Evaluation of the Full-Flow PIT-Tag Interrogation System at Ice Harbor Dam, 2005

Sandra L. Downing and Gordon A. Axel

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Fish Ecology Division
Northwest Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
2725 Montlake Boulevard East
Seattle, Washington 98112-2097

for

Division of Fish and Wildlife
Bonneville Power Administration
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EXECUTIVE SUMMARY

During spring 2005, we conducted tests to evaluate performance of the newly installed full-flow passive integrated transponder (PIT) tag interrogation system at Ice Harbor Dam. We evaluated performance using both direct and indirect methods. For direct evaluations, we released a known number of fish under different test conditions and determined the proportions detected. For indirect evaluation, we used statistics to evaluate detection proportions of river-run fish. In addition, we compared performance of the TX1400ST PIT tag with that of a newer model, the TX1400SGL tag.

From the direct evaluations, we found that reading efficiencies for all of the fish tests at Ice Harbor Dam were greater than 98.0%. Therefore, even at the highest tagged-fish density tested (around 30 fish/min), the full-flow interrogation system was able to detect tagged fish at levels well above the acceptable standard of 95%. However, at the highest tagged-fish density, around 20% of the fish were detected on only 1 or 2 antennas instead of all 4 antennas. Furthermore, individual coil reading efficiencies decreased as tagged-fish densities increased (dropping from around 90 to 80%). The direct evaluation also demonstrated that with the mid-size antennas in the full-flow system, there was no difference in detection rates between fish tagged with TX1400ST and those tagged with TX1400SGL PIT tags.

From the indirect evaluations, we found

1) During the dates at Ice Harbor Dam with the highest fish densities during the juvenile smolt migration season (other than the day of direct evaluations), less than 3% of river-run fish were detected on only 1 or 2 of the 4 antennas that make up full-flow bypass system.
2) The full-flow system at Ice Harbor detected different salmonid populations equally well, with less than 4% of fish from the populations tested having fish detected on only 1 or 2 antennas.
3) At McNary Dam, where there are more antennas below the full-flow system, we were able to confirm that only a few tags were missed by the full-flow system during the peak of the smolt migration, when it detected almost as many tags in 1 day as the Ice Harbor system did over the whole season.

Results from both types of tests demonstrated that the full-flow system at Ice Harbor Dam detected tagged salmonids well. Since Ice Harbor Dam experiences much lower tagged-fish densities than McNary Dam, the fisheries community can be confident that the full-flow detection system will perform well as long as it is well tuned.

CONTENTS

INTRODUCTION

Bonneville Power Administration (BPA) contracted National Marine Fisheries Service (NMFS) to evaluate the newly installed full-flow PIT-tag interrogation system at Ice Harbor Dam in 2005. NMFS was tasked with determining whether the new system detected PIT-tagged fish at an acceptable level. Typically, an acceptable level is defined as having an overall reading efficiency of at least 95%. We evaluated the performance using both direct and indirect evaluation methods. For the direct evaluation, we released a known number of fish under different conditions and determined how many were detected. For the indirect evaluation, we used statistics to evaluate detections of river-run fish. We also used the direct evaluation method to compare a new PIT tag model, the TX1400SGL (SGL tag), with the current tag model, the TX1400ST (ST tag).

NMFS started development of full-flow bypass PIT-tag systems in 2001 and installed the first system at McNary Dam in 2002 (Nunnallee and Prentice 2002; Axel et al. 2003). The design of the full-flow PIT-tag system at Ice Harbor Dam is very similar to that of the system at McNary Dam. Both full-flow systems consist of four individual antennas (Figure 1 and Table 1).

Figure 1. Photo showing the four RF shields for the full-flow PIT-tag system at Ice Harbor Dam. The individual antennas are wrapped inside of the shields.

Table 1. Comparison of several characteristics of the full-flow systems at McNary and Ice Harbor Dams.

System description	McNary Dam	Ice Harbor Dam
Transport pipe internal diameter	91.4 cm (36 in)	88.9 cm (35 in)
Water velocity (ft/s)	11	12
Distance from pipe entrance to first antenna (ft)	255	251
Spacing between RF clamps	25 and 30 in	33 in

The internal diameter of the transport pipe at Ice Harbor Dam is 35 in or (88.9 cm) compared to an id of 36 in (91.4 cm) in the transport pipe at McNary Dam (Axel et al. 2003, 2005). Water in the center of the transport pipe flows at 12 ft/s, which is a little faster than at McNary Dam (11 ft/s). The first antenna at Ice Harbor Dam is located approximately 251 ft from the beginning of the transport pipe compared to 255 ft at McNary Dam. Each subsequent antenna is approximately 24 ft downstream from the preceding antenna when measured from the midpoints of both antennas.

PIT-tag antennas and transceivers for the system at Ice Harbor Dam were installed by Pacific States Marine Fisheries Commission (PSMFC). PSMFC finished the installation on 19 April 2005. Details on how the system was installed (e.g., how the antennas are wrapped) were similar to those for the system installed at McNary Dam in 2002 (see Axel et al. 2003). For the tests at McNary Dam, spacing between RF clamps was 25 in for two antennas and 30 in for the other two (Figure 2). Currently at McNary Dam, spacing is 25 in between RF clamps for three antennas, and one remains at 30 in. At Ice Harbor Dam, spacing between RF clamps was approximately 33 in for all four antennas. This produced a tag-energizing field that yielded 6-8 reads for each tag transiting a coil or antenna. A larger field was employed at Ice Harbor Dam because the density of the in-river fish population is substantially lower than at McNary Dam; therefore, problems such as tag collision (where neither tag is read because both tags are in the field simultaneously) are less likely to occur.

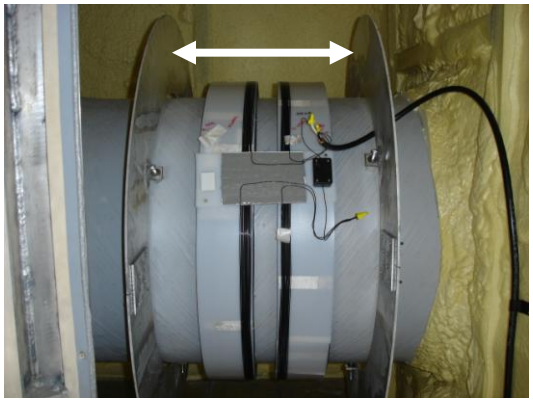


Figure 2. Photo of one antenna for the full-flow PIT-tag system at Ice Harbor Dam. White line delineates spacing (33 in) between the two RF clamps.

On 19 April 2005, PSMFC and NMFS ran spacing tests to determine how far apart two tags needed to be before tag collision became a problem. These tests determined that as long as tags were separated by at least 12 in, all tags were detected, regardless of tag model. When spacing between tags was reduced to 6-8 in, only one tag of the pair was typically detected in an antenna.

In these spacing tests, tags remained a set distance apart during passage down the flume; however, actual fish that are grouped close together during passage (for example, less than 6-8 inches apart), tend to separate as they move downstream. Therefore, by spacing the four antennas that make up the full-flow detection system 24 ft apart, we improve the chances that fish that are too close to other fish to be detected at one antenna, will have separated before they reach a downstream antenna.

DIRECT EVALUATIONS

Methods

Ice Harbor Dam

The full-flow system installed at McNary Dam in 2002 has had overall reading efficiencies in the upper 90s during the past 3 years (as determined by the indirect statistical methods of PSMFC). Therefore, we decided to base fish tests for the Ice Harbor system on the same test conditions used to evaluate the McNary Dam system in 2002 (Axel et al. 2003). Consequently, three out of the four test conditions evaluated were identical to tests at McNary Dam in terms of the number of fish released over time (e.g., 5 fish released every 15 seconds) (Table 2).

Table 2. Comparison of fish test conditions used to evaluate the full-flow PIT-tag interrogation systems at McNary and Ice Harbor Dams in 2005.

Test conditions	McNary Dam	Ice Harbor Dam
1 fish released every 15 sec	Yes	--
1 fish released every 5 sec	Yes	Yes
5 fish released every 15 sec	Yes	Yes
10 fish released every 15 sec	Yes	Yes
10 fish released every 10 sec	--	Yes

Given that PIT-tag technology has evolved to the point that 36-in antennas are now commonplace, we knew that there would be no difference in the ability of this system to detect a tag every 15 sec, or even every 1 sec. Therefore, we omitted the test for a single fish released every 15 seconds. Because the number of tags/min detected by the full-flow system at McNary Dam has sometimes been higher than the maximum of 40 fish/min tested in 2002 (Axel et al. 2003), we included a test that released 60 fish/min. To compare the SGL and ST tag models, duplicate sets of fish tests were run using fish tagged with either ST or SGL tags (Table 3). The original tests at McNary Dam were done with the previous tag model (TX1400BE or the BE tag).

Table 3. Numbers of tagged fish used for four fish tests of ST and SGL tag models.

Test conditions	ST tag	SGL tag
1 fish released every 5 sec	150	150
5 fish released every 15 sec	200	200
10 fish released every 15 sec	200	200
10 fish released every 10 sec	200	196

Unfortunately, because of delays in the construction contract issued by the U.S. Army Corps of Engineers, PSMFC was not able to start installing the electronic equipment until 1 April. As a result of that delay, combined with lower-than-normal river flow conditions experienced in 2005, we were unable to obtain yearling steelhead for the evaluation. This occurred because the fish had to be released from the hatchery before the fish tests could be run. Therefore, fish tests were conducted using only fall Chinook subyearlings (mean FL = 74.8 mm). Fall Chinook salmon were tagged at Lyons Ferry Hatchery on 18 April 2005 and transported to Ice Harbor Dam on 19 April. With a crane, the fish transport tank was lowered to the lower deck adjacent to the entrance of the fish transport pipe. A submersible pump transferred water from the collection channel directly into the fish tank. The fish tank was monitored overnight in case the pump failed. Fish tests were then conducted on 20 April.

Figure 3. Equipment used to scan test fish and automatically record tag code data.

Prior to release, each previously PIT-tagged fish was scanned and its tag code automatically recorded in a tagging file (Figure 3). The scanned fish was then placed either into a beaker for single fish releases or into a bucket for group releases. Fish were released into a hopper that had a continuous source of flush water added to its bottom to ensure that fish did not get trapped in the 7.6-cm diameter flexible hose that connected the hopper to the transport pipe (Figure 4). A larger hose (1.5 in) was used for the flush water than had been used at McNary Dam (0.75 in hose).

Based on detection results showing that spacing was more than 5 seconds apart during the first fish test for around 60% of the fish, we shortened the flexible hose so that it ended at the surface of the water in the transport pipe to reduce, if not eliminate, the possibility of fish being delayed in the hose (Figure 5).

Figure 4. Hopper used for releasing fish at Ice Harbor Dam.

Figure 5. Release hose end just below the surface of the water entering the transport pipe.

McNary Dam

To compare the two tag types under more natural river conditions, we examined how well the full-flow interrogation system at McNary Dam detected test fish tagged with the two tag models (ST and SGL). To achieve this, we compared arrival timing, number of tagged fish detected, and number of individual full-flow antennas that successfully detected each tagged fish.

Radio- and PIT-tagged Salmonids

During spring 2005, a separate NMFS research project released fish double-tagged with both a radio and ST PIT tag to evaluate fish passage and survival at Lower Monumental and Ice Harbor Dams. For this project, spring Chinook salmon, steelhead, and subyearling Chinook were tagged at Lower Monumental Dam. These researchers provided us with a list of their test fish that had been confirmed by radiotelemetry to have passed through the full-flow system at Ice Harbor Dam (Eric Hockersmith, NMFS, personal communication). We then used the list to determine how well the full-flow system detected tagged fish from these salmonid populations.

Results

Ice Harbor Dam

Fish Passage Rates or Distribution Patterns--Although release conditions were identical at both dams for most of the direct fish tests, it immediately became evident that fish behavior was different at the two dams (Tables 4 and 5). Fish at Ice Harbor moved through the system quickly: all fish passed through the set of 4 antennas within 1 min or less after the last fish, or previous group of fish, had been released. In contrast, at McNary Dam, some fish passed through the set of 4 antennas hours after they had been released. This meant that although the release conditions tested were identical, the fish densities passing the antennas were not.

Table 4. Elapsed time between first and last fish released and first and last detections for individual tests at McNary Dam in 2002.

	Elapsed time (h:min:sec)	
Test conditions at McNary Dam	First and last fish released	First and last fish detected
1 fish released every 15 sec	00:44:45	02:58:55
1 fish released every 5 sec	00:14:40	01:40:19
5 fish released every 15 sec	00:10:00	00:52:19
10 fish released every 15 sec	00:04:45	00:11:10
10 fish released every 10 sec		--

Table 5. Elapsed time between first and last fish released and first and last detections for individual tests at Ice Harbor Dam in 2005.

	Elapsed time (h:min:sec)		
		First and last fish detected	
Test conditions	First and last fish released	ST tag	SGL tag
1 fish released every 15 sec	--	--	--
1 fish released every 5 sec	00:12:50	00:14:30	00:12:47
5 fish released every 15 sec	00:10:00	00:09:44	00:08:48
10 fish released every 15 sec	00:05:00	00:05:07	00:04:46
10 fish released every 10 sec	00:03:33	00:03:48	00:03:47

Therefore, to compare tests between the two dams, we determined tag-detection distributions over time as recorded by the each of the four antennas at each respective dam. We constructed histograms showing the number of tags detected per clock second at each coil (Figure 6). By examining the tags-per-second histograms, we observed three general patterns:

1) Fish passed through antennas at densities of 1-2 fish/sec, with 80% or more passing at 1 fish/sec.

2) Fish passed through the antennas at densities of 1-4 fish/sec, with 60-80% passing at 1 fish/sec.

3) Fish passed through the antennas at densities of 1-5 fish/sec, with 40-60% passing at 1 fish/sec.

Based on the numbers of tags detected per second, data from the 12 fish tests from 20 April were divided into three groups that had similar patterns, regardless of fish release conditions (Table 6).

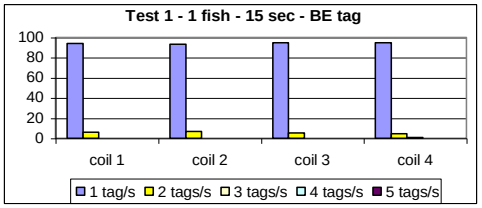
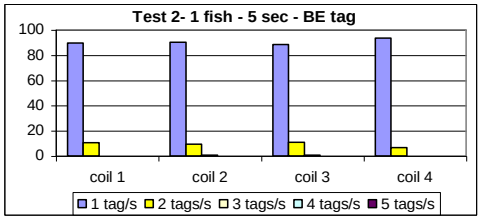
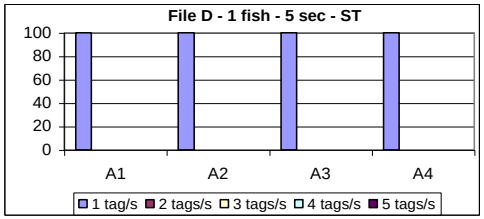
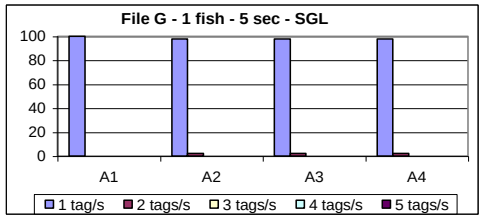
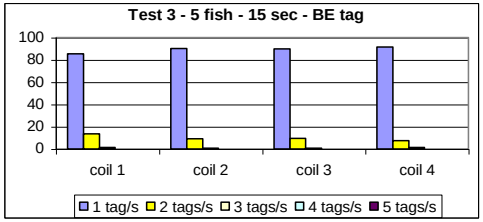


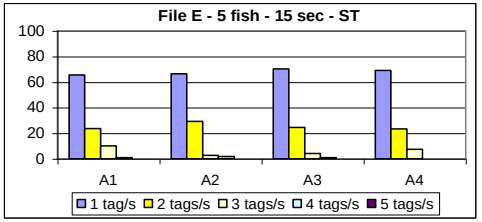
Figure 6. Tags detected per second per coil histograms for four test conditions at McNary Dam (Tests 1-4) and four test conditions each for ST and SGL tags at Ice Harbor Dam (Files D-K). Headers indicate test condition and tag type.

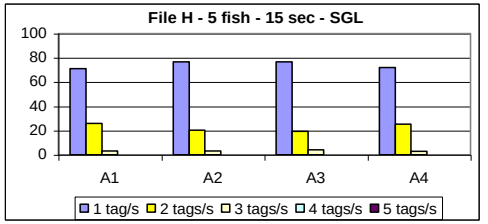


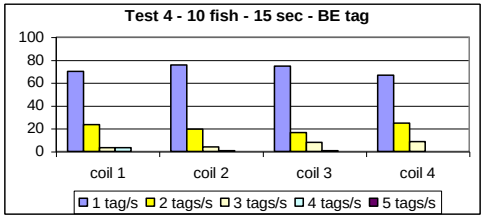


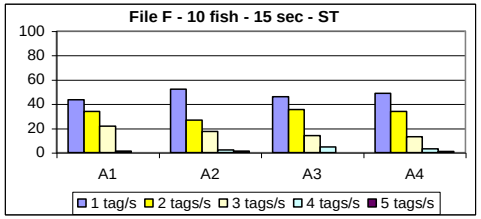


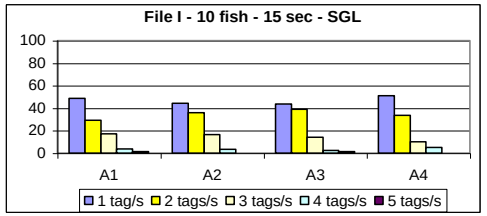


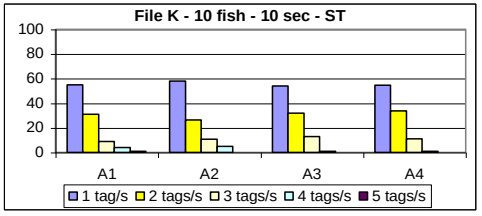












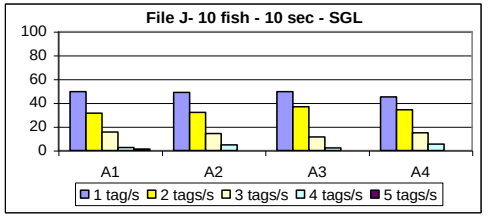


Table 6. Division of fish from the 12 tests into groups based on the number of tags per second that passed the full-flow system antennas. Group 1 (no shading) had over 80% of the fish passing in groups of 1-2 fish/sec; Group 2 (light shading) had 60-80% of the fish, and Group 3 (dark shading) had only 40-60% of fish passing in groups of 1-2 fish/sec.

		Ice Harbor Dam	
Test conditions	McNary Dam	ST tag	SGL tag
1 fish released every 15 sec	Group 1	--	--
1 fish released every 5 sec	Group 1	Group 1	Group 1
5 fish released every 15 sec	Group 1	Group 2	Group 2
10 fish released every 15 sec	Group 2	Group 3	Group 3
10 fish released every 10 sec	--	Group 3	Group 3

When we examined the median numbers of tagged fish/min for each test, overall results tended to form the same groupings as results for the tags/sec data, with median tagged-fish densities for each of three groups having similar values (Table 7). When classed by the median tagged-fish densities, Group 1 tests had around 10 or fewer fish/min, Group 2 tests had around 20 fish/min, and Group 3 tests had around 30 fish/min. Since all of these values were less than their theoretical values, they show that the fish were actively responding to release and flow conditions in the full-flow transport pipe.

Table 7. Median number of fish/min for the 12 fish tests of the full-flow bypass system at Ice Harbor Dam on 20 April 2005. Shading indicates group: Group 1, no shading; Group 2, light shading; Group 3, dark shading.

		Ice Harbor Dam	
Test conditions	McNary Dam	ST tag	SGL tag
1 fish released every 15 sec	3.0	--	--
1 fish released every 5 sec	4.0	9.0	10.5
5 fish released every 15 sec	3.0	17.0	18.5
10 fish released every 15 sec	25.0	29.0	31.0
10 fish released every 10 sec	--	37.5	29.0

Overall Reading Efficiencies--For each test, overall reading efficiencies were determined by dividing the number of fish detected on at least 1 of the 4 antennas by the total number released. Overall reading efficiencies for all 12 fish tests at Ice Harbor Dam were greater than 98.0% (Table 8). Therefore, even at the highest fish density tested, the full-flow interrogation system was able to detect tagged fish at levels well above the acceptable standard of 95%.

Table 8. Overall reading efficiencies for the 12 fish tests. Non-shaded cells are Group 1, ≤10 fish/min; light shaded cells are Group 2, ≈20 fish/min; dark shaded cells are Group 3, ≈30 fish/min.

		Ice Harbor Dam	
Test conditions	McNary Dam	ST tag	SGL tag
1 fish released every 15 sec	100.0	--	--
1 fish released every 5 sec	99.4	100.0	99.3
5 fish released every 15 sec	100.0	99.0	100.0
10 fish released every 15 sec	100.0	99.0	98.5
10 fish released every 10 sec	--	99.5	98.0

Tagged Fish Density--Tagged fish can be missed by the system under any conditions if they pass the entire system with their tag oriented at an angle adjacent to another tagged fish or at an angle of 45° to the antenna field (i.e., passing sideways). However by spreading the four antennas out over a long distance, the chance for these conditions to exist becomes extremely small until tagged fish densities get so high that groups of tagged fish are going through the system simultaneously. Therefore, we expect to observe a direct relationship between density and detection efficiency such that as tagged-fish density increases, the percentage of fish detected on only 1 or 2 antennas increases (Table 9). Based on results from fish tests, we noted that when the proportion of detections on only 1 or 2 antennas increases to 10% or higher, then the full-flow system will begin to entirely miss detecting some tagged fish.

Table 9. Percentages of fish that were detected on only 1 or 2 of the 4 antennas in the full-flow bypass system during the 12 tests at Ice Harbor Dam, 2005. Non-shaded cells are Group 1, ≤10 fish/min; light shaded cells are Group 2, ≈20 fish/min; dark shaded cells are Group 3, ≈30 fish/min.

		Ice Harbor Dam	
Test conditions	McNary Dam	ST tag	SGL tag
1 fish released every 15 sec	2.3	--	--
1 fish released every 5 sec	4.0	8.0	2.7
5 fish released every 15 sec	5.5	15.7	8.0
10 fish released every 15 sec	10.0	24.2	23.9
10 fish released every 10 sec	--	12.1	19.8

Another key parameter, which directly indicates a decrease in reading efficiency caused by groups of tagged fish passing the system simultaneously, is the reading efficiency rates of individual antennas. When we analyzed average reading efficiencies for individual antennas, we observed the impact of higher tagged fish densities, since reading efficiency values decreased as fish densities increased (Table 10). Group 1 typically had individual coil reading efficiencies around 90%, Group 2 around 85%, and Group 3 around 80%. Provided that the PIT-tag equipment is tuned properly, if reading efficiencies for individual antennas drop to 80% or lower, then fish densities are probably high enough to cause the system to miss detections of tagged fish.

Table 10. Average reading efficiencies for the 12 fish tests at Ice Harbor Dam, 2005. Non-shaded cells are Group 1, ≤10 fish/min; light shaded cells are Group 2, ≈20 fish/min; dark shaded cells are Group 3, ≈30 fish/min.

		Ice Harbor Dam	
Test conditions	McNary Dam	ST tag	SGL tag
1 fish released every 15 sec	94.6	--	--
1 fish released every 5 sec	92.6	87.8	90.3
5 fish released every 15 sec	90.8	82.8	85.8
10 fish released every 15 sec	87.4	76.3	77.4
10 fish released every 10 sec	--	83.3	77.2

Tag Comparison--Both tests with overall reading efficiencies below 99.0% were with fish tagged with SGL tags (see Table 8). Since the SGL tags have the longest read range of the three tag models, the lower efficiencies might have occurred because there were more tag collisions among fish spaced similarly for comparable tests. Alternatively, it may have been just due to fish behavior that was unique to a test. To distinguish between these two possibilities may be impossible, considering that the small 1-2% differences among overall reading efficiencies could be based on whether two or three fish passed closer to or farther apart from each other.

As previously noted, there was certainly evidence that fall Chinook salmon were able to swim in water flowing at 12 ft/s and actively delay their downward passage through the full-flow system at Ice Harbor Dam. It was not uncommon to see fish released in one group pass through the full-flow system with the following group, whereas tagged sticks or drones would have all passed downstream immediately.

Whether or not one tag affects the detection of another depends on their proximity to one another during passage, and for one tag to affect the detection of another tag, fish must be situated less than 1 ft apart. Unfortunately, the shortest time dimension recorded by the computer program Minimon is whole seconds, so fish detected within the same second could be separated by up to 11 feet.

Although we observed a decrease in average reading efficiencies as fish densities increased, we did not observe a significant difference in reading efficiencies between tag types (see Table 10). It is interesting that the ST tag test with highest median number of fish per minute (10 fish/10 sec, 37.5 fish/min) also had the highest average reading efficiency for individual antennas (83.3%) among the three higher density fish tests of the ST tag. This further supports the likelihood that differences among overall reading efficiencies of the two tag types were due to fish behavior rather than to a real difference in tag performance (given that all fish were tagged with the same ST tag model in these three tests).

McNary Dam

For fish tagged with ST tags and those with SGL tags, peak arrival time at McNary Dam was 7 weeks after release (i.e., first week of June; Figure 7). By this time, full bypass operation at the dam had stopped, and about 80-100 kcfs/day was being spilled. Therefore, fewer fish were detected than we had anticipated because many probably passed via the spillway. A slightly higher percentage of ST tags (19.6%) than SGL tags (18.2%) were detected overall (Table 11).

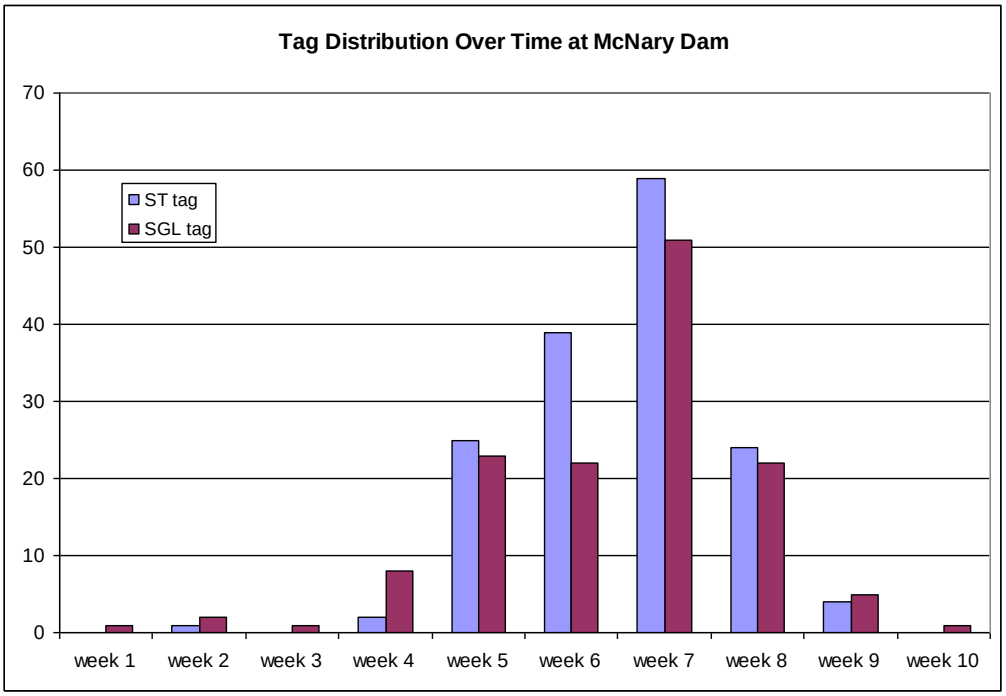


Figure 7. Distributions of the arrival times at McNary Dam for fish tagged with both ST and SGL tags.

Table 11. Numbers and percentages of ST- and SGL-tagged test fish released at Ice Harbor Dam and detected by the full-flow system at McNary Dam.

		Date detected		Number	Proportion
Tag type	Number released	First tag	Last tag	detected	detected (%)
ST	784	28 April	20 June	154	19.6
SGL	746	24 April	23 June	136	18.2

For fish tagged with either tag type, fewer than 2% were detected on only 1 or 2 antennas (Table 12). Furthermore, individual reading efficiencies for the four antennas at McNary Dam were in the 93-97% range with averages around 95% (Table 13). With such low percentages of fish being detected on only 1 or 2 antennas, and with these high individual reading efficiencies, it is unlikely that many, if any, fish with either tag type were missed. In fact, since McNary Dam has more antennas below the full-flow system, we were able to confirm that only one SGL-tagged fish was missed by the full-flow system. Based on these results, there did not appear to be any significant difference in detection performance between the two tag models in the full-flow system at McNary Dam. This conclusion agrees with the results from tests conducted at Ice Harbor Dam.

Table 12. Percentages of ST and SGL-tagged test fish that were detected on 1, 2, 3 or all 4 antennas that make up the full-flow system at McNary Dam in 2005.

	Proportion of total detected (%)	
Number of antennas that detected a tag	SGL-tagged fish	ST-tagged fish
0	0.7	0.0
1	0.0	1.3
2	0.7	0.0
3	13.2	15.6
4	85.3	83.1

Table 13. Average reading efficiencies of SGL and ST tags for the four individual antennas that make up the full-flow system at McNary Dam in 2005.

	Reading efficiency	
Antenna ID	SGL tags	ST tags
Antenna 1	97.8	96.8
Antenna 2	95.6	95.5
Antenna 3	96.3	95.5
Antenna 4	92.6	92.9
Average	95.6	95.1

Radio and PIT-tagged Salmonids

A total of 473 double-tagged salmonids with both a radio and PIT tag transited the full-flow system at Ice Harbor Dam between 5 May and 1 July 2005 (Ben Sandford, NMFS, personal communication). Unlike the direct evaluation with fall Chinook salmon, which were all released and detected on one day, these fish were detected over 57 days, and the maximum number detected within 1 day was around 50 fish (Figure 8). Unfortunately, much higher percentages of double-tagged salmonids than expected were not detected at all by the full-flow system (11.2% of the spring Chinook salmon, 7.6% of the steelhead, and 2.7% of the subyearling Chinook). The distribution pattern for undetected fish was similar to that of detected fish, and therefore, the 41 undetected fish were not all missed during a single time period.

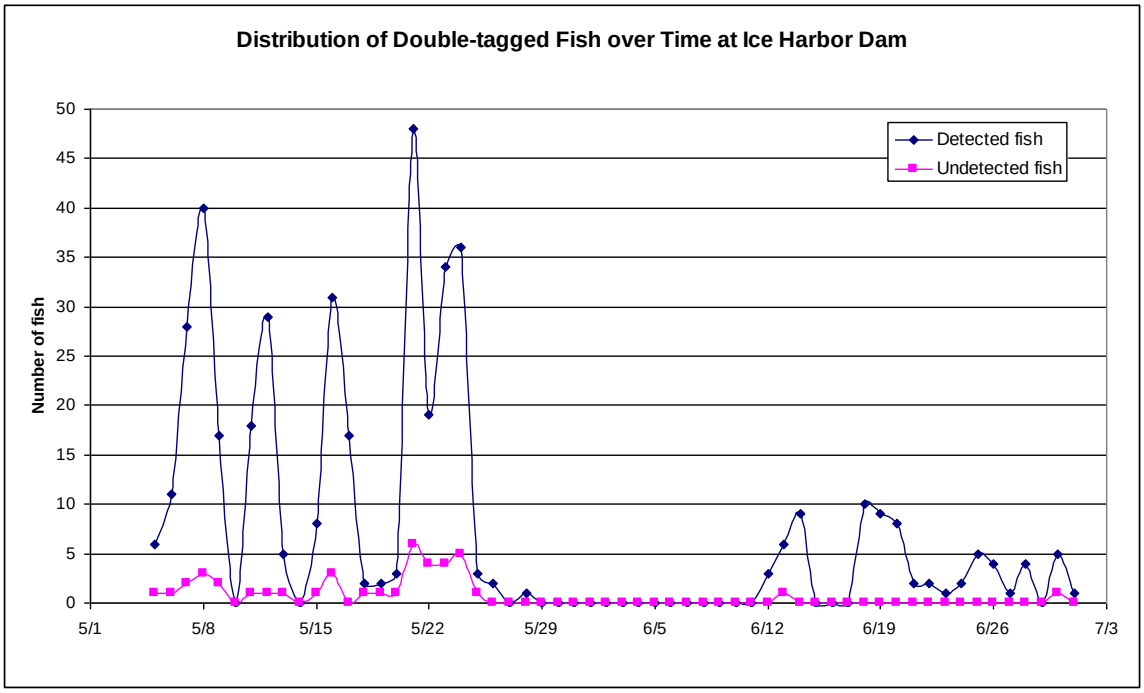


Figure 8. Distribution of fish tagged with both a radio and PIT tag that transited the full-flow system at Ice Harbor Dam. Double-tagged fish that were not detected were also plotted to indicate that their distribution pattern was similar to the fish that were detected.

Based on this information, and the fact that none of the 41 fish was ever detected in any PIT-tag system downstream from Ice Harbor Dam, the researchers who tagged these fish concluded that they had probably lost their PIT tags. We concurred that this was the only reasonable explanation for the following reasons. First, only 2.5% (11/432) of the double-tagged fish detected were detected on only 1 or 2 antennas in the full-flow bypass system at Ice Harbor Dam. Second, the average reading efficiency for individual antennas of the system was at least 93.9% during the time when these fish were passing.

Both of these results were better than the corresponding results for the lowest fish density tested (1 fish/5 sec) during direct evaluations (Tables 9-10 and Table 14). These double-tagged fish passed during a period of lower tagged fish densities than during our tests. Therefore, it is highly unlikely that they could have transited the full-flow system at Ice Harbor Dam and been detected at lower rates than those observed from the highest tag density tests during our direct evaluations (10 fish/10 sec). These results support the conclusion that the undetected fish had lost their PIT tags.

Table 14. Percentages of double-tagged (radio and PIT tagged) salmonids detected on 1, 2, 3, or all 4 antennas within the full-flow system at Ice Harbor Dam.

Number of antennas that detected a tag	Proportion of double-tagged salmonids detected (%)
1	0.2
2	2.3
3	19.0
4	78.5

INDIRECT EVALUATIONS

Methods

The main difference between direct and indirect evaluations of system performance is that for the indirect evaluations, we do not know exactly how many tagged fish passed through the detection system, and thus we do not know how many were entirely missed. Given that we could not conduct direct evaluations throughout the season, we analyzed the available data based on results from the direct evaluation to infer whether the system might be missing tagged fish.

We used these indirect evaluations to assess whether system performance changed with different tagged-fish densities or salmonid populations and whether it changed over time (month-to-month variation). We did this by analyzing whether there were significant differences among populations in the percentages of fish being detected by only 1 or 2 antennas or in the average reading efficiencies of the four antennas during the time when these different populations passed.

We also compared performance of the full-flow system at Ice Harbor and to that at McNary Dam by examining the detection performance at McNary Dam during its period of highest tagged-fish density. Data for these evaluations were downloaded from the PIT Tag Information System (PTAGIS; PSMFC 1996).

Results

Overview

The detection system for juvenile salmonids at Ice Harbor Dam detected far fewer PIT-tagged fish than those at any other Snake and Columbia River collector dams in 2005 (Table 15). This is because most tagged fish detected upstream at Little Goose Dam were diverted to transportation barges instead of being returned to the river. In addition, most fish passing Ice Harbor Dam went through the spillbays, where they were not detected. As a result, the fish we released during direct evaluations in April constituted both the largest number of tagged fish to pass through the system in a single day and the highest tagged-fish densities encountered by the full-flow system at Ice Harbor Dam over the entire 2005 juvenile migration season (Figure 9).

The direct evaluation tests we conducted were more rigorous than what the full-flow system would encounter naturally. Therefore, for the indirect evaluations, we

focused on assessing whether system performance changed with different tagged-fish densities, different salmonid populations, and whether it changed over time (month-to-month variation). We did this by analyzing whether there were significant differences among different groups in the percentages of fish being detected by only 1 or 2 antennas or in the average reading efficiencies of the four antennas when different groups passed.

Table 15. Number of PIT-tagged fish detected at four juvenile fish facilities on Snake River dams and McNary Dam between 1 April and 1 November 2005 (Site Tally Reports furnished by PTAGIS). Counts were made by the exit monitor for all interrogation sites besides Ice Harbor. Numbers for Ice Harbor were computed because the data from this site also included data collected at the antennas in the fish ladders, which mostly detect adult salmonids.

Site	Number of PIT-tagged fish detected in 2005
Lower Granite (GRJ)	208,457
Little Goose (GOJ)	202,092
Lower Monumental (LMJ)	89,113
Ice Harbor (ICH)	11,352
McNary Dam (MCJ)	175,165

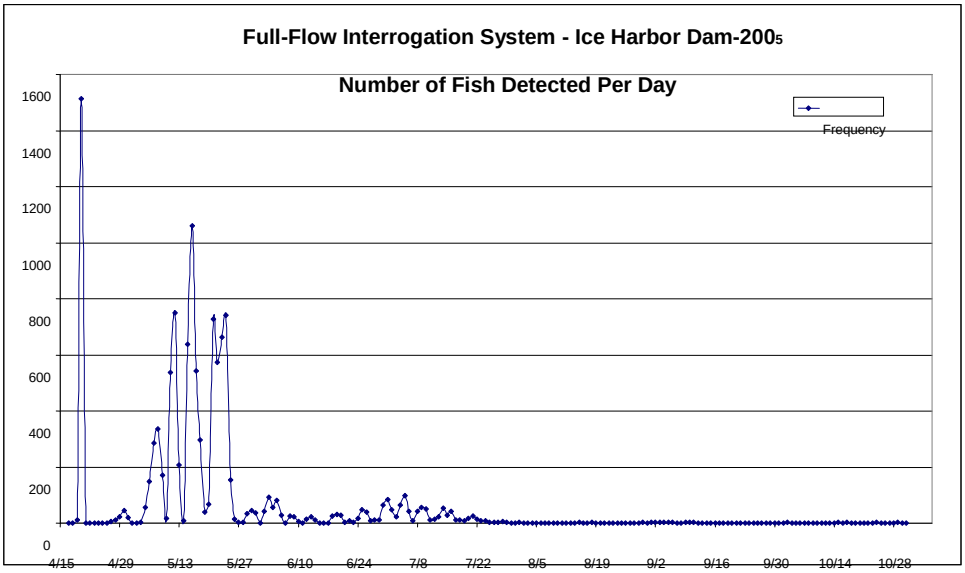


Figure 9. Number of PIT-tagged juvenile salmonids detected at Ice Harbor Dam during the 2005 smolt migration season. The total number of tagged fish detected between 17 April and 31 October was 11,352. After 31 July, there was not a single day when more than 3 tagged fish/day were detected.

Tagged-Fish Densities

Densities at Ice Harbor Dam were highest during the direct evaluation tests of 20 April (Figure 9). On that date, tags were detected within 1 sec of a previous tag being detected on the same coil 973 times. The second and third highest numbers of tagged fish were detected 12 and 16 May; on those dates, tags were detected within 1 sec of a previous detection on the same coil only 27 and 44 times, respectively. Furthermore, the maximum number of tagged fish/min was 8, and this density occurred only once. By comparison, the median number of tagged fish/min was greater than 8 during all our direct tests (Table 14).

As a result of these lower tagged-fish densities, low percentages of river-run fish (<3.0%) were detected on only 1 or 2 antennas (Table 16). In comparison, during the direct evaluations, only one test of eight (four conditions tested for each PIT tag model) had a lower percentage, at 2.7%, and in most tests, over 10% of the fish were detected on 1 or 2 antennas (see Table 7). Furthermore, the average individual coil reading efficiencies on these two May dates were around 95%, which again was higher than during any of our eight tests (Table 17). It certainly is reasonable to expect that individual antennas would detect tags better if there were fewer tagged fish going through the system simultaneously.

Table 16. Percentages of tagged fish detected by 1, 2, 3, or all 4 of the antennas in the full-flow system at Ice Harbor Dam on the 2 days in May 2005 when the highest numbers of river-run fish were detected.

Number of antennas that detected a tag	Proportion of total river-run fish detected (%)	
	12 May (n = 795)	16 May (n = 1,094)
1	0.5	0.9
2	2.4	2.0
3	12.7	15.2
4	84.4	81.9

Table 17. Individual and overall average reading efficiencies for the four antennas that make up the full-flow system at Ice Harbor Dam on the two dates in May 2005 with the highest numbers of river-run fish detected.

	Reading efficiency for river-run fish at Ice Harbor Dam	
Antenna ID	12 May (n = 795)	16 May (n = 1,094)
A1	94.7	92.3
A2	95.6	95.6
A3	93.5	92.4
A4	97.2	97.7
Average	95.3	94.5

Detection of Different Salmonid Populations

At Ice Harbor Dam, most fish transited the system in May (Figure 9). For all salmonid populations that transited the system in May, less than 4% of fish were detected on only 1-2 antennas (Table 18). Steelhead had a slightly higher percentage of tags read by only 1 or 2 antennas, perhaps because they had more fish detected within 1 sec of a previous tag than any other population. These results suggest that the full-flow system detected all salmonid populations well.

Table 18. Percentages of tagged fish from different species that were detected on 1, 2, 3, or all 4 antennas of the full-flow bypass detection system at Ice Harbor Dam in May 2005. The system detected 1,788 fish that were identified only as wild or hatchery Chinook; these were not included in this analysis.

	Proportions of total detected in May 2005 (%)				
Number of antennas that detected a tag	Spring Chinook n = 2,003	Summer Chinook n = 632	Fall Chinook n = 238	Coho n = 62	Steelhead n = 3,424
1	0.3	0.0	0.0	0.0	0.4
2	1.7	1.1	0.8	0.0	3.1
3	10.3	13.4	7.1	8.1	17.3
4	87.6	85.4	92.0	91.9	79.2
Number of tags detected within 1 sec of a previous tag					
	6	2	0	0	66

Performance over Time

The percentages of fish detected on 1, 2, 3, or 4 antennas each month appeared to indicate that reading efficiencies for the system dropped in June and stayed lower for the rest of the season (Table 19). Average monthly reading efficiencies for individual antennas also decreased starting in June (Table 20). Event logs of any problems that occur during maintenance of PIT-tag interrogation systems are recorded by PSMFC for each of the sites for which they are responsible. At the Ice Harbor site in 2005, PSMFC recorded observations of high noise on Antenna A3 at the end of May. The facility also had noise problems on several of the full-flow antennas during the second half of July when University of Idaho started operating a half-duplex PIT-tag system at the dam.

Table 19. Percentages by month of tagged fish detected on 1, 2, 3, or all 4 antennas of the full-flow system at Ice Harbor Dam. Too few fish transited the full-flow system during August to make a reasonable estimate.

Number of antennas that detected a tag	Total detections in the full-flow system at Ice Harbor Dam (%)				
	May	June	July	August	September
	n = 8,176	n = 699	n = 803	too few	n = 25
1	0.3	0.1	0.6		0.0
2	2.1	4.7	6.8		4.0
3	13.6	21.5	29.8		28.0
4	84.0	73.7	62.8		68.0
Number of tags detected within 1 sec of a previous tag					
	196	3	3		0

Table 20. Reading efficiencies by month for the individual antennas that make up the full-flow system at Ice Harbor Dam. Too few fish transited the full-flow system in August to make a reasonable estimate.

	PIT-tag reading efficiency				
	May	June	July	August	September
Antenna ID	n = 8,176	n = 699	n = 803	too few	n = 25
A1	94.2	90.8	85.2		92.0
A2	95.5	93.8	89.7		92.0
A3	94.0	89.7	87.9		84.0
A4	97.7	94.3	91.9		100.0

University of Idaho is investigating a shielded antenna design for 2006. This will hopefully have less impact on the full duplex systems (both the full-flow and in-ladder systems). Based on the lower reading efficiencies for individual antennas and the slightly higher percentages of fish detected on only 1 or 2 antennas, some tagged fish were probably missed completely by the system in July. However, with the low numbers of fish transiting the system at that time, it probably was not more than a handful.

Full-Flow System at McNary Dam

As with the direct evaluation, we compared performance of the full-flow systems at Ice Harbor and McNary Dams with our indirect evaluation. For this comparison, we used detections at the McNary full-flow antennas, which are located downstream from the Ice Harbor full-flow system. This allowed us to confirm or disprove our inferences regarding when fish might be missed based on how well individual antennas at McNary detected fish that had been previously detected at Ice Harbor.

The most helpful analysis was to examine detection performance at McNary Dam during the peak of the smolt migration (i.e., highest tagged-fish density). During the peak of the juvenile migration, the number of fish detected on one day at McNary Dam (n = 9,264 on 20 May) was nearly the equivalent of that detected during the entire year at Ice Harbor Dam (Figures 9-10; Table 15).

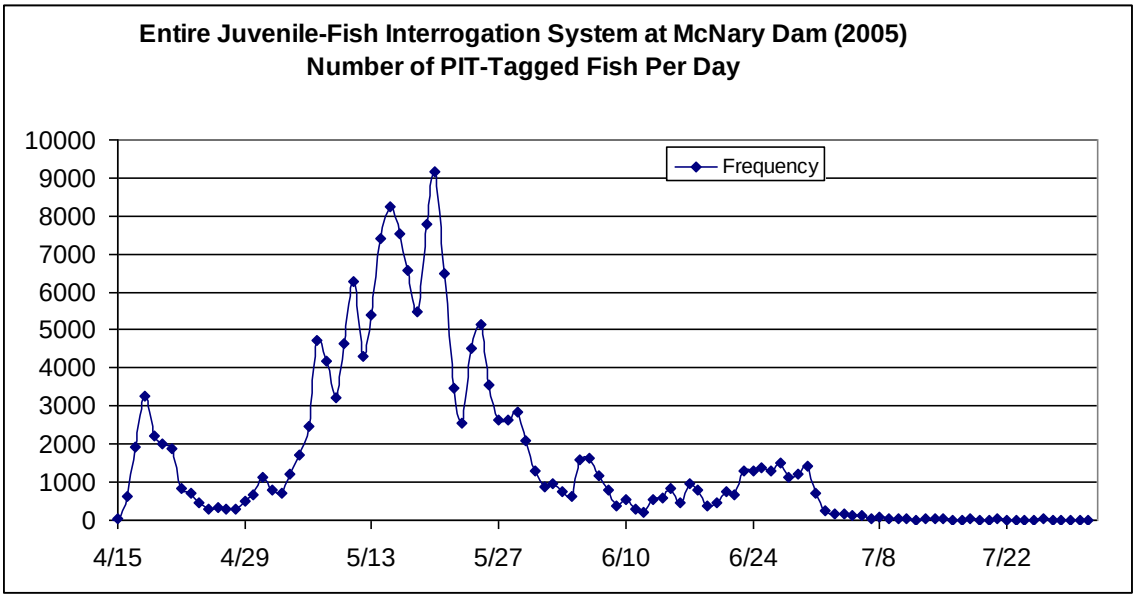


Figure 10. The number of PIT-tagged juvenile salmonids detected at McNary Dam during the 2005 smolt migration. The total number of tagged fish detected between 15 April and 31 October was 175,165.

Detection performance of the full-flow system at McNary Dam did not appear to be impacted until tagged fish densities reached levels similar to those of test conditions with group releases. During the hour of highest fish density (the first hour of 20 May; 802 fish/hour), the percentage of fish detected on only 1 or 2 antennas increased to almost 15%. Based on our direct evaluation, this would suggest that tagged fish were being missed (Table 21). However, the facility was in full bypass mode during this time, meaning that all bypassed fish were returned to the river after going through the full-flow system. Therefore, we could not confirm that fish were missed by examining detections in the juvenile fish facility downstream from the full-flow system.

However, the results for 0600 to 0659, after the facility was switched out of bypass mode, did appear to support this inference. During this hour, 525 fish were detecting entering the rest of the facility, 3 of which were confirmed as having been missed by the full-flow system. Although these results showed that fish were indeed missed during the peak migration, they also showed that even at extremely high tagged-fish densities, few fish were missed. In other words, the full-flow detection systems are highly effective overall.

Table 21. Percentages of fish detected on 20 May 2005 by 1, 2, 3, or all 4 antennas that make up the full-flow system at McNary Dam. This was the date when the highest numbers of river-run fish were detected in the system.

	Detections of river-run fish in the full-flow system at McNary Dam on 20 May 2005 (%)	
Number of antennas that detected a tag	Hour of highest fish density (0000 to 5959) n = 802	First hour after full bypass operations concluded (0600 to 0659) n = 525
0	?	0.6
1	4.0	2.5
2	10.4	4.2
3	20.8	18.7
4	64.8	74.1

CONCLUSIONS

Results from both the direct and indirect evaluations showed that even at high tagged-fish densities, the full-flow PIT-tag interrogation systems missed very few tagged fish. During fish tests, the lowest overall reading efficiency was 98% even when tagged-fish densities reached around 30 fish/min. Furthermore, with these mid-size antennas, there was no difference in the detection rates between the ST and SGL-tagged fish. The results also demonstrated that the full-flow system detected all of the different salmonid populations well.

By verifying how few tags were missed by the full-flow system at McNary Dam during the peak of the smolt migration, when it detected almost as many tags as the Ice Harbor system did over the whole season, we realize how well these systems do perform. Since Ice Harbor Dam has much lower tagged-fish densities than McNary Dam, the fisheries community should have confidence that it will perform well as long as the full-flow system is well tuned.

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