Passage Behavior and Survival for River-run Subyearling Chinook Salmon at Ice Harbor Dam, 2005

Darren A. Ogden, Eric E. Hockersmith, Gordon A. Axel, Brian Burke, Kinsey Frick, and Benjamin P. Sandford

Report of research by

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

to

Walla Walla District
Northwestern Division
U.S. Army Corps of Engineers
201 North 3rd Avenue
Walla Walla, Washington 99362-1876
Contract W68SBV92844866

June 2007

EXECUTIVE SUMMARY

In recent years, surface collection and bypass systems have been identified as a viable alternative for increasing fish passage efficiency (FPE) and survival for migrating juvenile salmonids at hydroelectric dams on the Snake and Columbia Rivers. In an effort to increase passage and survival for juvenile salmon, the U.S. Army Corps of Engineers installed a removable spillway weir (RSW) at Ice Harbor Dam in spring 2005.

In 2005, NOAA Fisheries Service evaluated passage behavior and estimated relative survival for radio-tagged, river-run subyearling Chinook salmon at Ice Harbor Dam on the Snake River. Voluntary spill at Ice Harbor Dam during the study alternated between 1) a bulk spill pattern (without the RSW), with spill limited only by the maximum total dissolved gas levels allowed by state and local agencies, and 2) an RSW spill pattern (using the RSW), where spill averaged 46% of river flow.

Fish were collected, surgically tagged with a radio transmitter, and PIT tagged at Lower Monumental Dam. Treatment groups were comprised of 2,102 radio and PIT-tagged fish released 4 km upstream of Ice Harbor Dam. Reference groups were comprised of 2,140 radio- and PIT-tagged fish released into the tailrace of Ice Harbor Dam. Releases occurred during both daytime and nighttime operations for 20 d from 10 June to 1 July. The study occurred during the period coinciding with the 38th to 80th percentiles of the cumulative smolt passage index for subyearling Chinook salmon at Lower Monumental Dam. For survival estimation, radiotelemetry detection arrays were installed at multiple locations between Ice Harbor Dam on the lower Snake River and the forebay of McNary Dam on the lower Columbia River.

Bulk and RSW spill operations were both effective at guiding fish away from turbines with FPE estimates of 99.6 (95% CI, 98.6-100.5) and 95.2% (95% CI. 88.8-101.6), respectively. Spill efficiency was 98.5% (95% CI, 96.1-100.8) for bulk spill and 87.3% (95% CI, 76.9-97.8) for RSW spill. Spill effectiveness was 1.17 (95% CI, 1.12-1.23) and 1.90 (95% CI, 1.40-2.40) for bulk and RSW spill, respectively. Forebay residence times were short during both operations, with median times of 4 h during bulk spill operation and 5 h during RSW operation. Horizontal fish passage distribution for bulk spill was 98% through the spillway, 1% through the juvenile bypass, and 1% through turbines. Fish passage distribution for RSW spill was 87% through the spillway, 8% through the juvenile bypass system, and 5% through turbines. Median tailrace egress times were 3 and 5 min for bulk and RSW spill operations, respectively. Relative spillway passage survival for radio-tagged fish passing during bulk spill operation was estimated at 99.8% (95% CI, 97.3-102.2) compared to 98.3% (95% CI, 95.5-101.1) for

RSW spill operations. Relative dam survival for radio-tagged fish passing during bulk spill operations was 95.1% (95% CI, 92.4-97.8) compared to 92.9% (95% CI, 90.0-95.9) for RSW spill operations. During RSW spill operations, 60% of the fish passed Ice Harbor Dam through the RSW and their estimated relative survival was 99.4% (95% CI, 96.3-102.4)(Table 1).

Table 1. Final study results of conditions, passage behavior, and relative survival for radio-tagged subyearling Chinook salmon at Ice Harbor Dam, 2005 (95% CI in parentheses).

	RSW	Bulk
Conditions		
Average project discharge (kcfs)	50	49
Average spill discharge (kcfs)	23 (46%)	41 (84%)
Average RSW discharge (kcfs)	9 (18%)	---
Average training flow discharge (kcfs)	14 (28%)	---
Average tailwater elevation (ft msl)	341	341
Average water temperature °C	15.8	16.0
Average Secchi depth (m)	1.7	1.7
Passage metric		
Median forebay delay (hours)	4	3
Spillway passage	87%	98%
JBS passage	8%	1%
Turbine passage	5%	1%
RSW passage	60%	---
FPE	95.1% (88.8–101.6)	99.4% (98.6–100.5)
Spill efficiency	87.3% (76.9–97.8)	98.5% (96.1–100.8)
Spill effectiveness	1.90 (1.40 – 2.40)	1.17 (1.12-1.23)
RSW effectiveness	3.40	---
FGE	61.5% (46.4-76.7)	62.5% (24.0-101.1)
Tailrace Egress (minutes)	4	3
Relative survival		
Relative Dam survival (forebay BRZ to tailrace)	95.1% (87.0-104.0)	96.0% (92.0-97.8)
Relative Concrete survival (all fish passing the dam)	98.6% (93.0-104.0)	99.9% (98.0-102.0)
Relative Spillway survival (fish passing through the spillway)	98.9% (94.5-104.0)	100% (98.0-102.0)
Relative RSW survival (fish passing only through the RSW)	99.7% (96.0-104.0)	---
Relative Training Spill survival (fish passing through the spillway without RSW)	97.3% (91.0-104.0)	---
Relative JBS survival (fish passing only through the JBS)	98.8% (91.6-106.1)	---

CONTENTS

INTRODUCTION

Fall Chinook salmon *Oncorhynchus tshawytscha* in the Snake River Basin were listed under the U.S. Endangered Species Act (ESA) in 1992 (Connor et al. 2005). Survival studies on 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 (Iwamoto et al. 1994; Muir et al. 1995a,b, 1996, 1998, 2001; Smith et al. 1998).

Most Columbia River and Snake River Basin juvenile salmon and steelhead tend to stay in the upper 10 to 20 feet of the water column as they migrate downstream. Juvenile fish passage routes at the U.S. Army Corp of Engineers Columbia and Snake river dams require fish to dive to depths of 50 to 60 feet to find the passage routes. In recent years, surface collection and bypass systems have been identified as viable alternatives for increasing fish passage efficiency (FPE) and survival for migrating juvenile salmonids at hydroelectric dams on the Snake and Columbia Rivers. The surface collector at Wells Dam on the Columbia River, where the spillway is located over the turbine units, passed 90% of the fish while spilling just 7% of the total discharge (Johnson et al. 1992).

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

The U.S. Army Corps of Engineers installed a prototype RSW at Lower Granite Dam on the Snake River in summer 2001 and evaluated its performance in spring 2002. Evaluation of the RSW was compared to current management strategy of spilling water to the "gas cap," that is, to state and local limits based on resulting levels of dissolved gas. These evaluations indicated that 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 U.S. Army Corps of Engineers installed a RSW in spillbay 2 at Ice Harbor Dam in February 2005.

Passage survival studies at Ice Harbor Dam were also conducted during several years preceding the evaluations of 2005. In 2003, survival estimates were based on a 2-day block design: two days of no spill were alternated with two days of bulk spill, concentrated into 2 to 4 spillbays. Abosolon et al. (2005) reported relative spillway-passage survival estimates of 96% for PIT-tagged fall Chinook salmon released during summer 2003 under bulk spill conditions (bulk spill was BiOp spill volume through fewer bays). These estimates were significantly higher than estimates obtained in 2000 (t = 2.24, P = 0.036) and 2002 (t = 2.72, P = 0.012) of 88.5 and 89.4% respectively (Eppard et al. 2002, 2004).

In 2004, a 4-day block study design was used to estimate relative spillway passage and dam survival for radio-tagged, river-run subyearling Chinook salmon volitionally passing Ice Harbor Dam. The bulk spill pattern was compared with a standard flat spill pattern. The bulk spill pattern used fewer bays, with a minimum gate opening of 6 stops and a spill volume equivalent to BiOp-recommended nighttime spill (up to 100% of river flow or to dissolved gas limits). The standard flat spill pattern used all bays, a maximum gate opening of 3 stops, and spill volumes equivalent to BiOp-recommended daytime spill (45,000 ft^3/s) (Ogden et al. 2005). Spillway passage survival for radio-tagged fish passing during bulk spill operations was estimated at 97.2% (95% CI, 90.3-104.5) compared to 93.3% (95% CI, 88.2-98.6) for flat spill operations. Estimated dam survival for all radio-tagged fish passing during bulk spill operations was 86.2% (95% CI, 69.2-107.5) compared to 84.6% (95% CI, 73.6-97.2) during flat spill operations (Ogden et al. 2005).

In 2005, a 2-day randomized block study design was used to estimate relative survival for radio-tagged, river-run subyearling Chinook salmon volitionally passing Ice Harbor Dam under a bulk spill pattern with the RSW closed versus the RSW open with training spill in adjacent spillbays. Training spill is spill used to draw flow toward the RSW and to encourage tailrace flow from the RSW to move downstream instead of eddying in the tailrace).

Fish passage behavior performance metrics, project survival, and route-specific survival as used in this report are defined as follows:

Bulk Spill: Spill pattern with the RSW closed, using fewer bays with a minimum gate opening of 6 stops and a spill volume equivalent to BiOp-recommended nighttime spill (up to 100% of river flow or to dissolved gas limits).

RSW Spill: Spill pattern with the RSW open with training spill in adjacent bays.

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): The proportion of fish passing the dam via the spillway divided by the proportion of water spilled.

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 and release location of reference groups downstream from the dam.

Results of this study will be used to help make management decisions that will optimize survival for juvenile salmonids arriving at Ice Harbor Dam. This study addresses the reasonable and prudent alternatives listed in sections 9.6.1.4.5 and 9.6.1.4.6 of the NMFS 2000 Biological Opinion (NMFS 2000). This study also addresses questions 3 and 7 of the 10 key questions for salmon recovery in the Northwest Fisheries Science Center Salmon Research Plan (NWFSC 2002).

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. 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 chose fish that did not have any gross injury or deformity and were at least 105 mm in length and 10 g in weight. Only fish not previously tagged with a passive integrated transponder (PIT) were used. 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.,† had a predetermined tag life of 10 d, and were pulse-coded for unique identification of individual fish at 30 MHz. Each radio tag measured 14 mm in length. The potting of the tag was ground down lengthwise to reduce the weight of the tag. One end of the tag measured 6 mm in diameter, while the other end measured 4.2 mm, bringing the volume of the tag to 350 mm^3. The tags weighed 0.9 g in air and 0.4 g in water.

Fish were surgically implanted with radio transmitters using techniques described by Adams et al. (1998). Each fish also received a PIT tag before the incision was closed in order to monitor radio-tag performance. Immediately following tagging, fish were

---

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

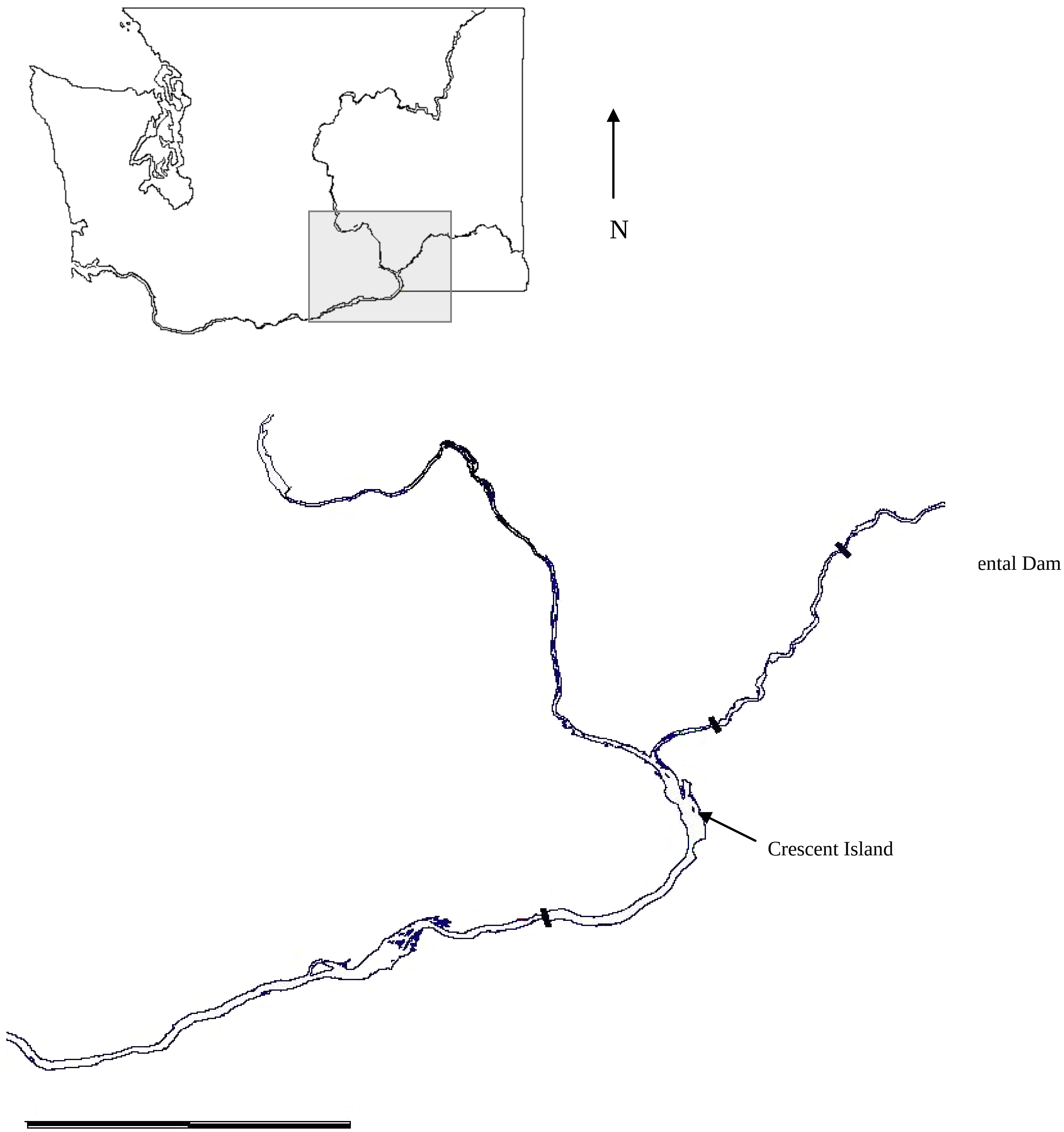


Figure 1. Study area showing location of radiotelemetry transects used for estimating survival at Ice Harbor Dam, 2005. (Note: 1=Mouth of the Snake River at Sacajawea Park, WA; 2=Railroad Bridge, WA; 3=McNary Dam Forebay.)

placed into a 19-L recovery container (2 fish per container) with aeration until recovery from the anesthesia. Recovery containers were then closed and transferred to a 1,152-L holding tank designed to accommodate up to 28 containers. 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 holding. All holding tanks were supplied with flow-through water during tagging and holding and were aerated with oxygen during transport to release locations. After tagging, fish were held a minimum of 24 h with flow-through water for recovery and determination of post-tagging mortality.

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). 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. Two fish were released every 15 min in order to distribute the releases over a period of 4-5 h.

Daytime releases occurred between 0830 and 1730 PDT. Nighttime releases occurred between 2100 and 0430 PDT. We released 82 groups of approximately 27-57 fish per group. A total of 2,101 radio-tagged fish were released 4 km upstream of Ice Harbor Dam during both daytime and nighttime project operations. A total of 2,114 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, individual spillbays, and all turbine unit gate slots (gatewells).

Telemetry data were retrieved through an automated process that downloaded data from network telemetry receivers up to four times daily and placed them on an FTP server once daily for downloading into the database. All compressed 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).

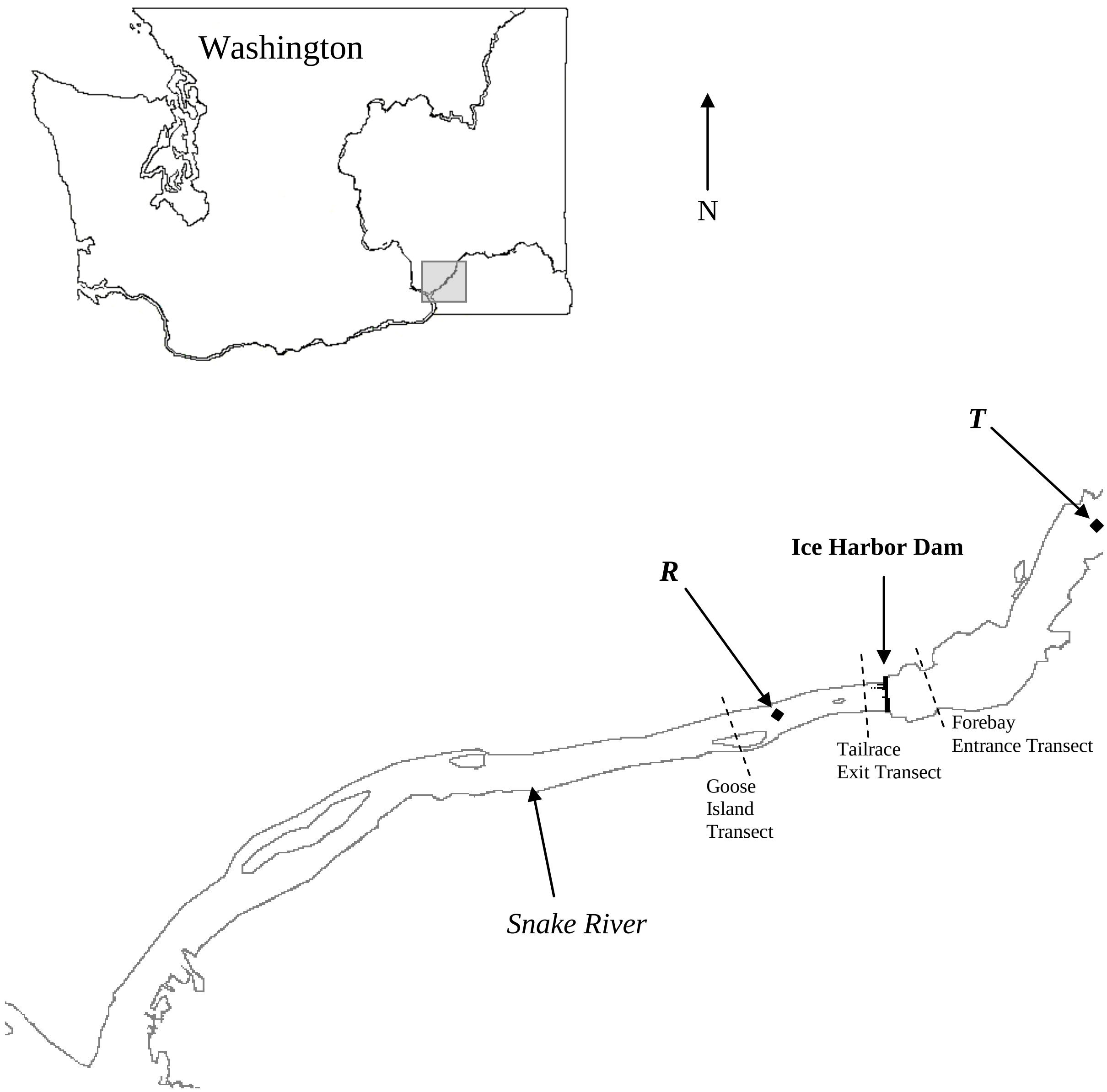


Figure 2. The Lower Snake River and Ice Harbor Dam showing the release locations for treatment ***T*** and reference ***R*** groups of radio-tagged subyearling Chinook salmon, 2005. Also shown are radiotelemetry transects used to detect fish entering the immediate forebay (rkm 538.5) and subsequently exiting the tailrace (rkm 537.7), 2005.

Using the detailed detection history, 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 the tailrace of the dam, meaning at least one detection on the stilling basin, tailrace exit transect, or at Goose Island (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 juvenile bypass system (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.

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 the release dates were used to pair them with the treatment fish which entered the forebay on the same date.

The Cormack-Jolly-Seber (CJS) single-release 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 provided unbiased estimates if certain assumptions were met (Zabel et al. 2002; Smith et al. 2003), in particular that detection and survival probabilities downstream from detection sites were not conditional on radiotelemetry detection at upstream sites. Model assumptions are addressed in Appendix A.

Relative spillway passage survival was then expressed as the ratio of CJS survival estimates for treatment fish to reference fish. Average relative survival was calculated using weighted geometric 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 juvenile bypass system. 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 20 and 40 ft. 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 juvenile bypass system, 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 from the Caspian Tern 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 tags and PIT tags were recovered on the tern colony at Crescent Island during fall 2005 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 (B. Ryan, NMFS, personal communication; see also 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 active Caspian Tern colonies in the region conducted by NOAA Fisheries 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 20 d from 9 June to 29 June. Tagging began after 38% of the juvenile subyearling Chinook salmon had passed Lower Monumental Dam and was completed when 80% of these fish had passed (Figure 4). Overall mean fork length was 115.5 mm for treatment fish and 115.5 mm for reference fish (Table 2). Weight for treatment and reference fish was not taken. Mean length and weight of the run at large sampled at the Lower Monumental smolt collection facility was 106.55 mm and 12.98 g, respectively (Tables 3 and 4). During the study period, handling and tagging mortality for subyearling Chinook salmon held for a minimum of 24 h after tagging was 0.9%.

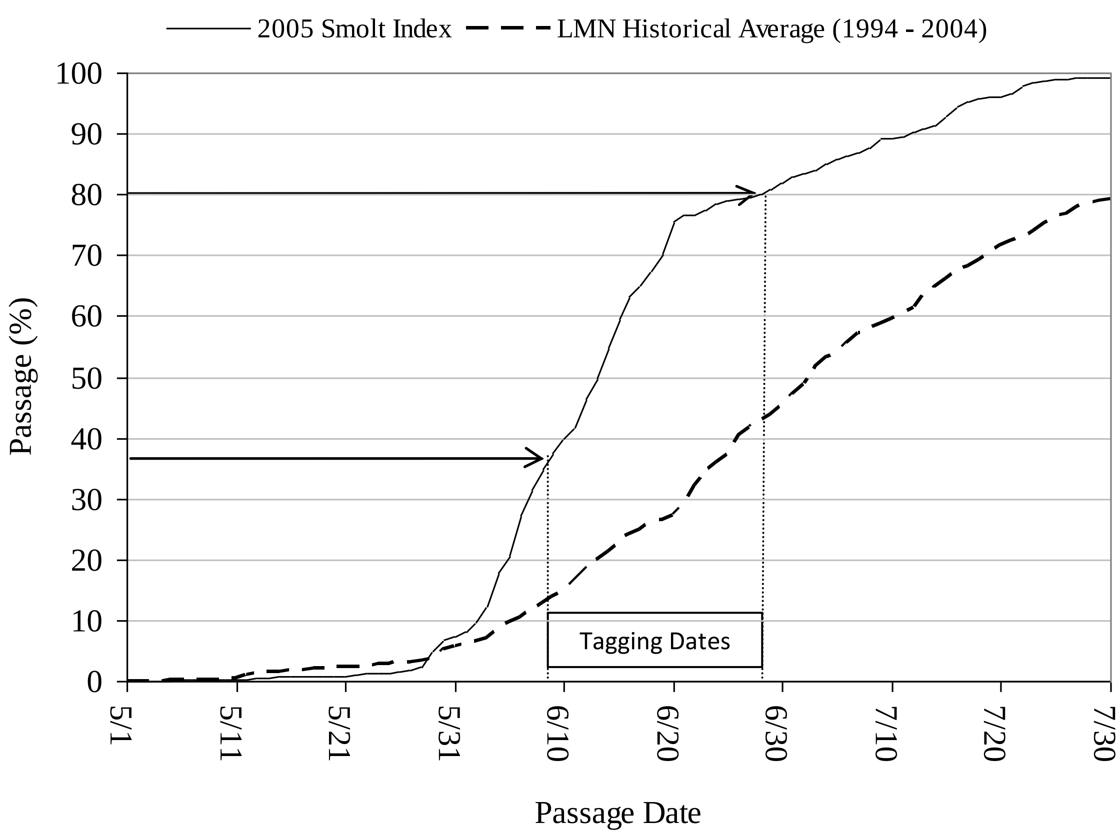


Figure 4. The 2005 cumulative smolt passage distribution compared to the historical average (1994-2004) for subyearling Chinook salmon passing Lower Monumental Dam.

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 bulk and RSW spill patterns, 2005.

		Mean length of radio-tagged fish (mm)							
	Release	Treatment				Reference			
Tag day	date	N	Mean	SD	Range	N	Mean	SD	Range
9-Jun	10-Jun	60	115.7	4.8	107-126	60	115.5	4.3	109-127
10-Jun	11-Jun	81	115.0	4.8	106-133	76	114.0	4.5	106-129
11-Jun	12-Jun	107	116.0	5.0	105-134	106	115.9	4.1	108-127
12-Jun	13-Jun	81	116.2	3.8	108-127	86	116.1	4.0	107-126
13-Jun	14-Jun	109	117.1	5.4	107-136	109	116.6	4.4	106-130
14-Jun	15-Jun	112	116.2	5.1	106-137	108	117.6	5.1	108-134
15-Jun	16-Jun	108	115.6	5.4	107-136	111	117.1	5.2	106-134
16-Jun	17-Jun	110	114.4	4.8	106-127	110	114.2	4.3	107-130
17-Jun	18-Jun	112	114.8	4.6	108-127	109	115.2	5.0	108-134
18-Jun	19-Jun	109	116.3	4.8	106-132	110	116.6	4.5	107-135
19-Jun	20-Jun	114	115.9	5.2	106-131	109	114.7	4.2	108-127
20-Jun	21-Jun	112	115.4	4.1	108-126	109	116.0	4.6	108-129
21-Jun	22-Jun	112	116.0	4.7	107-130	112	116.0	4.8	109-132
22-Jun	23-Jun	110	116.9	4.8	108-129	112	116.8	5.3	107-136
23-Jun	24-Jun	111	114.7	4.8	107-136	109	115.4	5.2	107-134
24-Jun	25-Jun	112	114.3	5.3	107-133	80	114.4	5.1	105-128
25-Jun	26-Jun	107	115.0	5.1	107-136	108	113.9	5.1	107-133
26-Jun	27-Jun	112	113.9	5.1	107-132	113	114.7	4.6	108-131
27-Jun	28-Jun	111	115.0	5.6	107-134	112	114.8	6.6	107-136
28-Jun	29-Jun	111	116.2	6.9	107-136	111	114.1	5.9	107-132
29-Jun	30-Jun	---	---	---	---	54	116.4	7.5	106-145
Total		2,101	115.5	5.1	105-137	2,114	115.5	5.1	105-145

Table 3. Sample size, mean, median, range, and standard deviation (SD) of length (mm) by tagging date for river-run, subyearling Chinook salmon from the smolt monitoring sample at Lower Monumental Dam, 2005.

	Mean length (mm) smolt monitoring sample				
Date	N	Mean	Median	Range	SD
9-Jun	200	103.58	105	70.00-130.00	7.02
10-Jun	200	106.90	110	55.00-125.00	9.02
11-Jun	200	107.98	110	55.00-125.00	8.71
12-Jun	200	106.70	105	55.00-135.00	9.44
13-Jun	200	106.83	105	60.00-130.00	7.40
14-Jun	200	106.53	105	70.00-130.00	8.54
15-Jun	199	102.89	105	55.00-115.00	7.81
16-Jun	200	105.30	105	90.00-125.00	6.81
17-Jun	200	106.85	105	65.00-130.00	7.90
18-Jun	200	106.25	105	55.00-125.00	8.95
19-Jun	200	107.25	110	65.00-125.00	7.63
20-Jun	200	106.88	105	65.00-135.00	8.85
21-Jun	105	105.00	105	80.00-130.00	8.09
22-Jun	50	107.60	110	75.00-135.00	9.60
23-Jun	200	108.05	105	90.00-135.00	7.19
24-Jun	200	106.08	105	85.00-130.00	7.45
25-Jun	70	106.07	105	85.00-125.00	7.80
26-Jun	72	107.57	110	75.00-130.00	9.96
27-Jun	200	108.58	110	70.00-135.00	9.00
28-Jun	200	107.20	105	50.00-140.00	9.41
29-Jun	187	108.05	110	75.00-130.00	7.90
Total	3,683	106.55	105	50.00-140.00	8.37

Table 4. 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, 2005.

	Mean weight (g) smolt monitoring sample				
Date	N	Mean	Median	Range	SD
9-Jun	200	11.79	12	5.44-23.13	2.27
10-Jun	200	13.02	12	1.81-117.93	7.97
11-Jun	200	12.98	13	2.72-19.50	2.61
12-Jun	200	12.35	12	1.36-19.05	2.64
13-Jun	200	12.41	12	2.27-22.23	2.40
14-Jun	200	12.91	12	6.35-23.59	2.97
15-Jun	200	11.99	12	2.72-20.41	2.57
16-Jun	200	12.35	12	6.35-21.32	2.70
17-Jun	200	12.61	12	4.08-21.77	2.58
18-Jun	200	12.42	12	2.27-20.87	2.55
19-Jun	200	12.62	13	3.18-19.50	2.28
20-Jun	200	12.71	13	3.18-29.03	2.93
21-Jun	105	12.94	13	6.35-22.23	2.84
22-Jun	50	13.73	14	4.99-28.58	3.56
23-Jun	200	13.73	13	7.71-27.22	2.90
24-Jun	200	13.31	13	6.80-25.40	2.79
25-Jun	70	13.23	14	6.80-18.60	2.48
26-Jun	72	13.56	13	5.44-24.95	3.52
27-Jun	200	14.15	14	4.08-27.67	3.42
28-Jun	200	14.58	15	4.08-34.02	3.55
29-Jun	187	14.44	14	4.99-25.85	3.28
Total	3,684	12.98	13	1.36-117.93	3.40

Project Operations

From 10 June to 2 July 2005, voluntary spill at Ice Harbor Dam during the study was operated in a 2-d randomized block interval that alternated between a bulk spill pattern (RSW off) with spill limited by maximum dissolved gas levels, and an RSW spill pattern (RSW on) with bulk "training" spill, that is, spill intended to draw water toward the RSW spillbay (Table 5). Total project discharge was regulated by the Bonneville Power Administration and the U.S. Army Corps of Engineers for changing regional power needs and varied greatly on many days during this period (Figure 5 and Table 6). Median spill was 40,100 ft^3/s during bulk spill and 20,100 ft^3/s during RSW spill operations. Median and mean spill for each treatment group is displayed in Table 6. Primary spillbays opened during bulk spill operation were 3, 5, 7, 9, and 10. Primary spillbays opened during the RSW spill operation for training spill were 3, 4, 5, 7, and 9.

Table 5. Start time, end time, and duration of test blocks (B = bulk spill, R = RSW spill) at Ice Harbor Dam, 2005.

Test block	Start time	End time	Duration (h)
B1	6/10 06:00	6/12 05:45	48
R1	6/12 05:50	6/14 06:00	48
B2	6/14 06:05	6/18 05:50	96
R2	6/18 05:55	6/21 23:55	90
B3	6/22 00:00	6/24 06:00	54
R3	6/24 06:05	6/26 06:00	48
B4	6/26 06:05	6/30 05:50	96
R4	6/30 05:55	7/2 06:00	48

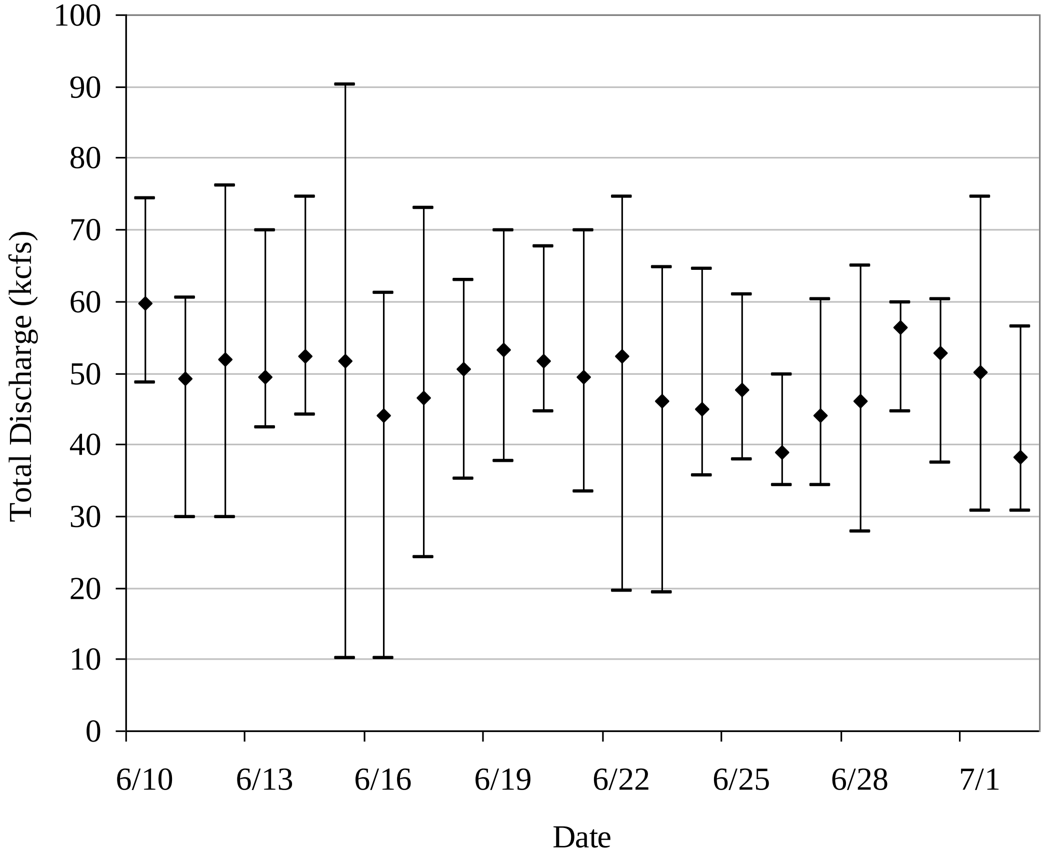


Figure 5. Average daily total project discharges at Ice Harbor Dam during the 2005 passage survival study (whisker bars represent the range of project discharge for each day).

Table 6. Mean, range, and standard deviation (SD) of operations and/or conditions by test block (B = bulk spill, R = RSW spill) at Ice Harbor Dam, 2005.

Test	Total discharge (1,000 ft^3/s)				Total spill (1,000 ft^3/s)				Total turbine (1,000 ft^3/s)				Spill proportion (%)				Tailwater elevation (ft)			
block	Median	Mean	Range	SD	Median	Mean	Range	SD	Median	Mean	Range	SD	Median	Mean	Range	SD	Median	Mean	Range	SD
									Bulk spill											
B01	58.8	52.7	29.8-74.2	12.6	50.1	46.5	29.8-65.3	11.1	8.8	6.2	0.0-16.9	4.1	0.8	0.9	0.7-1.0	0.1	341.4	341.2	338.9-343.3	1.0
B02	45.2	47.7	10.0-90.2	19.5	40.3	41.0	10.0-80.5	18.2	9.2	6.8	0.0-10.6	4.2	0.8	0.8	0.5-1.0	0.1	340.7	340.6	337.1-343.8	1.5
B03	56.3	50.2	19.3-74.5	17.3	47.0	41.7	10.1-65.1	16.7	9.4	8.6	0.0-9.7	2.7	0.8	0.8	0.5-1.0	0.1	341.6	340.9	338.2-342.7	1.4
B04	44.7	47.0	27.6-64.9	11.3	35.2	37.7	18.4-55.4	11.2	9.4	9.4	9.0-14.4	0.3	0.8	0.8	0.6-0.9	0.0	340.4	340.6	338.6- 42.3	0.9
Total	49.0	48.8	10.0-90.2	15.8	40.1	40.9	10.0-80.5	15.1	9.3	7.9	0.0-16.9	3.4	0.8	0.8	0.5-1.0	0.1	340.9	340.7	337.1-343.8	1.3
									RSW spill											
R01	46.4	51.3	29.8-76.0	8.4	20.0	18.2	15.0-39.7	2.6	29.5	33.1	8.9-56.0	7.0	0.4	0.4	0.3-0.7	0.0	341.1	341.3	339.6-343.4	0.8
R02	53.4	52.2	33.2-69.8	10.4	21.3	27.7	15.1-59.9	11.7	23.1	24.5	0.0-48.6	13.9	0.4	0.5	0.3-1.0	0.2	341.5	341.1	338.8-343.5	1.3
R03	43.1	43.8	34.4-60.8	6.0	21.3	22.3	15.2-36.7	6.2	22.7	21.6	9.2-39.5	8.2	0.4	0.5	0.4-0.8	0.2	340.4	340.5	339.5-341.8	0.6
R04	53.3	49.2	30.5-74.6	11.5	20.0	18.7	13.4-29.6	3.0	33.2	30.4	9.4-54.5	9.1	0.4	0.4	0.3-0.8	0.1	342.0	341.6	340.0-343.8	1.0
Total	49.7	49.7	29.8-76.0	10.0	20.1	22.8	13.4-59.9	9.0	28.9	26.9	0.0-56.0	11.6	0.4	0.5	0.3-1.0	0.2	341.1	341.1	338.8-343.8	1.1

Migration Behavior and Passage Distribution

Forebay Behavior and Timing

Of the 2,101 radio-tagged treatment fish released above Ice Harbor Dam, 1,957 (93.1%) were detected entering the forebay. Based on the time of first detection, 1,089 (55.6%) of these fish entered the forebay during bulk spill and 868 (44.4%) during RSW spill operations. Of these same 1,957 fish, 1,886 (96.4%) were detected approaching the dam, with 1,063 (56.4%) detected during bulk spill and 823 (43.6%) during RSW spill operations. For fish entering the immediate forebay during bulk spill operations, 95.2% were first detected approaching in front of the spillway, and 4.8% in front of the powerhouse (Figure 6). During RSW spill operations 84.1% were first detected approaching in front of the spillway and 15.9% in front of the powerhouse. For approach at the RSW, 18.8% of the fish approached during bulk spill operations, and 37.5% of the fish approached during RSW spill operation.

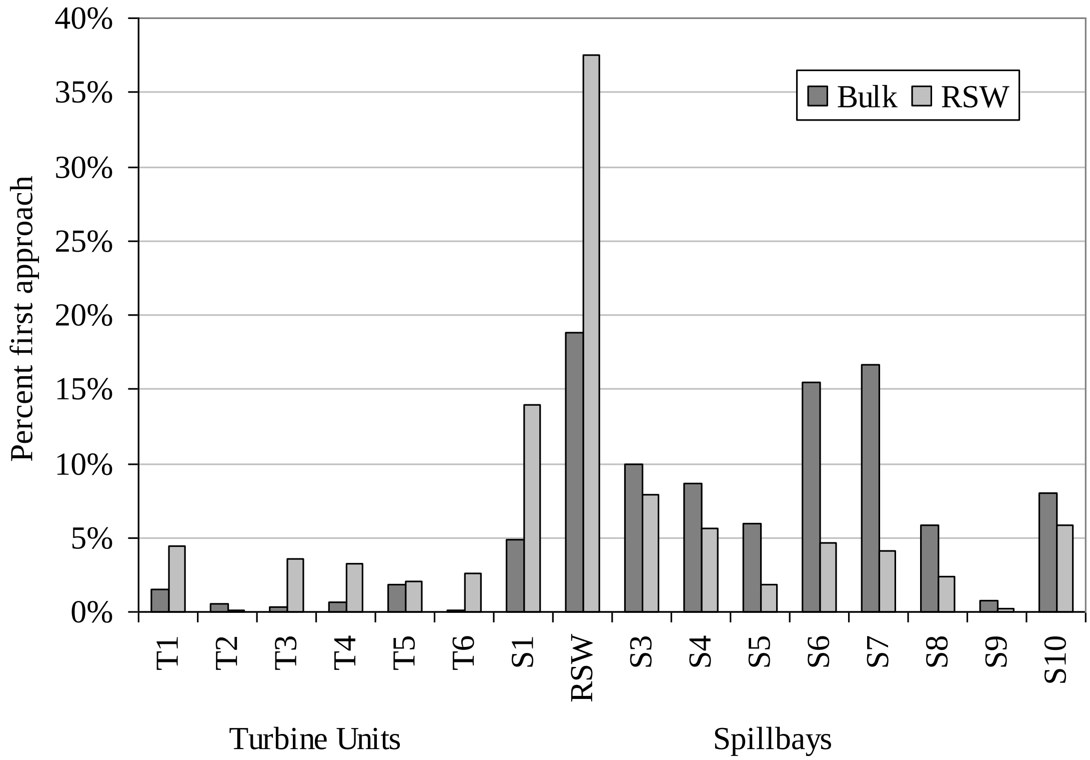


Figure 6. Approach patterns during bulk and RSW spill for radio-tagged, river-run subyearling Chinook salmon in the forebay of Ice Harbor Dam, 2005.

Forebay residence times were calculated for 1,569 fish, each with detections on both the forebay entrance transect and a passage-route receiver. Of these fish, 912 (58.1%) passed during bulk spill and 657 (41.9%) during RSW spill. Forebay residence time by operational test block was calculated for these fish (Table 7). Median forebay times for these fish were 3.29 h during bulk spill and 4.25 h during RSW spill. Forebay residence time was consistently longer during RSW than during bulk spill operations; however, the difference was not statistically significant (P = 0.230).

Table 7. Forebay residence time in hours by operations grouping (see Table 4) for radio-tagged, river-run subyearling Chinook salmon during bulk and RSW spill at Ice Harbor Dam, 2005.

	Forebay residence time (h)			
		Percentiles		
Operations grouping	N	10th	50th	90th
	Bulk spill			
B1	51	1.07	2.87	15.61
B2	317	1.09	4.93	23.73
B3	199	0.89	2.54	14.09
B4	345	0.95	2.82	14.36
Overall Mean		1.00	3.29	16.95
	RSW spill			
R1	110	1.59	5.52	20.57
R2	365	1.16	4.05	18.31
R3	148	1.13	4.06	21.32
R4	34	0.98	3.36	8.48
Overall Mean		1.22	4.25	17.17

Passage Distribution and Metrics

Of the 1,957 radio-tagged treatment fish detected entering the forebay, 1,862 (95.1%) were detected at or below Ice Harbor Dam and 95 (4.9%) entered the forebay but were not recorded as passing the dam. Of the 1,862 fish, 1,738 (93.3%) passed the dam through the spillway, 74 (4.0%) through the juvenile bypass system, 46 (2.5%) through turbines, and 4 (0.2%) 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 1,040 fish last detected during bulk spill operations, 1,022 (98.3%) passed through the spillway, 10 (1.0%) through the juvenile bypass, 6 (0.6%) through turbines, and 2 (0.2%) passed through an undetermined route. Of the 95 fish that entered the forebay but were not recorded as passing the dam, 49 (51.6%) entered during bulk spill operations.

Of the 822 radio-tagged fish last detected in the forebay during RSW spill operations, 716 (87.1%) passed the dam through the spillway, 64 (7.8%) through the juvenile bypass system, 40 (4.9%) through turbines, and 2 (0.2%) passed through an undetermined route. Of the 95 fish that entered the forebay but were not recorded as passing the dam, 46 (48.4%) entered during RSW spill operations (Figure 7). Distribution through individual spillbays is presented in Figure 8.

Overall fish passage efficiency (FPE) at Ice Harbor Dam was 0.994 (SE = 0.003, 95% CI 0.984-1.004) for bulk spill operations and 0.951 (SE = 0.020, 95% CI 0.887-1.015) for RSW spill operations. Spill efficiency (SPE) was 0.985 (SE = 0.007, 95% CI 0.961-1.008) and 0.873 (SE = 0.033, 95% CI 0.769-0.978) for bulk and RSW spill operations, respectively. Spill effectiveness (SPF) was 1.17:1 (SE = 0.016, 95% CI 1.112-1.226) and 1.90:1 (SE = 0.157, 95% CI 1.402-2.403) for bulk and RSW spill operations, respectively. Fish guidance efficiency (FGE) was 0.625 (SE = 0.121, 95% CI 0.240-1.010) for bulk spill operations and 0.615 (SE = 0.048, 95% CI, 0.464-0.767) for RSW spill operations (Table 8).

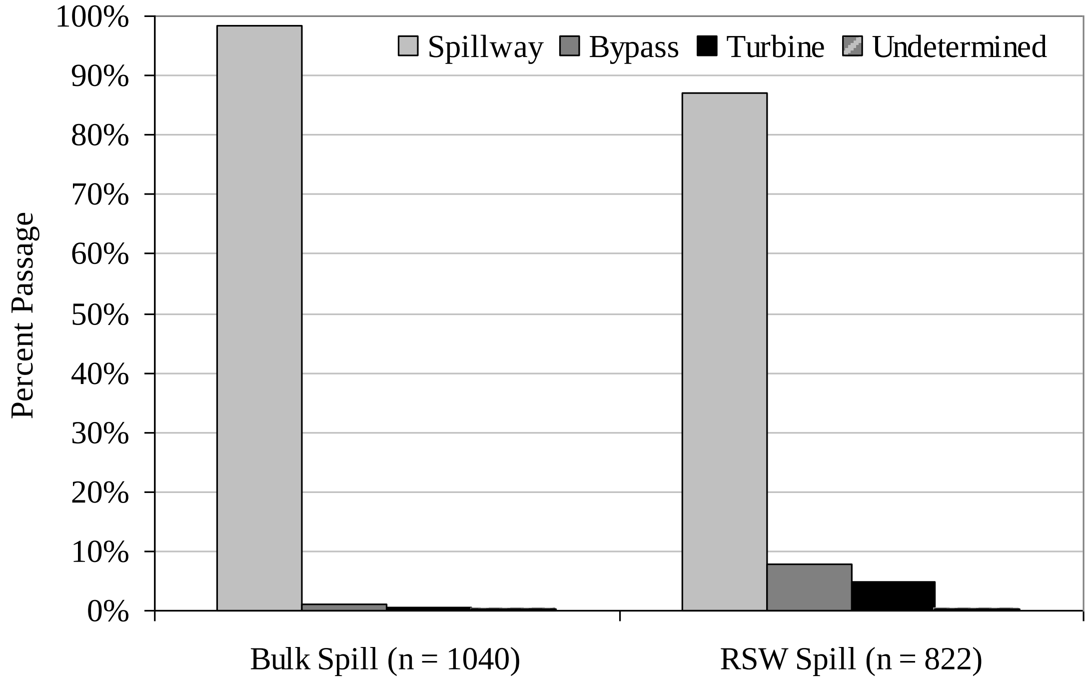


Figure 7. Passage distribution of radio-tagged, subyearling Chinook salmon during bulk spill and RSW spill operations at Ice Harbor Dam, 2005.

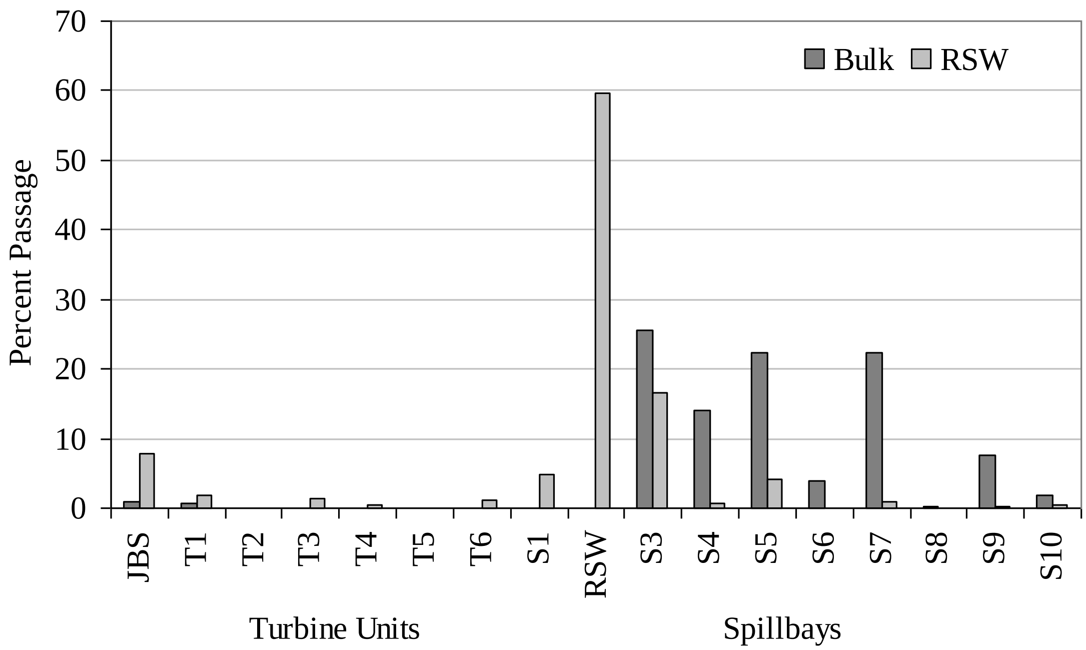


Figure 8. Individual passage route distribution for radio-tagged, river-run subyearling Chinook salmon during bulk and RSW spill testing at Ice Harbor Dam, 2005.

Table 8. Estimates of spill efficiency (SPE), spill effectiveness (SPF), fish passage efficiency (FPE), and fish guidance efficiency by test block for radio-tagged, river-run subyearling Chinook salmon passing Ice Harbor Dam during bulk (B) and RSW (R) spill operations, 2005.

Operations grouping	Fish Passage Metrics			
	SPE	SPF	FPE	FGE
Bulk Spill				
B1	1.000	1.13	1.000	---
B2	1.000	1.17	1.000	---
B3	0.978	1.18	0.996	0.800
B4	0.971	1.21	0.987	0.545
Overall	0.985	1.17	0.994	0.625
RSW Spill				
R1	0.763	1.87	0.904	0.594
R2	0.896	1.57	0.963	0.644
R3	0.893	1.62	0.941	0.450
R4	0.894	2.04	1.000	1.000
Overall	0.873	1.90	0.951	0.615

Tailrace Behavior and Timing

Tailrace egress time was calculated for 1,783 radio-tagged, river-run subyearling Chinook salmon. Of these, 1,005 and 778 fish passed through the spillway during bulk and RSW spill operations, respectively. Tailrace egress time by operational test block was calculated for these fish (Table 9). Median egress times were similar between operations at 3.19 min during bulk spill and 4.22 min during RSW spill. Radio-tagged fish passing during bulk spill operations exited the tailrace slightly faster than fish passing during RSW spill operations, and the difference was significant statistically ($P = 0.033$) but most likely not significant biologically.

Table 9. Tailrace egress time in minutes by operations grouping (see Table 4) for radio-tagged, river-run subyearling Chinook salmon during bulk and RSW spill at Ice Harbor Dam, 2005.

Operations grouping	N	Percentiles for tailrace egress time (min) 10th	50th	90th
Bulk spill				
B1	50	2.16	3.23	15.74
B2	363	2.00	3.13	20.98
B3	213	1.97	3.05	16.62
B4	379	1.97	3.33	18.91
Overall Mean		2.02	3.19	18.07
RSW spill				
R1	128	1.92	4.60	22.98
R2	411	1.87	4.88	29.80
R3	176	1.64	4.23	26.03
R4	63	1.46	3.18	13.54
Overall Mean		1.72	4.22	23.09

Detection Probability and Estimated Survival

Detection probabilities at Sacajawea Park were similar for both treatment and reference groups at 0.978 (SE = 0.010) and 0.982 (SE = 0.010), respectively. The overall estimated relative dam survival at Ice Harbor Dam using the weighted geometric mean was 0.960 (SE = 0.013, 95% CI 0.920-1.000) for bulk spill operations and 0.951 (SE = 0.027, 95% CI 0.870-1.040) for RSW spill operations. Survival estimates by test block ranged from 0.938 (SE = 0.033) to 1.013 (SE = 0.050) for bulk spill and from 0.833 (SE = 0.035) to 0.975 (SE = 0.022) for RSW spill operations (Table 10). There was no statistically significant difference in relative survival estimates of dam passage between the two operations (t = 0.300, P = 0.774).

Table 10. Estimated survival (CJS and relative dam survival) for radio-tagged, subyearling Chinook salmon passing Ice Harbor Dam under bulk and RSW spill operations, 2005. Standard errors are in parenthesis; overall relative survival estimates are weighted geometric means.

	Treatment		Reference		Relative dam
Test Block	n	CJS survival	n	CJS survival	survival
			Bulk spill		
B01	51	0.962 (0.027)	136	0.949 (0.019)	1.013 (0.035)
B02	392	0.893 (0.016)	438	0.937 (0.012)	0.954 (0.020)
B03	240	0.843 (0.024)	255	0.898 (0.019)	0.938 (0.033)
B04	404	0.862 (0.017)	444	0.903 (0.014)	0.954 (0.024)
Overall	1,087	0.874 (0.010)	1,273	0.919 (0.008)	0.960 (0.013)
			RSW spill		
R01	137	0.950 (0.019)	193	0.974 (0.011)	0.975 (0.022)
R02	452	0.895 (0.015)	409	0.927 (0.013)	0.965 (0.021)
R03	201	0.777 (0.029)	219	0.932 (0.017)	0.833 (0.035)
R04	69	0.783 (0.050)	54	0.835 (0.051)	0.938 (0.082)
Overall	859	0.867 (0.012)	875	0.933 (0.009)	0.951 (0.027)

Overall estimated relative spillway survival at Ice Harbor Dam using the weighted geometric mean was 1.000 (SE = 0.006, 95% CI 0.980-1.020) for bulk spill operations and 0.989 (SE = 0.016, 95% CI 0.940-1.040) for RSW spill operations. Survival estimates by test block ranged from 0.989 (SE = 0.019) to 1.013 (SE = 0.035) and from 0.932 (SE = 0.033) to 1.052 (SE = 0.083) for bulk and RSW spill operations, respectively (Table 11). There was no statistically significant difference in relative survival estimates of spillway passage between the two operations (t = 0.640, P = 0.543).

Table 11. Estimated survival (CJS and relative spillway survival) for radio-tagged, subyearling Chinook salmon passing through the spillway at Ice Harbor Dam under bulk and RSW spill operations, 2005. Standard errors are in parenthesis; overall relative survival estimates are weighted geometric means.

	Treatment		Reference		Relative spillway
Test Block	n	CJS survival	n	CJS survival	survival
	Bulk spill				
B01	51	0.962 (0.027)	136	0.949 (0.019)	1.013 (0.035)
B02	378	0.926 (0.014)	438	0.937 (0.012)	0.989 (0.019)
B03	221	0.898 (0.021)	255	0.898 (0.019)	0.999 (0.031)
B04	372	0.911 (0.015)	444	0.903 (0.014)	1.009 (0.023)
Overall	1,022	0.917 (0.009)	1,273	0.919 (0.008)	1.000 (0.006)
	RSW spill				
R01	103	0.962 (0.019)	193	0.974 (0.011)	0.987 (0.023)
R02	387	0.931 (0.013)	409	0.927 (0.013)	1.005 (0.020)
R03	167	0.869 (0.026)	219	0.932 (0.017)	0.932 (0.033)
R04	57	0.878 (0.044)	54	0.835 (0.051)	1.052 (0.083)
Overall	714	0.917 (0.010)	875	0.933 (0.009)	0.989 (0.016)

Overall estimated relative concrete survival at Ice Harbor Dam using the weighted geometric mean was 0.999 (SE = 0.005, 95% CI 0.980-1.020) for bulk spill operations and 0.986 (SE = 0.018, 95% CI 0.930-1.040) for RSW spill operations. Survival estimates by test block ranged from 0.989 (SE = 0.019) to 1.013 (SE = 0.035) and from 0.918 (SE = 0.032) to 1.030 (SE = 0.082) for bulk and RSW spill operations, respectively (Table 12). There was no statistically significant difference in relative survival estimates of spillway passage between the two operations (t = 0.670, P = 0.527).

Table 12. Estimated survival (CJS and relative concrete survival) for radio-tagged, subyearling Chinook salmon passing Ice Harbor Dam under bulk and RSW spill operations, 2005. Standard errors are in parenthesis; overall relative survival estimates are weighted geometric means.

	Treatment		Reference		Relative concrete
Test block	n	CJS survival	n	CJS survival	survival
			Bulk spill		
B01	51	0.962 (0.027)	136	0.949 (0.019)	1.013 (0.035)
B02	378	0.926 (0.014)	438	0.937 (0.012)	0.989 (0.019)
B03	226	0.895 (0.021)	255	0.898 (0.019)	0.997 (0.031)
B04	385	0.909 (0.015)	444	0.903 (0.014)	1.007 (0.023)
Overall	1,040	0.915 (0.009)	1,273	0.919 (0.008)	0.999 (0.005)
			RSW spill		
R01	136	0.957 (0.018)	193	0.974 (0.011)	0.982 (0.021)
R02	433	0.934 (0.012)	409	0.927 (0.013)	1.008 (0.019)
R03	187	0.856 (0.026)	219	0.932 (0.017)	0.918 (0.032)
R04	64	0.860 (0.044)	54	0.835 (0.051)	1.030 (0.082)
Overall	820	0.914 (0.010)	875	0.933 (0.009)	0.986 (0.018)

Spillway survival during the RSW operation was partitioned into fish passing exclusively through the RSW (spillbay 2) or fish passing through the training spill (spillbays 3, 4, 5, 7, and 9). Overall estimated relative RSW survival at Ice Harbor Dam using the weighted geometric mean was 0.997 (SE = 0.013, 95% CI 0.960-1.040) and 0.973 (SE = 0.021, 95% CI 0.910-1.040) for the training spill. Survival estimates by test block ranged from 0.950 (SE = 0.023) to 1.068 (SE = 0.085) for the RSW survival and 0.903 (SE = 0.052) to 0.980 (SE = 0.152) for the training spill (Table 13).

Table 13. Estimated survival (CJS and relative survival) for radio-tagged, subyearling Chinook salmon passing through the spillway during RSW spill operations at Ice Harbor Dam, 2005. Spillway survival was partitioned into fish passing exclusively through the RSW or fish passing through the training spill. Standard errors are in parenthesis; overall relative survival estimates are weighted geometric means.

	Treatment		Reference		Relative
Test Block	n	CJS survival	n	CJS survival	survival
			RSW (spillbay 2)		
R01	90	0.968 (0.019)	193	0.974 (0.011)	0.993 (0.023)
R02	249	0.937 (0.016)	409	0.927 (0.013)	1.010 (0.022)
R03	104	0.885 (0.031)	219	0.932 (0.017)	0.950 (0.038)
R04	46	0.891 (0.046)	54	0.835 (0.051)	1.068 (0.085)
Overall	489	0.927 (0.012)	875	0.933 (0.009)	0.997 (0.013)
			Training spill (spillbays 3, 4, 5, 7, and 9)		
R01	13	0.923 (0.074)	193	0.974 (0.011)	0.947 (0.077)
R02	138	0.922 (0.023)	409	0.927 (0.013)	0.995 (0.029)
R03	62	0.841 (0.046)	219	0.932 (0.017)	0.903 (0.052)
R04	11	0.818 (0.116)	54	0.835 (0.051)	0.980 (0.152)
Overall	224	0.894 (0.021)	875	0.933 (0.009)	0.973 (0.021)

Latent Mortality Analysis

As detailed in Methods above, estimates of Ice Harbor project and passage route survival for radio-tagged subyearling Chinook salmon were constructed using the Cormack-Jolly-Seber single-release model (CJS). Estimates were generated for fish passing the dam (treatment) and released in the tailrace (reference), and the ratio of these was used to estimate the specific survival component through the project or each passage route (i.e. spillway, RSW, turbine, and juvenile bypass system). The data used in generating these estimates was obtained from radiotelemetry detections downstream from Ice Harbor Dam at Sacajawea Park, the Railroad Bridge just below the confluence of the Snake and Columbia Rivers, and the forebay of McNary Dam. Detections at Sacajawea Park were used as the primary "detection array" or "recapture period" and all detections downstream from this location were used as the secondary "detection array" in the CJS model.

The CJS model specifically estimated project survival from the entry line above the Ice Harbor Dam forebay, or passage survival from detection at the upstream end of each route, to Sacajawea Park. Similarly, tailrace-released reference survival was estimated from release to Sacajawea Park. Therefore, the ratio of treatment to reference CJS estimates produced appropriate estimates of project-specific (i.e. forebay to tailrace) or passage-route-specific (i.e. passage route to tailrace) survival if the "treatment effect" was fully expressed before fish passed Sacajawea Park. If fish were injured due to passage through a particular route and survived below Sacajawea Park before dying, this model design would underestimate the "true" treatment effect.

We examined whether this bias occurred by making similar ratio estimates using data only from detections downstream from Sacajawea Park. If the bias occurred, these ratios would yield lower survival estimates than the original estimates. For these ratios, we did not use data from Railroad Bridge detections because that location was quite close to Sacajawea Park. This left two options. One was to use only radiotelemetry detections in the forebay of McNary Dam, and the other was to use these detections in conjunction with PIT-tag detections at John Day and/or Bonneville Dams. The second option was not pursued primarily due to relatively small numbers of PIT-tag detections at dams, as well as possible assumption violations due to using two different tagging methodologies.

We assessed survival using only detections in the McNary Dam forebay. The proportions detected there were products of the estimates of "survival from release to McNary forebay" and "detection at the McNary forebay." We assumed that detection probabilities were similar between treatment and reference fish (assessed elsewhere in this report), and therefore, the ratio of treatment to reference detection proportions was an estimate of passage route-to-tailrace survival. (Note that project survival could be estimated similarly, but we did not make those estimates under the assumption that the potential bias we were assessing would most likely occur for injury/mortality in passage routes rather than in the Ice Harbor Dam forebay.)

Weighted geometric means (as described in the report) of survival for each passage route under both dam operation condition were compared between the Sacajawea Park-based and McNary Dam forebay-based approaches. We compared the estimates using *t*-tests under the null hypothesis that the McNary forebay estimates were similar to the Sacajawea Park estimates. Since the study was not designed to evaluate these different approaches, only substantial differences would be expected to be significant ($\alpha = 0.05$).

There were significant differences between Ice Harbor Dam passage-route survival estimates using these two approaches for radio-tagged subyearling Chinook salmon passing primarily via spill during the "bulk spill" treatment periods, but not for any passage route during RSW operation (Table 14). In nearly all cases, estimated survival was lower using the McNary Dam forebay approach. During the RSW operation, the differences were fairly small (4%) and highly variable, while during the bulk spill operation, survival was 100% for Sacajawea Park-based estimates, but only 89% for McNary forebay-based estimates.

It does appear possible that mortality experienced by subyearling Chinook salmon passing through the Ice Harbor Dam spillway under the bulk spill operation may not have been expressed until after the fish passed Sacajawea Park. However, since this study was not designed to assess survival of radio-tagged fish to McNary Dam forebay (i.e. by including telemetry detection below McNary Dam), we cannot rule out the possibility that our results are somewhat due to the two groups having dissimilar detection probabilities at the McNary Dam forebay detection array.

Table 14. Weighted geometric means of survival for each passage route under both treatments were compared between Sacajawea Park and McNary Dam forebay survival transects for river-run, radio-tagged subyearling Chinook salmon, 2005.

Test	Passage	IHR to SAC		IHR to MCN (Rel Rec)					
Group	route	S	se	S	SE	Difference	SE	*t*-test	*P*-value
Bulk	Spill	1.00	0.01	0.89	0.03	0.11	0.03	3.48	0.01
	All	1.00	0.01	0.89	0.03	0.11	0.03	3.48	0.01
RSW	Bypass	0.99	0.04	1.01	0.12	-0.02	0.13	0.16	0.88
	RSW	1.00	0.01	0.96	0.04	0.04	0.04	0.97	0.37
	Spill	0.97	0.02	0.93	0.04	0.04	0.04	0.89	0.41
	All	0.99	0.02	0.95	0.04	0.04	0.04	0.89	0.41

Avian Predation

When the Crescent Island Caspian Tern colony had left the island for the season, we initiated a recovery effort for the radio tags that were deposited on the island. There were 133 total mortalities recorded within the tern colony, representing approximately 3.2% of the fish we released into the Snake River. Tern predation accounted for 3.1% of the fish we released into the forebay of Ice Harbor Dam as treatment fish and 3.2% of the fish that were released into the tailrace of Ice Harbor Dam as reference fish.

DISCUSSION

As reported above, we began tagging after 38% of the juvenile subyearling Chinook salmon had passed Lower Monumental Dam and finished when 80% of these fish had passed. In 2005, the subyearling Chinook salmon run at Lower Monumental Dam began migrating past the dam during the beginning of the observed 10-year average and were of size that allowed us to tag the target portion of the run.

Operations at Ice Harbor 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 quickly. The median forebay residence times were not significantly different between bulk and RSW spill operations with only a 0.96-h difference ($P = 0.230$). There was a tendency for forebay residence times to be slightly shorter during bulk spill operations, which could be attributed to the increased flow through fewer spillbays.

The variation of spill treatment blocks (Table 5) appeared to have a small effect on passage distribution and fish passage metrics at Ice Harbor Dam. Previous studies have shown that the majority of yearling Chinook salmon typically pass through the spillway with relatively few entering either powerhouse route (Eppard et al. 2000). Nearly 98% of radio-tagged river-run subyearling Chinook salmon during bulk spill and 87% during RSW spill passed via the spillway. For RSW spill, 60% of the subyearling Chinook salmon passed through the RSW in spillbay 2. There was a tendency during RSW spill for fish to be attracted toward the powerhouse. There were 11% more fish passing through the turbines and juvenile bypass system during RSW spill operations than bulk spill operations. This may have been due to an increased flow-net created by turbine loading during RSW spill operations.

Spill efficiency, spill effectiveness, and fish passage efficiency were not significantly different between bulk and RSW spill operations. Although tailrace egress was slightly longer for fish that passed during RSW spill than during bulk spill, the difference was not statistically significant. Ninety percent of all radio-tagged fish passing through the spillway exited the tailrace in less than 30 minutes. Based on both survival estimates and timing through the tailrace, predation on fish in the tailrace appears to be minimal.

We found no statistically significant difference between survival estimates for radio-tagged fish passing through the spillway or the dam as a whole during bulk or RSW spill operations. Overall, it appears that the RSW was extremely effective in passing more fish with less water. Survival estimates were not different between treatments and the RSW provided very high survival. A reduction in spill through spillbay 1 may allow for more subyearling Chinook salmon to be directed away from the powerhouse and through the RSW. This may also increase passage metrics resulting in fewer turbine passed fish as spill levels are decreased.

Survival estimates between years are not directly comparable due to the differences among years in the tagging methodologies used and spill patterns evaluated. However, estimates of subyearling Chinook salmon survival through spillway have increased over the past few years. Eppard et al. (2002) reported spillway survival at 88.5% (PIT tag) for subyearling Chinook salmon in 2000. Since then, improved spill patterns and the installment of the RSW have increased survival estimates up to 98-100% (radio tag) for subyearling Chinook salmon in 2005.

As requested by the Walla Walla District USACE, we assessed latent mortality to McNary Dam forebay (see results section above) for radio-tagged subyearling Chinook salmon passing Ice Harbor Dam via the spillway. However, this request came after field operations for the study had finished, and it is important to note that the study was not designed to estimate survival to McNary Dam forebay. The technique used to assess latent mortality to the McNary Dam forebay did indicate lower estimated survival than indicated by the traditional technique (based on detections from the array at Sacajawea Park for the bulk spill treatment). However, installation of radio telemetry detection arrays below McNary Dam would be required for a valid comparison of the two survival estimates. A study may be needed in the future to understand whether latent mortality is occurring and what its effects may be.

ACKNOWLEDGMENTS

We express our appreciation to all who assisted with this research. We thank the U.S. Army Corps of Engineers (Walla Walla District) who funded this research. We particularly thank Ken Fone (Lower Monumental Dam Project Biologist), Mark Plummer (Ice Harbor Dam Project Biologist), Brad Eby (McNary Dam Project Biologist), and Tim Wik, Ann Setter, Mark Smith, Marvin Shutters, Dave Hurson, and Rebecca Kalamasz (Walla Walla Environmental Analysis Branch) for their help coordinating research activities at Lower Monumental and Ice Harbor Dams and the Ice Harbor Dam operators for their time and patience during equipment installation and fish releases. Monty Price and the staff of the Washington Department of Fish and Wildlife provided valuable assistance with the collecting and sorting of study fish. Carter Stein and staff of the Pacific States Marine Fisheries Commission provided valuable assistance in data acquisition. For their ideas, assistance, encouragement, and guidance, we also thank Thomas Ruehle, Scott Davidson, Ronald Marr, Byron Iverson, Sam Rambo, Mark Kaminski, Jeffrey Moser, Galen Wolf, and Douglas Dey of the Fish Ecology Division, Northwest Fisheries Science Center, National Marine Fisheries Service.

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 (Onchorynchus 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.

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.

Connor, W. P., J. G. Sneva, K. F. Tiffan, R. K. Steinhorst, and D. Ross. 2005. Two alternative juvenile life history types for fall Chinook salmon in the Snake River Basin. Transactions of the American Fisheries Society 134:291-304.

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.

Iwamoto, R. N., W. D. Muir, B. P. Sandford, K. W. McIntyre, D. A. Frost, J. G. Williams, S. G. Smith, and J. R. Skalski. 1994. Survival estimates for the passage of juvenile salmonids through dams and reservoirs. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Project 93-29, Contract DE_AI79-93BP10891.

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

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.

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

Mehta, C., and N. Patel. 1992. StatXact User’s Manual. Cytel Software Corp., Cambridge, MA 02139.

Muir, W. D., C. Pasley, P. Ocker, R. Iwamoto, T. Ruehle, and B. P. Sandford. 1995a. Relative survival of juvenile chinook salmon after passage through spillways at Lower Monumental Dam, 1994. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla District, Contract E86940101.

Muir, W. D., S. G. Smith, E. E. Hockersmith, S. Achord, R. F. Absolon, P. A. Ocker, B. M. Eppard, T. E. Ruehle, J. G. Williams, R. N. Iwamoto, and J. R. Skalski. 1996. Survival estimates for the passage of yearling chinook salmon and steelhead through Snake River dams and reservoirs, 1995. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Contract DE-AI79-93BP10891, Project 93-29, and to the U.S. Army Corps of Engineers, Project E86940119.

Muir, W. D., S. G. Smith, R. N. Iwamoto, D. J. Kamikawa, D. W. McIntyre, E. E. Hockersmith, B. P. Sandford, P. A. Ocker, T. E. Ruehle, J. G. Williams, and J. R. Skalski. 1995b. Survival estimates for the passage of juvenile salmonids through Snake River dams and reservoirs, 1994. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Contract DE-AI79-93BP10891, Project 93-29, and to the U.S. Army Corps of Engineers, Project E86940119.

Muir, W. D., S. G. Smith, K. W. McIntyre, and B. P. Sandford. 1998. Project survival of juvenile salmonids passing through the bypass system, turbines, and spillways with and without flow deflectors at Little Goose Dam, 1997. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla District, Contract E8670085.

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). 2000. Reinitiation of consultation on operation of the Federal Columbia River power system, including the juvenile fish transportation program and 19 Bureau of Reclamation projects in the Columbia Basin. Endangered Species Act - Section 7 Consultation, Biological Opinion. www.nwr.noaa.gov/1hydrop/hydroweb/docs/Final/2000Biop.html (April 2005).

NWFSC (Northwest Fisheries Science Center). 2002. National Marine Fisheries Service Salmon Research Plan Vol. I & II. Northwest Fisheries Science Center, Seattle, WA. Available online at research.nwfsc.noaa.gov/.

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, E. E. Hockersmith, S. Achord, M. B. Eppard, T. E. Ruehle, J. G., Williams, and J. R. Skalski. 1998. Survival estimates for the passage of juvenile salmonids through Snake River dams and reservoirs, 1996. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland, Oregon, Contract DE-AI79-93BP10891, Project 93-29.

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

Evaluations 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 close to 100% for both treatment (97.8%) and reference groups (98.2%) (Appendix Table A1). With detection probabilities at or near 100% for all fish, there was no disparity between detection of treatment and reference groups.

Appendix Table A1. Detection probabilities at Ice Harbor Dam for evaluating survival of river-run, subyearling Chinook salmon passing

	Treatment group		Reference group	
Operations group	$\hat{p}$	SE	$\hat{p}$	SE
		Bulk spill		
B1	0.979	0.021	0.984	0.011
B2	0.974	0.009	0.978	0.007
B3	0.964	0.014	0.991	0.007
B4	0.997	0.003	0.992	0.004
		RSW spill		
R1	0.961	0.017	0.984	0.009
R2	0.967	0.009	0.971	0.009
R3	0.987	0.009	0.980	0.010
R4	1.000	0.000	0.976	0.024
Mean	0.978	0.010	0.982	0.010

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 by using contingency tables (chi-square goodness-of-fit) to test for differences in arrival distributions. The treatment fish at Ice Harbor Dam were paired with the release reference fish by the project operations at the time of treatment fish passage. *P*-values were calculated using the Monte Carlo approximation of the exact method described in the StatXact software user manual (Mehta and Patel 1992; $\alpha < 0.05$).

Treatment and corresponding reference groups were not evenly mixed at the Sacajawea Park detection array. However, differences in temporal arrival distributions between treatment and reference groups at Sacajawea Park were small. Nearly all fish from both groups were detected within a few hours after passage or release (Appendix Tables A2 and A3). Treatment fish passed Ice Harbor Dam almost continuously, while reference groups were released over a few hours twice daily. Since Sacajawea Park is relatively close to Ice Harbor Dam, the reference groups did not necessarily spread out sufficiently before passing that location. All but one of the tests proved not significant (Appendix Table A4). It is reasonable to conclude that the survival estimates were not significantly biased by violation of the assumption regarding mixing through the common reach.

Appendix Table A2. Passage distribution at Sacajawea Park for treatment (T) and reference (R) groups of radio-tagged, river-run subyearling Chinook salmon used for estimating relative dam and spillway survival at Ice Harbor Dam during periods of bulk spill, 2005.

Detection	B01		B02		B03		B04	
date	T	R	T	R	T	R	T	R
10-Jun	0.06	0.21						
11-Jun	0.48	0.46						
12-Jun	0.44	0.31						
13-Jun	0.02	0.01						
14-Jun		0.01	0.13	0.11				
15-Jun			0.30	0.26				
16-Jun			0.19	0.23				
17-Jun			0.25	0.24				
18-Jun			0.12	0.16				
19-Jun								
20-Jun								
21-Jun								
22-Jun			0.01		0.32	0.34		
23-Jun					0.41	0.42		
24-Jun					0.26	0.22		
25-Jun					0.01			
26-Jun						0.01	0.11	0.11
27-Jun						0.01	0.24	0.24
28-Jun							0.29	0.27
29-Jun							0.28	0.26
30-Jun							0.08	0.12
1-Jul								

Appendix Table A3. Passage distribution at Sacajawea Park for treatment ***T*** and reference ***R*** groups of radio-tagged, river-run subyearling Chinook salmon used for estimating relative dam and spillway survival at Ice Harbor Dam during periods of RSW spill, 2005.

Detection	R01		R02		R03		R04	
date	T	R	T	R	T	R	T	R
10-Jun								
11-Jun								
12-Jun	0.21	0.28						
13-Jun	0.51	0.49						
14-Jun	0.26	0.23						
15-Jun	0.01							
16-Jun	0.01							
17-Jun								
18-Jun			0.14	0.14				
19-Jun			0.26	0.27				
20-Jun			0.29	0.28				
21-Jun			0.27	0.24				
22-Jun			0.03	0.07				
23-Jun			0.01					
24-Jun					0.20	0.24		
25-Jun					0.50	0.50		
26-Jun					0.27	0.26		
27-Jun					0.02			
28-Jun								
29-Jun					0.01			
30-Jun							0.81	0.48
1-Jul							0.19	0.52

Appendix Table A4. Test of homogeneity of arrival timing at the Sacajawea survival transect for treatment (forebay) and reference groups (tailrace) of radio-tagged, subyearling Chinook salmon used for estimating survival at Ice Harbor Dam. The treatment fish at Ice Harbor Dam were paired with the reference fish according to project operations at the time of passage.

Treatment Group	χ^2	Degrees of freedom	*P*-value
		Bulk Spill	
B1	7.01	4	0.119
B2	8.24	6	0.185
B3	3.89	5	0.636
B4	4.84	4	0.308
		RSW Spill	
R1	4.68	5	0.482
R2	8.19	7	0.286
R3	2.37	4	0.731
R4	12.37	1	0.000

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 which is used to estimate survival for the passage route.

The distance between our releases in the Ice Harbor Dam tailrace and our 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 4,320 tags were implanted in river-run subyearling Chinook salmon of which 11 (0.3%) were not working 24h after tagging. Tags which were not functioning properly were not used in the study.

In addition, a total of 63 radio transmitters 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. Forty-six tags (73%) failed prior to the preprogrammed shut-down after 10d (Appendix Table A5). Of these only 2 (3.2%) failed within 5d of activation. Median travel time from release to the primary survival line at Sacajawea Park was 0.4d overall with less than 0.6% of the fish taking 5d or more to reach the primary survival line (Appendix Table A6). Although we documented transmitters failing during our study the short travel times to our survival line were such that they would not have significantly changed our findings.

Appendix Table A5. Number of days tags lasted in tag life testing.

Tags (n)	Tag life (d)	Tags (%)
0	1	0.0
1	2	1.6
0	3	0.0
0	4	0.0
1	5	1.6
31	6	49.2
0	7	0.0
8	8	12.7
5	9	7.9
10	10	15.9
7	11	11.1

Appendix Table A6. Travel time from release to detection at primary survival line at Sacajawea Park for river-run subyearling Chinook salmon released into the forebay and tailrace of Ice Harbor Dam, 2005.

	Travel time(d) to Primary Survival line at Sacajawea Park		
Percentile	Forebay	Tailrace	Overall
Min	0.2	0.0	0.0
10	0.4	0.2	0.2
20	0.6	0.2	0.2
30	0.7	0.2	0.2
40	0.8	0.8	0.3
50	1.0	0.2	0.4
60	1.1	0.3	0.6
70	1.4	0.3	0.8
80	1.7	0.3	1.1
90	2.5	0.4	1.7
Max	7.9	5.9	7.9
n	1651	1949	3600
Travel time > 5d	22 (1.3%)	1 (0.1%)	23 (0.6%)

APPENDIX B

Telemetry Data Processing and Reduction Flowchart

Overview

The database stores the data collected for the Juvenile Salmon Radio Telemetry project in the Fish Ecology Division at NOAA Fisheries' 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") surgically implanted into the 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 available for 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.

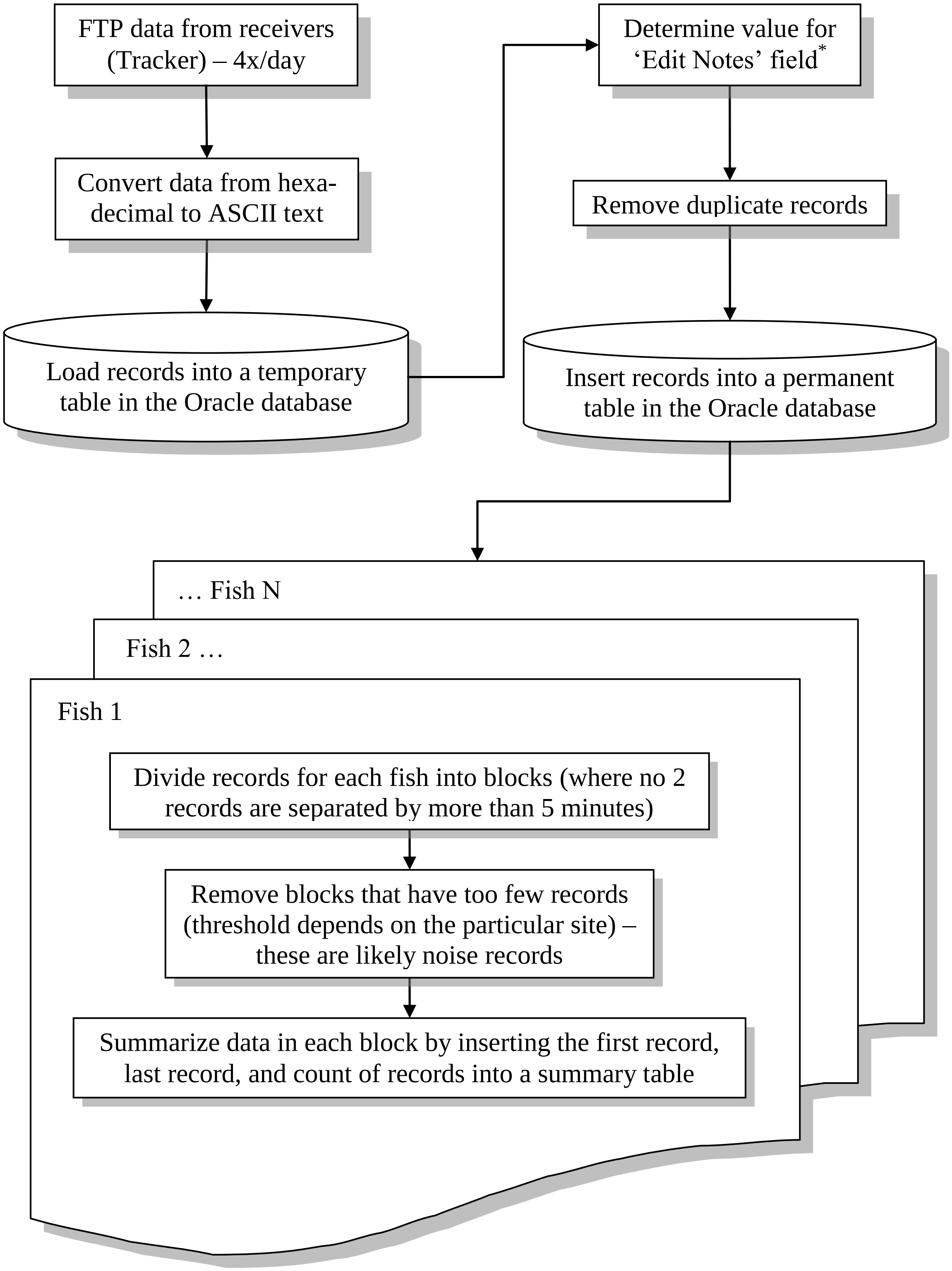
B. Data Validation During the validation process, the records stored in the preliminary tables are analyzed. We determine which study year, site identifier, antenna identifier, and tag identifier they belong to, flagging them as invalid if one or more of these relationships cannot be determined. Records 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).
- Gt end time: Assigned to records occurring after the end time on a tag (they run for 10 days once activated).
- 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/minute). Such patterns indicate 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) – 4x/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 minutes)
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