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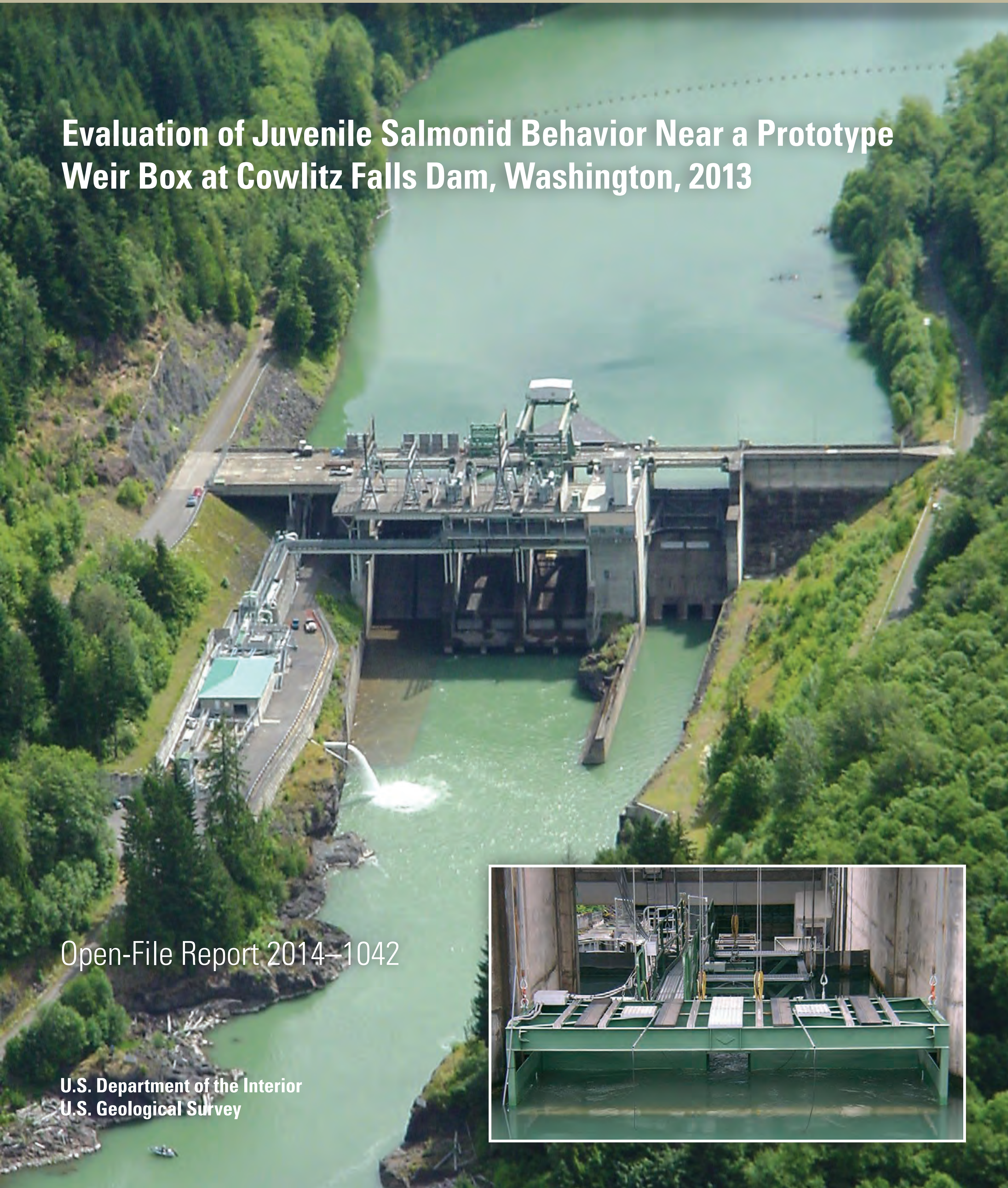
Evaluation of Juvenile Salmonid Behavior Near a Prototype Weir Box at Cowlitz Falls Dam, Washington, 2013



Open-File Report 2014–1042

U.S. Department of the Interior
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Cover: Photographs showing Cowlitz Falls Dam and the prototype weir box (inset).
Photographs taken by John Serl, Washington Department of Fish and Wildlife.

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Conversion Factors

SI to Inch/Pound

Multiply	By	To obtain
	Length	
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
	Flow rate	
meter per second (m/s)	3.281	foot per second (ft/s)
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)

Inch-pound to SI

Multiply	By	To obtain
	Flow rate	
cubic foot per second (ft^3/s)	3.281	foot per second (ft/s)

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Executive Summary

Collection of juvenile salmonids at Cowlitz Falls Dam is a critical part of the effort to restore salmon in the upper Cowlitz River because the majority of fish that are not collected at the dam pass downstream and enter a large reservoir where they become landlocked and lost to the anadromous fish population. However, the juvenile fish collection system at Cowlitz Falls Dam has failed to achieve annual collection goals since it first began operating in 1996. Since that time, numerous modifications to the fish collection system have been made and several prototype collection structures have been developed and tested, but these efforts have not substantially increased juvenile fish collection. Studies have shown that juvenile steelhead (*Oncorhynchus mykiss*), coho salmon (*Oncorhynchus kisutch*), and Chinook salmon (*Oncorhynchus tshawytscha*) tend to locate the collection entrances effectively, but many of these fish are not collected and eventually pass the dam through turbines or spillways. Tacoma Power developed a prototype weir box in 2009 to increase capture rates of juvenile salmonids at the collection entrances, and this device proved to be successful at retaining those fish that entered the weir. However, because of safety concerns at the dam, the weir box could not be deployed near a spillway gate where the prototype was tested, so the device was altered and re-deployed at a different location, where it was evaluated during 2013. The U.S. Geological Survey conducted an evaluation using radiotelemetry to monitor fish behavior near the weir box and collection flumes.

The evaluation was conducted during April–June 2013. Juvenile steelhead and coho salmon (45 per species) were tagged with a radio transmitter and passive integrated transponder (PIT) tag, and released upstream of the dam. All tagged fish moved downstream and entered the forebay of Cowlitz Falls Dam. Median travel times from the release site to the forebay were 0.8 d for steelhead and 1.2 d for coho salmon. Most fish spent several days in the dam forebay; median forebay residence times were 4.4 d for juvenile steelhead and 5.7 d for juvenile coho salmon. A new radio transmitter model was used during the study period. The transmitter had low detection probabilities on underwater antennas located within the collection system, which prevented us from reporting performance metrics (discovery efficiency, entrance efficiency, retention efficiency) that are traditionally used to evaluate fish collection systems.

Most tagged steelhead (98 percent) and coho salmon (84 percent) were detected near the weir box or collection flume entrances during the study period; 39 percent of tagged steelhead and 55 percent of tagged coho salmon were detected at both entrances. Sixty-three percent of the tagged steelhead that were detected at both entrances were first detected at the weir box, compared to 52 percent of the coho salmon. Twelve steelhead and 15 coho salmon detected inside the weir box eventually left the device and were collected in collection flumes or passed the dam. Overall, collection rates were relatively high during the study period. Sixty-five percent of the steelhead and 80 percent of the coho salmon were collected during the study, and most of the remaining fish passed the dam and entered the tailrace (24 percent of steelhead; 13 percent of coho salmon). The remaining 11 percent of steelhead and 7 percent of coho salmon did not pass the dam while their transmitters were operating.

We were able to confirm collection of tagged fish at the fish facility using three approaches: (1) detection of radio transmitters in study fish; (2) detection of PIT-tags in study fish; (3) observation of study fish by staff at the fish facility. Data from all three methods were used to develop a multistate mark-recapture model that estimated detection probabilities for the various monitoring methods. These estimates then were used to describe the percent of tagged fish that were collected through the weir box and collection flumes. Detection probabilities of PIT-tag antennas in the collection flumes were 0.895 for juvenile steelhead and 0.881 for juvenile coho salmon, although radiotelemetry detection probabilities were 0.654 and 0.646 for the two species, respectively. The multistate model estimates showed that all steelhead and most coho salmon (94.5 percent) that were collected at the dam entered the collection system through the flumes rather than through the weir box. None of the tagged steelhead and only 5.5 percent of the tagged coho salmon were collected through the weir box. These data show that juvenile steelhead and coho salmon collection rates were much higher through the collection flumes than through the weir box.

Low detection probabilities of tagged fish in the fish collection system resulted in uncertainty for some aspects of our evaluation. Missing detection records within the collection system for fish that were known to have been collected resulted in four tagged steelhead and seven tagged coho salmon being removed from the dataset, which was used to assess discovery rates of the weir box and collection flumes. However, the multistate model allowed us to provide unbiased estimates of the percentage of tagged fish that were collected through each route, and these data showed that few fish were collected through the weir box.

Overall, the fish collection system performed reasonably well in collecting juvenile steelhead and coho salmon during the 2013 collection season. Fish collection efficiency estimates from the Washington Department of Fish and Wildlife showed that steelhead collection efficiency was slightly higher than the 10-year average (46 percent compared to 42 percent), whereas coho salmon collection efficiency was more than twice as high as the 10-year average (63 percent compared to 30 percent). However, the performance of the weir box was poor because most fish were collected through the collection flumes.

Introduction

Surface collection systems can increase survival for juvenile salmonids at dams, but to be effective they must collect a large proportion of the population because fish that are not collected will pass through other routes where injury or death can occur. Most dams provide multiple passage routes (for example, collection systems, turbines, spillways) for juvenile fish migrating downstream. Juvenile salmonids rely on factors, such as water velocity and turbulence, to guide downstream movements, so routes that pass large volumes of water are highly effective at passing fish (Coutant, 2001; Tiffan and others, 2009). Surface collection systems are effective because juvenile salmonids typically migrate near the surface, but these systems must create conditions in a dam forebay that are conducive to discovery, entry, and retention (Coutant and Whitney, 2000; Adams and others, 2001; Johnson and Dauble, 2006; Evans and others, 2008). Otherwise, the risk of passing through alternate routes is greatly increased.

The surface collection system at Cowlitz Falls Dam is known to attract juvenile salmonids effectively under a variety of configurations, but rejection of the collection system entrances is common, and this factor is largely responsible for the failure of the system to meet annual collection goals. Juvenile salmonids that arrive at Cowlitz Falls Dam are either collected or they pass the dam and enter Riffe Lake. Fish that are collected are transported via tanker truck downstream around the Cowlitz River hydrosystem and released into a series of stress-relief ponds from which they can volitionally enter the free-flowing river and migrate to the ocean. With the exception of fish that are collected through supplemental methods, fish that enter Riffe Lake become landlocked and are lost to the anadromous population. Studies have shown that discovery rates of the surface collection system routinely exceed 90 percent at Cowlitz Falls Dam (Hausmann and others, 2001; Farley and others, 2003; Liedtke and others, 2009). However, mark-recapture findings indicate that only about 50 percent of juvenile steelhead (*Oncorhynchus mykiss*), 21 percent of juvenile coho salmon (*Oncorhynchus kisutch*), and 20 percent of juvenile Chinook salmon (*Oncorhynchus tshawytscha*) were collected annually during 1996–2012 (Serl and Heimbigner, 2013). In 2003, Perry and others (2004) used radiotelemetry and an acoustic camera to monitor fish behavior within 1 m of the flume entrances at Cowlitz Falls Dam. They reported that “at most only 25 percent of the fish that come within 1 m of the flume entrances subsequently pass into the entrance” (Perry and others, 2004). These studies have shown that most fish locate collection entrances but many reject entering the collection system and eventually pass the dam and enter Riffe Lake. The high rejection rates are the factor that is limiting the collection system from achieving annual collection goals, so recent attempts to improve collection at the dam have focused on improving entry and retention rates of the collection entrances.

Tacoma Power developed and tested two prototype fish collection devices at Cowlitz Falls Dam during 2006–2010 in an attempt to improve annual fish collection efficiencies. The first device was a fish screen that was designed as a single collection entrance that attached to collection flume 3 and extended upstream 12.2 m to baffle panel 3 (fig. 1; Liedtke and others, 2010). The fish screen was designed with a 6.1-m wide, 6.1-m deep entrance that gradually narrowed in the downstream direction to provide uniform water acceleration (0–2.1 m/s), which has been an important factor in optimizing surface collection of juvenile fish (Haro and others, 1998). The second device was a weir box that was designed as a wide (8.5 m), shallow (0.6 m) structure that attached at the upstream entrance to collection flumes 1 and 2, inside spillbay 2 (fig. 1; Liedtke and others, 2010). The weir box created a wide, shallow flow field that spilled over the weir crest and captured smolts in a high flow, turbulent holding box where they were susceptible to entrainment in collection flumes. In 2009, the fish screen and weir box were evaluated simultaneously during a radiotelemetry evaluation in which 318 juvenile coho salmon and 317 juvenile Chinook salmon were monitored. Discovery efficiencies of the fish screen and weir box by juvenile salmonids were similar for each species (about 80 percent for coho salmon; about

60 percent for Chinook salmon) but capture efficiencies were substantially higher for the weir box (Liedtke and others, 2010). For coho salmon, the capture efficiency of the weir box was 93 percent, whereas the capture efficiency of the fish screen was 16 percent (Liedtke and others, 2010). This relationship was similar for Chinook salmon, as capture efficiencies of the weir box were 91 percent compared to 38 percent for the fish screen (Liedtke and others, 2010). Given these findings, the weir box appeared to be a promising option for improving capture efficiencies, and thereby increasing fish collection at Cowlitz Falls Dam.

In 2013, Tacoma Power developed a plan to install and evaluate a weir box during the peak outmigration period for juvenile steelhead and coho salmon at Cowlitz Falls Dam. The deployment location and size of the weir box differed from when the device was tested during 2009 because of dam safety concerns that disallowed deployment in the original location. During 2013, the weir box was deployed at baffle panel 3, and the overall width of the device was reduced from 8.5 to 6.1 m (fig. 1). A weir crest was located on the upstream side of the device, and water depths over the crest were 0.15–0.30 m. The evaluation plan, which was developed by Tacoma Power, consisted of using three approaches to determine the performance of the device: (1) quantitative fish capture data would be collected by monitoring relatively large numbers of fish tagged with passive integrated transponders (PIT-tags; 500–1,000 fish per species) in the weir box, in collection flumes, and in the fish facility; (2) hydraulic data would be collected throughout the evaluation to determine if flow-related performance trends were apparent; and (3) qualitative fish behavior data would be collected by monitoring radio-tagged fish (45 fish per species). Fieldwork was scheduled to be conducted during mid-April to late-June, and Tacoma Power was responsible for conducting the PIT-tag and hydraulic measurement components, and the U.S. Geological Survey was responsible for conducting the radiotelemetry component of the evaluation. This report summarizes findings from the radiotelemetry evaluation.

Methods

Fish Collection, Tagging, and Release

Juvenile steelhead and coho salmon were collected and tagged with a radio transmitter and a PIT-tag at the Cowlitz Falls Dam fish facility during 2013. Fish were collected and held for 24 h prior to tagging. A total of 90 fish (45 steelhead; 45 coho salmon) were tagged and released during the study (table 1; fig. 2). Three releases were made for each species, and release groups ranged from 8 to 23 fish per group (table 1). Radio transmitters (Model NTQ-2; Lotek© Wireless Inc.; Newmarket, Ontario, Canada) weighed 0.30 g (in air) and had an expected operating life of 23 d. Fish weights ranged from 8.9 to 115.2 g (table 1), so the weight of the transmitter comprised 0.3–3.4 percent of the individual body weights of fish in our study. Transmitters were surgically implanted using methods described by Liedtke and others (2012). During each surgical procedure, a PIT-tag (Model HPT12 12.5 mm 134.2 kHz ISO FDXB; Biomark©, Inc.; Boise, Idaho) and a radio transmitter were implanted into the body cavity of individual fish . After tagging, fish were held for approximately 24 h prior to release to monitor short-term mortality related to the handling and tagging process. Tagged fish were then transported and released at the Cowlitz Falls Day Use Park, located 3.9 rkm upstream of the dam.

Monitoring Array

During 2013, juvenile salmonids could be collected at Cowlitz Falls Dam through collection flumes in spillbay 2 (above turbine 1) or through the weir box in spillbay 3 (above turbine 2; fig. 1). The primary objectives of our monitoring effort were to describe fish behavior near the collection flumes and weir box and to quantify tagged fish that entered through these routes. To accomplish these objectives, we operated a single telemetry receiver that monitored 22 underwater antennas located in and around the collection system. These antennas were grouped at several areas to create a series of detection zones (fig. 3). A pair of antennas were grouped immediately upstream of the weir box to create the weir box discovery zone that detected tagged fish within 4.6 m of the weir box entrance (fig. 3). Inside the weir box, a pair of antennas were grouped to detect tagged fish that entered the device. These antennas were attenuated to ensure that fish were not detected upstream of the weir box entrance. The areas near baffle panels 1 and 2 were monitored with one antenna each and comprised the discovery zones of those two areas, respectively (fig. 3). The entrances to flumes 1 and 2, and the area immediately downstream of the entrances, were monitored with two antennas each, creating the discovery zones of those areas. The weir box and flume discovery zones were important areas for monitoring fish behavior because detection within these zones confirmed that individual tagged fish had discovered a collection entrance. The four additional zones, downstream of the collection entrances, were used to confirm fish collection passage routes (fig. 3). We also used PIT-tag detectors located immediately downstream of collection flumes 1 and 2, and in the fish collection system to confirm that individual fish had been collected. Finally, staff from the fish facility visually assessed collected fish for the presence of a radio transmitter and when observed, the fish was scanned with a PIT-tag reader to obtain the individual fish identification data.

We also operated three fixed monitoring sites upstream of the dam and two fixed sites downstream of the dam to collect additional information on the movement of tagged fish. The most upstream site was located at the Lewis County Public Utility District (LCPUD) boat launch, 1.3 rkm upstream of the dam, and the remaining sites were located on Cowlitz Falls Dam and monitored the forebay for tagged fish. Fixed monitoring sites were located 0.2 and 4.8 rkm downstream of the dam to detect fish that passed Cowlitz Falls Dam and entered Riffe Lake.

Data Analysis

Reservoir Travel Times and Forebay Residence Times

We calculated reservoir travel times and forebay residence times for tagged fish as basic descriptors of fish movement patterns following release. Although these metrics provide little information that could be useful for assessing how the weir box and fish collection flumes performed during 2013, they do provide a measure of comparing fish behavior among years to determine if behavior patterns were consistent with those observed during previous studies. Reservoir travel times were calculated by subtracting the date and time of release from the first date and time of detection in the forebay of Cowlitz Falls Dam. Forebay residence times were calculated by subtracting the first date and time of detection from the last date and time of detection in the forebay of Cowlitz Falls Dam.

Behavior Near Collection Entrances

We analyzed telemetry detection records near collection entrances to describe four measures that were used for assessing the performance of the collection entrances. Evaluations of fish collection devices generally report performance metrics such as discovery efficiency, entrance efficiency, and retention efficiency. However, tag performance issues during our study precluded us from presenting these metrics. Therefore, we used the following measures: (1) number of tagged fish that were detected within 4.6 m of the weir box and collection flume entrances; (2) which collection entrance was first discovered by individual fish that encountered both entrances; (3) number of trips individual fish made to each collection entrance; and (4) number of fish that entered an entrance but later exited and were detected elsewhere in the forebay. Data from the two collection flumes in spillbay 2 were pooled for these analyses.

Passage Routes and Fish Collection through the Flumes and Weir Box

We used a multistate mark-recapture model to obtain unbiased estimates of collection numbers through each passage route. Tagged fish that entered the collection system could be observed through detection of a radio transmitter, detection of a PIT-tag, or visually observed by fish facility staff when fish were being processed for transportation downstream. Observations from each method were pooled, and these data were used to develop a multistate model that provided unbiased estimates of the proportions of tagged fish that were collected through each route. The multistate model (Perry and others, 2012; fig. 4) included six parameters; four parameters represented detection probabilities within the collection system, and two parameters represented the estimated proportion of tagged fish collected through the collection flumes and weir box (fig. 4; table 3). The detection probability parameters were:

- p_{f1}, probability of a fish being detected on PIT-tag antennas in the collection flumes;
- p_{f2}, probability of a fish being detected on radiotelemetry antennas in the collection flumes;
- p_{w}, probability of a fish being detected on radiotelemetry antennas in the weir box; and
- p_{c}, probability of a fish being detected on PIT-tag antennas or observed by fish facility staff in the collection facility.

The passage route parameters were:

- C_{f}, proportion of tagged fish that were collected through the collection flumes; and
- C_{wb}, proportion of tagged fish that were collected through the weir box.

Results

Reservoir Travel Times and Forebay Residence Times

All tagged steelhead and coho salmon moved downstream of the release site and entered the forebay of Cowlitz Falls Dam during the study period. Median travel times from the release site to the forebay were 0.8 d for steelhead and 1.2 d for coho salmon (table 2; appendixes A and B). Travel times ranged from 0.2 d (4.3 h) to 18.7 d for steelhead and from 0.3 d to 19.9 d for coho salmon. Median forebay residence times for steelhead were 4.4 d compared to 5.7 d for coho salmon. Three coho salmon and two steelhead spent less than 1 h in the forebay; the remaining forebay residence times ranged from approximately 1 h to 36.9 d for steelhead and 42.5 d for coho salmon (table 2).

Behavior Near Collection Entrances

Detection probabilities were low for some of the radio transmitters used on underwater antennas located in the collection system, so a subset of the detection records were used to determine discovery rates and behavior patterns near the collection entrances. Although we detected every tagged fish on aerial antennas during the study period, some of the transmitters were not detected on underwater antennas when it was known that specific fish were present in monitored locations. Four tagged steelhead and seven tagged coho salmon were collected at the fish facility, but were not detected on underwater antennas located in and around the collection system. These fish were removed from analyses related to behavior patterns near the collection entrances to reduce bias associated with poor transmitter performance. By removing these fish, we were left with detection histories for 41 steelhead and 38 coho salmon (table 2).

Nearly all steelhead and coho salmon used in behavioral analyses were detected near at least one of the collection entrances during the study period. Forty steelhead (98 percent) and 32 coho salmon (84 percent) were detected within 3 m of the flumes or weir box while in the forebay (table 2; appendixes A–B). Thirty-nine percent of the steelhead and 55 percent of the coho salmon were detected within 3 m of both collection devices. Of the steelhead that were detected near both entrances, 63 percent were first detected at the weir box entrance compared to 37 percent at the flume entrances. For coho salmon, the pattern of first detections was nearly equal between the two collection locations (52 percent at the weir box; 48 percent at the flumes; table 2). Fish that were detected near collection entrances usually made multiple trips to these locations. Tagged steelhead averaged 4.2 trips (range = 1–15) to the weir box and 3.7 trips (range = 1–16) to the flumes during their forebay residence time, and coho salmon averaged 3.9 trips (range = 1–9) to the weir box and 3.7 trips (range = 1–10) to the flumes. Thirty-four steelhead (83 percent) and 24 coho salmon (63 percent) were detected at the weir box entrance during the study period.

We did not observe tagged steelhead or coho salmon rejecting the collection flumes once they entered through those routes, but a substantial number of steelhead (12 fish; 27 percent) and coho salmon (15 fish; 33 percent) were known to have been inside the weir box and not collected. These fish entered the weir box and then moved out of the device and were later collected through the flumes or passed the dam and entered the tailrace.

Passage Routes and Fish Collection through the Flumes and Weir Box

A high proportion of tagged steelhead and coho salmon were collected during our study period. Sixty-five percent of the steelhead and 80 percent of the coho salmon were collected at the fish facility (table 2). Tagged fish that were not collected either passed the dam (24 percent of steelhead; 13 percent of coho salmon) or remained upstream of the dam (11 percent of steelhead; 7 percent of coho salmon) (table 2; appendixes A–B) during the period when their radio transmitters were operating.

Estimates from the multistate model indicated that detection probabilities of radio-tagged fish were low and that tagged coho salmon and steelhead primarily were collected through the flumes rather than through the weir box. Detection probabilities for PIT-tags in collection flumes were 0.895 for steelhead and 0.881 for coho salmon, which were higher than for radio transmitters (0.654 for steelhead; 0.646 for coho salmon; table 3). Detection probabilities for tagged fish in the collection facility were high (0.964 for steelhead; 0.971 for coho salmon; table 3). Estimates from the multistate model showed that all steelhead and 94.5 percent of the coho salmon were collected through the collection flumes (table 3).

Discussion

The fish collection system at Cowlitz Falls Dam performed reasonably well during the 2013 fish collection season, although collection of juvenile salmonids through the weir box was low. We observed that 65 percent of the tagged steelhead and 80 percent of the tagged coho salmon from our study were collected. Tacoma Power's PIT-tag study was conducted across a broader time scale than our study, and preliminary results from their research support the assertion that overall fish collection was reasonable in 2013. Their estimates suggest that 49 percent of the steelhead and 71 percent of the coho salmon were collected (Matt Bleich, Tacoma Power, written commun., 2013). By comparison, average collection rates from 2003 to 2012 were 46 percent for steelhead and 30 percent for coho salmon (Serl and Heimbigner, 2013). Although collection rates were at or above average in 2013, the weir box made a minimal contribution to collection success. Discovery rates of the weir box were fairly high, as 83 percent of the steelhead and 63 percent of the coho salmon were detected near the weir box entrance. Tagged fish also made repeated trips between the weir box and collection flumes. However, none of the tagged steelhead, and a few coho salmon (5.5 percent), were collected through the device. Rejection rates at the weir box were apparently high, based on detections of tagged fish inside the weir box that were subsequently followed by detections at other locations in the forebay. These findings show that the configuration of the collection system in 2013 resulted in similar issues to those which have previously been observed at Cowlitz Falls Dam. Reasonable numbers of fish discovered the collection entrances. but low capture efficiencies resulted in many fish passing the dam rather than being collected.

Our study was limited by low detection probabilities of tagged fish on underwater antennas in the collection system. In previous studies at Cowlitz Falls Dam, detection probabilities on underwater antennas typically exceeded 95 percent. However, the transmitters used for this study were a relatively new model that had not been previously tested on the monitoring system used to monitor underwater antennas at the dam. Detections on aerial antennas located upstream of the dam, in the forebay, and downstream of the dam were consistent with previous studies (Kock and others, 2007; Liedtke and others, 2007; Kock and others, 2012), but detections on underwater antennas within the system were lower than observed in the past. Study transmitters were originally purchased for the 2012 fish collection season, but were not used that year because high debris loads at the dam precluded operating the device during most of the 2012 fish collection season. Therefore, the transmitters were more than 1-year old when they were used for the 2013 evaluation. The signal output of individual transmitters was highly variable when monitored prior to tagging, which may explain why some transmitters provided the anticipated high detections whereas other transmitters did not. Another possible contributor to the low detections is the PIT-tag information system, which was new during 2013. It is possible that this new system introduced some level of electronic interference with our monitoring array that may have negatively affected detection probabilities. However, we conducted pre-season and in-season testing with two randomly selected transmitters, and found that detection probabilities of those transmitters within the system were consistent with previous evaluations.

The multistate model allowed us to provide unbiased estimates of collection proportions through the flumes and weir box. Detection probabilities (0.654 for steelhead and 0.646 for coho salmon) for radiotelemetry antennas located downstream of the flume entrances showed that one in every three tagged fish were not detected when they entered the collection system. Study fish also were PIT-tagged, and detection probabilities for PIT-tag antennas located near the telemetry antennas were 0.895 for steelhead and 0.881for coho salmon. These estimates showed that telemetry antennas did not detect about one-third of the tagged fish, whereas PIT-tag antennas did not detect about 10 percent of the study fish at this location. The combination of monitoring techniques located in the collection facility itself was less than perfect. Tagged fish in the fish facility were identified by PIT-tag antennas or by facility staff at a rate of 0.964 for steelhead and 0.971 for coho salmon. Because a small percentage (3–4 percent) of study fish were not identified in the collection facility, collection estimates from the collection facility alone would have underestimated the true collection rate. These observations demonstrate how redundancy in monitoring systems can be beneficial in areas where less than perfect detection probabilities can occur. Finally, collection estimates from the multistate model showed that nearly all study fish collected during 2013 entered the collection system through the collection flumes rather than the weir box.

The performance of the weir box during 2013 was substantially different than the performance of the weir box in 2009. During 2009, 81 percent of the coho salmon were detected near the weir box entrance, but the discovery rate during 2013 (63 percent) was substantially lower (Liedtke and others, 2010). The most promising aspect of the weir box's performance in 2009 was the retention efficiency; 93 percent of the coho salmon and 91 percent of the Chinook salmon that entered the device were collected (Liedtke and others, 2010). However, of the 12 steelhead and 17 coho salmon that entered the device during 2013, all steelhead and most of the coho salmon (88 percent) eventually left and passed the dam through another route. Although the weir box was conceptually similar between years, the device was structurally different and was operated at different locations. In 2009, the weir box was 8.5 m wide and attached directly to both flumes in spillbay 2; during 2013, the device was narrowed to 6.1 m wide and was deployed 12.2 m upstream of collection flume 3, at the entrance to spillbay 3. These alterations apparently had a major effect on fish response. Although the 2009 evaluation suggested that the device was a promising concept for increasing capture efficiencies at Cowlitz Falls Dam, the performance of the weir box during 2013 indicated that the device collected few fish during steelhead and coho salmon evaluations.

Results from this study can help inform decisions regarding future collection efforts at Cowlitz Falls Dam. The overall fish collection system performance in 2013 was slightly above average for steelhead and more than double the average for coho salmon, but this was mostly due to capture through the collection flumes rather than capture through the weir box. Another variable to consider when observing increased collection in 2013 is trash rack cleaning by LCPUD prior to the fish collection season. The prototype weir box was not tested as expected in 2012 because debris occluded much of the trash rack on the intake of turbine 2. This changed intake flow, which in turn negatively affected the weir box, and created an unsafe dam operating environment in certain conditions. As a result, the tests were terminated. Provisions were made to remove most of the debris, and weir box prototype tests resumed in 2013 during the steelhead and coho salmon season. Collection success at Cowlitz Falls Dam is inversely related to river flows (John Serl, Washington Department of Fish and Wildlife, oral commun., 2013) but our study did not allow for these comparisons because of our small sample sizes. The radiotelemetry data provided information on fish behavior, but the larger PIT-tag study may be insightful for determining if the performance of the collection system was influenced by river flows. Collectively, the two studies should provide information that can be used to direct future efforts aimed at improving fish collection at Cowlitz Falls Dam.

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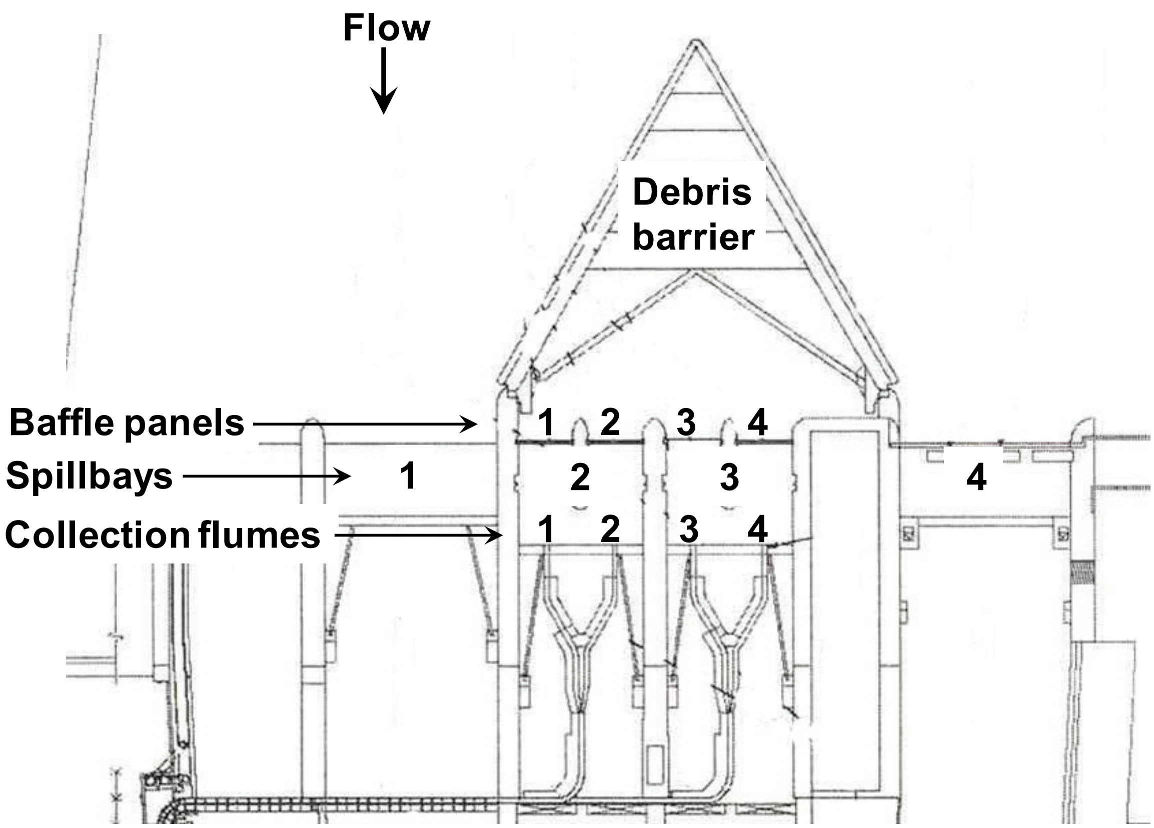

Figure 1. Schematic of Cowlitz Falls Dam showing the locations of baffle panels, spillbays, and collection flumes.

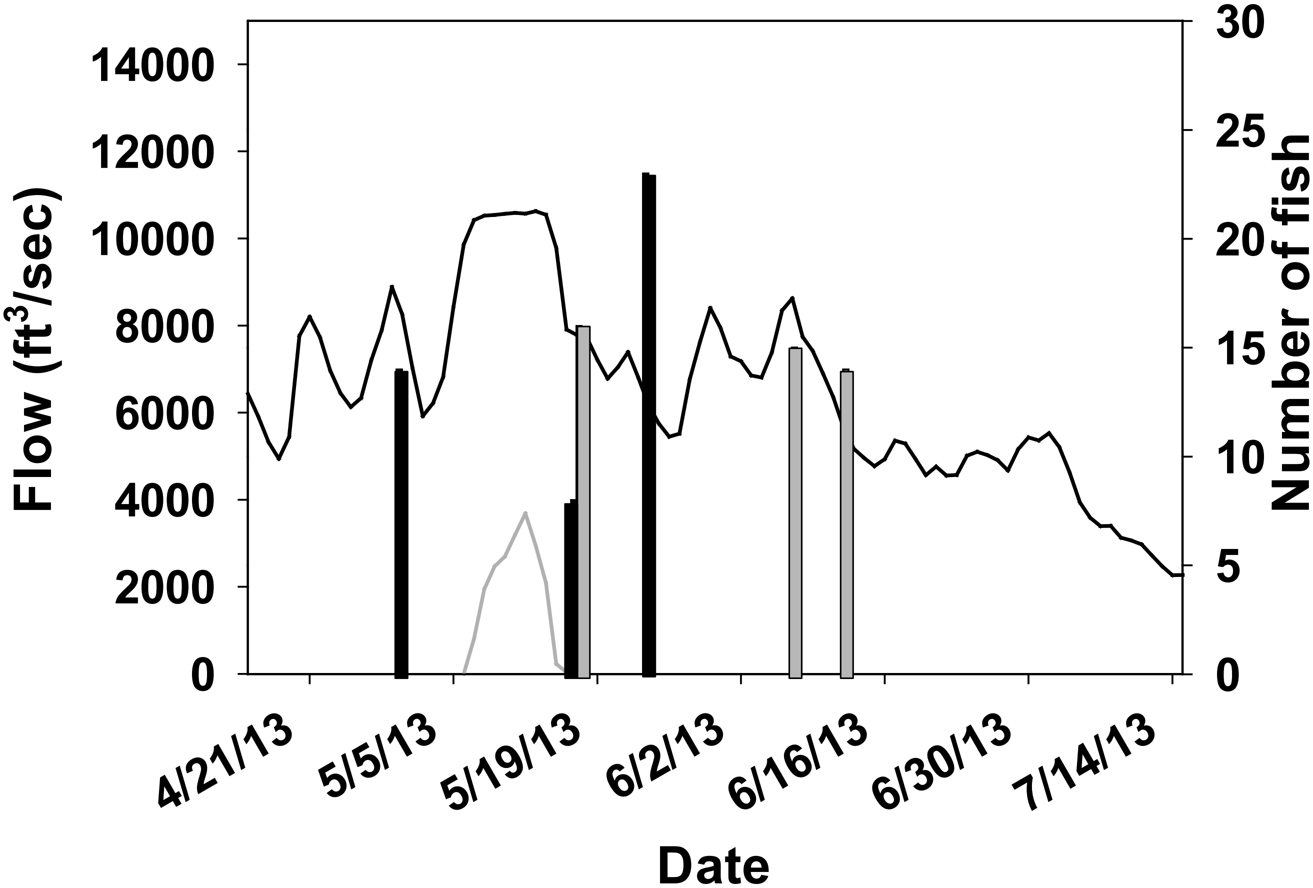

Figure 2. River flows passed through turbines (black line) and spillbays (gray line) at Cowlitz Falls Dam during April–July 2013. Bars show the number of radio-tagged juvenile steelhead (black bars) and juvenile coho salmon (gray bars) that were released on specific days during the study period.

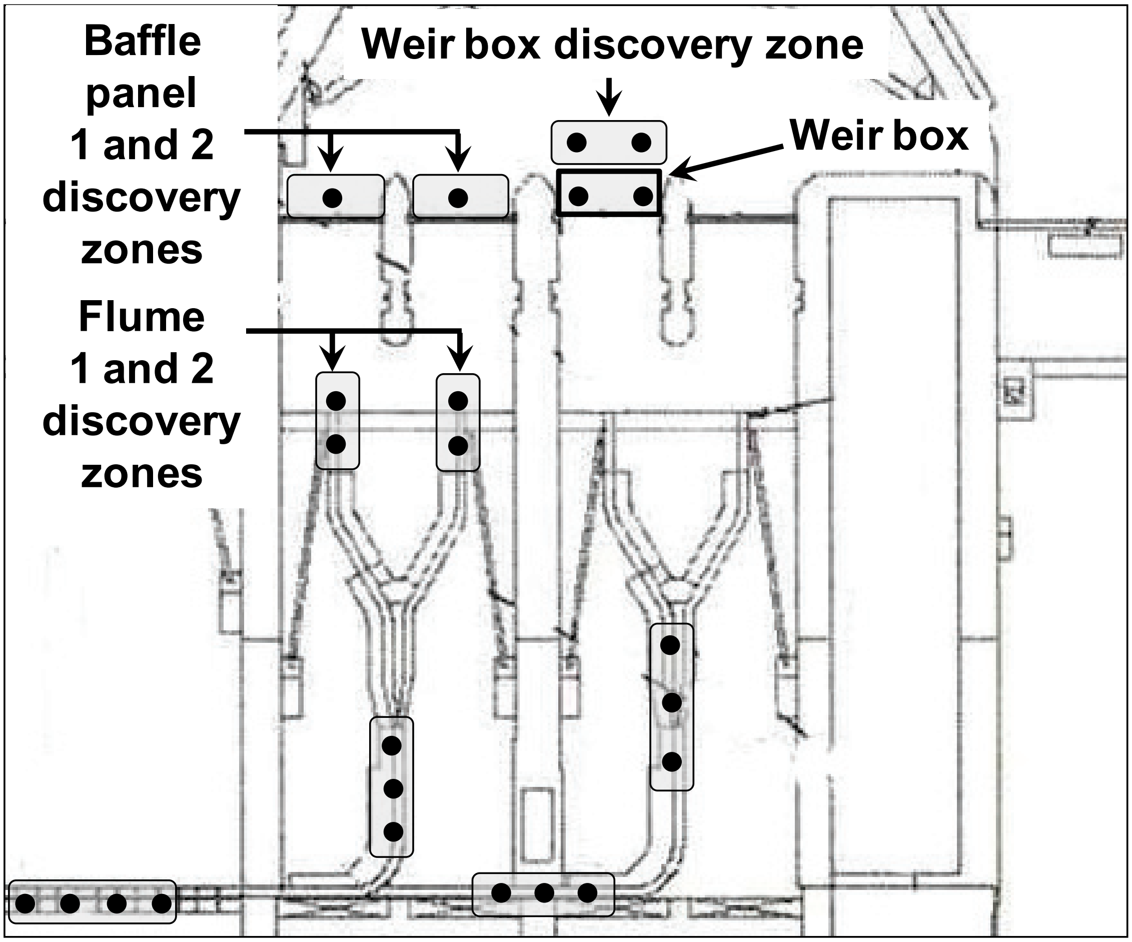

Figure 3. Schematic of underwater antenna locations in and around the fish collection system at Cowlitz Falls Dam, 2013.

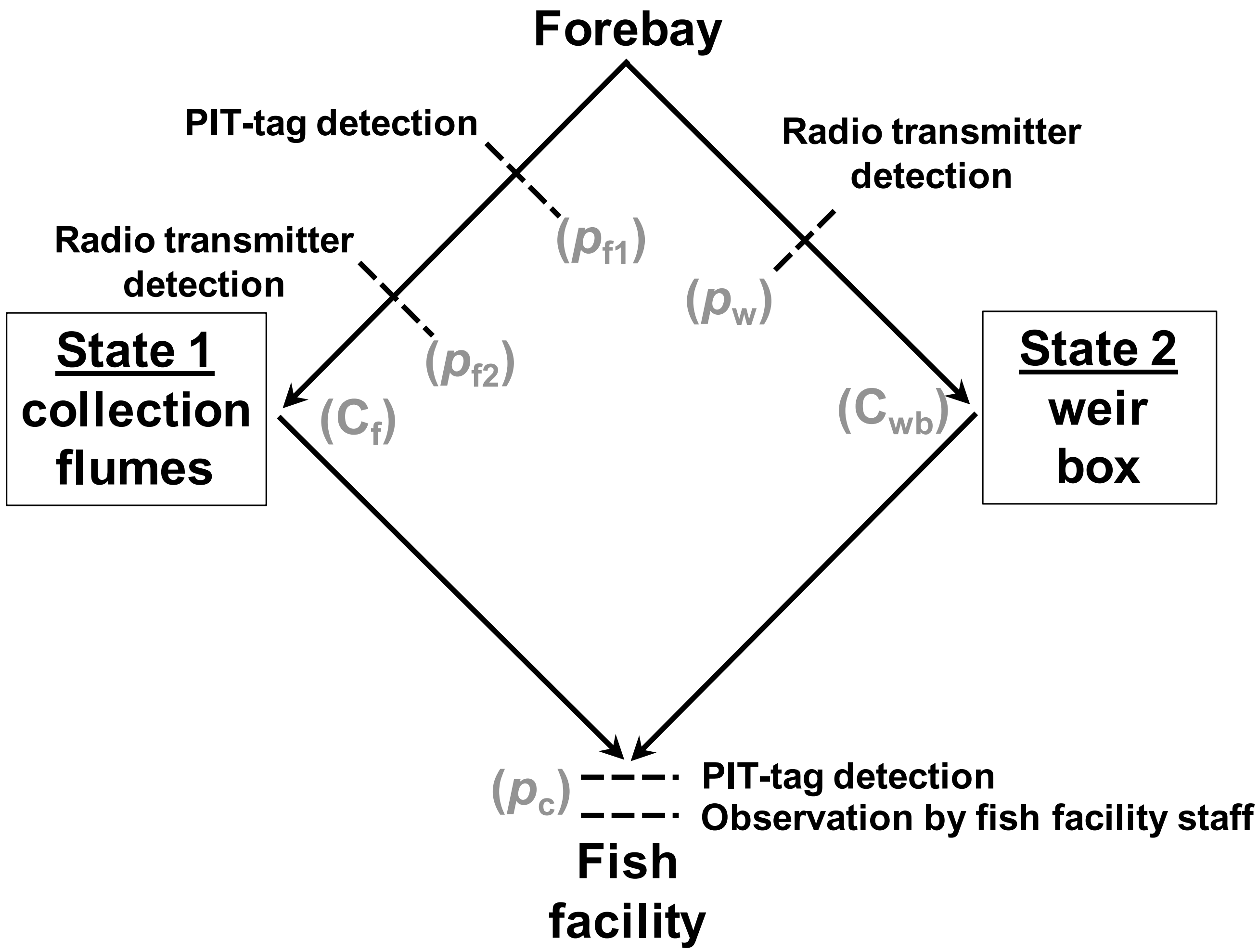

Figure 4. Schematic of the multistate model that was used to estimate the probability of tagged fish being collected through the collection flumes and weir box at Cowlitz Falls Dam, 2013.

Table 1. Summary of release dates, number of fish released, and average sizes of fish released during a radiotelemetry evaluation at Cowlitz Falls Dam, 2013.

[Numbers in parentheses are one standard deviation from the mean]

Species	Release date	Number of fish released	Weight (g)	Fork length (mm)
Steelhead	4/30/2013	14	65.3 (17.9)	191.0 (14.7)
Steelhead	5/17/2013	8	48.9 (10.3)	173.8 (12.9)
Steelhead	5/24/2013	23	55.6 (10.6)	182.7 (12.4)
Totals		45	57.4 (14.3)	183.7 (14.3)
Coho salmon	5/17/2013	16	16.9 (3.7)	115.1 (9.9)
Coho salmon	6/7/2013	15	24.7 (4.3)	133.6 (6.6)
Coho salmon	6/12/2013	14	24.9 (4.5)	134.0 (6.8)
Totals		45	21.9 (5.6)	127.1 (11.9)

Table 2. Summary of the number of fish released and detected at specific locations within the study area along with travel times, forebay residence times, and passage routes used during the study.

Descriptor	Steelhead	Coho salmon
Travel Time and Forebay Residence		
Number of fish released	45	45
Median travel time from release to forebay	0.8 d (range = 0.2–18.7 d)	1.2 d (range = 0.3–19.9 d)
Number of fish that arrived in the forebay	45 (100 percent)	45 (100 percent)
Median residence time in forebay	4.4 d (range = <1 h–36.9 d)	5.7 d (range = <1 h–42.5 d)
Near-Dam Behavior		
Number of fish with unreliable near-dam detections	4	7
Number of fish with reliable near-dam detections	41	38
Number of fish detected at weir box or flumes	40 (98 percent)	32 (84 percent)
Number of fish detected at weir box and flumes	16 (39 percent)	21 (55 percent)
Number of fish detected first at weir box (if detected at both locations)	10 (63 percent)	11 (52 percent)
Number of fish detected first at flumes (if detected at both locations)	6 (37 percent)	10 (48 percent)
Dam Passage		
Number of fish collected	29 (65 percent)	36 (80 percent)
Number of fish passed into tailrace	11 (24 percent)	6 (13 percent)
Number of fish that didn’t pass dam	5 (11 percent)	3 (7 percent)

Table 3. Estimates from a multistate model for detection probabilities and proportion of tagged fish collected through the weir box and collection flumes, 2013.

[Numbers in parentheses are standard errors]

Parameter	Descriptor	Steelhead	Coho salmon
p_{f1}	Detection probability of radio-tagged fish in collection flumes	0.654 (0.088)	0.646 (0.082)
p_{f2}	Detection probability of PIT-tagged fish in collection flumes	0.895 (0.057)	0.881 (0.056)
p_w	Detection probability of radio-tagged fish in weir box	1.000	1.000
p_c	Detection probability of PIT-tagged fish in collection facility	0.964 (0.035)	0.971 (0.028)
C_f	Proportion of fish collected through collection flumes	1.000	0.945 (0.038)
C_{wb}	Proportion of fish collected through weir box	0.000	0.055 (0.038)

Appendix A. Summary of Individual Detection Histories of Juvenile Steelhead during a Radiotelemetry Evaluation at Cowlitz Falls Dam, 2013

[To conserve space only the last 7 digits of each PIT-tag code are reported. The first 7 digits (3D9.1C2) were identical for all fish. Fates were assigned as flumes or weir box if fish were collected through a known route, otherwise collected fish were assigned a fate of the fish facility (CFFF). Fish that passed the dam were assigned a tailrace fate. **Bold** date/time values identify which collection device was first encountered for fish detected at the flumes and weir box]

Radio tag ID	PIT tag ID	Date and time of release	Date and time of first detection in forebay	Elapsed time from release (d)	Fate	Date fate occurred	Date and time of first detection at weir box	Date and time of first detection at flume entrances	Number of times detected at weir box/flume entrances	Date and time of last detection in forebay	Elapsed time in forebay (d)
1027	E0B32A1	4/30/13 12:39	4/30/13 17:35	0.2	CFFF	5/3/2013			0/0	5/19/2013 03:58	18.4
1028	E0A3DD4	4/30/13 12:39	5/02/13 05:24	1.7	FLUMES	5/5/2013	5/03/13 09:22	**5/03/13 08:32**	2/4	5/05/2013 02:41	2.9
1030	E0B4F9C	4/30/13 12:39	4/30/13 16:55	0.2	FLUMES	5/5/2013	**5/01/13 05:21**	5/01/13 14:53	6/6	5/05/2013 20:27	5.1
1039	E0A70C7	4/30/13 12:39	4/30/13 20:29	0.3	FLUMES	5/3/2013		5/02/13 15:10	0/1	5/03/2013 14:19	2.7
1015	E0AF440	4/30/13 12:39	5/01/13 00:00	0.5	DID NOT PASS		5/04/13 21:26	**5/04/13 20:13**	1/1	5/06/2013 14:59	5.6
1036	E0AE1A5	4/30/13 12:39	5/08/13 19:36	8.3	DID NOT PASS				0/0	5/09/2013 02:24	0.3
1037	E0B472C	4/30/13 12:39	5/19/13 05:14	18.7	DID NOT PASS				0/0	5/24/2013 03:39	4.9
1011	E0A27CA	4/30/13 12:39	4/30/13 17:21	0.7	TAILRACE	5/7/2013	**5/01/13 05:25**	5/01/13 20:26	8/7	5/07/2013 23:23	7.3
1012	DF7D602	4/30/13 12:39	5/19/13 01:26	18.5	TAILRACE	6/3/2013			0/0	5/19/2013 01:29	0.0
1013	E0A343A	4/30/13 12:39	5/01/13 03:33	0.6	TAILRACE	5/5/2013	5/03/13 14:22	**5/02/13 19:55**	1/1	5/04/2013 23:28	3.8
1016	E0A4AA9	4/30/13 12:39	5/02/13 00:43	1.5	TAILRACE	5/5/2013	5/02/13 11:32		2/0	5/05/2013 11:03	3.4

Radio tag ID	PIT tag ID	Date and time of release	Date and time of first detection in forebay	Elapsed time from release (d)	Fate	Date fate occurred	Date and time of first detection at weir box	Date and time of first detection at flume entrances	Number of times detected at weir box/flume entrances	Date and time of last detection in forebay	Elapsed time in forebay (d)
1026	E0ADFA8	4/30/13 12:39	4/30/13 18:54	0.3	TAILRACE	5/8/2013	**5/01/13 01:47**	5/01/13 20:38	6/7	5/07/2013 23:39	7.2
1038	E0A4687	4/30/13 12:39	4/30/13 19:07	0.3	TAILRACE	5/1/2013			0/0	5/01/2013 01:29	0.3
1040	E0B06AB	4/30/13 12:39	4/30/13 17:15	0.2	TAILRACE	5/7/2013	**5/02/13 14:40**	5/02/13 19:49	6/6	5/07/2013 21:09	7.2
1018	E0B5860	5/17/13 09:59	5/18/13 04:28	0.8	CFFF	5/22/2013			0/0	5/20/2013 12:38	2.3
1019	E0A98F3	5/17/13 09:59	5/18/13 01:50	0.7	CFFF	5/22/2013			0/0	5/22/2013 02:08	4.0
1020	E0B527B	5/17/13 09:59	5/18/13 02:39	0.7	CFFF	5/21/2013	**5/20/13 18:00**	5/20/13 22:27	1/1	5/21/2013 08:26	3.2
1032	E0ACEC7	5/17/13 09:59	5/17/13 18:47	0.4	CFFF	5/21/2013		5/17/13 23:07	0/1	5/20/2013 01:34	2.3
1025	E0B4D6C	5/17/13 09:59	5/18/13 07:37	0.9	FLUMES	5/28/2013	**5/19/13 04:25**	5/19/13 04:28	9/8	5/27/2013 15:20	9.3
1033	E0A9916	5/17/13 09:59	5/17/13 16:37	0.3	FLUMES	5/18/2013	**5/17/13 17:05**	5/17/13 17:52	2/2	5/18/2013 00:39	0.3
1031	E0A3239	5/17/13 09:59	5/18/13 05:35	0.8	DID NOT PASS		**5/18/13 05:35**	5/18/13 06:12	12/9	5/25/2013 15:54	7.4
1042	E0A81F9	5/17/13 09:59	5/18/13 04:39	0.8	DID NOT PASS				0/0	5/18/2013 04:44	0.0
2055	E0A83E6	5/24/13 09:11	5/25/13 11:44	1.1	CFFF	5/30/2013			0/0	5/30/2013 01:59	4.6
2056	E0A5AB7	5/24/13 09:11	5/25/13 04:22	0.8	CFFF	6/4/2013			0/0	6/03/2013 03:43	9.0
2057	E0B5BBA	5/24/13 09:11	5/24/13 23:32	0.6	CFFF	6/2/2013			0/0	6/01/2013 11:45	7.5
2069	E0B5DEE	5/24/13 09:11	5/25/13 09:43	1.0	CFFF	5/26/2013			0/0	5/26/2013 21:25	1.5

Radio tag ID	PIT tag ID	Date and time of release	Date and time of first detection in forebay	Elapsed time from release (d)	Fate	Date fate occurred	Date and time of first detection at weir box	Date and time of first detection at flume entrances	Number of times detected at weir box/flume entrances	Date and time of last detection in forebay	Elapsed time in forebay (d)
2072	E0A5ADB	5/24/13 09:11	5/25/13 00:44	0.6	CFFF	5/28/2013			0/0	5/27/2013 21:07	2.8
2048	E0B3E84	5/24/13 09:11	5/25/13 03:49	0.8	FLUMES	6/14/2013		6/06/13 02:33	0/5	6/14/2013 02:02	19.9
2051	E0B1521	5/24/13 09:11	5/24/13 22:24	0.6	FLUMES	6/2/2013	**5/25/13 06:49**	5/25/13 16:45	3/5	6/01/2013 09:46	7.5
2053	DF7AFFB	5/24/13 09:11	5/27/13 16:20	3.3	FLUMES	5/30/2013		5/29/13 03:13	0/2	5/30/2013 02:16	2.4
2059	E0A9B22	5/24/13 09:11	5/25/13 03:09	0.7	FLUMES	6/4/2013	**5/25/13 16:14**	5/30/13 11:41	9/7	6/02/2013 11:01	8.3
2061	DF7D690	5/24/13 09:11	5/25/13 03:40	0.8	FLUMES	5/27/2013	5/25/13 17:26	**5/25/13 15:55**	1/2	5/26/2013 14:09	1.4
2062	E0A690A	5/24/13 09:11	5/26/13 08:57	2.0	FLUMES	5/30/2013	5/29/13 07:50	**5/26/13 16:40**	1/2	5/29/2013 16:53	3.3
2063	E0B19C3	5/24/13 09:11	5/26/13 02:03	1.7	FLUMES	5/31/2013	**5/27/13 03:39**	5/27/13 03:51	5/2	5/31/2013 02:30	5.0
2064	E0AD3F1	5/24/13 09:11	5/25/13 09:22	1.0	FLUMES	5/30/2013	**5/25/13 09:22**	5/29/13 18:19	1/1	5/29/2013 18:27	4.4
2065	E0B0B30	5/24/13 09:11	5/26/13 00:43	1.6	FLUMES	5/31/2013	**5/26/13 04:33**	5/27/13 14:42	3/3	5/30/2013 10:14	4.4
2067	E0AF60C	5/24/13 09:11	5/25/13 18:31	1.4	FLUMES	5/26/2013	**5/26/13 14:26**	5/26/13 14:32	1/1	5/26/2013 14:32	0.8
2070	DF7CBA6	5/24/13 09:11	5/24/13 14:49	0.2	FLUMES	5/31/2013	5/24/13 14:59	**5/24/13 14:55**	15/16	5/30/2013 22:06	6.3
2071	E0A9E30	5/24/13 09:11	5/25/13 10:49	1.1	FLUMES	5/31/2013	**5/25/13 12:09**	5/25/13 19:29	1/2	5/28/2013 10:55	3.0
2073	E0B14DE	5/24/13 09:11	5/26/13 11:55	2.1	FLUMES	5/26/2013	**5/26/13 12:55**	5/26/13 16:40	2/2	5/26/2013 20:59	0.4
2074	DF7A2CB	5/24/13 09:11	5/26/13 12:31	2.1	FLUMES	6/17/2013		6/08/13 11:28	0/2	6/15/2013 10:17	19.9

Radio tag ID	PIT tag ID	Date and time of release	Date and time of first detection in forebay	Elapsed time from release (d)	Fate	Date fate occurred	Date and time of first detection at weir box	Date and time of first detection at flume entrances	Number of times detected at weir box/flume entrances	Date and time of last detection in forebay	Elapsed time in forebay (d)
2046	E0AEF84	5/24/13 09:11	5/26/13 01:39	1.7	TAILRACE	5/30/2013		5/26/13 11:28	0/2	6/15/2013 00:57	20.0
2049	E0AE745	5/24/13 09:11	5/25/13 10:46	1.1	TAILRACE	7/1/2013			0/0	7/01/2013 08:20	36.9
2066	E0A763A	5/24/13 09:11	5/26/13 07:50	1.9	TAILRACE	5/28/2013	**5/26/13 11:28**	5/27/13 18:37	3/1	6/13/2013 02:30	17.8
2068	E0A4B6A	5/24/13 09:11	5/26/13 08:35	2.0	TAILRACE	5/28/2013	**5/26/13 13:42**	5/26/13 14:48	4/3	5/28/2013 19:14	2.4

Appendix B. Summary of Individual Detection Histories of Juvenile Coho Salmon during a Radiotelemetry Evaluation at Cowlitz Falls Dam, 2013

[To conserve space only the last 7 digits of each PIT-tag code are reported. The first 7 digits (3D9.1C2) were identical for all fish. Fates were assigned as flumes or weir box if fish were collected through a known route; otherwise collected fish were assigned a fate of the fish facility CFFF. Fish that passed the dam were assigned a tailrace fate. **Bold** date/time values identify which collection device was first encountered for fish detected at the flumes and weir box]

Radio tag ID	PIT tag ID	Date and time of release	Date and time of first detection in forebay	Elapsed time from release (d)	Fate	Date fate occurred	Date and time of first detection at weir box	Date and time of first detection at flume entrances	Number of times detected at weir box/flume entrances	Date and time of last detection in forebay	Elapsed time in forebay (d)
1017	E0BD6AB	5/17/13 09:59	5/23/13 14:38	6.2	CFFF	5/28/2013			0/0	5/28/2013 07:43	4.7
1022	E0AFDF6	5/17/13 09:59	6/05/13 01:28	18.6	CFFF	6/7/2013	6/05/13 06:07	**6/05/13 05:48**	3/3	6/08/2013 03:18	3.1
1029	E0AE8C3	5/17/13 09:59	5/20/13 16:19	3.3	CFFF	5/31/2013			0/0	5/30/2013 14:03	9.9
1035	E0A5B12	5/17/13 09:59	5/19/13 04:48	1.8	CFFF	5/26/2013	5/21/13 09:43	**5/21/13 09:24**	1/1	5/26/2013 04:14	7.0
2044	E0AFD62	5/17/13 09:59	5/18/13 02:49	0.7	CFFF	7/2/2013	**5/18/13 07:53**	5/18/13 20:02	8/7	6/29/2013 13:56	42.5
2054	E0B59E7	5/17/13 09:59	5/21/13 20:51	4.5	CFFF	6/2/2013			0/0	5/31/2013 19:05	9.9
1021	E0A3C27	5/17/13 09:59	5/17/13 18:06	0.3	FLUMES	5/23/2013	**5/19/13 15:43**	5/19/13 18:56	5/4	5/23/2013 20:33	6.1
1023	E0B46E5	5/17/13 09:59	5/18/13 14:18	1.2	FLUMES	5/20/2013	5/20/13 01:25	**5/18/13 20:05**	½	5/20/2013 03:03	1.5
1041	E0B3756	5/17/13 09:59	5/18/13 01:39	0.7	FLUMES	5/25/2013	**5/19/13 09:58**	5/19/13 20:05	7/7	5/25/2013 16:50	7.6
2045	E0AF91D	5/17/13 09:59	5/19/13 04:14	1.8	FLUMES	5/29/2013		5/21/13 10:55	0/1	5/28/2013 09:50	9.2
2047	E0A83CA	5/17/13 09:59	5/18/13 02:32	0.7	FLUMES	6/6/2013		5/19/13 12:18	0/3	6/01/2013 07:00	14.2
2050	E0A9EA8	5/17/13 09:59	5/17/13 21:13	0.5	FLUMES	5/18/2013	**5/17/13 21:59**	5/18/13 08:36	1/1	5/18/2013 13:10	0.7

Radio tag ID	PIT tag ID	Date and time of release	Date and time of first detection in forebay	Elapsed time from release (d)	Fate	Date fate occurred	Date and time of first detection at weir box	Date and time of first detection at flume entrances	Number of times detected at weir box/flume entrances	Date and time of last detection in forebay	Elapsed time in forebay (d)
2052	E0A64BE	5/17/13 09:59	5/18/13 04:08	0.8	FLUMES	5/27/2013	5/18/13 17:50	**5/18/13 17:29**	8/8	5/26/2013 16:54	8.5
2058	E0ABCD6	5/17/13 09:59	5/18/13 00:41	0.6	FLUMES	5/22/2013		5/21/13 14:02	0/1	5/22/2013 03:26	4.1
2060	E0B575C	5/17/13 09:59	5/18/13 15:42	1.2	FLUMES	5/30/2013	**5/18/13 15:42**	5/20/13 14:32	3/3	5/29/2013 13:45	10.9
1034	DF7C85E	5/17/13 09:59	6/06/13 07:27	19.9	TAILRACE	6/7/2013	6/06/13 07:31		1/0	6/07/2013 01:57	0.8
3075	E0A9E53	6/07/13 10:18	6/09/13 17:23	2.3	CFFF	6/17/2013		6/10/13 05:40	0/3	6/15/2013 10:56	5.7
3078	E0B359E	6/07/13 10:18	6/08/13 00:53	0.6	CFFF	6/13/2013		6/09/13 03:39	0/3	6/13/2013 07:08	5.3
3086	E0A3FA4	6/07/13 10:18	6/09/13 15:22	2.2	CFFF	6/16/2013			0/0	6/15/2013 11:28	5.8
3076	E0A901C	6/07/13 10:18	6/08/13 08:16	0.9	FLUMES	6/10/2013		6/09/13 23:19	0/1	6/10/2013 00:24	1.7
3088	E0B195B	6/07/13 10:18	6/07/13 19:41	0.4	FLUMES	6/22/2013	**6/07/13 23:58**	6/08/13 03:29	7/6	6/21/2013 18:05	13.9
3090	E0AC943	6/07/13 10:18	6/08/13 01:23	0.6	FLUMES	6/12/2013	**6/09/13 06:22**	6/09/13 06:50	4/5	6/11/2013 10:23	3.4
3095	E0AB331	6/07/13 10:18	6/09/13 07:03	1.9	FLUMES	6/14/2013		6/09/13 08:57	0/2	6/13/2013 14:05	4.3
3098	E0B175A	6/07/13 10:18	6/09/13 01:28	1.6	FLUMES	6/11/2013		6/11/13 16:58	0/1	6/11/2013 16:58	2.6
3103	E0B54A7	6/07/13 10:18	6/07/13 23:16	0.5	FLUMES	6/19/2013	6/08/13 08:25	**6/08/13 06:38**	5/6	6/18/2013 20:29	10.9
3105	E0B44FF	6/07/13 10:18	6/08/13 01:07	0.6	FLUMES	6/15/2013	6/12/13 05:08	**6/08/13 19:27**	1/3	6/14/2013 18:16	6.7
3080	E0B5A7A	6/07/13 10:18	6/08/13 01:21	0.6	TAILRACE	6/8/2013			0/0	6/08/2013 01:22	0.0
3083	E0B102B	6/07/13 10:18	6/09/13 18:00	2.3	TAILRACE	7/4/2013			0/0	7/04/2013 01:16	24.3

Radio tag ID	PIT tag ID	Date and time of release	Date and time of first detection in forebay	Elapsed time from release (d)	Fate	Date fate occurred	Date and time of first detection at weir box	Date and time of first detection at flume entrances	Number of times detected at weir box/flume entrances	Date and time of last detection in forebay	Elapsed time in forebay (d)
3085	E0B4F98	6/07/13 10:18			TAILRACE	6/8/2013			0/0		
3093	E0B1036	6/07/13 10:18	6/08/13 01:56	0.7	TAILRACE	6/8/2013	6/08/13 10:34		1/0	6/08/2013 13:44	0.5
3100	E0AD0CC	6/07/13 10:18	6/08/13 00:52	0.6	TAILRACE	6/8/2013			0/0	6/08/2013 01:59	0.0
3079	E0B31A7	6/12/13 08:24	6/12/13 22:59	0.6	CFFF	6/17/2013			0/0	6/15/2013 12:09	2.5
3081	E0AEE74	6/12/13 08:24	6/15/13 00:07	2.7	CFFF	6/16/2013			0/0	6/15/2013 10:56	0.5
3087	E0A64D8	6/12/13 08:24	6/12/13 15:02	0.3	CFFF	6/14/2013			0/0	6/13/2013 13:18	0.9
3094	DF7D5CA	6/12/13 08:24	6/13/13 09:41	1.1	CFFF	6/15/2013			0/0	6/14/2013 08:50	1.0
3084	E0ADAF1	6/12/13 08:24	6/13/13 18:40	1.4	FLUMES	6/20/2013	**6/17/13 06:48**	6/17/13 07:12	4/3	6/19/2013 09:40	5.6
3092	E0B924B	6/12/13 08:24	6/14/13 06:58	1.9	FLUMES	6/18/2013			0/0	6/17/2013 14:34	3.3
3097	E0AB510	6/12/13 08:24	6/12/13 19:05	0.4	FLUMES	6/17/2013	6/16/13 08:29	**6/12/13 19:13**	1/2	6/16/2013 08:38	3.6
3101	E0B3970	6/12/13 08:24	6/19/13 04:19	6.8	FLUMES	7/3/2013	**6/19/13 12:26**	6/26/13 04:00	9/5	7/02/2013 07:34	13.1
3102	DF7BDC3	6/12/13 08:24	6/12/13 23:38	0.6	FLUMES	6/23/2013	6/13/13 10:41	**6/13/13 10:37**	7/6	6/22/2013 12:47	9.5
3089	E0A6A1B	6/12/13 08:24	6/14/13 13:36	2.2	DID NOT PASS	n/a	6/16/13 16:48		1/0	6/17/2013 04:46	2.6
3091	DF7D7ED	6/12/13 08:24	6/13/13 14:37	1.3	DID NOT PASS	n/a	6/18/13 01:37	**6/14/13 03:46**	2/6	6/26/2013 17:21	13.1
3096	E0B0786	6/12/13 08:24	6/13/13 18:22	1.4	DID NOT PASS	n/a	6/14/13 10:52		1/1	6/20/2013 04:48	6.4

Radio tag ID	PIT tag ID	Date and time of release	Date and time of first detection in forebay	Elapsed time from release (d)	Fate	Date fate occurred	Date and time of first detection at weir box	Date and time of first detection at flume entrances	Number of times detected at weir box/flume entrances	Date and time of last detection in forebay	Elapsed time in forebay (d)
3077	E0ADE9D	6/12/13 08:24	6/14/13 02:38	1.8	WEIR BOX	7/1/2013	**6/22/13 12:54**	5/27/13 18:37	5/3	7/01/2013 04:12	17.1
3082	E0AF229	6/12/13 08:24	6/15/13 06:27	2.9	WEIR BOX	7/1/2013	**6/16/13 16:07**	5/26/13 14:48	8/10	6/30/2013 10:48	15.2

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