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Detection of PIT-Tagged Juvenile Salmonids Migrating in the Columbia River Estuary, 2025

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Detection of PIT-Tagged Juvenile Salmonids Migrating in the Columbia River Estuary, 2025

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Executive Summary

In 2025, we continued a multi-year study in the Columbia River estuary to detect migrating 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 673 h.

To coincide with arrival in the estuary of spring-migrating juvenile salmon and steelhead, sampling began on 2 April with a single daytime shift operating 4-5 d/week. As numbers of juvenile migrants increased, we intensified the sample effort with two daily shifts: one operating 7 d/week during daylight hours and a second operating 6 d/week during darkness hours. Intensive sampling continued from 28 April through 12 June. During intensive sampling, the trawl was deployed for an average of 12.3 h/d, which was similar to the 12.4 h/d average in 2024. We ended sampling on 12 June after most spring migrants had passed.

During this period, the matrix system detected 9,530 PIT-tagged fish, of which 16% were wild origin and 76% were hatchery origin (8% unknown). Species composition of detected fish was 41% spring and summer Chinook salmon, 4% fall Chinook salmon, 41% steelhead, 5% coho, 2% sockeye, less than 1% cutthroat trout, and 7% unknown.

During the intensive sample period, average hourly detections were significantly higher during darkness than daylight hours for hatchery yearling Chinook (9.7 vs. 3.4 fish/h; P=0.004), and for wild yearling Chinook (0.7 vs. 0.4 fish/h; P<0.001). For hatchery steelhead, hourly detection rates were significantly higher during daylight than darkness hours (5.1 vs. 2.9 fish/h; P<0.001). Similarly, for wild steelhead, there was a significant difference between daylight and darkness hours (1.9 vs. 1.0 fish/h; P<0.001).

During the intensive sample period, we detected 1.5% of the yearling Chinook and 2.1% of the steelhead transported and released below Bonneville Dam. These proportions were lower than those for transported fish in 2024, when we detected 1.7% of the yearling Chinook and 2.4% of the steelhead. Additionally, we detected 1.9% of the yearling Chinook and 3.1% of the steelhead detected at Bonneville. These proportions were lower compared to those for in-river migrants in 2024, when we detected 2.4% of the yearling Chinook and 4.4% of the steelhead detected at Bonneville Dam.

In 2025, 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, there was no significant interaction between migration history and arrival date (P=0.934), migration history and date-squared (P=0.548), date-squared (P=0.729), migration history (P=0.440) or arrival date (P=0.397). Similarly, for steelhead detected with the trawl, there was no significant interaction between migration history and arrival date (P=0.811), migration history and date-squared (P=0.201), or date-squared (P=0.399). On average, we detected transported and in river Chinook at a rate of 1.9% throughout the season.

For steelhead detected with the trawl, we found a significant effect for migration history (P=0.025) and arrival date (P=0.001) and therefore those terms were included in the resulting best model. On average, we detected transported steelhead at a rate of 1.3% at the beginning of the season, increasing to 5.2% by the end of the season. Estimated detection rates for in river steelhead were 1.9% at the beginning of the season and increased to 7.5% by the end of the spring migration season.

Over the last 30 years, we have observed an inverse relationship between river flow and detection rates in the trawl. Mean flow volume at Bonneville Dam during intensive sampling was remarkably similar in 2025 and 2024 (5,968 vs. 5,866 m^3/s), and was also 28% lower than the 20-year average for 2005-2025 (8,259 m^3/s). Despite similar flows, detection rates in 2025 were lower than in 2024.

Of all juvenile salmonids detected by the trawl in 2025, 5% had been transported, while 12% had been detected passing Bonneville Dam. The remaining 83% had neither been transported nor detected at Bonneville Dam, although at least 88% of our total detections originated upstream from Bonneville Dam. Relative detections of barged fish were slightly higher in 2025 than 2024 (5% vs. 4%, respectively), and was the second lowest number of transported fish in the history of the project.

Mean migration rate to the estuary (rkm 75) was significantly higher for yearling Chinook salmon detected at Bonneville Dam than for those released from barges just below the dam (84.3 vs. 51.3 km/d, $P<0.001$). Similar differences were observed for subyearling Chinook salmon (87.8 vs. 41.1 km/d).

Mean migration rate for steelhead was also significantly higher for in-river migrants (101.9 km/d) vs. transported fish (76.4 km/d; $P<0.001$). There were insufficient data to determine a significant difference for sockeye (98.3 vs. 75.5 km/d; n = 1 paired group). Overall, migration rates to the sample reach were lower for most in-river and transported fish in 2025 than in 2024 across all species.

Detections of subyearling Chinook salmon on the trawl have decreased in recent years, commensurate with reduced tagging effort for these fish and reduced sample effort after peak migration. In 2025, we detected 352 subyearling fall Chinook, with the majority of detections occurring from late May through mid-June. Of these 352 fish, 279 originated from the Snake River Basin (240 in-river migrants and 39 transported). The remaining 73 were in-river migrants from Columbia River stocks, with 26 subyearlings released above McNary Dam, and 47 released between McNary and Bonneville Dam.

Of the 204 sockeye detected, 64% were from the Snake River, 33% were from the upper Columbia River above McNary Dam, and 3% originated from the middle Columbia River between McNary and Bonneville Dam. Rear types of detected sockeye were 66% hatchery, 22% wild, and 12% unknown origin. Migration histories of detected sockeye were 91% in-river migrant and 9% transported.

Using new faired antenna cable on half of the antennas, we rebuilt the entire towed flexible array in 2025. We sampled 1-4 d/week with the towed flexible array during the intensive sample period based on crew availability. Like the trawl, this system is towed behind two vessels to detect passing juvenile salmon, but does not require use of a net to guide fish within reading range of the antennas. We again aimed to reduce electromagnetic interference (EMI) by implementing a new custom faired cable which was tested alongside newly assembled non-faired cable antennas. Faired cable was implemented in hopes of lowering EMI on the system by reducing vibrations on the cable while under tow. Sampling with a towed flexible array eliminates potential fish impingement occasionally observed with the trawl net, preventing negative impacts to salmonids listed under the U.S. Endangered Species Act.

For sampling conducted in 2024 and 2025, the towed flexible array was deployed with eight 6.1- by 2.4-m rectangular cable antennas configured horizontally to sample from the surface to a depth of approximately 2.5 m. Four antennas constructed from custom faired cable were placed in alternating positions with four un-faired cable antennas. Sampling was conducted intermittently from 14 April to 27 May 2025 in a targeted approach to favor detections of juvenile steelhead. This was intended to supplement detections from stationary pile dike arrays in the same reach, which generally show a bias towards juvenile Chinook salmon.

By changing the antenna array from the vertical configuration used in 2017-2019 to a horizontal orientation, we effectively reduced sample depth from 6.2 to 2.5 m while expanding sample width from ~30 to 50 m. This allowed us to maximize sample area along the surface, increasing the likelihood of detecting more surface-oriented steelhead. We also focused sampling efforts during daylight hours, as historical trawl data show higher steelhead detection rates during daylight hours.

In 2025, the towed flexible array detected 434 PIT-tagged salmonids. Species composition was 88% steelhead, 5% spring/summer Chinook, and 2% coho. Of the remainder, less than 1% were sockeye and 5% were unknown species. Total detections by rear type were 18% wild, 77% hatchery, and 5% unknown origin at the time of this report. Reduced detection totals and rates in 2025 compared to 2024 were influenced by project priorities that reduced personnel, limiting our ability to sample during peak steelhead migration periods, as well as likely fish avoidance caused by the faired antennas.

In 2025, sampling with the towed flexible array focused on reducing electromagnetic interference (EMI), exploring new sampling strategies, and improving the overall system design. Following a full rebuild of antennas, we saw an observable decrease in systemic EMI compared to 2024. Despite lower noise, detections were much lower overall, particularly on faired antennas. Additionally, we permanently sealed each node capsule prior to deployment, which successfully prevented water intrusion as experienced in 2024. While the flexible antenna system detects fish as a mid-river, thalweg-based towed system, it continues to lack functionality as a reliable sample method, and has not yet shown it can detect comparable volumes of fish to the trawl or pile dike arrays.

Transitioning to stationary sampling strategies may reduce EMI caused by towing the array. Near the conclusion of our sample season, we pivoted our towed deployment strategy to partial deployment of the array between two fixed points, spanning a large gap between pilings at a pile dike near the mouth of the Westport slough. These trials represent new applications for using the flexible array to detect steelhead. We will expand this approach in 2026 to exploit similar structures within the sample reach that may concentrate fish in areas beyond reach of our standard pile dike antennas.

In 2025, 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 matrix 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 (including 2025), 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 2025, we continued a multi-year study to collect data on migrating juvenile Pacific salmon *Oncorhynchus* spp. implanted with passive integrated transponder (PIT) tags (Ledgerwood et al. 2004; Vinarcsik et al. 2025). This study began in 1995 and has continued annually except in 1997 and 2020, with sampling conducted in the Columbia River estuary near Jones Beach, approximately 75 river kilometers (rkm) upstream from the mouth.

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 1996-2025). 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. Approximately 2.0 million Snake and Columbia River juvenile salmonids were PIT-tagged and released prior to or during the spring 2025 migration season, based on records in PTAGIS (PSMFC 1996-2025). A proportion of these fish were detected at dams equipped with PIT-tag monitoring systems (Prentice et al. 1990a, b), where detection information is automatically uploaded to PTAGIS.

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 type, tagging/release time and location, and date/time of each detection at interrogation sites downstream from release. Since 1998, except 2020, 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. 2024). These survival estimates are used to evaluate impacts of hydroelectric dams on fish and inform management actions that mitigate those impacts to maximize juvenile survival, such as adjusting spill levels.

In 2025, 27,892 PIT-tagged fish were transported from dams on the Snake River and released below Bonneville Dam, and over 62,227 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 (Gosselin et al. 2018; 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.

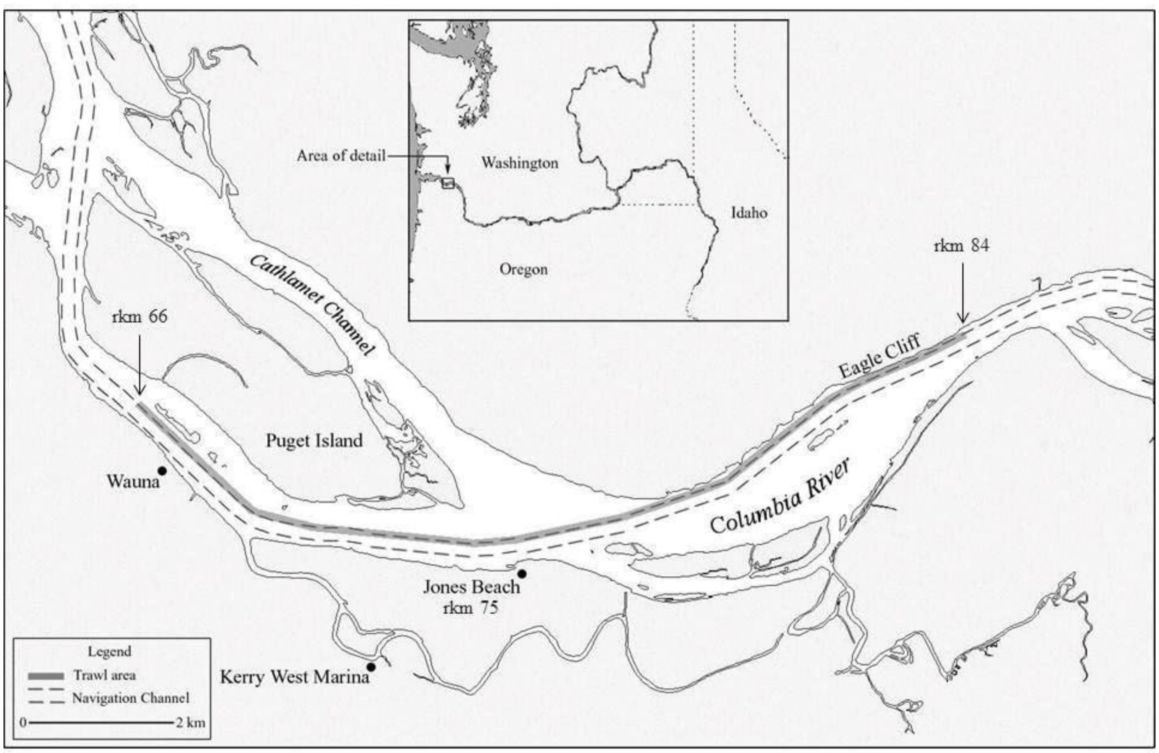


Figure 1. Trawl sampling area adjacent to the navigation channel in the upper Columbia River estuary between rkm 66 and 84, 2025.

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 1996-2025). Specific groups of tagged fish targeted for detection included over 196,029 fish released for a comparative survival study, 27,892 fish diverted to barges for NMFS transportation studies, and smaller groups released for other studies.

Each year, migrating juvenile fish 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 distance of approximately 461 km from the tailrace of Lower Granite to the tailrace of Bonneville Dam (Marsh et al. 2005; 2008; 2010; 2012).

In 2025, 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 2 April and continued through the migration season to 12 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 5.2 h/d. Sample effort was defined as full deployment of the trawl net. During peak spring migration (28 April through 12 June), we sampled with two daily shifts, covering both daylight and darkness periods, for an average daily sample effort of 12.3 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 generally scheduled between 1300 and 1800 PST.

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 using wet-mate connectors (HydroVolt, AK Industries, Rancho Dominguez, CA).[1] and cut to lengths of 21 m. This length provided maximum antenna current after accounting for necessary distances from the antenna.

A fish-passage corridor was formed using one front and one rear antenna array, with each array 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.

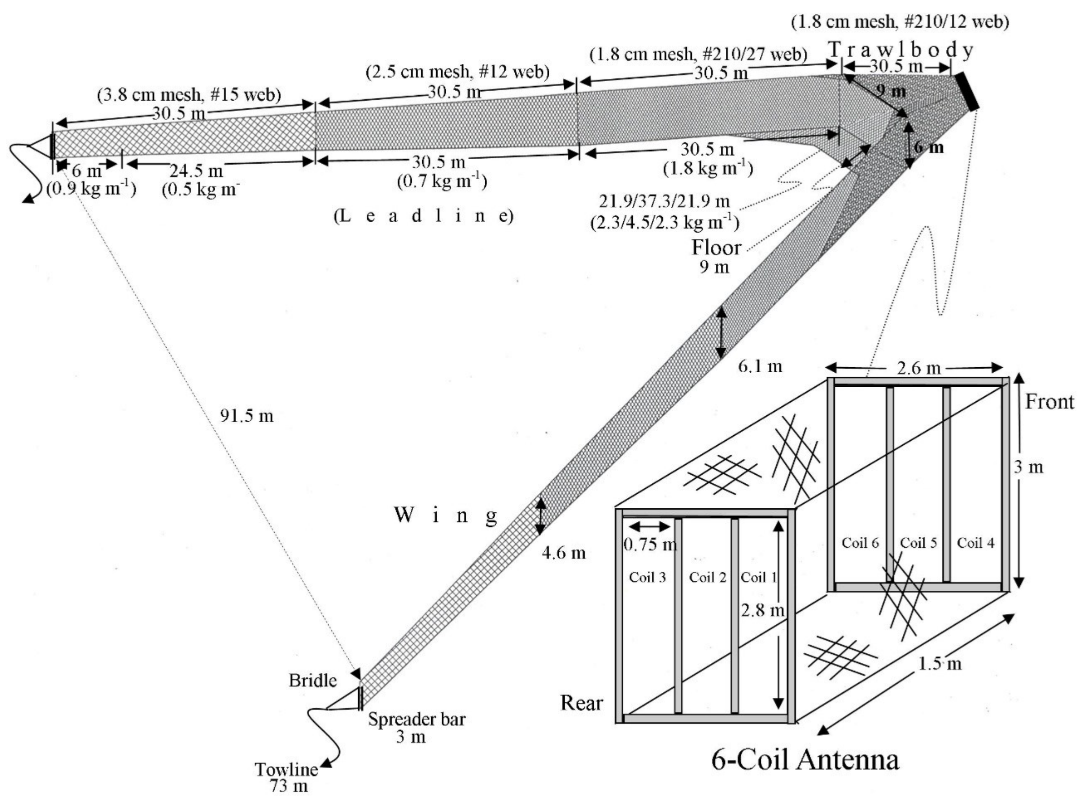


Figure 2. Basic design of the surface pair trawl used with the matrix antenna system to sample juvenile salmonids in the Columbia River estuary (rkm 75), 2025.

[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 and required 114 kg of counterweight to achieve neutral buoyancy in the water column (total weight of front and rear components was 456 kg in air).

Trawl net—The 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. The trawl body, which was open at the cod end for attachment of the antenna array, measured 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 fish passed through the trawl and antenna while towing with the wings extended, we continued to bring the trawl wings 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 antenna system, we continued sampling with the IS1001MUX transceiver in 2025. Electronic components 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 one of the tow vessels. During the season, status reports generated by the transceiver were monitored 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, and coil identification number, were recorded automatically using the PTAGIS software program M5 Control Panel, version 2.2.8 (PSMFC 2024). 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 1996-2025). The specification document, PTAGIS operating software, and user manuals are available from the PTAGIS website (PSMFC 1996-2025). Matrix trawl detections were designated in the PTAGIS database with site code TWX (towed array-experimental).

Pre-season comparative transceiver efficiency testing— 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 suspended the matrix antenna panels from the ceiling of our shop at the Jones Beach field station and pulled the test tape through the center of each antenna pair.

Funnel tests were conducted independently on port, middle, and starboard antennas. We attached a series of PIT tags to a vinyl-coated tape measure, spaced at intervals of 30, 60, and 90 cm, at orientations of 45 or 90 degrees relative to the tape edge. A fixed pulley was used to keep the tape centered and the full tape was passed through the center of each antenna pair for a minimum of 6 passes (trials) per pair. 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 of 34% and 13% when oriented at 45 or 90 degrees, respectively. With spacing between tags increased to 60 cm, detection efficiency increased to 95% and 99% for tags oriented at 45 and 90 degrees, respectively. For test tags spaced 90 cm apart, respective detection efficiency was 98% and 100% for tags oriented at 45 or 90 degrees. Results in 2025 were similar to those in 2024 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 intensive sample period of 28 April -12 June 2025, mean river flow volume at Bonneville Dam was comparable during similar dates in 2024 (5,968 vs. 5,866 m^3/s; Figure 3). Flows in 2025 were 28% lower than the 20-year average for 2005-2025 (8,259 m^3/s). The 2025 season was generally characterized by low flows, with slight increases occurring in mid-April, mid-May, and early June.

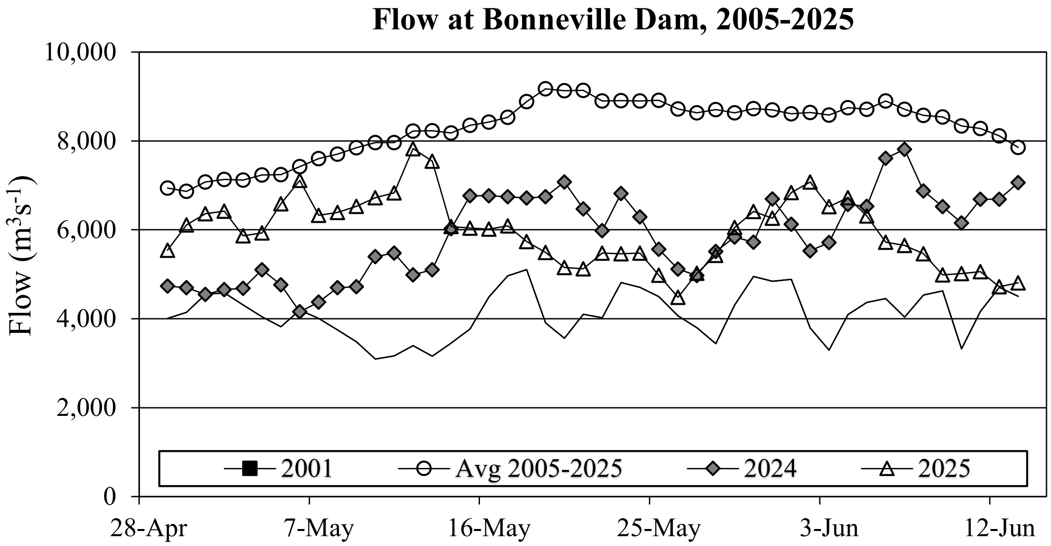


Figure 3. Columbia River flows (m^3/s) at Bonneville Dam during the intensive sample period in 2025 and similar dates in 2024, compared to the average flow from 2005 to 2025. Drought-year flows for 2001 are shown for comparison.

Presence of tagged fish in the sample reach—We estimated that intensive sampling in 2025 coincided with arrival time in the estuary for 73% of the yearling Chinook salmon and 91% of the steelhead passing Bonneville Dam (tagged and non-tagged). In comparison, 74% of yearling Chinook salmon and 88% of steelhead that passed Bonneville were estimated to be present in the estuary during intensive sampling in 2024. A higher proportion of yearling Chinook migrants passed Bonneville Dam prior to intensive sampling in both 2024 and 2025 (21 and 22% respectively) compared to the previous 5 years (8% on average), indicating earlier run timing in 2024 and 2025.

Our intensive sample period also coincided with arrival in the estuary of 86% of the yearling Chinook salmon transported for NMFS studies, which was the same as the proportion in 2024. In 2025, 84% of transported steelhead were estimated to be in the estuary during intensive sampling which was slightly lower than 2024 when 87% of transported study fish were estimated to be in the estuary during intensive sampling.

After the intensive sample period, the majority of fish detected at Bonneville Dam were subyearling Chinook, although yearling Chinook, coho, sockeye, and steelhead were also detected. Subyearlings comprised 62% of the detections at Bonneville Dam after intensive sampling ended in 2025 and 65% of the detections at Bonneville Dam after intensive sampling in 2024. Fish transportation from upstream dams continued until the end of June (Chris Peery, USACE, Walla Walla Dist.; personal communication).

Detection Rates

We sampled with the matrix trawl system for 673 h during 2025 and detected 9,530 PIT-tagged fish. In contrast, we sampled for 655 h during 2024 and detected 12,370 fish (Figure 4). Detection rates were much lower in 2025 than in 2024 (14.0 and 18.9 fish/h, respectively). Slightly lower numbers of PIT-tagged fish in the estuary, unanticipated vessel maintenance, and the scheduled weekly shift break coinciding with peak fish migration likely contributed to lower detection rates.

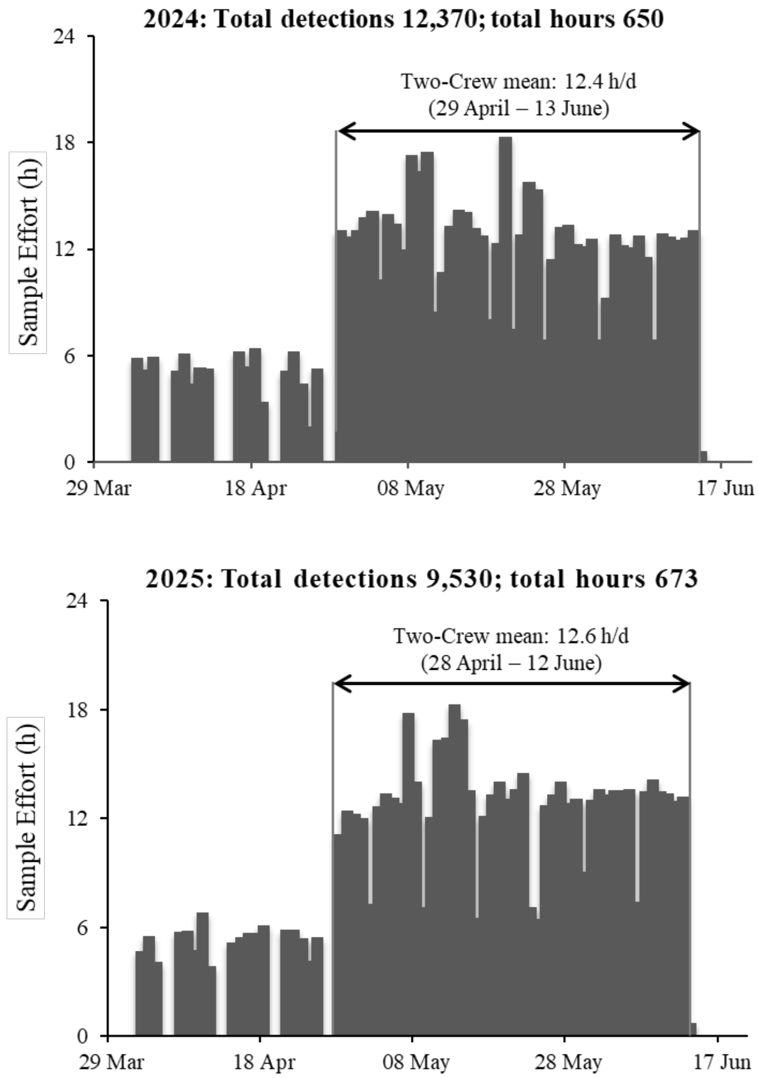


Figure 4. Daily sample effort in spring/summer 2024 and 2025 using the matrix trawl system to detect PIT-tagged juvenile salmon migrating in a tidal freshwater reach of the Columbia River estuary between rkm 66 and 84.

Flow based detection rates for thalweg and nearshore detection methods— Due to the size and depth of the trawl net, the matrix trawl has been constrained to sample the thalweg of the lower Columbia River for the entirety of its operation. Expansion of stationary pile dike detection sites beginning in 2022 has presented an opportunity to sample previously inaccessible nearshore habitat. Higher flows seem to yield a positive relationship with detection rates on pile dike sites, contrary to matrix trawl observations, which typically yield higher detection rates in lower flow years (Morris et al. 2015). Thus, the combined use of thalweg and nearshore sampling methods (trawl and pile dikes) may provide a sustained increase in detection rates for high and low flow years, anticipating further development of non-trawl detection methods.

Species, Rear Type, and Migration History of Detected Salmonids

In 2025, the matrix antenna trawl system detected a total of 8,808 fish of known species and rear type (hatchery and wild) plus another 722 fish lacking release information in PTAGIS (Table 1, Appendix Table 1). Of those 722 fish, at least some species information was available; however, at the time of our analysis, 642 detected fish had no release or species information associated with their respective tags.

Species composition—Of the 8,808 fish detected with the matrix system in 2025, species composition was 41% spring/summer Chinook, 4% fall Chinook, 41% steelhead, 2% sockeye, and 5% coho. Of the remainder, less than 1% were cutthroat trout and 7% were unknown species. Total detections by rear type were 16% wild, 76% hatchery, and 8% unknown origin at the time of this report. These numbers may change slightly as PTAGIS records are 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 2025.

	Rear type			
Species/run	Hatchery	Wild	Unknown	Total
Spring/summer Chinook salmon	3,627	304	20	3,951
Fall Chinook salmon	358	0	0	358
Coho salmon	247	208	0	455
Steelhead	2,878	977	36	3,891
Sockeye salmon	135	45	24	204
Sea-run cutthroat	0	29	0	29
Unknown	0	0	642	642
Grand total	7,245	1,563	722	9,530

For yearling Chinook, subyearling Chinook, and sea-run cutthroat, proportions of detected fish by rear type in 2025 were similar to those in 2024, yet a higher proportion of wild coho, steelhead, and sockeye were detected in 2025 compared to 2024. In 2024 and 2025, all subyearling Chinook detected on the trawl were hatchery fish and all sea-run cutthroat were wild; while the vast majority of yearling Chinook detected on the trawl were of hatchery origin, at a 9:1 ratio to wild fish. Proportions of detected fish by migration history in 2025 were similar to those in 2024. 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).

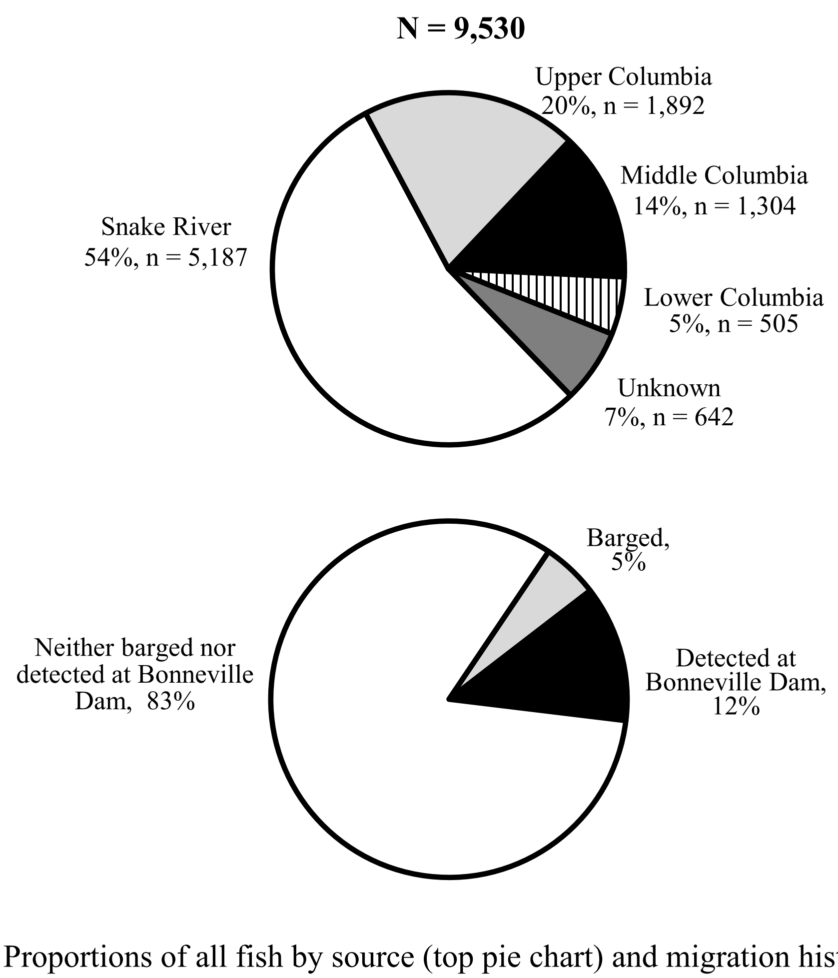


Figure 5. Proportions of all fish by source (top pie chart) and migration history (bottom pie chart) detected in the Columbia River estuary by the matrix trawl in 2025. Upper and middle Columbia River sources were defined relative to McNary Dam. Fish that originated in the Columbia River below Bonneville 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 2025. Based on these criteria, we detected 39 transported and 313 in-river migrant subyearling fall Chinook in the estuary between early April and mid-June (Figure 6). Of the 352 total subyearlings detected, 79% originated in the Snake River, 7% in the Upper Columbia River at or above McNary Dam, and 13% in the Mid-Columbia River between Bonneville and McNary Dam. No subyearlings were detected from the Lower Columbia River below Bonneville Dam.

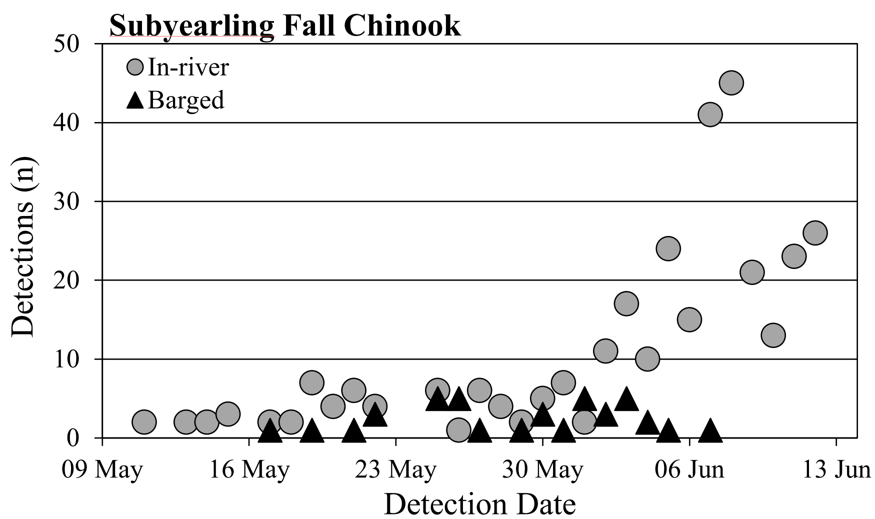


Figure 6. Temporal distribution of subyearling fall Chinook salmon detections in the Columbia River estuary near rkm 75 during in-river migration (n = 313) or following release from barges below Bonneville Dam (n = 39), 2025.

Juvenile subyearling fall Chinook salmon begin 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 2025.

Sockeye salmon—We detected 204 sockeye salmon between 2 April and 12 June (Figure 7). Of these, 66% were hatchery fish, 22% were wild fish, and the remaining 12% were of unknown origin. Fish released upstream from McNary Dam in the Snake and Columbia River Basin, respectively comprised 64% and 33% of our sockeye salmon detections, with 3% of fish released between McNary and Bonneville Dam. Transported fish accounted for 18 of the sockeye salmon detections. Of those transported, 14 had been collected at Lower Granite Dam, 2 had been collected at Lower Monumental Dam, and 2 had been collected at Little Goose Dam.

In the last ten years prior to 2025, sockeye released in the reach between McNary and Bonneville have been less than 2% of total sockeye detections. All sockeye detected between McNary and Bonneville Dam in 2024 and 2025 were wild fish originating in the upper Deschutes River (2 and 6 fish, respectively). Migration of sockeye salmon in this watershed had been blocked since the construction of the Pelton Round Butte dams (in 1958 and 1964, respectively), resulting in a landlocked population of sockeye salmon ("kokanee"). A selective water withdrawal structure was installed in 2009, which opened downstream passage for juvenile salmonids and allowed the juvenile population of kokanee to once again migrate to the ocean and subsequently return as adult sockeye salmon (Smith et.al 2020). Recovery of this sockeye population has resulted in increased detections of juvenile sockeye on the matrix trawl originating from the Deschutes River basin

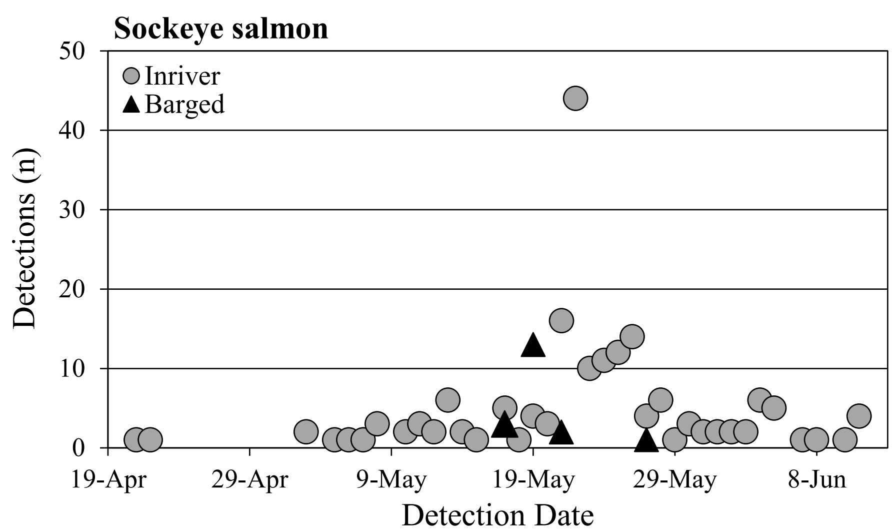


Figure 7. Temporal distribution of sockeye salmon detections in the Columbia River estuary near rkm 75 during in-river migration (n = 204) or following release from barges below Bonneville Dam (n = 18), 2025.

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 2025, we recovered 131 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 exit 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).

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 towed flexible array since 2015 and pile dike detection systems since 2022, although these data were excluded from our report.

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. 2024).

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. Releases of PIT-tagged fish in the Columbia River Basin prior to or during the spring migration season were just over 2.0 million in 2024 and just under 2.0 million in 2025. Lower detection rates in 2025 compared to 2024 may be partially attributed to a slightly lower number of PIT-tagged fish in the estuary. Sampling effort was higher in 2025, flows and antenna performance were comparable in both years. Although the main factors attributing to reduced detection rates remain uncertain, unanticipated vessel maintenance reduced our ability to switch day and night crews on the water during peak migration. These sampling gaps, paired with a scheduled night off during the highest migration timing may have contributed to lower detection rates in 2025. 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.

Travel Time and Migration Rate

In 2025, as in 2024 and years prior to the COVID-19 pandemic, we compared juvenile performance metrics such as detection rate, travel time, and migration rate by species and migration history using data from estuary detections. Data used in these analyses were collected by the matrix trawl.

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 2025, fish were transported from Lower Granite, Little Goose, and Lower Monumental Dam on the Snake River. Our analysis of travel time 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 1996-2025). 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 2025 transportation season (Chris Peery, 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 2.1 and 1.7 d, respectively in 2025. Median travel times were higher for yearling Chinook and lower for steelhead in 2025 than they were in 2024 (1.8 and 1.9 d, respectively). Median travel times for yearling Chinook and steelhead were also higher than 15-year average of 1.8 and 1.7 d, respectively (Table 2). Similarly, for transported yearling Chinook and steelhead, respective median travel times were 2.9 and 1.8 d in 2025 compared with 2.1 and 1.9 d in 2024. Transported yearling Chinook travel times in 2025 were tied with 2001 for the slowest on record. Several groups of transported fish released in late April had exceptionally long travel times, which increased the median travel time for yearling Chinook. Additionally, barged fish totals were much lower in 2024 and 2025 than previous years, which may account for a less precise median travel time for all species.

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, 2000-2025. 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
2023	1.6	422	1.5	413	2.0	297	1.5	576	8,727
2024	1.8	561	1.9	618	2.1	65	1.9	70	5,866
2025	2.1	379	1.7	450	2.9	77	1.8	101	5,968

* 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 51.3 vs. 84.3 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 (76.4 vs. 101.9 km/d; P<0.001). These differences in travel speed by migration history were similar to observations from previous years (Figure 8).

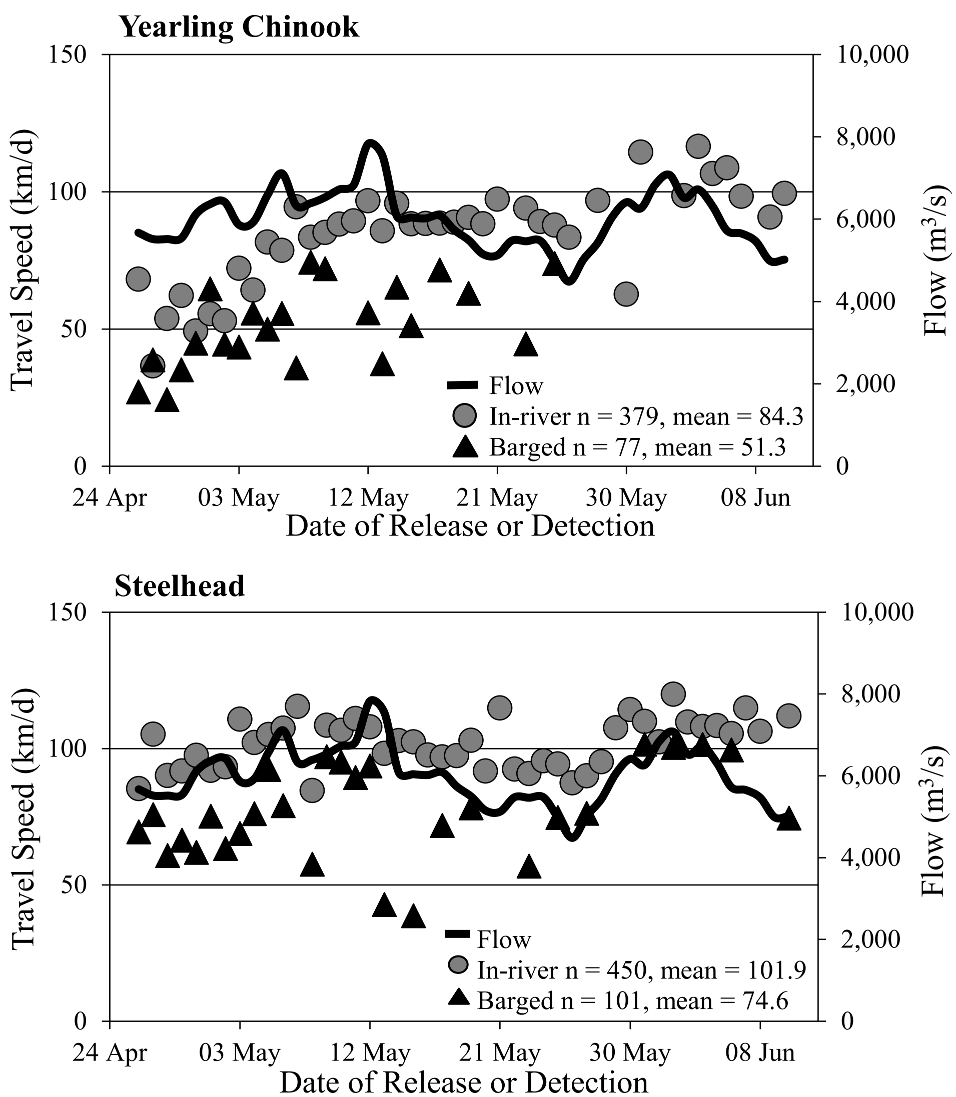


Figure. 8. Daily median travel speed (km/d) of yearling Chinook salmon and steelhead following detection at Bonneville Dam or release from a barge to detection in the Columbia River estuary, 2025. Seasonal means are shown for comparison with flow.

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 (28 April-12 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, steelhead, and sockeye, but not for 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 12.3 h/d (Appendix Table 3). In general, sampling was suspended each day between 1300 and 1800 PST for crew changes and refueling.

For hatchery yearling Chinook salmon, hourly detection rates were significantly different during darkness vs. daylight hours (9.7 vs. 3.4 fish/h; P=0.004; Figure 9). Similarly, for wild Chinook salmon, average detection rates were significantly different during darkness vs. daylight hours (0.7 vs. 0.4 fish/h; P<0.001). 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 (5.1 vs. 2.9 fish/h; P<0.001). Similarly, for wild steelhead, there was a significant difference in hourly detection rate between daylight and darkness hours (1.9 vs. 1.0 fish/h; P<0.001).

For hatchery sockeye, hourly detection rates were not significantly different between daylight and darkness hours (0.19 vs. 0.33 fish/h; P=0.059). Similarly, for wild sockeye, there was no significant difference in hourly detection rate between daylight and darkness hours (0.08 vs. 0.05 fish/h; P=0.969).

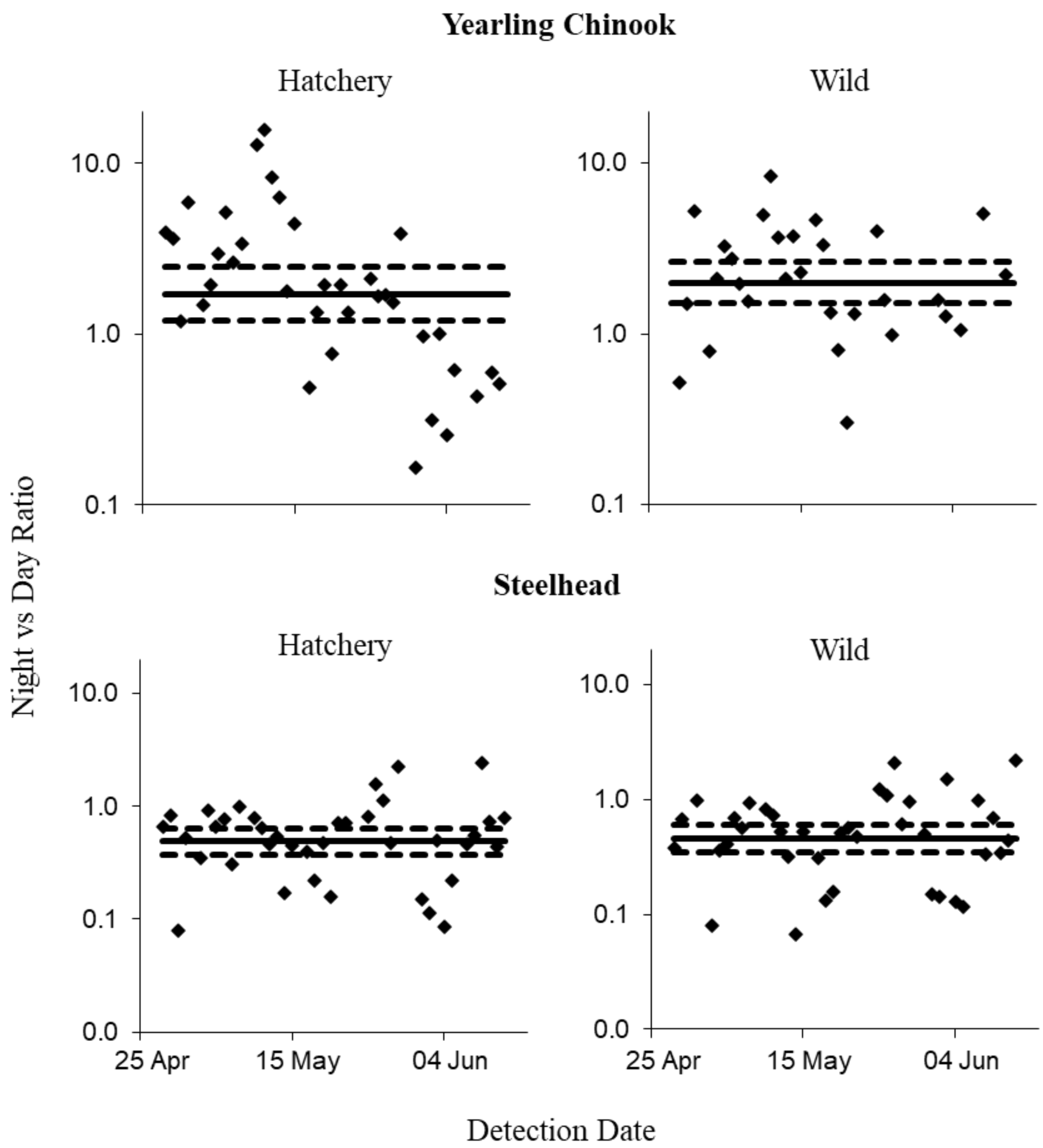


Figure 9. Daily ratios of darkness/daylight detection rates for wild and hatchery yearling Chinook salmon and steelhead in the Columbia River estuary during intensive sampling, 28 April-12 June 2025. Ratios greater than 1.0 indicate higher detection rates in darkness hours, and values less than 1.0 indicate higher detection rates in daylight hours. Solid lines are estimated mean ratios, and dotted lines are estimated 95% confidence intervals.

In each year since 2003, hourly detection distributions have been similar between wild and hatchery rear types for both yearling Chinook salmon and steelhead. These numbers were similar again in 2025, so we pooled rear types for both species, in the multi-year summary shown in Figure 10. 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. Detection rates of steelhead have generally been significantly higher during daylight hours.

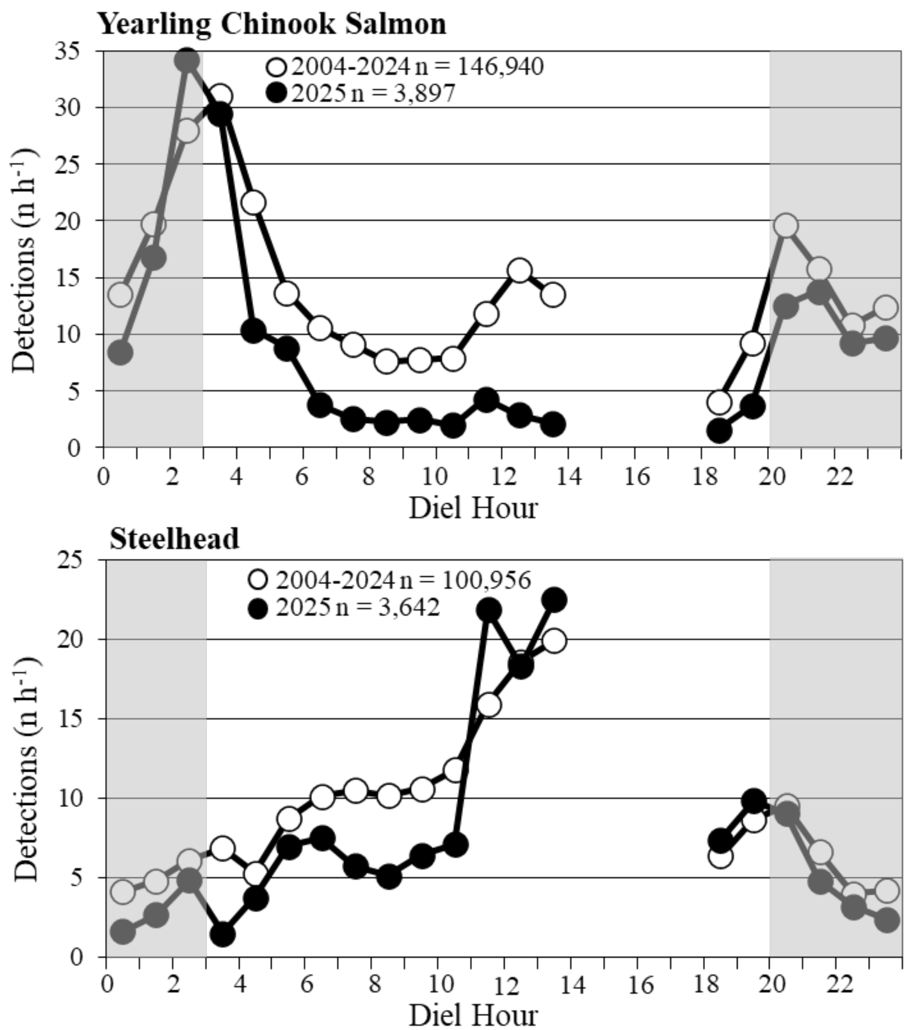


Figure 10. Average hourly detection rates (PST) of yearling Chinook salmon and steelhead during intensive sampling with the matrix trawl system in the Columbia River estuary during 2004-2024 (excluding 2020 & 2021), vs. 2025 Hatchery and wild rear types are combined for both Chinook and steelhead because there was no difference between their diel detection patterns. Shaded areas indicate hours of darkness.

Factors Affecting Detection Rates

Methods

We compared daily detection rates in the trawl between transported fish and in-river migrants previously detected at Bonneville Dam during the intensive sampling period (28 April-12 June 2025). These data were evaluated to assess whether differences in detection rate were related to either migration history or arrival timing in the estuary.

Additionally, we pooled data collected from the trawl, flexible antenna array, and pile dike arrays and replicated these analyses for the same time period (Appendix II). Pooling data from all sample methods presents an opportunity to increase detection recovery rates of fish previously detected at Bonneville, improving the precision of our analyses.

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, migration history treatment indicator, 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 have shown that within each species, daily transported and in-river groups exhibit similar diel distributions in the sampling area during annual intensive sampling periods and therefore presumably pass the sample area at similar times (Magie et al. 2011). Thus, our model 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 5,979 tagged yearling Chinook salmon and 14,334 tagged steelhead were transported and released below Bonneville Dam during our intensive sample period (28 April-12 June). These included fish diverted to barges for NMFS transport studies and fish tagged and transported for other studies. Of these transported fish, we detected 89 yearling Chinook salmon and 301 steelhead in the upper estuary (1.5 and 2.1%, respectively).

Transported fish totals were only slightly higher in 2025 than in 2024, and still well below the number of transported fish prior to 2024. Several factors likely contributed to the reduced number of transported fish in 2024 and 2025 compared to previous years. Early run timing in both years resulted in a much higher proportion of fish passing Lower Granite Dam before juvenile collection began, and the Snake River Max Spill Program coupled with low river flows forced more fish to utilize the spillway rather than the bypass system, preventing collection and subsequent barging (Widener et al. 2024).

A total of 19,987 tagged yearling Chinook salmon and 14,396 tagged steelhead were released upstream from McNary Dam and detected at Bonneville Dam during intensive sampling. Of these in-river migrants, we detected 379 yearling Chinook salmon and 450 steelhead (1.9 and 3.1%, 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 sample period. We estimated the proportions of tagged fish from these groups that were available in the estuary during our intensive sample period (28 April-12 June), allowing 2 d for fish to reach the sample area after release or detection at Bonneville.

For tagged yearling Chinook salmon, we estimated that 95% of in-river migrants and 86% of transported fish passed through the sample reach during our intensive sample period. For tagged steelhead, we estimated that 91% of in-river migrants and 84% of transported fish passed the sample reach during our intensive sample period. For yearling Chinook, estimated percentages of fish passing the sample area in 2025 were the same for in-river migrants and transported fish in 2024. For steelhead, estimated percentages of tagged fish passing the sample area in 2025 were also similar for in-river fish and slightly lower for transported fish than those in 2024.

During intensive sampling in 2025, average sample effort was 12.3 h/d, which was similar to the average effort of 12.4 h/d in 2024. For both yearling Chinook and steelhead, both transported fish and those detected passing Bonneville Dam had lower rates of trawl detection in 2025 than 2024 (Table 3).

Table 3. Trawl detection rates of PIT-tagged Chinook salmon and steelhead released from barges or detected passing Bonneville Dam and detected in the trawl during intensive sample periods in 2024 and 2025.

	Transported fish originating upstream from McNary Dam			In-river fish detected at Bonneville Dam*		
	Released	Detected		Released	Detected	
Year/species	(n)	(n)	(%)	(n)	(n)	(%)
2024						
Chinook salmon	4,682	78	1.7	23,224	561	2.4
Steelhead	12,165	289	2.4	14,097	617	4.4
2025						
Chinook salmon	5,979	89	1.5	19,987	379	1.9
Steelhead	14,334	301	2.1	14,396	450	3.1

* In-river fish included only those released at or upstream from McNary Dam. No fish were transported from McNary Dam in 2024 or 2025.

For yearling Chinook salmon detected with the trawl, logistic regression analysis showed no significant interaction between migration history and arrival date (P=0.934), migration history and date-squared (P=0.548), date-squared (P=0.729), migration history (P=0.440) or arrival date (P=0.397). Throughout the peak spring migration, average detection rates for yearling Chinook salmon remained at 1.9% for both transported fish and in river migrants (Figure 11, top panel). The adjustment for overdispersion was 1.8.

For steelhead detected with the trawl, logistic regression showed a significant effect for arrival date (P=0.001) and migration history (P=0.025), therefore those terms were included in the resulting best model. There was no significant interaction between migration history and arrival date (P=0.811), migration history and date-squared (P=0.201), or date-squared (P=0.399). Estimated detection rates for transported steelhead were 1.3% at the beginning of the season and increased to 5.2% by the end of the season; estimated detection rates for in river steelhead were 1.9% at the beginning of the season and increased to 7.5% by the end of the season (Figure 11, lower panel). The adjustment for overdispersion was 5.5.

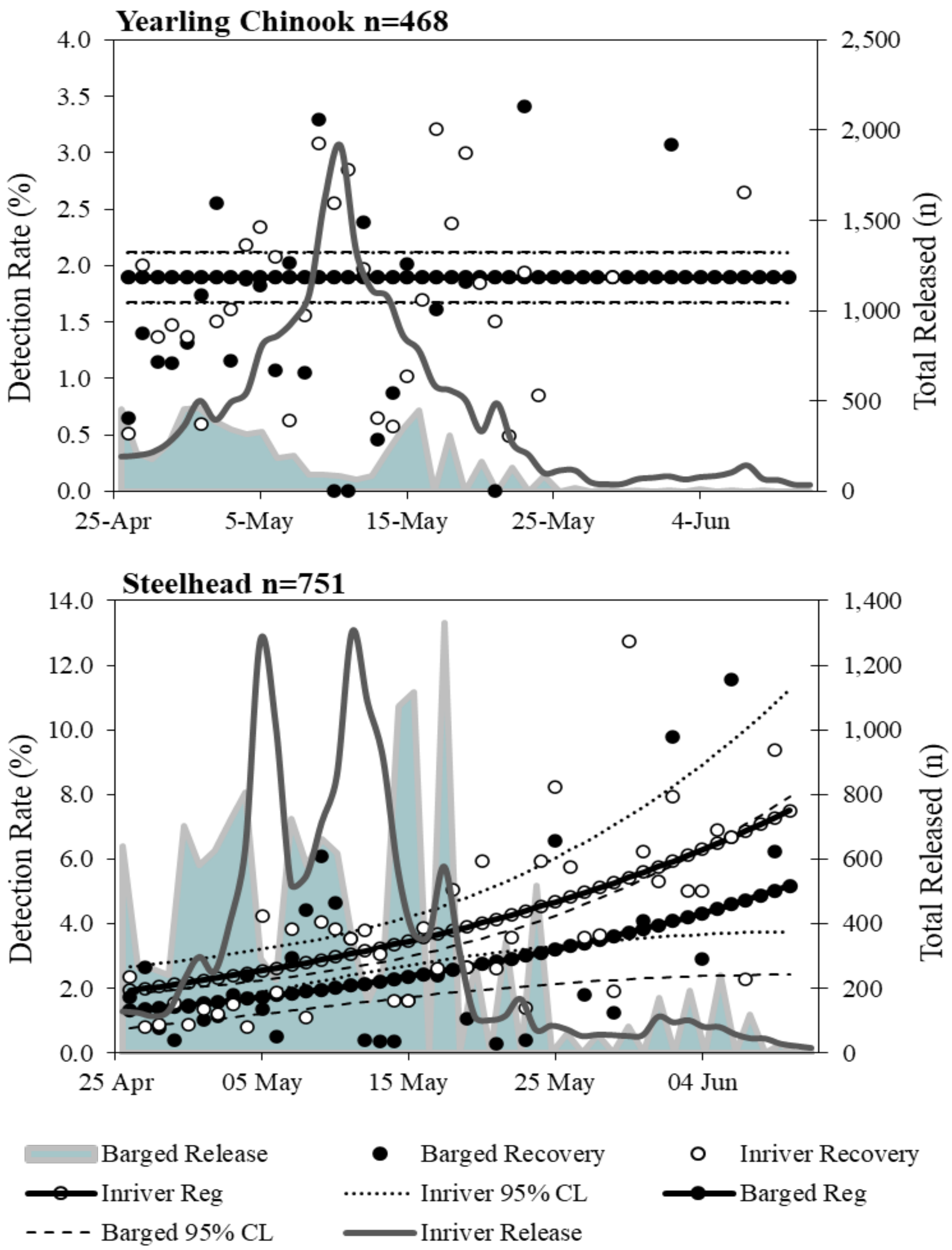


Figure 11. Estimated daily detection rates in the matrix trawl system for transported and in-river migrant yearling Chinook salmon and steelhead, 28 April-12 June 2025. All fish were either detected at Bonneville Dam or released from a barge just downstream from the dam on the same date.

For steelhead, estimated daily detection rates were higher among in-river migrants than transported fish, while there was no significant difference for yearling Chinook salmon. Over the last 15 years, we've observed a general trend toward higher detection rates of in-river migrant Chinook salmon than transported fish, though this trend was not apparent in 2025, likely due to the small sample size of transported migrants (Morris et al. 2014).

Development of a Flexible Antenna Detection System

In 2025, 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:

1. Reduce costs associated with sampling juvenile salmonids in the estuary
2. Improve sample efficiency using recent advances in PIT technology
3. Eliminate impacts on species listed under the U.S. Endangered Species Act (ESA)

By removing impacts to listed species, we would also eliminate the requirement for an ESA permit to conduct annual sampling, since no take of salmonids would occur using the flexible system.

Prototype and Testing from 2015 to 2019

In 2012, the advent of small-diameter flexible PIT antennas and the IS1001 multiplexing transceiver inspired the development of a new towed array (Morris et al. 2023). The advantages of this system were numerous: increased energy output of the IS1001 meant the antennas could be larger and more powerful, slimmer components meant fewer staff were required to operate the system, and the absence of a net allowed the system to be towed with smaller and more fuel-efficient vessels. Finally, this system eliminated the risk of mortality for ESA-listed species.

The main 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 primary goal was to hone operational stability of the system, assuming this was achievable. Our secondary 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 toward steelhead that was associated with sample depth (Morris et al. 2017). Thus, in 2017 the rectangular antennas were rotated 90 degrees, from a horizontal to a vertical orientation toward 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 2017 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 flexible 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. As a result, the flexible antenna system detected over three times the number of fish in 2018 as in 2017 (Holcombe et al. 2019).

After the 2018 sample period, controller area network (CAN)-bus cables 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 and made for a more successful sample season in 2019, where we detected 2,707 fish - a large increase from the 755 fish detected in 2018 (Holcombe et al. 2020).

Advances from 2022 to 2025

Due to COVID-19 restrictions and limited staff, we were unable to sample with the flexible antenna system during the spring migration seasons of 2020 or 2021. After completion of trawl sampling in 2022, we returned our focus to increasing sampling efficiency and safety using mechanical methods for deployment and retrieval of flexible antenna gear. To achieve this, we redesigned the towed flexible array using manufactured aluminum reader 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 compensate for excess strain from winding the array onto a net reel. 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.

Following the observation that systemic noise increases during periods of heavy towing or increased river flow, a new faired antenna cable was designed and tested in 2025. The fairing was intended to reduce trailing eddies created when the cable is towed through water, which would theoretically reduce drag, vibrations, and ultimately noise. Six faired flexible antennas were constructed from this new custom cable and dyed grey to reduce fish avoidance. Faired antennas were integrated into the array in an alternating pattern with un-faired antennas.

Coordination with Trawl and Stationary Systems

Prior to testing the towed flexible array in 2022, we installed and operated two stationary pile dike detection sites within the trawl sample reach. In 2022-2025, we observed a bias towards the detection of Chinook salmon on our stationary pile dike detection sites and a bias towards the detection of steelhead on the flexible antenna array (Vinarcsik et al. 2025). As noted above, results from testing the towed flexible array in a horizontal configuration during 2016 indicated a strong bias towards the detection of steelhead (Morris et al. 2017). Thus, to counter species bias across both methods, we tested the towed flexible array in a horizontal configuration in 2022 and sampled with this configuration and our pile dike sites concurrently in 2023, 2024, and 2025.

In previous years, detection rates of steelhead on the matrix system have typically been significantly higher during daylight hours (Jaenecke et al. 2023). Therefore, in addition to modifying antenna orientation on the flexible array, sampling was conducted during daylight hours to maximize steelhead detections.

The newly configured flexible array was first tested in late 2022 and included 8-12 antennas rotated to a horizontal orientation (6.1-m wide and 2.4-m deep), with one 3-m spreader bar attached to each end, as was done in 2016 (Figure 12). To prevent excess cable from interfering with the detection field, CAN-bus jumpers were extended to 18.3 m between antennas. This significantly reduced EMI across the array. Field testing in 2022 showed optimal system performance with 8 antennas, although future development will aim to expand this configuration to 12 antennas once transceiver technology can support a larger array and maintain low EMI.

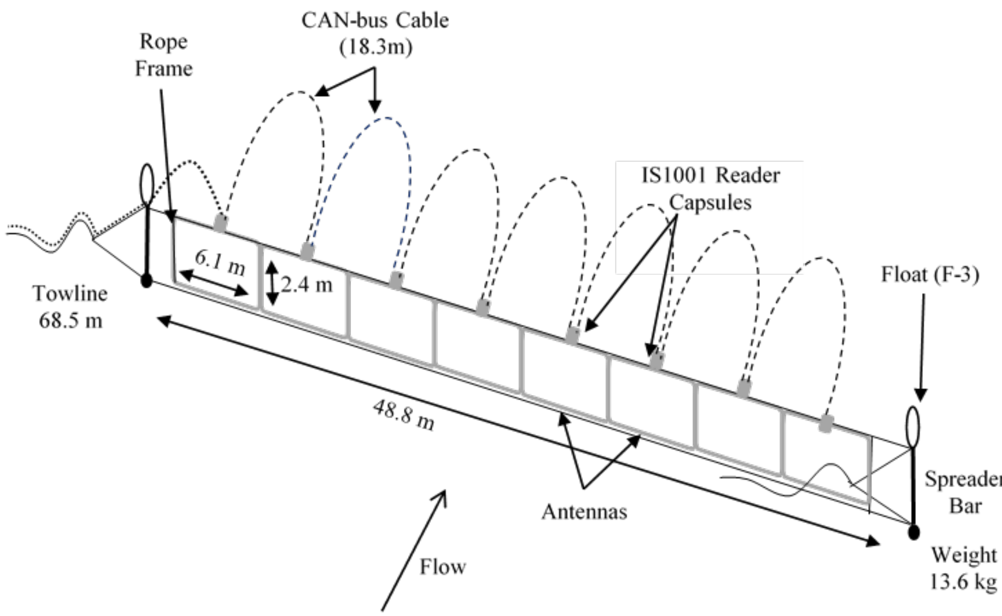
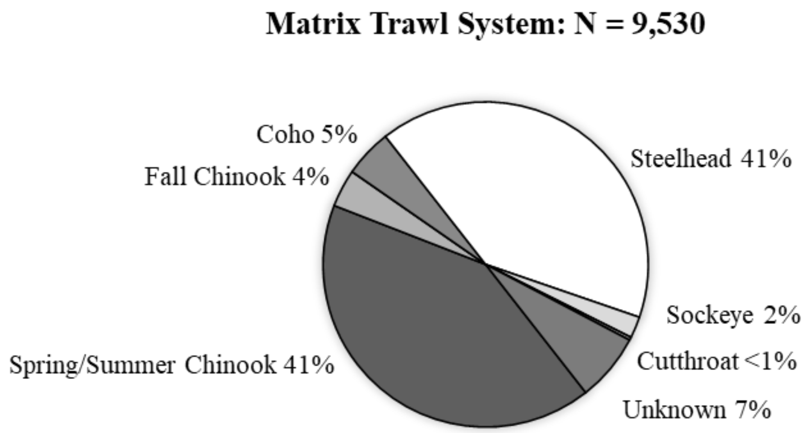


Figure 12. Horizontal layout of the towed flexible antenna array as sampled in 2025.

Prior to the 2023 field season, we mounted a net reel to the deck of a 38-ft aluminum landing craft (Packcat hull, Munson Boats, Burlington, WA) for full system deployment in water. We fully implemented this design for the 2023 sampling season, which drastically simplified operations and improved operations. Throughout the season, we refined deployment and retrieval methods to improve safety and efficiency, which resulted in the mid-season addition of a hydraulic governor to the net reel. Prior to sampling in 2024, we installed a new hydraulic net reel power pack and cushioning for the net reel drum.

From 14 April to 27 May 2025, we continued sampling with the towed flexible antenna array during daylight hours. Of the 434 fish detected with the flexible antenna array in 2025, species composition was 5% spring and summer Chinook, 88% steelhead, and 2% coho. Of the remainder, less than 1% were sockeye and 5% were unknown species. Total detections by rear type were 18% wild, 77% hatchery, and 5% unknown origin at the time of this report.

Sampling effort in 2025 was less than half of 2024 due to personnel availability and project priorities. Detection rates were slightly lower in 2025 than in 2024 (4.0 fish/h vs. 5.4 fish/h), likely due to fish avoidance caused by the antenna fairing and reduced sample effort during the peak steelhead migration period.



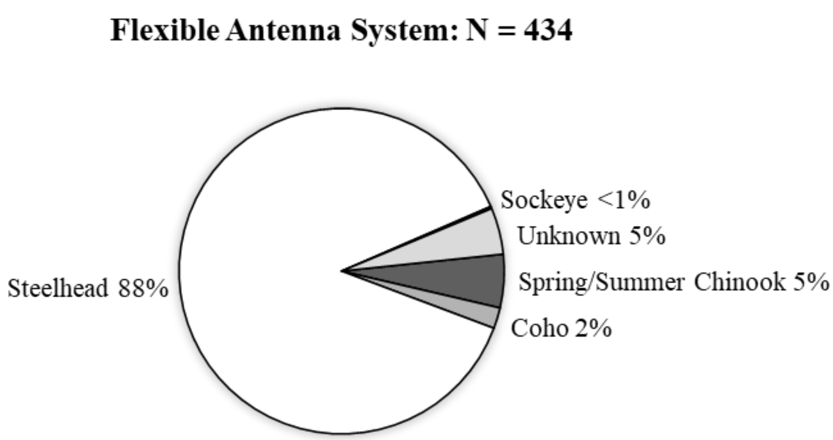


Figure 13. Proportions of fish detected by the matrix trawl and flexible antenna array during sampling season in the Columbia River estuary by species, 2025.

In 2025, we made several modifications to address issues experienced in 2024. Mainly, we rebuilt the entire array with new components, introduced a new custom-faired antenna cable that we hoped would reduce the impact of EMI-causing vibrations experienced under tow, and modified reader capsules to limit wire interference and eliminate water intrusion.

We sealed each capsule by lining the mated surfaces with room temperature vulcanizing (RTV) silicone and applied 4200 Marine sealant around the outside seams. For added measure, we reinforced cable gland entries with double-walled heat shrink tubing. Fabricated "windows" were added to each capsule, allowing clearer access to terminal blocks and preventing antenna wire leads from running alongside the reader boards (to reduce EMI). The window lids were fastened to the capsules using a double N-Buna gasket. We also deployed the system by hand for the entire 2025 season to prevent CAN-Bus cable degradation from winding the array onto the net reel to eliminate that as a factor.

Minor water intrusion occurred in one capsule during the 2025 season, which was correlated with intermittent EMI - highlighting the importance of limiting water intrusion. Overall, the array experienced low levels of EMI during normal operation. Periods of boat maneuvering and outgoing tides destabilize antenna shape, which amplify noise spikes, as antennas are continuously attempting to retune. Despite low EMI, we observed lower than expected read ranges when compared to other deployed flexible antennas. Despite exhibiting similar performance, detection rates were much lower on faired antennas compared to un-faired antennas, likely due to fish avoidance (Figure 14). Given the overall performance relative to prior years, it is likely that the fairing also decreased detections across the array on non-faired antennas.

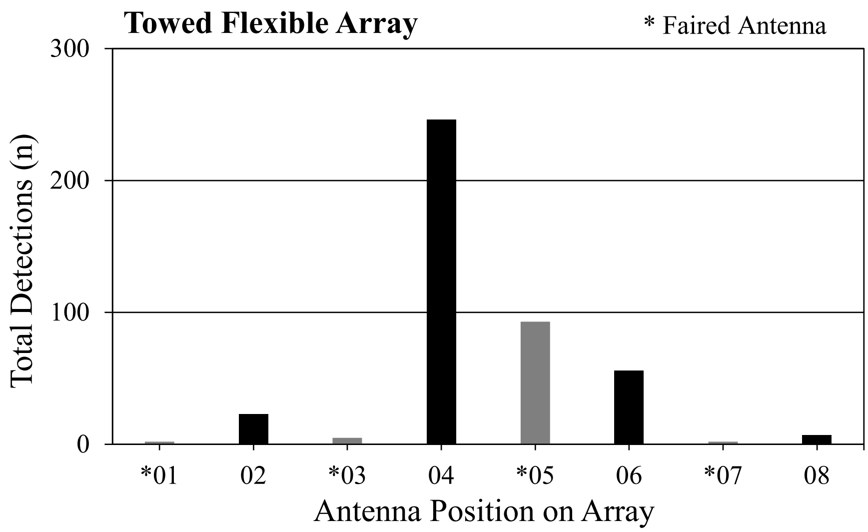


Figure 14. Detections on the towed flexible array by antenna position (01 on the WA shore side and 08 on the OR shore side) and type during sampling season in the Columbia River estuary, 2025.

In conclusion, while the flexible antenna system detects fish as a mid-river, thalweg-based towed system, multiple factors have limited its capability relative to the trawl. This system still contributes value to the overall estuary PIT detection effort, largely by offsetting the sampling biases of the pile dike system, but it has not yet shown it can reach numbers comparable to that of the trawl. As such, future development will aim to explore other deployment strategies in conjunction with piles dikes. We have seen success in using pile dikes to passively concentrate fish into specific areas, so we will focus on these areas using a hybrid towed-fixed point sampling approach and spanning large pile dike gaps with this antenna system.

Discussion

In summary, detections from all sample methods in 2025 were sufficient to complete all analyses for yearling Chinook and steelhead. The matrix trawl yielded similar detection data in 2025 as it did in 2024, however detection rates were much lower. Considering similar river flow, sampling effort, run timing, and system performance, the primary reasons for reduced detection rates remain unknown, however, we suggest fish presence in the estuary and sampling logistics could be contributing factors.

Transported fish totals were higher in 2025 than 2024, but were still far below transported fish totals of previous years. Low river flows and early run timing paired with the Snake River Max Spill Program likely resulted in fewer fish being collected at Lower Granite Dam with more fish directed over the spillway rather than the through the bypass system.

The flexible array has undergone extensive development to improve detection rates, durability, function, and system performance. This year our goal with the flexible array was to optimize the system as a towed, thalweg-based sampling tool. After building a new system, we achieved our goals of reducing EMI and preventing water intrusion. Despite these improvements, detection rates were lower than previous years. Faired antennas detected roughly half the number of fish compared to non-faired antennas, indicating likely fish avoidance.

It has become increasingly clear over the years that a towed, thalweg sampling method may not be the best application of this technology. Maintaining antenna shape under tow remains a challenge, and the high turnover of electrical components indicate the system is under a lot of strain. As a sampling method, the flexible antenna array may be better suited for specific environments and in conjunction with areas of the river known to concentrate fish, such as immediately downstream of a pile dike.

The Snake River Max Spill program was implemented in 2020 to improve juvenile salmonid survival through the hydrosystem. This has resulted in a higher proportion of PIT tagged fish migrating over spillways undetected, rather than utilizing juvenile bypass systems equipped with PIT detectors. Consequently, this decrease in detections reduces the precision of survival estimates (Widener et al. 2024). In these scenarios, increasing estuary detections will likely increase the precision of these estimates, highlighting the importance of expanding estuary detection methods.

As accurate survival estimates continue to be a high priority for fishery management, it remains clear that a diverse strategy for detecting PIT-tagged juvenile salmonids in the Columbia River estuary is as important as ever. Annual variations in river flow and fish availability highlight the advantages of a multi-system approach to expand PIT interrogation. Continued investment in new technologies may increase sampling efficiency and improve our understanding of fish behavior.

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Appendix I

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), 2025.

Date	Total time underway (h)	PIT tag detections (n)						
		Unknown	Chinook salmon	Coho salmon	Steelhead	Sockeye salmon	Cutthroat trout	Total
2 Apr 25	4.57	0	3	0	0	0	0	3
3 Apr 25	5.40	--	--	--	--	--	--	--
4 Apr 25	3.95	0	0	0	0	0	0	0
5 Apr 25	0.00	--	--	--	--	--	--	--
6 Apr 25	0.00	--	--	--	--	--	--	--
7 Apr 25	5.63	0	2	0	0	0	0	2
8 Apr 25	5.68	0	3	0	0	0	0	3
9 Apr 25	4.60	0	2	0	0	0	0	2
10 Apr 25	6.72	1	1	0	0	0	0	2
11 Apr 25	3.72	0	1	0	0	0	0	1
12 Apr 25	0.00	--	--	--	--	--	--	--
13 Apr 25	0.00	--	--	--	--	--	--	--
14 Apr 25	5.05	0	1	0	1	0	0	2
15 Apr 25	5.33	0	2	0	14	0	0	16
16 Apr 25	5.57	0	1	4	20	0	0	25
17 Apr 25	5.57	2	2	0	36	0	0	40
18 Apr 25	5.97	1	2	0	30	0	0	33
19 Apr 25	0.00	--	--	--	--	--	--	--
20 Apr 25	0.00	--	--	--	--	--	--	--
21 Apr 25	5.75	3	4	0	27	1	0	35
22 Apr 25	5.73	2	6	1	20	1	0	30
23 Apr 25	5.28	2	7	1	31	0	0	41
24 Apr 25	4.05	2	1	1	15	0	0	19
25 Apr 25	5.32	0	2	1	23	0	0	26
26 Apr 25	0.00	--	--	--	--	--	--	--
27 Apr 25	0.00	--	--	--	--	--	--	--
28 Apr 25	11.02	8	33	2	63	0	1	107
29 Apr 25	12.32	6	25	6	50	0	1	88
30 Apr 25	12.15	2	45	7	26	0	1	81
1 May 25	11.87	10	38	1	27	0	1	77
2 May 25	7.13	5	27	1	26	0	0	59
3 May 25	12.57	24	110	5	71	2	2	214
4 May 25	13.25	29	110	1	74	0	0	214
5 May 25	13.00	30	116	3	72	1	1	223
6 May 25	12.75	32	142	1	92	1	0	268
7 May 25	17.67	50	284	7	336	1	0	678
8 May 25	13.88	24	181	4	102	3	0	314

Appendix Table 1. Continued.

Date	Total time underway (h)	PIT tag detections (n) Unknown	Chinook salmon	Coho salmon	Steelhead	Sockeye salmon	Cutthroat trout	Total
9 May 25	7.00	3	24	3	39	0	0	69
10 May 25	11.95	17	200	8	84	2	1	312
11 May 25	16.20	26	407	7	274	3	0	717
12 May 25	16.35	23	272	14	199	2	0	510
13 May 25	18.15	26	286	6	183	6	0	507
14 May 25	17.32	17	236	8	174	2	1	438
15 May 25	13.45	12	93	11	88	1	0	205
16 May 25	6.40	2	58	2	14	0	0	76
17 May 25	12.02	9	95	7	62	8	0	181
18 May 25	13.20	14	103	10	95	1	1	224
19 May 25	13.90	17	105	5	150	16	1	294
20 May 25	12.98	15	111	7	124	3	1	261
21 May 25	13.47	21	126	16	113	18	2	296
22 May 25	14.38	31	159	17	130	44	2	383
23 May 25	6.98	12	46	9	47	10	1	125
24 May 25	6.32	8	21	8	38	11	0	86
25 May 25	12.58	17	84	18	86	12	1	218
26 May 25	13.17	11	44	13	97	14	1	180
27 May 25	13.88	11	62	11	80	5	0	169
28 May 25	12.70	7	36	14	30	6	0	93
29 May 25	12.98	8	22	9	59	1	0	99
30 May 25	8.95	9	36	6	30	3	0	84
31 May 25	12.88	2	21	6	24	2	0	55
1 Jun 25	13.50	10	34	13	51	2	1	111
2 Jun 25	13.18	8	36	6	69	2	3	124
3 Jun 25	13.42	9	37	5	40	2	2	95
4 Jun 25	13.45	4	35	18	75	6	0	138
5 Jun 25	13.47	5	60	20	40	5	2	132
6 Jun 25	7.27	0	23	8	29	0	1	61
7 Jun 25	13.37	6	75	26	46	1	1	155
8 Jun 25	14.00	11	82	23	50	1	0	167
9 Jun 25	13.37	5	32	13	34	0	0	84
10 Jun 25	13.23	7	20	19	25	1	0	72
11 Jun 25	12.83	12	41	30	31	4	0	118
12 Jun 25	13.07	14	36	13	25	0	0	88
13 Jun 25	0.58	0	0	0	0	0	0	0
Total	664.12	642	4309	455	3891	204	29	9,530

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), 2025.

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

Appendix Table 2. Continued.

Date	Yearling Chinook	Subyearling Chinook	Coho	Steelhead	Sockeye	Chum
11 May	4	0	1	0	0	0
12 May	1	0	0	1	0	0
13 May	10	0	2	2	0	0
14 May	5	0	0	1	1	0
15 May	1	0	0	0	0	0
16 May	0	0	0	0	0	0
17 May	2	0	0	0	0	0
18 May	1	0	0	0	1	0
19 May	1	0	0	0	0	0
20 May	1	0	0	1	1	0
21 May	1	0	0	0	0	0
22 May	1	0	0	0	0	0
23 May	0	0	0	0	0	0
24 May	0	0	0	0	0	0
25 May	6	0	1	1	2	0
26 May	1	0	0	0	0	0
27 May	1	0	0	1	1	0
28 May	1	0	0	0	0	0
29 May	2	0	2	0	2	0
30 May	0	0	0	0	0	0
31 May	2	0	0	0	1	0
1 Jun	0	0	0	0	0	0
2 Jun	1	0	0	0	0	0
3 Jun	4	1	0	0	0	1
4 Jun	0	3	1	0	0	0
5 Jun	0	3	2	0	0	0
6 Jun	0	0	0	0	0	0
7 Jun	0	6	2	0	0	0
8 Jun	0	2	3	0	0	0
9 Jun	0	2	0	0	0	0
10 Jun	0	1	0	0	0	0
11 Jun	0	2	0	0	0	2
12 Jun	0	0	0	0	0	0
13 Jun	0	0	0	0	0	0
14 Jun	0	0	0	0	0	0
Total	68	20	19	12	9	3

Appendix Table 3. Mean diel detections by hour for yearling Chinook salmon and steelhead during intensive sampling (2 April-12 June) using the matrix trawl system in the upper Columbia River estuary (rkm 75), 2025.

		Yearling Chinook salmon				Steelhead			
Diel	Total effort	(n)		Mean detections/h		(n)		Mean detections/h	
hour	(h)	Hatchery	Wild	Hatchery	Wild	Hatchery	Wild	Hatchery	Wild
0	37.2	298	15	8.02	0.40	45	15	1.21	0.40
1	9.7	157	6	16.16	0.62	22	4	2.26	0.41
2	3.1	104	2	33.55	0.65	10	5	3.23	1.61
3	2.0	57	2	28.50	1.00	2	1	1.00	0.50
4	24.8	238	20	9.58	0.81	61	33	2.46	1.33
5	45.4	358	42	7.89	0.93	216	100	4.76	2.21
6	46.0	152	24	3.30	0.52	266	80	5.78	1.74
7	45.7	107	11	2.34	0.24	172	90	3.76	1.97
8	44.4	82	18	1.85	0.41	166	62	3.74	1.40
9	44.7	94	18	2.10	0.40	215	72	4.81	1.61
10	36.9	69	5	1.87	0.14	206	56	5.58	1.52
11	10.7	42	4	3.94	0.38	195	38	18.28	3.56
12	5.9	16	1	2.71	0.17	93	15	15.76	2.54
13	3.7	8	0	2.14	--	75	9	20.09	2.41
14	0.4	0	0	--	--	0	0	--	--
15	--	--	--	--	--	--	--	--	--
16	--	--	--	--	--	--	--	--	--
17	--	--	--	--	--	--	--	--	--
18	24	34	4	1.42	0.17	121	56	5.05	2.34
19	39.0	134	10	3.44	0.26	269	115	6.90	2.95
20	39.0	442	47	11.33	1.21	267	85	6.85	2.18
21	39.0	512	27	13.13	0.69	143	44	3.67	1.13
22	39.0	330	30	8.46	0.77	98	27	2.51	0.69
23	39.0	359	18	9.21	0.46	66	27	1.69	0.69
Total	579.6	3,593	304			2,708	934		

Appendix II

Pooled Transport Analysis

The addition of other sampling methods such as the flexible antenna array and pile dike arrays have presented an opportunity to strengthen transport and recovery analysis in the Columbia River Estuary. We pooled data from all three systems using the methods and parameters discussed above as a means of bolstering recovery rates and strengthening statistical comparisons. We limited analysis to the intensive trawl season as all detection methods were sampling consistently and concurrently.

As previously discussed, a total of 5,979 yearling Chinook salmon and 14,334 steelhead were transported and released below Bonneville Dam during our intensive sample period (28 April-12 June). Of these transported fish, we detected 230 yearling Chinook salmon and 485 steelhead in the upper estuary (3.8 and 3.4%, respectively).

A total of 19,987 yearling Chinook salmon and 14,396 steelhead were released upstream from McNary Dam and detected at Bonneville Dam during intensive sampling. Of these in-river migrants, we detected 901 yearling Chinook salmon and 702 steelhead (4.5 and 4.9%, respectively).

Table 4. Pooled trawl, flex, and pile dike detection rates of PIT-tagged Chinook salmon and steelhead released from barges or detected passing Bonneville Dam and detected in the trawl during intensive sample periods in 2024 and 2025.

	Transported fish originating upstream from McNary Dam			In-river fish detected at Bonneville Dam*		
	Released	Detected		Released	Detected	
Year/species	(n)	(n)	(%)	(n)	(n)	(%)
2024						
Chinook salmon	4,682	194	4.1	23,224	1,034	4.5
Steelhead	12,165	594	4.9	14,097	978	6.9
2025						
Chinook salmon	5,979	230	3.8	19,987	901	4.5
Steelhead	14,334	485	3.4	14,396	702	4.9

* In-river fish included only those released at or upstream from McNary Dam. No fish were transported from McNary Dam in 2024 or 2025.

For yearling Chinook salmon detected with all three detectors, logistic regression analysis showed no significant interaction between migration history and arrival date (P=0.489), migration history and date-squared (P=0.320), or migration history (P=0.383). There was a significant effect for date-squared (P=0.001), therefore both arrival date terms were included in the resulting best model. Throughout the peak spring migration, average detection rates for yearling Chinook salmon were 4.1% at the beginning of the season and rose to 16.1% by the end of the season for both transported fish and in river migrants (Figure 14, top panel). The adjustment for overdispersion was 2.2.

For steelhead detected with all three systems, logistic regression showed no significant interaction between, migration history and arrival date (P=0.986), or migration history and date-squared (P=0.078) or for arrival date-squared (P=0.591). However, logistic regression showed a significant effect for arrival date (P<0.001) and migration history (P=0.005), therefore these terms were included in the resulting best model. Estimated detection rates for transported steelhead were 2.2% at the beginning of the season and increased to 8.1% by the end of the season; estimated detection rates for in river steelhead were 3.1% at the beginning of the season and increased to 11.2% by the end of the season (Figure 14, lower panel). The adjustment for overdispersion was 4.6.

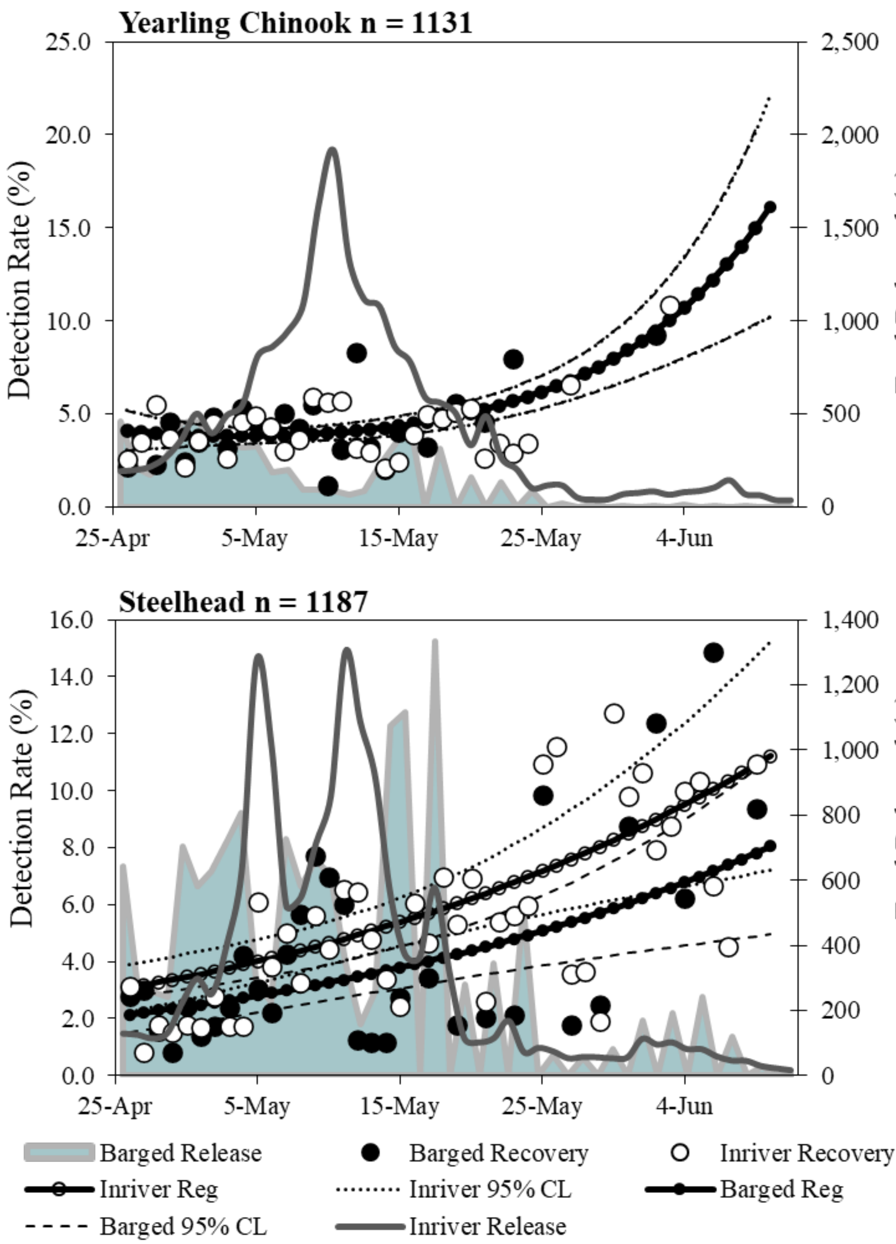

Figure 14. Estimated daily detection rates in the matrix trawl system, flexible antenna array, and pile dike arrays for transported and in-river migrant yearling Chinook salmon and steelhead, 28 April-12 June 2025. All fish were either detected at Bonneville Dam or released from a barge just downstream from the dam on the same date.

We'd like to thank the Bonneville Power Administration (BPA) and the Army Corp of Engineers for funding PIT Trawl sampling and BPA for funding the flexible antenna system sampling and aspects of the pile dike detection systems (including via the PIT Research and Development Project). Pairing the use of these estuary sampling methods strengthens historic datasets allowing for improved analytical precision.

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