Passage Behavior and Survival of River-Run Subyearling Chinook Salmon at Ice Harbor Dam, 2007

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EXECUTIVE SUMMARY

In an effort to increase passage and survival for juvenile salmon, the U.S. Army Corps of Engineers, in conjunction with regional fishery managers, installed a removable spillway weir (RSW) at Ice Harbor Dam on the Snake River in spring 2005. During 2007, the National Marine Fisheries Service (NMFS) continued evaluation of operations with the RSW at Ice Harbor Dam to optimize fish passage efficiency and survival.

In 2007, NMFS evaluated passage behavior and estimated relative survival for radio-tagged, river-run subyearling Chinook salmon at Ice Harbor Dam. Voluntary spill during the study alternated between a volume equivalent to that recommended by NMFS Biological Opinion for nighttime (BiOp spill) and a reduced spill volume (Reduced spill). Fish were collected, surgically implanted with a radio transmitter, and PIT tagged at Lower Monumental Dam. Spill test groups were comprised of 1,464 radio-tagged subyearling Chinook salmon released 5 km above Ice Harbor Dam. The reference group was comprised of 1,301 radio-tagged subyearling Chinook salmon released into the tailrace of Ice Harbor Dam. Releases occurred during both daytime and nighttime operations for 19 d from 11 June to 4 July. These 19 d coincided with the period between the 51st and 83rd percentile of the cumulative smolt passage index for subyearling Chinook salmon at Lower Monumental Dam.

BiOp and Reduced spill operations were both effective at guiding fish away from turbines, with FPE estimates of 99.5 and 95.2% respectively (Table 1). Spill efficiency was 97.2% during BiOp and 83.9% during Reduced spill. Spill effectiveness was 1.32 during BiOp and 1.89 during Reduced spill. Forebay residence times were short during both operations, with median times of 2.63 h during BiOp and 3.33 h during Reduced spill. Passage route distribution during BiOp spill was 96.8% through the spillway, 2.3% through the juvenile bypass, 0.5% through turbines, and 0.4% unknown passage route. Passage route distribution during Reduced spill was 83.6% through the spillway, 11.2% through the juvenile bypass system, 4.8% through turbines, and 0.4% unknown passage route. Median tailrace egress times were 14.6 and 15.5 min during BiOp and Reduced spill operations, respectively.

Relative survival for radio-tagged fish passing via the spillway was estimated at 100.2% for fish that passed during BiOp spill vs. 102.1% for those that passed during Reduced spill operations (Table 1). Relative survival from the forebay boat restricted zone to the tailrace (dam survival) was 95.6% for study fish passing during BiOp spill vs. 95.3% for those passing during reduced spill. Relative survival for all radio-tagged fish passing the dam (concrete survival) was 95.8% during BiOp spill vs. 95.5% during Reduced spill operations. Finally, relative survival for fish passing via the RSW only was 101.4% during BiOp and 102.9% during Reduced spill operations.

Table 1. Study results of conditions, passage behavior, and relative survival for radio-tagged, river-run subyearling Chinook salmon at Ice Harbor Dam, 2007 (95% CIs are shown in parentheses).

	BiOp spill	Reduced spill
Conditions		
Average project discharge (kcfs)	34.6	34.1
Average spill discharge (kcfs)	25.0 or 73%	15.2 or 44%
Average RSW discharge (kcfs)	8.0 or 21%	8.0 or 22%
Average training flow discharge (kcfs)	20.7 or 54%	7.5 or 20%
Average tailwater elevation (ft msl)	340.3	340.7
Average water temperature (°C)	17.0	17.0
Passage route distribution (%)		
Juvenile bypass	2.3	11.2
Turbine unit 1	--	1.3
Turbine unit 2	--	--
Turbine unit 3	0.5	2.9
Turbine unit 4	--	--
Turbine unit 5	--	--
Turbine unit 6	--	0.6
Turbine passage	0.5	4.8
Spill bay 1	--	--
Spill bay 3	0.2	1.7
Spill bay 4	29.8	--
Spill bay 5	0.2	--
Spill bay 6	13.6	--
Spill bay 7	3.6	2.0
Spill bay 8	1.7	2.4
Spill bay 9	1.2	1.8
Spill bay 10	3.1	2.0
Spillway passage	96.8	83.6
RSW	43.4	73.7
Training spill passage	53.4	9.9
Unknown route	<0.4	<0.4
Fish passage metrics		
Median forebay delay (h)	2.6	3.3
FPE (%)	99.5(99.0-100.0)	95.2 (94.0-96.4)
Spill efficiency (%)	97.2 (95.9-98.5)	83.9 (80.7-87.1)
Spill effectiveness	1.32 (1.31-1.34)	1.89 (1.84-1.94)
RSW effectiveness	2.09	3.39
Training spill effectiveness	0.99	0.49
FGE (%)	83.3	70.1
Median tailrace egress (min)	14.6	15.5
Relative survival (%)		
Dam (forebay BRZ to tailrace)	95.6 (90.7-100.4)	95.3 (90.5-100.1)
Concrete (all fish passing the dam)	95.8 (90.9-100.7)	95.5 (90.7-100.4)
Spillway (fish passing through the spillway)	100.2 (95.4-105.0)	102.1 (97.3-106.9)
RSW(fish passing only through the RSW)	101.4 (95.3-107.6)	102.9 (98.0-107.9)

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INTRODUCTION

Fall Chinook salmon *Oncorhynchus tshawytscha* in the Snake River Basin were listed under the U.S. Endangered Species Act (ESA) in 1992 by the National Marine Fisheries Service (NMFS 1992). Survival studies of juvenile salmonid passage through various routes at dams on the lower Snake River have indicated that among the different passage routes, survival was highest through spillways, followed by bypass systems, then turbines (Muir et al. 2001).

Most Pacific salmonids *Oncorhynchus* spp. in the Columbia and Snake River Basin tend to stay in the upper 3 to 6 m of the water column as they migrate downstream (Johnson et al. 2000; Beeman and Maule 2006). In opposition to this tendency, juvenile fish passage routes at many dams on the Columbia and Snake River require fish to dive to depths of 15 to 18 m to enter. In recent years, surface collection and bypass systems have been identified as viable alternatives to increase juvenile fish passage efficiency and survival at dams operated by the U.S. Army Corp of Engineers (USACE) on the Columbia and Snake Rivers. For example, at Wells Dam on the Columbia River, where the spillway is located over the turbine units, a surface collector passed 90% of the fish while spilling just 7% of total discharge (Johnson et al. 1992).

Efforts to improve spillway passage have led to development of a removable spillway weir (RSW) to provide a surface-oriented spillway passage route. The design of the RSW allows juvenile salmonids to pass via the spillway near the water surface, over a raised spillway crest, in a configuration similar to a waterslide. The RSW creates a surface passage route with lower accelerations and lower pressures, conditions that should increase passage efficiency and overall survival of juvenile salmonids, while reducing the amount of water spilled.

The USACE installed a prototype RSW at Lower Granite Dam on the Snake River in summer 2001 and evaluated its performance in spring 2002. This evaluation compared passage using the RSW to passage under the previous management strategy of spilling water to the "gas cap" (i.e., to maximum state and local limits based on resulting levels of dissolved gas). These evaluations indicated the RSW was an effective and efficient passage structure (Angela 2003; Plumb et al. 2003). With the success of the prototype RSW at Lower Granite Dam, the USACE installed a RSW in spillbay 2 at Ice Harbor Dam in February 2005.

At Ice Harbor Dam, passage survival studies had been conducted for several years preceding installation of the RSW. For example, in 2003 passage survival had been estimated based on a 2-d block design wherein 2 d of no spill were alternated with 2 d of "bulk" spill (i.e., spill at levels recommended by NMFS BiOp, but concentrated into only 2-4 spillbays). These tests resulted in relative spillway passage survival estimates of 96% for PIT-tagged fall Chinook salmon during the bulk spill operation (Absolon et al. 2005). This was significantly higher than either the 88.5% survival estimate obtained in 2000 (t = 2.24, P = 0.036) or the 89.4% obtained in 2002 (t = 2.72, P = 0.012; Eppard et al. 2002, 2004).

"Bulk" spill was further evaluated in 2004, when a 4-d block design was used to compare bulk spill with a standard flat spill operation. This study estimated relative spillway passage and dam survival for radio-tagged, river-run subyearling Chinook salmon volitionally passing Ice Harbor Dam. The bulk spill pattern concentrated spill into fewer bays, with a minimum gate opening of 6 stops. Bulk spill volume was equivalent to levels recommended by the NMFS BiOp for nighttime spill (up to 100% of river flow or to dissolved gas limits). The standard flat spill pattern used all bays, with a maximum gate opening of 3 stops. Flat spill volumes were equivalent to levels recommended by the BiOp for daytime spill (45,000 ft^3/s; Ogden et al. 2005). Spillway passage survival was estimated at 97.2% (95% CI, 90.3–104.5) for radio-tagged fish passing during bulk spill and 93.3% (95% CI, 88.2-98.6) for those passing during flat spill operations in 2005. Estimated dam survival was 86.2% (95% CI, 69.2-107.5) for all radio-tagged fish passing during bulk spill operations vs. 84.6% (95% CI, 73.6-97.2) for fish passing during flat spill operations (Ogden et al. 2005).

In 2005, the bulk spill pattern with the RSW closed was compared to a "training" spill pattern with the RSW open. A 2-d randomized block study design was used to estimate relative survival of radio-tagged subyearling Chinook salmon volitionally passing the dam. Bulk spill conditions were similar to those described above for evaluations during 2004, but with the RSW in spillbay 2 closed. Training spill used the spillbays adjacent to the RSW to draw flow toward the RSW and to encourage tailrace flow from the RSW to move downstream instead of eddying in the tailrace (Ogden et al 2007). Training spill was used with the RSW in spillbay 2 open.

Spillway passage survival was estimated at 100% (95% CI, 98.0-102.0%) for radio-tagged fish passing during bulk spill vs. 98.9% (95% CI, 94.5-104.0%) for their cohorts passing with the RSW open during training spill operations. Dam survival for all radio-tagged fish was estimated at 96.0% (95% CI, 92.0-97.8%) during bulk spill operations vs. 95.1% (95% CI, 87.0-104.0%) during RSW spill operations. Survival for fish passing through the RSW only was estimated at 99.7% (95% CI, 96.0-104.0%) (Ogden et al 2007).

In 2006, spill levels recommended by the NMFS BiOp (45,000 ft^3/s spill during the day with spill to the gas cap during the night) were compared to a spill regime that called for 30% spill of the total river flow during both day and night. A 2-d randomized block design was planned to develop estimates of relative passage survival for radio-tagged, river-run subyearling Chinook salmon volitionally passing Ice Harbor Dam. However, fish that entered the study area after 2 July had to be omitted from analysis due to observations of a considerable number of fish suspending their migrations. Because there were an insufficient number of days (blocks) between the time that tagging began and the time fish stopped migrating, analysis of the data by treatment block was not possible. Instead we analyzed temporal trends in survival related to spill level (Ogden et al. 2008).

Thus, from studies at Ice Harbor in 2006, relative dam survival was estimated at 0.952 (95% CI, 0.938-0.967), relative spillway survival at 0.988 (95% CI, 0.950-1.025), relative concrete survival at 0.977 (95% CI, 0.935-1.019), and relative RSW survival (fish passing only through the RSW) was 0.980 (95% CI, 0.925-1.035) (Ogden et al. 2008).

During 2007, NMFS continued evaluation of the RSW at Ice Harbor Dam in order to optimize operations to increase FPE and survival. Both treatments utilized the RSW, but the first treatment would evaluate spill operations under the NMFS 2000 BiOp recommendation of 45,000 ft^3/s spill during the day and spill to the gas cap at night. The second treatment would be a reduced spill volume of the first treatment. For these evaluations, we again used a 2-d randomized block interval design that alternated between 2 treatment operations utilizing the RSW. Fish passage behavior performance metrics, project survival, and route-specific survival as used in this report are defined as follows:

Spill Efficiency (SPE): Number of fish passing the dam through the spillway divided by the total number of fish passing the dam.

Spill Effectiveness (SPF): Proportion of fish passing the dam via the spillway divided by the proportion of water spilled.

RSW Efficiency: Number of fish passing the dam through the RSW divided by the total number of fish passing the dam through the spillway.

RSW Effectiveness: The proportion of fish passing the dam via the RSW divided by the proportion of water spilled.

Fish Passage Efficiency (FPE): The number of fish passing the dam through non-turbine routes divided by number passing the dam.

Fish Guidance Efficiency (FGE): The number of fish passing the dam through the juvenile bypass system divided by the total number of fish passing the dam through the powerhouse.

Forebay residence: Elapsed time from arrival in the forebay of the dam until passage through the spillway, bypass, or turbines.

Tailrace egress: Elapsed time from dam passage to exit from the tailrace.

Dam survival: Relative survival from the upstream limit of the boat restricted zone at Ice Harbor Dam to the release location of reference groups downstream from the dam.

Concrete survival: Relative survival of all fish passing Ice Harbor Dam to the release location of reference groups downstream from the dam.

Route survival: Relative survival between detection within a passage route at Ice Harbor Dam to the release location of reference groups downstream from the dam.

Results of this study will be used to inform management decisions in passage and recovery programs to optimize survival for juvenile salmonids arriving at Ice Harbor Dam.

METHODS

Study Area

The study area included a 72-km reach of the Snake and Columbia Rivers from Ice Harbor Dam to the forebay of McNary Dam (Figure 1). Ice Harbor Dam, the first dam upstream from the mouth of the Snake River, is located 16 km upstream from the confluence of the Snake and Columbia Rivers. McNary Dam, the fourth dam on the Columbia River, is located 470 km upstream from the river mouth. Ice Harbor and McNary Dam are 68 km apart. Additional radiotelemetry transects used for estimating survival at Ice Harbor Dam were located at the mouth of the Snake River at Sacajawea Park and the Burbank Railroad bridge downstream from the confluence of the Columbia and Snake Rivers (Figure 1).

Fish Collection, Tagging, and Release

River-run subyearling Chinook salmon were collected at the Lower Monumental Dam smolt collection facility. We tagged only fish that did not have any gross injury or deformity and were at least 100 mm in length and 10 g in weight. Fish previously tagged with a passive integrated transponder (PIT) were also excluded. Fish were anesthetized with tricaine methane sulfonate (MS-222) and sorted in a recirculating anesthetic system. Fish for treatment and reference release groups were transferred through a water-filled, 10.2-cm hose to a 935-L tank. Following collection and sorting, fish were maintained via flow-through river water and held for 24 h prior to radio transmitter implantation.

Radio tags were purchased from Advanced Telemetry Systems Inc.,[1] had a predetermined tag life of 10 d, and were pulse-coded for unique identification of individual fish at 30 MHz. Each radio tag consisted of two components connected together; a circuit board and a battery. Each circuit measured 7 mm in length, 5 mm in width, and 3 mm in depth. Each battery measured 5 mm in diameter and 6 mm in depth. The total volume of the radio tags was 232 mm^3 and tags weighed 0.7 g in air.

[1] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

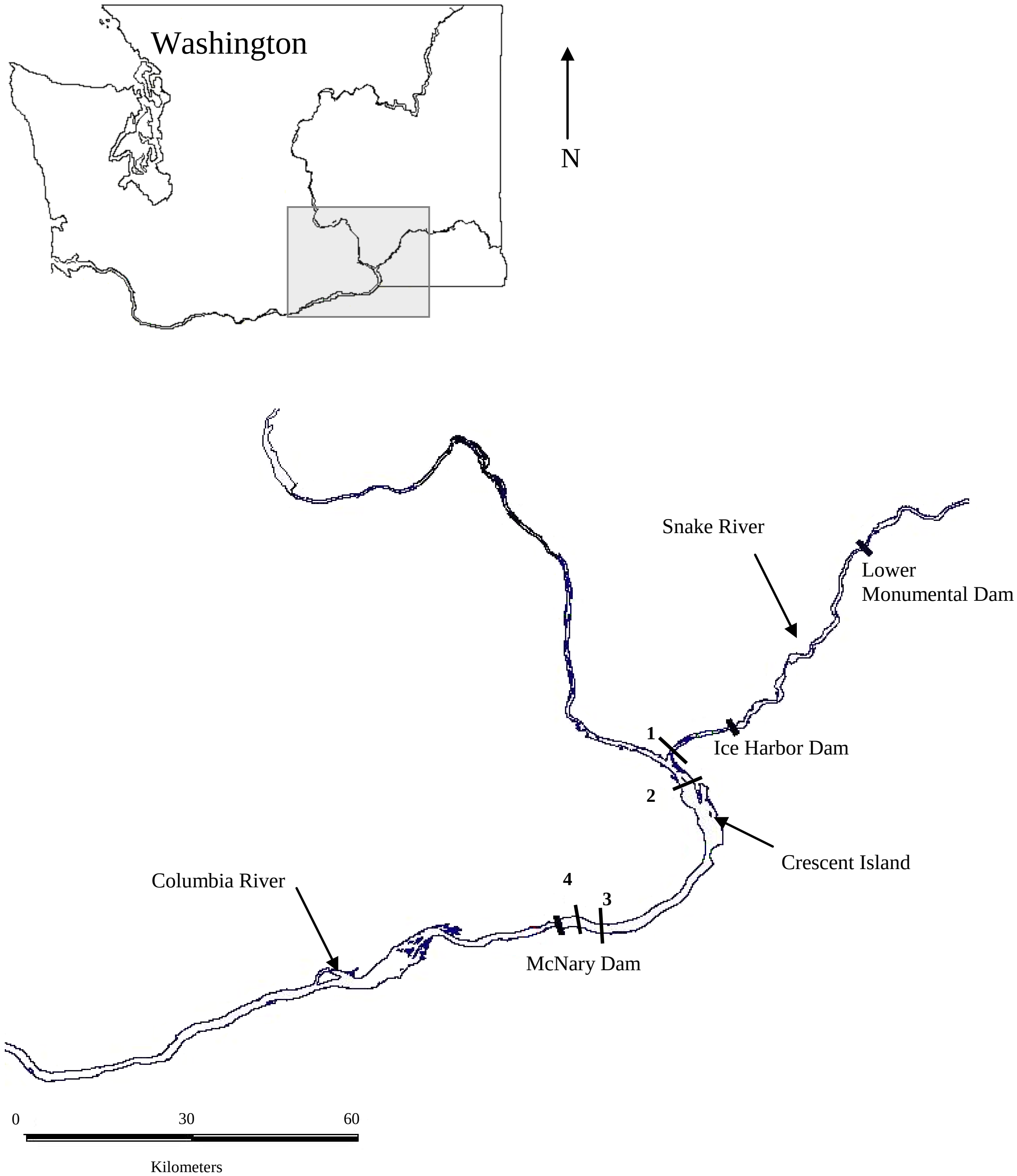

Figure 1. Study area showing location of radiotelemetry transects used for estimating survival at Ice Harbor Dam, 2007. (Note: 1 = Mouth of the Snake River at Sacajawea Park, WA, rkm 523; 2 = Columbia Bank, WA, rkm 518; 3 = McNary Beach, OR, rkm 477 ;4 = McNary Dam Forebay, rkm 472.)

Fish were surgically implanted with radio transmitters using techniques described by Adams et al. (1998a). Each fish also received a PIT tag before the incision was closed in order to monitor radio tag performance. Immediately following tagging, fish were placed into 19-L buckets (2 fish per bucket) into which aeration lines were inserted until recovery from the anesthesia. The buckets were then closed and placed into a large holding tank (1.49 × 2.48 × 0.46 m) that accommodate up to 28 buckets and into which flow-through water was applied during tagging and holding. Fish were held a minimum of 24 h with flow-through water for recovery and determination of post-tagging mortality.

Each bucket was perforated with 1.3-cm holes in the top 30.5-cm of the container to allow an exchange of water during holding. Aeration of the holding tank with oxygen was used during transport to release locations.

After the post-tagging recovery period, radio-tagged fish were moved in their recovery containers from the holding area to release areas (Ice Harbor Dam forebay and tailrace). Forebay release groups were transferred from holding tanks to a release tank mounted on an 8.5 × 2.4-m barge, transported to the release location, and released mid-channel water-to-water. Tailrace release groups were transferred to holding tanks mounted on a truck, transported to the release location, and released into the river through a flume with the terminus located a minimum distance of 7.6 m from the bank. Two fish were released every 15 min in order to distribute releases over a period of 4-5 h.

Daytime releases occurred between 0900 and 1600 PDT. Nighttime releases occurred between 2000 and 0315 PDT. We released 74 groups of approximately 14-48 fish per group. A total of 1,464 radio-tagged fish were released 5 km upstream from Ice Harbor Dam during both daytime and nighttime project operations. A total of 1,301 radio-tagged fish were released 2 km downstream from Ice Harbor Dam at river kilometer 535.7 during both daytime and nighttime operations (Figure 2).

Monitoring and Data Analysis

Radiotelemetry receivers and multiple-element aerial antennas were used to establish detection transects between the forebay of Ice Harbor Dam and the forebay of McNary Dam (Figure 1). Receivers using underwater dipole or multiple-element aerial antennas were used to monitor entrance into the forebay and approach to and exit from Ice Harbor Dam (Figure 2). Underwater antennas were used to monitor passage routes (Figure 3). Monitored passage routes included the juvenile fish bypass system (JBS), individual spillbays, and all turbine unit gate slots (gatewells).

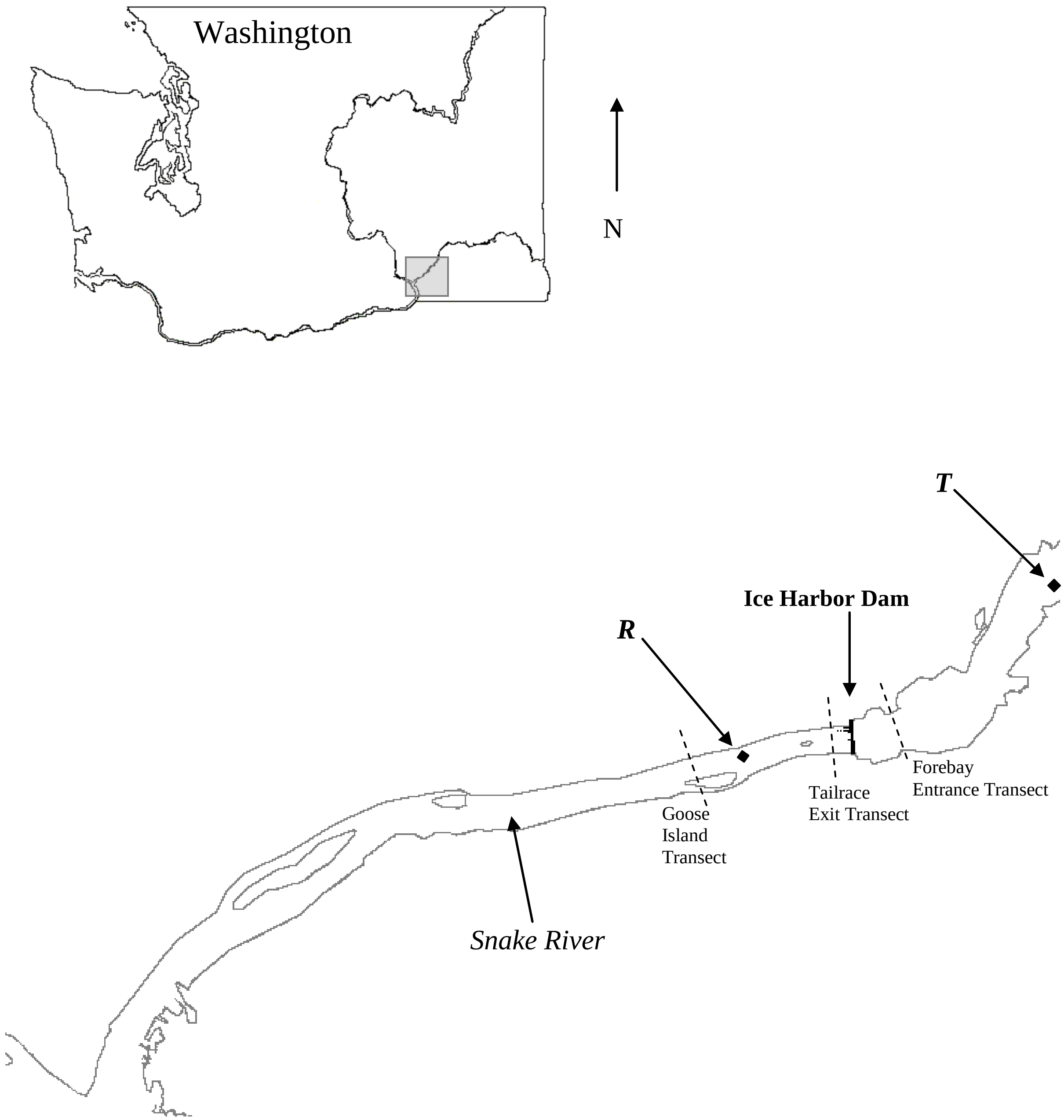

Figure 2. The Lower Snake River and Ice Harbor Dam showing the release locations for treatment (***T***) and reference (***R***) groups of radio-tagged subyearling Chinook salmon, 2007. Also shown are radiotelemetry transects used to detect fish entering the immediate forebay (rkm 538.5) and subsequently exiting the tailrace (rkm 537.7), 2007.

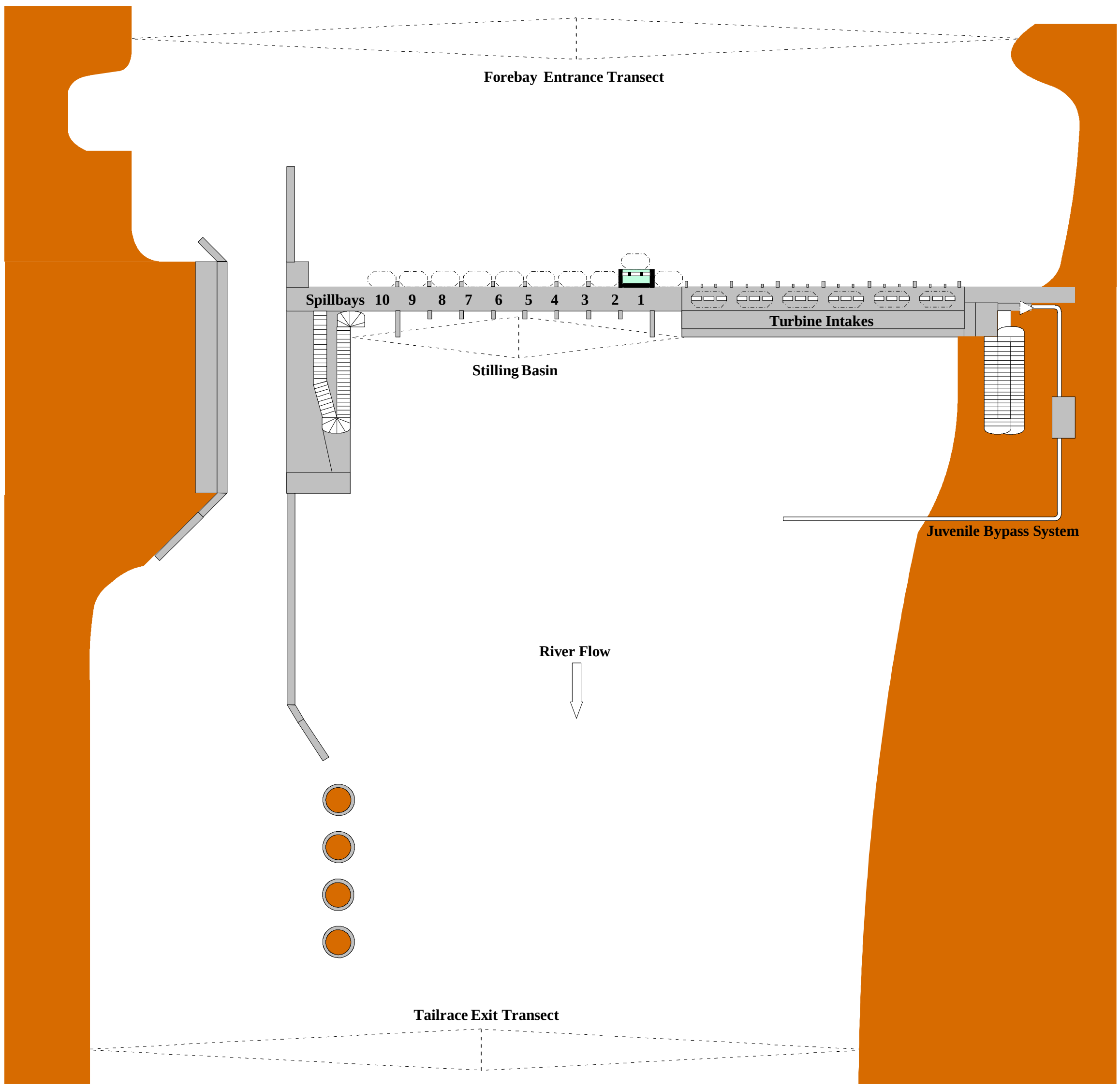

Figure 3. Plan view of Ice Harbor Dam showing approximate radiotelemetry detection zones in 2007 (Note: Dashed ovals represent underwater antennas. Dashed triangles represent aerial antennas).

Telemetry data were retrieved through an automated process that downloaded data from network telemetry receivers up to four times daily. The data were placed on an FTP server once daily for downloading into the database. All data were combined and loaded to a database where automated queries and algorithms were used to remove erroneous data, thus creating a detailed detection history for each radio-tagged fish (Appendix B).

Using detailed detection histories, we determined forebay arrival time, dam approach pattern, passage distribution and timing, exit from the tailrace, and timing of downstream detection for individual radio-tagged fish. Forebay arrival time was based on the first time a fish was detected in the forebay of the dam. Approach patterns were established based on the first detection at either underwater dipole spillway antennas (Beeman et al. 2004) or on stripped coax underwater antennas (Knight et al. 1977) on the standard-length traveling screens.

Route of passage through the dam was based on the last time a fish was detected on a passage-route receiver prior to detection in the tailrace. Routes were assigned only to fish detected in at least once on either the stilling basin, tailrace exit, or Goose Island receiver transects (Figures 2 and 3). Spillway passage was assigned to fish last detected in the forebay on one of the 10 antenna arrays deployed in the spillway. Similarly, turbine passage was assigned to fish last detected in a turbine intake and not detected in the JBS prior to detection in the tailrace. Passage through the JBS was assigned to fish detected in the collection channel prior to detection in the tailrace.

Project Operations

From 11 June to 8 July 2006, the voluntary spill program followed a 2-d randomized block interval design that alternated between 2 spill treatment operations that both utilized the RSW. The first treatment operation was spill at volumes recommended by the NMFS 2000 BiOp, or 45,000 ft^3/s spill during the day with spill to the gas cap at night (BiOp spill). The second treatment operation was spill at a reduced volume from that of the first treatment (Reduced spill).

Survival Estimates

A paired-release study design was used for estimating relative survival where groups of radio-tagged fish were released at one of two sites; upstream (treatment) and downstream (reference) from Ice Harbor Dam (Figure 2). Treatment groups were formed by grouping daily detections of radio-tagged fish as they entered the forebay of Ice Harbor Dam. Reference groups were released directly into the tailrace of Ice Harbor Dam (Figure 2) and were paired with treatment groups based on release date so that paired groups would enter the forebay on the same date.

The single-release or Cormack-Jolly-Seber (CJS) model (Cormack 1964; Jolly 1965; Seber 1965) was used to estimate probability of detection and survival for both treatment and reference groups from release to the mouth of the Snake River at Sacajawea Park. This model provides unbiased survival estimates if model assumptions are met (Zabel et al. 2002; Smith et al. 2003). In particular the model requires that probabilitites of downstream detection and survival are not affected by previous detection at upstream sites. Testing of model assumptions is addressed in Appendix A.

Relative spillway passage survival was then expressed as the ratio of survival estimates for treatment fish to reference fish. Average relative survival was calculated using pooled means. The weights were the inverses of the respective sample variances (Burnham et al. 1987; Muir et al. 2003). A primary assumption made when using a paired-release study design is that treatment and reference groups have similar survival probabilities in the reach that is common to both groups; that is, groups are mixed temporally upon detection at the primary detection array. This assumption is addressed in Appendix A.

Passage Behavior and Timing

Forebay residence was defined as elapsed time from detection on the forebay entrance transect to last detection on a passage-route receiver. Tailrace egress was defined as the time from last detection on a passage route to first detection on the tailrace exit transect. We compared forebay residence and tailrace egress time between treatments using paired *t*-tests on the 50th percentiles of the temporally-paired replicate groups. The alpha level was 0.05 for determination of significant differences.

Passage Route Distribution

To determine the route of passage used by individual fish at Ice Harbor Dam, we monitored the spillway, standard-length submersible traveling screens (fish guidance screens), and JBS. The spillway was monitored by four underwater dipole antennas in each spillbay; two antennas were installed along each of the two pier noses of each spillbay at depths of 6 and 12 m. Pre-season range testing showed that this configuration monitored the entire spillbay. In addition, we mounted aerial antennas to the handrail of the RSW and the downstream pier noses in the tailrace in order to ensure that we detected all fish that passed over the RSW. We used armored coaxial cable, stripped at the end, to detect fish passage in the turbine units. Antennas in turbine units were attached on both ends of the downstream side of the fish screen support frame located within each slot of the turbine intake. For the JBS, two loop antennas were placed on the handrail at the collection channel exit located upstream from the juvenile bypass pipe. Fish that were detected on the fish guidance screen telemetry antennas, but were not subsequently detected on the PIT-detection system or the telemetry monitor in the collection channel were designated turbine-passed fish.

Fish Passage Metrics

The standard fish-passage metrics of spill efficiency, spill effectiveness, fish passage efficiency, and fish guidance efficiency were also evaluated at Ice Harbor Dam using radiotelemetry detections in the locations used for passage route evaluation (described above).

Avian Predation

Predation by Caspian terns *Hydroprogne caspia* from the colony on Crescent Island, located 12.9 km downstream from the Snake River mouth (Figure 1), was evaluated by physical recovery of radio transmitters that were visible on the island and by PIT tag detection. Radio and PIT tags were recovered on the tern colony at Crescent Island during fall 2007 after the birds left the island. Radio-tag serial numbers were used to identify individual tagged fish. PIT-tag detections and recovery of radio transmitters at Crescent Island were provided by NMFS (S. Sebring, NMFS, personal communication; also see Ryan et al. 2001) and Real Time Research, Inc. (A. Evans, Real Time Research, Inc., personal communication). There is an ongoing monitoring effort to recover PIT tags from Caspian tern colonies in the region conducted by NMFS and by the Columbia Bird Research group.

RESULTS

Fish Collection, Tagging, and Release

River-run, subyearling Chinook salmon were collected and tagged at Lower Monumental Dam for 19 d from 11 June to 4 July. Tagging began after 51% of the juvenile subyearling Chinook salmon had passed Lower Monumental Dam and was completed when 83% of these fish had passed (Figure 4). Mean fork length averaged 116.0 mm for treatment fish and 116.2 mm for reference fish (Table 2). Mean weight averaged 14.1 g for treatment fish and 14.3 g for reference fish (Table 3). Mean length and weight of the run at large sampled at the Lower Monumental smolt collection facility during this time period averaged 109.0 mm and 15.0 g, respectively (Tables 4 and 5). During the study period, handling and tagging mortality for subyearling Chinook salmon held for a minimum of 24 h after tagging was 1.4%.

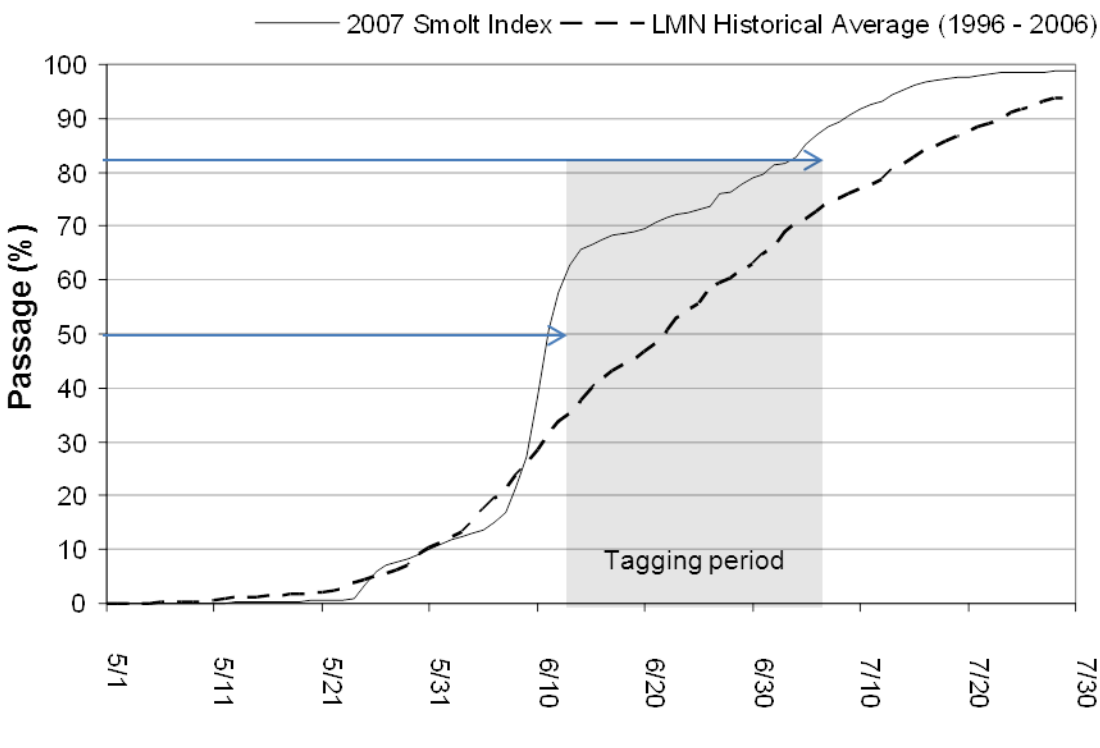

Figure 4. The 2007 cumulative passage distribution compared to the historical average (1996-2006) for subyearling Chinook salmon passing Lower Monumental Dam.

Table 2. Mean length of radio-tagged subyearling Chinook salmon (sample size, mean, standard deviation, and range) releases at Ice Harbor Dam to evaluate passage behavior and relative survival during BiOp and Reduced spill patterns, 2007.

		Mean length of radio-tagged fish (mm)							
		Treatment				Reference			
Tag date	Release date	N	Mean	SD	Range	N	Mean	SD	Range
11-Jun	12-Jun	39	113.7	5.1	104-127	66	115.0	5.6	102-133
12-Jun	13-Jun	81	115.0	5.2	105-133	74	115.0	5.0	106-130
13-Jun	14-Jun	81	113.7	4.9	105-131	70	112.9	4.8	104-131
14-Jun	15-Jun	81	114.0	5.6	105-133	69	112.2	5.2	104-133
15-Jun	16-Jun	79	112.4	4.7	103-127	55	111.2	3.9	105-123
16-Jun	17-Jun	67	112.2	5.1	106-127	67	111.7	4.5	105-124
17-Jun	18-Jun	74	111.7	5.0	101-126	71	112.7	7.1	104-145
22-Jun	23-Jun	95	117.1	16.7	106-264	80	114.5	6.1	104-141
23-Jun	24-Jun	85	114.4	5.4	105-130	85	114.1	5.6	104-130
24-Jun	25-Jun	94	114.1	5.8	104-143	83	116.9	6.9	106-134
25-Jun	26-Jun	92	116.0	6.3	105-136	80	117.6	6.5	105-139
26-Jun	27-Jun	91	117.4	7.4	104-138	79	117.8	6.0	105-136
27-Jun	28-Jun	92	117.1	5.0	105-126	86	119.8	6.6	110-141
28-Jun	29-Jun	93	119.5	6.5	106-140	84	119.3	6.4	108-139
29-Jun	30-Jun	91	117.5	5.6	107-132	72	116.6	4.2	106-125
30-Jun	1-Jul	83	118.2	4.6	107-130	81	120.2	5.6	108-137
1-Jul	2-Jul	87	119.6	5.7	109-138	71	121.3	6.0	109-138
2-Jul	3-Jul	74	120.5	6.0	109-145	29	118.8	3.9	111-127
3-Jul	4-Jul	--	--	--	--	30	120.2	4.2	114-127
Total		1,479	116.0	7.3	101-264	1,332	116.2	6.5	102-145

Table 3. Mean weight of radio-tagged subyearling Chinook salmon (sample size, mean, standard deviation, and range) releases at Ice Harbor Dam to evaluate passage behavior and relative survival during BiOp and Reduced spill patterns, 2007.

		Mean weight of radio-tagged fish (g)							
	Release	Treatment				Reference			
Tag day	date	N	Mean	SD	Range	N	Mean	SD	Range
11-Jun	12-Jun	39	12.7	2.0	10-19	66	13.6	2.5	10-23
12-Jun	13-Jun	81	13.4	2.2	10-22	74	13.5	2.1	11-19
13-Jun	14-Jun	81	13.0	2.2	10-24	70	12.7	2.2	10-22
14-Jun	15-Jun	81	13.0	2.2	10-23	69	12.2	1.9	10-20
15-Jun	16-Jun	79	12.4	1.7	10-20	25	12.8	1.8	11-17
16-Jun	17-Jun	57	12.4	2.2	10-20	67	12.4	1.6	10-16
17-Jun	18-Jun	59	12.8	1.9	10-19	36	13.3	3.6	10-29
22-Jun	23-Jun	95	14.5	3.0	11-28	80	14.0	2.6	11-24
23-Jun	24-Jun	85	14.0	2.2	10-20	85	13.6	2.3	10-21
24-Jun	25-Jun	94	13.6	2.7	10-32	81	15.0	3.1	11-25
25-Jun	26-Jun	91	14.7	2.7	11-22	80	15.1	3.0	11-27
26-Jun	27-Jun	90	15.1	3.5	10-29	78	14.9	2.7	11-26
27-Jun	28-Jun	92	14.6	2.1	11-21	86	15.8	3.5	11-28
28-Jun	29-Jun	91	15.6	3.1	11-28	84	15.5	3.0	11-26
29-Jun	30-Jun	90	14.6	2.3	11-21	72	13.9	1.5	11-17
30-Jun	1-Jul	83	14.7	2.1	11-22	81	15.9	3.1	11-27
1-Jul	2-Jul	87	15.3	2.8	11-28	71	16.1	3.1	11-27
2-Jul	3-Jul	74	16.0	3.3	12-31	29	15.0	1.5	12-19
3-Jul	4-Jul	--	--	--	--	30	15.0	2.3	11-21
Total		1,449	14.1	2.7	10 - 32	1,264	14.3	2.9	10 - 29

Table 4. Sample size, mean, median, range, and standard deviation (SD) of fork length (mm) by tagging date for river-run, subyearling Chinook salmon from the smolt monitoring sample at Lower Monumental Dam, 2007.

	Mean fork length (mm) of the daily smolt monitoring sample				
Date	N	Mean	Median	Range	SD
11-Jun	200	108	110	80-130	7.6
12-Jun	200	104	105	85-125	6.8
13-Jun	200	104	105	65-130	8.3
14-Jun	176	102	105	70-130	8.3
15-Jun	200	103	105	80-120	6.9
16-Jun	191	104	105	70-125	7.7
17-Jun	173	105	105	75-140	8.5
18-Jun	134	106	105	60-135	10.8
19-Jun	81	107	110	65-135	11.5
20-Jun	144	108	105	80-140	8.2
21-Jun	200	107	105	45-140	9.5
22-Jun	200	109	110	75-140	8.9
23-Jun	187	109	110	75-130	8.8
24-Jun	158	110	110	75-135	11.2
25-Jun	154	111	110	80-135	8.2
26-Jun	170	115	115	95-135	8.1
27-Jun	200	113	115	95-130	7.6
28-Jun	73	111	110	90-125	8.3
29-Jun	200	114	115	65-140	7.9
30-Jun	152	113	115	80-135	8.3
1-Jul	115	113	115	95-135	7.1
2-Jul	171	113	115	75-135	8.7
3-Jul	53	111	110	100-125	6.3
4-Jul	116	111	110	90-125	6.3
Total	3,848	109	110	45-140	9.3

Table 5. Sample size, mean, median, range, and standard deviation (SD) of weight (g) by tagging date for river-run, subyearling Chinook salmon from the smolt monitoring sample at Lower Monumental Dam, 2007.

	Mean weight (g) smolt monitoring sample				
Date	N	Mean	Median	Range	SD
11-Jun	200	13.8	13.2	5.9-117.9	7.9
12-Jun	200	13.0	12.7	7.7-33.6	3.1
13-Jun	200	12.4	12.0	4.1-26.3	3.0
14-Jun	176	12.1	11.8	5.0-27.2	2.9
15-Jun	200	12.8	12.2	7.3-21.8	2.5
16-Jun	191	13.0	12.7	4.1-25.9	2.8
17-Jun	173	12.9	11.8	5.0-52.2	4.4
18-Jun	134	13.3	12.7	3.2-26.3	3.7
19-Jun	81	14.7	14.5	4.5-30.8	4.0
20-Jun	144	15.4	15.0	5.9-29.9	3.5
21-Jun	200	14.7	14.5	1.8-30.4	3.3
22-Jun	200	15.6	14.1	4.1-195.0	14.8
23-Jun	187	15.0	15.0	4.1-25.9	3.3
24-Jun	158	15.7	15.0	4.5-30.8	4.5
25-Jun	154	15.0	14.5	5.9-29.9	3.4
26-Jun	170	17.9	17.2	10.0-33.1	4.2
27-Jun	200	17.4	16.8	10.4-30.8	3.7
28-Jun	73	17.8	16.3	7.7-154.2	16.6
29-Jun	200	17.6	17.5	4.1-40.4	3.7
30-Jun	152	16.9	15.4	5.4-127.0	9.6
1-Jul	115	16.2	15.9	8.2-30.4	3.6
2-Jul	171	16.8	16.8	5.0-30.4	3.6
3-Jul	53	16.8	16.8	12.2-23.1	3.0
4-Jul	116	17.0	16.3	10.0-26.3	3.0
Total	3,848	15.0	14.5	1.8-195.0	6.1

Migration Behavior and Passage Distribution

Forebay Behavior and Timing

Of the 1,464 radio-tagged treatment fish released above Ice Harbor Dam, 1,251 (85.5%) were detected entering the forebay, 163 (11.1%) were not detected entering the forebay, and 50 (3.4%) entered the forebay during one spill treatment and passed during the other. Based on the time of first detection, of the 1,251 fish entering the forebay, 676 (54.0%) entered during BiOp spill and 575 (46.0%) during Reduced spill operations. Of these same 1,251 fish, 1,246 (99.6%) were detected approaching the dam, with 671 (53.9%) detected during BiOp spill and 575 (46.1%) during Reduced spill operations. For fish entering the immediate forebay during BiOp spill operations, 657 (97.9%) were first detected approaching in front of the spillway, and 14 (2.1%) in front of the powerhouse (Figure 6). During Reduced spill operations, 530 (92.2%) were first detected approaching in front of the spillway and 45 (7.8%) in front of the powerhouse. At the RSW, 269 (40.9%) fish approached during BiOp spill operations, and 363 (63.1%) fish approached during Reduced spill operation.

Forebay residence times were calculated for 1,093 fish, each with detections on both the forebay entrance transect and a passage-route receiver. Of these fish, 588 (53.8%) passed during BiOp spill and 505 (46.2%) during Reduced spill. Forebay residence time by operational test block was calculated for these fish (Table 8). Median forebay times for these fish were 2.63 h during BiOp spill and 3.33 h during Reduced spill. Median forebay residence time was consistently longer during Reduced spill than during BiOp spill operations; however, the difference was not statistically significant ($P = 0.427$). Median forebay residence time was calculated for each passage route (Table 9). The difference in median forebaby residence time for fish passing through the RSW during BiOp vs. Reduced spill was not statistically significant ($P = 0.879$).

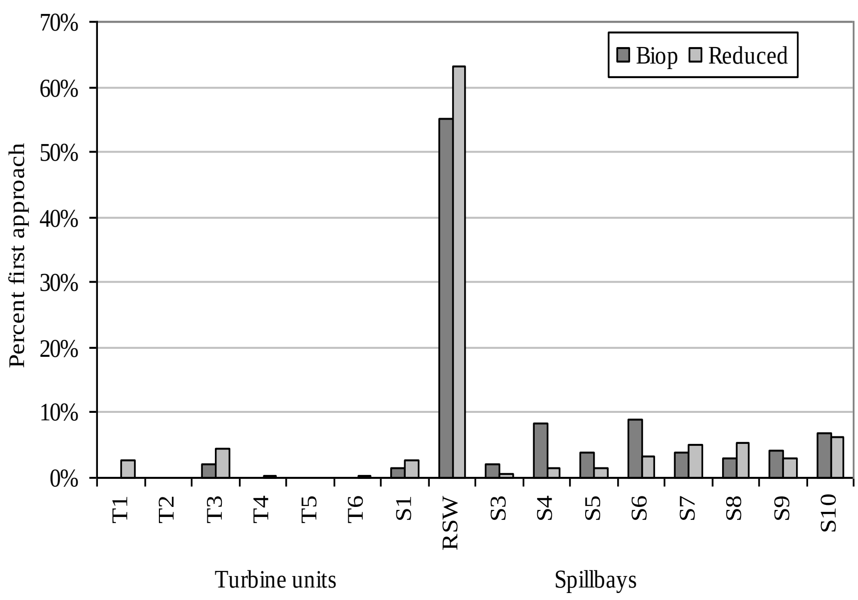

Figure 6. Approach patterns for radio-tagged, river-run subyearling Chinook salmon in the forebay of Ice Harbor Dam, 2007.

Table 8. Forebay residence time by operations grouping (see Table 6) for radio-tagged, river-run subyearling Chinook salmon during BiOp and Reduced spill at Ice Harbor Dam, 2007.

Spill operations group	n	Forebay residence time (h) Mean	Median	Mode	Min	Max
BiOp 1	23	1.43	1.13	0.60	0.44	7.78
BiOp 2	193	5.39	2.69	0.87	0.50	51.57
BiOp 3	4	31.88	34.68	--	5.62	52.54
BiOp 4	172	7.94	3.57	0.86	0.27	66.55
BiOp 5	196	5.58	2.12	0.57	0.46	121.99
Overall	588	6.23	2.63	0.65	0.27	121.99
Reduced 1	105	4.48	2.15	0.65	0.44	26.29
Reduced 2	55	13.82	6.90	--	0.64	75.92
Reduced 3	203	7.04	3.46	0.67	0.46	130.89
Reduced 4	136	7.36	2.94	0.66	0.47	109.26
Reduced 5	6	10.76	9.69	--	2.34	21.87
Overall	505	7.38	3.33	0.67	0.44	130.89

Table 9. Forebay residence time in hours by passage route for radio-tagged river-run subyearling Chinook salmon during BiOp and Reduced spill at Ice Harbor Dam, 2007.

	Forebay residence time (h) by passage route: Turbine	Spillway	RSW	Juvenile bypass system
BiOp spill				
n	2	309	263	14
Mean	4.55	5.80	6.61	8.58
Median	4.55	2.25	2.87	6.03
Mode	--	0.50	0.65	--
Min	1.46	0.40	0.27	1.17
Max	7.63	59.80	121.99	27.81
Reduced spill				
n	24	49	373	59
Mean	5.76	7.90	7.35	7.79
Median	5.71	4.48	3.02	4.15
Mode	--	0.67	1.34	1.79
Min	1.12	0.48	0.44	0.86
Max	16.99	41.91	130.89	75.92

Passage Distribution and Metrics

Of the 1,251 radio-tagged treatment fish detected entering the forebay, 1,191 (95.2%) were detected at or below Ice Harbor Dam and 60 (4.8%) entered the forebay but were not recorded as passing the dam. Of the 1,191 fish, 1,081 (90.8%) passed the dam through the spillway, 76 (6.4%) through the JBS, 29 (2.4%) through turbines, and 5 (0.4%) passed the dam through an undetermined route.

We assigned an operation to radio-tagged fish based on last detection in the forebay at Ice Harbor Dam. Of the 647 fish last detected during BiOp spill operations, 626 (96.8%) passed through the spillway, 15 (2.3%) through the JBS, 3 (0.5%) through turbines, and 3 (0.4%) passed through an undetermined route. Of the 60 fish that entered the forebay but were not recorded as passing the dam, 29 (48.3%) entered during BiOp spill operations.

Of the 544 radio-tagged fish last detected in the forebay during Reduced spill operations, 455 (83.6%) passed the dam through the spillway, 61 (11.2%) through the JBS, 26 (4.8%) through turbines, and 2 (0.4%) passed through an undetermined route. Of the 60 fish that entered the forebay but were not recorded as passing the dam, 31 (51.7%) entered during Reduced spill operations (Figure 7). Distribution of passage through individual spillbays varied (Figure 8).

For radio-tagged subyearling Chinook salmon with a known passage route, overall fish passage metrics are summarized below; passage metrics by individual test block are shown in Tables 10 and 11.

	Passage metrics (95% CI)	
	BiOp spill	Reduced spill
FPE (%)	0.995 (0.985-1.005)	0.952 (0.928-0.976)
Spill efficiency (%)	0.972 (0.946-0.998)	0.839 (0.775-0.903)
FGE (%)	0.833 (0.733-0.933)	0.701 (0.589-0.813)
Spill effectiveness	1.32:1 (1.290-1.350)	1.89:1 (1.786-1.994)
RSW effectiveness	2.09:1 (2.004-2.176)	3.39:1 (3.234-3.546)
Training spill effectiveness	0.99:1 (0.942-1.038)	0.49:1 (0.048-0.932)

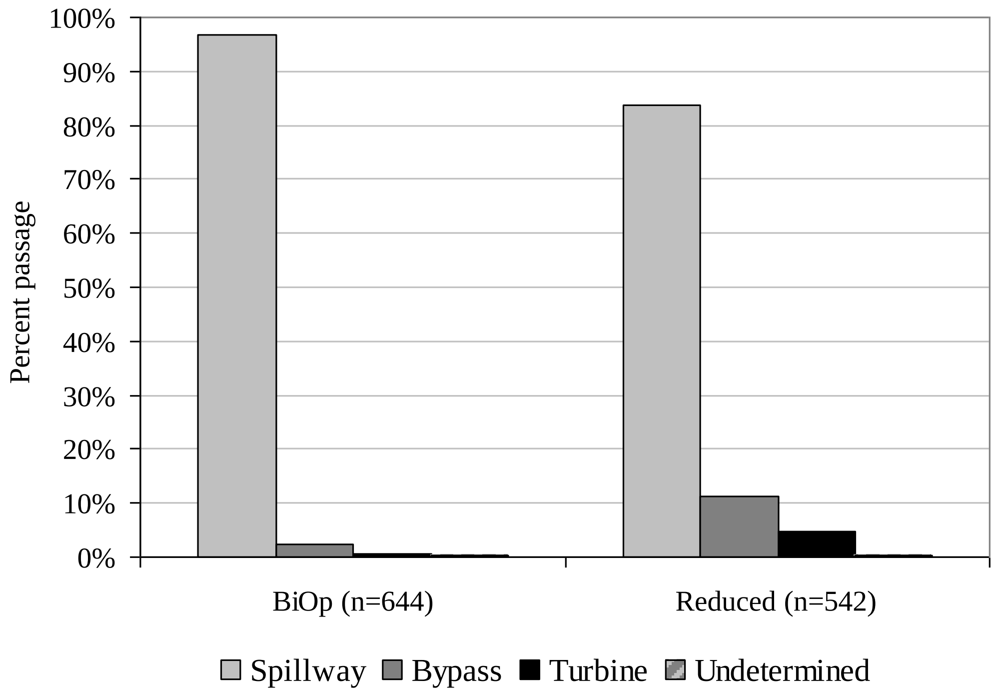

Figure 7. Passage distribution of radio-tagged, subyearling Chinook salmon at Ice Harbor Dam, 2007.

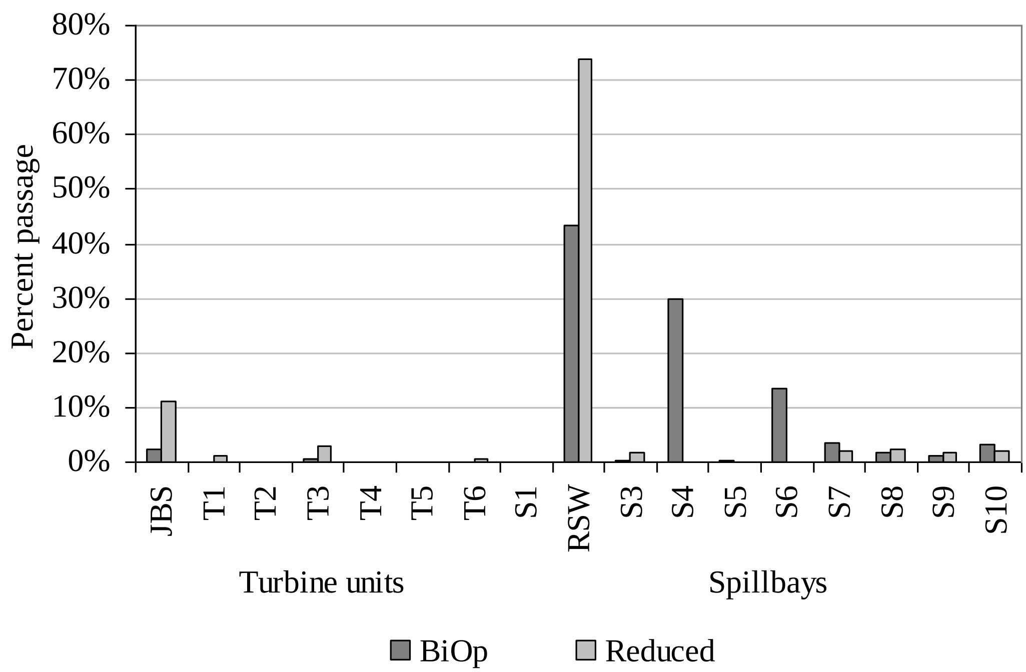

Figure 8. Individual passage route distribution for radio-tagged, river-run subyearling Chinook salmon during spill testing at Ice Harbor Dam, 2007.

Table 10. Estimates of spill efficiency, fish passage efficiency, and fish guidance efficiency by test block for radio-tagged, river-run subyearling Chinook salmon passing Ice Harbor Dam during BiOp and Reduced spill operations, 2007.

Spill operations grouping	Fish passage metrics					
	Spill efficiency	SE	Fish passage efficiency	SE	Fish guidance efficiency	SE
BiOp 1	0.957	0.085	1.000	--	1.000	--
BiOp 2	0.964	0.027	1.000	--	1.000	--
BiOp 3	0.750	0.433	1.000	--	1.000	--
BiOp 4	0.973	0.023	0.995	0.005	0.800	0.054
BiOp 5	0.983	0.017	0.992	0.007	0.500	0.067
Overall	0.972	0.013	0.995	0.005	0.833	0.050
Reduced 1	0.849	0.070	0.972	0.009	0.813	0.048
Reduced 2	0.673	0.127	0.945	0.013	0.833	0.046
Reduced 3	0.846	0.049	0.935	0.014	0.576	0.061
Reduced 4	0.894	0.048	0.969	0.010	0.706	0.056
Reduced 5	0.500	0.408	0.833	0.021	0.667	0.058
Overall	0.839	0.032	0.952	0.012	0.701	0.056

Table 11. Estimates of spill effectiveness, RSW effectiveness and training spill effectiveness by test block for radio-tagged, river-run subyearling Chinook salmon passing Ice Harbor Dam during BiOp and Reduced spill operations, 2007.

Spill operations grouping	Spill effectiveness	SE	RSW effectiveness	SE	Training spill effectiveness	SE
BiOp 1	1.22	0.098	1.13	0.692	1.23	0.114
BiOp 2	1.25	0.031	1.77	0.110	1.08	0.044
BiOp 3	1.01	0.580	1.22	1.914	0.90	0.824
BiOp 4	1.39	0.028	2.13	0.063	0.95	0.053
BiOp 5	1.40	0.020	1.82	0.048	1.14	0.035
Overall	1.32	0.015	2.09	0.043	0.99	0.024
Reduced 1	2.54	0.131	4.78	0.207	0.66	0.500
Reduced 2	1.61	0.238	2.70	0.369	0.57	0.872
Reduced 3	1.76	0.077	3.14	0.114	0.33	0.382
Reduced 4	1.89	0.075	3.19	0.111	0.53	0.300
Reduced 5	1.09	0.851	1.41	1.453	0.79	2.179
Overall	1.89	0.052	3.39	0.078	0.49	0.221

Tailrace Behavior and Timing

Tailrace egress time was calculated for 1,078 radio-tagged, river-run subyearling Chinook salmon. Of these, 630 (58.4%) and 448 (41.6%) fish passed Ice Harbor dam during BiOp and Reduced spill operations, respectively. Tailrace egress time by operational test block was calculated for these fish (Table 12). Median egress times were similar between operations at 14.6 min during BiOp spill and 15.5 min during Reduced spill. Radio-tagged fish passing during BiOp spill operations exited the tailrace slightly faster than fish passing during Reduced spill operations, but the difference was not statistically significant (P = 0.520). Tailrace egress time was calculated for each passage route (Table 13). The difference in median tailrace egress time between fish passing through the RSW during BiOp spill and those passing during Reduced spill was not statistically significant (P = 0.981).

Table 12. Tailrace egress time in minutes by operations grouping (see Table 6) for radio-tagged, river-run subyearling Chinook salmon during BiOp and Reduced spill at Ice Harbor Dam, 2007.

Spill operations grouping	n	Tailrace egress time (min)				
		Mean	Median	Mode	Min	Max
BiOp 1	21	27.4	11.1	--	3.0	188.5
BiOp 2	189	49.4	12.2	8.5	1.8	2319.5
BiOp 3	4	23.3	23.5	--	12.0	34.2
BiOp 4	183	106.8	15.6	6.1	6.0	7224.7
BiOp 5	233	89.4	16.1	12.7	1.6	10,892.5
Overall	630	80.0	14.6	12.7	1.55	10,892.5
Reduced 1	104	150.4	12.6	6.7	2.2	11,213.9
Reduced 2	51	30.8	15.5	12.5	6.8	514.8
Reduced 3	169	108.7	16.4	6.4	3.5	8308.3
Reduced 4	158	113.0	16.5	9.6	4.3	10,427.7
Reduced 5	6	121.1	29.8	--	10.0	507.0
Overall	488	111.0	15.5	8.7	2.2	11,213.9

Table 13. Tailrace egress time in minutes by passage route for radio-tagged river-run subyearling Chinook salmon during BiOp and Reduced spill at Ice Harbor Dam, 2007.

	Tailrace egress time (min)			
	Turbine	Spill	RSW	Bypass
BiOp spill				
n	3	339	273	15
Mean	24.1	70.1	93.8	63.5
Median	26.1	14.6	14.2	16.7
Mode	--	12.7	10.6	--
Min	17.5	1.8	1.6	11.3
Max	28.8	10,892.5	7,224.7	657.8
Reduced spill				
n	25	50	361	52
Mean	361.3	124.5	102.8	34.3
Median	24.6	18.3	13.5	20.8
Mode	--	--	12.7	--
Min	10.9	4.3	2.2	8.3
Max	8,308.3	2,495.2	11,213.9	239.8

Detection Probability and Estimated Survival

Detection probabilities at Sacajawea Park were similar between spill operations. During BiOp spill operations, detection probability was 0.943 (SE = 0.014) for treatment fish and 0.962 (SE = 0.011) for reference fish. During Reduced spill, probabilities of detection was 0.955 (SE = 0.014) for treatment fish and 0.967 (SE = 0.010) for reference fish.

At Ice Harbor Dam, overall mean dam survival was estimated at 0.956 (95% CI 0.907-1.004) for BiOp spill operations and 0.953 (95% CI 0.905-1.001) for Reduced spill operations. Survival estimates by test block ranged from 0.935 (SE = 0.045) to 0.994 (SE = 0.054) for BiOp spill and from 0.915 (SE = 0.038) to 1.020 (SE = 0.052) for Reduced spill (Table 14). There was no statistically significant difference in relative survival estimates of dam passage between the two operations (t = 0.016, P = 0.988).

Table 14. Estimated survival (CJS and relative dam survival) for radio-tagged, subyearling Chinook salmon passing Ice Harbor Dam under BiOp (B) and Reduced spill (R) operations, 2007. Standard errors are in parenthesis; overall relative survival estimates are pooled means.

Spill operations grouping	Treatment		Reference		Relative dam survival
	n	Survival (*s*)	n	Survival (*s*)	
BiOp 1	25	0.840 (0.073)	--	--	--
BiOp 2	200	0.853 (0.026)	250	0.900 (0.019)	0.948 (0.035)
BiOp 3	4	--	--	--	--
BiOp 4	181	0.870 (0.034)	159	0.876 (0.034)	0.994 (0.054)
BiOp 5	205	0.826 (0.031)	258	0.883 (0.026)	0.935 (0.045)
Overall	615	0.845 (0.017)	667	0.884 (0.014)	0.956 (0.024)
Reduced 1	111	0.845 (0.036)	133	0.921 (0.024)	0.917 (0.046)
Reduced 2	57	0.825 (0.050)	69	0.837 (0.052)	0.986 (0.086)
Reduced 3	222	0.814 (0.028)	245	0.890 (0.021)	0.915 (0.038)
Reduced 4	138	0.956 (0.039)	157	0.938 (0.029)	1.020 (0.052)
Reduced 5	6	--	30	0.900 (0.055)	--
Overall	534	0.859 (0.018)	634	0.901 (0.013)	0.953 (0.024)

Overall estimated relative spillway survival at Ice Harbor Dam using the pooled mean was 1.002 (95% CI 0.954-1.050) for BiOp spill operations and 1.021 (95% CI 0.973-1.069) for Reduced spill operations. Survival estimates by test block ranged from 0.972 (SE = 0.043) to 1.050 (SE = 0.055) and from 0.997 (SE = 0.043) to 1.056 (SE = 0.054) for bulk and RSW spill operations, respectively (Table 15). There was no statistically significant difference in relative survival estimates of spillway passage between the two operations (t = 0.827, P = 0.446).

Overall estimated relative concrete survival at Ice Harbor Dam using the pooled mean was 0.958 (95% CI 0.909-1.007) for BiOp spill operations and 0.955 (95% CI 0.907-1.004) for Reduced spill operations. Survival estimates by test block ranged from 0.934 (SE = 0.045) to 0.998 (SE = 0.055) and from 0.917 (SE = 0.046) to 1.017 (SE = 0.052) for BiOp and Reduced spill operations, respectively (Table 16). There was no statistically significant difference in relative survival estimates of spillway passage between the two operations (t = 0.099, P = 0.925).

Table 15. Estimated spillway survival for treatment (BiOp or Reduced spill) and reference groups and relative spillway survival of radio-tagged, subyearling Chinook salmon passing Ice Harbor Dam, 2007. Standard errors are in parenthesis; overall relative survival estimates are pooled means.

Spill operations grouping	Treatment		Reference		Relative spillway survival
	n	Survival (*s*)	n	Survival (*s*)	
BiOp 1	22	0.909 (0.061)	--	--	--
BiOp 2	186	0.880 (0.024)	250	0.900 (0.019)	0.977 (0.034)
BiOp 3	1	--	--	--	--
BiOp 4	166	0.919 (0.033)	159	0.876 (0.034)	1.050 (0.055)
BiOp 5	192	0.859 (0.029)	258	0.883 (0.026)	0.972 (0.043)
Overall	567	0.886 (0.016)	667	0.884 (0.014)	1.002 (0.024)
Reduced 1	89	0.918 (0.032)	133	0.921 (0.024)	0.997 (0.043)
Reduced 2	37	0.865 (0.056)	69	0.837 (0.052)	1.034 (0.093)
Reduced 3	169	0.893 (0.026)	245	0.890 (0.021)	1.004 (0.038)
Reduced 4	119	0.990 (0.041)	157	0.938 (0.029)	1.056 (0.054)
Reduced 5	2	--	30	0.900 (0.055)	--
Overall	416	0.919 (0.017)	634	0.901 (0.013)	1.021 (0.024)

Table 16. Estimated concrete survival for treatment (BiOp and Reduced spill) and reference groups and relative survival (ratio of treatment to reference groups) of radio-tagged, subyearling Chinook salmon passing Ice Harbor Dam, 2007. Standard errors are in parenthesis; overall relative survival estimates are pooled means.

Spill operatios grouping	Treatment		Reference		Relative concrete survival
	n	Survival (*s*)	n	Survival (*s*)	
BiOp 1	25	0.840 (0.073)	--	--	--
BiOp 2	200	0.853 (0.026)	250	0.900 (0.019)	0.948 (0.035)
BiOp 3	3	--	--	--	--
BiOp 4	178	0.874 (0.034)	159	0.876 (0.034)	0.998 (0.055)
BiOp 5	204	0.825 (0.031)	258	0.883 (0.026)	0.934 (0.045)
Overall	610	0.847 (0.017)	667	0.884 (0.014)	0.958 (0.024)
Reduced 1	111	0.845 (0.036)	133	0.921 (0.024)	0.917 (0.046)
Reduced 2	56	0.839 (0.049)	69	0.837 (0.052)	1.003 (0.086)
Reduced 3	220	0.816 (0.028)	245	0.890 (0.021)	0.918 (0.038)
Reduced 4	136	0.954 (0.039)	157	0.938 (0.029)	1.017 (0.052)
Reduced 5	5	--	30	0.900 (0.055)	--
Overall	528	0.860 (0.018)	634	0.901 (0.013)	0.955 (0.024)

Overall estimated relative RSW survival at Ice Harbor Dam using the pooled mean was 1.014 (95% CI 0.953-1.076) and 1.029 (95% CI 0.980-1.079) for BiOp and Reduced spill operations, respectively. Survival estimates by test block ranged from 0.969 (SE = 0.049) to 1.079 (SE = 0.064) for the BiOp spill and 0.984 (SE = 0.047) to 1.086 (SE = 0.053) for the Reduced spill (Table 17).

Table 17. Estimated RSW survival for treatment (BiOp and Reduced spill) and reference groups and relative survival (ratio of treatment to reference groups) of radio-tagged, subyearling Chinook salmon passing Ice Harbor Dam, 2007. Standard errors are in parenthesis; overall relative survival estimates are pooled means.

Spill operations grouping	Treatment		Reference		Relative RSW survival
	n	Survival (*s*)	n	Survival (*s*)	
BiOp 1	3	--	--	--	--
BiOp 2	63	0.873 (0.042)	250	0.900 (0.019)	0.970 (0.051)
BiOp 3	--	--	--	--	--
BiOp 4	96	0.945 (0.043)	159	0.876 (0.034)	1.079 (0.064)
BiOp 5	97	0.856 (0.036)	258	0.883 (0.026)	0.969 (0.049)
Overall	259	0.897 (0.023)	667	0.884 (0.014)	1.014 (0.031)
Reduced 1	77	0.906 (0.037)	133	0.921 (0.024)	0.984 (0.047)
Reduced 2	31	0.871 (0.060)	69	0.837 (0.052)	1.041 (0.097)
Reduced 3	154	0.894 (0.027)	245	0.890 (0.021)	1.005 (0.039)
Reduced 4	105	1.018 (0.039)	157	0.938 (0.029)	1.086 (0.053)
Reduced 5	2	--	30	0.900 (0.055)	--
Overall	369	0.927 (0.018)	634	0.901 (0.013)	1.029 (0.025)

Avian Predation

When the Crescent Island Caspian tern colony had left the island for the season, we initiated a recovery effort for radio tags that were deposited on the island. There were 102 total radio tags found on the tern colony, representing approximately 3.7% of the fish we released into the Snake River. Known tern predation accounted for 4.5% of the fish we released into the forebay as treatment fish and 2.8% of the fish that were released into the tailrace of Ice Harbor Dam as reference fish.

DISCUSSION

During 2007, we began tagging after the 51st percentile of juvenile subyearling Chinook salmon had passed Lower Monumental Dam, and we finished when the 83rd percentile of these fish had passed. We would have preferred to tag during passage of the 30th to 70th percentiles, based on the 10-year average observed at Lower Monumental Dam. However, our tagging period still allowed us to tag the bulk of the run, and the average size of fish tagged was consistent with that of the run-at-large. This meant that our estimates of passage survival would be reasonably representative.

Operations at Ice Harbor Dam continue to be effective at passing migrating juvenile Chinook salmon quickly while efficiently guiding fish away from turbines. Under both spill operations evaluated in this study, radio-tagged fish entered the forebay and passed the project with minimal delay. Median forebay residence times were not significantly different between spill operations (P = 0.427), with median time only 0.70 h longer for Reduced than for BiOp spill. For fish passing through the RSW, median forebay time during Reduced spill was only 0.14 h longer than during BiOp spill, with the difference again being not statistically significant (P = 0.879) between operations. The tendency for forebay residence time to be slightly lower during BiOp operations could be attributed to the increased spill levels during this operation.

Variation in spill treatment blocks (Table 6) appeared to have little effect on passage distribution and fish passage metrics at Ice Harbor Dam. Previous studies have shown the majority of yearling Chinook salmon typically pass through the spillway, with relatively few entering either the turbine or juvenile bypass system routes (Eppard et al. 2000). In our study, the spillway route was used by nearly 97% of radio-tagged subyearling Chinook during BiOp spill and by 84% of these fish during Reduced spill.

Within the spillway, 43% of the fish passed through the RSW during BiOp spill, while 74% passed the RSW during Reduced spill. Thus about 30% more fish used the RSW during Reduced spill. Also during Reduced spill, there was a tendency for fish to be attracted toward the powerhouse: 4.3% more fish passed through the turbines and juvenile bypass system during Reduced spill than during BiOp spill. This difference in passage-route distribution is likely because of greater attraction flow toward the spillbays during BiOp spill, wherein more spillbays were open than during reduced spill.

Although tailrace egress was also slightly longer for fish passing during Reduced spill, this difference was only 0.9-min and was not statistically significant (P = 0.520).

Eighty percent of all radio-tagged fish passing through the spillway exited the tailrace in less than 35 min. Based on both survival estimates and timing through the tailrace, predation on fish in the tailrace appeared to be minimal.

Survival estimates between years at Ice Harbor Dam are not directly comparable due to differences among years in the tagging methodologies used and spill patterns evaluated. However, for subyearling Chinook salmon, estimates of survival through the spillway have increased over the past few years. From evaluations based on PIT-tagged subyearling Chinook salmon passing Ice Harbor Dam, Eppard et al. (2002, 2004) estimated spillway survival at 88.5% in 2000 and 89.4% in 2002, and Absolon et al. (2005) estimated spillway survival of 96.4% in 2003.

Survival rates estimates in 2007 were consistent with those estimated during spill operations utilizing the RSW since it was first installed at Ice Harbor Dam in 2005 (Ogden et al. 2007, 2008). Radio-tag studies of spillway passage during 2005 and 2006 estimated dam survival at 95%, concrete survival at 98-99%, spillway survival at 99%, and survival through the RSW at 98-100% (Ogden et al. 2007, 2008). By comparison, estimates in 2007 were dam survival at 95%, concrete survival at 96%, spillway survival at 100%, and survival through the RSW at 100%.

During 2007, we found no statically significant differences between survival estimates for dam (P = 0.988), concrete (P = 0.925), spillway (P = 0.446), or RSW (P = 0.598) for radio-tagged fish passing during BiOp or Reduced spill operations. Overall, it appears the RSW at Ice Harbor Dam continues to be effective in passing more fish with less water and very high survival.

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REFERENCES

Absolon, R. F., B. P. Sandford, M. B. Eppard, D. A. Brege, K. W. McIntyre, E. E. Hockersmith, and G. M. Matthews. 2005. Survival of juvenile Chinook salmon through Ice Harbor Dam, 2003. Annual report to the U.S. Army Corps of Engineers, Contract W68SBV92844866, Walla Walla, Washington.

Adams, N. S., D. W. Rondorf, S. D. Evans, and J. E. Kelly. 1998a. Effects of surgically and gastrically implanted radio transmitters on swimming performance and predator avoidance of juvenile Chinook salmon (*Oncorynchus tshawytscha*). Canadian Journal of Fisheries and Aquatic Science 55:781-787.

Adams, N. S., D. W. Rondorf, S. D. Evans, and J. E. Kelly. 1998b. Effects of surgically and gastrically implanted radio transmitters on growth and feeding behavior of juvenile Chinook salmon. Transactions of the American Fisheries Society 127:128-136.

Angela, S. M., K. D. Ham, G. E. Johnson, M. A. Simmons, C. S. Simmons, E. Kudera, and J. Skalski. 2003. Hydroacoustic evaluation of the removable spillway weir at Lower Granite Dam in 2002. Annual report to the U.S. Army Corps of Engineers, Contract DACW68-02-D-0001, Walla Walla, Washington.

Beeman, J. W., C. Grant, and P. V. Haner. 2004. Comparison of three underwater antennas for use in radiotelemetry. North American Journal of Fisheries Management 24:275-281.

Beeman, J. W., and A. G. Maule. 2006. Migration depths of juvenile Chinook salmon and steelhead relative to total dissolved gas supersaturation in a Columbia River reservoir. Transactions of the American Fisheries Society 135:584-594.

Burnham, K. P., D. R. Anderson, G. C. White, C. Brownie, and K. H. Pollock. 1987. Design and analysis methods for fish survival experiments based on release-recapture. American Fisheries Society Monograph 5:1-437.

Cormack, R. M. 1964. Estimates of survival from the sightings of marked animals. Biometrika 51:429-438.

Eppard, M. B., G. A. Axel, B. P. Sandford, and D. B. Dey. 2000. Effects of spill on the passage of hatchery yearling Chinook salmon at Ice Harbor Dam, 1999. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla District, Contract W66QKZ91521282.

Eppard, M. B., E. E. Hockersmith, G. A. Axel, and B. P. Sandford. 2002. Spillway survival for hatchery yearling and subyearling Chinook salmon passing Ice Harbor Dam, 2000. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington.

Eppard, M. B., E. E. Hockersmith, G. A. Axel, and B. P. Sandford. 2004. Spillway survival for hatchery yearling and subyearling Chinook salmon passing Ice Harbor Dam, 2002. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington.

Hockersmith, E. E., W. D. Muir, S. G. Smith, B. P. Sandford, R. W. Perry, N. S. Adams, and D. W. Rondorf. 2003. Comparison of migration rate and survival between radio-tagged and PIT-tagged migrant yearling Chinook salmon in the Snake and Columbia Rivers. North American Journal of Fisheries Management 23:404-413.

Johnson, G. E., N. S. Adams, R. L. Johnson, D. W. Rondorf, D. D. Dauble, and T. Y. Barila. 2000. Evaluation of the prototype surface bypass for salmonid smolts ins spring 1996 and 1997 at Lower Granite Dam on the Snake River, Washington. Transactions of the American Fisheries Society 129:381-397.

Johnson, G. E., C. M. Sullivan, and M. W. Echo. 1992. Hydroacoustic studies for developing a smolt bypass system at Wells Dam. Fisheries research 14:221-237.

Jolly, G. M. 1965. Explicit estimates from capture-recapture data with both death and immigration—stochastic model. Biometrika 52:225-247.

Knight, A .E., G. Marancik, and J. B. Layzer. 1977. Monitoring movements of juvenile anadromous fish by radiotelemetry. Progressive Fish-Culturist 39:148-150.

Muir, W. D., S. G. Smith, J. G. Williams, and B. P. Sandford. 2001. Survival of juvenile salmonids passing through bypass systems, turbines, and spillways with and without flow deflectors at Snake River dams. North American Journal of Fisheries Management 21:135-146.

Muir, W. D., S. G. Smith, R. W. Zabel, D. M. Marsh, and J. G. Williams. 2003. Survival estimates for the passage of spring-migrating juvenile salmonids through Snake and Columbia River dams and reservoirs, 2002. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Project 1993-02900.

NMFS (National Marine Fisheries Service). 1992. Threatened status for Snake River spring-summer Chinook salmon, threatened status for Snake River fall Chinook salmon. Federal Register 57:78 (22 April 1992):14653-14663.

Ogden, D. A., E. E. Hockersmith, G. A. Axel, B. J. Burke, K. E. Frick, and B. P. Sandford. 2007. Passage behavior and survival for river-run subyearling Chinook salmon at Ice Harbor Dam, 2005. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla District, Contract W68SBV92844866.

Ogden, D. A., E. E. Hockersmith, G. A. Axel, B. J. Burke, K. E. Frick, R. F. Absolon, and B. P. Sandford. 2008. Passage behavior and survival for river-run subyearling Chinook salmon at Ice Harbor Dam, 2006. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla District, Contract W68SBV92844866.

Ogden, D. A., E. E. Hockersmith, M. B. Eppard, G. A. Axel, and B. P. Sandford. 2005. Passage behavior and survival for river-run subyearling Chinook salmon at Ice Harbor Dam, 2004. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla District, Contract W68SBV92844866.

Plumb, J. M., A. C. Braatz, J. N. Lucchesi, S. D. Fielding, J. M. Sprando, G. T. George, N. S. Adams, and D. W. Rondorf. 2003. Behavior of radio-tagged juvenile Chinook salmon and steelhead and performance of a removable spillway weir at Lower Granite Dam, Washington, 2002. Annual report to the U.S. Army Corps of Engineers, Contract W68SBV00104592, Walla Walla, Washington.

Ryan, B. A., J. W. Ferguson, R. D. Ledgerwood, and E. P. Nunnallee. 2001. Methods to detect passive integrated transponder tags on piscivorous bird colonies in the Columbia River Basin. North American Journal of Fisheries Management 21:971-975.

Seber, G. A. F. 1965. A note on the multiple recapture census. Biometrika 52:249-259.

Smith, S. G., W. D. Muir, R. W. Zabel, D. M. Marsh, R. A. McNatt, J. G. Williams, and J. R. Skalski. 2003. Survival estimates for the passage of spring-migrating juvenile salmonids through Snake and Columbia River dams and reservoirs, 2003. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland, Oregon.

Zabel, R. W. , S. G. Smith, W. D. Muir, D. M. Marsh, J. G. Williams, and J. R. Skalski. 2002. Survival estimates for the passage of spring-migrating juvenile salmonids through Snake and Columbia River dams and reservoirs, 2001. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland, Oregon.

APPENDIX A

Evaluation of Model Assumptions

We used the CJS single-release model (Cormack 1964; Jolly 1965; Seber 1965) to estimate survival and probability of detection for both treatment and reference groups from detection in the forebay of Ice Harbor Dam (treatment groups) or release into the tailrace (reference groups) to the mouth of the Snake River at Sacajawea Park. The ratios of these survival estimates (dam or spillway survival divided by tailrace survival) were calculated to determine relative dam or spillway survival. Critical assumptions associated with the survival estimates that were evaluated using statistical tests include:

A1. All tagged fish have the same probability of being detected at a detection location.

Radio-tag detection probabilities at the Sacajawea Park array in the mouth of the Snake River were similar for both operations group (Appendix Table A1). With detection probabilities at or near 100% for all fish, there was no disparity between detection of treatment and reference groups. Detection histories for dam, spillway, concrete, and RSW survival are shown in Appendix Tables A2 to A5, respectively.

Appendix Table A1. Detection probabilities at Sacajawea Park array for evaluating survival of radio-tagged, river-run, subyearling Chinook salmon passing Ice Harbor Dam, 2007.

Operations	Treatment group		Reference group	
group	$\hat{p}$	SE	$\hat{p}$	SE
BiOp 1	1.000	0.000	--	--
BiOp 2	0.990	0.010	1.000	0.000
BiOp 3	--	--	--	--
BiOp 4	0.870	0.035	0.927	0.032
BiOp 5	0.957	0.025	0.935	0.024
Overall	0.943	0.014	0.962	0.011
Reduced 1	0.982	0.018	0.988	0.012
Reduced 2	1.000	0.000	0.936	0.044
Reduced 3	0.969	0.018	0.977	0.013
Reduced 4	0.902	0.042	0.931	0.030
Reduced 5	--	--	1.000	0.000
Overall	0.955	0.014	0.967	0.010

Appendix Table A2. Detection histories used in dam passage survival estimates of radio-tagged subyearling Chinook salmon at Ice Harbor Dam, 2007. The first digit indicates detection status on the primary survival array (1= detected; 0 = not detected). The second digit indicates detection status on additional arrays.

	Detection history							
Operations	Treatment group				Reference group			
grouping	0-0	1-0	0-1	1-1	0-0	1-0	0-1	1-1
BiOp 1	4	6	--	15	--	--	--	--
BiOp 2	31	92	--	77	25	88	--	137
BiOp 3	2	--	--	2	--	--	--	--
BiOp 4	33	36	11	101	24	42	6	87
BiOp 5	39	64	4	98	36	89	9	124
Overall	109	198	15	293	85	219	15	348
Reduced 1	18	30	1	62	12	49	--	72
Reduced 2	9	14	1	33	14	17	1	37
Reduced 3	44	67	3	108	30	72	2	141
Reduced 4	10	46	8	74	16	34	4	103
Reduced 5	--	1	3	2	3	15	--	12
Overall	81	160	14	279	75	187	7	365

Appendix Table A3. Detection histories used in spillway passage survival estimates of radio-tagged subyearling Chinook salmon at Ice Harbor Dam, 2007. The first digit indicates detection status on the primary survival array (1= detected; 0 = not detected). The second digit indicates detection status on additional arrays.

	Detection history							
Operations	Treatment group				Reference group			
grouping	0-0	1-0	0-1	1-1	0-0	1-0	0-1	1-1
BiOp 1	2	6	--	14	--	--	--	--
BiOp 2	24	87	--	75	25	88	--	137
BiOp 3	--	--	--	1	--	--	--	--
BiOp 4	21	35	11	99	24	42	6	87
BiOp 5	27	64	4	97	36	89	9	124
Overall	74	15	192	286	85	219	15	348
Reduced 1	8	25	1	55	12	49	--	72
Reduced 2	5	9	--	23	14	17	1	37
Reduced 3	19	53	2	95	30	72	2	141
Reduced 4	4	40	7	68	16	34	4	103
Reduced 5	--	1	--	1	3	15	--	12
Overall	36	10	128	242	75	187	7	365

Appendix Table A4. Detection histories used in concrete passage survival estimates of radio-tagged subyearling Chinook salmon at Ice Harbor Dam, 2007. The first digit indicates detection status on the primary survival array (1= detected; 0 = not detected). The second digit indicates detection status on additional arrays.

Operations grouping	Detection history							
	Treatment group				Reference group			
	0-0	1-0	0-1	1-1	0-0	1-0	0-1	1-1
BiOp 1	4	--	6	15	--	--	--	--
BiOp 2	31	92	--	77	25	88	--	137
BiOp 3	1	--	--	2	--	--	--	--
BiOp 4	16	40	11	111	24	42	6	87
BiOp 5	38	64	4	98	36	89	9	124
Overall	90	202	15	303	85	219	15	348
Reduced 1	18	30	1	62	12	49	--	72
Reduced 2	8	14	1	33	14	17	1	37
Reduced 3	42	67	3	108	30	72	2	141
Reduced 4	8	46	8	74	16	34	4	103
Reduced 5	--	3	--	2	3	15	--	12
Overall	76	160	13	279	75	187	7	365

Appendix Table A5. Detection histories used in RSW passage survival estimates of radio-tagged subyearling Chinook salmon at Ice Harbor Dam, 2007. The first digit indicates detection status on the primary survival array (1= detected; 0 = not detected). The second digit indicates detection status on additional arrays.

Operations grouping	Detection history							
	Treatment group				Reference group			
	0-0	1-0	0-1	1-1	0-0	1-0	0-1	1-1
BiOp 1	--	--	--	3	--	--	--	--
BiOp 2	8	20	--	35	25	88	--	137
BiOp 3	--	--	--	--	--	--	--	--
BiOp 4	10	18	6	62	24	42	6	87
BiOp 5	12	38	1	46	36	89	9	124
Overall	30	7	76	146	85	219	15	348
Reduced 1	8	20	1	48	12	49	--	72
Reduced 2	4	8	--	19	14	17	1	37
Reduced 3	17	49	2	86	30	72	2	141
Reduced 4	1	34	7	63	16	34	4	103
Reduced 5	--	1	--	1	3	15	--	12
Overall	30	10	112	217	75	187	7	365

A2. Treatment and corresponding reference groups are evenly mixed and travel together through downstream reaches.

To test that treatment and reference fish mixed evenly and traveled together downstream, we evaluated mixing of release groups at the Sacajawea survival transect. An assumption of the CJS model is that within groups, all fish have equal probabilities of survival and detection downstream from the point of release (i.e., the tailrace of Ice Harbor Dam). This assumption is valid if release groups have similar passage distributions at downstream detection sites (Sacajawea transect). To evaluate this assumption, we evaluated mixing of release groups at Sacajawea by comparing specific passage percentiles (10th, 50th, 90th) for differences in passage distribution. Treatment groups (BiOp or Reduced spill) were paired with the same reference groups as used in the survival analysis, and distributions were compared using *t*-tests with 95% confidence intervals about the means.

Tests of homogeneity in passage distributions at Sacajawea were not statistically significantly different between treatment and reference groups used to calculate relative survival estimates (Appendix Table A6). While there were few replicates (three or four per treatment and seven overall), the average differences between median passage times were less than an hour overall and less than three hours by treatment type, far smaller than the two or three day time-width of the treatment blocks. The differences were negative under the BiOp spill condition (i.e. treatment fish passed earlier than reference fish) and positive under the Reduced spill condition. It is reasonable to conclude that the survival estimates were not significantly biased by any violation of the assumption regarding mixing through the common reach.

Appendix Table A6. Test of homogeneity of arrival timing at the Sacajawea survival transect for treatment (forebay) and reference groups (tailrace) of radio-tagged, river-run subyearling Chinook salmon used for estimating survival at Ice Harbor Dam, 2007. Paired treatment and reference groups were the same as those used in survival analyses.

Spill operations		Treatment - reference difference (h)		
grouping	n	10th	50th	90th
BiOp 1	21	--	--	--
BiOp 2	394	-0.6	-5.3	-6
BiOp 3	2	--	--	--
BiOp 4	282	-0.5	3.4	2.2
BiOp 5	405	-0.4	-1.3	0.5
Reduced 1	213	5	3.7	2.3
Reduced 2	101	2.6	3.4	19.4
Reduced 3	399	-19.7	-4.6	0.8
Reduced 4	276	1.7	1.6	1.3
Reduced 5	32	--	--	--
Mean		-1.7	0.1	2.9
SE		3.1	1.5	2.9
95% CI		-9.3-5.9	-3.4-3.7	-4.3-10.1
t		-0.5	0.1	1
df		6	6	6
P		0.6	0.9	0.4

Evaluation of Biological Assumptions

In addition to model assumptions, this study also had several biological assumptions which included:

A3. The individuals tagged for the study are a representative sample of the population of interest.

A4. The tag and/or tagging method do not significantly affect the subsequent behavior or survival of the marked individual.

Assumption A3 was not tested for validation in this study; fish were size-selected for radio tagging. Assumption A4 has been evaluated previously by Adams et al. (1998a,b) and Hockersmith et al. (2003), who reported the effects of radio tagging on survival, predation, growth, and swimming performance of juvenile salmonids.

A5. Fish that die as a result of passing through a passage route are not subsequently detected at a downstream array used to estimate survival for the passage route.

The distance between releases to the Ice Harbor Dam tailrace and the first downstream array used to estimate survival (Sacajawea Park) was approximately 14 km. Dead radio-tagged fish released concurrently with live fish into the tailrace of the dam during our study were not detected on the Sacajawea Park detection array.

A6. The radio transmitters functioned properly and for the predetermined period of time.

All transmitters were checked upon receipt from the manufacturer, prior to implantation into a fish, and prior to release to ensure that the transmitter was functioning properly. A total of 2,811 tags were implanted in river-run subyearling Chinook salmon of which 20 (0.7%) not were working 24 h after tagging. Tags that were not functioning properly were not used in the study.

In addition, a total of 47 radio transmitters distributed throughout the study were tested for tag life by allowing them to run in river water and checking them 2 times daily to determine if they functioned for the predetermined period of time. Fifteen tags (32%) failed prior to the preprogrammed shut-down after 10 d (Appendix Table A7). Of these only 3 (6.4%) failed within 5 d of activation. Median travel time from release to the primary survival line at Sacajawea Park was 0.5 d overall with less than 0.8% of the fish taking 5 d or more to reach the primary survival line (Appendix Table A8). Although we documented transmitter failure, the short travel times to our survival line, and the low tag failure rate were such that these failures could not have significantly changed our results.

Appendix Table A7. Number of days tags lasted in tag life testing, 2007.

Tags (n)	Tag life (d)	Tag (%)
1	0	2.1
0	1	0.0
0	2	0.0
0	3	0.0
2	4	4.3
1	5	2.1
1	6	2.1
1	7	2.1
1	8	2.1
8	9	17.0
13	10	27.7
9	11	19.1
8	12	17.0
1	13	2.1
1	14	2.1

Appendix Table A8. Travel time from release to detection at the primary survival line at Sacajawea Park for river-run subyearling Chinook salmon released into the forebay and tailrace of Ice Harbor Dam, 2007.

	Travel time (d) to primary survival line at Sacajawea Park		
Percentile	Forebay	Tailrace	Overall
Min	0.3	0.0	0.0
10	0.5	0.2	0.2
20	0.6	0.2	0.3
30	0.8	0.2	0.3
40	1.0	0.3	0.4
50	1.2	0.3	0.5
60	1.3	0.3	0.6
70	1.5	0.4	1.0
80	1.8	0.4	1.3
90	2.5	0.5	1.8
Max	7.8	7.6	7.8
n	1,009	1,119	2,128
Travel time > 5d	14 (1.4%)	2 (0.2%)	16 (0.8%)

APPENDIX B: Telemetry Data Processing and Reduction

Overview

The database stores the data collected for the Juvenile Salmon Radio Telemetry project in the Fish Ecology Division at NMFS' Northwest Fisheries Science Center. This project tracks the migration routes and passage of juvenile salmon and steelhead past dams within the Columbia and Snake Rivers using a network of radio receivers to record signals emitted from radio transmitters ("tags") implanted into fish. Special emphasis is placed on the routes of passage, and survival for individual routes at the various hydroelectric dams on the lower Columbia and Snake Rivers. The data stored in the database include observations of tagged fish and the locations and configurations of radio receivers and antennas.

Database Inputs

The majority of data supplied to the database are observations of tagged fish recorded at the various radio receivers, which the receivers store in hexadecimal-formal files ("hex" files). The files are saved to a central computer four times daily, and placed on an FTP server automatically once daily for downloading into the database.

In addition, data arrives in the form of a daily updated tag file, which contains the attributes of each fish tagged, along with the channel and code of the transmitter used and the date, time, and location or release after tagging.

Database Outputs

Data are consolidated into a summary form that lists each fish and receiver on which it was detected, and includes the specifics of the first and last hits and the total number of detections for each series where there was no more than a 5-minute gap between detections. This summarized data is immediately available for preliminary data analyses.

Processes

The processes in this database fall into three main categories or stages in the flow of data from input to output; loading, validation, and summarization.

A. Data Loading The loading process consists of copying data files from their initial locations to the database server, converting the files from their original format into a format readable by SQL, and having SQL read the files and store the data in preliminary tables.

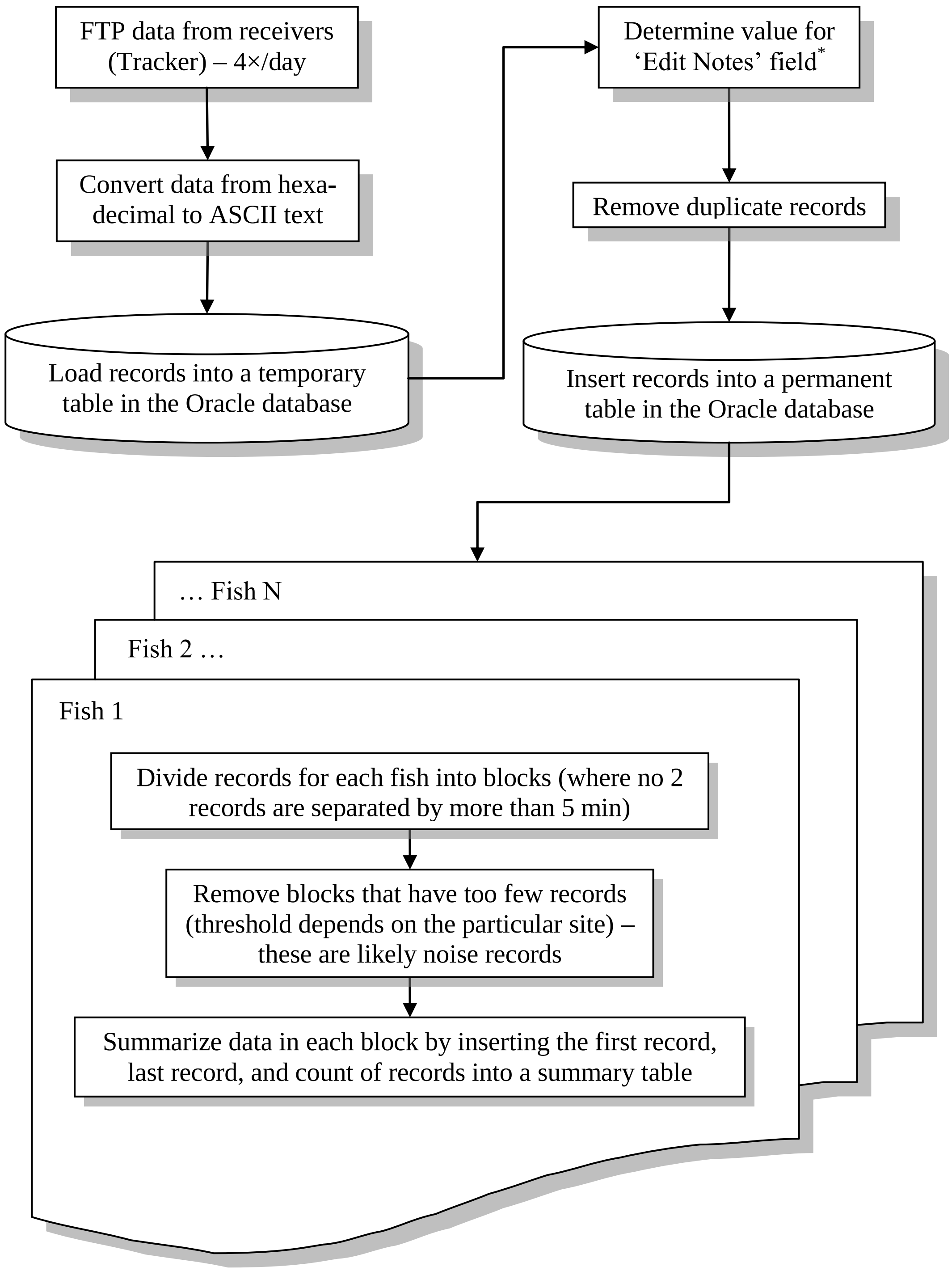
B. Data Validation During the validation process, the records stored in the preliminary tables are analyzed. We determine which study year, site identifier, antenna identifier, and tag identifier they belong to, flagging them as invalid if one or more of these relationships cannot be determined. Records are flagged by storing brief comments in the edit notes field. Values of edit notes are as follows:

- Null: denotes a valid observation of a tag.
- Not tagged: Denotes an observation of a channel-code combination that was not in use at the time. Such values are likely due to radio-frequency noise being picked up at an antenna.
- Noise record: Denotes an observation where the code equal to 995, 997, or 999. These are not valid records, and relate to radio-frequency noise being picked up at the antenna.
- Beacon record: Hits recorded on channel = 5, code=575, which is being used to ensure proper functioning of the receivers. This combination does not indicate the presence of a tagged fish.
- Invalid record date: Denotes an observation whose date/time is invalid (occurring before we started the database; prior to Jan. 1, 2004, or some time in the future). Due to improvements in the data loading process, such records are unlikely to arise.
- Invalid site: Denotes an observation attributed to an invalid (non-existent) site: These are typically caused by typographical errors in naming hex files at the receiver end. They should not be present in the database, since they should be filtered out during the data loading process.
- Invalid antenna: Denotes an observation attributed to an invalid (non-existent) antenna. These are most likely due to electronic noise within the receiver.
- Lt start time: Assigned to records occurring prior to the time a tag was activated (its start time). Note: These records represent noise.
- Gt end time: Assigned to records occurring after the end time on a tag (they run for 10 days once activated). Note: These records represent noise.
- Gt 40 records: Denotes tags that registered more than 40 records per minute on an individual receiver. This is not possible as the tags emit a signal every 2 seconds (30/min). Note: these patterns represent noise.

In addition, duplicate records (records for which the channel, code, site, antenna, date and time are the same as those of another record) are removed. Finally, the records are copied from the preliminary tables into the appropriate storage table based on study year. The database can accommodate multiple years with differing site and antenna configuration. Once a record's study year has been determined, its study year, site, and antenna are used to match it to a record in the site table.

C. Generation of the Summary Tables The summary table summarizes the first detection, last detection, and count of detections for blocks of records within a site for a single fish where no two consecutive records are separated by more than a specified number of minutes (currently using 5 min).

Flow Chart


FTP data from receivers (Tracker) – 4×/day
Convert data from hexa-decimal to ASCII text
Load records into a temporary table in the Oracle database
Determine value for 'Edit Notes' field*
Remove duplicate records
Insert records into a permanent table in the Oracle database
… Fish N
Fish 2 …
Fish 1
Divide records for each fish into blocks (where no 2 records are separated by more than 5 min)
Remove blocks that have too few records (threshold depends on the particular site) – these are likely noise records
Summarize data in each block by inserting the first record, last record, and count of records into a summary table