NOAA Contract Report NMFS-NWFSC-CR-2025-02

https://doi.org/10.25923/tkz0-rx68

Detection of PIT-Tagged Juvenile Salmonids Migrating in the Columbia River Estuary, 2024

Project **1993-029-00**, Contract **46273 REL 58**

June 2025

U.S. DEPARTMENT OF COMMERCE

National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Northwest Fisheries Science Center

NOAA Contract Report Series NMFS-NWFSC-CR

Recommended citation:

(Vinarcsik et al. 2025)[1]

[1] Vinarcsik, J. H., K. E. Jaenecke, A. F. Palik, B. P. Sandford, P. J. Bentley, G. Brooks, and M. S. Morris. 2025. Detection of PIT-Tagged Juvenile Salmonids Migrating in the Columbia River Estuary, 2024. U.S. Department of Commerce, NOAA Contract Report NMFS-NWFSC-CR-2025-02.

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Detection of PIT-Tagged Juvenile Salmonids Migrating in the Columbia River Estuary, 2024

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https://doi.org/10.25923/tkz0-rx68

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June 2025

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"This report was funded by the Bonneville Power Administration (BPA), U.S.Department of Energy, as part of BPA's program to protect, mitigate, and enhance fish and wildlife affected by the development and operation of hydroelectric facilities on the Columbia River and its tributaries. The views in this report are the authors' and do not necessarily represent the views of BPA."

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Executive Summary

In 2024, 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 655 h.

During this period, the matrix system detected 12,370 PIT-tagged fish, of which 13% were wild origin and 80% were hatchery origin (7% unknown). Species composition of detected fish was 43% spring/summer Chinook, 3% fall Chinook, 39% steelhead, 5% coho, 4% sockeye, less than 1% cutthroat trout, and 6% unknown.

To coincide with arrival in the estuary of spring-migrating juvenile salmon and steelhead, sampling began on 3 April 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 hours and a second operating 6 d/week during darkness hours. Intensive sampling continued from 29 April through 13 June. During intensive sampling, the trawl was deployed for an average of 12.4 h/d, which was slightly higher than the 12.1 h/d average in 2023. We ended sampling on 13 June after most spring migrants had passed.

During the intensive sample period, average hourly detections were significantly different during darkness and daylight hours for hatchery yearling Chinook (11.0 vs. 5.5 fish/h; $P = 0.001$), but not for wild yearling Chinook (0.9 vs. 0.7 fish/h; $P = 0.073$). For hatchery steelhead, hourly detection rates were significantly higher during daylight than darkness hours (7.5 vs. 4.3 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; $P < 0.001$).

We detected 1.7% of the yearling Chinook and 2.4% of the steelhead transported and released below Bonneville Dam. These proportions were higher than those for transported fish in 2023, when we detected 0.8% of the yearling Chinook and 2.1% of the steelhead. Additionally, we detected 2.4% of the yearling Chinook and 4.4% of the

steelhead detected at Bonneville. These proportions were higher compared to those for in-river migrants in 2023, when we detected 1.4% of the yearling Chinook and 1.9% of the steelhead detected at Bonneville Dam. Increased detection rates were likely a result of lower flows.

In 2024, 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 ($P = 0.670$), migration history and date-squared ($P = 0.945$), date-squared ($P = 0.608$), migration history ($P = 0.085$) or arrival date ($P = 0.260$). Since migration history was close to significant (i.e, between 0.05 and 0.10), we estimated average detection rates throughout the peak spring migration for yearling Chinook salmon at 1.7% for transported fish and 2.4% for in river migrants.

For steelhead detected with the trawl, we found a significant effect for migration history and date-squared ($P = 0.002$) and therefore all terms were included in the resulting best model. On average, we detected transported steelhead at a rate of 4.9% at the beginning of the season, decreasing to 1.3% during mid-May, and increasing to 6.0% by the end of the season. Estimated detection rates for in river steelhead were 4.2% at the beginning of the season and increased to 5.1% 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 intensive sampling was 33% lower in 2024 than in 2023 (5,866 vs. 8,727 m^3/s), and was also 30% lower than the 20-year average for 2004-2024 (8,331m^3/s). A strong El Nino southern oscillation event occurred during the 2023-2024 winter and resulted in lower flows that remained well below the 20-year average for the entire sampling season in 2024. These lower flows likely contributing to higher detection rates for the 2024 season.

Of all juvenile salmonids detected by the trawl in 2024, 4% had been transported, while 14% had been detected passing Bonneville Dam. The remaining 82% had neither been transported nor detected at Bonneville Dam, although at least 89% of our total detections originated upstream from Bonneville Dam. Relative detections of barged fish were much lower in 2024 than 2023 (4% vs. 15%, respectively), due to the 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 (87.5 vs. 63.5 km/d, $P < 0.001$). Similar differences were observed for subyearling Chinook salmon (81.3 vs. 53.4 km/d).

Mean migration rate for steelhead was also significantly higher for in-river migrants (95.9 km/d) vs. transported fish (84.9 km/d; $P < 0.001$). There were insufficient data to determine a significant difference for sockeye (105.2 vs. 110.7 km/d; n = 0 paired groups). Overall, migration rates to the sample reach were lower for most in-river and transported fish in 2024 than in 2023 across all species. This was likely a function of lower flow volumes in 2024.

Detections of subyearling Chinook salmon have decreased in recent years, commensurate with reduced tagging effort for these fish and reduced sample effort after peak migration. In 2024, we detected 387 subyearling fall Chinook, with the majority of detections occurring from late May through the end of the sampling period. Of these 387 fish, 360 originated from the Snake River Basin (311 in-river migrants and 49 transported). The remaining 27 were in-river migrants from Columbia River stocks, with 11 subyearlings released above McNary Dam, and 16 released between McNary and Bonneville Dam.

Of the 472 sockeye detected, 82% were from the Snake River and 18% 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, 5% wild, and 13% unknown origin. Migration histories of detected sockeye were >99% in-river migrant and <1% transported.

Using modifications made in 2022 and 2023, we sampled 5 d/week with the towed flexible array during the 2024 intensive sample period. 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. Technical developments in 2023 focused on improving deployment and retrieval methods by reengineering the net reel on the primary sampling vessel. Besides those improvements, flexible antenna array operations replicated the 2023 sampling season.

Moving to a towed array of flexible cable antennas would improve the efficiency of our primary sampling method by eliminating the use of a net and therefore potential fish impingement. This would prevent negative impacts to salmonids listed under the U.S. Endangered Species Act. Testing thus far has shown that a flexible antenna system of scale would also simplify logistics, increase sample efficiency, and reduce the cost of sampling PIT-tagged fish in the estuary.

For sampling conducted in 2023 and 2024, 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. Sampling was conducted from 12 April to 7 June 2024 in a targeted approach to favor detections of juvenile steelhead. This was intended to supplement pile dike detections, which showed a bias towards juvenile Chinook salmon in 2022-2024.

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 2024, the towed flexible array detected 1,208 PIT-tagged salmonids. Species composition was 88% steelhead, 4% spring/summer Chinook, and 4% coho. Of the remainder, less than 1% were fall Chinook, sockeye, or cutthroat trout and 4% were unknown species. Total detections by rear type were 18% wild, 78% hatchery, and 4% unknown origin at the time of this report.

In 2025, sampling with the towed flexible array will focus on resolving technical issues and experimenting with new sampling strategies. Using new materials and cable fairing, we aim to reduce systemic electromagnetic interference (EMI) and also eliminate water intrusion with a redesign of the node capsule. Additionally we hope to explore new sampling approaches with the flexible antenna array to increase total detections. We plan to test the operation of our towed flexible array near the pile dikes to extend our reach into the thalweg and determine if the funneling effect of the dikes concentrate fish just below the structures.

In 2024, 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, annual releases of PIT-tagged fish in the Columbia River Basin have totaled nearly 2 million, exceeding 2 million in 2024. 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 2024, 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. 2024). 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 1996-2024). 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 2024 migration season, based on records in PTAGIS (PSMFC 1996-2024). 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, 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).

In 2024, 25,558 PIT-tagged fish were transported from dams on the Snake River and released below Bonneville Dam, and over 72,212 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.

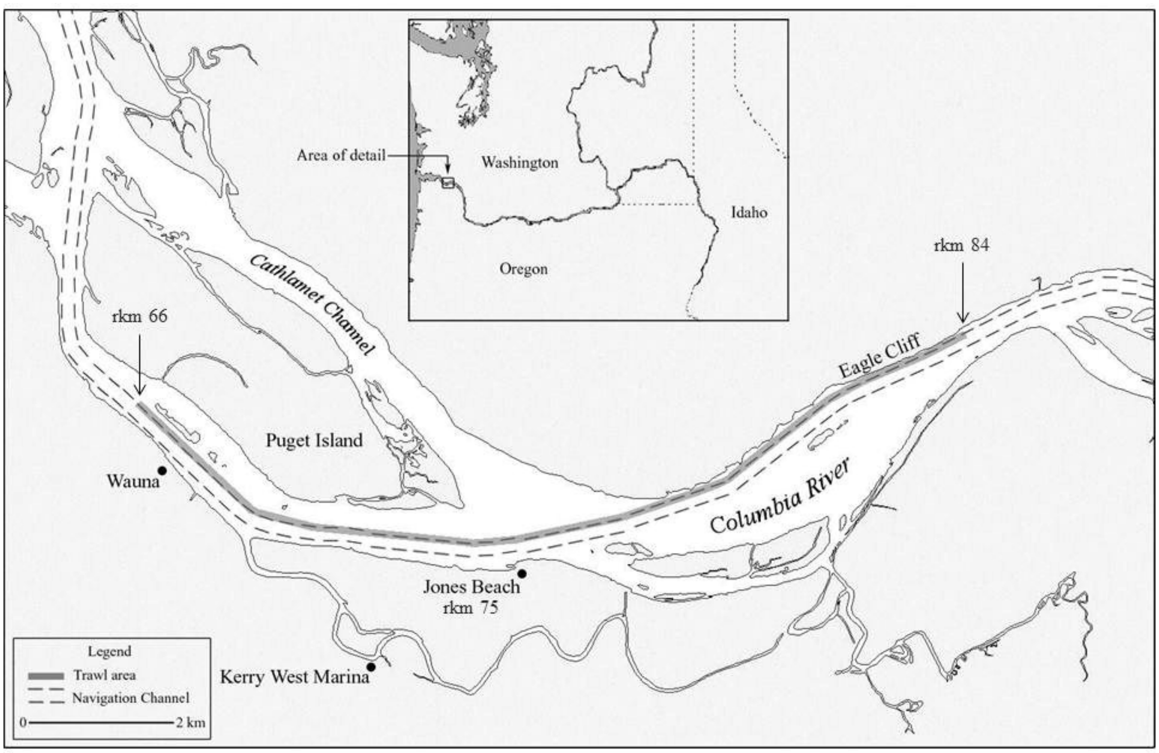

Figure 1. Trawl sampling area adjacent to the navigation channel in the upper Columbia River estuary between rkm 66 and 84, 2024.

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 1996-2024). Specific groups of tagged fish targeted for detection included over 219,616 fish released for a comparative survival study, 25,558 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 2024, 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 3 April and continued through the migration season 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 5.0 h/d. Sample effort was defined as full deployment of the trawl net. During peak spring migration (29 April through 13 June), we sampled with two daily shifts, covering both daylight and darkness periods, for an average daily sample effort of 12.4 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.

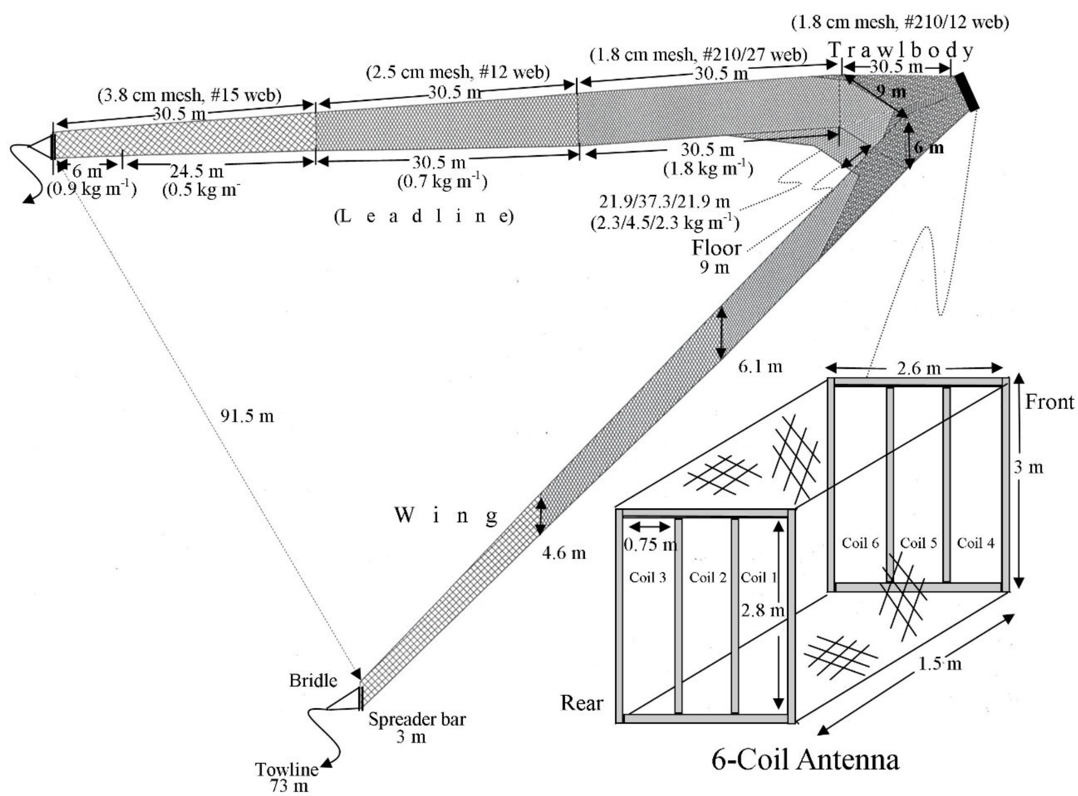

Figure 2. Basic design of the surface pair trawl used with the matrix antenna system to sample juvenile salmonids in the Columbia River estuary (rkm 75), 2024.

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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 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).

Towards the end of the 2023 season, the forward middle antenna in the matrix sustained a leak due to a crack in the bulkhead connector. We fully replaced both the front and rear matrices post season. This also allowed us to transition to the IS1001M Multiplexing transceiver (IS1001MUX) for the 2024 season.

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 upgraded the transceiver to a single IS1001MUX in 2024. The transceiver had not been upgraded since 2006, when we started sampling with the FS1001MUX. Both transceivers are capable of simultaneously powering the detection fields while recording and transmitting detection data from all six antennas, however the upgraded IS1001MUX is compatible with current Biomark Device Manager and PTAGIS M5/I5 software, simplifies antenna tuning, and can generate a larger detection field. Removable antenna end caps allow for manual capacitance adjustments to accommodate both the FS1001MUX and the IS1001MUX. 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 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 2.0.2 (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 1996-2024). The specification document, PTAGIS operating software, and user manuals are available from the PTAGIS website (PSMFC 1996-2024). Matrix trawl detections were designated in the PTAGIS database with site code TWX (towed array-experimental).

Pre-season comparative transceiver efficiency testing—After upgrading to the IS1001MUX following the 2023 sample season, we conducted a series of land based comparative tests between the new IS1001MUX and the FS1001MUX. Tests were conducted by suspending the antenna in our Jones Beach Sample Stations shop. Internal antenna capacitance was manually adjusted with jumpers and set specific to each antenna.

Estimated detection efficiencies from these tests were positively correlated with spacing between test tags, regardless of tag orientation (45 vs. 90 degrees to the detection field). For the FS1001MUX, of the 630 test tags passed through the matrix antenna, those spaced at 30-cm intervals were detected at rates less than 13% and 0% when oriented at 45 or 90 degrees, respectively. With spacing between tags increased to 60 cm, respective detection efficiency increased to 100% and 98% for tags oriented at 45 and 90 degrees. For test tags spaced 90 cm apart, respective detection efficiency was 100% for tags oriented at both 45 and 90 degrees.

For the IS1001MUX set to a maximum exciter voltage of 20V, of the 756 test tags passed through the matrix antenna, those spaced at 30-cm intervals were detected at rates less than 13% and 0% when oriented at 45 or 90 degrees, respectively. With spacing between tags increased to 60 cm, respective detection efficiency increased to 94% and 92% for tags oriented at 45 and 90 degrees. For test tags spaced 90 cm apart, respective detection efficiency was 100% for tags oriented at both 45 and 90 degrees.

For the IS1001MUX set to a minimum exciter voltage of 12V, of the 756 test tags passed through the matrix antenna, those spaced at 30-cm intervals were detected at rates less than 40% and 11% when oriented at 45 or 90 degrees, respectively. With spacing between tags increased to 60 cm, respective detection efficiency increased to 100% and 98% for tags oriented at 45 and 90 degrees. For test tags spaced 90 cm apart, respective detection efficiency was 100% for tags oriented at both 45 and 90 degrees.

Based on these findings, we determined that sampling with the IS1001MUX at specific exciter voltages resulted in the highest detection rates. Due to signal and current attenuation when sampling in water vs. dry air, we increased antenna exciter voltage to 14V to achieve the same level of current observed during our most successful dry land tests with the IS1001MUX.

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 29 April -13 June 2024, mean river flow volume at Bonneville Dam was 33% lower than during similar dates in 2023 (5,866 vs. 8,727 m^3/s; Figure 3). Flows in 2024 were 27% lower than the 20-year average for

2004-2024 (8,063 m^3/s). In general, the 2024 season was characterized by low flows throughout the season with a slight increase in early June, likely a result of a strong El Nino during the 2023-2024 winter (Becker 2023). By March 2024, the snow water equivalent (SWE) in the upper Columbia basin was roughly three quarters of the average and slightly above average throughout much of the Cascade range (Drought.gov. 2024). These observations suggest the below average flows in the lower reaches of the Columbia River were likely due to less water available in the snowpack. We hypothesize that low flows contributed to increased detection rates on the PIT trawl for the 2024 season.

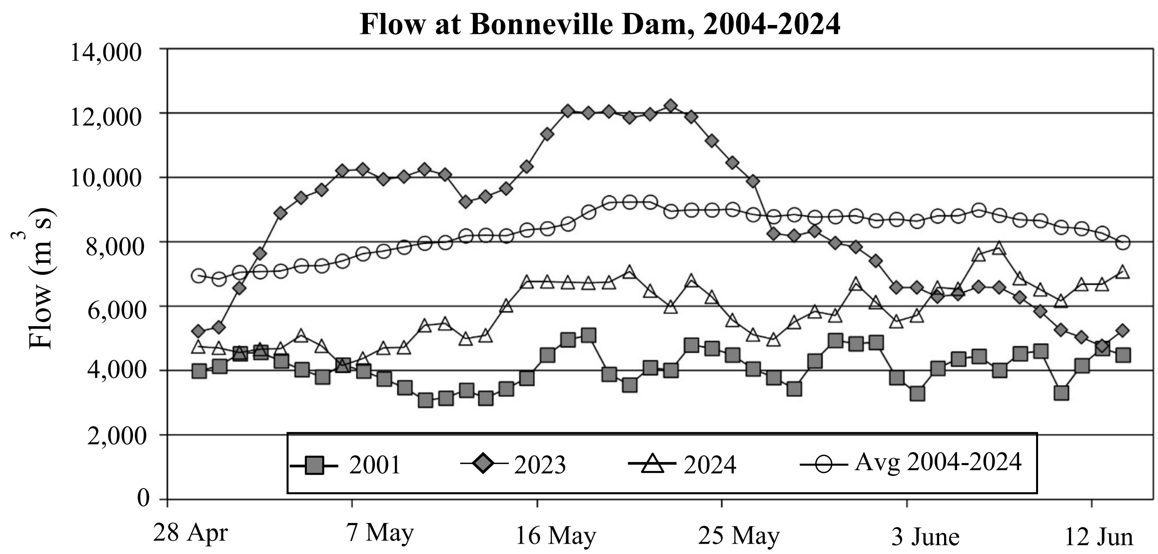


Figure 3. Columbia River flows (m^3/s) at Bonneville Dam during the intensive sample period in 2024 and similar dates in 2023, compared to the average flow from 2004 to 2024. Drought-year flows for 2001 are shown for comparison.

Presence of tagged fish in the sample reach—We estimated that intensive sampling in 2024 coincided with arrival time in the estuary for 74% of the yearling Chinook salmon and 88% of the steelhead passing Bonneville Dam (tagged and non-tagged). In comparison, 90% of yearling Chinook salmon and 96% of steelhead that passed Bonneville were estimated to be present in the estuary during intensive sampling in 2023. Early run timing in 2024 meant that more yearling Chinook and steelhead passed Bonneville Dam prior to intensive sampling (22% and 8% respectively) than in 2023, meaning fewer fish were present in the estuary during our intensive sample period.

Our intensive sample period also coincided with arrival in the estuary of 86% of the yearling Chinook salmon transported for NMFS studies. This estimate was slightly lower in 2024 than in 2023, when 95% of transported study fish were estimated to be in the estuary during intensive sampling. In 2024, 87% of transported steelhead were estimated to be in the estuary during intensive sampling compared to 94% in 2023.

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. Fish transportation from upstream dams continued until the end of June (Chris Peery, USACE, Walla Walla Dist.; personal communication).

Since 2013, the tagging effort for subyearling Chinook has been reduced considerably; however, these fish comprised 65% of the detections at Bonneville Dam after intensive sampling ended in 2024 and 72% of the detections at Bonneville Dam after intensive sampling in 2023.

Detection Rates

We sampled with the matrix trawl system for 655 h during 2024 and detected 12,370 PIT-tagged fish. In contrast, we sampled for 650 h during 2023 and detected 9,754 fish (Figure 4). Detection rates were much higher in 2024 than in 2023 (18.9 and 15.0 fish/h, respectively).

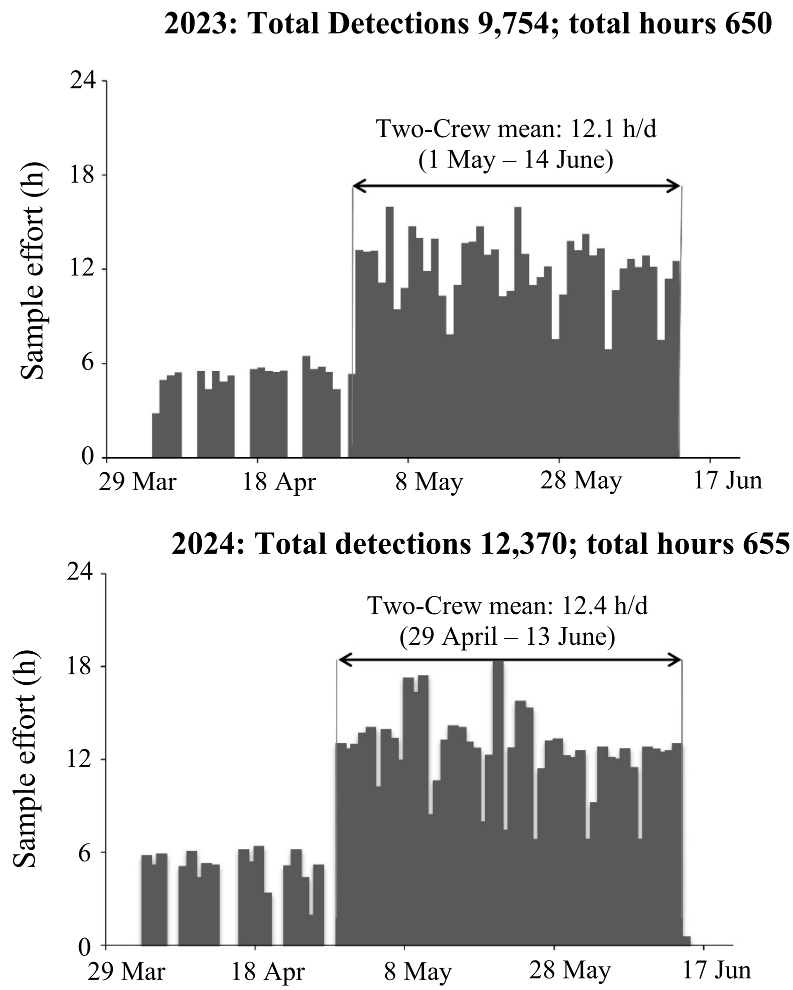


Figure 4. Daily sample effort in spring/summer 2023 and 2024 using the matrix trawl system to detect PIT-tagged juvenile salmon migrating in a tidal freshwater reach of the Columbia River estuary between rkm 66 and 84.

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 2024, the matrix antenna trawl system detected a total of 11,523 fish of known species and rear type (hatchery and wild) plus another 847 fish lacking release information in PTAGIS (Table 1, Appendix Table 1). Of those 847 fish, at least some species information was available; however, at the time of our analysis, 784 detected fish had no release or species information associated with their respective tags.

Species composition—Of the 12,370 fish detected with the matrix system in 2024, species composition was 43% spring/summer Chinook, 3% fall Chinook, 39% steelhead, 4% sockeye, and 5% coho. Of the remainder, less than 1% were cutthroat trout and 6% were unknown species. Total detections by rear type were 13% wild, 80% hatchery, and 7% 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 2024.

	Rear type			
Species/run	Hatchery	Wild	Unknown	Total
Spring/summer Chinook salmon	4,797	460	0	5,257
Fall Chinook salmon	424	0	0	424
Coho salmon	423	214	0	637
Steelhead	3,850	927	4	4,781
Sockeye salmon	389	24	59	472
Sea-run cutthroat	0	15	0	15
Unknown	0	0	784	784
Grand total	9,883	1,640	847	12,370

For all species, proportions of detected fish by rear type in 2024 were similar to those in 2023, although there was a lower percentage of fish originating in the Snake River and a higher percentage of fish with unknown origin 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).

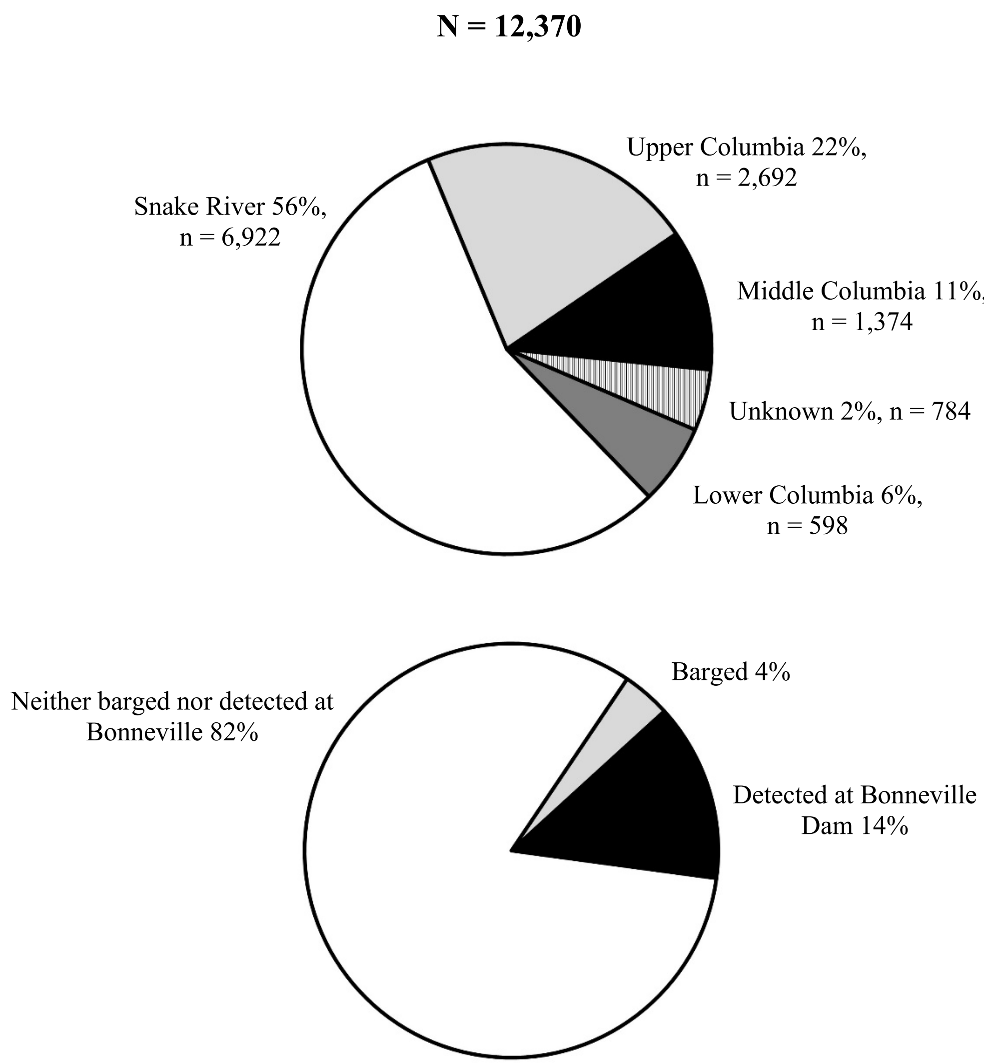


Figure 5. Proportions of fish detected in the Columbia River estuary by source and migration history, 2024. Upper and middle Columbia River sources were defined relative to McNary Dam. Fish that originated in the Columbia River below Bonneville Dam could not be transported, nor could they pass Bonneville 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 2024. Based on these criteria, we detected 49 transported and 338 in-river migrant subyearling fall Chinook in the estuary between early April and mid-June (Figure 6). Of the 387 total subyearlings detected, 93% originated in the Snake River, 3% in the Upper Columbia River at or above McNary Dam, and 4% 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 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 2024.

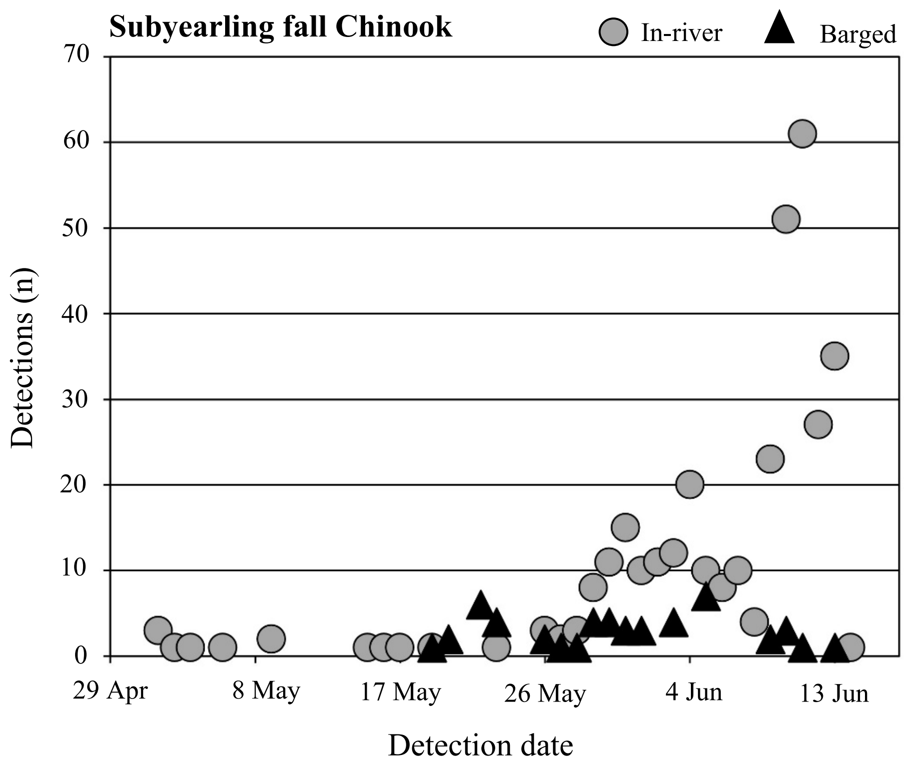


Figure 6. Temporal distribution of subyearling fall Chinook salmon detections in the Columbia River estuary near rkm 75 during in-river migration (n = 338) or following release from barges below Bonneville Dam (n = 49), 2024.

Sockeye salmon—We detected 472 sockeye salmon between 5 May and 12 June (Figure 7). Of these, 82% were hatchery fish, 5% were wild fish, and the remaining 13% were of unknown origin. Fish released upstream from McNary Dam in the Snake and Columbia River Basin, respectively comprised 82% and 18% of our sockeye salmon detections, with <1% of fish released between McNary and Bonneville Dam. Transported fish accounted for 3 of the sockeye salmon detections. Of those transported, 2 had been collected at Lower Granite Dam and 1 had been collected at Little Goose Dam.

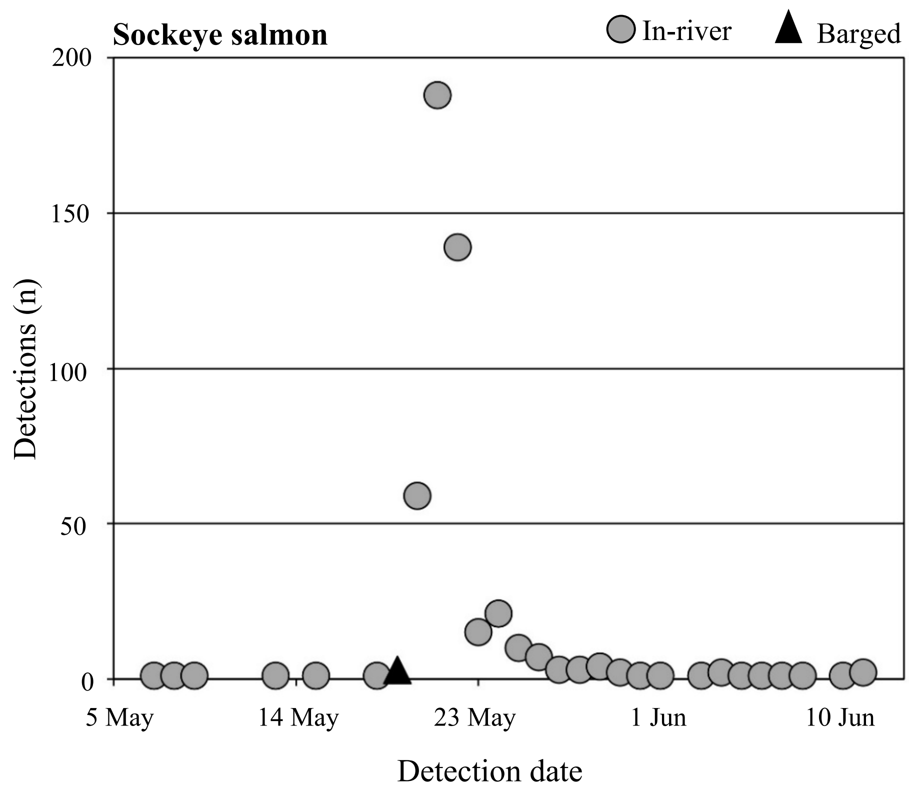


Figure 7. Temporal distribution of sockeye salmon detections in the Columbia River estuary near rkm 75 during in-river migration (n = 469) or following release from barges below Bonneville Dam (n = 3), 2024.

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 2024, we recovered 123 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 17 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 flexible antenna system since 2015 and pile dike detection systems since 2022.

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 approximately 1.8 million in 2023 and just over 2.0 million in 2024. Higher detection rates and totals for the 2024 season are likely attributed to lower than average flows and a slightly higher number of PIT tagged fish in the estuary. 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 2024, as in 2023 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 presented below were collected by the matrix trawl.

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 2024, 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 1996-2024). 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 2024 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

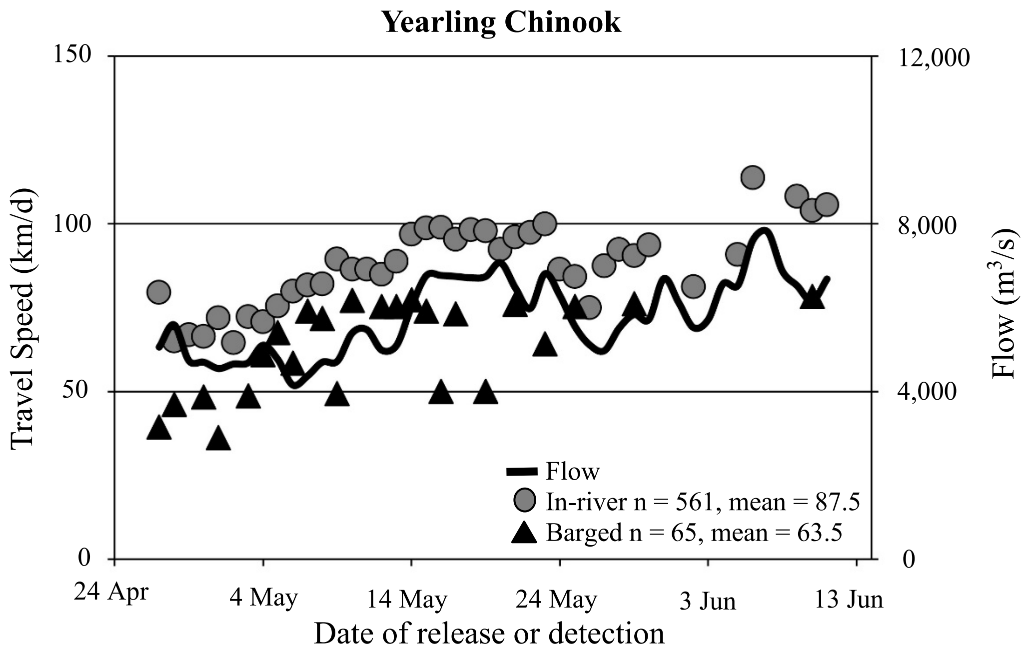
Travel time—For in-river migrant yearling Chinook and steelhead, median travel times were 1.8 and 1.9 d, respectively in 2024. These were higher than the median travel times of 1.6 and 1.5 d in 2023 and the 15-year average of 1.7 d for both species (Table 2). Similarly, for transported yearling Chinook and steelhead, respective median travel times were 2.1 and 1.9 d in 2024 compared with 2.0 and 1.5 d in 2023.

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, 2000-2024. 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

* 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 63.5 vs. 87.5 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 (84.9 vs. 95.9 km/d; P <0.001). These differences in travel speed by migration history were similar to observations from previous years (Figure 8).



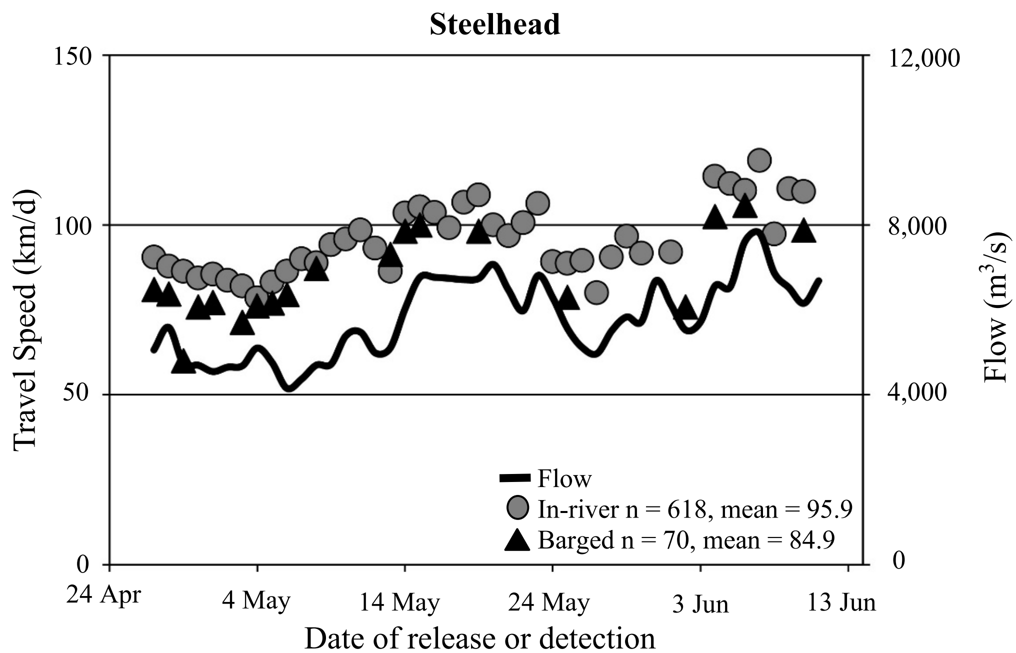


Figure. 8. Daily median travel speed (km/d) of yearling Chinook salmon and steelhead following detection at Bonneville Dam or release from a barge to detection in the Columbia River estuary, 2024. Seasonal means are shown for comparison with flow.

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 (29 April-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 12.4 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 (11.0 vs. 5.5 fish/h; $P = 0.001$; Figure 9). For wild Chinook salmon, average detection rates were not significantly different during darkness vs. daylight hours (0.9 vs. 0.7 fish/h; $P = 0.073$). 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 (7.5 vs. 4.3 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; $P < 0.001$).

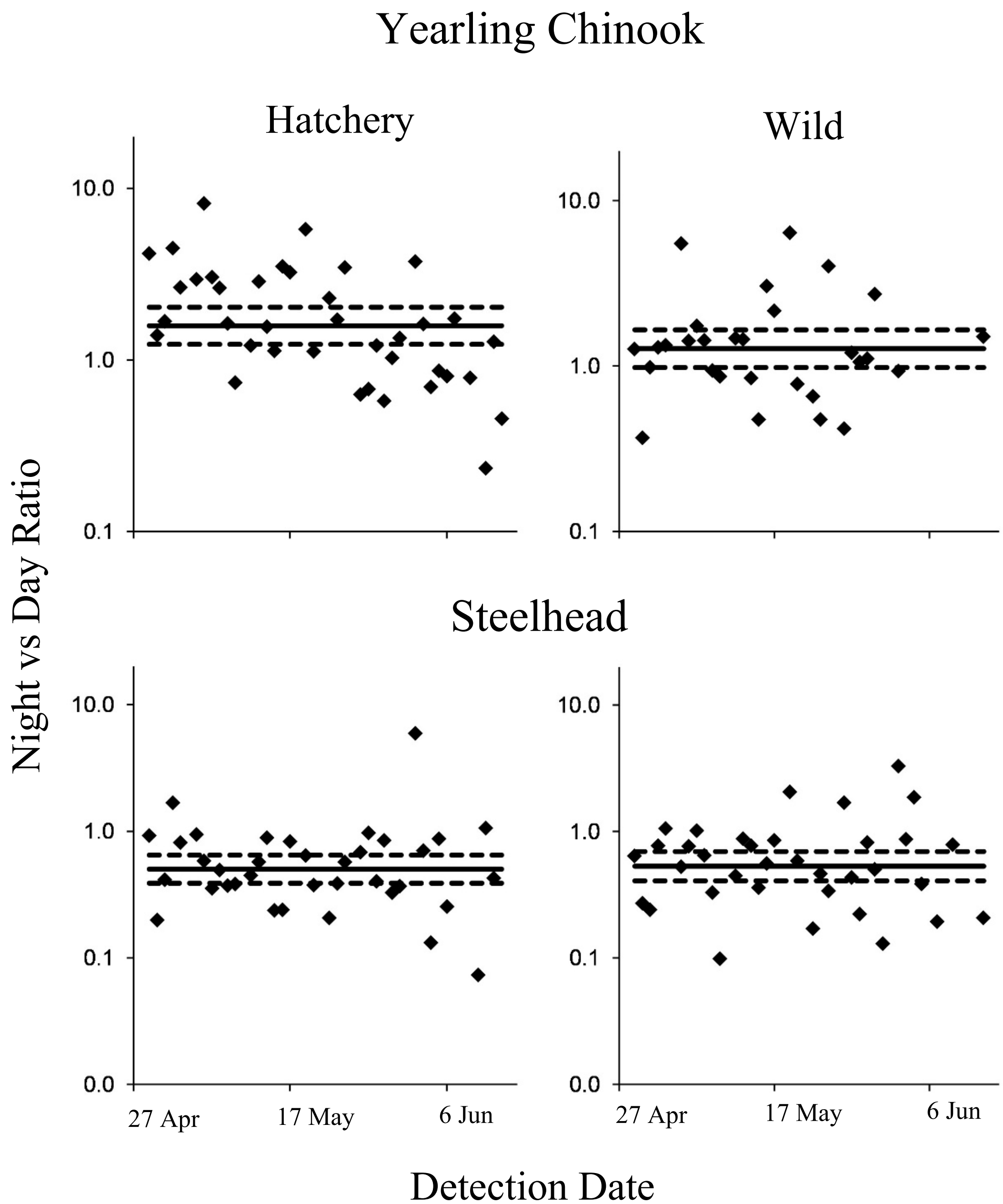


Figure 9. Daily ratios of darkness/daylight detection rates for wild and hatchery yearling Chinook salmon and steelhead in the Columbia River estuary during intensive sampling, 29 April-13 June 2024. Ratios greater than 1.0 indicate higher detection rates in darkness hours, and values less than 1.0 indicate 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. For steelhead, these numbers were similar again in 2024, so we pooled steelhead rear types for 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. In 2024, there was no significant difference between darkness and daylight detection rates for wild fish. Detection rates of steelhead have generally been higher during daylight hours, with daylight detection rates significantly higher in recent years.

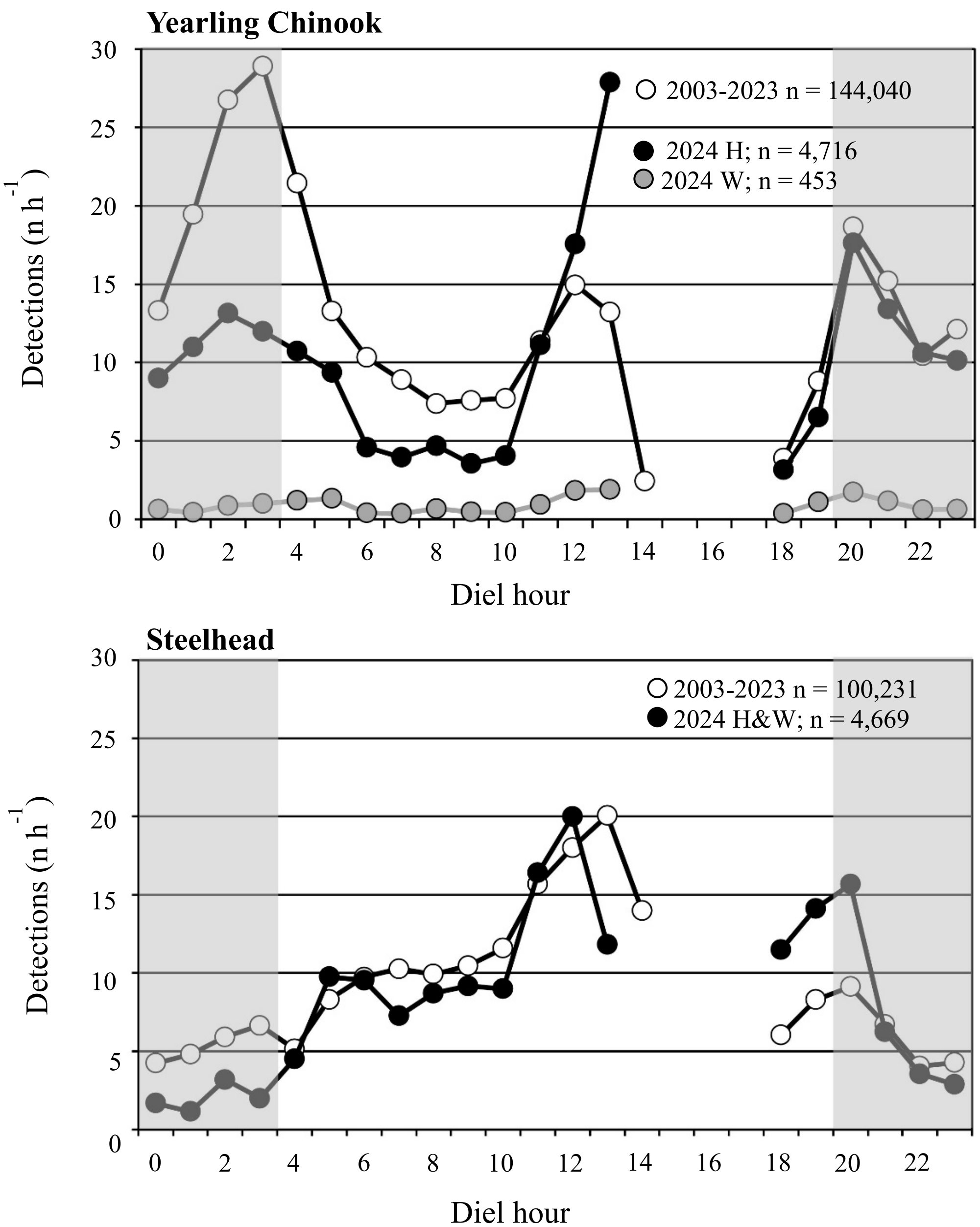


Figure 10. Average hourly detection rates (PST) of yearling Chinook salmon and steelhead during intensive sampling with the matrix trawl system in the Columbia River estuary during 2003-2023 (excluding 2020 & 2021), vs. 2024 Hatchery and wild rear types are plotted separately for Chinook in 2024 due to different diel patterns; steelhead rear types are combined 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 (1 May-14 June 2024). 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 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 4,682 yearling Chinook salmon and 12,165 steelhead were transported and released below Bonneville Dam during our intensive sample period (29 April-13 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 78 yearling Chinook salmon and 289 steelhead in the upper estuary (1.7 and 2.4%, respectively).

Transported fish totals were 80% lower in 2024 than in 2023 due to the reduced number of transported fish: Several factors likely contributed to the reduced number of transported fish. Early run timing resulted in a much higher proportion of fish passing Lower Granite Dam before juvenile collection began, and the newly implemented 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 23,224 yearling Chinook salmon and 14,097 steelhead were released upstream from McNary Dam and detected at Bonneville Dam during intensive sampling. Of these in-river migrants, we detected 561 yearling Chinook salmon and 617 steelhead (2.4 and 4.4%, 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 sample period. We estimated the proportions of tagged fish from these groups that were available in the estuary during our intensive sample period (29 April-13 June), allowing 2 d for fish to reach the sample area after release or detection at Bonneville.

For tagged yearling Chinook, 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 90% of in-river migrants and 87% of transported fish passed the sample reach during our intensive sample period. For yearling Chinook, estimated percentages of fish passing the sample area in 2024 were lower for in-river migrants and transported fish in 2023. For steelhead, estimated percentages of tagged fish passing the sample area in 2024 were also lower than those in 2023 for both in-river and transported fish.

During intensive sampling in 2024, average sample effort was 12.4 h/d, which was slightly higher than the average effort of 12.1 h/d in 2023. For yearling Chinook, both transported fish and those detected passing Bonneville Dam had higher rates of trawl detection in 2024 than 2023 (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 2023 and 2024.

	Transported fish originating upstream from McNary Dam			In-river fish detected at Bonneville Dam*		
	Released	Detected		Released	Detected	
Year/species	(n)	(n)	(%)	(n)	(n)	(%)
2023						
Chinook salmon	41,200	348	0.8	30,545	421	1.4
Steelhead	44,519	942	2.1	22,287	413	1.9
2024						
Chinook salmon	4,682	78	1.7	23,224	561	2.4
Steelhead	12,165	289	2.4	14,097	617	4.4

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

For yearling Chinook salmon detected with the trawl, logistic regression analysis showed no significant interaction between migration history and arrival date ($P = 0.670$), migration history and date-squared ($P = 0.945$), date-squared ($P = 0.608$), migration history ($P = 0.085$) or arrival date ($P = 0.260$), although migration history was nearly significant (i.e., between 0.05 and 0.10) so we kept it in the model for estimating detection rates. Throughout the peak spring migration, average detection rates for yearling Chinook salmon remained at 1.7% for transported fish and 2.4% for in river migrants (Figure 11, top panel). The adjustment for overdispersion was 3.3.

For steelhead detected with the trawl, logistic regression showed a significant effect for migration history and date-squared ($P = 0.002$) and therefore all terms were included in the resulting best model. Estimated detection rates transported steelhead were 4.9% at the beginning of the season, dropped to 1.3% in mid-May, and rose to 6.0% at the end of the season; estimated detection rates for in river steelhead were 4.2% at the beginning of the season and rose to 5.1% by the end of the season (Figure 11, lower panel). The adjustment for overdispersion was 3.5.

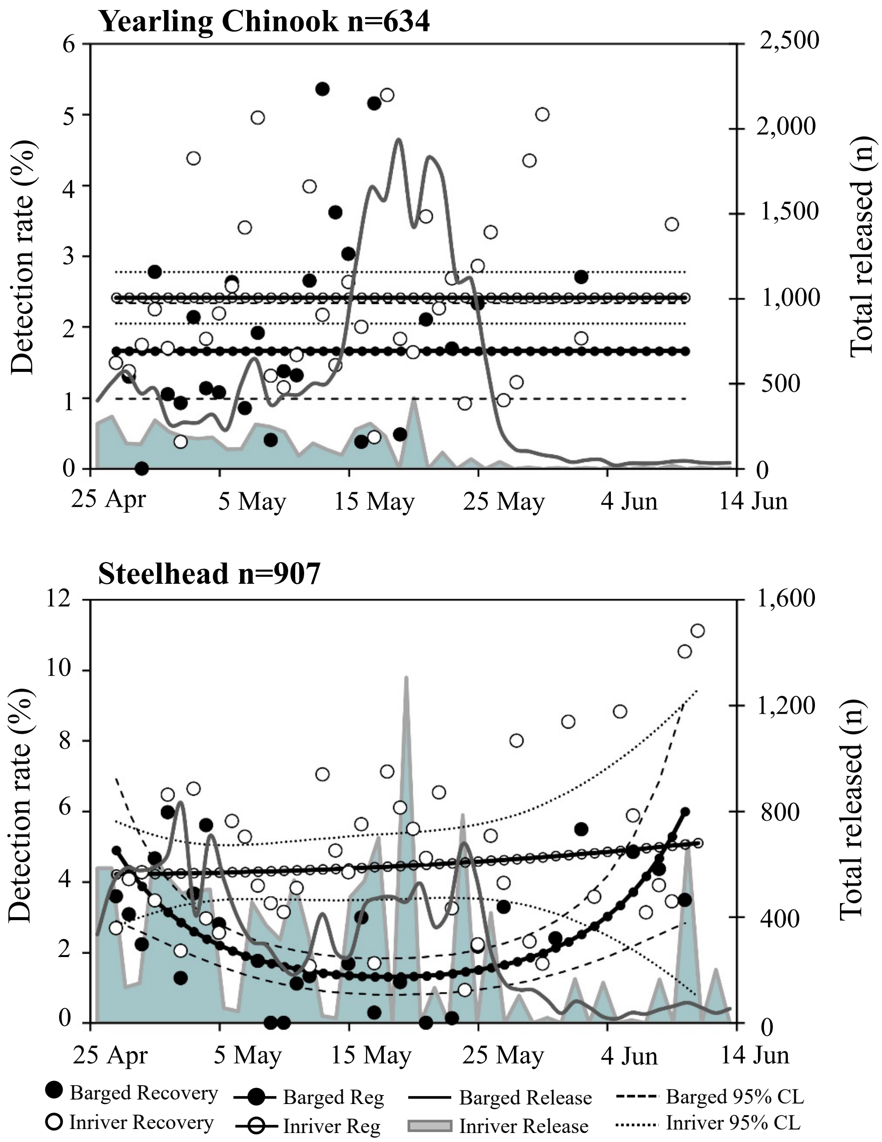


Figure 11. Estimated daily detection rates in the matrix trawl system for transported and in-river migrant yearling Chinook salmon and steelhead, 29 April-13 June 2024. All fish were either detected at Bonneville Dam or released from a barge just downstream from the dam on the same date.

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, 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). Detection rates in 2024 were the opposite of the 15-year trend, with significantly higher detection rates of in-river migrant steelhead and no significant difference for Chinook salmon.

Development of a Flexible Antenna Detection System

In 2024, 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

Since 2013, we have used a multiplexing transceiver (model IS1001MTS, Biomark, Inc., Boise, ID), which has allowed us to construct much larger rectangular antennas than were possible with previous transceiver technology. Antennas used in the flexible system measure 2.4 by 6.1 m and produce a detection field at least six times larger than that of the 0.8- by 3.0-m antennas previously used in the matrix trawl system.

In addition to increased reading range, the multiplexing transceiver allowed antennas to be constructed from 1.9-cm-diameter flexible cable instead of the much larger 10.2-cm-diameter rigid PVC or HDPE pipe used previously. This larger, heavier pipe is still used on the matrix antenna system. Transceiver and antenna advancements have dramatically increased antenna utility and led to a number of new applications.

In 2015, the first year of sampling with the new flexible antenna 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 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 2024

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.

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 2022-2024 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. 2024). 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 and 2024.

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 13). 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.

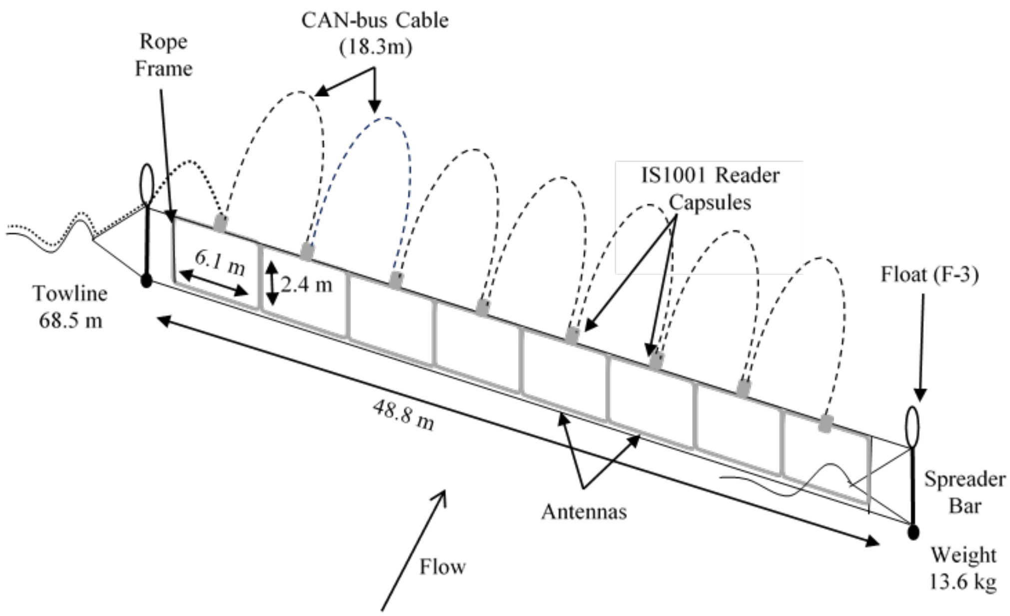
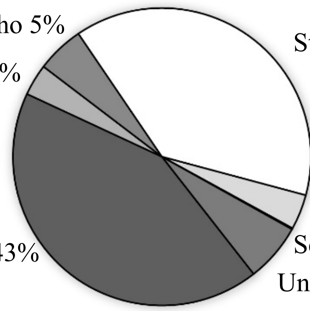


Figure 12. Horizontal layout of the towed flexible antenna array as sampled in 2024.

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 safety conditions. 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 12 April to 7 June 2024, we continued sampling with the towed flexible antenna array during daylight hours. Of the 1,208 fish detected with the flexible antenna array in 2024, 88% were steelhead (Figure 14). Total detections by rear type were 18% wild, 78% hatchery, and 4% unknown origin at the time of this report.

Matrix trawl system: N = 12,370



Flexible antenna system: N = 1,208

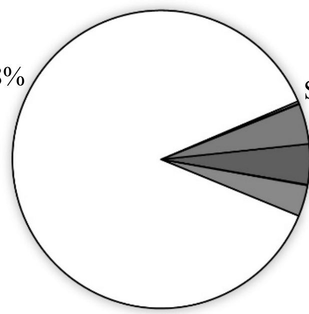


Figure 13. Proportions of fish detected by the matrix trawl and flexible antenna array during sampling season in the Columbia River estuary by species, 2024.

Unfortunately, a combination of technical difficulties, capsule leakage, and equipment strain contributed to significantly lower detection rates in 2024 than in 2023 (5.4 fish/h vs. 11.0 fish/h, respectively). Water intrusion in antenna capsules resulted in current drop and EMI, reducing read range and overall system performance. Modifications to the capsule design in 2025 will aim to eliminate water intrusion by replacing neoprene gaskets with channelized N Buna gaskets, using stronger fasteners, covering all cable glands with double-walled heat shrink, and adding marine adhesive to all seals. Additionally, creating capsule "windows" will allow antenna connections to be routed directly into the reader, eliminating any overlap of high voltage wire and internal reader components, which might be causing EMI.

To solve these equipment shortfalls, the flexible antenna array will return to an experimental state for the 2025 season. Designing a more robust system that produces reliable data year to year is necessary as a long-term solution to supplementing estuary detections. Additionally, experimental testing will allow further exploration of alternative sampling methods, such as a hybridized flex/pile dike detection system that can extend beyond existing pilings.

Species Composition Targets

Species composition data from 2016 and 2022-2024 has highlighted the ability of the flexible antenna array to detect steelhead and balance the species composition across all sampling systems.

The towed flexible antenna array has many advantages and potential uses that highlight its importance for future estuary sampling. The system is modular, so that antennas and other components can be easily exchanged or replaced. It does not impact fish; therefore, no ESA permitting is required for sampling. The flexible system can also be maneuvered to sample shallow-water areas and can potentially be organized in a hybrid model with pile dike sites. Most importantly, this system can be used in a targeted approach that increases juvenile steelhead detections, balancing out other methods and providing data necessary to estimate survival through the hydrosystem. When sampled in conjunction with pile dike arrays, the combined species composition is closer to that of the matrix trawl, with the two systems together potentially providing a replacement technique in out years for matrix trawl detections.

Discussion

In summary, detections from all sample methods in 2024 were sufficient to complete all analyses for yearling Chinook and steelhead. The upgraded matrix trawl antenna and transceiver improved detection rates, and efficiency of data processing.

Reduced detection rates on the flexible antenna array were attributed to system performance: repeated water intrusion hampered antenna function and reduced read ranges across the array. Addressing these issues will be the primary focus in future development of the flexible antenna array.

Compared to 2023, estuary detection rates were 23 % higher for the matrix trawl, yet 43% lower for the flexible antenna array. We hypothesize several factors influenced the changes in detection rates from 2023 to 2024:

1. Lower flow years generally result in higher detection rates on the matrix trawl, following the pattern observed in 2024. Lower flow decreases the overall channel volume, effectively reducing the area fish can inhabit. This narrowing of the thalweg may concentrate higher densities of out-migrating juveniles within the trawl sample area, leading to higher detection rates. Conversely, higher flow years increase the channel volume and accessible habitat within the sample reach and are usually coupled with heavier debris loads, further hampering the effectiveness of the net by causing tears and requiring frequent retrieval to clear passage. For example, the average detection rate in 2015 was 24 fish/h (average flow was 5,133 m^3/s) compared to 17 fish/h in 2014 (average flow was 7,529 m^3/s) (Morris et al. 2015). As previously described, similar flow related detection rate differences were observed between the 2024 and 2023 seasons.

2. The flexible antenna array experienced consistent technical issues throughout the 2024 sample season, which likely accounts for lower detection rates. Without these issues, a lower flow year like the one observed 2024 may have produced higher detection rates for the same reasons as the matrix trawl.

While the implementation of the Snake River Max Spill program in 2020 has likely improved juvenile salmonid survival through the hydrosystem, it has reduced the precision of survival estimates and hampered fish collection for subsequent transport (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.

Unpredictable flows and reduced tagging effort from historical peaks also highlights the importance of expanding detection capability in the Columbia River estuary. Furthermore, the combined use of these systems offer consistent detections amid annual fluctuations in water level, and contribute more reliable data for juvenile survival estimates in the Columbia River basin. The estuary PIT detection project continues to contribute valuable data to management of the Columbia River basin, and ongoing technical development provides valuable advancements to PIT interrogation as a whole. For these reasons, the Jones Beach reach of the lower Columbia continues to be one of the most important locations for recovery of juvenile salmonid PIT tags in the Columbia River basin.

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Appendix

Links to Data

PIT Tag related Data:
https://www.ptagis.org/Data/AdvancedReporting
Report Filter: (Site = TWX - Estuary Towed Array (Exp.) And ({Last Year} = 2024)

Report Filter: (Site = PD6 - Columbia River Estuary rkm68, PD7 - Columbia River Estuary rkm 70, PD5 - Columbia River Estuary rkm 62, PD8 - Columbia River Estuary rkm 82) And ({Last Year} = 2024)

Bonneville Dam Environmental Data:
https://www.cbr.washington.edu/dart/wrapper?type+php&fname=riverdaily_1750105846_127.php

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), 2024.

	Total time underway	PIT tag detections (n)						
Date	(h)	Unknown	Chinook salmon	Coho salmon	Steelhead	Sockeye salmon	Cutthroat trout	Total
3 Apr 24	5.72	0	7	0	0	0	0	7
4 Apr 24	5.10	0	2	0	0	0	0	2
5 Apr 24	5.82	1	5	0	0	0	0	6
6 Apr 24	0.00	--	--	--	--	--	--	--
7 Apr 24	0.00	--	--	--	--	--	--	--
8 Apr 24	5.02	1	4	0	0	0	0	5
9 Apr 24	5.98	0	3	0	0	0	0	3
10 Apr 24	4.30	0	3	0	0	0	0	3
11 Apr 24	5.18	0	2	0	1	0	0	3
12 Apr 24	5.12	0	4	0	0	0	0	4
13 Apr 24	0.00	--	--	--	--	--	--	--
14 Apr 24	0.00	--	--	--	--	--	--	--
15 Apr 24	0.00	--	--	--	--	--	--	--
16 Apr 24	6.10	0	10	0	3	0	0	13
17 Apr 24	5.28	1	2	0	4	0	0	7
18 Apr 24	6.30	0	16	0	13	0	0	29
19 Apr 24	3.28	0	1	0	4	0	0	5
20 Apr 24	0.00	--	--	--	--	--	--	--
21 Apr 24	0.00	--	--	--	--	--	--	--
22 Apr 24	5.05	0	18	0	15	0	1	34
23 Apr 24	6.10	2	29	0	20	0	0	51
24 Apr 24	4.30	1	9	0	19	0	0	29
25 Apr 24	1.87	0	1	0	0	0	0	1
26 Apr 24	5.12	1	9	4	29	0	0	43
27 Apr 24	0.00	--	--	--	--	--	--	--
28 Apr 24	0.00	--	--	--	--	--	--	--
29 Apr 24	11.95	19	142	7	142	0	2	312
30 Apr 24	12.58	26	109	3	187	0	0	325
1 May 24	12.92	42	201	3	184	0	0	430
2 May 24	13.63	45	175	5	242	0	1	468
3 May 24	14.00	70	231	9	303	0	0	613
4 May 24	11.15	37	102	8	74	0	0	221
5 May 24	12.87	59	168	13	329	0	0	569
6 May 24	13.28	45	95	5	168	0	1	314
7 May 24	11.87	24	88	4	158	0	2	276
8 May 24	17.18	51	142	12	144	0	0	349
9 May 24	16.27	30	169	14	140	1	0	354

Appendix Table 1. Continued.

Date	Total time underway (h)	PIT tag detections (n)						
		Unknown	Chinook salmon	Coho salmon	Steelhead	Sockeye salmon	Cutthroat trout	Total
10 May 24	17.35	23	319	12	150	1	1	506
11 May 24	9.35	6	90	6	79	1	1	183
12 May 24	9.57	15	96	10	77	0	0	198
13 May 24	13.18	17	117	13	87	0	0	234
14 May 24	14.10	22	197	21	105	0	0	345
15 May 24	13.98	11	246	15	339	1	0	612
16 May 24	13.03	8	186	7	72	0	0	273
17 May 24	12.65	13	237	14	83	1	0	348
18 May 24	8.90	8	100	6	64	0	0	178
19 May 24	11.20	7	284	25	67	0	0	383
20 May 24	18.22	19	391	19	179	1	1	610
21 May 24	8.35	2	81	14	69	3	0	169
22 May 24	11.68	14	314	36	135	59	0	558
23 May 24	15.68	21	324	52	73	188	1	659
24 May 24	15.23	19	168	45	141	139	1	513
25 May 24	7.75	2	38	16	53	15	0	124
26 May 24	10.32	8	99	24	93	21	0	245
27 May 24	13.13	16	53	19	68	10	1	167
28 May 24	13.27	12	46	17	104	7	0	186
29 May 24	12.17	13	44	26	111	3	0	197
30 May 24	12.03	14	49	28	67	3	0	161
31 May 24	12.48	13	50	19	55	4	0	141
1 Jun 24	7.77	4	29	7	38	2	1	81
2 Jun 24	8.12	7	20	13	30	1	0	71
3 Jun 24	12.72	5	20	14	44	1	0	84
4 Jun 24	12.07	7	30	9	34	0	0	80
5 Jun 24	11.95	7	24	7	14	1	0	53
6 Jun 24	12.62	3	16	7	13	2	0	41
7 Jun 24	11.40	3	13	3	22	1	1	43
8 Jun 24	7.78	3	8	3	19	1	0	34
9 Jun 24	11.73	2	30	1	9	1	0	43
10 Jun 24	12.60	0	57	3	46	1	0	107
11 Jun 24	12.42	1	73	9	7	0	0	90
12 Jun 24	12.50	4	37	15	23	1	0	80
13 Jun 24	12.95	0	47	15	32	2	0	96
14 Jun 24	1.47	0	1	0	0	0	0	1
Total	655.05	784	5,681	637	4781	472	15	12,370

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), 2024.

Date	Yearling Chinook	Subyearling Chinook	Coho	Steelhead	Sockeye	Chum
3 Apr	0	0	0	0	0	0
4 Apr	0	0	0	0	0	0
5 Apr	0	0	0	0	0	0
6 Apr	-	-	-	-	-	-
7 Apr	-	-	-	-	-	-
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	0	0	0	0	0	0
13 Apr	-	-	-	-	-	-
14 Apr	-	-	-	-	-	-
15 Apr	-	-	-	-	-	-
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	0	0	0	0	0	0
20 Apr	-	-	-	-	-	-
21 Apr	-	-	-	-	-	-
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	0	0	0	0	0	0
26 Apr	1	0	0	0	0	0
27 Apr	-	-	-	-	-	-
28 Apr	-	-	-	-	-	-
29 Apr	8	0	1	2	0	0
30 Apr	2	0	0	0	0	0
1 May	1	0	0	0	0	0
2 May	14	0	2	2	0	0
3 May	3	0	1	1	0	0
4 May	0	0	0	0	0	0
5 May	2	0	2	1	0	0
6 May	2	0	0	1	0	0
7 May	1	0	0	0	0	0
8 May	2	0	1	0	0	0
9 May	2	0	1	0	0	1
10 May	3	0	0	0	0	0

Appendix Table 2. Continued.

Date	Yearling Chinook	Subyearling Chinook	Coho	Steelhead	Sockeye	Chum
11 May	1	0	0	1	0	0
12 May	0	0	0	0	0	0
13 May	3	0	1	0	0	0
14 May	0	0	0	0	0	0
15 May	1	0	0	0	0	0
16 May	1	0	0	0	0	0
17 May	3	0	0	0	0	0
18 May	0	0	1	0	0	0
19 May	0	0	0	0	0	0
20 May	0	0	0	0	0	0
21 May	4	2	0	0	1	0
22 May	2	3	0	0	0	0
23 May	0	0	0	0	0	0
24 May	3	7	0	0	0	0
25 May	0	1	0	0	1	0
26 May	0	0	0	0	0	0
27 May	0	0	0	0	2	0
28 May	0	0	0	0	0	0
29 May	0	1	0	0	0	0
30 May	0	1	0	0	1	0
31 May	1	3	0	0	0	0
1 Jun	2	2	0	0	0	0
2 Jun	1	0	0	0	1	0
3 Jun	0	0	0	0	0	0
4 Jun	2	4	0	0	0	0
5 Jun	0	1	0	0	0	0
6 Jun	0	1	0	0	0	0
7 Jun	0	1	0	0	0	0
8 Jun	0	3	0	0	0	1
9 Jun	0	0	0	0	0	0
10 Jun	0	0	0	0	0	0
11 Jun	0	0	0	0	0	1
12 Jun	1	2	0	0	0	0
13 Jun	0	0	0	0	0	0
15 Jun	0	0	0	0	0	0
Total	65	32	10	7	6	3

Appendix Table 3. Mean diel detections by hour for yearling Chinook salmon and steelhead during intensive sampling (29 April-13 June) using the matrix trawl system in the upper Columbia River estuary (rkm 75), 2024.

		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	36.9	332	23	8.99	0.62	54	8	1.46	0.22
1	14.0	154	6	11.00	0.43	10	6	0.71	0.43
2	5.6	74	5	13.14	0.89	13	5	2.31	0.89
3	4.0	48	4	12.00	1.00	6	2	1.50	0.50
4	19.2	206	23	10.71	1.20	72	15	3.74	0.78
5	43.1	404	57	9.37	1.32	331	90	7.67	2.09
6	44.6	205	18	4.59	0.40	325	101	7.28	2.26
7	44.3	175	16	3.95	0.36	247	75	5.57	1.69
8	44.5	209	30	4.70	0.67	302	85	6.79	1.91
9	45.1	160	21	3.55	0.47	339	75	7.51	1.66
10	32.6	132	14	4.05	0.43	245	48	7.52	1.47
11	11.6	129	11	11.14	0.95	160	30	13.81	2.59
12	4.9	86	9	17.55	1.84	78	20	15.92	4.08
13	2.1	59	4	27.87	1.89	20	5	9.45	2.36
14	0.4	0	0	0.00	0.00	0	0	0.00	0.00
15	--	--	--	--	--	--	--	--	--
16	--	--	--	--	--	--	--	--	--
17	--	--	--	--	--	--	--	--	--
18	21	68	8	3.18	0.37	213	33	9.95	1.54
19	39.0	254	43	6.51	1.10	450	101	11.54	2.59
20	39.0	688	67	17.64	1.72	515	96	13.21	2.46
21	39.0	523	45	13.41	1.15	197	46	5.05	1.18
22	39.0	415	24	10.64	0.62	102	37	2.62	0.95
23	39.0	395	25	10.13	0.64	83	29	2.13	0.74
Total	569.4	4,716	453			3,762	907		

Addendum: Advancements of Pile Dike Detection Systems

Introduction

Infrastructure at dams, such as fish bypass systems and spillways, inherently allow for permanent installation of stationary PIT detection systems. As such, the vast majority of PIT interrogation in the Columbia River basin is made up of passive, autonomous, and stationary detection systems that utilize this infrastructure to funnel fish toward these systems. In the lower estuary, implementing similar passive interrogation systems has proven more challenging due to its dynamic characteristics: higher flow, limited infrastructure, larger surface area, and unrestrained debris loads.

Because of these challenges, estuary PIT detection methods have historically relied on active towed arrays like the NOAA PIT Trawl. These interrogation methods are far more intensive, requiring a fleet of vessels and a large permanent and seasonal crew. In an attempt to expand PIT interrogation methods in the lower estuary, we began installing autonomous, stationary arrays on pile dikes - the only prevalent form of infrastructure in the estuary. Since we began targeting juvenile salmonids with these sites in 2022, we've observed comparable detection data to the matrix trawl and flexible antenna array.

Advancement of these pile dike sites continued during the 2024 season. From the installation of PD7 as a prototype in 2011 to the expansion of four large sites operating nearly 40 antennas in 2024, this PIT interrogation method has undergone significant development. In 2023 and 2024, the pile dike sites detected over 12,000 PIT tagged fish annually. These successes encourage continued development and exploration of new pile dike locations. .

Early Development

From 1885 to 1969, the US Army Corps of Engineers (USACE) built over 233 pile dikes within the lower Columbia River estuary as a means to maintain commercial navigation channels (AECOM 2011). Each pile dike structure was built to maintain the navigation channel at a specific region, and were labeled by river mile, from the mouth incrementally upstream. In 2011, the first pile dike PIT array (site code PD7 in PTAGIS) was installed at the terminus of spur dike 43.33, located at rkm 70 (46.14661 N, -123.379867 W); adjacent to navigation marker R58. An IS1001 Master Controller and associated electronics were housed in an enclosure fixed to the dike's king piling. The original objective of this site was to target adult salmonid detections (Magie et al 2015). In subsequent years, detection data from PD7 showed potential for detecting adult, jack, and juvenile salmonids, as well as other species such as white sturgeon.

PD7 has sampled continuously since its installation, except for a full shutdown from fall 2020 – spring 2022. Detection totals at PD7 varied from year to year due to many factors (number of antennas, antenna placement, seasonal effort, antenna function, etc.), averaging 571 detections of PIT tagged fish annually from 2011 to 2024. Modifying antenna placement and orientation along the dike also resulted in a variety of species and life history observations. For instance, downstream antennas tended to detect adult and juvenile salmonids, sturgeon, and other species, while upstream antennas almost exclusively detected juvenile salmonids: from 2018-2019, PD7 detected 1,226 salmonids of varying life stages with juvenile salmonids accounting for 577 of 611 (~94%) of salmonid detections on upstream antennas. Conversely, 192 of 217 (88%) of adult salmonid detections were recorded on downstream antennas. The potential to target detections of juvenile salmonids on pile dike arrays by orienting antennas on the upstream side of pile dikes sparked the expansion to an additional pile dike site prior to the 2022 sampling season.

Site expansion

In spring 2022, we expanded pile dike PIT detection to include a new site (PD6 in PTAGIS) that intended to specifically target detections of juvenile salmonids. PD6 is located across the main river channel from PD7, at the terminus of training dike 42.93 (rkm 69: 46.205748 N, -123.431179 W), adjacent to navigation marker 57. Due to the degraded state of the pile dike, electronics were housed in a floating barge tethered downstream of the pile dike. Like PD7, antennas were installed in various locations and orientations along the dike.

We operated PD6 from March through September in 2022-2024, with PD7 operating continuously since its re-installment in 2022. Each site operated 6-8 antennas mounted from aluminum brackets attached to piling structures. During the 2022 sample season, PD6 detected a total of 3,230 PIT-tagged fish, and PD7 a total of 483. The majority of detections at both sites were juvenile salmonids detected by antennas mounted on the upstream side of the dikes.

Success at PD6 underscored the potential for pile dike sites to supplement detections of juvenile salmonids in the estuary. In 2023, we again expanded pile dike interrogation with two additional sites installed along similarly oriented training dikes: one upstream and one downstream of PD6. The new sites, referred to as PD5 (near rkm 62; 46.205748 N, -123.431179 W) and PD8 (near rkm 82; 46.166489 N, -123.225002 W) in PTAGIS, were installed at the terminus of training dikes 38.26 and 51.10, respectively (Figure 1). Like PD6, electronics were housed in floating barges tethered on the downstream side of both dikes.

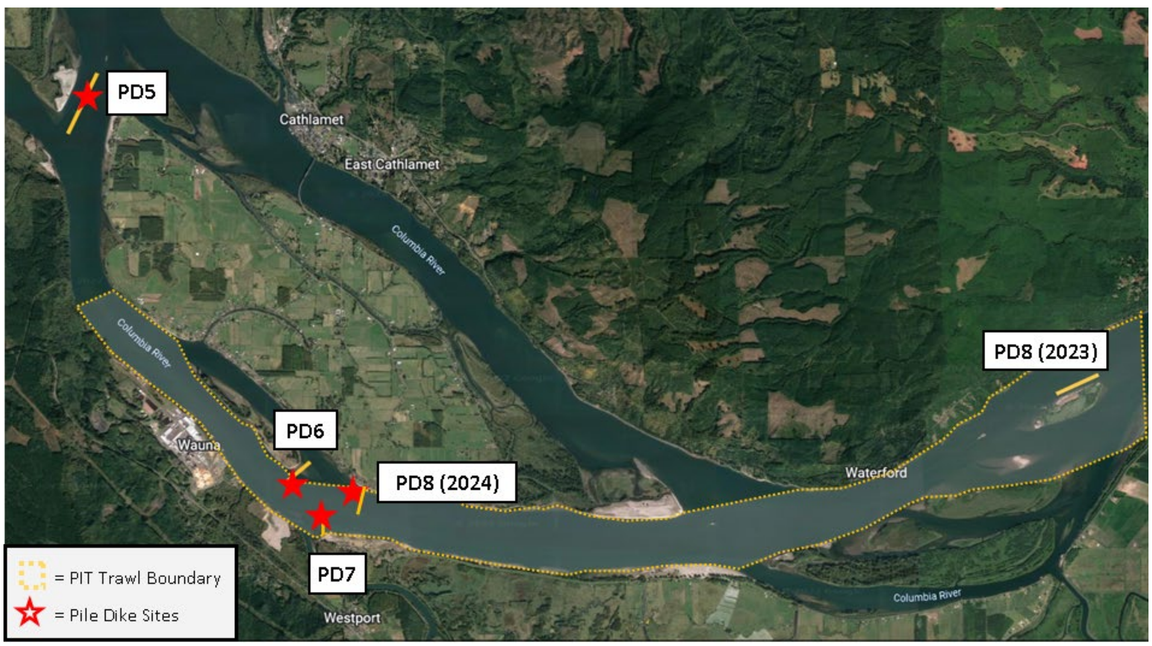

Figure 1. Columbia River estuary pile dike locations within the Jones Beach sample reach from 2022-2024. *PD8 relocated in 2023.

Site installation in 2023 began on 3 March and sampling continued until the removal of PD5 on 11 October, with PD7 running year-round. During the 2023 season, pile dike sites detected a total of 15,542 unique fish of varying species and age class. These included 7,328 detections at PD5, 6,712 at PD6, 785 at PD7, and 717 at PD8 (Table 1). Reduced detections at PD8 ultimately led to the relocation of this site prior to the 2024 sampling season. In 2023, combined detections across pile dike sites favored juvenile Chinook salmon over steelhead at a ratio of 1.8:1.

Table 1 : Total unique detections at pile dike sites within the Jones Beach sample reach in 2023 and 2024

Year/species	PD5	PD6	PD7	PD8	Total
2023					
Chinook	3,962	4,562	547	515	9,586
Coho	760	298	69	43	1,170
Sockeye	116	105	17	4	242
Steelhead	2,369	1,700	94	125	4,288
Cutthroat Trout	30	7	4	1	42
Green Sturgeon	0	1	0	0	1
White Sturgeon	57	8	40	14	119
Northern Pikeminnow	2	0	0	5	7
Unknown	32	31	14	10	87
Total	**7,328**	**6,712**	**785**	**717**	**15,542**
2024					
Chinook	2,889	2,938	523	2,475	8,825
Coho	461	248	43	200	952
Sockeye	32	14	13	122	181
Steelhead	1,240	651	200	416	2,507
Cutthroat Trout	20	16	4	8	48
White Sturgeon	17	9	36	7	69
Northern Pikeminnow	4	6	1	0	11
Unknown	94	67	27	46	234
Total	**4,757**	**3,949**	**847**	**3,274**	**12,827**

In 2024, we doubled the number of antennas to create two separate arrays at both PD5 and PD6, and moved PD8 to pile dike 43.55 just upstream of PD6 (rkm 70: 46.149669 N, -123.372903 W). While heavily degraded, the new PD8 location shared flow characteristics with PD5 and PD6 and was in proximity of a well-known ‘detection hot-spot’ for the NOAA PIT trawl. We considered this site experimental in 2024, and housed electronics in a floating barge to allow for potential relocation. Five antennas were deployed at PD8 in various locations and orientations from April – September 2024.

Two independent arrays were installed at both PD5 and PD6, each containing an IS1001 Transceiver (and associated electronics) housed within enclosures mounted to single robust pilings (Figure 2). Each system supported up to 8 antennas in an array. We experienced increased EMI at these sites throughout the season, likely attributed to proximity interference between arrays. Four antennas were deployed at PD7 in 2024.

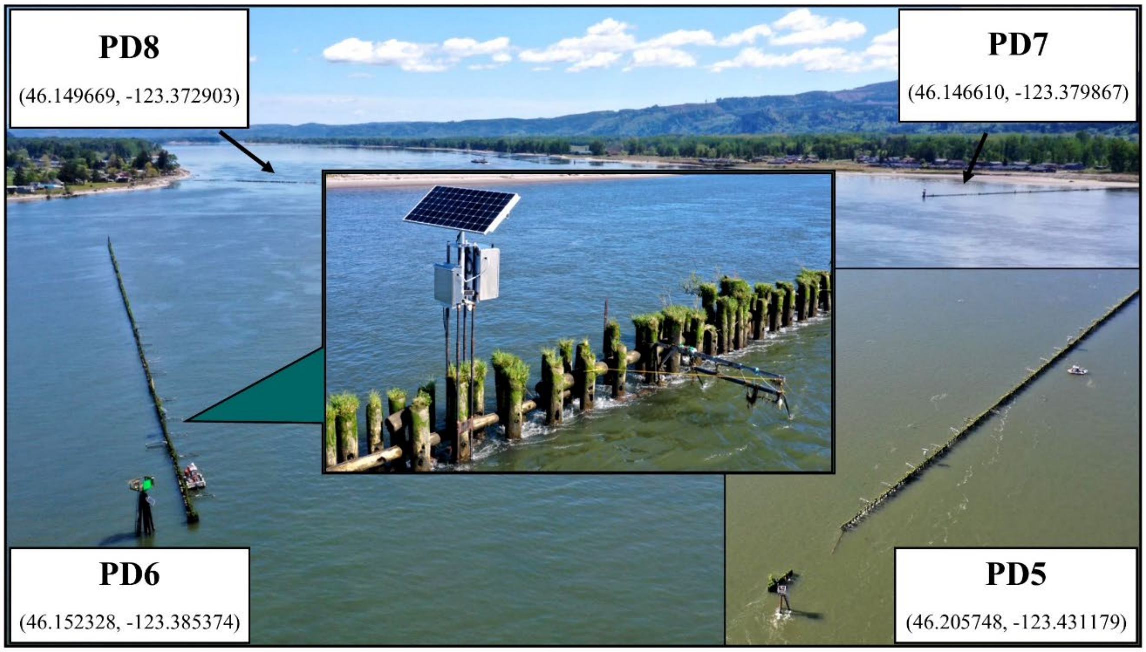

Figure 2. Upstream view of pile dike interrogation sites looking east from Puget Island. Bottom right inset image is a bird's eye view of PD5, approximately 7 km downstream of PD6. Center inset image is one of the piling mounted electronics enclosures and an upstream antenna.

During the 2024 sampling season, pile dike sites detected a total of 12,827 unique fish, which included 4,757 detections at PD5, 3,949 at PD6, 847 at PD7, and 3,274 at PD8 (Table 1). Detections at pile dike sites continued to favor Chinook over steelhead in 2024, at a ratio of nearly 2:1. Detection totals at PD8 neared those at PD5 and PD6 despite having significantly less antennas.

Discussion and Future Development

In 2024, detection rates on pile dikes were nearly 23% lower than in 2023, despite significant site expansions that increased the number of active antennas by 50%. Flows were much higher in 2023, leading us to hypothesize that pile dikes may demonstrate higher detection rates during these higher flow years due to stronger currents along the dikes funneling fish towards antennas and more nearshore habitat available for outmigration.

In 2025, we plan to continue improving and developing pile dike sites. Due to technical issues in 2024 relating to array proximity at PD5 and PD6, we plan to reduce these sites to once again operate a single array operating 8-10 antennas at each location. We also plan to reinstall PD7 and PD8 to similar configurations as deployed in 2024, and install two new sites at pile dikes 46.87 and 47.35, both located at the head of Puget Island. Continued expansion of pile dike sites to new locations remains a promising means of supplementing juvenile salmonid detections in the estuary.

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