Development of a Passive Integrated Transponder (PIT) Tag Detection System for Adult Salmonids in the Lower Columbia River

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EXECUTIVE SUMMARY

We installed and operated a prototype fixed-site monitoring system to detect migrating adult PIT-tagged salmonids in the tidal-freshwater portion of the Columbia River estuary during 2011-2012. Detections were used to evaluate arrival timing and subsequent timing and survival to detection locations upstream. The system was installed during August 2011 at the terminus of a pile dike structure (PD7) at rkm 70. The system was initially comprised of an array of four antennas that spanned the entire water column at low tide. This array was oriented parallel to the current about 8 m from the thalweg.

During fall 2011, we evaluated the system using a DIDSON (dual-frequency identification sonar) acoustic video camera and found that adult salmonids were reluctant to pass through the antenna. We concluded that although the system had been installed in a migration pathway used by some salmonid stocks, most adult detections were from fish passing near the detection field rather than through the antenna array. In 2012, we deployed a short mesh wing on the downstream end of the pile dike to improve passage by discouraging fish from swimming around the array.

After evaluating net wings of different mesh-size and length, we found that a 6-m square, large-mesh wing effectively blocked the avoidance path observed in 2011. The net wing appeared to increase occurrences of adult fish circling near the antenna array; however, these fish were still reluctant to pass though. For example, some adults that avoided the antennas were observed passing through a gap between the pilings near the upstream end of the array. To detect fish using this avoidance path, we installed two additional vertical antennas during August 2012.

The prototype monitoring system at PD7 was operated between August 2011 and October 2012. During this period, a total of 136 adult and juvenile PIT-tagged fish were detected, with 21 detections in 2011 and 115 in 2012. Although the system was designed to detect adults, we also detected juvenile salmonids and other PIT-tagged species. Detections of adult fall Chinook salmon were higher in 2012 than in 2011, when the wing was not present (25 vs. 4 fish total, respectively).

Technology presently under development would allow for antenna openings in excess of 3 × 6 m. These larger openings would eliminate the need for an array of four individual coils. The array could be replaced by a single coil large enough to span the same area, but with no internal framework to disrupt or block fish migration. Specifications for this new equipment also imply that longer cables can be used to connect antennas with their power supply, allowing for larger arrays than are possible with the present technology. Larger antenna openings and larger arrays would likely

reduce or eliminate fish avoidance of the pile dike detection system, allow more appropriate customization of detection systems at individual sites, and result in higher detection efficiency rates for migrating adult salmonids.

Finally, we propose testing of a mobile platform detection system just downstream and shoreward from PD7 near the 10-m depth contour. We believe adult salmon migrate along this contour and would be intercepted and guided through an antenna system before reaching the pile dike. The pile dike would provide some protection from debris accumulation within the mobile platform system. If successful, this mobile platform system could be used to evaluate other locations during the spring or fall adult salmon migration periods. We believe multiple PIT-tag detection systems are needed to appropriately evaluate adult salmon mortality below Bonneville Dam.

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INTRODUCTION

Since the 1980s, the passive integrated transponder (PIT) tag has been used to monitor the migration behavior, timing, and survival of juvenile and adult Pacific salmon *Oncorhynchus* spp. in the Columbia River Basin. In recent years approximately 2.5 million PIT-tagged juvenile salmonids have been released annually (PSMFC 2011).

Detection of PIT tags occurs through an electromagnetic wave transmitted through an antenna, which excites the transponder within the tag. Detection antennas have been installed throughout much of the basin to record passing PIT-tagged fish. They are typically installed in locations where flow is manageable and fish pass within reading range, such as at hydroelectric facilities or in tributary streams (Prentice et al. 1990, Downing et al. 2001). However, few antennas are deployed along the ~250 km of riverine and estuarine habitat used by migrating adult salmonids below Bonneville Dam.

Returning adult salmonids may spend considerable time in the estuary, where they are exposed to predation by marine mammals prior to reaching Bonneville Dam. Although many of these fish are PIT-tagged, there is presently no system in place to detect them below Bonneville Dam. Such detection ability would be helpful in assessing survival, run timing and predation effects in the lower Columbia River and estuary. At present, estimates of smolt-to-adult return (SAR) ratios and survival of adult salmonids are based on initial adult detections at Bonneville Dam (Dehart et al. 2012).

Detection of these adults in the estuary could provide a basis for understanding of adult timing and survival to Bonneville or Willamette Falls Dam. Unfortunately, studies in this river reach are complicated by size of the study area and diversity of conditions. To begin to address this issue, we installed a prototype fixed-site antenna detection system in the tidal-freshwater portion of the upper Columbia River estuary. Detections at this site (rkm 70) were used to evaluate arrival timing of individual adult salmonids into the estuary and their subsequent timing and survival to upstream detection locations.

In August 2011, we selected a suitable pile-dike structure and installed a passive antennae detection system at its terminus. This system covered a depth of about 8 m from near the surface to the bottom in an area adjacent to the thalweg. The prototype system was designed to detect returning adult PIT-tagged salmonids, although it also detected juvenile salmonids and other PIT-tagged species.

Study objectives were:

1) Identify suitable sites and evaluate logistics required to mount remote autonomous PIT-tag detection systems on or near pile dikes or other navigation structures in the Columbia River estuary.
2) Install a PIT-tag detection system on a pile dike and evaluate system integrity under varying hydraulic/weather and debris-loading conditions.
3) Evaluate the effectiveness of the PIT-tag detection system at a specific site.
4) Calculate survival and travel time of adult salmonids from lower Columbia River (rkm 70) to Bonneville (rkm 234) or Willamette Falls Dam (rkm 206) by comparing detections at rkm 70 with those at the dams.

METHODS

During spring and summer 2011, we searched for a suitable location to install an in-river PIT-tag detection system in the Columbia River estuary. We used a DIDSON (dual-frequency identification sonar) acoustic video camera to monitor potential sites for the presence and frequency of migrating adult fish. Selected candidate sites were near the thalweg and downstream from a pile dike, which offered some protection from high current velocities and debris loading (Figure 1). It was critical that the site have a stable structure above the spring high-water line for mounting system electronics, batteries, and solar panels. In August 2011, we installed a prototype antenna system on the terminus of a pile dike on the Oregon shore at rkm 70 (46.14661°N latitude 123.379867°W longitude; PTAGIS site code PD7).

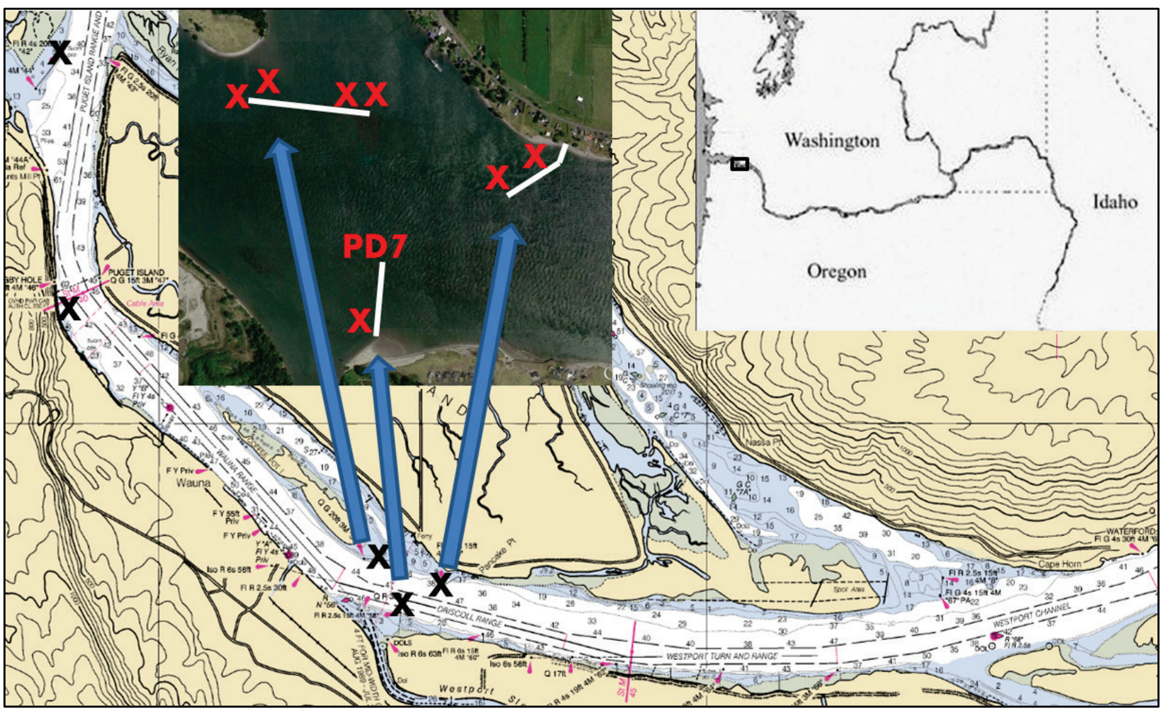


Figure 1. Locations surveyed using a DIDSON acoustic video camera to identify adult salmonid migration pathways in the lower Columbia River, summer/fall 2011. Also shown is the location of the installed PIT-tag detection system (PD7). White lines outline pile dike locations, and each red × indicates a survey site.

System installation was completed on 9 August 2011 and consisted of an array of four antennas (3.5 × 6.1 m high) at the terminus of the 230-m-long pile dike. The pile dike array spanned the entire water column at 0 m low tide (Figure 2). The array was constructed of components similar to those used with the PIT-detection trawl system, which is deployed annually in the adjacent navigation channel (Morris et. al 2012). A multiplex transceiver was used to record PIT-tag interrogation data and generate system status reports which were downloaded daily via cellular modem (Destron Fearing FS1001M).

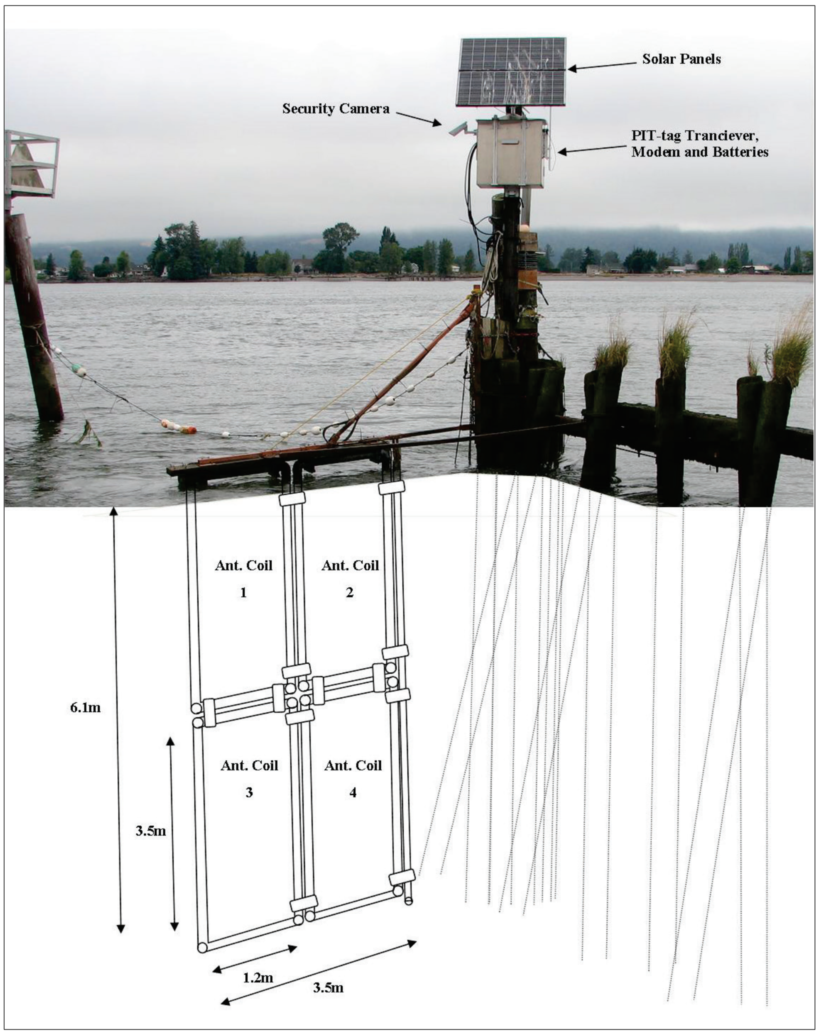


Figure 2. Configuration of antennas for the PIT-tag detection system at rkm 70 in the Columbia River estuary (PD7), August 2011.

Mounts for the antenna and an enclosure box for the electronic components were chained to a bundle of 6 pilings at the end of the pile dike. The top of the piling bundle was approximately 3 m above the extreme high tide mark. A crank and trolley system was installed on the piling, allowing us to maneuver the electronics box up or down for access from a boat as needed. A variety of anchors and lines were used to secure the antenna system in the lee of the pile bundle at a right angle to the pile dike. All data were relayed to computers onshore daily using a cellular modem. Transferred data files were post-processed and submitted to PTAGIS on a weekly basis.

The PD7 antenna system was monitored visually using a wireless security camera. The entire system was powered by 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, the antenna and electronics box were removed on 25 October 2011, when battery failure was imminent.

The antenna system was reinstalled at PD7 on 24 March 2012. The system remained operational until 24 October 2012, when it was again removed for the winter. Our goal was to maintain a consistent sample through the adult salmon migration periods from spring through fall. Incidental PIT-tag detections of juvenile salmonids and other species were also anticipated.

A DIDSON acoustic camera was used periodically to determine the presence/absence of adult fish, assess effectiveness of the system, observe whether adult fish avoided the system, and evaluate and test in situ modifications aimed at reducing fish avoidance. We deployed a short mesh wing on the antenna array in 2012 to prevent passing fish from swimming around the antenna. The wing was attached parallel to the downstream end of the pile dike. We evaluated wings of different mesh-size and length, using the DIDSON camera to quantify fish behavior during approach to the antennas. We also used the DIDSON camera to evaluate other potential locations for a pile dike antenna system.

RESULTS

The prototype PIT-tag detection/monitoring system was operated at PD7 between 9 August and 25 October 2011, and between 24 March and 24 October 2012. A total of 136 PIT-tagged fish were detected during this period, with 21 detections in 2011 and 115 in 2012; 59 of these detections were adult salmon (Table 1).

Except for brief periods of high environmental noise or during testing, the system operated continuously. For example, in spring 2012, a loose sub-surface bolt in the mounting structure caused environmental noise that affected performance of antenna coil 1 for approximately 2 h daily. In June, the loose bolt was discovered and tightened, eliminating the noise. Following this adjustment, operation was nearly noise-free until the system was removed in late October 2012.

Based on DIDSON camera observations during fall 2011, adult salmonids were clearly reluctant to pass through the antenna system, and that most detections were from fish passing by the antenna field rather than passing through the coils. These "pass-by" fish theoretically swam within 45 cm of the antenna opening. Unfortunately, the majority of adult salmon we observed approaching the antenna did not move within this range. It was also clear that detection numbers would increase substantially if more of the adult salmon present would pass through the antenna system rather than avoiding it.

The 6-m square, large-mesh wing installed in 2012 effectively blocked the avoidance path. Placement of the wing encouraged adult salmon to pass through or near the antennas. As a result, detections of adult fall Chinook salmon in 2012 were improved over 2011, when the wing was not present (25 vs. 4 fish total, respectively). However, we observed adult salmon avoiding the antenna by passing around the wing or through a gap in pilings near the upstream side of the 4-coil array. To detect fish passing through this gap, we installed two additional vertical coils in August 2012 (coils 5 and 6).

Table 1. Total PIT-tagged fish detected at PD7, mean travel time and survival to Bonneville Dam or Willamette Falls Dam, during two sample periods: 9 August and 24 October 2011 and 21 March to 24 October 2012.

Species/year	Number Detected (N)	Bonneville Dam Travel time (d)	Bonneville Dam Survival (%)	Willamette Falls Dam Travel time (d)	Willamette Falls Dam Survival (%)
	Salmonids				
Fall Chinook[a]					
Adult 2011	4	4.3	75	--	
Jack 2011	1		0		
Adult 2012	25	3.9	88	--	
Jack 2012	8	3.8	71	--	
Spring Chinook					
Adult 2012[b]	5	17.6	100	13.6	100
Jack 2012	7	4.9	86	--	
Steelhead					
Adult 2011	7	4.5	100	--	--
Adult 2012[b]	17	5.3	80	5.4	100
Coho					
Adult 2011	1	5.0	100	--	
Jack 2012	1	7	100	--	
	Juveniles and non-salmonid species 2011-2012				
Sturgeon[c]	15				
Juvenile salmonids	44				
Northern Pikeminnow[d]	1				
Total fish all species	136				

[a] Counts include 2 summer Chinook salmon "jacks" salmon detected 19 Aug 2011 and 8 Aug 2012.

[b] Includes 2 spring Chinook salmon and 1 steelhead detected at Willamette Falls Dam.

[c] Includes 3 fish detected multiple times in both years.

[d] A lone northern pikeminnow was detected on 27 August 2011 and had been 444 m at tagging on 18 April near Longview, Washington (rkm 111).

Adult Chinook Salmon and Steelhead

Fall Migration 2011

Of the 21 PIT-tagged fish detected at PD7 in fall 2011, 5 were adult Chinook salmon, and 3 of these 5 were later detected at Bonneville Dam (Table 1; Appendix Table 1). Mean travel time from PD7 to Bonneville Dam for these three fish was 4.3 d. Of the 2 adult Chinook detected at PD7 but not at Bonneville, one had been reared at Spring Creek Hatchery (rkm 269) but had been transported and released below Bonneville Dam at Tenasillahe Island (rkm 60). Its potential classification as a mortality is uncertain due the possibility of straying. The other Chinook salmon was a mini-jack (summer Chinook stock) released in the Snake River at Dryden Acclimation Pond (rkm 780). This fish was presumably lost to predation or harvest, but also could have strayed.

In 2011, all adult steelhead detected at PD7 had originated upstream from Bonneville Dam, and all were subsequently detected at the dam (mean travel time 4.5 d). The one adult coho salmon detected at PD7 took 5.0 d to reach Bonneville Dam.

The DIDSON acoustic camera was used during days of expected peak adult salmon passage. On 7 September 2011, near the height of the fall run at Bonneville Dam, we observed 227 adult salmonids near the antenna within a 4.5-h period. However, only 5 of these 227 fish passed through the antenna, and none of them were tagged. Most of these fish (135 of the 227) were observed guiding along the pilings. As they neared the antenna, adult salmonids abruptly turned downstream and circumvented the system completely (Figure 3).

Of the remaining 92 fish, 47 exited the vicinity of the antenna by either passing upstream through gaps in the pilings or by reversing direction. The remaining 45 adult salmon left the camera view field before an exit route could be determined. Large numbers of smaller fish were observed readily passing through the antenna coils (DIDSON camera resolution is generally insufficient for speciation of fish of similar size and morphology).

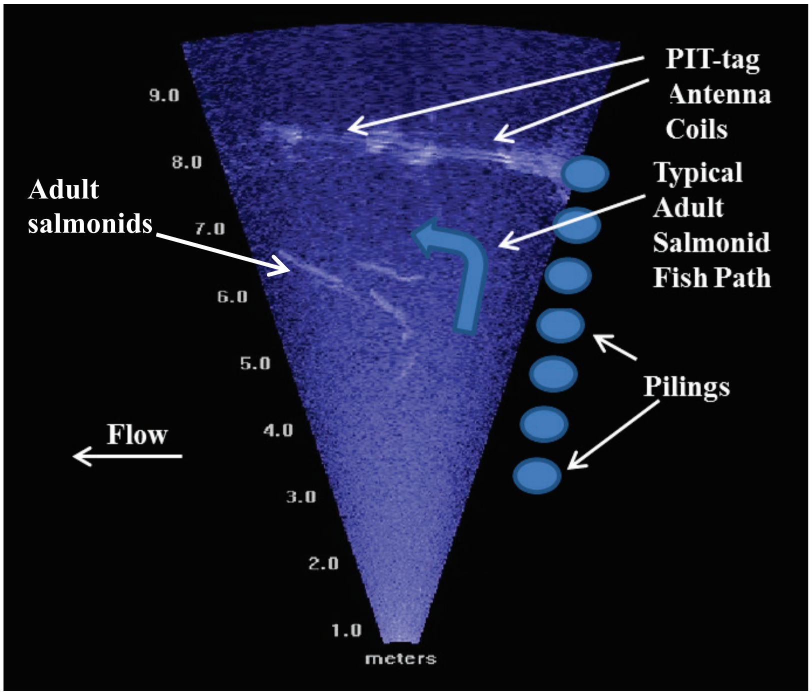


Figure 3. Typical adult salmonid antenna avoidance at PD7 (rkm 70) as observed with a DIDSON acoustic camera, 2011.

Spring Migration 2012

We reinstalled the prototype detection system at PD7 on 21 March 2012. We anticipated that during spring, the high levels of flow and turbidity, relative to those during fall, would result in less avoidance of the antenna array by adult salmon. Spring flows remained well above average, but few adult salmon were detected; we thus attempted installation of a small mesh wing (0.1-m mesh) to improve detection rates by confining fish near the antenna. Unfortunately the initial wing installation collapsed due to high current and heavy debris loading, and it had to be removed after only a few hours. We detected only 5 adult and 7 jack spring Chinook salmon in spring 2012 (Table 1; Appendix Table 2). Four of these fish were detected passing Bonneville Dam (travel time 9-33 d), and one was detected at Willamette Falls (travel time 14 d).

The DIDSON camera did not reveal large concentrations of adult salmon near PD7 during the spring migration period in 2012. However, adults may have migrated upstream past PD7 prior to our observation period. Between 24 April and 11 May, we explored other potential antenna installation sites in the vicinity of PD7 using the DIDSON camera (Figure 4). We observed no adult salmon migration pathways at any alternative location. As a result, we did not attempt to establish a second site to deploy an antenna system targeting adult spring Chinook in 2012.

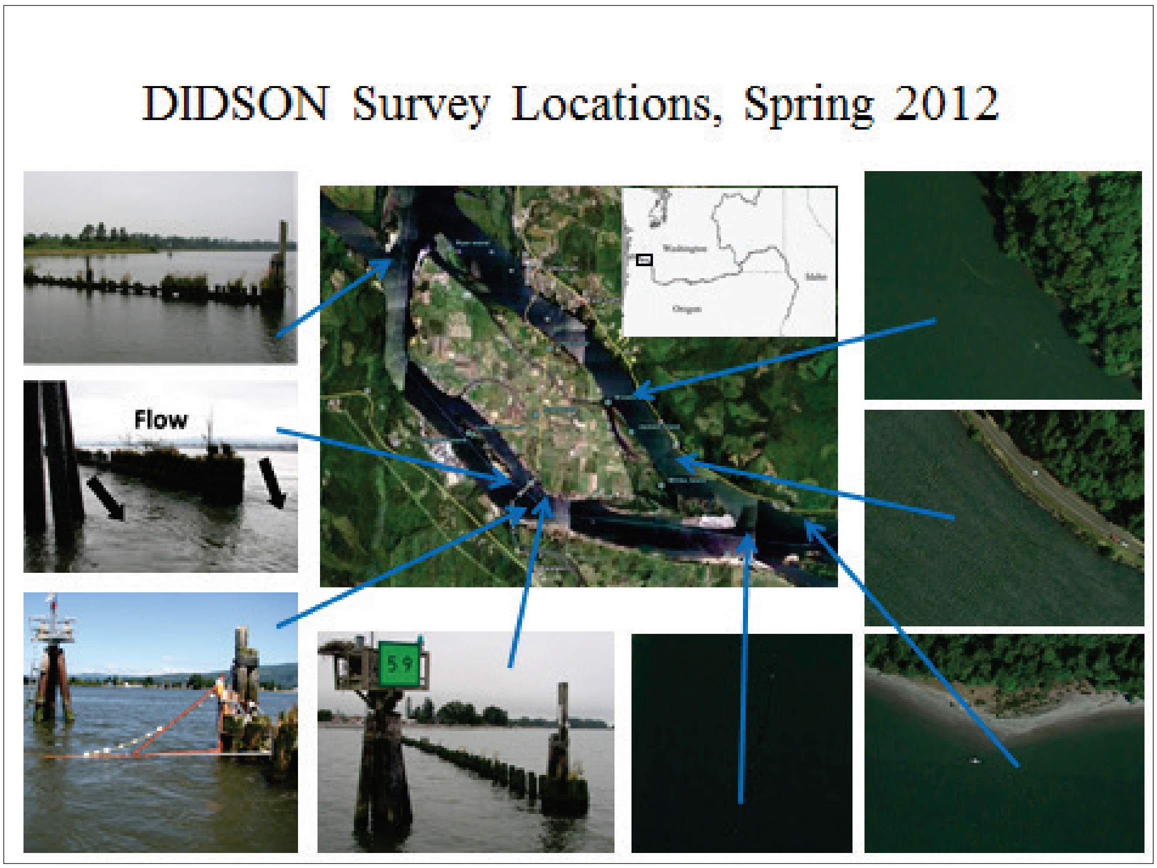


Figure 4. Locations in the Columbia River estuary near Puget Island in spring 2012 surveyed as potential adult spring Chinook salmon migration pathways and suitable for deploying a PIT-tag antenna system similar to PD7 (lower left photo) using a DIDSON underwater acoustic camera.

Fall Migration 2012

To reduce adult salmonid antenna avoidance we experimented with a small guidance wing in fall 2012. This wing was designed to obstruct, but not completely block the observed avoidance route of adult salmonids around the downstream end of the antenna array. On 14 August 2012, just prior to the expected peak run of adult fall Chinook, we installed a 6.1-m square wing of 46-cm stretch mesh (bright orange color about #90 twine). The wing was positioned perpendicular to the downstream edge of the antenna. At zero tide; the float line of the wing was about 0.9 m below the surface, and the wing itself extended down within about 1 m from the bottom. The large-mesh wing was stretched tight between anchors and buoys to form a barrier that still allowed adult fish to pass completely through the wing without entanglement. Fish could also pass over or around the wing, particularly near high tide.

The effect of the wing on adult salmonid behavior near the antenna was immediately apparent using the DIDSON camera. Adult fish attempting to avoid the antenna encountered the wing and turned toward the antenna and pile dike (Figure 5). Observations indicated that about 78% of the adult-sized fish would circle multiple times (2 to 5 circles) between the wing and the antenna/piles. Unfortunately, most of these fish eventually turned south towards the shore and away from the detection system.

This milling and circling behavior was especially apparent during flood tide/slack current conditions. Using the DIDSON camera, we observed that some fish found an alternate passage route through the pilings (most frequently during strong currents), and a few exited the area through the antenna (Table 2). Although we observed only a small increase in passage through the antenna after installation of the wing, detection opportunities increased because the likelihood of fish passing within detection range (45 cm) of the antenna (detection field range) was higher during this circling behavior.

After installation of the wing, we observed a 15.1% increase in adult salmon exiting the containment area through gaps between the pilings adjacent to the antenna array, especially during ebb tide/high currents. As a result, on 31 August 2012, we added two vertical antenna coils to the array to cover this gap. The new 6-coil configuration provided a coverage area of 1.2 by 6.1 m (Figure 6). To discourage passage through gaps between piles nearby, we also installed orange twine weighted with rock backs and flagged with high-visibility tape.

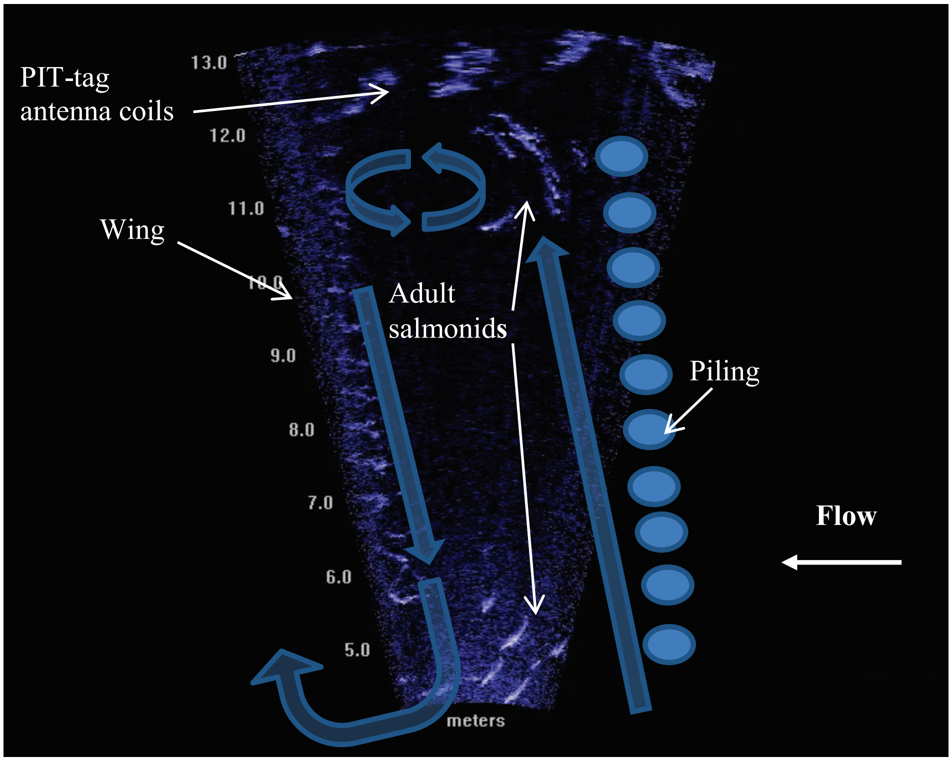


Figure 5. Diagram of adult salmonid movement after wing installation at PD7 in 2012. Blue arrows show typical antenna avoidance path observed with a DIDSON acoustic camera. The wing was 6-m square and constructed of bright orange 46-cm stretch mesh.

Table 2. Adult salmon behavioral categories based on DIDSON acoustic camera observation at PD7 during fall 2012.

Observation date	Hours observed	Total adult salmonids	Passed within detection range (%)	Passed around wing (%)	Passed through piles (%)	Passed through antenna (%)
28 Aug	6.6	288	12.8	65.0	23.3	5.8
9 Sep	4.9	290	1.7	90.9	6.8	2.3
Mean	N/A	N/A	7.3	78.0	15.1	4.0
Total	11.5	578	N/A	N/A	N/A	N/A

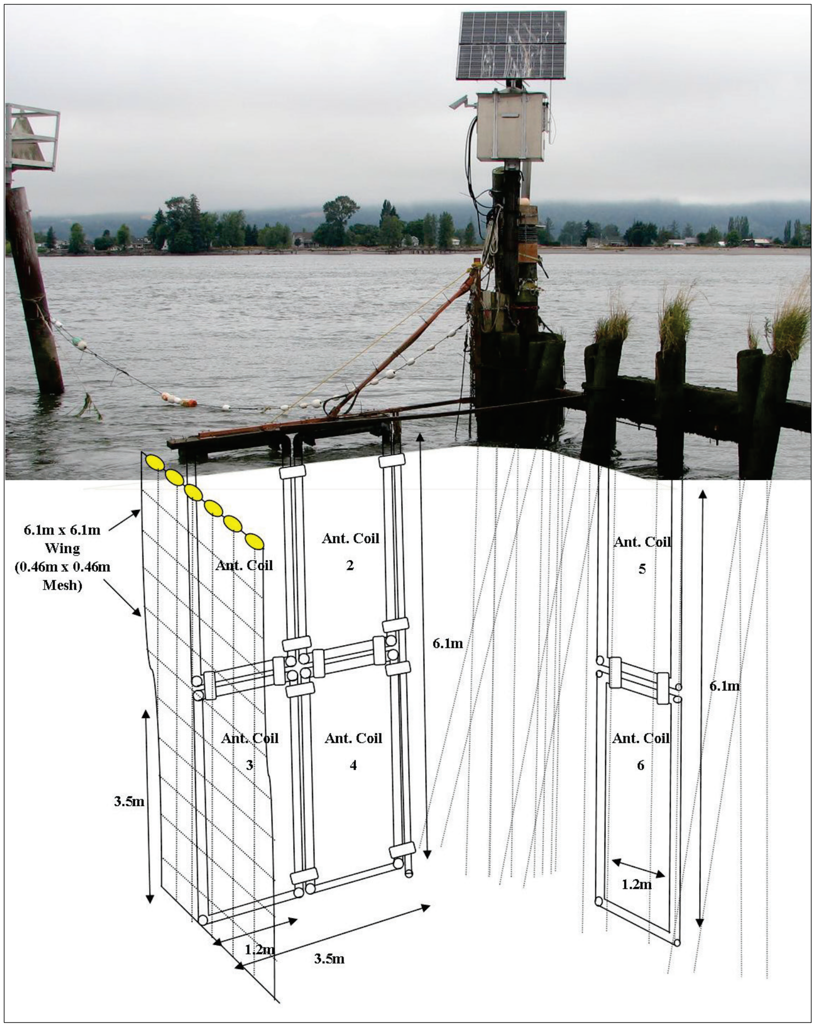


Figure 6. PIT-tag antenna system configuration in the Columbia River estuary after installation of a guidance wing and additional coils (antenna coils 5 and 6) in August 2012.

After these modifications were complete, detections of adult fall Chinook salmon increased to 24 fish in fall 2012, compared to just 4 in 2011. However, detections still appeared to come primarily from fish circling near the antenna rather than from those passing through the array.

Mean travel time of adult fall Chinook salmon from PD7 to Bonneville Dam was slightly faster in 2012 than in 2011 (3.9 vs. 4.3 d). Fall Chinook salmon jacks had an average travel time from PD7 to Bonneville Dam of 3.8 d in 2012 (no fall Chinook jack salmon were detected in 2011). Adult fall Chinook salmon detected at PD7 in 2012 had a survival rate to Bonneville Dam of 88% (75% in 2011). Fall Chinook salmon jacks had an estimated 71% survival to Bonneville Dam in 2012.

Detections of adult steelhead during August-October 2012 were slightly higher than during a similar period in 2011 (11 vs. 7). Behavior of adult steelhead was difficult to categorize, since we did not observe a large migration of steelhead in the absence of other species. Acoustic signatures of Chinook salmon and steelhead are similar, and the behavior of fish observed near the antenna was consistent during all DIDSON observations. This suggests that steelhead exhibited antenna avoidance behavior similar to that of fall Chinook salmon.

The larger number of steelhead detections in fall 2012 (wing installed) supported this hypothesis. Of the 11 steelhead detected at PD7 during August-October 2012, 9 passed Bonneville Dam with an average mean travel time of 5.3 d. In fall 2011, seven steelhead were detected at PD7, and all of them were detected at Bonneville Dam (mean travel time 4.5 d). In July 2012, two steelhead were detected at PD7, but only one of them subsequently passed Bonneville Dam (travel time 5.1 d).

Juvenile Salmonids

Due to its close proximity to the thalweg and to the reach sampled by the estuary pair-trawl, we expected higher detection numbers of PIT-tagged juvenile salmonids than were observed at PD7 in 2011 (N = 3) and 2012 (N = 41, Table 3). This lack of juvenile salmonid detections was particularly noteworthy during spring 2012 because over 16,000 juvenile salmonids were detected by the pair-trawl system (Morris et al. 2012). The low number of detections at PD7 could have been related to either a limited number of salmonids passing through the habitat or poor detection efficiency by the antenna system.

Using the DIDSON camera in fall 2011, we observed multiple schools of fish passing back and forth through the antenna. These fish were the size of juvenile salmon, and they did not avoid the antenna array. Unfortunately, we could not identify them by species, but we assumed they were juvenile salmonids or shad, since these are the most prevalent species in the study area (Dawley et al. 1986).

The poor detection efficiency of the antenna system for juvenile salmonids may be related to the orientation of the antenna coils. There is an eddy behind the piles, and since the antenna system is in line with the flow, juvenile salmon may not pass through it during high current periods. Antenna system coils 5 and 6 were perpendicular to the current but were not installed until fall 2012. It appears that juvenile salmonids migrating in spring did not use or frequent this potential refuge area behind the pile dike. Trawl data suggest that juvenile spring migrants move rapidly through this reach at rates similar to flow.

The last juvenile salmon detected at PD7 in 2012 was a Chinook salmon tagged at Lower Granite Dam, but this fish was detected on multiple dates (14 and 16 Oct). This fish (run unknown, length 170 mm) had been transported by truck and released below Bonneville Dam on 19 September 2012. This suggests a period of residency in the lower Columbia River/estuary for some juvenile salmonids released during fall.

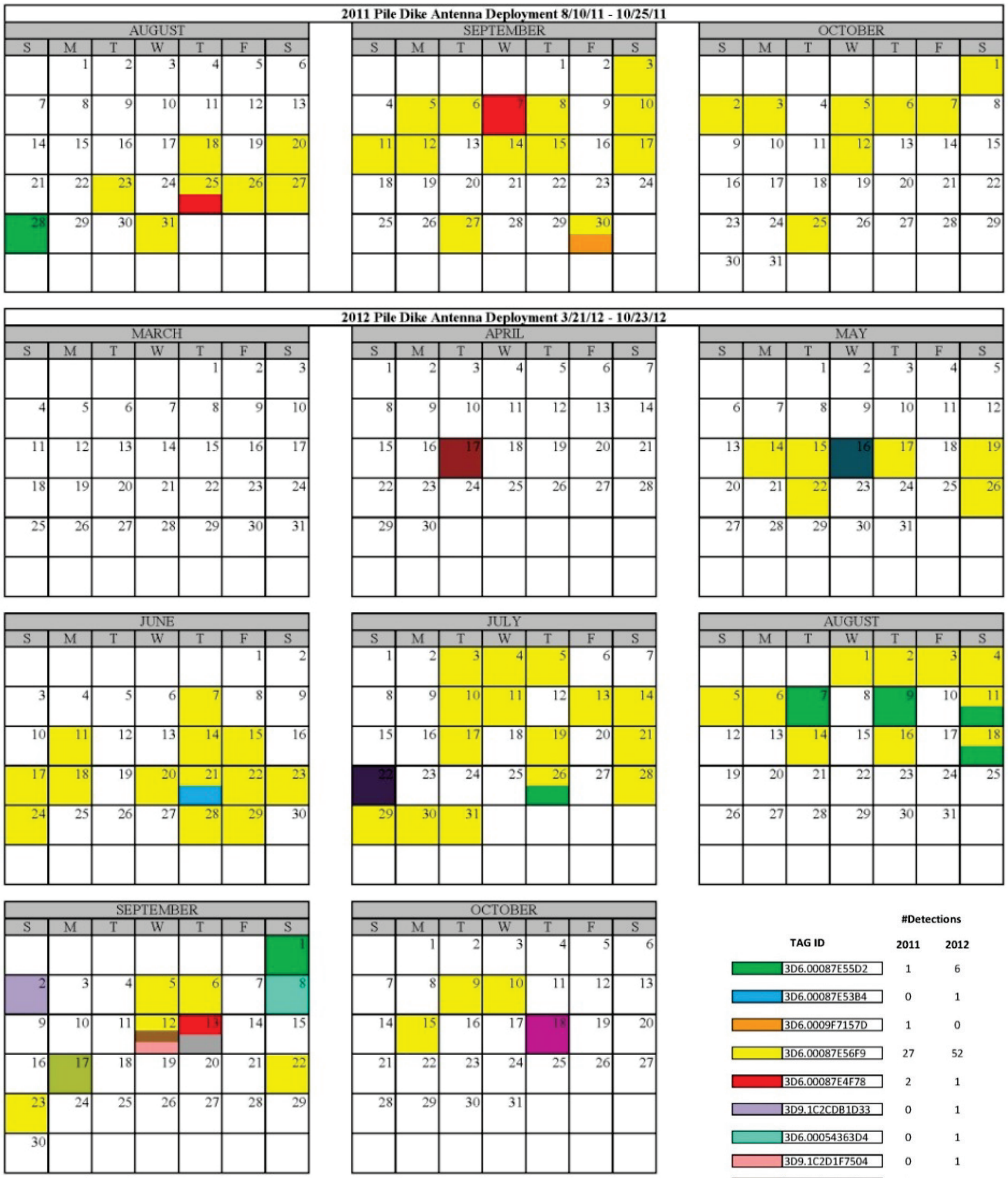
Table 3. Number of juvenile salmonids detected at PD7 (rkm 70) from 21 March to 24 October 2012 by coil where first detected. Antennas 1, 2, and 5 were near the surface. Antennas 5 and 6 were installed after the spring juvenile migration (31 August); other antennas were present year round.

	First detection antenna 2012					
Species (juveniles)	1	2	3	4	5	6
Chinook	8	8	5	11	3	0
Steelhead	3	0	0	2	0	0
Sockeye	0	1	0	0	0	0

White Sturgeon

Four white sturgeon were detected at PD7 in 2011 and 14 in 2012. Researchers from Oregon Department of Fish and Wildlife (ODFW) have been PIT-tagging and releasing white sturgeon in the Columbia River estuary for population abundance estimates for many years (Jones et al. 2012). All sturgeon detected at PD7 had been tagged by ODFW. The first sturgeon was detected on 3 September 2011, and detections of sturgeon continued until the site was shut down for the winter.

Of the 4 white sturgeon detected in fall 2011, 2 were detected on multiple days, and one of these 2 fish was detected at the site on 27 different days. Three of the 4 sturgeon detected in fall 2011 were also detected in 2012 (Figure 7). In both years, 12 sturgeon were detected only once, while 3 others were detected on multiple days (3, 7, and 79 d); 2 of these 3 were detected in both study years.



TAG ID	#Detections 2011	#Detections 2012
3D6.00087E55D2	1	6
3D6.00087E53B4	0	1
3D6.0009F7157D	1	0
3D6.00087E56F9	27	52
3D6.00087E4F78	2	1
3D9.1C2CDB1D33	0	1
3D6.00054363D4	0	1
3D9.1C2D1F7504	0	1
3D6.00087E4B95	0	1
3D6.00054354DB	0	1
3D6.0009F756E1	0	1
3D9.1BF1D4A9DB	0	1
3D9.1BF1B5EEFF	0	1
3D6.0009F71882	0	1
3D6.0009F70B87	0	1

Figure 7. Detection dates of PIT-tagged white sturgeon at PD7 in late 2011 and 2012. Colors represent individual fish.

DISCUSSION

Observations using the DIDSON acoustic camera indicated that the PD7 site is located within an active migration pathway for adult salmon. Unfortunately, despite several camera surveys, we were unable to identify other potential antenna locations with similar concentrations of adult salmonids. However, in a few of the alternate sites, our inability to locate adult salmon could be related to timing and the fact that some potential migration pathways were not accessible to us at key times during the migration period due anchored fishing vessels in the area.

An obstacle to finding appropriate installation sites is the need to mount detection system components above high tide levels on an existing pile or other stable structure. The antenna cable length for the FS1001M transceiver is also limited to 30 m. This prevented installation of the solar panel and electronic components at otherwise suitable sites.

Camera surveys in 2011 indicated that detections were low due to adult salmon avoidance of the antenna system. During the peak of the adult fall Chinook salmon migration, we observed adult fall Chinook circling near the antennas, but they avoided passage through the antenna array (on one occasion species was confirmed through DIDSON observation and simultaneous PIT-tag detection). Detection rates increased considerably with the installation a short net wing in fall 2012. However, the net wing increased circling behavior near the antennas; adult fish still did not effectively pass though the antenna system.

Based on the daily passage index at Bonneville Dam, less than 1% of adult fall Chinook salmon bore a PIT-tag during the study period. Given that the detection field was only about 45 cm for antennas deployed in 2011-2012, many adult fall Chinook salmon bearing PIT-tags were not detected because they circled out of range and did not pass through the antenna system.

Acoustic camera observations have provided valuable insight into fish response to the pile dike and antenna structures. These observations indicated that only 1 in ~14 adult fish that approached the PD7 antenna array came close enough to be detected. Additionally, the camera allowed us to verify that there was no "energized antenna effect." Adult fish were observed in similar numbers while the antenna was off vs. on, and we saw no change in behavior coinciding with status of the antenna electronic field. We concluded that the electronic field was not influencing either the detection rates or migratory behavior, although our observations with the system off were somewhat limited.

The primary cause for low detection rates appeared to be the small size of the antenna array openings. In addition, the configuration of our antenna array and its position in the water column may have presented a visual obstruction to passage. A large potential obstruction cue is presented at the location between the top and bottom antenna coils; this junction is situated near the preferred swimming depth of adult salmon (3-5 m). A larger, unencumbered opening would probably allow fish to pass through the antenna array readily and would reduce avoidance behavior.

Recent developments in PIT-tag technology allow for antennas with much larger fish-passage openings, more antenna coils/site and more dispersed antenna arrays around a common power source. Tests of a new transceiver (Destron Fearing IS1001-MTS) suggest antennas up to 4 times larger than those used in 2011 and 2012 with the MUX system are possible. A single antenna of this size could replace the existing 4-coil antenna at PD7 while maintaining the same exterior dimensions, thus eliminating the existing obstructions to passage. Observations using DIDSON acoustic camera showed that adult fish did not hesitate to pass through a 3-m wide gap between the end of the guidance wing and the pile dike to approach the antenna.

Specifications for the new IS1001 system indicate that the cable length between antenna arrays and electronic components can also be increased by an order of magnitude (from 30 to 300 m). This increase would allow installation of detection systems at sites with adequate above-water structure (for electronics storage), but where the area of interest for detecting fish is more than 30 m away from the structure.

The low detection numbers for adult spring Chinook salmon and steelhead were probably not entirely related to antenna avoidance. Adult spring Chinook salmon and steelhead probably exhibit different migration behavior than fall Chinook salmon. During fall, when currents through the pile dike are low and flow reversal occurs on flood tides, adult fish were observed to mill behind the pile dike and circle the antenna. In contrast, no flow reversal occurred at PD7 during spring 2012. For adult salmon migrating in spring, the strong downstream currents would preclude the milling and circling behavior observed during fall. Spring currents in 2012 created more of a resting sanctuary behind individual pilings for adult salmon traveling upstream.

In these higher flow conditions, antennas installed perpendicular to flow would probably be more successful. An antenna array installed across piles and close to shore, similar to antenna coils 5 and 6 (installed in fall 2012), might be more efficient for detecting migrating adult salmon during spring. Spring adult migrants were observed passing between pilings, and sport fishermen were observed catching spring Chinook salmon closer to the shoreline adjacent to PD7.

The five adult spring Chinook salmon detected at PD7 in 2012 exhibited relative long travel times to Bonneville or Willamette Falls Dam. Four of these five fish either traveled slowly to Bonneville Dam (compared to other runs or spring Chinook jacks) or traveled quickly and then milled in the tailrace. If the latter is true, then exposure to predation was also extended for these fish, since large numbers of marine mammals are known to congregate below Bonneville Dam.

Relatively few juvenile salmonids were detected at PD7 in 2012. Although the DIDSON camera surveys indicated that many small fish passed through and around the antenna, particularly in fall, few of these fish were PIT tagged. Because detection rates in the adjacent thalweg with the PIT-trawl system are relatively high, it is possible that an antenna configuration targeting juveniles near PD7 should be considered. Alternatively, the habitat adjacent to the pile dike may not be exploited by migrating juvenile salmon at rates similar to those observed in the thalweg. Nevertheless, the detection of one juvenile Chinook salmon during late fall suggests that the pile dike detection system has the potential to detect fish that suspend migration and reside in the estuary during fall and winter.

Configuration of antennas parallel to the current and between piles (e.g., coils 5 and 6) would be likely more effective for detecting juvenile salmon than the present configuration (e.g., perpendicular to the current, as coils 1-4). Tracking data from acoustic-tagged juvenile spring Chinook salmon indicate that these fish pass pile dikes both by actively swimming around them and passing directly through them (Ledgerwood et al. 2000, McComas et al. 2009).

Detections of sturgeon on PD7 were not surprising, since they are known to use a wide range of habitats up and down the Columbia River. Previous work with acoustically tagged sturgeon (Parsley et al. 2008) indicated strong site fidelity for some sturgeon, as well as documenting the run-timing of these fish.

Sturgeon appeared to slowly pass or linger near the antenna, generating multiple relays of their tag code and potentially blocking other tags from being read. In both years sturgeon were among the last fish recorded before the antenna system was removed for the winter. The PD7 installation represents one of the few opportunities to passively interrogate these PIT-tagged fish in situ in the lower Columbia River. Additional antenna deployments could provide substantial information on sturgeon migrations and movements.

RECOMMENDATIONS

1. Install a single large antenna to replace the array of four individual antennas. The new system that supports a single large antenna could support additional large coils mounted parallel on the pile dike. Larger antennas would substantially increase passage rates. If new pilings were driven, the experimental net wing could be replaced with a large antenna.

2. Before attempting to drive piles and install complicated underwater mounting apparatus, we recommend creating a mobile platform on which to install detection equipment and net wings. This structure would mimic a pile dike; a conceptual drawing of such a mobile platform is shown in Figure 8.

   A mobile platform would work with either FS1001M or IS1001 transceiver systems and could be used to evaluate adult spring Chinook salmon migration pathways. If the migration of these fish is more dispersed, and they are not concentrated and guided by the pile dikes, a mobile platform would allow researchers to evaluate other potential sites. Such evaluations would provide far more certainty than can be achieved with DIDSON camera observations. For example, the mobile platform would allow continuous monitoring and thus validation of potential pathway sites based on actual PIT-tag detections over several days or weeks.

   Specifically, we propose to test a spud-barge mobile platform just downstream from the PD7 site, but closer to shore near the 10 m depth. Adult salmon appear to migrate along this contour and could potentially be guided through an antenna and detected before reaching the pile dike, while the dike itself would provide some protection from floating debris.

   Tests of the large-mesh net wings tested at PD7 in fall 2012, when many adult salmonids were observed in the area, showed that no entanglements occurred. Similar wings would be used on the mobile platform, where they would be attached to the sides of the antenna to funnel migrating adults (Figure 8). One wing would extend toward the shallow shelf and the other would be oriented toward mid-river. If this platform system is successful, it could be readily moved for use in other locations during the spring or fall adult migration periods.

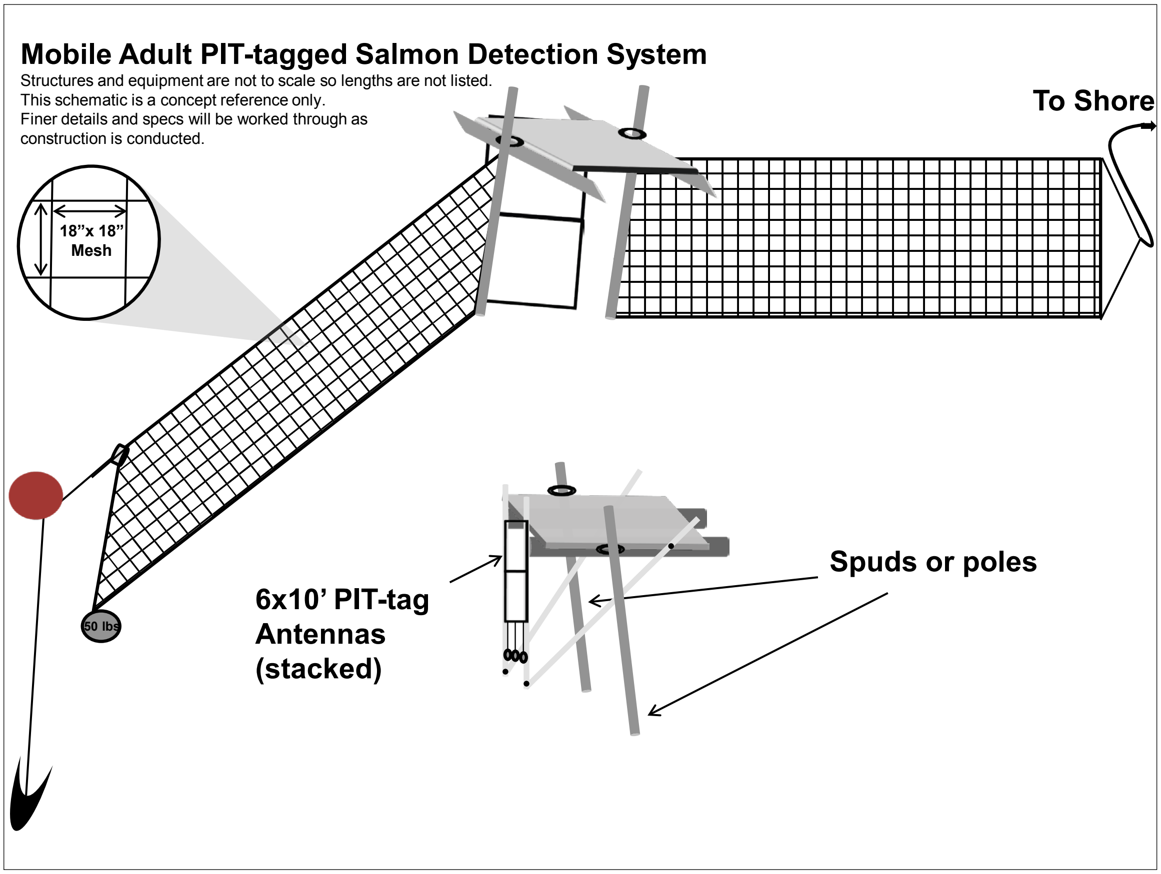


Figure 8. Conceptual design of a mobile PIT-tag detection system targeting adult salmonids deployed in the Columbia River estuary from a "spud-barge."

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APPENDIX

Appendix Table 1. Information on individual PIT-tagged fish detected at PD7 (rkm 70) during 10 August-25 October 2011, including travel time to upstream dams for adult migrating salmonids. N/A indicates that the fish originated upstream from Bonneville Dam but was not detected there. Dashes indicate that the fish did not originate upstream from Bonneville Dam.

Detection Date	Tag ID	Release site	Migration year	Life stage	Travel time (d) BON	MCN	LGR	WILL
			Summer Chinook					
19 Aug 11	3D9.1C2D1E6495	DRYP	2011	Jack	N/A	N/A	--	--
			Steelhead					
18 Aug 11	3D9.1C2C944383	SLAT2C	2009	Adult	4.37	N/A	N/A	--
21 Aug 11	3D9.1C2D0334DC	RI2BYP	2009	Adult	5.43	23.39	--	--
23 Aug 11	3D9.1C2CCDAE66	TWISPR	2009	Adult	4.50	13.43	--	--
25 Aug 11	3D9.1C2CBE8327	WENATT	2010	Adult	3.74	9.32	--	--
28 Aug 11	3D9.1C2D3672ED	PAHTRP	2010	Adult	4.20	17.76	23.75	--
08 Sep 11	3D9.1C2D46F69C	CLWRSF	2010	Adult	5.16	12.94	22.83	--
18 Sep 11	3D9.1C2CE33A6E	CLEARC	2009	Adult	4.14	10.51	19.29	--
					Mean travel time (d)			
Totals	Survival 7/7			Mean	4.51	14.56	21.96	--
			Coho					
31 Aug 11	3D9.1C2CBCA547	KOOS	2010	Adult	4.97	42.73	53.94	--
			Pikeminnow					
27 Aug 11	3D9.1C2D493808	COLR2	2011	--	--	--	--	--
			Fall Chinook					
11 Aug 11	3D9.1C2D62D81F	LWSH	2011	Juvenile	--	--	--	--
31 Aug 11	3D9.1C2CBE0173	SNAKE3	2008	Adult	3.20	8.81	13.85	--
03 Sep 11	3D9.1C2DC2248B	BCCAP	2011	Juvenile	--	--	--	--
05 Sep 11	3D9.1C2D583B1D	SNAKE3	2010	Adult	5.74	13.90	22.73	--
09 Sep 11	3D9.1C2CF74F49	TENNAI	2009	Adult	--	--	--	--
10 Sep 11	3D9.1C2CED4CCE	YAKIM1	2009	Adult	3.81	8.77	--	--
19 Sep 11	3D9.1C2DC7149A	BCCAP	2011	Juvenile	--	--	--	--
					Adult mean travel time (d)			
Totals	3 juvenile, 4 adult: adult survival 3/4				4.25	10.49	18.29	--

Appendix Table 2. Information on PIT-tagged detected adult and jack salmon at PD7 during 21 March-24 October 2012, including travel time to the nearest upstream dam and mean survival for by species. N/A indicates that the fish originated upstream from the dam but was not detected there; Dashes indicate that the fish did not originate upstream from the dam.

Detection date (2012)	Tag ID	Release site (PTAGIS code)	Migration year	Travel Time (d) BON	MCN	LGR	WILL
		Adult Spring Chinook					
12 Apr	3D9.1C2D56DE92	LGRRRR	2010	32.64	37.27	41.87	--
30 Apr	3D9.1C2D287A85	DWORNF	2010	16.73	22.19	28.54	--
02 May	3D9.1C2D4B249E	JDAR1	2010	12.38	--	--	--
03 May	3D9.1C2D586517	WILRMF	2010	--	--	--	13.56
08 May	3D9.1C2D57502F	LGRRRR	2010	8.56	N/A	N/A	--
		Spring Chinook Jacks					
14 Jun	3D9.1C2DCF70E9	CURP	2012	5.04	15.97	--	--
14 Jun	3D9.1C2DBA8958	POWP	2012	N/A	N/A	N/A	--
16 Jun	3D9.1C2DD45156	CURP	2012	3.81	9.07	--	--
26 Jun	3D9.1C2C621D6E	PELTON	2012	5.83	--	--	--
10 Jul	3D9.1C2DB33267	WINTBC	2012	6.41	N/A	--	--
21 Jul	3D9.1C2DCBB745	CHIP	2012	3.97	13.27	--	--
26 Jul	3D9.1C2DBF84EA	RAPH	2012	4.43	12.92	N/A	--
	Survival (%)			Average travel time (d)			
Adults	100.0 (5/5)			17.58	29.73	35.20	13.56
Jacks	85.7 (6/7)			4.91	12.81	--	--
Total	91.7 (11/12)			9.98	18.45	35.20	13.56
		Adult steelhead					
20 Apr	3D9.1C2D3DBF18	SULBYP	2009	--	--	--	4.68
29 Apr	3D9.1C2D3F76B8	SULBYP	2009	--	--	--	6.10
11 Jun	3D9.1C2D7B6950	LYFE	2010	5.00	13.97	--	--
22 Jun	3D9.1C2D7ADA9C	TUCR	2010	5.51	13.44	--	--
16 Jul	3D9.1C2D7016B7	COTP	2011	N/A	N/A	N/A	--
20 Jul	3D9.1C2DCDAF55	LYFE	2011	5.13	12.91	--	--
01 Aug	3D9.1C2DC31792	WALH	2011	9.94	71.63	78.02	--
31 Aug	3D9.1C2D7CB8C7	SALR3	2011	4.34	N/A	N/A	--
11 Sep	3D9.1C2D6583B9	KOOS	2010	4.44	14.02	24.35	--
14 Sep	3D9.1C2D65A91D	CLWRSF	2010	4.04	17.21	23.96	--
15 Sep	3D9.1C2D9FA66A	CHEWUR	2011	3.97	N/A	--	--
15 Sep	3D9.1C2D03F51F	SALREF	2010	N/A	N/A	N/A	--
19 Sep	3D9.1C2D6556F3	WALH	2010	5.90	15.63	25.83	--
21 Sep	3D9.1C2D655D79	CLWRSF	2010	4.71	15.00	N/A	--
26 Sep	3D9.1C2D65F58F	CLWRSF	2010	N/A	N/A	N/A	--
05 Oct	3D9.1C2D627BCF	LOLOC	2010	6.23	N/A	N/A	--
19 Oct	3D9.1C2D654E23	CLWRSF	2010	3.88	N/A	N/A	--
	Survival (%)			Average travel time (d)			
Total	82.4 (14/17)			5.26	21.73	38.04	5.39

Appendix Table 2. Continued.

Detection date (2012)	Tag ID	Release site (PTAGIS code)	Migration year	Travel Time (d)			
				BON	MCN	LGR	WILL
		Coho jacks					
19 Sep 12	3D9.1C2D8859AE	YAKIM2	2012	6.96	18.77	--	--
		Summer Chinook jacks					
08 Aug 12	3D9.1C2DD30D27	CROOKR	2012	N/A	N/A	N/A	--
		Fall Chinook adult and jack					
07 Aug 12	3D9.1C2C659801	BCCAP	2008	4.79	12.89	24.89	--
17 Aug 12	3D9.1C2D9851F6	SNAKE3	2011	3.30	8.98	16.04	--
24 Aug 12	3D9.1C2D992CE0	GRAND1	2011	3.32	7.93	12.43	--
26 Aug 12	3D9.1C2D0338E7	BCCAP	2009	2.97	9.48	15.87	--
27 Aug 12	3D9.1C2D944116	BCCAP	2011	3.03	8.99	17.00	--
27 Aug 12	3D9.1C2D49501C	PLAP	2010	2.88	6.89	13.86	--
28 Aug 12	3D9.1C2D50E146	CJRAP	2011	4.22	11.14	N/A	--
29 Aug 12	3D9.1C2D3A16F3	LGRRTR	2009	N/A	N/A	N/A	--
30 Aug 12	3D9.1C2D9858A0	SNAKE3	2011	4.17	10.00	17.04	--
31 Aug 12	3D9.1C2DA7F349	LUGUAF	2011	3.74	10.43	N/A	--
01 Sep 12	3D9.1C2DD39FC5	LYFE	2012*	N/A	N/A	--	--
02 Sep 12	3D9.1C2D47EB27	PRDH	2010	N/A	N/A	--	--
03 Sep 12	3D9.1C2D602710	BCCAP	2010	4.20	9.08	16.03	--
06 Sep 12	3D9.1C2D516781	BCCAP	2011	3.18	9.24	14.77	--
08 Sep 12	3D9.1C2DA1386C	SNAKE3	2011	4.90	13.82	20.96	--
09 Sep 12	3D9.1C2D467591	GRAND1	2010	3.80	N/A	N/A	--
10 Sep 12	3D9.1C2D69CB0D	SPRC	2010	3.96	--	--	--
10 Sep 12	3D9.1C2DDE18E9	BCCAP	2012*	N/A	N/A	N/A	--
11 Sep 12	3D9.1C2DC7D974	BCCAP	2011	4.40	12.06	19.05	--
11 Sep 12	3D9.1C2DC758AC	PLAP	2012*	4.14	11.08	17.99	--
11 Sep 12	3D9.1C2DD55EA2	CJRAP	2012*	4.21	11.97	18.37	--
11 Sep 12	3D9.1C2D5E913C	SNAKE3	2010	4.10	9.94	15.96	--
12 Sep 12	3D9.1C2D3589DA	SNAKE3	2010	4.33	9.11	15.04	--
12 Sep 12	3D9.1C2D9B0C87	SNAKE3	2011	N/A	N/A	N/A	--
13 Sep 12	3D9.1C2D4AEF55	BCCAP	2012*	4.18	10.22	15.83	--
15 Sep 12	3D9.1C2D0FA76C	CJRAP	2011	3.85	8.84	15.65	--
16 Sep 12	3D9.1C2DCFDE74	CJRAP	2012*	3.38	N/A	N/A	--
16 Sep 12	3D9.1C2D9603E5	PLAP	2011	4.10	9.14	15.78	--
21 Sep 12	3D9.1C2D7B6AFF	LYFE	2011	3.58	8.37	--	--
22 Sep 12	3D9.1C2DC17FF3	PLAP	2012*	3.26	8.14	16.14	--
23 Sep 12	3D9.1C2DB55403	DESCH1	2011	4.01	--	--	--
05 Oct 12	3D9.1C2CEB3B01	COLR6	2011	5.13	11.03	--	--
	Survival (%)			Average travel time (d)			
Adults	88 (22/25)			3.91	9.86	16.69	--
Jacks	71.4 (5/7)			3.83	10.35	17.08	--
Total	84.4 (27/32)			3.89	9.95	16.77	--

* Jacks