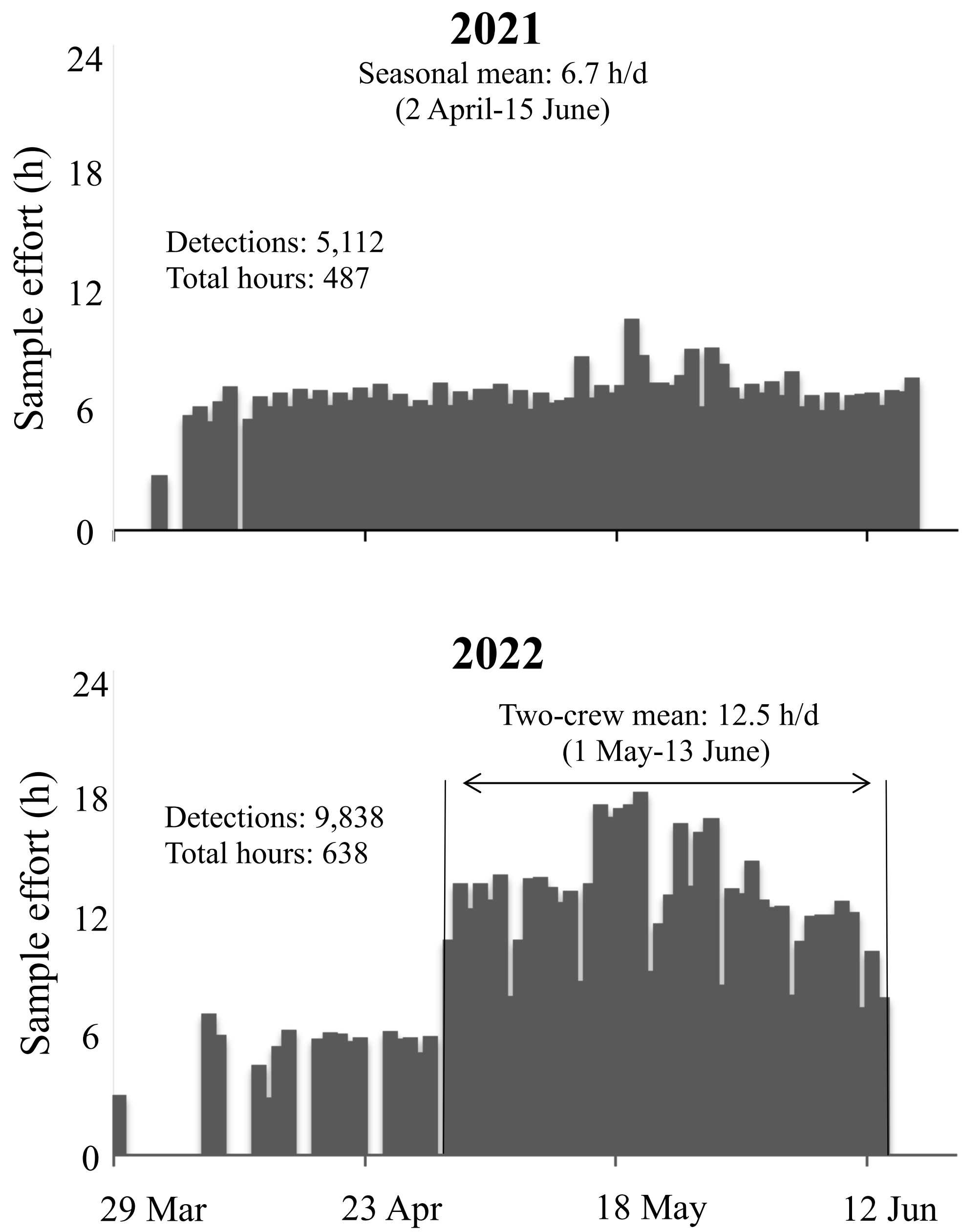

Figure 4. Daily sample effort in spring/summer 2021 and 2022 using the matrix trawl system to detect PIT-tagged juvenile salmon migrating in a tidal freshwater reach of the Columbia River estuary between rkm 66 and 84.

Species, Rear Type, and Migration History of Detected Salmonids

In 2022, the trawl detected a total of 9,515 fish of known species and rear types (hatchery and wild) plus another 323 fish lacking release information in PTAGIS (Table 1, Appendix Table 1). Of those fish, at least some species information was available; however, at the time of our analysis, 288 detected fish had no release or species information associated with their respective tags.

Species composition—Of the 9,838 fish detected with the matrix system in 2022, species composition was 43% spring/summer Chinook, 2% fall Chinook, 43% steelhead, 5% sockeye, and 4% coho salmon. Of the remainder, less than 1% were cutthroat trout and 3% were unknown species. Total detections by rear type were 13% wild, 84% hatchery, and 3% unknown origin at the time of this report. These numbers may change slightly as PTAGIS records are completed or updated.

Table 1. Species composition and rear type of PIT-tagged fish detected with the trawl system in the upper Columbia River estuary near rkm 75 in 2022.

	Rear type			
Species/Run	Hatchery	Wild	Unknown	Total
Spring/Summer Chinook salmon	3,872	402	1	4,275
Fall Chinook salmon	194	1	0	195
Coho salmon	345	32	0	377
Steelhead	3,471	765	23	4,259
Sockeye salmon	361	70	11	442
Sea-run Cutthroat	0	2	0	2
Unknown	0	0	288	288
Grand total	8,243	1,272	323	9,838

For all species, proportions of fish detected by rear type in 2022 were similar to those in 2021. Differences in PIT-tagging strategies, hydrosystem operations, and numbers of fish transported all contribute to annual variation in the sources and migration histories of fish detected in the estuary (Figure 5).

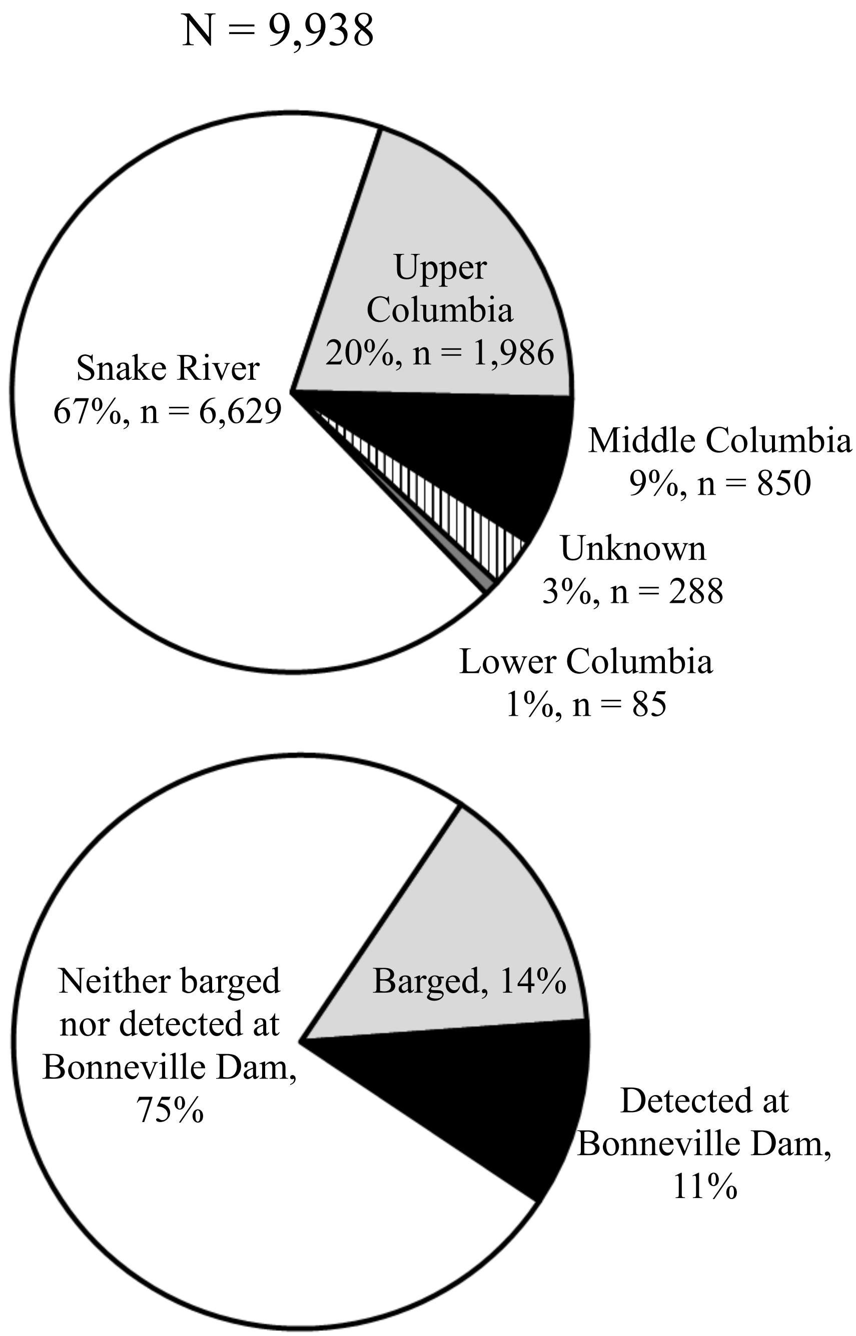

Figure 5. Proportions of fish detected in the Columbia River estuary by source and migration history, 2022. Upper and middle Columbia River sources were defined relative to McNary Dam. Fish that originated in the Columbia River below Bonneville Dam could not be transported, nor could they pass Bonneville Dam.

Subyearling fall Chinook salmon—Fish considered subyearlings were those that measured less than 130 mm fork length (FL) at tagging and were released after April 2022. Based on these criteria, we detected 46 transported and 91 in-river migrant subyearling fall Chinook in the estuary between early April and mid-June (Figure 6). Of the 137 total subyearlings detected, 87% originated in the Snake River, 4% in the Upper Columbia River at or above McNary Dam, and 9% in the Mid-Columbia River between Bonneville and McNary Dam. No subyearlings were detected from the Lower Columbia River below Bonneville Dam.

Juvenile subyearling fall Chinook salmon begin the downstream migration from late spring to fall, but some of these fish suspend migration and overwinter in freshwater, resuming migration in the following spring. Fish adopting this strategy are referred to as "holdovers" (Connor et al. 2005). In years with high numbers of tagged subyearling Chinook salmon, we commonly detect a few fish exhibiting this life history type; however, none of these holdover fish were detected in 2022.

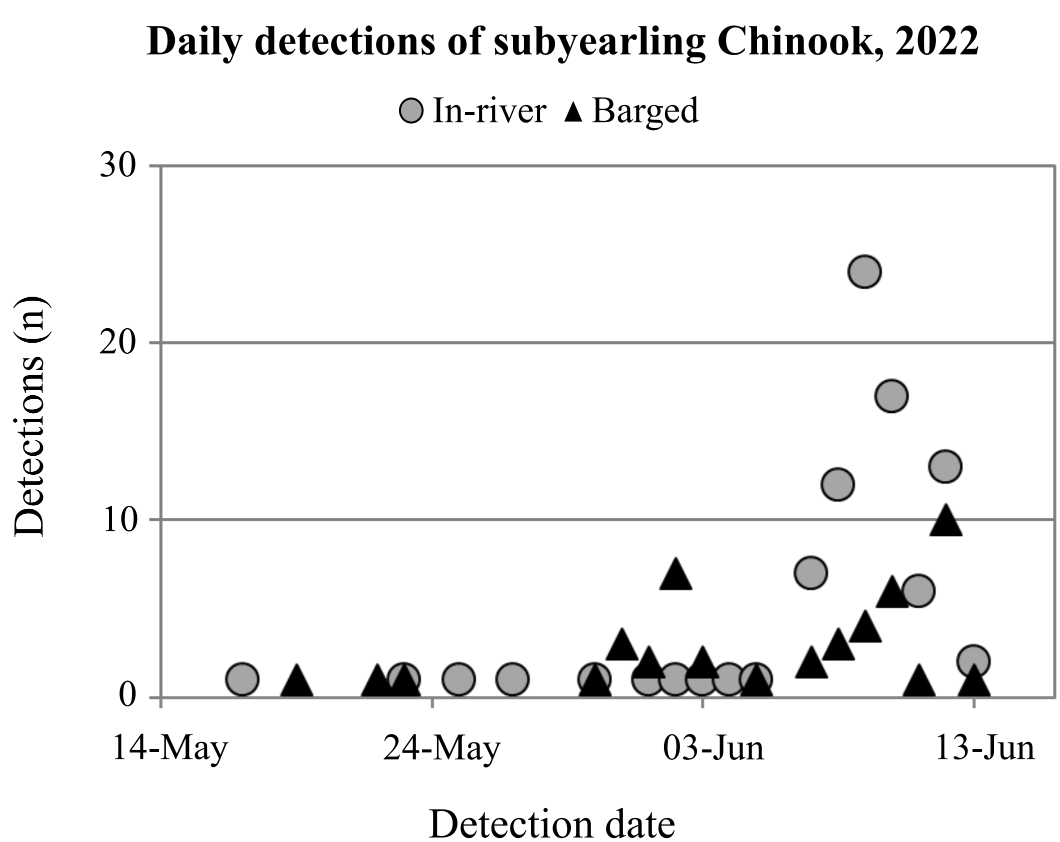

Figure 6. Temporal distribution of subyearling fall Chinook salmon detections in the Columbia River estuary near rkm 75 during in-river migration (n = 91) or following release from barges below Bonneville Dam (n = 46), 2022.

Sockeye salmon—We detected 442 sockeye salmon between 26 April and 10 June (Figure 7). Of these, 82% were hatchery fish, 16% were wild fish, and the remaining 2% were of unknown origin. Fish released upstream from McNary Dam in the Snake and Columbia River Basin, respectively comprised 88 and 12% of our sockeye salmon detections, with <1% of fish released between McNary and Bonneville Dam. Transported fish accounted for 45 of the sockeye salmon detections. Of those transported, 25 had been collected at Lower Granite Dam, 6 at Little Goose Dam, and 14 at Lower Monumental Dam.

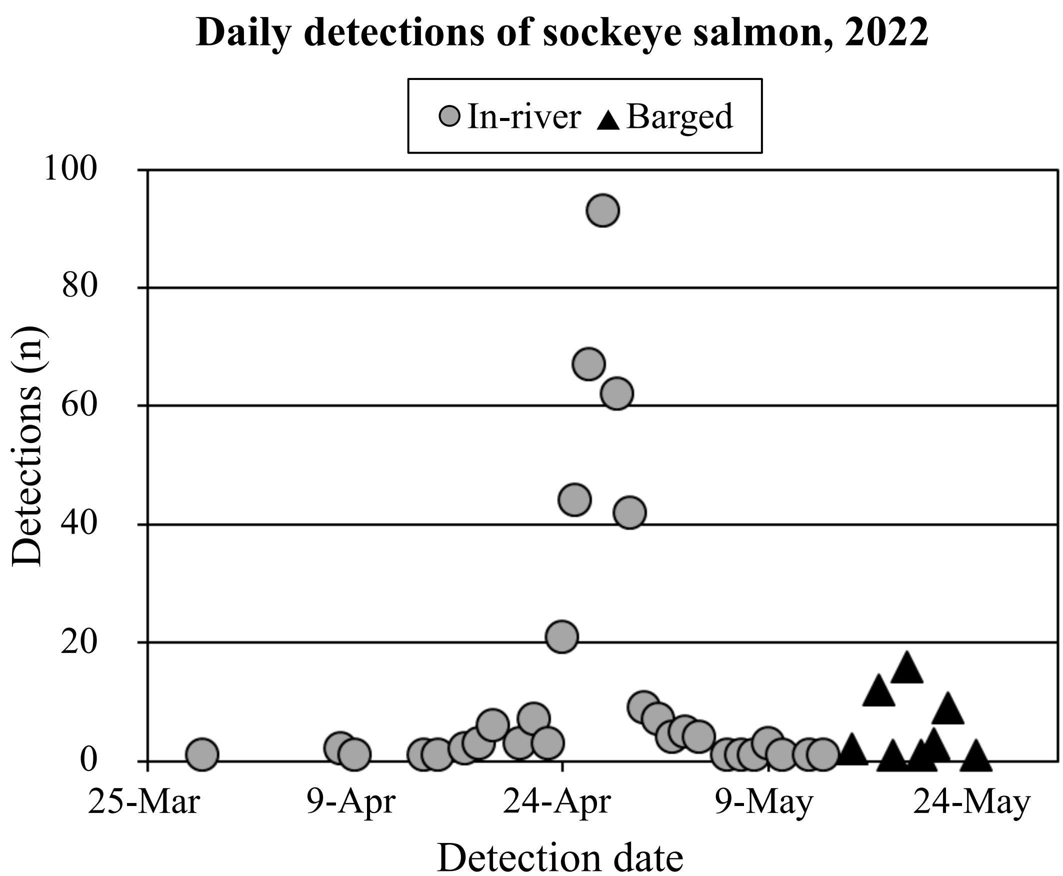

Figure 7. Temporal distribution of sockeye salmon detections in the Columbia River estuary near rkm 75 during in-river migration (n = 397) or following release from barges below Bonneville Dam (n = 45), 2022.

Impacts on Fish

To minimize effects on fish, we regularly inspected the cod end of the trawl for debris accumulation near the antenna. Other sections of the net were monitored visually from a skiff, and accumulated debris were removed periodically. During retrieval, the matrix antenna was hoisted onto a tow vessel while still attached to the trawl net. Debris that remained in the net was removed by hand through zippers in the top of the trawl body.

During debris-removal activities, we recorded all impinged or trapped fish as mortalities, although most fish were released alive. In 2022, we recovered 174 such salmonids from the matrix trawl system (Appendix Table 2). In previous years, divers inspected the trawl body and wing areas of the net while underway and reported that fish rarely swim close to the webbing. Rather, fish tended to linger near the entrance to the trawl body and directly in front of the antenna, likely because the sample gear was more visible in these areas.

Through the years, we have modified the net to minimize visible transition areas between the trawl, wings, and other components. Visible transition areas were found mainly at the seams joining net sections of different web size or weight. We now use a uniform color (black) mesh for the trawl body and cod end areas. These modifications reduced fish training and expedited passage out of the net.

Although volitional passage through the antenna occurred with the wings extended, we continued to "flush" entrained fish out of the net by bringing the trawl wings together. To expedite fish passage, we flushed the net every 15 minutes. We kept the trawl wings together for 5 minutes during each flush, with a 2-minute transition between opening and closing the trawl wings. Flushing also helped clear debris and may have reduced delay and possible fatigue of fish pacing transition areas or lingering near the antenna. The majority of detections were recorded during these 5-minute periods.

A floor extending forward from the trawl body is designed to discourage fish from sounding to escape the trawl; however, fish likely sense the head rope and cork line that crosses between wings at the surface of the trawl body. Since we began using the larger matrix antenna system, detections during periods when the wings were held open have increased by about 10% (Magie et al. 2010).

Development of a Flexible Antenna Detection System

In 2022, we continued development of a towed, flexible antenna system that did not require a net to concentrate and guide fish within range of the antennas. This design was based on antenna technology adapted from a stationary PIT-tag monitoring system installed along a pile dike at rkm 70 (Magie et al. 2015). Our goals in developing this system were to reduce costs associated with sampling juvenile salmonids in the estuary, improve sample efficiency using recent advances in PIT technology, and eliminate impacts on species listed under the U.S. Endangered Species Act (ESA), as well as the requirement for ESA permitting (no take of salmonids would occur).

Since 2013, we have used a multiplexing transceiver (model IS1001MTS, Biomark, Inc., Boise, ID) which allowed us to construct much larger rectangular antennas than were possible with previous transceiver technology. These antennas measured 2.4 by 6.1 m and produced a detection field at least six times larger than that of the 0.8- by 3.0-m antennas previously used in our trawl system. In addition to increased reading range, the multiplexing transceiver allowed antennas to be constructed from 1.9-cm-diameter flexible hose instead of the much larger 10.2-cm-diameter rigid PVC pipe used previously. These advancements have dramatically increased antenna utility and led to a number of new applications.

In 2015, the first year of sampling with the new system, we focused on developing protocols for deployment, pinpointing electronics issues, increasing antenna read range, and reducing electromagnetic interference (EMI) while under tow (Morris et al. 2015). In 2016, we used these developed protocols and focused on concurrent sampling with the matrix trawl. The primary configuration used for sampling in 2016 was an array of six flexible antennas, oriented horizontally, which sampled to a depth of approximately 3 m. This system was deployed using two 6.4-m skiffs, with the first skiff deploying the array and the second supporting deployment. Our goal was to determine the feasibility of replacing the matrix antenna system with the flexible system in future years.

Detection data from 2016 showed a bias towards steelhead that was associated with sample depth (Morris et al. 2017). For sampling in 2017, the rectangular antennas were rotated 90 degrees, from a horizontal to a vertical orientation toward the flow. This increased sample depth to 6.0 m and increased the proportion of Chinook salmon detected (Morris et al. 2018). In addition, after the spring migration season, we resolved a firmware issue and redesigned the grounding configuration of the electronics cables, which allowed us to increase the array size to a maximum of twelve antennas.

In 2018, we replaced our hand-assembled hose antennas with a new manufactured antenna cable. In addition, for the first time, the maximum array size of twelve antennas was used for the entire sampling season, and the flexible antenna system detected over three times the number of fish detected in 2017 (Holcombe et al. 2019).

After the 2018 sample period, the CAN bus cables used in the array were redesigned to eliminate electrical coupling between drain wires. This coupling was caused by poor insulation of power and communication networks within the cable. These changes addressed the electrical issues that compromised sampling in 2018, allowing for a more successful sample season in 2019. We again increased the number of fish detected by over threefold in 2019 compared to 2018 (Holcombe et al. 2020).

Due to COVID-19 restrictions and limited staff, we were unable to sample with the flexible antenna system during the spring migration season of 2020 or 2021. However, after completion of trawl sampling in 2022, we continued development and focused on increasing sampling efficiency and safety using mechanical methods for deployment and retrieval of flexible antenna gear.

Throughout the development of this system, we have been setting and retrieving the flexible antennas by hand. This process can be extremely difficult and dangerous, especially during inclement weather. To use the flexible antenna system as our principal sample system in the lower estuary, we need to incorporate an automated deployment system. This will alleviate complications that arise during deployment and will ensure seasonal staff can deploy and retrieve the gear safely and efficiently.

In 2022, our main objective was to redesign the towed flexible array using manufactured aluminum capsules. The new capsule design increased hydrodynamics and durability, allowing the system to be deployed and retrieved via net reel for the first time. Aluminum cable glands equipped with wire mesh strain relief were installed on all cable entry points to prevent water intrusion due to excess strain from towing and winding the array onto a net reel (Figure 8). Additionally, we attached halved crab floats to the four center capsules to maintain buoyancy across the array and ensure antennas were reading tags near the surface.

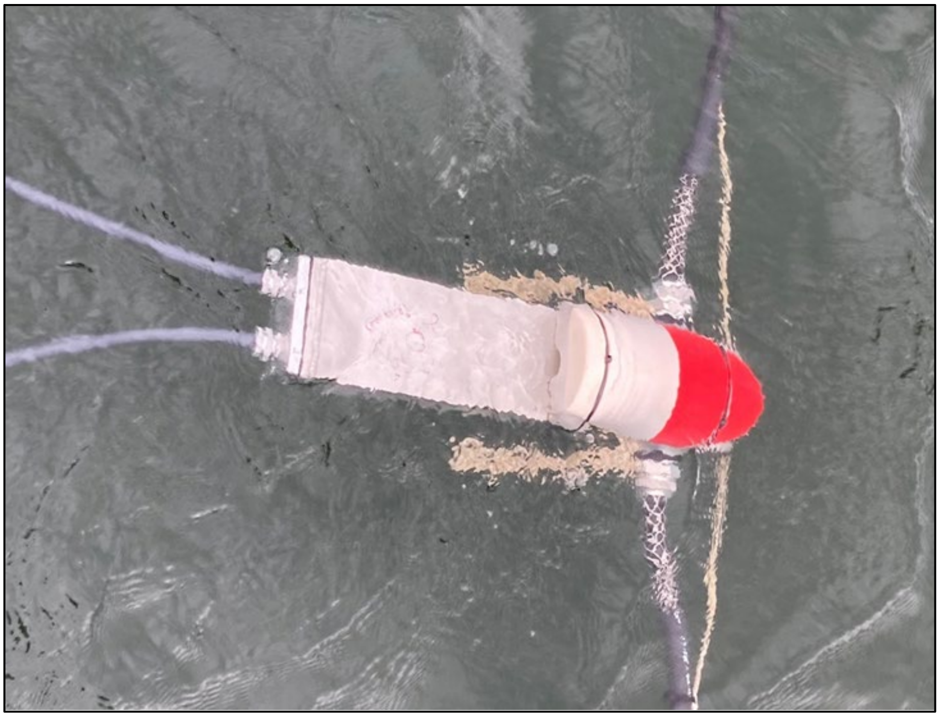

Figure 8. Aluminum capsule with strain-relief cable glands and added floatation.

The newly assembled flexible array was tested in late 2022, and included 8-12 antennas rotated back to a horizontal orientation (6.1-m wide and 2.4-m deep), with one 3-m spreader bar attached to each end (Figure 9). To prevent excess cable from entering the detection field, CAN-bus jumpers were extended to 18.3 m between antennas. This significantly reduced electromagnetic interference (EMI) across the array. Field testing in 2022 found optimal system performance with eight antennas, although future development will aim to expand this configuration while maintaining low EMI and a large detection field.

The feasibility of winding the flexible array onto a net reel was first tested on land using a net reel fixed to a flatbed trailer. Recycled trawl-net mesh was added to the base of the drum to provide a cushion for the reader capsules and lessen strain where the antenna cable entered the capsule (at the cable glands). After successful tests on land, we deployed and retrieved the system from a net reel on one of the 41-ft tow vessels.

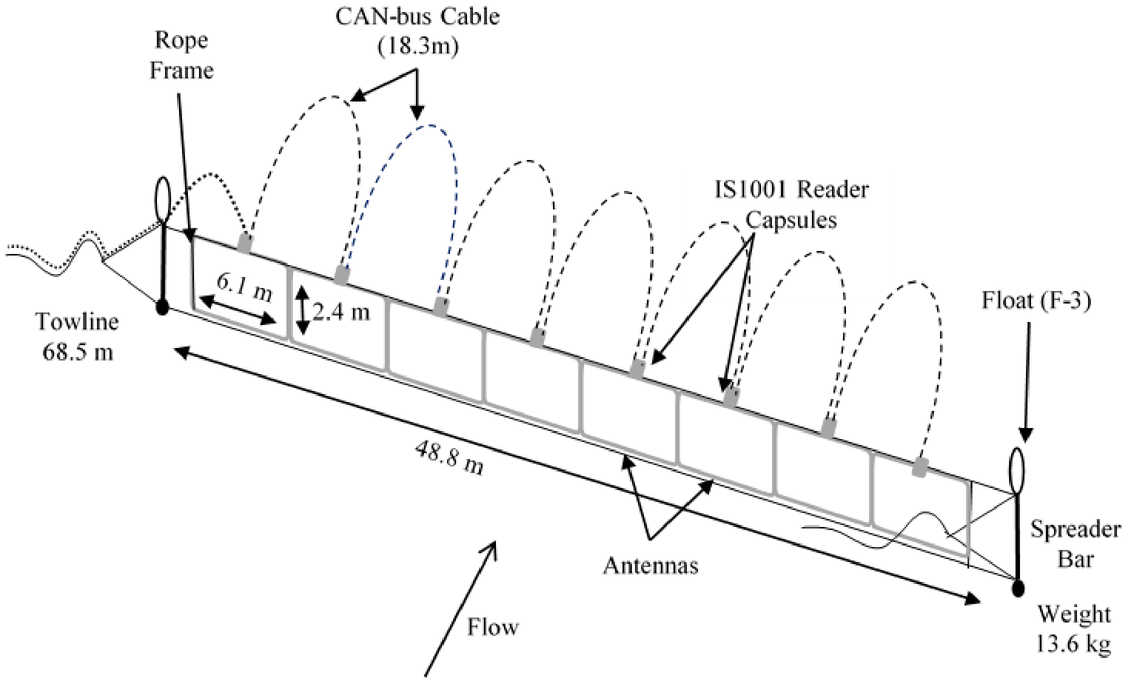

Figure 9. Horizontal layout of the towed flexible antenna array as tested in 2022.

Initial tests showed that the higher tension caused by retrieving the system from the water increased strain on the antenna cable glands, possibly allowing for water intrusion. Upon confirming that new cable glands with built-in strain relief did not increase EMI, we retrofitted the entire array to include the new glands. We deployed the system again from the net reel on the tow vessel and found that the new glands solved the strain issue.

With this confirmation, we are planning for future tests that will include a net reel mounted to the deck of a 38-ft aluminum landing craft (Packcat hull, Munson Boats, Burlington, WA) for full system deployment in water. Testing of this design will take place prior to the 2023 sampling season, and if successful, this design will be used throughout the 2023 season.

In addition to developing the towed flexible array in 2022, we operated two stationary pile-dike sites within the trawl sample reach. The array has been deployed at one site since 2011 and has largely focused on adult salmonid detection (registered as "PD7" in PTAGIS). Our new site (registered as "PD6" in PTAGIS) was erected as a test site to target detections of juvenile salmonids.

The new PD6 site operated from 29 April through 11 June and detected a total that represented nearly one-third of all trawl detections in the same period. Duplicate detections between systems were minimal. However, detections at this new site heavily favored yearling Chinook salmon over steelhead, with a ratio of nearly 3:1 compared to 1:1 with the trawl.

As noted above, testing in 2016 with the towed flexible array oriented horizontally indicated a strong bias towards the detection of steelhead (Morris et al. 2017). Thus, to counter species bias across both systems, in 2023 we intend to deploy a horizontally oriented towed flexible array concurrent with additional pile dike sites.

While further development is needed for the flexible antenna system, there are considerable advantages of continuing its development and moving away from use of the matrix trawl system. First, the transceiver for the new IS1001 sampling equipment is easier to maintain than the older FS1001M transceiver, which is no longer commercially manufactured or serviced (both models from Biomark, Inc., Boise ID).

Second, the flexible antenna array is modular, so that antennas and other system components can be easily exchanged to replace broken or malfunctioning parts. In contrast, the large trawl net is expensive and requires extensive maintenance. Third, the flexible system does not impact fish, including ESA-listed fish. Therefore, no ESA permitting would be required for sampling with the flexible antenna. In contrast, permitting is mandatory for use of the trawl system because of its net.

Finally, the flexible system can be maneuvered to sample shallow-water areas, while the matrix trawl system is restricted to the deepest channel of the river. The flexible system has potential to sample new habitats, and the technology is transferrable to small streams, reservoirs, and large open bodies of water. These are each important objectives for future development and utilization of the flexible antenna system.

Analyses from Estuary Detection Data

Detection data from estuary sampling efforts are used to calculate survival probabilities to the tailrace of Bonneville Dam, the last dam encountered by juvenile migrant salmonids (Muir et al. 2001; Williams et al. 2001; Zabel et al. 2002). Operation of the trawl system has provided data to calculate annual detection probabilities at Bonneville Dam each year since 1998, except in 2020. These data have been supplemented by detections from the flexible antenna system since 2015.

These detection data are necessary for unbiased estimates of survival because they provide the means to distinguish probability of detection vs. probability of survival at Bonneville Dam. Unbiased estimates of survival, in turn, are critical to research and management programs for endangered salmonids in the Snake and Columbia River Basins and in other basins of the Pacific Northwest (Widener et al. 2021).

Estuary detections also allow comparison of relative detection percentages, travel speed, and other parameters between in-river migrant and transported fish groups after they pass or are released below Bonneville Dam. Annual releases of PIT-tagged fish in the Columbia River Basin have approached or exceeded 2 million for the past several years. The ability to monitor these fish as they pass the estuary has increased our understanding of behavior and survival during the critical freshwater-to-saltwater transition period.

In past years, we have compared juvenile performance metrics such as detection rate, travel time, and migration rate by species, origin (hatchery vs. wild), and migration history. In 2022, we explored differences in travel time and migration rate by species and migration history and detection rates by migration history using estuary detection data.

Travel Time and Migration Rate

Methods

We coordinated estuary sampling with the expected passage timing of yearling fish tagged and released for transportation and survival studies. During our sample period in 2022, fish were transported from Lower Granite, Little Goose, and Lower Monumental Dam on the Snake River. Our analysis included all transported fish detected in the trawl, regardless of collection location. We compared paired groups of transported fish released below Bonneville Dam to groups of fish detected at Bonneville Dam on the same date (within the same 24-h period).

At transport dams, PIT-tagged fish that entered the juvenile collection system were diverted to transport barges using separation-by-code (SbyC) systems. The SbyC systems automatically upload detection data from fish en route to transport collection raceways (PSMFC 1996-2022). We considered a fish transported only if its last recorded detection was at a dam on a transport raceway. For this analysis, we created an independent database (Microsoft Access) using data downloaded from PTAGIS.

The U.S. Army Corps of Engineers provided individual barge-loading dates and times for each dam throughout the 2022 transportation season (Scott St. John, USACE, personal communication). We compared barge-loading times with the last detection time of fish diverted to transport raceways to determine timing of the individual barge-transport trip for each fish. With this information, we were able to derive the exact date, time, and release location of each individual transported fish. We then created paired comparison groups of transported fish released from barges and in-river migrants detected at Bonneville Dam on the same date.

For yearling Chinook salmon and steelhead, we plotted seasonal distributions of travel time for in-river migrants detected at Bonneville vs. transported fish released just downstream from the dam. These distributions were plotted using group median travel time. Travel time (in days) to the estuary was calculated for each fish on each date by subtracting time of barge release or detection at Bonneville from time of detection in the trawl.

For comparisons of migration rate (km/d), we used a paired-sample *t*-test to evaluate differences in average daily mean travel speed to the estuary between paired groups of in-river migrants detected at Bonneville and transported fish released just below the dam. We calculated migration rate by dividing distance traveled by travel time. Daily median travel speeds were plotted against flow data, based on daily average discharge rates at Bonneville Dam (m^3/s).

Results and Discussion

Travel time—For in-river migrant yearling Chinook and steelhead, median travel times were 1.8 and 1.6 d, respectively in 2022. These were similar to the median travel times of 1.8 and 1.9 d in 2021 and to the 21-year average of 1.8 and 1.7 d (Table 2). Similarly, for transported yearling Chinook and steelhead, respective median travel times were 2.2 and 1.5 d in 2022 compared with 2.4 and 1.6 d in 2021. Median travel time in 2022 was the second shortest travel time on record for transported steelhead.

Table 2. Median travel time to detection in the estuary during intensive sampling for yearling Chinook salmon and steelhead previously detected at Bonneville Dam or released from barges just downstream from Bonneville Dam, 2000-2022. Also shown are mean flow rates at Bonneville (mid-April through June).

	Detected at Bonneville Dam (rkm 234)				Transported and released below Bonneville Dam (rkm 225)				
	Yearling Chinook		Steelhead		Yearling Chinook		Steelhead		
Year	Travel time (d)	(n)	Travel time (d)	(n)	Travel time (d)	(n)	Travel time (d)	(n)	Flow (m^3/s)
2000	1.7	479	1.7	296	1.9	495	1.6	301	7,415
2001	2.3	792	2.5	59	2.9	1,329	2.3	244	3,877
2002	1.8	1,137	1.7	156	2.0	1,958	1.6	296	8,071
2003	1.8	1,721	1.7	567	2.1	2,382	1.7	435	7,120
2004	1.9	672	2.0	110	2.2	2,997	1.9	333	6,663
2005	1.8	81	2.0	471	2.2	2,910	1.9	400	5,776
2006	1.7	888	1.6	131	2.1	1,315	1.6	170	9,435
2007	1.7	1,510	1.7	362	2.2	1,096	1.7	143	6,858
2008	1.7	749	1.6	830	2.1	1,884	1.6	788	8,714
2009	1.7	1,438	1.7	892	2.1	1,681	1.6	1,325	7,871
2010	2.0	3,258	1.9	2,188	2.2	1,149	2.0	1,068	6,829
2011a*	1.8	240	1.6	216	2.1	673	1.6	831	7,911
2011b*	1.5	39	1.3	47	1.6	418	1.5	275	13,462
2012	1.6	485	1.5	321	2.0	567	1.5	1,116	10,056
2013	1.6	645	1.6	745	2.2	1,029	1.6	1,333	7,470
2014	1.6	431	1.6	412	2.1	1,012	1.5	1,206	8,281
2015	2.1	1,065	2.2	1,885	2.5	714	2.3	611	5,333
2016	1.9	670	1.7	1,067	2.1	674	1.6	844	6,769
2017	1.6	237	1.4	191	2.0	306	1.4	604	11,807
2018	1.5	218	1.4	277	1.6	523	1.5	1208	11,284
2019	1.9	643	1.7	814	2.5	866	1.6	970	7,984
2021	1.8	167	1.9	897	2.4	10	1.6	32	5,587
2022	1.8	305	1.6	421	2.2	318	1.5	486	6,746

* Migration periods in 2011 were divided between early migrants passing prior to the increase in river flow around 16 May (2011a) and late migrants passing during the high flow event (2011b).

Migration rate—For yearling Chinook salmon, average daily median travel speed to the estuary was significantly slower for transported fish than for in-river migrants detected at Bonneville Dam on the same day, at 73.42 vs. 90.0 km/d, respectively ($P < 0.001$). Similarly, for steelhead, average daily median travel speed was significantly slower for transported fish than for those detected at Bonneville Dam on the same day (96.54 vs. 101.89 km/d; $P < 0.005$). These differences in travel speed by migration history were similar to observations from previous years (Figure 10).

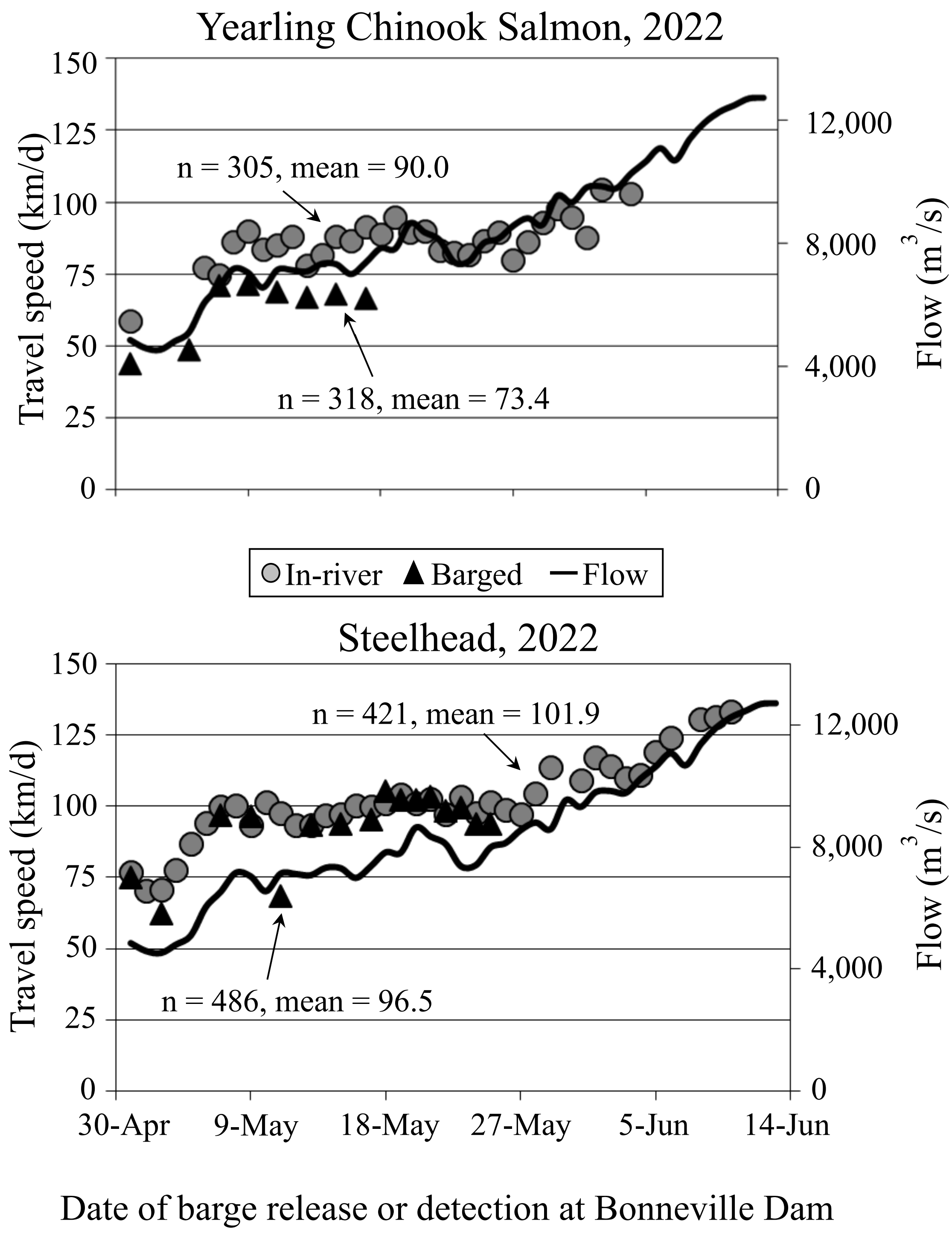

Figure 10. Daily median travel speed (km/d) of yearling Chinook salmon and steelhead following detection at Bonneville Dam or release from a barge to detection in the upper Columbia River estuary, 2022. Seasonal means are shown for comparison with flow.

Subyearling Chinook and sockeye salmon— Of the 137 in-river migrant subyearlings detected in the estuary, only 6 had been previously detected at Bonneville Dam. In addition, we detected 46 transported subyearlings. Mean migration rate from Bonneville Dam to the estuary was slower for transported fish than for fish detected at Bonneville Dam (56.4 vs. 99.8 km/d). Analysis in prior years has consistently shown faster migration rates for subyearling fall Chinook detected at Bonneville Dam than for those transported and released below the dam (Holcombe et al. 2022).

Of the 442 sockeye salmon detected in the estuary, 57 had been previously detected at Bonneville Dam and 45 had been transported. Mean migration rate was slower for transported (98 km/d) than for in-river migrant sockeye (103 km/d).

Diel Detection Patterns

Methods

For analysis of diel detection rates, we compared detection numbers between darkness and daylight hours using a one-sample *t*-test (Zar 1999) of the daily ratios of darkness vs. daylight detections per hour. For this test, we used the natural log of detection ratios to improve normality, and estimated means were back-transformed.

Fish included in this analysis were only those with a known rear type (hatchery or wild) and a detection in the trawl during the intensive sample period (1 May-13 June). For each date within this period, we separated the number of detections and total sampling effort (in minutes) into darkness and daylight intervals by hour. Daily darkness/daylight detections for each species were weighted by the number of minutes the detection system was operating on that date. We excluded dates when missed or partially missed shifts reduced sample effort. Detection numbers for this analysis were sufficient for yearling Chinook salmon and steelhead but not for sockeye or subyearling Chinook salmon.

Results and Discussion

During the intensive sample period, we detected yearling Chinook salmon and steelhead with the matrix trawl system operating an average of 12.5 h/d (Appendix Table 3). In general, sampling was suspended each day between 1400 and 1900 PDT for crew changes and refueling.

For hatchery yearling Chinook salmon, hourly detection rates were significantly higher during darkness hours than during daylight hours (10.5 vs. 3.9 fish/h; $P < 0.001$; Figure 11). For wild Chinook salmon, average detection rates were also higher during darkness than during daylight hours (1.0 vs. 0.5 fish/h; $P = 0.006$). We assumed that the diel difference in hourly detection rates was constant through the season.

For hatchery steelhead, hourly detection rates were significantly higher during daylight than darkness hours (7.7 vs. 2.6 fish/h; $P < 0.001$). Similarly, for wild steelhead, there was a significant difference between daylight and darkness hours (1.8 vs. 0.5 fish/h; $P < 0.001$).

In each year since 2003, hourly detection distributions have been similar between rear-types for both yearling Chinook salmon and steelhead. Because these numbers were again similar in 2022, we pooled data by species and origin for a multi-year summary as shown in Figure 12. Detection rates for yearling Chinook salmon have often been significantly higher during darkness than daytime hours; however, in 2017 and 2018, the opposite was true for wild fish. In contrast, detection rates of steelhead have generally been significantly higher during daylight hours.

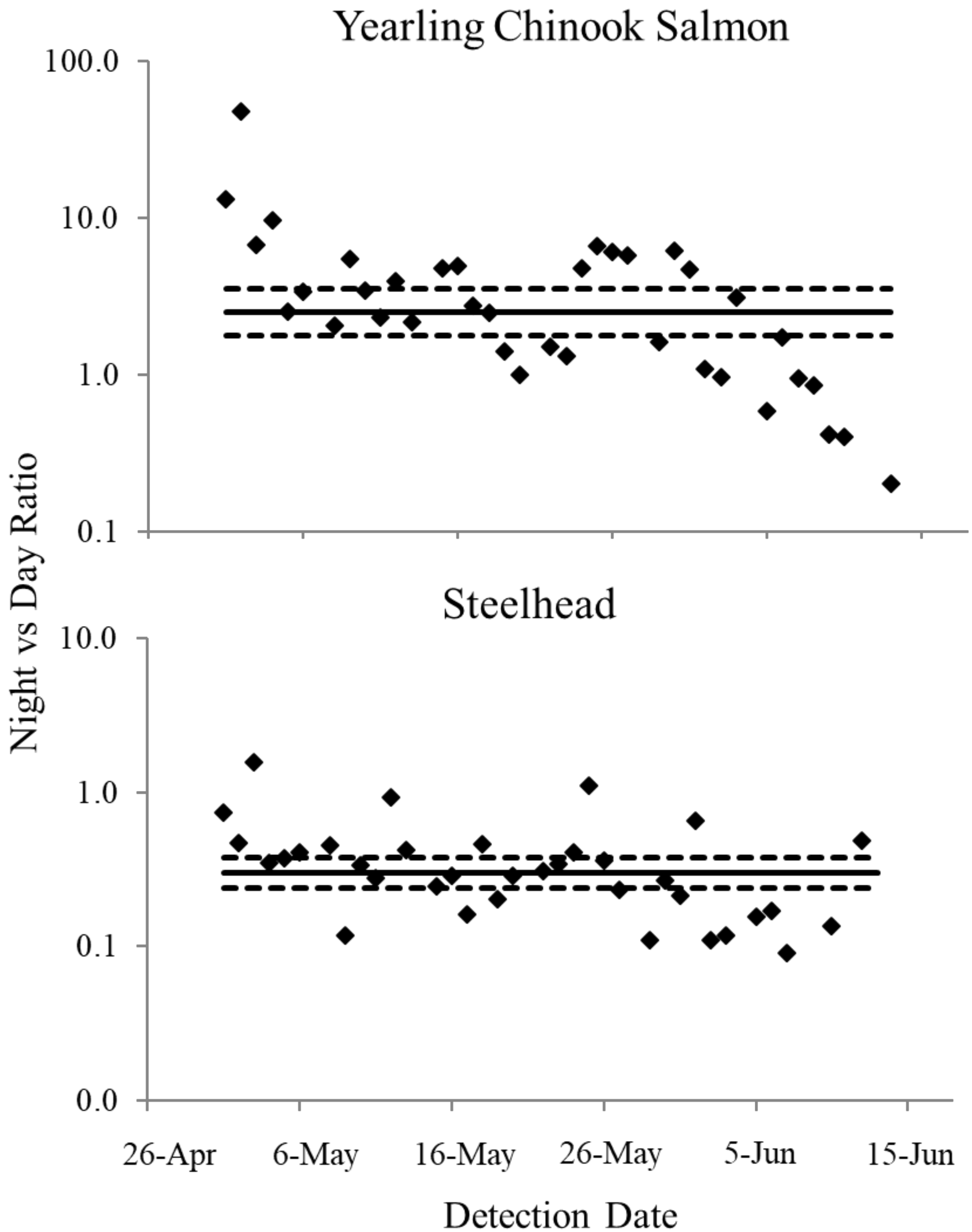

Figure 11. Daily ratios of darkness/daylight detection rates for wild and hatchery yearling Chinook salmon and steelhead in the Columbia River estuary during intensive sampling, 1 May-13 June 2022. Ratios greater than 1.0 indicate higher detection rates in darkness hours, and values less than 1.0 indicate higher detection rates in daylight hours. Solid lines are estimated mean ratios, and dotted lines are estimated 95% confidence intervals.

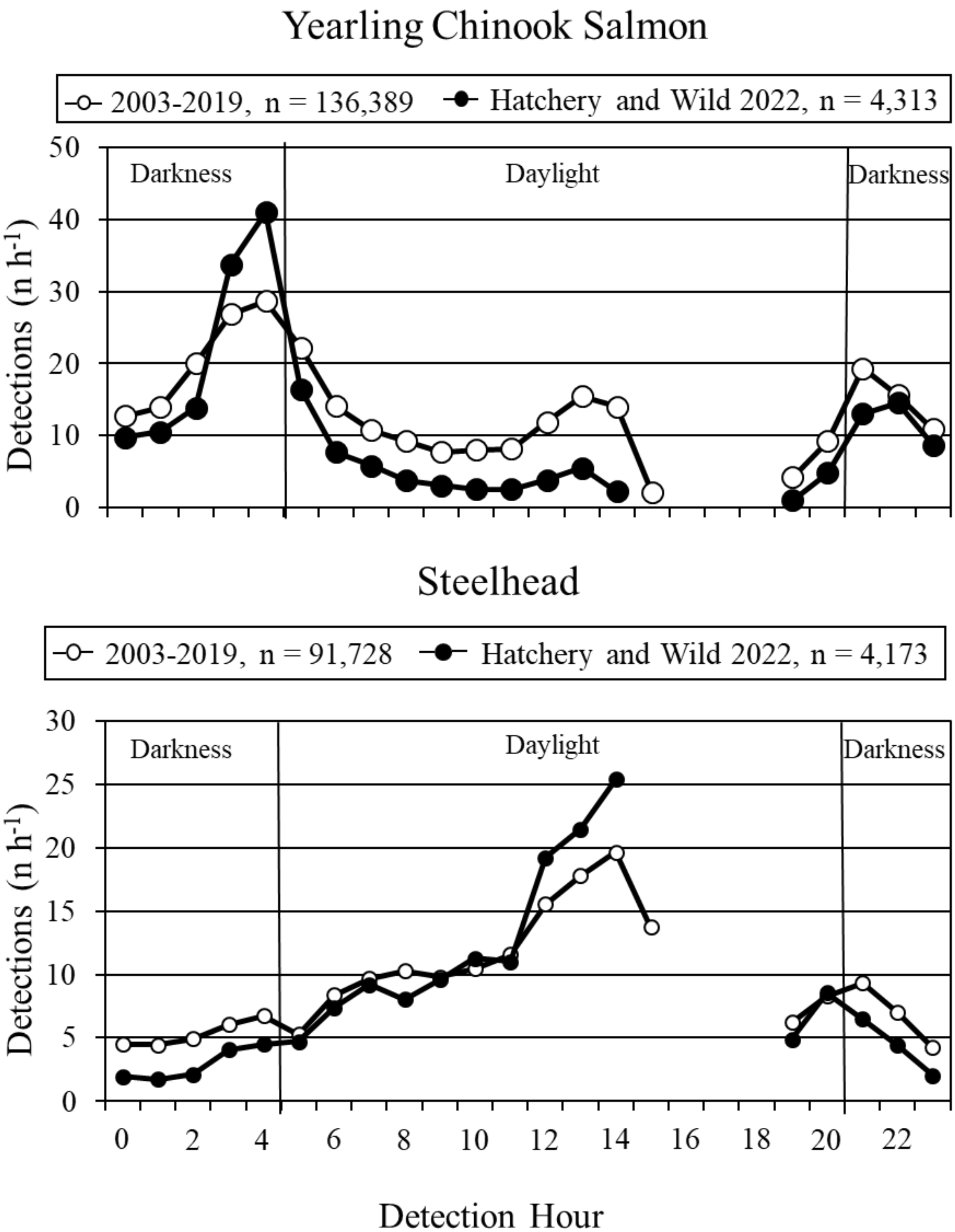

Figure 12. Average hourly detection rates of yearling Chinook salmon and steelhead during intensive sampling with the matrix trawl system in the Columbia River estuary during 2003-2019, vs. 2022. Hatchery and wild rear types combined for both Chinook in 2022 and steelhead because there was no difference between them for either species.

Detection Rates

Methods

We compared daily detection rates in the trawl between transported fish and in-river migrants previously detected at Bonneville Dam. These data were evaluated to assess whether differences in detection rate were related to either migration history or arrival timing in the estuary.

Detection rates were compared using logistic regression (Hosmer and Lemeshow 2000; Ryan et al. 2003). Daily groups of in-river migrants detected at Bonneville were compared with daily groups of fish released from a barge on the same day. For this comparison, we included only yearling fish released at or upstream from McNary Dam.

We compared fish released from a barge just after midnight with fish detected the previous day at Bonneville Dam. Components of the logistic regression model were migration history (in-river or transport) as a "treatment" factor, with date and date-squared as covariates. The model estimated the log odds of detection for *i* daily cohorts (i.e., $\ln[p_i/(1-p_i)]$) as a linear function of model components, assuming a binomial error distribution. Daily detection rates were estimated as:

$$\hat{p}_i = \frac{e^{\hat{\beta}_0 + \hat{\beta}_1 day_i + \hat{\beta} X_i}}{1 + e^{\hat{\beta}_0 + \hat{\beta}_1 day_i + \hat{\beta} X_i}}$$

where $\hat{\beta}$ was the coefficient of the components (i.e., $\hat{\beta}_0$ for the intercept, $\hat{\beta}_1$ for day *i*, and $\hat{\beta}$ for the set "X_i" of day-squared and/or interaction terms). The following stepwise procedure was used to select the appropriate model.

First, we fit the model containing interactions between treatment and date and date-squared. We then determined the amount of overdispersion relative to that assumed from a binomial distribution (Ramsey and Schafer 1997). We estimated overdispersion as "σ," the square root of the model deviance statistic divided by the degrees of freedom. Overdispersion was the difference between expected and observed model variances, after accounting for treatment, date, and date-squared.

If σ was greater than 1.0, we adjusted the standard errors and *z*-test of model coefficients by multiplying by σ (Ramsey and Schafer 1997). Finally, if interaction terms were not significant (likelihood ratio test $P > 0.05$), these terms were removed, and we fit a reduced model.

The model was further reduced depending on the significance(s) between treatment and date and/or date-squared. The final model was the most reduced from this process. One constraint was that date-squared could not be included in the model unless date was included as well. We examined various diagnostic plots to assess the appropriateness of the models. Extreme or highly influential data points were identified and included or excluded on an individual basis.

Previous data show daily transported and in-river groups exhibit similar diel distributions in the sampling area and presumably pass the sample area at similar times (Magie et al. 2011). Thus, we assumed these groups were subject to the same sampling bias (sample effort). If these assumptions were correct, then differences in relative detection rate between groups would reflect true differences in survival.

Results and Discussion

A total of 31,171 yearling Chinook salmon and 31,160 steelhead were transported and released below Bonneville Dam during our intensive sample period. These included fish diverted to barges for NMFS transport studies and fish tagged and transported for other studies. Of these transported fish, we detected 358 yearling Chinook salmon and 931 steelhead in the upper estuary (1.2 and 3%, respectively).

A total of 21,357 yearling Chinook salmon and 17,376 steelhead were released upstream from McNary Dam and detected at Bonneville Dam. Of these in-river migrants, we detected 307 yearling Chinook salmon and 422 steelhead (1.4 and 2.4%, respectively).

As in previous years, a portion of tagged fish from both the transport and in-river migrant groups passed through the estuary either before or after the intensive sampling period. We estimated the proportions of tagged fish from these groups that were available in the estuary during our intensive sample period (1 May-13 June 2022), allowing 2 d for fish to reach the sample area from Bonneville Dam.

For tagged yearling Chinook, we estimated that 99% of in-river migrants and 96% of transported fish passed through the sample reach during our intensive sample period. For tagged steelhead, we estimated that 98% of in-river migrants and 94% of transported fish passed the sample reach during our intensive sample period. For yearling Chinook and steelhead, estimated percentages of tagged fish passing the sample area in 2022 were about the same as those in 2021 for both in-river and transported fish.

During intensive sampling in 2022, average sample effort was 12.5 h/d, which was nearly double the average effort of 6.7 h/d in 2021 (no night sampling in 2021). For yearling Chinook, both transported fish and those detected passing Bonneville Dam had much higher rates of trawl detection in 2022 than 2021 (Table 3).

Table 3. Trawl detection rates of PIT-tagged Chinook salmon and steelhead released from barges or detected passing Bonneville Dam during the intensive sample periods in the upper Columbia River estuary near rkm 75, 2021 and 2022.

	Barged fish originating upstream from McNary Dam			In-river fish detected at Bonneville Dam*		
	Released	Detected		Released	Detected	
Year/species	(n)	(n)	(%)	(n)	(n)	(%)
2021						
Chinook salmon	5,921	18	0.30	37,039	174	0.47
Steelhead	13,986	150	1.07	40,121	900	2.24
2022						
Chinook salmon	31,171	358	1.15	21,357	307	1.44
Steelhead	31,160	931	2.99	17,376	422	2.43

* In-river fish included only those released at or upstream from McNary Dam. No fish were transported from McNary Dam in 2022.

For yearling Chinook salmon, logistic regression analysis showed no interaction between date-squared and migration history ($P = 0.972$) or between date and migration history ($P = 0.810$), and no effect of migration history ($P = 0.148$). However, these analyses did show an effect for date-squared ($P = 0.031$). Detection rates for both transported and in-river yearling Chinook rose from 0.75% to nearly 1.5% and then back down to 0.6% across the season (Figure 13, top panel). The adjustment for overdispersion was 2.8.

For steelhead, logistic regression analysis showed no significant effect of interaction between migration history and date-squared ($P = 0.734$) or between migration history and date ($P = 0.366$). However, there was a significant effect for both date-squared ($P = 0.010$) and migration history ($P = 0.042$). Estimated detection rates for transported steelhead rose from 1.3 to 3.9% and then back down to 2.0% across the season. For in-river fish, detection rates went from nearly 1.0% early in the season up to 2.8% during peak migration and then back down to 1.5% by the end of the season (Figure 13, lower panel). The adjustment for overdispersion was 7.7.

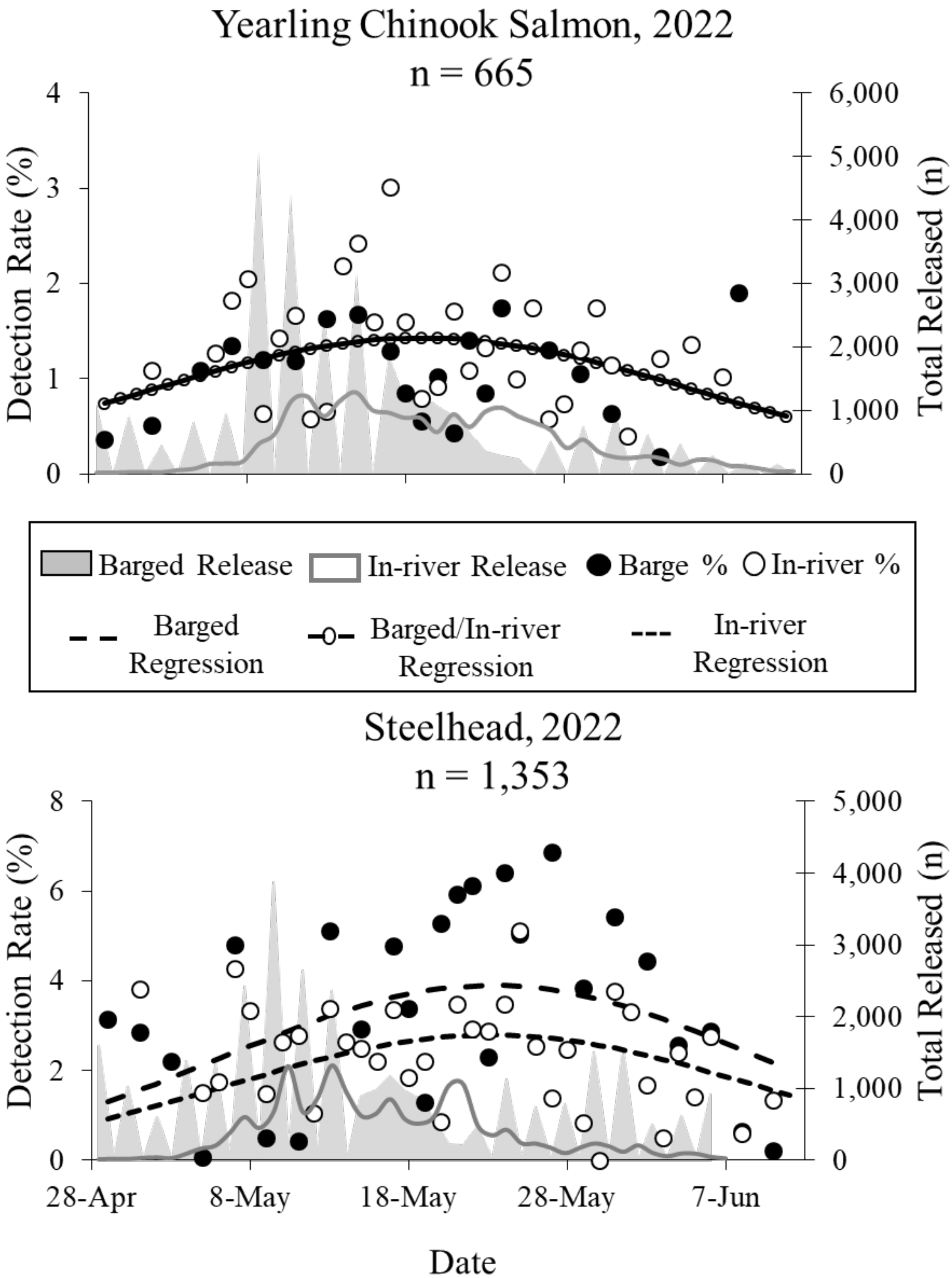

Figure 13. Estimated daily detection rates in the matrix trawl system for transported and in-river migrant yearling Chinook salmon and steelhead in the Columbia River estuary, 2022. All fish were either detected at Bonneville Dam or released from a barge just downstream from the dam on the same date.

For both yearling Chinook salmon and steelhead, estimated daily detection rates in the trawl were higher among in-river migrants than transported fish. In years where differences were present, lower detection rates in one group may represent higher mortality in that group. Over the last 15 years, there has been a general trend toward higher detection rates of in-river migrant Chinook salmon, but no apparent trend for steelhead (Morris et al. 2014). However, detection rates were similar between migration history groups for both species in 2022.

In summary, estuary detection rates were much higher in 2022 than in 2021. This was especially true for transported yearling Chinook salmon, with a detection rate in 2022 that was nearly quadruple the rate in 2021. This increase was likely due to nighttime sampling in 2022 that did not occur in 2021. Detection rates for transported steelhead in 2022 were also nearly three times the rates observed in 2021.

References

Connor, W. P., J. G. Sneva, K. F. Tiffan, R. K. Steinhorst, and D. Ross. 2005. Two alternative juvenile life history types for fall Chinook salmon in the Snake River Basin. Transactions of the American Fisheries Society 134: 291-304.

Holcombe, E. F., A. J. Borsky, J. M. Biron, P. J. Bentley, and B. P. Sandford. 2019. Detection of PIT-Tagged Juvenile Salmonids Migrating in the Columbia River Estuary, 2018. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland, Oregon.

Holcombe, E. F., J. M. Biron, P. J. Bentley, B. P. Sandford, and K. E. Jaenecke. 2020. Detection of PIT-Tagged Juvenile Salmonids Migrating in the Columbia River Estuary, 2019. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland, Oregon.

Holcombe, E. F., J. M. Biron, P. J. Bentley, B. P. Sandford, and K. E. Jaenecke. 2022. Detection of PIT-Tagged Juvenile Salmonids Migrating in the Columbia River Estuary, 2021. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland, Oregon.

Hosmer, D. W., and S. Lemeshow. 2000. Applied Logistic Regression, 2nd ed. John Wiley & Sons, Inc., 375 pp.

Ledgerwood, R. D., J. W. Ferguson, B. A. Ryan, E. M. Dawley, and E. P. Nunnallee. 2004. A surface trawl to detect migrating juvenile salmonids tagged with passive integrated transponder tags. North American Journal of Fisheries Management 24:440-451.

Ledgerwood, R. D., A. S. Cameron, B. P. Sandford, L. B. Way, and G. M. Matthews. 2005. Detection of PIT-tagged juvenile salmonids in the Columbia River estuary using a pair-trawl, 2002. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla, Washington.

Magie, R. J., M. S. Morris, R. D. Ledgerwood, A. L. Cook, B. P. Sandford, and G. M. Matthews. 2010. Detection of PIT-tagged juvenile salmonids in the Columbia River estuary using pair-trawls, 2008. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla, Washington.

Magie, R. J., M. S. Morris, R. D. Ledgerwood, A. L. Cook, and B. P. Sandford. 2011. Detection of PIT-tagged juvenile salmonids in the Columbia River estuary using pair-trawls, 2010. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla, Washington.

Magie, R. J., M. S. Morris, J. P. Bender, B. F. Jonasson, B. P. Sandford, and R. D. Ledgerwood. 2015. Development of a passive integrated transponder (PIT) tag detection system for adult salmonids in the lower Columbia River, 2013. Internal report of the Fish Ecology Division, Northwest Fisheries Science Center. Available from www.nwfsc.noaa.gov/publications/scipubs/index.cfm

Marsh, D. M., J. R. Harmon, N. N. Paasch, K. L. Thomas, K. W. McIntyre, B. P. Sandford, G. M. Matthews. 2005. Research related to transportation of juvenile salmonids on the Columbia and Snake Rivers, 2004: final report for the 2001 spring/summer Chinook salmon juvenile migration. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla, Washington.

Marsh, D. M., J. R. Harmon, N. N. Paasch, K. L. Thomas, K. W. McIntyre, B. P. Sandford, G. M. Matthews, and W. D. Muir. 2008. Transportation of juvenile salmonids on the Snake River, 2005: Final report for 2003 steelhead juveniles with updates on other transport studies. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla, Washington.

Marsh, D. M. J. R. Harmon, N. N. Paasch, K. L. Thomas, K. W. McIntyre, B. P. Sandford, and G. M. Matthews. 2010. Transport of juvenile salmonids on the Snake River, 2007: final report for the 2004 wild spring/summer Chinook salmon juvenile migration. Draft report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla, Washington.

Marsh, D. M., W. D. Muir, B. P. Sandford, S. G. Smith, and Diane Elliott. 2012. Alternative barging strategies to improve survival of salmonids transported from Lower Granite Dam: final report from the 2006-2008 spring/summer Chinook salmon and steelhead juvenile migration. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla, Washington.

Morris, M. S., R. J. Magie, B. P. Sandford, J. P. Bender, A. L. Cook, and R. D. Ledgerwood. 2013. Detection of PIT-Tagged Juvenile Salmonids in the Columbia River Estuary using a Pair-Trawl, 2012. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland, Oregon.

Morris, M. S., R. J. Magie, J. P. Bender, B. P. Sandford, and R. D. Ledgerwood. 2014. Detection of PIT-Tagged Juvenile Salmonids in the Columbia River Estuary using a Pair-Trawl, 2014. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland, Oregon.

Morris, M. S., L. N. Webb, P. J. Bentley, A. J. Borsky, B. P. Sandford, and R. D. Ledgerwood. 2015. Detection of PIT-Tagged Juvenile Salmonids in the Columbia River Estuary using a Pair-Trawl, 2015. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland, Oregon.

Morris, M. S., A. J. Borsky, P. J. Bentley, L. N. Webb, and B. P. Sandford. 2017. Detection of PIT-Tagged Juvenile Salmonids in the Columbia River Estuary using a Pair-Trawl, 2016. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland, Oregon.

Morris, M. S., E. F. Holcombe, A. J. Borsky, P. J. Bentley, and B. P. Sandford. 2018. Detection of PIT-Tagged Juvenile Salmonids Migrating in the Columbia River Estuary, 2017. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland, Oregon.

Muir, W. D., S. G. Smith, J. G. Williams, E. E. Hockersmith, and J. R. Skalski. 2001. Survival estimates for migrant yearling Chinook salmon and steelhead tagged with passive integrated transponders in the lower Snake and lower Columbia Rivers, 1993-1998. North American Journal of Fisheries Management 21:269-282.

Prentice, E. F., T. A. Flagg, and C. S. McCutcheon. 1990a. Electronic tags. American Fisheries Society Symposium 7:317-322.

Prentice, E. F., T. A. Flagg, C. S. McCutcheon, and D. F. Brastow. 1990b. PIT-tag monitoring systems for hydroelectric dams and fish hatcheries. American Fisheries Society Symposium 7:323-334.

PSMFC (Pacific States Marine Fisheries Commission). 1996. The Columbia Basin PIT Tag Information System (PTAGIS). Online interactive regional database administered by the Pacific States Marine Fisheries Commission, Gladstone, Oregon. Available from ptagis.org (December 2021).

PSMFC (Pacific States Marine Fisheries Commission). 2002. MiniMon. Field interrogation software for the Columbia Basin PIT Tag Information System (PTAGIS) regional database. Available from ptagis.org/software/legacy/minimon (December 2021).

PSMFC (Pacific States Marine Fisheries Commission). 2019. PTAGIS Data Specification. Data requirements manual for the Columbia Basin PIT Tag Information System (PTAGIS) regional database. Available from ptagis.org/DataSpecification (December 2021).

Ramsey, F., and Schafer, D. 1997. The Statistical Sleuth. Duxbury Press.

Ryan, B. A., S. G. Smith, J. M. Butzerin, and J. W. Ferguson. 2003. Relative vulnerability to avian predation of PIT-tagged juvenile salmonids in the Columbia River estuary, 1998-2000. Transactions of the American Fisheries Society 132:275-288.

Widener, D. L., J. R. Faulkner, S. G. Smith, T. M. Marsh, and R. W. Zabel. 2021. Survival Estimates for the Passage of Spring-Migrating Juvenile Salmonids through Snake and Columbia River Dams and Reservoirs, 2020. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland, Oregon.

Williams, J. G., S. G. Smith, and W. D. Muir. 2001. Survival estimates for downstream migrant-yearling juvenile salmonids through the Snake and Columbia River hydropower system, 1966 to 1980 and 1993 to 1999. North American Journal of Fisheries Management 21:310-317.

Zabel, R. W. and J. G. Williams. 2002. Selective mortality for fish length and migrational timing in Chinook salmon: what is the role of human disturbance? Ecological Applications 12:173-183.

Appendix

Appendix Table 1. Daily sampling effort (h) and detections (n) for each species using the matrix trawl system in the upper Columbia River estuary (rkm 75), 2022.

Date	Total time underway (h)	PIT tag detections (n)						
		Unknown	Chinook salmon	Coho salmon	Steelhead	Sockeye salmon	Cutthroat trout	Total
29 Mar 22	2.87	0	0	0	0	0	0	0
30 Mar 22	--	--	--	--	--	--	--	--
31 Mar 22	--	--	--	--	--	--	--	--
1 Apr 22	--	--	--	--	--	--	--	--
2 Apr 22	--	--	--	--	--	--	--	--
3 Apr 22	--	--	--	--	--	--	--	--
4 Apr 22	--	--	--	--	--	--	--	--
5 Apr 22	--	--	--	--	--	--	--	--
6 Apr 22	--	--	--	--	--	--	--	--
7 Apr 22	6.85	0	0	0	0	0	0	0
8 Apr 22	5.82	0	0	0	0	0	0	0
9 Apr 22	--	--	--	--	--	--	--	--
10 Apr 22	--	--	--	--	--	--	--	--
11 Apr 22	--	--	--	--	--	--	--	--
12 Apr 22	4.32	0	1	0	1	0	0	2
13 Apr 22	2.70	0	1	0	0	0	0	1
14 Apr 22	5.27	0	0	0	0	0	0	0
15 Apr 22	6.07	0	0	0	1	0	0	1
16 Apr 22	--	--	--	--	--	--	--	--
17 Apr 22	--	--	--	--	--	--	--	--
18 Apr 22	5.63	0	0	0	6	0	0	6
19 Apr 22	5.93	0	0	0	7	0	0	7
20 Apr 22	5.83	2	2	0	3	0	0	7
21 Apr 22	5.47	0	0	0	4	0	0	4
22 Apr 22	5.68	1	3	0	5	0	0	9
23 Apr 22	--	--	--	--	--	--	--	--
24 Apr 22	--	--	--	--	--	--	--	--
25 Apr 22	5.97	0	5	0	9	0	0	14
26 Apr 22	5.60	2	2	0	6	1	0	11
27 Apr 22	5.68	1	4	0	6	0	0	11
28 Apr 22	4.95	1	1	1	11	0	0	14
29 Apr 22	5.73	2	0	1	4	0	0	7
30 Apr 22	--	--	--	--	--	--	--	--
1 May 22	10.50	2	12	0	40	0	0	54
2 May 22	13.28	1	34	0	41	0	0	76
3 May 22	12.03	3	48	1	40	0	0	92

Appendix Table 1. Continued.

Date	Total time underway (h)	PIT tag detections (n)						
		Unknown	Chinook salmon	Coho salmon	Steelhead	Sockeye salmon	Cutthroat trout	Total
4 May 22	13.25	1	25	0	28	0	1	55
5 May 22	12.45	4	46	1	26	0	0	77
6 May 22	13.68	10	35	0	55	2	0	102
7 May 22	7.73	8	6	1	18	1	0	34
8 May 22	10.48	4	43	0	29	0	0	76
9 May 22	13.52	8	72	0	133	0	0	213
10 May 22	13.58	8	76	4	95	0	0	183
11 May 22	13.10	4	149	3	78	0	0	234
12 May 22	12.33	5	165	2	70	1	0	243
13 May 22	12.88	6	225	4	102	1	0	338
14 May 22	8.47	2	140	3	50	0	0	195
15 May 22	13.25	1	129	1	306	4	0	441
16 May 22	17.15	10	275	7	219	3	0	514
17 May 22	16.55	5	359	7	242	18	0	631
18 May 22	16.93	5	311	12	141	1	0	470
19 May 22	17.15	9	349	15	234	19	0	626
20 May 22	17.77	15	272	10	184	8	0	489
21 May 22	8.93	5	45	3	84	6	0	143
22 May 22	11.30	2	142	2	178	30	0	354
23 May 22	15.70	14	125	11	176	44	0	370
24 May 22	16.22	9	108	24	256	68	0	465
25 May 22	13.12	6	154	23	149	93	0	425
26 May 22	15.77	14	176	24	203	62	0	479
27 May 22	16.48	5	188	26	156	42	0	417
28 May 22	8.23	7	79	10	19	9	0	124
29 May 22	13.02	19	77	12	178	7	0	293
30 May 22	12.77	4	61	24	48	4	0	141
31 May 22	14.40	12	86	25	79	5	1	208
1 Jun 22	12.48	10	45	13	29	4	0	101
2 Jun 22	12.07	12	36	15	98	0	0	161
3 Jun 22	12.17	10	20	9	53	1	0	93
4 Jun 22	7.80	2	16	8	104	1	0	131
5 Jun 22	10.42	6	27	8	39	1	0	81
6 Jun 22	11.65	4	36	13	73	3	0	129
7 Jun 22	11.72	6	43	8	21	1	0	79
8 Jun 22	11.70	7	40	11	34	0	0	92
9 Jun 22	12.37	4	44	8	24	1	0	81
10 Jun 22	11.85	6	56	13	30	1	0	106
11 Jun 22	7.17	2	20	5	12	0	0	39
12 Jun 22	9.93	1	42	4	14	0	0	61
13 Jun 22	7.62	1	14	5	8	0	0	28
Total	641.33	288	4,470	377	4,259	442	2	9,838

Appendix Table 2. Combined daily totals of impinged or injured fish resulting from the matrix trawl system in the upper Columbia River estuary (rkm 75), 2022.

Date	Yearling Chinook	Subyearling Chinook	Coho	Steelhead	Sockeye	Chum
29 Mar	0	0	0	0	0	0
30 Mar	-	-	-	-	-	-
31 Mar	-	-	-	-	-	-
1 Apr	-	-	-	-	-	-
2 Apr	-	-	-	-	-	-
3 Apr	-	-	-	-	-	-
4 Apr	-	-	-	-	-	-
5 Apr	-	-	-	-	-	-
6 Apr	-	-	-	-	-	-
7 Apr	0	0	0	0	0	0
8 Apr	0	0	0	0	0	0
9 Apr	-	-	-	-	-	-
10 Apr	-	-	-	-	-	-
11 Apr	-	-	-	-	-	-
12 Apr	0	0	0	0	0	0
13 Apr	0	0	0	0	0	0
14 Apr	0	0	0	0	0	0
15 Apr	0	0	0	0	0	0
16 Apr	-	-	-	-	-	-
17 Apr	-	-	-	-	-	-
18 Apr	0	0	0	0	0	0
19 Apr	0	0	0	0	0	0
20 Apr	0	0	0	0	0	0
21 Apr	0	0	0	0	0	0
22 Apr	0	0	0	0	0	0
23 Apr	-	-	-	-	-	-
24 Apr	-	-	-	-	-	-
25 Apr	0	0	0	0	0	0
26 Apr	0	0	0	0	0	0
27 Apr	0	0	0	0	0	0
28 Apr	0	0	0	0	0	0
29 Apr	0	0	0	0	0	0
30 Apr	0	0	0	0	0	0
1 May	1	0	0	0	0	0
2 May	1	0	0	0	0	0
3 May	1	0	0	0	0	0
4 May	0	0	0	0	0	0
5 May	0	1	0	1	0	0
6 May	1	1	0	0	0	0
7 May	3	0	0	0	0	0
8 May	0	0	0	2	0	0
9 May	4	2	0	2	0	0

Appendix Table 2. Continued.

Date	Yearling Chinook	Subyearling Chinook	Coho	Steelhead	Sockeye	Chum
10 May	0	0	0	1	0	0
11 May	3	3	0	0	0	0
12 May	0	0	0	0	0	0
13 May	0	2	0	2	0	0
14 May	0	0	0	0	0	0
15 May	0	0	0	0	0	0
16 May	0	3	0	0	0	0
17 May	3	1	3	2	0	0
18 May	0	6	1	0	0	0
19 May	0	0	0	1	1	0
20 May	1	2	0	0	0	0
21 May	0	0	0	0	0	0
22 May	0	1	1	1	0	1
23 May	4	8	1	2	0	0
24 May	0	0	0	0	0	0
25 May	4	0	0	1	0	1
26 May	3	2	1	0	1	0
27 May	2	9	0	1	0	0
28 May	3	8	0	0	0	0
29 May	0	0	0	0	0	0
30 May	1	2	2	3	0	1
31 May	2	0	0	0	1	0
1 Jun	0	0	0	0	0	0
2 Jun	0	0	0	0	0	0
3 Jun	0	0	0	0	0	0
4 Jun	2	1	0	0	0	0
5 Jun	0	0	0	0	0	0
6 Jun	0	0	0	0	0	1
7 Jun	4	10	1	2	1	0
8 Jun	1	2	1	1	0	0
9 Jun	1	1	1	1	0	0
10 Jun	1	6	0	0	0	0
11 Jun	3	4	1	0	0	0
12 Jun	0	0	0	0	0	0
13 Jun	3	3	0	0	0	0
Total	52	78	13	23	4	4

Appendix Table 3. Mean diel detections by hour for yearling Chinook salmon and steelhead during intensive sampling (1 May-13 June) using the matrix trawl system in the upper Columbia River estuary (rkm 75), 2022.

		Yearling Chinook salmon				Steelhead			
		(n)		Mean detections/h		(n)		Mean detections/h	
Diel hour	Total effort (h)	Hatchery	Wild	Hatchery	Wild	Hatchery	Wild	Hatchery	Wild
0	37.1	328	33	8.84	0.89	59	13	1.59	0.35
1	36.6	359	25	9.81	0.68	47	15	1.28	0.41
2	17.1	220	17	12.88	1.00	30	6	1.76	0.35
3	6.4	201	14	31.41	2.19	19	7	2.97	1.09
4	6.0	236	16	39.33	2.67	25	3	4.17	0.50
5	9.1	135	16	14.84	1.76	42	3	4.62	0.33
6	35.1	235	29	6.70	0.83	192	60	5.47	1.71
7	43.1	218	29	5.06	0.67	298	89	6.92	2.07
8	43.2	135	24	3.13	0.56	289	55	6.69	1.27
9	39.2	103	16	2.63	0.41	329	58	8.39	1.48
10	41.0	97	14	2.37	0.34	384	78	9.37	1.90
11	39.9	108	8	2.71	0.20	391	75	9.81	1.88
12	20.0	54	7	2.71	0.35	284	54	14.24	2.71
13	11.0	47	6	4.29	0.55	181	33	16.53	3.01
14	6.2	13	1	2.10	0.16	124	30	20.05	4.85
15	0.0	--	--	--	--	--	--	--	--
16	0.0	--	--	--	--	--	--	--	--
17	0.0	--	--	--	--	--	--	--	--
18	0.0	--	--	--	--	--	--	--	--
19	11.0	11	0	1.00	0.00	45	7	4.08	0.64
20	35.2	155	13	4.41	0.37	241	52	6.85	1.48
21	38.0	433	56	11.39	1.47	206	35	5.42	0.92
22	38.0	501	50	13.18	1.32	138	27	3.63	0.71
23	38.0	301	27	7.92	0.71	69	6	1.82	0.16
Total	551.0	3,890	401			3,393	706		