Detection of PIT-Tagged Juvenile Salmonids in the Columbia River Estuary Using a Pair-Trawl, 2015

Matthew S. Morris, Lindsey N. Webb, Paul J. Bentley, Alexander J. Borsky
Benjamin P. Sandford, and Richard D. Ledgerwood

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Fish Ecology Division, Northwest Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
2725 Montlake Boulevard East
Seattle, Washington 98112-2097

for

Division of Fish and Wildlife, Bonneville Power Administration
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Executive Summary

In 2015, 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. We used a pair-trawl fitted with an open array (matrix) of PIT detection antennas in the cod end; this configuration concentrated fish within detection range of the antennas, but allow them to exit the trawl safely, without capture or handling. We deployed the trawl in the navigation channel between river kilometer (rkm) 61 and 83 and sampled for a total of 813 h between 19 March and 2 July.

During this period, we detected a total of 19,889 PIT-tagged juvenile salmonids comprised of 15% wild and 81% hatchery-reared fish (4% were of unknown origin). Species composition of detected fish was 44% spring/summer Chinook and 4% fall Chinook salmon, 41% steelhead, 4% sockeye salmon, 3% coho salmon, less than 1% cutthroat trout, and 4% unknown species.

Sampling effort began on 19 March with a single daytime shift operating 3-5 d/week. Sampling was timed to coincide with arrival in the estuary of migrating juvenile PIT-tagged salmon and steelhead. As numbers of juvenile migrants increased, we intensified sample effort by using two shifts, with one operating 7 d/week during daylight and a second operating 6 d/week during darkness. Intensive sampling continued from 4 May through 11 June.

During the intensive sample period, detections of yearling Chinook salmon averaged 10/h during daylight and 18/h during darkness (P = 0.004); detections of steelhead averaged 14/h during daylight and 11/h during darkness (P = 0.016). After 11 June, we returned to a single-shift schedule, and we continued until numbers of fish in the estuary declined to a point where few or no juvenile salmonids were being detected. Our sample effort ended on 2 July. During intensive sampling, the trawl was deployed for an average of 15 h/d. By comparison, the trawl was deployed for an average of 13 h/d during intensive sampling in 2014.

Also during the intensive sampling period, we detected 3.3% of the yearling Chinook and 4.6% of the steelhead detected at Bonneville Dam. These proportions were much higher than in 2014, when we detected 1.8% of the yearling Chinook and 2.4% of the steelhead detected at Bonneville Dam. We also detected 3.4% of the yearling Chinook and 3.9% of the steelhead transported and released below Bonneville Dam. Again, these rates were considerably higher than those for yearling Chinook and steelhead transported in 2014 (1.5 and 3.1%, respectively).

In 2015, we continued development of a new, flexible antenna system that could be towed behind two small vessels to detect juvenile salmon without a net. We tested a series of towed arrays made from 2.4 by 6.1 m antennas housed in 1.9-cm diameter flexible PVC hose. Early season testing of various modular designs revealed new problems with system electronics. Remediation included lengthening the power and communication cable to increase distance between the cable and antenna wires. We also changed transceiver settings to extend antenna switching time. This modification produced stronger antenna fields and considerably improved detection efficiency.

We tested the flexible antenna system concurrently with the matrix trawl system during the spring juvenile migration. In fall, when fewer fish were present, we continued testing larger array sizes and electronics configurations. In total, we detected 124 fish using the flexible antenna, with 53.9 h of sampling across 18 d in 2015. Concurrent sampling effort yielded five comparable deployments, with 98 total detections on the new system in 14.4 h of sampling.

The mean detection ratio between the flexible antenna and matrix trawl detection systems was 31%. There did not appear to be selective pressure for any particular species on either system when compared to each other on the same dates. However, sample sizes were too small for definitive conclusions to be reached based on these comparisons.

Over 3 days in October, we also deployed and tested electronic configurations and operating procedures for a larger array of six flexible antennas (one-by-six horizontal orientation). This array sampled an area 37-m wide by 2.3-m deep. We intend to test this configuration 2 d/week throughout the juvenile spring migration of 2016. After these tests, we will have more definitive results from comparisons between the flexible antenna and trawl systems. With these data, we hope to determine the feasibility of replacing the trawl with the flexible antenna system in future years. The primary goal in development of the towed flexible antenna array is to simplify project logistics and reduce costs of sampling PIT-tagged fish in the estuary.

As in previous study years, we examined PIT-tag detection data collected in 2015 to discern potential factors related to detection probability and to compare survival and travel time among fish groups by rearing type, migration history (transported vs. migration inriver), and species. For yearling Chinook, we found a weak linear relationship between date and detection rate (P = 0.030), but no significant effect of migration history on detection rate (P = 0.160). For steelhead, there were no temporal trends in detection rate, but there was a significant effect of migration history on detection rate, with inriver migrating fish detected at a higher rate (P = 0.018).

Over the years, detection rates in the trawl have typically been inversely related with flow. Mean flow volumes in the Columbia River at Bonneville Dam were 40% lower during the two-shift sample period of 2015 (5,333 $m^3 s^{-1}$; Figure 3) than during the two-shift period of 2014 (8,890 $m^3 s^{-1}$); and 35% lower than the 13-year average during the same period (8,191 $m^3 s^{-1}$). Mean flow volume in 2015 was the lowest on record since the drought year of 2001 (4,111 $m^3 s^{-1}$).

Of fish detected with the trawl system in 2015, 10% had been transported, while 21% had been detected at Bonneville Dam. The remaining 69% had neither been transported nor detected at Bonneville Dam, although at least 93% of them had originated upstream from Bonneville.

Based on PIT detection histories, we estimated survival from Lower Granite to Bonneville Dam at 43.7% for Snake River yearling Chinook salmon (Table 1). This was lower than the 54.9% estimated through the same reach for these fish in 2014. For Snake River steelhead, estimated survival from Lower Granite to Bonneville was 41.3%, substantially lower than the 75.7% survival estimated for these fish in 2014. Estimated survival for Snake River sockeye salmon through the same reach was 37.3% in 2015, which was again considerably lower than the 71.3% estimated in 2014. Low flow volume and elevated temperature contributed to lower system survival for all species in 2015. By comparison, estimated survival during the drought year of 2001 was 27.9% for yearling Chinook, 4.2% for steelhead, and 2.2% for sockeye.

Table 1. Estimated survival by species and stock from Lower Granite and McNary Dam to Bonneville Dam in 2014 and 2015. All estimates are tailrace-to-tailrace. Standard errors shown in parentheses.

	Tailrace-to-tailrace estimated survival percentages (SE)			
Combined wild and hatchery	Lower Granite to Bonneville		McNary to Bonneville	
stocks	2014	2015	2014	2015
Snake River				
Yearling Chinook	54.9 (±8.3)	43.7 (±3.9)	71.5 (±10.7)	62.9 (±4.3)
Steelhead	75.7 (±6.9)	41.3 (±3.2)	102.3 (±8.8)	66.3 (±3.9)
Sockeye	71.3 (±11.0)	37.3 (±3.7)	81.7 (±11.5)	53.1 (±15.0)
Upper Columbia R (above Yakima R)				
Yearling Chinook			92.9 (± 10.0)	81.6 (±5.1)
Steelhead			97.2 (±10.8)	54.8 (±3.5)
Sockeye			56.5 (±26.9)	44.6 (±20.0)
Yakima River yearling Chinook			74.5 (±16.6)	48.6 (±7.3)

In the reach from McNary to Bonneville Dam, estimated survival was lower in 2015 than in 2014 for yearling Chinook released to the Snake River (62.9 vs. 71.5%), to the Columbia River upstream from its confluence with the Yakima (81.6 vs. 92.9%), and to the Yakima River (48.6 vs. 74.5%). In this same reach, lower survival in 2015 vs. 2014 was also observed for steelhead released to the Snake (66.3 vs. 102.3%) and upper Columbia Rivers (54.8 vs. 97.2%). Upper Columbia River sockeye salmon also had lower estimated rates of survival from McNary to Bonneville Dam; however, these estimates lacked precision due to small sample sizes in both 2015 (44.6% ± 20.0) and 2014 (56.5% ± 26.9).

Mean travel speed to the estuary (rkm 75) was significantly faster for yearling Chinook detected at Bonneville Dam (76 km/d) than for those released from barges just below the dam (60 km/d, $P \leq 0.001$). Similar differences were noted for steelhead, with travel rates of 71 km/d for inriver vs. 65 km/d for transported fish ($P < 0.001$). There was also a significant difference in travel speed between fish detected at Bonneville and those released from barges on the same day for sockeye (85 vs. 67 km/d, $P < 0.001$) and subyearling Chinook salmon (67 vs 57 km/d, $P < 0.001$).

We detected a total of 528 subyearling fall Chinook, with the majority of detections occurring towards the end of and after the intensive sample period. Of these 528 fish, 355 originated in the Snake River basin (142 inriver migrants and 213 transported). The remaining 173 were Columbia River stocks (22 released above McNary, 119 released between McNary and Bonneville Dam and 32 released below Bonneville Dam). We did not detect residual yearling Chinook in 2015 (subyearling Chinook released in 2014 that overwintered before migrating).

Of the 744 sockeye salmon detected in the trawl, 78% had been released into the Snake River and 22% into the upper Columbia River. Sockeye detected in 2015 were 73% hatchery reared, 19% wild, and 8% of unknown origin. Inriver migrant sockeye made up 85% of these detections, with 15% comprised of transported sockeye.

Contents

Introduction

In 2015, 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. 2014). Data from estuary detections were used to estimate the 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 place of 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 2015). When PIT-tagged fish passed through the trawl and antennas, the tag code, GPS position, and date and time of detection was 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.

Over 1.9 million Snake and Columbia River juvenile salmonids were PIT-tagged and released prior to or during the spring 2015 migration season (PSMFC 2015). During the season, 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 2015).

We uploaded trawl detection records to PTAGIS and downloaded information on the fish we detected. This information included the species, run, tagging/release time and location, and date/time of detection at interrogation sites downstream from release. These data were used to evaluate migration timing of transported fish between Bonneville Dam and the estuary, and to evaluate survival and migration timing of yearling Chinook salmon *O. tshawytscha*, steelhead *O. mykiss*, and Sockeye salmon *O. nerka* migrating through the hydrosystem in 2015 and annually since 1998.

In 2015, 58,488 PIT-tagged fish were transported from dams on the Snake River and released below Bonneville and over 124,000 PIT tagged inriver migrants were detected at Bonneville Dam. Seasonal trends in our estuarine detection data for these fish may provide insight into the relationship observed between smolt-to-adult return ratios and juvenile migration timing (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 with a range of 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.

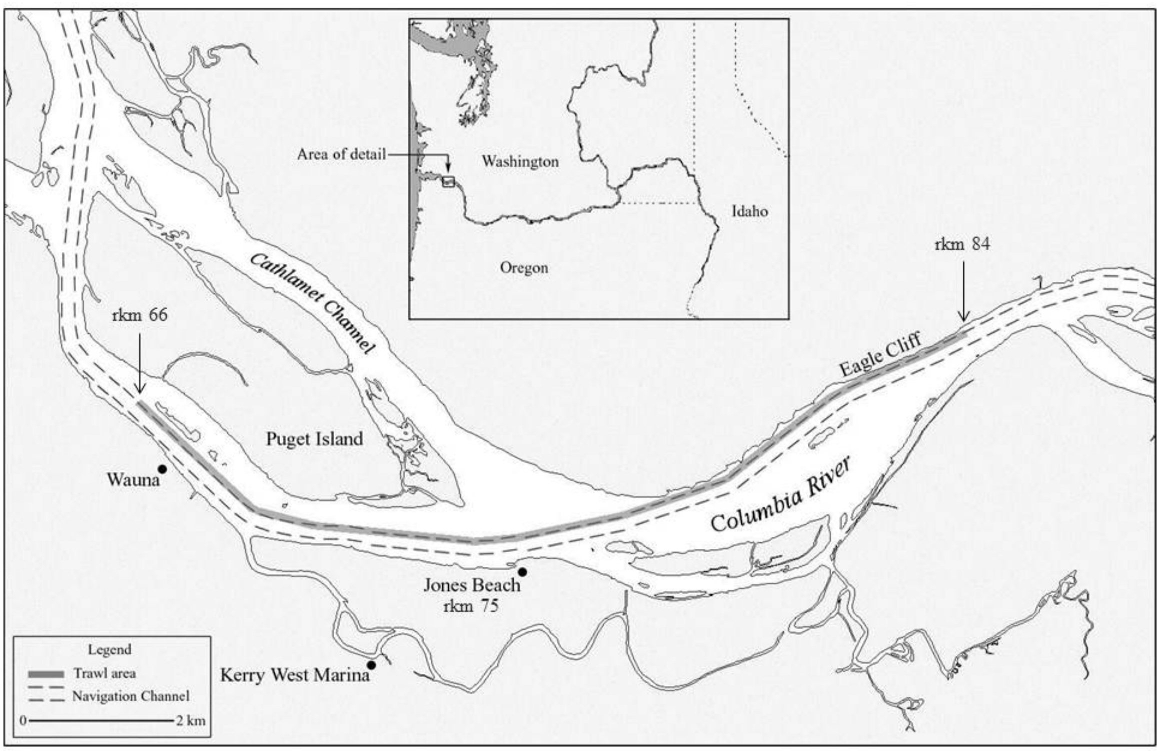

Figure 1. Trawling area adjacent to the navigation channel in the upper Columbia River estuary between rkm 66 and 84.

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 (PSFMC 2015). Specific groups of tagged fish targeted for detection included over 204,000 fish released for a comparative survival study of hatchery fish, and some 58,000 fish diverted to barges for NMFS transportation studies, as well as smaller groups released for other studies.

Migrating juvenile fish released in the upper Snake River must traverse eight dams and reservoirs or be transported from one of three collector dams to reach the tailrace of Bonneville Dam. Transported fish can potentially avoid inriver passage of 7 dams and migration through approximately 461 km of river from the tailrace of Lower Granite Dam to the tailrace of Bonneville Dam (Marsh et al. 2005; 2008; 2010; 2012).

Detection numbers in the pair trawl were sufficient for analyses of timing and survival for yearling Chinook salmon and steelhead. Trawl detections of sockeye and subyearling Chinook salmon were fewer, and analyses were limited due to smaller sample sizes for these fish. We also detected PIT-tagged coho salmon *O. kisutch* and coastal cutthroat trout *O. clarki*.

Sample Period

Spring sampling began on 19 March and continued through the summer migration period to 2 July 2015. Our sample effort varied commensurate with fish availability in the estuary. Early and late in the migration season, we sampled 2-5 d week^{-1} with a single shift, for an average daily sample effort of 6 h/d (sample effort was defined as full deployment of the trawl). During the peak of the spring migration from 4 May through 11 June, we sampled daily with two shifts, both day and night, for an average daily effort of 15h/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. Sampling was intended 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

In 2015, sampling was conducted with the matrix-antenna trawl system (Figure 2). The fish-passage corridor was configured with three parallel antenna coils in front and three in the rear, for a total of six detection coils. Inside dimensions of individual coils measured 0.75 by 2.8 m. Front and rear components were connected by a 1.5-m length of net mesh, and the overall fish-passage opening was 2.6 by 3.0 m. The matrix antenna was attached at the rear of the trawl and suspended by buoys 0.6 m beneath the surface.

This configuration allowed fish collected in the trawl to exit through the antenna while remaining in the river. Each 3-coil component weighed approximately 114 kg in air and required an additional 114 kg of lead weight to suspend in the water column (total weight of front and rear components was 456 kg in air). The trawl and antenna were transported to the sample area aboard a 12.5-m tow vessel.

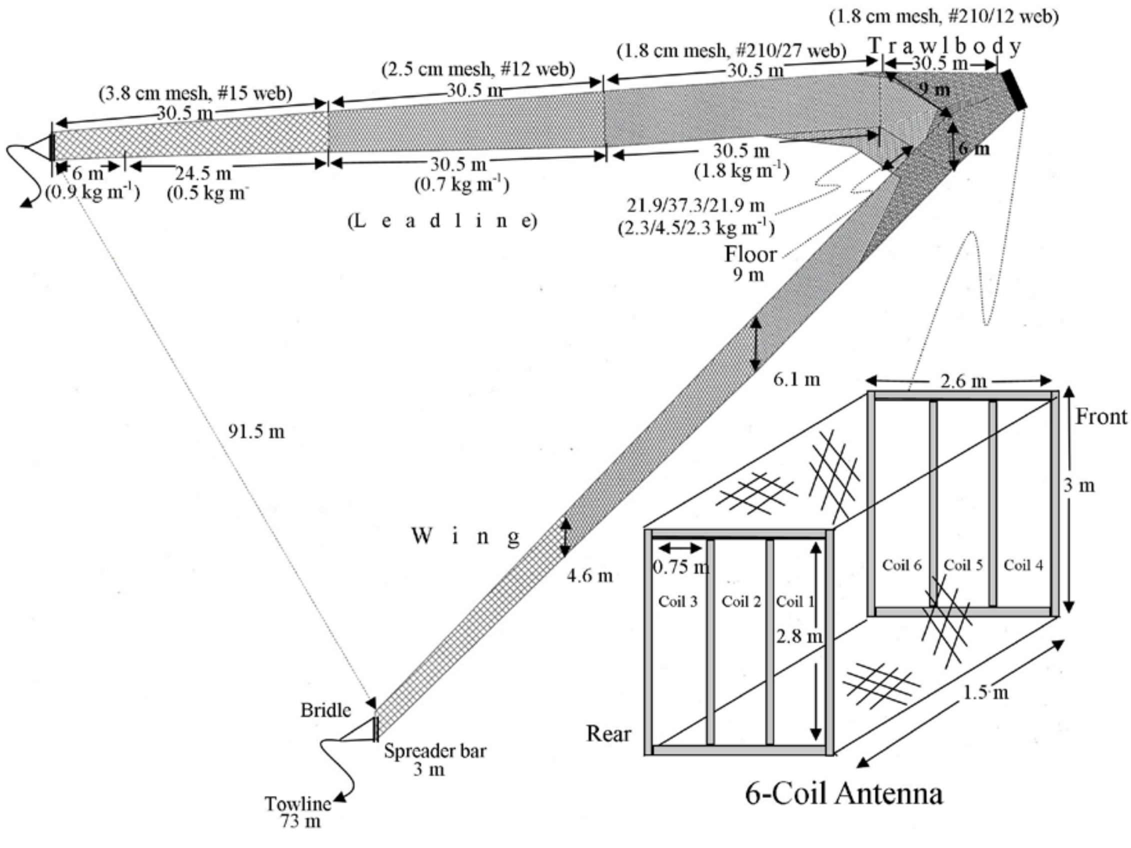

Figure 2. Basic design of the surface pair trawl used with the matrix antenna system to sample juvenile salmonids in the Columbia River estuary (rkm 75), 2015.

Basic configuration of the pair-trawl net has changed little through the years, despite changes to the PIT-tag 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 for antenna attachment at the cod end. The mouth of the trawl body had an opening 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 the trawl and antenna were deployed, one tow line 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 Equipment and Operation

For the pair-trawl detection system, we used essentially the same electronic components and procedures as in 2006-2014. A single FS1001M multiplexing transceiver was used, which was capable of simultaneously powering, recording, and transmitting data for up to six antenna detection coils. 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.

Detection efficiency tests were conducted prior to the sample season to verify system performance (see below). During the season, status reports generated by the transceiver were monitored in real time to confirm performance, and each antenna coil was tested 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 2015). Written logs were maintained 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 periodically (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 2015). Pair-trawl detections are designated in the PTAGIS database with site code TWX (towed array-experimental).

Detection Efficiency and Performance of Matrix Antenna

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

Tests were conducted independently on port, middle, and starboard coil sets. We attached PIT tags to a vinyl-coated tape measure at spacing intervals of 30, 60, and 90 cm, and at different orientations. The tape was then passed back and forth through the pipe and retrieved/returned from a second vessel. Detection efficiency was evaluated based on the proportion of tags on the tape that were detected during a single pass of the tape.

Impacts on Fish

We regularly inspected the cod-end of the net for debris accumulation near the antenna that could impact fish. Other sections of the net were monitored visually from a skiff, and accumulated debris was removed as necessary. During retrieval, the matrix antenna was hoisted onto a tow vessel while remaining attached to the pair-trawl net. This retrieval method saved time and was possible due to the larger fish-passage opening of the matrix antenna configuration, with its lower rates of debris accumulation.

Previous antenna designs, such as the cylindrical antenna (0.9-m diameter) last used in 2008, have resulted in significant accumulation of debris in the trawl body. When using antennas with smaller openings, the trawl net had to be completely inverted for debris removal prior to retrieval, requiring the antenna to be disconnected from the net (Magie et al. 2010). In contrast, the matrix antenna design has allowed most debris to pass through the system, resulting in an overall reduction of debris accumulation, and less interference with sample effort. Debris that remained in the net was removed by hand through zippers in the top of the trawl body. During debris-removal activities, we recorded all impinged or trapped fish as mortalities, although most fish were released alive.

Results and Discussion

Fish Availability and Abiotic Factors Affecting Detection Rate

From 4 May through 11 June 2015, the entire two-shift daily sample period was characterized by below-average river flows and light debris loads. Mean flow volumes at Bonneville Dam were 40% lower during the intensive sample period of 2015 (5,333 $m^3 s^{-1}$; Figure 3) than during the intensive sample period of 2014 (8,890 $m^3 s^{-1}$). Mean flow during 4 May-11 June 2015 was also 35% lower than the 13-year average for the same period (8,191 $m^3 s^{-1}$). This was the lowest mean flow volume on record since the drought year of 2001 (4,111 $m^3 s^{-1}$).

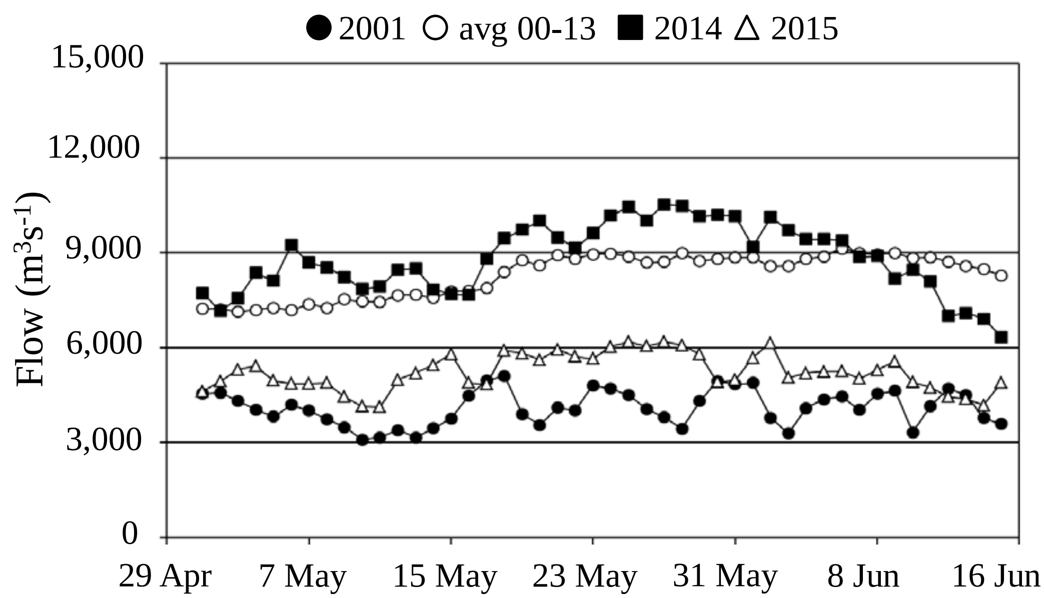

Figure 3. Columbia River flows at Bonneville Dam during the two-shift sample periods in 2014 and 2015, as compared to the average flow from 2000 to 2013 (excluding 2001). Drought-year flows for 2001 are also shown for comparison.

We estimate that intensive sampling in 2015 coincided with arrival time in the estuary of 80% of the yearling Chinook and 88% of the steelhead passing Bonneville Dam (tagged and non-tagged). Our intensive sample period also coincided with 96% of the yearling Chinook and 95% of the steelhead transported for NMFS studies. These numbers were slightly lower than for the intensive sample period of 2014, when we estimated that 88% of the yearling Chinook and 93% of steelhead passing Bonneville Dam arrived in the estuary, along with 99% of the yearling Chinook and 97% of the steelhead that were transported.

In 2015, no transported yearling Chinook salmon or steelhead were released before our intensive sampling period began. After the intensive sampling period had ended, the majority of fish detected at Bonneville Dam were subyearling Chinook. Fish transportation from upstream dams continued until the end of October (John Bailey, USCOR, Walla Walla Dist., personal communication).

While subyearling Chinook salmon were still the most abundant species detected after our intensive sampling period ended, yearling Chinook, coho, and steelhead were also detected. Since 2013, there has been a significant reduction in tagging effort for subyearling Chinook, and these fish comprised only 64% of the detections after our intensive sample period ended in 2015. This proportion was higher than in 2014, but lower than in previous years, and most likely varied in relation to flow.

We sampled with the matrix trawl system for 813 h during 2015 and detected 19,889 PIT-tagged fish. In contrast, we sampled for 925 h during 2014 and detected only 15,904 fish (Figure 4). A similar number of PIT-tagged fish were released during the spring migration in both years, but average detection rates were considerably higher in 2015 (24/h) than in 2014 (17 fish/h).

Through years of sampling we have observed an inverse relationship between river flow volumes and trawl detection rates. Lower flow volume has been consistently associated with higher trawl 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 estuary detection efficiency with the trawl).

A variety of factors contribute to the relationship between low river flows and higher detection rates. First, lower flows carry fish downstream more slowly. This increases the amount of time that a given fish is present in the sample reach and available for detection. Second, lower flows constrict migrants to a narrower cross-sectional area of water. For any given fish present in the estuary during sampling, we expect that decreased dispersion would increase its likelihood of entering the trawl.

Lower flows also increase actual sample time in three ways. First, low flows decrease the transit time required for vessels to return to the upstream end of the sample reach, where the trawl is initially deployed. Second, low flows increase the time available for sampling with the trawl deployed because vessels drift more slowly to the downstream end of the sample reach, where the trawl must be retrieved. Finally, lower flows typically yield less debris accumulation in the trawl net, reducing sample time lost to debris removal.

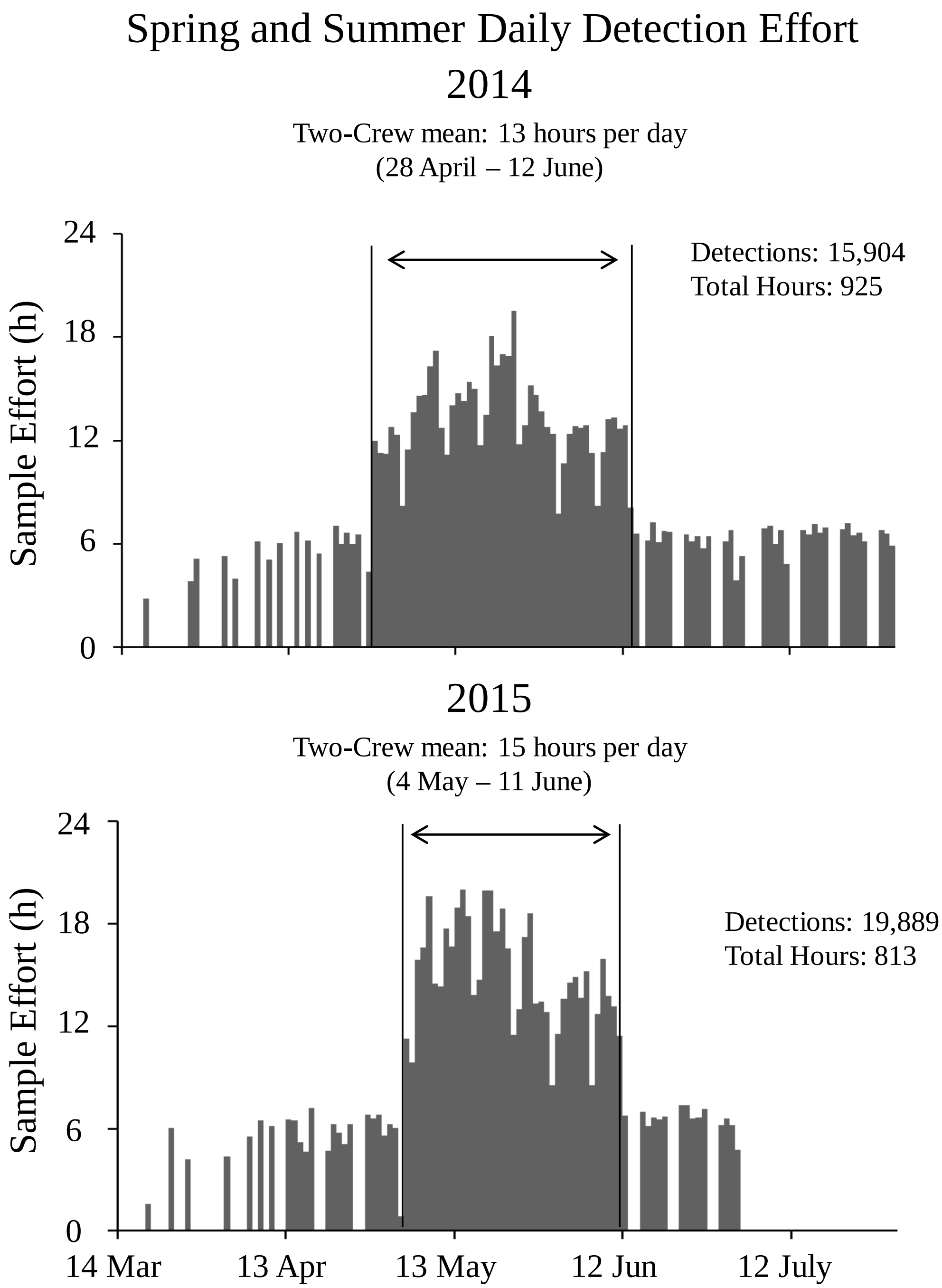

Figure 4. Daily sample effort in spring/summer 2014 and 2015 using a pair-trawl fitted with a "matrix" antenna for PIT-tag detection. Sampling was conducted in tidal fresh-water near Jones Beach between rkm 61 and 83.

Antenna Performance

Estimated detection efficiencies from pre-season testing were positively correlated with spacing between test tags, regardless of tag orientation (45 vs. 90 degrees to the edge of the test tape). Of the 1,512 PIT-tags passed through the matrix antenna, no test-tags spaced at 30-cm intervals were detected. When spacing between tags was increased to 60 cm, detection efficiency increased to 77% for angled tags and 87% for perpendicular tags. For test tags spaced 90 cm apart, reading efficiency increased to 93% for angled tags and 100% for perpendicular tags. Results in 2015 were similar to those in previous years and showed the matrix antenna was performing as expected.

Species Composition

In 2015, we detected a total of 19,071 juvenile salmonids of known species and origin (hatchery and wild) plus another 818 fish lacking release information in PTAGIS (Table 2; Appendix Table 1). For most identified fish, at least some release information was available; however, 718 detected fish had no release or species information associated with their respective tags.

Table 2. Species composition and origin of PIT-tagged fish detected with the trawl system in the upper Columbia River estuary near rkm 75 in 2015.

	Rear type of detected fish			
Species/Run	Hatchery	Wild	Unknown	Total
Spring/Summer Chinook salmon	7,799	1,005	2	8,806
Fall Chinook salmon	707	23	0	730
Coho salmon	550	50	3	603
Steelhead	6,404	1,842	38	8,284
Sockeye salmon	546	141	57	744
Sea-run cutthroat	0	4	0	4
Unknown	0	0	718	718
Grand total	16,006	3,065	818	19,889

Of detected fish with release information, 44% were spring/summer Chinook, 4% were fall Chinook, 41% were steelhead, 4% were sockeye, and 3% were coho salmon; less than 1% were cutthroat trout, and the remaining 4% were unknown salmonid species. Total detections by origin were 15% wild, 81% hatchery, and 4% unknown origin at the time of this report. These numbers may change slightly as PTAGIS records are completed or updated by entities who released these fish.

For all species except steelhead, the proportions detected in 2015 were similar to proportions detected in recent years. The proportion of hatchery steelhead detected in 2015 (77%) was higher than the proportion detected in 2014 (69%). Differences in PIT-tagging strategies, hydrosystem operations, and numbers of fish transported contribute to annual variation in the proportion of each species or rearing type detected in the estuary (Figure 5).

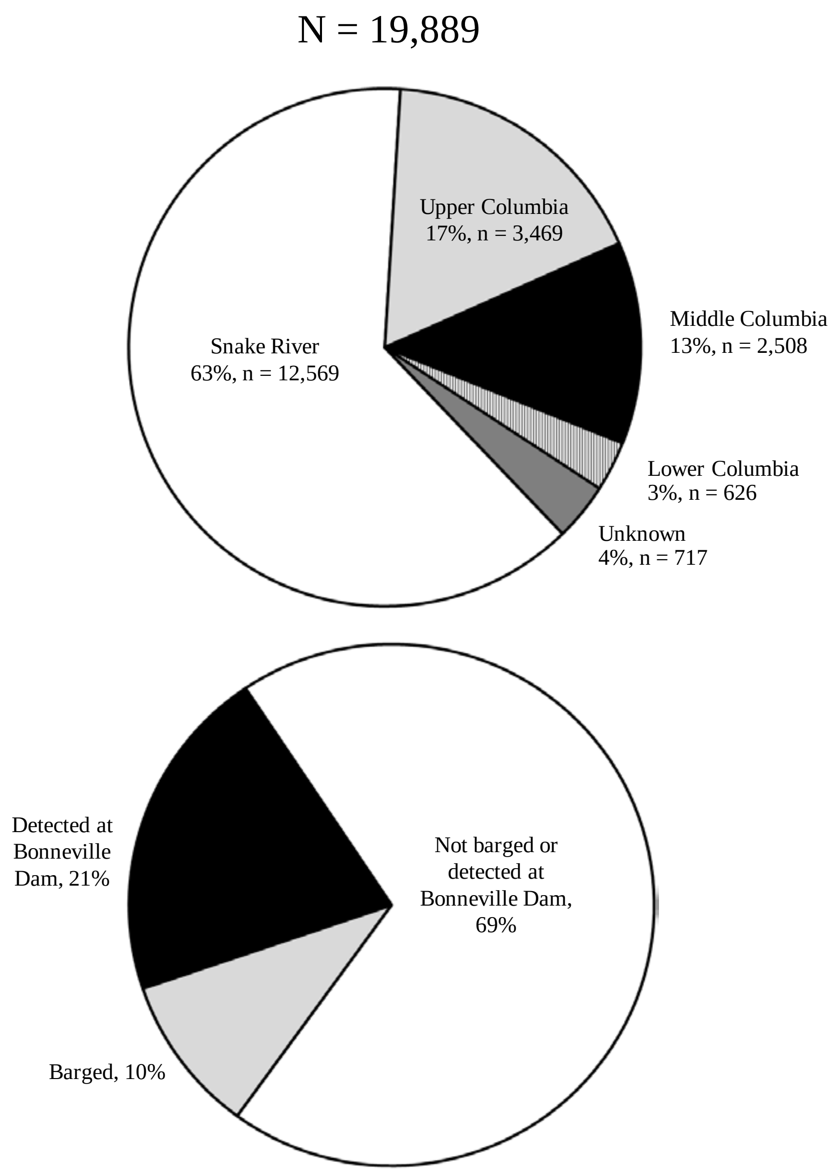

Figure 5. Proportions of fish detected in the trawl by source and migration history, 2015. Upper and mid-Columbia River sources were defined relative to McNary Dam. Fish that originated in the Columbia River below Bonneville Dam could not be transported, nor could they pass Bonneville Dam.

Juvenile 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 have been said to adopt a "reservoir-type" life-history strategy (Connor et al. 2005). In years with high numbers of tagged subyearlings, we commonly detect a few (highest was 53 in 2013) fish exhibiting this life history type; however, no overwintering fish were detected this year.

Impacts on Fish

During inspection or retrieval of the trawl, we recovered juvenile salmonids that had been inadvertently impinged, injured, or killed during sampling. In 2015, we recovered 253 such salmonids from the matrix antenna and trawl system (Appendix Table 2). In previous years, divers have inspected the trawl body and wing areas of the net while underway, and they reported that fish rarely swam close to the webbing. Rather, fish tended to linger near the entrance to the trawl body and directly in front of the antenna, likely because the sample gear is more visible in these areas.

Through the years, we have modified the net to eliminate many visible transition areas between the trawl, wings, and other components. Visible transition areas were found mainly in 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 have 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 the net (bring the trawl wings together). To expedite fish passage, we flushed the net every 17 minutes and 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 to clear debris and may have reduced delay, and possible fatigue, of fish pacing transition areas or lingering near the antenna. A majority of detections were recorded during these 7-minute periods.

Fish appeared to move more readily through the system at night, probably because the trawl and antenna were less visible during darkness hours. Lower visibility at night also appeared to reduce the tendency of fish to pace near the entrance of the trawl body. A floor extending forward from the trawl body is meant 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 are held open have increased by about 10% (Magie et al. 2010).

Development of a Flexible Antenna Detection System

Background

In 2015, we continued development of a flexible antenna system that is towed but does not require a net to concentrate and guide fish within range of the antennas. This new antenna design is based on technology adapted for a stationary PIT-tag monitoring system installed along a pile dike at rkm 70 (PTAGIS site code PD7; Magie et al. 2015). Our goals in developing this antenna are to reduce costs associated with sampling juvenile salmonids in the estuary and to improve sample efficiency using recent advances in PIT technology.

Since 2013, we have used a new multiplex transceiver (Biomark model IS1001MTS) that has allowed us to build much larger antennas than have been used previously in any of our PIT monitoring systems (2.4 × 6.1 m vs. 0.8 × 3.0 m). In addition to increasing read range, the new transceiver allows antenna shielding to be constructed from small-diameter (1.9-cm) flexible hose instead of the large-diameter (10.2 cm), heavier, rigid PVC used previously. These changes have dramatically increased antenna utility and led to new applications.

We tested several arrays using flexible antennas with a modular rope-frame, which was designed to attach and connect multiple antennas, maintain the shape of the array, and reduce strain on the antennas while under tow. Arrays were deployed using either two 6.4-m skiffs, with the first skiff deploying the array and the second supporting the tow, or by tying one end of the array to a stationary site, such as a pile dike, and holding the array against the current with a single skiff.

In 2014, the first flexible antenna array we tested had only two antennas. Nevertheless, this array provided a detection field about 12 m (40 ft) wide and 3.0 m (10 ft) deep. These tests were conducted after the juvenile spring migration, but the array performed well electronically and proved feasibility of the design. In 2015, we scaled up to a larger array (Morris et al. 2014) and redesigned the electronic components to reduce drag. Our primary objectives for the flexible antenna array in 2015 were:

1. Further streamline construction to reduce EMI (electromagnetic interference) from external vibration while under tow.

2. Continue testing a two-antenna array prior to the spring migration to evaluate design and performance and to finalize deployment logistics.
3. Deploy a four-antenna array simultaneously with the matrix trawl system during the juvenile migration when more PIT-tagged fish are present to test the system.
4. Acquire design and logistics information for a six-antenna array to be tested during the juvenile salmonid migration period in 2016.

Methods

Initial testing was conducted in March 2015, prior to the juvenile migration season, using a revised version of the two-antenna flexible array tested in 2014. As the season progressed, we scaled up to a four-antenna flexible array, which was tested intermittently during April-June (Figure 6). Finally, feasibility tests of a six-antenna array were conducted in early fall to prepare for testing in 2016.

Components of each array were the 2.4- by 6.1-m (~8 × 20 ft) antennas housed in 1.9-cm-diameter flexible PVC hose. All arrays were towed in an end-to-end, horizontal orientation with a sample depth of approximately 3 m (Figure 6). To provide additional stability and strength, all antennas were attached to a rope frame (13-mm, non-stretchable rope). The rope frame was attached to two 2.4-m aluminum spreader bars, which were used to maintain the shape of the antenna (width) under tow.

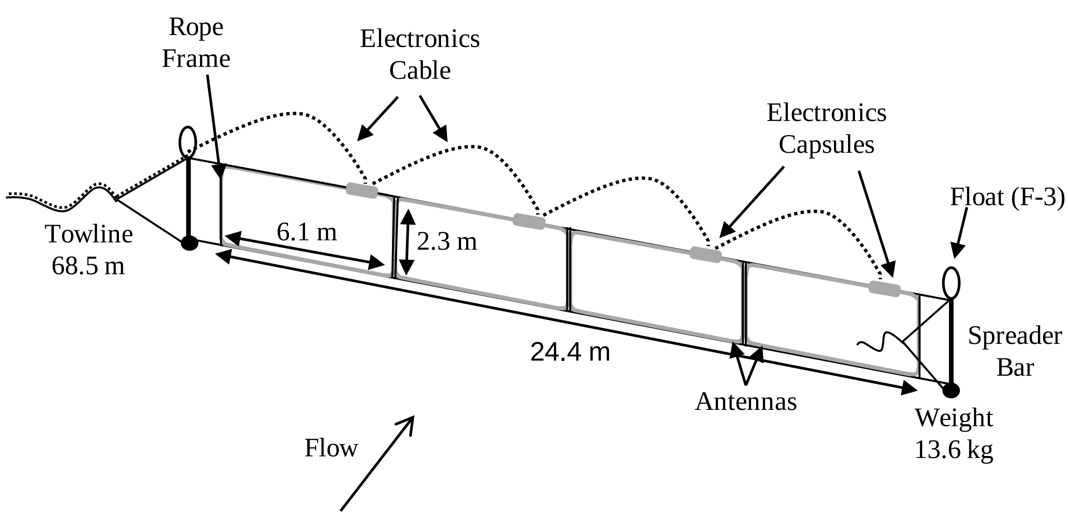

Figure 6. Basic configuration of the four-antenna array and modular rope frame system with new electronics capsules tested in 2015. This array had a total reading distance of 24.4 m and was made up of four 2.3- by 6.1-m flexible antennas.

During the off-season between 2014 and 2015, we redesigned the electronic reader capsules connecting the communications cables. The new capsule design was lighter, easier to deploy, and more streamlined than the previous design (Figure 7). We also redesigned the wire gallery within the antennas (Figure 8). Within each antenna, foam backer rods were installed to support and separate the three antenna wires. These support rods also reduce internal vibration and wire movement, which had been found to create interference in 2014. The new gallery design strengthened antenna current by reducing resistance from nearby conductors (Figure 8).

2014 2015

Figure 7. Picture of the old reader capsule used in 2014 compared to the new capsule used in 2015. Photos are not to scale.

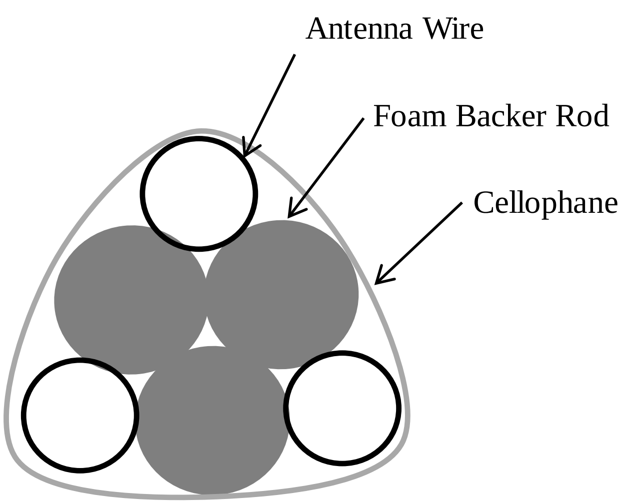

Figure 8. Cross-sectional area of the flexible antenna wire gallery. Antenna wires are placed around three glued foam backer rods, and then wrapped in cellophane to hold the wires in position.

These revisions supported a modular system design wherein antennas could be added to or removed from the array. For each flexible antenna array, a controller area network (CAN bus) power and communications cable (dotted line in Figure 6) was routed along the tow line, from the deployment skiff to the water-tight capsule on the first antenna, which housed the reader board. Additional short CAN bus cables were then connected consecutively between additional capsules until all antennas were connected.

During testing, we discovered the need for additional distance between the CAN bus cable and antenna wires. Therefore, we used CAN bus cables that were about 1 m longer than the distance between antennas, and we attached these cables only at the capsules. This allowed CAN bus cables to drift behind and farther away from the antenna wires while under tow. The transceiver master controller and power source (two 12 volt batteries) were located in the tow skiff, where we could monitor real-time EMI and detection data.

For deployments in 2014 and early 2015, we first laid out the entire array on the shoreline to ensure proper system configuration. We then pulled the antenna array into the current from the beach using one of the tow skiffs. In spring 2015, we began deploying the system directly from a tow skiff.

For stationary deployments, a skiff crew of two deckhands and one operator would gradually maneuver the array into the river with the tow line tied to a pile dike and the skiff backing into the river as the system was deployed. A radar range finder was used to maintain a consistent distance between the array and the piling during these deployments, and a second skiff was used during testing to ensure proper system and to conduct tests of antenna performance.

In deployments using two skiffs, the antenna would be payed out by one skiff until fully extended, at which point both skiffs motored upstream holding the antenna open into the current. We alternated between stationary and mobile deployments as tidal currents varied.

Tow vessels were two 6.7-m-long skiffs powered by 135-hp outboard motors. Occasionally, a third skiff was used to monitor antenna configuration and to test system performance at different tow speeds. These tests were conducted using a "stick fish" comprised of a PIT tag attached to a pole.

While it was difficult to judge vessel speed against strong river currents, we estimated tow speed at approximately 1.7 knots. This estimate represented the difference between a tow speed of 0 knots at 1,300 rpm and a drift speed of 1.7 knots for the third skiff. Skiffs were essentially at idle (drift speed) at 900 rpm. By comparison, the large trawl system tows at about 1.2 knots with the net fully deployed.

To compare detections between the pair trawl and flexible antenna systems, we examined detections per hour and species composition ratios. Data used for comparison were taken only from days and times when both systems were fully operational. Detection data obtained during tests of electronic settings were omitted from the comparison because these tests often altered the performance of flexible antennas.

Results and Discussion

We completed off-season modifications to the electronic capsule and antenna wire gallery designs in winter 2015. On 27 March, we began testing the flexible antenna system with a two-antenna array. During the first deployment, we immediately noticed an improvement from the previous design in terms of reduced drag. While the design used in 2014 was heavier and placed substantial strain on the antenna and rope frame, the new design was lighter and imposed no noticeable drag effect on the system. Unfortunately, EMI levels were unstable and much higher than expected (0-40%).

Cable and Transceiver Adjustments

We added a third antenna to the array, but further testing produced similar results. However, we noted that while under tow, electrical current was much weaker in the first antenna (closest to the transceiver) than in the other two. We then returned the system to test facilities at Jones Beach and evaluated the three-antenna configuration in air. Results showed no issues with EMI or weak current out of water. Follow-up tests with the system redeployed in water produced EMI and current problems similar to those observed during initial tests of the three-array system.

After significant troubleshooting, we narrowed the problem down to the proximity of the CAN bus cable to the antenna wires. For our original configuration, we had attached the short CAN bus cables (dotted lines in Figure 6) to the antennas themselves. This caused varying levels of interference when deployed in water. However, once we lengthened the cables and attached them only to the reader capsules, they drifted behind the system between capsules, and antenna performance improved.

Although the longer CAN bus cables improved performance in terms of reduced EMI, the three-antenna array as a group still did not perform as well as its antennas did individually. Thus, solving the problem of cable and antenna proximity exposed another problem.   We continued testing, and by June we had identified the problem.

The multiplex transceiver controls up to six antennas by operating one antenna at a time in a programmable sequence, with each antenna cycling through active and inactive periods. This allows antennas to be placed adjacent to one another without interference and with no additional power requirement. In an array of six antennas, there is typically a maximum inactive cycle of 500–msec for each antenna.

In our case, the default cycle rate of the transceiver was not allowing each of our three antennas to be active (cycled "on") long enough to establish a complete, functional detection field. This was corrected by manually setting the transceiver to increase the active period for each coil. These settings were accessed using the “master” sync mode rather than the "stand-along" sync mode of the transceiver.

Detections

Detections using the towed flexible antenna system, including all array sizes, totaled 124 fish in 53.9 h of sampling across 18 d (Table 3). This included 23 Chinook salmon (18%), 12 coho salmon (10%), 74 steelhead (60%), 3 sockeye salmon (2%), and 12 fish without species data available in PTAGIS (10%).

Table 3. Deployment dates of the flexible antenna system with total daily sample time, number of antennas in the array, and total detections.

Date	Sample time (h)	Antennas (n)	Detections(n)
27 Mar	3.0	2	0
8 Apr	1.0	3	0
28 Apr	1.8	3	0
5 May	2.1	2	0
7 May	1.5	1	2
12 May	4.0	3	5
14 May	4.9	3	1
19 May	5.4	3	25
21 May	5.7	4	14
28 May	2.9	4	28
2 Jun	4.9	4	39
4 Jun*	4.0	4	6
9 Jun	1.2	4	4
17 Jun	3.3	4	0
25 Jun	2.1	4	0
1 Oct	1.4	6	0
6 Oct	1.8	6	0
8 Oct	3.0	6	0
Total	53.9	--	124

*Night deployment

Testing continued into the summer and early fall to fine tune electronic settings, develop standard operating procedures for deployment/retrieval, and test a six-antenna horizontal array.

Comparison between the Matrix and Flexible Antenna Systems

While testing the flexible antenna and transceiver settings, we made several attempts to sample in tandem with the pair trawl system so that we could compare detections per hour and species composition between the two systems. We sampled with both systems simultaneously on nine dates in May and June. However, on four of these dates, performance of the flexible antenna system was impaired by electronics problems and system diagnostic tests. Thus, data from these four dates was unusable.

There were five dates (14.4 h) when the towed flexible antenna system was operational and could be compared to the trawl system (Table 4). We used a four-antenna array for all of these tests except on 19 May, when 3 antennas were used. Tests were conducted during daylight hours on all dates except 4 June.

Following the 4 June deployment, we corrected the "active" periods for each antenna determined by the multiplex transceiver. This correction dramatically improved antenna functionality and reliability. Unfortunately, by this time the migration season was winding down, and numbers of fish in the estuary no longer warranted intensive sampling effort. Thus, the deployment on 9 June was the last concurrent sampling effort with the matrix trawl and flexible antenna systems. Thereafter, detection numbers on both systems were too low for meaningful comparison.

Table 4. Total detections by system, sample hours, detections per hour by system, and the ratio of flexible antenna detections to trawl detections on days when samples were comparable.

	Total detections			Detections/h (n)		
Date	Flex antenna (n)	Trawl (n)	Sample time (h)	Flex antenna	Trawl	Flex/trawl (%)
19 May	22	132	3.5	6.3	38.1	17
28 May	28	84	2.8	10.0	30.0	33
2 June	38	115	2.9	13.0	39.4	33
4 June	6	27	4.0	1.5	6.8	22
9 June	4	8	1.2	3.3	6.6	50
Total/mean	98	366	14.4	6.8	25.4	31

During concurrent deployments, the average ratio of detections between the flexible antenna and the trawl systems was 31%. These data lack sufficient statistical power for inferences. However, they did not indicate that the flexible antenna system detected any one species preferentially over another when compared to trawl detections during the same period (Table 5).

Table 5. Daily species composition ratios of the flexible antenna system compared to the trawl system, 2015. Ratios greater than 1 indicate higher proportions detected on the flexible antenna system, and less than 1 indicates higher proportional detections on the trawl.

	Species ratio (trawl/flexible antenna)			
Date	Chinook	Coho	Steelhead	Sockeye
19 May	0.46	0.00	1.51	0.00
28 May	0.82	2.00	0.84	0.43
2 June	0.66	0.98	0.94	0.00
4 June	0.75	4.50	0.53	0.00
9 June	0.80	0.00	2.00	0.00
Mean	0.70	1.50	1.16	0.09

Steelhead and coho salmon were detected at slightly higher rates on the flexible antenna system, whereas the trawl system detected a slightly higher proportion of Chinook salmon. Sample depth of the flexible system (3.0 m) vs. the trawl system (4.9 m) may have contributed to some of the difference between systems in species composition of detected fish. However, additional data will be required before any definitive conclusions can be drawn.

Sampling with the flexible antenna towed detection system achieved all primary objectives in 2015. We reduced drag, vibration, and EMI, developed new operational procedures to improve performance under tow. We tested a four-antenna array during the juvenile spring migration. In addition, we identified and isolated electronics issues that slowed progress. By October were able to test a fully-functional six-antenna array system. We plan more rigorous testing of the six-antenna array in 2016. Our goal will be to determine the adequacy of the flexible antenna system to replace the trawl in future years while reducing costs and simplifying logistics of estuary sampling.

Analyses from Trawl Detection Data

Estimated Survival

Methods

To estimate survival probabilities, we used the Cormack-Jolly-Seber single-release model (CJS model; Cormack 1964; Jolly 1965; Seber 1965; Skalski et al. 1998), with detections designated as recaptures. To differentiate between fish that did not survive to a given point vs. those that passed without being detected, the CJS model requires estimates of detection probability at the location of interest (i.e., Bonneville Dam). To estimate the probability of detection at a given point, detections downstream from this point are required. Thus, for CJS estimates of survival to Bonneville Dam, detections in the estuary are required.

For this analysis, weekly "release groups" of Snake River yearling Chinook salmon and steelhead were created from fish detected passing McNary Dam during the same period. For fish originating in the upper Columbia River in 2015, detections at McNary Dam were insufficient to form weekly groups, but these detections were used to estimate mean survival over the migration season (Faulkner et al. 2015). Similarly, for Snake and upper Columbia River sockeye salmon, estimates were limited to mean survival over the season due to small numbers of detections. Overwintering behavior of subyearling Chinook precluded use of the CJS survival estimates for these stocks.

Estimates of survival probability under the CJS model are random variables, subject to sampling variability. When true survival probabilities are close to 100% and when sampling variability is high, it is possible for estimates of survival to exceed 100%. For practical purposes, these estimates should be considered equal to 100%.

Results and Discussion

Survival probabilities were estimated from McNary to John Day, John Day to Bonneville, and McNary to Bonneville Dam (Table 6). We compared weighted annual survival estimates for the years 1999-2015 for both Snake and Columbia River stocks (Figure 9). In some years, there were insufficient detections of some species to compare estimates between basins.

Table 6. Average survival from the tailrace of McNary Dam to the tailrace of Bonneville Dam for weekly, biweekly, or seasonal groups of PIT-tagged salmonids by species, 2015. All estimates are hatchery and wild pooled groups, and fish were released from various locations upstream from McNary Dam. Standard error for each weighted mean estimate is shown in parenthesis.

Date of detection	Number detected at McNary Dam	McNary to John Day Dam (SE)	John Day to Bonneville (SE)	McNary to Bonneville (SE)
	Snake River wild and hatchery pooled groups			
Yearling Chinook				
20 Apr-26 Apr	1,839	94.3 (35.6)	71.3 (42.2)	67.2 (30.7)
27 Apr-03 May	6,921	88.1 (20.9)	67.2 (19.1)	59.3 (9.2)
04 May-10 May	11,869	52.8 (5.9)	44.3 (26.7)	76.2 (11.3)
11 May-17 May	6,976	81.7 (9.5)	75.3 (13.9)	61.5 (8.9)
18 May-24 May	3,446	83.0 (13.6)	60.2 (15.7)	49.9 (10.2)
25 May-31 May	481	122.9 (115.4)	31.9 (33.6)	39.2 (18.7)
Weighted mean		72.4 (6.9)	93.7 (16.0)	62.9 (4.3)
Steelhead				
20 Apr-26 Apr	686	52.5 (16.4)	40.0 (12.7)	21.0 (1.6)
27 Apr-03 May	1,346	83.2 (24.2)	92.5 (34.5)	77.0 (18.0)
04 May-10 May	2,897	105.5 (27.5)	66.3 (19.4)	69.9 (9.2)
11 May-17 May	2,938	85.1 (12.0)	81.5 (15.4)	69.4 (8.7)
18 May-24 May	2,396	77.3 (13.9)	76.4 (16.9)	59.1 (7.6)
25 May-31 May	1,130	50.9 (17.2)	16.4 (49.1)	59.3 (15.0)
Weighted mean		79.2 (6.6)	84.2 (5.0)	66.3 (3.9)
Sockeye	--	--	--	53.1 (15.0)
	Upper Columbia River wild and hatchery pooled groups			
Yearling Chinook				
Above Yakima R.	198,380	85.7 (3.9)	95.2 (6.6)	81.6 (5.1)
Yakima River	57,445	85.0 (8.1)	57.2 (9.6)	48.6 (7.3)
Steelhead	74,084	72.0 (5.8)	76.1 (6.3)	54.8 (3.5)
Sockeye	--	--	--	44.6 (20.0)

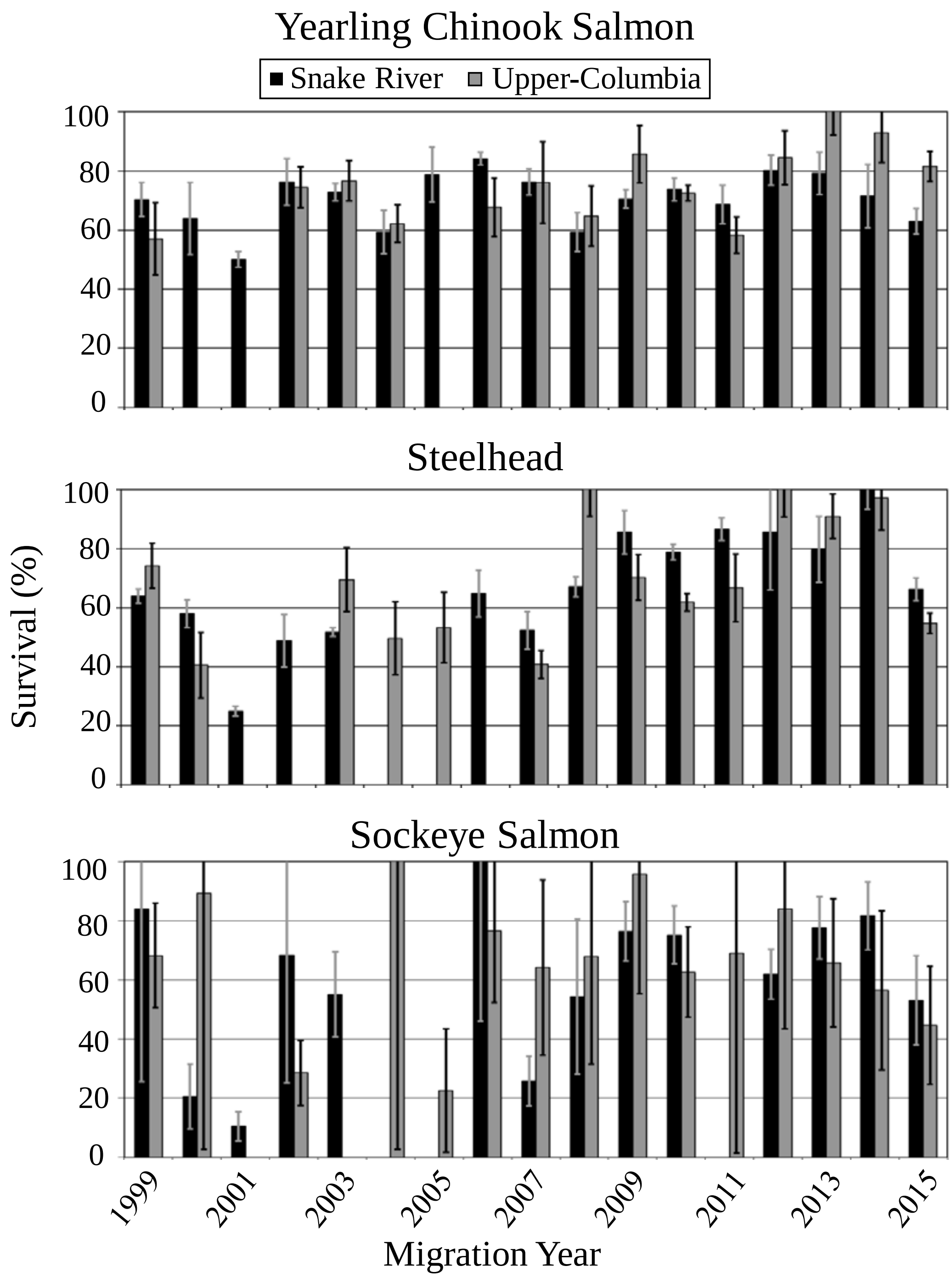

Figure 9. Weighted average annual survival and SE from the tailrace of McNary Dam to the tailrace of Bonneville Dam, for Snake and Columbia River yearling Chinook salmon, steelhead, and sockeye salmon, 1999-2015.

For Snake River **yearling Chinook salmon**, estimated survival from McNary to Bonneville Dam tailrace was 62.9% in 2015; survival over this reach has ranged from 50.1% in 2001 to 84.2% in 2006 for these fish. For yearling Chinook originating in the upper Columbia River (upstream of the confluence with the Yakima River), estimated survival was 81.6% in 2015 and has ranged from 57.0% in 1999 to 102.5% in 2013. For yearling Chinook originating in the Yakima River and its tributaries, estimated survival was 48.6% in 2015. This is the lowest estimate on record for this group, and previous estimates have ranged from 55.8% in 2012 to 88.3% in 2009. No estimate was possible for Yakima River yearling Chinook in 2000, 2001, and 2005.

For Snake River **steelhead**, estimated survival from McNary to Bonneville Dam tailrace was low in 2015, at 66.3%; compared to 102.3% in 2014, the highest on record. The lowest estimate of survival for Snake River steelhead over this reach was 25.0% during the drought year of 2001. For upper Columbia River steelhead, survival in this reach was 54.8% in 2015, again, considerably lower than 2014 (97.2%), and has ranged from 40.5% in 2000 to 107.7% in 2008. No estimate was possible for upper Columbia River steelhead in 2001, 2002, and 2006.

For Snake River **Sockeye salmon**, estimated survival from McNary to Bonneville Dam tailrace was 53.1% in 2015, and survival of these fish has ranged from 10.5% in 2001 to 111.3% in 2006. For upper Columbia River sockeye, survival through this same reach was estimated at 44.6% in 2015 and has ranged from 22.6% in 2005 to over 100% in 1998 and 2004. Survival estimates for sockeye stocks in all years have suffered from poor precision due to small sample sizes. Complete estimates of survival for these and other stocks are reported by Faulkner et al. (2015).

In 2015, seasonal average estimated survival through the entire hydropower system, from Lower Granite to Bonneville Dam tailrace, was 43.7% for yearling Chinook salmon and 41.3% for steelhead (Table 7). In 2014, overall hydrosystem survival estimates were 54.9% for yearling Chinook and 75.7% for steelhead. Estimates for the same reach for sockeye salmon were 37.3 and 71.3% in 2015 and 2014, respectively.

The benefit of transportation for fish can be expressed as the ratio of smolt-to-adult return rates (SARs) for transported vs. inriver migrant fish (T:I) in a given year (Marsh et al. 2012). The annual T:I depends in part on conditions experienced during the juvenile migration in the river and hydropower system, as well as timing of the transportation program. Lower survival for inriver juvenile migrants may be associated with lower flow volumes and slower transit times, although flow often varies widely within a single year, and seasonal average estimates of downstream survival do not reflect this variation.

For example, survival probabilities for yearling Chinook salmon were much lower in 2001 (27.9%), 2004 (39.5%), and 2015 (43.7%) than in other years, and these three years were all characterized by extremely low river flows due to regional drought. Most fish were transported in 2001 and 2004 because of the poor river conditions.

Table 7. Weighted annual mean survival probabilities and standard errors from the tailrace of Lower Granite Dam to the tailrace of Bonneville Dam for yearling Chinook salmon, steelhead and Sockeye salmon, 1998-2015.

	Estimated average survival from Lower Granite to Bonneville Dam tailrace					
Migration	Yearling Chinook salmon		Steelhead		Sockeye salmon	
year	(%)	SE	(%)	SE	(%)	SE
1998	53.8	4.6	50.0	5.4	17.7	9.0
1999	55.7	4.6	44.0	1.8	54.8	36.3
2000	48.6	9.3	39.3	3.4	16.1	8.0
2001[a]	27.9	1.6	4.2	0.3	2.2	0.5
2002	57.8	6.0	26.2	5.0	34.2	21.2
2003	53.2	2.3	30.9	1.1	40.5	9.8
2004[a,b]	39.5	5.0	--	--	--	--
2005[b]	57.7	6.9	--	--	--	--
2006	64.3	1.7	45.5	5.6	82.0	45.4
2007	59.7	3.5	36.4	4.5	27.2	7.3
2008	46.5	5.2	48.0	2.7	40.4	17.9
2009	55.5	2.5	67.6	5.9	57.3	7.3
2010	56.9	3.2	60.8	2.6	54.4	7.7
2011	51.3	4.9	60.0	2.9	--	--
2012	63.4	4.2	59.7	13.8	47.2	6.2
2013	62.2	5.2	51.5	7.5	53.6	6.6
2014	54.9	8.3	75.7	6.9	71.3	11.0
2015	43.7	3.9	41.3	3.2	37.3	3.7

[a] Drought year when nearly all collected fish were transported rather than being returned to the river.

[b] In 2004 and 2005, the corner collector bypass structure at Bonneville Dam had no PIT-tag detection capability; as a result, detection numbers were too low for accurate survival estimates for some species in those years.

Similarly, survival estimates from the tailrace of Lower Granite Dam to the tailrace of Bonneville Dam were exceptionally low for steelhead (4.2%) and sockeye (2.2%) in 2001. However, in the drought years of both 2001 and 2004, all wild fish and most hatchery fish collected at juvenile facilities were transported, with few returned to migrate in the river. In contrast, while 2015 was also a low flow year, estimated transportation rates for yearling Chinook and steelhead were the lowest on record, which was largely due to the arrival timing of both species compared to the start date of transportation and low collection probabilities at collector dams (Faulkner et al. 2015).

Flow volumes at Bonneville Dam in 2015 were the lowest on record since the drought year of 2001, with the seasonal average 35% below the 13-year average. At no time during the sampling season did flows approach levels considered typical for this reach and time of year. During the juvenile migration season of 2015, average temperature at Bonneville Dam was the highest on record, at 15.8°C. This average was 2.4°C warmer than the 14-year average of 13.4°C. Numbers of PIT-tag detections at Bonneville Dam were considerably higher in 2015 (125,000) than 2014 (78,000), a year when flows were above average during most of the spring migration season. In both years, detections were recorded at Bonneville Dam from annual releases of about 1.9 million tagged fish.

For yearling Chinook salmon, estimated survival from the tailrace of Lower Granite Dam to the tailrace of Bonneville Dam was lower in 2015 than the long-term average (1998-2015). Steelhead survival in this reach was also below average. According to Faulkner et al. (2015), estimates of survival through the entire hydropower system for yearling Chinook have remained relatively stable since 1999, with the exception of 2001, 2004, and 2015. Estimates for steelhead have been relatively stable since 2009, but were substantially lower in 2015.

Relatively high survival for yearling Chinook and steelhead in recent years may be related to the operation of surface bypass structures at dams (Hockersmith et al. 2010; Axel et al. 2010; Plumb et al. 2004). These devices may particularly benefit juvenile steelhead, which tend to be more surface-oriented during migration. Surface bypass structures are currently used at six of the eight USACE dams on the lower Columbia and Snake Rivers. Lower-than-average spill rates in 2015 (Faulkner et al. 2015) may have reduced some benefit of surface bypass structures in expediting fish passage. However, the observed improvement in inriver survival in 2015 compared to earlier drought years 2001 and 2004 may reflect these management changes and improved bypass structures.

The ability to estimate survival for sockeye salmon depends on detection rates and numbers of fish tagged each year. Recently, there has been an increased effort to tag upper Columbia and Snake River sockeye. As a result, sufficient data has been available for annual estimates of survival for Snake River sockeye. However, with increasing use of surface passage routes over the last few years, detection rates of these fish, and thus the accuracy of estimates, have remained relatively low despite the increased tagging effort. At present, we can only assume sockeye survival is dependent on factors similar to those affecting survival of yearling Chinook salmon and steelhead. As tagging efforts for sockeye increase, it is increasingly important to consider development of PIT-tag detection capability for the surface bypass structures.

Detection data from the trawl 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 survival probabilities for fish detected at Bonneville Dam. These estimates are used in various research and management programs for endangered salmonids in the Snake and Columbia River basins and in other basins of the Pacific Northwest (Faulkner et al. 2015).

Trawl detections also allow comparison of relative detection percentages, travel speed, and other parameters between inriver migrant and transported fish groups after they comingle in the estuary. Annual releases of PIT-tagged fish in the Columbia River basin have been near or exceeded 2 million for the past several years. Detections of these fish passing through the estuary have increased our understanding of behavior and survival during the critical freshwater-to-saltwater transition period.

Travel Time of Transported vs. Inriver Migrant Fish

Methods

We coordinated trawl system sample cruises with the expected estuary passage timing of yearling fish tagged and released for transportation and survival studies. A portion of study fish were collected at Lower Granite Dam (rkm 695) and either loaded to transport barges or returned to the river. Fish not collected and those returned to the river could potentially be collected and transported at downstream dams.

Snake River dams with transport facilities are Lower Granite, Little Goose (rkm 635), and Lower Monumental Dam (rkm 589). Transportation from McNary Dam (rkm 470) has not occurred during our intensive sampling period since 2005, and transportation from McNary Dam was suspended altogether in 2012. Our analysis included all transported fish detected in the trawl, regardless of the location from which they were transported.

To track fish recorded as having been diverted for transportation at any of the three Snake River transport dams, we created an independent database (Microsoft Access) using data downloaded from PTAGIS. At the transport dams, PIT-tagged fish were diverted to transport barges using separation-by-code (SbyC) systems (Marvin and

Nighbor 2009). Diversion to a transport barge was verified using the last PIT-tag detection at a dam on a route that ended at a transport raceway, according to monitor locations on the PTAGIS site map.

Some fish had a tag code that indicated the fish was pre-designated for transport (if they entered a bypass system), but there was no record of detection on a transport raceway. These fish may have been misdirected at the SbyC gate or removed as biological samples; therefore, records for these fish were excluded from our transportation analysis.

The U.S. Army Corps of Engineers provided individual barge-loading dates and times for each dam throughout the 2015 transportation season (John Bailey, 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.

Travel time and relative rate of survival to the estuary were compared between fish released from transport barges and those detected at Bonneville Dam on the same day. We modified our database to include these migration-history data from PTAGIS. We then created paired comparison groups of fish either released from transported barges or detected at Bonneville Dam on the same date.

For PIT-tagged yearling Chinook salmon and steelhead, we plotted seasonal distributions of travel-time for fish detected at Bonneville Dam and for fish transported and released just downstream from the dam. These distributions were plotted using the medians from daily travel-time distributions by group. Travel time (in days) to the estuary was calculated for each fish on each date by subtracting time of barge release or detection at Lower Granite or Bonneville Dam from time of detection at Jones Beach.

A paired *t*-test was used to evaluate differences in mean travel speed to Jones Beach between inriver migrants and transported fish. Daily travel speeds (km/d) were calculated based on the distance traveled from barge release or Bonneville detection to detection in the estuary, divided by travel time. Daily median travel speeds were plotted through their respective periods of availability for comparison, along with flow data based on daily average discharge rates at Bonneville Dam (m^3 s^{-1}). For statistical analyses, means were necessary, but for visual presentation we chose medians to reduce any influence from outliers.

Results and Discussion

Yearling Chinook salmon and steelhead—Seasonal median travel time (d) 2000-2015 from Lower Granite Dam (rkm 695) to detection in the trawl at rkm 75 is presented for yearling Chinook salmon and steelhead (Table 8).

For yearling Chinook salmon detected during the intensive sampling period (4 May to 11 June), median travel time from Lower Granite Dam to the estuary was longer in 2015 (17.0 d) than in 2014 (16.4 d). Median travel time for steelhead through the same reach in 2015 was the longest since 2005 at 16.2 d (12.3 d in 2014 for reference). Thus, travel times from Lower Granite Dam to the estuary in 2015 were longer than the 15-year average for both yearling Chinook (16.6 d) and steelhead (14.8 d).

Median travel time to the estuary from Bonneville Dam was longer than the 15-year average of 1.7 d for both inriver-migrant yearling Chinook and steelhead. For yearling Chinook, median travel time was one-half day longer in 2015 (21 d) than in 2014 (1.6 d). For steelhead, median travel time was just over one-half day longer in 2015 (2.2 d) than in 2014 (1.6 d). Similarly, for transported yearling Chinook, median travel time from just below Bonneville Dam to the estuary was longer in 2015 than in 2014 (2.5 vs. 2.1 d). For transported steelhead, median travel time was considerably longer in 2015 than in 2014 (2.3 vs. 1.5 d).

We also compared daily differences in travel speed to the estuary relative to changing river flow volume between transported and inriver-migrant fish (Figure 7). Overall, seasonal mean travel speed to the estuary was significantly slower for yearling Chinook salmon released from barges (60 km/d) than for those migrating inriver and detected at Bonneville Dam (76 km/d; $P \leq 0.001$). Mean travel speed was also significantly slower for steelhead released from barges (65 km/d) than for those detected at Bonneville Dam (71 km/d; $P \leq 0.001$) on the same day. These differences in travel speed by migration history were similar to observations from previous years.

Table 8. Median travel time to detection in the upper estuary for yearling Chinook salmon and steelhead detected at Lower Granite or Bonneville Dam or released from barges just downstream from Bonneville Dam, 2000-2015. Also shown are mean flow rates at Bonneville Dam from mid-April through June (approximate spring migration periods).

	Detection at Lower Granite Dam (rkm 695)				Detection at Bonneville Dam (rkm 234)				Release from transport barge (rkm 225)				
	Yearling Chinook salmon		Steelhead		Yearling Chinook salmon		Steelhead		Yearling Chinook salmon		Steelhead		
Year	Travel time (d)	Sample (n)	Travel time (d)	Sample (n)	Travel time (d)	Sample (n)	Travel time (d)	Sample (n)	Travel time (d)	Sample (n)	Travel time (d)	Sample (n)	Flow ($m^3 s^{-1}$)
2000	17.4	681	17.1	833	1.7	479	1.7	296	1.9	495	1.6	301	7,415
2001	32.9	680	30.1	44	2.3	792	2.5	59	2.9	1,329	2.3	244	3,877
2002	18.2	538	17.8	93	1.8	1,137	1.7	156	2.0	1,958	1.6	296	8,071
2003	17.0	563	16.5	95	1.8	1,721	1.7	567	2.1	2,382	1.7	435	7,120
2004	16.6	867	16.6	153	1.9	672	2.0	110	2.2	2,997	1.9	333	6,663
2005	17.3	1,183	16.9	278	1.8	81	2.0	471	2.2	2,910	1.9	400	5,776
2006	14.7	628	12.5	110	1.7	888	1.6	131	2.1	1,315	1.6	170	9,435
2007	15.7	1,196	15.6	117	1.7	1,510	1.7	362	2.2	1,096	1.7	143	6,858
2008	18.3	568	14.4	392	1.7	749	1.6	830	2.1	1,884	1.6	788	8,714
2009	18.7	1,188	15.4	1,321	1.7	1,438	1.7	892	2.1	1,681	1.6	1,325	7,871
2010	16.1	581	14.8	303	2.0	3,258	1.9	2,188	2.2	1,149	2.0	1,068	6,829
2011a	17.8	335	15.5	348	1.8	240	1.6	216	2.1	673	1.6	831	7,911
2011b	13.2	259	10.0	198	1.5	39	1.3	47	1.6	418	1.5	275	13,462
2012	15.4	755	11.2	627	1.6	485	1.5	321	2.0	567	1.5	1,116	10,056
2013	14.1	542	11.6	366	1.6	645	1.6	745	2.2	1,029	1.6	1,333	7,470
2014	16.4	744	12.3	573	1.6	431	1.6	412	2.1	1,012	1.5	1,206	8,281
2015	17.0	400	16.2	264	2.1	1,065	2.2	1,885	2.5	768	2.3	794	5,333

[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.

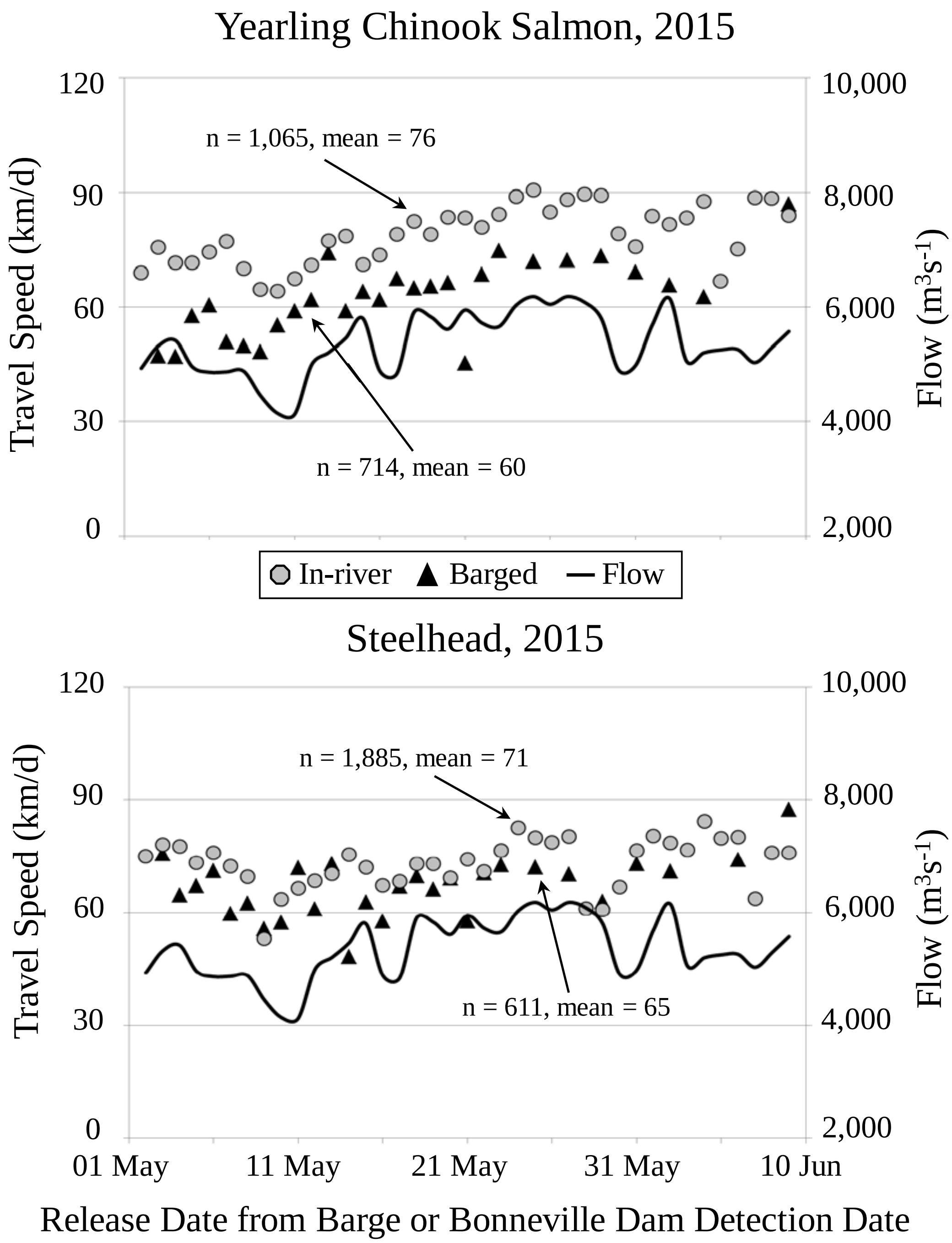

Figure 7. Daily median travel speed to the estuary of yearling Chinook salmon (top) and steelhead (bottom) following detection at Bonneville Dam or release from a barge to detection in the estuary (rkm 75), 2015. Seasonal means are shown for comparison with flow.

Subyearling fall Chinook salmon—We detected 528 subyearling fall Chinook, all of which had been released after 2 April 2015 and all of which were less than 100 mm fork length (FL) at tagging. Most fall Chinook released prior to 30 April were yearlings and were greater than 120 mm FL when tagged. We detected 213 transported and 315 inriver migrant subyearling fall Chinook between late April and early July (Figure 8). Of all subyearlings detected by the trawl system, 67% originated in the Snake River, 4% in the Upper Columbia River (at or upstream from McNary Dam), 23% in the mid-Columbia River (between Bonneville and McNary Dam), and 6% from the Lower Columbia River (downstream from Bonneville Dam).

Of the 528 inriver migrant subyearling fall Chinook we detected, 12 had been previously detected at Bonneville Dam. Mean travel speed from Bonneville Dam to detection in the trawl was significantly slower for transported fish (57 km/d) than for fish detected at Bonneville Dam (67 km/d; $P \leq 0.001$; Figure 10). Analysis in prior years has consistently shown significantly faster travel speeds for subyearlings detected at Bonneville than for those released from transport barges (Morris et al. 2014).

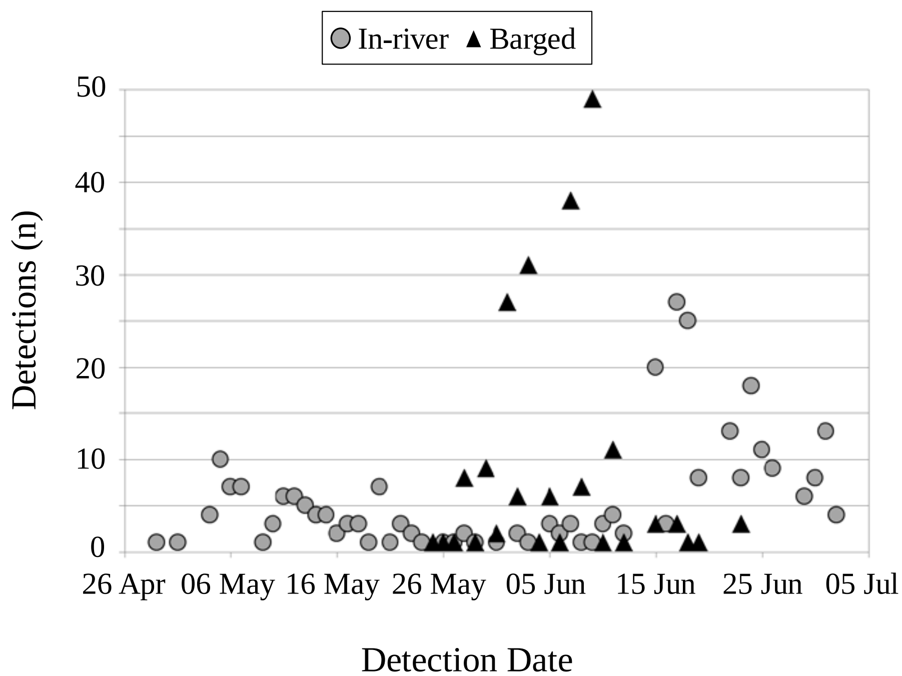

Figure 8. Temporal distribution for subyearling Chinook salmon detected in the estuary after being detected as inriver migrants at Bonneville Dam (n = 283) or after being released from barges below the dam (n = 213), 2015.

Sockeye Salmon—We detected 744 sockeye salmon between 8 May and 17 June (Figure 9). Of these, 73% were hatchery fish, 19% were wild fish, and the remaining 8% were of unknown origin. Fish released in the Snake River Basin made up 78% of our sockeye detections, while fish released in the Columbia River Basin upstream from McNary Dam made up 22%. Transported fish accounted for 112 of the 744 sockeye detections. Of those transported, 53 had been transported from Lower Granite Dam, 45 from Little Goose Dam, and 14 from Lower Monumental Dam. Of the 632 inriver migrant sockeye we detected, 153 had been previously detected at Bonneville Dam. Mean travel speed from Bonneville Dam to detection in the trawl was significantly slower for transported sockeye (67 km/d) than for sockeye detected at Bonneville Dam (85 km/d; $P \leq 0.001$; Figure 10).

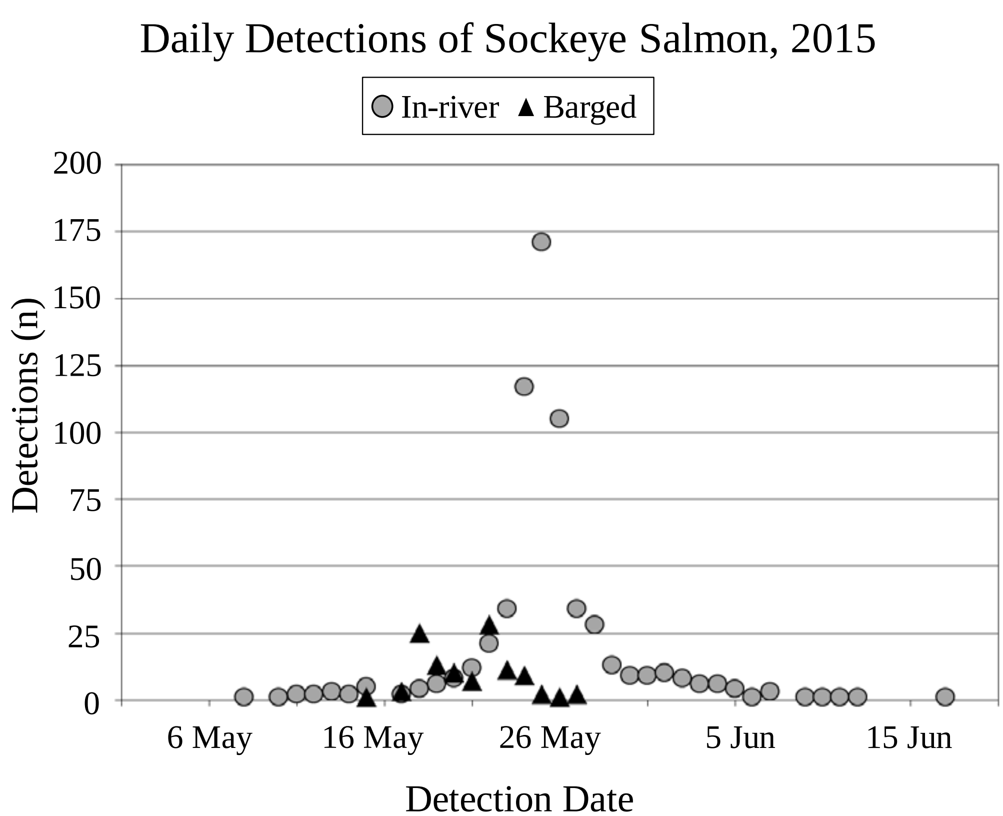

Figure 9. Temporal distribution of sockeye salmon detections in the estuary during inriver migration (n = 632, gray circles) or following release from barges below Bonneville Dam (n = 112, black triangles), 2015.

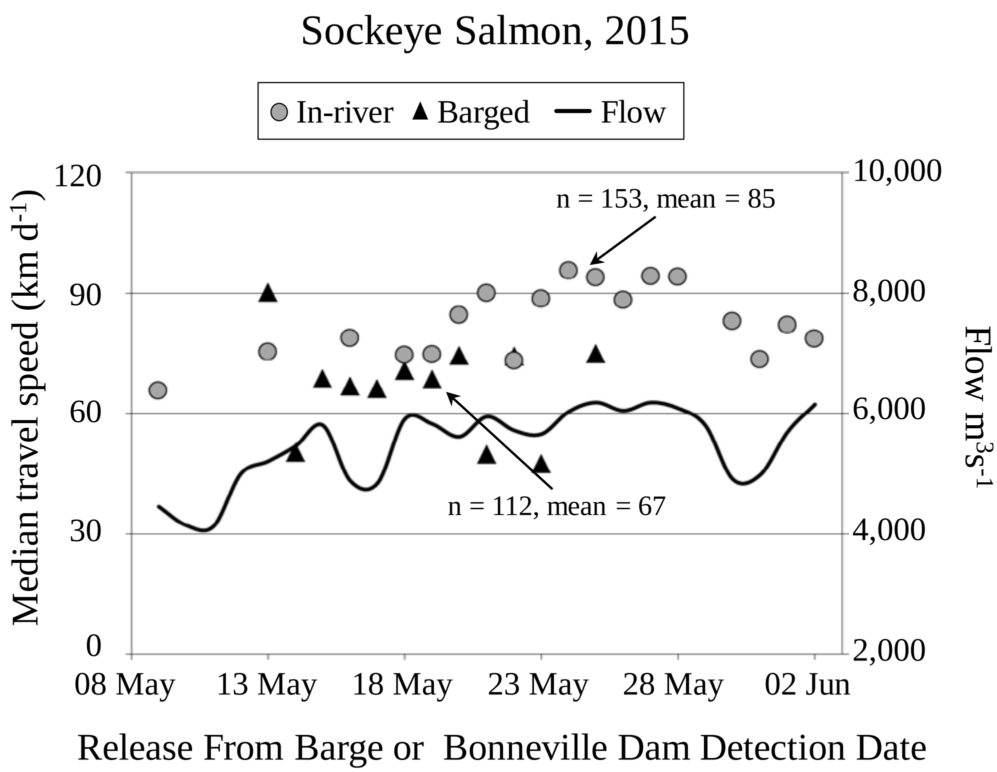

Figure 10. Daily median travel speed to the estuary for transported vs. inriver migrant Sockeye salmon following detection at Bonneville Dam or release from a barge to detection in the estuary (rkm 75), 2015. Daily river flow volume at Bonneville Dam is shown for comparison.

In summary, travel time in 2015 was consistent with that observed in previous low-flow years (2001 and 2005) for all migration histories and species of juvenile salmonids. For both yearling Chinook and steelhead, travel time was the slowest on record since 2001, regardless of migration history. Travel time from Lower Granite Dam to the estuary was similar to previous years for yearling Chinook, but was among the slowest on record for steelhead.

Use of surface bypass structures at the dams has contributed to faster travel speeds through the hydrosystem for salmonids in recent years, especially for steelhead. While travel time from Lower Granite Dam to the trawl was near the long-term (15-year) average for yearling Chinook in 2015, it was 1.4 d slower than the average over the last 5 years. Similarly, steelhead traveled 1.4 d slower in 2015 than the 15-year average, but they traveled 3.3 d slower than the average from 2010-2014.

These data highlight how much longer travel time was in 2015 compared to recent years with higher flows. Nevertheless, they also indicate that surface bypass structures contributed to fish traveling at rates near the long-term average, even during a flow year that was the second lowest in our dataset.

Diel Detection Patterns

Methods

As in previous years, we found that wild and hatchery fish (as designated in PTAGIS) had similar diel detection trends. Detection numbers during daylight and darkness (2030-0430 PDT) hours were compared using a one-sample *t*-test (Zar 1999) of the daily ratios of detection numbers per hour. For this test, we used the natural log of detection ratios to improve normality, and estimated means were back-transformed).

For this analysis, the number of detections and the number of minutes that the system was operated were separated into daylight and darkness-hour categories for each date that fell within the intensive sampling period. Daily daylight/darkness detections for each species were weighted by the number of minutes the detection system was operating on that date. We excluded dates when sample effort was reduced by missed or partially missed shifts. Detection numbers for this analysis were sufficient for yearling Chinook salmon and steelhead but not for sockeye and subyearling Chinook.

Results and Discussion

During the two-shift sample period of 4 May-11 June, we detected 8,869 yearling Chinook salmon and 7,806 steelhead with the detection system operating an average of 15 h/d (Appendix Table 3). We generally stopped sampling each day between 1400 and 1900 PDT for crew changes and fueling.

For hatchery yearling Chinook salmon, hourly detection rates were significantly higher during nighttime than during daytime hours (16.4 vs. 8.4 fish/h or 2.0 times higher; P = 0.002). We assumed that the diel difference in hourly detection rates was constant through the season. However, for hatchery yearling Chinook, average nighttime detection totals were 3 to 14 times higher than average daytime totals during the first week of intensive sampling. From the second week through the remainder of intensive sample period, nighttime and daytime detection ratios were relatively constant, at around 1.6 (Figure 11). This discrepancy is apparent in Figure 11. There was no significant difference between daytime and nighttime hours in terms of hourly detection rates for wild yearling Chinook (1.4 vs. 1.5 fish/h, P = 0.595).

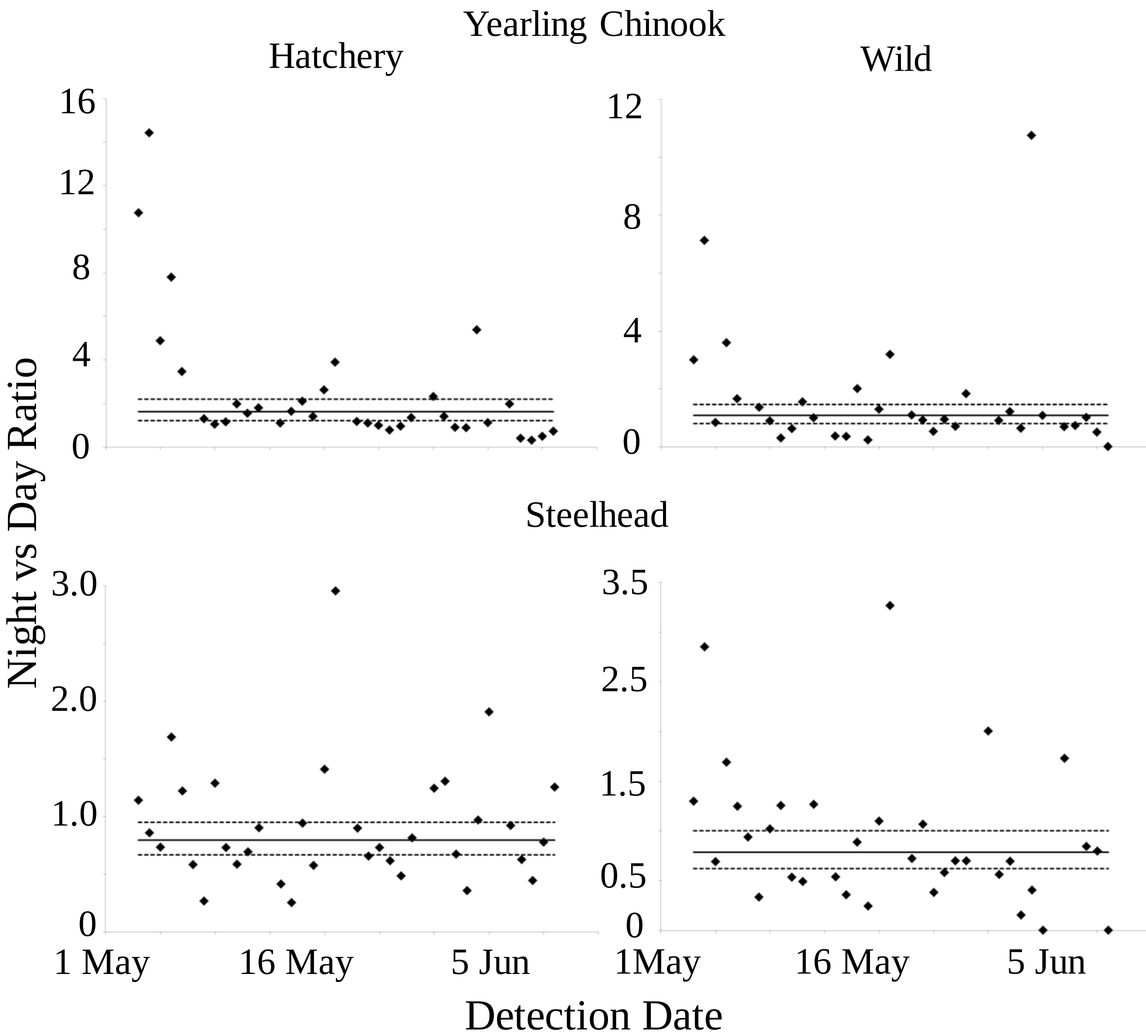

Figure 11. Daily nighttime-to-daytime detection ratios for wild and hatchery yearling Chinook and steelhead (4 May to 11 June). Daily ratios greater than 1.0 indicate a higher catch per hour in darkness hours, and values less than 1.0 indicate a higher catch per hour in daylight hours. Solid lines are estimated mean ratios, and dotted lines are estimated 95% confidence intervals. (Note that data were log-transformed for the estimation.)

For hatchery steelhead, hourly detection rates were significantly higher during daylight than darkness hours (10.9 vs. 8.2 hatchery fish/h, or 1.3 times higher, $P < 0.015$). For wild steelhead, there was a measurable difference between daylight and darkness hours (3.2 vs 2.5; $P < 0.056$). Diel detection rates remained constant throughout the intensive sampling period.

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 2015, so we pooled data by species and origin for a multi-year summary (Figure 12). Detection rates for yearling Chinook have often been significantly higher during darkness than daytime hours. Detection rates of steelhead have generally been higher during daylight hours, with more recent years often significantly higher.

Detection rates in 2015 were again higher during darkness for hatchery and wild Chinook salmon. For steelhead, detection rates for both hatchery and wild rearing types were higher during daylight than darkness hours. Present configuration of the matrix antenna system probably resulted in less gear avoidance than in earlier years, particularly during daylight hours with improved visibility.

Purse-seine sampling in this river reach has indicated peak catches for steelhead in the afternoon hours between 1400 and 1600 PDT (Ledgerwood et al. 1991). In 2015, steelhead made up 41% of total pair-trawl detections. We likely missed detections of steelhead during late-afternoon fueling, crew-change, and maintenance periods.

Increased detection of steelhead in the first 2 h of darkness indicates that lower river flows in 2015 may have reduced fish travel speeds and extended the distribution of steelhead into nighttime hours. Recurring late-afternoon periods of difficult weather and high wind typically interfere with sampling during these hours. Thus, we may have missed these fish even if we had refueled at other times. Sampling at both dusk and dawn was accomplished by extending the evening shift until relieved by the day shift; this strategy probably maximized detection of yearling Chinook salmon.

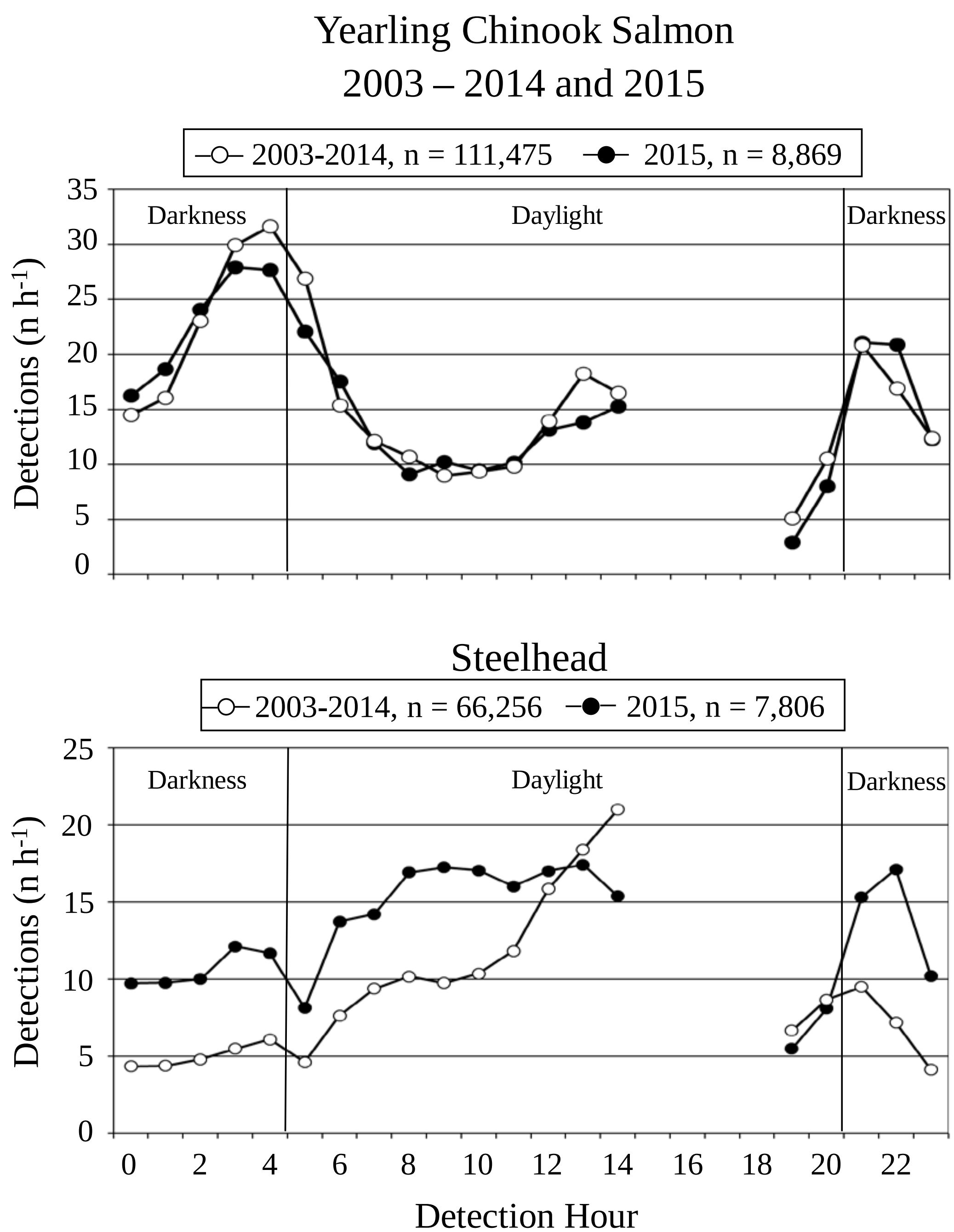

Figure 12. Average hourly detection rates of yearling Chinook salmon and steelhead during the two-shift sampling periods of 2003 through 2014, vs. 2015, using the matrix antenna system in the upper estuary near river kilometer 75.

Detection Rates of Transported vs. Inriver Migrant Fish

Methods

We compared daily detection rates in the trawl between transported fish and inriver migrants previously detected at Bonneville Dam during the two-shift sample period. Detection data was evaluated to assess whether differences in detection rates were related to migration history or arrival timing in the estuary.

Estuary detection rates of PIT-tagged salmonids released from barges were compared to those of inriver migrants detected at Bonneville Dam using logistic regression (Hosmer and Lemeshow 2000; Ryan et al. 2003). Daily groups of inriver 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.

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

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

where $\hat{\beta}$ was the coefficient of the components (i.e., $\hat{\beta}_0$ for the intercept, $\hat{\beta}_1$ for day *i*, and $\hat{\beta}$ for the set "X_i" of day-squared and/or interaction terms). A stepwise procedure was used to determine 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). Overdispersion was estimated as "σ," the square root of the model deviance statistic divided by the degrees of freedom. Over-dispersion was the "difference" between the expected and the observed model variances, after accounting for treatment, date, and date-squared). If $\sigma > 1.0$, we adjusted the standard errors and *z*-test of the model coefficients by multiplying by σ (Ramsey and Schafer 1997). Finally, if the interaction terms were not significant (likelihood ratio test $P > 0.05$), these terms were removed and we fit a reduced model.

The model was further reduced depending on the significance(s) between treatment and date and/or date-squared. The final model was the most reduced from this process. One constraint was that date-squared could not be in the model unless date was included as well. Various diagnostic plots were examined 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 inriver 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 rates would reflect differences in survival between the two groups during passage from Bonneville Dam to the trawl.

Results and Discussion

A total of 23,139 yearling Chinook salmon and 21,531 steelhead were transported and released upstream from our sample site during the 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 774 yearling Chinook and 809 steelhead in the upper estuary (Appendix Tables 4-5).

A total of 32,363 yearling Chinook salmon were released upstream from McNary and detected at Bonneville Dam. We detected a total of 1,065 (3.3%) of these fish. For steelhead, we detected 1,886 (4.8%) of the 39,513 fish released upstream from McNary and detected at Bonneville Dam (Appendix Table 6).

As in previous years, a portion of tagged fish from both the inriver migrant and barged 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 (4 May-11 June 2015). Allowing 2 d for fish to reach the sample area from Bonneville Dam, we estimate that 78% of inriver migrant yearling Chinook salmon and 89% of inriver migrant steelhead passed through our sample reach during intensive sampling.

We estimated that 97% of transported yearling Chinook and 95% of transported steelhead were at or near rkm 75 during the intensive sample period. These percentages were similar to those estimated in 2014 for both migration history groups.

During the intensive sampling period of 2015, we averaged 15 sampling h/d and in 2014, we averaged 13 h/d. For both transported fish and those detected passing Bonneville Dam, rates of detection were higher in 2015 than in 2014 (Table 9). We believe the higher detection rates of all groups in 2015 were related primarily to low flow conditions.

Table 9. Trawl detection rates of PIT-tagged fish released from barges or detected passing Bonneville Dam during the intensive sample periods, 2014 and 2015.

	Barged fish originating upstream from McNary Dam			In-river fish detected at Bonneville Dam*		
	Released	Detected		Released	Detected	
	n	n	(%)	n	n	(%)
2014						
Chinook salmon	75,149	1,115	1.5	23,554	431	1.8
Steelhead	60,112	1,855	3.1	17,326	411	2.4
2015						
Chinook salmon	22,499	768	3.4	32,363	1,065	3.3
Steelhead	20,540	794	3.9	39,513	1,886	4.8

*Inriver fish included only those released at or upstream from McNary Dam, although no fish were transported from McNary Dam in 2015.

For yearling Chinook salmon, logistic regression analysis showed no significant interaction between date-squared and migration history ($P = 0.629$) or for date-squared as a factor ($P = 0.216$). However, for inriver fish, there was significant interaction between date and migration history ($P = 0.030$) indicating a weak linear relationship. This relationship was not observed for barged fish, and no significant effect on rate of detection was observed for migration history ($P = 0.160$).

Estimated detection rates for inriver Chinook salmon decreased steadily from 4.2% in early May to 1.6% by mid-June. Estimated detection rates for transported migrants remained fairly constant at 3.4%, with a decrease of less than 0.1 percentage points over the course of the season (Figure 13, top panel). The adjustment for over-dispersion was 2.28.

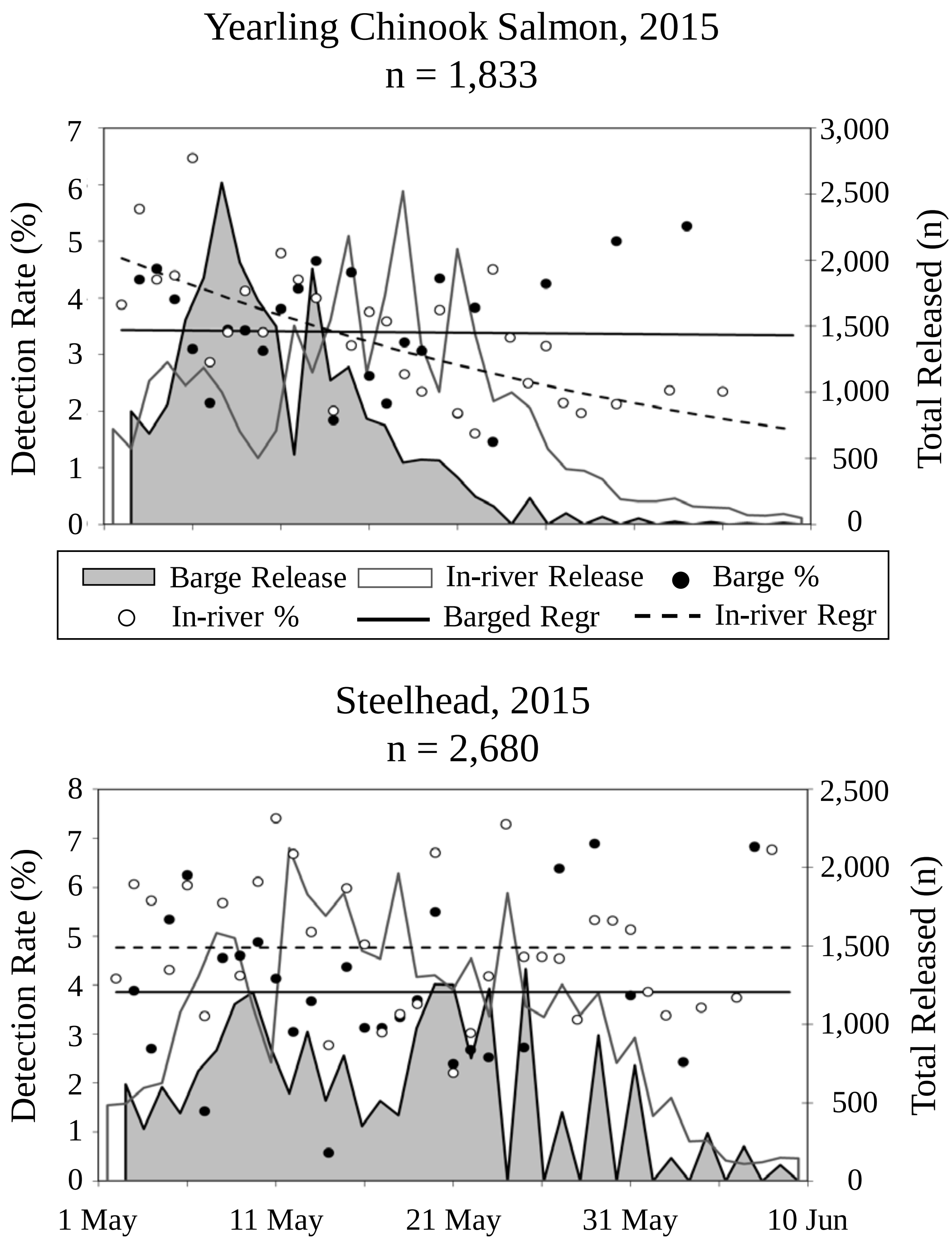

Figure 13. Logistic regression analysis of the daily detection percentage of transported and inriver migrant yearling Chinook salmon and steelhead detected at or released near Bonneville Dam on the same dates, 2015.

For steelhead, logistic regression analysis showed no significant temporal trends in detection rate for any factor (migration history and date-squared interaction; $P = 0.490$, migration history and day interaction; $P = 0.513$, day-squared; $P = 0.201$, and day; $P = 0.531$). However, there was a significant effect for migration history ($P = 0.018$). Through the season, estimated detection rates for steelhead remained steady at 4.8% for inriver and 3.9% for transported fish (Figure 13, lower panel). The adjustment for over-dispersion was 4.69.

Mean detection rates in the trawl for yearling Chinook salmon were higher early in the season and lower later in season for inriver migrants previously detected at Bonneville Dam compared to transported fish released below the dam. For steelhead, estimated detection rates were higher for inriver migrants than for transported fish 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 12 years there has been a general trend towards higher detection rates of inriver migrating Chinook, but there has been no apparent trend for steelhead (Morris et al. 2014).

In summary, estuary detection rates were considerably higher in 2015 than in 2014, when flows were higher. Detection rates of fish at Bonneville Dam were also higher in 2015 than in last 4 years and were similar to those seen in other low flow years.

Since 2012, the Bonneville Dam second powerhouse turbines have been were operated at middle-1% efficiency. This mode of operation increases flow to the first powerhouse and spillway, where there are no PIT monitors. In 2015, operation at the middle-1% of peak efficiency continued at the second powerhouse turbines; however, low river flows contributed to an increase in the number of fish detected in the estuary. Estuary detections of fish previously detected at Bonneville Dam are required to estimate probabilities of survival of inriver migrants to the tailrace of Bonneville Dam, as well as estimates through the entire hydrosystem. Nevertheless, reduced rates of detection at Bonneville Dam may impair the accuracy of survival estimates, especially for species with fewer tagged fish.

References

Axel, A. A., E. E. Hockersmith, B. J. Burke, K. Frick, B. P. Sandford, W. D. Muir, R. F. Absolon, N. Dumdei, J. J. Lamb, and M. G. Nesbit. 2010. Passage behavior and survival of radio-tagged yearling and subyearling Chinook salmon and juvenile steelhead at Ice Harbor Dam, 2009. Report to the Army Corps of Engineers, Walla Walla, Washington.

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

Cormack, R. M. 1964. Estimates of survival from the sightings of marked animals. Biometrika 51:429-483.

Faulkner, J. R., S. G. Smith, D. L. Widener, T. M. Marsh, and R. W. Zabel. 2015. Survival estimates for the passage of spring-migrating juvenile salmonids through Snake and Columbia River dams and reservoirs, 2015. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland, Oregon.

Hockersmith, E. E., G. A. Axel, R. F. Absolon, B. J. Burke, K. E. Frick, J. J. Lamb, M. G. Nesbit, N. D. Dumdei, and B. P. Sandford. 2010. Passage behavior and survival for radio-tagged yearling Chinook salmon and juvenile steelhead at Lower Monumental Dam, 2009. Report to the Army Corps of Engineers, Walla Walla, Washington.

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

Jolly, G. M. 1965. Explicit estimates from capture-recapture data with both death and immigration—stochastic model. Biometrika 52:225-247.

Ledgerwood, R. D., F. P. Thrower, and E. M. Dawley. 1991. Diel sampling of migratory juvenile salmonids in the Columbia River Estuary. U.S. Fishery Bulletin 68:203-217.

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

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

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

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

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

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

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

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

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

Marvin, D. and J. Nighbor, editors. 2009. 2009 PIT tag specification document. Report of the Pacific States Marine Fisheries Commission to the PIT tag Technical Steering Committee. Gladstone, Oregon (www.ptagis.org/resources/document-library/ptagis-program-documents).

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

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

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

Plumb, J. M., A. C. Braatz, J. N. Lucchesi, S. D. Fielding, A. D. Cochran, T. K. Nation, J. M. Sprando, J. L. Schei, R. W. Perry, N. S. Adams, and D.W. Rondorf. 2003. Behavior and survival of radio-tagged juvenile Chinook salmon and steelhead and performance of a removable spillway weir at Lower Granite Dam, Washington, 2003. Annual Report by the U. S. Geological Survey to the U. S. Army Corps of Engineers, contract W68SBV00104592, Walla Walla, Washington. Prentice, E. F., T. A. Flagg, and C. S. McCutcheon. 1990a. Electronic tags. American Fisheries Society Symposium 7:317-322.

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

Prentice, E. F., T. A. Flagg, C. S. McCutcheon, D. F. Brastow, and D. C. Cross. 1990b. Equipment, methods, and an automated data-entry station for PIT tagging. American Fisheries Society Symposium 7:335-340.

PSMFC (Pacific States Marine Fisheries Commission). 2015. The Columbia Basin PIT-Tag-Information System (PTAGIS). Online interactive database, Pacific States Marine Fisheries Commission, Gladstone, Oregon (available via the internet at www.psmfc.org/pittag).

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

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

Seber, G. A. F. 1965. A note on the multiple recapture census. Biometrika 52:249-259.

Skalski, J. R., S. G. Smith, R. N. Iwamoto, J. G. Williams, and A. Hoffmann. 1998. Use of passive integrated transponder tags to estimate survival of migrant juvenile salmonids in the Snake and Columbia Rivers. Canadian Journal of Fisheries and Aquatic Sciences 55:1484-1493.

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

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

Zar, J. H. 1999. Biostatistical analysis, 4th edition. Prentice Hall, Upper Saddle River, New Jersey.

Appendix

Data Tables

Appendix Table 1. Daily total sample time and detections for each salmonid species using the matrix pair trawl antenna system at Jones Beach, 2015.

Date	Total time underway (h)	PIT-tag Detections (N)						
		Unknown	Chinook Salmon	Coho Salmon	Steelhead	Sockeye Salmon	Cutthroat	Total
19 Mar	1.58	0	0	0	0	0	0	0
20 Mar	0.00	--	--	--	--	--	--	--
21 Mar	0.00	--	--	--	--	--	--	--
22 Mar	0.00	--	--	--	--	--	--	--
23 Mar	6.02	0	0	0	0	0	0	0
24 Mar	0.00	--	--	--	--	--	--	--
25 Mar	0.00	--	--	--	--	--	--	--
26 Mar	4.18	0	0	0	0	0	0	0
27 Mar	0.00	--	--	--	--	--	--	--
28 Mar	0.00	--	--	--	--	--	--	--
29 Mar	0.00	--	--	--	--	--	--	--
30 Mar	0.00	--	--	--	--	--	--	--
31 Mar	0.00	--	--	--	--	--	--	--
1 Apr	0.00	--	--	--	--	--	--	--
2 Apr	4.33	0	0	0	0	0	0	0
3 Apr	0.00	--	--	--	--	--	--	--
4 Apr	0.00	--	--	--	--	--	--	--
5 Apr	0.00	--	--	--	--	--	--	--
6 Apr	5.55	0	0	0	1	0	0	1
7 Apr	0.00	--	--	--	--	--	--	--
8 Apr	6.45	0	0	0	1	0	0	1
9 Apr	0.00	--	--	--	--	--	--	--
10 Apr	6.17	0	0	0	3	0	0	3
11 Apr	0.00	--	--	--	--	--	--	--
12 Apr	0.00	--	--	--	--	--	--	--
13 Apr	6.55	1	2	0	2	0	0	5
14 Apr	6.45	1	5	0	1	0	0	7
15 Apr	5.18	0	2	0	2	0	0	4
16 Apr	4.63	0	1	0	1	0	0	2
17 Apr	7.20	0	3	0	1	0	0	4
18 Apr	0.00	--	--	--	--	--	--	--
19 Apr	0.00	--	--	--	--	--	--	--
20 Apr	4.72	2	1	0	13	0	0	16
21 Apr	6.25	4	2	3	11	0	0	20
22 Apr	5.75	2	0	1	14	0	0	17
23 Apr	5.07	1	4	0	8	0	0	13
24 Apr	6.27	0	3	0	12	0	0	15
25 Apr	0.00	--	--	--	--	--	--	--
26 Apr	0.00	--	--	--	--	--	--	--
27 Apr	6.80	5	15	0	54	0	0	74

Appendix Table 1. Continued.

Date	Total time underway (h)	PIT-tag Detections (N)						
		Unknown	Chinook Salmon	Coho Salmon	Steelhead	Sockeye Salmon	Cutthroat	Total
28 Apr	6.57	5	13	1	21	0	0	40
29 Apr	6.78	4	7	1	40	0	0	52
30 Apr	5.57	3	9	0	43	0	0	55
1 May	6.23	4	11	1	59	0	0	75
2 May	6.05	5	4	0	39	0	0	48
3 May	0.87	0	1	0	0	0	0	1
4 May	11.25	23	157	0	115	0	0	295
5 May	9.85	23	370	1	164	0	0	558
6 May	15.88	17	283	4	114	0	0	418
7 May	16.60	10	428	4	118	0	0	560
8 May	19.60	24	779	9	294	1	0	1,107
9 May	14.50	16	571	10	248	0	0	845
10 May	14.30	19	346	7	284	1	0	657
11 May	17.75	11	458	9	198	2	0	678
12 May	16.67	20	428	4	409	2	2	865
13 May	18.95	37	425	11	586	3	0	1,062
14 May	19.98	31	658	12	406	2	0	1,109
15 May	18.47	37	498	13	482	6	0	1,036
16 May	13.82	14	334	10	298	0	0	656
17 May	14.72	30	272	14	269	5	0	591
18 May	19.95	13	369	16	281	29	0	708
19 May	19.93	22	409	15	196	19	0	661
20 May	17.55	20	336	9	267	18	0	650
21 May	18.90	18	155	11	158	19	0	361
22 May	16.57	29	201	19	232	49	0	530
23 May	11.48	22	210	6	281	45	0	564
24 May	12.97	18	179	19	166	126	0	508
25 May	17.23	24	237	25	223	173	0	682
26 May	18.60	35	222	34	343	106	0	740
27 May	13.30	31	119	17	193	36	0	396
28 May	13.43	16	94	15	157	28	0	310
29 May	12.82	22	54	18	157	13	0	264
30 May	8.55	12	45	11	96	9	0	173
31 May	11.55	6	24	12	112	9	0	163
1 Jun	13.58	12	69	33	266	10	0	390
2 Jun	14.55	20	68	33	304	8	0	433
3 Jun	14.90	10	78	26	142	6	1	263
4 Jun	13.67	3	24	10	50	6	0	93
5 Jun	15.23	8	71	19	53	4	0	155
6 Jun	8.55	3	18	7	25	1	0	54
7 Jun	12.73	0	61	8	27	3	0	99
8 Jun	15.92	2	34	7	36	0	0	79
9 Jun	13.77	4	78	22	30	1	0	135
10 Jun	13.13	8	21	15	39	1	0	84
11 Jun	11.43	2	27	10	25	1	0	65
12 Jun	6.73	2	11	5	10	1	1	30
13 Jun	0.00	--	--	--	--	--	--	--
14 Jun	0.00	--	--	--	--	--	--	--
15 Jun	6.97	0	33	10	34	0	0	77

Appendix Table 1. Continued.

Date	Total time underway (h)	PIT-tag Detections (N)						
		Unknown	Chinook Salmon	Coho Salmon	Steelhead	Sockeye Salmon	Cutthroat	Total
16 Jun	6.12	1	7	4	6	0	0	18
17 Jun	6.65	2	40	12	7	1	0	62
18 Jun	6.53	1	34	8	3	0	0	46
19 Jun	6.70	0	9	4	2	0	0	15
20 Jun	0.00	--	--	--	--	--	--	--
21 Jun	0.00	--	--	--	--	--	--	--
22 Jun	7.37	1	15	4	11	0	0	31
23 Jun	7.37	0	12	1	7	0	0	20
24 Jun	6.58	1	22	8	10	0	0	41
25 Jun	6.67	0	16	6	7	0	0	29
26 Jun	7.17	0	10	2	7	0	0	19
27 Jun	0.00	--	--	--	--	--	--	--
28 Jun	0.00	--	--	--	--	--	--	--
29 Jun	6.22	0	7	0	5	0	0	12
30 Jun	6.60	0	9	3	2	0	0	14
1 Jul	6.22	0	13	3	3	0	0	19
2 Jul	4.75	0	5	1	0	0	0	6
Total	812.50	717	9,536	603	8,284	744	4	19,889

Appendix Table 2. Combined daily total of impinged or injured fish on the matrix antenna system used in the upper Columbia River estuary, 2015.

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

Appendix Table 2. Continued.

Date	YCS	SYCS	Coho	Stlhd	Sockeye	Chum	Date	YCS	SYCS	Coho	Stlhd	Sockeye	Chum
18 Apr	--	--	--	--	--	--	20 May	2	3	1	0	1	0
19 Apr	--	--	--	--	--	--	21 May	3	0	0	1	0	0
22 May	1	0	0	0	0	0	12 Jun	0	0	0	0	0	0
23 May	1	0	0	0	0	0	13 Jun	--	--	--	--	--	--
24 May	0	1	0	0	0	0	14 Jun	--	--	--	--	--	--
25 May	0	3	0	0	3	1	15 Jun	2	3	6	0	0	1
26 May	4	1	3	0	0	0	16 Jun	0	0	0	0	0	0
27 May	0	1	0	0	4	1	17 Jun	0	0	0	0	0	0
28 May	1	0	0	0	3	0	18 Jun	0	0	0	0	0	0
29 May	1	0	2	0	1	0	19 Jun	0	0	0	0	0	0
30 May	0	0	0	0	0	0	20 Jun	--	--	--	--	--	--
31 May	3	0	1	0	2	0	21 Jun	--	--	--	--	--	--
1 Jun	3	0	2	0	1	0	22 Jun	0	1	0	0	0	0
2 Jun	2	4	2	0	0	0	23 Jun	0	0	0	0	0	0
3 Jun	1	4	0	0	0	0	24 Jun	0	0	0	0	0	0
4 Jun	0	5	0	0	0	0	25 Jun	0	0	0	0	0	0
5 Jun	6	6	7	3	1	0	26 Jun	0	0	0	0	0	0
6 Jun	0	0	0	0	0	0	27 Jun	--	--	--	--	--	--
7 Jun	0	0	0	0	0	0	28 Jun	--	--	--	--	--	--
8 Jun	1	4	0	0	3	0	29 Jun	0	0	0	0	0	0
9 Jun	0	0	0	0	0	0	30 Jun	0	0	0	0	0	0
10 Jun	7	8	3	0	0	1	1 Jul	0	0	0	0	0	0
11 Jun	3	10	1	3	0	1	2 Jul	0	1	0	0	0	0
							Total	96	61	35	22	30	9

Appendix Table 3. Diel sampling of yearling Chinook salmon and steelhead using a PIT-tag detector surface pair-trawl at Jones Beach (rkm 75), 2015. The intensive sampling period (4 May-11 June) was rounded to the nearest tenth and presented as a decimal hour.

		Yearling Chinook salmon				Steelhead			
		n		n/h		n		n/h	
Diel hour	Effort (h)	Hatchery	Wild	Hatchery	Wild	Hatchery	Wild	Hatchery	Wild
0	32.9	496	38	15.09	1.16	239	81	7.27	2.46
1	31.5	539	48	17.12	1.52	218	90	6.92	2.86
2	26.2	587	44	22.38	1.68	213	50	8.12	1.91
3	21.3	551	43	25.91	2.02	208	50	9.78	2.35
4	19.8	496	51	25.09	2.58	179	52	9.06	2.63
5	31.1	623	62	20.06	2.00	180	73	5.80	2.35
6	37.2	550	102	14.77	2.74	349	163	9.37	4.38
7	38.7	394	67	10.19	1.73	394	156	10.19	4.03
8	39.0	290	65	7.44	1.67	502	158	12.87	4.05
9	39.0	337	61	8.64	1.56	549	124	14.08	3.18
10	39.0	321	47	8.23	1.21	531	134	13.62	3.44
11	36.5	319	53	8.74	1.45	486	99	13.32	2.71
12	20.6	230	41	11.18	1.99	284	66	13.81	3.21
13	13.8	151	40	10.92	2.89	206	35	14.89	2.53
14	8.5	117	13	13.74	1.53	107	24	12.56	2.82
15	2.2	6	1	2.73	0.45	51	8	23.18	3.64
16	0.0	--	--	--	--	--	--	--	--
17	0.0	--	--	--	--	--	--	--	--
18	0.0	--	--	--	--	--	--	--	--
19	15.1	33	11	2.19	0.73	62	21	4.11	1.39
20	31.6	220	33	6.97	1.05	176	80	5.58	2.54
21	33.0	622	73	18.85	2.21	399	107	12.09	3.24
22	33.0	633	56	19.18	1.70	450	115	13.64	3.48
23	33.0	382	23	11.58	0.70	256	81	7.76	2.45
Total	582.8	7,897.0	972.0			6,039.0	1,767.0		

Appendix Table 4. Number of PIT-tagged yearling Chinook salmon loaded for transport at dams and numbers detected in the estuary. Transport dates were 17 Apr-2 Jul; trawl operation 19 Mar-2 Jul, intensive sampling 4 May-11 Jun 2015. Season totals are shown.

	Numbers loaded by dam (n)				Detections by transport dam (%)			Total trawl detections	
Release date and time	Lower Granite	Little Goose	Lower Monumental	Total fish loaded (n)	Lower Granite	Little Goose	Lower Monumental	n	(%)
4/17/15 8:20 PM	237	0	0	237	0.84	--	--	2	0.84
4/24/15 8:00 PM	263	0	0	263	0.76	--	--	2	0.76
5/3/15 9:00 PM	393	384	79	856	4.07	4.69	3.80	37	4.32
5/4/15 11:30 PM	406	262	19	687	3.69	4.96	15.79	31	4.51
5/5/15 10:20 PM	407	243	256	906	3.93	4.53	3.52	36	3.97
5/6/15 9:00 PM	517	461	570	1548	1.55	1.74	5.61	48	3.10
5/7/15 9:20 PM	695	635	535	1865	2.01	1.26	3.36	40	2.14
5/8/15 8:40 PM	1759	635	193	2587	3.75	2.83	2.59	89	3.44
5/9/15 8:20 PM	1354	412	216	1982	3.18	4.61	2.78	68	3.43
5/10/15 7:30 PM	735	653	308	1696	3.27	3.22	2.27	52	3.07
5/11/15 9:20 PM	462	825	211	1498	2.60	4.12	5.21	57	3.81
5/12/15 7:40 PM	407	0	121	528	4.42	--	3.31	22	4.17
5/13/15 8:45 PM	453	1401	80	1934	5.52	4.35	5.00	90	4.65
5/14/15 8:40 PM	322	669	99	1090	2.17	1.94	0.00	20	1.83
5/15/15 8:45 PM	554	595	42	1191	4.15	4.54	7.14	53	4.45
5/16/15 7:25 PM	499	232	69	800	2.40	3.45	1.45	21	2.63
5/17/15 8:20 PM	280	411	59	750	2.14	1.95	3.39	16	2.13
5/18/15 7:20 PM	112	274	81	467	3.57	3.28	2.47	15	3.21
5/19/15 8:30 PM	108	268	113	489	0.93	4.48	1.77	15	3.07
5/20/15 9:00 PM	155	243	85	483	5.16	3.70	4.71	21	4.35
5/21/15 8:15 PM	180	133	44	357	3.89	0.00	0.00	7	1.96
5/22/15 9:15 PM	60	101	48	209	1.67	2.97	8.33	8	3.83
5/23/15 7:50 PM	81	44	12	137	1.23	2.27	0.00	2	1.46
5/25/15 8:15 PM	78	91	30	199	1.28	3.30	3.33	5	2.51
5/27/15 8:45 PM	18	57	8	83	5.56	10.53	0.00	7	8.43
5/29/15 8:05 PM	16	27	13	56	0.00	0.00	7.69	1	1.79
5/31/15 8:05 PM	7	26	11	44	0.00	11.54	9.09	4	9.09
6/2/15 6:55 PM	7	7	6	20	14.29	0.00	0.00	1	5.00

Appendix Table 4. Continued.

Release date and time	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	(%)
6/4/15 8:50 PM	7	3	7	17	14.29	0.00	0.00	1	5.88
6/6/15 8:40 PM	5	3	1	9	0.00	0.00	0.00	0	0.00
6/9/15 4:40 AM	1	7	3	11	0.00	14.29	0.00	1	9.09
6/10/15 8:00 PM	15	2	1	18	0.00	0.00	0.00	0	0.00
6/12/15 8:45 PM	1	11	0	12	0.00	0.00	--	0	0.00
6/14/15 7:05 PM	1	13	1	15	0.00	0.00	0.00	0	0.00
6/16/15 8:25 PM	2	14	1	17	0.00	0.00	0.00	0	0.00
6/18/15 8:20 PM	5	8	1	14	0.00	0.00	0.00	0	0.00
6/20/15 8:45 PM	1	4	0	5	0.00	25.00	--	1	20.00
6/22/15 7:45 PM	3	14	0	17	0.00	7.14	--	1	5.88
6/24/15 7:45 PM	0	5	0	5	--	0.00	--	0	0.00
6/26/15 8:05 PM	3	6	0	9	0.00	0.00	--	0	0.00
6/28/15 11:10 PM	2	12	0	14	0.00	0.00	--	0	0.00
6/30/15 8:00 PM	0	9	0	9	--	0.00	--	0	0.00
7/2/15 7:40 PM	0	3	2	5	--	0.00	0.00	0	0.00
Totals/means	10,611	9,203	3,325	23,139	3.16	3.43	3.70	774	3.35

Appendix Table 5. Number of PIT-tagged steelhead loaded for transport at dams and numbers detected in the estuary. Transport dates 14 Apr-2 Jul; trawl operation 19 Mar-2 Jul, with intensive sampling 4 May-11 Jun 2015. Season totals are shown.

	Numbers loaded by dam (n)				Detections by transport dam (%)			Total trawl detections	
Release date and time	Lower Granite	Little Goose	Lower Monumental	Total fish loaded (n)	Lower Granite	Little Goose	Lower Monumental	n	(%)
4/17/15 8:20 PM	7	0	0	7	0.00	--	--	0	0.00
5/3/15 9:00 PM	188	273	156	617	5.85	3.30	2.56	24	3.89
5/4/15 11:30 PM	136	118	79	333	2.21	1.69	5.06	9	2.70
5/5/15 10:20 PM	153	257	189	599	5.23	5.45	5.29	32	5.34
5/6/15 9:00 PM	220	124	88	432	6.82	8.06	2.27	27	6.25
5/7/15 9:20 PM	361	202	140	703	0.83	1.98	2.14	10	1.42
5/8/15 8:40 PM	411	327	97	835	3.89	4.59	7.22	38	4.55
5/9/15 8:20 PM	445	491	193	1129	2.92	5.91	5.18	52	4.61
5/10/15 7:30 PM	267	652	288	1207	8.24	3.37	5.21	59	4.89
5/11/15 9:20 PM	124	518	204	846	3.23	4.63	3.43	35	4.14
5/12/15 7:40 PM	470	0	89	559	3.19	--	2.25	17	3.04
5/13/15 8:45 PM	301	590	61	952	4.98	2.88	4.92	35	3.68
5/14/15 8:40 PM	335	131	48	514	0.30	1.53	0.00	3	0.58
5/15/15 8:45 PM	482	131	188	801	3.73	6.11	4.79	35	4.37
5/16/15 7:25 PM	206	83	62	351	3.40	2.41	3.23	11	3.13
5/17/15 8:20 PM	177	297	38	512	4.52	2.69	0.00	16	3.13
5/18/15 7:20 PM	116	243	60	419	3.45	3.29	3.33	14	3.34
5/19/15 8:30 PM	90	729	156	975	6.67	3.29	3.85	36	3.69
5/20/15 9:00 PM	580	480	196	1256	6.55	5.63	2.04	69	5.49
5/21/15 8:15 PM	966	196	91	1253	2.48	2.04	2.20	30	2.39
5/22/15 9:15 PM	350	341	92	783	2.86	2.64	2.17	21	2.68
5/23/15 7:50 PM	960	214	55	1229	2.71	2.34	0.00	31	2.52
5/25/15 8:15 PM	980	282	92	1354	3.16	1.77	1.09	37	2.73
5/27/15 8:45 PM	108	287	44	439	10.19	5.57	2.27	28	6.38
5/29/15 8:05 PM	694	159	76	929	6.77	7.55	6.58	64	6.89
5/31/15 8:05 PM	479	191	68	738	3.34	4.19	5.88	28	3.79
6/2/15 6:55 PM	52	69	26	147	3.85	7.25	7.69	9	6.12
6/4/15 8:50 PM	252	37	17	306	0.79	0.00	0.00	2	0.65

Appendix Table 5. Continued.

Release date and time	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	(%)
6/6/15 8:40 PM	159	44	17	220	5.66	11.36	11.76	16	7.27
6/9/15 4:40 AM	79	12	11	102	5.06	0.00	18.18	6	5.88
6/10/15 8:00 PM	353	22	1	376	0.85	0.00	0.00	3	0.80
6/12/15 8:45 PM	267	54	4	325	3.75	3.70	0.00	12	3.69
6/14/15 7:05 PM	88	25	7	120	0.00	0.00	0.00	0	0.00
6/16/15 8:25 PM	6	27	3	36	0.00	0.00	0.00	0	0.00
6/18/15 8:20 PM	4	22	4	30	0.00	0.00	0.00	0	0.00
6/20/15 8:45 PM	3	6	1	10	0.00	0.00	0.00	0	0.00
6/22/15 7:45 PM	1	11	0	12	0.00	0.00	--	0	0.00
6/24/15 7:45 PM	0	2	0	2	--	0.00	--	0	0.00
6/26/15 8:05 PM	1	5	0	6	0.00	0.00	--	0	0.00
6/28/15 11:10 PM	1	19	1	21	0.00	0.00	0.00	0	0.00
6/30/15 8:00 PM	1	30	1	32	0.00	0.00	0.00	0	0.00
7/2/15 7:40 PM	0	12	2	14	--	0.00	0.00	0	0.00
Totals/means	10,873	7,713	2,945	21,531	3.70	3.84	3.77	809	3.76

Appendix Table 6. Trawl system detections of PIT-tagged juvenile Chinook salmon and steelhead previously detected at Bonneville Dam, 2015.

Date detected at Bonneville	Tag detections: Bonneville Dam (n) Chinook	Bonneville Dam (n) Steelhead	Jones Beach (n) Chinook	Jones Beach (n) Steelhead	Bonneville and Jones Beach (%) Chinook	Bonneville and Jones Beach (%) Steelhead
19 Mar	34	5	0	0	0.00	0.00
20 Mar	91	1	0	0	0.00	0.00
21 Mar	165	3	0	0	0.00	0.00
22 Mar	109	1	0	0	0.00	0.00
23 Mar	114	3	0	0	0.00	0.00
24 Mar	44	5	0	0	0.00	0.00
25 Mar	23	4	0	0	0.00	0.00
26 Mar	13	1	0	0	0.00	0.00
27 Mar	7	8	0	0	0.00	0.00
28 Mar	7	3	0	0	0.00	0.00
29 Mar	5	3	0	0	0.00	0.00
30 Mar	1	9	0	0	0.00	0.00
31 Mar	5	5	0	0	0.00	0.00
1 Apr	10	8	0	0	0.00	0.00
2 Apr	10	12	0	0	0.00	0.00
3 Apr	13	3	0	0	0.00	0.00
4 Apr	33	3	0	0	0.00	0.00
5 Apr	56	7	0	1	0.00	14.29
6 Apr	68	6	0	0	0.00	0.00
7 Apr	60	9	1	1	1.67	11.11
8 Apr	59	12	0	1	0.00	8.33
9 Apr	87	8	0	0	0.00	0.00
10 Apr	65	11	0	0	0.00	0.00
11 Apr	52	18	0	0	0.00	0.00
12 Apr	47	11	0	0	0.00	0.00
13 Apr	76	27	1	0	1.32	0.00
14 Apr	206	25	1	0	0.49	0.00
15 Apr	349	15	2	0	0.57	0.00
16 Apr	103	23	0	0	0.00	0.00
17 Apr	105	10	1	0	0.95	0.00
18 Apr	267	20	1	0	0.37	0.00
19 Apr	144	37	1	1	0.69	2.70
20 Apr	288	52	5	1	1.74	1.92
21 Apr	289	56	2	1	0.69	1.79
22 Apr	222	43	0	0	0.00	0.00
23 Apr	272	67	1	0	0.37	0.00
24 Apr	362	191	4	2	1.10	1.05
25 Apr	365	516	2	11	0.55	2.13
26 Apr	427	653	1	4	0.23	0.61
27 Apr	736	1,008	6	11	0.82	1.09
28 Apr	670	722	7	4	1.04	0.55
29 Apr	1,156	629	10	10	0.87	1.59
30 Apr	976	394	11	2	1.13	0.51
1 May	1,467	670	34	1	2.32	0.15
2 May	1,722	728	72	34	4.18	4.67
3 May	1,521	739	63	38	4.14	5.14

Appendix Table 6. Continued.

Date detected at Bonneville	Tag detections					
	Bonneville Dam (n)		Jones Beach (n)		Bonneville and Jones Beach (%)	
	Chinook	Steelhead	Chinook	Steelhead	Chinook	Steelhead
4 May	1,905	816	76	41	3.99	5.02
5 May	1,982	843	73	38	3.68	4.51
6 May	1,649	1,372	92	88	5.58	6.41
7 May	1,520	1,748	45	53	2.96	3.03
8 May	1,164	2,138	41	103	3.52	4.82
9 May	774	2,056	31	76	4.01	3.70
10 May	556	1,386	20	85	3.60	6.13
11 May	753	943	36	68	4.78	7.21
12 May	1,548	2,613	67	171	4.33	6.54
13 May	1,182	2,254	49	110	4.15	4.88
14 May	1,560	2,081	32	63	2.05	3.03
15 May	2,211	2,273	71	123	3.21	5.41
16 May	1,155	1,756	43	82	3.72	4.67
17 May	1,737	1,675	61	50	3.51	2.99
18 May	2,531	2,458	68	80	2.69	3.25
19 May	1,390	1,664	32	57	2.30	3.43
20 May	1,014	1,615	39	101	3.85	6.25
21 May	2,088	1,518	40	34	1.92	2.24
22 May	1,439	1,677	23	48	1.60	2.86
23 May	947	1,200	42	48	4.44	4.00
24 May	999	1,987	33	137	3.30	6.89
25 May	875	1,224	21	56	2.40	4.58
26 May	605	1,304	20	60	3.31	4.60
27 May	430	1,430	9	63	2.09	4.41
28 May	418	1,258	8	43	1.91	3.42
29 May	344	1,363	3	70	0.87	5.14
30 May	205	825	4	41	1.95	4.97
31 May	176	991	9	52	5.11	5.25
1 Jun	183	484	1	20	0.55	4.13
2 Jun	204	577	6	19	2.94	3.29
3 Jun	138	281	5	11	3.62	3.91
4 Jun	129	281	4	7	3.10	2.49
5 Jun	126	153	3	7	2.38	4.58
6 Jun	76	122	1	3	1.32	2.46
7 Jun	71	135	1	13	1.41	9.63
8 Jun	85	154	3	6	3.53	3.90
9 Jun	65	160	1	9	1.54	5.63
10 Jun	47	95	0	4	0.00	4.21
11 Jun	36	64	0	0	0.00	0.00
12 Jun	31	58	1	0	3.23	0.00
13 Jun	46	31	1	1	2.17	3.23
14 Jun	53	10	1	0	1.89	0.00
15 Jun	207	20	3	2	1.45	10.00
16 Jun	102	16	2	0	1.96	0.00
17 Jun	58	19	0	0	0.00	0.00
18 Jun	47	31	0	0	0.00	0.00
19 Jun	41	67	0	0	0.00	0.00

Appendix Table 6. Continued.

Date detected at Bonneville	Tag detections: Bonneville Dam (n)		Jones Beach (n)		Bonneville and Jones Beach (%)	
	Chinook	Steelhead	Chinook	Steelhead	Chinook	Steelhead
20 Jun	34	99	0	4	0.00	4.04
21 Jun	33	103	4	5	12.12	4.85
22 Jun	48	72	0	2	0.00	2.78
23 Jun	29	19	0	0	0.00	0.00
24 Jun	34	26	1	3	2.94	11.54
25 Jun	12	19	0	0	0.00	0.00
26 Jun	40	18	1	1	2.50	5.56
27 Jun	47	22	0	3	0.00	13.64
28 Jun	41	8	0	0	0.00	0.00
29 Jun	48	14	1	0	2.08	0.00
30 Jun	58	17	0	0	0.00	0.00
01 Jul	39	12	0	0	0.00	0.00
02 Jul	55	6	0	0	0.00	0.00
Totals	48,321	54,445	1,354	2,284	2.80	4.20