Detection of PIT-Tagged Juvenile Salmonids Migrating in the Columbia River Estuary, 2017

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Executive Summary

In 2017, 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 detection 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 closing the wings of the trawl net to guide fish toward the cod end, where they would come within detection range of the antennas. Entrained fish were able to exit the trawl safely, 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 711 h.

During this period, the matrix system detected 8,419 PIT-tagged fish, of which 24% were wild, 4% were unknown, and 72% were of hatchery origin. Species composition of detected fish was 38% spring/summer Chinook, 6% fall Chinook, 49% steelhead, 2% sockeye, 2% coho, less than 1% cutthroat trout and Pacific lamprey, and 3% unknown.

Sampling began on 17 March with a single daytime shift operating 2-5 d/week to coincide with arrival in the estuary of spring-migrating juvenile salmon and steelhead. 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 30 April through 15 June. We ended sampling on 16 June after most spring migrants had passed.

During the intensive sample period, average hourly detections of hatchery yearling Chinook were not significantly different between darkness and daylight hours (4.5 vs. 3.9 fish/h; $P = 0.164$). Conversely, average hourly detections of wild yearling Chinook were significantly different between darkness and daylight hours (0.6 vs 1.0 fish/h; $P = 0.001$). For hatchery steelhead, hourly detection rates were significantly higher during daylight than darkness hours (4.8 vs. 2.5 fish/h; $P < 0.001$). Similarly, for wild steelhead, there was a significant difference between daylight and darkness hours (2.9 vs 1.6 fish/h; $P < 0.001$). During intensive sampling, the trawl was deployed for an average of 13 h/d, which was less than in 2016 (15 h/d).

Also during the intensive sampling period, we detected 1.0% of the yearling Chinook salmon and 1.3% of the steelhead detected at Bonneville Dam. These

proportions were lower than those in 2016, when we detected 2.0% of the yearling Chinook and 3.4% of the steelhead detected at Bonneville Dam.

We also detected 0.9% of the yearling Chinook and 3.0% of the steelhead transported and released below Bonneville Dam. These rates were lower than in 2016 for yearling Chinook, when we detected 1.6% of transported fish, but higher than in 2016 for steelhead, when we detected 2.8% of transported fish.

In 2017, we continued development of a flexible antenna array, which is towed behind two small vessels to detect juvenile salmon without a net. Objectives of this development effort were to simplify logistics, increase sample efficiency, and reduce the cost of sampling PIT-tagged fish in the estuary.

For these tests, the flexible antenna array was configured with six to twelve 2.4- by 6.1-m rectangular antennas, each housed in 1.9-cm-diameter flexible PVC hose, and sampled to a depth of approximately 6 m. Sampling efforts were conducted simultaneously with deployments of the matrix trawl system. Although as many as 12 antennas were tested at a time, the 6-antenna array was the most electronically stable configuration. We compared detection efficiency between the two systems to evaluate the feasibility of transitioning entirely to the flexible system in future years. For all comparative analysis with the trawl system, we used only detections occurring when the flexible system was fully functional with six antennas.

The flexible antenna system detected a total of 220 fish across 35 d of operation in 2017 (136.3 h total); however, the majority of these were testing days when the system was not fully operational. Of the total detections, 56% were spring/summer Chinook, 4% were fall Chinook, 37% were steelhead, 1% were coho, and 2% were unknown species. Daily ratios of mean detection rate (fish/h) between the two systems were calculated for each concurrent deployment, which totaled 62.3 h over 12 d. Over the 12 d of simultaneous deployment, the overall mean ratio of detection rates for the flexible vs. the matrix trawl systems was 16%.

In 2016, juvenile steelhead were detected in disproportionately high numbers in the flexible antenna system, comprising 78% of total detections—more than double the proportion of steelhead detected in the matrix trawl for that year (35%). This discrepancy was likely due to the shallow sample depth of the flexible antenna system compared to the matrix trawl system (3.0 vs. 5.0 m). We concluded that the relatively shallow sample depth of the flexible antenna system allowed Chinook salmon to pass below the array without being detected. In 2017, rectangular antennas in the flexible array were rotated 90 degrees (from a horizontal to vertical orientation), which increased sample depth to

6.0 m. This orientation resulted in an increase in the proportion of Chinook salmon detected by the flexible system (60% in 2017 vs. 14% in 2016).

After the spring migration season, we tested various electrical modifications and wiring configurations in the flexible antenna system with the goal of achieving an electrically stable array that utilized twelve antennas, the maximum allowed for the transceiver. After identifying a firmware issue and reconfiguring our grounding method, testing confirmed the feasibility of expanding our array to its full capacity. We plan to use the larger array in 2018 sampling and expect that it will increase our sample area and overall detections of PIT-tagged fish.

As in previous study years, we examined PIT-tag detection data collected in 2017 to evaluate potential factors related to detection probability and to compare passage performance metrics among fish groups by species, rearing type (hatchery or wild), and migration history (transported vs. in-river).

For yearling Chinook salmon, we found a significant interaction between date and migration history ($P = 0.040$). We detected a nearly constant proportion of 1.1% in-river migrants, which was higher than the proportion of transported fish early in the season, but lower than the proportion of transported fish later in the season.

The opposite was true for steelhead. We found a significant effect of migration history and arrival date on detection rate ($P < 0.001$ and $P = 0.045$, respectively), but no interaction between date and migration history ($P = 0.858$). We detected in-river migrant steelhead at half the rate of transported steelhead. Detection rates for both steelhead groups increased from early to mid-season, then decreased from mid to late-season.

Over the years, we have observed an inverse relationship between river flow and detection rates in the trawl. Mean flow volumes at Bonneville Dam were 41% higher during the two-shift sample period of 2017 than during the two-shift period of 2016 (11,807 vs. 6,953 m^3/s). Mean flows during this period in 2017 were also 31% higher than the 15-year average for 2000-2015 (8,122 m^3/s, excluding 2001). Mean daily river flows remained well above average for the entire intensive sampling season.

Of all juvenile salmonids detected in the estuary in 2017, 23% were transported, while 7% were detected passing Bonneville Dam. The remaining 70% had neither been transported nor detected at Bonneville Dam, At least 96% 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 (103 vs. 87 km/d, $P < 0.001$). Similar differences were noted for steelhead, with travel rates of 116 km/d for in-river migrants vs. 106 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 (111 vs. 102 km/d) and subyearling Chinook salmon (93 vs. 92 km/d); however, for both species, detection numbers were insufficient for meaningful statistical analysis. Overall, migration rates between Bonneville Dam and the sample reach for both in-river and transported fish were faster in 2017 than in 2016 across all species. This was likely a function of high flow volumes throughout the sample season.

Detections of subyearling Chinook salmon have decreased in recent years, commensurate with reduced tagging effort for these fish. In 2017, we detected 482 subyearling fall Chinook, with the majority of detections occurring from late May through the end of the sampling season. Of these 482 fish, 400 originated from the Snake River Basin (247 in-river migrants and 153 transported). The remaining 82 were in-river migrants from Columbia River stocks, with 54 released above McNary Dam, 20 released between McNary and Bonneville Dam and 8 released below Bonneville Dam. We did not detect holdover subyearlings in 2017 (holdovers overwinter in freshwater and resume downstream migration in spring).

Of the 175 sockeye salmon detected in the trawl, 34% had been released into the Snake River, 64% into the upper Columbia River above McNary Dam, and 2% into the middle Columbia River between McNary and Bonneville Dam. Of sockeye detected in 2017, 32% were hatchery, 9% were wild, and 59% were of unknown origin. Migration history of detected sockeye was 85% in-river migrant and 15% transported.

As in previous years, detection data from the estuary in 2017 were essential for calculating annual survival probabilities to the tailrace of Bonneville Dam, the last dam encountered by migrating juvenile salmonids. Operation of a detection system in the estuary has provided data for estimates of survival to Bonneville Dam 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.

Detection data are also used to estimate travel time, migration rate, and other performance metrics between juvenile fish groups of differing migration history, origin, rearing type, and species. Annual releases of PIT-tagged fish in the Columbia River basin have been near 2 million for the past several years. 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 2017, 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; Morris et al. 2017). We used 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 detection antennas mounted in the cod end of the trawl. Target fish were those PIT-tagged by other researchers for various research projects at natal streams, hatcheries, collection facilities at dams, and other upstream locations (PSMFC 2017).

When PIT-tagged fish are entrained in the trawl, they must pass through the detection field of the antennas in the cod end to exit. Upon detection, the tag code, GPS position, and date and time of detection are electronically recorded. 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.

In 2017, over 1.7 million Snake and Columbia River juvenile salmonids were PIT-tagged and released prior to or during the spring migration season (PSMFC 2017). 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 *PIT Tag Information System* database (PTAGIS), a regional database that stores and disseminates information on PIT-tagged fish (PSMFC 2017).

We uploaded trawl detection records to PTAGIS and downloaded information on the fish we detected. We used data on the species, run, tagging/release time and location, and date/time of detection at interrogation sites downstream from release to evaluate migration performance metrics between Bonneville Dam and the estuary. Since 1998, these data have been used for annual estimates of survival for yearling Chinook salmon *O. tshawytscha*, steelhead *O. mykiss*, and sockeye salmon *O. nerka* from points of release to Bonneville Dam. Estuary detections are critical to complete estimates of survival through the entire hydrosystem (Widener et al. 2017).

In 2017, 110,612 PIT-tagged fish were transported from dams on the Snake River and released below Bonneville Dam; over 70,000 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 is a freshwater reach characterized by frequent ship traffic, occasional severe weather, and river currents often exceeding 1.1 m s^{-1}. Tides in this area are semi-diurnal, with about 7 h of ebb and 4.5 h of flood that differ in height within a range 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.

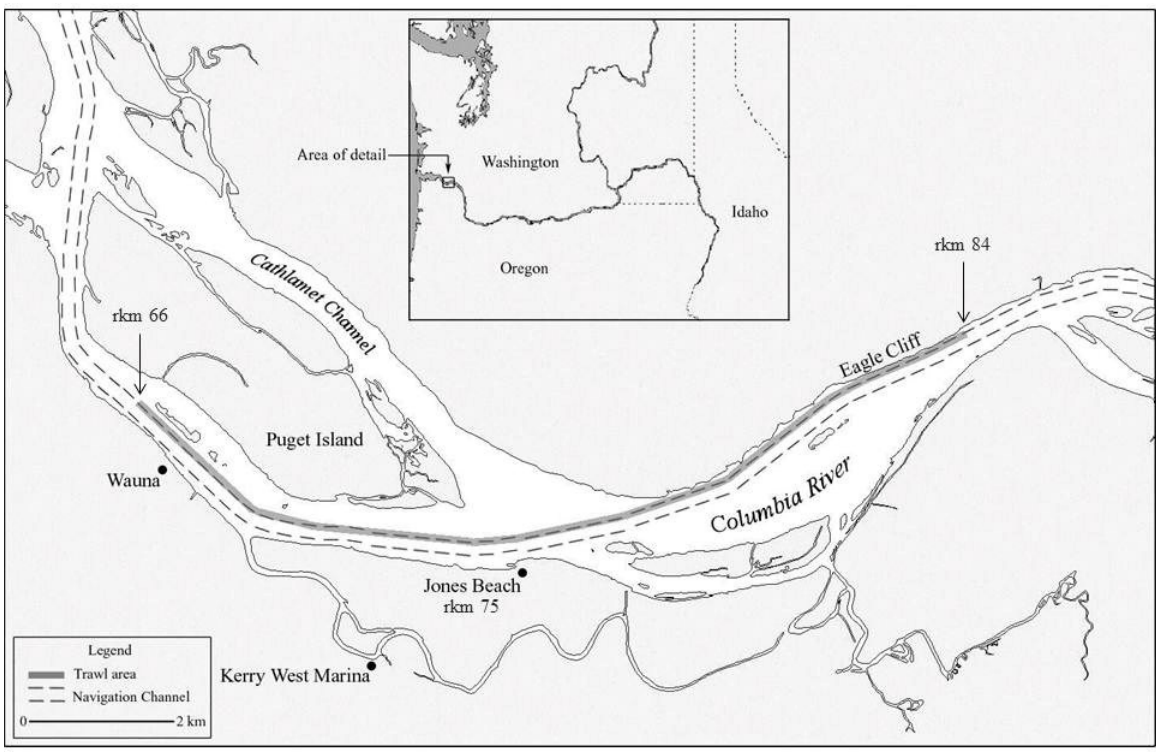

Figure 1. Trawl sampling area adjacent to the navigation channel in the upper Columbia River estuary between rkm 66 and 84, 2017.

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 2017). Specific groups of tagged fish targeted for detection included over 202,000 fish released for a comparative survival study and 110,612 fish diverted to barges for NMFS transportation studies. Smaller fish groups were also released for various other studies.

To reach the Columbia River below Bonneville Dam, juvenile fish released in the upper Snake River either traversed eight dams and reservoirs or were transported from one of three collector dams. Fish transported from Lower Granite Dam avoided passage of up to seven dams as well as migration through approximately 461 km of river to reach the tailrace of Bonneville Dam (Marsh et al. 2005; 2008; 2012).

For yearling Chinook salmon and steelhead, numbers of fish detected in the pair trawl were sufficient for analyses of timing and survival. Trawl detections of sockeye and subyearling Chinook salmon were fewer, so analyses were limited. We also detected PIT-tagged coho salmon *O. kisutch*, coastal cutthroat trout *O. clarki*, and Pacific lamprey *Lampetra tridentata*.

Sample Period

Spring sampling began on 17 March and continued through the summer migration period to 16 June. Our sample effort varied commensurate with fish availability in the estuary. Early in the migration season, we sampled 2-5 d/week with a single shift, for an average daily sample effort of 5 h/d. Sample effort was defined as full deployment of the trawl. During the peak of the spring migration from 30 April through 15 June, we sampled with two daily shifts, covering both daylight and darkness periods, for an average daily sample effort of 13 h/d.

During the two-shift period, day shifts began before dawn and continued for 6-11 h, while night shifts began in early evening and continued through most of the night or until relieved by the day crew. We intended sampling to be nearly continuous throughout the two-shift period except between 1400 and 1900 PDT, when we interrupted sampling for refueling and maintenance.

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 components, and the overall fish-passage opening was 2.6 by 3.0 m. The matrix antenna array was attached to the cod-end of the trawl and suspended by buoys 0.6 m beneath the surface.

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 weighed approximately 114 kg in air and required an additional 114 kg of lead weight to suspend them in the water column (total weight of front and rear components was 456 kg in air).

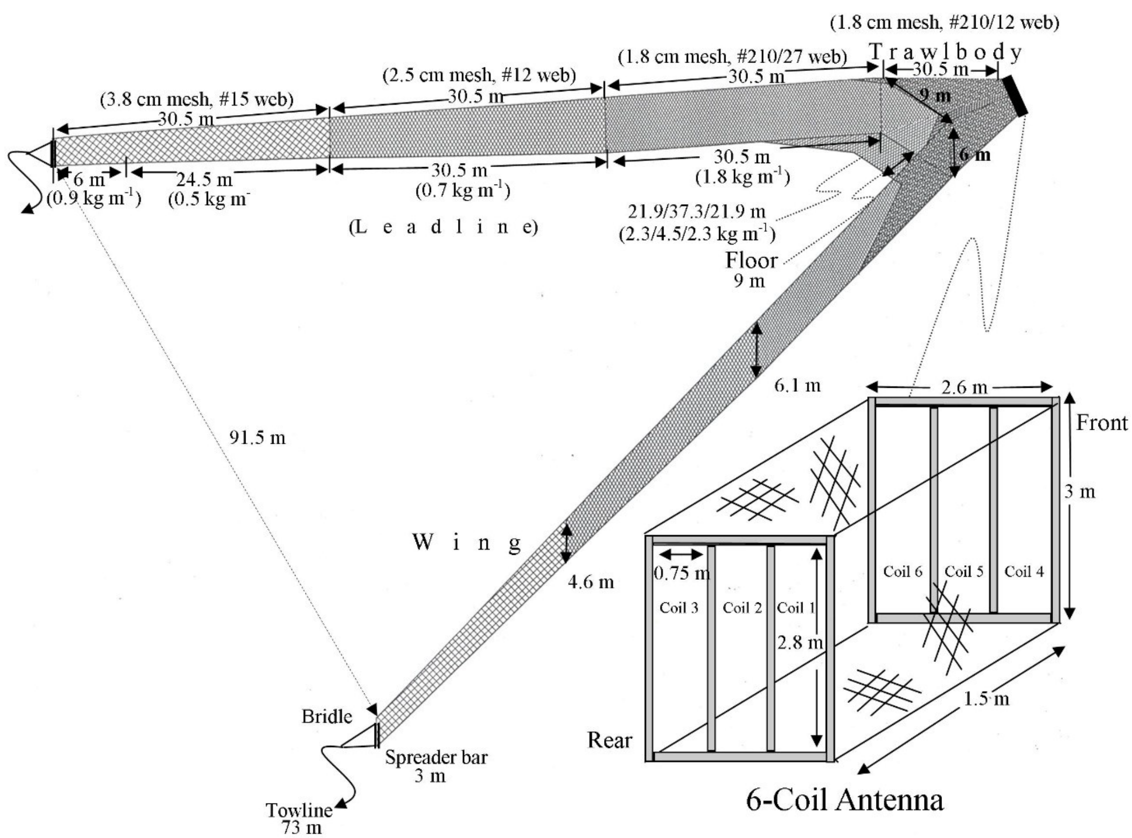

Figure 2. Basic design of the surface pair trawl used with the matrix antenna system to sample juvenile salmonids in the Columbia River estuary (rkm 75), 2017.

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). The upstream end of each trawl wing was shackled to a 3-m-long spreader bar. The downstream end of each wing was attached to the 30.5-m-long trawl body, which was modified at the cod-end for attachment of the matrix array. The trawl mouth opening was 9 m wide by 6 m tall with a 6.3-m floor extending forward from the mouth. Sample depth was about 5.0 m due to curvature in the side-walls 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 towline was passed to an 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 electronic components and procedures similar to those used in 2006-2016. In 2017, we again used a single FS1001M multiplexing transceiver, which was capable of simultaneously powering the detection field then recording and transmitting detection data for up to six antennas. Electronic components for the trawl system were contained in a water-tight 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 (PSMFC 2017). 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 about weekly to PTAGIS using standard methods described in the *PIT Tag Specification Document* (Marvin and Nighbor 2009). The specification document, PTAGIS operating software, and user manuals are available from the PTAGIS website operated by Pacific States Marine Fisheries Commission (PSMFC 2017). Pair-trawl detections were designated in the PTAGIS database with site code TWX (towed array-experimental).

Pre-season tests of detection efficiency—As in previous years, we used PIT tags attached to a test tape to evaluate performance of the matrix antenna system (Ledgerwood et al. 2005; Morris et al. 2013). For these tests, we positioned a 2.5-cm-diameter PVC pipe through the center of both the front and rear antenna arrays. 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 passed back and forth through the pipe and was 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 1% of the time when oriented at 45 or 90 degrees. With spacing between tags increased to 60 cm, detection efficiency increased to 82 and 95% for tags oriented at 45 and 90 degrees, respectively. For test tags spaced 90 cm apart, respective reading efficiency was 96 and 100% for tags oriented at 45 and 90 degrees. Results in 2017 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—During the 2017 intensive sampling period of 30 Apr-15 June, mean river flow volume at Bonneville Dam was the second highest since the project started and 41% higher than during the same period in 2016 (11,807 vs. 6,953 m^3/s; Figure 3). Mean flow during intensive sampling in 2017 was also 32% higher than the 16-year average for 2000-2016 (8,037 m^3/s, excluding 2001). In general, the 2017 season was characterized by extremely high flows and heavy debris loads.

Through years of sampling, we have observed an inverse relationship between river flow volumes and trawl detection rates. Higher flow volume has been consistently associated with lower detection rates of fish previously detected at Bonneville Dam. (Detection in the pair trawl of fish previously detected at Bonneville provides a rough index of detection efficiency with the trawl).

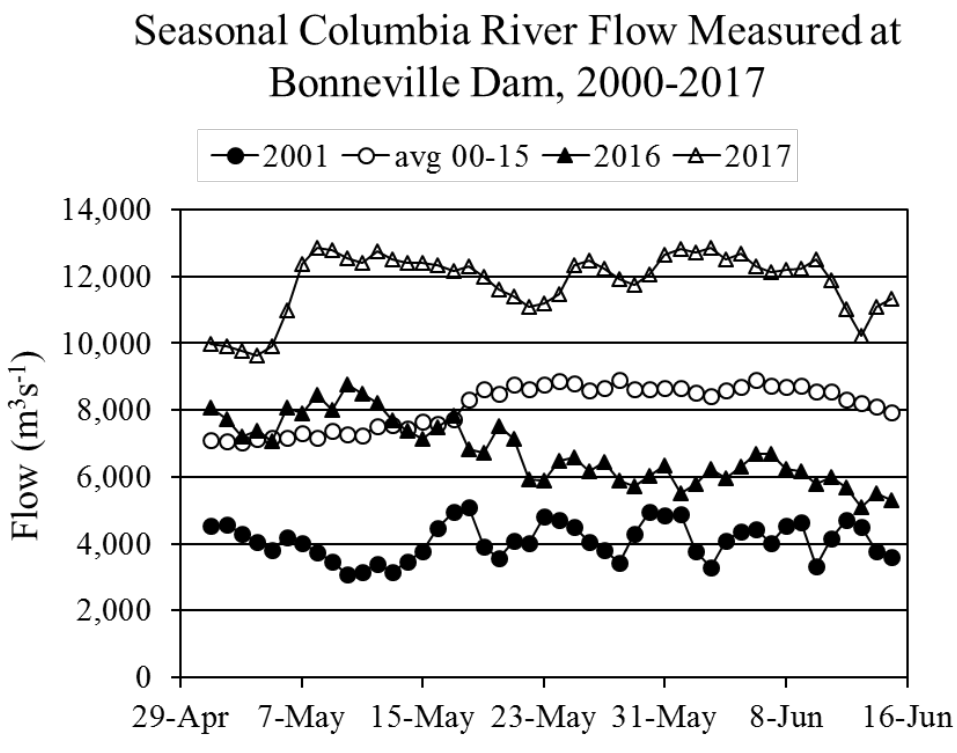

Figure 3. Columbia River flows ($m^3 s^{-1}$) at Bonneville Dam during the two-shift sample periods in 2016 and 2017 compared to the average flow from 2000 to 2015 (excluding 2001). Drought-year flows for 2001 are also shown for comparison.

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.

Presence of tagged fish in the sample reach—We estimated that intensive sampling in 2017 coincided with arrival time in the estuary of 80% of the yearling Chinook salmon and 86% of the steelhead passing Bonneville Dam (tagged and non-tagged). Our intensive sample period also coincided with 89% of the yearling Chinook salmon and 94% of the steelhead transported for NMFS studies.

The availability of in-river migrant yearling Chinook salmon and steelhead was greater in 2017 than in 2016, when we estimated that 75% of the yearling Chinook salmon and 80% of steelhead that had passed Bonneville Dam were in the estuary during our intensive sampling period. In contrast, the availability of transported yearling Chinook salmon and steelhead was less in 2017 than in 2016, when 99% of transported yearling Chinook salmon and steelhead were available during intensive sampling.

In 2017, no transported fish were released before our intensive sampling period. After the intensive sampling period, the majority of fish detected at Bonneville Dam were subyearling Chinook salmon, 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 salmon has been reduced considerably; however, these fish comprised 73% of the detections at Bonneville after intensive sampling ended in 2017. In contrast, subyearlings comprised only 32% of the detections at Bonneville after intensive sampling in 2016. Release dates for subyearling Chinook in 2016 and 2017 were comparable; however, the total number of tagged subyearlings released was considerably higher in 2017 than in 2016 (225,136 vs. 175,647) and may have accounted for the difference in detection rates.

Detection Rates

We sampled with the matrix trawl system for 711 h during 2017 and detected 8,419 PIT-tagged fish. In contrast, we sampled for 829 h during 2016 and detected 12,165 fish (Figure 4). The difference in sample hours was largely from reduced effort in late June and July, following the yearling migration period. Higher-than-average flows likely contributed to lower detection rates in 2017 (12 fish/h) than in 2016 (15 fish/h).

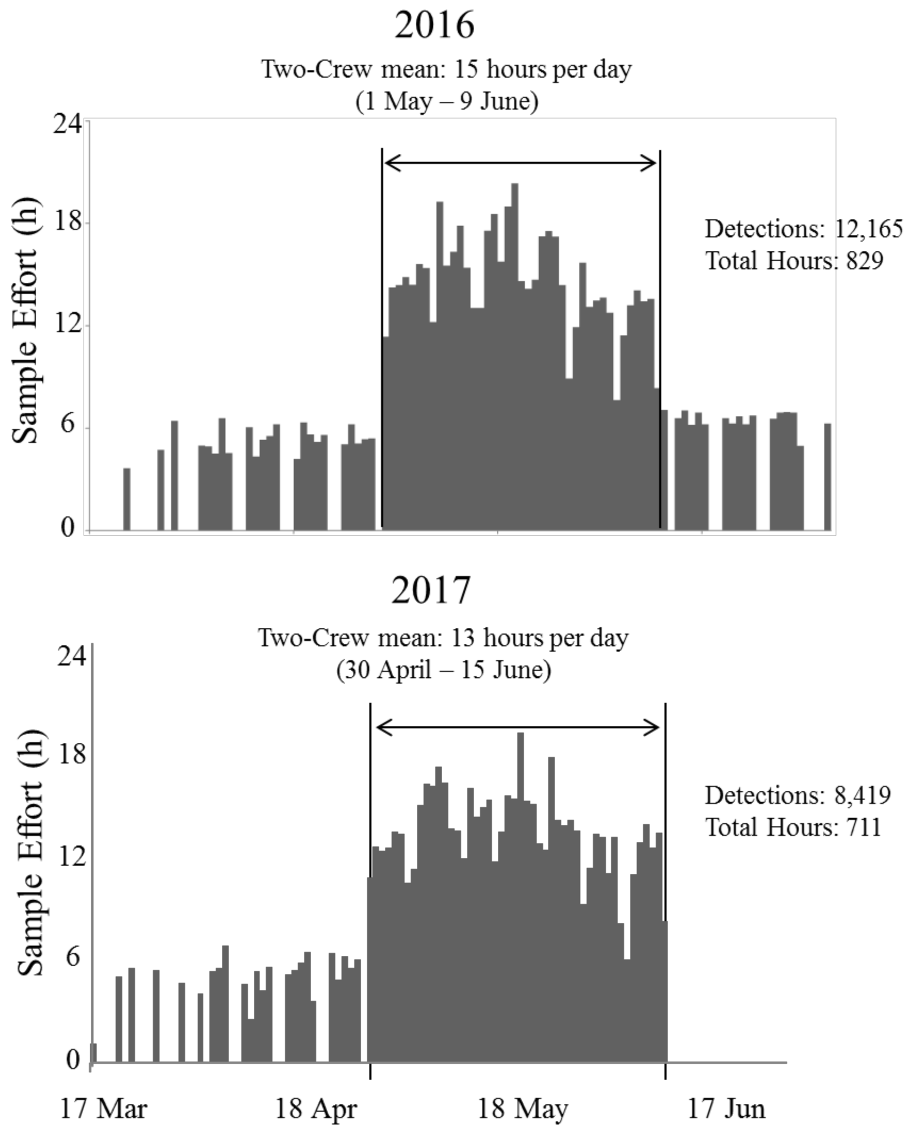

Figure 4. Daily sample effort in spring/summer 2016 and 2017 using a pair trawl fitted with a "matrix" antenna for PIT tag detection. Sampling was conducted in a tidal freshwater reach of the Columbia River estuary near Jones Beach between rkm 66 and 84.

Species, Origin, and Migration History of Detected Fish

In 2017, trawl detections totaled 8,058 fish of known species and origin (hatchery and wild) plus another 361 fish lacking release information in PTAGIS (Table 1; Appendix Table 1). Of those fish, at least some species information was available; however, 220 detected fish had no release or species information associated with their respective tags.

Species composition—Of fish detected with the matrix system, 38% were spring/summer Chinook, 6% were fall Chinook, 49% were steelhead, 2% were sockeye, and 2% were coho salmon. Of the remainder, less than 1% were cutthroat trout or Pacific lamprey and 3% were unknown salmonid species. Total detections by origin were 24% wild, 72% 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 origin of PIT-tagged fish detected with the trawl system in the upper Columbia River estuary near rkm 75 in 2017.

	Rear type			
Species/run	Hatchery	Wild	Unknown	Total
Spring/Summer Chinook salmon	2,647	508	14	3,169
Fall Chinook salmon	534	1	0	535
Coho salmon	190	17	0	207
Steelhead	2,591	1,494	24	4,109
Sockeye salmon	56	16	103	175
Sea-run Cutthroat	0	2	0	2
Pacific Lamprey	0	2	0	2
Unknown	0	0	220	220
Grand total	6,018	2,040	361	8,419

Similar to 2016, there was an unusually high proportion of sockeye salmon with unknown origin in 2017 (59%). Greater proportions of sockeye with unknown origin were due to a lack of release information associated with tags originating from select hatcheries. Differences in PIT-tagging strategies, hydrosystem operations, and numbers of fish transported also contribute to annual variation in proportions of each species or rearing type detected in the estuary (Figure 5).

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. These fish adopt a "holdover" or "reservoir-type" life-history strategy (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, no overwintering fish were detected in 2017.

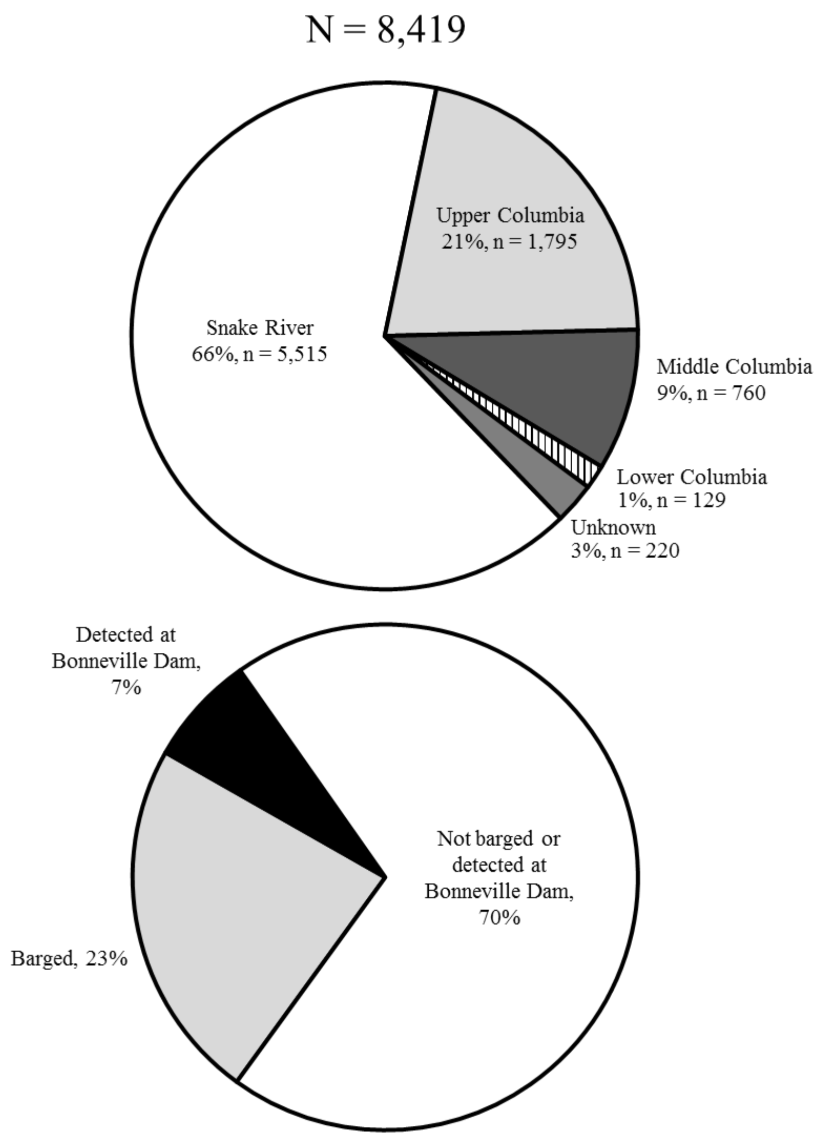

Figure 5. Proportions of fish detected using the matrix trawl by source and migration history, 2017. Upper and middle Columbia River sources were defined relative to McNary Dam. Fish that originated in the Columbia River below Bonneville Dam could not be transported, nor could they pass Bonneville Dam.

Subyearling fall Chinook salmon—Fish considered subyearlings were those that measured less than 130 mm fork length (FL) at tagging and were released after 10 April 2017. Most fall Chinook released prior to 30 April were yearling fish, as indicated by a fork length greater than 130 mm at tagging. Based on these criteria, we detected 152 transported and 321 in-river-migrant subyearling fall Chinook in the matrix trawl system between early May and mid-June (Figure 6).

Of the 473 total subyearlings detected by the trawl system, 83% originated in the Snake River, 11% in the Upper Columbia River at or above McNary Dam, 4% in the Mid-Columbia River between Bonneville and McNary Dam, and 2% from the Lower Columbia River below Bonneville Dam.

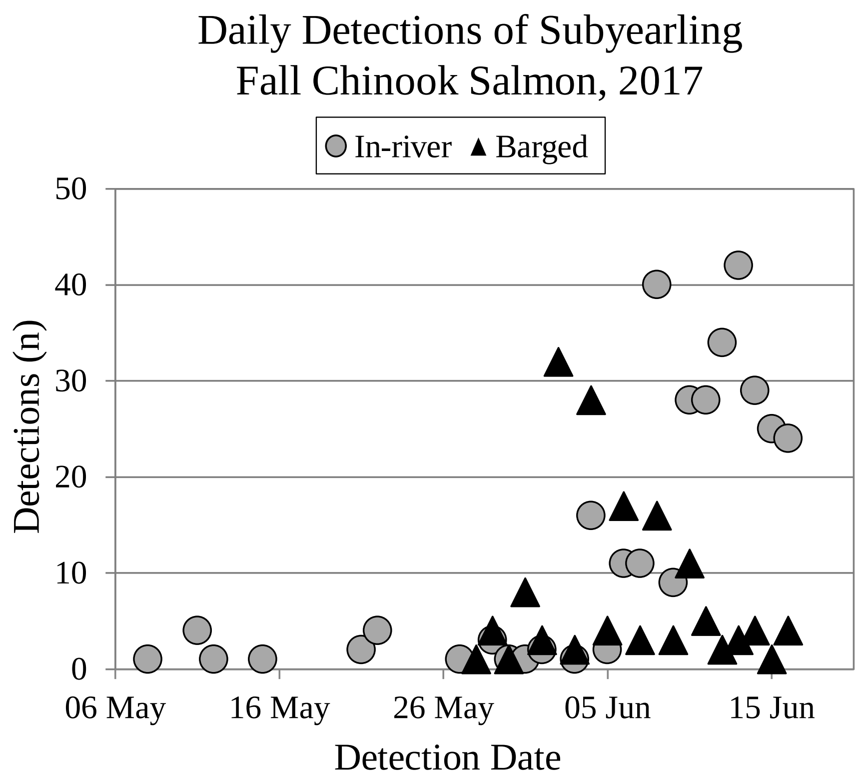

Figure 6. Temporal distribution of subyearling Chinook salmon detections in the Columbia River estuary near rkm 75 during in-river migration (n = 321) or following releases from barges below Bonneville Dam (n = 152), 2017.

Sockeye salmon—We detected 175 sockeye salmon between 24 April and 14 June (Figure 7). Of these, 32% were hatchery fish, 9% were wild fish, and the remaining 59% were of unknown origin. The disproportionate amount of unknown-origin sockeye salmon in 2017 was attributed to the altered designation of "wild" to "unknown" fish at a key Upper Columbia River release site (Osoyoos Lake).

Among sockeye salmon detected in the matrix trawl system, 34% had been released in the Snake River Basin, 65% in the Columbia River Basin upstream from McNary Dam, and less than 2% had been released below McNary Dam. Transported fish accounted for 26 of the 175 sockeye salmon detections. Among the 26 transported fish, 12 had been barged from Lower Granite Dam, 3 from Little Goose Dam, and 11 from Lower Monumental Dam.

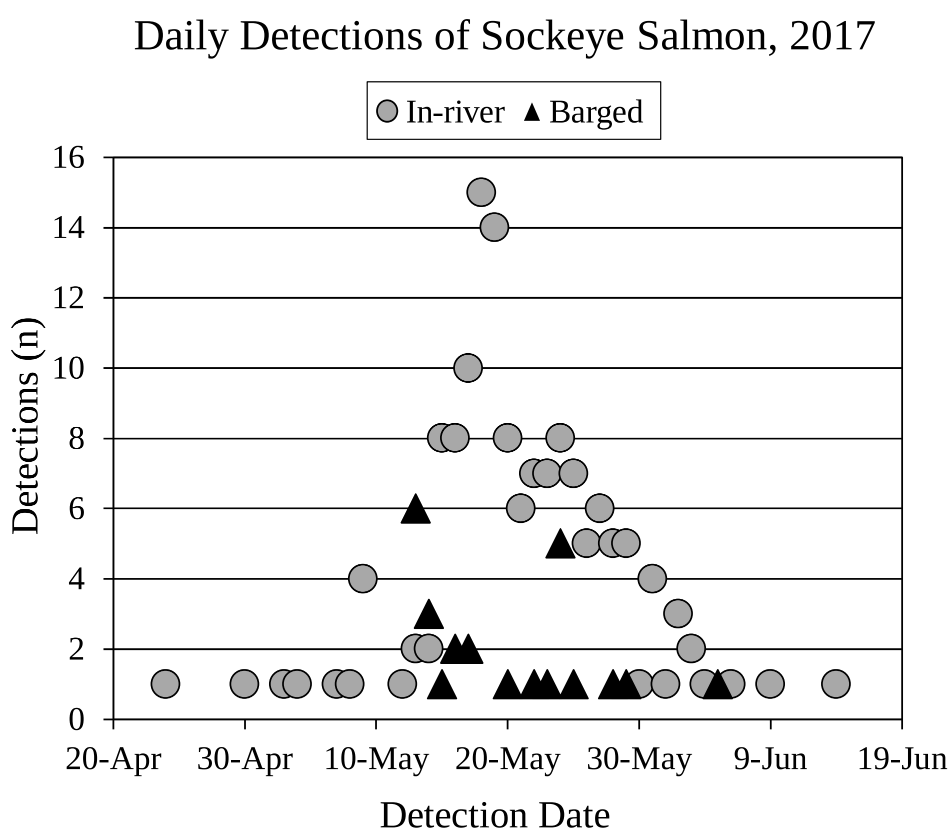

Figure 7. Temporal distribution of sockeye salmon detections in the Columbia River estuary near rkm 75 during in-river migration (n = 149) or following releases from barges below Bonneville Dam (n = 26), 2017.

Impacts on Fish

We regularly inspected the cod-end of the trawl for debris accumulation near the antenna, which could affect fish. 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 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 2017, we recovered 198 such salmonids from the matrix antenna and 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 tend 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) of netting 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 of the gear 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 2017, we continued development of a towed, flexible antenna system that does not require a net to concentrate and guide fish within range of the antennas. This new design was based on 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 antenna were to reduce costs associated with sampling juvenile salmonids in the estuary and to improve sample efficiency using recent advances in PIT tag technology.

Since 2013, we have used a new multiplexing transceiver (Biomark model IS1001MTS) that allows us to construct larger rectangular antennas (2.4 × 6.1 m). These antennas provided a detection field at least six times larger than that of the 0.8- by 3.0-m antennas used previously in towed PIT tag monitoring systems. In addition to increased reading range, the new transceiver allows antennas to be constructed from 1.9-cm-diameter flexible hose instead of the much larger 10.2-cm-diameter rigid PVC used previously. These changes dramatically increased antenna utility and led to new applications.

In 2015, the first year of development, sampling with the new system focused on developing protocols for deployment, pinpointing electronics issues, increasing antenna read range, and reducing EMI (electromagnetic interference) while under tow (Morris et al. 2015). In 2016, we used the developed protocols and focused on concurrent sampling with the matrix trawl.

In 2016, the primary configuration used for sampling was an array of six flexible antennas, oriented horizontally, which sampled to a depth of approximately 2 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 using the flexible antenna system to replace the trawl system in future years.

Detection data from 2016 showed a bias towards higher proportions of steelhead, which we believe was associated with the sample depth of horizontal antennas (Morris et al. 2017). Our objective in 2017 was to increase the depth sampled while maximizing the array size (12 antennas were supported by the transceiver).

By simultaneously sampling with both systems during the peak juvenile migration period, we were able to compare species composition and sample efficiency between systems during daylight and darkness periods. After the migration period, we continued to test various antenna configurations to maximize detection efficiency of the twelve-antenna flexible system.

Methods

We initially conducted tests in April 2017, prior to the peak juvenile migration season. During this period, we tested different orientations of the flexible antennas. This included a stacked configuration of two rows of horizontally oriented antennas. These tests were intended to increase sample depth and for stratification of the sample, while maintaining system stability. We concluded that a single row of vertically oriented antennas was the most stable configuration and the easiest to deploy. During the peak of the juvenile migration (May), we continued testing with different numbers of antennas in the array, ranging from five to twelve, while simultaneously sampling with the matrix trawl system.

We deployed the matrix trawl system following its normal schedule, and the flexible antenna system was generally deployed within 1 km of the trawl. Following concurrent testing, and after the juvenile migration season concluded, we continued testing various electrical modifications to the flexible system in an effort to maintain connectivity and stable parameters for a 12-antenna array.

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 skiff 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.

Initial testing in 2015 and 2016 utilized two 6.7-m-long skiffs to tow the system. Sampling in 2017 included an 8.5-m primary vessel that transported the array and housed the electronics, and a 7.3-m-long secondary tow vessel. Occasionally, a third vessel was used (6.7-m-long work skiff) to monitor antenna configuration and test system performance. 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 full extension of the array.

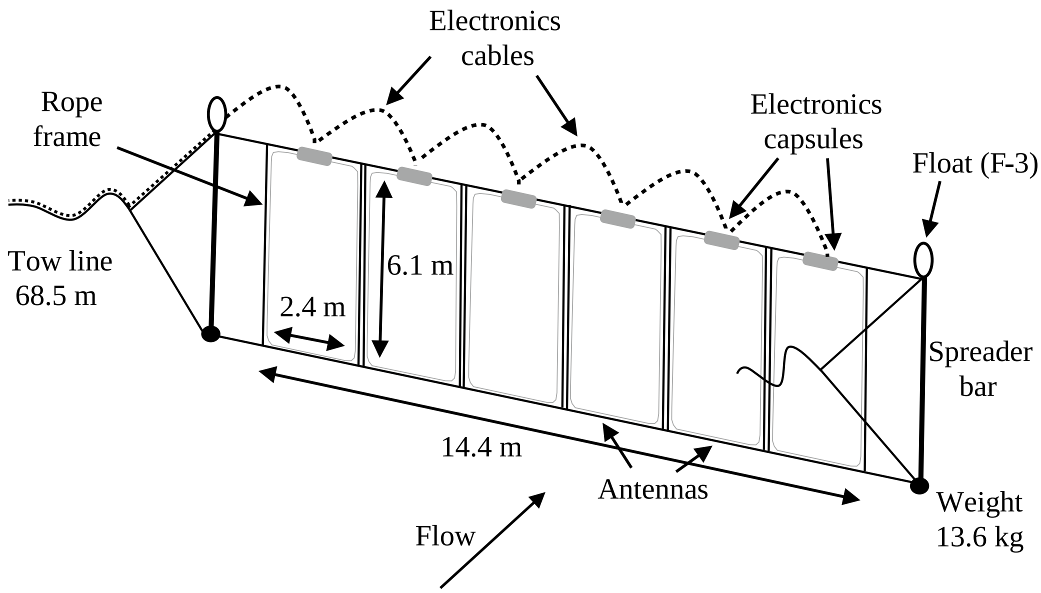

Figure 8. Basic configuration of the six-antenna array and modular rope frame system tested in 2017. This array produced a total reading range approximately 15 m wide by 6 m deep and was made up of six 2.4- by 6.1-m flexible antennas.

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 knots was the maximum tow speed that could be maintained without excessive vibration-related EMI, which compromised read efficiency. This estimate represented the difference between a dead-drift speed of 1.9 knots measured by the skiff and a downstream movement rate of 0.2 knots 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 knots with the net fully deployed.

We chose an array of six flexible antennas to evaluate performance in comparison with the six-antenna matrix trawl system during simultaneous testing. The detection field generated by the flexible array was approximately 15 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 boats is 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. Thus, results from the six-antenna array theoretically represented one-half of the potential detection field, as the IS1001 transceiver system is capable of powering up to 12 antennas.

Rectangular antennas within the array were towed in a side-by-side, vertical orientation at a pace that matched the trawl (1.2 knots). To provide additional stability and strength, all antennas were attached to a 13-mm-diameter non-stretch rope frame. The rope-frame extended 3 m beyond the antennas and was attached to two 6-m aluminum spreader bars, one on each distal end of the array. Each bar contained a 13.6-kg 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.

During simultaneous testing, the matrix trawl system sample design, operation, and equipment was not modified in any way to accommodate comparative sampling. The flexible system was deployed based on the location of the trawl system. Simultaneous deployment did not affect the availability of fish for potential detection in the trawl system because the distance between systems was 1 km. 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 average daily detection ratios, species composition ratios, and diel detection patterns. Data for comparison were taken only from days and times when both systems were deployed and operational. Detection data obtained during tests of electronic settings, system equipment, and antenna configuration were omitted from any comparative analyses because these tests often altered the performance of the flexible system.

Results and Discussion

Detection Rates

In 2017, we detected 220 fish in 136.3 h of sampling across 35 d using the towed flexible antenna system. This included 131 Chinook salmon (60%), 2 coho salmon (1%), 82 steelhead (37%), and 5 fish without species data available in PTAGIS (2%). In comparison, we detected 549 fish in 78.2 h of sampling across 21 d in 2016 using the towed flexible antenna system. Species detected in 2016 were composed of 77 Chinook salmon (14%), 20 coho salmon (4%), 433 steelhead (79%), 3 sockeye salmon (<1%), and 16 fish without species data (3%).

We believe that the lower detection efficiency in 2017 was largely due to the reduced sample width of the entire array from 36.6 to 14.6 m after changing antenna orientation from horizontal to vertical. This change reduced the proportion of steelhead detections from 2016, but increased the proportions of Chinook detections. Lower detection efficiency in 2017 was also a result of the significant testing required to sample with more than six antennas.

It was our goal to sample with 12 vertically oriented antennas throughout the spring juvenile migration and to compare sample results with those from the matrix trawl system. However, grounding and communication issues between antennas and a previously unknown firmware glitch limited our sampling to six flexible antennas during the spring migration. Tests after the juvenile migration season were conducted to identify the sources of these problems, and comparative sampling between a 12-flexible antenna array and the matrix trawl system is planned for 2018.

Performance of the Flexible Antenna vs. Matrix Trawl System

In 2017, we continued our comparisons of detection efficiency, species composition, and diel detection patterns between the flexible antenna and matrix trawl systems. We used these comparisons to determine the feasibility of replacing the matrix trawl with the flexible antenna in future years. We sampled both systems simultaneously during May and June, with intermittent days for system testing. Testing days were omitted from comparative analyses.

There were 12 dates (62.3 h) when the towed flexible antenna system was fully operational and sampling was comparable to the trawl system (Table 2). Most sampling of the flexible system occurred during daylight hours (46.5 h), except during 10-12 May, when sampling was conducted during darkness hours (15.8 h). Over the 12 days of concurrent sampling, the average daily detection ratio between the 6-antenna flexible and matrix trawl systems was 16%, with daily flex/matrix ratios ranging 2-33%.

Species composition of detections from both systems was compared to the species composition of fish detected at Bonneville Dam. In contrast to the higher proportions of steelhead detected with the horizontal orientation used in 2016, species composition of the vertical flexible array in 2017 was comparable to that of fish detected at Bonneville Dam and in the matrix trawl (Table 3). These proportions indicate that the vertical orientation is optimal for the flexible antenna array.

The vertical configuration provides the required sample depth to detect adequate numbers of both Chinook salmon and steelhead. Adequate detection numbers for both these species are important to annual hydrosystem survival estimates (Widener et al. 2017). An expanded array of 12 antennas with increased electronic stability should dramatically improve system function and increase total detections relative to the matrix trawl.

We also compared diel detection patterns between the flexible antenna and matrix trawl systems during concurrent sampling efforts (Figure 9). Both systems exhibited similar trends in average hourly detection rates, with detection rates of yearling Chinook peaking during crepuscular periods, and detection rates of steelhead peaking near mid-morning.

For yearling Chinook salmon, average detections of fish per hour were higher in the matrix trawl than in the flexible antenna system for every hour sampled; however, during dusk, darkness, and dawn periods, detections in the trawl were dramatically higher than in the flexible antenna system. Similar results were observed for steelhead.

These observations may have been related in part to greater avoidance of the trawl by fish during daylight periods, when the net is more visible. Therefore, we concluded that avoidance behavior was not likely responsible for the lower detection rates in the flexible antenna system.

Table 2. Daily detections (n) by species of the flexible and matrix trawl antenna systems during simultaneous sampling in the Columbia River estuary, 2017. Also shown are daily ratios between detection totals and mean ratio (*) for the season. Sampling was conducted during daylight except for 15.8 h of night sampling during 10-12 May.

	Flexible antenna system (F)						Matrix antenna trawl system (M)						F/M ratio
Date	Chinook	Coho	Steelhead	Sockeye	Unknown	Total	Chinook	Coho	Steelhead	Sockeye	Unknown	Total	(%)
5 May	4	0	8	0	1	13	10	0	26	0	3	39	33
10 May	3	0	0	0	0	3	47	0	14	0	2	63	5
11 May	20	0	2	0	1	23	123	1	33	0	8	165	14
12 May	13	0	6	0	1	20	82	3	47	0	13	145	14
15 May	14	0	19	0	1	34	48	2	97	6	12	165	21
16 May	8	0	9	0	0	17	65	1	67	3	7	143	12
17 May	17	2	14	0	2	35	62	8	71	9	16	166	21
18 May	15	0	4	0	1	20	24	1	31	7	6	69	29
12 June	4	0	0	0	0	4	19	2	8	0	1	30	13
14 June	1	0	0	0	0	1	20	2	23	1	0	46	2
15 June	3	0	1	0	0	4	13	0	5	0	0	18	22
16 June	2	0	0	0	0	2	33	0	6	0	0	39	5
Total	104	2	63	0	7	176	546	20	428	26	68	1,088	*16

Table 3. Total detections and species composition of catch in the flexible antenna vs. matrix trawl detection system. Species composition of detections at Bonneville Dam during our intensive sample period are included as a reference.

	Flexible antenna system		Matrix trawl system		Detection at Bonneville Dam	
Species	(n)	(%)	(n)	(%)	(n)	(%)
Chinook salmon	104	59.1	546	50.2	25,981	54.3
Steelhead	63	35.8	428	39.3	17,709	37.0
Coho salmon	2	1.1	20	1.8	1,911	4.0
Sockeye salmon	0	0.0	26	2.4	834	1.7
Unknown	7	4.0	68	6.3	1,423	3.0
Total	176	100	1,088	100	47,858	100

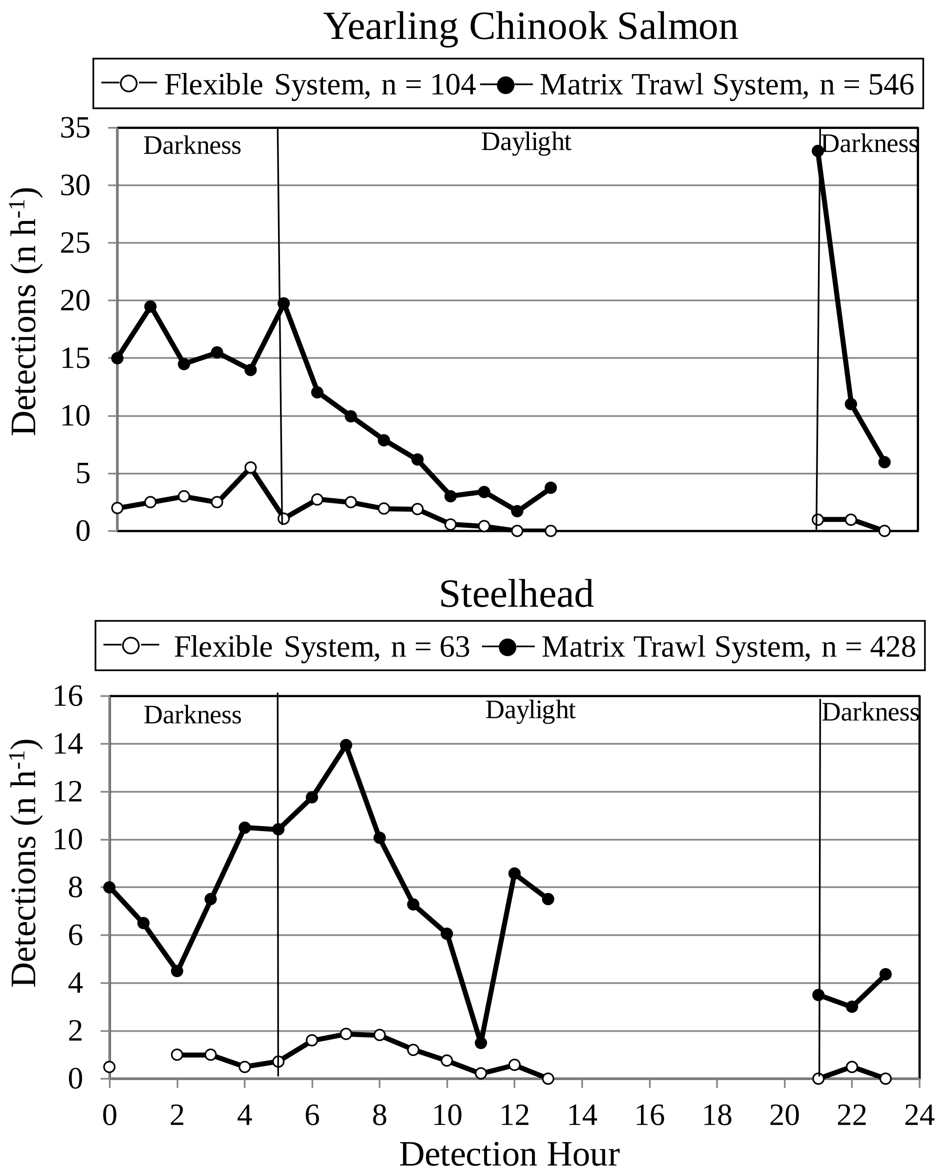

Figure 9. Average hourly detection rates of yearling Chinook salmon and steelhead during concurrent sampling periods between the flexible and matrix trawl antenna systems near rkm 75 in the upper Columbia River estuary, 2017.

Post Season Testing

After the 2017 sample period, we reviewed results and continued testing different electrical configurations to troubleshoot the grounding and communication issues encountered during comparative sampling, which limited the array to six antennas. These issues also likely reduced the performance of the six-antenna array during system comparisons.

After significant testing, we identified a firmware issue that was causing antennas to appear to disconnect at random intervals. This issue was exacerbated by adding additional antennas. After this problem was corrected, we changed the configuration of our CAN bus connectors throughout the array to isolate grounding wires. This retrofit was successful at restoring full communication and stability to a 12-antenna system. To further increase system stability, new grounding configurations will continue to be tested.

Manufactured Antenna Cable

During post-season evaluations in 2016, we also tested a new manufactured antenna cable to replace our hand-assembled antennas. This cable was constructed in conjunction with a Sacramento Delta PIT feasibility study (Rundio et al. 2016). The manufactured cable antennas supported higher amperage (a stronger detection field) than hand-assembled flexible antennas with no difference in EMI. During preseason evaluations in 2018, we will test a 12-cable antenna array to determine the feasibility of fully replacing our hand-assembled flexible-hose antennas for use in 2018 comparative sampling. Complete details of comparative tests between antenna types were reported by Rundio et al. (2016).

Objectives for Future Development

The primary objective to determine the sample rate of a vertically oriented flexible antenna system relative to the matrix trawl system was achieved in 2017. However, we were unable to compare a 12-antenna system due to electrical issues, which compromised the size of the array and limited the comparison between systems.

Electrical issues that compromised comparisons in 2017 were identified in continued off-season tests. A combination of a firmware correction and a new grounding schematic allowed for successful testing of a 12-array antenna system. Further testing is needed to fine-tune the system, but the major issues have been identified and addressed.

Testing in 2017 showed that species composition of catch from the vertical antenna orientation was similar to that from the matrix trawl, and the bias towards steelhead seen with the horizontal orientation in 2016 was eliminated. Based on these results, we determined that the vertical orientation provided optimal sampling coverage. Therefore, comparative sampling in 2018 will utilize this layout for comparisons to the matrix trawl system.

With the major antenna performance issues addressed and the positive species composition results, our focus in 2018 will be on increased system efficiency. We plan to achieve this in four ways. First, to improve antenna stability through proper grounding: this will contribute to higher antenna current and lower EMI, both of which will increase the size of the detection field produced by each antenna. Maximizing the size of the detection field will allow us to detect more fish, and will also provide more time for tag decoding in the field. Fish that pass quickly through the antenna field are less likely to be detected than those that pass slowly. A larger detection field will detect more of those fast-movers.

Second, to use the manufactured cable design: the internal windings of the antenna are more stable compared to the hose antennas. This stability is from decreased movement of the wires while under tow (relative to each other) and improves antenna resiliency to vibration at higher tow speeds. While towing at higher speeds, the system can sample more water volume.

Third, this resiliency to vibration also allows us to stay in areas where fish densities are higher. River constrictions and bends focus fish to certain areas. High river flows during the spring migration limit the amount of time we are able to remain in these areas. The manufactured cable will allow us to tow faster, and therefore stay in these areas longer.

Finally, simply doubling the size of the array should, theoretically, double detection totals. By incorporating all of these improvements, we expect our sample size to increase by more than double in 2018.

While further development is needed for the flexible antenna system, there are considerable advantages of moving away from use of the matrix trawl system, which requires fish to be guided and concentrated for detection. First, the transceiver for the new IS1001 sampling equipment is easier to maintain than the older FS1001M transceiver, which is no longer manufactured (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. In contrasts, the large trawl net is expensive and requires extensive maintenance. Third, a smaller vessel and support crew are sufficient to operate the flexible antenna system, while the matrix trawl system requires a larger, more expensive vessel and larger crew.

Finally, the flexible system provides more versatility to sample different areas of the river than the matrix trawl system, which is restricted to deep channel areas. In past years, we attempted to monitor PIT-tagged fish in shallow-water areas using a downscaled trawl system, but the smaller trawl could not produce adequate detection numbers (Ledgerwood et al. 2007). The flexible system has potential to sample new habitats, and the technology is transferrable to small streams, reservoirs, and large open bodies of water. All of these objectives are important for future development of the flexible antenna system.

Analyses from Estuary Detection Data

Detection data from the estuary sampling efforts are essential for calculating survival probabilities to the tailrace of Bonneville Dam, the last dam encountered by seaward juvenile migrants (Muir et al. 2001; Williams et al. 2001; Zabel et al. 2002). Operation of the trawl detection system in the estuary has provided data to calculate detection probabilities at Bonneville Dam since 1998, and has been supplemented by data 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. Unbiased estimates of survival, in turn, provide information that is 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. 2017).

Estuary detections also allow comparison of relative detection percentages, travel speed, and other parameters between in-river migrant and transported fish groups after they comingle in the estuary. 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 this section, we compare travel time and migration rate by species and migration history, patterns in diel detection by origin and species, and detection rates by migration history using data collected in 2017.

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 2017, 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 the transport location. We compared groups of transported fish to groups of fish detected at Bonneville Dam on the same day (24-h period).

At the transport dams, PIT-tagged fish were diverted to transport barges using separation-by-code (SbyC) systems, which automatically upload detections of fish en route to transport raceways (Marvin and Nighbor 2009). We considered a fish transported only if the last detection of that fish recorded in PTAGIS was at a dam on a route to a transport raceway. We created an independent database (Microsoft Access) using data downloaded from PTAGIS for this analysis.

The U.S. Army Corps of Engineers provided individual barge-loading dates and times for each dam throughout the 2017 transportation season (Eric Hockersmith, USACE, personal communication). By comparing barge-loading times with the last detection time of fish diverted to transport raceways, we determined the individual barge-transport trip for each fish. With this information, we were able to derive the specific date, time, and release location of each individual transported fish. We then created paired comparison groups of fish either released from transported barges or detected at Bonneville Dam on the same date.

For yearling Chinook salmon and steelhead, we plotted seasonal distributions of travel time for fish detected at Bonneville Dam vs. those transported and 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 Dam from time of detection in the trawl or flexible antenna system.

We used a two-sample *t*-test to evaluate differences in the average daily mean travel speed to the estuary between in-river migrants detected at Bonneville Dam and transported fish released just below the dam. We calculated travel speeds (km/d) by dividing the distance traveled from barge release or Bonneville detection to detection in the estuary 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 yearling Chinook and steelhead—For in-river migrants, median travel time to the estuary from Bonneville Dam for the season was among the fastest on record and shorter than the 16-year average for both yearling Chinook salmon and steelhead (1.8 d and 1.7 d, respectively; Table 4). For yearling Chinook salmon, median travel time was 1.6 d in 2017, compared to 1.9 d in 2016. For steelhead, median travel time was 1.4 d in 2017, compared to 1.7 d in 2016. Similarly, for transported yearling Chinook, median travel time from just below Bonneville Dam to the estuary was among the fastest on record at 2.0 d (compared to 2.1 d in 2016). For transported steelhead, median travel time was the fastest on record in 2017 at 1.4 d (1.6 d in 2016).

Table 4. Median time to detection in the estuary during intensive sample periods for yearling Chinook salmon and steelhead detected at Bonneville Dam or released from barges just downstream from Bonneville Dam, 2000-2017. Also shown are mean flow rates at Bonneville Dam 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^3s^{-1})
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	110	2.2	2,997	1.9	333	6,663
2005	1.8	81	2	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
2011[a]	1.8	240	1.6	216	2.1	673	1.6	831	7,911
2011[b]	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	6,953
2017	1.6	237	1.4	191	2.0	306	1.4	604	10,968

a Early migration period prior to the increase in river flow about 16 May.

b Late migration period during the high flow event beginning about 16 May.

Migration rate for yearling Chinook and steelhead—We also compared daily differences in migration rate to the estuary between transported fish and in-river migrants detected at Bonneville Dam relative to river flow volumes (Figure 10). 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 (87.2 vs. 103.2 km/d; $P < 0.001$). Similarly, for steelhead, average daily median travel speed was significantly slower for transported steelhead than for those detected at Bonneville Dam on the same day (105.5 vs. 116.3 km/d; $P < 0.001$). These differences in travel speed by migration history were similar to observations from previous years.

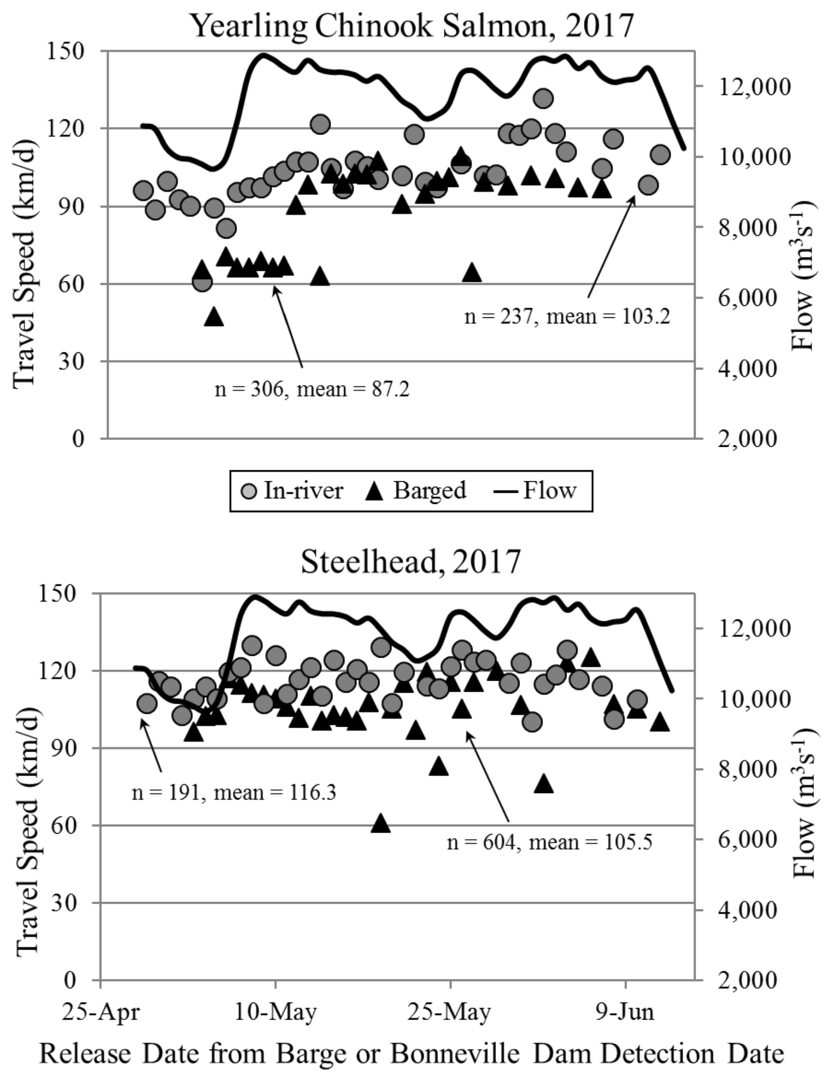

Figure 10. Daily median travel speed (km/d) to the estuary of yearling Chinook salmon (top) and steelhead (bottom) following detection at Bonneville Dam or release from a barge to detection in the upper Columbia River estuary, 2017. Seasonal means are shown for comparison with flow.

Subyearling fall Chinook and Sockeye salmon—Of the 329 in-river migrant subyearling Chinook detected, only 34 were previously detected at Bonneville Dam. In addition, 153 were transported. Mean migration rate from Bonneville Dam to the estuary was slower for transported fish than for fish detected at Bonneville Dam (91.7 vs. 92.6 km/d), but there were not enough data for a meaningful 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 (Morris et al. 2017).

Of the 175 sockeye salmon detected, 19 were previously detected at Bonneville Dam and 26 were transported. Mean migration rate from Bonneville Dam to detection in the estuary was slower for transported sockeye (102.4 km/d) than for in-river migrant sockeye (111.3 km/d), but there were not enough data 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 for this analysis were only those detected in the matrix trawl system during the intensive sample period (30 April-15 June). We separated the number of detections and number of minutes of system operation into darkness and daylight hour categories for each date within this period. 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 and subyearling Chinook salmon.

Results and Discussion

During the intensive sample period, we detected 3,160 yearling Chinook salmon and 3,827 steelhead, with the matrix trawl system operating an average of 13 h/d (Appendix Table 3). We generally stopped sampling each day between 1400 and 1900 PDT for crew changes and refueling.

For hatchery yearling Chinook salmon, hourly detection rates were higher during darkness than daylight hours; however, results between diel periods were not significantly different (4.5 vs. 3.9 fish/h, darkness/daylight ratio 1.2; $P = 0.164$; Figure 11). For wild Chinook salmon, average detection rates were significantly lower during darkness than daylight hours (0.6 vs. 1.0 fish/h; $P = 0.001$). We assumed that the diel difference in hourly detection rates was constant through the season.

For hatchery steelhead, hourly detection rates were significantly higher during daylight than darkness hours (4.8 vs. 2.5 fish/h, darkness/daylight ratio 0.5; $P < 0.001$). Similarly, for wild steelhead, there was a significant difference between daylight and darkness hours (2.9 vs 1.6 fish/h, darkness/daylight ratio 0.6; $P < 0.001$). 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 6 times greater during darkness than during daylight hours (Figure 11).

In each year since 2003, hourly detection distributions have been similar between rear types for both yearling Chinook salmon and steelhead. These numbers were similar again in 2017 for steelhead, so we pooled data by species and origin for a multi-year summary (Figure 12).

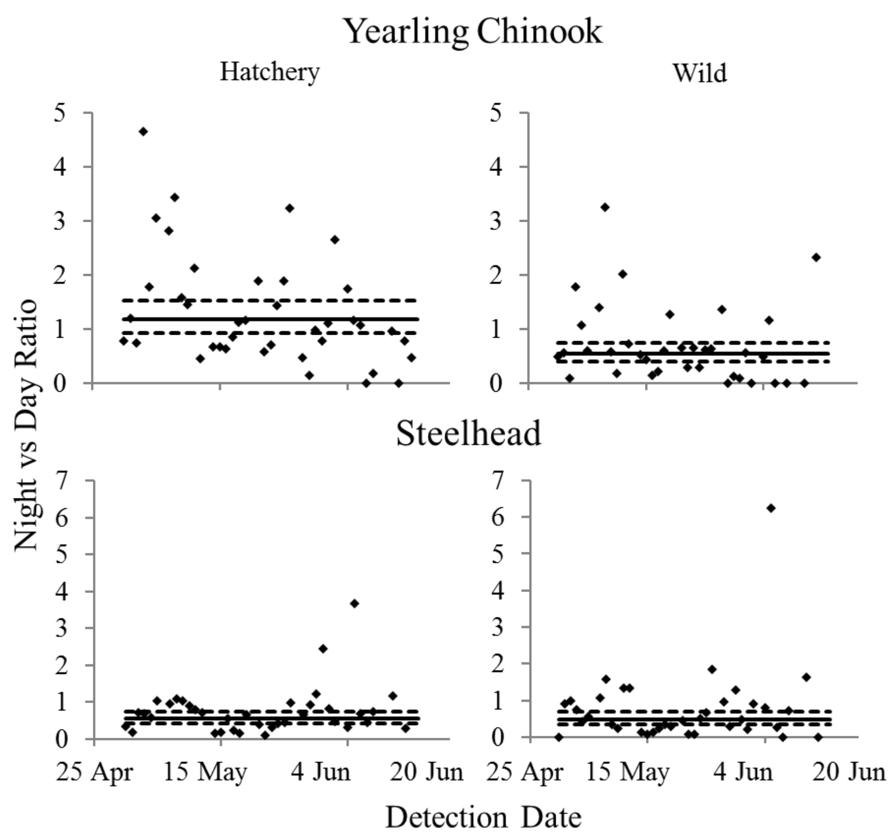

Figure 11. Daily ratios of darkness/daylight detection rates for wild and hatchery yearling Chinook salmon and steelhead during intensive sampling (30 April-15 June). Ratios greater than 1.0 indicate higher detection rates in darkness hours, and values less than 1.0 indicate higher detection rates in daylight hours. Solid lines are estimated mean ratios, and dotted lines are estimated 95% confidence intervals.

For yearling Chinook salmon, detection rates have often been significantly higher during darkness than daytime hours; however, in 2017, the opposite was true for wild fish. The cause of this anomaly is not known but could have been a function of unusually low sample size or extremely high flow. Because of this anomaly, wild and hatchery rear types were separated in the multi-year summary. Detection rates of steelhead have generally been higher during daylight hours, with daylight detection rates often significantly higher in recent years.

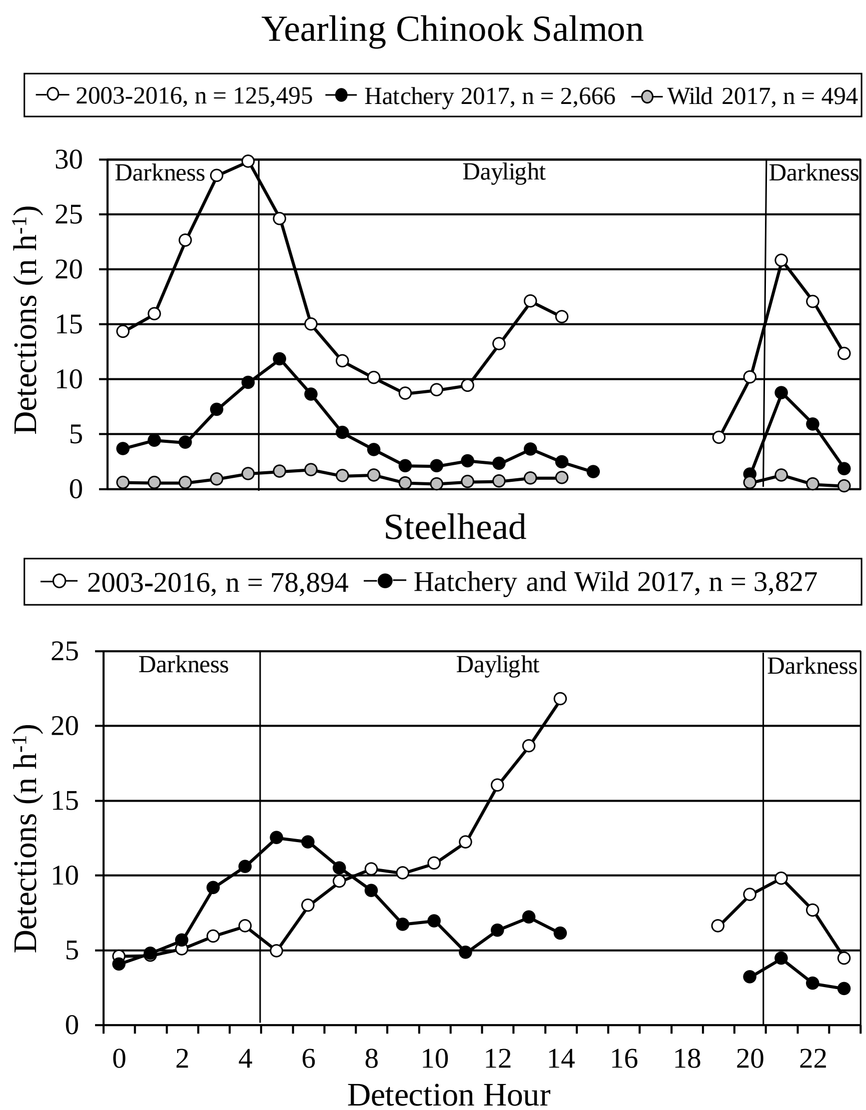

Figure 12. Average hourly detection rates of yearling Chinook salmon and steelhead during intensive sampling with the matrix antenna system during 2003-2016 vs. 2017. Hatchery and wild Chinook were plotted separately because of their different diel patterns in 2018, whereas steelhead were combined because they exhibited no difference in diel detection patterns between rearing types.

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 two-shift sample period (30 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 of transported salmonids were compared to those of in-river migrants detected at Bonneville Dam using logistic regression (Hosmer and Lemeshow 2000; Ryan et al. 2003). Daily groups of in-river migrants detected at Bonneville Dam 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[*pi*/(1 - *pi*)]) 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 one 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 had 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 biases (sample effort). If these assumptions were correct, then differences in relative detection rate between groups would reflect differences in survival from Bonneville Dam to the trawl.

Results and Discussion

A total of 38,935 yearling Chinook salmon and 46,159 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 350 yearling Chinook salmon and 1,400 steelhead in the upper estuary (Appendix Tables 4-5).

A total of 21,388 yearling Chinook salmon and 14,254 steelhead were released upstream from McNary Dam and detected at Bonneville Dam. We detected a total of 229 yearling Chinook and 183 steelhead released upstream from McNary and detected at Bonneville Dam (1.1 and 1.3%, respectively; Appendix Table 6).

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 trawl sampling period. We estimated the proportions of fish from these groups that were available in the estuary during our intensive sample period (30 April-15 June 2017), allowing 2 d for fish to reach the sample area from Bonneville Dam.

For yearling Chinook, we estimated that 80% of in-river migrants and 89% of transported fish passed through the sample reach during our intensive sample period. For steelhead, we estimated that 86% of in-river migrants and 94% of transported fish passed through our sample reach during intensive sampling. These percentages were slightly higher than those estimated in 2016 for in-river fish, but slightly lower than those in 2016 for transported fish.

During the intensive sampling period of 2017 average sample effort was 13 h/d, which was slightly less than the 15 h/d average in 2016. For yearling Chinook, both transported fish and those detected passing Bonneville Dam had lower rates of detection in 2017 than 2016. For steelhead, transported fish had higher rates of detection in 2017. Rates of detection were lower in 2017 than in 2016 for steelhead detected passing Bonneville Dam (Table 5).

Table 5. Trawl detection rates of PIT-tagged fish released from barges or detected passing Bonneville Dam during the intensive sample periods in the upper Columbia River estuary near rkm 75, 2016 and 2017.

	Barged fish originating upstream from McNary Dam			In-river fish detected at Bonneville Dam*		
	Released	Detected	%	Released	Detected	%
2016						
Chinook salmon	47,360	736	1.55	33,114	669	2.02
Steelhead	37,098	1,054	2.84	30,319	1,065	3.51
2017						
Chinook salmon	38,935	350	0.90	21,388	229	1.07
Steelhead	46,161	1,400	3.03	14,254	183	1.28

* In-river fish included only those released at or upstream from McNary Dam, although no fish were transported from McNary Dam in 2017.

For yearling Chinook salmon, logistic regression analysis showed no significant interaction between date-squared and migration history (P = 0.522) or for date-squared as a factor (P = 0.802). However, for transported fish, there was a significant interaction between date and migration history (P = 0.040). This relationship was that in-river fish were detected at a nearly constant rate of 1.1%, while transported fish were detected at a lower rate of around 0.7% early in the season and at a higher rate (> 1.7%) in June (Figure 13, top panel). The adjustment for overdispersion was 2.18.

For steelhead, logistic regression analysis showed no significant interaction between migration history and date-squared (P = 0.467), or between migration history and date (P = 0.858), or for date-squared as a factor (P = 0.231). However, there was a significant effect for migration history (P < 0.001) and for date (P = 0.045). Through the season, estimated detection rates for transported steelhead remained around double those for in-river steelhead. For both groups, detection rates increased from the early to mid-season and decreased from mid to late-season (Figure 13, lower panel). The adjustment for overdispersion was 6.60.

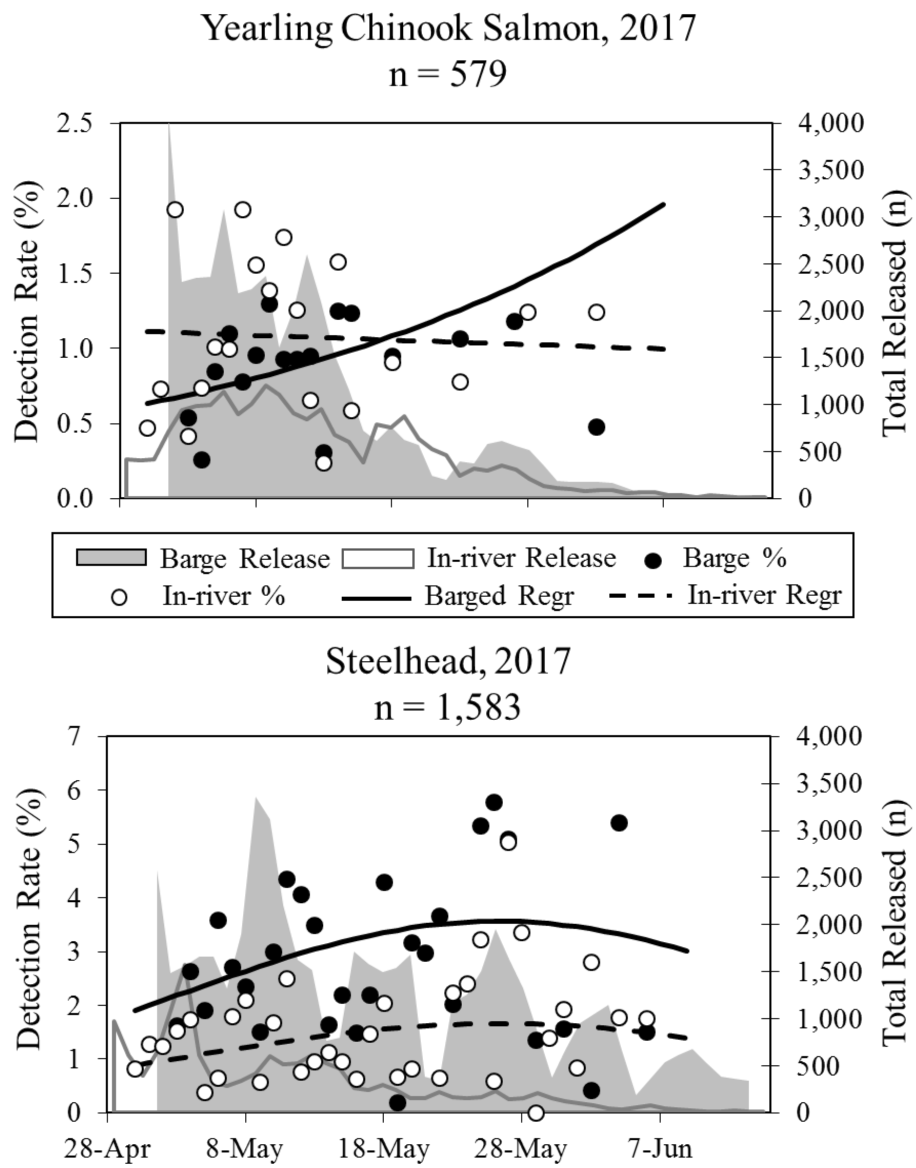

Figure 13. Estimated daily detection rates in the matrix trawl system for transported and in-river migrant yearling Chinook salmon and steelhead. All fish were either detected at Bonneville Dam or released from a barge just downstream from the dam on the same date.

Estimated daily detection rates in the trawl for yearling Chinook salmon were higher early in the season and lower later in the season for in-river migrants compared to transported fish. For steelhead, estimated detection rates were higher for transported fish than for in-river migrants throughout the season. In years where differences are present, it is possible that lower detection rates of one group represent higher mortality in that group between Bonneville Dam and the estuary. Over the last 14 years, there has been a general trend towards higher detection rates of in-river migrant Chinook salmon, but no apparent trend for steelhead (Morris et al. 2014).

In summary, estuary detection rates were considerably lower in 2017 than in 2016, when flows were lower. Detection rates of fish at Bonneville Dam were also lower in 2017 than in 2016 but were similar to those seen in other high flow years.

Since 2012, the Bonneville Dam second powerhouse turbines have been operated at middle or upper 1% efficiency. This mode of operation increased flow to the first powerhouse and spillway, which are not equipped with PIT-tag monitoring systems. In addition, higher river flows in 2017 contributed to a decrease in numbers of fish detected in the estuary.

Estuary detections of fish previously detected at Bonneville Dam are required to estimate probabilities of survival to the tailrace of Bonneville Dam, as well as estimates through the entire hydrosystem, for in-river migrant fish. Reduced rates of detection at Bonneville Dam and/or the trawl impair the accuracy of survival estimates, especially for species with fewer tagged fish.

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Appendix

Appendix Table 1. Daily total sample time and detections for each species using the matrix pair-trawl antenna system in the upper Columbia River estuary near Jones Beach (rkm 75), 2017.

Date	Total time underway (h)	PIT-tag detections (n) Unknown	Chinook salmon	Coho salmon	Steelhead	Sockeye salmon	Cutthroat	Pacific lamprey	Total
17 Mar	1.07	0	0	0	0	0	0	0	0
18 Mar	0.00	--	--	--	--	--	--	--	--
19 Mar	0.00	--	--	--	--	--	--	--	--
20 Mar	0.00	--	--	--	--	--	--	--	--
21 Mar	4.73	0	1	0	0	0	0	0	1
22 Mar	0.00	--	--	--	--	--	--	--	--
23 Mar	5.18	0	0	0	0	0	0	0	0
24 Mar	0.00	--	--	--	--	--	--	--	--
25 Mar	0.00	--	--	--	--	--	--	--	--
26 Mar	0.00	--	--	--	--	--	--	--	--
27 Mar	5.05	0	0	0	0	0	0	0	0
28 Mar	0.00	--	--	--	--	--	--	--	--
29 Mar	0.00	--	--	--	--	--	--	--	--
30 Mar	0.00	--	--	--	--	--	--	--	--
31 Mar	4.37	0	1	0	0	0	0	0	1
1 Apr	0.00	--	--	--	--	--	--	--	--
2 Apr	0.00	--	--	--	--	--	--	--	--
3 Apr	3.82	0	0	0	3	0	0	0	3
4 Apr	0.00	--	--	--	--	--	--	--	--
5 Apr	5.02	0	1	0	6	0	0	0	7
6 Apr	5.17	0	0	0	4	0	0	0	4
7 Apr	6.40	0	1	0	6	0	0	0	7
8 Apr	0.00	--	--	--	--	--	--	--	--
9 Apr	0.00	--	--	--	--	--	--	--	--
10 Apr	4.28	0	0	0	1	0	0	0	1
11 Apr	2.40	0	0	0	0	0	0	0	0
12 Apr	5.00	0	0	0	1	0	0	0	1
13 Apr	3.95	0	2	0	0	0	0	0	2
14 Apr	5.25	0	2	0	4	0	0	0	6
15 Apr	0.00	--	--	--	--	--	--	--	--
16 Apr	0.00	--	--	--	--	--	--	--	--
17 Apr	4.82	0	1	0	6	0	0	0	7
18 Apr	5.08	2	0	0	16	0	0	0	18
19 Apr	5.45	0	5	0	24	0	0	0	29
20 Apr	6.02	0	4	0	13	0	0	0	17
21 Apr	3.40	0	0	0	5	0	0	0	5
22 Apr	0.00	--	--	--	--	--	--	--	--
23 Apr	0.00	--	--	--	--	--	--	--	--
24 Apr	6.00	1	5	0	18	1	0	0	25
25 Apr	4.53	0	2	1	6	0	0	0	9
26 Apr	5.80	0	8	0	36	0	0	0	44
27 Apr	5.17	0	6	0	52	0	0	0	58
28 Apr	5.63	1	12	0	50	0	0	0	63
29 Apr	0.00	--	--	--	--	--	--	--	--

Appendix Table 1. Continued.

Date	Total time underway (h)	PIT-tag detections (n)							
		Unknown	Chinook salmon	Coho salmon	Steelhead	Sockeye salmon	Cutthroat	Pacific lamprey	Total
30 Apr	10.08	1	26	0	52	1	0	0	80
1 May	11.80	1	39	1	68	0	0	0	109
2 May	11.55	0	55	1	49	0	1	0	106
3 May	11.70	1	50	0	36	1	0	0	88
4 May	12.58	3	54	1	45	1	0	0	104
5 May	12.47	5	80	1	124	0	0	0	210
6 May	9.78	2	72	0	86	0	0	0	160
7 May	10.55	6	115	0	141	1	0	0	263
8 May	14.00	6	201	0	131	1	0	0	339
9 May	15.20	4	223	2	125	4	0	0	358
10 May	15.05	3	192	0	96	0	0	0	291
11 May	16.12	4	201	1	102	0	0	0	308
12 May	15.23	11	257	8	187	1	0	0	464
13 May	12.78	13	208	9	337	8	0	0	575
14 May	12.67	7	197	10	228	5	0	0	447
15 May	11.15	8	127	6	149	9	0	0	299
16 May	14.97	7	133	2	113	10	0	0	265
17 May	13.40	5	112	14	111	12	0	0	254
18 May	13.90	4	75	4	99	15	0	0	197
19 May	14.33	8	98	6	97	14	1	0	224
20 May	10.98	6	62	7	124	9	0	0	208
21 May	12.57	6	57	8	55	6	0	1	133
22 May	14.55	13	99	12	123	8	0	0	255
23 May	14.38	5	45	8	82	8	0	0	148
24 May	17.95	10	43	7	92	13	0	0	165
25 May	14.25	11	35	5	72	8	0	0	131
26 May	14.10	7	25	4	69	5	0	0	110
27 May	11.97	8	48	9	143	6	0	0	214
28 May	11.62	6	34	10	148	6	0	0	204
29 May	16.63	7	80	4	127	6	0	0	224
30 May	13.22	5	25	12	32	1	0	0	75
31 May	12.92	3	36	3	37	4	0	0	83
1 Jun	13.23	6	20	7	42	1	0	0	76
2 Jun	12.67	4	44	3	30	3	0	0	84
3 Jun	8.63	4	7	4	29	2	0	0	46
4 Jun	10.63	0	54	5	35	1	0	0	95
5 Jun	12.48	2	15	5	54	1	0	1	78
6 Jun	12.28	4	35	5	40	1	0	0	85
7 Jun	10.33	0	16	2	14	0	0	0	32
8 Jun	12.28	2	72	5	23	0	0	0	102
9 Jun	7.62	0	15	2	15	1	0	0	33
10 Jun	5.65	1	44	2	16	0	0	0	63
11 Jun	10.25	2	37	1	12	0	0	0	52
12 Jun	11.98	2	40	5	21	0	0	0	68
13 Jun	13.00	3	51	1	11	0	0	0	66
14 Jun	11.73	0	38	3	24	1	0	0	66
15 Jun	12.53	0	27	1	5	0	0	0	33
16 Jun	7.73	0	34	0	7	0	0	0	41
Total	711.06	220	3,704	207	4,109	175	2	2	8,419

Appendix Table 2. Combined daily totals of impinged or injured fish resulting from the matrix pair-trawl antenna system used in the upper Columbia River estuary (rkm 75), 2017.

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

Appendix Table 2. Continued.

Date	Yearling Chinook	Subyearling Chinook	Coho	Steelhead	Sockeye	Chum
1 May	0	0	0	0	0	0
2 May	4	0	1	0	0	1
3 May	0	0	0	1	0	0
4 May	3	0	0	0	0	0
5 May	2	0	1	0	0	0
6 May	2	0	0	3	0	1
7 May	2	0	0	5	1	0
8 May	3	1	1	1	0	0
9 May	1	0	0	3	0	1
10 May	10	1	4	1	2	2
11 May	1	0	0	3	0	0
12 May	2	0	3	0	0	0
13 May	1	0	0	0	0	0
14 May	6	0	3	0	1	0
15 May	4	1	1	0	1	1
16 May	2	1	0	0	1	0
17 May	4	1	1	0	1	0
18 May	3	2	0	0	0	0
19 May	1	0	0	0	0	1
20 May	2	0	0	0	0	0
21 May	2	0	0	1	0	0
22 May	1	0	1	0	4	0
23 May	0	0	0	0	0	0
24 May	0	0	0	0	0	0
25 May	0	0	0	0	0	0
26 May	0	0	0	0	1	0
27 May	0	0	0	0	1	0
28 May	0	2	0	0	3	0
29 May	1	1	0	0	11	1
30 May	0	2	0	0	3	0
31 May	2	3	1	0	0	0
1 Jun	0	1	0	1	2	0
2 Jun	0	1	0	0	0	0
3 Jun	1	0	0	0	0	0
4 Jun	0	1	2	0	1	0
5 Jun	1	3	0	0	0	0
6 Jun	1	2	0	0	1	0
7 Jun	0	1	0	0	0	0
8 Jun	0	1	0	0	2	0
9 Jun	0	0	0	0	0	0
10 Jun	0	0	0	0	0	0
11 Jun	0	0	0	0	0	0
12 Jun	2	2	1	1	0	0
13 Jun	0	0	0	0	1	0
14 Jun	1	2	0	2	0	0
15 Jun	0	1	0	0	0	0
16 Jun	0	0	0	0	0	0
Total	76	30	21	25	37	9

Appendix Table 3. Mean diel catch by hour for yearling Chinook salmon and steelhead during intensive sampling (30 Apr-15 June) with a PIT-tag detector surface pair trawl at Jones Beach in the upper Columbia River estuary (rkm 75), 2017. Total effort was rounded to the nearest tenth of an hour.

		Yearling Chinook salmon				Steelhead			
	Total	(n)		Mean detections/h		(n)		Mean detections/h	
Diel hour	effort (h)	Hatchery	Wild	Hatchery	Wild	Hatchery	Wild	Hatchery	Wild
0	39.5	145	23	3.67	0.58	111	50	2.81	1.27
1	38.6	171	22	4.43	0.57	108	77	2.80	2.00
2	29.9	126	17	4.22	0.57	96	73	3.22	2.45
3	13.4	97	12	7.24	0.90	58	65	4.33	4.85
4	10.0	97	14	9.70	1.40	56	50	5.60	5.00
5	17.5	207	28	11.83	1.60	108	111	6.17	6.34
6	43.3	373	76	8.62	1.76	284	245	6.57	5.66
7	42.6	218	51	5.12	1.20	242	205	5.68	4.81
8	39.1	140	49	3.58	1.25	229	123	5.85	3.14
9	41.9	88	23	2.10	0.55	198	84	4.73	2.00
10	37.6	78	17	2.08	0.45	172	89	4.58	2.37
11	40.7	104	27	2.56	0.66	136	61	3.34	1.50
12	22.9	53	16	2.31	0.70	96	49	4.19	2.14
13	19.0	69	19	3.63	1.00	97	40	5.10	2.10
14	9.8	24	10	2.44	1.02	45	15	4.58	1.53
15	1.3	2	--	1.56	--	--	--	--	--
16	0.0	--	--	--	--	--	--	--	--
17	0.0	--	--	--	--	--	--	--	--
18	0.0	--	--	--	--	--	--	--	--
19	0.7	--	--	--	--	--	--	--	--
20	24.4	33	14	1.35	0.57	59	19	2.42	0.78
21	38.0	333	48	8.76	1.26	129	40	3.39	1.05
22	39.7	234	17	5.89	0.43	72	38	1.81	0.96
23	40.0	74	11	1.85	0.28	64	33	1.60	0.83
Total	589.8	2,666	494			2,360	1,467		

Appendix Table 4. Number of PIT-tagged yearling Chinook salmon loaded for transport at dams and numbers detected in the upper Columbia River estuary (rkm 75). Transport dates were 14 Apr-16 June; trawl operations 17 March-16 June, intensive sampling 30 Apr-15 June 2017. Season totals are shown.

	Numbers loaded by dam (n)				Detections by transport dam (%)			Total trawl detections	
Release date and time (2017)	Lower Granite	Little Goose	Lower Monumental	Total fish loaded (n)	Lower Granite	Little Goose	Lower Monumental	n	(%)
14 Apr 6:15 pm	2,167	0	0	2,167	0.14	--	--	3	0.14
21 Apr 9:45 pm	1,056	0	0	1,056	0.57	--	--	6	0.57
28 Apr 5:45 pm	1,559	0	0	1,559	0.58	--	--	9	0.58
3 May 7:25 pm	2,117	1,149	836	4,102	0.47	0.61	0.60	22	0.54
4 May 10:45 pm	917	592	800	2,309	0.44	0.17	0.13	6	0.26
5 May 9:10 pm	1,066	617	672	2,355	0.47	1.13	1.19	20	0.85
6 May 7:45 pm	1,143	706	517	2,366	1.31	1.13	0.58	26	1.10
7 May 7:40 pm	1,445	211	1,424	3,080	1.04	0.47	0.56	24	0.78
8 May 8:10 pm	1,345	82	760	2,187	0.97	1.22	0.92	21	0.96
9 May 8:35 pm	1,242	54	938	2,234	1.61	0.00	0.96	29	1.30
10 May 8:40 pm	1,425	87	863	2,375	0.91	0.00	1.04	22	0.93
11 May 7:40 pm	1,067	80	459	1,606	0.37	3.75	1.74	15	0.93
12 May 8:15 pm	1,258	84	667	2,009	0.79	0.00	1.35	19	0.95
13 May 11:25 pm	1,422	104	1,074	2,600	0.28	0.00	0.37	8	0.31
14 May 8:30 pm	937	293	858	2,088	1.07	1.02	1.52	26	1.25
15 May 7:30 pm	181	395	953	1,529	0.00	1.01	1.57	19	1.24
16 May 8:10 pm	177	434	548	1,159	0.56	0.92	1.64	14	1.21
17 May 8:20 pm	360	230	133	723	0.28	1.74	0.00	5	0.69
18 May 9:00 pm	304	191	122	617	0.00	0.00	0.82	1	0.16
19 May 7:30 pm	348	318	101	767	0.86	0.00	0.00	3	0.39
20 May 8:18 pm	297	231	100	628	2.36	1.30	4.00	14	2.23
21 May 10:40 pm	289	175	107	571	0.35	0.00	0.00	1	0.18
22 May 9:00 pm	68	134	41	243	0.00	0.75	0.00	1	0.41
23 May 7:45 pm	46	118	30	194	0.00	1.69	0.00	2	1.03
24 May 8:15 pm	274	102	20	396	2.55	1.96	0.00	9	2.27

Appendix Table 4. Continued.

Release date and time (2017)	Numbers loaded by dam (n) Lower Granite	Little Goose	Lower Monumental	Total fish loaded (n)	Detections by transport dam (%) Lower Granite	Little Goose	Lower Monumental	Total trawl detections n	(%)
25 May 8:10 pm	269	76	33	378	1.49	2.63	0.00	6	1.59
26 May 9:00 pm	524	39	22	585	0.76	7.69	0.00	7	1.20
27 May 7:00 pm	524	31	63	618	2.10	3.23	6.35	16	2.59
29 May 8:00 pm	292	129	90	511	2.05	0.78	1.11	8	1.57
31 May 8:45 pm	74	70	39	183	1.35	0.00	0.00	1	0.55
2 Jun 9:00 pm	156	2	21	179	1.28	0.00	4.76	3	1.68
4 Jun 7:35 pm	152	3	14	169	0.00	0.00	7.14	1	0.59
6 Jun 8:25 pm	26	26	7	59	0.00	0.00	14.29	1	1.69
8 Jun 8:20 pm	12	10	3	25	0.00	0.00	0.00	0	0.00
10 Jun 8:30 pm	18	9	4	31	0.00	0.00	0.00	0	0.00
12 Jun 7:30 pm	15	8	5	28	0.00	0.00	0.00	0	0.00
14 Jun 8:15 pm	22	7	2	31	0.00	0.00	0.00	0	0.00
16 Jun 8:00 pm	15	7	3	25	0.00	0.00	0.00	0	0.00
Totals	24,609	6,804	12,329	43,742	0.77	0.85	0.98	368	0.84

Appendix Table 5. Number of PIT-tagged steelhead loaded for transport at dams and numbers detected in the upper Columbia River estuary (rkm 75). Transport dates were 14 Apr-16 June; trawl operations 17 March-16 June, intensive sampling 30 Apr-15 June 2017. Season totals are shown.

	Numbers loaded by dam (n)				Detections by transport dam (%)			Total trawl detections	
Release date and time (2017)	Lower Granite	Little Goose	Lower Monumental	Total fish loaded (n)	Lower Granite	Little Goose	Lower Monumental	n	(%)
14 Apr 6:15 pm	927	0	0	927	0.11	--	--	1	0.11
21 Apr 9:45 pm	743	0	0	743	0.00	--	--	0	0.00
28 Apr 5:45 pm	807	0	0	807	0.00	--	--	0	0.00
3 May 7:25 pm	1,012	569	994	2,575	1.88	2.11	1.11	42	1.63
4 May 10:45 pm	700	189	594	1,483	3.14	3.70	1.68	39	2.63
5 May 9:10 pm	930	189	440	1,559	2.15	0.53	2.05	30	1.92
6 May 7:45 pm	1,163	229	274	1,666	3.53	2.62	4.74	60	3.60
7 May 7:40 pm	1,108	86	464	1,658	2.98	1.16	2.37	45	2.71
8 May 8:10 pm	947	57	314	1,318	2.43	5.26	1.59	31	2.35
9 May 8:35 pm	1,187	71	647	1,905	1.18	7.04	1.55	29	1.52
10 May 8:40 pm	2,027	156	1,180	3,363	3.16	1.28	2.97	101	3.00
11 May 7:40 pm	2,162	95	867	3,124	4.86	6.32	2.88	136	4.35
12 May 8:15 pm	1,484	68	659	2,211	4.51	4.41	3.03	90	4.07
13 May 11:25 pm	989	68	575	1,632	3.64	2.94	3.30	57	3.49
14 May 8:30 pm	1,070	80	371	1,521	1.96	2.50	0.54	25	1.64
15 May 7:30 pm	329	117	324	770	1.52	1.71	3.09	17	2.21
16 May 8:10 pm	289	213	296	798	1.38	1.41	1.69	12	1.50
17 May 8:20 pm	1,383	196	140	1,719	2.31	1.02	2.86	38	2.21
18 May 9:00 pm	1,317	157	112	1,586	4.48	3.18	3.57	68	4.29
19 May 7:30 pm	1,216	173	103	1,492	0.16	0.58	0.00	3	0.20
20 May 8:18 pm	1,336	105	103	1,544	3.52	0.95	0.97	49	3.17

Appendix Table 5. Continued.

Release date and time (2017)	Numbers loaded by dam (n) Lower Granite	Little Goose	Lower Monumental	Total fish loaded (n)	Detections by transport dam (%) Lower Granite	Little Goose	Lower Monumental	Total trawl detections n	(%)
21 May 10:40 pm	1,475	120	85	1,680	2.98	1.67	4.71	50	2.98
22 May 9:00 pm	179	126	77	382	2.79	5.56	2.60	14	3.66
23 May 7:45 pm	118	158	70	346	2.54	2.53	0.00	7	2.02
24 May 8:15 pm	965	133	74	1,172	1.66	0.00	2.70	18	1.54
25 May 8:10 pm	1,103	100	57	1,260	9.25	8.00	3.51	112	8.89
26 May 9:00 pm	1,395	53	57	1,505	5.88	1.89	7.02	87	5.78
27 May 7:00 pm	1,784	38	138	1,960	5.33	0.00	3.62	100	5.10
29 May 8:00 pm	848	225	245	1,318	1.53	1.78	0.41	18	1.37
31 May 8:45 pm	137	113	130	380	1.46	1.77	1.54	6	1.58
2 Jun 9:00 pm	901	1	53	955	0.22	0.00	3.77	4	0.42
4 Jun 7:35 pm	1,062	17	65	1,144	5.56	5.88	3.08	62	5.42
6 Jun 8:25 pm	57	86	43	186	1.75	0.00	0.00	1	0.54
8 Jun 8:20 pm	486	30	26	542	1.85	0.00	3.85	10	1.85
10 Jun 8:30 pm	627	41	13	681	2.23	2.44	0.00	15	2.20
12 Jun 7:30 pm	310	47	25	382	4.52	8.51	4.00	19	4.97
14 Jun 8:15 pm	313	16	13	342	0.96	12.50	0.00	5	1.46
16 Jun 8:00 pm	509	12	4	525	0.00	0.00	0.00	0	0.00
Totals	35,395	4,134	9,632	49,161	3.05	2.42	2.30	1,401	2.85

Appendix Table 6. Trawl system detections of PIT-tagged juvenile Chinook salmon and steelhead previously detected at Bonneville Dam, 2017.

Date detected at Bonneville	Tag detections					
	Bonneville Dam (n)		Jones Beach (n)		Bonneville and Jones Beach (%)	
	Chinook	Steelhead	Chinook	Steelhead	Chinook	Steelhead
23 Mar	0	1	0	0	--	0.00
24 Mar	1	1	0	0	0.00	0.00
25 Mar	0	0	0	0	--	--
26 Mar	0	0	0	0	--	--
27 Mar	1	0	0	0	0.00	--
28 Mar	0	0	0	0	--	--
29 Mar	0	2	0	0	--	0.00
30 Mar	0	0	0	0	--	--
31 Mar	1	2	0	0	0.00	0.00
1 Apr	4	8	0	0	0.00	0.00
2 Apr	10	20	0	0	0.00	0.00
3 Apr	8	13	0	1	0.00	7.69
4 Apr	14	5	0	0	0.00	0.00
5 Apr	11	6	0	0	0.00	0.00
6 Apr	9	7	0	0	0.00	0.00
7 Apr	8	8	0	0	0.00	0.00
8 Apr	15	13	0	0	0.00	0.00
9 Apr	20	8	0	0	0.00	0.00
10 Apr	239	18	0	0	0.00	0.00
11 Apr	198	11	2	0	1.01	0.00
12 Apr	143	12	0	0	0.00	0.00
13 Apr	208	34	0	0	0.00	0.00
14 Apr	256	34	0	0	0.00	0.00
15 Apr	264	24	0	1	0.00	4.17
16 Apr	207	46	2	0	0.97	0.00
17 Apr	167	75	2	1	1.20	1.33
18 Apr	155	80	0	0	0.00	0.00
19 Apr	192	107	0	0	0.00	0.00
20 Apr	223	250	0	0	0.00	0.00
21 Apr	427	121	2	0	0.47	0.00
22 Apr	454	102	2	0	0.44	0.00
23 Apr	347	133	3	2	0.86	1.50
24 Apr	297	133	2	0	0.67	0.00
25 Apr	365	234	2	1	0.55	0.43
26 Apr	326	416	2	1	0.61	0.24
27 Apr	381	633	0	3	0.00	0.47
28 Apr	452	469	1	0	0.22	0.00
29 Apr	475	423	2	6	0.42	1.42
30 Apr	543	1028	2	8	0.37	0.78
1 May	553	650	3	8	0.54	1.23
2 May	531	419	8	5	1.51	1.19
3 May	837	711	3	10	0.36	1.41
4 May	1,121	1,264	7	20	0.62	1.58
5 May	1,199	1,867	10	8	0.83	0.43

Appendix Table 6. Continued.

Date detected at Bonneville	Tag detections					
	Bonneville Dam (n)		Jones Beach (n)		Bonneville and Jones Beach (%)	
Bonneville	Chinook	Steelhead	Chinook	Steelhead	Chinook	Steelhead
6 May	1,118	778	11	10	0.98	1.29
7 May	1,220	443	22	7	1.80	1.58
8 May	1,035	365	14	6	1.35	1.64
9 May	1,128	441	14	3	1.24	0.68
10 May	1,247	482	22	7	1.76	1.45
11 May	1,131	696	13	16	1.15	2.30
12 May	924	558	7	4	0.76	0.72
13 May	830	593	2	7	0.24	1.18
14 May	949	699	15	6	1.58	0.86
15 May	687	585	4	8	0.58	1.37
16 May	603	535	5	3	0.83	0.56
17 May	400	318	4	6	1.00	1.89
18 May	777	302	8	6	1.03	1.99
19 May	736	355	0	2	0.00	0.56
20 May	869	310	10	4	1.15	1.29
21 May	615	201	2	1	0.33	0.50
22 May	533	225	6	1	1.13	0.44
23 May	462	292	4	7	0.87	2.40
24 May	250	222	0	5	0.00	2.25
25 May	311	198	7	5	2.25	2.53
26 May	289	197	0	1	0.00	0.51
27 May	337	263	7	12	2.08	4.56
28 May	298	183	2	5	0.67	2.73
29 May	212	183	2	1	0.94	0.55
30 May	129	237	4	3	3.10	1.27
31 May	101	173	1	3	0.99	1.73
1 Jun	97	141	3	1	3.09	0.71
2 Jun	83	127	1	3	1.20	2.36
3 Jun	101	123	1	1	0.99	0.81
4 Jun	137	70	0	3	0.00	4.29
5 Jun	154	47	0	1	0.00	2.13
6 Jun	303	71	6	0	1.98	0.00
7 Jun	393	98	5	3	1.27	3.06
8 Jun	286	63	3	1	1.05	1.59
9 Jun	352	64	1	1	0.28	1.56
10 Jun	277	38	6	1	2.17	2.63
11 Jun	417	24	8	0	1.92	0.00
12 Jun	215	28	4	0	1.86	0.00
13 Jun	220	25	2	1	0.91	4.00
14 Jun	107	15	2	0	1.87	0.00
15 Jun	91	13	0	0	0.00	0.00
16 Jun	127	30	0	0	0.00	0.00
Totals	31,213	20,199	283	230	0.91	1.14