Detection of PIT-Tagged Juvenile Salmonids in the Columbia River Estuary using a Pair-Trawl, 2014

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Executive Summary

In 2014, we continued a multi-year study to detect juvenile Pacific salmonids *Oncorhynchus* spp. using a pair-trawl fitted with antennas to detect passive integrated transponder (PIT) tags. The trawl was deployed within the navigation channel in the upper Columbia River estuary between river kilometer (rkm) 61 and 83 and sampled for a total of 925 h between 18 March and 30 July 2014. During this period, we detected a total of 15,904 PIT-tagged juvenile salmonids comprised of 18% wild and 77% hatchery-reared fish (5% were of unknown origin). Species composition of fish detected in the trawl was 42% spring/summer and 4% fall Chinook, 43% steelhead, 6% sockeye, 3% coho, less than 1% cutthroat trout, and 2% unknown species.

Sampling began with a single daily shift operating 3-5 d/week to coincide with arrival in the estuary of early migrating juvenile PIT-tagged salmon and steelhead. As numbers of juvenile migrants increased, sample effort was increased to two daily shifts operating 7 d/week during daylight and 6 d/week during darkness. Intensive sampling continued from 28 April through 12 June.

During the intensive sample period, detections averaged 8 h^{-1} during daylight and 13 h^{-1} during darkness for yearling Chinook salmon (P = 0.009), and 14 h^{-1} during daylight and 4 h^{-1} during darkness for steelhead (P = <0.001). After 12 June, we continued with a single daily shift until numbers of fish in the sampling reach declined, and sampling ended on 30 July. During intensive sampling, the trawl was deployed for an average of 13 h d^{-1}. By comparison, the trawl was deployed for an average of 14 h d^{-1} during intensive sampling in 2013.

Also during the intensive sample period, we detected 1.8% of the yearling Chinook and 2.4% of the steelhead detected at Bonneville Dam. These proportions were lower than in 2013, when we detected 2.7% of the yearling Chinook and 3.8% of the steelhead detected at Bonneville Dam. We also detected 1.5% of the yearling Chinook salmon and 3.1% of the steelhead transported and released below Bonneville Dam in 2014. Again, these rates were lower than those for transported fish in 2013 (1.9% of yearling Chinook and 3.7% of steelhead).

Detection rates in the trawl are typically inversely related with flow, where detection rates are lower in moderate-to-high flow years. Flow measured at Bonneville Dam was above average, at 8,890 m^3 s^{-1}during intensive sampling in 2014. In comparison, flow volume at Bonneville Dam during this period in 2013 was below average, at 8,013 m^3 s^{-1}.

Of fish detected with the trawl system in 2014, 21% had been transported, while 9% had been detected in the juvenile bypass system or corner collector at Bonneville Dam. The remaining 70% had neither been transported nor detected at Bonneville Dam, although at least 97% of them had originated upstream from Bonneville.

We estimated survival from Lower Granite to Bonneville Dam at 54.9% for Snake River yearling Chinook salmon (Table 1). This was lower than the 62.2% estimated through the same reach for these fish in 2013. For Snake River steelhead, estimated survival from Lower Granite to Bonneville was 75.7%, the highest estimate on record, and much higher than the 51.5% survival estimated for these fish in 2013. Estimated survival for Snake River sockeye through the same reach was 71.3% in 2014, which was again considerably higher than the 53.6% estimated in 2013.

Table 1. Estimated survival by species and run from Lower Granite and McNary Dam to Bonneville Dam in 2013 and 2014. All estimates are tailrace-to-tailrace. Standard errors shown in parenthesis.

	Tailrace-to-tailrace estimated survival percentages (SE)			
	Lower Granite to Bonneville		McNary to Bonneville	
Combined wild and hatchery stocks	2013	2014	2013	2014
Snake River				
Yearling Chinook	62.2 (±5.2)	54.9 (±8.3)	79.2 (±7.1)	71.5 (±10.7)
Steelhead	51.5 (±7.5)	75.7 (±6.9)	79.8 (±11.2)	102.3 (±8.8)
Sockeye	53.6 (±7.5)	71.3 (±11.0)	77.6 (±10.6)	81.7 (±11.5)
Upper Columbia R (above Yakima R)				
Yearling Chinook			102.5 (±10.3)	92.9 (± 10.0)
Steelhead			91.0 (±7.5)	97.2 (±10.8)
Yakima River yearling Chinook			76.0 (±12.1)	74.5 (±16.6)

In the reach from McNary to Bonneville Dam, estimated survival was lower in 2014 than in 2013 for Snake River yearling Chinook (71.5 vs. 79.2%). Lower rates of survival were also estimated for upper Columbia River yearling Chinook released above the confluence of the Yakima River (92.9 vs. 102.5%) or below the Yakima River confluence (74.5 vs. 76.0%).

Estimated survival for Snake River steelhead through this reach was much higher in 2014 than in 2013 (102.3 vs. 79.8%). For upper Columbia River steelhead, estimated survival was 97.2% in 2014 (vs. 91.0% in 2013). For upper Columbia River sockeye salmon, survival estimates from McNary to Bonneville Dam lacked precision due to low tagging effort in both 2014 (56.5% ± 26.9) and 2013 (65.8% ±21.7).

Overall mean travel speed to the estuary (rkm 70) was significantly faster for yearling Chinook detected at Bonneville Dam (95 km d^{-1}) than for those released from barges just below the dam (72 km d^{-1}, $P \leq 0.001$). Similar differences in travel speed were noted for steelhead (inriver vs. transported fish, 103 vs. 95 km d^{-1}, $P < 0.001$). There was also a significant difference in travel speed between sockeye salmon detected at Bonneville (113 km d^{-1}) and those released from barges on the same day (107 km d^{-1}, $P < 0.005$). However, the sample size for inriver detections was small (n = 66). Detections of subyearling Chinook in 2014 were insufficient to estimate travel speed.

We detected a total of 344 subyearling fall Chinook, with the majority of detections occurring after the intensive sample period. Of these 344 fish, 132 originated in the Snake River basin (112 inriver migrants and 20 transported). The remaining 212 were Columbia River stocks (51 released above McNary and 161 released between McNary and Bonneville Dam). We also detected two fall Chinook from the Snake River basin that had been released as subyearlings in 2013. One of these fish had overwintered above Little Goose Dam; the other had no detection history prior to detection in the trawl.

Of the 886 sockeye salmon detected in the trawl, 91% had been released into the Snake River and 9% into the upper Columbia River. Sockeye detected in 2014 were 86% hatchery reared, 5% wild, and 9% of unknown origin. Inriver migrants sockeye made up 64% of these detections, with 36% made up of transported sockeye.

In 2014, we continued developing a flexible antenna system that could be towed behind two small vessels (6.7 m). We conducted towed tests of a 2.4 by 6.1 m antenna housed in 1.9-cm diameter flexible PVC hose. These tests showed improvements from off-season modifications to improve deployment methods, hydrodynamics, and speed. To reduce electromagnetic interference, we wrapped antenna wires inside the flexible housing. This was effective in reducing vibration and EMI.

Following successful deployments of the single-coil antenna, we built and tested a two-coil antenna array. Performance of the two-coil array was similar to that of the single-coil array, indicating no interaction between antennas under tow. Testing in 2015 will include an array of up to six antennas. We are continuing work to further reduce vibration under tow to increase speed without attenuation of the detection field.

Contents

Introduction

In 2014, 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 2014). 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.

Nearly 1.9 million Snake and Columbia River juvenile salmonids were PIT-tagged and released prior to or during the spring 2014 migration season (PSMFC 2014). 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 2014).

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 2014 and annually since 1998.

In 2014, over 146,000 PIT-tagged fish were transported from dams on the Snake River and over 77,000 inriver migrants were detected at Bonneville Dam. Seasonal trends in our estuarine detection data for these same 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. 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.

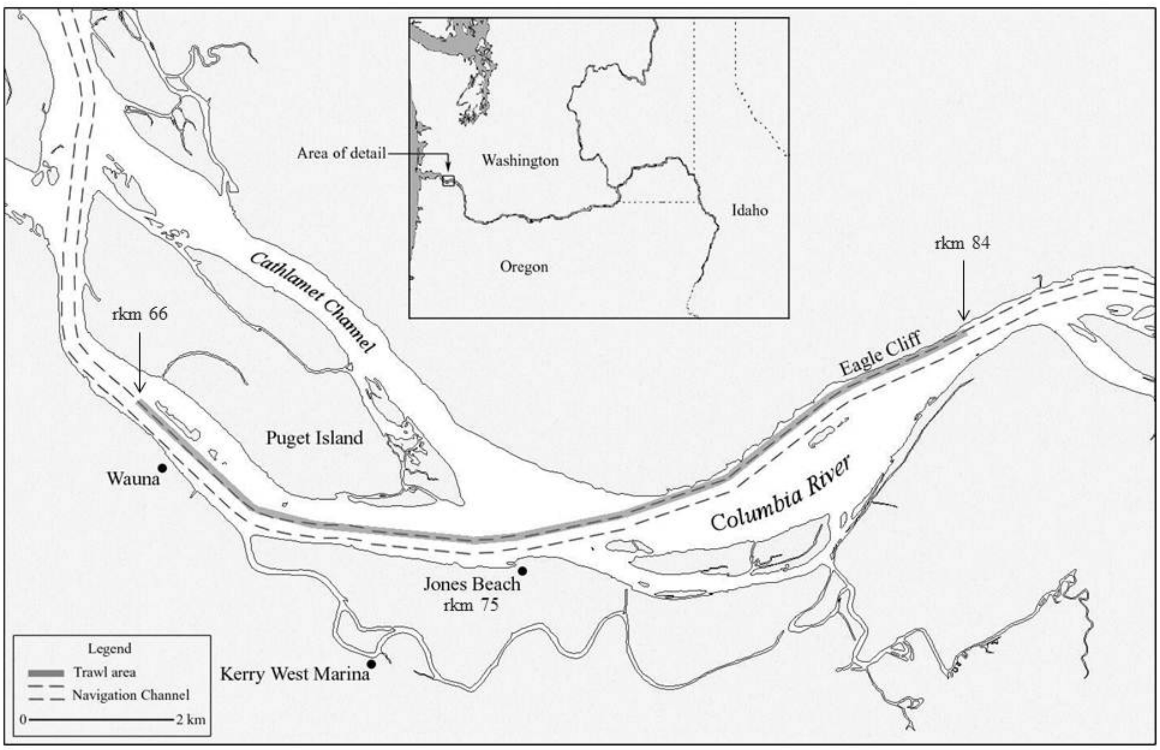

Figure 1. Trawling area adjacent to the navigation channel in the upper Columbia River estuary between rkm 66 and 84.

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 arrive in the upper estuary from late April through late June. Release dates and locations of fish detected with the trawl were retrieved from the *PIT Tag Information System* (PTAGIS) database (PSFMC 2014). Specific groups of tagged fish targeted for detection included over 220,000 fish released for a comparative survival study of hatchery fish, and some 146,000 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. In 2014, no fish were transported from McNary 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 18 March and continued through the summer migration period to 30 July 2014. 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 effort of 6 h d^{-1} (effort was defined as full deployment of the trawl). During the peak of the spring migration, from 28 April through 12 June, we sampled daily with two shifts, both day and night, for an average daily effort of 13 h d^{-1}.

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 14:00 and 19:00 PDT, when we interrupted sampling for refueling and maintenance.

Trawl System Design

In 2014, 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.

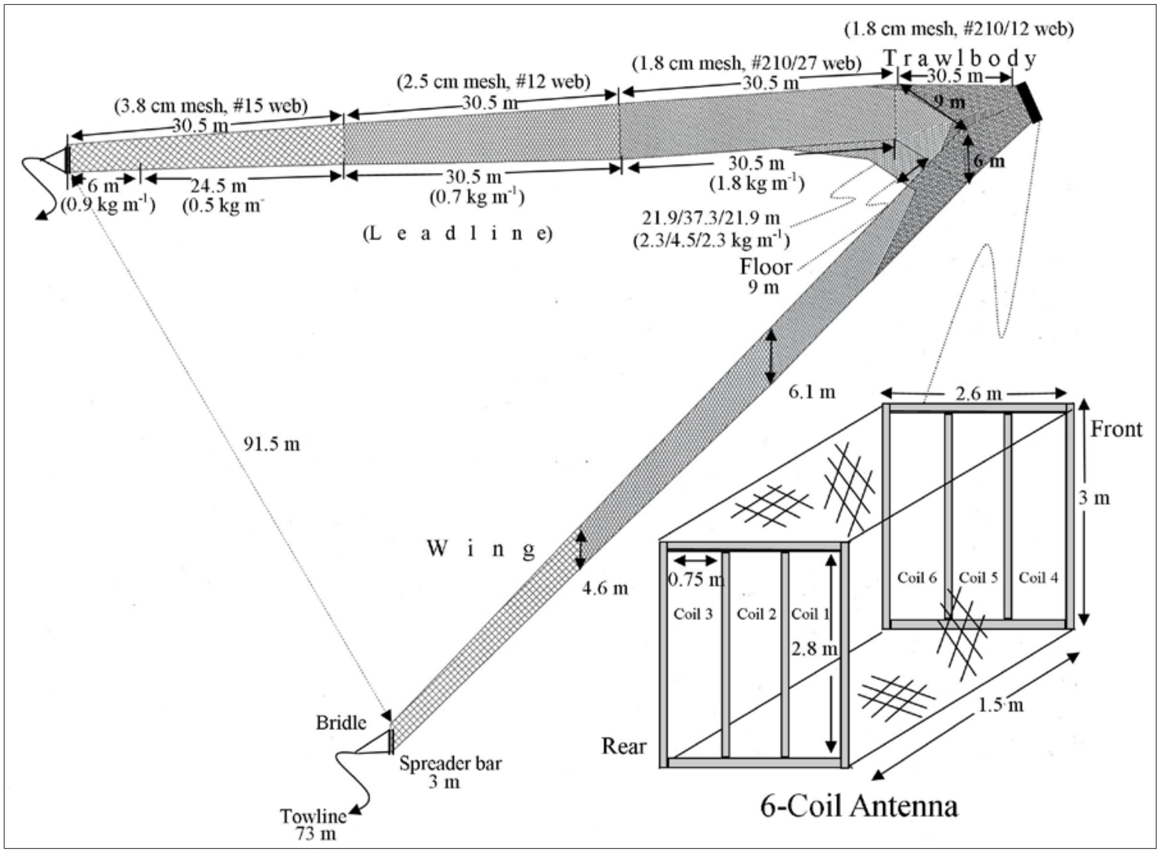

Figure 2. Basic design of the surface pair trawl used with the matrix antenna system to sample juvenile salmonids in the Columbia River estuary (rkm 75), 2014.

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.

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

We used essentially the same electronic components and procedures as in 2006-2013. 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 onboard 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.

The date and time of detection, tag code, coil identification number, and GPS location for each fish detected were received from the antenna and recorded automatically using the computer software program MiniMon (PSMFC 2014). 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 2014). 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 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.

Previous antenna designs, such as the cylindrical antenna (0.9-m diameter) last used in 2008, allowed significant accumulation of debris in the trawl body. When using these smaller antenna designs, 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 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

In 2014, the majority of the two-shift daily sampling period was characterized by above-average river flows and with normal-to-high debris loads. Mean flow volumes in the Columbia River at Bonneville Dam were about 11% higher during the two-shift sample period of 2014 (8,890 $m^3 s^{-1}$) than during the two-shift period of 2013 (8,013 $m^3 s^{-1}$; Figure 3). However, flow volume in 2013 was slightly below the 11-year average (8,261 $m^3 s^{-1}$).

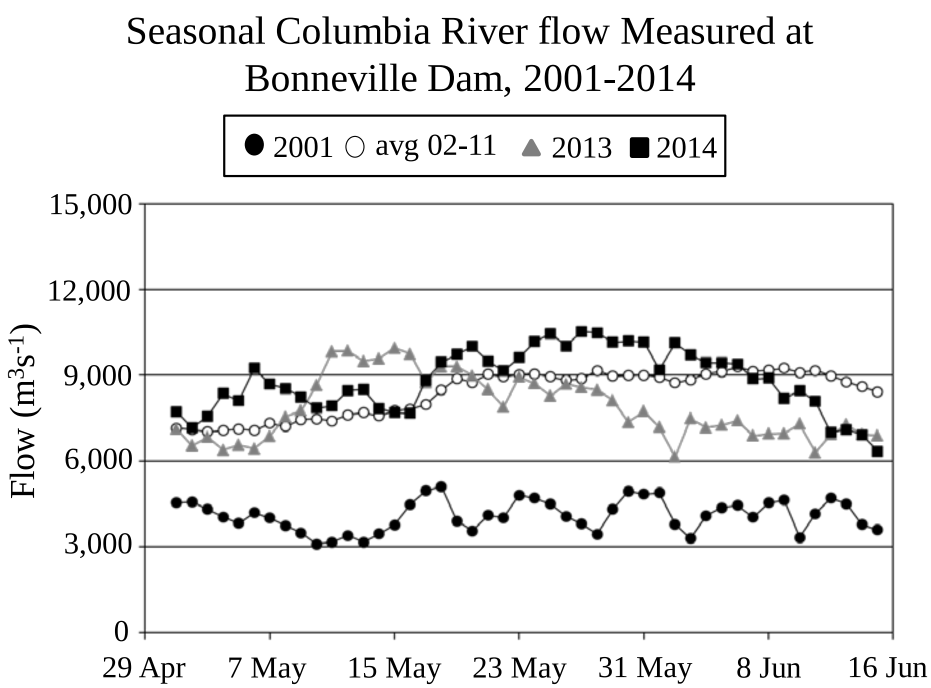

Figure 3. Columbia River flows at Bonneville Dam during the two-shift sample periods in 2013 and 2014, as compared to the average flow from 2002 to 2012. Drought-year flows for 2001 are also shown for comparison.

We estimate that intensive sampling in 2014 coincided with arrival time in the estuary of 88% of yearling Chinook and 93% of steelhead passing Bonneville Dam (tagged and non-tagged), as well as 99% of the yearling Chinook and 97% of steelhead transported for NMFS transportation studies. These numbers were similar to 2013 when we estimated that 81% of yearling Chinook and 89% of steelhead that passed Bonneville Dam arrived in the estuary during intensive sampling, along with 99% of transported yearling Chinook and 95% of transported steelhead.

In 2014 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 salmon. Transportation continued until the end of October.

After we reverted to a single daily crew, 47% of fish detected passing through the estuary were subyearling Chinook salmon. This proportion was much lower than in previous years. The change was primarily due to a significant reduction in tagging of subyearling Chinook in 2013 and 2014. While subyearlings were still the most abundant species detected after our intensive sampling period, yearling Chinook salmon, coho salmon, and steelhead were also present. Subyearling life history strategies include migration during summer and fall, and a portion of these fish overwinter in freshwater and complete their juvenile migration the following spring.

We sampled with the matrix trawl system for 925 h during 2014 and detected 15,904 PIT-tagged fish. By comparison, in 2013 we sampled for 889 h and detected 22,879 fish (Figure 4). A similar number of PIT-tagged fish were released during the spring migration in both years, but average detection rates were lower in 2014 (17 h^{-1}) than in 2013 (26 fish h^{-1}). Through years of sampling we have observed an inverse relationship between river flow volumes and trawl detection rates. Increased river flow volume has been consistently associated with decreased trawl detection rates of fish previously detected at Bonneville Dam. Detection of fish previously detected at Bonneville provides a rough measure of sample efficiency (Morris et al. 2013). In 2012, a high flow year, detection rates were comparable to those in 2014 (18 fish h^{-1}).

A variety of factors contribute to the relationship between higher river flows and lower detection rates. First, high flows carry fish downstream faster than low flows. This decreases the amount of time that a given fish is present in the sample reach and available for detection. Second, higher flows likely disperse migrants across a larger cross-sectional area of water. For any given fish present in the estuary during sampling, we expect that increased dispersion would decrease its likelihood of entering the trawl.

Higher flows also decrease actual sample time in three ways. First, high flows increase the transit time required for vessels to reach the upstream end of the sample reach, where the trawl is initially deployed. Second, high flows decrease the time available for sampling with the trawl deployed because vessels drift more quickly to the downstream end of the sample reach, where the trawl must be retrieved. Finally, higher flows are typically accompanied by more debris accumulation in the trawl net. The larger fish-passage corridor of the matrix antenna mitigates this problem somewhat by allowing most debris to pass through, but some sample time is still lost to debris removal effort.

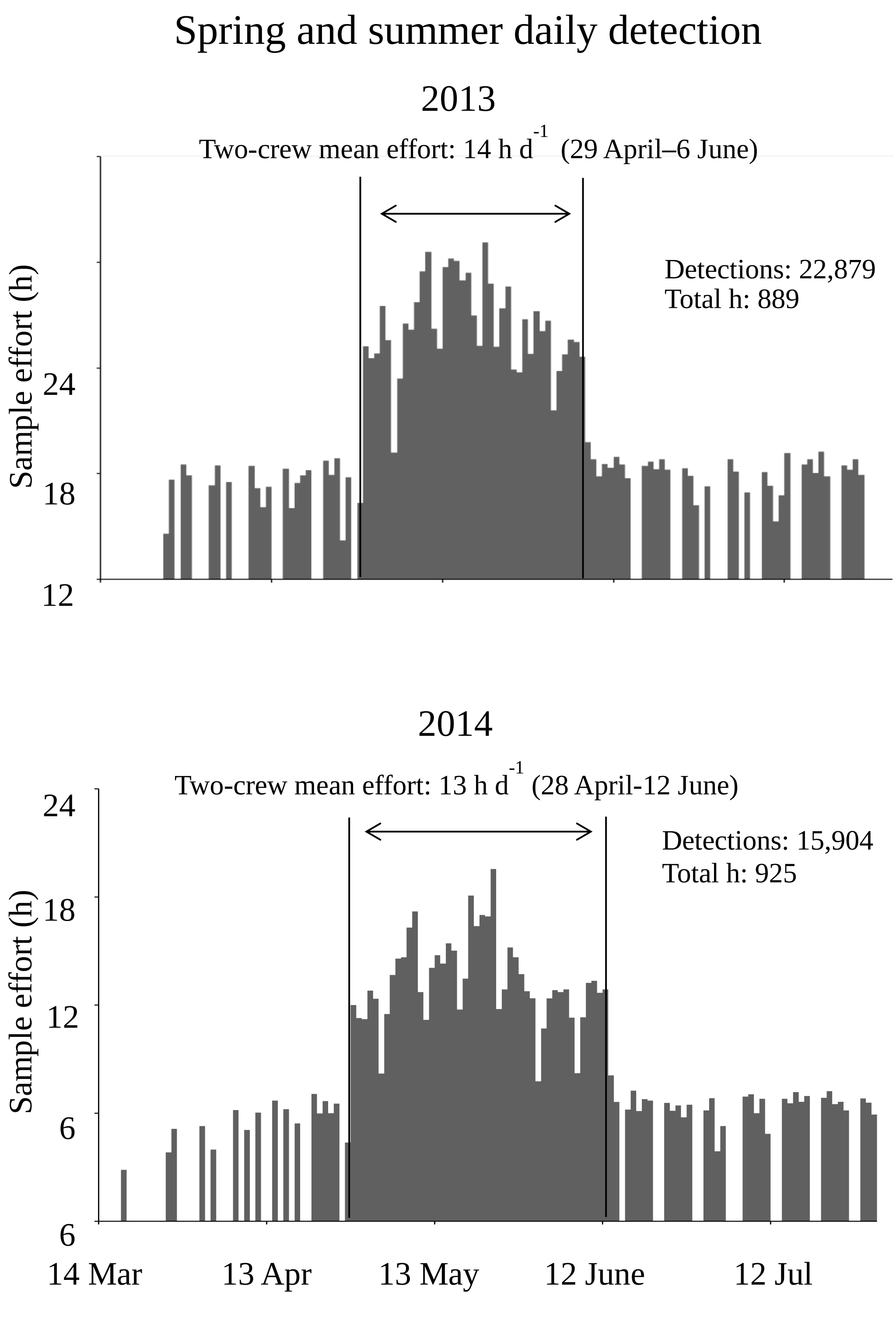

Figure 4. Daily sample effort in spring/summer 2013 and 2014 using a pair-trawl fitted with a "matrix" antenna for PIT-tag detection. Sampling was conducted in tidal fresh-water near Jones Beach between rkm 61 and 83.

Antenna Performance

Estimated detection efficiencies from pre-season testing were positively correlated with spacing between test tags, regardless of tag orientation. Of the 336 PIT-tags passed through the matrix antenna, no test-tags spaced 30 cm apart were detected. This was the closest spacing interval tested. When spacing between tags was increased to 60 cm, detection efficiency increased to 89% for tags, regardless of orientation to the electronic field. For test tags spaced 90 cm apart, reading efficiency increased to 98% for angled tags and 100% for perpendicular tags. Results in 2014 were similar to previous years and showed the antenna was performing as expected.

Species Composition

In 2014 we detected a total of 15,186 juvenile salmonids of known species and origin (hatchery and wild) plus another 718 fish lacking release information in PTAGIS (Table 2; Appendix Table 1). For most identified fish, at least some release information was available; however, 273 detected fish had no information associated with their respective tags.

Of detected fish with PIT-tag release information, 42% were spring/summer Chinook, 4% were fall Chinook, 43% were steelhead, 6% were sockeye, and 3% were coho salmon; less than 1% were cutthroat trout, and the remaining 2% were unknown salmonid species. Total detections by origin were 18% wild, 77% hatchery, and 5% unknown origin at the time of this report. These numbers may change slightly as PTAGIS records are completed by entities who released these fish.

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 2014.

	Rear type			
Species/run	Hatchery	Wild	Unknown	Total
Spring/summer Chinook salmon	5,688	947	109	6,744
Fall Chinook salmon*	580	62	42	684
Coho salmon	521	10	14	545
Steelhead	4,695	1,868	202	6,765
Sockeye salmon	766	42	78	886
Sea-run Cutthroat	0	7	0	7
Unknown	0	0	273	273
Grand total	12,250	2,936	718	15,904

* Includes 2 Snake River fall Chinook salmon released in 2013 that had overwintered in freshwater.

Differences in PIT-tagging strategies, hydrosystem operations, and the numbers of fish transported contribute to annual variation in the proportion of each species detected passing through the estuary (Figure 5). However, for all species, the proportions detected in 2014 were similar to proportions detected in recent years.

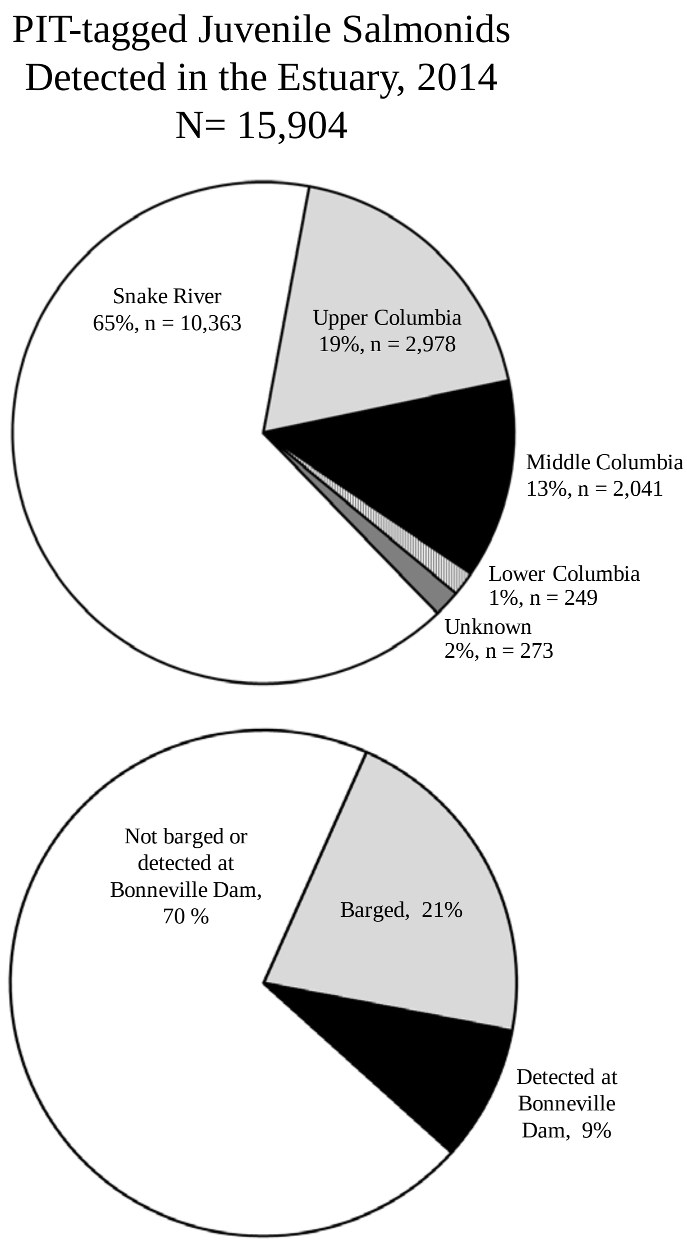

Figure 5. Proportions of fish detected in the trawl by source and migration history, 2014. Upper and mid-Columbia River sources were defined relative to McNary Dam. Fish that originated in the Columbia River below Bonneville Dam could not be transported, nor could they pass Bonneville Dam.

A proportion of juvenile fall Chinook salmon begin downstream migration from late spring to fall but suspend migration to overwinter in freshwater and resume migration the following spring. These fish are said to adopt a “reservoir-type” life-history strategy (Connor et al. 2005). We detected two “reservoir-type” Snake River fall Chinook juvenile in the upper estuary (5 and 8 May 2014). According to release information in PTAGIS, both were released during 2013 on the Clearwater River (rkm 803), a tributary to the Snake River. We likely detected less of this life-history type in 2014 than previous years because of the sharp decline in subyearling tagging in 2013.

Using detection histories, we were able to narrow the overwintering location for one of the reservoir-type fish. The subyearling Chinook detected at the trawl on 5 May was released on 27 June 2013 and detected at Little Goose Dam on 7 April 2014. Thus we were able to determine that this fish overwintered somewhere between its release location and Little Goose Dam. The subyearling detected on 8 May had been released on 20 June 2013 but was not detected again until the following year in the trawl. This detection history verified that the fish had a reservoir-type life history strategy, but did not allow us to narrow down its overwintering location. Detections in 2014 and prior years contribute important information toward a better understanding of the life history diversity of Snake River fall Chinook salmon.

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 2014, we recovered 248 such salmonids from the matrix antenna system and trawl (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 eliminated 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, which has 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).

Analyses from Trawl Detection Data

Estimated Survival

Methods

Survival probabilities were estimated from PIT-tag detection data using a multiple-recapture model for single release groups (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 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 calculating 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 2014, 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. 2014). 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 among subyearling Chinook salmon precludes the use of single-release survival estimates.

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 Dams (Table 3). We compared weighted annual survival estimates for the years 1999-2014 for both Snake and Columbia River stocks (Figure 6). In some years, there were insufficient detections of some species for comparison between basins.

Table 3. 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, 2014. 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	John Day to Bonneville Dam	McNary to Bonneville Dam
	Snake River wild and hatchery pooled groups			
Yearling Chinook				
20 Apr-26 Apr	2,830	0.783 (0.057)	0.728 (0.293)	0.570 (0.226)
27 Apr-03 May	8,451	0.860 (0.049)	0.617 (0.127)	0.530 (0.105)
04 May-10 May	11,607	0.924 (0.053)	0.977 (0.200)	0.903 (0.177)
11 May-17 May	16,039	1.074 (0.087)	0.918 (0.189)	0.986 (0.187)
18 May-24 May	3,906	1.378 (0.256)	0.292 (0.086)	0.402 (0.092)
25 May-31 May	860	0.880 (0.181)	0.448 (0.280)	0.394 (0.233)
Weighted mean		0.912 (0.053)	0.752 (0.104)	0.715 (0.107)
Steelhead				
20 Apr-26 Apr	1,003	1.266 (0.280)	0.986 (0.692)	1.248 (0.831)
27 Apr-03 May	3,982	1.030 (0.106)	1.106 (0.347)	1.139 (0.337)
04 May-10 May	3,469	1.321 (0.186)	0.590 (0.184)	0.779 (0.216)
11 May-17 May	2,490	0.823 (0.146)	1.542 (0.784)	1.269 (0.605)
18 May-24 May	847	0.810 (0.225)	1.297 (0.936)	1.051 (0.700)
25 May-31 May	572	1.206 (0.446)	0.993 (1.010)	1.198 (1.135)
Weighted mean		1.082 (0.080)	0.983 (0.147)	1.023 (0.088)
Sockeye				0.817 (0.115)
	Upper Columbia River wild and hatchery pooled groups			
Yearling Chinook				
Above Yakima R	113,114	0.939 (0.038)	0.990 (0.110)	0.929 (0.100)
Yakima River	76,731	0.900 (0.051)	0.828 (0.189)	0.745 (0.166)
Steelhead	75,578	0.899 (0.061)	1.082 (0.124)	0.972 (0.108)
Sockeye				0.565 (0.269)

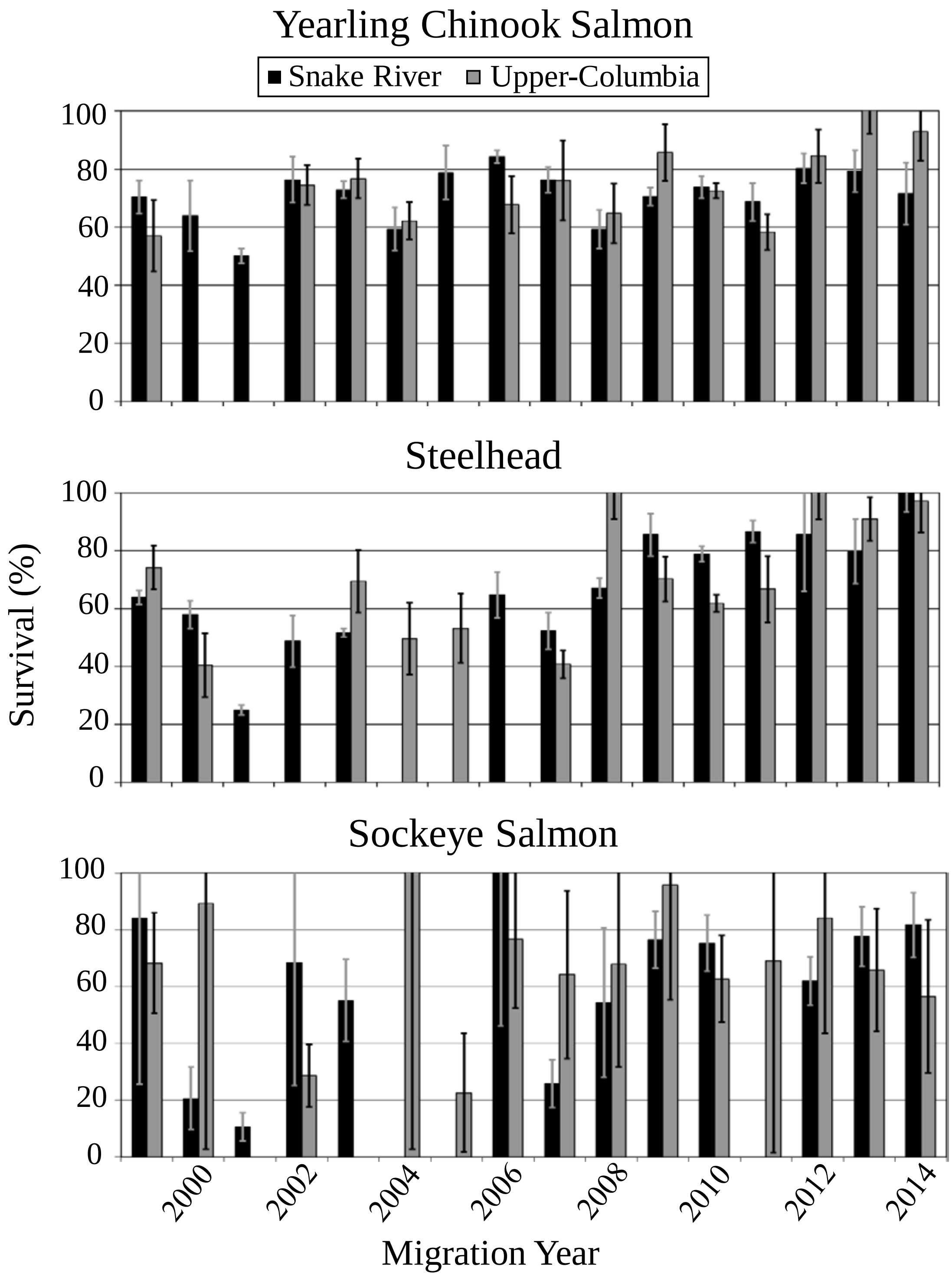

Figure 6. Weighted average annual survival and SE from the tailrace of McNary Dam to the tailrace of Bonneville Dam, for Snake and Columbia River yearling Chinook salmon, steelhead, and sockeye, 1999-2014.

For Snake River **yearling Chinook salmon**, estimated survival from McNary to Bonneville Dam tailrace was 71.5% in 2014; survival over this reach fish 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 92.9% in 2014 and has ranged from 102.5% in 2013 to 57.0% in 1999. For yearling Chinook originating in the Yakima River and its tributaries, estimated survival was 74.5% in 2014 and has 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 the highest on record in 2014, at 102.8%. 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 97.5% in 2014 and has ranged from 107.7% in 2008 to 40.5% in 2000. No estimate was possible for upper Columbia River steelhead in 2001, 2002, and 2006.

In 2014, estimated survival for Snake River **sockeye** salmon from McNary to Bonneville Dam tailrace was 81.7%. Historically, estimated survival of these fish has ranged from 10.5% in 2001 to 111.3% in 2006. For upper Columbia River sockeye salmon, survival through this same reach was estimated at 56.5% in 2014 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. (2014).

In 2014, seasonal average estimated survival through the entire hydropower system, from Lower Granite to Bonneville Dam tailrace, was 54.9% for yearling Chinook salmon and 75.7% for steelhead (Table 4). In 2013, overall hydrosystem survival estimates were 62.2% for yearling Chinook salmon and 51.5% for steelhead. Estimates for the same reach for sockeye salmon were 71.3% and 53.6% in 2014 and 2013, 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. 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. Higher survival for inriver juvenile migrants may be associated with higher flow volumes and faster transit times, although flow often varies widely within a single year, and seasonal average estimates of downstream survival do not reflect this variation.

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

Table 4. 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, 1998-2014.

	Estimated seasonal average survival from Lower Granite to Bonneville Dam					
Migration	Yearling Chinook		Steelhead		Sockeye	
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	6.8	--	--	--	--
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	61.9	5.7	51.5	7.5	53.6	6.6
2014	54.9	8.3	75.7	6.9	71.3	11.0

[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.

Flow volumes at Bonneville Dam in 2014 were high throughout the season, peaking at 31% above the 10-year average. Flow levels fell below average in mid-June but returned to average by late June and remained near average until sampling concluded. Numbers of PIT-tag detections at Bonneville Dam were lower in 2014 than to 2013, a year when flows were below average for the majority of the spring migration season. Bonneville detection numbers in 2014 were similar to those in 2011 and 2012, even though basin wide tagging was significantly lower in 2014 compared to those years. For example, in 2014 about 78,000 PIT-tag detections were recorded at Bonneville Dam from releases of 1.9 million tagged fish, while in 2013 there were 91,000 detections at Bonneville from releases of 2.3 million tagged fish.

In 2014, estimated survival from the tailrace of Lower Granite Dam to the tailrace of Bonneville Dam for yearling Chinook was near the long-term average for this reach (since 1998). However, for steelhead in this reach, survival was the highest estimated to date. According to Faulkner et al. (2014), estimates of survival through the entire hydropower system for yearling Chinook have remained relatively stable since 1999, with the exception of 2001 and 2004. Estimates for steelhead have been relatively stable since 2009, but were much higher in 2014.

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.

The ability to estimate survival for sockeye salmon is dependent 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 salmon. 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 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 (Faulkner et al. 2014).

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 and just prior to ocean entry. 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 expected passage periods through the estuary of primarily 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) did not occur during our sample season. 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 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 tag codes that indicated the fish was pre-designated for transport, but there was no record of detection on a transport raceway. These fish may have been misdirected at the SbyC gate or removed for 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 2014 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 survival to the estuary was compared between fish released from transport barges and fish 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 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 of daily group travel-time distributions. 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 travel speed to Jones Beach between inriver migrants and transported fish. Daily median travel speeds (km d^{-1}) were calculated based on the distance traveled from barge release or dam 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}).

Results and Discussion

Yearling Chinook salmon and steelhead—Seasonal median travel time (d) from Lower Granite Dam (rkm 695) to detection in the trawl at rkm 75 is presented for yearling Chinook salmon and steelhead (Table 5).

For yearling Chinook salmon detected during the intensive sampling period (28 April to 12 June), median travel time from Lower Granite Dam to the estuary was slower in 2014 (16.4 d) than in 2013 (14.1 d). However, travel speed in 2013 was the fastest on record for yearling Chinook in this reach. Median travel time for steelhead through the same reach was also slower in 2014 (12.3 d) than in 2013 (11.6 d), but was the third most rapid seasonal median since 2000. Thus, travel times from Lower Granite Dam to the estuary in 2013 were near the 10-year average for yearling Chinook (16.3 d) and among the fastest on record for steelhead.

Median travel time to the estuary from Bonneville Dam was the same in 2014 as in 2013 for yearling Chinook and steelhead (1.6 d). For transported yearling Chinook salmon, median travel time from just below Bonneville Dam to the estuary was slightly faster in 2014 than in 2013 (median 2.1 vs. 2.2 d). For transported steelhead, median travel time was also faster in 2014 than in 2013 (1.5 vs. 1.6 d).

We also compared daily differences in travel speed to the estuary relative to changing river flow volume between transported and inriver migrating fish (Figure 7). Overall, seasonal mean travel speed to the estuary was significantly slower for yearling Chinook salmon released from barges (72 km d^{-1}) than for those traveling inriver and detected at Bonneville Dam (95 km d^{-1}; $P \leq 0.001$). Mean travel speed was also significantly slower for steelhead released from barges (95 km d^{-1}) than for those detected at Bonneville Dam (103 km d^{-1}; $P \leq 0.001$) on the same day. These differences in travel speed by migration history, particularly for yearling Chinook salmon, were similar to observations from previous years.

Table 5. 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, 2000-2014. 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) to rkm 75				Detection at Bonneville Dam (rkm 234) to rkm 75				Release from transportation barge (rkm 225) to rkm 75				
	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
2011[a]	17.8	335	15.5	348	1.8	240	1.6	216	2.1	673	1.6	831	7,911
2011[b]	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

[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.

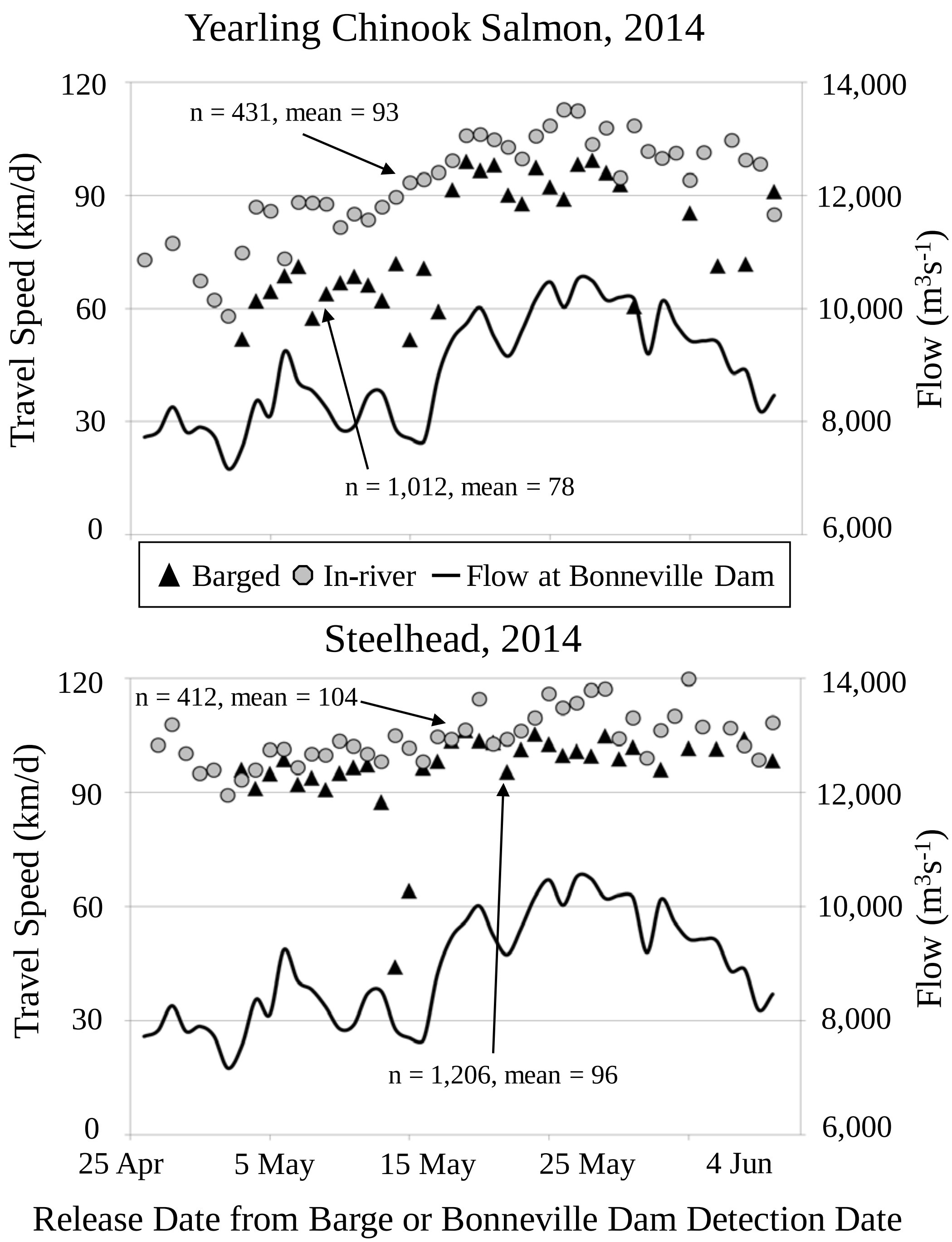

Figure 7. Daily median travel speed to the estuary of yearling Chinook salmon (top) and steelhead (bottom) following detection at Bonneville Dam or release from a barge to detection in the estuary (rkm 75), 2014. Seasonal means of daily medians are shown for comparison with flow.

Subyearling fall Chinook salmon—We detected 344 subyearling fall Chinook salmon, all of which had been released after 29 April 2014, all of these subyearlings were less than 125 mm FL at tagging. Most fall Chinook salmon released prior to 30 April were yearlings and were greater than 125 mm FL when tagged. We detected 20 transported and 324 inriver migrant subyearling fall Chinook between late April and late July (Figure 8). Of all subyearlings detected by the trawl system, 38% originated in the Snake River, 15% in the Upper Columbia River (at or upstream from McNary Dam), and 49% in the mid-Columbia River (between Bonneville and McNary Dam). No subyearlings from the Lower Columbia River (downstream from Bonneville Dam) were detected. Due to a large subyearling tagging study in the Snake River that ended in 2012, these proportions have shifted from predominately Snake River origin to a more dispersed distribution of release sites.

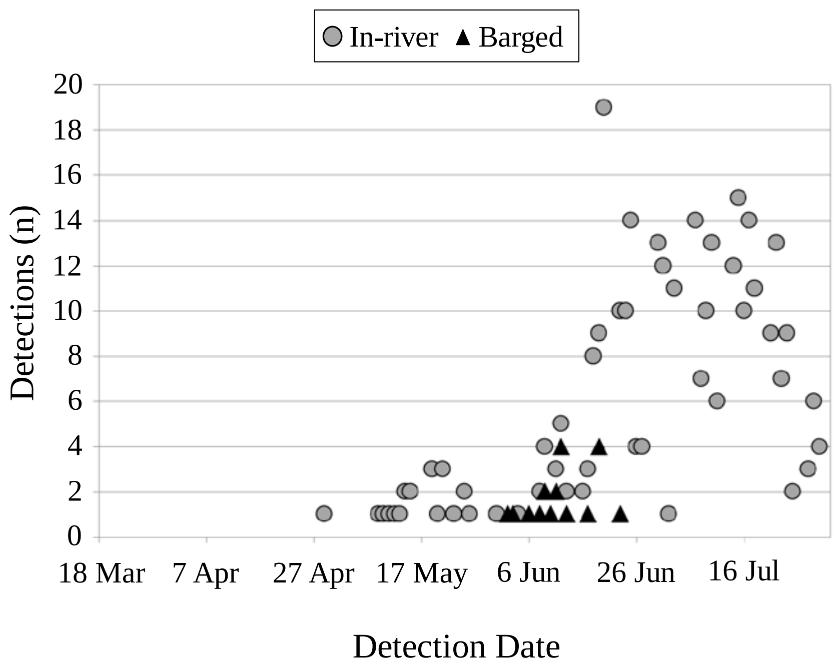

Figure 8. Temporal distribution for subyearling Chinook salmon detected in the estuary after being detected as inriver migrants at Bonneville Dam (n = 324) or after being released from barges below the dam (n = 20), 2014.

In prior years we have compared daily median travel speed to the estuary for subyearling fall Chinook salmon detected at Bonneville Dam (inriver migrants) with transported fish released just downstream from Bonneville Dam. In 2014, a meaningful comparison could not be made due to lack of trawl detections for both groups (22 inriver and 20 transported fish). This drop in detection numbers was due to a decrease in tagging of subyearling Chinook in the Snake River basin (over 610,000 released in 2012 and only

65,000 in 2014). Analysis in prior years has consistently shown significantly faster travel speeds for subyearling fall Chinook detected at Bonneville than for those released from transport barges (Morris et al. 2013).

Sockeye Salmon—We detected 886 sockeye salmon between 14 May and 14 June (Figure 9). Of these, 86% were hatchery fish, 5% were wild fish, and the remaining 9% were of unknown origin. Transported fish accounted for 318 of the 886 sockeye detections. Of those transported, 181 had been transported from Lower Granite Dam, 44 from Little Goose Dam, and 93 from Lower Monumental Dam. Fish released in the Snake River Basin made up 91% of our sockeye detections, while fish released in the Columbia River Basin upstream from McNary Dam made up 9%. Of the 568 inriver migrant sockeye we detected, 66 had been previously detected at Bonneville Dam. Mean travel speed from Bonneville Dam to detection in the trawl was significantly slower for transported fish released below Bonneville (107 km d^{-1}) than for fish detected at Bonneville Dam (113 km d^{-1}; $P \leq 0.005$; Figure 10).

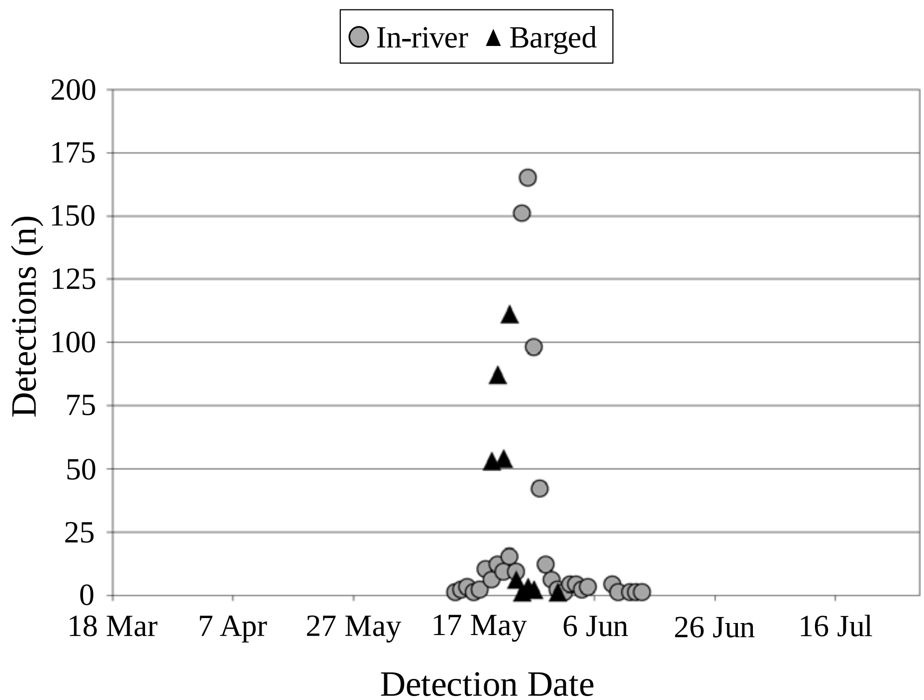

Figure 9. Temporal distribution of sockeye salmon detections in the estuary during inriver migration (n = 568, gray circles) or following release from barges below Bonneville Dam (n = 318, black triangles), 2014.

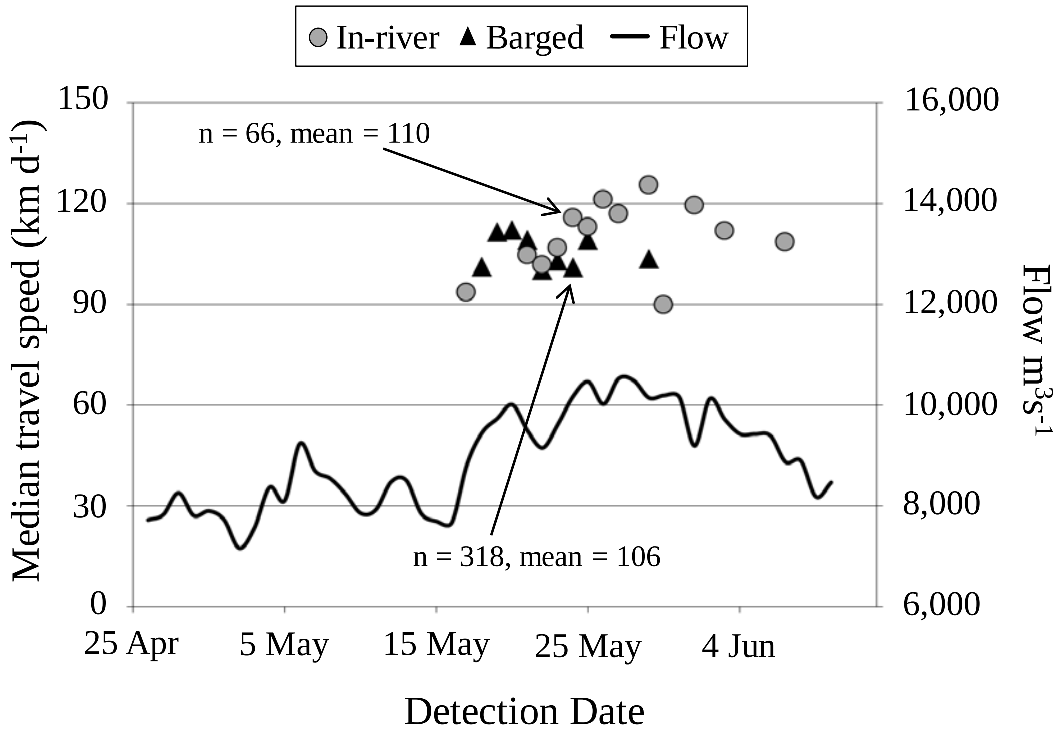

Figure 10. Daily median travel speed to the estuary for transported vs. inriver migrant sockeye salmon following detection at Bonneville Dam or release from a barge to detection in the estuary (rkm 75), 2014. Daily river flow volume at Bonneville Dam is shown for comparison.

In summary, travel speed for all migration histories and species of juvenile salmonids from the area of Bonneville Dam to the estuary was similar to that of previous years with moderate-to-high flows. Travel speed from Lower Granite Dam to the estuary was similar to previous years for yearling Chinook; however, it was among the fastest on record for steelhead. While faster travel speeds have been correlated with higher flow volumes in the past, faster speed for steelhead in 2014 was likely a combination of high flow and increased use of surface bypass structures during lower flow periods (Faulkner et al. 2014).

Diel Detection Patterns

Methods

As in previous years, we found that wild and hatchery fish (as designated in PTAGIS) had similar trends in diel availability. Detection numbers during daylight and darkness (2030-0430 PDT) hours were compared using a one-sample *t*-test (Zar 1999) on the daily ratios of detection numbers per hour (note: test was computed using natural log transformation to improve normality assumption, 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 during the intensive sampling period. Daily daylight/darkness detections for each species were weighted by the number of minutes that the detection system was operating during that date. For this analysis, we excluded dates when sample effort was reduced, i.e., missed or partially missed shifts. Detections of yearling Chinook salmon and steelhead were sufficient to complete this analysis; detections of sockeye and subyearling Chinook salmon were not.

Results and Discussion

During the two-shift sample period of 28 April-12 June, we detected 6,711 yearling Chinook salmon and 6,390 steelhead with the detection system operating an average of 13 h d^{-1} (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 during intensive sampling were significantly higher during nighttime than during daytime hours (11 vs. 6 fish h^{-1} or 1.7 times higher; P 0.004). We assumed that the diel difference in hourly detection rates was constant through the season. However, for hatchery yearling Chinook salmon during the first 3 weeks of intensive sampling, average nighttime detection totals were over 4 times higher than average daytime totals. From the third week through the remainder of the season, total nighttime detection numbers were around 1.3 times higher than total daytime numbers (Figure 11). The discrepancy is apparent from Figure 11.

There was no measurable difference between daytime and nighttime hours in terms of hourly detection rates for wild yearling Chinook salmon (1 vs. 1 fish h^{-1}, $P = 0.589$). Hourly detections rates were significantly higher during daylight than darkness hours for both hatchery and wild steelhead (10 vs. 3 hatchery fish h^{-1}, or 3 times higher, $P < 0.001$ and 4 vs. 1 wild fish h^{-1}, $P < 0.001$).

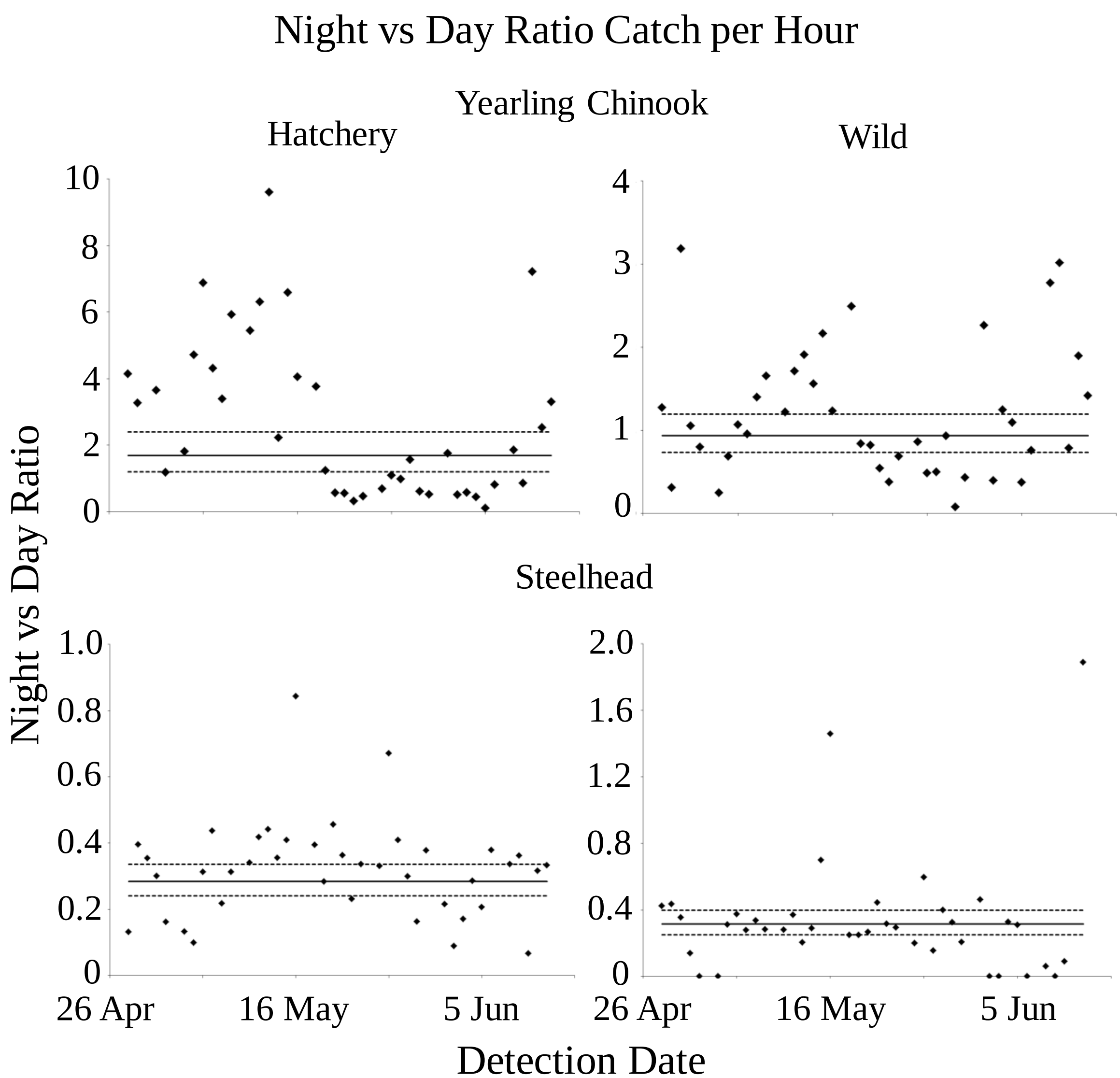

Figure 11. Daily nighttime-to-daytime detection ratios for wild and hatchery yearling Chinook and steelhead (28 April to 12 June). Daily ratios greater than 1.0 indicate a higher catch per hour in darkness hours, and values less than 1.0 indicate a higher catch per hour in daylight hours. Solid lines are estimated mean ratios, and dotted lines are estimated 95% confidence intervals. (Note that data were log-transformed for the estimation.)

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 2014, so we pooled data by species and origin for a multi-year summary (Figure 12). Detection rates for yearling Chinook salmon have typically been higher, and often significantly higher, during darkness than daytime hours. Detection rates of steelhead have generally been higher during daylight hours, but often not significantly higher.

Detection numbers in 2014 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. The larger fish-passage opening of the matrix antenna system and its location near the surface probably resulted in less gear avoidance than in earlier years using smaller antennas, 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 2014, steelhead made up 43% of total pair-trawl detections. We likely missed detections of steelhead during late-afternoon fueling, crew-change, and maintenance periods. However, recurring late-afternoon periods of difficult weather and high wind would have interfered with sampling during these hours, even had we refueled at other times. Similarly, sampling at both dusk and dawn was made possible by extending the evening shift overnight until relieved by the day shift, and this strategy probably maximized detection of yearling Chinook salmon.

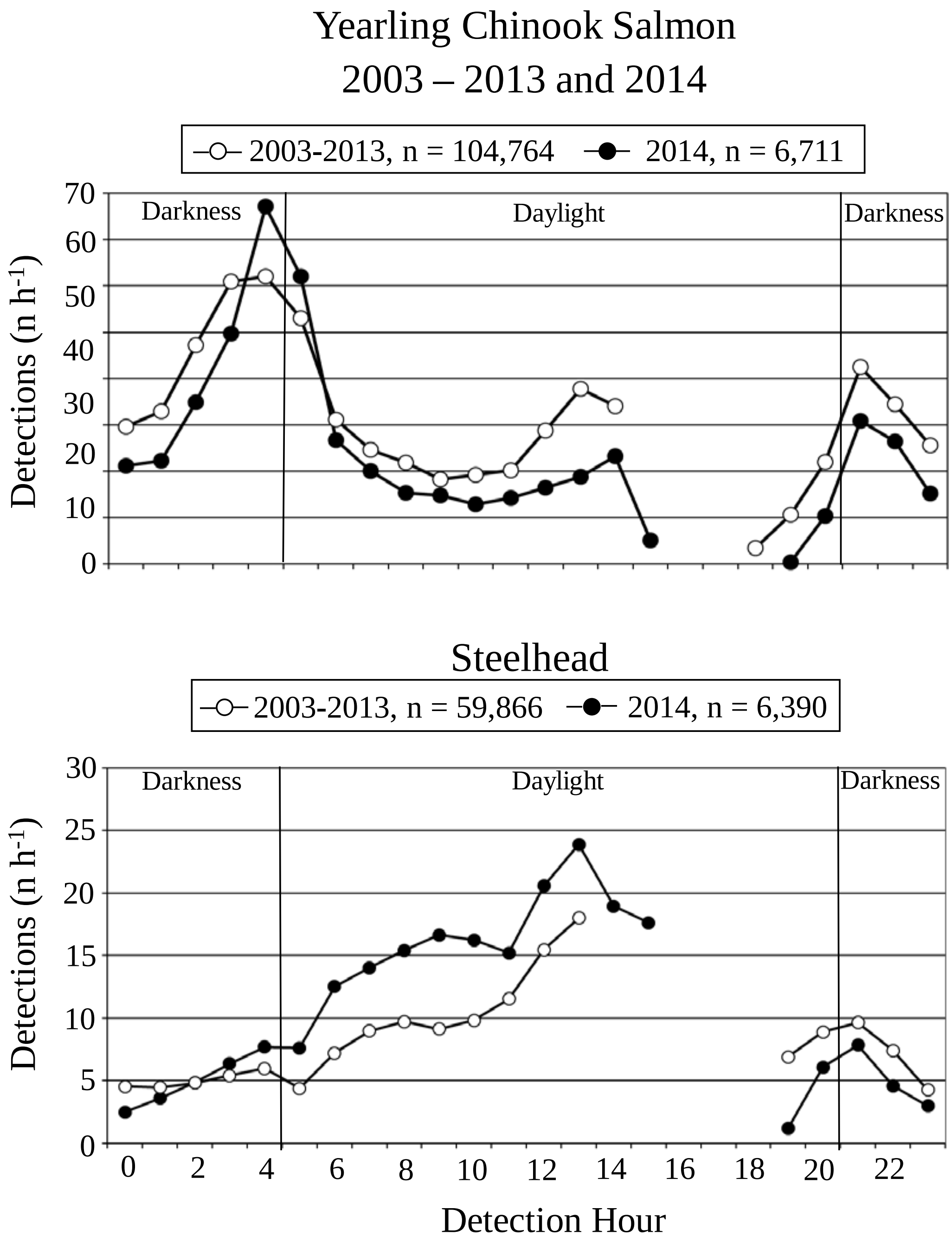

Figure 12. Average hourly detection rates of yearling Chinook salmon and steelhead during the two-shift sampling periods of 2003 through 2013, vs. 2014, using the matrix antenna system in the upper estuary near river kilometer 75.

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.

Estuarine 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 fish released from a barge on the same day. Study groups 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 treatment 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. Overdispersion was the "difference" between the expected and 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

Including river-run fish diverted to barges and fish tagged and transported for other studies, a total of 75,149 yearling Chinook salmon and 60,112 steelhead were transported and released upstream from our sample site during the intensive sample period. Of these fish, we detected 1,115 yearling Chinook salmon and 1,855 steelhead in the upper estuary (Appendix Tables 4-5). Of yearling Chinook released upstream from McNary and detected at Bonneville Dam, we detected 431 (1.8%) of 23,554 fish. For steelhead we detected 411 (2.4%) of the 17,326 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 in (28 April-12 June 2014). Allowing 2 d for fish to reach the sample area from Bonneville Dam, we estimate that 94% of inriver migrant yearling Chinook and 93% of inriver migrant steelhead were present near rkm 75 during intensive sampling. We estimated that 99% of transported yearling Chinook and 97% of transported steelhead were at or near rkm 75 during intensive sampling. These percentages were similar to those estimated in 2013 for both migration history groups.

During the intensive sampling period of 2014 we averaged 13 sampling h d^{-1} and in 2013 we averaged 14 h d^{-1}. In 2014 detection rates of both transported fish and fish detected passing Bonneville Dam were lower than in 2013 (Table 6). We believe the lower detection rates of all groups in 2014 were related primarily to higher flow conditions.

Table 6. Trawl detection rates of PIT-tagged fish released from barges or detected passing Bonneville Dam during the intensive sample periods, 2013 and 2014.

	Barged fish originating upstream from McNary Dam			In-river fish detected at Bonneville Dam*		
	Released	Detected		Released	Detected	
	n	n	(%)	n	n	(%)
2013						
Chinook salmon	64,730	1,243	1.92	24,045	649	2.70
Steelhead	60,660	2,228	3.67	19,599	752	3.84
2014						
Chinook salmon	75,149	1,115	1.48	23,554	431	1.83
Steelhead	60,112	1,855	3.09	17,326	411	2.37

* Inriver fish included only those released at or upstream from McNary Dam, although no fish were transported from McNary Dam in 2014.

For yearling Chinook salmon, logistic regression analysis showed a significant interaction between detection rate and date-squared ($P = 0.010$), indicating the date relationship was non-linear on the logistic scale. There was not a significant interaction between detection rate and migration history ($P = 0.154$), nor was there a temporal relationship between migration history and date ($P = 0.340$), or between migration history and date-squared ($P = 0.155$).

Estimated detection rates for inriver and transported migrants increased gradually from around 0.6% early in the season to 2.1% by late May (Figure 13, top panel). After peaking in late May, estimated detection rates decreased gradually to 1.2% by mid-June. The adjustment for over-dispersion was 3.51.

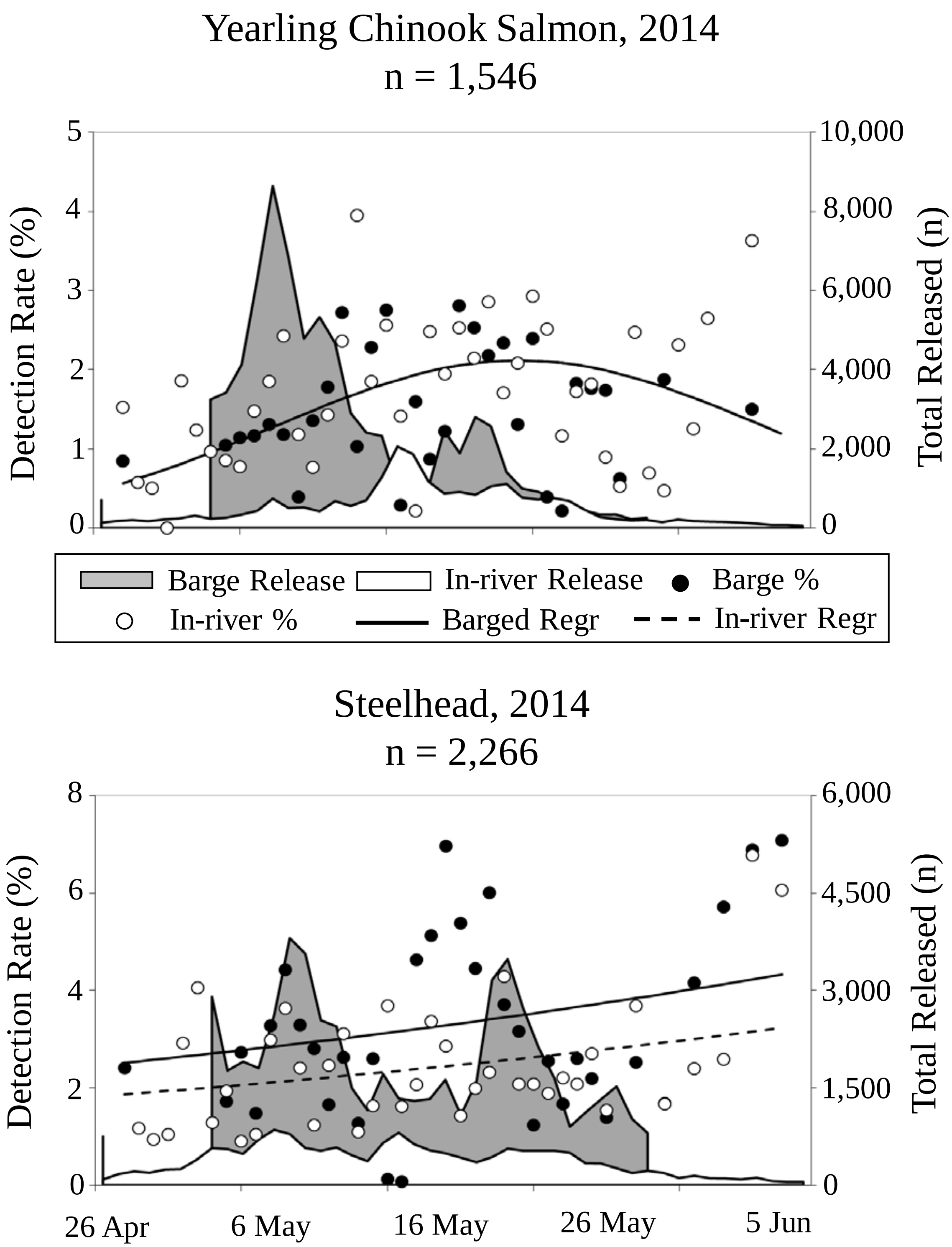

Figure 13. Logistic regression analysis of the daily detection percentage of transported and inriver migrant yearling Chinook salmon and steelhead detected at or released near Bonneville Dam on the same dates, 2014. Yearling Chinook salmon regressions are equal for barged and in-river migration histories.

For steelhead, there was a significant interaction between detection rate and date (P = 0.027) and between detection rate and migration history (P = 0.037). The date relationship was linear on the logistic scale, as date-squared was not significant (P = 0.642). There was not a significant interaction between migration history and date or between migration history and date-squared (P = 0.960 and 0.607, respectively). Estimated detection rates of inriver migrant steelhead increased steadily from 1.9% in late April to 3.3% in mid-June (Figure 13, lower panel). Estimated detection rates for transported steelhead increased from 2.5% in late April to 4.3% in mid-June. The adjustment for over-dispersion was 6.72.

Mean detection rate in the trawl for yearling Chinook salmon was the same for fish previously detected at Bonneville Dam as for transported migrants released below the dam. For steelhead, estimated detection rates were higher for transported fish than for inriver migrants. In years where differences are present, it is possible that the lower detection rates for one group represent higher mortality following release from the barges or following detection at Bonneville Dam. Over the last 10 years there has been a general trend towards higher detection rates of inriver migrating fish (Morris et al. 2014); however, in 2014 yearling Chinook showed no difference between migration histories, and steelhead showed a higher detection rate of transported migrants.

In summary, estuary detection rates were lower in 2014 than in the lower flow year of 2013. Detection rates of fish passing Bonneville Dam were lower in 2014 than last year as well, but were similar to those seen in other high flow years like 2011 and 2012.

Detection rates at Bonneville Dam have decreased over the last 4 years for two reasons. First, fish guidance structures were removed due to high debris loading in 2011. As a result, fish were not guided into the juvenile bypass system, where all of the juvenile PIT-tag monitors are located, except those at the second powerhouse corner collector. Second, in 2012-2014, second powerhouse turbines were operated at middle-1% efficiency; this increased flow to the first powerhouse and spillway, neither of which is equipped with monitors.

Although the middle-1% operation of second powerhouse turbines continued in 2014, higher river flows contributed to a further decrease 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 to the tailrace of Bonneville Dam as well as estimates through the entire hydrosystem.

Development of a Towed Antenna using a Flexible Housing

Background

In 2014, we continued experiments with a flexible antenna system designed to be towed behind smaller vessels. This research was an extension of technology adapted for use as a stationary PIT-tag monitoring system installed along a pile dike at rkm 70 (PTAGIS site code PD7; Magie et al. 2013).

In 2011 and 2012 we used a multiplexing transceiver (MUX; Digital Angel model FS1001M)[1] to power a vertical array of four antennas submerged along the pile dike. This system was primarily intended to target adult salmonids, though some juvenile detection was anticipated. The matrix antenna configuration used at the pile dike initially had limited success. Investigation with cameras showed adult fish avoiding the relatively small antenna openings. These installations were also restricted electronically to a limited distance from the power source (15.2 m; Magie et al. 2013).

In 2013, to reduce antenna avoidance, we experimented with a new multiplexing transceiver system (Biomark model IS1001MTS). The new transceiver allowed us to build an antenna array with an overall area similar to that of our initial four-coil array but with a single undivided fish passage opening (2.4 × 6.1 m). Antenna housing for the new array was built using the same rigid 10.1-cm-diameter PVC pipe used in both the initial pile dike array and in our trawl detection system. We expanded the new system with two additional antennas along the pile dike, and using the improved electronics extended the installation over 115 m from the power source.

Also in 2013, we began experimentation with an alternative antenna housing made of small-diameter (1.9-m) flexible hose. We theorized that a flexible housing would not be as vulnerable to vibration (caused by river current) as the 10.1-cm rigid pipe. We also hoped the flexible hose would conform more readily to the variable configuration of piles at each attachment point. Finally, the flexible housing offered the potential for use with a mobile system.

[1] Reference to trade name does not imply endorsement by the National Marine Fisheries Service, NOAA.

In October 2013, we conducted preliminary testing of the flexible antenna housing in a mobile system. Our prototype array was attached to a rope-frame for added strength (Morris et al. 2014). These tests showed that the flexible array could withstand the stress of towing and that the antenna could tune and read tags. While these initial results were promising, more testing was needed to develop deployment/retrieval logistics, to reduce vibration, and possibly develop a multi-antenna coil configuration.

For tests during 2014, our primary objectives for the towed flexible detection array were:

1. Further streamline the flexible antenna under tow to reduce EMI (electromagnetic interference) from external vibration
2. Secure antenna wires within the flexible housing to reduce EMI from internal vibration
3. Determine maximum tow speed of the antenna before it was overcome by EMI
4. Test the system during the spring migration with adequate PIT-tagged fish present to better judge effectiveness.

Additional goals were to increase the number of antenna coils in the towed flexible array (up to 12 antennas are supported by the IS1001 transceiver) and to eliminate the necessity for towing a pontoon raft behind the system. As with the trawl detection system, we used a pontoon raft with the flexible antenna system in 2013 to provide power and house the transceiver and communication equipment.

Given the higher potential tow speeds of the flexible antenna system, the pontoon raft dragged considerably and was difficult to maintain upright. The IS1001 transceiver provides for a reader to be placed inside the antenna and controlled by a master controller located up to 300 m away, according to the manufacturer. Therefore, we believed it would be feasible to rout the power and communication cable from the antennas up the tow line to a vessel within 120 m. With the IS1001 system, power/communication can also be run sequentially between coils, allowing multiple coils to be operated with a single cable.

Methods

We continued towing tests of the 2.4- by 6.1-m antenna array with housing of 1.9-cm diameter flexible PVC hose. The antenna was towed horizontally with the original cork and lead lines removed to reduce external vibration. We attached the antenna to a small-diameter spectra rope frame for stability. Antenna coils within the flexible housing were encased with heat-shrink material to reduce internal vibration by maintaining coils in a fixed position relative to each other. To provide additional stability, we attached the net frame to 2.4-m spreader bars using extensions to keep the antenna clear of the metal bars. Buoys and lead weights were used on either end of the spreader bars to maintain the array vertically in the water column with the top of the antenna floating just beneath the surface.

Initial testing was conducted on a single-coil design, but in 2014 we began testing a double-coil modular design (Figure 14). A power and communications cable was routed along the net frame from the water-tight enclosure mounted on the antennas to the tow line bridle and along the tow line to a skiff. The transceiver master controller and power source (two 12 volt batteries) were located in the skiff, where we could monitor real-time EMI and detection data.

The entire system was towed using two outboard skiffs (135 HP motors), and a third skiff was used to monitor the antenna configuration and to test system performance at different tow speeds using "stick" fish. While it was difficult to judge speed in strong river currents, we estimated tow speed at approximately 2.6 knots. This estimate was based on the differential between GPS tow speeds of 2,100 RPMs (1.1 knots) and drifting speed of the third skiff (1.5 knots). Skiffs were essentially at idle (drift speed) at 900 RPMs. As a point of reference, our large trawl system tows at about 1.2 knots with the trawl net fully deployed.

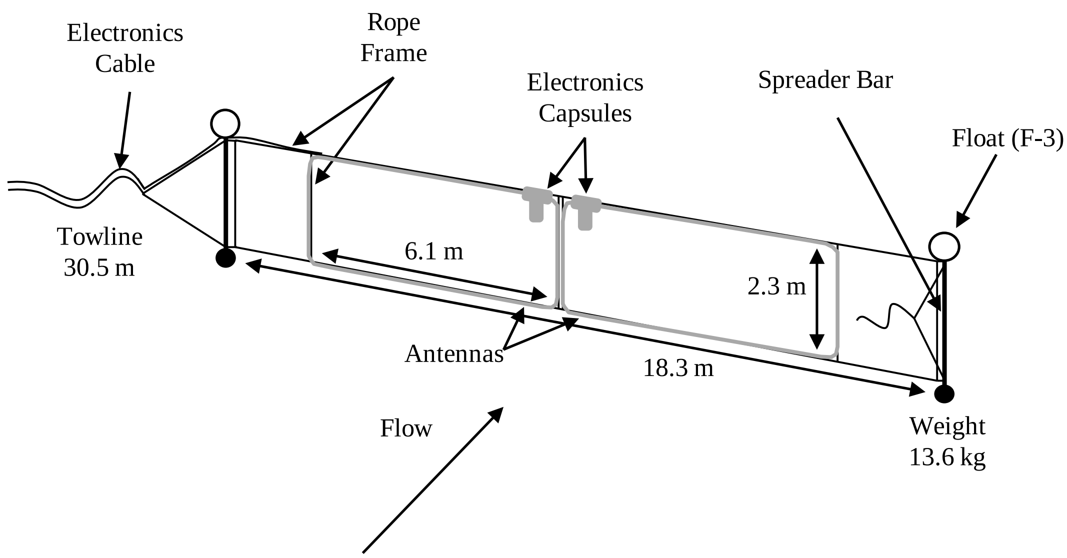

Figure 14. Basic configuration of the rope frame system with two 2.3 by 6.1 m flexible antennas tested in 2014.

Results and Discussion

We tested off-season modifications to the single-coil system on 21-22 May and 4 June. Routing power and communication cables to the tow skiff removed the speed limitations caused by the raft and simplified deployment logistics. Deployment and monitoring were also simplified by having the transceiver and power system in the tow skiff. The net frame and additional weight on bridle pipes improved hydrodynamics of the system, which appeared more stable in the water at all tow speeds.

Keeping bridle pipes nearly vertical in the water column was critical in maintaining vertical position of the antenna. With bridle pipes vertical, the antenna still showed a slight porpoising effect at higher speeds; however, this movement was not nearly as pronounced as it had been in 2013 using large corks and lead line. These changes reduced vibration markedly, and by encasing the antenna wires in heat shrink, we were able to reduce EMI levels at every speed tested (Figure 15).

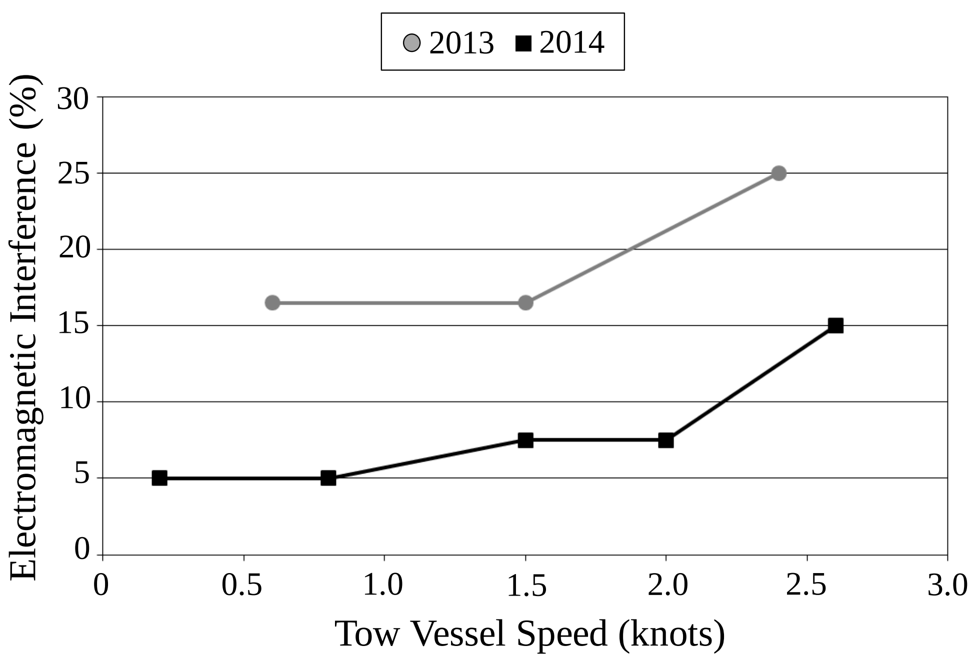

Figure 15. Electromagnetic interference (EMI) levels encountered while towing the flexible antenna array at various speeds during 2013 and 2014.

We were able to verify the speed at which we could detect a tag in the center of the antenna using radio communications between a third skiff and the vessel towing the transceiver (Table 7). To assess read range at different tow speeds in real time, we used a PIT tag attached to a pole that reached an area near the center of the antenna. In 2013, pole tests revealed that the antenna detection field was not overcome by EMI at 1.5 knots. However, at the next rate of speed tested (2.4 knots) the field was attenuated to within about 1 m from the antenna walls, presumably because of vibration. In 2014, we tested additional speeds and found the field slightly reduced in the center of the antenna at 2.0 knots. At 2.6 knots, EMI was high enough to completely attenuate the detection field in the center of the antenna.

Table 7. PIT-tag read range of a flexible antenna as measured in the center of the antenna under tow at various speeds in a pass through orientation.

	Read range (m)	
Speed (knots)	2013	2014
0.6	1.3	--
0.8	--	1.3
1.5	1.3	1.3
2.0	--	0.6
2.4	0	--
2.6	--	0

These deployments were intended to assess system modifications, and we operated the antenna in a functional "sampling" state infrequently during 9 h of testing. Nevertheless, during these deployments, we detected a total of nine juvenile salmonids: four yearling Chinook and one steelhead released to the Snake River; one yearling Chinook, one steelhead, and one sockeye salmon released to the Upper Columbia River; and one coho salmon released to the Lower Columbia River.

After successfully testing a single-coil antenna, we expanded the rope frame to support two flexible antennas towed in tandem. To support both antennas, we connected two rectangular net frames using plastic thimbles and metal shackles. Bridles, spreader bars, tow lines, and detection equipment were attached the same as with a single antenna. However, a single cable was used to connect the first and second antenna. Deployment for the single- and double-coil systems was similar except that to avoid entanglement, we deployed the double-coil system by laying it out on the shoreline and towing from the beach to launch.

We deployed the double-coil array three times between July and August (with very low densities of PIT-tagged fish present) to develop safe deployment logistics and assess antenna functionality. No fish were detected during these two months. Antenna performance was nearly identical to the single antenna deployments. There did not appear to be an electronic interaction between antennas, and vibration seemed to be slightly reduced with additional drag from the second antenna. The second antenna appeared to actually stabilize the system as it was towed through the water.

Test of EMI and read-range also indicated that performance of the double-coil array was similar to that assessed during deployments of the single-coil array. Based on these tests, functionality of the first antenna was not decreased by the addition of a second antenna. Additional antennas can potentially increase stability of the entire system by increasing drag and helping to maintain a more uniform shape. Increased stability should help reduce vibration and increase antenna performance.

Further efforts to reduce vibration are needed in both the system design and for individual antenna coils. Our effort to stabilize coils using heat-shrink appeared to be effective. However, for these coils, further reductions in vibration will be necessary to reduce EMI at faster tow speeds. Testing may identify an optimal point in the tradeoff between tow speed and collection/concentration of fish.

If we can further reduce or eliminate vibration induced by high-speed towing of the flexible antenna, then a multiple coil design could theoretically provide a thalweg sample similar to that obtained with the existing estuary trawl system. A six-coil antenna array configured in two rows of three would sample an 18.3-m swath of water at a depth of 4.9 m (similar to the trawl). However, in contrast to the existing estuary trawl system, a modular, flexible antenna array could be applied over a range of locations. Sampling would be possible along shorelines, across inner channels and small streams, or within the forebay and tailrace of a dam.

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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, 2014.

Date	Time underway (h)	PIT-tag detections (N)						
		Unknown	Chinook salmon	Coho salmon	Steelhead	Sockeye salmon	Cutthroat	Total
18 Mar	2.85	0	1	0	0	0	0	1
19 Mar	0.00	--	--	--	--	--	--	--
20 Mar	0.00	--	--	--	--	--	--	--
21 Mar	0.00	--	--	--	--	--	--	--
22 Mar	0.00	--	--	--	--	--	--	--
23 Mar	0.00	--	--	--	--	--	--	--
24 Mar	0.00	--	--	--	--	--	--	--
25 Mar	0.00	--	--	--	--	--	--	--
26 Mar	3.82	0	1	0	0	0	0	1
27 Mar	5.13	0	0	0	0	0	0	0
28 Mar	0.00	--	--	--	--	--	--	--
29 Mar	0.00	--	--	--	--	--	--	--
30 Mar	0.00	--	--	--	--	--	--	--
31 Mar	0.00	--	--	--	--	--	--	--
1 Apr	5.28	1	0	0	0	0	0	1
2 Apr	0.00	--	--	--	--	--	--	--
3 Apr	3.98	0	0	0	0	0	0	0
4 Apr	0.00	--	--	--	--	--	--	--
5 Apr	0.00	--	--	--	--	--	--	--
6 Apr	0.00	--	--	--	--	--	--	--
7 Apr	6.17	0	0	0	1	0	0	1
8 Apr	0.00	--	--	--	--	--	--	--
9 Apr	5.07	0	0	0	0	0	0	0
10 Apr	0.00	--	--	--	--	--	--	--
11 Apr	6.03	0	1	0	1	0	0	2
12 Apr	0.00	--	--	--	--	--	--	--
13 Apr	0.00	--	--	--	--	--	--	--
14 Apr	6.70	0	0	0	3	0	0	3
15 Apr	0.00	--	--	--	--	--	--	--
16 Apr	6.22	0	1	0	5	0	0	6
17 Apr	0.00	--	--	--	--	--	--	--
18 Apr	5.43	0	0	0	3	0	0	3
19 Apr	0.00	--	--	--	--	--	--	--
20 Apr	0.00	--	--	--	--	--	--	--
21 Apr	7.07	0	0	0	4	0	0	4
22 Apr	5.98	1	0	0	6	0	0	7
23 Apr	6.67	0	2	0	5	0	0	7
24 Apr	6.00	0	4	0	13	0	0	17
25 Apr	6.53	0	4	0	7	0	0	11
26 Apr	0.00	--	--	--	--	--	--	--
27 Apr	4.37	2	10	0	15	0	0	27

Appendix Table 1. Continued.

Date	Time underway (h)	PIT-tag detections (N)						
		Unknown	Chinook salmon	Coho salmon	Steelhead	Sockeye salmon	Cutthroat	Total
28 Apr	12.00	5	22	0	39	0	0	66
29 Apr	11.28	1	28	0	23	0	0	52
30 Apr	11.22	2	22	0	20	0	0	44
1 May	12.80	2	28	0	25	0	0	55
2 May	12.35	4	30	0	52	0	0	86
3 May	8.20	6	23	0	71	0	0	100
4 May	11.50	4	62	0	72	0	0	138
5 May	13.67	11	86	0	145	0	0	242
6 May	14.58	8	104	0	164	0	0	276
7 May	14.65	4	152	2	135	0	0	293
8 May	16.30	6	221	5	263	0	0	495
9 May	17.20	11	316	4	418	0	0	749
10 May	12.72	7	222	5	298	0	0	532
11 May	11.18	2	147	4	260	0	0	413
12 May	14.07	6	259	3	169	0	0	437
13 May	14.77	5	323	9	224	0	0	561
14 May	14.30	4	374	5	121	1	0	505
15 May	15.43	4	283	12	193	2	0	494
16 May	15.02	7	451	11	125	3	0	597
17 May	11.75	7	476	11	113	1	0	608
18 May	13.47	12	154	8	259	2	0	435
19 May	18.08	15	422	13	300	10	1	761
20 May	16.38	13	331	20	306	59	0	729
21 May	17.00	9	312	17	211	99	1	649
22 May	16.92	12	299	33	179	63	0	586
23 May	19.55	11	341	34	407	126	0	919
24 May	11.78	9	177	16	315	15	0	532
25 May	12.87	11	239	33	272	152	0	707
26 May	15.20	13	180	41	195	168	0	597
27 May	14.65	8	149	31	205	100	0	493
28 May	13.72	7	112	42	136	42	0	339
29 May	12.77	2	87	40	132	12	0	273
30 May	12.38	5	62	13	111	6	0	197
31 May	7.77	2	25	4	84	3	0	118
1 Jun	10.70	6	42	9	60	1	0	118
2 Jun	12.37	3	24	11	82	4	0	124
3 Jun	12.83	0	28	7	31	4	1	71
4 Jun	12.72	0	22	13	41	2	0	78
5 Jun	12.87	3	27	14	30	3	1	78
6 Jun	11.30	1	29	10	46	0	0	86
7 Jun	8.22	3	23	5	32	0	0	63
8 Jun	11.32	2	33	5	70	0	0	110
9 Jun	13.23	2	44	12	21	4	1	84
10 Jun	13.35	2	22	4	86	1	0	115
11 Jun	12.68	4	22	6	20	0	0	52
12 Jun	12.87	1	32	7	30	1	0	71
13 Jun	8.10	0	11	2	10	1	1	25
14 Jun	6.62	1	3	2	14	1	0	21
15 Jun	0.00	--	--	--	--	--	--	--
16 Jun	6.20	0	4	1	1	0	1	7

Appendix Table 1. Continued.

Date	Time Underway (h)	PIT-tag Detections (N)						
		Unknown	Chinook Salmon	Coho Salmon	Steelhead	Sockeye Salmon	Cutthroat	Total
17 Jun	7.25	0	5	0	6	0	0	11
18 Jun	6.12	1	10	2	3	0	0	16
19 Jun	6.78	0	20	2	4	0	0	26
20 Jun	6.70	0	22	4	15	0	0	41
21 Jun	0.00	--	--	--	--	--	--	--
22 Jun	0.00	--	--	--	--	--	--	--
23 Jun	6.57	1	12	1	9	0	0	23
24 Jun	6.13	1	13	1	10	0	0	25
25 Jun	6.43	0	16	0	3	0	0	19
26 Jun	5.77	0	5	0	12	0	0	17
27 Jun	6.47	0	7	0	2	0	0	9
28 Jun	0.00	--	--	--	--	--	--	--
29 Jun	0.00	--	--	--	--	--	--	--
30 Jun	6.15	0	29	1	5	0	0	35
1 Jul	6.83	0	22	0	1	0	0	23
2 Jul	3.88	0	4	0	2	0	0	6
3 Jul	5.28	0	17	3	2	0	0	22
4 Jul	0.00	--	--	--	--	--	--	--
5 Jul	0.00	--	--	--	--	--	--	--
6 Jul	0.00	--	--	--	--	--	--	--
7 Jul	6.92	1	39	1	2	0	0	43
8 Jul	7.05	0	35	1	4	0	0	40
9 Jul	6.00	0	20	0	1	0	0	21
10 Jul	6.80	0	32	2	2	0	0	36
11 Jul	4.85	0	24	0	1	0	0	25
12 Jul	0.00	--	--	--	--	--	--	--
13 Jul	0.00	--	--	--	--	--	--	--
14 Jul	6.80	0	25	0	0	0	0	25
15 Jul	6.55	0	35	0	0	0	0	35
16 Jul	7.17	0	24	0	0	0	0	24
17 Jul	6.63	0	28	0	0	0	0	28
18 Jul	6.95	1	17	1	0	0	0	19
19 Jul	0.00	--	--	--	--	--	--	--
20 Jul	0.00	--	--	--	--	--	--	--
21 Jul	6.85	0	10	0	1	0	0	11
22 Jul	7.22	1	15	0	1	0	0	17
23 Jul	6.50	0	8	0	0	0	0	8
24 Jul	6.63	0	9	0	0	0	0	9
25 Jul	6.15	0	2	1	0	0	0	3
26 Jul	0.00	--	--	--	--	--	--	--
27 Jul	0.00	--	--	--	--	--	--	--
28 Jul	6.82	0	3	0	0	0	0	3
29 Jul	6.58	0	7	1	0	0	0	8
30 Jul	5.92	0	4	0	0	0	0	4
Total	924.96	273	7,428	545	6,765	886	7	15,904

Appendix Table 2. Combined daily total of impinged or injured fish on the matrix antenna system used in the upper Columbia River estuary, 2014. .

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

Appendix Table 2. Continued.

Date	Yearling Chinook	Subyearling Chinook	Coho	Steelhead	Sockeye	Chum	Date	Yearling Chinook	Subyearling Chinook	Coho	Steelhead	Sockeye	Chum
22 May	0	0	0	0	0	0	23 Jun	0	0	0	0	0	0
23 May	2	0	2	2	4	0	24 Jun	0	0	0	0	0	0
24 May	1	0	0	0	0	0	25 Jun	0	0	0	0	0	0
25 May	0	0	0	0	0	0	26 Jun	0	0	0	0	0	0
26 May	0	0	0	0	0	0	27 Jun	0	2	0	0	0	0
27 May	4	0	1	0	3	0	28 Jun	--	--	--	--	--	--
28 May	2	0	1	0	2	0	29 Jun	--	--	--	--	--	--
29 May	4	0	0	0	2	0	30 Jun	0	0	0	0	0	0
30 May	3	0	3	1	3	0	1 Jul	0	0	0	0	0	0
31 May	1	0	0	0	0	0	2 Jul	0	0	0	0	0	0
1 Jun	1	0	0	0	0	0	3 Jul	0	4	0	0	0	0
2 Jun	2	0	0	0	0	0	4 Jul	--	--	--	--	--	--
3 Jun	5	0	2	1	4	0	5 Jul	--	--	--	--	--	--
4 Jun	2	0	0	0	1	0	6 Jul	--	--	--	--	--	--
5 Jun	3	2	2	0	5	0	7 Jul	0	4	0	0	0	0
6 Jun	4	0	0	0	0	0	8 Jul	0	9	0	0	0	0
7 Jun	0	0	0	0	0	0	9 Jul	0	4	0	0	0	0
8 Jun	0	3	0	0	0	0	10 Jul	0	0	0	0	0	0
9 Jun	0	2	0	0	0	0	11 Jul	0	0	0	0	0	0
10 Jun	0	7	0	0	0	0	12 Jul	--	--	--	--	--	--
11 Jun	0	6	1	1	0	0	13 Jul	--	--	--	--	--	--
12 Jun	0	3	0	0	0	0	14 Jul	0	0	0	0	0	0
13 Jun	0	4	0	0	0	0	15 Jul	0	0	0	0	0	0
14 Jun	0	0	0	0	0	0	16 Jul	0	0	0	0	0	0
15 Jun	--	--	--	--	--	--	17 Jul	0	0	0	0	0	0
16 Jun	0	0	0	0	0	0	18 Jul	0	0	0	0	0	0
17 Jun	0	0	0	0	0	0	19 Jul	--	--	--	--	--	--
18 Jun	0	0	0	0	0	0	20 Jul	--	--	--	--	--	--
19 Jun	0	0	0	0	0	0	21 Jul	0	0	0	0	0	0
20 Jun	0	0	0	0	0	0	22 Jul	0	0	0	0	0	0
21 Jun	--	--	--	--	--	--	23 Jul	0	0	0	0	0	0
24-Jul	0	0	0	0	0	0	28-Jul	0	1	0	0	0	0
25-Jul	0	0	0	0	0	0	29-Jul	0	0	0	0	0	0
26-Jul	--	--	--	--	--	--	30-Jul	0	0	0	0	0	0
27-Jul	--	--	--	--	--	--	**Total**	**104**	**51**	**35**	**25**	**24**	**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), 2014. The intensive sampling period (28 April-12 June) was rounded to the nearest tenth and presented as a decimal hour.

		Yearling Chinook salmon				Steelhead			
Diel	Effort	n		n/h		n		n/h	
hour	(h)	Hatchery	Wild	Hatchery	Wild	Hatchery	Wild	Hatchery	Wild
0	40.0	378	46	9.45	1.15	75	24	1.88	0.60
1	40.0	408	38	10.21	0.95	109	34	2.73	0.85
2	25.5	403	41	15.83	1.61	90	33	3.54	1.30
3	16.1	366	34	22.76	2.11	75	27	4.66	1.68
4	9.6	345	26	35.88	2.70	47	27	4.89	2.81
5	12.4	355	28	28.74	2.27	64	30	5.18	2.43
6	34.5	394	66	11.44	1.92	272	159	7.90	4.62
7	45.5	348	107	7.65	2.35	381	257	8.38	5.65
8	45.5	286	63	6.29	1.38	487	214	10.70	4.70
9	45.0	280	53	6.22	1.18	499	250	11.08	5.55
10	46.0	237	57	5.15	1.24	518	228	11.26	4.96
11	41.4	236	57	5.70	1.38	479	151	11.57	3.65
12	25.6	166	44	6.49	1.72	414	112	16.19	4.38
13	13.4	109	17	8.15	1.27	265	54	19.83	4.04
14	7.0	69	12	9.90	1.72	102	30	14.64	4.31
15	2.4	3	3	1.26	1.26	38	4	15.94	1.68
16	0.0	--	--	--	--	--	--	--	--
17	0.0	--	--	--	--	--	--	--	--
18	0.0	--	--	--	--	--	--	--	--
19	6.8	1	0	0.15	0.00	5	3	0.74	0.44
20	35.8	131	55	3.66	1.54	173	44	4.83	1.23
21	40.0	522	96	13.05	2.40	242	72	6.05	1.80
22	40.0	468	60	11.70	1.50	139	44	3.48	1.10
23	40.0	280	23	7.00	0.58	85	34	2.13	0.85
Total	612.2	5,785	926			4,559	1,831		

Appendix Table 4. Number of PIT-tagged yearling Chinook salmon loaded for transport at dams and numbers detected in the estuary. Transport dates were 26 Apr-17 Aug; trawl operation 18 Mar-30 Jul, intensive sampling 28 Apr-12 Jun 2014. 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	(%)
26 Apr 14 8:55 PM	709	0	0	709	0.85	--	--	6	0.85
3 May 10:20 PM	1,676	1,197	372	3,245	1.25	0.50	1.88	34	1.05
4 May 8:35 PM	1,536	1,019	868	3,423	1.24	0.79	1.38	39	1.14
5 May 8:40 PM	1,805	1,357	966	4,128	1.39	1.25	0.62	48	1.16
6 May 8:50 PM	3,383	1,663	1,238	6,284	0.98	1.62	1.78	82	1.30
7 May 8:10 PM	5,713	1,844	1,083	8,640	1.07	1.41	1.39	102	1.18
8 May 8:00 PM	3,661	1,739	1,451	6,851	0.33	0.46	0.48	27	0.39
9 May 6:40 PM	2,601	1,515	669	4,785	1.31	1.85	0.45	65	1.36
10 May 9:00 PM	2,192	1,813	1,325	5,330	1.46	1.99	2.04	95	1.78
11 May 8:20 PM	1946	2,104	622	4,672	2.36	2.99	2.89	127	2.72
12 May 6:50 PM	,929	1,565	412	2,906	1.18	1.02	0.73	30	1.03
13 May 6:00 PM	880	1,208	323	2,411	1.93	2.15	3.72	55	2.28
15 May 2:35 AM	1,155	932	236	2,323	2.34	3.11	3.39	64	2.76
15 May 11:00 PM	554	400	92	1,046	0.18	0.50	0.00	3	0.29
16 May 9:15 PM	591	401	74	1,066	2.20	1.00	0.00	17	1.59
17 May 7:40 PM	400	302	335	1,037	1.50	0.99	0.00	9	0.87
18 May 8:25 PM	824	667	969	2,460	0.49	1.35	1.75	30	1.22
19 May 6:20 PM	720	691	478	1,889	1.25	3.18	4.60	53	2.81
20 May 7:20 PM	1,240	819	744	2,803	1.53	1.83	4.97	71	2.53
21 May 8:45 PM	1,313	488	769	2,570	1.37	2.87	3.12	56	2.18
22 May 8:05 PM	651	423	338	1,412	1.84	2.84	2.66	33	2.34
23 May 7:05 PM	516	268	212	996	1.36	1.49	0.94	13	1.31
24 May 6:55 PM	536	240	143	919	1.87	3.33	2.80	22	2.39
25 May 7:45 PM	487	164	110	761	0.21	0.61	0.91	3	0.39
26 May 8:25 PM	149	206	112	467	0.00	0.00	0.89	1	0.21
27 May 7:35 PM	117	230	91	438	0.85	2.17	2.20	8	1.83
28 May 7:10 PM	97	168	75	340	0.00	2.98	1.33	6	1.76
29 May 7:50 PM	167	128	50	345	0.60	1.56	6.00	6	1.74

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	(%)
30 May 7:15 PM	102	73	46	221	0.00	1.37	2.17	2	0.90
31 May 7:30 PM	165	78	16	259	0.00	1.28	0.00	1	0.39
2 Jun 7:05 PM	89	29	23	141	0.00	0.00	0.00	0	0.00
4 Jun 8:05 PM	33	25	14	72	3.03	4.00	14.29	4	5.56
6 Jun 7:05 PM	39	27	20	86	2.56	0.00	0.00	1	1.16
8 Jun 8:30 PM	47	7	7	61	2.13	0.00	0.00	1	1.64
10 Jun 7:15 PM	35	11	7	53	2.86	0.00	0.00	1	1.89
12 Jun 7:30 PM	27	6	14	47	0.00	0.00	0.00	0	0.00
14 Jun 7:50 PM	14	6	4	24	0.00	0.00	0.00	0	0.00
16 Jun 7:30 PM	19	23	5	47	0.00	0.00	0.00	0	0.00
18 Jun 8:20 PM	14	19	3	36	0.00	0.00	0.00	0	0.00
20 Jun 7:40 PM	20	35	2	57	0.00	0.00	0.00	0	0.00
22 Jun 7:45 PM	11	6	2	19	0.00	0.00	0.00	0	0.00
24 Jun 7:05 PM	14	6	1	21	0.00	0.00	0.00	0	0.00
26 Jun 7:15 PM	23	1	2	26	0.00	0.00	0.00	0	0.00
28 Jun 7:00 PM	23	12	0	35	0.00	8.33	--	1	2.86
30 Jun 7:40 PM	8	21	4	33	0.00	0.00	0.00	0	0.00
2 Jul 7:55 PM	12	16	8	36	0.00	0.00	0.00	0	0.00
4 Jul 7:30 PM	11	7	0	18	0.00	0.00	--	0	0.00
6 Jul 7:10 PM	6	6	1	13	0.00	0.00	0.00	0	0.00
8 Jul 6:45 PM	7	7	6	20	0.00	0.00	0.00	0	0.00
10 Jul 6:00 PM	5	6	1	12	0.00	0.00	0.00	0	0.00
12 Jul 7:05 PM	2	2	1	5	0.00	0.00	0.00	0	0.00
14 Jul 5:40 PM	0	2	3	5	0.00	0.00	0.00	0	0.00
16 Jul 5:25 PM	2	9	1	12	0.00	0.00	0.00	0	0.00
18 Jul 7:30 PM	1	4	1	6	0.00	0.00	0.00	0	0.00
20 Jul 6:00 PM	2	4	0	6	0.00	0.00	--	0	0.00
22 Jul 6:55 PM	2	0	0	2	0.00	--	--	0	0.00
24 Jul 6:35 PM	1	1	0	2	0.00	0.00	--	0	0.00
28 Jul 7:40 PM	1	0	0	1	0.00	--	--	0	0.00
30 Jul 8:20 PM	1	0	0	1	0.00	--	--	0	0.00
Totals/means	37,284	24,000	14,349	75,633	1.88	2.15	1.56	1,116	1.48

Appendix Table 5. Number of PIT-tagged steelhead loaded for transport at dams and numbers detected in the estuary. Transport dates 27 Apr-17 Aug; trawl operation 18 Mar-30 Jul, with intensive sampling 28 Apr-12 Jun 2014. Season totals are shown.

Release date and time	Numbers loaded by dam (n)			Total fish loaded (n)	Detections by transport dam (%)			Total trawl detections	
	Lower Granite	Little Goose	Lower Monumental		Lower Granite	Little Goose	Lower Monumental	n	(%)
26 Apr 8:55 PM	749	0	0	749	2.40	--	--	18	2.40
3 May 10:20 PM	1,528	910	465	2,903	0.92	2.20	3.44	50	1.72
4 May 8:35 PM	874	541	348	1,763	2.86	2.40	2.87	48	2.72
5 May 8:40 PM	857	664	383	1,904	1.63	1.36	1.31	28	1.47
6 May 8:50 PM	528	896	378	1,802	3.60	2.90	3.70	59	3.27
7 May 8:10 PM	1,593	547	480	2,620	4.33	4.75	4.38	116	4.43
8 May 8:00 PM	2,203	1,091	511	3,805	3.90	2.47	2.35	125	3.29
9 May 6:40 PM	2,132	1,066	367	3,565	2.53	3.19	3.27	100	2.81
10 May 9:00 PM	1,157	790	592	2,539	1.21	1.52	2.70	42	1.65
11 May 8:20 PM	1,684	491	270	2,445	2.20	3.05	4.44	64	2.62
12 May 6:50 PM	623	635	233	1,491	0.64	2.05	0.86	19	1.27
13 May 6:00 PM	379	509	265	1,153	2.64	2.36	3.02	30	2.60
15 May 2:35 AM	1,043	403	264	1,710	0.19	0.00	0.00	2	0.12
15 May 11:00 PM	1,006	236	92	1,334	0.10	0.00	0.00	1	0.07
16 May 9:15 PM	1,012	165	121	1,298	5.24	1.21	4.13	60	4.62
17 May 7:40 PM	975	134	217	1,326	4.62	8.96	5.07	68	5.13
18 May 8:25 PM	1,257	230	136	1,623	6.76	7.39	8.09	113	6.96
19 May 6:20 PM	464	496	117	1,077	5.17	5.24	6.84	58	5.39
20 May 7:20 PM	906	400	291	1,597	5.52	4.00	1.72	71	4.45
21 May 8:45 PM	2,030	796	334	3,160	6.45	5.28	5.09	190	6.01
22 May 8:05 PM	2,498	475	507	3,480	4.16	3.16	1.97	129	3.71
23 May 7:05 PM	2,157	251	315	2,723	3.29	3.59	1.90	86	3.16
24 May 6:55 PM	1,614	307	192	2,113	1.18	1.30	1.56	26	1.23
25 May 7:45 PM	1086	406	159	1,651	2.67	1.97	3.14	42	2.54
26 May 8:25 PM	376	311	213	900	1.86	1.61	1.41	15	1.67
27 May 7:35 PM	431	421	265	1,117	2.55	2.38	3.02	29	2.60
28 May 7:10 PM	506	499	317	1,322	1.98	2.40	2.21	29	2.19
29 May 7:50 PM	1,031	324	165	1,520	1.65	1.23	0.00	21	1.38

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	(%)
30 May 7:15 PM	650	237	133	1,020	0.62	1.27	0.00	7	0.69
31 May 7:30 PM	559	146	96	801	4.65	4.79	6.25	39	4.87
2 Jun 7:05 PM	655	179	118	952	1.22	2.79	2.54	16	1.68
4 Jun 8:05 PM	503	116	78	697	4.97	3.45	0.00	29	4.16
6 Jun 7:05 PM	655	113	72	840	5.95	5.31	4.17	48	5.71
8 Jun 8:30 PM	752	78	56	886	7.05	3.85	8.93	61	6.88
10 Jun 7:15 PM	112	76	38	226	8.93	6.58	2.63	16	7.08
12 Jun 7:30 PM	510	46	38	594	1.76	0.00	0.00	9	1.52
14 Jun 7:50 PM	352	26	12	390	0.28	0.00	0.00	1	0.26
16 Jun 7:30 PM	181	32	16	229	0.00	3.13	0.00	1	0.44
18 Jun 8:20 PM	32	41	15	88	9.38	9.76	20.00	10	11.36
20 Jun 7:40 PM	35	45	4	84	0.00	0.00	0.00	0	0.00
22 Jun 7:45 PM	14	14	2	30	14.29	14.29	0.00	4	13.33
24 Jun 7:05 PM	21	14	4	39	9.52	0.00	25.00	3	7.69
26 Jun 7:15 PM	26	17	3	46	0.00	0.00	0.00	0	0.00
28 Jun 7:00 PM	17	16	5	38	0.00	12.50	0.00	2	5.26
30 Jun 7:40 PM	13	10	3	26	0.00	10.00	0.00	1	3.85
2 Jul 7:55 PM	6	10	4	20	0.00	0.00	0.00	0	0.00
4 Jul 7:30 PM	5	2	5	12	0.00	0.00	0.00	0	0.00
6 Jul 7:10 PM	3	9	1	13	33.33	22.22	0.00	3	23.08
8 Jul 6:45 PM	3	4	0	7	0.00	0.00	--	0	0.00
10 Jul 6:00 PM	3	0	2	5	0.00	--	0.00	0	0.00
12 Jul 7:05 PM	1	1	1	3	0.00	0.00	0.00	0	0.00
14 Jul 5:40 PM	0	1	0	1	--	0.00	--	0	0.00
16 Jul 5:25 PM	0	1	1	2	--	0.00	0.00	0	0.00
24 Jul 6:35 PM	0	1	1	2	--	0.00	0.00	0	0.00
28 Jul 7:40 PM	0	0	1	1	--	--	0.00	0	0.00
30 Jul 8:20 PM	0	1	0	1	--	0.00	--	0	0.00
Totals/means	37,807	15,230	8,706	61,743	3.19	2.85	2.86	1,889	3.06

Appendix Table 6. Trawl system detections of PIT-tagged juvenile Chinook salmon and steelhead previously detected at Bonneville Dam, 2014.

	Tag Detections					
Date detected at	Bonneville Dam (n)		Jones Beach (n)		Bonneville and Jones Beach (%)	
Bonneville	Chinook	Steelhead	Chinook	Steelhead	Chinook	steelhead
18 Mar	4	0	0	0	0.00	--
19 Mar	5	2	0	0	0.00	0.00
20 Mar	4	1	0	0	0.00	0.00
21 Mar	4	3	0	0	0.00	0.00
22 Mar	7	1	0	0	0.00	0.00
23 Mar	5	0	0	0	0.00	--
24 Mar	4	2	0	0	0.00	0.00
25 Mar	7	2	0	0	0.00	0.00
26 Mar	8	1	0	0	0.00	0.00
27 Mar	3	2	0	0	0.00	0.00
28 Mar	2	2	0	0	0.00	0.00
29 Mar	4	4	0	0	0.00	0.00
30 Mar	5	7	0	0	0.00	0.00
31 Mar	8	0	0	0	0.00	--
1 Apr	10	1	0	0	0.00	0.00
2 Apr	3	1	0	0	0.00	0.00
3 Apr	6	0	0	0	0.00	--
4 Apr	5	6	0	0	0.00	0.00
5 Apr	6	8	0	0	0.00	0.00
6 Apr	11	5	0	0	0.00	0.00
7 Apr	19	3	0	0	0.00	0.00
8 Apr	16	7	0	0	0.00	0.00
9 Apr	14	8	0	0	0.00	0.00
10 Apr	19	10	0	0	0.00	0.00
11 Apr	19	3	0	0	0.00	0.00
12 Apr	468	15	1	0	0.21	0.00
13 Apr	77	14	0	0	0.00	0.00
14 Apr	32	26	0	0	0.00	0.00
15 Apr	40	34	0	0	0.00	0.00
16 Apr	44	19	0	0	0.00	0.00
17 Apr	46	25	0	0	0.00	0.00
18 Apr	146	30	1	1	0.68	3.33
19 Apr	322	44	3	0	0.93	0.00
20 Apr	354	58	4	1	1.13	1.72
21 Apr	300	50	3	1	1.00	2.00
22 Apr	261	78	3	1	1.15	1.28
23 Apr	228	31	2	0	0.88	0.00
24 Apr	467	64	3	0	0.64	0.00
25 Apr	506	79	6	0	1.19	0.00
26 Apr	487	102	8	0	1.64	0.00
27 Apr	458	181	2	3	0.44	1.66
28 Apr	585	215	4	2	0.68	0.93
29 Apr	416	205	2	2	0.48	0.98
30 Apr	658	298	8	8	1.22	2.68
1 May	514	294	7	11	1.36	3.74
2 May	606	489	5	9	0.83	1.84

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
3 May	507	721	6	14	1.18	1.94
4 May	528	713	3	10	0.57	1.40
5 May	581	619	10	9	1.72	1.45
6 May	778	911	11	23	1.41	2.52
7 May	1,472	1,190	29	41	1.97	3.45
8 May	1,108	1,146	12	26	1.08	2.27
9 May	895	799	6	11	0.67	1.38
10 May	708	704	13	19	1.84	2.70
11 May	866	754	21	22	2.42	2.92
12 May	790	604	27	8	3.42	1.32
13 May	858	489	17	6	1.98	1.23
14 May	1,474	782	33	30	2.24	3.84
15 May	2,238	906	31	15	1.39	1.66
16 May	2,007	738	4	15	0.20	2.03
17 May	1,326	644	34	20	2.56	3.11
18 May	951	570	18	17	1.89	2.98
19 May	987	497	24	8	2.43	1.61
20 May	893	428	20	10	2.24	2.34
21 May	1,089	515	29	11	2.66	2.14
22 May	1,152	629	19	27	1.65	4.29
23 May	809	627	17	13	2.10	2.07
24 May	748	639	23	15	3.07	2.35
25 May	785	610	19	13	2.42	2.13
26 May	706	561	9	11	1.27	1.96
27 May	489	416	9	7	1.84	1.68
28 May	297	416	5	10	1.68	2.40
29 May	234	329	2	7	0.85	2.13
30 May	202	234	1	5	0.50	2.14
31 May	217	281	5	13	2.30	4.63
01 Jun	171	248	1	3	0.58	1.21
02 Jun	215	149	2	3	0.93	2.01
03 Jun	178	187	3	7	1.69	3.74
04 Jun	178	139	3	1	1.69	0.72
05 Jun	165	126	4	6	2.42	4.76
06 Jun	159	114	0	1	0.00	0.88
07 Jun	119	149	7	9	5.88	6.04
08 Jun	89	89	4	6	4.49	6.74
09 Jun	92	73	6	3	6.52	4.11
10 Jun	84	87	5	4	5.95	4.60
11 Jun	88	84	2	2	2.27	2.38
12 Jun	122	135	2	1	1.64	0.74
13 Jun	97	131	0	0	0.00	0.00
14 Jun	62	66	0	0	0.00	0.00
15 Jun	95	62	2	4	2.11	6.45
16 Jun	107	35	3	0	2.80	0.00
17 Jun	100	43	5	2	5.00	4.65
18 Jun	129	40	6	1	4.65	2.50

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
19 Jun	97	52	0	0	0.00	0.00
20 Jun	130	54	0	0	0.00	0.00
21 Jun	125	44	0	2	0.00	4.55
22 Jun	157	37	1	3	0.64	8.11
23 Jun	98	24	0	1	0.00	4.17
24 Jun	110	34	0	1	0.00	2.94
25 Jun	97	29	0	0	0.00	0.00
26 Jun	179	32	0	0	0.00	0.00
27 Jun	141	14	0	0	0.00	0.00
28 Jun	153	29	2	0	1.31	0.00
29 Jun	126	18	0	1	0.00	5.56
30 Jun	83	9	0	0	0.00	0.00
01 Jul	75	9	2	1	2.67	11.11
02 Jul	59	13	0	0	0.00	0.00
03 Jul	74	20	0	0	0.00	0.00
04 Jul	109	8	0	0	0.00	0.00
05 Jul	119	10	0	0	0.00	0.00
06 Jul	106	11	0	1	0.00	9.09
07 Jul	149	4	2	1	1.34	25.00
08 Jul	139	8	2	1	1.44	12.50
09 Jul	174	2	0	0	0.00	0.00
10 Jul	213	2	0	0	0.00	0.00
11 Jul	260	4	3	0	1.15	0.00
12 Jul	215	2	2	0	0.93	0.00
13 Jul	175	4	3	0	1.71	0.00
14 Jul	76	6	1	0	1.32	0.00
15 Jul	108	1	1	0	0.93	0.00
16 Jul	108	3	1	0	0.93	0.00
17 Jul	87	1	0	0	0.00	0.00
18 Jul	99	1	2	1	2.02	100.00
19 Jul	100	0	0	0	0.00	--
20 Jul	111	2	2	0	1.80	0.00
21 Jul	62	2	1	0	1.61	0.00
22 Jul	96	3	1	0	1.04	0.00
23 Jul	70	1	0	0	0.00	0.00
24 Jul	79	3	2	0	2.53	0.00
25 Jul	59	1	0	0	0.00	0.00
26 Jul	70	0	1	0	1.43	--
27 Jul	65	0	0	0	0.00	--
28 Jul	61	0	0	0	0.00	--
29 Jul	50	1	0	0	0.00	0.00
30 Jul	48	1	0	0	0.00	0.00
Totals	39,870	23,358	603	541	1.51	2.32