Passage Behavior and Survival for River-run Subyearling Chinook Salmon at Ice Harbor Dam, 2004

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EXECUTIVE SUMMARY

Recent studies to evaluate spillway-passage at Ice Harbor Dam have resulted in lower-than-expected survival estimates. It was hypothesized, based on research from 2003, that increasing the volume of water spilled through individual bays would increase survival for fish passing that route. To increase the volume of water through individual spillbays, fewer bays were opened to spill total amounts equivalent to spill volumes mandated by the 2000 National Marine Fisheries Service biological opinion for nighttime spill (100% of river flow or to total dissolved gas limits). This pattern was termed “bulk” spill. To test this hypothesis, in 2004, Ice Harbor Dam was operated in a 4-day block study design where the spillway was operated under a bulk spill pattern for 2 d followed by 2 d of a “flat” spill pattern (daytime spill of 45 kcfs through all 10 bays).

Subyearling Chinook salmon were collected and radio tagged (surgical implants) at Lower Monumental Dam on the Snake River. From 25 June through 21 July, 2,121 radio-tagged fish were released above Ice Harbor Dam. Of these, 1,375 entered the forebay of Ice Harbor Dam and were regrouped by arrival date and time for evaluations of passage behavior and estimates of spillway and dam passage survival. To estimate relative survival through the dam and spillway, 2,111 additional radio-tagged fish were released into the tailrace of Ice Harbor Dam. For the survival estimates, we used detections from arrays installed at multiple locations between Ice Harbor Dam on the lower Snake River and Irrigon, Oregon, on the lower Columbia River.

Both spill operations were effective at guiding fish to the spillway, with spill efficiency estimates of 93.3% (95% CI, 89.1-97.5) under bulk spill and 93.3% (95% CI, 87.6-98.9) under flat spill. Forebay residence times were short during both operations with median times of 3.0 h during bulk spill and 4.3 h during flat spill. Median tailrace egress times were 4.4 and 5.9 min for bulk and flat spill operations, respectively. Spillway passage survival for radio-tagged fish passing during bulk spill operation 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.

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INTRODUCTION

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). Recent studies to evaluate spillway passage at Ice Harbor Dam have resulted in lower-than-expected survival estimates. It was hypothesized, based on research from 2003, that increasing the volume of water spilled through individual bays would increase survival for fish passing that route. The preferred passage route for juvenile salmonids is through the spillway, since this is the passage option with the lowest mortality; the use of additional spill (within dissolved-gas water quality standards) for fish passage allows more smolts to avoid both turbine intakes and bypass systems (NMFS 2000).

Subyearling 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). The listing of salmonid stocks of the Columbia and Snake River Basins under the ESA (NMFS 1991, 1992, 1998, 1999) has led to consultation between the regional action agencies and the National Marine Fisheries Service (NMFS), resulting in a series of biological opinions. The current voluntary spill program specified in the 2000 biological opinion (NMFS 2000) calls for Ice Harbor Dam operations to spill volumes of water at or near the total dissolved gas limits to increase fish passage efficiency of migrating juvenile salmonids. The current spill program calls for daytime (0600-1800 PDT) spill volumes of 45,000 ft^3/s and nighttime spill volumes up to 100% of total river flow or to state and federal limits for total dissolved gas levels.

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 under a bulk spill pattern versus the standard flat spill pattern. Additionally, we evaluated behavior and timing for radio-tagged fish entering the forebay, approaching and passing the project, and exiting the tailrace of Ice Harbor Dam.

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

Bulk Spill: Spill pattern 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).

Flat Spill: Standard flat spill pattern using all bays at a maximum gate opening of 3 stops and with volumes equivalent to BiOp-recommended daytime spill (45,000 ft3/s).

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.

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

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 of the dam.

Route survival: Relative survival between detection within a passage route at Ice Harbor Dam and release location of reference groups downstream of 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 an 88-km reach of the Snake and Columbia Rivers from Ice Harbor Dam to Irrigon, Oregon (Figure 1). Ice Harbor Dam, the first dam on the Snake River, is located 16 km upstream from the confluence of the Snake and Columbia Rivers. Irrigon is located 455 km upstream from the mouth of the Columbia River. Additional radiotelemetry transects used for estimating survival at Ice Harbor Dam were located at the mouth of the Snake River at Sacajawea Park and at Port Kelley, Washington (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 12 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. Each radio tag measured 16 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 400 mm^3. The tags weighed 0.96 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. Immediately following tagging, fish were 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

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

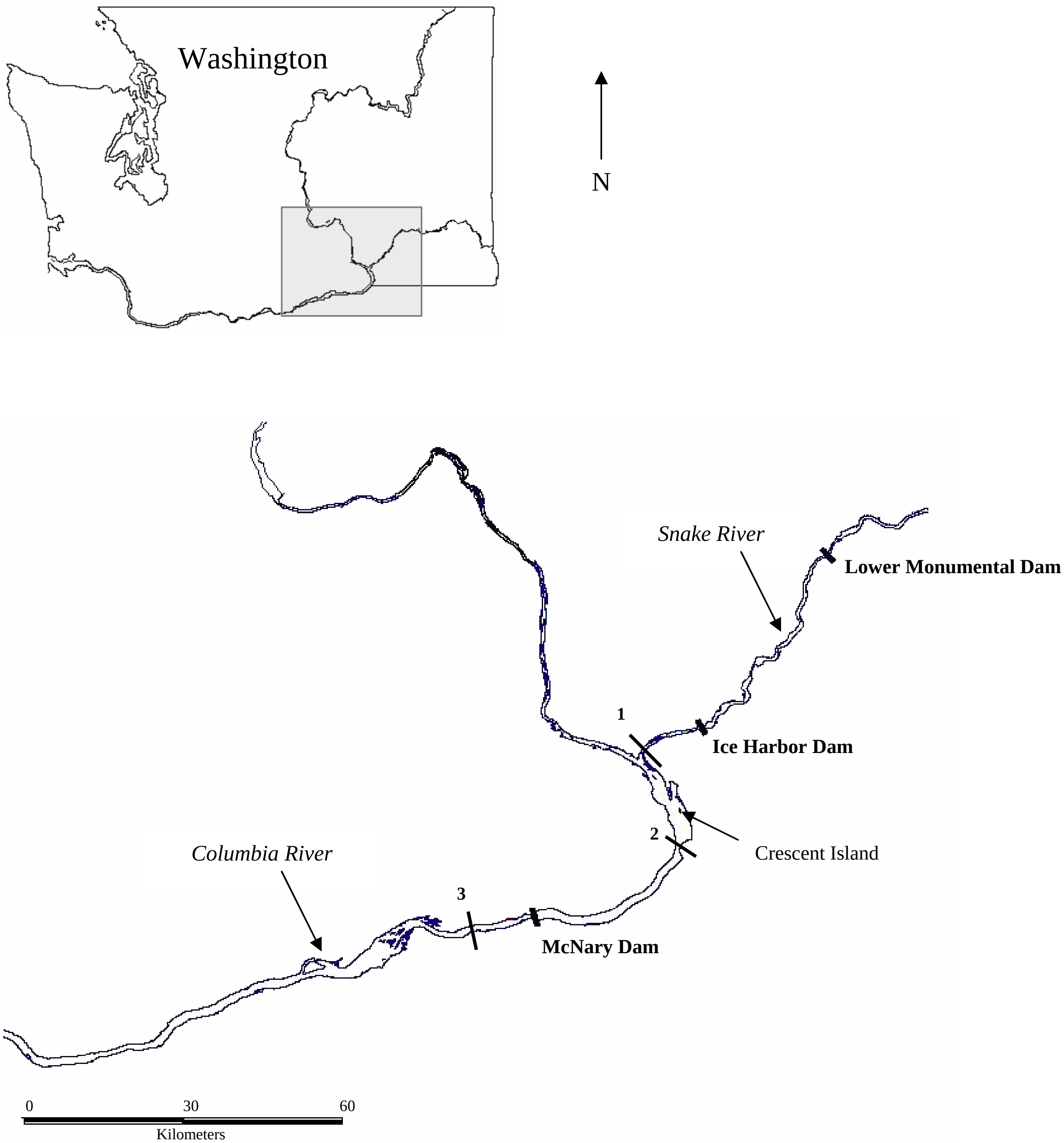

Figure 1. Study area showing location of radiotelemetry transects used for estimating survival at Ice Harbor Dam, 2004. Note: 1 = Mouth of the Snake River at Sacajawea Park, WA; 2 = Port Kelley, WA; 3 = Irrigon, OR.

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 0900 and 1645 PDT. Nighttime releases occurred between 2000 and 0530 PDT. We released 26 groups of approximately 26-72 fish per group. A total of 2,121 radio-tagged fish were released 3.7 km upstream of Ice Harbor Dam during both daytime and nighttime project operations. A total of 2,111 radio-tagged fish were released 2 km downstream of 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 Irrigon, Oregon (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. Underwater antennas were used to monitor passage routes (Figures 2 and 3). Monitored passage routes included the juvenile fish bypass system, individual spillbays, and all turbine unit gate slots (gatewells).

Telemetry data was retrieved through an automated process that downloaded network telemetry receivers up to four times daily. After downloading, individual data files were compressed by recording the first time a radio-tagged fish was detected and counting the number of subsequent detections at the same location where the time difference between detections was less than or equal to 1 min. When that difference became greater than 1 min, the last detection time was recorded and a new line of data was created. 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).

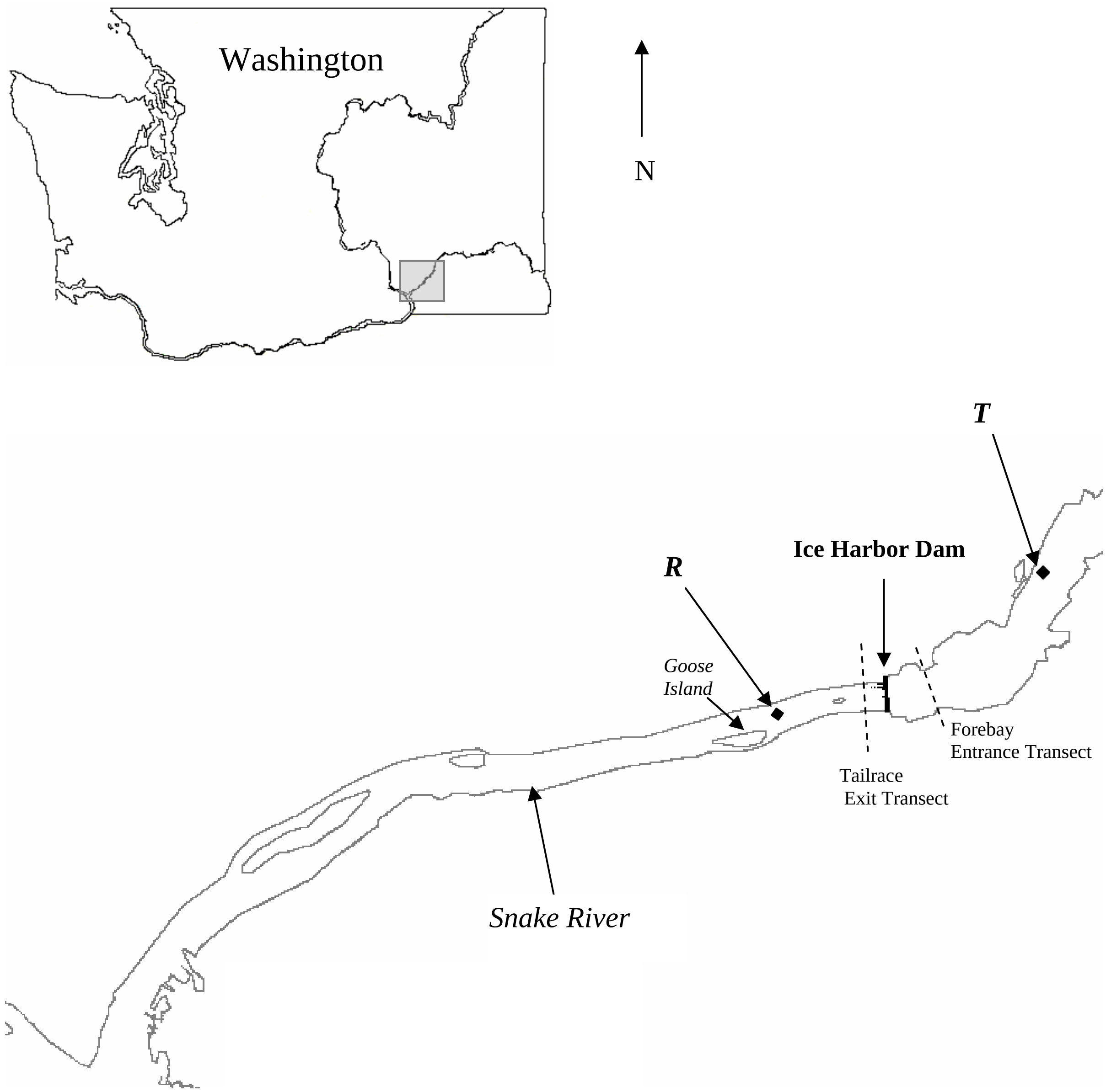

Figure 2. The Lower Snake River and Ice Harbor Dam showing release locations for treatment (***T***) and reference (***R***) groups of radio-tagged subyearling Chinook salmon, 2004. Also shown are radiotelemetry transects used to detect fish entering the immediate forebay (rkm 538.5) and subsequently exiting the tailrace (rkm 537.7), 2004.

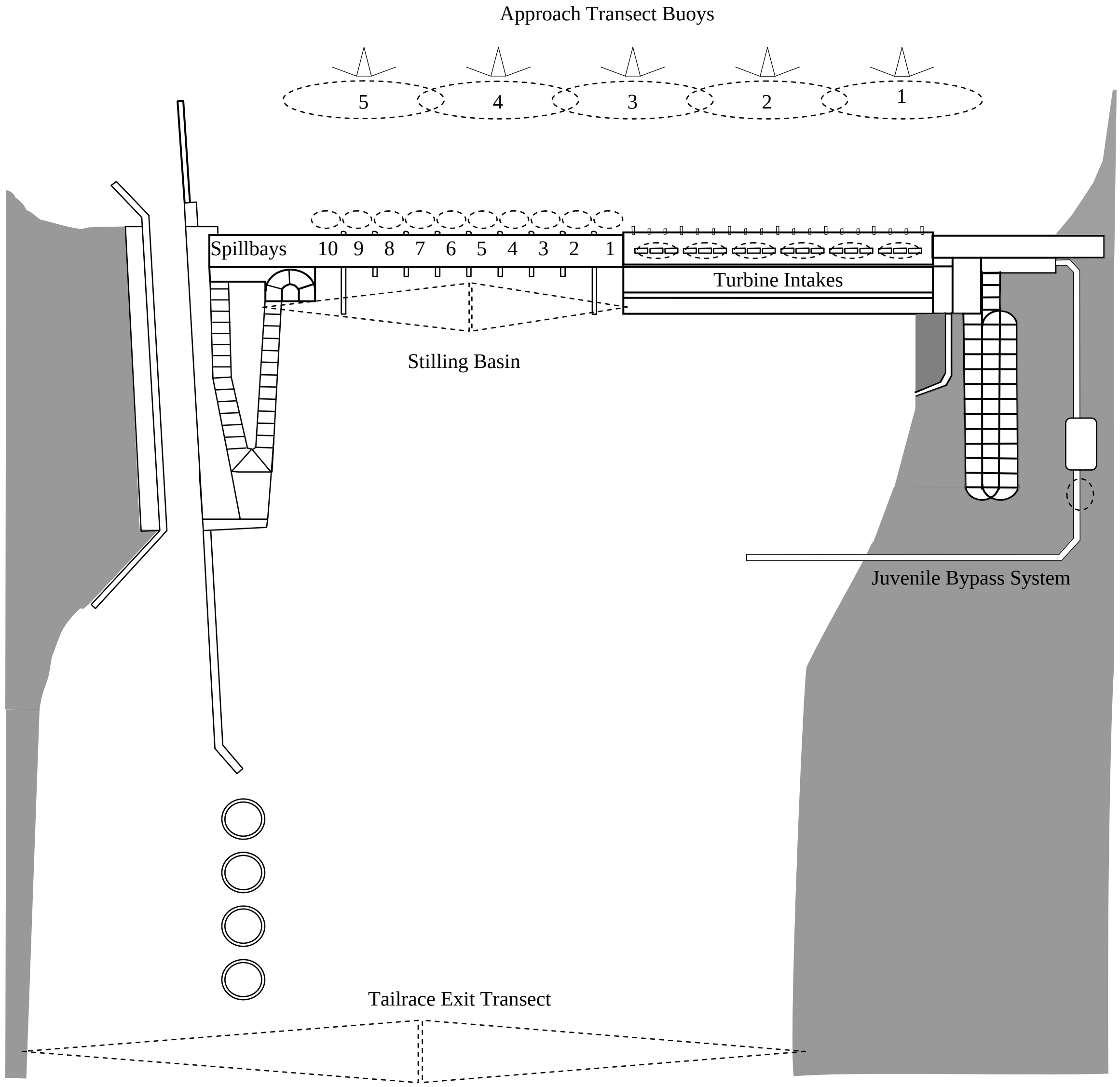

Figure 3. Plan view of Ice Harbor Dam showing approximate radiotelemetry detection zones in 2004. (Note: Dashed ovals represent underwater antennas. Dashed triangles represent aerial antennas.)

Using the detailed detection history, we determined arrival time into the forebay, 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 on one of five telemetry buoys equally spaced across the lower forebay, 185 m upstream from the dam.

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 each spillbay. Similarly, turbine passage was assigned to fish last detected in a turbine intake prior to detection in the tailrace. Passage through the juvenile bypass system (JBS) was assigned to fish detected in the collection channel and/or bypass outfall pipe immediately downstream of the smolt monitoring facility 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).

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 detection on a passage-route receiver; tailrace egress was defined as the time from 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 a significant difference.

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. We used armored coaxial cable, stripped at the end, to detect fish passage in the turbine units and bypass system. 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.

We also placed an underwater antenna in the fish separator located upstream from the smolt monitoring facility. Fish that were detected on the fish screen antennas but were not subsequently detected on the PIT-detection system or the telemetry monitor located in the separator were designated as turbine-passed fish.

Fish Passage Metrics

The standard fish-passage metrics of spill efficiency, spill effectiveness, and fish passage 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 2004 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 26 d from 25 June to 21 July. Tagging began after 52% of the juvenile subyearling Chinook salmon had passed Lower Monumental Dam and was completed when 94% of these fish had passed (Figure 4). Overall mean fork length was 122.9 mm for treatment fish and 123.6 mm for reference fish (Table 1). Overall mean weight was 17.7 g for treatment fish and 17.6 g for reference fish (Table 2). Mean length and weight of the run at large sampled at the Lower Monumental smolt collection facility was 112.21 mm and 16.65 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 3.3%.

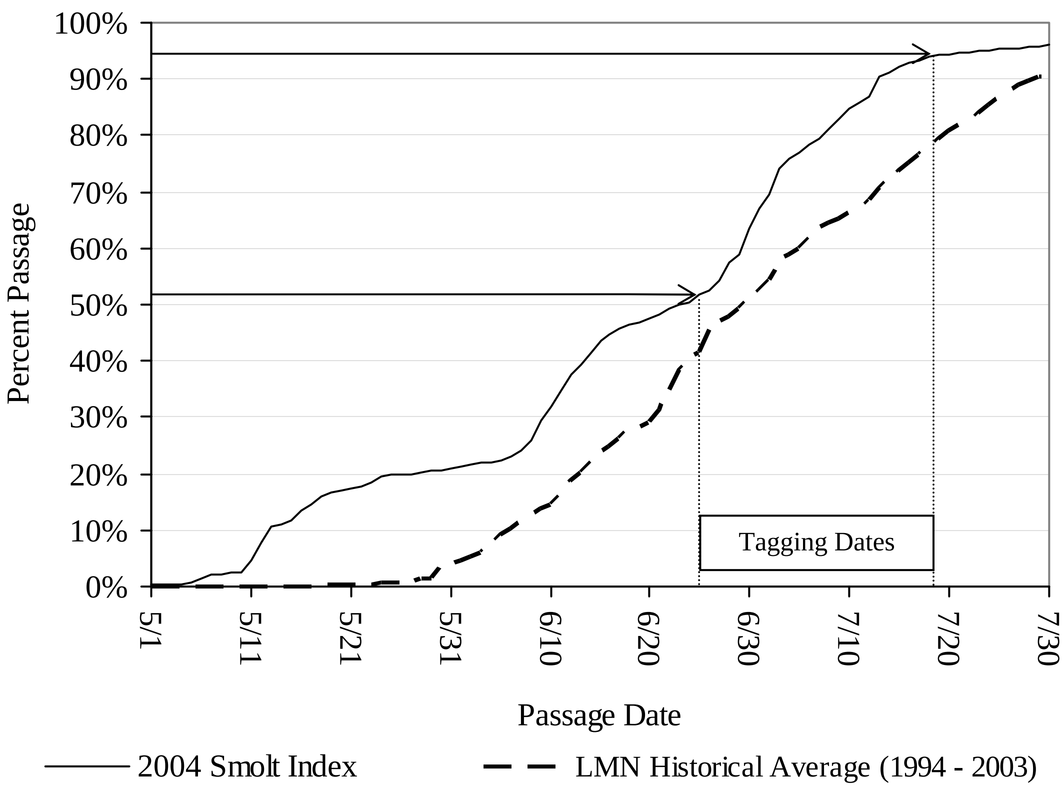

Figure 4. The 2004 cumulative distribution compared to the historical average (1994-2003) for subyearling Chinook salmon passing Lower Monumental Dam.

Table 1. 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 dam and spillway survival during bulk (B) and flat (F) spill patterns, 2004.

Test Block	Mean length of radio-tagged fish (mm)							
	Treatment				Reference			
	N	Mean	SD	Range	N	Mean	SD	Range
B01	161	117.1	3.8	111-130	162	116.9	4.1	109-133
B02	196	125.8	6.2	111-147	196	126.4	7.2	111-155
B03	---	---	---	-------	---	---	---	-------
B04	219	118.7	4.8	109-137	221	119.0	4.8	109-144
B05	215	124.6	5.1	114-144	215	124.1	4.7	114-138
B06	484	124.8	7.6	107-149	475	125.4	7.4	109-150
F01	207	126.2	6.9	110-151	214	126.5	5.9	113-145
F02	112	118.2	4.7	110-133	111	117.5	4.3	108-134
F03	90	118.6	6.6	109-149	88	118.2	4.9	104-130
F04	220	124.4	5.7	110-142	217	124.7	5.3	112-139
F05	217	122.7	6.2	110-145	213	127.5	6.3	113-146
Total	2,121	122.9	6.8	107-151	2,112	123.6	6.9	104-155

Table 2. 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 dam and spillway survival during bulk (B) and flat (F) spill patterns, 2004.

Test Block	Mean weight of radio-tagged fish (g)							
	Treatment				Reference			
	N	Mean	SD	Range	N	Mean	SD	Range
B01	161	15.2	1.7	12.3-21.7	162	15.0	1.8	12.0-26.1
B02	196	15.5	1.9	12.2-23.0	196	15.4	1.7	12.2-23.2
B03	---	---	---	-------	---	---	---	-------
B04	219	16.6	2.2	12.6-25.3	221	16.7	2.2	13.1-32.1
B05	215	18.3	2.0	14.1-31.0	215	18.2	2.1	14.1-26.8
B06	484	21.0	3.1	13.4-32.9	475	20.9	2.8	14.0-30.2
F01	207	15.6	2.6	12.2-42.4	214	15.5	2.0	12.1-32.4
F02	112	15.9	2.2	12.4-23.5	111	15.8	2.1	12.2-23.0
F03	90	16.1	2.5	12.8-27.5	88	16.0	2.2	11.8-23.5
F04	220	17.1	2.1	13.4-23.3	217	17.1	2.1	13.5-25.4
F05	217	18.4	2.2	14.1-27.5	213	18.6	2.3	14.3-28.7
Total	2,121	17.7	3.2	12.2-42.4	2,112	17.6	3.1	11.8-32.4

Table 3. Sample size, mean, median, range, and standard deviation (SD) of length (mm) by tagging date for smolt monitoring facility sampled, river-run, subyearling Chinook salmon at Lower Monumental Dam, 2004.

	Mean length (mm) smolt monitoring sample				
Date	N	Mean	Median	Range	SD
25-Jun	200	104.78	105.00	55.00-125.00	11.59
26-Jun	164	106.04	105.00	65.00-130.00	9.52
27-Jun	175	110.03	110.00	70.00-135.00	7.38
28-Jun	150	109.67	110.00	55.00-140.00	8.82
29-Jun	136	106.40	105.00	65.00-130.00	8.79
30-Jun	187	106.31	105.00	60.00-135.00	8.72
1-Jul	200	106.60	105.00	80.00-135.00	6.61
2-Jul	191	107.67	105.00	90.00-135.00	7.09
3-Jul	200	109.68	110.00	95.00-130.00	6.75
4-Jul	178	109.86	110.00	75.00-130.00	6.75
5-Jul	200	111.33	110.00	55.00-135.00	8.51
6-Jul	200	111.88	110.00	65.00-135.00	8.04
7-Jul	162	110.83	110.00	90.00-140.00	7.05
8-Jul	200	111.35	110.00	85.00-130.00	7.17
9-Jul	200	112.80	115.00	70.00-135.00	7.87
10-Jul	200	115.50	115.00	90.00-135.00	6.95
11-Jul	200	116.73	115.00	90.00-140.00	6.13
12-Jul	200	113.53	115.00	85.00-135.00	8.00
13-Jul	200	114.85	115.00	95.00-135.00	7.23
14-Jul	196	116.05	115.00	85.00-140.00	7.45
15-Jul	200	116.85	120.00	85.00-135.00	7.90
16-Jul	200	118.20	120.00	80.00-145.00	9.42
17-Jul	182	119.97	120.00	95.00-135.00	7.94
18-Jul	200	120.83	125.00	85.00-135.00	10.05
19-Jul	43	120.81	125.00	100.00-145.00	9.88
Total	4,614	112.21	110.00	55.00-145.00	9.24

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, 2004.

	Mean weight (g) smolt monitoring sample				
Date	N	Mean	Median	Range	SD
25-Jun	200	12.83	13.15	0.45-38.56	3.66
26-Jun	164	13.00	13.15	4.08-24.04	3.01
27-Jun	175	14.32	14.06	5.90-26.31	2.85
28-Jun	200	13.78	13.61	1.81-27.67	3.05
29-Jun	136	13.35	13.38	3.18-24.49	2.89
30-Jun	187	13.32	13.15	3.18-29.03	2.99
1-Jul	200	13.41	13.15	7.26-20.87	2.36
2-Jul	191	13.92	13.61	1.59-27.22	3.23
3-Jul	200	14.19	13.61	9.07-25.40	2.82
4-Jul	178	14.36	14.06	4.99-21.32	2.52
5-Jul	200	15.19	14.97	3.18-26.31	3.26
6-Jul	200	15.74	15.42	4.08-25.40	3.11
7-Jul	162	16.11	15.88	9.07-30.39	2.86
8-Jul	200	17.06	17.24	7.26-25.40	2.93
9-Jul	200	16.91	17.24	4.54-26.76	3.11
10-Jul	200	18.01	17.69	9.07-28.12	2.97
11-Jul	200	18.75	18.60	9.53-35.83	3.00
12-Jul	200	17.62	18.14	7.26-29.94	3.31
13-Jul	200	18.78	18.82	10.43-26.76	3.23
14-Jul	196	19.90	19.96	9.07-31.75	3.64
15-Jul	200	20.23	20.41	8.62-28.58	3.70
16-Jul	200	20.67	20.87	6.35-34.93	4.37
17-Jul	182	21.88	22.23	9.98-30.39	3.99
18-Jul	200	22.81	23.59	7.71-33.57	4.96
19-Jul	43	22.68	22.68	11.34-36.74	5.29
Total	4,614	16.65	16.33	0.45-38.56	4.48

Project Operations

From 25 June to 21 July 2004, Ice Harbor Dam was operated in six 4-day block intervals with 2 d of bulk spill followed by 2 d of flat spill. 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 5). Mean spill was 38,500 ft^3/s during bulk spill and 45,800 ft^3/s during flat spill operations. Mean spill for each treatment group is displayed in Table 5. Spillbays opened during bulk spill operation were 3, 5, 7, and 9.

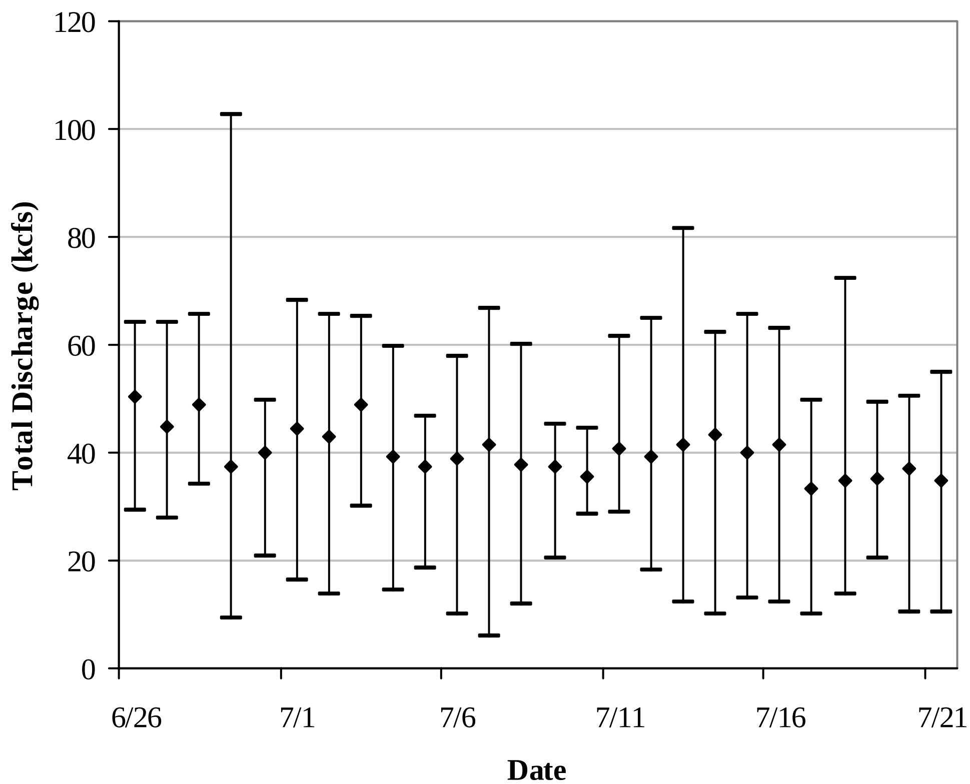

Figure 5. Average daily total project discharges at Ice Harbor Dam during the 2004 passage survival study (whisker bars represent the range of operations for each day).

Table 5. Mean, range, and standard deviation (SD) of operations and/or conditions by test block (B = bulk spill, F = flat spill) at Ice Harbor Dam, 2004.

Test block	Date range		Total discharge (1,000 ft^3/s)			Total spill (1,000 ft^3/s)			Spill proportion			Tailwater elevation (ft)		
	Start	End	Mean	Range	SD	Mean	Range	SD	Mean	Range	SD	Mean	Range	SD
			Bulk spill											
B01	6/26 07:10	6/28 04:55	47.3	27.7-64.2	11.3	40.6	20.0-55.2	11.6	0.8	0.7-1.0	0.1	340.7	339.1-342.4	0.9
B02	6/30 04:40	7/02 04:45	42.6	16.3-68.3	13.8	32.2	7.7-45.9	8.9	0.8	0.5-1.0	0.2	341.4	339.9-343.8	1.0
B03	7/04 04:50	7/06 06:40	36.7	10.1-59.6	11.8	30.3	10.1-45.5	10.3	0.8	0.5-1.0	0.1	340.3	338.3-342.0	0.9
B04	7/08 01:20	7/10 09:00	37.2	12.0-59.9	14.7	31.1	4.9-50.9	12.4	0.8	0.4-1.0	0.1	339.9	337.6-342.1	1.3
B05	7/12 04:55	7/14 07:00	38.6	10.0-81.3	20.3	32.0	8.4-69.8	19.3	0.8	0.4-1.0	0.2	340.1	337.5-343.6	1.7
B06	7/16 04:40	7/24 23:55	36.6	60.-72.3	15.5	29.4	0.0-60.7	13.9	0.8	0.0-1.0	0.2	340.5	338.2-343.6	1.2
			Flat spill											
F01	6/28 05:00	6/30 04:35	41.0	9.4-102.6	21.5	29.2	9.4-45.0	12.5	0.8	0.2-1.0	0.2	340.7	338.1-346.0	
F02	7/02 04:50	7/04 04:45	47.2	19.7-65.4	13.4	37.9	19.7-44.9	8.8	0.8	0.7-1.0	0.1	341.7	339.3-343.4	
F03	7/06 06:45	7/08 01:15	43.0	6.0-66.6	15.5	33.8	5.2-45.1	11.8	0.8	0.4-1.0	0.2	340.9	338.8-343.0	
F04	7/10 09:05	7/12 04:50	37.3	19.8-61.3	11.0	30.7	19.8-44.9	8.8	0.8	0.7-1.0	0.1	340.0	338.3-342.2	
F05	7/14 07:05	7/16 04:35	48.3	14.4-65.5	15.9	39.0	14.4-45.2	10.5	0.8	0.7 – 1.0	0.1	341.4	338.9-343.1	

Migration Behavior and Passage Distribution

Forebay Behavior and Timing

Of the 2,121 radio-tagged treatment fish released above Ice Harbor Dam, 1,375 were detected entering the forebay. Based on the time of first detection, 774 (56.3%) of these fish entered the forebay during bulk spill and 601 (43.7%) during flat spill operations. Of these same 1,375 fish, 871 (63.3%) were detected on the approach transect, with 488 (56.0%) detected during bulk spill and 383 (44.0%) during flat spill operations. For fish entering the immediate forebay during bulk spill operations, 74.4% were first detected on approach transect buoys in front of the spillway, and 25.6% on buoys in front of the powerhouse (Figure 6). During flat spill operations 68.7% were first detected on the approach transect buoys in front of the spillway and 31.3% on buoys in front of the powerhouse.

Forebay residence times were calculated for 1,042 fish, each with detections on both the forebay entrance transect and a passage-route receiver. Of these fish, 585 (56.1%) passed during bulk spill and 457 (43.9%) during flat spill. Median forebay residence times for these fish were 3.0 h during bulk and 4.3 h during flat spill (Table 6). We further calculated forebay residence time by operational test block. Forebay residence time was consistently longer during flat than during bulk spill operations (Figure 7); however, the difference was not statistically significant (P = 0.101).

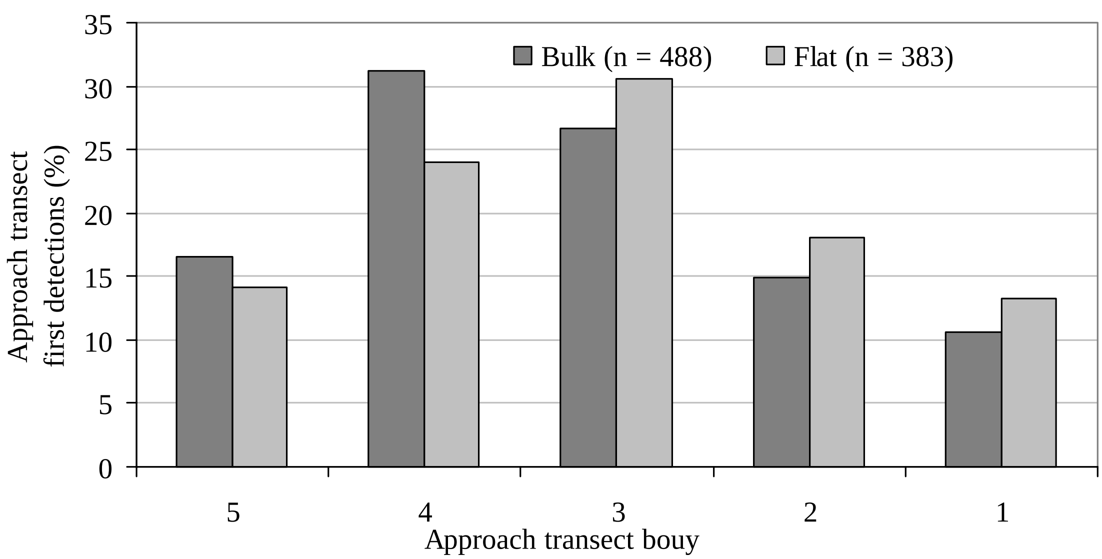

Figure 6. Approach patterns during bulk and flat spill for radio-tagged, river-run subyearling Chinook salmon in the forebay of Ice Harbor Dam, 2004 (see Figure 3 for location of approach transect buoys).

Table 6. Forebay residence time for radio-tagged, river-run subyearling Chinook salmon during bulk vs. flat spill at Ice Harbor Dam, 2004.

	Forebay residence time (h)	
Percentile	Bulk spill (n = 585)	Flat spill (n = 457)
Minimum	0.4	0.4
10th	0.9	1.0
20th	1.3	1.5
30th	1.7	2.2
40th	2.2	3.0
50th (median)	3.0	4.3
60th	4.3	5.6
70th	6.5	8.1
80th	10.0	12.0
90th	16.3	18.6
95th	22.3	26.0
100th	68.0	204.4

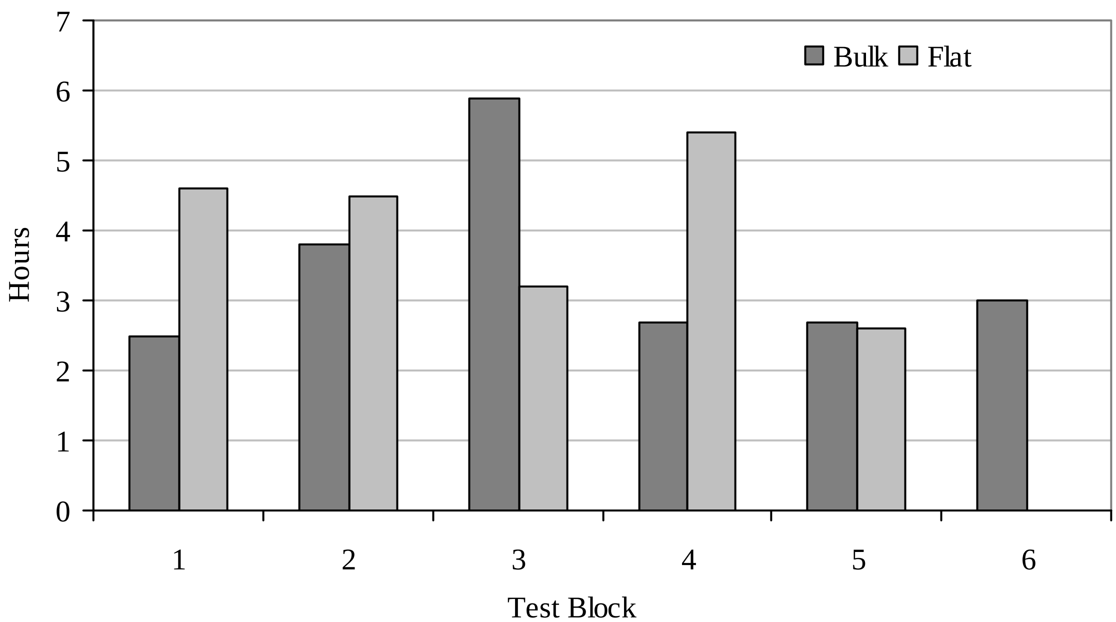

Figure 7. Median forebay residence times in hours by test block (see Table 1) for radio-tagged, river-run subyearling Chinook salmon during bulk and flat spill at Ice Harbor Dam, 2004.

Passage Distribution and Metrics

Of the 2,121 radio-tagged treatment fish released, 1,311 (61.8%) were detected at or below Ice Harbor Dam. Of these fish 1,055 (80.5%) passed the dam through the spillway, 26 (2.0%) through the juvenile bypass system, and 12 (0.9%) through turbines. Of the remaining 218 fish, 181 (13.8%) entered the forebay but were not recorded as passing the dam, and 37 (2.8%) 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 784 fish last detected during bulk spill operations, 612 (78.1%) passed through the spillway, 10 (1.3%) through the juvenile bypass, and 7 (0.9%) through turbines. Of the remaining 155 fish, 127 (16.2%) were never detected downstream from Ice Harbor Dam, and 28 (3.6%) passed through an undetermined route.

Of the 527 radio-tagged fish last detected in the forebay during flat spill operations, 443 (84.1%) passed the dam through the spillway, 16 (3.0%) through the bypass system, and 5 (0.9%) through turbines. Of the remaining fish, 54 (10.2%), were never detected downstream of Ice Harbor Dam, and 9 (1.7%) passed through an undetermined route (Figure 8). Distribution through individual spillbays is presented in Figure 9.

Fish passage efficiency (FPE) at Ice Harbor Dam was 0.948 (SE = 0.016, 95% CI 0.904-0.991) for bulk spill operations and 0.970 (SE = 0.016, 95% CI 0.920-1.020) for flat spill operations. Spill efficiency (SPE) was 0.933 (SE = 0.015, 95% CI 0.891-0.975) and 0.933 (SE = 0.018, 95% CI 0.876-0.989) for bulk and flat spill operations, respectively. Spill effectiveness was 1.15:1 (SE = 0.04, 95% CI 1.05-1.25) and 1.19:1 (SE = 0.05, 95% CI 1.04-1.34) for bulk and flat spill operations, respectively. Minimum and maximum estimates for test blocks are shown in Table 7.

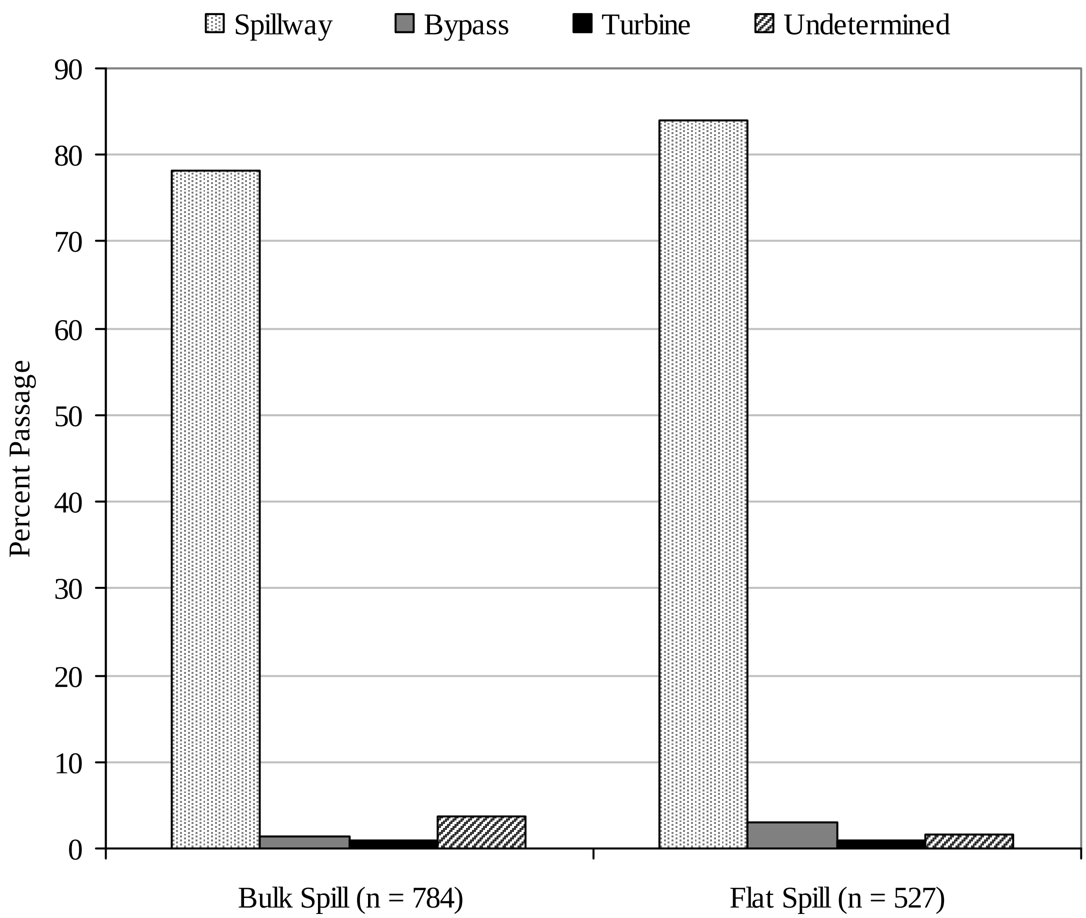

Figure 8. Passage distribution of radio-tagged, subyearling Chinook salmon during bulk spill and flat spill operations at Ice Harbor Dam, 2004.

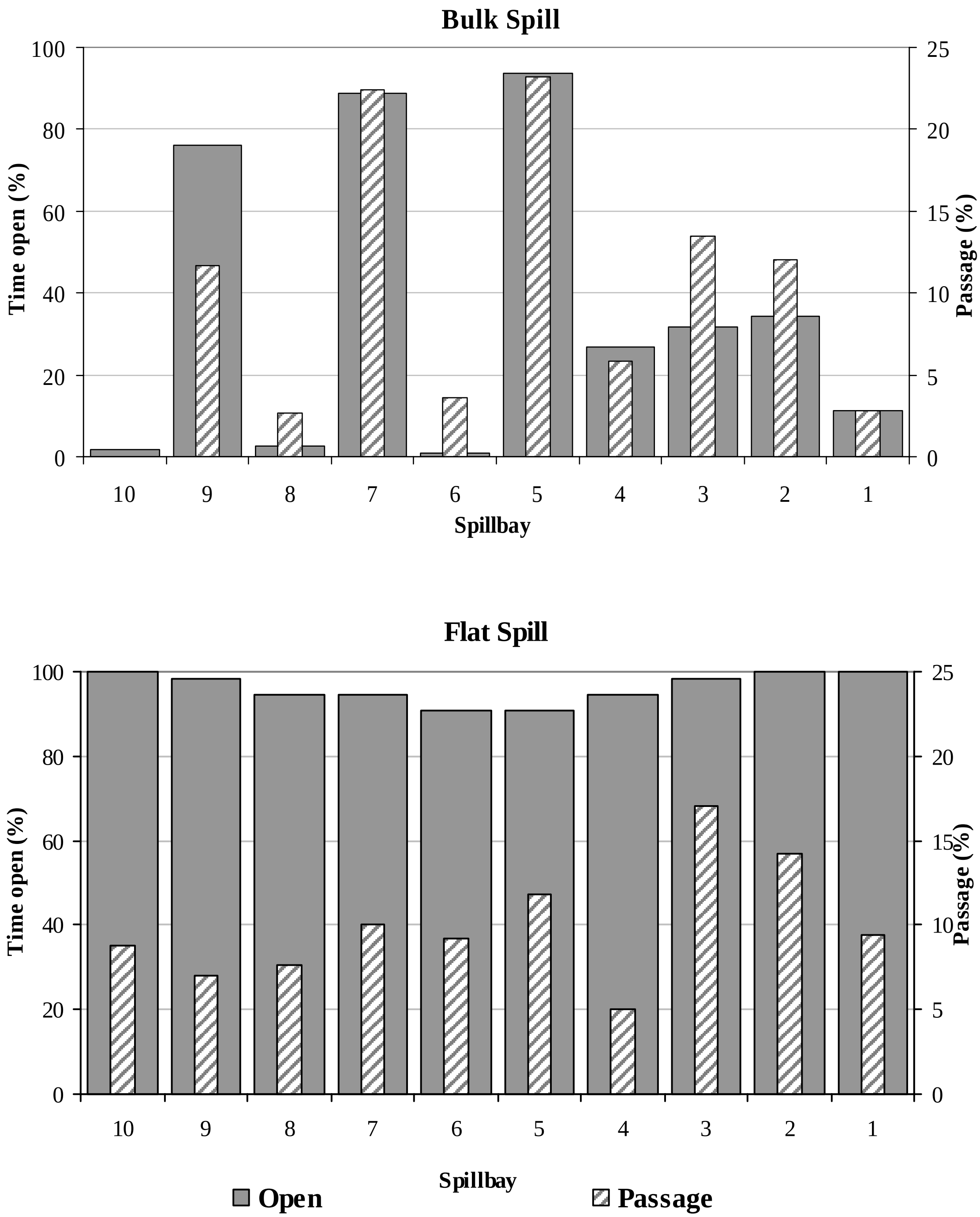

Figure 9. Percent time individual spillbay was opened and passage distribution for radio-tagged, river-run subyearling Chinook salmon during bulk and flat spill testing at Ice Harbor Dam, 2004.

Table 7. Minimum and maximum estimates of spill efficiency (SPE), spill effectiveness (SPF) and fish passage efficiency (FPE) by test block for radio-tagged, river-run subyearling Chinook salmon passing Ice Harbor Dam during bulk (B) and flat (F) spill operations, 2004.

Operations grouping	Fish passage metrics					
	Minimum estimates			Maximum estimates		
	SPE	SPF	FPE	SPE	SPF	FPE
	Bulk spill					
B01	0.958	1.1	0.979	0.979	1.1	1.000
B02	0.972	1.3	0.989	0.977	1.3	0.994
B03	---	---	---	---	---	---
B04	0.939	1.1	0.939	1.000	1.2	1.000
B05	0.893	1.1	0.914	0.971	1.2	0.993
B06	0.904	1.2	0.916	0.958	1.2	0.970
Overall	0.933	1.15	0.948	0.977	1.21	0.991
	Flat spill					
F01	0.934	1.3	0.993	0.934	1.3	0.993
F02	0.969	1.2	1.000	0.969	1.2	1.000
F03	---	---	---	---	---	---
F04	0.943	1.1	0.951	0.984	1.2	0.992
F05	0.885	1.1	0.936	0.936	1.2	0.987
Overall	0.933	1.19	0.970	0.956	1.22	0.993

Tailrace Behavior and Timing

Tailrace egress time was calculated for 1,043 radio-tagged, river-run subyearling Chinook salmon. Of these, 602 and 441 fish passed through the spillway during bulk and flat spill operations, respectively. Overall median egress times were similar between operations at 4.4 min during bulk spill and 5.9 min during flat spill (Table 8). We calculated and compared tailrace egress by test block (Figure 10). Radio-tagged fish passing during bulk spill operations exited the tailrace slightly faster than fish passing during flat spill operations, but the difference was not significant statistically ($P = 0.116$) and very likely not significant biologically.

Detection Probability and Estimated Survival

Detection probabilities at Sacajawea Park were similar for both treatment and reference groups at 0.990 (SE = 0.004) and 0.974 (SE = 0.005), respectively. The overall estimated relative dam survival at Ice Harbor Dam using the weighted geomean was 0.862 (SE = 0.060, 95% CI 0.692-1.075) for bulk spill operations and 0.846 (SE = 0.042, 95% CI 0.736-0.972) for flat spill operations. Survival estimates by test block ranged from 0.714 (SE = 0.051) to 0.961 (SE = 0.050) for bulk spill and from 0.702 (SE = 0.071) to 0.918 (SE = 0.049) for flat spill operations (Table 9). There was no statistically significant difference in relative survival estimates of dam passage between the two operations ($t = 1.115$, $P = 0.334$).

Overall estimated route-specific survival through the spillway using the weighted geomean was 0.972 (SE = 0.026, 95% CI 0.903-1.045) for bulk spill operations and 0.933 (SE = 0.019, 95% CI 0.882-0.986) for flat spill operations. Survival estimates by test block ranged from 0.899 (SE = 0.049) to 1.041 (SE = 0.039) and from 0.830 (SE = 0.129) to 0.969 (SE = 0.044) for bulk and flat spill operations, respectively (Table 10). Insufficient numbers of fish passed through the turbines or juvenile bypass system (powerhouse) to enable us to estimate survival with precision through either of these routes. There was no statistically significant difference in relative survival estimates of spillway passage between the two operations ($t = 2.51$, $P = 0.066$).

Table 8. Tailrace egress times in minutes for radio-tagged, river-run subyearling Chinook salmon passing through the spillway during bulk and flat spill at Ice Harbor Dam, 2004.

	Tailrace egress (min)	
Percentile	Bulk (n = 602)	Flat (n = 441)
Minimum	0.4	2.6
10th	2.6	3.8
20th	2.9	4.2
30th	3.3	4.7
40th	3.8	5.2
50th (median)	4.4	5.9
60th	5.7	7.0
70th	9.7	8.5
80th	17.2	13.6
90th	42.0	32.1
95th	80.6	92.9
100th	1,498.0	8,960.0

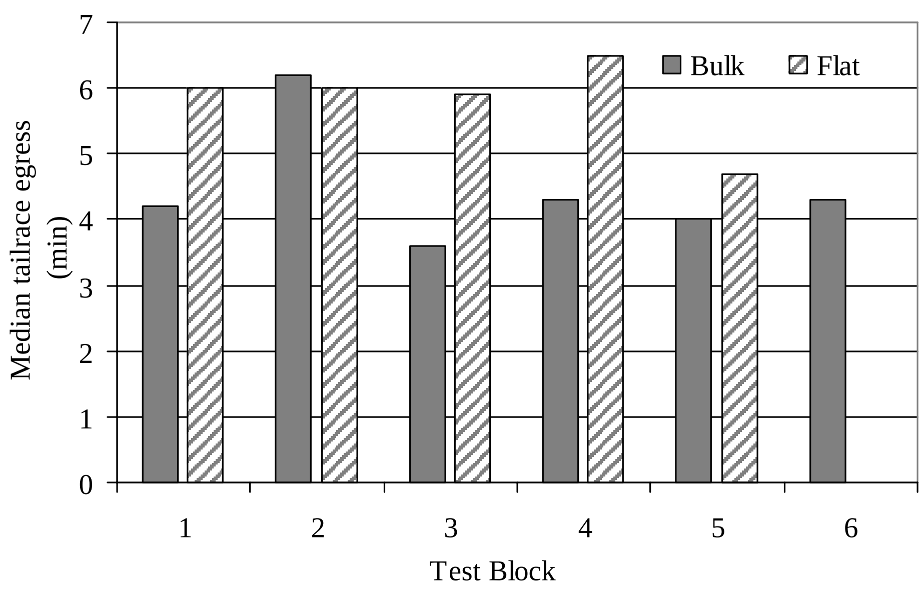

Figure 10. Median tailrace egress time in minutes by test block (see Table 1) for radio-tagged, river-run subyearling Chinook salmon passing through the spillway during bulk and flat spill at Ice Harbor Dam, 2004.

Table 9. Estimated survival (CJS and relative dam survival) for radio-tagged, subyearling Chinook salmon passing Ice Harbor Dam under bulk and flat spill operations, 2004. Standard errors are in parenthesis; overall relative survival estimates are weighted geometric means; test blocks without estimates contained no fish or too few fish for valid estimates.

	Treatment		Reference		Relative dam survival
Test Block	n	CJS survival	n	CJS survival	
			Bulk spill		
B01	61	0.885 (0.041)	162	0.921 (0.021)	0.961 (0.050)
B02	184	0.849 (0.027)	196	0.932 (0.020)	0.911 (0.035)
B03	11	---	0	---	---
B04	114	0.663 (0.045)	221	0.928 (0.019)	0.714 (0.051)
B05	157	0.622 (0.039)	215	0.870 (0.023)	0.715 (0.049)
B06	0	---	0	---	---
Overall	516	0.743 (0.019)	794	0.912 (0.010)	0.862 (0.060)
			Flat spill		
F01	166	0.833 (0.029)	214	0.938 (0.017)	0.888 (0.035)
F02	112	0.833 (0.036)	111	0.907 (0.029)	0.918 (0.049)
F03	23	0.696 (0.096)	88	0.926 (0.029)	0.752 (0.106)
F04	162	0.620 (0.038)	217	0.861 (0.024)	0.720 (0.048)
F05	93	0.559 (0.051)	152	0.796 (0.034)	0.702 (0.071)
Overall	556	0.719 (0.019)	782	0.883 (0.012)	0.846 (0.042)

Table 10. Estimated survival (CJS and relative spillway survival) for radio-tagged, subyearling Chinook salmon passing through the spillway at Ice Harbor Dam under bulk and flat spill operations, 2004. Standard errors are in parenthesis; overall relative survival estimates are weighted geometric means; test blocks without estimates contained no fish or too few fish for valid estimates.

	Treatment		Reference		Relative spillway
Test Block	n	CJS survival	n	CJS survival	survival
	Bulk spill				
B01	49	0.959 (0.028)	162	0.921 (0.021)	1.041 (0.039)
B02	129	0.901 (0.027)	196	0.932 (0.020)	0.967 (0.036)
B03	15	0.867 (0.088)	0	---	---
B04	84	0.866 (0.039)	221	0.928 (0.019)	0.934 (0.097)
B05	132	0.782 (0.037)	215	0.870 (0.023)	0.933 (0.046)
B06	161	0.706 (0.037)	484	0.746 (0.020)	0.899 (0.049)
Overall	570	0.817 (0.017)	1,278	0.850 (0.010)	0.972 (0.026)
	Flat spill				
F01	148	0.887 (0.026)	214	0.938 (0.017)	0.946 (0.033)
F02	139	0.879 (0.028)	111	0.907 (0.029)	0.969 (0.044)
F03	13	0.769 (0.117)	88	0.926 (0.029)	0.830 (0.129)
F04	129	0.763 (0.038)	217	0.861 (0.024)	0.886 (0.051)
F05	81	0.691 (0.051)	152	0.796 (0.034)	0.868 (0.074)
Overall	510	0.819 (0.017)	782	0.883 (0.012)	0.933 (0.019)

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 185 total mortalities recorded within the tern colony representing approximately 4.4% of the fish we released into the Snake River. Tern predation accounted for 3.7% of the fish we released into the forebay of Ice Harbor Dam as treatment fish and 5.0% of the fish that were released into the tailrace of Ice Harbor Dam as reference fish.

DISCUSSION

As reported above, we began tagging after 52% of the juvenile subyearling Chinook salmon had passed Lower Monumental Dam and finished when 94% of these fish had passed. Typically we would prefer to have tagged during the period when approximately 30–70% had passed the project based on the 9-year average observed at Lower Monumental Dam. The shift occurred because we were waiting for the weight of the fish sampled at the Lower Monumental Dam smolt monitoring facility to reach a size that would accommodate radio tags. In 2004, the subyearling Chinook run at Lower Monumental Dam was early and the fish were too small to tag.

One goal for this study was to spread out our releases of radio-tagged fish in order to have equal numbers of fish passing Ice Harbor Dam throughout a given 24-hour period. The diel distribution of fish entering the forebay was fairly even within the study period, but was slightly higher during daylight hours. The hour of dam passage was also fairly consistent throughout the study, except for a slight decline every 2 d during the predawn hours, when operational changes occurred.

Although the diel distribution of fish entering the forebay was fairly even, we did see an increasing trend of treatment fish not reaching the forebay of Ice Harbor Dam during the study. In all, 746 (35.2%) treatment fish released were not detected at the forebay or down river. As the water temperature of the Snake River increased during the last half of the study, estimated survival of fish to the forebay of Ice Harbor Dam decreased (Figures 11 and 12). Temperatures in the latter half of the study well exceeded 20°C with a maximum average temperature of 21.63°C between 6 and 21 July. Maximum daily temperatures exceeded 20°C between 5 and 21 July, with a maximum daily high temperature of 22.61°C on 7 July.

Temperatures above 20°C increase predation (Vigg and Burley 1991), disrupt physiological processes (Mesa et al. 2002), reduce levels of smoltification, and decrease growth (Marine and Cech 2004) of young fall Chinook salmon and are a few of the possible explanations for a high percentage of fish not reaching the Ice Harbor Dam forebay. Another possible explanation may be related to low river flow. The low water flow in the Snake River in 2004 may have caused some fish to slow their migration and to exhibit a reservoir-type juvenile life history instead of an ocean-type life history as described by Connor et al. (2005). Also, the combination of low flows and a high percentage of fish transported in 2004 may have influenced predator/prey dynamics by increasing the vulnerability of the radio-tagged fish.

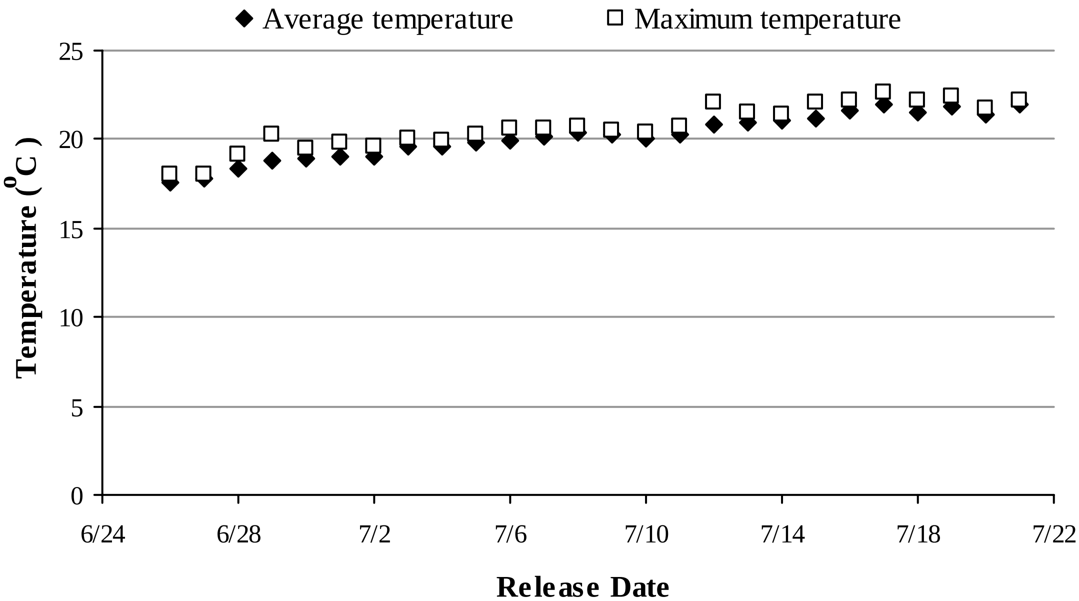

Figure 11. Average and maximum daily water temperatures of the Snake River at Ice Harbor Dam during study releases, 2004.

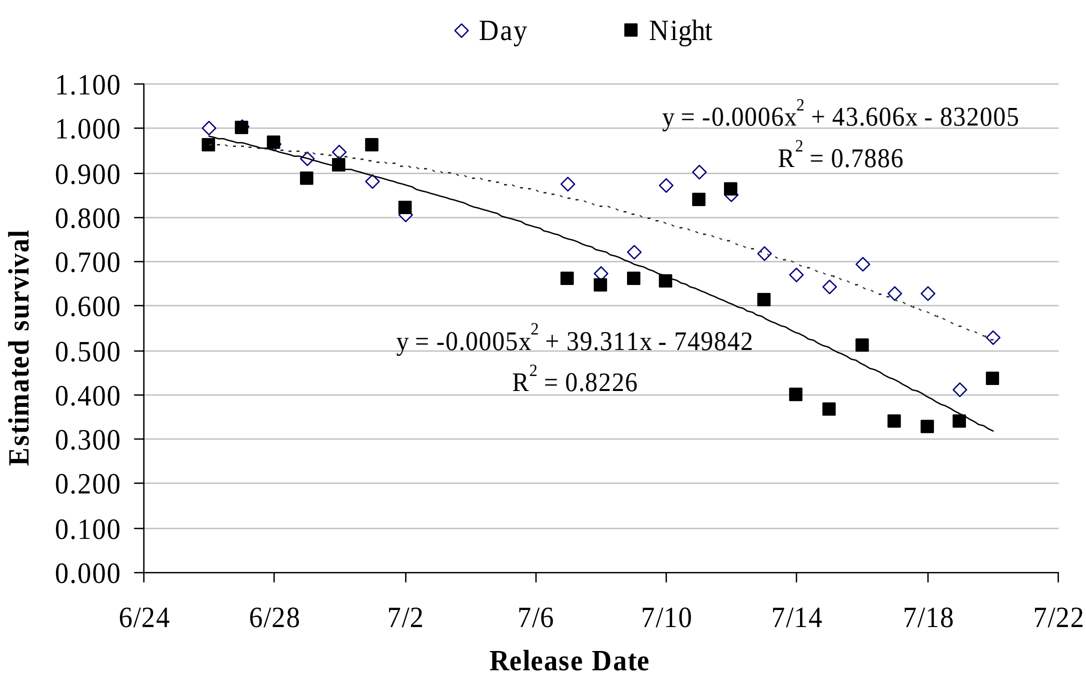

Figure 12. Estimated survival of river-run subyearling Chinook salmon treatment fish from release to the forebay entry line of Ice Harbor Dam, 2004.

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 quickly. The median forebay residence times were not significantly different between bulk and flat spill operations with only a 1.3-h difference. 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 (2 d bulk spill, 2 d flat spill) did not seem to have much of an effect on passage distribution or 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 81% of the radio-tagged, river-run subyearling Chinook salmon detected in the forebay chose the spillway for passage. Spill efficiency, spill effectiveness, and fish passage efficiency were not significantly different between bulk and flat spill operations. Although tailrace egress was slightly longer for fish that passed during flat spill than during bulk spill operations, the difference was not statistically significant. Ninety percent of all radio-tagged fish passing through the spillway exited the tailrace in less than 1 hour. 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 either through the spillway or the dam as a whole during bulk or flat spill operations. However, estimated spillway and dam survival rates were higher under bulk spill. Absolon et al. (2005) reported relative spillway-passage survival estimates of 96% for PIT-tagged fall Chinook salmon released during the summer of 2003 under bulk spill condition (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). The comparison of these results suggests that the increased spill volume through individual spillbays during a bulk spill pattern allows fish to pass over the ogee at a shallower depth, avoiding the potentially injurious hydraulic conditions created in the vicinity of the flow deflector. We conclude that operating the Ice Harbor Dam spillway using a bulk spill pattern when total project discharge is low may increase survival of migrating juvenile salmonids passing the project through that route.

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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 (99.0%) and reference groups (97.4%). With detection probabilities at or near 100% for all fish, there was no disparity between detection of treatment and reference groups.

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

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. Releases occurred over 2 d, and nearly all fish from both groups were detected within a few hours after passage or release (Appendix Tables A1 and A2). 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, creating “patchy” or “bimodal” distributions.

Appendix Table A1. 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, 2004.

Detection	B01		B02		B03		B04		B05		B06	
date	T	R	T	R	T	R	T	R	T	R	T	R
26-Jun	0.10	0.21										
27-Jun	0.52	0.61										
28-Jun	0.38	0.18										
29-Jun												
30-Jun			0.35	0.46								
1-Jul			0.62	0.46								
2-Jul			0.03	0.07								
3-Jul												
4-Jul					0.59							
5-Jul					0.41							
6-Jul												
7-Jul												
8-Jul							0.47	0.39				
9-Jul							0.41	0.41				
10-Jul							0.12	0.20				
11-Jul												
12-Jul									0.51	0.49		
13-Jul									0.45	0.50		
14-Jul									0.04	0.01		
15-Jul												
16-Jul											0.22	0.18
17-Jul											0.15	0.19
18-Jul											0.23	0.22
19-Jul											0.15	0.15
20-Jul											0.11	0.17
21-Jul											0.10	0.08
22-Jul											0.02	0.01
23-Jul											0.02	

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 flat spill, 2004.

Detection	F01		F02		F03		F04		F05	
date	T	R	T	R	T	R	T	R	T	R
26-Jun										
27-Jun										
28-Jun	0.45	0.44								
29-Jun	0.48	0.53								
30-Jun	0.07	0.03								
1-Jul										
2-Jul			0.49	0.53						
3-Jul			0.49	0.47						
4-Jul			0.02							
5-Jul										
6-Jul					0.20					
7-Jul					0.80	1.00				
8-Jul										
9-Jul										
10-Jul							0.13	0.38		
11-Jul							0.78	0.59		
12-Jul							0.08	0.02		
13-Jul										
14-Jul									0.58	0.49
15-Jul									0.41	0.49
16-Jul									0.01	0.02
17-Jul										
18-Jul										
19-Jul										
20-Jul										
21-Jul										
22-Jul										
23-Jul										

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 does 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.

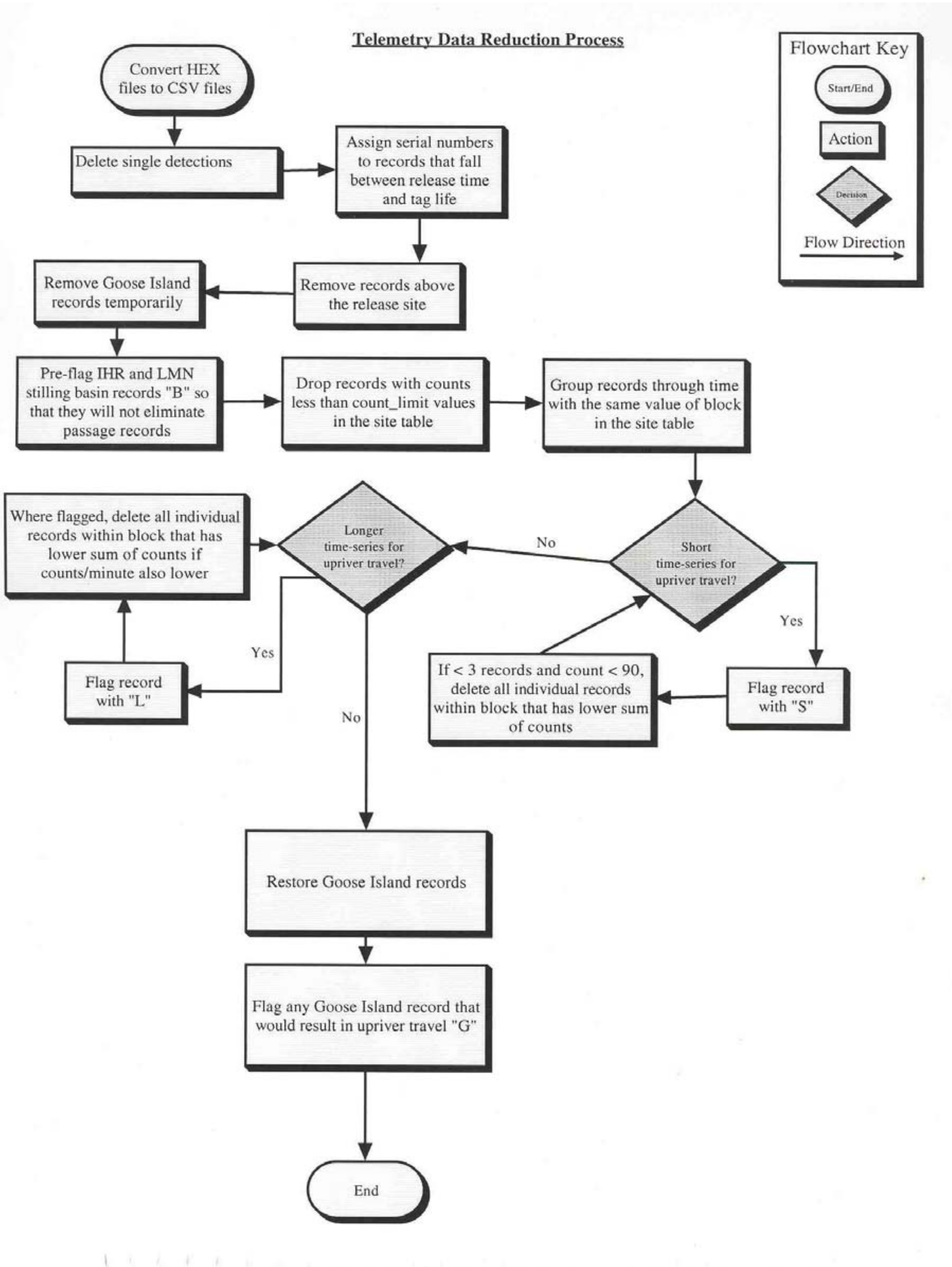
A5. Fish that die as a result of passing through a passage route are not subsequently detected at a downstream array which is used to estimate survival for the passage route.

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. Tags which were not functioning properly were not used in the study. In addition, some of the radio transmitters from tagging mortalities throughout the study were tested for tag life by allowing them to run in river water and checking them daily to determine if they functioned for the predetermined period of time. None of the tags tested for tag life failed prior to the preprogrammed shut down after 10 d.

APPENDIX B



Telemetry Data Reduction Process
Flowchart Key
Start/End
Action
Decision
Flow Direction
Convert HEX files to CSV files
Delete single detections
Assign serial numbers to records that fall between release time and tag life
Remove records above the release site
Remove Goose Island records temporarily
Pre-flag IHR and LMN stilling basin records "B" so that they will not eliminate passage records
Drop records with counts less than count_limit values in the site table
Group records through time with the same value of block in the site table
Short time-series for upriver travel?
Yes
No
Flag record with "S"
If < 3 records and count < 90, delete all individual records within block that has lower sum of counts
Longer time-series for upriver travel?
Yes
No
Flag record with "L"
Where flagged, delete all individual records within block that has lower sum of counts if counts/minute also lower
Restore Goose Island records
Flag any Goose Island record that would result in upriver travel "G"
End