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Fish Ecology Division

Northwest Fisheries Science Center

National Marine Fisheries Serv

Seattle, Washington

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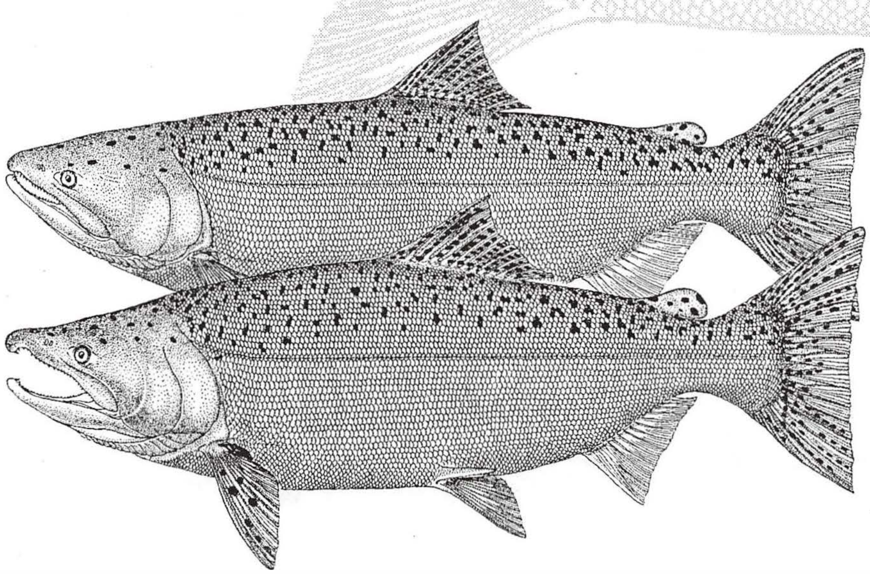
August 2003



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Report of research by

Fish Ecology Division
Northwest Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
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Seattle, Washington 98112

to

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EXECUTIVE SUMMARY

In 2001, the National Marine Fisheries Service (NMFS) conducted research to evaluate survival and approach and passage behavior at Ice Harbor Dam for river-run hatchery yearling chinook salmon (*Oncorhynchus tshawytscha*). This study took place during a drought year which resulted in no spill at dams like Ice Harbor Dam, which have no holding raceways for transporting fish. Specific goals of the research were:

1) to estimate project and bypass survival through Ice Harbor Dam,
2) to estimate survival through partitioned reaches between Ice Harbor and McNary Dam,
3) to evaluate approach and passage behavior at Ice Harbor and McNary Dam, and
4) to compare methodologies (PIT tag vs. radiotelemetry) for use in estimating survival.

Study fish were collected at Lower Monumental Dam, tagged either with a PIT tag or with both a radio transmitter and a PIT tag, and released 5.0 km upstream from Ice Harbor Dam or into the juvenile bypass outfall pipe just downstream from the Ice Harbor Dam smolt monitoring facility. Reach survival was estimated for radio-tagged fish from detections at radiotelemetry receiver transects located in the forebay and tailrace of Ice Harbor Dam, Strawberry Island, Sacajawea Park at the mouth of the Snake River, Port Kelley, McNary Dam, and at the mouth of the Umatilla River. Tagging methodologies were compared using PIT-tag detections from McNary, John Day, and Bonneville Dams and from detections in the Columbia River estuary by the NMFS PIT-tag detector trawl.

Project survival through Ice Harbor Dam (from the forebay of Ice Harbor Dam to Strawberry Island) for radio-tagged hatchery yearling chinook salmon was 0.936 (95% CI: 0.895-0.977). Survival estimates to McNary Dam for radio-tagged fish and PIT-tagged fish released 5 km upstream from Ice Harbor Dam were 0.744 (95% CI: 0.715-0.773) and 0.724 (95% CI: 0.708-0.740), respectively. An estimate of survival from the Ice Harbor juvenile bypass system to Strawberry Island for radio-tagged fish released 5 km upstream from Ice Harbor Dam was 0.996 (95% CI: 0.947-1.045). Survival probability to McNary Dam for radio-tagged fish released into the bypass outfall pipe at Ice Harbor Dam was estimated at 0.801 (95% CI: 0.774-0.828).

For radio-tagged yearling chinook salmon, residence time in the Ice Harbor forebay was longer in 2001 (7.3 h) than in 1999 (1.3 h), which was considered a normal flow year with spill at Ice Harbor Dam. Median tailrace egress was 9.3 min overall, 9.0 min for fish passing through the juvenile fish bypass system, and 14.7 min for fish passing through a turbine unit.

Survival for PIT-tagged fish between the forebays of Ice Harbor and McNary Dam was estimated at 0.724 (95% CI: 0.708-0.740), similar to the estimate of 0.744 (95% CI: 0.715-0.773) for radio-tagged fish. This demonstrated that under these conditions, the two methodologies can obtain similar survival estimates. However, because of exceptionally low river flows during 2001, we recommend that environmental conditions be considered when interpreting the results of this study. We also recommend that the Caspian tern colony on Crescent Island be evaluated annually to determine consumption rates and overall effects on Snake River salmonids.

CONTENTS

INTRODUCTION

Survival estimates for juvenile chinook salmon (*Oncorhynchus tshawytscha*) that migrate through reservoirs, hydroelectric projects, and free-flowing sections of the Snake and Columbia Rivers are essential for developing effective strategies to recover depressed stocks. The National Marine Fisheries Service (NMFS) has undertaken studies to estimate passage survival along specific reaches and through various passage routes through all dams on the lower Snake River except Ice Harbor Dam (Muir et al. 2001). In 2001, we initiated a study to evaluate passage behavior and survival through Ice Harbor Dam.

Our previous studies have indicated that among the different dam passage routes, survival is highest through spillways, followed by the juvenile bypass systems, and then turbines (Iwamoto et al. 1994; Muir et al. 1995a,b, 1996, 1998; Smith et al. 1998). Therefore, the current spill program prescribed by the 2000 Federal Columbia River Power System Biological Opinion (NMFS 2000) was designed to maximize spillway passage for migrating juvenile salmonids (*Oncorhynchus* spp.) at hydroelectric dams. However, the use of spill was precluded in 2001 throughout the Columbia River Basin because of extremely low river flows. Regional managers of the power system were compelled to implement an alternate strategy to maximize transportation of juvenile migrant salmonids.

Therefore, the 2001 survival and passage study at Ice Harbor Dam was modified to determine survival estimates and fish behavior with respect to operational conditions which resulted from low river flows. The following were specific goals of the research:

1) estimate project and bypass survival through Ice Harbor Dam,
2) estimate survival through partitioned reaches between Ice Harbor and McNary Dam,
3) evaluate approach and passage behavior at Ice Harbor and McNary Dam, and
4) compare radiotelemetry techniques to PIT-tag techniques for estimating survival of hatchery yearling chinook salmon.

The comparison of survival estimation techniques is needed to determine if radiotelemetry can confidently be used in survival studies at lower Columbia River projects where PIT-tag studies are not feasible due to insufficient detection capabilities downstream (Hockersmith et al. 2003).

Results of this study will be used to inform management decisions to optimize survival for juvenile salmonids arriving at Ice Harbor and McNary Dams during a low flow year. The study addresses research needs outlined in SPE-W-00-1 and SPE-W-00-2 of the U.S. Army Corps of Engineers, Northwestern Division, Anadromous Fish Evaluation Program (USACE 2001).

METHODS

Fish Collection

We collected river-run hatchery yearling chinook salmon at the Lower Monumental Dam smolt collection facility. Collection and tagging began on 7 May and continued through 26 May 2001. Our tagging schedule consisted of 6 consecutive days of tagging followed by 1 day off over the 3-week study period. Fish were obtained using the protocol of the sampling facility staff at Lower Monumental Dam. Sample rates were changed as necessary during the collection period to obtain approximately 800 fish per replicate for PIT-tag releases and 100 fish per replicate for radio-tag releases.

Prior to sorting, fish were preanesthetized with tricaine methane sulfonate (MS-222). During the sorting and tagging procedure, fish were contained in a recirculating anesthetic system. Only adipose fin-clipped or coded-wire tagged fish that were not previously PIT tagged were used, and fish less than 20 g were not radio-tagged. Fish that weighed more than 20 g were measured to the nearest mm and tagged. None of the fish collected were too small to PIT-tag.

PIT Tagging

Fish were PIT tagged by hand (Prentice et al. 1990a,b) using individual syringes with a 12-gauge hypodermic needle. Used syringes were sterilized in ethyl alcohol for a minimum of 10 min before reloading with PIT tags. PIT-tagged fish were transferred from the smolt monitoring facility through a water-filled pipe to 935-L tanks mounted on trucks. After tagging, fish were held a minimum of 30 h for recovery from the anesthetic and to determine post-tagging mortality. Holding tanks were supplied with flow-through water during tagging and holding and were aerated with oxygen during transport to release locations. Holding density did not exceed 800 fish/tank.

Radio Tagging

The radio tags used in this study had an expected battery life of about 10 days and were pulse-coded for unique identification of individual fish. Each radio tag measured 17 mm in length by 7 mm in diameter and weighed 1.4 g in air.

Fish used in the radio-tag portion of this study were collected and held in a tank with flow-through water for 24 h prior to tagging for recovery from the initial anesthetic. After recovery, they were re-anesthetized and first PIT-tagged and then radio-tagged using gastric implantation techniques similar to those described by Adams et al. (1998). This protocol was followed to minimize the impact of extended periods of time fish would spend in the anesthetic system due to the slower radio-tagging procedure.

Following tagging, fish were placed in 19-L containers (2-3 fish per container). Each container was covered and loaded into 1,150-L tanks designed to hold a number of these containers while suppling aeration and/or flow-through water. Fish holding containers were perforated with 1.3-cm holes in the top 30.5 cm of the container to allow an exchange of water during the second holding period. Radio tagged fish were transported to their respective release locations after an additional 30-h holding period to recover from the anesthetic and tagging procedure and to evaluate post-tagging mortality.

Release Procedures

Tagged fish were transported in post-tagging recovery containers from Lower Monumental Dam to Ice Harbor Dam. All of the PIT-tagged fish and half of the radio-tagged fish were transferred to a small barge for transport to mid-channel for release. These fish were released water-to-water, 5 km upstream from Ice Harbor Dam. The remaining radio-tagged fish were released, water-to-water, into the juvenile bypass system outfall pipe just downstream from the Ice Harbor Dam smolt monitoring facility.

Releases each day were alternated between day and night conditions. Daytime releases occurred between 1100 and 1500 PST. Nighttime releases occurred between 2100 and 2300 PST. Dead radio-tagged fish were released at both Ice Harbor Dam and McNary Dam to test the assumption that downstream detections occur only for live fish.

Data Analyses

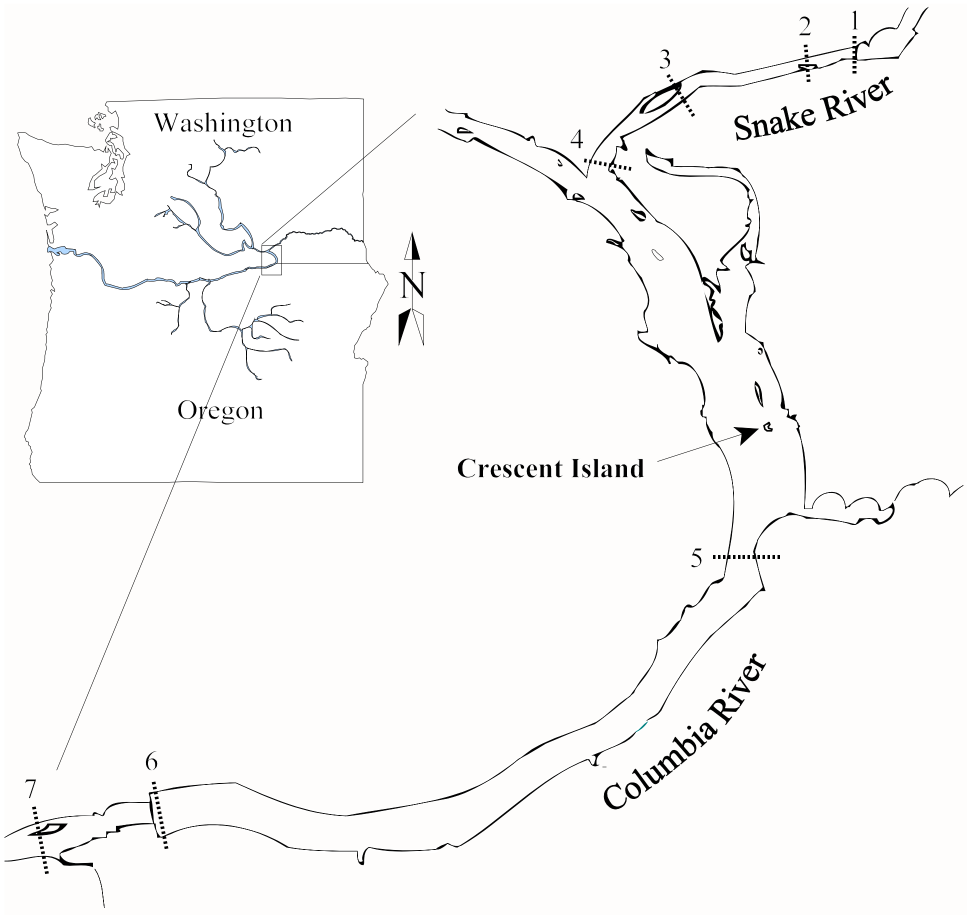
Sample sizes for release were determined by evaluating detection probabilities for PIT-tagged salmonids released into the Snake and Columbia Rivers in 1997, 1998, 1999, and 2000 and detection probabilities of radio-tagged salmonids passing telemetry monitors in 1999 and 2000. The number of release groups per release location and number of fish per release group were calculated to maximize precision in survival estimates given the constraints imposed by the logistics of collecting, tagging, and transporting fish.

For PIT-tag evaluations, the study was designed to release 16 replicate groups of yearling chinook salmon with approximately 800 fish released per group. For the radiotelemetry survival estimates, we planned to release 17 replicate groups of 100 radio-tagged yearling chinook salmon. We ended up with one additional radiotelemetry group, which was originally meant to be a PIT-tag group, because numbers of fish arriving at Lower Monumental Dam had dropped too far for completion of an additional PIT-tag replicate group.

Survival Estimates and Tests of Assumption

Analyses of PIT-tag data were based on detections at the juvenile collection and detection facilities at McNary, John Day, and Bonneville Dams and detections from the PIT-tag detection trawl in the Columbia River estuary (Ledgerwood et al. in press). The radiotelemetry analysis was based on detections of individual fish at telemetry monitoring transects set up at Ice Harbor Dam, Goose Island, Strawberry Island, Sacajawea Park at the Snake River mouth, Port Kelley, McNary Dam, and mouth of the Umatilla River (Figure 1). Radiotelemetry antenna locations at Ice Harbor Dam are depicted in Figure 2.

In addition, radio tags and PIT tags were recovered on the Caspian tern colony at Crescent Island (located 12.9 km downstream from the Snake River mouth) during fall 2001 after the birds left the island. PIT-tag detections at Crescent Island were provided by NMFS and Biomark (B. Ryan, NMFS, personal communication; see also Ryan et al. 2001). We physically recovered radio tags that were visible on the island and used radio-tag serial numbers to identify individual tagged fish. For comparisons of tagging methodology, we analyzed differences in avian predation rates at Crescent Island in addition to survival estimates, travel time and migration rates.



Telemetry monitoring transects

Snake River	Columbia River
1 Ice Harbor Dam	5 Port Kelley
2 Goose Island	6 McNary Dam
3 Strawberry Island	7 Umatilla River
4 Snake River mouth	

Figure 1. Telemetry monitoring transects on the Snake and Columbia Rivers, 2001.

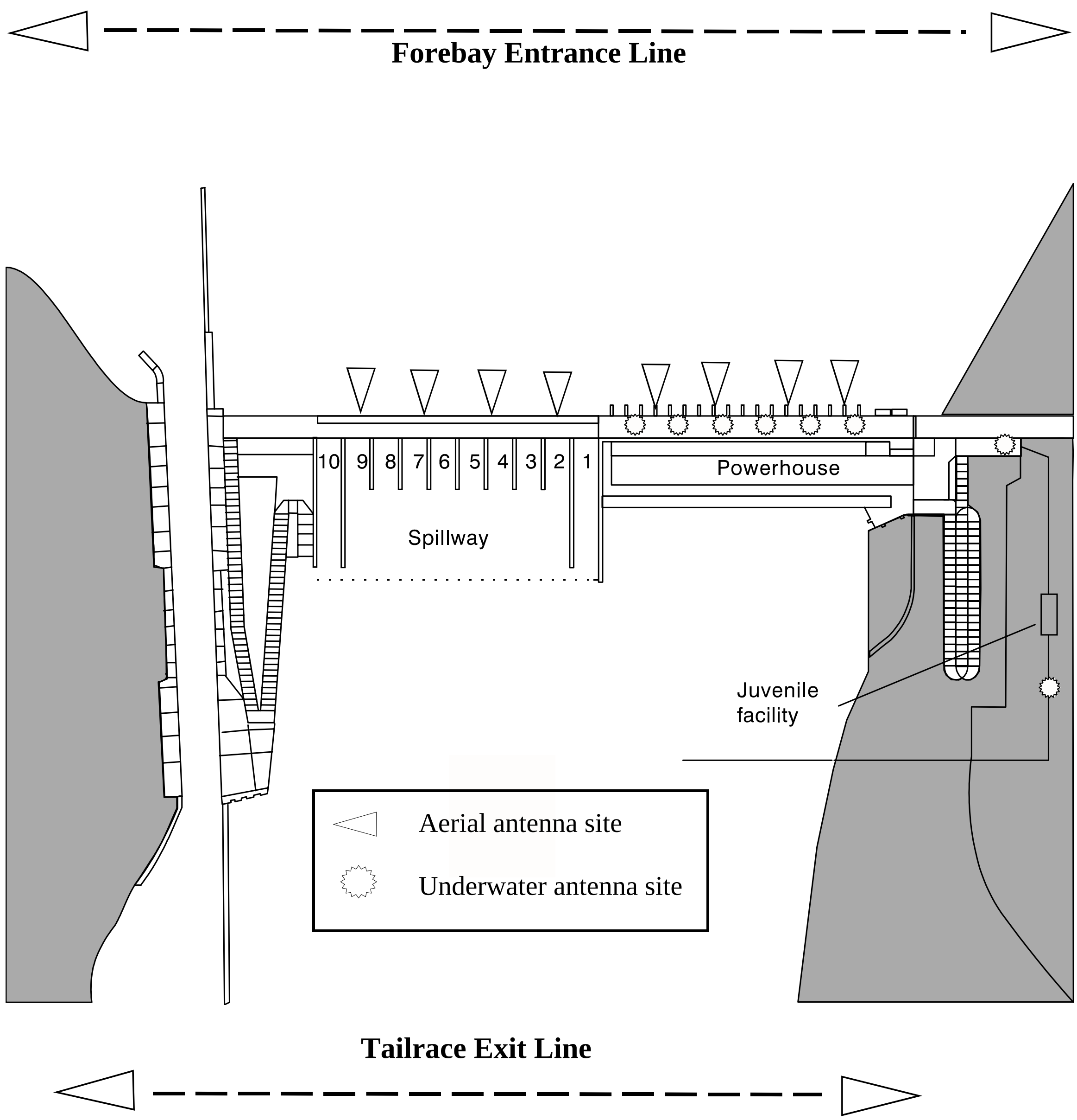


Figure 2. Overhead schematic of Ice Harbor Dam and radiotelemetry antenna sites.

Survival estimates were based on the detection histories of individual fish modeled as a series of events (detection or non-detection) using the single-release (SR) model of Cormack (1964), Jolly (1965), and Seber (1965). Because each fish experiences exactly one of a finite number of possible detection histories, the SR model represents the data for each group of tagged fish as a multinomial distribution. Each multinomial cell probability (i.e., detection history probability) is a function of the underlying survival and detection event probabilities.

Critical assumptions of the SR model are that survival and detection probabilities are homogenous and independent at each detection site and among all fish in a release group (Iwamoto et al. 1994). If fish were subjected to heavy predation at a bypass outfall, for example, while fish passing via turbines or spillways were not, then survival probability to the next detection site would no longer be equal for detected and non-detected fish. Violations of these assumptions would be evidenced by discrepancies among the distributions of detection histories under the SR model. A series of contingency tables was constructed from the observed detection histories (Burnahm et al. 1997), and Fisher's exact test (Agresti 1990) was used to identify deviations from the expected distribution of values.

Travel Time and Migration Rate

Travel times and migration rates were calculated for the following reaches: Ice Harbor to McNary Dam (68 km), Ice Harbor to John Day Dam (191 km), and Ice Harbor to Bonneville Dam (460 km). Migration rate through a reach was calculated as the length of the reach (km) divided by the travel time (days) and included delays associated with residence time in forebays before passing dams and delays during passage through the bypass system. Migration rates for PIT-tagged and radio-tagged fish were compared using a two-factor analysis of variance (ANOVA) with release day as a random (blocking) factor and the treatment as a fixed factor. We also looked for a systematic temporal trend by including date as a covariate. Residuals were examined to assess the performance of the analysis.

RESULTS

We released 14,053 PIT-tagged fish and 882 radio-tagged fish 5 km upstream from Ice Harbor Dam. Eight hundred seventeen radio-tagged fish were released into the Ice Harbor Dam bypass outfall pipe located downstream from the smolt monitoring facility. Post-tagging mortality was 0.6% for PIT-tagged fish and 0.3% for radio-tagged fish. Median fork lengths were 145.5 mm (SD = 8.9) for forebay release groups and 146.0 mm (SD = 9.9) for bypass release groups.

During the releases, no water was spilled except on 19 May, when the breakdown of a juvenile fish transportation barge and subsequent release of fish into the Ice Harbor Dam forebay precipitated an emergency period of spill. Water temperature during the study ranged from 11.9 to 13.9°C (Table 1). Snake River flow measured at Ice Harbor Dam during May 2001 averaged 69.5 kcfs and peaked on 17 May at 92.1 kcfs. This was the fifth lowest Snake River flow on record at Ice Harbor Dam during May over the previous 40 years, when the average flow was 107.1 kcfs (Figure 3). Columbia River flow measured at McNary Dam during May 2001 averaged 129.9 kcfs and peaked on 24 May at 170.1 kcfs. This was the lowest Columbia River flow recorded at McNary Dam in May over the previous 41 years, during which the average flow was 278.5 kcfs (Figure 4).

Ice Harbor Dam

Approach and Passage Behavior

Of the 882 radio-tagged yearling chinook salmon released 5 km above Ice Harbor Dam, 870 were detected at the dam (Table 2). Of these fish, 563 (63.8%) passed through the juvenile fish bypass system, 41 (4.6%) passed through a turbine unit, 228 (25.9%) had unknown routes of passage, 38 (4.3%) were detected in the forebay but never detected below the dam, and 12 (1.4%) were never detected after release. Minimum estimates of fish guidance efficiency (FGE) among release groups ranged from 33.3 to 77.1%, and overall FGE was 67.7%. The low FGE of 33.3% resulted from fish released on 18 May passing via an unknown route, which was probably due to the unexpected voluntary spill from approximately 0500 to 1100 on 19 May. For estimates of minimum FGE, fish with unknown passage routes were grouped with turbine-passed fish, since both groups were undetected in the collection channel or bypass flume.

Table 1. Ice Harbor Dam operations and discharge conditions during releases of hatchery yearling chinook salmon for survival evaluation, 2001.

Date	Powerhouse (kcfs)	Spillway (kcfs)	Total Discharge (kcfs)	Temperature (°C)
08 May	47.6	0.0	47.6	12.3
09 May	55.5	0.0	55.5	12.7
10 May	56.3	0.0	56.3	13.1
11 May	60.1	0.0	60.1	13.1
12 May	56.2	0.0	56.2	12.8
13 May	59.4	0.0	59.4	12.7
14 May	77.4	0.0	77.4	12.3
15 May	74.9	0.0	74.9	11.9
16 May	91.8	0.0	91.8	12.1
17 May	90.9	0.0	90.9	12.4
18 May	92.1	0.0	92.1	12.6
19 May	74.9	9.8	84.7	13.0
20 May	72.5	0.0	72.5	13.2
21 May	65.5	0.0	65.5	13.5
22 May	61.0	0.0	61.0	13.7
23 May	64.0	0.0	64.0	13.9
24 May	67.0	0.0	67.0	13.9
25 May	71.1	0.0	71.1	13.8
26 May	75.3	0.0	75.3	13.7
27 May	67.7	0.0	67.7	13.7
28 May	69.2	0.0	69.2	13.8
Average	69.1	0.5	69.5	13.1

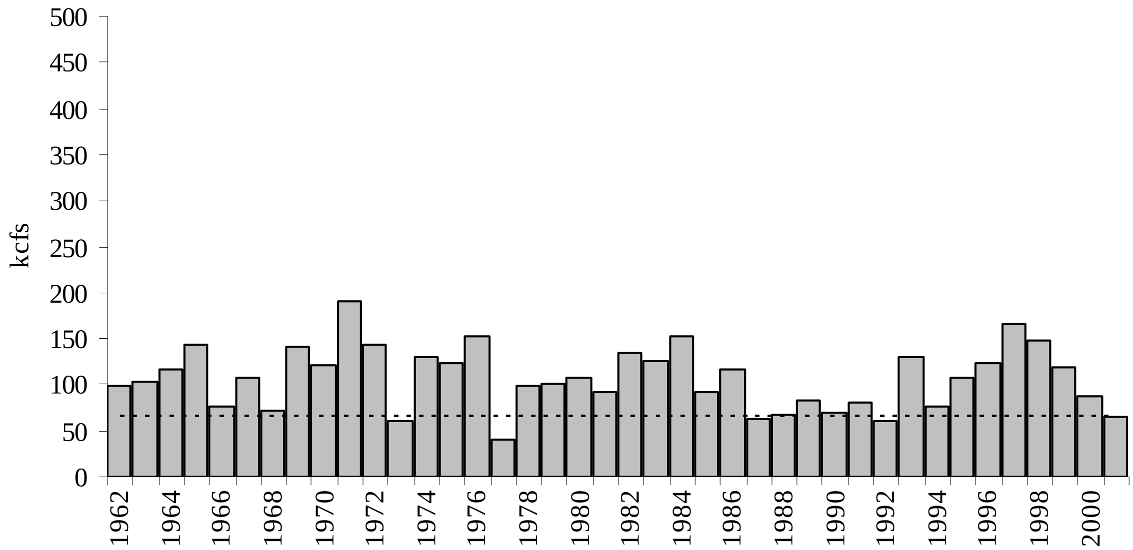


Figure 3. Average Snake River flow at Ice Harbor Dam during May 1962-2001. Dotted line shows 2001 flow in relation to historical flows.

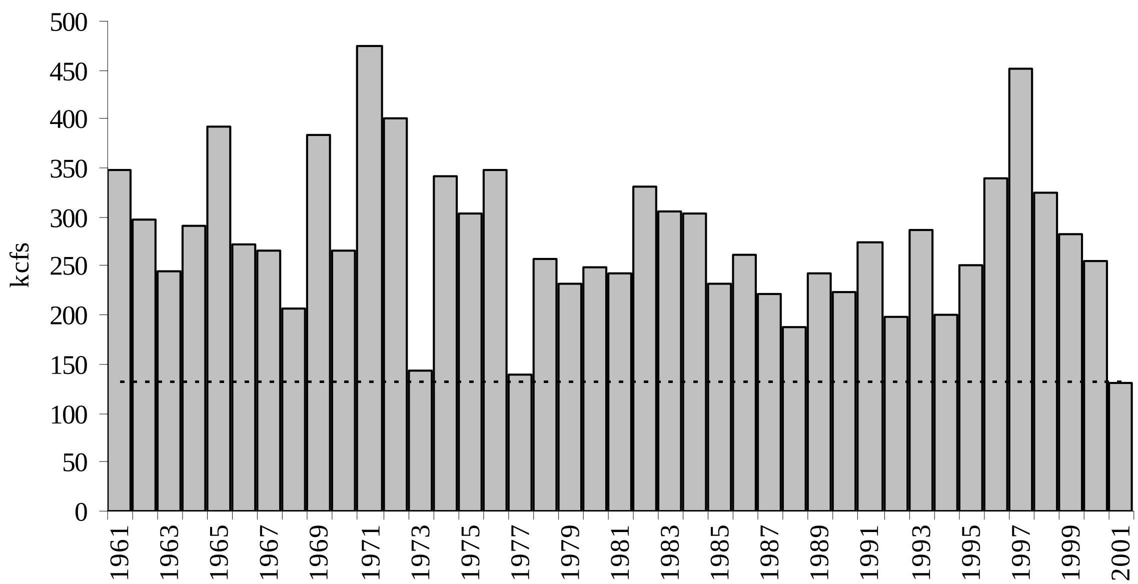


Figure 4. Average Columbia River flow at McNary Dam during May 1961-2001. Dotted line shows 2001 flow in relation to historical flows.

Table 2. Passage distribution by release date of radio-tagged hatchery yearling chinook salmon at Ice Harbor Dam, 2001 (Note: Unknown route is defined as fish seen below the dam but not on a passage route receiver; No passage is defined as fish detected at or above the dam but not downstream from the dam; Not detected is defined as fish that were never detected following release).

Release	Turbine		Bypass system		Unknown route		No passage		Not detected		Number
date	n	Percent	n	Percent	n	Percent	n	Percent	n	Percent	released
08 May	1	2.1	34	70.8	9	18.8	1	2.1	3	6.3	48
09 May	1	2.0	36	70.6	11	21.6	2	3.9	1	2.0	51
10 May	3	6.1	33	67.3	10	20.4	2	4.1	1	2.0	49
11 May	2	4.0	30	60.0	15	30.0	2	4.0	1	2.0	50
12 May	4	8.2	29	59.2	12	24.5	3	6.1	1	2.0	49
13 May	3	5.9	32	62.7	13	25.5	2	3.9	1	2.0	51
15 May	3	6.3	28	58.3	11	22.9	5	10.4	1	2.1	48
16 May	3	7.0	27	62.8	11	25.6	1	2.3	1	2.3	43
17 May	1	2.0	36	70.6	12	23.5	2	3.9	0	0.0	51
18 May*	0	0.0	17	33.3	34	66.7	0	0.0	0	0.0	51
19 May	1	2.0	35	70.0	12	24.0	2	4.0	0	0.0	50
20 May	3	6.3	33	68.8	11	22.9	1	2.1	0	0.0	48
22 May	2	4.4	27	60.0	15	33.3	1	2.2	0	0.0	45
23 May	4	8.3	31	64.6	7	14.6	5	10.4	1	2.1	48
24 May	3	6.1	37	75.5	8	16.3	1	2.0	0	0.0	49
25 May	1	2.0	37	74.0	10	20.0	1	2.0	1	2.0	50
26 May	4	7.8	32	62.7	14	27.5	1	2.0	0	0.0	51
27 May	2	4.0	29	58.0	13	26.0	6	12.0	0	0.0	50
Total	41	4.6	563	63.8	228	25.9	38	4.3	12	1.4	882

* The high number of fish passing through an unknown route on 18 May was probably due to an emergency release of fish into the forebay of Ice Harbor Dam after mechanical breakdown of a juvenile salmon transportation barge. This resulted in a period of voluntary spill from approximately 0500 to 1100 on 19 May 2001.

Median forebay residence time for radio-tagged yearling chinook salmon with known entrance and passage routes was 7.3 h at Ice Harbor Dam and ranged from 0.4 to 159.8 h (residence time for the 99th percentile was 42.4 h). Schools of yearling chinook salmon were observed holding within the immediate forebay of Ice Harbor Dam on a daily basis throughout the study.

Median gatewell residence time was 0.9 h and ranged from 0.01 to 50.5 h. Median tailrace egress was 9.3 min overall, 9.0 min for fish passing through the juvenile bypass system, and 14.7 min for fish passing through a turbine unit. We released 16 dead radio-tagged fish into the bypass pipe to determine how far a dead fish would travel. We observed one dead fish at Goose Island (3.2 km downstream). No dead fish were detected below Goose Island.

Survival Estimates

Project survival for yearling chinook salmon released 5 km upstream from Ice Harbor Dam was estimated at 0.936 (95% CI: 0.895-0.977). Bypass survival for radio-tagged fish released 5 km upstream from the dam, detected in the Ice Harbor bypass system, and subsequently detected at Strawberry Island was estimated at 0.996 (95% CI: 0.947-1.045; Figure 5). Survival to McNary Dam for fish released 5 km upstream from Ice Harbor Dam was estimated at 0.744 (95% CI: 0.715-0.773) for radio-tagged fish and 0.724 (95% CI: 0.708-0.740) for PIT-tagged fish (Table 3). Estimated survival to McNary Dam for radio-tagged fish released to the bypass outfall pipe at Ice Harbor Dam was 0.801 (95% CI: 0.774-0.828). Due to the small numbers that passed via turbines at Ice Harbor Dam, we were unable to estimate survival for these fish.

Detection histories from most release groups indicated no violation of the assumption that survival and detection probabilities were homogeneous and independent among cohorts. In the forebay release, there was some indication that detection probabilities were not homogeneous: Fisher's exact tests showed that in two cases, fish detected at a given location were more likely to be detected at a successive location (Appendix Table 1).

This could result from behavior that makes the tags of some fish more easily detectable. For example, if some fish swam higher in the water column, they might be more prone to detection at radiotelemetry transects or to guidance by juvenile bypass screens. Alternatively, there may have been a portion of tags that were somewhat more readable, independent of fish behavior. It should be noted also that this sort of violation will tend to inflate detection probability estimates, which in turn will lead to deflated survival estimates. That is, if a bias occurred, it resulted in survival estimates that were too low.

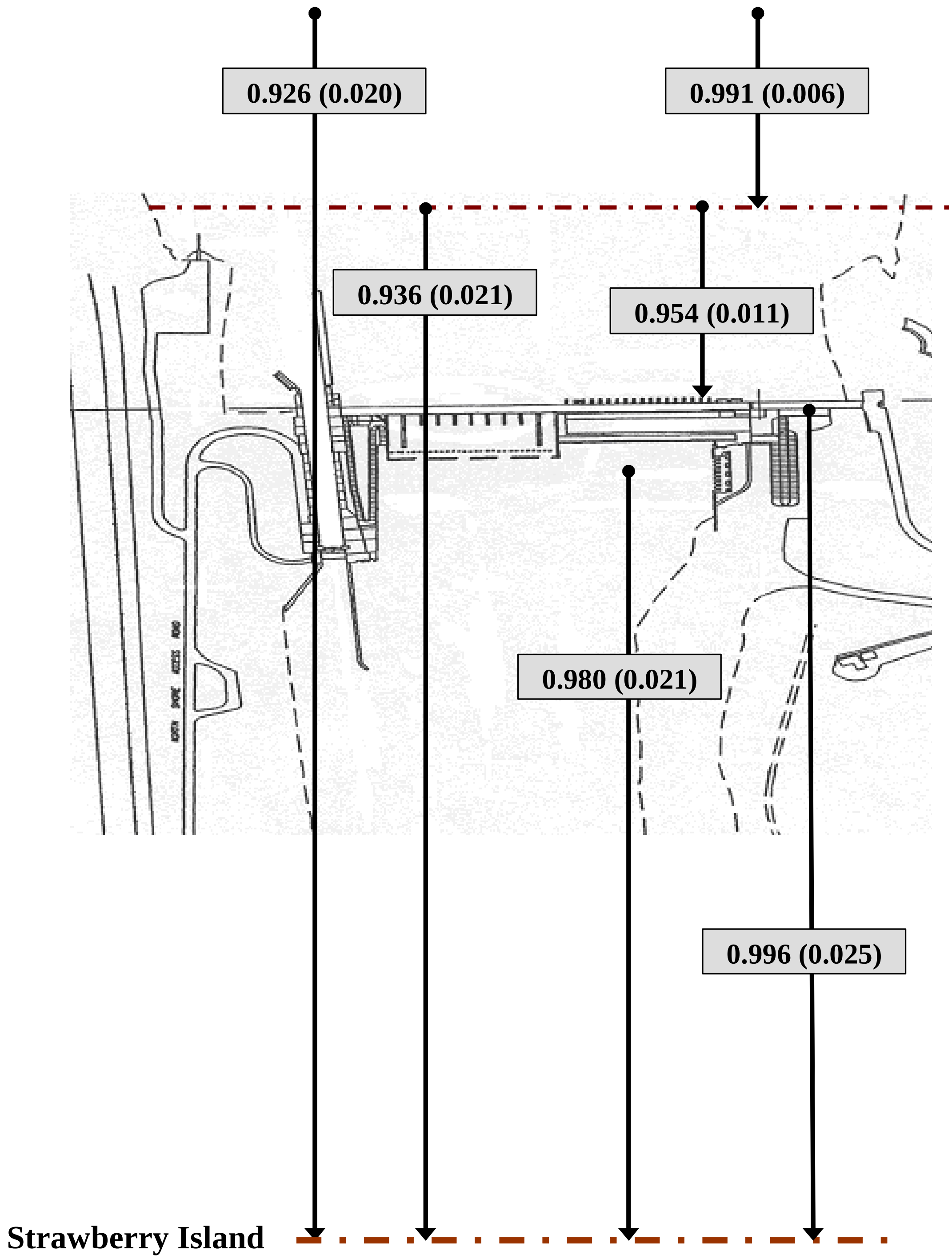


Figure 5. Schematic representation of survival estimates generated from radio-tagged hatchery yearling chinook salmon passing Ice Harbor Dam, 2001.

Table 3. Survival estimates to McNary Dam for PIT-tagged and radio-tagged hatchery yearling chinook salmon released 5 km upstream from the Ice Harbor Dam and into the bypass outfall pipe at Ice Harbor Dam, 2001.

Estimates of survival from release at Ice Harbor to McNary Dam

		PIT tags		Radio tags	
Release location	Tag type	Survival estimate	95% CI	Survival estimate	95% CI
5 km upstream from Ice Harbor Dam	PIT tag only	0.724	0.708-0.740	-----	
	Radio tag/PIT tag	0.698	0.657-0.739	0.744	0.715-0.773
Bypass outfall pipe	Radio tag/PIT tag	0.784	0.739-0.829	0.801	0.774-0.828

Reach survival estimates from Ice Harbor to McNary Dam based on radiotelemetry

		Release 5 km upstream from dam		Release to bypass outfall pipe	
Reach	Length of reach (km)	Survival estimate	95% CI	Survival estimate	95% CI
5 km upstream from Ice Harbor Dam to Ice Harbor forebay	5.0	0.991	0.979-1.003	----	
Ice Harbor forebay to Ice Harbor Dam	0.5	0.954	0.952-0.956	----	
Ice Harbor Dam tailrace to Strawberry Island	8.5	0.980	0.939-1.021	0.965	0.926-1.004
Strawberry Isl. to Snake River Mouth (Sacajawea Park)	7.2	0.982	0.933-1.031	0.979	0.930-1.028
Snake River Mouth to Port Kelley	21.0	0.905	0.856-0.954	0.915	0.868-0.962
Port Kelley to McNary Dam	31.0	0.904	0.861-0.947	0.927	0.888-0.966

McNary Pool

Travel Times

Travel times for PIT-tagged and radio-tagged yearling chinook salmon from Ice Harbor Dam to McNary Dam, Ice Harbor Dam to John Day Dam, and Ice Harbor Dam to Bonneville Dam are shown in Figure 6. A comparison of median travel times between radio-tagged groups released to the forebay and those released to the bypass outfall pipe showed 24-h delay associated with passage through Ice Harbor Dam. This delay remained fairly constant during the rest of the migration for these fish (Table 4). Mean migration rates to McNary Dam of fish released 5 km upstream from Ice Harbor Dam were 2.2 km/day faster (P = 0.001) for radio-tagged than for PIT-tagged fish. Migration rates increased over the study period (P <0.001), but the difference in migration rate between the two tag types did not (P = 0.185). The faster migration rate for radio-tagged fish persisted during migration to John Day Dam and Bonneville Dams (Figure 7).

Survival Estimates

For radio-tagged fish, partitioned reach survival estimates ranged from 0.904 (95% CI: 0.861-0.947) to 0.982 (95% CI: 0.933-1.031) for releases 5 km upstream from Ice Harbor Dam and from 0.915 (95% CI: 0.868-0.962) to 0.979 (95% CI: 0.930-1.028) for releases into the bypass outfall pipe at the dam (Table 3). The lowest survival probabilities were estimated for the two reaches between the mouth of the Snake River and Port Kelley (21 km) and from Port Kelley to McNary Dam (31 km). However, these were also the longest reaches, and were likely the reaches where fish were most vulnerable to avian predation, as the Caspian tern colony on Crescent Island is located 12.9 km downstream from the mouth of the Snake River.

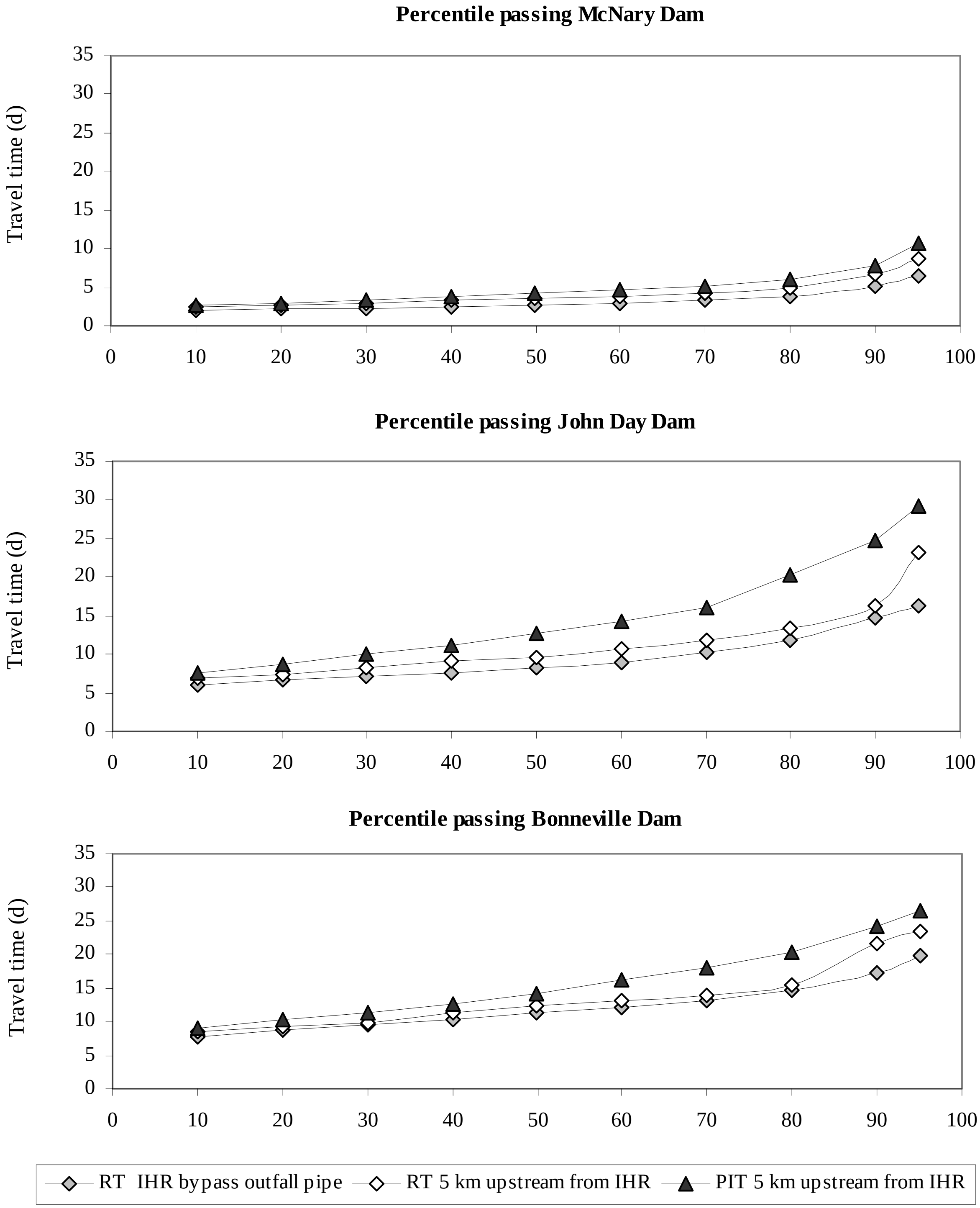


Figure 6. Travel times (days) to McNary, John Day, and Bonneville Dam for PIT-tagged (PIT) and radio-tagged (RT) hatchery yearling chinook salmon released into the forebay and bypass pipe at Ice Harbor Dam (IHR), 2001.

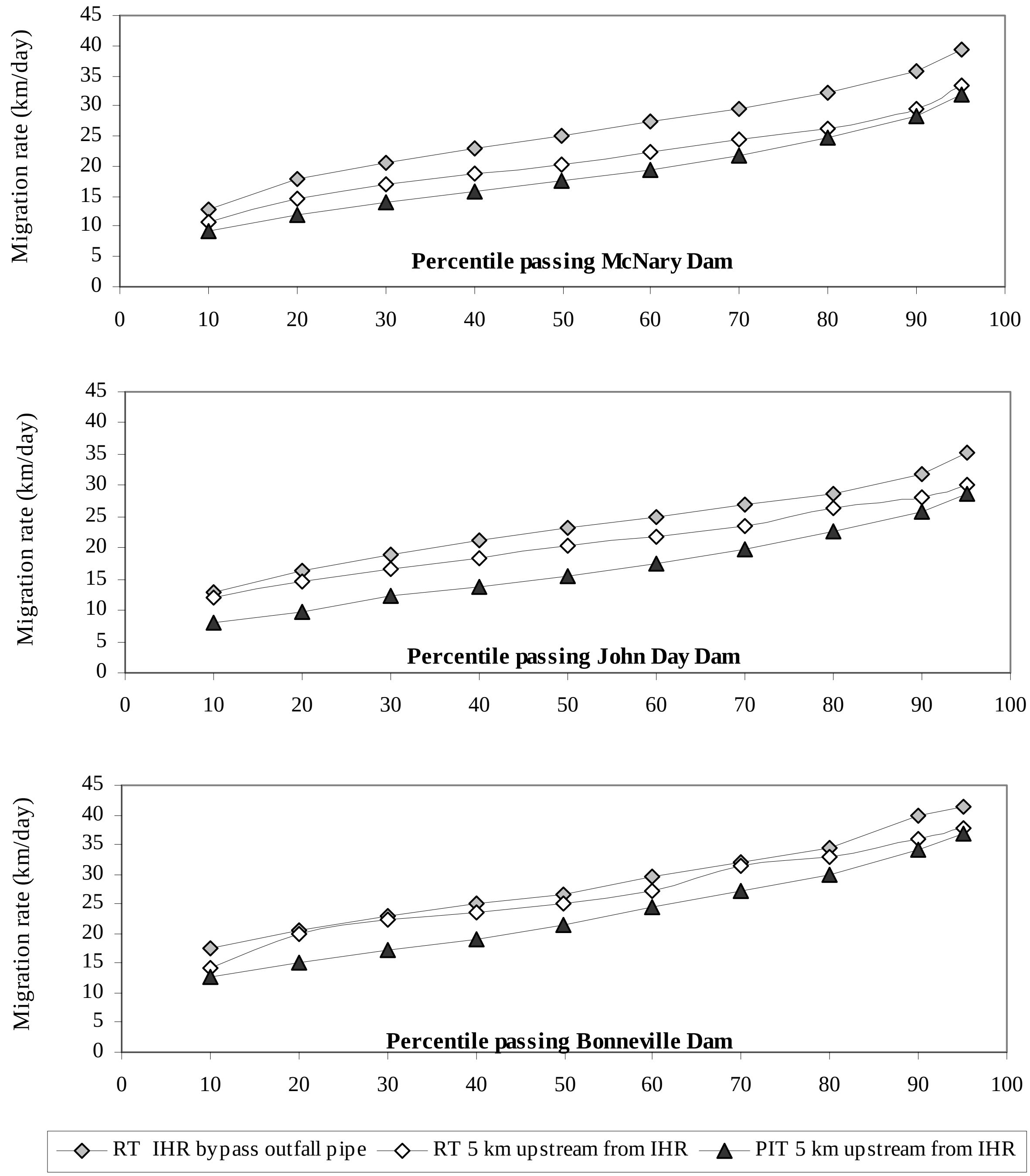


Figure 7. Migration rates (km/day) to McNary, John Day, and Bonneville Dam for PIT-tagged (PIT) and radio-tagged (RT) hatchery yearling chinook salmon released 5 km upstream from and into the bypass outfall pipe at Ice Harbor Dam (IHR), 2001.

Table 4. Travel time and migration rate for PIT-tagged (PIT) and radio-tagged (RT) hatchery yearling chinook salmon at Ice Harbor Dam, 2001.

Travel Time (days)												
Tag type	Ice Harbor to McNary				Ice Harbor to John Day				Ice Harbor to Bonneville			
	N	20%	Med.	80%	*N*	20%	Med.	80%	*N*	20%	Med.	80%
Released to Ice Harbor Dam bypass outfall pipe												
Radio tag	549	2.1	2.7	3.8	201	6.6	8.2	11.7	101	8.8	11.4	14.8
Released 5 km upstream from Ice Harbor Dam												
Radio tag	536	2.8	3.6	5.0	200	7.5	9.7	13.5	92	9.4	12.3	15.5
PIT-tag	7538	3.0	4.2	6.1	1841	8.7	12.7	20.2	1473	10.3	14.3	20.2

Migration Rate (km/day)												
	Ice Harbor to McNary				Ice Harbor to John Day				Ice Harbor to Bonneville			
Tag type	*N*	20%	Med.	80%	*N*	20%	Med.	80%	*N*	20%	Med.	80%
Released to Ice Harbor Dam bypass outfall pipe												
Radio tag	549	17.8	25.1	32.1	201	16.3	23.3	28.8	101	20.5	26.7	34.4
Released 5 km upstream from Ice Harbor Dam												
Radio tag	536	14.7	20.3	26.2	200	14.6	20.3	26.3	92	19.9	25.1	32.8
PIT tag	7538	12.0	17.6	24.6	1841	9.7	15.4	22.5	1473	15.2	21.6	29.9

Avian Predation

Recoveries from the Crescent Island Caspian tern and gull colonies for releases 5 km upstream from Ice Harbor Dam were 3.9% (542 tags) and 5.1% (45 tags) for PIT-tagged and radio-tagged fish, respectively. For radio-tagged fish released to the bypass outfall, 6.6% (54 tags) were recovered on the Crescent Island Caspian tern colony. The proportion of radio tags found on Crescent Island was not significantly different from the proportion of PIT-tags for fish released 5 km upstream from the dam during the study period (Figure 8). These differences ranged from -0.09 to 4.1% and averaged 1.1% overall.

The proportion of radio tags recovered on the Crescent Island tern colony from releases to the bypass outfall pipe at night was slightly higher than those from releases to the outfall pipe during the day or releases 5 km upstream from the dam during night or day (Figure 8). However, we were unable to relate downstream passage route with tern predation rates due to the small number of radio tags recovered from Crescent Island and to the small proportion of fish passing Ice Harbor Dam through a known route of passage (other than the bypass outfall). Thirty percent of the radio tags recovered from the Caspian tern colony were last observed last observed on the telemetry transect at the mouth of the Snake River (Figure 9), and approximately 9% were last observed in the McNary Dam forebay. This indicated that the Caspian terns preyed on salmonids as far as 39 km downstream from their colony. The recoveries also included tags that were last observed at each of the telemetry transects between Ice Harbor and McNary Dam forebays.

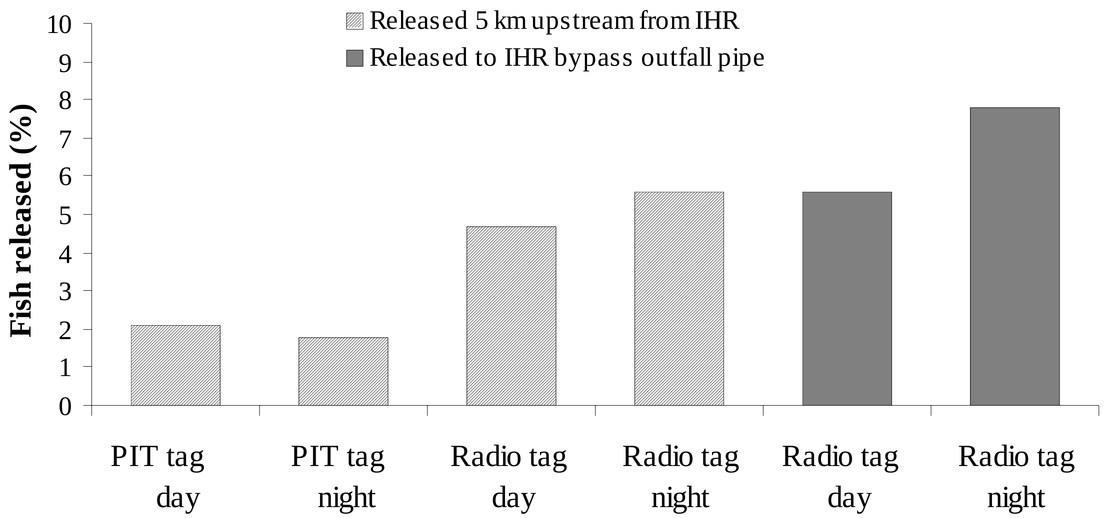


Figure 8. Percent of tagged hatchery yearling chinook salmon preyed upon by Crescent Island Caspian terns by tag type, release location at Ice Harbor Dam (IHR), and diel release time during 2001.

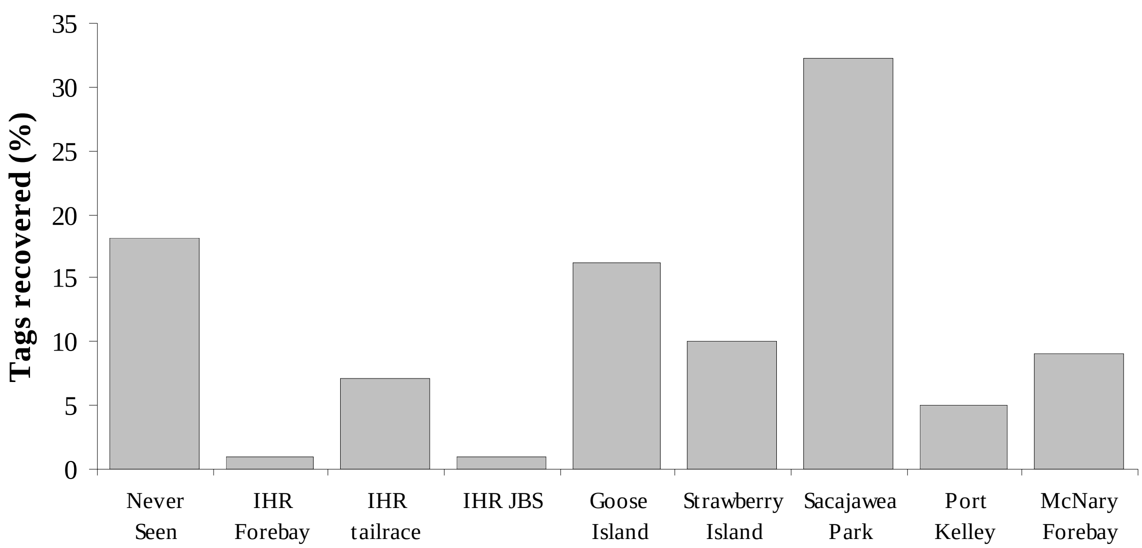


Figure 9. Site of last known telemetry detection prior to predation by Crescent Island Caspian terns on fish released at Ice Harbor Dam, 2001.

McNary Dam

Of the 1,699 radio-tagged yearling chinook salmon released at Ice Harbor Dam, 1,353 were detected at McNary Dam. Radiotelemetry data indicated that the prolonged residence within the forebay at McNary Dam was associated with lower flows. Detection histories indicated that once fish entered the forebay, they constantly moved back and forth across the spillway and powerhouse before passing. Median forebay residence time at McNary Dam was 7.6 h. For fish arriving during daylight hours, median forebay residence was 8.5 h. During nighttime hours, median forebay residence was 5.6 h.

We observed considerable delay in approach and passage behavior within the forebay at McNary Dam as fish searched for a passage route. Survival estimates to John Day Dam for fish that passed via the bypass system at McNary Dam were similar for both radio-tagged fish and PIT-tagged fish. Unfortunately, we were unable to accurately determine gatewell residence times because power to our radiotelemetry monitors was disconnected on repeated occasions during the study period.

Median tailrace egress was difficult to measure given the low flows at McNary in 2001. Fish exiting the bypass outfall pipe traveled across to the north side of the tailrace and sounded below the detection range of our telemetry monitors. A similar pattern of movement was observed in releases of dead fish. Of 11 dead fish released into the bypass outfall pipe, none were detected on fixed telemetry receivers. Mobile tracking of dead fish near the outfall pipe projected a course toward the north shore before the signals disappeared and were never detected downstream. Median travel time from passage at McNary Dam to the Umatilla River, located 4.0 km downstream, was 1.8 h.

DISCUSSION

We observed longer forebay residence times and tailrace egress times at Ice Harbor Dam than we had seen for hatchery yearling chinook salmon during 1999 (Eppard et al. 2000). Average river flows during the study periods in 1999 and 2001 were 109.7 and 69.5 kcfs, respectively. Throughout the study period, operations at Ice Harbor Dam were limited to powerhouse flow as a result of low river flows and a regional power deficit during 2001. As stated above, this was the fifth lowest Snake River flow on record at Ice Harbor Dam and the lowest Columbia River flow on record at McNary Dam during May over the previous 41 years.

The minimum estimate of FGE at Ice Harbor Dam during 2001 was 67.7%, which was slightly lower than the estimate of 74.5% obtained in 1999 (Eppard et al. 2000) for fish with known passage routes. Forebay residence time for radio-tagged yearling chinook salmon was longer in 2001 with a median of 7.3 h compared to 1.3 h in 1999. Median tailrace egress for 2001 was 9.3 min overall, 9.0 min for fish passing through the juvenile fish bypass system, and 14.7 min for fish passing through a turbine unit compared to 2.8 min overall, 5.7 min for fish exiting the bypass system, and 7.3 min for fish exiting the turbines during 1999.

Because of low river flows, which precluded the used of spill, approximately 93% of unmarked chinook salmon arriving at the upper Snake River dams were diverted for transportation during 2001. Thus, the majority of the fish available to predators were PIT-tagged and radio-tagged fish released to migrate in the river for research purposes. Therefore, while adequately representing in-river survival for 2001, these estimates may be highly variable when compared with normal or high flow years with voluntary and involuntary spill at Columbia Basin hydroelectric projects.

In the absence of spill during 2001, we observed similar behavior at both dams for fish exiting the bypass outfall pipe: live and dead fish alike traveled across the tailrace towards the navigation lock wall before continuing downstream. These conditions may result in a higher vulnerability to predation as the fish are subjected to longer tailrace egress times, although we observed 98% survival from the tailrace of Ice Harbor Dam to Strawberry Island.

Project survival at Ice Harbor Dam includes the near forebay environment within the estimate. Survival was measured to Strawberry Island because there were no dead fish releases which reached the telemetry line.

Partitioned reach survivals appeared to reflect the effects of the Crescent Island tern colony (between Ice Harbor and McNary Dams) on smolts migrating through the McNary reservoir. The size of the tern colony was approximately 720 breeding pairs during 2001, an increase of 26% compared to 2000 (Collis et al. 2001). Survival estimates were lowest between the mouth of the Snake River and McNary Dam.

Zabel et al. (2002) reported that 4.1% of the PIT-tagged spring/summer chinook salmon detected at Lower Monumental Dam during 2001 were subsequently detected on Crescent Island. We found a similar proportion of PIT tags (3.9%) on Crescent Island from our releases 5 km upstream from Ice Harbor Dam.

A higher proportion of radio tags (5.8%) than PIT tags (3.9%) were recovered on Crescent Island from fish released 5 km upstream from Ice Harbor Dam. Although these differences in proportion may indicate that radio-tagged fish were slightly more susceptible to tern predation than PIT-tagged fish; they also may have been a result of the disparity in sample size between tag groups.

The last detection of radio-tagged fish subsequently found on Crescent Island indicated that, at a minimum, terns foraged from Ice Harbor Dam forebay to McNary Dam forebay, a distance of nearly 70 km. The largest proportion of tags recovered from the tern colony (>30%) were last seen at the mouth of the Snake River, the last detection line above Crescent Island. Telemetry data also showed that several fish were detected in the forebay of McNary Dam, had no subsequent detection, and ended up on the tern colony. Low river flows caused longer travel times and forebay residence times, which may have resulted in higher predation rates by terns and other predators.

Our survival estimate of 0.724 (95% CI: 0.708-0.740) for PIT-tagged fish between the forebays of Ice Harbor and McNary Dam was very close to the survival estimate of 0.720 (95% CI: 0.702-0.738) for yearling chinook from Lower Monumental Dam to McNary Dam during 2001 (Zabel et al. 2002). Our survival estimate of 0.744 (95% CI: 0.715-0.773) for radio-tagged fish also demonstrated that under these conditions, the two methodologies can obtain similar results. Skalski et al. (2001) detected no difference between survival estimates derived from PIT-tagged and surgically radio-tagged juvenile steelhead (*O. mykiss*) for harmonic mean travel times of less than 2 days (migration distance of 68 km). However, similar to our results, he reported faster migration rates for radio-tagged fish which may warrant additional study.

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APPENDIX

Tests of Assumption

Appendix Table 1. Sequence of contingency tables (Burnham et al. 1987) and Fisher's exact *P* values from tests of assumption based on observed detection histories of radio-tagged fish released into the forebay of Ice Harbor Dam (IHR).

Test 2.C2 Ice Harbor Dam forebay to McNary Dam

	First site detected below Ice Harbor forebay					
P = 0.116 df = 4	Ice Harbor	Strawberry Island	Sacajawea Park	Port Kelley	McNary Dam	Below McNary*
Not detected at IHR forebay	111	15	15	10	11	0
Detected at IHR forebay	495	54	51	16	35	0

* Detections below McNary Dam were in most cases too few for inclusion in the analysis.

Test 2.C3 Forebay to McNary Dam

	First site detected below IHR				
P = 0.109 df =3	Strawberry Island	Sacajawea Park	Port Kelley	McNary Dam	Below McNary
Not detected at IHR	69	66	26	46	0
Detected at IHR	146	224	59	120	2

Test 2.C4 Forebay to McNary Dam

	First site detected below Strawberry Island			
P = 0.078 df =2	Sacajawea Park	Port Kelley	McNary Dam	Below McNary Dam
Not detected at Strawberry Isl	290	85	166	2
Detected at Strawberry Isl*	113	18	63	0

*Fish were less likely to be detected at Port Kelley

Test 2.C5 Forebay to McNary Dam

	First site detected below Sacajawea Park		
P = 0.674 df = 1	Port Kelley	McNary Dam	Below McNary Dam
Not detected at Sacajawea Pk	103	229	2
Detected at Sacajawea Pk	98	239	0

Appendix Table 1. Continued.

Test 2.C6 Forebay to McNary Dam

*NA**	First site detected below Port Kelley: McNary Dam	Below McNary Dam
Not detected at Port Kelley	468	2
Detected at Port Kelley	179	1

* Too few detections below McNary Dam

Test 3.SR3 Forebay to McNary Dam

$P = 0.467$ df = 1	Detected again at Strawberry Island or below: YES	NO
Detected at IHR, not detected at forebay	99	12
Detected at IHR, detected at forebay	452	43

Test 3.Sm3 Forebay to McNary Dam

$P = 0.018$ df = 3	Site first detected below IHR: Strawberry Island	Sacajawea Park	Port Kelley	McNary Dam	below McNary
Detected at IHR, not detected at forebay	19	34	13	32	1
Detected at IHR, detected at forebay*	127	190	46	88	1

* Fish were more likely to be detected at Strawberry Island and Sacajawea Park.

Test 3.SR4 Forebay to McNary Dam

NA	Detected again at Sacajawea Park or below: YES	NO
Detected at Strawberry Isl, not detected previously	14	1
Detected at Strawberry Isl, detected previously	180	20

Appendix Table 1. Continued.

Test 3.Sm4 Forebay to McNary Dam

		Site first detected below Strawberry Island			
		Sacajawea		McNary	below
P = 0.298	df = 2	Park	Port Kelley	Dam	McNary
Detected at Strawberry Isl, not detected previously		7	0	7	0
Detected at Strawberry Isl, detected previously		106	18	56	0

Test 3.SR5 Forebay to McNary Dam

		Detected again at Port Kelley or below	
P = 0.721	df = 1	YES	NO
Detected at Sacajawea Pk, not detected previously		12	3
Detected at Sacajawea Pk, detected previously		325	63

Test 3.Sm5 Forebay to McNary Dam

		Site first detected below Sacajawea Park		
				below
P = 0.751	df = 1	Port Kelley	McNary Dam	McNary
Detected at Sacajawea Pk, not detected previously		4	8	0
Detected at Sacajawea Pk, detected previously		94	231	0

Test 3.SR6 Forebay to McNary Dam

		Detected again at McNary Dam or below	
P = 0.014	df = 1	YES	NO
Detected at Port Kelley, not detected previously*		7	3
Detected at Port Kelley, detected previously		173	8

* Fish were much less likely to be detected at McNary Dam or below.

Appendix Table 1. Continued.

Test 3.Sm6 Forebay to McNary Dam

	Site first detected below Port Kelley	
NA	McNary Dam	below McNary Dam
Detected at Port Kelley, not detected previously	7	0
Detected at Port Kelley, detected previously	172	1

Test 3.SR7 Forebay to McNary Dam

		Detected below McNary Dam	
P = 0.350	df = 1	Yes	No
Detected at McNary Dam, not detected previously		2	9
Detected at McNary Dam, detected previously		216	420

Appendix Table 2. Sequence of contingency tables (Burnham et al. 1987) and Fisher's exact *P* values from tests of assumption based on observed detection histories of radio-tagged fish released through the outfall pipe to the tailrace of Ice Harbor Dam (IHR).

Test 2.C2 Tailrace to McNary Dam

	First site detected below Strawberry Island			
P = 0.528 df = 2	Sacajawea Park	Port Kelley	McNary Dam	Below McNary Dam*
Not detected at Strawberry Isl	268	64	205	0
Detected at Strawberry Isl	98	18	63	0

* Detections below McNary Dam were in this and in most cases too few for use in analysis.

Test 2.C3 Tailrace to McNary Dam

	First site detected below Sacajawea Park		
P = 0.132 df = 1	Port Kelley	McNary Dam	Below McNary Dam
Not detected at Sacajawea Pk	82	268	0
Detected at Sacajawea Pk	91	224	1

Test 2.C4 Tailrace to McNary Dam

	First site detected below Port Kelley	
NA	McNary Dam	Below McNary Dam
Not detected at Port Kelley	492	1
Detected at Port Kelley	160	0

Test 3.SR3 Tailrace to McNary Dam

	Detected again at Port Kelley or below	
P = 0.493 df = 1	YES	NO
Detected at Sacajawea Pk, not detected at Strawberry Isl	229	39
Detected at Sacajawea Pk, detected at Strawberry Isl	87	11

Appendix Table 2. Continued.

Test 3.Sm3 Tailrace to McNary Dam

		Site first detected below Sacajawea Park		
P = 0.270	df = 1	Port Kelley	McNary Dam	below McNary
Detected at Sacajawea Pk, not detected at Strawberry Isl		62	166	1
Detected at Sacajawea Pk, detected at Strawberry Isl		29	58	0

Test 3.SR4 Tailrace to McNary Dam

		Detected again at McNary Dam or below	
P = 0.377	df = 1	YES	NO
Detected at Port Kelley, not detected previously		61	3
Detected at Port Kelley, detected previously		99	10

Test 3.Sm4 Tailrace to McNary Dam

	Site first detected below Port Kelley	
NA	McNary Dam	below McNary Dam
Detected at Port Kelley, not detected previously	61	0
Detected at Port Kelley, detected previously	99	0

Test 3.SR5 Tailrace to McNary Dam

		Detected below McNary Dam	
P = 0.383	df = 1	Yes	No
Detected at McNary Dam, not detected previously		70	135
Detected at McNary Dam, detected previously		169	278