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Seattle, Washington

by
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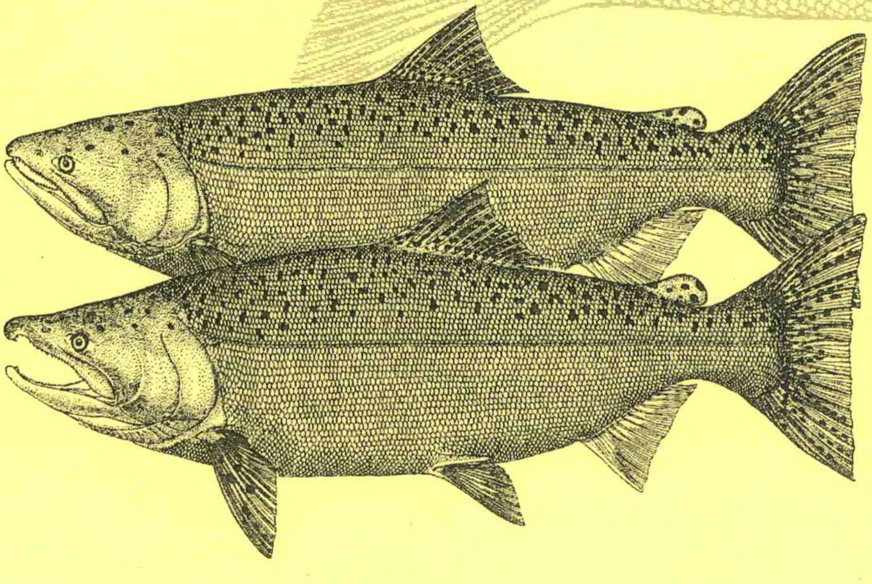
December 2006



Detection Efficiency of a Passive Integrated Transponder (PIT) Tag Interrogator for Adult Chinook Salmon at Bonneville Dam, 2005

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Project ADS-00-14

December 2006

EXECUTIVE SUMMARY

We tagged over 700 adult Chinook salmon in 2005 with both a radiotelemetry tag and a PIT tag to determine detection efficiency of the vertical-slot PIT-tag interrogator, which was installed in the Washington Shore Fish Ladder at Bonneville Dam (site code used in PTAGIS database is BO4) during winter 2004-2005. Detection efficiency of BO4 was very high during the spring (cumulative efficiency of 100%), when water temperatures were relatively low. However, efficiency was slightly lower in the fall (cumulative efficiency of 96%), partially due to higher water temperatures and partially to the types of PIT tags used. Differences between efficiencies recorded during the spring and fall may also be due to behavioral differences between runs of Chinook salmon, though we did not specifically test fish behavior in this study.

The rate of false positives for dam passage was reduced by the inclusion of the BO4 interrogator. Furthermore, overall interpretation of PIT-tag data was improved when we altered our algorithm for assigning passage using PIT-tag data to interpret fish passing the Washington Shore Ladder only when fish are last detected at one of the BO4 coils. However, this requirement may be dropped if cumulative detection efficiency at BO4 drops below 96%.

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INTRODUCTION

Thirteen populations of salmon and steelhead in the Columbia River Basin are listed as threatened or endangered under the U.S. Endangered Species Act (NOAA Fisheries Service). Due to their complex life history, studying these migrating animals requires multiple methods at local and regional scales. Researchers have been using several tagging methods to track adult fish in the Columbia River Basin for decades (Johnson 2004; Keefer et al. 2005; Prentice et al. 1990). As technology advances and management of the system changes, testing various tagging methods is critical to assuring appropriate use of the data collected.

Of the 13 major hydropower dams in the Columbia and Snake Rivers that have adult fish passage facilities, 7 now have PIT-tag detection systems in adult fishways (Figure 1). Bonneville, McNary, and Wells Dams have had adult detection systems since 2002. Detection systems were installed into the fish ladders at Ice Harbor, Lower Granite, Priest Rapids, and Rock Island Dams in 2003. A system was installed at Prosser Dam in 2004. Moreover, detection systems have been upgraded or expanded at several dams since their initial installations. For example, the U.S. Army Corps of Engineers installed additional vertical-slot detection systems in adult fishways at Bonneville Dam in 2005 and 2006 and a new counting-window system in the Washington Shore Ladder at McNary Dam for 2006.

Detection efficiencies of PIT-tag detection systems can vary substantially among dams, years, and species (Downing and Prentice 2004). Initial designs for fishway detection systems monitored the orifices at the base of weirs, and most antennas were deployed on multiple, consecutive weirs to increase detection efficiencies. Downing and Prentice (2004) found that more fall Chinook and coho salmon swam over the tops of weirs, rather than through the orifices, than other salmonid populations. This behavior reduced detection probabilities for these runs by up to 20% in certain fish ladders. Similarly, jacks (precocious males) of all populations tended to have lower detection probabilities than adult fish, presumably because of behavioral differences.

Advancements in PIT-tag technology permitted larger antennas to be fabricated in 2003 than had been possible even in 2002. Consequently, antennas could be installed into the vertical slots at Ice Harbor and Lower Granite Dams. Unlike orifice-based antennas, the vertical-slot antennas covered the entire water column, and therefore all fish passing through the ladder had to go through these antennas. Similarly, vertical-slot antennas were installed into the top of the Washington Shore Fish Ladder at Bonneville Dam in 2005 (Figure 2; after this research was complete, a similar system was installed into the Bradford Island Fish Ladder at Bonneville Dam in early 2006).

In addition to maximizing detection efficiencies, the new Bonneville Dam detection systems were designed to detect dam passage events. Salmonids in the Columbia River Basin swim both upstream and downstream in fishways. Therefore, detection of a fish in a dam fishway does not necessarily imply the fish passed the dam. At Bonneville Dam, the adult detection systems were initially located between Weirs 34 and 59. Fish often swam up through the orifices of these weirs (and were detected by the PIT-tag system), only to swim back downstream. Moreover, the downstream movements were often over the tops of the weirs, which meant that the orifice-based PIT-tag systems did not detect this movement. The placement of the vertical-slot detectors at Bonneville Dam (at the tops of the ladders) was intended to reduce this problem (Figure 2).

As with any new equipment, these detection systems need to be evaluated. We used fish tagged with both a PIT tag and a radiotelemetry tag to determine detection efficiencies for the new Bonneville Dam vertical-slot PIT-tag detection system. The two tagging systems provided independent and complementary measures of fish behavior for this analysis.

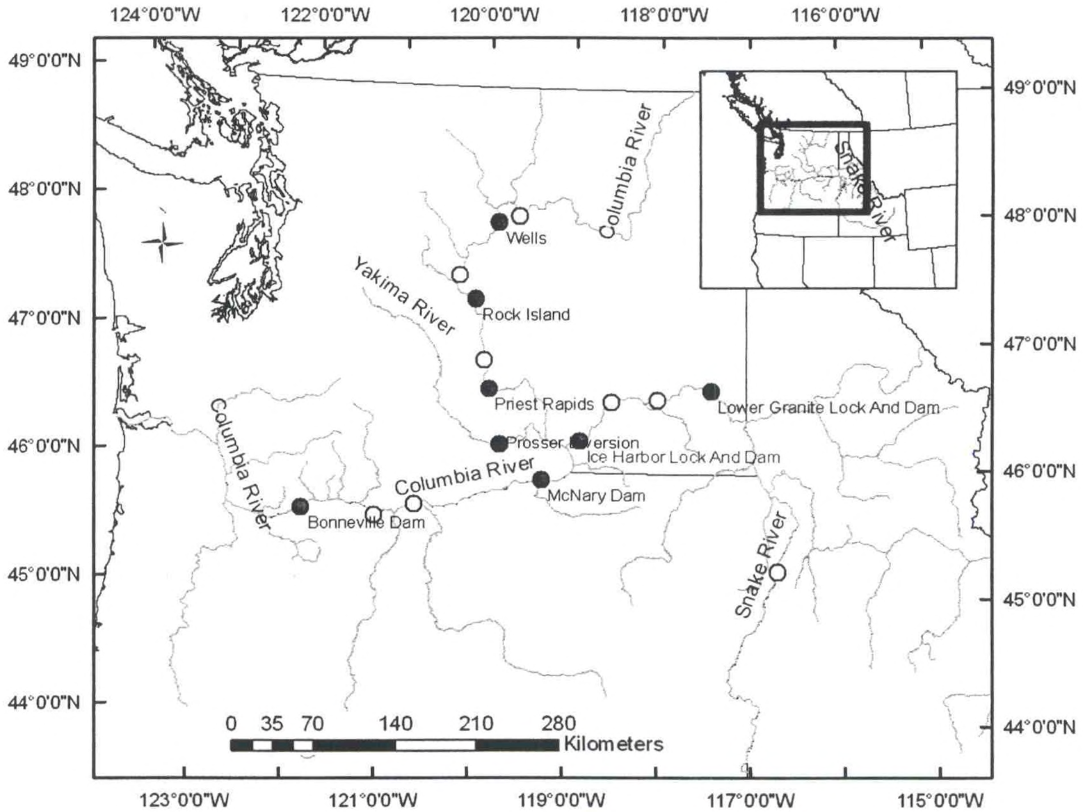

Figure 1. Columbia River Basin including location of mainstem hydropower dams (circles). Fish ladders at Bonneville, McNary, Priest Rapids, Rock Island, and Well Dams on the Columbia River, Ice Harbor and Lower Granite Dams on the Snake River, and Prosser Dam on the Yakima River (shaded circles) are equipped with adult PIT-tag interrogation systems.

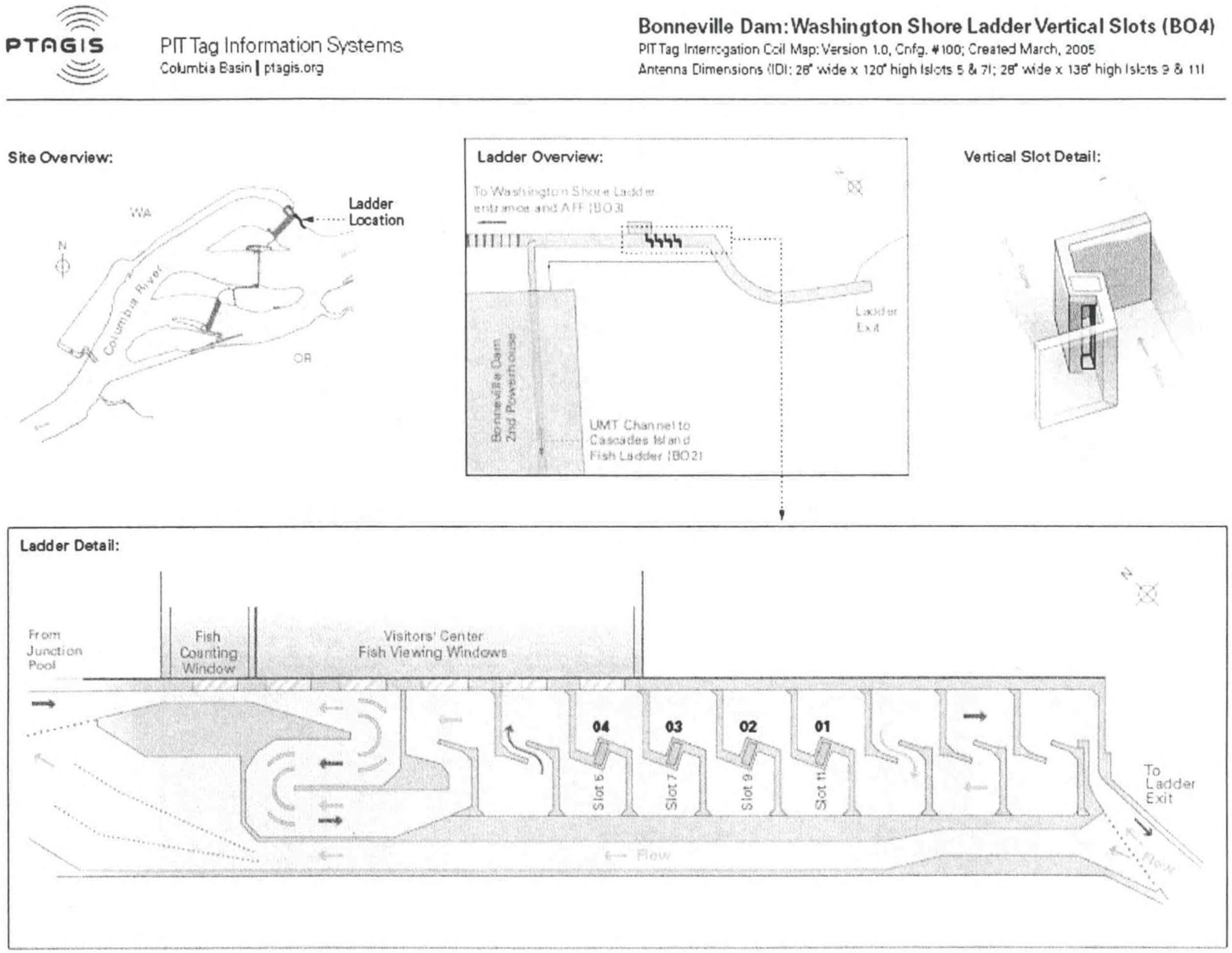

Figure 2. Location of Bonneville Dam PIT-tag interrogation system, BO4. Reprinted with permission (http://www.ptagis.org/ptagis/sites/data/bo4_100.pdf).

METHODS

From 21 May to 1 October 2005, we collected adult spring/summer and fall Chinook salmon at the Adult Fish Facility (AFF) in the Washington Shore Fish Ladder at Bonneville Dam. We measured and weighed each fish and gastrically inserted a radiotelemetry tag. For those fish that did not already have a PIT tag, we inserted one in the body cavity. All other selection, capture, handling, and tagging procedures were the same as described by Keefer et al. (2004).

We interpreted radiotelemetry data in two steps; we first assigned codes to particular records using an automated program and then reviewed these codes manually for accuracy and completeness. Interpretations of PIT-tag data were performed using an algorithm developed by Burke and Jepson (2006). The two main 'rules' of the algorithm were

1) No more than a 12-h gap in time between consecutive PIT-tag detections was allowed for a single passage attempt (if a gap in time ≥12 h existed, data were treated as two separate passage attempts) and

2) Directionality (if the last known direction of the fish was upstream, a passage event was assigned to that fish).

Directionality can be determined by consecutive detections among detection systems (e.g., BO2 followed by BO3 or BO4) or among coils; coils are the antennas deployed at individual weirs that constitute each interrogation system. Coils within the BO4 site were treated similarly to all other sites: coil 1 was upstream from coil 2, coil 2 upstream from coil 3, etc. (Figure 2).

The potential exists for misinterpreting PIT-tag data when a fish passes through two or more coils, yet does not fully pass the ladder (e.g., when a fish turns around, swims downstream, and exits the ladder into a transition pool or the tailrace; see Burke et al. (2005) for frequency of turn-around behavior within fishways). In fact, the location of BO4 within the ladder was chosen, in part, to reduce this potential. In addition to the directionality condition, we also required that fish passing through the Washington Shore Ladder be last detected at one of the four BO4 coils (as opposed to any of the BO2 or BO3 coils). Results with and without this additional criterion are presented for comparison.

After all radiotelemetry and PIT-tag data were interpreted, we compared detection efficiencies for individual fish between tagging methods or detection technologies. We combined interpretations from both technologies to get a best estimate of individual fish behavior and then compared interpretations from individual technologies to the combined interpretation.

RESULTS

Spring/Summer Chinook

From 21 May through 26 June 2005, we captured and radio tagged 142 adult spring/summer Chinook salmon at the Adult Fish Facility (AFF) in the Washington Shore Ladder at Bonneville Dam (Figure 3). Because we had more than one objective during this field season, we used two separate release locations. We released 47 spring and summer Chinook salmon back into the ladder at the AFF and allowed them to volitionally reinitiate upstream migration. Additionally, we released 95 summer Chinook salmon at the Hamilton Island boat ramp, approximately 3.6 km downstream from Bonneville Dam. All fish detections were analyzed using the same techniques, regardless of release location.

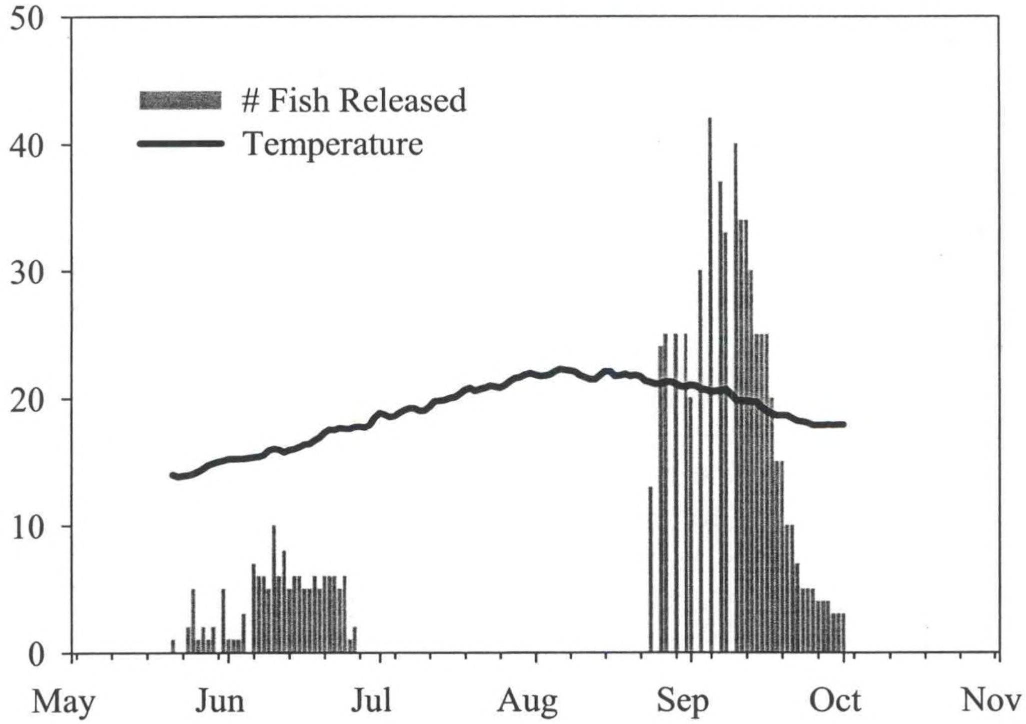

Figure 3. Number of Chinook salmon released per day during 2005 and daily average temperatures (°C).

We analyzed passage events at the dam as a whole separately from passage events specifically through the Washington Shore Ladder. For the dam as a whole, all 142 fish passed Bonneville Dam at least once. According to radiotelemetry, six fish fell back over the dam. Of those, four reascended the dam, one of which fell back again and reascended a second time. Among the 142 Chinook salmon, there were 147 passage events at Bonneville Dam with which we could compare results between tagging methods. Of these 147 passage events, 145 were detected by both radiotelemetry and PIT-tag systems. The two passage events that were not detected by the PIT-tag system were fish that passed via the Bradford Island Ladder on the Oregon shore, where the vertical slot PIT-tag antennas had not been installed at the time of this research.

We defined a false positive as a detection of a passage event when the fish did not actually pass the dam. Without including the additional algorithm constraint that requires that all passage events end with detection at one of the BO4 coils, there were five false positive passage events determined by the PIT-tag system for spring/summer Chinook salmon. Three of these were fish that spent more than 12 h in the Washington Shore Ladder, between BO3 and BO4, before passing the dam. By design, when more than 12 h elapsed between detections, the PIT-tag interpretive algorithm divided the detections into two separate passage events.

Both sets of detections met all other conditions for a successful passage event, so two passages were assigned when the fish passed only once. Similarly, another fish ascended the Washington Shore Ladder, passed BO3, turned around, and swam downstream to the tailrace. PIT-tag detections for this fish met all of the conditions for a successful passage event (the last detection showed it swimming in an upstream direction).

The only other event that might be considered a false positive by the PIT-tag system was a fish that entered the AFF in the Washington Shore Ladder. This fish was assigned a successful passage event (it was heading upstream) based on PIT-tag data from BO3, but was diverted, radio tagged (for this project), and released downstream. Although circumstances did not truly afford the fish an opportunity to pass the dam, without knowledge of the fate of this fish, we would have interpreted the detections as a successful passage.

One fish was detected passing the Bradford Island Ladder at Bonneville Dam by the PIT-tag system but not by the radiotelemetry system. However, this was because the passage event (as well as a subsequent fallback event over the dam) occurred before the fish was radio tagged.

Passage Efficiency Evaluation

In addition to overall passage comparisons, we compared passage metrics among tagging methods in the Washington Shore Ladder specifically to determine the efficiency of the new vertical-slot PIT-tag detection system, BO4. Of the 142 fish in this study, 90 passed Bonneville Dam via the Washington Shore Ladder; one of those passed three times, for a total of 92 passage events through this ladder.

All 92 passage events were detected by both radiotelemetry and the PIT-tag system. Furthermore, all 92 passage events were detected by at least one of the four coils at BO4, yet none of the four individual coils detected all 92 passage events (Table 1; Figure 4). Detection efficiencies for individual coils ranged from 0.94 at coils 1 and 2 to 0.99 at coil 4.

Two fish (2.2% of those that passed) fell back at Bonneville Dam but did not reascend. Because (partial) reascension is necessary for the PIT-tag system to detect a fallback in most cases, these two fallback events were not detected.

To decrease the number of false positives by the PIT-tag system, we modified the interpretive algorithm to require that the detection history of a fish passing through the Washington Shore Ladder end with detection at one of the four coils at BO4. Since the cumulative detection efficiency of the four coils at BO4 is 1.0, this additional requirement eliminated all of the false positives. With this requirement in place, the interpretation of fish behavior using the two tagging methods had five differences: two fish passed through the Bradford Island Ladder without being detected by the PIT-tag system, two fish fell back (and did not reascend) without being detected by the PIT system, and one fish passed Bonneville Dam without being detected by the radiotelemetry system (it passed before being radio tagged, but had been PIT tagged as a juvenile).

Table 1. Number of fish detected passing through the BO4 PIT-tag coils and the corresponding detection efficiencies.

	Spring/Summer Chinook salmon N = 92		Fall Chinook salmon N = 582	
Interrogator-coil	Number of fish detected	Detection efficiency	Number of fish detected	Detection efficiency
BO4-1	86	0.935	399	0.686
BO4-2	86	0.935	431	0.741
BO4-3	89	0.967	513	0.881
BO4-4	91	0.989	530	0.911
Cumulative	92	1.0	560	0.962

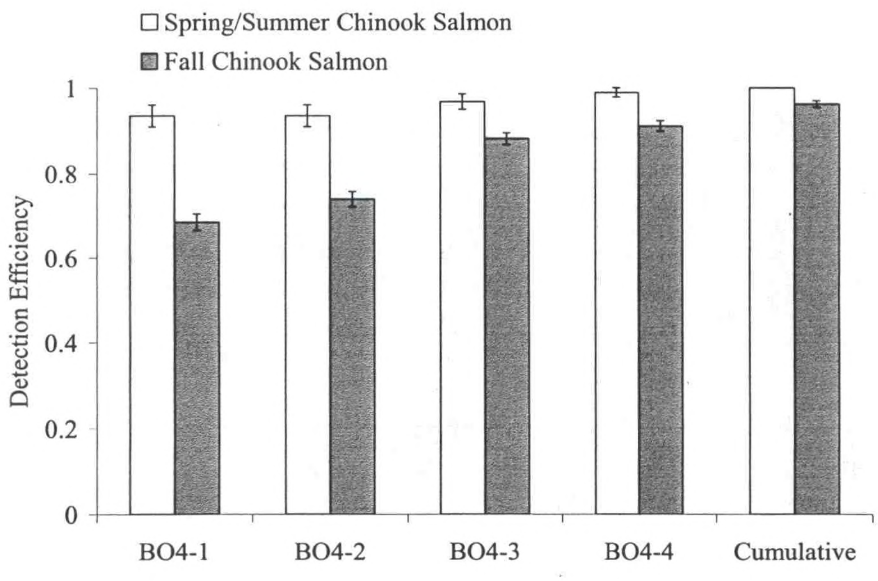

Figure 4. Detection efficiency (+/- SE) of the PIT-tag interrogation system. BO4-1 is coil 1 (upstream-most coil) at the BO4 detector. BO4-4 is the downstream-most coil.

Fall Chinook

From 24 August through 1 October 2005, we trapped and radio tagged 600 fall Chinook in the Washington Shore Ladder at Bonneville Dam (Figure 3); all fish were released back into the ladder to maximize the number of fish passing through BO4. Determining directionality for these fish was somewhat compromised as the AFF (release location) is located upstream from part of the BO3 PIT-tag detection system in the Washington Shore Ladder. Because of the positive effect of the additional constraint that all passage events in the Washington Shore Ladder end in detection at one of the four BO4 coils, we used this constraint for initial analysis of all fall Chinook PIT-tag data.

According to radiotelemetry detection data, 27 of the 589 fish that passed Bonneville Dam fell back over the dam at least once. Of those, six reascended the dam, four of which fell back again and remained downstream. Among the 600 tagged fall Chinook salmon, there were 596 passage events at Bonneville Dam with which we could compare results between tagging methods, and 582 of these were through the Washington Shore Ladder (Table 1; Figure 4).

Regardless of which ladder was used, most passage events were detected by both radiotelemetry and the PIT-tag system (98%, or 582 out of 596). Twelve passage events that were not detected by the PIT-tag system were fish that passed via the Washington Shore Ladder, but were missed by the BO4 detection system completely or were only detected at one coil, preventing determination of directionality. One fish was detected passing Bonneville Dam by PIT tags, but not radiotelemetry; we speculate that this fish expelled its radio tag prior to passing the dam.

One fish spent over 45 d swimming up and down in the fishway, as well as in the tailrace. Although it was not directly detected passing the dam by radiotelemetry, it was detected upstream from the dam. This would be expected if the fish passed through the navigation lock, which was not monitored with radiotelemetry during 2005. The PIT-tag system did not detect the actual passage event, but did interpret the upstream and downstream movements of this fish as passage events (false positives) on four separate occasions. Three of these were in the Bradford Island Ladder and the fourth was in the Washington Shore Ladder. The behavior exhibited by this fish represented the only false positives for fall Chinook salmon in this study.

When just considering Washington Shore Ladder passage events, the BO4 detection system did not detect 15 fall Chinook salmon (2.6% of passage events through the Washington Shore Ladder) that were later detected at McNary Dam by the PIT-tag system, confirming passage at Bonneville Dam. Four of these fish were detected by one coil only, preventing determination of directionality, the others were not detected at all. Although these fish were interpreted as passing the dam by both methods, they are important to consider when discussing detection efficiency at the BO4 PIT-tag detection system.

Twenty-one fish (3.6%) fell back at Bonneville Dam, but did not reascend. Because (partial) reascension is necessary for the PIT-tag system to detect a fallback in most cases, these fallback events were not detected. Six fish reascended the dam after falling back, two of which were detected by the PIT-tag system. Four fish that reascended fell back a second time, none of which reascended a second time and therefore these fallback events were not detected by the PIT-tag system.

Although we ran the PIT-tag interpretive algorithm for fall Chinook salmon using the requirement that any Washington shore passage event include a detection at one of the BO4 coils, we checked the impact that this requirement had on results. When detection efficiency is high, as in spring/summer Chinook salmon, this requirement reduced the number of false positives, improving algorithm performance. This was also true for fall Chinook salmon (removing this requirement would have resulted in six additional false positives). However, 7 of the 12 fish that were not detected passing through BO4 were in fact detected passing through BO3; removal of the requirement of BO4 detection would have resulted in these seven fish being correctly interpreted as passing the dam.

SUMMARY AND CONCLUSIONS

Detection efficiency of the BO4 detection system for spring/summer Chinook salmon is higher than for many detection systems in Columbia and Snake River dam fishways. Individual coils detected over 91% of all fish passing through, and the set of four coils together detected every double-tagged fish. However, results from other research show slightly lower detection efficiencies (Downing, personal communication). Detection efficiency for fall Chinook salmon was quite a bit lower for individual coils (69-91%). Moreover, the four coils together missed detecting 4% of the fall Chinook passing through BO4.

There are several reasons why detection efficiency might be reduced for fall Chinook salmon. Downing and Prentice (2004) found that efficiency was negatively affected by transceiver performance at air temperatures above 45°C, which is above the tolerance levels of some of the electronic components. However, that was not the case at BO4, where the highest air temperatures recorded were below 40°C. These transceivers did have different analog boards, which is why they worked with such large antennas, and their tune was impacted by changing temperatures over the course of a day. This was still not completely fixed by August and September, though new boards were installed for 2006 in March.

Spring/summer Chinook salmon passed Bonneville Dam when temperatures were relatively low (average daily water temperature during tagging was 15.7°C; Figure 3). However, during the time we tagged fall Chinook salmon, water temperatures had risen to over 19.6°C on average. This change may partially explain the differences between the two runs of Chinook salmon, but does not explain the differences observed among coils during the fall Chinook salmon run.

Coils 1 and 2 at BO4 are larger than coils 3 and 4 (26 × 138 in compared to 26 × 120 in). Larger antennas usually result in a larger gap in the zone of detection (in this case, in the center of the rectangular antenna). During initial testing of these antennas, BE PIT tags (the original FDX-B ISO tags manufactured by Digital Angel) were detected significantly less well in the centers of Antennas 1 and 2 than in Antennas 3 and 4 (Downing, personal communication). This was corroborated by results from this study, where detection efficiencies at coils 1 and 2 were 5% (for spring/summer Chinook salmon) to 20% (for fall Chinook salmon) less than at coils 3 and 4.

Finally, we believe that the type of tag used in our study affected detection efficiency. Data from initial testing of the system at BO4 suggest that BE tags are detected significantly less often than ST (model of tags that Digital Angel started to manufacture in 2003) and SGL tags (Downing, personal communication). Of the 142 spring/summer Chinook salmon in this study, 108 (76%) were tagged using BE tags. The remainder were tagged by other researchers with a variety of tag types. For fall Chinook salmon, the proportion of BE tags used was 95% (572 out of 600). Given that a higher percentage of fall Chinook salmon in our study had BE tags than did spring/summer Chinook salmon, we believe the lower detection efficiency of these tags had a greater impact on detection efficiency of fall Chinook salmon than on spring/summer Chinook salmon.

Together, these three factors likely explain most of the differences observed between runs of Chinook salmon. However, it is possible that behaviors specific to the two runs can also influence results. For example, if fall Chinook salmon tend to swim faster through constricted areas, such as where the vertical-slot detectors are located, they may be less likely to be detected. This may also explain why jack Chinook salmon have lower detection rates than adult salmon (Downing and Prentice 2004). Although we have no evidence that jack Chinook salmon swim faster than adults through the fishways, Zabel et al. (in prep.) and Caudill et al. (in review) have observed a negative relationship between fish size and fishway passage times.

False positives (data that suggest a passage event occurred, when the fish did not pass the dam) can be problematic when using PIT-tag data to adjust visual counts or estimate passage rates. Burke et al. (2004) estimated false positive rates of 5% at some dams. The installation of BO4 at Bonneville Dam reduced the false positive rate for PIT-tag data to almost zero. We observed four false positives, all from the same fish. Three of these were in the Bradford Island Ladder, where there were no vertical-slot PIT-tag antennas installed at the time. The fourth false positive was observed in the Washington Shore Ladder when the fish turned around in the ladder (within the BO4 area) but was not detected heading back downstream.

When we removed the requirement in the PIT-tag interpretive algorithm that all Washington shore passage events end with detection at one of the BO4 coils, several more false positives were found. Many fish passed through the fishway section where the BO3 detector was deployed, but changed direction and swam downstream (or went down the BO2 ladder). These fish may be incorrectly interpreted as passing the dam when the BO4 requirement is not in place. However, it is also true that some fish (fall Chinook salmon) that passed the dam were detected passing BO3 but missed at BO4. Interpretation of data from these fish was improved by removing the BO4 requirement.

Overall, the BO4 requirement improves data interpretation as long as detection efficiency at BO4 is relatively high. If detection efficiency at BO4 is too low, many fish that pass the dam will not be interpreted as having passed it, even if they were detected at BO2 and BO3. At what level of detection efficiency should one remove the BO4 requirement? Since the requirement created a balance between false positives and missed passage events for fall Chinook salmon (as many fish were missed due to the requirement as would have been identified as false positives if the requirement were removed), we suggest using the requirement unless detection efficiency drops below that observed for fall Chinook salmon (average coil detection efficiency of about 80% or cumulative efficiency of 96%).

It should be noted that the large number of fish that were missed at BO4 may not matter as much with fish PIT tagged as juveniles because they are likely to be detected at several of the BO3 antennas. For this research, we released fish in the ladder, between the upper and lower segments of BO3. Fish coming from the tailrace will have an opportunity to be detected on the antennas in the lower segment of BO3 in addition to the upper segment of BO3. If a fish is detected at more than one antenna, directionality can be established, and detection at BO4 is not necessary.

As observed with other PIT-tag detectors, the first year of use does not always provide the highest detection efficiencies. Tuning of the BO4 detector should improve detection efficiencies in future years, and other changes will likely stabilize performance.

ACKNOWLEDGMENTS

We gratefully thank all of the people working on the radiotelemetry project, including Ken Tolotti, Carol Morat, Steve Lee, Dan Joosten, and Matt Keefer. Thanks to Doug Dey and Mary Moser at NOAA Fisheries Service for their sounding board properties and to Sandy Downing for advice, information, and review of this work. Thanks also to JoAnne Butzerin for reviewing this report. Funding for this project was provided by the U.S. Army Corps of Engineers, Portland District.

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