# Development of a passive integrated transponder (PIT) detection system for adult salmonids in the lower Columbia River, 2013

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# Executive Summary


For the third year, we deployed a new system to detect adult salmon tagged with passive integrated transponder (PIT) tags in the tidal freshwater portion of the Columbia River estuary. The system was installed in the river along a pile dike near river kilometer (rkm) 70, with above-water components at the terminal piling. It was designed to detect adult salmonids for estimates of survival and travel time to upstream sites, but juvenile salmonids and other PIT-tagged fish were also detected.

In 2013, we replaced the system transceiver with a new model that promised greater read range. Based on capability of the new transceiver, we built new submersible antennas that covered four times the area of antennas used in the prototype system (2.4 × 6.1 m). We initially installed three of the larger antennas housed in 10-cm-diameter rigid PVC pipe. However, after several weeks of operation, stress fractures developed in two of these antennas. We replaced these antennas, and constructed new antennas using 1.9-cm-diameter flexible PVC tubing.

By late August, we had replaced all but one of the rigid antennas with antennas housed with small-diameter flexible tubing. We also expanded the site to include two additional flexible antennas placed further inshore along the pile dike. The new transceiver worked well for these antennas, which were installed 55 m and 76 m from the power source. Except for interruptions to replace antennas, and some brief solar-power shortages late in the season, the system remained operational from March through July (3 antennas) and from August to October (5 antennas).

To evaluate fish behavior near the system, we periodically used a DIDSON acoustic camera. Camera observations confirmed that fish passed more readily through the enlarged antennas, which nearly eliminated the avoidance behavior observed in previous years.

During 2013, the pile dike system detected 375 adult and jack salmonids, representing 1.6% of all PIT-tagged adult and jack salmonids passing Bonneville Dam in 2013. For spring, summer, and fall Chinook, as well as steelhead, these detections were sufficient for estimates of survival and travel time to Bonneville Dam (Table 1). Most detections of adult and jack salmonids came from a single 2.4- by 6.1-m antenna located on the terminus of the pike dike.

Only two adult Chinook salmon detected on the pile dike system were destined for Willamette Falls Dam. However, the system detected 620 juvenile salmonids

Table 1. Detections by species from the pile dike monitoring system in 2013 and the respective proportions detected at Bonneville Dam (for adults and jack). Also shown are estimates for survival and travel time for species groups with sufficient detection numbers.

| | Detections on pile dike system | | Estimated survival to Bonneville Dam (%) | Median travel time to Bonneville (d) |
|---|---|---|---|---|
| | N | Proportion relative to Bonneville detections (%) | | |
| Spring Chinook | | | | |
| Adult | 22 | 2.1 | 90.5 | 4.0 |
| Jack | 74 | | 67.6 | 4.4 |
| Summer Chinook | | | | |
| Adult | 68 | 2.8 | 89.6 | 3.7 |
| Jack | 36 | | 83.3 | 3.7 |
| Fall Chinook | | | | |
| Adult | 101 | 1.2 | 92.1 | 3.2 |
| Jack | 5 | | 80.0 | 4.2 |
| Steelhead | 54 | 0.9 | 92.5 | 4.5 |
| Sockeye | 12 | 3.1 | 100.0 | 3.1 |
| Coho | | | | |
| Adult | 2 | 0.4 | 50.0 | 3.0 |
| Jack | 1 | | 0.0 | 0.0 |

comprised of 464 Chinook salmon, 98 steelhead, 53 coho salmon, 4 sockeye, and 1 cutthroat trout. Ten white sturgeon adults and 1 northern pikeminnow were also detected in 2013.

Although we will continue development and testing of the pile dike system, its performance has already shown proof of concept for potential expansion to other large riverine habitats. The ability to deploy large, submerged antennas at long distances from a power source (>75 m) represents a significant advance to instream PIT-tag monitoring technology. Site selection for such deployments will rely on many of the methods established for existing instream monitoring, such as evaluation of ambient EMI (electromagnetic interference). However, flexible antennas can be built and potentially deployed at a much lower cost than the rigid antenna arrays used in our prototype system (and presently deployed in most instream PIT-tag monitoring applications).

Expanded deployment of flexible antenna systems in the estuary can maximize detections of adult salmonids, augmenting the accuracy of survival and travel time estimates and helping to pinpoint problems in specific reaches. Such estimates can provide insight into mortality from pinniped predation and fishing pressure as well as stock-specific run timing in tidal freshwater reaches. As a next step, we plan to adopt the flexible antenna for use in a mobile application that can target juvenile or adult salmonids in a variety of riverine or reservoir conditions.

# Contents

# Introduction

Since 1993, the National Marine Fisheries Service (NMFS) has used the passive integrated transponder (PIT) tag to for studies of juvenile salmon survival and timing (Prentice et al. 1990a). Detection data from PIT-tags form the basis for annual estimates of downstream migrant survival of salmonids from depressed stocks that pass through the Columbia River hydropower system (Faulkner et al. 2013). These estimates provide managers with a means to evaluate sources of mortality during juvenile migration as well as the impact of hydrosystem operation changes to improve juvenile passage.

A high proportion of returning adult salmon retain their PIT tags, and for those that enter fishways, a very high proportion are detected during the return migration. Adult PIT-tag detection data form the basis for calculations of smolt-to-adult returns (SARs) as well as survival and timing during the upstream migration. Detection data from adult salmonids also provide insight on the hydrosystem operations that affected them as juveniles and on ocean conditions they experienced following the juvenile migration. However, most SARs are calculated based on the first adult detection at a dam, subsequent to passage through the estuary (Dehart et al. 2013). Therefore, detection data from fishways provide no information on adult timing or mortality in the estuary.

The Columbia River estuary extends from Bonneville Dam (rkm 234) downstream to the mouth of the river. The estuary must be transited by all anadromous fishes, including juvenile and adult Pacific salmon *Oncorhynchus* spp. It is a critical area for fish transitioning between marine and freshwater. Bottom et al. (2001) characterized the estuary as having three distinct regions:

1. A tidal freshwater region from Bonneville Dam to the maximum upstream extent of salinity intrusion (rkm 234 to ~55)
2. A brackish-oligohaline region (rkm 55 to ~30)
3. A broad, euryhaline region in the lower estuary (rkm 0-30)

Although many returning salmon are PIT-tagged, there has been no means of detecting these tags in areas below Bonneville or Willamette Falls Dam. In 2010, Wargo Rub et al. (2012a,b) captured adult spring Chinook salmon in the estuary near rkm 44. Adults were tagged with acoustic and PIT-tags, released, and monitored using mobile tracking methods as they continued upstream. Wargo et al. (2012b) used acoustic data to estimate survival and timing for these adults and to evaluate predation by marine mammals. They also collected tissue samples and used genetic stock identification to estimate the proportion of adults that had originated upstream of Bonneville Dam.

In this study we utilized recent advances in PIT-tag technology to develop an inriver monitoring system to detect returning adult salmon tagged as juveniles. We installed a prototype system on a pile dike at Columbia River rkm 70, 164 km below Bonneville Dam. Using data from the Columbia River PIT tag Information System (PTAGIS; PSMFC 2014), we estimated adult timing and survival to Bonneville Dam for species detected in sufficient numbers on the pile dike system and at the dam.

Within the Columbia River Basin, the number of juvenile salmon PIT-tagged and released has varied through the years but has generally increased since the late 1990s (PSMFC 2014). Since 2010, over 2 million PIT-tagged juveniles have been released each year, and adults detected in 2013 represent these releases (PSMFC 2014). Although the majority of juveniles originating above Bonneville Dam appear to migrate rapidly through the estuary (Dawley et al. 1986), returning adults may reside there for a considerable period. In addition to experiencing physiological changes during the transition from marine to freshwater, adults in the estuary are exposed to predation by marine mammals and may encounter fishing pressure (Stansell et al. 2013).

Therefore, adult detection data from the estuary is critical in providing insight into marine mammal predation, migration timing, residence time, travel rates, and survival of adults in areas below the lowermost dam. These data are also essential in segregating mortality that occurs in the estuary from that which occurs in the ocean or during estuarine passage as juveniles. Such data can improve our understanding of adult recruitment to the estuary and passage through its tidal freshwater regions.

In 2011, we installed a prototype PIT-tag detection system on a pile dike in the tidal freshwater region of the estuary (rkm 70). This structure is typical of many encountered by migrating adults in the estuary. Success of the prototype system was limited due to fish avoidance of detection antennas and limited distance from a power source allowed by the equipment used (Magie et al. 2013). In 2013, we tested a new transceiver system with extended reading range. The new transceiver used a single cable for communications and power, allowed greater distance between antennas and power source, and worked with antennas four times larger than the prototype. Specific objectives for the study in 2013 were:

1) Design, construct, and test the reliability of a new instream PIT-tag monitoring system antennas based on the new (IS1001) transceiver.
2) Expand the monitoring system to utilize additional antennas with larger passage openings for fish to improve coverage and detection efficiency along the pile dike.
3) Using detection data from the pile dike system at rkm 70:
    a) Estimate species and stock-specific travel time and survival of adult salmonids from rkm 70 to Bonneville (rkm 234) or Willamette Falls Dam (rkm 206).
    b) Evaluate timing, stock composition, and distribution of juvenile salmonids along the pile dike.
    c) Report detections of sturgeon and other PIT-tagged species.

# Methods

## Study Site

We installed the PIT-tag monitoring system in March 2013 on the same pile dike used for our prototype system in 2011-2012 (rkm 70). In this tidal freshwater reach, the pile dike is used to help control sediment accumulation in the adjacent navigation channel. The pile dike extends about 230 m from the Oregon shore, and average depth where antennas were installed was approximately 7.5 m at mean lower low water (MLLW). This site was chosen from several locations surveyed to identify adult migration pathways in the area (Figure 1; Magie et al. 2013).

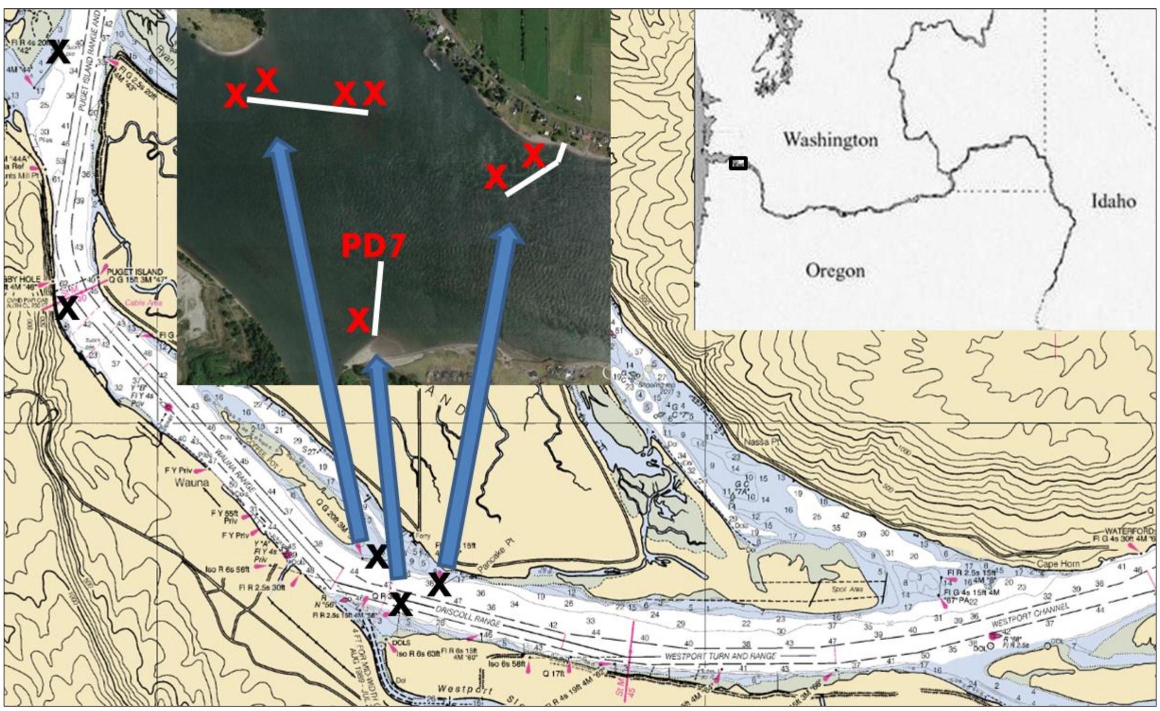


Figure 1. Site of pile dike PIT detection system operated in the lower Columbia River (rkm 70; red × marked PD7) during 2013. White lines with unmarked red × show locations of other pile dikes that were surveyed to identify adult salmonid migration pathways using dual-frequency identification sonar (DIDSON) imaging.

# Detection System

## Initial Deployment

The pile dike PIT-tag monitoring system first installed in August 2011 consisted of a multiplex transceiver (Destron Fearing FS1001M)[1] controlling four 1.2- by 3.5-m antennas (Figure 2; Magie et al. 2013). The submerged components were comprised of four antennas spanning an area 3.5 m wide by 6.1 m deep and covering the entire water column at low tide. Above-water components were similar to those described for the estuary trawl detection system (Morris et. al 2012). In March 2012, we redeployed the system using a similar configuration, but added two antennas stacked vertically and placed upstream from the pile dike near its terminus (1.2 × 6.1 m; Figure 2).

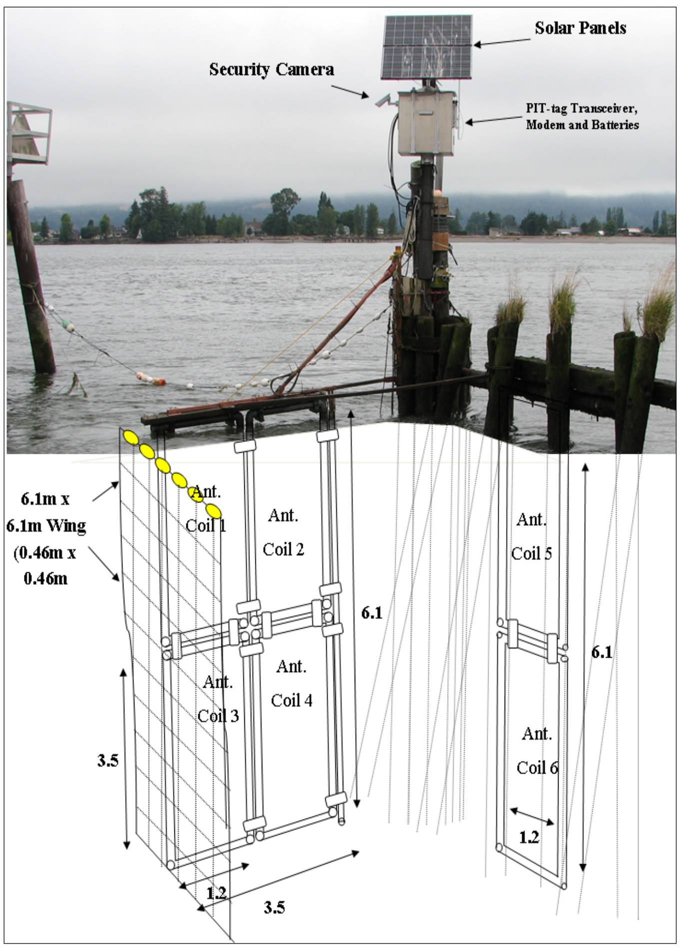


Figure 2. Photo and drawing show above-water and submerged sections of prototype monitoring system in the Columbia River estuary, 2011-2012. Configuration shows guidance wing and additional coils (antenna coils 5 and 6) installed in 2012.

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

This system was designed to detect returning adult salmon tagged with 12-mm, full-duplex PIT tags, which are most commonly used in the Columbia River Basin. However, it was capable of reading other full-duplex tags, and juvenile salmonids and other PIT-tagged species were also detected on the pile dike system.

During deployment in 2012, we used dual-frequency identification sonar (DIDSON) imaging to observe fish interaction with the pile dike system. These images indicated that adult fish were avoiding system antennas (Figure 3). Thereafter, we installed a 6.1- by 6.1-m mesh wing (0.46- × 0.46-m mesh) to encourage fish to pass and discourage milling on the downstream side of the array. Although the mesh wing increased milling near the antenna (thus increasing detection numbers), it did not increase fish passage in 2012.

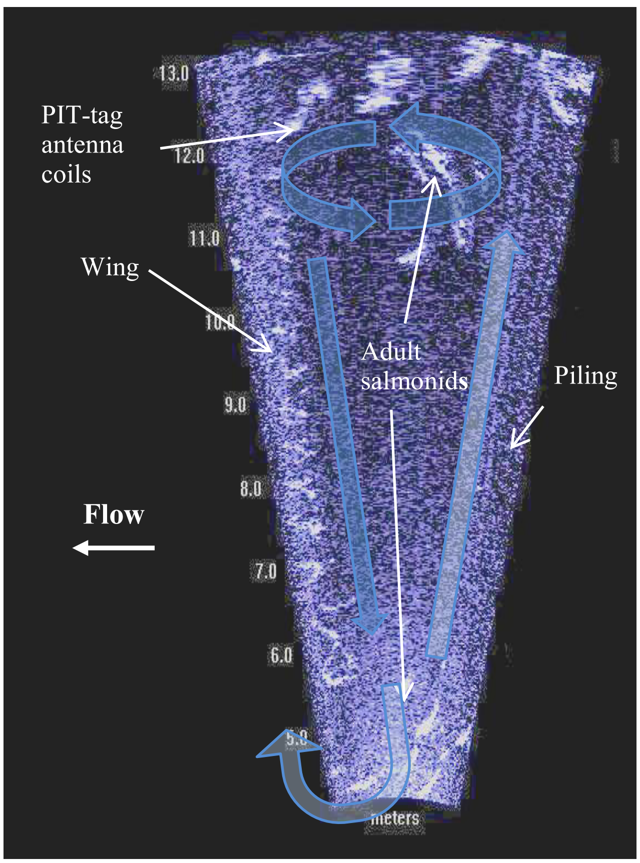


Figure 3. Image from DIDSON acoustic camera shows adult fish near the pile dike antenna array. Blue arrows indicate the typical path followed by adult salmon, which continued after mesh-wing installation in 2012.

## Transceiver

In early 2013, we experimented with a new multiplex transceiver system (IS1001, Biomark, Inc.). We hoped to reduce fish avoidance behavior by using antennas with a much larger, uninterrupted fish-passage area (14.6 $m^2$ as compared to the 4.2 $m^2$ area of the original antennas). By mounting the readers in a capsule directly on the antennas as described by the transceiver manufacturer, we pushed the technology and successfully tested much larger antennas. Each new antenna provided width and depth coverage similar to that of the entire 4-coil matrix configuration used previously, but with a single undivided opening (2.4 by 6.1 m).

Initially, the larger antennas were built using the same rigid 10.1-cm-diameter PVC pipe used for the prototype antennas. We installed three large antennas in the pile dike system during 5-6 March 2013. A single antenna (coil 1) replaced the four coils used in 2012 at the pile dike terminus. Two additional antennas (coils 2 and 3) were added adjacent to one another on the upstream side of the pile dike (Figure 4).

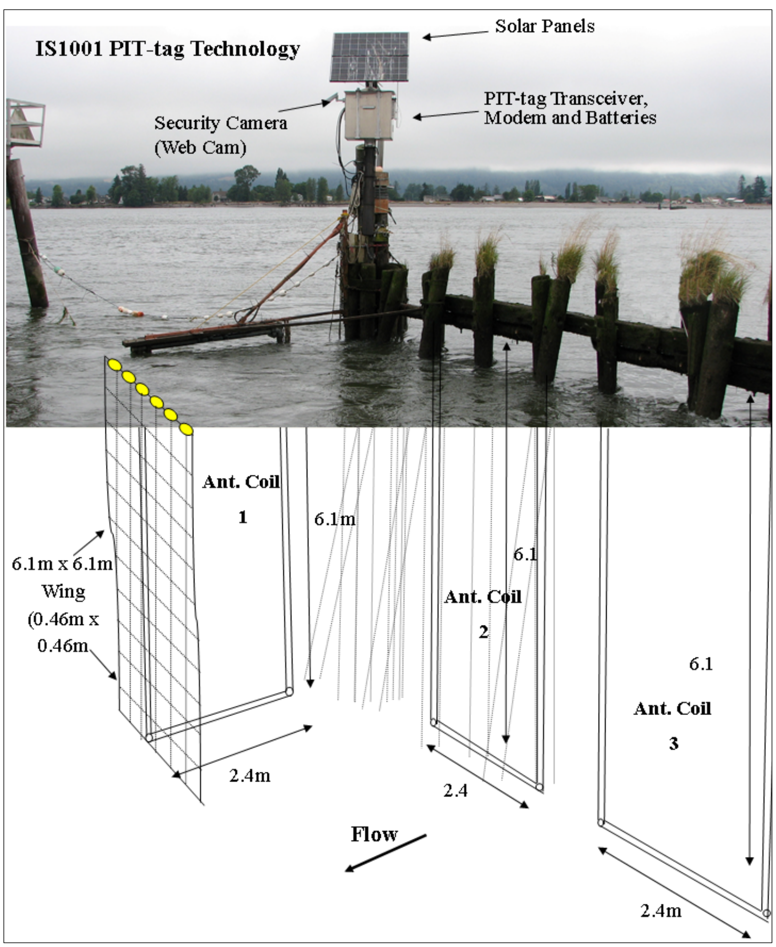


Figure 4. Pile dike detection system at rkm 70 as configured using new transceiver and rigid PVC antennas installed during March-July 2013.

Antenna coils 2 and 3 quadrupled the detection coverage area through the piles from 7.3 to 29.2 $m^2$. We tested antenna function and read range periodically using a PIT tag attached to a 3-m pole and passed through the center of the detection field for each antenna.

Mounts for the antennas and an enclosure box for above-water electronic components were configured as described in previous reporting for this project (Magie et al. 2013). Power for the system was drawn from solar panels charging a bank of four 12-volt batteries mounted inside a water-tight aluminum box along with the transceiver and modem. Specifications for the solar panels suggested that between November and February, manual changing of batteries would be required. Therefore, as in previous years, we installed the antenna and electronics box in early March and removed them in early November, when battery failure was imminent.

Thus, from 5 March to 4 November 2013, the system generated detection data and status reports, which were stored in system memory and downloaded daily using an automated software routine (Bruce Jonasson, National Marine Fisheries Service, pers. commun.). Data files were transferred over an autonomous wireless internet connection housed with the detection equipment and delivered via email each morning.

The system could also be accessed manually using the same internet connections. Daily detection data files were uploaded periodically (about weekly) to PTAGIS using standard methods described in the *2009 PIT-tag Specification Document* (Marvin and Nighbor 2009). The specification document, PTAGIS operating software and user manuals are free and publicly available via the internet (PSMFC 2014). Pile dike system detections are designated in the PTAGIS database with site code PD7 (pile dike rkm 70).

## Flexible Antennas

Eventually, flow-induced vibration on the rigid antenna housings created stress fractures on antenna coils 2 and 3 (Figure 4), which were located on the upstream side of the pilings. Stress fractures at the corners caused these housings to leak, and both antennas were replaced using two backup antennas made from the same rigid material.

In July, we began to experiment with an alternative antenna housing made of small-diameter (1.9 cm) flexible hose. Our hope was that the flexible housing would not be as vulnerable to vibration caused by river current and would better conform to the uneven configuration of pilings at each antenna location.

During August 2013, we installed four flexible antennas of the same dimensions as those made from rigid PVC pipe (2.4- by 6.1-m; Figure 4). The flexible replacement for antenna coil 2 was installed on the downstream side of the pilings, while the replacement for antenna coil 3 remained on the upstream side. The third flexible antenna (coil 4) was installed downstream from the pile dike and at a 90-degree angle to flow. This installation used a system of anchors similar to those used for antenna coil 1, but further inshore (49 m from coil 1). Flexible antenna coil 5 was installed even further inshore along the abrupt change between the 6.1- and 3.7-m depth contours (76 m from coil 1). Rigid PVC coil 1 was position downstream and behind the terminal pile bundle, in the lee of the current; this coil never needed replacement and remained in service for the entire season.

A single power supply and transceiver was used for all five antenna coils. As we replaced and added antennas during the season, we continued testing the feasibility and performance of antennas at greater distances from the power supply. Detections on the new antennas helped gain perspective on fish distribution along the entire pile dike.

Installation of the flexible antennas was less complex and difficult than that of rigid antennas, mainly because of their smaller diameter and lighter weight. Because of their larger air gap (10.1-cm-diameter), the rigid antennas required more lead weight to counter buoyancy so that they could be positioned correctly in the water column (113 kg). In contrast, correct placement and orientation of the flexible antennas required only two 34-kg weights, which we fixed to the bottom corner of each antenna using a PVC spreader-bar (68 kg total; Figure 5).

Although the recommended air gap for optimal antenna performance is 5 cm between the antenna wires and water, the air gap provided by 1.9-cm-diameter flexible antennas was much smaller. The new transceiver eliminated the need for this air gap, and the antennas performed well as long as they were kept dry and insulated.

Flexible antennas were also less difficult to transport than the rigid antennas. Moving the rigid antennas into position required one large vessel with a tall lifting davit and a second or third support vessel to assist in positioning. In contrast, because the flexible antennas could be collapsed for transport, only a single small vessel was needed for installation and retrieval. We secured lines along each side of the flexible antenna housing to support the lead weight, taking strain off the housing itself (Figure 5). These lines were also used to secure antennas to the pile dike. Finally, the antennas made from flexible hose cost less to construct than those made from rigid PVC.

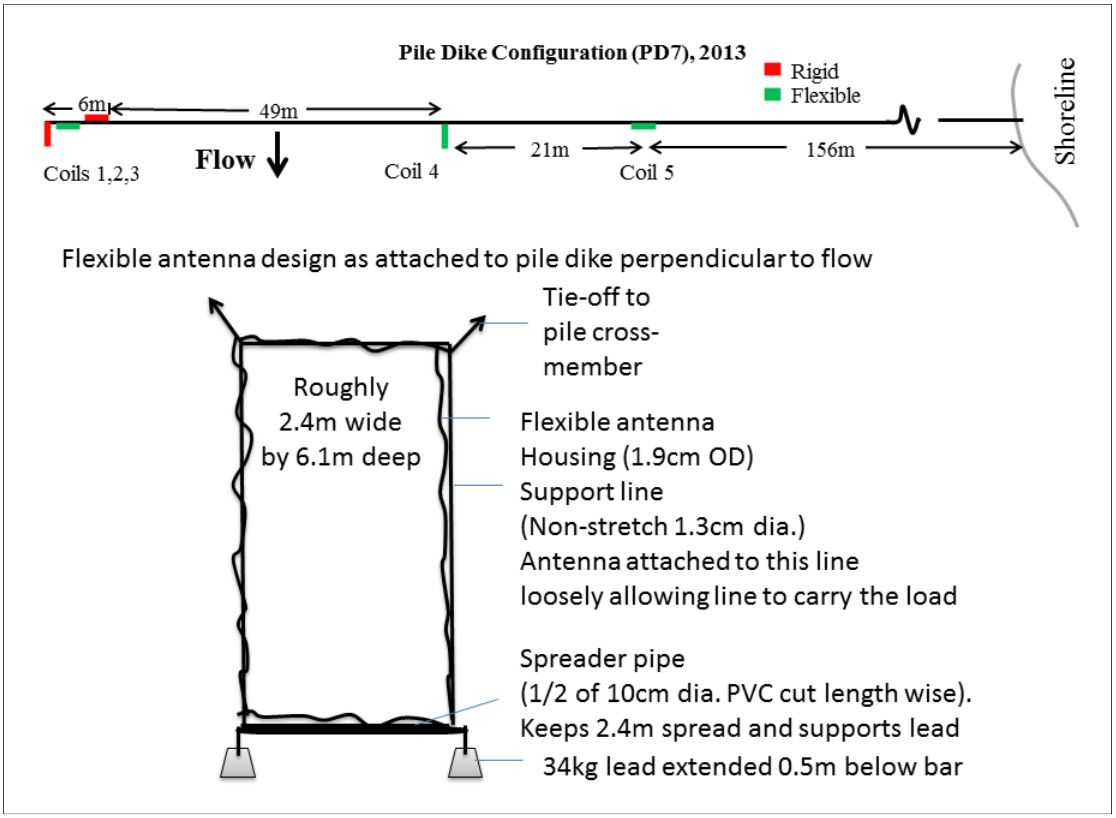


Figure 5. Top: site configuration of pile dike detection system in August 2013 after installation of flexible antennas (PD7; rkm70). Bottom: typical construction of a flexible antenna for attachment to pile dike.

# Data Analysis

## Survival and Travel Time

Estimates of survival to Bonneville Dam for jack and adult spring, summer, and fall run Chinook salmon and steelhead were calculated as the proportion of fish detected at the pile dike that were subsequently detected at Bonneville Dam. Travel time for survivors was merely the time difference between last detection on the pile dike and first detection at the dam. We did not make separate estimates by evolutionary significant unit (ESU); however, membership in an ESU can be determined from the release site, species, and run code data recorded in PTAGIS for an individual adult tag. Chinook ESUs from the lower Columbia River are of particular concern because these stocks originate from sources both above and below Bonneville Dam.

Based on studies of detection efficiency at Bonneville Dam, detection probabilities for PIT-tagged adults in fishways are close to 100% (DeHart 2013; Burke et al. 2006). Given the relatively small number of adult detections at the pile dike, we would not be able to observe small differences in detection rate between release groups at Bonneville Dam. Therefore, for each species, we used the proportion detected at Bonneville Dam from those detected on the pile dike to estimate the rate of survival. We assumed a binomial distribution for survival and substituted the number of fish detected at the pile dike for the release number (n). Thus we calculated the standard error (SE) for the probability of survival ($p$) as:

$$\mathrm{SE} = \sqrt{p(1-p)/\mathrm{n}}$$

We constructed approximate 95% confidence intervals (CIs) using the estimate ± 2SE.

Migration timing was generally quantified using daily means and range. Median travel rate to Bonneville Dam was calculated along with SEs and 95% CIs (± 2SE). Due to the small sample sizes, we made only qualitative assessments of temporal trends in travel time (using daily means). However, we report the median travel time for each overall seasonal estimate.

## Detection Efficiency

Detections of adult migrants at Bonneville Dam were downloaded from PTIAGIS (PSMFC 2014) and totaled by species (adults and jacks combined). These detection data were used for rough estimates of detection efficiency at the pile dike array. Again, because detection efficiency at Bonneville Dam is nearly 100% for adult migrants, we calculated detection efficiency at the pile dike array as the proportion of adults detected at Bonneville Dam that were previously detected on the pile dike. Separate estimates were made for fish originating upstream from Bonneville Dam based on tag information from PTAGIS. For these estimates, we calculated SEs and constructed CIs as described above. Similar estimates were not possible for fish originating above Willamette Falls Dam due to small sample sizes.

## Juvenile Salmon

We charted the proportions of juvenile fish detected on the pile dike system compared to those detected in the adjacent thalweg using a surface pair trawl (site code TWX in PTAGIS, Morris et al. 2014). Data on fish by basin of origin was obtained from tag information in the PTAGIS database. These charts generally reflected the proportions of tagged juvenile fish originally released from each basin.

Not all stocks are equally represented in annual tagging effort, and our estuary detections reflect tagging effort, not necessarily abundance, for different stocks. For example, of the 2.3 million juvenile salmonids tagged in 2013, 50% were from the Snake River, 26% from the Upper Columbia (above McNary Dam), 12% from the middle Columbia (between McNary and Bonneville Dam), and 13% from the Lower Columbia River below Bonneville Dam (including the Willamette River and other tributaries).

However, not all fish tagged and released in a given year migrate during that year; some overwinter in reservoirs or the estuary and migrate year following release. Thus, the proportions of juvenile fish detected in the estuary may also reflect differential survival rates. Different survival rates have been estimated for fish that migrate downstream immediately after release vs. those that hold overwinter or are transported (nearly all transported fish are assumed to survive to the point of barge release). Detection proportions of adult fish also reflect differences in juvenile survival and in multiple years of ocean residency. Proportions of fish detected in 2013 may reflect these differences in releases dating back to 2009.

Estimated survival and travel time are reported for adults and jacks from the pile dike to Bonneville Dam; however, these estimates reflect only the performance of these individual fish and cannot be inferred to represent the performance of any specific group. Comparisons of detection rate and timing of juveniles between the trawl and pile dike systems reflect tagged populations of fish passing through the estuary at presumably similar times. Median travel times were compared to better understand the lateral distribution of juvenile migrants in the reach.

## Fish Behavior

Beginning in 2011, we used dual-frequency identification sonar (DIDSON) acoustic cameras to evaluate the presence and behavior of adult salmonids near pile dikes and other structures. These evaluations included the pile dike at rkm 70 and were intended to identify a structure within the adult migration pathway that was capable of supporting at least one PIT-tag detection system installation.

After deployment of the prototype pile dike detection system, we continued using the DIDSON cameras to observe and record fish behavior near the system. Logbooks were used to summarize the presence and absence of fish by time and video frame. These records were later used to categorize adult fish behaviors as: 1) avoidance or no exit determination; 2) passed through the piles undetected; and 3) passed through the antenna. Short video clips are available upon request showing examples of these behaviors. While smaller fishes were observed, their behavior did not seem affected by the presence of antennas.

We could not identify specific fish or schools of fish based on camera observation. Therefore, fish that disappeared from the view field may have reappeared and had their behavior recorded more than once. Comparisons between years were made for the two days with the highest adult salmonid presence for each antenna system.

# Results

## Species Composition

The pile dike detection system was installed and operated between 5 March and 4 November 2013. Operation was continuous except for brief outages associated with electronics issues or antenna failures. A total of 1,025 PIT-tagged fish were detected during this period (Table 2). Detected fish were comprised of 375 adult and 619 juvenile salmonids, 10 adult sturgeon, 2 adult northern pikeminnow, and 11 salmonids with undetermined life stage (juvenile or jack). There were also 8 "orphans" or detections with no tag release information recorded in PTAGIS.

Table 2. Total PIT-tagged fish detected on pile dike array, 5 March-4 November 2013. Adult and jack salmonids are broken into species and run-type showing median travel times and survival to Bonneville or Willamette Falls Dam.

| | | | Bonneville Dam | | Willamette Falls Dam | | |
|---|---|---|---|---|---|---|---|
| Species/Run | | Number detected (N) | Travel time (d) (± 2 SE) | Survival (%) (± 2 SE) | (N) | Travel time (d) | Survival (%) |
| Spring Chinook | Adult | 22 | 4.0 (± 1.7) | 90.5 (± 14.6) | 1 | 7.9 | 100 (0.0) |
| | Jack | 74 | 4.4 (± 0.5) | 67.6 (± 10.8) | | -- | -- |
| Summer Chinook | Adult | 68 | 3.7 (± 0.3) | 89.6 (± 7.4) | 1 | -- | 0.00 |
| | Jack | 36 | 3.7 (± 0.3) | 83.3 (± 12.4) | | -- | -- |
| Fall Chinook | Adult | 101 | 3.2 (± 0.3) | 92.1 (± 5.4) | | -- | -- |
| | Jack | 5 | 4.2 (± 1.3) | 80.0 (± 35.8) | | -- | -- |
| Adult steelhead | | 54 | 4.5 (± 0.6) | 92.5 (± 7.2) | | -- | -- |
| Adult sockeye | | 12 | 3.1 (± 0.4) | 100.0 (± 0.0) | | -- | -- |
| Coho | Adult | 2 | 3.0 | 50.0 (± 71.7) | | -- | -- |
| | Jack | 1 | 0.0 | 0.0 (± 0) | | -- | -- |
| Juvenile salmonids | | 619 | | | | | |
| Other salmonids* | | 11 | | | | | |
| Sturgeon | | 10 | | | | | |
| Northern pikeminnow | | 2 | | | | | |
| No information | | 8 | | | | | |
| Total | | 1,025 | | | | | |

* Life stage not determined

Fish detected on the pile dike system represented tagged groups from multiple release sites and brood years from throughout the Columbia River basin. We combined adult and jack salmonids by species and run-type for survival and travel time analyses. Fish originating from sources below Bonneville Dam were excluded from these analyses. Fish originating in the Willamette River basin were evaluated separately.

## Detection Efficiency

Detections of adult and jack salmonids at Bonneville Dam were downloaded from PTAGIS and used to provide a rough estimate of detection efficiency at the pile dike array (Table 3). Two adult Chinook salmon (one spring run and one fall run) originating from the Willamette Basin and one adult steelhead from Abernathy Creek were excluded from this analysis, as were adult fish tagged and released at Bonneville Dam.

Table 3. Detections of combined adult and jack salmonids by species showing fish detected at Bonneville Dam and on the pile dike array in 2013. Gross detection efficiency was measured as the proportion of fish detected on the pile dike array and subsequently detected at Bonneville Dam in adult fishways 1-4.

| Species/run | Total detections at Bonneville Dam (N) | Prior detection at pile dike array (N) | |
|---|---|---|---|
| | | (N) | (%) |
| Spring Chinook | 4,630 | 96 | 2.1 |
| Summer Chinook | 3,673 | 104 | 2.8 |
| Fall Chinook | 8,860 | 106 | 1.2 |
| Steelhead | 5,789 | 54 | 0.9 |
| Sockeye | 384 | 12 | 3.1 |
| Coho | 694 | 3 | 0.4 |
| Total | 24,030 | 375 | 1.6 |

Efficiency at the pile dike array was highest for summer Chinook salmon (2.8%) and lowest for coho salmon (0.4%). Detection efficiency for all adult and jack salmonid species and run types combined was 1.6% in 2013. Detection efficiencies may be higher for fish that did not pass through the pile dike antenna array but did pass the terminal pile within reading range of system antennas. Likewise, detection efficiencies may be lower for fish that passed through the piles undetected, migrated in the thalweg, or migrated in shallow water closer to the shoreline.

To understand how migrating fish interacted with the pile dike, we looked at relative detection numbers for individual antenna coils (Table 4). Coils 1, 2, and 3 were installed in early March. However, coils 4 and 5 were not installed until August, after most migrating juvenile and adult spring Chinook had passed the site.

Antenna location and orientation (Figure 2) strongly influenced the life stage detected. For example, antenna coils 1 and 4 were placed perpendicular to the pile dike and oriented parralel to the flow. These two antenna coils together recorded over 90% of the adults and 99% of the jacks detected on the system, but recorded very few juveniles (8%). In contrast, coils 2, 3 and 5 were placed parralel to the pile dike, and over 90% of all juveniles detected were detected on antenna coils 2 and 3. No juveniles were detected on antenna coil 5, but this coil was installed after the spring migration season had ended.

Table 4. Proportions of fish by life stage detected on each antenna coil (%) at the pile dike array. Antenna coils 1, 2, and 3 were active March through October and antenna coils 4 and 5 were active from August through October 2013. Distance from terminal pile and orientation to the flow are also shown.

| | March-October | | | August-October | |
|---|---|---|---|---|---|
| Antenna Coil | 1 | 2 | 3 | 4 | 5 |
| Distance from terminal pile (m) | 0 | 3 | 6 | 55 | 76 |
| Orientation to flow | 0° | 90° | 90° | 0° | 90° |
| Adult (%) | 84.6 | 3.5 | 5.0 | 6.2 | 0.8 |
| Jack (%) | 98.3 | 0.9 | 0.0 | 0.9 | 0.0 |
| Juvenile (%) | 7.9 | 53.0 | 38.9 | 0.0 | 0.2 |

# Fish Behavior

We used DIDSON acoustic camera observations to compared the behavior of adult-sized fish near the pile dike antennas in 2013 vs. 2012 (Table 5). Images from this comparison showed clearly that fish avoidance was reduced by the larger fish passage openings in the new antennas. Mean passage rate of adult fish that approached the pile dike array was 51.2% in 2013 compared with 4.2% in 2012; this represented over a tenfold increase. The proportion of adult fish that avoided the antennas and traveled around the antennas or dissapeared from view before an exit route could be determined also declined in 2013 (46.1%) compared with 2012 (92.2%).

In addition to the larger antenna openings used in 2013, we also reinstalled the 6.1- by 6.1-m guidance wing along the downtream side of antenna coil 1. This installation was similar to that used in 2012 to encourage fish passage through the antenna and to discourage fish from avoiding antenna passage by exiting downstream to detour around the terminal piles. The wing extended from the surface of the water column at MLLW to the river bottom.

Table 5. Adult salmonid behavior and passage in 2012 (small antennas) and 2013 (large antennas) using a DIDSON acoustic camera to monitor fish behavior.

| Observation | Time observed (h) | Total adult salmonid observed (N)* | Adult behavior class (%) Avoided detection | Passed through piles | Passed through an antenna |
|---|---|---|---|---|---|
| 28 Aug 2012 | 6.6 | 289 | 87.5 | 5.2 | 7.3 |
| 9 Sep 2012 | 4.9 | 290 | 96.9 | 2.1 | 1.0 |
| Mean | -- | -- | 92.2 | 3.6 | 4.2 |
| Total | 11.5 | 579 | -- | -- | -- |
| | | | | | |
| 20 Aug 2013 | 6.3 | 145 | 37.2 | 5.5 | 57.2 |
| 27 Aug 2013 | 1.8 | 182 | 54.9 | 0 | 45.1 |
| Mean | -- | -- | 46.1 | 5.5 | 51.2 |
| Total | 8.1 | 327 | -- | -- | -- |

* The majority of the fish observed in both years were likely adult fall Chinook salmon based on run timing and general body shape; it was not possible to reliably distinguish adult steelhead.

# Species Composition

## Adult Salmonids

**Spring Chinook—**Detection equipment was re-installed and activated in early March 2013, prior to the migration period for adult spring Chinook salmon. Between 8 April and 6 July, we detected only 21 adult spring Chinook salmon originating upstream from Bonneville Dam. For these 21 fish, survival to Bonneville Dam was 90.5% (± 14.6%; Table 2). Travel time to Bonneville Dam ranged 2.9-6.4 d for these individuals, with longer travel times for fish arriving earlier (April-early May) than for those arriving later in the season (Figure 6).

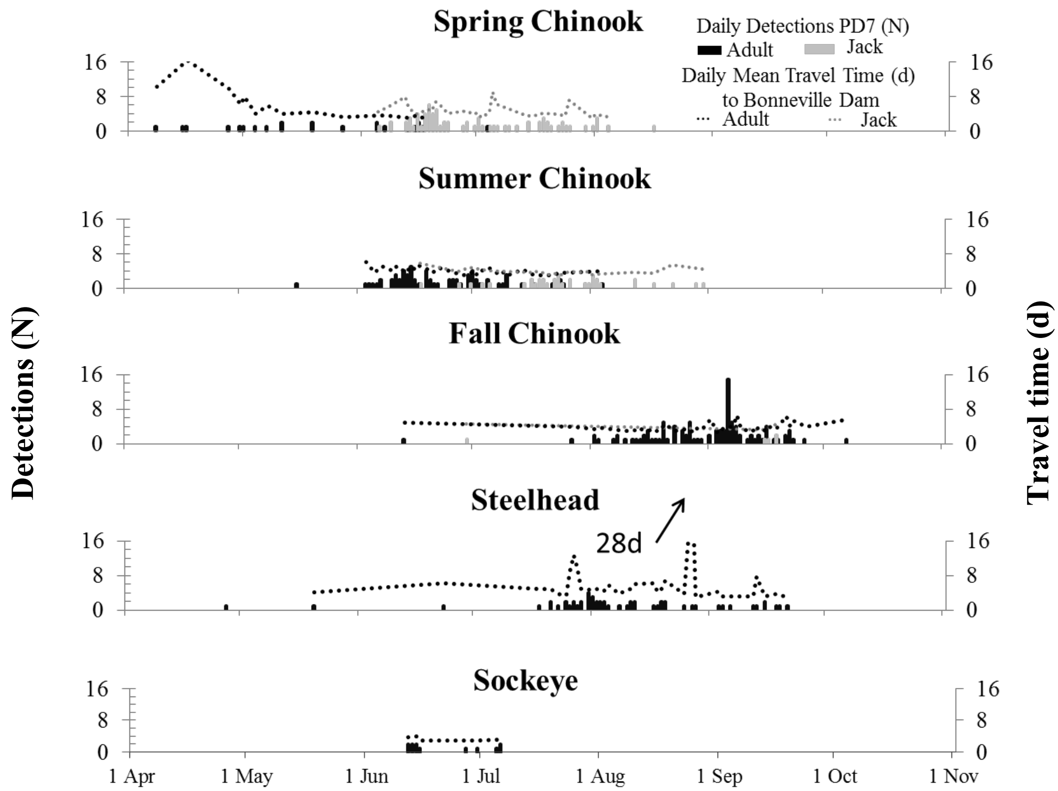


Figure 6. Daily detection numbers and daily mean travel time (d) from the pile dike array to Bonneville Dam for adult and jack salmonids in 2013 (coho not shown, N = 3, mean 3.0 d). Most dates show travel time for a single fish; for dates with more than one fish present, mean travel time was plotted.

We detected one adult spring Chinook salmon that originated from the Willamette River Basin. This fish had been caught, tagged, and released as a juvenile into the McKenzie River on 5 November 2010. We detected this fish at the pile dike on both 4 and 6 July 2013, and it was later detected at Willamette Falls Dam on 14 July. This fish was the only adult salmonid detected on multiple days at the pile dike and the only fish subsequently detected at Willamette Falls Dam.

For jack spring Chinook salmon, survival to Bonneville Dam was lower than for adults (67.6% ± 10.8%, N = 74; Table 2). Detection dates at the pile dike array were much later in the season for jack than for adult spring Chinook (5 June-16 August). However, for jack spring Chinook, travel time from the pile dike array to Bonneville Dam was similar to that of adults (3.0-12.6 d; Figure 6).

**Summer Chinook**—Between 16 May and 4 August we detected 68 adult summer Chinook salmon. For these fish, survival to Bonneville Dam was 89.6% (± 7.4%) and median travel time was 3.7 d (range 2.7-6.6 d; Table 2). The larger sample size of adult summer Chinook produced a more accurate survival estimate than was possible for adult spring Chinook. Travel times to Bonneville Dam were also more consistent for summer than for spring Chinook salmon throughout their respective migration periods.

Two adult summer Chinook exhibited abnormal migration behavior and were excluded from our travel time analysis. One of these individuals (3D9.1C2E0858EF), was tagged and released as an adult at Bonneville Dam in 2013. This fish migrated upstream to The Dalles Dam and was detected in a fishway 4 d after release. It then fell back downstream and was detected on the pile dike array 10 days later (17 June) but was never detected subsequently.

The second fish was transported as a juvenile from Little Goose Dam on 10 May 2012 and released below Bonneville Dam (McCall hatchery source -3D9.1C2DBEE489). As an adult, this fish was detected ascending fishways at Bonneville Dam on 17 June and at The Dalles Dam on 20 June. It then fell back, reascended, and was detected again on 25 June at Bonneville and on 27 June at The Dalles. This fish fell back a second time and was detected at the pile dike on 2 July. It again reascended and was detected on 5 July at Bonneville and on 6 July at The Dalles. It fell back one last time and was detected for a third time at Bonneville on 11 July, after which it migrated upstream and was detected at The Dalles, McNary, Ice Harbor, and Lower Granite Dam and the South Fork Salmon River. It was recaptured for spawning on 23 August at McCall Hatchery.

For the 36 jack summer Chinook salmon detected at the pile dike in 2013, survival to Bonneville Dam was 83.3% (± 12.4%; Table 2), higher than any other jack salmonid group. Summer Chinook jacks migrate later than adults, and these fish were detected between 17 June and 3 September (Figure 6); travel times to Bonneville Dam ranged 2.9-5.8 d (median 3.7 d).

**Fall Chinook**—Between 18 June and 13 October, we detected 101 adult fall Chinook at the pile dike array, (Table 2, Figure 6); survival of these fish to Bonneville Dam was 92.1% (± 5.4%). Higher detection rates contributed to more accurate estimates of survival for this group than for other groups. Median travel time to Bonneville Dam was 3.2 d for adult fall Chinook and was among the shortest travel time of all groups measured (range 2.2-15.0 d). Between 29 June and 18 September, five fall Chinook salmon jacks were detected (4 during 15-18 September). Survival to Bonneville Dam was 80.0% (± 35.8%) for jacks from this group, and median travel time was 4.2 d (range 3.2-5.0 d; Table 2, Figure 6).

**Steelhead, Sockeye, and Coho**—Fifty four adult steelhead were detected on the pile dike array between 27 April and 21 September; however, all but 4 of these fish were detected between 18 July and 21 September (Figure 6). For these steelhead adults, suvival to Bonneville Dam was 92.5% (±7.2%) and median travel time was 4.5 d (range 3.1-28.7 d; Table 2). One individual, originating from Abernathy Fish Hatchery in the lower Columbia River, was excluded from these analyses.

Twelve adult sockeye salmon were detected on the pile dike array between 12 June and 6 July; all 12 were subsequently detected passing Bonneville Dam (survival 100.0% ± 0%; Table 3). Median travel time for these fish was 3.1 d (range 2.7-4.7 d).

Two adults and one jack coho salmon were detected on the pile dike array in 2013 (Table 2). One of the two coho adults was detected at Bonneville Dam 3 days later on 6 September. The remaining adult and jack were detected at the pile dike on 7 September and 1 June, respectively, but were never detected at the dam.

## Juvenile Salmonids

Between 10 April and 26 August 2013, 619 juvenile salmonids were detected at the pile dike (Table 2; Figure 7). Presence of juveniles peaked during 5-16 May, when daily detections exceeded 9 per day. This peak coincided with the period of highest abundance measured with the trawl PIT-tag detection system, which was operated in the thalweg adjacent to the pile dike (Morris et al. 2014).

Based on data from tags with release information recorded in PTAGIS, detections of juvenile Chinook were most prevalent, with 236 spring, 33 summer, and 195 fall run Chinook detected on the pile dike array (5 unknown). Of the 97 juvenile steelhead detected, 82 were summer run (2 winter run and 13 unknown). Also detected were 52 juvenile coho, 4 sockeye, and 1 cutthroat trout (detected 21 April).

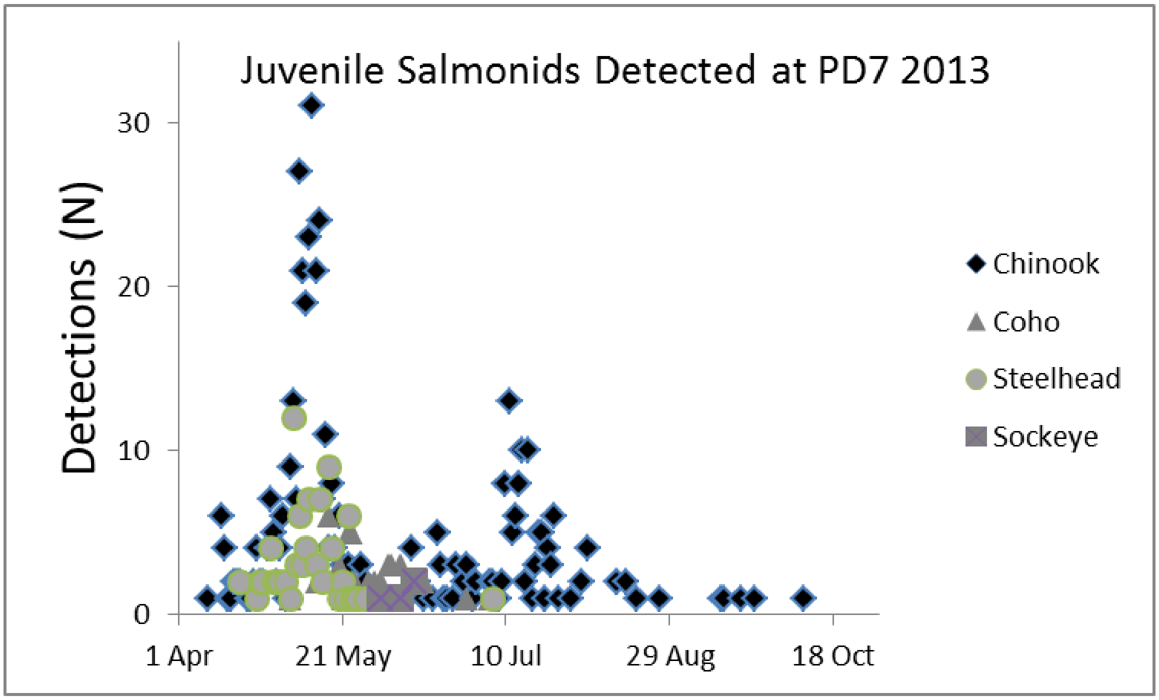


Figure 7. Temporal distribution of juvenile salmonids detected on the pile dike detection system at rkm 70 during 2013 (N = 619). Not shown is the cutthroat trout detected on 21 April.

## Sturgeon and Other Species

Of the non-salmonid species detected at the pile dike array, perhaps the most interesting was white sturgeon. Since 2011, a total of 21 individual sturgeon have been detected at the pile dike, with 10 detected for the first time in 2013. All detected sturgeon were tagged by the Oregon Department of Fish and Wildlife between 2008 and 2013, and all were released to the main-stem Columbia River between rkm 25 and 329.

One sturgeon (3D6.00087E56F9) was first detected on 18 August 2011 and remained near the pile dike through fall when antennas were removed for the winter. This sturgeon reappeared the following May and was detected almost daily through fall 2012. The same sturgeon again reappeared at the pile dike array in May 2013, again remaining through fall. Its behavior suggested strong fidelity to the pile dike area (Parsley et al. 2008). However, most sturgeon (18 of 21) were detected for a few minutes on a single day, suggesting migration past the pile dike (or mortality).

Since 2011, we have detected 3 northern pike minnow (27 Aug 2011, 27 May 2013, and 4 Sep 2013). We also detected 8 fish with no release information in PTAGIS.

# Origins of Detected Fish

## Adults and Jacks

Adult salmonids detected on the pile dike array at rkm 70 represented many groups released from multiple hatcheries and other sites. We grouped adult and jack detections by regional basin of origin as Snake River, upper Columbia River, mid-Columbia River, and lower Columbia River (including the Willamette River).

For adult and jack salmonids, origins of detected fish varied by life history and run type (Figure 8). However, most of these adults had originated in the Snake River, including 50% of the spring Chinook adults, 75% of summer Chinook jacks, and 89 and 100% of fall Chinook adults and jacks, respectively. For steelhead, 65% of adults detected on the pile dike had originated in the Snake River Basin.

In contrast, 81% of summer Chinook adults and 58% of sockeye had originated in the Columbia River upstream from McNary Dam. The largest proportion of spring Chinook jacks (47%) had originated in the middle Columbia River downstream from McNary Dam.

For brood years returning in 2013, annual effort to PIT-tag juvenile salmonids was low for fish originating downstream from Bonneville Dam compared to tagging effort in other areas. There were a few detections of fish released to the lower Columbia River in all adult groups except sockeye. However, no jacks were detected that had originated in the lower Columbia River Basin. Two of the three coho salmon (1 adult and 1 jack) had originated in the upper Columbia River; the remaining adult coho had originated in the Snake River Basin.

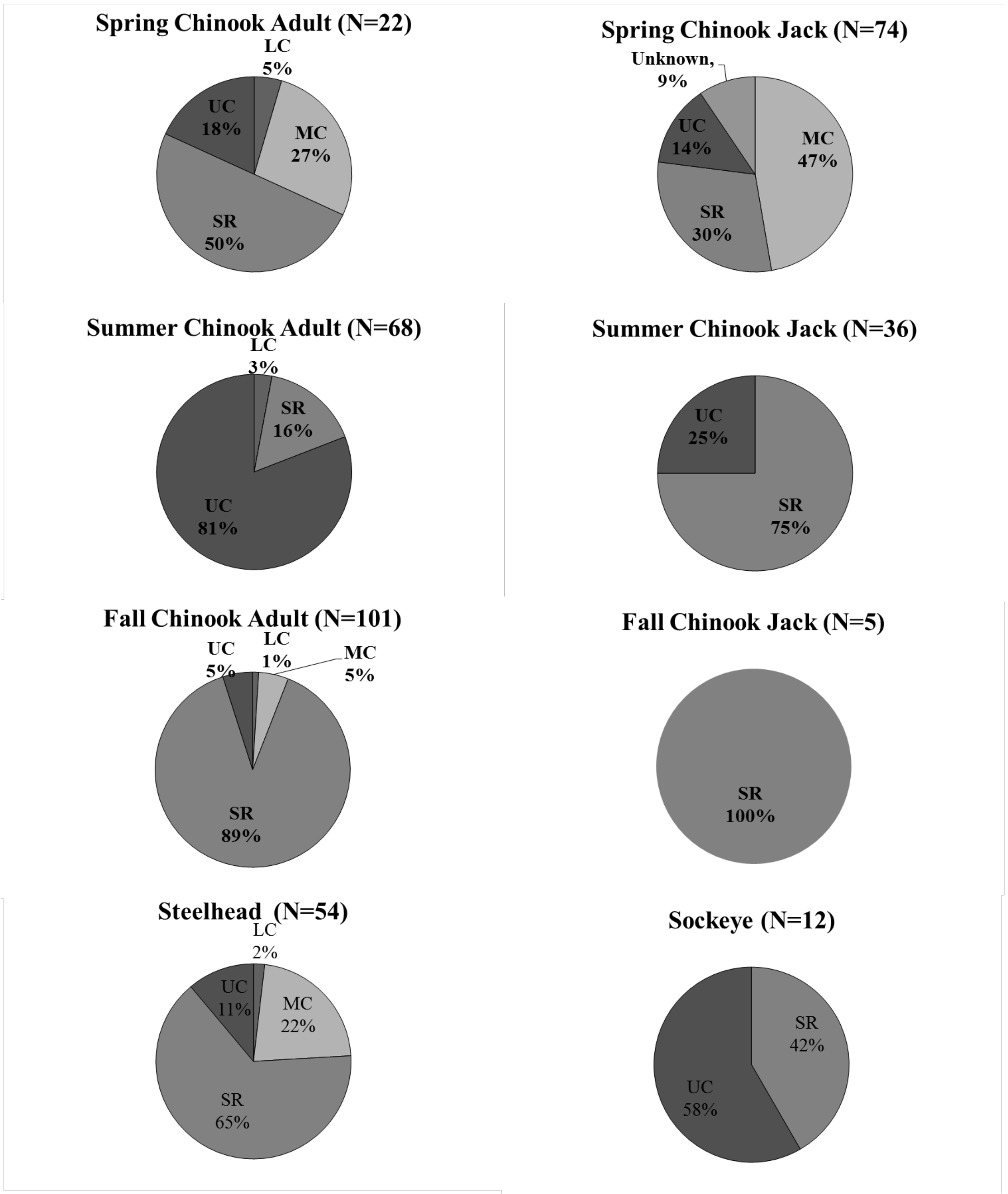


Figure 8. Origin of adult and jack salmonids detected on the pile dike array at rkm 70 in 2013 (3 coho not plotted). Abbreviations: Snake River Basin, SR; Upper Columbia, UC; Middle Columbia, MC; Lower Columbia River Basin, LC.

## Juvenile Salmon

We compared origin and run composition between juvenile salmonids detected on the pile dike array with those detected in the estuary pair trawl during the same date range (Morris et al. 2014). Both systems detected PIT-tagged juvenile salmonids near rkm 70, but the pile dike array is located closer to shore and adjacent to the thalweg, whereas the trawl samples entirely within the thalweg.

Of the 619 juvenile salmonid detections on the pile dike array in 2013, most (98.1%) occurred during the sample period for the pair trawl (25 March-25 July). Trawl sampling intensity was intermittent, with a single daily shift operating 3-5 d week$^{-1}$ until 29 April followed by an increase to 13 h d$^{-1}$ using two daily crews until 9 June (commensurate with the abundance of PIT-tagged fish in the area). Thereafter, trawl sampling returned to a schedule of 3-5 d week$^{-1}$ until 25 July, when sampling concluded with over 22,000 detections.

River basin source of origin for juvenile fish differed between sample methods (Figure 9). Most fish, (42%) detected on the pile dike had originated in the middle Columbia River between McNary and Bonneville Dam. In contrast, most fish detected in the trawl were from the Snake River (67%). Only 13% of juvenile fish detected in the trawl had originated in the middle Columbia River, and 31% of the juveniles detected at the pile dike had originated in the Snake River.

This inverse relationship between detection location and source of origin suggests that juvenile fish originating below McNary Dam are more shoreline-oriented during migration through the estuary than fish released further upstream. For fish from other major release areas and for those of unknown origin, detection rates were similar between thalweg (trawl) and shoreline (pile dike) detection areas.


Figure 9. Origin of PIT-tagged juvenile salmonids detected on the pile dike vs. with the trawl system in 2013. River basin abbreviations: Snake River SR, Upper Columbia UC, Middle Columbia MC, and Lower Columbia LC.

Juvenile salmonid species and run composition also varied between sample methods (Table 6). Although proportions of spring and summer Chinook salmon in the total catch were similar between the trawl and pile dike systems, the proportion of fall Chinook was considerably higher in the pile dike (31%) than in the trawl sample (5%). Conversely, from the total number of juvenile fish detected in each system, those detected in the trawl contained a higher proportion of steelhead (41%) than those detected at the pile dike (16%). Both methods sampled similar proportions of coho, sockeye and cutthroat trout.

Table 6. Percent of juvenile PIT-tagged fish detected at the pile dike array vs. in the trawl detection system during 2013. Species\run categories were determined using release information in PTAGIS.

| | Pile dike array | | Trawl detection system | |
|---|---|---|---|---|
| Species/run | (N) | (%) | (N) | (%) |
| Spring/summer Chinook | 265 | 43 | 10,400 | 45 |
| Fall Chinook salmon | 195 | 31 | 1,061 | 5 |
| Coho salmon | 52 | 8 | 747 | 3 |
| Steelhead | 97 | 16 | 9,298 | 41 |
| Sockeye salmon | 4 | 1 | 1,023 | 4 |
| Chum salmon | 0 | 0 | 1 | 0 |
| Sea-run cutthroat trout | 1 | 0 | 7 | 0 |
| Unknown | 5 | 1 | 342 | 1 |
| Total | 619 | 100 | 22,879 | 100 |

Dawley et al. (1986) found relative abundances of subyearling fall Chinook salmon many times greater in near-shore waters at Jones Beach (rkm 75) based on evaluations of species composition between catches from a beach seine and those from a purse seine set in adjacent channel areas. At the pile dike array, there were 3 release groups of subyearling fall Chinook with more than 10 detections. These fish were detected in June and July, and we compared their median travel times to those of fish from the same release groups that were detected in the thalweg using the trawl (Table 7). Median dates of detection between these groups were within 3 d of one another. Thus, it appeared that each method sampled fish from the same population that migrated through different areas of the same reach. We did not find a distinction between shoreline migrants and mid-river migrants (i.e., different median dates of passage), which might have occurred due to slowing of fish that moved along the shoreline.

Table 7. Date of median fish detection for three release groups of subyearling fall Chinook salmon detected in the thalweg using the trawl system and detected adjacent to the thalweg on the pile dike array during June and July 2013. Only groups of fish with 10 or more detections on the pile dike array are shown.

| Release site | Pile dike array | | Trawl detection system | |
|---|---|---|---|---|
| code | N | Median detection date | N | Median detection date |
| DESCH1 | 10 | 12 Jul | 39 | 15 Jul |
| LWSH | 42 | 17 Jul | 77 | 16 Jul |
| PRDH | 32 | 11 Jul | 91 | 12 Jul |

# Discussion

Much work during 2013 was focused on upgrades to the pile dike detection system using the larger antennas made possible by the IS1001 transceiver system (Biomark, Inc.). In early March, we deployed the system using a configuration similar to that used during 2011-2012, but with larger antennas. These antenna coils were 8 times larger than the maximum size possible using the FS1001M transceiver (Destron Fearing, Inc.). The new antennas allowed us to increase the PIT-tag detection coverage area by 60% over the area covered in 2012 with fewer antenna coils (3 vs. 6 coils). These changes considerably increased detection efficiency of the pile dike detection system.

Initially, the larger antennas were housed with rigid, PVC pipe. However, several eventually leaked. In August, we replaced all but one of the rigid antennas with flexible antennas housed in 1.9-cm-diameter hose. By late August we were able to deploy two additional flexible antennas on the pile dike array, further increasing detection efficiency.

In their summary of research using PIT-tag instream monitoring systems, Downing et al. (2013) enumerated major technological limitations to instream monitoring systems, most of which were related to transceiver limitations. This list included a limited number of antennas that can be operated with a single transceiver (6), and limited allowable distance between the transceiver and antennas (45 m). Perhaps most importantly, Downing et al. (2013) pointed out the need to eliminate the recommended 5-cm air gap around antenna wires.

They suggested a transceiver that could operate with a thinner air gap, or no gap, to reduce the cost, complexity, and footprint of antennas in stream or river applications. Smaller antennas would reduce drag and improve stability under high flows. We have constructed and deployed waterproof rigid antennas with the 5-cm gap for both the trawl and pile dike systems and have experienced the difficulties associated with deployment of buoyant antennas (Magie et al. 2013; Morris et al. 2014).

Four flexible antennas were deployed and operational on the pile dike from late August through early November, when the system was removed due to seasonal loss of solar power. Initial deployment of the IS1001 transceiver has shown that it appears to address many of the previous limitations. In addition to increasing detection efficiency, the flexible antennas proved less expensive to construct and were in fact easier to deploy and retrieve than the rigid PVC antennas. To the extent they were evaluated in 2013, the flexible antennas appear to be less susceptible than rigid antennas to fractures (and subsequent leaks) caused by vibration from the river current.

Overall, the IS1001 transceiver system was able to operate antennas successfully at a distance of over 75 m. The new transceiver makes feasible the expansion of instream monitoring to other large riverine environments. Antenna arrays can be built and deployed at much lower cost than was possible using rigid antennas with a 5-cm air gap. Flexible antennas can be installed at other pile dike locations and may also be useful in mobile applications that target juvenile or adult salmonids in a variety of riverine or reservoir habitats.

It should be noted that site selection for any PIT monitoring system should include evaluation of ambient EMI (Downing et al. 2013). No shielding of antennas was required at the pile dike location, which had relatively low levels of EMI. This may not be the case for other potential installations sites; it will certainly not be the case for installations near dams, which require shielding of PIT monitoring system due to the many sources of EMI at these locations.

Detections at the pile dike array showed a pattern of variation by life history stage based on antenna location and orientation to the flow. Adult and jack salmon were detected almost exclusively on antennas oriented parallel to the flow. Conversely, juvenile salmonids were detected mostly on antennas oriented perpendicular to the flow. Locations near the terminus of the pile seemed important for both life history types. We lacked sufficient detection data to evaluate such patterns for antennas placed closer to shore, since these were not installed until after the majority of spring run fish and juveniles had passed.

To date, the pile dike antennas located parallel to and in the lee of the current, behind the terminal pilings (nearest the thalweg) have detected the most adults and jacks. The low numbers and short time frame for juveniles detected at this location suggests that juveniles did not mill on the downstream side of the pile dike. Most juveniles were detected on the upstream side of the pile structure and may have avoided it entirely by navigating around the terminus to continue downstream (Ledgerwood et al. 2000). Both pass-by and pass-through detection was possible on all antenna coils.

Impacts to survival of adult salmonids by pinnipeds have been difficult to measure except in the tailrace of Bonneville Dam (Stansell et al. 2013). In the estuary, it is particularly difficult to enumerate the pinniped population, which is mostly transitory. However, evidence of pinniped predation on salmon in this area has been observed by researchers and anglers for many years (Harmon et al. 1994; angler reports of catch lost to sea lions). While fishing may be closely regulated, pinniped recruitment to the estuary has increased steadily since the passage of the Marine Mammal Protection Act of 1972.

Reports by anglers indicate that spring Chinook in this reach migrate near the shoreline at shallower depths than other Chinook run types (J. Mather, sport fisher, pers. commun.). Spring-run stocks may be more dispersed than other run-types because they migrate during the spring freshet, when river volume is highest. It is possible that spring Chinook sought out the areas behind piling as rest locations. Although pinnipeds prey on salmon of all run types, predation in tidal freshwater reaches is probably highest for adult salmon that migrate between February and May, the period of highest pinniped abundance.

For individuals from stocks released above Bonneville Dam, detection at the pile dike with no subsequent detection at Bonneville or another upstream dam indicates straying or mortality. The most likely sources of mortality in tidal freshwater reaches of the estuary are fishing pressure and pinniped predation.

Adult fish that move downstream through spillways, turbines, or fishways after initially ascending a fish ladder are termed "fallbacks." It is not unusual for a PIT-monitoring system to record fallbacks at a dam. However, the pile dike detected two fallbacks that descended much further downstream (160 km) than has been recorded previously. Our observation that a fallback may descend all the way to brackish or salt-water areas of the estuary is novel. Both of these fish were detected again at the pile dike array during re-ascension.

Fallback and straying behavior has been associated with transportation of juvenile salmonids (Boggs et al. 2004, Keefer et al. 2008), and our observations partly supported this relationship: one fallback we observed in the estuary had indeed been transported. Detections from the pile dike array have provided limited but valuable insight to fallback behavior.

We detected 2.6% of all adult and jack summer Chinook salmon detected ascending fish ladders at Bonneville Dam in 2013. Summer Chinook thus had higher detection efficiency at the pile dike than any other salmonid species or run type. Timing at the pile dike differed markedly between adult and jack summer Chinook: most adults were detected before 10 July (88%), while most jacks were detected after this date (86%). We also detected 101 adult and 5 jack fall Chinook salmon at the pile dike array, more than any other species or run type. However, these detections represented only 0.7% of the adult and jack fall Chinook detected in fishways at Bonneville Dam.

Differences among fish species, origin, detection proportion, run-type, and detection number were observed among fish detected at the pile dike array in 2013. This variation indicates a mixing of stocks in the estuary. Adults groups with higher rates of detection at the pile dike probably reflect juvenile releases with more PIT-tagged cohorts.

They may also reflect higher SARs. However, the most likely factor affecting detection numbers at the pile dike is fish behavior and the variation in migration pathways selected by different stocks.

Some information on juvenile migration behavior has also been derived from detections on the pile dike system, which samples the same tidal freshwater area as the trawl system (near rkm 70). For example, compared to the trawl, the pile dike system detected a higher proportion of mid-Columba stocks (42 vs. 13%) and a lower proportion of Snake River stocks (31 vs. 67%). This pattern was similar to that observed by Dawley et al. (1986) when they compared purse- and beach-seine catches in the same area and found mid- and lower-Columbia River fish migrating closer to the shoreline and Snake and Upper Columbia River fish closer to the thalweg. Proportions of juvenile fish from the upper Columbia River were similar between detection systems (22 vs. 16%).

Expanded deployment of the IS1001 transceiver and flexible antenna systems in the estuary can maximize detections of both juvenile and adult salmonids, augmenting the accuracy of survival and travel time estimates and helping to pinpoint problems in specific reaches. Such estimates can provide insight into mortality from pinniped predation and fishing pressure as well as stock-specific run timing in tidal freshwater reaches. As a next step, we plan to adopt the flexible antenna for use in a mobile application that can target juvenile or adult salmonids in a variety of riverine or reservoir conditions.

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