Detection of PIT-Tagged Juvenile Salmonids Migrating in the Columbia River Estuary, 2019

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Executive Summary

In 2019, we continued a multi-year study in the Columbia River estuary to detect juvenile Pacific salmon *Oncorhynchus* spp. marked with passive integrated transponder (PIT) tags. Fish were detected using a surface pair trawl with a matrix of rectangular PIT antennas fitted into the cod end. The matrix was configured with three parallel antennas in front and three in the rear for a total of 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 kilometer (rkm) 66 and 84 and sampled for a total of 749 h.

During this period, the matrix system detected 11,579 PIT-tagged fish, of which 19% were wild, 77% were of hatchery origin, and 4% were of unknown rear type. Species composition of detected fish was 41% spring/summer Chinook, 6% fall Chinook, 43% steelhead, 4% sockeye, 3% coho, less than 1% cutthroat trout, and 2% unknown.

To coincide with arrival in the estuary of spring-migrating juvenile salmon and steelhead, sampling began on 27 March 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 and a second operating 6 d/week during darkness. Intensive sampling continued from 28 April through 15 June. During intensive sampling, the trawl was deployed for an average of 13 h/d, which was slightly more than the 12 h/d average in 2018. We ended sampling on 15 June after most spring migrants had passed.

During the intensive sample period, average hourly detections of hatchery yearling Chinook were significantly different between darkness and daylight hours (9.0 vs. 4.5 fish/h; $P < 0.001$). Conversely, average hourly detections of wild yearling Chinook were not significantly different between darkness and daylight hours (1.1 vs 0.8 fish/h; $P = 0.073$). For hatchery steelhead, hourly detection rates were significantly higher during daylight than darkness hours (6.2 vs. 2.9 fish/h; $P < 0.001$). Similarly, for wild steelhead, there was a significant difference in detection rate between daylight and darkness hours (2.7 vs 1.0 fish/h; $P < 0.001$).

Also during the intensive sampling period, we detected 1.7% of the yearling Chinook salmon and 2.7% of the steelhead detected at Bonneville Dam. These

proportions were greater than those in 2018, when we detected 1.0% of the yearling Chinook and 1.5% of the steelhead detected at Bonneville Dam.

Additionally, we detected 1.5% of the yearling Chinook and 2.6% of the steelhead transported and released below Bonneville Dam. These rates were greater than those in 2018, when we detected 0.7% of the yearling Chinook and 2.2% of the steelhead transported and released below Bonneville Dam.

In 2019, we continued development of a flexible antenna array, which is towed behind two small vessels to detect passing juvenile salmon without capture in a net. Objectives of this development effort were to simplify logistics, increase sample efficiency, eliminate unintentional take of ESA listed salmonids, and reduce the cost of sampling PIT-tagged fish in the estuary.

For these tests, the flexible antenna array was configured with twelve 2.4- by 6.1-m rectangular cable antennas and sampled to a depth of approximately 6 m. Sampling efforts were conducted simultaneously with deployments of the matrix trawl system. We compared detection efficiency between the two systems to evaluate the feasibility of transitioning entirely to the flexible system in future years. Only detections occurring when the flexible antenna system was fully functional were used for comparative analyses with the trawl.

The flexible antenna system detected a total of 2,707 fish across 41 d of operation in 2019 (229.6 total hours of operation). However, during certain deployments of the flexible system, interruptions for testing likely impaired detection efficiency; therefore, data from these deployments were not used for comparison with trawl system deployments.

Of total detections from the flexible antenna system, 46% were spring/summer Chinook, 7% were fall Chinook, 32% were steelhead, 7% were coho, 5% were sockeye, less than 1% were cutthroat trout and white sturgeon, and 2% were unknown species. The proportion of total detections occurring on the flexible system was calculated for each comparative deployment, which totaled 214.9 hours over 40 d. The overall proportion of total detections for the flexible system was 38%.

In 2019, as in previous study years, we examined PIT-tag detection data to evaluate potential factors related to detection probability and to compare passage performance metrics among fish groups by species, rear type (hatchery or wild), and migration history (transported vs. in-river).

For yearling Chinook salmon detected with the trawl, we found no significant effect for arrival date ($P = 0.193$), date-squared ($P = 0.946$), or migration history ($P = 0.454$). On average, we detected approximately 1.5% of transported and in-river migrants for the entire spring migration season.

For steelhead detected with the trawl, we found a significant effect of arrival date on detection rate ($P < 0.001$), but no effect for migration history ($P = 0.990$). On average, we detected transported and in-river migrant steelhead at a rate of about 2.0% in the early season, and at roughly 6.0% 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 was 29% lower during the two-shift sample period of 2019 than during the two-shift period of 2018 (7,984 vs. 11,284 m^3/s), and thus aligned more closely with the 17-year average for 2000-2017 (8,261 m^3/s, excluding 2001). Daily river flows remained average until the end of May and then dropped to below-average levels by 5 June.

Of all juvenile salmonids detected by the trawl and flexible systems combined in 2019, 21% had been transported, while 16% had been detected passing Bonneville Dam. The remaining 63% had neither been transported nor detected at Bonneville Dam, although at least 95% of total detections originated upstream from Bonneville.

Mean migration rate to the estuary (rkm 75) was significantly faster for yearling Chinook salmon detected at Bonneville Dam than for those released from barges just below the dam (85 vs. 61 km/d, $P < 0.001$). Similar differences were observed for steelhead, with travel rates of 97 km/d for in-river migrants vs. 86 km/d for transported fish ($P < 0.001$).

This trend was repeated in observations of mean migration rate between in-river migrant and transported sockeye (106 vs. 95 km/d) and subyearling Chinook salmon (78 vs. 46 km/d). However, for both species, detection numbers were insufficient for meaningful statistical analysis. Overall, migration rates to the sample reach were slower for both in-river and transported fish in 2019 than in 2018 across all species. This was likely a function of lower flow volumes in 2019.

Detections of subyearling Chinook salmon have decreased in recent years, commensurate with reduced tagging effort for these fish. In 2019, we detected 792 subyearling fall Chinook, with the majority of detections occurring from late May through the end of the sampling season. Of these 792 fish, 746 originated from the Snake River Basin (473 in-river migrants and 273 transported). The remaining 46 were in-river migrants from Columbia River stocks, with 6 released above McNary Dam, and 40 released between McNary and Bonneville Dam. We detected three *holdover* subyearlings in 2019. Holdovers are migrating subyearling Chinook that suspend downstream migration, overwinter in freshwater, and resume migration the following spring.

Of the 676 sockeye salmon detected, 75% were from the Snake River, 24% were from the upper Columbia River above McNary Dam, and less than 2% were from the middle Columbia River between McNary and Bonneville Dam. Rear types of detected sockeye were 71% hatchery, 7% wild, and 22% unknown origin. Migration histories of detected sockeye were 93% in-river migrant and 7% transported.

In 2019, as in previous years, detection data from the estuary were essential for calculating survival probabilities to the tailrace of Bonneville Dam, the last dam encountered by migrating juvenile salmonids. Detections from the estuary trawl have provided data for estimates of survival through the hydrosystem since 1998. These estimates are critical to research and management programs for endangered salmonids in the Snake and Columbia River Basin and in other basins of the Pacific Northwest.

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

Contents

Introduction

In 2019, we continued a multi-year study in the Columbia River estuary to collect data on migrating juvenile Pacific salmon *Oncorhynchus* spp. implanted with passive integrated transponder (PIT) tags (Ledgerwood et al. 2004; Holcombe et al. 2019). This study began in 1995 and has continued annually (except 1997) in the estuary near Jones Beach, approximately 75 river kilometers (rkm) upstream from the mouth of the Columbia River. We use data from estuary detections to estimate survival and downstream migration timing of these fish.

As in previous years, we used a large surface pair trawl to guide fish through an array of PIT antennas mounted in the open cod end. Target fish were PIT-tagged juveniles with records in the *Columbia Basin PIT Tag Information System* (PTAGIS), a regional database that stores and disseminates information on PIT-tagged fish (PSMFC 1996-). 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 antenna detection field to exit. Upon detection, the tag code, GPS position, and date and time of detection are electronically recorded. Over 1.6 million Snake and Columbia River juvenile salmonids were PIT-tagged and released prior to or during the spring 2019 migration season, based on records in PTAGIS (PSMFC 1996-). A portion of these fish were detected at dams equipped with PIT-tag monitoring systems (Prentice et al. 1990a, b). These systems automatically upload detection information to the PTAGIS database.

We uploaded trawl detection records to PTAGIS and downloaded information on the fish we detected. To evaluate migration performance metrics between Bonneville Dam and the estuary, we used data on the species, run, tagging/release time and location, and date/time of detection at interrogation sites downstream from release. Since 1998, trawl detection data have been used for annual survival estimates of yearling Chinook salmon *O. tshawytscha*, steelhead *O. mykiss*, and sockeye salmon *O. nerka* from points of release to Bonneville Dam. Estuary detections are necessary for complete estimates of survival through the entire hydrosystem (Widener et al. 2018).

In 2019, 136,112 PIT-tagged fish were transported from dams on the Snake River and released below Bonneville, and over 97,000 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.

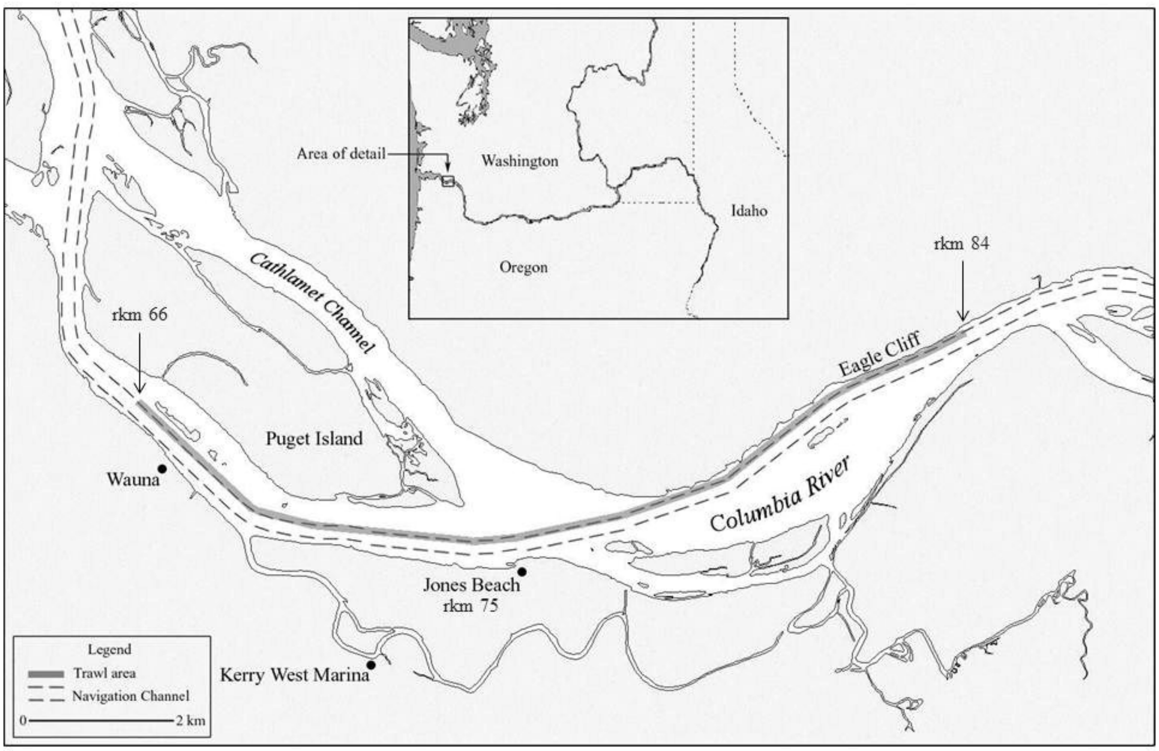

Figure 1. Trawl sampling area adjacent to the navigation channel in the upper Columbia River estuary between rkm 66 and 84, 2019.

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. The vast majority of these fish migrate through the tidal freshwater reach of the estuary from late April through late June.

Release dates and locations of fish detected with the trawl were retrieved from the PTAGIS database (PSMFC 1996-). Specific groups of tagged fish targeted for detection included over 199,007 fish released for a comparative survival study, 136,112 fish diverted to barges for NMFS transportation studies, and smaller groups released for other studies.

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

In 2019, 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, so analyses were limited. 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 27 March and continued through the migration period to 15 June. Our sample effort was adjusted 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 6 h/d. Sample effort was defined as periods during which the trawl was fully deployed. During peak spring migration (28 April-15 June), we sampled with two daily shifts, covering both daylight and darkness periods, for an average sample effort of 13 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 night crews were relieved by the day crew. We intended sampling to be nearly continuous throughout the two-shift period, though it was necessary to interrupt sampling for refueling, maintenance, and crew changes. These interruptions generally occurred between 1400 and 1900 PDT.

Trawl System Design

Antenna Configuration—Configuration of the matrix antenna was similar to the design used since 2013 (Figure 2). A fish-passage corridor was formed using a front and rear antenna array, each consisting of three parallel antennas, for a total of six antennas. Inside dimensions of individual antennas measured 0.75 by 2.8 m. A 1.5-m length of net mesh connected front and rear arrays, and the overall fish-passage opening was 2.6 by 3.0 m. The matrix antenna array was attached to the open cod end of the trawl and suspended by buoys at a depth of 0.6 m.

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

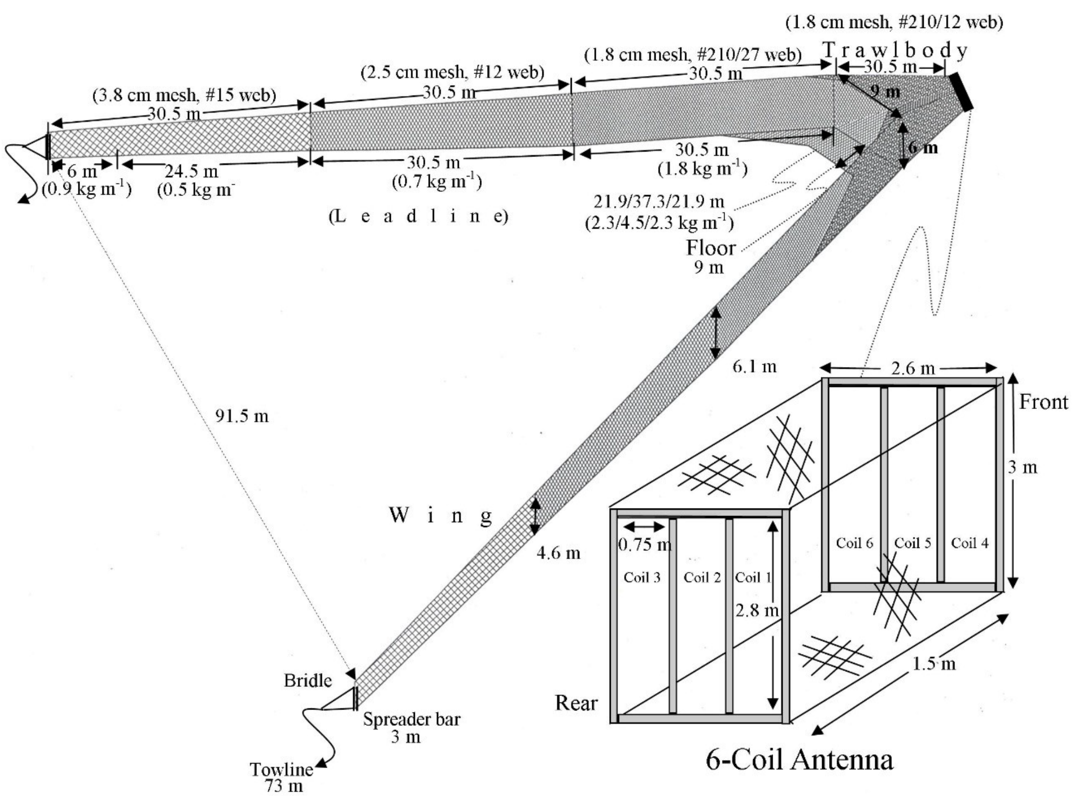

Figure 2. Basic design of the surface pair trawl used with the matrix antenna system to sample juvenile salmonids in the Columbia River estuary (rkm 75), 2019.

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

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

Electronic components and data transmission—For the matrix trawl detection system, we used essentially the same electronic components and procedures as in 2006-2018. In 2019, we again used a single FS1001M multiplexing transceiver, which is capable of simultaneously powering the detection fields while recording and transmitting detection data from all six antennas. Electronic components for the trawl system were contained in a watertight box (0.8 × 0.5 × 0.3 m) mounted on a 2.4- by 1.5-m pontoon raft tethered behind the antenna.

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

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

Detection data files were uploaded weekly to PTAGIS using standard methods described in the *PTAGIS Data Specification* (PSMFC 2019). The specification document, PTAGIS operating software, and user manuals are available from the PTAGIS website operated by Pacific States Marine Fisheries Commission (PSMFC 1996-). Matrix trawl detections were designated in the PTAGIS database with site code TWX (towed array-experimental), and were distinguished from flexible system detections using the antenna group name “Matrix Trawl [current].”

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

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

Estimated detection efficiencies from these tests were positively correlated with spacing between test tags, regardless of tag orientation (45 vs. 90 degrees). Of the 1,512 test tags passed through the matrix antenna, those spaced at 30-cm intervals were detected less than 3% of the time when oriented at 45 or 90 degrees. With spacing between tags increased to 60 cm, detection efficiency increased to 98 and 99% for tags oriented at 45 and 90 degrees, respectively. For test tags spaced 90 cm apart, reading efficiency was 100% for tags oriented at 45 or 90 degrees. Results in 2019 were similar to those in previous years and showed the matrix antenna was performing as expected.

Results and Discussion

Factors Affecting Detection Rate

Flow volumes—Through years of sampling, we have observed an inverse relationship between river flow volume and trawl detection rate. Higher flow volume has been consistently associated with lower detection rates of fish previously detected at Bonneville Dam (detection of fish previously detected at Bonneville provides a rough 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 more quickly. 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, increasing sample time lost to debris removal.

During the 2019 intensive sampling period of 28 April-15 June, mean river flow volume at Bonneville Dam was 29% lower than during the same period in 2018 (7,984 vs. 11,284 m^3/s; Figure 3). Flows in 2019 were more similar to the 17-year average for 2000-2017 (8,261 m^3/s, excluding 2001). In general, the 2019 season was characterized by average flows and light debris loads.

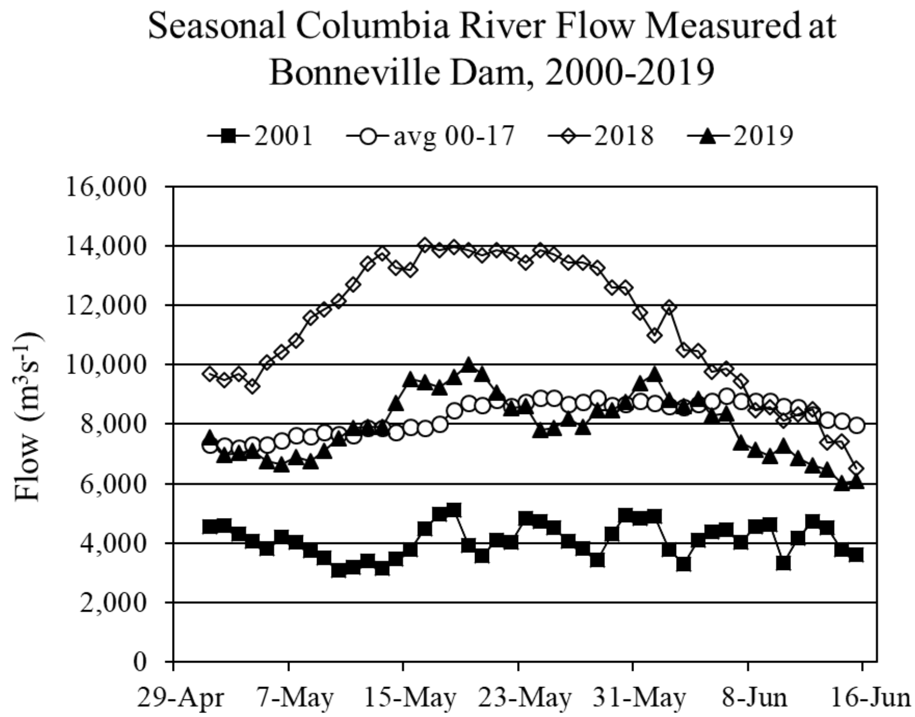

Figure 3. Columbia River flows (m^3/s) at Bonneville Dam during the two-shift sample periods in 2019 and 2018 compared to the average flow from 2000 to 2017 (excluding 2001). Drought-year flows for 2001 are shown for comparison.

Presence of tagged fish in the sample reach—We estimated that intensive sampling in 2019 coincided with arrival time in the estuary for 84% of the yearling Chinook salmon and 90% of the steelhead passing Bonneville Dam (tagged and non-tagged). These availability estimates exceeded those made in 2018 for in-river migrants, when 78% of yearling Chinook salmon and 78% of steelhead were estimated to be present in the estuary.

Our intensive sample period also coincided with arrival in the estuary for 93% of the yearling Chinook salmon transported for NMFS studies. This estimate was greater in 2019 than in 2018, when 91% were estimated to be in the estuary during intensive sampling. For transported steelhead in 2019, 84% were estimated to be in the estuary during intensive sampling, which was less than the 91% estimated to be present in 2018.

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

Since 2013, tagging effort for subyearling Chinook has been reduced considerably; however, these fish comprised 66% of the detections at Bonneville after intensive sampling ended in 2019 and 81% of the detections at Bonneville after intensive sampling in 2018. Release dates and totals for tagged subyearling Chinook were comparable between 2019 and 2018 (212,974 and 225,073, respectively).

Detection Rates

We sampled with the matrix trawl system for 749 h during 2019 and detected 11,579 PIT-tagged fish. In contrast, we sampled for 695 h during 2018 and detected 9,990 fish (Figure 4). Higher-than-average flows and heavy debris loads likely contributed to the decreased sample time and lower detection rate in 2018 (14 fish/h) compared to 2019 (15 fish/h).

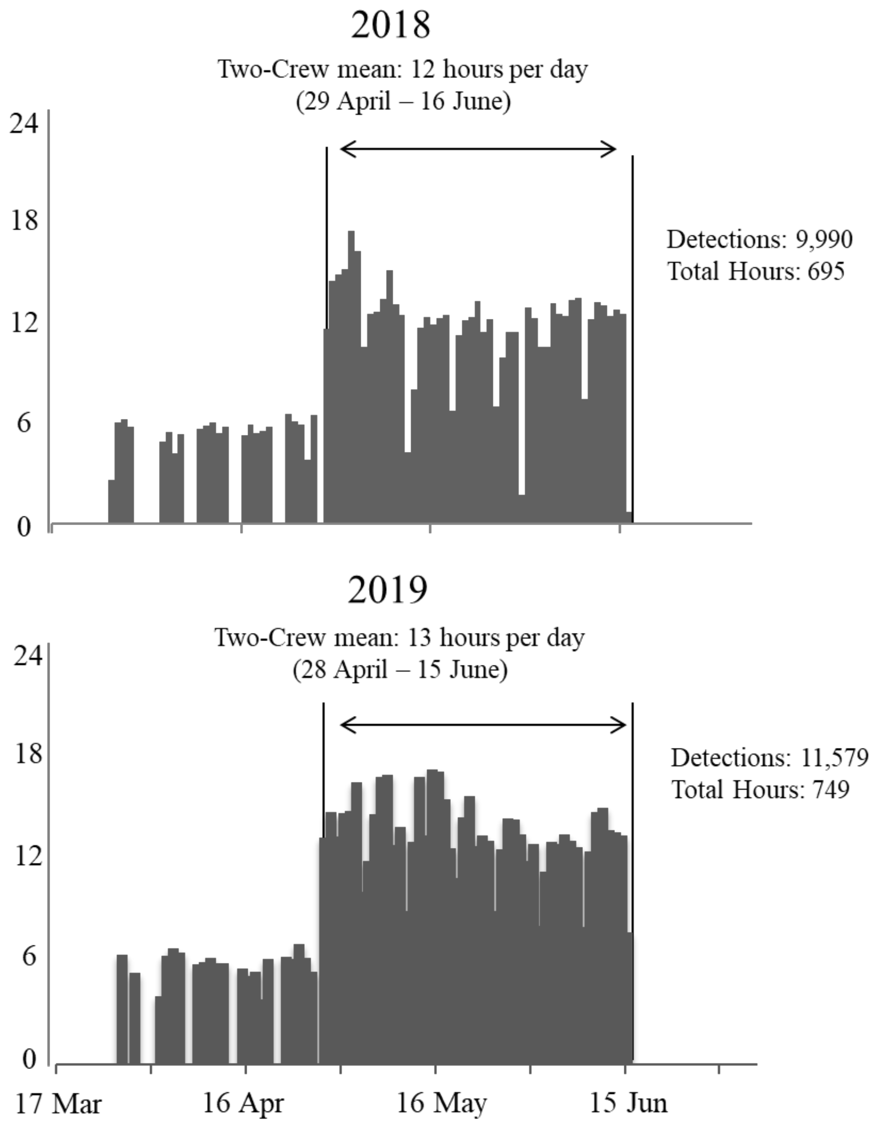

Figure 4. Daily sample effort in spring/summer 2018 and 2019 using the matrix trawl system to detect PIT-tagged juvenile salmon migrating in a tidal freshwater reach of the Columbia River estuary between rkm 66 and 84.

Species, Rear Type, and Migration History of Detected Salmonids

In 2019, the matrix trawl detected a total of 11,144 fish of known species and rear type (hatchery vs. wild) plus another 435 fish lacking release information in PTAGIS (Table 1; Appendix Table 1). Of those fish, at least some species information was available; however, 289 detected fish had no release or species information associated with their respective tags.

Species composition—Of fish detected with the matrix system, species composition was 41% spring/summer Chinook, 6% fall Chinook, 43% steelhead, 4% sockeye, and 3% coho salmon. Of the remainder, less than 1% were cutthroat trout and 2% were unknown salmonid species. Total detections by rear type were 19% wild, 77% hatchery, and 4% unknown origin at the time of this report. These numbers may change slightly as PTAGIS records are completed or updated.

Table 1. Species composition and rear type of PIT-tagged fish detected with the trawl system in the upper Columbia River estuary near rkm 75 in 2019.

	Rear type			
Species/Run	Hatchery	Wild	Unknown	Total
Spring/Summer Chinook salmon	4,075	620	19	4,714
Fall Chinook salmon	662	1	2	665
Coho salmon	269	130	0	399
Steelhead	3,551	1,403	21	4,975
Sockeye salmon	393	36	104	533
Sea-run Cutthroat	0	4	0	4
Unknown	0	0	289	289
Grand total	8,950	2,194	435	11,579

For all species, proportions of fish detected by rear type in 2019 were similar to those in 2018. 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).

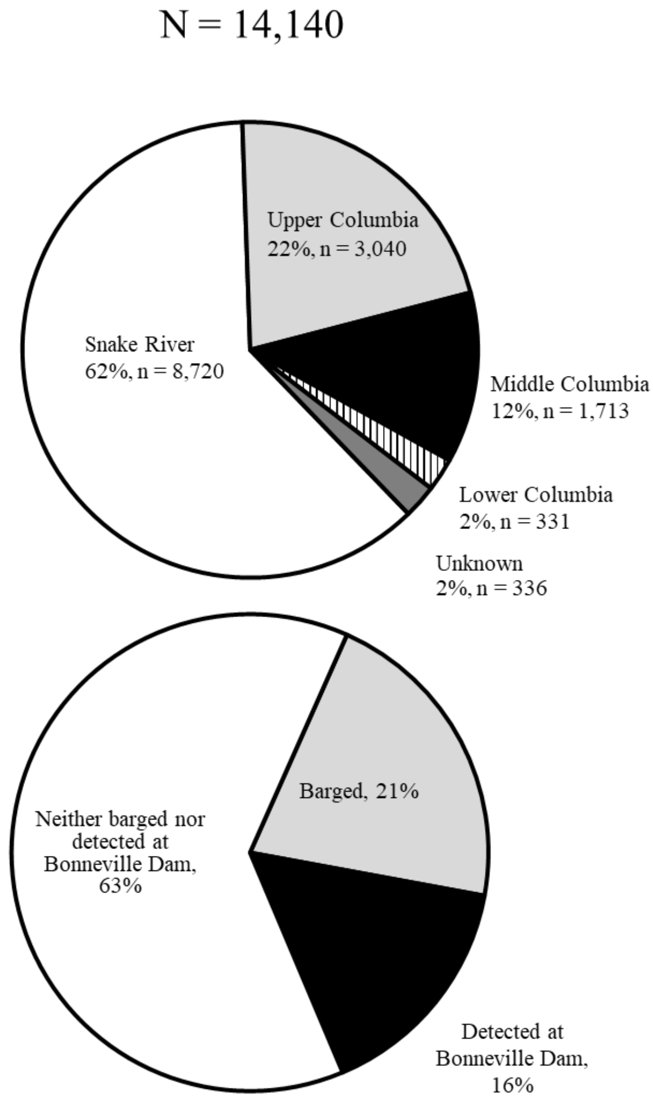

Figure 5. Proportions of fish detected in the Columbia River estuary by source and migration history, 2019. Upper and middle Columbia River sources were defined relative to McNary Dam. Fish that originated in the Columbia River below Bonneville Dam could not be transported, nor could they pass Bonneville Dam. These data include detections from both matrix trawl and flexible antenna systems.

Subyearling fall Chinook salmon—Fish considered subyearlings were those that measured less than 150 mm fork length (FL) at tagging and were released after 8 April 2019. Based on these criteria, we detected 273 transported and 519 in-river migrant subyearling fall Chinook in the estuary between early April and mid-June (Figure 6). Of the 792 total subyearlings detected, 94% originated in the Snake River, 1% in the Upper Columbia River at or above McNary Dam, and 5% in the Mid-Columbia River between Bonneville and McNary Dam. No subyearlings were detected from the Lower Columbia River below Bonneville Dam.

Juvenile subyearling fall Chinook salmon begin the downstream migration from late spring to fall, but some of these fish suspend migration and overwinter in freshwater, resuming migration in the following spring. Fish adopting this strategy are referred to as "holdovers" (Connor et al. 2005). In years with high numbers of tagged subyearling Chinook salmon, we commonly detect a few fish exhibiting this life history type; however, we detected only three holdover fish in 2019.

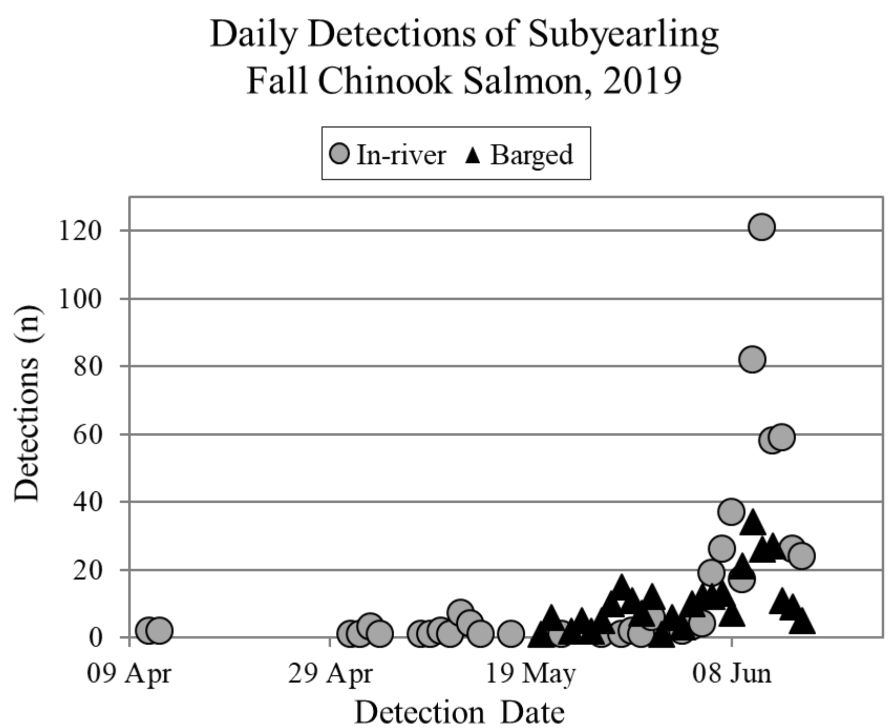

Figure 6. Temporal distribution of subyearling fall Chinook salmon detections in the Columbia River estuary near rkm 75 during in-river migration (n = 519) or following release from barges below Bonneville Dam (n = 273), 2019. These data include detections from both matrix trawl and flexible antenna systems.

Sockeye salmon—We detected 676 sockeye salmon between 2 May and 15 June (Figure 7). Of these, 71% were hatchery fish, 7% were wild fish, and the remaining 22% were of unknown origin. Fish released in the Snake and Columbia River Basin upstream from McNary Dam comprised 75 and 24%, respectively, of our sockeye salmon detections, while fish released between McNary and Bonneville Dam comprised less than 2%. Transported fish accounted for 48 of the sockeye salmon detections. Of those transported, 26 had been collected at Lower Granite Dam, 10 at Little Goose Dam, and 12 at Lower Monumental Dam.

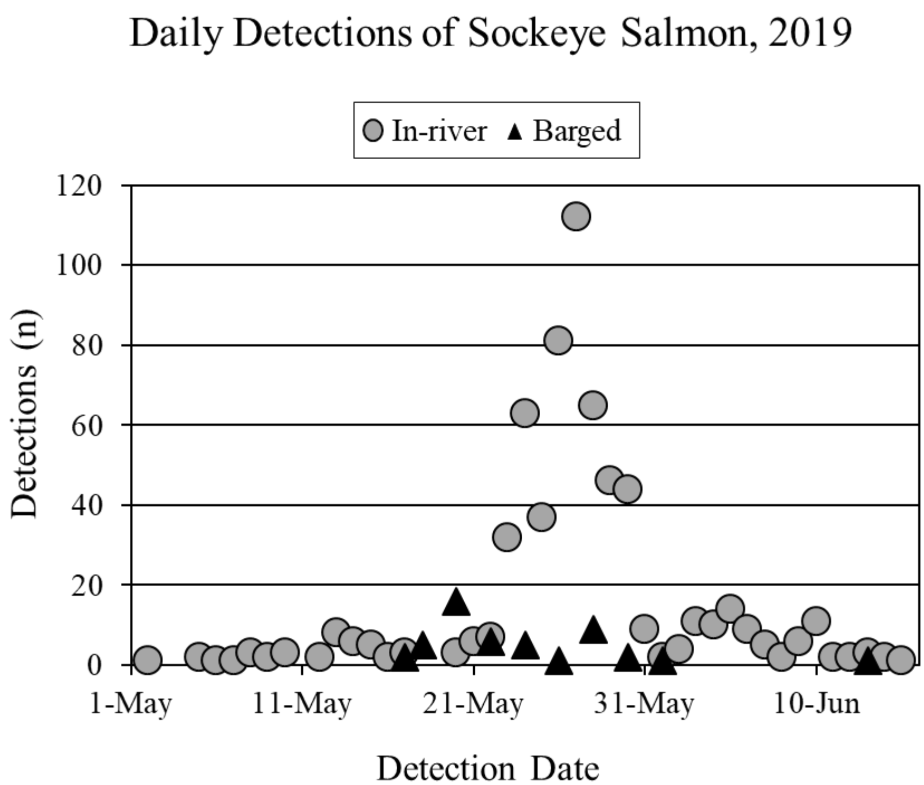

Figure 7. Temporal distribution of sockeye salmon detections in the Columbia River estuary near rkm 75 during in-river migration (n = 628) or following release from barges below Bonneville Dam (n = 48), 2019. These data include detections from both matrix trawl and flexible antenna systems.

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 remaining 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 2019, we recovered 238 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 1-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 7-minute periods.

Fish appeared to move more readily through the system at night, probably because the trawl and antenna were less visible during darkness hours. Lower visibility at night also appeared to reduce the tendency of fish to pace near the entrance of the trawl body. A floor extending forward from the trawl body is designed to discourage fish from sounding to escape the trawl; however, fish likely sense the head rope and cork line that crosses between wings at the surface of the trawl body. Since we began using the larger matrix antenna system, detections during periods when the wings were held open have increased by about 10% (Magie et al. 2010).

Development of a Flexible Antenna Detection System

Background

In 2019, we continued development of a towed, flexible antenna system that eliminated the need for a net to concentrate and guide fish within range of the antennas. This new design was based on antenna technology adapted for a stationary PIT-tag monitoring system installed along a pile dike at rkm 70 (Magie et al. 2015). Our goals in developing this system were to reduce costs associated with sampling juvenile salmonids in the estuary, improve sample efficiency using recent advances in PIT technology, and eliminate impacts on ESA listed species, as well as the requirement for ESA permitting (no take of salmonids would occur).

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

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

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

In 2018, we replaced our hand-assembled hose antennas with a new manufactured antenna cable. In addition, for the first time, the maximum array size of twelve antennas was used for the entire sampling season, and the flexible antenna system detected over three times the number of fish detected in 2017 (Holcombe et al. 2019). Our main objectives in 2019 were to continue comparative sampling with the flexible and matrix trawl systems while utilizing the twelve-antenna array and to continue to reduce EMI while under tow. By simultaneously sampling with both systems during the peak juvenile migration period, we were able to compare species composition and sample efficiency between the two systems.

Methods

We designed the flexible antenna system to be modular, wherein antennas could be easily added or removed from an array (Figure 8). A controller area network (CAN bus) power and communications cable was routed along the towline, extending from the deployment vessel to the watertight reader capsule on the first antenna. Additional short CAN bus cables were then connected consecutively between additional capsules until all antennas were connected.

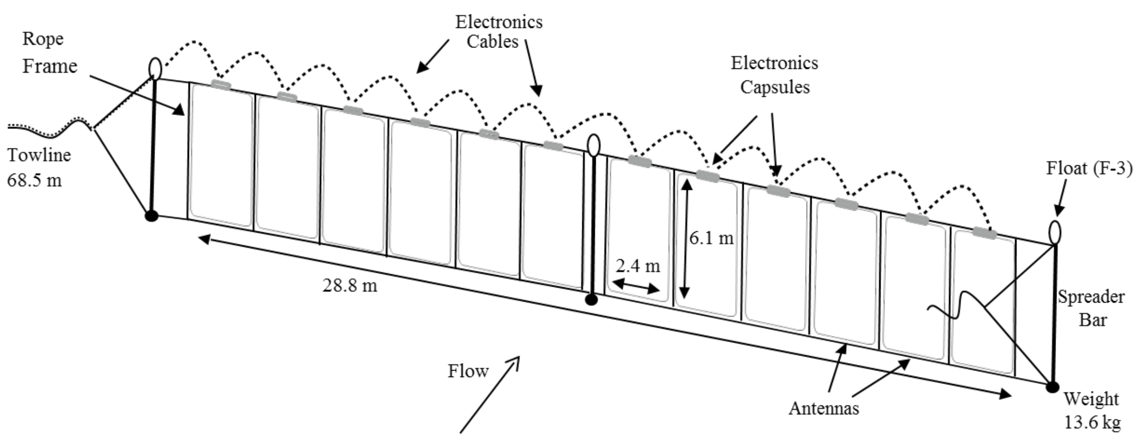

Figure 8. Basic configuration of the twelve-antenna flexible array and modular rope frame system tested in 2019. This array produced a total reading range approximately 29 m wide by 6 m deep.

After the 2018 sample period, we continued efforts to improve flexible antenna system performance by redesigning the CAN bus cables used in the array. Our new design eliminated electrical coupling between drain wires. Coupling observed in the previous CAN bus cable had resulted from poor insulation of power and communication networks within the cable. The primary objective of these efforts was to further reduce EMI and improve detection efficiency of the system. Cables were constructed in the off-season, and initial testing was conducted in February 2019, prior to the peak juvenile migration season. The new cables showed positive results and were used throughout the 2019 sample season.

Sampling in 2019 utilized an 11.5-m primary vessel that transported the array and housed the electronics, as well as a 7.3-m secondary tow vessel. A third vessel (6.4-m work skiff) monitored antenna configuration and tested system performance using a "stick fish" comprised of a PIT tag attached to a pole. Once the antenna array was fully deployed and extended, both tow vessels motored upstream into the current while holding the array open. A radar range finder was used to maintain a distance of roughly 152 m between vessels for full extension of the array.

Similar to the matrix trawl system, the flexible antenna system moved downstream within the sample reach during deployment. While it was difficult to judge tow speed through the water against strong river currents, we estimated that approximately 1.7 kn was the maximum tow speed possible without producing excessive vibration-related EMI, which compromised detection efficiency. This estimate represented the difference between a dead drift speed of 1.9 kn, measured by the skiff, and a downstream movement rate of 0.2 kn, based on GPS data for the main tow vessel. Vessels were essentially idle (dead drift speed) at 900 rpm. By comparison, the matrix trawl system tows at about 1.2 kn with the net fully deployed.

We chose an array of twelve flexible antennas to evaluate performance in comparison with the matrix trawl system during simultaneous sampling. The detection field generated by the flexible array was approximately 29 m wide by 6 m deep (Figure 8). Under tow, there was a slight curve to the array that varied with the distance between tow boats. The distance between vessels was critical to maximize width of the detection field without over-straining the system. Measured depth of the flexible array was about 6 m, but the detection field extended about 0.3 m above and below the antennas.

Rectangular antennas within the array were towed in a side-by-side, vertical orientation at a pace that matched the trawl (1.2 kn). To provide additional stability and strength, all antennas were attached to a 6.4-mm-diameter static rope frame. The rope frame extended 3 m beyond the antennas and attached to two 6.7-m aluminum spreader bars, with one bar on each distal end of the array. Each bar contained 13.6 kg of weight on one end and a buoy on the other to maintain the array in a vertical orientation in the water column and submerged about 0.5 m below the surface (Figure 8). Previous evaluations showed a decline in detections when the top meter of water was not sampled, so these weights and buoys were used to maintain the system near the surface. An additional spreader bar (with no weight) was placed in the center of the array to maintain vertical spread and shape of the array while under tow.

Detection data files were uploaded weekly to PTAGIS using standard methods described in the *PTAGIS Data Specification* (PSMFC 2019). Flexible system detections were designated in the PTAGIS database with site code TWX, and were distinguished from trawl detections using the antenna group name “Towed Flexible Antenna System.”

Trawl sample design, operation, and equipment remained unchanged during comparative sampling. We deployed the matrix trawl system following its normal schedule, and the flexible antenna system was generally deployed nearby and within 1 km of the trawl. Distance between the two systems was adequate to ensure that simultaneous deployment did not affect the availability of fish for potential detection in the trawl system. Based on detections in the trawl system, we observed no migration delay or avoidance behavior of juvenile migrants after passing through the flexible system. Performance of the trawl system was meant to act as a reference from which to measure performance of the new system, so every effort was made to ensure standard operations were conducted.

To evaluate performance differences between the matrix trawl and flexible antenna system, we compared daily detection ratios and species composition as we have done in previous years. We expanded this analysis in 2019 by evaluating daily detection data to assess any differences in detection rate between the two systems after accounting for overall differences in date, river flow, and tidal change. Fish included were those detected in the matrix trawl system or the flexible antenna system during the intensive sample period (28 April-15 June). Our metric to make this assessment was the proportion of daily total detections that occurred on the flexible antenna system.

The proportion of daily total detections by the flexible system was estimated using logistic regression (Hosmer and Lemeshow 2000; Ryan et al. 2003). Components of the logistic regression model included the proportion of all detections occurring on the flexible antenna system as the response variable, with date and date-squared, river flow (m^3/s), tidal change (ft/h), and interactions 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 flexible antenna detection proportions were estimated as:

$$\widehat{p_i} = \frac{e^{\widehat{\beta_0}+\widehat{\beta X_i}}}{1 + e^{\widehat{\beta_0}+\widehat{\beta X_i}}}$$

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

First, we fit the model containing all covariates and interactions. 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 tested covariates. 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).

Next, the model was reduced depending on the significance(s) of coefficients, starting with the least significant term. We fit the reduced model and repeated that step. The final model was the most reduced from this process where all remaining terms were significant. One constraint was that interaction terms were only included if both covariates were in the model. Another 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.

We assumed that daily groups of PIT-tagged fish were subject to the same sampling effort. Therefore, differences in relative detection rate between the matrix trawl and flexible antenna system would reflect differences in sample rates between methods. Data for all comparisons were taken only from periods when both systems were deployed and operational. Detection data obtained during tests of electronic settings or system equipment were omitted from comparative analyses.

Results and Discussion

Detection Rates

In 2019, we detected 2,707 PIT-tagged fish during 229.6 h of sampling across 41 d using the twelve-antenna flexible system. These included 1,442 Chinook (53%), 192 coho (7%), 869 steelhead (32%), 150 sockeye (5%), 2 cutthroat trout (0.1%), 4 white sturgeon (0.2%), and 48 fish without species data available in PTAGIS (2%). These detection rates were considerably higher than in 2018, when we detected 755 fish during 136.0 h of sampling across 30 d using the twelve-antenna flexible system.

Detected species in 2018 included 296 Chinook (39%), 29 coho (4%), 368 steelhead (49%), 50 sockeye (7%), and 12 fish without species data (2%). Increased detection efficiency in 2019 was largely due to the use of newly constructed CAN bus cables and the resulting decrease in testing and troubleshooting that was required compared to 2018.

Performance of the Flexible Antenna vs. Matrix Trawl System

During the 2019 season, there were 40 dates (214.9 h total) when the towed flexible antenna system was fully operational, and sampling was comparable to the trawl system (Appendix Table 3). During these deployments, the average proportion of daily total detections occurring on the flexible antenna array was 35%, with daily flex/total ratios ranging from 11 to 74%.

Species composition of detections from both systems was compared to the species composition of fish detected at Bonneville Dam, a proxy for fish available for detection within the sample reach (Table 2). These proportions indicated that the present configuration of the flexible system detected adequate numbers of Chinook salmon and steelhead; both are species of importance for annual hydrosystem survival estimates (Widener et al. 2018). The increased electronic stability dramatically improved system function and increased total detections relative to the matrix trawl from 2018 to 2019.

For Chinook salmon, logistic regression analysis showed no significant effect for flow ($P = 0.561$) or tidal change ($P = 0.560$) or for interaction terms (P-range = 0.209-0.654). However, there were significant effects for both date ($P = 0.028$) and date-squared ($P = 0.029$). The estimated proportion of flexible antenna detections started at around 0.25 early in the season, increased to 0.50 between mid-May and early June, and then decreased to 0.35 by the end of the season (Figure 9, top panel). Therefore, during the middle of the intensive sampling period, average detection rates were fairly equal between the flexible antenna and matrix trawl system. The adjustment for overdispersion was 7.3.

Table 2. Total detections (n) and species composition (%) for the flexible antenna and matrix trawl systems in the Columbia River estuary, 2019. Species composition of detections at Bonneville Dam during our intensive sample period is included as a reference for species composition of tagged fish present in the estuary during sampling.

	Flexible antenna system		Matrix trawl system		Detection at Bonneville Dam	
Species	(n)	(%)	(n)	(%)	(n)	(%)
Chinook salmon	1,141	52.4	1,438	40.8	35,945	45.8
Steelhead	710	32.6	1,716	48.7	31,465	40.1
Coho salmon	159	7.3	124	3.5	3,974	5.1
Sockeye salmon	124	5.7	147	4.2	5,305	6.8
Cutthroat trout	2	<1	3	<1	17	<1
White Sturgeon	4	<1	0	0	3	<1
Unknown	37	1.7	96	2.7	1,779	2.3
Total	2177	100	3524	100	78,488	100

For steelhead, logistic regression analysis showed no significant effect for date (P = 0.060), date-squared (P = 0.063), flow (P = 0.298), or interaction terms (P-range = 0.647 to 0.818). However, tidal change had a significant effect (P = 0.051). The estimated proportion of detections occurring on the flexible antenna system was around 0.30 for the season, except for the weeks starting 5 May and 3 June, when strong ebb tides occurred during sampling, and the estimated detection proportion increased to nearly 0.40 (Figure 9, lower panel). The average proportion of steelhead detections on the flexible antenna system was 0.38 during ebb tides but only 0.23 during flood tides (Figure 10). The adjustment for overdispersion was 5.7.

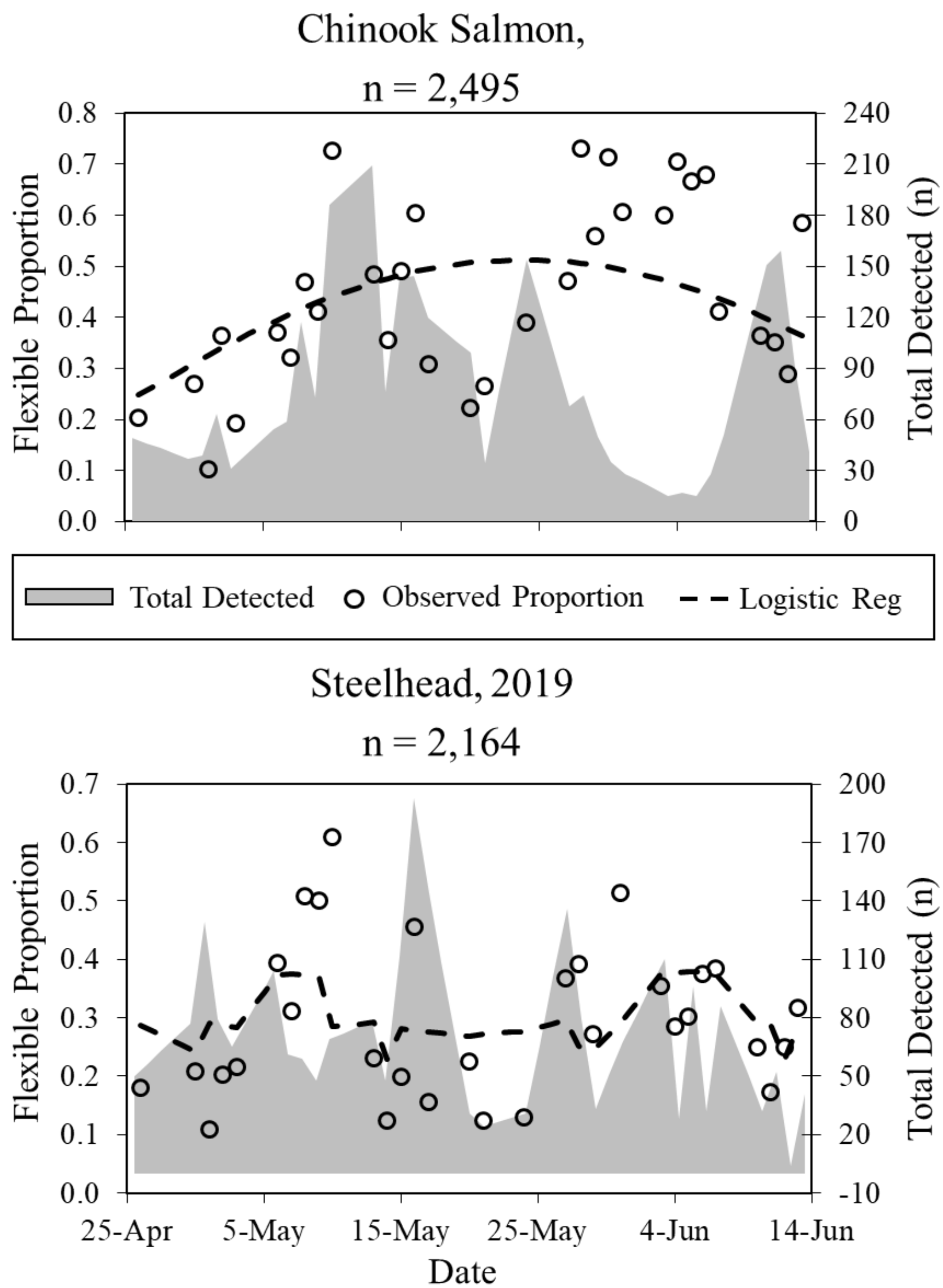

Figure 9. Estimated daily proportion of total detections occurring on the flexible antenna system for Chinook salmon and steelhead in the Columbia River estuary, 2019. Total detections included those occurring on both the flexible antenna and matrix trawl systems.

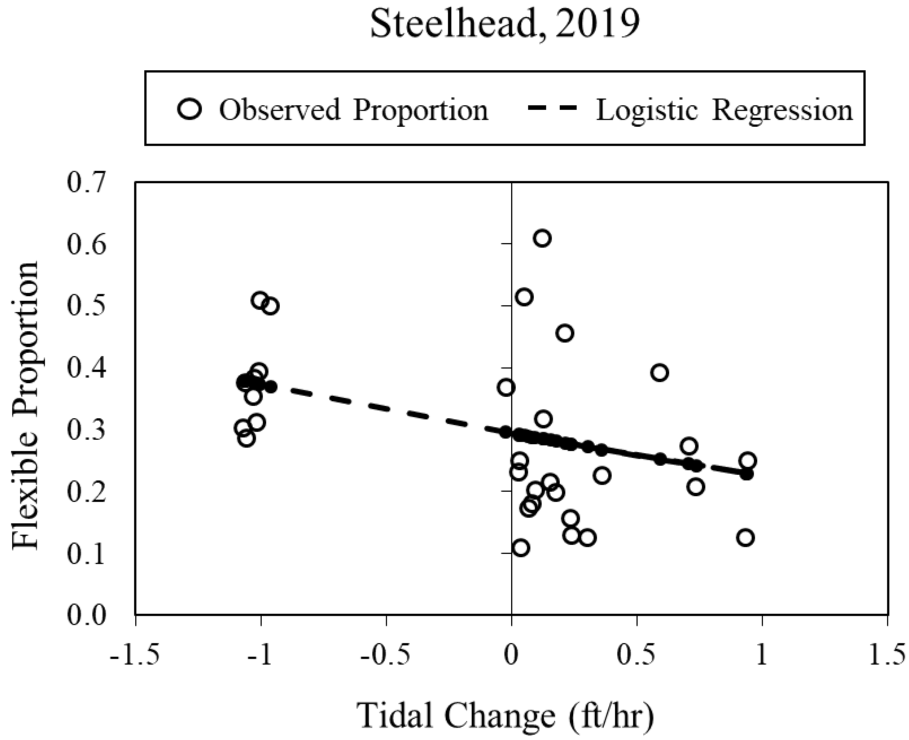

Figure 10. Estimated proportion of total steelhead detections on the flexible antenna system by tidal direction in the Columbia River estuary, 2019. Negative tidal change values indicate an ebb (outgoing) tide, while positive values indicate a flood (incoming) tide.

Objectives for Future Development

During 2019, we achieved our primary objective of determining detection rate of the flexible antenna relative to the matrix trawl system. Electrical issues that compromised the comparison in 2018 had been addressed, allowing for a more successful sample season in 2019 with more than three times the number of detections. Our new CAN bus cables improved system performance and considerably decreased EMI.

In 2020, we will focus on increasing sampling efficiency and safety using mechanical methods for deployment and retrieval of flexible antenna gear. Thus far, our main goals have been to develop functional antennas and improve their detection capability relative to the matrix trawl. Through this development period, we have been setting and retrieving the flexible antennas by hand. This process can be extremely difficult, especially during inclement weather.

To use the flexible antenna system as our principle sample system in the lower estuary, we need to incorporate an automated net reel. This will alleviate complications that arise during deployment and will ensure seasonal staff are able to deploy and retrieve the gear safely and efficiently. The transition to a net reel will require a redesign of the capsules used to house the IS1001 readers. A flat, more hydrodynamic design for the reader capsules will allow them to lay flat and be stacked on the net reel without damage, as well as reducing drag on the system while under tow. Both of these improvements will be developed and tested during the 2020 season.

While further development is needed for the flexible antenna system, there are considerable advantages of moving away from use of the matrix trawl system. First, the transceiver for the new IS1001 sampling equipment is easier to maintain than the older FS1001M transceiver, which is no longer commercially manufactured or serviced (Biomark Inc.). Second, the flexible antenna array is modular so that antennas and other system components can be easily exchanged to replace broken or malfunctioning parts. The large trawl net is expensive and requires extensive maintenance. Third, the flexible system does not impact fish, including ESA-listed fish.

Therefore, no ESA permitting would be required for sampling with the flexible antenna system because no salmonid take would occur. In contrast, permitting is mandatory for use of the trawl net. Finally, the flexible system is easier to maneuver and can thus sample shallower water than the matrix trawl system, which is restricted to the deepest channel of the river. The flexible system has potential to sample new habitats, and the technology is transferrable to small streams, reservoirs, and large open bodies of water. These are each important objectives for future development and utilization of the flexible antenna system.

Analyses from Estuary Detection Data

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

These detection data are necessary for unbiased estimates of survival because they provide the means to distinguish probability of detection vs. probability of survival at Bonneville Dam. Unbiased estimates of survival, in turn, are critical to research and management programs for endangered salmonids in the Snake and Columbia River Basins and in other basins of the Pacific Northwest (Widener et al. 2018).

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

In the following section, we explore differences in travel time and migration rate by species and migration history, patterns in diel detection by rear type and species, and detection rates by migration history using data collected in 2019.

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 2019, fish were transported from Lower Granite, Little Goose, and Lower Monumental Dam on the Snake River. Our analysis included all transported fish detected in the trawl or flexible antenna system, regardless of collection location. We compared groups of transported fish released below Bonneville Dam to groups of fish detected at Bonneville Dam on the same date (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-). We considered a fish transported only if the last detection of that fish recorded in PTAGIS 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 2019 transportation season (Eric Hockersmith, USACE, personal communication). By comparing barge-loading times with the last detection time of fish diverted to transport raceways, timing of the individual barge-transport trip for each fish could be determined. 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 or flexible antenna system.

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 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 both yearling Chinook salmon and steelhead, median travel time for in-river migrants was slower in 2019 than in 2018, and more similar to the 18-year average (1.8 d; Table 3). For yearling Chinook, median travel time was 1.9 d in 2019, compared to 1.5 d in 2018. For steelhead, median travel time was 1.7 d in 2019, compared to 1.4 d in 2018. Similarly, for transported yearling Chinook, median travel time was slower in 2019 at 2.5 d, compared to 1.6 d in 2018. For transported steelhead, median travel time was also slower in 2019 (1.6 d) than in 2018 (1.5 d), but was the third fastest travel time on record for that group.

Table 3. Median travel time to detection in the estuary during intensive sample periods for yearling Chinook salmon and steelhead previously detected at Bonneville Dam or released from barges just downstream from Bonneville Dam, 2000-2019. Also shown are mean flow rates at Bonneville from 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

* 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 migration rate was significantly slower for transported fish than for in-river migrants detected at Bonneville Dam (61.1 vs. 84.8 km/d; $P < 0.001$). Similarly, for steelhead, average daily median migration rate was significantly slower for transported fish than for those detected at Bonneville Dam on the same day (85.8 vs. 96.7 km/d; $P < 0.001$). These differences in travel speed by migration history were similar to observations from previous years (Figure 11).

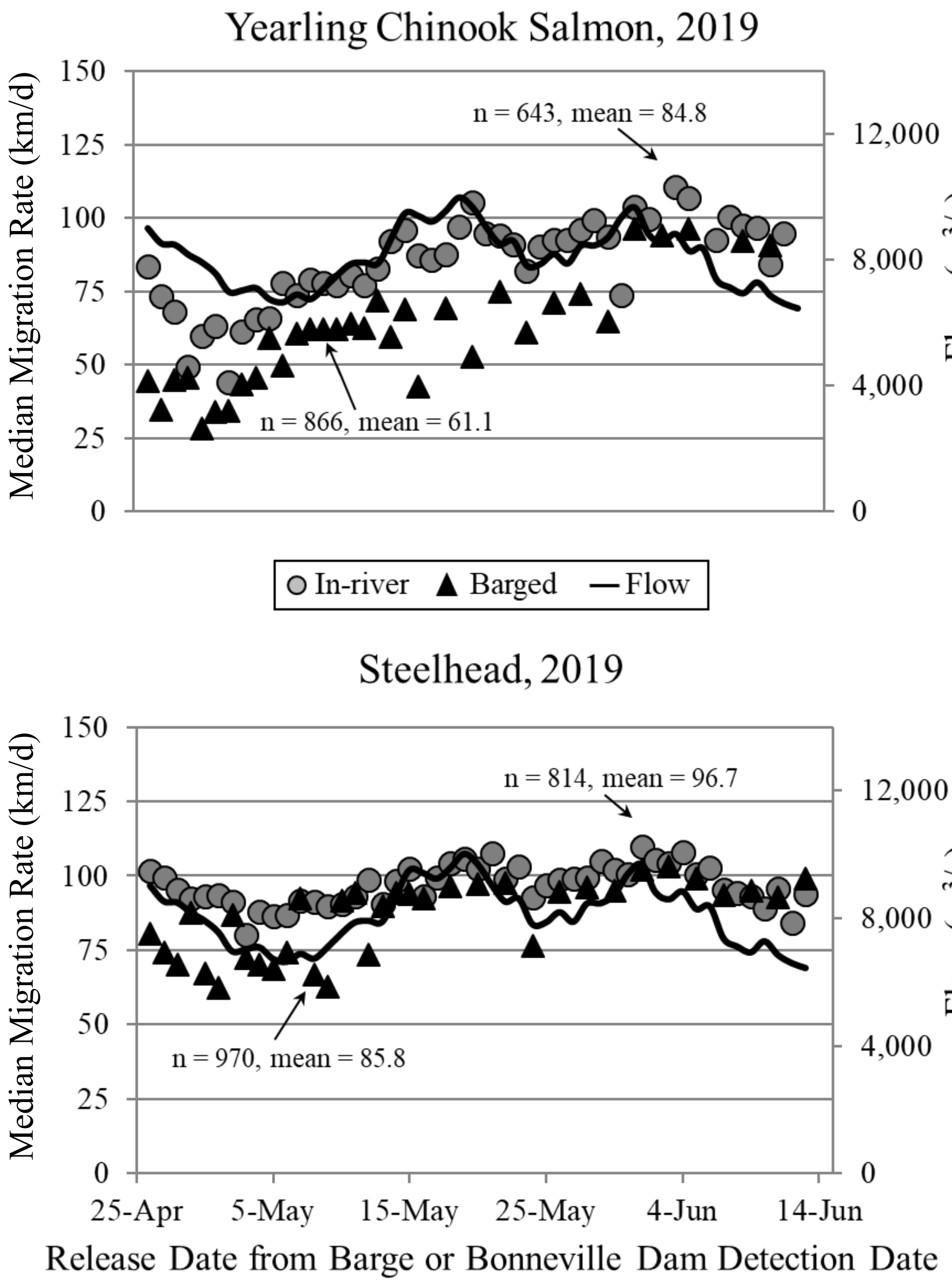

Figure 11. Daily median migration rate of yearling Chinook salmon and steelhead following detection at Bonneville Dam or release from a barge to detection in the upper Columbia River estuary, 2019. Seasonal means are shown for comparison with flow.

Subyearling Chinook and sockeye salmon—Of the 519 in-river migrant subyearling Chinook detected in the estuary, only 35 had been previously detected at Bonneville Dam. In addition, we detected 273 transported subyearlings. Mean migration rate from Bonneville Dam to the estuary was slower for transported fish than for fish detected at Bonneville Dam (46.1 vs. 78.5 km/d), though data were insufficient for statistical comparison. Analysis in prior years has consistently shown faster migration rates for subyearling fall Chinook detected at Bonneville Dam than for those transported and released below the dam (Holcombe et al. 2019).

Of the 676 sockeye salmon detected in the estuary, 191 had been previously detected at Bonneville Dam and 48 had been transported. Mean migration rate was slower for transported (95.3 km/d) than for in-river migrant sockeye (105.9 km/d), though data were insufficient for statistical comparison.

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 detected in the matrix trawl system during the intensive sample period (28 April-15 June). For each date within this period, we grouped the number of detections and total sampling effort (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 4,673 yearling Chinook salmon and 4,677 steelhead, with the matrix trawl system operating an average of 13 h/d (Appendix Table 4). In general, sampling was suspended each day between 1400 and 1900 PDT for crew changes and refueling.

For hatchery yearling Chinook salmon, hourly detection rates were significantly higher during darkness than during daylight hours (9.0 vs. 4.5 fish/h; $P < 0.001$; Figure 12). For wild Chinook salmon, average detection rates were also higher during darkness than during daylight hours; however, the differences were not statistically significant (1.1 vs. 0.8 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 (6.2 vs. 2.9 fish/h; $P < 0.001$). Similarly, for wild steelhead, there was a significant difference in detection rate between daylight and darkness hours (2.7 vs 1.0 fish/h; $P = 0.001$).

Differences in diel detection rates of steelhead remained constant throughout the intensive sampling period, although there were two nights in early June when average detection rates were up to 2.4 times greater during darkness than during daylight hours (Figure 12). This anomaly was analogous to those seen on two nights in June 2017 and late May 2018, when detection rates for steelhead were up to 6 and 7 times greater, respectively, during darkness than daylight hours.

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 2019, so we pooled steelhead rear types for the multi-year summary shown in Figure 13. 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 2019, 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 often significantly higher in recent years.

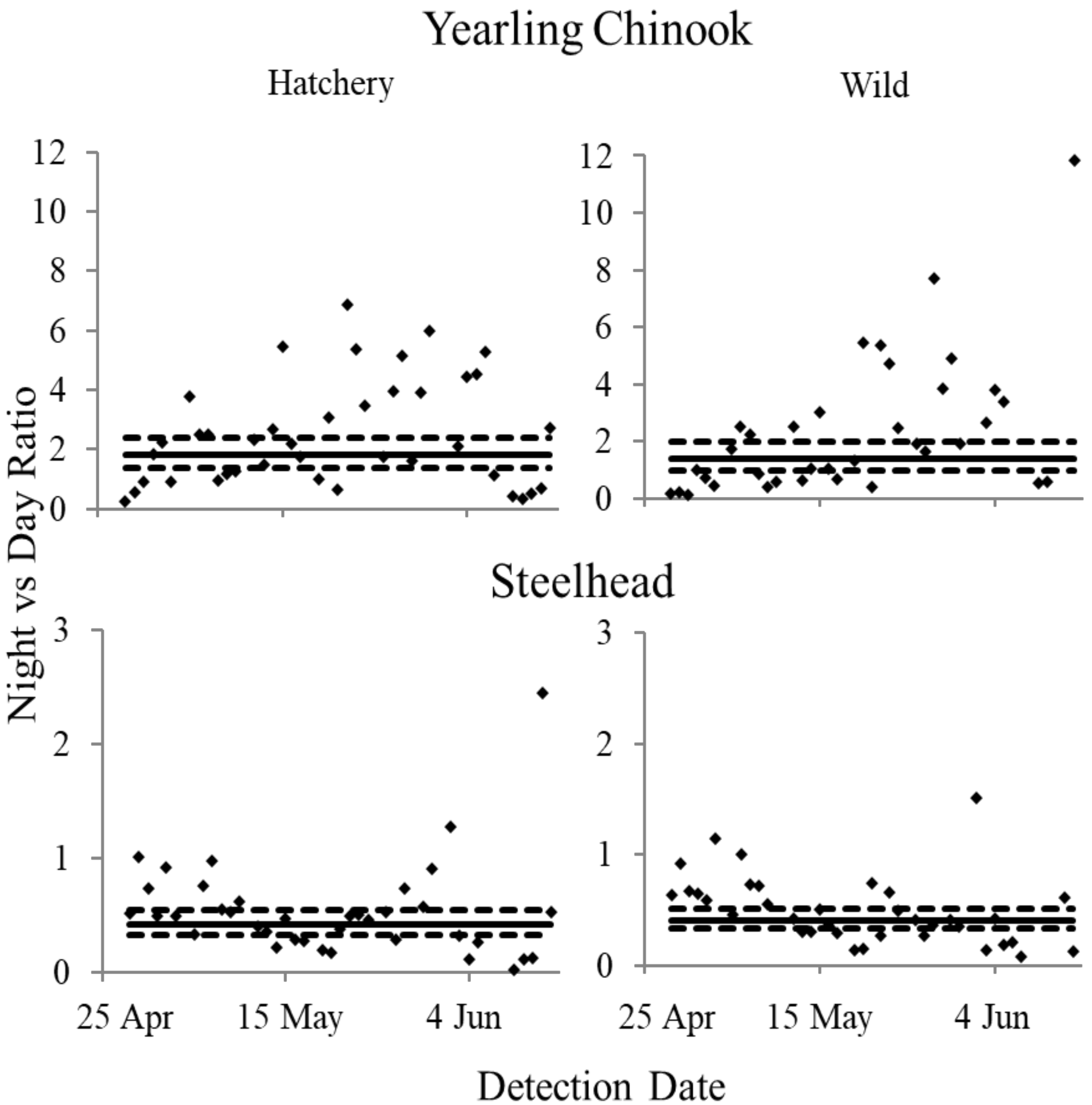

Figure 12. Daily ratios of darkness/daylight detection rates for wild and hatchery yearling Chinook salmon and steelhead in the Columbia River estuary during intensive sampling, 28 April-15 June 2019. Ratios greater than 1.0 indicate higher detection rates in darkness hours, and values less than 1.0 indicate higher detection rates in daylight hours. Solid lines are estimated mean ratios, and dotted lines are estimated 95% confidence intervals.

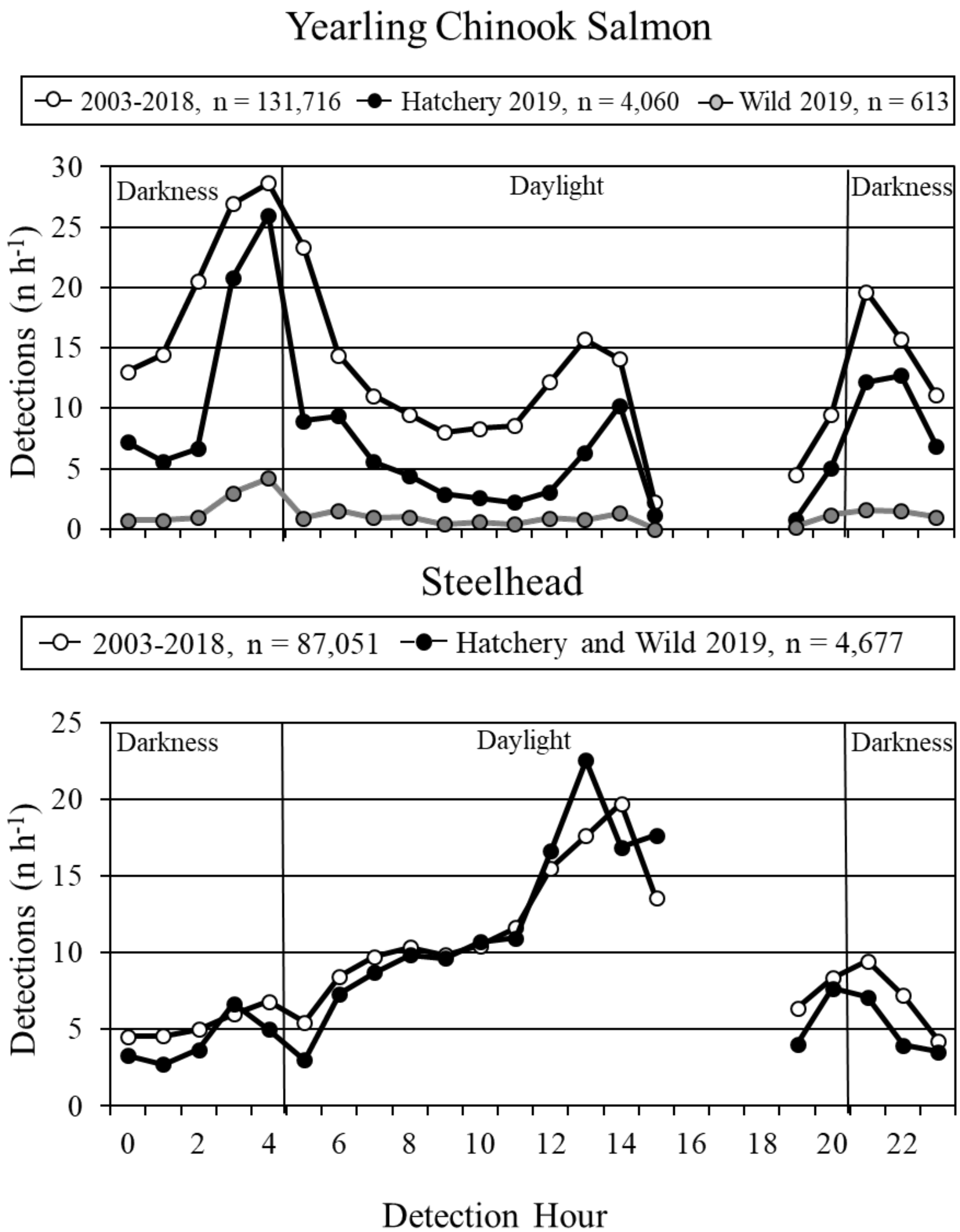

Figure 13. Average hourly detection rates of yearling Chinook salmon and steelhead during intensive sampling with the matrix trawl system in the Columbia River estuary during 2003-2018, vs. 2019. Hatchery and wild rear types are plotted separately for Chinook in 2019 due to different diel patterns; steelhead rear types are combined because there was no difference between their diel detection patterns.

Detection Rates of Transported vs. Inriver Migrant Fish

Methods

We compared daily detection rates in the trawl between transported fish and in-river migrants previously detected at Bonneville Dam. Fish included were only those detected in the matrix trawl system during the intensive sample period of 28 April-15 June. We evaluated these data to assess whether differences in detection rate were related to 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.

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

Results and Discussion

A total of 49,735 yearling Chinook salmon and 53,971 steelhead were transported and released below Bonneville Dam during our intensive sample period. These included fish diverted to barges for NMFS transport studies and fish tagged and transported for other studies. Of these transported fish, we detected 751 yearling Chinook salmon and 1,403 steelhead in the upper estuary (1.5 and 2.6%, respectively).

A total of 31,017 yearling Chinook salmon and 25,172 steelhead were released upstream from McNary Dam and detected at Bonneville Dam. Of these in-river migrants, we detected 514 yearling Chinook salmon and 675 steelhead (1.7 and 2.7%, respectively).

As in previous years, a portion of tagged fish from both the transport and in-river migrant groups passed through the estuary either before or after the intensive sampling period. We estimated the proportions of tagged fish from these groups that were available in the estuary during our intensive sample period (28 April-15 June 2019), allowing 2 d for fish to reach the sample area from Bonneville Dam.

For yearling Chinook, we estimated that 84% of tagged in-river migrants and 93% of tagged transported fish passed through the sample reach during our intensive sample period. For steelhead, we estimated that 90% of tagged in-river migrants and 84% of tagged transported fish passed during our intensive sample period. For yearling Chinook, these percentages were higher than those estimated in 2018 for both in-river and transported fish. For steelhead, these percentages were higher than those in 2018 for in-river fish, but lower than those in 2018 for transported fish.

During intensive sampling in 2019, average sample effort was 13 h/d, which was slightly more than the average effort of 12 h/d in 2018. For yearling Chinook and steelhead, both transported fish and those detected passing Bonneville Dam had higher rates of trawl detection in 2019 than 2018 (Table 4).

Table 4. Trawl detection rates of PIT-tagged Chinook salmon and steelhead released from barges or detected passing Bonneville Dam during the intensive sample periods in the upper Columbia River estuary near rkm 75, 2018 and 2019.

	Barged fish originating upstream from McNary Dam			In-river fish detected at Bonneville Dam*		
	Released	Detected		Released	Detected	
Year/species	(n)	(n)	(%)	(n)	(n)	(%)
2018						
Chinook salmon	73,831	547	0.74	19,265	196	1.02
Steelhead	75,535	1,637	2.17	18,309	269	1.47
2019						
Chinook salmon	49,735	751	1.51	31,017	514	1.66
Steelhead	53,971	1,403	2.60	25,172	675	2.68

* In-river fish included only those released at or upstream from McNary Dam. No fish were transported from McNary Dam in 2019.

For yearling Chinook salmon, logistic regression analysis showed no significant effect from interaction between date-squared and migration history (P = 0.158), or between date and migration history (P = 0.374). Neither were there significant effects for date, date-squared, or migration history (P = 0.193, 0.946, and 0.454, respectively). The estimated detection rate remained at about 1.5% for both transported and in-river yearling Chinook for the entire season (Figure 14, top panel). The adjustment for overdispersion was 4.8.

For steelhead, logistic regression analysis showed no significant effect of interaction between migration history and date-squared (P = 0.414) or between migration history and date (P = 0.360). There were also no significant effects of migration history or date-squared (P = 0.990 and 0.104, respectively). However, there was a significant effect for date (P < 0.001). Estimated detection rates for transported and in-river steelhead increased from under 2.0% at the beginning of the season to over 6.0% by the end of the season (Figure 14, lower panel). The adjustment for overdispersion was 8.4.

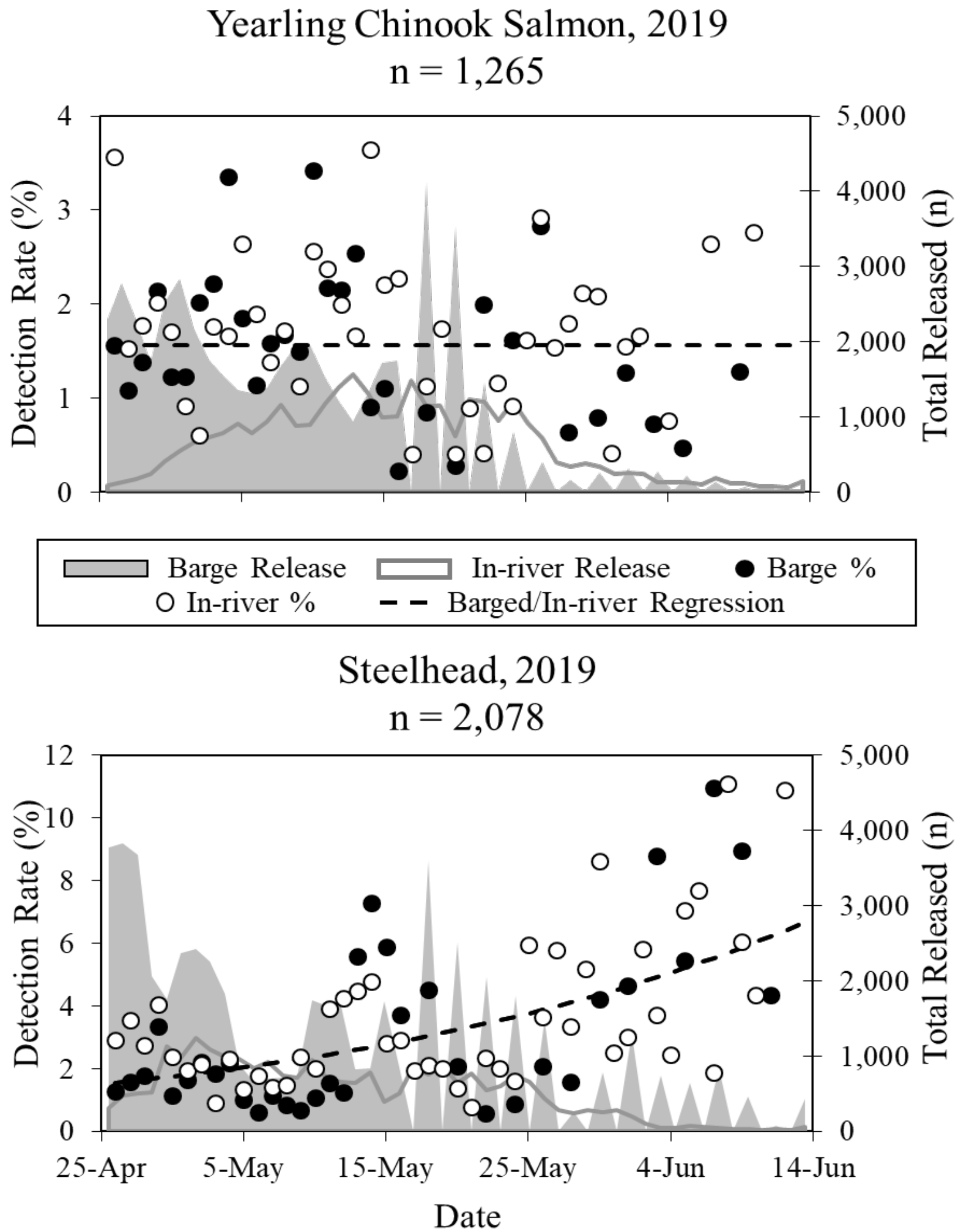

Figure 14. Estimated daily detection rates in the matrix trawl system for transported and in-river migrant yearling Chinook salmon and steelhead in the Columbia River estuary, 2019. All fish were either detected at Bonneville Dam or released from a barge just downstream from the dam on the same date.

For both yearling Chinook salmon and steelhead, estimated daily detection rates in the trawl were similar among in-river migrants and transported fish. In years where differences are present, lower detection rates in one group may represent higher mortality in that group. Over the last 15 years, there has been a general trend toward higher detection rates of in-river migrant Chinook salmon, but no apparent trend for steelhead (Morris et al. 2014). However, detection rates were similar between groups for both species in 2019.

In summary, estuary detection rates were higher in 2019 than in 2018 for all groups. This increase was especially pronounced for transported yearling Chinook, with a detection rate in 2019 more than double the rate in 2018. Decreased river flows likely contributed to the increased detection rates and slower travel times observed in 2019.

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Appendix

Appendix Table 1. Daily sampling effort (h) and detections (n) for each species using the matrix trawl system in the upper Columbia River estuary (rkm 75), 2019.

Date	Total time underway (h)	PIT tag detections (n)						
		Unknown	Chinook salmon	Coho salmon	Steelhead	Sockeye salmon	Cutthroat trout	Total
27 Mar	6.17	0	0	0	0	0	0	0
28 Mar	0.00	--	--	--	--	--	--	--
29 Mar	5.15	0	0	0	0	0	0	0
30 Mar	0.00	--	--	--	--	--	--	--
31 Mar	0.00	--	--	--	--	--	--	--
1 Apr	0.00	--	--	--	--	--	--	--
2 Apr	3.78	0	0	0	0	0	0	0
3 Apr	6.10	0	0	0	0	0	0	0
4 Apr	6.55	0	0	0	1	0	0	1
5 Apr	6.27	0	0	1	0	0	0	1
6 Apr	0.00	--	--	--	--	--	--	--
7 Apr	0.00	--	--	--	--	--	--	--
8 Apr	5.60	0	0	0	4	0	0	4
9 Apr	5.73	0	2	0	0	0	0	2
10 Apr	6.00	0	4	0	1	0	0	5
11 Apr	5.65	0	5	0	0	0	0	5
12 Apr	5.65	0	5	0	2	0	0	7
13 Apr	0.00	--	--	--	--	--	--	--
14 Apr	0.00	--	--	--	--	--	--	--
15 Apr	5.38	0	2	0	4	0	0	6
16 Apr	4.95	0	2	0	4	0	0	6
17 Apr	5.20	1	1	0	13	0	0	15
18 Apr	3.58	1	1	0	3	0	0	5
19 Apr	5.93	0	2	0	20	0	0	22
20 Apr	0.00	--	--	--	--	--	--	--
21 Apr	0.00	--	--	--	--	--	--	--
22 Apr	6.03	2	0	1	47	0	0	50
23 Apr	5.90	2	5	0	26	0	0	33
24 Apr	6.77	0	3	0	64	0	0	67
25 Apr	5.98	1	7	0	47	0	0	55
26 Apr	5.18	2	40	0	41	0	0	83
27 Apr	0.00	--	--	--	--	--	--	--
28 Apr	12.88	2	64	3	200	0	0	269
29 Apr	14.32	5	60	0	138	0	0	203
30 Apr	12.95	3	61	3	144	0	0	211
1 May	14.27	11	79	1	204	0	0	295
2 May	14.37	10	101	5	145	1	0	262
3 May	16.03	12	138	6	140	0	0	296
4 May	9.78	6	32	0	120	0	0	158

Appendix Table 1. Continued.

Date	Total time underway (h)	PIT tag detections (n)						
		Unknown	Chinook salmon	Coho salmon	Steelhead	Sockeye salmon	Cutthroat trout	Total
5 May	11.55	5	70	5	112	2	0	194
6 May	14.23	10	121	3	126	1	0	261
7 May	16.37	6	211	2	125	1	0	345
8 May	16.45	13	306	7	96	1	0	423
9 May	12.43	5	117	1	41	1	0	165
10 May	13.48	5	107	2	59	2	1	176
11 May	8.67	5	72	5	55	0	0	137
12 May	12.63	11	220	6	129	2	0	368
13 May	16.33	8	276	2	147	8	0	441
14 May	12.98	5	182	9	87	4	0	287
15 May	16.80	10	378	9	214	5	0	616
16 May	16.63	13	214	6	227	2	0	462
17 May	15.05	4	259	10	189	4	0	466
18 May	12.28	5	190	14	129	5	1	344
19 May	10.53	5	77	2	131	0	0	215
20 May	14.03	7	126	10	263	19	0	425
21 May	15.28	6	208	6	73	5	0	298
22 May	12.40	3	62	8	83	13	0	169
23 May	12.98	4	62	11	81	32	0	190
24 May	12.67	8	127	13	75	54	0	277
25 May	8.67	2	45	4	30	36	0	117
26 May	12.18	8	106	11	58	82	0	265
27 May	14.00	7	97	19	117	88	0	328
28 May	13.90	6	94	11	65	48	0	224
29 May	13.07	8	47	10	55	35	0	155
30 May	11.52	4	53	7	37	21	0	122
31 May	12.48	3	47	9	38	4	0	101
1 Jun	7.83	3	14	3	85	3	0	108
2 Jun	10.93	3	18	7	44	4	0	76
3 Jun	12.62	7	22	10	84	7	0	130
4 Jun	12.48	5	26	5	35	5	0	76
5 Jun	13.05	4	30	18	89	7	0	148
6 Jun	12.68	1	35	9	23	4	1	73
7 Jun	12.35	6	56	10	61	3	0	136
8 Jun	7.72	1	56	3	23	2	0	85
9 Jun	12.08	5	82	37	134	6	0	264
10 Jun	14.33	4	144	23	29	9	1	210
11 Jun	14.60	8	158	11	64	1	0	242
12 Jun	13.33	2	83	13	8	1	0	107
13 Jun	13.18	1	68	12	41	2	0	124
14 Jun	12.97	5	51	13	25	2	0	96
15 Jun	7.43	0	48	3	20	1	0	72
Total	749.32	289	5,379	399	4,975	533	4	11,579

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), 2019.

Date	Yearling Chinook	Subyearling Chinook	Coho	Steelhead	Sockeye	Chum
27 Mar	0	0	0	0	0	0
28 Mar	-	-	-	-	-	-
29 Mar	0	0	0	0	0	0
30 Mar	-	-	-	-	-	-
31 Mar	-	-	-	-	-	-
1 Apr	-	-	-	-	-	-
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	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	0	0	0	0	0	0
16 Apr	1	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	1	1	0	0	0	0
23 Apr	1	0	0	0	0	0
24 Apr	1	0	1	0	0	0
25 Apr	0	1	0	0	0	0
26 Apr	0	0	0	0	0	0
27 Apr	-	-	-	-	-	-
28 Apr	6	0	1	0	2	0
29 Apr	10	2	4	2	0	0
30 Apr	0	0	0	0	1	1
1 May	1	3	1	3	0	0
2 May	0	0	0	0	0	0
3 May	3	3	2	0	0	0
4 May	0	0	0	1	0	0
5 May	0	0	0	0	0	0
6 May	3	0	0	0	0	0
7 May	0	0	0	0	0	2
8 May	4	1	1	0	1	0

Appendix Table 2. Continued.

Date	Yearling Chinook	Subyearling Chinook	Coho	Steelhead	Sockeye	Chum
9 May	0	2	0	0	1	0
10 May	3	1	0	0	0	0
11 May	0	2	0	0	0	0
12 May	3	1	0	1	0	0
13 May	10	7	0	1	1	1
14 May	0	0	2	0	6	0
15 May	2	0	1	0	2	0
16 May	3	0	1	0	0	0
17 May	0	2	0	0	3	0
18 May	0	0	0	0	0	0
19 May	3	0	1	0	1	0
20 May	1	2	0	0	0	0
21 May	2	1	0	0	6	1
22 May	2	0	0	0	0	0
23 May	0	3	0	2	2	0
24 May	3	3	3	1	1	0
25 May	0	0	0	0	0	0
26 May	0	1	0	0	0	0
27 May	0	2	0	1	0	0
28 May	2	5	2	0	2	1
29 May	0	2	0	0	0	0
30 May	0	0	0	0	0	0
31 May	0	0	0	0	2	0
1 Jun	0	0	0	0	0	0
2 Jun	0	2	0	0	0	0
3 Jun	1	3	0	0	0	0
4 Jun	1	0	0	1	1	2
5 Jun	0	2	0	0	1	0
6 Jun	2	4	0	0	1	1
7 Jun	1	2	0	0	0	0
8 Jun	0	0	0	0	0	0
9 Jun	0	2	0	0	4	0
10 Jun	0	2	0	0	1	0
11 Jun	1	3	0	0	3	0
12 Jun	0	1	0	0	3	0
13 Jun	1	0	0	0	5	0
14 Jun	2	0	0	0	6	0
15 Jun	0	0	0	0	0	0
Total	74	66	20	13	56	9

Appendix Table 3. Daily detections (n) by species of the flexible antenna and matrix trawl systems during comparative sampling in the Columbia River estuary, 2019. Also shown are the percent of daily detections occurring on the flexible system and mean percent (*) for the season. Sampling was conducted during daylight for all dates except 20-24 May.

	Flexible antenna system (F)								Matrix trawl system (M)							F/Total
Date	Chinook	coho	steelhead	sockeye	cutthroat	sturgeon	unknown	total	Chinook	coho	steelhead	sockeye	cutthroat	unknown	total	(%)
17 Apr	0	0	3	0	0	0	1	4	1	0	9	0	0	1	11	27
18 Apr	0	0	2	0	0	0	0	2	1	0	3	0	0	1	5	29
19 Apr	1	0	2	0	0	0	0	3	2	0	18	0	0	0	20	13
22 Apr	3	0	5	0	0	0	0	8	0	1	39	0	0	2	42	16
23 Apr	2	0	14	0	0	0	0	16	5	0	23	0	0	2	30	35
24 Apr	3	0	5	0	0	0	0	8	3	0	42	0	0	0	45	15
25 Apr	7	0	5	0	0	0	0	12	7	0	42	0	0	1	50	19
26 Apr	10	0	9	0	0	0	2	21	39	0	41	0	0	2	82	20
30 Apr	10	0	16	0	0	0	0	26	27	1	61	0	0	0	89	23
1 May	4	1	14	0	0	0	1	20	35	1	115	0	0	4	155	11
2 May	23	2	16	0	0	0	0	41	40	3	63	1	0	6	113	27
3 May	6	1	14	0	0	1	0	22	25	1	51	0	0	3	80	22
6 May	20	1	41	0	0	0	0	62	34	2	63	1	0	5	105	37
7 May	19	3	19	0	0	0	1	42	40	0	42	1	0	3	86	33
8 May	55	4	30	1	0	0	0	90	62	2	29	1	0	4	98	48
9 May	30	2	24	1	0	0	1	58	43	1	24	1	0	3	72	45
10 May	135	5	42	1	0	0	2	185	51	2	27	1	1	3	85	69
13 May	101	5	18	0	0	0	2	126	108	1	60	4	0	4	177	42
14 May	27	2	6	3	0	0	0	38	49	3	42	3	0	1	98	28
15 May	70	4	22	0	0	0	1	97	73	4	89	4	0	4	174	36
16 May	87	4	88	0	0	0	4	183	57	1	105	1	0	4	168	52
17 May	37	1	23	0	0	0	0	61	83	4	124	3	0	1	215	22
20 May	22	0	7	0	0	0	1	30	77	3	24	3	0	2	109	22
21 May	9	1	3	1	0	0	1	15	25	2	21	2	0	0	50	23

Appendix Table 3. Continued.

Date	Flexible antenna system (F)								Matrix trawl system (M)							F/Total
	Chinook	coho	steelhead	sockeye	cutthroat	sturgeon	unknown	total	Chinook	coho	steelhead	sockeye	cutthroat	unknown	total	(%)
24 May	60	3	4	10	0	0	0	77	94	9	27	29	0	5	164	32
27 May	32	13	50	25	0	0	5	125	36	8	86	31	0	4	165	43
28 May	54	4	31	24	0	1	1	115	20	1	48	25	0	4	98	54
29 May	28	15	9	12	0	0	1	65	22	4	24	8	0	5	63	51
30 May	25	13	27	21	0	0	1	87	10	3	9	7	0	1	30	74
31 May	17	7	8	5	0	1	1	39	11	5	24	1	0	0	41	49
3 Jun	9	7	39	3	0	0	1	59	6	2	71	0	0	1	80	42
4 Jun	12	5	8	4	0	0	4	33	5	1	20	2	0	2	30	52
5 Jun	10	9	29	5	0	1	1	55	5	12	67	5	0	3	92	37
6 Jun	19	8	12	4	1	0	0	44	9	4	20	1	1	0	35	56
7 Jun	21	11	33	2	0	0	3	70	30	8	53	3	0	4	98	42
10 Jun	55	11	8	1	1	0	2	78	96	14	24	5	1	3	143	35
11 Jun	56	3	9	0	0	0	0	68	103	6	43	0	0	5	157	30
12 Jun	26	6	1	0	0	0	0	33	64	5	3	1	0	1	74	31
13 Jun	24	4	13	1	0	0	0	42	17	4	28	2	0	0	51	45
14 Jun	12	4	1	0	0	0	0	17	23	6	12	1	0	2	44	28
Total	1,141	159	710	124	2	4	37	2,177	1,438	124	1,716	147	3	96	3,524	*35

Appendix Table 4. Mean diel detections by hour for yearling Chinook salmon and steelhead during intensive sampling (28 Apr-15 June) using the matrix trawl system in the upper Columbia River estuary (rkm 75), 2019.

Diel hour	Total effort (h)	Yearling Chinook salmon (n) Hatchery	Yearling Chinook salmon (n) Wild	Yearling Chinook salmon Mean detections/h Hatchery	Yearling Chinook salmon Mean detections/h Wild	Steelhead (n) Hatchery	Steelhead (n) Wild	Steelhead Mean detections/h Hatchery	Steelhead Mean detections/h Wild
0	42.0	303	30	7.21	0.71	98	40	2.33	0.95
1	41.3	231	30	5.60	0.73	83	30	2.01	0.73
2	15.8	105	15	6.65	0.95	41	17	2.60	1.08
3	5.7	118	17	20.76	2.99	30	8	5.28	1.41
4	5.0	130	21	26.00	4.20	20	5	4.00	1.00
5	21.7	194	20	8.95	0.92	39	26	1.80	1.20
6	47.8	448	74	9.37	1.55	227	124	4.75	2.59
7	49.0	272	47	5.55	0.96	295	132	6.02	2.70
8	48.3	214	47	4.43	0.97	317	159	6.57	3.29
9	47.5	137	19	2.89	0.40	314	144	6.62	3.03
10	47.3	123	28	2.60	0.59	355	152	7.51	3.21
11	45.2	100	19	2.21	0.42	362	133	8.00	2.94
12	17.3	53	16	3.06	0.92	228	60	13.15	3.46
13	7.6	48	6	6.33	0.79	129	42	17.01	5.54
14	2.3	23	3	10.22	1.33	25	13	11.11	5.78
15	0.9	1	0	1.18	0.00	12	3	14.12	3.53
16	0.0	--	--	--	--	--	--	--	--
17	0.0	--	--	--	--	--	--	--	--
18	0.0	--	--	--	--	--	--	--	--
19	20.0	15	4	0.75	0.20	50	31	2.50	1.55
20	41.5	211	48	5.09	1.16	226	93	5.45	2.24
21	42.0	511	66	12.17	1.57	214	84	5.10	2.00
22	42.0	534	62	12.73	1.48	131	36	3.12	0.86
23	42.0	289	41	6.88	0.98	108	41	2.57	0.98
Total	631.8	4,060	613			3,304	1,373		