Pair-Trawl Detection of PIT-Tagged Juvenile Salmonids Migrating in the Columbia River Estuary, 2009

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EXECUTIVE SUMMARY

In 2009, we continued a multi-year study using a surface pair trawl in the upper Columbia River estuary (river kilometer 61-83) to sample migrating juvenile Pacific salmonids *Oncorhynchus* spp. tagged with passive integrated transponder (PIT) tags. As in previous years, the cod-end of the trawl was replaced with a PIT-tag detection antenna system. The antenna system used in 2009 was comprised of a three-coil front component and a three-coil rear component for a total of six antennas. Front and rear components were separated by a 1.5-m section of net mesh, and this configuration provided a fish passage opening 2.5 m wide by 3.0 m tall. The antenna system was attached to a 105-m long pair trawl net, which under tow had a 91.5-m opening between the wings. The approximate sample depth was 4.9 m when towed into the river current at about 1.5 knots.

Intermittent sampling with the pair-trawl detection system began on 6 March with a single daily shift targeting yearling Chinook salmon *O. tshawytscha* and steelhead *O. mykiss*. Intensive sampling with two daily shifts began on 1 May and continued through 13 June; during this period, we detected 3.3% of all juvenile salmonids previously detected at Bonneville Dam, a measure of sample efficiency. Sampling with a single crew continued after 13 June through 12 August and targeted subyearling Chinook salmon. We detected 10,843 yearling Chinook salmon, 3,028 subyearling Chinook salmon, 499 coho salmon *O. kisutch*, 7,698 steelhead, and 952 sockeye salmon *O. nerka* in the upper estuary.

The goal of sampling was to provide the required data to calculate reach survival estimates for the entire Federal Columbia River Power System (FCRPS) from Lower Granite Dam on the Snake River to Bonneville Dam, the lowermost dam on the system. These estimates are obtained using the single-release model,which requires detection or recapture of fish downstream from the lowest reach measured. Trawl sampling at the entrance to the estuary is the primary source of data for survival estimates from McNary Dam to reaches downstream. Mean survival rates from the reservoir of Lower Granite to the tailrace at Bonneville Dam for yearling Chinook salmon and steelhead were 56% (SE 2.8%) and 69% (SE 6.2%), respectively. In addition to fish migrating through the FCRPS, over 178,500 PIT-tagged salmonids were transported from collection facilities at Lower Granite, Little Goose, Lower Monumental and McNary Dam, and we detected 4,743 of these fish.

In 2009, we developed and tested a prototype separation-by-code (SbyC) vessel to potentially sample PIT-tagged fish exiting the pair trawl system. Equipment for the SbyC system was installed on the *RV* Electric Barge by personnel based at NOAA Fisheries, Pasco, WA shop. In October 2009, the SbyC vessel was briefly deployed in the lower Snake River, independent of a trawl. During the first deployment 'stick fish' and other

non-animate objects with implanted PIT tags were released into the system to test plumbing, flow, and diversion-gate operations. These initial tests showed the system was effective at separating PIT-tagged from non-PIT-tagged objects.

During a second deployment period, PIT-tagged and untagged yearling Chinook salmon and steelhead were released into the underwater fish-collection chamber. The chamber entrance was occluded with netting to prohibit escape, and fish behavior was observed using underwater cameras mounted within the chamber. Fish generally avoided the zone of suction current leading into the diversion system. However, some fish did enter and move through, and for those fish the SbyC resulted in 100% separation efficiency.

To induce fish to pass more rapidly into the collection chamber, we installed an air bubbler on the collection-tube floor. After this installation, all but 3 of 56 tagged and untagged fish moved completely through the system within 90 seconds. However, because these fish moved through in clumps, separation efficiency for tagged and untagged fish dropped to as low as 50%. Few, if any, impacts to diverted or non-diverted fish (captured exiting the plumbing discharge) were observed. Additional changes in operating protocols and logistics are planned, and we have applied for the appropriate permits to test the device behind the pair-trawl detection system in the estuary during 2010.

CONTENTS

INTRODUCTION

In 2009, we continued a multi-year study of survival and migration timing for juvenile Pacific salmon *Oncorhynchus* spp. in the Columbia River estuary (Ledgerwood et al. 2006, 2007; Magie et al. 2008). This study was funded by the Bonneville Power Administration (BPA) and the U.S. Army Corps of Engineers (USACE). Here we report on survival and timing of yearling Chinook salmon and steelhead related to river of origin and migration history, which are specific objectives of the BPA. The BPA objective under this study is a companion to the ongoing BPA study to estimate survival of juvenile salmonids through the entire Federal Columbia River Power System (FCRPS). In addition to estimates of survival through the FCRPS, the BPA survival study also includes estimates of survival through individual reaches of river from the reservoir of Lower Granite Dam on the Snake River to the tailrace of Bonneville Dam on the Columbia River (Faulkner et al. 2007, 2010). Detections of migrating fish implanted with passive integrated transponder (PIT) tags were utilized by both of these BPA studies.

Juvenile salmonids are generally implanted with PIT-tags after being captured in natal streams, hatcheries, or collector dams prior to or during migration (PSMFC 2009). Once tagged, these fish can be interrogated without further handling as they pass through detection antennas during their seaward migration. PIT-tag detection systems are presently located in the bypass systems at dams (Prentice et al. 1990a,b,c), in some natal streams and side-channel areas (Downing, et al.; Achord et al.), and the estuary pair trawl. Tagging and detection data is stored and disseminated with the Columbia Basin PIT tag Information System (PTAGIS), a publicly available regional database. We recorded and uploaded all data collected with the trawl to PTAGIS, including detection times and locations. We downloaded from PTAGIS the associated release and migration information for fish detected with the trawl, including species, origin, and migration history of individual PIT-tagged fish.

Procedures for using PIT-tag detection data to estimate survival and travel time for juvenile salmonids migrating during spring 2009 are described in detail by Faulkner et al. (2010). Briefly, PIT-tag data were automatically uploaded to PTAGIS from interrogation facilities at Lower Granite, Little Goose, Lower Monumental, and Ice Harbor Dams on the Snake River and at McNary, John Day, and Bonneville Dams on the Columbia River. Survival estimates were calculated using a statistical model for tag-recapture data from single-release groups.

To estimate survival from any given point in the FCRPS to Bonneville Dam, the lowermost dam in the FCRPS at river kilometer (rkm) 234, sampling of PIT-tagged fish downstream from the dam is required. In this report we describe the methodology for sampling PIT-tagged fish in the upper estuary between rkm 61 and 83. We interrogated tags using surface pair-trawls fitted with specialized detection equipment in a free-flowing riverine environment (Ledgerwood et al. 2004). These samples provided all the data to estimate reach survival from the tailrace of John Day Dam (rkm 347) to the tailrace of Bonneville Dam and also contributed substantial data required to complete the reach survival estimates from McNary Dam (rkm 470) to Bonneville Dam.

Over 2.3 million PIT-tagged juvenile salmonids were released to migrate in the Snake and Columbia River basins during 2009 (PSMFC 2009). In addition to bypassing fish at dams, fishery managers have the option to transport and release fish downstream from Bonneville Dam. In 2009, over 178,500 PIT-tagged fish were transported. Trawling effort in the estuary provided data to estimate survival probabilities of PIT-tagged fish that migrated through the hydropower system (BPA study) and to compare relative survival and temporal differences in the estuary between transported and in-river migrants previously detected at Bonneville Dam (USACE study).

METHODS

Study Fish

In 2009, we continued to focus trawl sampling on detection of the large groups of PIT-tagged fish migrating through the upper Columbia River estuary (rkm 75) from late April through late June. In addition, we extended sampling into July and August to detect PIT-tagged subyearling fall Chinook salmon released later in the migration season. During the spring and summer migration seasons combined, we targeted approximately 730,000 yearling Chinook salmon, over 630,000 subyearling fall Chinook salmon, and over 400,000 steelhead that had been PIT-tagged and released into the Snake and upper and mid-Columbia Rivers.

Targeted fish had either been allowed to migrate in river to the estuary or had been collected and transported past dams and reservoirs on the Snake and Columbia River. Transported fish were collected from facilities at Lower Granite, Little Goose, Lower Monumental and McNary Dam, loaded to barges for transport, and released downstream from Bonneville Dam. These transport groups included approximately 770,000 PIT-tagged fish released for a transportation study on the Snake River (D. Marsh, NMFS, personal communication) and nearly 196,000 PIT-tagged fish released for a comparative survival study (PSMFC 2009). Fish from other major and minor PIT-tagging studies were detected as well.

In addition to the Snake River transportation study, several other studies in the Columbia River basin released large numbers of spring-migrating, PIT-tagged juvenile salmonids. For analyses, we used detection data from the more numerous PIT-tagged yearling Chinook salmon and steelhead; however, detections of PIT-tagged coho *O kisutch*, sockeye *O. nerka*, and subyearling Chinook salmon were also recorded.

Sample Periods

Daily sampling began in early March and ended in mid-August, a period coincidental with the passage of PIT-tagged yearling Chinook salmon and steelhead from the Snake River transportation study. Beginning on 1 May and extending through 13 June, sampling increased from a single daily sampling shift to two daily shifts for an average of 15 h d^{-1}. Generally, the day shift began before daylight and sampled for 8 to 10 h, and the night shift began in late afternoon and sampled until well after dark or until relieved by the day shift. Intermittent daily sampling with a single daily shift continued from mid-June into mid-August.

Study Sites

We conducted trawl operations at the entrance to the estuary from approximately Eagle Cliff (rkm 83) downstream to the west end of Puget Island (rkm 61; 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 semidiurnal, with roughly 7 h of ebb and 4.5 h of flood. During the spring freshet periods (April-June), little or no flow reversal occurs at the study site during flood tides, particularly during years of medium-to-high river flow. The net was deployed adjacent to a 200-m-wide navigation channel which is maintained at a depth of 14 m.

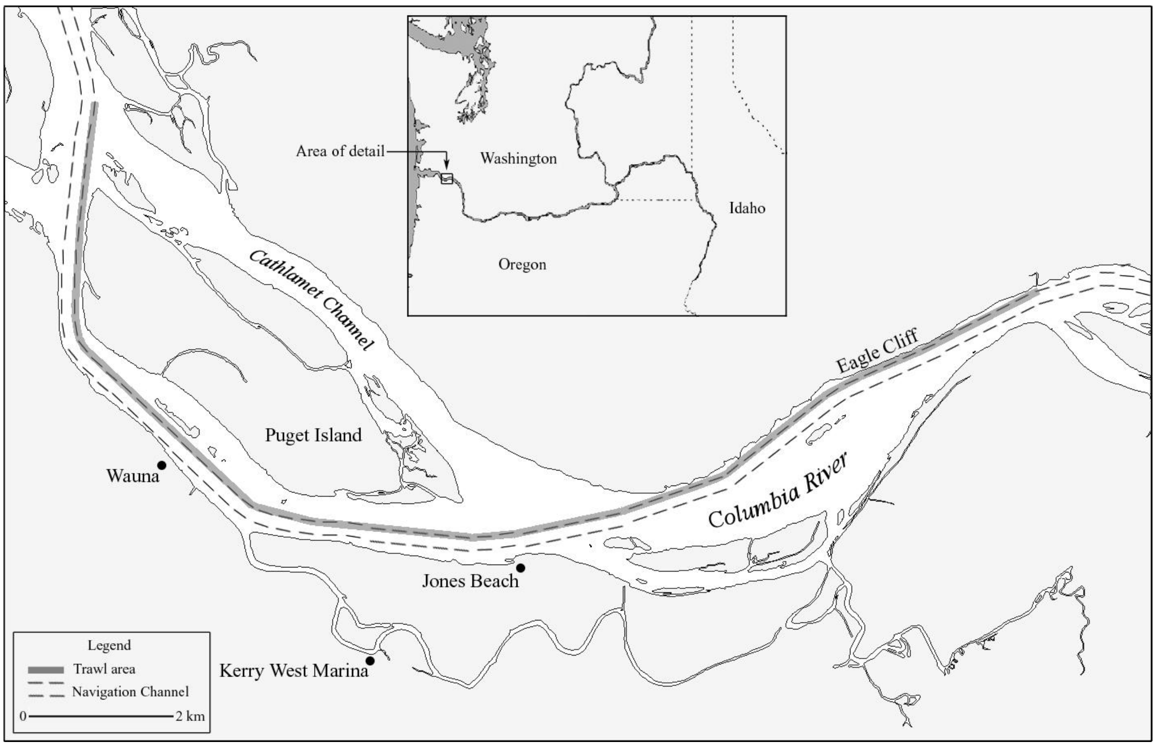


Figure 1. Trawling area adjacent to the ship navigation channel in the upper Columbia River estuary near rkm 75.

Trawls and System Designs

The surface pair trawl components are described below, and the basic configuration has remained fairly constant through the years of study (Ledgerwood et al. 2004; Figure 2). To prevent turbulence on the net from propellers of the tow vessel, long tow lines (73 m) were used. The upstream end of each wing of the trawl initiated with a 3-m-long spreader bar, which was shackled to the wing section. The end of each wing was attached to the 15-m-long trawl body followed by a 2.8-m-long cod end modified for antenna attachment. The mouth of the trawl body opened between the wings and from the surface to a depth of 6 m; a floor extended 9 m forward from the mouth. Under tow, we maintained a distance of 91.5 m between the wings of the trawl, which resulted in an effective sample depth of 4.6 m (measured at the center of the floor lead line). Fish that entered between the wings were guided to the trawl body to exit through the antenna.

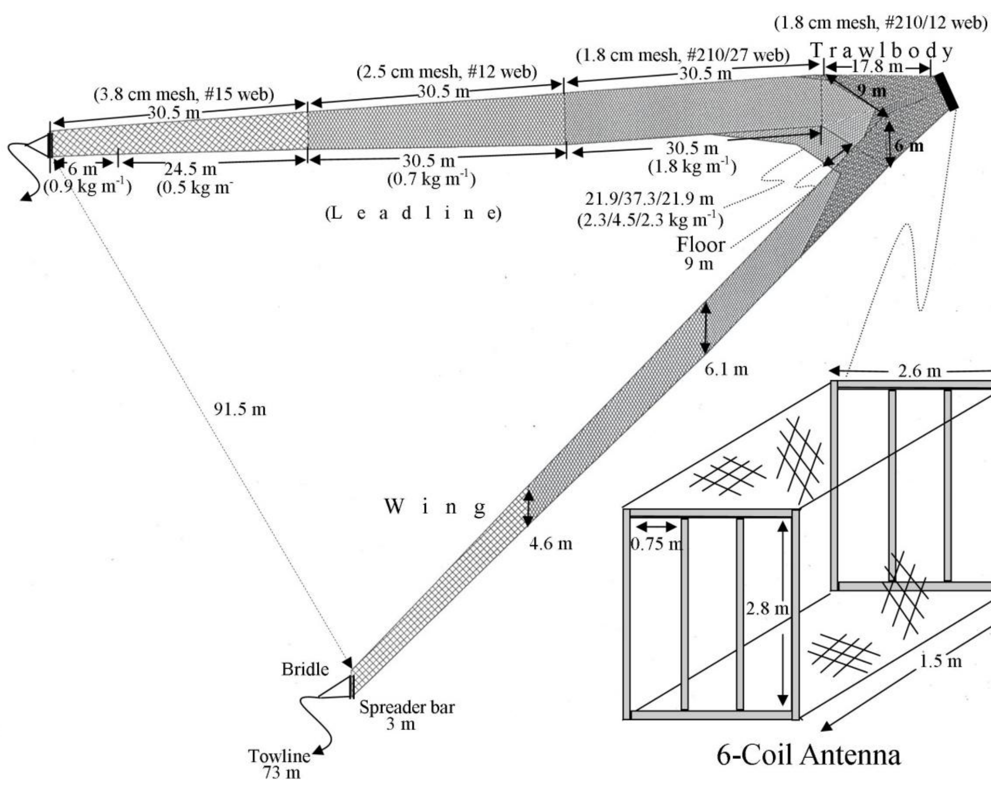


Figure 2. Design of the surface pair trawl and matrix antenna used to sample PIT-tagged juvenile salmonids in the Columbia River estuary (rkm 75), 2009.

The matrix system incorporated a much larger antenna system than did the cylindrical antenna used in previous years. The matrix antenna consisted of two three-coil components (outside dimension of each component was 2.6 × 3.0 m) connected by a 1.5-m-long webbed fish-passage tunnel. Inside dimensions of individual coils measured 0.75 by 2.8 m. Each component of the matrix antenna weighed approximately 114 kg in air and required an additional 114 kg of lead weight to sink in the water column (452 kg total weight in air).

Electronic Equipment and Operation

The matrix antenna system used essentially the same electronic components and procedures as in 2008. These included a Digital Angel[†] model FS1001M multiplex transceiver which provided power to, and decoded data from, all six antennas. The transceiver was encased in a metal box from the manufacturer, and mounted in a secondary instrument box (NEMA-4 rated, 0.8 × 0.5 × 0.3 m). The instrument box also housed a wireless modem, which transmitted PIT-tag detection data and electronic status reports from the transceiver to a computer stationed aboard one of the tow vessels. Two 12-V batteries were provided to power the transceiver and modem. The instrument box and batteries were mounted on a pontoon barge (2.4 × 1.5 m) attached to the trawl near the antenna system.

Data transmitted from the wireless modem to a computer on the tow vessel was recorded to individual fish records using MiniMon, a freeware available from the PTAGIS web site (PSMFC 2009). Each detection record included the GPS position of the computer receiving the data, as well as the date and time of the detection, the tag code of the fish, and the coil identification number of the antenna that made the detection. For each sampling cruise, written and electronic logs were maintained noting the time and duration of net deployment, total detections, number of impinged fish, and start and end of each net-flushing period.

PIT-tag detection data files were uploaded periodically (about weekly) to PTAGIS using standard methods described in the *PIT-tag Specification Document* (Stein et al. 2004). Pair-trawl detections in the PTAGIS database were identified with site code TWX (towed array experimental).

[†] Use of trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

Records of PIT-tagged fish detected at Bonneville Dam were downloaded from PTAGIS to compare with our detections (PSMFC 2009). Also, the USACE provided the site, date, and time of barge loading, along with the corresponding date, time, and location (rkm) of each transport barge release. An independent database (Microsoft Access) of detection information was also maintained to facilitate data management and analysis. Dates and locations of barge release were assigned to an independent subset of transported fish based on the last detection date and site recorded at the transport dam.

Detection Efficiency Tests

To evaluate electronic performance of the various trawls and antenna systems, we used test tags attached to a vinyl-coated tape, similar to the method described in earlier study years (Ledgerwood et al. 2005). In 2009, we developed an additional test for evaluating the matrix antenna in a dry environment because in-water testing was difficult and time consuming with the larger matrix antenna.

During in-water testing, the matrix antenna system was detached from the trawl and suspended underwater between the stern of an anchored tow vessel and a skiff. A 2.5-cm-diameter PVC pipe was positioned through the center of the antenna system, extending beyond the range of the electronic field (at least 0.5 m beyond both the front and rear components; Figure 3). A test tape was then pulled back and forth several times through the PVC pipe. We evaluated detection efficiency by attempting to detect test tags attached to the tape at known intervals and orientations.

Dry detection efficiency tests were conducted in our shop using a back-up antenna. The antenna was suspended horizontally, and pulleys mounted on the ceiling were used to guide test tapes through the center of coils. The start time of each test tape pass was recorded in a logbook, and standard PIT-tag software (MiniMon) was used to record detections.

Efficiency was calculated as the total number of unique target tags decoded during each pass divided by the total number of target tags passed through the antenna. Target tags were defined as those having spacing and orientation identical to that of the tag immediately in front of or behind it on the test tape. We verified performance of test tags periodically and replaced damaged or defective tags. Periodic in-water evaluation of the matrix antenna system occurred throughout the season, and we tested backup components in the shop to verify performance, to properly tune the equipment, and to experiment with various techniques to improve read efficiency.

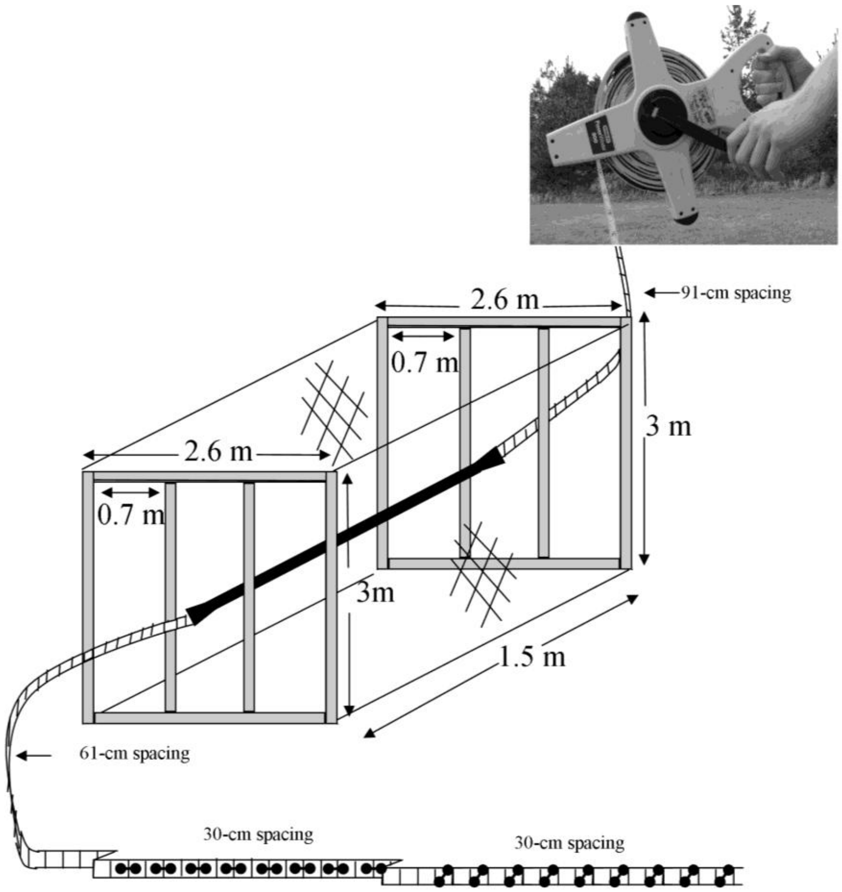


Figure 3. Funnel testing system depicting a vinyl tape measure fitted with test tags being passed through the center of the front and rear component of the six-coil matrix antenna system, 2009. Tags attached to the tape were oriented at 0 and 45 degrees and spaced in combinations at 30, 61, and 91 cm apart.

Detection efficiency, the ability to read PIT-tags, was evaluated for the matrix system at the center of the antenna and was expected to be positively correlated with orientation, spacing, and proximity to the electronic field. As the PIT-tag system technology advances, new antennas have been designed through the years to maximize both the fish-passage opening and detection efficiency. Development of the larger fish passage opening of the matrix antenna was facilitated by the longer read range of newer SST-type PIT tags. Detection efficiency tests were purposely conducted in the weakest area of the antenna field (center).

In 2009, 94% of the PIT tags released throughout the basin were the newer and more powerful SST-type tags, and roughly 5% were the older ST-type tags (PTAGIS). We constructed separate test tapes for each tag-type, but both tapes had identical tag-spacing intervals and orientations so that possible differences in detection efficiency between tag types could be compared (Appendix Tables 1-2).

Test results did not reflect the detection efficiency for PIT-tagged fish, but helped to indentify performance weaknesses in antenna design and subtle differences affected by electronic tuning and tag type. Detection efficiency would be higher for fish than for the test tape because fish can be presumed to pass in the more optimal areas of the antenna field (closer to the antenna wall) and with their tags perpendicular to the field.

Impacts to Fish

When under tow, the trawl was monitored visually from a skiff and tow vessels. The wings of the trawl were brought together in a net-flushing maneuver every 15 min for 5 min (plus 2 min for transition time) to help break up debris loads and flush debris and fish out of the trawl and through the antenna. Net-flushing also helped avoid delay for fish that tend to swim with (pace) trawl components.

Retrieval of the matrix trawl system differed from that of the cylindrical system in that the matrix antenna could be lifted directly on to a tow vessel, without detachment from or inversion of the trawl net. One drawback of this design was the occasional accumulation of significant quantities of debris in the wings. (With the cylindrical antenna system, debris had been emptied from the net during the inversion and detachment process required for each retrieval).

The larger fish-passage opening of the matrix antenna was more efficient at passing debris, but occasionally accumulations of debris had to be removed by hand before retrieval to the vessel. Removal of debris through the zippers in the trawl body during the retrieval process required longer drifts, and occasionally debris was cleared after moorage. Divers and underwater video were used periodically to evaluate debris accumulation, net configuration and possible fish impact sites. During all debris-removal, net-retrieval, and redeployment activities, we recorded impinged or trapped fish as mortalities, even if fish were observed to escape and swim away.

Development of a Separation by Code Vessel

In 2009, we continued the development and testing of a prototype mobile separation-by-code (SbyC) system to be used either with the existing matrix antenna or as an independent sampling system. The SbyC system technology has been utilized in juvenile fish passage facilities at dams on the Columbia and Snake Rivers since the early 1990s. The system may be programmed to divert individual PIT-tag codes, groups of codes, or all PIT-tagged fish. This recapture method allows examination of physical, physiological, disease, or genetic traits. The method is also used to select fish of known sources for loading to transportation barges as they migrate past the dams. A mobile SbyC system in the estuary will provide a diversion system location downstream from existing SbyC facilities at Bonneville Dam.

The matrix antenna system constitutes a likely maximum antenna size for deployment from our vessels and provides an optimal-sized fish passage opening while maintaining high detection capability. The techniques required to deploy this large structure also allowed us to initiate development a mechanism for independent deployment of SbyC equipment. We were able to use the *RV* Electric Barge for evaluations of the SbyC, since it was no longer required for antenna system deployment after we began using the matrix antenna. The mobile SbyC system was intended to be attached directly to the exit of the matrix antenna by a short netting collar. Alternatively, the SbyC system could be used independently with small tow vessels and separate trawl.

If deployed with the matrix system, fish would enter the SbyC system after entry and passage through the matrix antenna system (Figure 4). The SbyC vessel would be fixed to the matrix antenna via a net sock, which would guide fish into a 3-ft diameter collection tube (monitored by underwater cameras). Fish would then be pumped from the collection tube to a 25.4-cm diameter pipe on the SbyC vessel. Diversion would be accomplished at a flow rate of 2.4-3 m s^{-1} using a switch gate activated by PIT-tag antenna coils surrounding the 25.4 cm pipe. Non-diverted fish would continue through the system and be routed back to the river at the stern of the vessel.

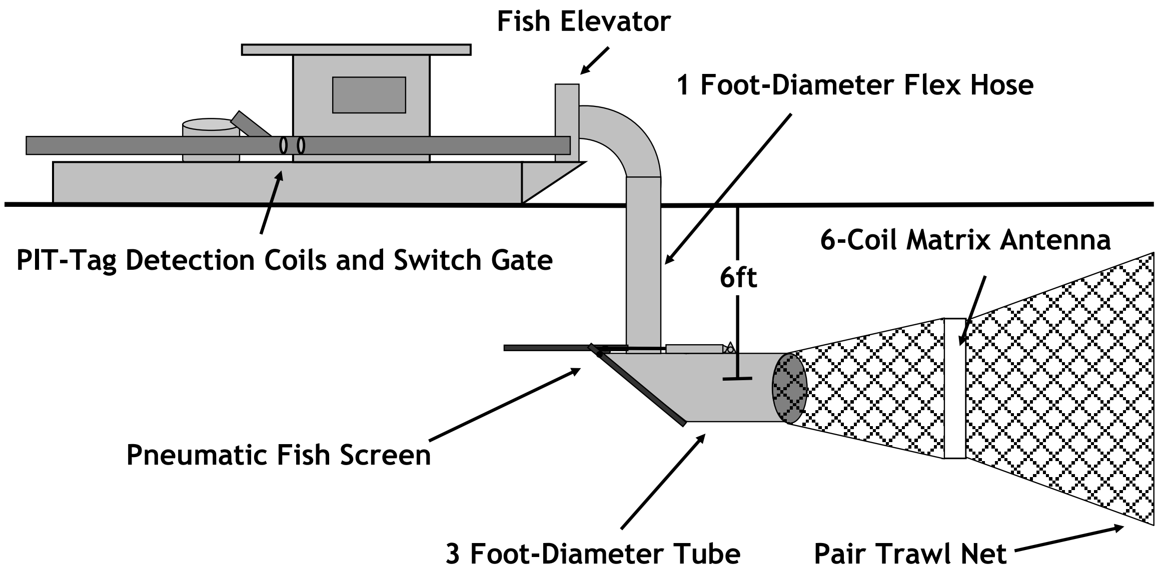


Figure 4. Diagram of a proposed prototype vessel to separate fish by PIT-tag code after passing through the surface trawl and matrix antenna.

Statistical Analyses

Detection data from the estuary are essential to estimate survival of juvenile salmonids at Bonneville Dam, the last dam encountered by seaward migrants (Muir et al. 2001; Williams et al. 2001; Zabel et al. 2002). The probability of survival through an individual river reach is 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). To estimate survival through the entire hydropower system, the CJS model requires detection probability estimates at Bonneville Dam, the lowermost dam on the Columbia River. Detections on the estuary trawl provided the data required for these estimates in 2009. Complete methodologies for these estimates and analyses of these detection data, along with survival estimates for individual river reaches, were reported by Faulkner et al. (2010).

RESULTS AND DISCUSSION

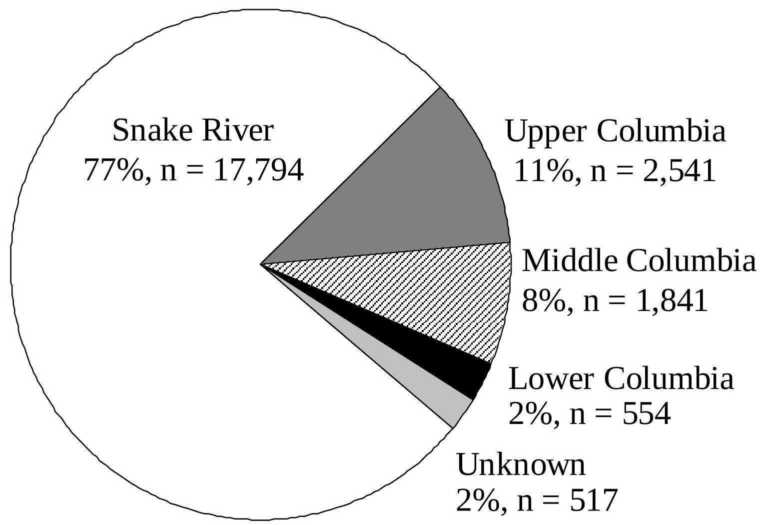
Estuary Detections

In 2009, we detected 23,247 PIT-tagged juvenile salmonids using the matrix detection system in the estuary near Jones Beach. Fish detected in the estuary were of various species, runs, and rearing types (Table 1). For example, 47% were yearling Chinook, 13% were subyearling Chinook, 33% were steelhead, 4% were sockeye, and the remaining 3% were other salmonid species (with the exception of 4 Northern Pikeminnow). Among all estuary detections, 17% were wild fish, 80% were hatchery fish, and 3% had no release information available in PTAGIS.

River basin source and migration history for PIT-tagged fish detected in the estuary are shown in Figure 5. Annual variation in the proportions of PIT-tags detected from these sources is influenced by the annual differences in hydrosystem operations, river conditions, and proportions of fish PIT tagged and transported throughout the basin. These differences have complicated attempts to compare trawl detection data among years. For example, no definite inference can be made based on a comparison of detection data between years with differing proportions of fish from different sources, species, and run or rearing types. However, proportions of fish detected in 2009 were similar to those detected in 2008, and we present a series of comparisons between these years.

Table 1. Species composition and rearing-type of PIT-tagged fish detected in the matrix trawl systems near river kilometer 75, 2009.

	Rear Type			
Species/run	Hatchery	Wild	Unknown	Total
Spring/summer Chinook salmon	8,876	1,722	245	10,843
Fall Chinook salmon	2,943	32	53	3,028
Coho salmon	493	6	0	499
Steelhead	5,542	1,977	179	7,698
Sockeye	829	82	41	952
Sea-run Cutthroat	0	2	0	2
Northern pikeminnow	0	4	0	4
Unknown	0	0	221	221
Grand total	18,683	3,825	739	23,247



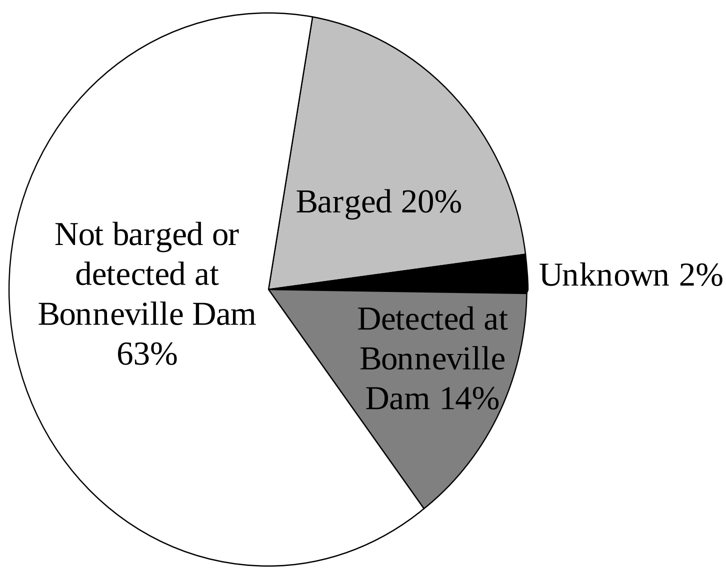


Figure 5. River basin sources and migration histories of all PIT-tagged fish detected in the estuary (rkm 75) during 2009 (n = 23, 247).

During 2009, the matrix detection system was operated for 1,097 h and detected 23,247 fish, and the shoreline system was operated for 42 h and detected no fish. By comparison, in 2008 the cylindrical antenna system was operated for 202 h, and the matrix system for 774 h, resulting in 16,560 total detections (Figure 6). It is important to note that although fewer PIT-tagged fish were released in 2009 than in 2008 (according to PTAGIS), we detected approximately 6,700 more fish in 2009 than in 2008.

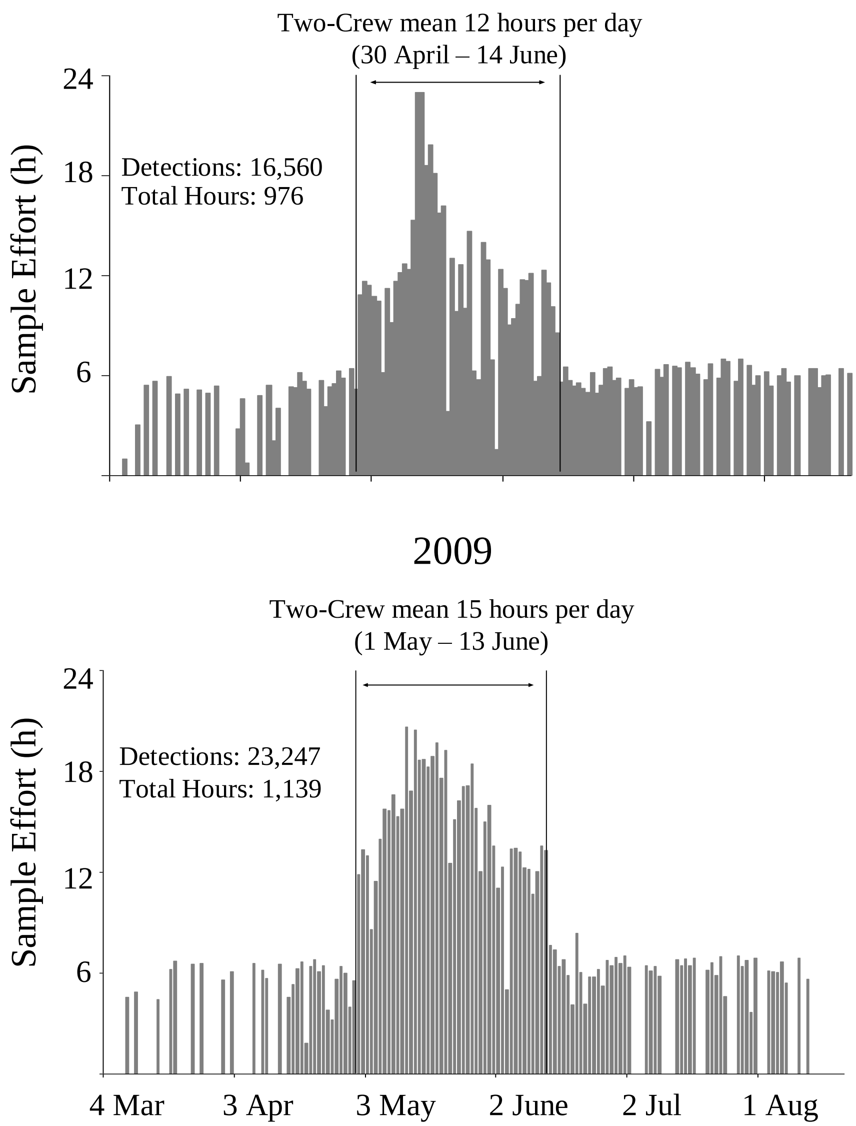


Figure 6. Daily detection effort during spring and summer using the matrix PIT-tag detection system in the upper Columbia River estuary (rkm 75) during 2008 and 2009.

The number of detections in 2009 was influenced by mean Columbia River flow volumes, which were considerably higher from mid-April through the end of June in 2008 than in 2009 (8,714 m^3 s^{-1} in 2008 vs. 7,871 m^3s^{-1} in 2009; Figure 7). Higher flows, like those seen in 2008, tend to speed passage of fish through the estuary sample area, reducing the likelihood of detection on the trawl system. We believe the lower flows in 2009 explain much of the increased detection rate (40% more detections with a 12% increase in sample effort, but with fewer tagged fish released).

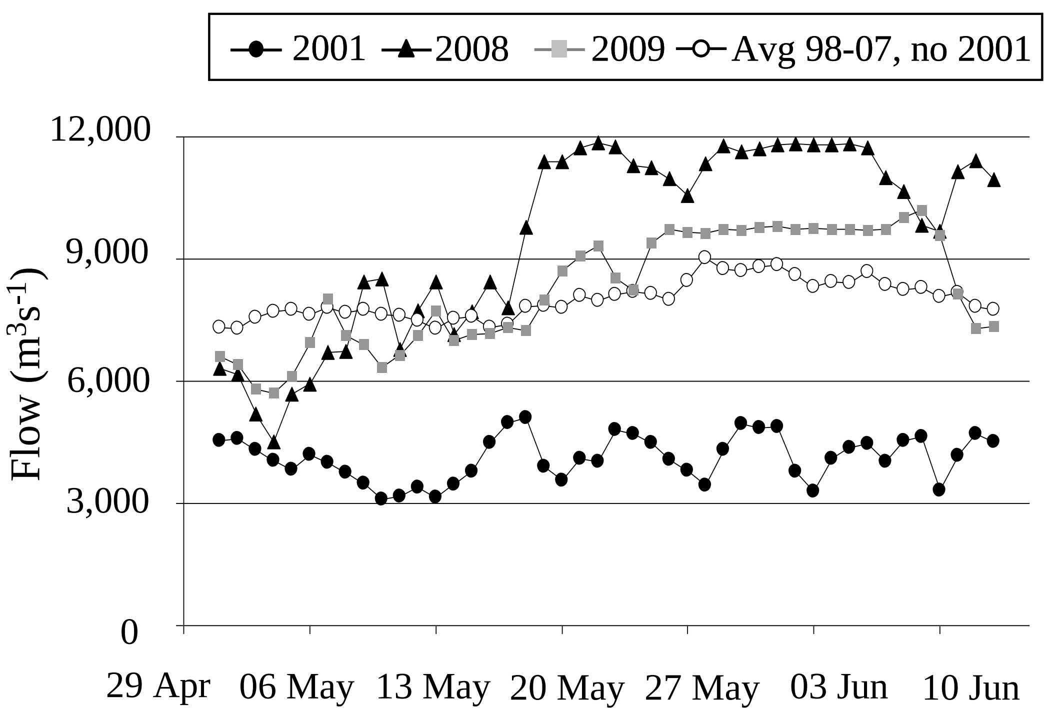


Figure 7. Columbia River flows at Bonneville Dam during the two-crew periods 2008 and 2009 as compared to 10-year average flow from 1998 to 2007 (excluding 2001). Drought-year flows for 2001 are shown for comparison.

Detection Efficiency

Detection efficiencies were higher for test tags oriented perpendicular to the electronic field; these tags were detected at equal or higher rates than those of tags placed at an angle. Fish tend to pass through the trawl antenna systems perpendicular to the detection field and spaced further apart than tags on our test tape. Therefore, our in situ evaluations of detection efficiency using different tag orientations and spacing were not a test of fish detection efficiency but did provide a rigorous test of antenna performance.

During tests with tags on the tape, decreases in detection efficiency were associated with collision of multiple PIT-tag codes within the electronic field. These collisions usually occurred with target tags that had shorter spacing between tags and poor orientation toward the coil. During 2009 fish were PIT-tagged primarily with the newer style SST tags which have longer read ranges, although some ST tags were used, We tested each coil of each antenna with both tag types.

When test tags were spaced 30 cm apart, the matrix antennas were rarely able to read either ST (< 4%) or SST tags (< 1%), regardless of orientation (Figure 8). When spacing between tags was increased to 61 cm, respective ST and SST detection efficiencies increased to 87 and 86% for tags perpendicular to the field and to 62 and 89% for tags at a 45-degree angle. At the 91-cm tag spacing, respective ST and SST reading efficiencies increased further, to 98 and 100% for tags passed perpendicular to the field and to 67 and 90% for tags passed at 45 degrees.

We also evaluated detection efficiency of the matrix antenna system by comparing daily proportions of fish detected on each coil (Figure 9). Ninety four percent of all fish detected were first recorded on one of the three front coils, and the remaining 6% were detected only on one of the three rear coils (missed by the front component). Some fish were detected only on the front coils, either because they were missed by the rear coils or possibly because they escaped the trawl by swimming forward and out of the mouth (we estimate that about 15% of fish detected on the front coils did this) . Seventy-nine percent of all fish detected were detected on the rear coils.

As in earlier years, the two-component antenna design provided redundant opportunities for detection of fish exiting the trawl. This was particularly valuable during periods when high numbers of PIT-tagged fish were passing. When numbers of unique detections were radically different between front and rear components, we suspected problems with the electronics. Based on previous observations using a camera in the fish-passage chamber of the cylindrical antenna system, we believe that the orientation of fish is better at the rear coils than at the front coils.

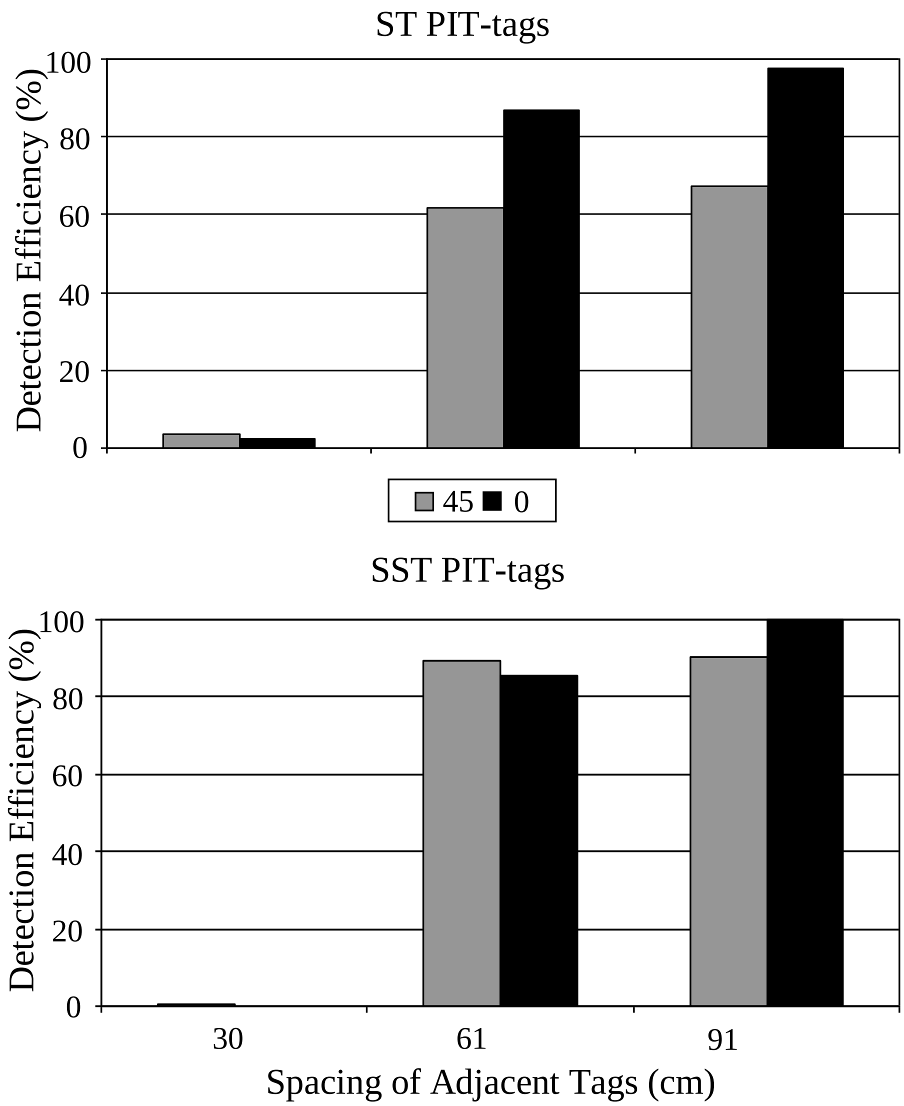


Figure 8. Average detection efficiency determined using ST and SST-style PIT tags attached to vinyl tape measures, 2009. Various spacing between tags and orientation to the electronic field were used, but all tape configurations were identical. Tags were repeatedly passed through the center of each 0.7 m by 2.8 m matrix antenna (336 tags for each spacing, orientation, and tag type).

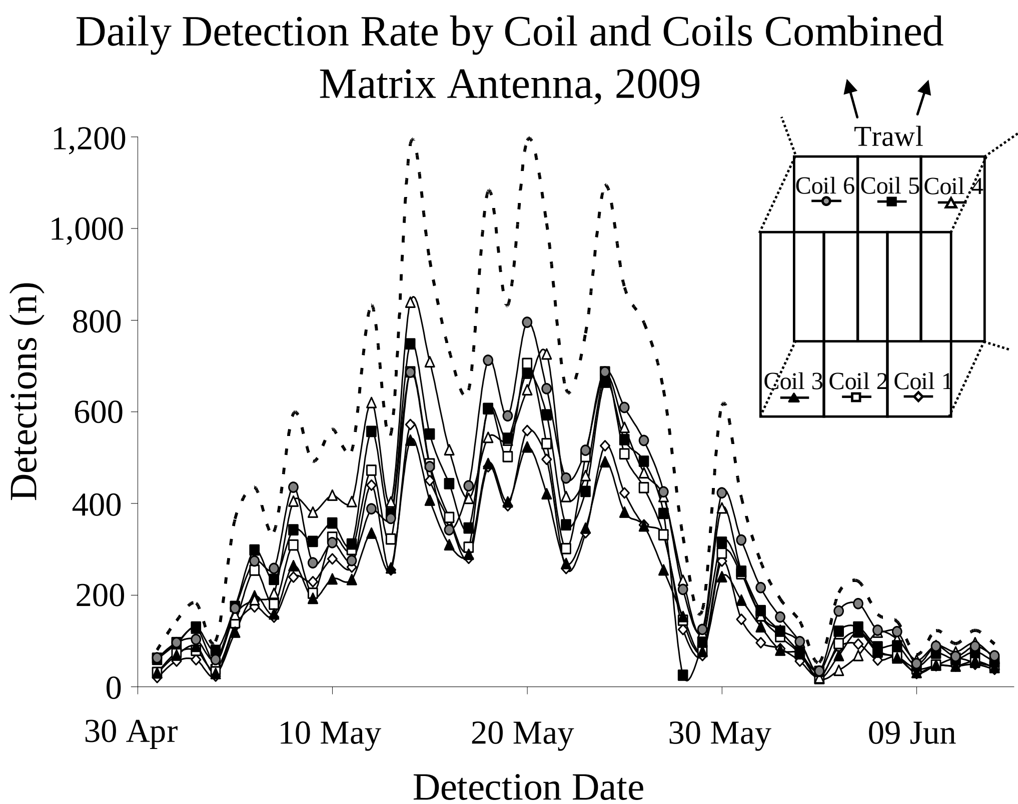


Figure 9. Daily detection rates by individual coils of the matrix antenna system used during the two-crew sample period (1 May-13 June). Coils 1-3 form the rear component and coils 4-6 form the front component. Inside dimension of each coil was 0.7 m wide by 2.8 m tall, and coils were connected by net around the perimeter maintaining a 1.5-m gap between the front and rear.

Impacts to Fish

During inspection or retrieval of the trawls, we occasionally recovered juvenile salmonids that had been inadvertently injured or killed during sampling. In 2009, we recovered 304 while using the matrix system (Appendix Table 3). In previous years, divers have inspected the trawl body and wing areas of the nets while the system was 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, areas where visual orientation to the sample gear is enhanced.

Through the years, we have eliminated many visible transition areas between the trawl, wings, and other components. These visible transitions mainly were found in the seams joining net sections with different mesh sizes or weights. We now use a uniform black net color for the trawl body and cod-end; this has reduced fish training and expedited passage through the antenna. We continued to flush the net (bring the trawl wings together) every 19 min (for 5 min): this helped to pass debris and reduced delay and possible fatigue of any fish pacing net transition areas or lingering near antenna components. The majority of detections occurred during these 5-min net-flushing periods. While some volitional passage occurred with the trawl wings extended, we continued flushing to avoid debris accumulations.

Separation-by-Code Vessel

A prototype SbyC system was deployed near Pasco, WA, on 7 October and again on 21-22 October. During initial tests, vessel stability, SbyC diversion gate timing, and separation efficiency were evaluated. Initial testing was done with PIT-tagged surrogates (stick fish, oranges, and small sausages) sent through the SbyC system. After gate-timing and other adjustments were completed, separation efficiency was nearly 100%.

On 21-22 October, we conducted live-fish trials of the SbyC to evaluate its impacts on fish using hatchery juvenile Chinook salmon and steelhead provided by Washington Department of Fish and Wildlife and Chelan County Public Utility District. Both tagged and untagged juvenile Chinook salmon and steelhead were released into the 3-ft diameter collection tube (Figure 4). Tagged test fish were either diverted to the sample collection tank or bypassed to a separate recovery tank. The recovery tank represented fish that would have been returned to the river in actual operation. Fish in both tanks were monitored for descaling, fin damage, haemorrhage, and opercula damage.

A camera was mounted inside the collection tube to monitor fish behavior and response to a "bubbler," which was added during the last test release. During the first test, approximately 80 fish were introduced to the system over a period of 30 min. Only 7 of these fish volitionally passed into the SbyC system, but both of the tagged fish among these 7 were successfully diverted to the sample tank. The remaining five non-tagged fish were recovered off the stern in a temporary recovery tank. During this test, we observed no negative impacts to fish passing through the system.

Prior to a second test, modifications were made to the collection tube to encourage volitional passage and to reduce delay of fish in the collection tube. These modifications included painting the collection tube black and adding a manually activated bubbler to move fish through the system. To test these changes and possible impacts to fish, 4 groups of 14 fish (tagged and non-tagged Chinook salmon and steelhead) were introduced into the system. By activating the bubbler at key moments through use of the underwater camera, all but 3 fish passed through the system within 90 seconds.

However, because fish moved through the system in small groups rather than individually, SbyC efficiency dropped: separated groups consisted of approximately 50% tagged and 50% non-tagged fish, and non-separated groups consisted of 15% tagged and 85% untagged fish. However, these tests did show that PIT-tagged fish can be separated and diverted to an onboard sample tank without injury or obvious negative impacts. Further improvements are planned to stabilize flow through the system, and we applied for the appropriate sampling permits to conduct additional SbyC testing in 2010.

Sampled PIT-Tagged Fish

Of in-river migrating fish from the Snake and Columbia River basin, 43,033 Chinook salmon and 25,257 steelhead were detected passing Bonneville Dam. Of these fish, we subsequently detected 1,436 yearling Chinook and 895 steelhead (Appendix Table 4). Detections in the estuary of fish previously detected at Bonneville Dam are essential for estimates of survival probability to the tailrace of Bonneville Dam.

Beginning in 2004, fish could exit the second powerhouse forebay at Bonneville Dam through a corner-collector flume, which carried fish to the tailrace. However, until 2006, only fish passing via the juvenile bypass facility could be interrogated for PIT-tags at Bonneville Dam. Although the corner-collector flume system was successful at passing fish safely, detections at Bonneville Dam were greatly reduced during its first 2 years of operation. Beginning in 2006, a PIT-tag detection system was installed in the corner collector. Since that year, about half of all PIT-tag detections at Bonneville Dam are from the corner-collector system, with the remainder from the juvenile bypass facility. The additional detection capability has improved the precision of survival estimates to the tailrace of Bonneville Dam (Faulkner et al. 2009).

As in previous years, only a small portion of either transported or in-river migrant fish passed through the estuary before or after the trawl sampling period. In 2009, we estimated that 88% of the transported fish and 79% of fish detected at Bonneville Dam were at or near river kilometer 75 during our two-crew sampling period from 1 May to 13 June (Table 2). During the two-crew sample period, we detected 2.7% of the barged PIT-tagged juvenile Chinook salmon released and 3.3% of those previously detected at Bonneville Dam; for steelhead, we detected 3.3% of the barged fish and 3.5% of fish previously detected at Bonneville Dam.

Table 2. Detections of PIT-tagged fish released from barges and in-river migrant fish detected previously at Bonneville Dam during the intensive two-crew daily sample period in the estuary from 1 May to 13 June 2009. The "release" totals for PIT-tagged fish during this sample period were selected allowing 2 days for fish to travel from Bonneville Dam to the sample area.

	Barged			In-river		
	Released	Detected	%	Released	Detected	%
Chinook salmon	72,788	1,950	2.68	43,033	1,436	3.34
Steelhead	55,874	1,857	3.32	25,257	895	3.54

Survival of In-river Migrants to the Bonneville Dam Tailrace

Detection data from the trawl are essential for calculating survival probabilities for juvenile salmonids to the tailrace of Bonneville Dam, the last dam encountered by seaward migrants (Muir et al. 2001; Williams et al. 2001; Zabel et al. 2002; Faulkner 2009). Detections of Snake River yearling Chinook salmon and steelhead arriving at McNary Dam were pooled weekly, while upper Columbia yearling Chinook and steelhead were pooled annually because of smaller sample size. Survival probabilities of fish released in the Snake and mid-Columbia Rivers were estimated from McNary to John Day, John Day to Bonneville, and McNary to Bonneville Dams. An example of weekly pooled survival estimates is shown in Table 3.

Table 3. Weekly average survival percentages from the tailrace of McNary Dam to the tailrace of Bonneville Dam for yearling Chinook salmon and steelhead from the Snake River, 2009. Dashes indicate sample size was too small to estimate survival with precision.

		McNary to John Day Dam		John Day to Bonneville Dam		McNary to Bonneville Dam	
	N	%	SE	%	SE	%	SE
Date	Snake River yearling Chinook salmon						
20 Apr-26 Apr	1,646	110.5	10.9	61.3	13.9	67.7	13.8
27 Apr-03 May	5,072	86.9	5.2	110.7	18.0	96.2	14.6
04 Apr-10 May	25,980	97.6	5.0	76.6	6.7	74.8	5.3
11 May-17 May	43,488	85.7	3.3	78.8	5.2	67.5	3.6
18 May-24 May	31,900	75.6	3.4	86.9	7.6	65.7	4.9
25 May-31 May	4,189	73.1	10.1	96.4	28.5	70.5	18.5
Wt. Avg.	112,275	86.6	4.2	82.1	4.3	70.5	3.1
	Snake River steelhead						
20 Apr-26 Apr	1,867	104.4	9.5	79.9	25.7	83.4	25.7
27 Apr-03 May	6,077	90.3	5.3	94.7	14.3	85.5	11.9
04 May-10 May	6,371	97.1	5.8	74.3	9.8	72.1	8.5
11 May-17 May	5,187	101.4	7.7	95.6	16.3	96.9	14.8
18 May-24 May	5,387	94.3	8.2	156.8	46.7	147.8	42.1
25 May-31 May	1,282	87.4	19.2	93.1	47.5	81.4	37.5
01 Jun-07 Jun	465	70.7	11.1	54.6	27.5	38.6	18.5
08 Jun-14 Jun	349	86.5	21.0	79.0	51.2	68.4	41.1
Wt. Avg.	26,985	95.1	2.6	90.0	7.9	85.6	7.4
	Mid-Columbia River yearling Chinook salmon						
Pooled Upper Columbia		84.7	3.8	101.2	12.1	85.7	9.8
Pooled Yakima		82	3.4	107.7	13.7	88.3	10.8
	Mid-Columbia River steelhead						
Pooled		79.2	4	88.8	10	70.3	7.7

Weighted annual survival was estimated from the tailrace of McNary Dam to the tailrace of Bonneville Dam for both Snake and upper-Columbia River basin stocks from 1999 to 2009 (Figure 10). In some years, an insufficient number of PIT tagged fish were released for survival estimates of a given species from one basin or the other. However, there did not appear to be a general trend in survival between the two watershed sources for either species. It is likely that the lowest survival for all stocks occurred during the extreme drought year 2001, but numbers were not sufficient for all stocks that year to provide meaningful survival estimates.

Annual survival estimates from the tailrace of McNary Dam to the tailrace of Bonneville Dam for Snake River yearling Chinook salmon ranged from 50.1% in 2001 to 84.2% in 2006 (70.6% in 2009). Similar estimates for upper-Columbia River stocks ranged from 57.0% in 1999 to 84.3% in 2009. Survival estimates for Snake River steelhead ranged from 25.0% in 2001 to 86.4% in 2009. Similar estimates for upper-Columbia River stocks ranged from 39.2% in 2007 to 74.2% in 1999 (72.5% in 2009). Complete analyses of these data are reported by Faulkner et al. (2010).

Fish are loaded for transport at Lower Granite, Little Goose, or Lower Monumental Dams on the Snake River or at McNary Dam on the Columbia River. These fish are transported past 3-7 downstream dams. The effectiveness of transportation is generally evaluated by comparing smolt to adult return (SAR) ratios between transported fish and in-river migrants. The benefit of transportation depends mostly on the arrival timing of fish in the estuary, but is also related to the conditions experienced by fish left to migrate in the river. In 2008, seasonal average survival of in-river migrant fish from the tailrace of Lower Granite Dam to the tailrace of Bonneville Dam was 46.5 for yearling Chinook and 48% for steelhead. In 2009, the survival estimates were higher for both yearling Chinook salmon and steelhead (55.6 and 69.1%, respectively) (Table 4).

We speculate that higher survival years for in-river migrants were related to increased flow volumes. In 2001 and 2004, two years characterized by extremely low river flows due to regional drought, survival probabilities for yearling Chinook salmon were much lower (27.9 and 39.5%, respectively) than in other years. In 2009, flow volumes were generally lower-than-average prior to mid-May and higher-than-average from mid-May to mid-June. Similarly, survival probabilities for Snake River steelhead through the entire hydropower system downstream from Lower Granite Dam in 2009 (69.1%) were higher than in any other year. Exceptionally low survival was estimated in 2001 for in-river migrant steelhead (4%). This was a drought year during which most fish were transported.

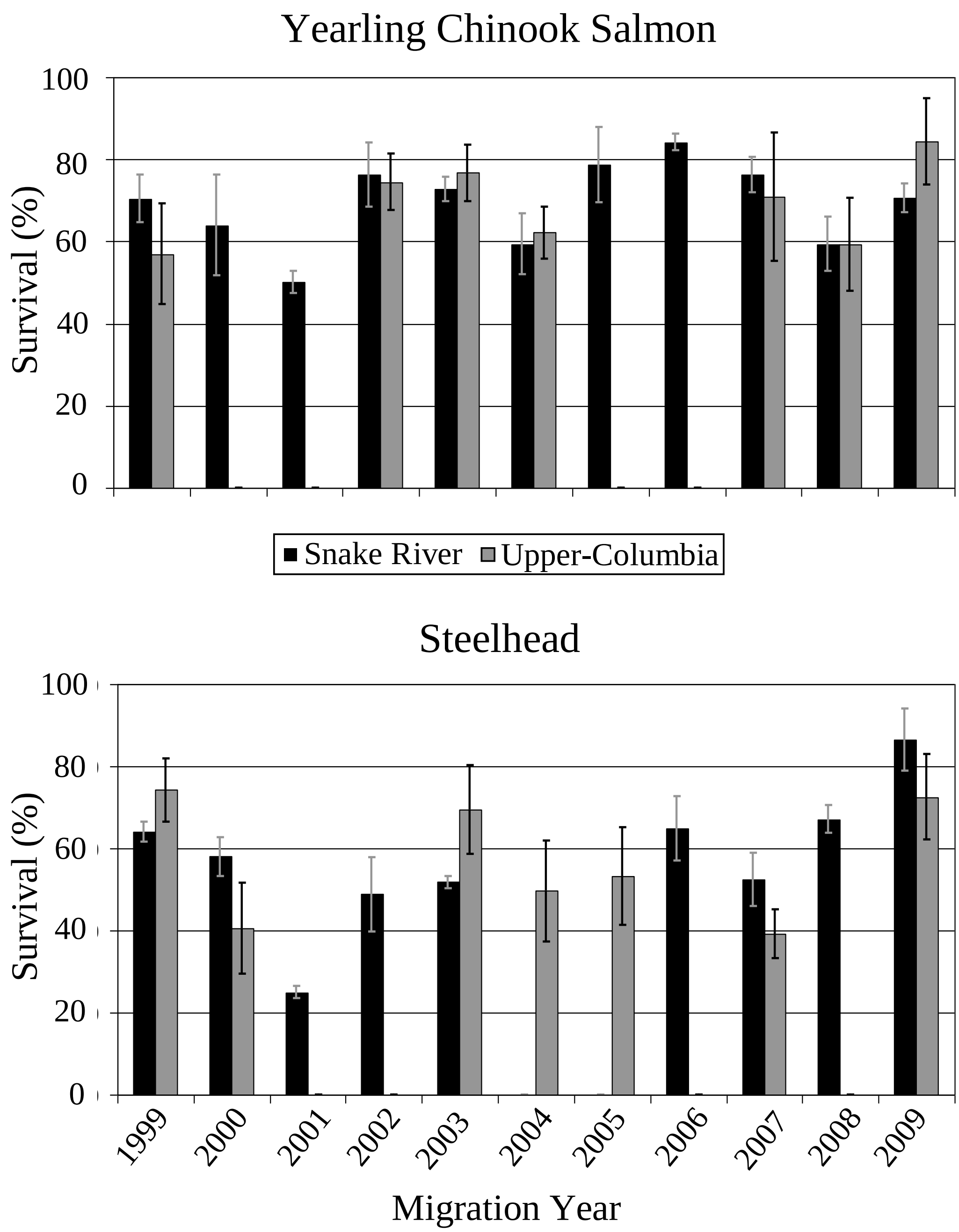


Figure 10. Weighted average annual survival probabilities and standard errors from the tailrace of McNary Dam to the tailrace of Bonneville Dam for yearling Chinook salmon and steelhead from the Snake and mid-Columbia Rivers, 1999-2009.

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 and steelhead, 1998-2009.

	Survival Estimates			
	Yearling Chinook salmon		Steelhead	
Migration year	(%)	SE	(%)	SE
1998	53.8	4.6	50	5.4
1999	55.7	4.6	44	1.8
2000	48.6	9.3	39.3	3.4
2001	27.9	1.6	4.2	0.3
2002	57.8	6	26.2	5
2003	53.2	2.3	30.9	1.1
2004	39.5	5	--*	--*
2005	57.7	6.9	--*	--*
2006	64.3	1.7	45.5	5.6
2007	59.7	3.5	36.4	4.5
2008	46.5	5.2	48	2.6
2009	55.6	2.8	69.1	6.2

* Sample size too small to estimate annual survival probability with precision

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APPENDIX

Data Tables

Appendix Table 1. Configuration of ST tags on the tape measure used to test antenna performance in 2009.

Position on tape measure (ft)	Orientation (°)	Distance from previous tag (ft)[a]		PIT tag code[b]
110	45	0		3D9.1BF1C45519
111	45	1		3D9.1BF1BFA4DC
112	45	1		3D9.1BF1C3CD41
113	45	1		3D9.1BF1BF9F9A
114	45	1		3D9.1BF1C35015
115	45	1		3D9.1BF1C5CD8F
116	45	1		3D9.1BF1BE0BB5
117	45	1		3D9.1BF1C3B99A
118	45	1		3D9.1BF1C5BF08
126	0	8		3D9.1BF1BCC1B9
127	0	1		3D9.1BF1C365E7
128	0	1		3D9.1BF1C44747
129	0	1		3D9.1BF1C5DF37
130	0	1		3D9.1BF1BE83BB
131	0	1		3D9.1BF1C3B5B6
132	0	1		3D9.1BF1C3B1B2
133	0	1		3D9.1BF1C44EC5
134	0	1		3D9.1BF1C356A3
142	45	8		3D9.1BF1C358EB
144	45	2		3D9.1BF1BE932D
146	45	2		3D9.1BF18087F3
148	45	2		3D9.1BF1BF9414
150	45	2		3D9.1BF24DAA3E
152	45	2		3D9.1BF1C5DD4F
154	45	2		3D9.1BF1BE9337
156	45	2		3D9.1BF176DB47
158	54	2		3D9.1BF1C3528A
166	0	8		3D9.1BF1BE9938
168	0	2		3D9.1BF1BE2774
170	0	2		3D9.1BF1C3B5AF
172	0	2		3D9.1BF1806F11
168	0	2		3D9.1BF1BE2774
170	0	2		3D9.1BF1C3B5AF

Appendix Table 1. Continued.

Position on tape measure (ft)	Orientation (°)	Distance from previous tag (ft)[a]		PIT tag code[b]
172	0	2		3D9.1BF1806F11
174	0	2		3D9.1BF1C34B9A
176	0	2		3D9.1BF1BE9980
178	0	2		3D9.1BF1BE83F4
180	0	2		3D9.1BF1BFABF7
182	0	2		3D9.1BF1BE882F
190	45	8		3D9.1BF1C3C2D1
193	45	3		3D9.1BF1BE6633
196	45	3		3D9.1BF1BF9F73
199	45	3		3D9.1BF1C34F97
202	45	3		3D9.1BF1BE843D
205	45	3		3D9.1BF1BF3F8D
208	45	3		3D9.1BF1BDA7C2
211	45	3		3D9.1BF1C333E3
214	45	3		3D9.1BF1BDA7BE
222	0	8		3D9.1BF1BF2EF5
225	0	3		3D9.1BF1C441DA
228	0	3		3D9.1BF1BF949B
231	0	3		3D9.1BF24DD1B9
234	0	3		3D9.1BF24D2DE4
237	0	3		3D9.1BF24D328C
240	0	3		3D9.1BF24D1AC6
243	0	3		3D9.1BF24D68E8
246	0	3		3D9.1BF25234BE

[a] Distance from previous tag as measured in the direction from 17 to 125 ft.
[b] PIT-tags were tested after each antenna evaluation with a hand-held reader and replaced as needed.

Appendix Table 2. Configuration of SST tags on the tape measure used to test antenna performance in 2009.

Position on tape measure (ft)	Orientation (°)	Distance from previous tag (ft)[a]	PIT tag code[b]
5	45	0	3D9.1C2CC4AE3F
6	45	1	3D9.1C2CC45A80
7	45	1	3D9.1C2CC42A83
8	45	1	3D9.1C2CC42AAA
9	45	1	3D9.1C2CC8107D
10	45	1	3D9.1C2CC711DF
11	45	1	3D9.1C2CC48B0F
12	45	1	3D9.1C2CC4E48C
13	45	1	3D9.1C2CC47161
21	0	8	3D9.1C2CC43D0C
22	0	1	3D9.1C2CC710F1
23	0	1	3D9.1C2CC4D578
24	0	1	3D9.1C2CC4625D
25	0	1	3D9.1C2CC440E7
26	0	1	3D9.1C2CC46137
27	0	1	3D9.1C2CC7008A
28	0	1	3D9.1C2CC81379
29	0	1	3D9.1C2CC6F306
37	45	8	3D9.1C2CC817E9
39	45	2	3D9.1C2CC4A641
41	45	2	3D9.1C2CC4B83D
43	45	2	3D9.1C2CC4E762
45	45	2	3D9.1C2CC6F1E5
47	45	2	3D9.1C2CC46298
49	45	2	3D9.1C2CC4C92B
51	45	2	3D9.1C2CC4E9E0
53	45	2	3D9.1C2CC43F3B
61	0	8	3D9.1C2CC4D3C5
63	0	2	3D9.1C2CC4CE33
65	0	2	3D9.1C2CC4393C
67	0	2	3D9.1C2CC45743
69	0	2	3D9.1C2CC4DE17
71	0	2	3D9.1C2CC43EB4
73	0	2	3D9.1C2CC713DC
75	0	2	3D9.1C2CC4C630
77	0	2	3D9.1C2CC4EFEB
85	45	8	3D9.1C2CC70808

Appendix Table 2. Continued.

Position on tape measure (ft)	Orientation (°)	Distance from previous tag (ft)[a]	PIT tag code[b]
88	45	3	3D9.1C2CC49929
91	45	3	3D9.1C2CC6F33E
94	45	3	3D9.1C2CC4AF9E
97	45	3	3D9.1C2CC43C37
100	45	3	3D9.1C2CC4634A
103	45	3	3D9.1C2CC44376
106	45	3	3D9.1C2CC4928D
109	45	3	3D9.1C2CC43F3A
117	0	8	3D9.1C2CC4C79D
120	0	3	3D9.1C2CC4B62B
123	0	3	3D9.1C2CC44382
126	0	3	3D9.1C2CC43AA4
129	0	3	3D9.1C2CC43EBE
132	0	3	3D9.1C2CC49BCA
135	0	3	3D9.1C2CC42A98
138	0	3	3D9.1C2CC46225
141	0	3	3D9.1C2CC43DF6

[a] Distance from previous tag as measured in the direction from 17 to 125 ft.
[b] PIT-tags were tested after each antenna evaluation with a hand-held reader and replaced as needed.

Appendix Table 3. Daily total of impinged fish found during sampling with the matrix system in the upper and lower Columbia River estuary, 2009.

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

Appendix Table 3. Continued.

Date	Chinook Salmon Yearling	Chinook Salmon Subyearling	Coho	Steelhead	Sockeye
22 Apr	1	0	0	0	0
23 Apr	0	0	0	0	0
24 Apr	0	0	0	0	0
25 Apr	0	0	0	0	0
26 Apr	1	0	0	0	0
27 Apr	0	0	0	0	0
28 Apr	1	0	0	1	0
29 Apr	0	0	0	0	0
30 Apr	0	0	0	0	0
1 May	1	0	0	1	0
2 May	5	0	2	2	1
3 May	5	0	1	1	0
4 May	0	0	0	0	0
5 May	43	0	5	4	3
6 May	15	0	6	7	3
7 May	1	0	0	0	0
8 May	7	0	1	2	0
9 May	18	0	3	3	1
10 May	2	0	1	0	0
11 May	5	0	1	2	0
12 May	9	0	2	1	0
13 May	1	0	0	0	0
14 May	7	0	0	2	0
15 May	5	0	2	5	2
16 May	3	0	1	0	0
17 May	1	0	2	1	0
18 May	0	0	0	0	0
19 May	3	0	1	4	1
20 May	1	0	0	1	0
21 May	0	0	2	0	0
22 May	0	0	1	0	0
23 May	1	0	1	0	0
24 May	1	0	0	0	0
25 May	2	0	0	0	0
26 May	4	0	0	0	0
27 May	0	0	1	2	0
28 May	0	0	2	0	0
29 May	0	0	0	0	1
30 May	0	0	0	0	0
31 May	1	0	1	0	0
1 Jun	1	0	0	0	0
2 Jun	0	0	0	0	0
3 Jun	1	0	1	0	0
4 Jun	0	0	2	0	1
5 Jun	2	0	1	0	0
6 Jun	2	0	1	8	0
7 Jun	1	0	0	1	0
8 Jun	0	0	1	0	0

Appendix Table 3. Continued.

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

26 Jul	--	--	--	--	--

Appendix Table 3. Continued.

	Chinook Salmon				
Date	Yearling	Subyearling	Coho	Steelhead	Sockeye
27 Jul	0	0	0	0	0
28 Jul	2	0	0	0	0
29 Jul	2	0	0	0	0
30 Jul	0	0	0	0	0
31 Jul	0	0	0	0	0
1 Aug	--	--	--	--	--
2 Aug	--	--	--	--	--
3 Aug	0	0	0	0	0
4 Aug	0	0	0	0	0
5 Aug	0	0	0	0	0
6 Aug	0	0	0	0	0
7 Aug	4	0	1	0	0
8 Aug	--	--	--	--	--
9 Aug	--	--	--	--	--
10 Aug	1	0	0	0	0
11 Aug	--	--	--	--	--
12 Aug	1	0	0	0	0
13 Aug	--	--	--	--	--
14 Aug	--	--	--	--	--
15 Aug	--	--	--	--	--
Totals	186	0	51	49	17

Appendix Table 4. Detections in the Columbia River estuary of PIT-tagged juvenile Chinook salmon and steelhead previously detected at Bonneville Dam, 2009. Totals for the entire season are shown.

Date of detection at Bonneville	Bonneville Dam Detections		Jones Beach Detections		Bonneville Detections detected at Jones Beach (%)	
	Chinook salmon (n)	Steelhead (n)	Chinook salmon (n)	Steelhead (n)	Chinook salmon (%)	Steelhead (%)
24 Feb	40	0	1	--	2.50	--
25 Feb	18	0	0	--	0.00	--
26 Feb	19	0	0	--	0.00	--
27 Feb	3	0	0	--	0.00	--
28 Feb	2	0	0	--	0.00	--
01 Mar	6	0	0	--	0.00	--
02 Mar	10	0	0	--	0.00	--
03 Mar	28	0	0	--	0.00	--
04 Mar	20	0	0	--	0.00	--
05 Mar	22	1	0	0	0.00	0.00
06 Mar	11	0	0	--	0.00	--
07 Mar	9	0	0	--	0.00	--
08 Mar	10	0	0	--	0.00	--
09 Mar	6	0	1	--	16.67	--
10 Mar	8	0	0	--	0.00	--
11 Mar	1	0	0	--	0.00	--
12 Mar	3	0	0	--	0.00	--
13 Mar	2	0	0	--	0.00	--
14 Mar	1	0	0	--	0.00	--
15 Mar	1	0	0	--	0.00	--
16 Mar	4	0	0	--	0.00	--
17 Mar	1	0	0	--	0.00	--
18 Mar	0	0	--	--	--	--
19 Mar	0	0	--	--	--	--
20 Mar	0	0	--	--	--	--
21 Mar	2	0	0	--	0.00	--
22 Mar	0	0	--	--	--	--
23 Mar	1	0	0	--	0.00	--
24 Mar	1	0	0	--	0.00	--
25 Mar	1	0	0	--	0.00	--
26 Mar	1	0	0	--	0.00	--
27 Mar	1	0	0	--	0.00	--
28 Mar	0	0	--	--	--	--
29 Mar	0	0	--	--	--	--
30 Mar	1	2	0	0	0.00	0.00
31 Mar	0	0	--	--	--	--
01 Apr	0	0	--	--	--	--
02 Apr	0	0	--	--	--	--
03 Apr	2	3	0	0	0.00	0.00

Appendix Table 4. Continued.

Date of detection at Bonneville Dam	Bonneville Dam Detections		Jones Beach Detections		Bonneville Detections detected at Jones Beach (%)	
	Chinook salmon (n)	Steelhead (n)	Chinook salmon (n)	Steelhead (n)	Chinook salmon (%)	Steelhead (%)
04 Apr	1	4	0	0	0.00	0.00
05 Apr	0	0	--	--	--	--
06 Apr	5	2	0	0	0.00	0.00
07 Apr	3	4	0	0	0.00	0.00
08 Apr	2	3	0	0	0.00	0.00
09 Apr	10	2	0	0	0.00	0.00
10 Apr	19	2	0	0	0.00	0.00
11 Apr	21	1	0	0	0.00	0.00
12 Apr	35	1	1	0	2.86	0.00
13 Apr	29	1	0	0	0.00	0.00
14 Apr	563	7	5	0	0.89	0.00
15 Apr	211	5	4	0	1.90	0.00
16 Apr	129	4	0	0	0.00	0.00
17 Apr	142	11	1	0	0.70	0.00
18 Apr	206	12	4	1	1.94	8.33
19 Apr	190	19	6	0	3.16	0.00
20 Apr	200	12	5	0	2.50	0.00
21 Apr	155	18	0	0	0.00	0.00
22 Apr	200	29	2	0	1.00	0.00
23 Apr	236	37	2	0	0.85	0.00
24 Apr	298	57	1	2	0.34	3.51
25 Apr	267	113	1	5	0.37	4.42
26 Apr	255	244	2	5	0.78	2.05
27 Apr	383	222	2	3	0.52	1.35
28 Apr	240	469	1	6	0.42	1.28
29 Apr	301	580	4	9	1.33	1.55
30 Apr	316	368	9	16	2.85	4.35
01 May	325	742	2	23	0.62	3.10
02 May	705	850	3	18	0.43	2.12
03 May	600	1,183	13	54	2.17	4.56
04 May	341	650	13	32	3.81	4.92
05 May	464	966	16	54	3.45	5.59
06 May	310	799	7	54	2.26	6.76
07 May	519	888	12	25	2.31	2.82
08 May	588	1,137	11	27	1.87	2.37
09 May	1,091	918	34	17	3.12	1.85
10 May	1,199	1,295	37	73	3.09	5.64
11 May	999	1,070	39	22	3.90	2.06
12 May	1,361	1,382	75	76	5.51	5.50
13 May	1,478	784	69	45	4.67	5.74
14 May	1,936	1,129	59	34	3.05	3.01
15 May	1,496	882	58	32	3.88	3.63
16 May	2,994	793	128	36	4.28	4.54
17 May	2,166	599	87	25	4.02	4.17

Appendix Table 4. Continued

Date of detection at Bonneville	Bonneville Dam Detections		Jones Beach Detections		Bonneville Detections detected at Jones Beach (%)	
	Chinook salmon (n)	Steelhead (n)	Chinook salmon (n)	Steelhead (n)	Chinook salmon (%)	Steelhead (%)
18 May	2,756	1,029	97	61	3.52	5.93
19 May	3,169	1,171	146	47	4.61	4.01
20 May	2,418	917	96	27	3.97	2.94
21 May	2,179	513	53	10	2.43	1.95
22 May	2,233	759	56	14	2.51	1.84
23 May	2,262	822	78	30	3.45	3.65
24 May	2,770	1,162	97	25	3.50	2.15
25 May	1,746	815	52	24	2.98	2.94
26 May	1,326	576	30	12	2.26	2.08
27 May	1,242	568	12	7	0.97	1.23
28 May	1,370	688	32	10	2.34	1.45
29 May	912	486	14	11	1.54	2.26
30 May	752	454	16	13	2.13	2.86
31 May	537	252	8	6	1.49	2.38
01 Jun	415	227	14	4	3.37	1.76
02 Jun	232	121	3	1	1.29	0.83
03 Jun	253	166	3	4	1.19	2.41
04 Jun	197	170	4	6	2.03	3.53
05 Jun	161	189	6	8	3.73	4.23
06 Jun	139	70	2	2	1.44	2.86
07 Jun	125	99	0	1	0.00	1.01
08 Jun	233	111	4	4	1.72	3.60
09 Jun	265	124	3	6	1.13	4.84
10 Jun	279	98	2	5	0.72	5.10
11 Jun	311	100	2	5	0.64	5.00
12 Jun	273	110	2	1	0.73	0.91
13 Jun	289	66	2	4	0.69	6.06
14 Jun	270	137	1	3	0.37	2.19
15 Jun	294	61	5	3	1.70	4.92
16 Jun	309	61	2	3	0.65	4.92
17 Jun	521	76	1	2	0.19	2.63
18 Jun	584	71	9	4	1.54	5.63
19 Jun	328	65	1	4	0.30	6.15
20 Jun	301	68	2	4	0.66	5.88
21 Jun	348	84		2	0.00	2.38
22 Jun	466	66	6	1	1.29	1.52
23 Jun	315	35	1	0	0.32	0.00
24 Jun	384	67	2	1	0.52	1.49
25 Jun	269	112	4	2	1.49	1.79
26 Jun	440	40	12	3	2.73	7.50
27 Jun	441	32	6	0	1.36	0.00
28 Jun	239	29	4	1	1.67	3.45
29 Jun	343	29	5	0	1.46	0.00
30 Jun	323	12	6	0	1.86	0.00
01 Jul	546	7	1	0	0.18	0.00

Appendix Table 4. Continued

Detection date at Bonneville Dam	Bonneville Dam Detections		Jones Beach Detections		Bonneville Detections detected at Jones Beach (%)	
	Chinook salmon (n)	Steelhead (n)	Chinook salmon (n)	Steelhead (n)	Chinook salmon (%)	Steelhead (%)
02 Jul	284	14	0	0	0.00	0.00
03 Jul	217	20	1	0	0.46	0.00
04 Jul	84	12	5	0	5.95	0.00
05 Jul	109	4	2	0	1.83	0.00
06 Jul	182	4	2	1	1.10	25.00
07 Jul	279	7	4	0	1.43	0.00
08 Jul	395	6	0	0	0.00	0.00
09 Jul	325	7	2	0	0.62	0.00
10 Jul	399	4	0	0	0.00	0.00
11 Jul	348	4	14	0	4.02	0.00
12 Jul	575	2	8	0	1.39	0.00
13 Jul	255	5	4	0	1.57	0.00
14 Jul	417	1	11	0	2.64	0.00
15 Jul	425	3	5	1	1.18	33.33
16 Jul	269	1	1	0	0.37	0.00
17 Jul	432	2	4	0	0.93	0.00
18 Jul	177	1	1	0	0.56	0.00
19 Jul	158	0	4	--	2.53	--
20 Jul	165	1	2	0	1.21	0.00
21 Jul	171	1	2	0	1.17	0.00
22 Jul	122	0	0	--	0.00	--
23 Jul	68	1	0	0	0.00	0.00
24 Jul	68	0	3	--	4.41	--
25 Jul	159	1	2	0	1.26	0.00
26 Jul	138	1	2	0	1.45	0.00
27 Jul	172	2	1	0	0.58	0.00
28 Jul	107	0	0	--	0.00	--
29 Jul	124	0	1	--	0.81	--
30 Jul	68	0	0	--	0.00	--
31 Jul	26	1	1	0	3.85	0.00
01 Aug	50	0	1	--	2.00	--
02 Aug	19	0	2	--	10.53	--
03 Aug	16	6	0	0	0.00	0.00
04 Aug	6	0	0	--	0.00	--
05 Aug	8	0	0	--	0.00	--
06 Aug	9	0	0	--	0.00	--
07 Aug	11	3	0	0	0.00	0.00
08 Aug	15	3	0	0	0.00	0.00
09 Aug	10	1	0	0	0.00	0.00
10 Aug	6	0	0	--	0.00	--
11 Aug	10	1	0	0	0.00	0.00
12 Aug	10	7	0	0	0.00	0.00
Totals	65,677	31,341	1,702	1,077	2.59	3.44