Spillway Passage Survival of Hatchery Yearling Chinook Salmon at Ice Harbor Dam, 2003

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EXECUTIVE SUMMARY

For hatchery yearling Chinook salmon at Ice Harbor Dam, spillway passage survival estimates were 0.978 in 2000 and 0.892 in 2002. For subyearling hatchery Chinook, respective spillway passage survival during these two years was estimated at 0.885 and 0.894. These relatively low estimates for subyearling Chinook in both years, and for yearling Chinook in 2002, may have resulted from hydraulic conditions in the stilling basin that occurred in summer during both years and in spring 2002, when total river flows were low (<90 kcfs).

Tests using a general model of Ice Harbor Dam at the U.S. Army Corps of Engineers Engineering Research and Development Center have shown that spill volumes above 50% spill (at most river flows) create a condition where water plunges into the stilling basin, whereas spill volumes at or near 50% create a skimming flow over the stilling basin. It was hypothesized that this skimming flow would increase spillway passage survival for migrating juvenile salmon.

To test this hypothesis, we evaluated relative spillway passage and dam survival for hatchery yearling Chinook salmon under both a 50% spill operation and under spill levels of 45 kcfs during the day and up to 100% at night (i.e., BiOp operation as prescribed by the 2000 National Marine Fisheries Service biological opinion). Spill operations were alternated in 2-day blocks through the study period.

To estimate overall dam survival and spillway passage survival, hatchery yearling Chinook salmon were collected and radio tagged (gastric implants) at Lower Monumental Dam. From 28 April through 2 June, 847 radio-tagged fish were released in conjunction with a spillway survival evaluation at Lower Monumental Dam. Of these, 746 were detected at or below Ice Harbor Dam. We formed "release groups" of test fish for the alternate spill conditions based on detections of these fish grouped by date and time of arrival at Ice Harbor Dam. For comparison to groups of test fish, we released an additional 822 radio-tagged hatchery yearling Chinook as reference fish into the upper and lower tailrace below Ice Harbor Dam. These fish were detected on radiotelemetry transects installed at five locations between Ice Harbor Dam on the Lower Snake River and Crow Butte on the Columbia River.

Relative spillway passage survival was estimated at 0.952 (95% CI, 0.917-0.989) under BiOp operations and 0.937 (95% CI, 0.890-0.988) under 50% spill operations. Relative dam survival was estimated at 0.948 (95% CI, 0.923-0.972) under BiOp operations and 0.927 (95% CI, 0.875-0.983) under 50% spill. The overall distribution of fish by passage route was 594 (79.6%) through the spillway, 41 (5.5%) through the juvenile bypass system, and 35 (4.7%) through turbines. Eleven (1.8%) fish entered the forebay but were not recorded as passing the dam, and 65 (8.7%) passed the dam but were never detected on a passage-route receiver.

The overall spill efficiency estimate was higher for radio-tagged fish passing Ice Harbor Dam during BiOp operations (93.4%) than for fish passing during 50% spill operations (82.0%), and the difference was significant. Spill effectiveness was also significantly different between the two operations, and was estimated at 1.4 for radio-tagged fish passing during BiOp and 1.6 for those passing during 50% spill.

Overall fish passage efficiency was higher for radio-tagged fish passing during BiOp operations (97.5%) than for fish passing during 50% spill (90.0%), and again, the difference was statistically significant. Median forebay residence time for radio-tagged fish was 1.1 h during BiOp operations and 1.8 h during 50% spill. Median tailrace egress time for radio-tagged fish was 0.36 and 0.37 h, respectively, during BiOp and 50% spill operations.

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INTRODUCTION

Spillway passage has long been considered the safest route for migrating juvenile salmonids at Snake and Columbia River dams. A review of thirteen estimates of spillway passage mortality published through 1995 concluded that the most likely range of mortality at standard spillbays is 0 to 2% (Whitney et al. 1997). Subsequent to the 1992 listing of Snake River sockeye salmon *Oncorhynchus nerka* as endangered under the Endangered Species Act and listings of other Columbia Basin salmon stocks, the National Marine Fisheries Service (NMFS) developed a series of biological opinions (BiOps) on operation of the Federal Columbia River Power System (FCRPS). The 2000 BiOp recommends specific timing, duration, and levels of spill at FCRPS dams. Recommendations are implemented by the Bonneville Power Administration, U.S. Army Corps of Engineers, and U.S. Bureau of Reclamation (Federal Action Agencies).

Since 1994 spill has been utilized increasingly at FCRPS dams to expedite the migration rates of juvenile salmonids past hydroelectric dams and to reduce the proportion of smolts passing through turbines, where passage survival is lower (Iwamoto et al. 1994; Muir et al. 2001). Pursuant to the 2000 biological opinion (NMFS 2000), operations at Ice Harbor Dam have relied on increased volumes of spill to maximize spillway passage by migrating juvenile salmonids. The current spill program calls for daytime spill volumes of 45 kcfs and nighttime spill volumes up to state and federal limits for total dissolved gas, or up to 100% of total river flow, as recommended by the 2000 BiOp.

In 1999, fish passage efficiency under BiOp operation was estimated at 97%, with 81% of hatchery yearling Chinook salmon migrants passing through the spillway of Ice Harbor Dam (Eppard et al. 2000). For hatchery yearling Chinook passing the dam under the BiOp operating conditions in 2000 and 2002, respective spillway passage survival estimates were 0.978 and 0.892. For hatchery subyearling Chinook passing under the same operating conditions, relative spillway passage survival was estimated at 0.885 in 2000 and 0.894 in 2002 (Eppard et al. 2002, 2005).

These results indicated that spillway passage survival at Ice Harbor Dam is correlated with total river flow and tailwater elevation. The relatively low survival estimates for subyearling Chinook in both years, and for yearling Chinook in 2002, may have resulted from hydraulic conditions in the stilling basin that occurred in summer during both years and in spring 2002, when total river flows were low (<90 kcfs).

Tests using a general model of Ice Harbor Dam at the U.S. Army Corps of Engineers Engineering Research and Development Center have shown that at most river flows, spill volumes above 50% spill create a condition where water plunges into the stilling basin. In contrast, spill volumes at or near 50% create a skimming flow over the stilling basin. It was hypothesized that this skimming flow could increase spillway passage survival for migrating juvenile salmon.

A related hypothesis was that predation in the tailrace of Ice Harbor Dam contributed to the lower survival probabilities: during hydraulic modeling, and based on observations of water flow through the tailrace, a shallow area in the lower tailrace was identified as a location where migrating juvenile salmonids may be more vulnerable to predation. Most water discharged through the Ice Harbor Dam spillway flows toward the north shoreline, immediately downstream from the navigation lock retaining wall. However, a small portion this water flows to a relatively shallow area between the south shoreline and Eagle Island, less than 1 km downstream.

During spill volumes that limit powerhouse operation (daytime operations during low flows and nighttime operations during moderate to high flows), an eddy is created just downstream from the powerhouse. This eddy extends downstream as far as Eagle Island, and some proportion of fish passing Ice Harbor Dam may be "guided" by the eddy into the shallow area between the island and the south shoreline.

To address these questions, in 2003 we evaluated relative spillway passage and dam survival for radio-tagged hatchery yearling Chinook salmon under the spill conditions prescribed by NMFS BiOp (plunging flow) and also under a 50% spill operation (skimming flow). We also evaluated behavior and timing of these fish as they entered the forebay, approached and passed the dam, and exited the tailrace at Ice Harbor Dam.

Specific fish passage metrics, behaviors, and passage survival estimates discussed in this report are defined as follows:

Spill efficiency (SPE):	Number of fish passing the dam via the spillway divided by the total number of fish passing the dam.
Spill effectiveness (SPF):	Proportion of fish passing the dam via the spillway divided by the proportion of water spilled.
Fish passage efficiency (FPE):	Number of fish passing the dam through non-turbine routes divided by total number passing the dam.

Tailrace egress:	Elapsed time from dam passage to exit from the tailrace.
Forebay residence time:	Elapsed time from arrival in the forebay of the dam until passage through the spillway, bypass, or turbines.
Dam survival (paired release):	Survival between the upstream limit of the boat restricted zone and the release location of reference groups downstream from the dam.
Route-specific survival:	Survival between detection within a passage route (paired release) and the release location of reference groups downstream from the dam.

Results of this study will be used to inform management decisions on actions to optimize survival for juvenile salmonids arriving at Ice Harbor Dam. This study addresses the research needs outlined in SPE-W-00-1 of the U.S. Army Corps of Engineers, North Pacific Division, Anadromous Fish Evaluation Program.

METHODS

Study Area

The study area included the 163-km reach of the Snake and Columbia Rivers from Lower Monumental Dam to Crow Butte (Figure 1). Lower Monumental Dam is located 67 km above the confluence of the Snake and Columbia Rivers. Ice Harbor Dam is located 16 km above the confluence of the Snake and Columbia Rivers, and Crow Butte is located on the lower Columbia River, 426 km above its mouth at the Pacific Ocean.

Fish Collection, Tagging, and Release

Radio Tags

Radio tags were purchased from Advanced Telemetry Systems Inc.,[†] had a programmatically defined life of 10 d, and were pulse-coded for unique identification of individual fish. Each radio tag measured 18 mm in length by 8 mm in diameter and weighed 1.8 g in air.

Tagging

River-run hatchery yearling Chinook salmon were collected at the Lower Monumental Dam smolt collection facility from 28 April to 6 June 2003. Only yearling Chinook salmon of hatchery origin, not previously PIT tagged, and weighing 25 g or more were used. Fish were anesthetized with tricaine methanesulfate (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 holding tank with flow-through river water and held 24 h prior to radio tagging.

Fish were gastrically implanted with radio transmitters using techniques described by Adams et al. (1998). Fish were also PIT tagged by hand as described by Prentice et al. (1990). Immediately following tagging, fish were placed into an aerated 19-L recovery container for recovery from the anesthesia. Recovery containers were closed and transferred to a 1,152-L holding tank designed to accommodate up to 28 containers.

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

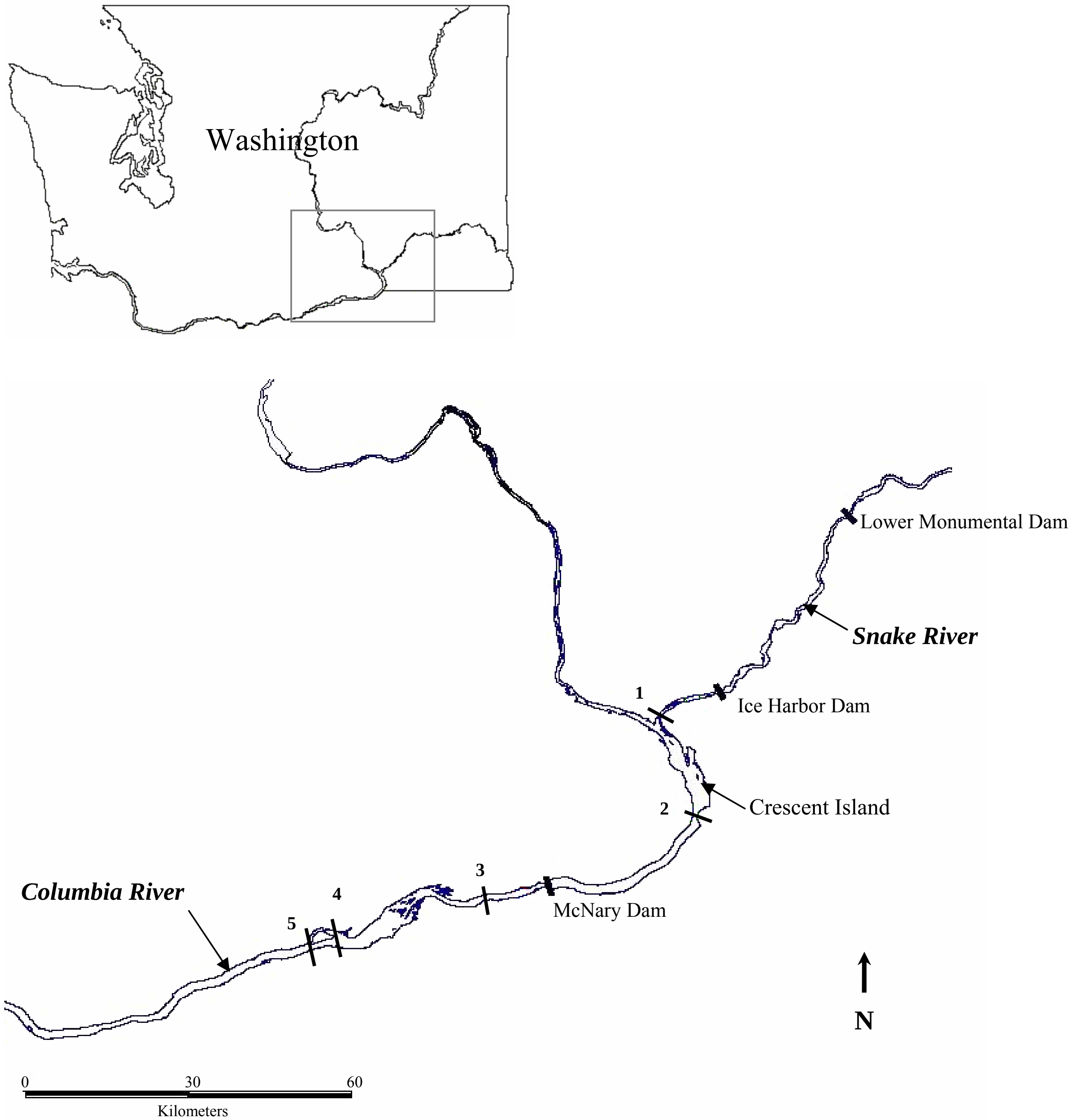


Figure 1. Study area showing location of radiotelemetry transects used for estimating spillway passage and overall dam survival at Ice Harbor Dam, 2003 (1 = Mouth of the Snake River; 2 = Port Kelley; 3 = Irrigon, OR; 4 = Crow Butte East; and 5 = Crow Butte West). The forebay, tailrace, and all routes of passage at Ice Harbor (see Figures 2 and 3) and McNary Dams were also monitored.

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 transportation to release locations. Holding density did not exceed two fish per recovery container. All tagged fish were held for a minimum of 20 h for recovery and determination of post-tagging mortality. Treatment fish were held for recovery at Lower Monumental Dam; reference fish were transported to Ice Harbor Dam immediately after tagging, where they were held in flow-through water for the 20-h recovery period.

Releases

After the post-tagging recovery period, radio-tagged fish were moved in their recovery containers from the holding area to release areas. Treatment fish were released into the spillway or tailrace of Lower Monumental Dam as part of a spillway passage survival study (Hockersmith et al. 2004). Reference groups were transferred in their recovery containers from holding tanks to a 1,152-L tank mounted on an 8.5 × 2.4-m barge in the forebay of Ice Harbor Dam, transported to the tailrace, and released at either the middle of the downstream section of the stilling basin (R_1) or the upstream end of Goose Island, approximately 2 km downstream from the dam (R_2, Figure 2).

Monitoring

Radiotelemetry receivers and multiple-element aerial antennas were used to establish detection transects between Ice Harbor Dam on the Snake River and Crow Butte on the Columbia River (Figure 1). Receiver arrays using underwater dipole, loop, or multiple-element aerial antennas were used to monitor arrival in the upper forebay, approach immediately upstream from the dam in the lower forebay, and exit from the immediate (upper) tailrace. A telemetry transect was also positioned in the lower tailrace at the downstream end of Goose Island. Underwater antennas were used to monitor passage routes through individual spillbays, the juvenile bypass system, and all turbine gate slots (Figures 2 and 3).

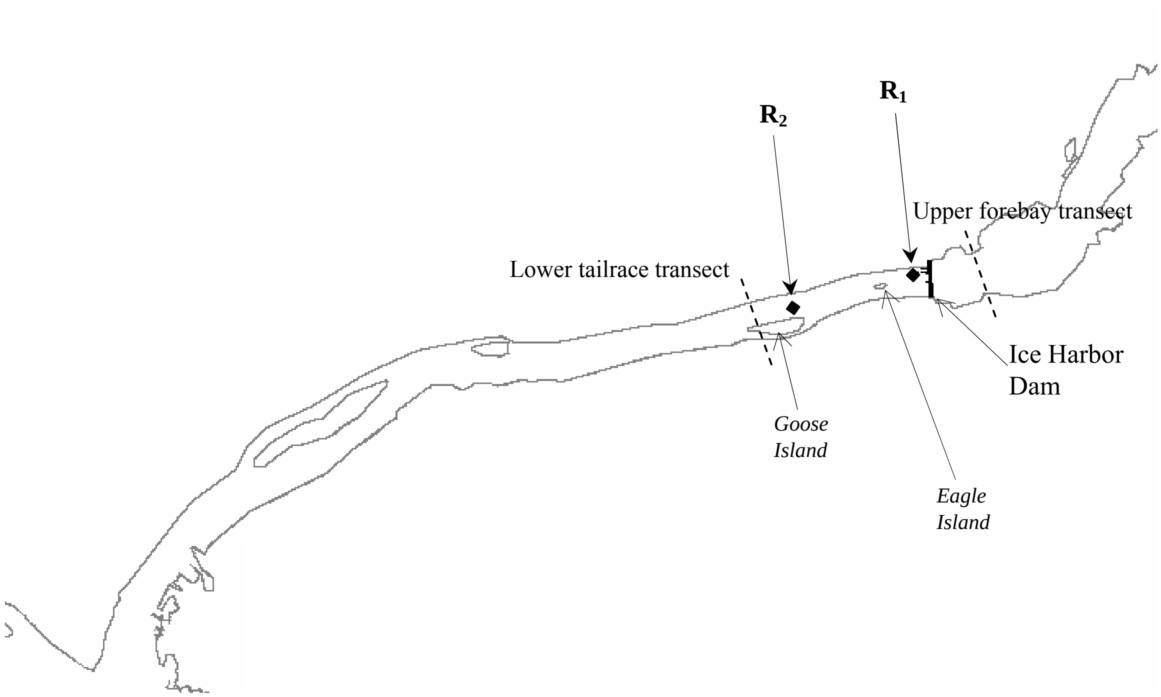


Figure 2. The Lower Snake River and Ice Harbor Dam (rkm 538) showing the location of reference group releases in 2003 (R_1 = immediate (upper) tailrace and R_2 = lower tailrace near Goose Island). Additional radiotelemetry arrays were used to detect radio-tagged yearling Chinook salmon approaching the forebay (upper forebay transect, rkm 538.5) and subsequently exiting the tailrace (lower tailrace transect, rkm 534.2).

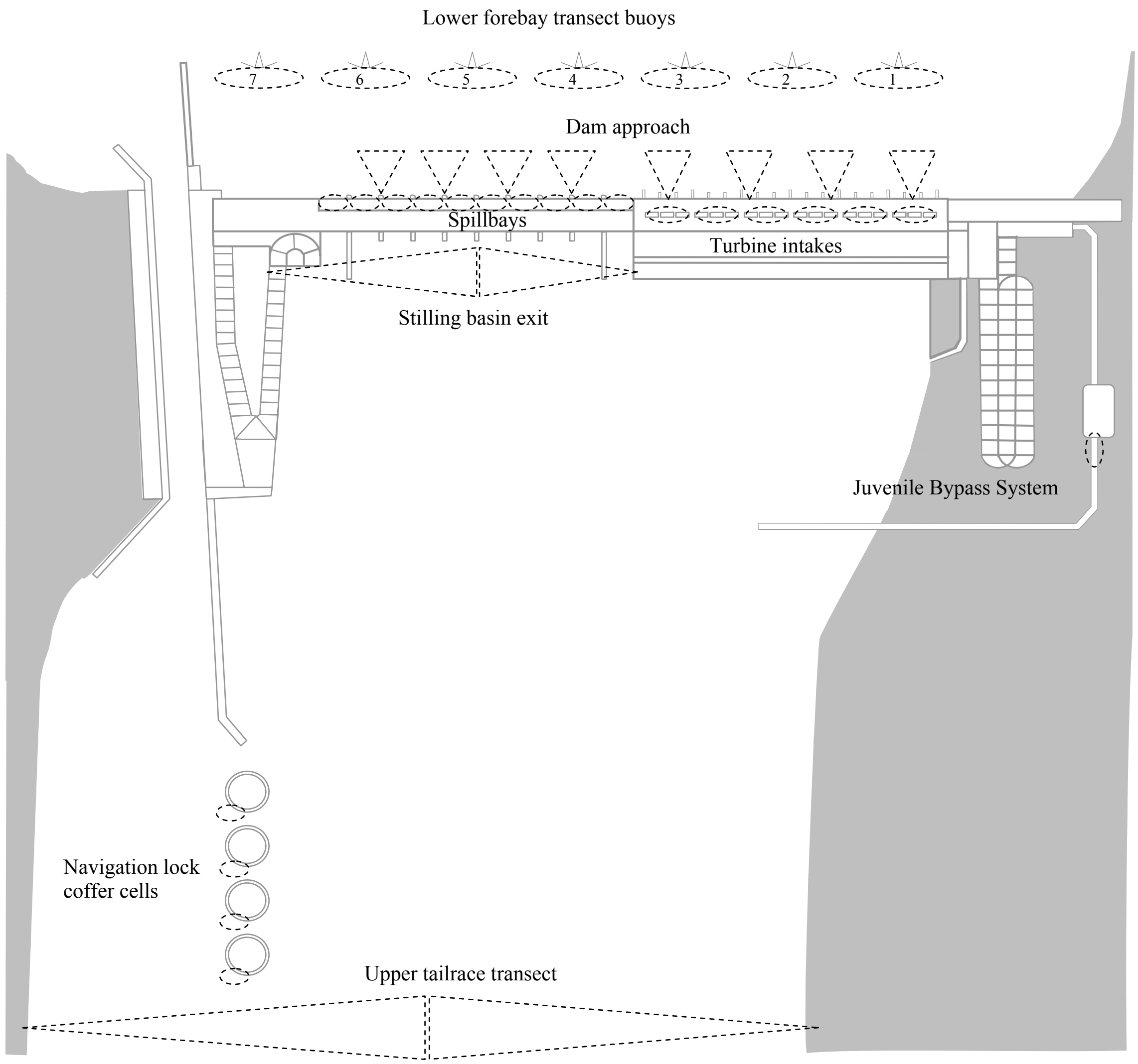


Figure 3. Plan view of Ice Harbor Dam showing approximate radiotelemetry detection zones in 2003. Dashed ovals represent underwater antennas; dashed triangles represent aerial antennas.

Data Analysis

Survival Estimates

A paired-release study design was used for estimating relative survival. Treatment and reference groups were composed of radio-tagged fish released at three sites: one upstream at Lower Monumental Dam (treatment) and two downstream from Ice Harbor Dam (these were later combined to form a single reference group). BiOp spill and 50% spill treatment groups were formed based on the time and date of first detection in the forebay at Ice Harbor Dam. Reference groups were released either to the immediate tailrace of Ice Harbor Dam (R_1) or to the lower tailrace at the upstream end of Goose Island (R_2; Figure 2).

The single-release model (Cormack 1964; Jolly 1965; Seber 1965) was used to estimate survival and probability of detection for both treatment and reference groups. Radio-tagged fish were also tagged with a PIT tag so that additional data for survival estimates could be collected from the juvenile collection/PIT-tag detection facilities at McNary, John Day, and Bonneville Dams and from the PIT-tag detection trawl operated in the Columbia River estuary.

Relative spillway passage survival was expressed as the ratio of survival estimates for treatment fish to those for reference fish. Mean relative survival was calculated using weighted geometric means with weights being the inverse of the respective sample variances (Burnham et al. 1987; Muir et al. 2003). Critical assumptions of the single-release model were evaluated using the methods of Burnham et al. (1987) and are detailed in Appendix A.

Migration Behavior and Timing

Fish passage behavior and timing analyses were based on detections of radio-tagged fish as they approached the dam, passed through one of three primary routes of passage (i.e., spillway, bypass, and turbines), and exited the immediate tailrace of the dam (Figure 3).

Forebay residence time was defined as elapsed time from first detection in the upper forebay to detection in a primary passage route at Ice Harbor Dam. Similarly, tailrace egress was defined as the time from detection on a passage-route receiver to detection on the lower tailrace transect at Goose Island. We compared timing among specific cohorts by testing the null hypothesis: that the true median time for tailrace egress or forebay residence was equal between treatment and reference cohorts.

For hypothesis testing, we used the permutation methods described by Efron and Tibshirani (1993). Data from the two cohorts were pooled, and a permutation of two samples (using the original sample sizes) was randomly generated without replacement. The medians of the two "permuted samples" were calculated as well as their difference. We repeated this process 1,000 times resulting in 1,000 median difference estimates. We then calculated *P*-values as the proportion of times these expected differences were "more extreme" (usually larger) than the observed difference (doubled for a 2-tailed test; $\alpha = 0.05$).

Confidence intervals (95%) for differences in median tailrace egress and median forebay residence time were calculated using bootstrap methods (Efron and Tibshirani 1993). We generated 1,000 bootstrap medians for each group and for the difference between the medians, then estimated 95% confidence intervals as the 2.5th and 97.5th percentiles of the ordered distribution of 1,000 differences. When meaningful bias was detected, an adjustment was made to correct for it using the bias-corrected intervals described by Efron And Tibshirani (1993). For each cohort, confidence intervals were constructed for median tailrace egress and forebay residence times using bootstrap methods analogous to the method used for paired cohorts.

RESULTS

Project Operations

From 28 April to 15 June 2003, Ice Harbor Dam was operated in 12 4-d block intervals with 2 d of BiOp spill and 2 d of 50% spill. The spill pattern was a flat pattern during both spill treatments. Due to power peaking operations regulated by the Bonneville Power Administration and the U.S. Army Corps of Engineers, total project discharge varied greatly on many days during this time period (Figure 4 and Table 1). Water temperature during the study period averaged 12.3°C (range 10.1-15.9°C).

Fish Collection, Tagging, and Release

Yearling Chinook salmon were collected and tagged at Lower Monumental Dam during 33 d from 28 April to 2 June. Tagging began after 27% of the yearling Chinook salmon had passed Lower Monumental Dam and was completed when 98% of these fish had passed (Figure 5). Handling and tagging mortality for yearling Chinook salmon was 4.9% overall, and tag loss due to regurgitation was 0.3%.

We released 847 radio-tagged fish to the spillway and tailrace at Lower Monumental Dam as part of a spillway survival study (Hockersmith et al. 2004). Of these fish, 741 were detected in the forebay of Ice Harbor Dam. For survival estimates, we formed "release groups" based on project operations at the time of detection in the forebay. For comparison to the spillway treatments, we released reference groups of 411 radio-tagged fish each to the immediate tailrace (R_1) and to the lower tailrace near Goose Island (R_2, Figure 2). Overall mean fork length was 150.5 mm (SD = 8.7) for spill treatment fish, 150.8 mm (SD = 8.5) for fish released to the upper tailrace, and 151.2 mm (SD = 8.9) for fish released to the lower tailrace (Table 2). Overall mean weight was 30.7 g (SD = 6.1) for treatment fish, 30.8 g (SD = 5.8) for upper tailrace fish, and 31.3 g (SD = 6.8) for lower tailrace fish (Table 3.)

Releases of treatment fish at Lower Monumental Dam occurred between 0925 and 1315 PDT; however, detection of these fish (entry into the forebay) at Ice Harbor Dam occurred across all hours during both BiOp and 50% spill test blocks (Figure 6). Therefore, to maximize commingling of reference and treatment fish, reference groups were released during both day and nighttime hours Daytime releases occurred from 0800 to 1500 and nighttime releases from 1800 to 2200 PDT.

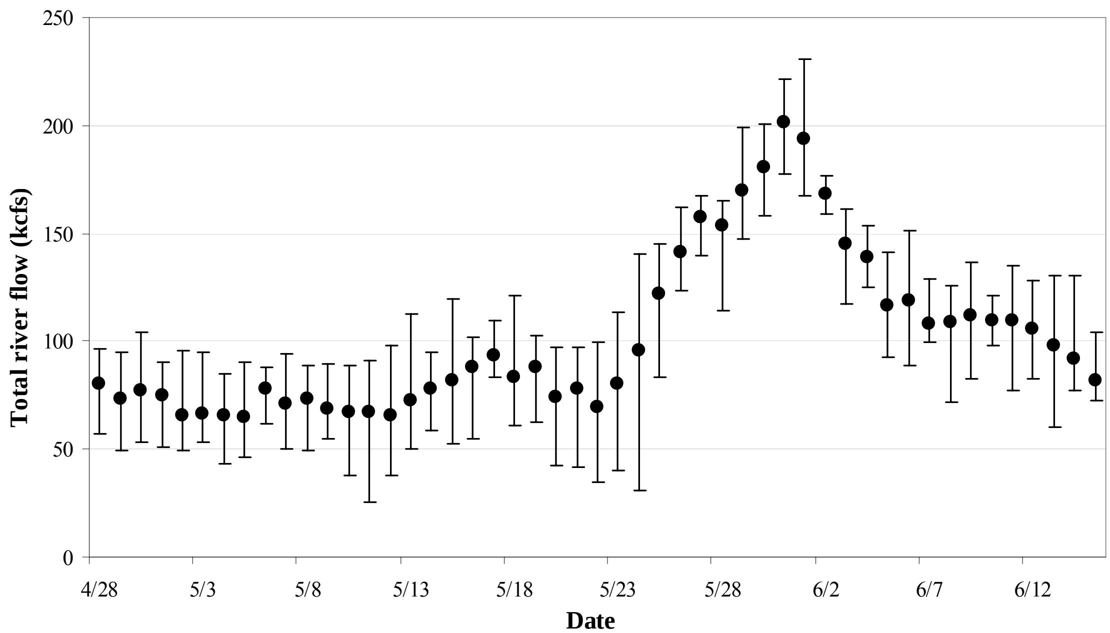


Figure 4. Average daily and range of total river flow (kcfs) during passage survival and behavior testing at Ice Harbor Dam, 2003.

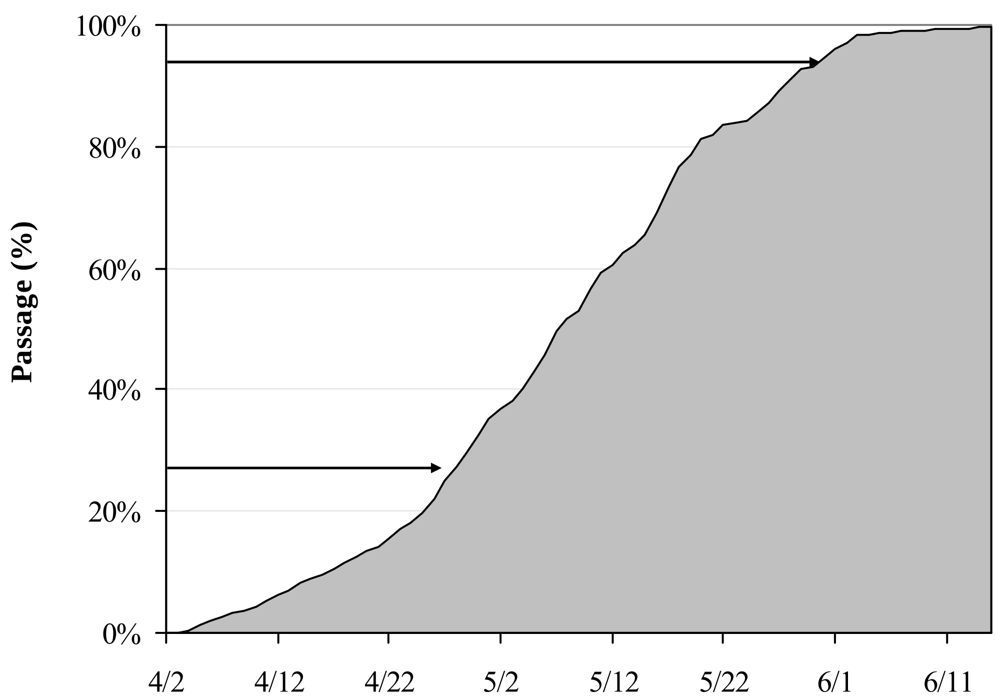


Figure 5. Cumulative passage distribution of hatchery yearling Chinook salmon at Lower Monumental Dam, 2003. Arrows indicate beginning and ending dates for radio-tagged yearling Chinook releases to evaluate Ice Harbor Dam passage survival.

Table 1. Mean volume (kcfs) with range and standard deviation (SD) for dam conditions and spill operation by test block at Ice Harbor Dam, 2003.

Test	Date range		Total discharge (kcfs)			Total spill (kcfs)			Percent spill (%)			Tailwater elevation (ft)		
Block	Start	End	Mean	Range	SD	Mean	Range	SD	Mean	Range	SD	Mean	Range	SD
						BiOp spill operation								
B01	4/28 05:00	4/30 04:55	77.5	49.7-96.3	12.2	56.7	38.2-94.9	16.6	74.2	48.1-100.0	20.2	343.5	340.8-345.4	1.1
B02	5/02 05:00	5/04 04:55	68.6	53.2-95.4	10.7	57.0	40.1-95.4	15.8	82.3	63.3-100.0	13.4	342.7	341.4-344.2	0.8
B03	5/06 05:00	5/08 04:55	73.8	49.9-94.2	11.8	52.2	44.1-74.9	10.8	72.6	47.4-100.0	17.8	343.5	341.0-345.4	1.1
B04	5/10 05:00	5/12 04:55	65.6	25.1-91.0	16.3	48.0	25.1-74.0	12.6	74.9	49.6-100.0	15.9	342.4	338.4-345.0	1.5
B05	5/14 05:00	5/16 04:55	82.5	52.8-119.9	12.8	60.3	43.2-100.2	18.9	73.4	49.1-100.0	19.8	344.0	341.9-346.6	1.2
B06	5/18 05:00	5/20 04:55	83.9	44.8-121.5	16.6	56.5	38.4-86.4	15.7	70.3	37.1-100.0	23.3	344.1	340.8-347.6	1.6
B07	5/22 05:00	5/24 05:55	75.6	30.7-113.2	21.6	54.5	21.8-99.8	19.7	73.8	44.4-100.0	19.2	343.4	339.5-346.4	1.9
B08	5/26 05:00	5/28 04:55	149.8	114.5-167.2	10.1	82.6	44.6-100.6	20.3	55.0	33.1-73.0	13.1	349.2	347.9-350.5	0.6
B09	5/30 10:00	6/01 12:55	198.1	158.5-230.9	19.8	109.1	69.6-140.4	19.1	54.6	43.4-61.1	4.5	352.3	350.0-354.4	1.2
B10	6/03 05:00	6/05 04:55	137.0	107.6-159.8	14.0	79.2	44.3-99.9	17.1	59.3	33.6-87.8	17.7	348.4	345.7-350.1	1.3
B11	6/07 05:00	6/09 04:55	110.0	72.1-125.9	11.1	63.7	44.2-95.4	21.5	58.4	36.8-90.6	20.0	346.6	343.5-348.3	0.9
B12	6/11 05:00	6/13 04:55	108.5	77.3-134.7	12.7	67.6	45.0-100.1	24.8	61.6	38.6-91.6	19.5	346.4	344.4-348.2	0.9
						50% spill operation								
T01	4/30 05:00	5/02 04:55	73.4	49.1-103.9	13.5	37.0	25.9-51.3	6.6	50.4	42.3-91.3	2.2	343.6	341.4-346.0	1.2
T02	5/04 05:00	5/06 04:55	65.1	43.4-90.6	11.1	32.6	22.0-57.0	5.6	50.1	44.9-100.0	2.4	342.7	340.8-344.5	1.0
T03	5/08 05:00	5/10 04:55	70.8	39.8-89.7	11.8	35.4	20.6-62.7	6.1	50.0	44.0-86.8	2.2	343.5	341.2-345.2	1.0
T04	5/12 05:00	5/14 04:55	69.6	37.8-112.8	14.2	34.9	27.1-54.7	6.9	50.2	46.4-71.7	2.1	343.2	340.4-346.6	1.2
T05	5/16 05:00	5/18 04:55	89.5	54.7-109.9	11.7	45.1	34.1-54.9	5.7	50.5	45.7-69.5	1.6	345.0	342.7-346.8	1.0
T06	5/20 05:00	5/22 04:55	74.6	34.5-97.2	18.6	37.7	17.4-48.5	9.0	50.7	45.1-62.1	2.0	343.6	339.8-345.8	1.7
T07	5/24 06:00	5/26 04:55	118.2	51.8-144.7	21.9	59.2	24.6-71.9	10.6	50.1	45.0-55.2	1.0	347.1	340.3-349.2	1.7
T08	5/28 05:00	5/30 09:55	167.5	119.4-199.2	16.5	86.1	69.3-108.4	10.6	51.3	43.2-59.5	1.7	350.4	347.7-352.4	1.0
T09	6/01 13:00	6/03 04:55	168.2	159.3-194.0	5.9	84.7	80.4-104.4	3.1	50.3	48.6-53.8	0.4	350.5	350.0-352.0	0.4
T10	6/05 05:00	6/07 04:55	117.7	89.0-151.1	16.3	59.2	44.5-73.9	7.8	50.4	44.3-75.5	1.5	347.2	345.1-349.4	1.1
T11	6/09 05:00	6/11 04:55	108.9	82.4-136.5	12.2	54.8	42.4-69.2	5.9	50.4	46.0-55.2	1.0	346.7	344.4-348.7	0.9
T12	6/13 05:00	6/15 04:55	90.6	60.1-130.5	20.3	45.7	29.4-65.3	10.2	50.5	42.1-60.3	1.5	345.2	342.4-348.4	1.6

Table 2. Sample size, mean fork length (mm) with standard deviation (SD), and range by test block for radio-tagged, yearling Chinook salmon released at Ice Harbor Dam to evaluate passage behavior, dam survival, and spillway survival during BiOp and 50% spill conditions, 2003. Treatment fish were released at Lower Monumental Dam and regrouped based on entry timing into the Ice Harbor Dam forebay.

	Treatment				Reference (R_1 upper tailrace)				Reference (R_2 Goose Island)			
Test block	N	Mean fork length (mm)	SD	Range	N	Mean fork length (mm)	SD	Range	N	Mean fork length (mm)	SD	Range
					BiOp spill condition							
B01	--	--	--	--	--	--	--	--	--	--	--	--
B02	44	151.0	8.6	138-170	30	151.1	10.2	137-175	22	153.9	10.6	139-179
B03	58	155.3	10.9	139-185	26	153.9	9.9	131-175	25	150.8	8.2	133-168
B04	31	150.3	6.5	133-161	26	150.5	8.5	138-176	27	150.6	7.7	134-171
B05	53	149.9	7.3	137-174	28	151.8	7.5	139-174	29	152.7	9	141-175
B06	--	--	--	--	14	151.9	9.4	141-169	11	157	9.1	147-176
B07	69	149.4	7.5	137-178	20	147.8	4.3	142-156	26	149.6	5.3	142-161
B08	29	148.4	6.7	135-165	30	149.8	7.5	142-177	28	151.3	10.3	141-181
B09	92	150.7	8.0	137-179	33	151.6	9.7	134-174	36	150.9	8.2	138-168
B10	2	141.5	3.5	139-144	14	147.7	6.3	142-164	13	148.6	8	135-162
B11	46	148.7	6.5	138-174	--	--	--	--	--	--	--	--
B12	2	142.0	2.8	140-144	--	--	--	--	--	--	--	--
					50% spill condition							
T01	20	148.7	8.2	138-175	21	152.7	11.9	138-174	19	154.1	14.4	139-192
T02	46	153.6	10.7	138-187	32	152.3	9.6	135-181	29	153.4	10.2	141-177
T03	7	151.3	13.8	136-180	11	154.9	10.5	142-177	14	152.9	9.7	139-176
T04	46	150.6	6.9	136-168	12	150.1	5.4	143-161	17	149.5	5.4	141-164
T05	28	149.7	6.3	141-162	25	151	8.3	138-169	26	153.1	11.2	136-186
T06	45	147.0	6.9	135-160	26	149	6.9	139-168	24	148.4	7.3	140-178
T07	68	151.0	12.8	139-220	26	149.8	6.4	140-162	27	150.4	7.2	140-165
T08	14	148.9	7.0	139-162	21	149.1	4.7	144-164	19	147.5	4	139-154
T09	39	150.2	6.8	137-163	16	147.4	8.3	136-163	19	149.2	9.6	138-174
T10	--	--	--	--	--	--	--	--	--	--	--	--
T11	2	160.5	13.4	151-170	--	--	--	--	--	--	--	--
T12	--	--	--	--	--	--	--	--	--	--	--	--
Total	741	150.5	8.7	133-220	411	150.8	8.5	131-181	411	151.2	8.9	133-192

Table 3. Sample size, mean, standard deviation (SD), and range of weights (g) by test block for radio-tagged yearling Chinook salmon released at Ice Harbor Dam to evaluate passage behavior and dam and spillway survival during BiOp and 50% spill conditions, 2003. Treatment fish were released at Lower Monumental Dam and regrouped based on entry timing into the Ice Harbor Dam forebay.

	Treatment				Reference (R_1 upper tailrace)				Reference (R_2 Goose Island)			
Test Block	N	Mean weight (g)	SD	Range	N	Mean weight (g)	SD	Range	N	Mean weight (g)	SD	Range
	BiOp spill condition											
B01	--	--	--	--	--	--	--	--	--	--	--	--
B02	44	31.1	6.2	25.0-47.9	30	30.8	6.9	25.0-49.2	22	33.7	9.1	25.0-54.4
B03	58	33.9	8.6	25.2-59.6	26	32.4	5.6	25.0-42.8	25	31.1	5.2	25.2-44.7
B04	31	30.2	4.1	25.3-41.7	26	30.8	5.6	25.4-51.4	27	31.0	5.9	25.0-53.4
B05	53	30.1	5.3	25.2-52.5	28	31	5.4	25.0-49.9	29	32.1	7.4	25.5-53.9
B06	--	--	--	--	14	31.6	6.4	25.2-44.8	11	33.6	5.6	27.3-44.8
B07	69	29.6	5.0	25.0-54.5	20	28.8	3.2	25.7-37.9	26	30.3	4.1	25.3-40.2
B08	29	29.2	4.3	25.1-41.4	30	30.1	5.8	25.0-54.7	28	31.6	9.2	25.0 – 59.0
B09	92	31.5	6.1	25.2-57.7	33	32.1	6.5	25.1-52.7	36	31.2	5.6	25.2-48.8
B10	2	27.3	2.8	25.3-29.2	14	28.6	4	25.1-38.8	13	30.8	5.9	25.8-46.5
B11	46	29.1	3.9	25.0-42.5	--	--	--	--	--	--	--	--
B12	2	25.4	0.5	25.0-25.7	--	--	--	--	--	--	--	--
	50% spill condition											
T01	20	29.9	6.2	25.1-49.5	21	34	9.4	25.1-59.4	19	34.8	11.2	25.2-63.0
T02	46	33.1	7.9	25.0-59.2	32	31.2	6.2	25.0-51.7	29	32.3	7	25.0-51.6
T03	7	32.3	9.2	26.3-52.6	11	34	9.2	25.0-54.5	14	32.1	8	25.7-54
T04	46	30.0	4.6	25.1-45.1	12	28.7	3.2	25.1-34.1	17	29.6	3.9	25.3-39.5
T05	28	30.2	4.7	25.0-40.1	25	31.1	5.9	25.0-45.7	26	32.3	8.2	25.2-57.2
T06	45	28.4	3.0	25.0-36.3	26	29.3	4	25.0-42.5	24	28.7	5.3	25.2-52.4
T07	68	30.3	8.1	25.0-85.7	26	29.6	3.7	25.3-38.1	27	29.9	4.9	25.1-44.4
T08	14	28.9	3.4	25.0-35.3	21	29.9	3.9	26.0-42.0	19	28.8	1.9	25.6-31.9
T09	39	31.7	4.3	25.2-41.0	16	29.4	3.7	25.3-37.8	19	30.6	6.3	25.1-46.9
T10	--	--	--	--	--	--	--	--	--	--	--	--
T11	2	40.7	0.0	40.7-40.7	--	--	--	--	--	--	--	--
T12	--	--	--	--	--	--	--	--	--	--	--	--
Total	741	30.7	6.1	25.0-85.7	411	30.8	5.8	25.0-59.4	411	31.3	6.8	25.0-63.0

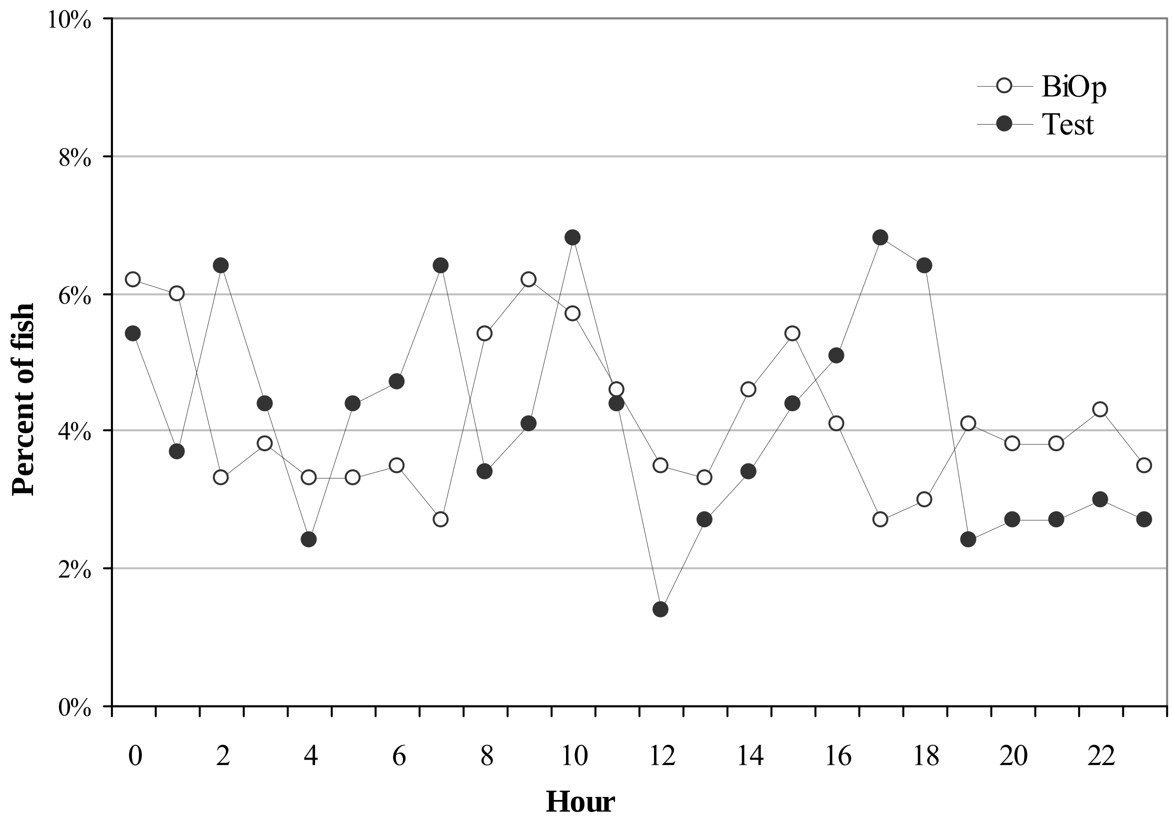


Figure 6. Hour of first detection for radio-tagged fish released at Lower Monumental Dam and detected in the forebay of Ice Harbor Dam during passage survival and behavior testing at Ice Harbor Dam, 2003.

Migration Behavior and Passage Distribution

Forebay Behavior and Timing

Of the 741 radio-tagged fish detected in the forebay of Ice Harbor Dam, 665 (89.7%) were detected on the upper forebay transect, with 369 (55.5%) of these arriving during BiOp operations and 296 (44.5%) during 50% spill operations. The upper forebay transect was made up of three receivers located on the north and south shorelines and at mid-channel. During both operations, most fish detected at this transect (55.2%) were first detected on the mid-channel receiver (Figure 7). Furthermore, 614 (82.9%) of the 741 fish detected in the forebay were detected on the lower forebay transect (Figure 3), with 343 (55.9%) detected during BiOp and 271 (44.1%) during 50% spill operations.

During BiOp operations 190 (55.4%) fish entered the lower forebay during daytime hours (0500-1800 PDT) and 153 (44.6%) during nighttime hours. Of the fish detected on lower forebay transect buoys during BiOp operations, 64.4% were first detected on buoys located in front of the spillway and 35.6% were detected on buoys in front of the powerhouse. During 50% spill operations, 157 fish (57.9%) entered the lower forebay during daytime hours and 114 (42%) during nighttime hours. For fish detected on the lower forebay transect buoys during 50% spill operations, 55.0% were first detected on buoys located in front of the spillway and 45.0% on buoys in front of the powerhouse (Figure 8).

Forebay residence times were calculated for 598 fish, each with detections on the upper forebay transect and on a passage-route receiver. For the 341 fish that entered under BiOp operations, 329 (96.5%) passed under BiOp operations while 12 (3.5%) passed under 50% spill operations. Median residence times were 1.1 h for fish that entered and passed during BiOp operations and 4.6 h for fish that entered during BiOp operations and passed during 50% spill operations.

For the 257 fish detected on the upper forebay transect under 50% spill operations, 227 (88.3%) passed under 50% spill operations while 30 (11.7%) passed under BiOp operations. Median residence times were 1.8 h for fish that entered and passed during 50% spill operations and 9.6 h for those that entered during 50% spill operations and passed during BiOp operations (Figure 9). Median residence time for fish that both entered the forebay and passed the dam during BiOp operations was 0.7 h less than for those that entered and passed during 50% spill operations. Although this difference was statistically significant ($P < 0.001$), it was not likely to have been biologically meaningful.

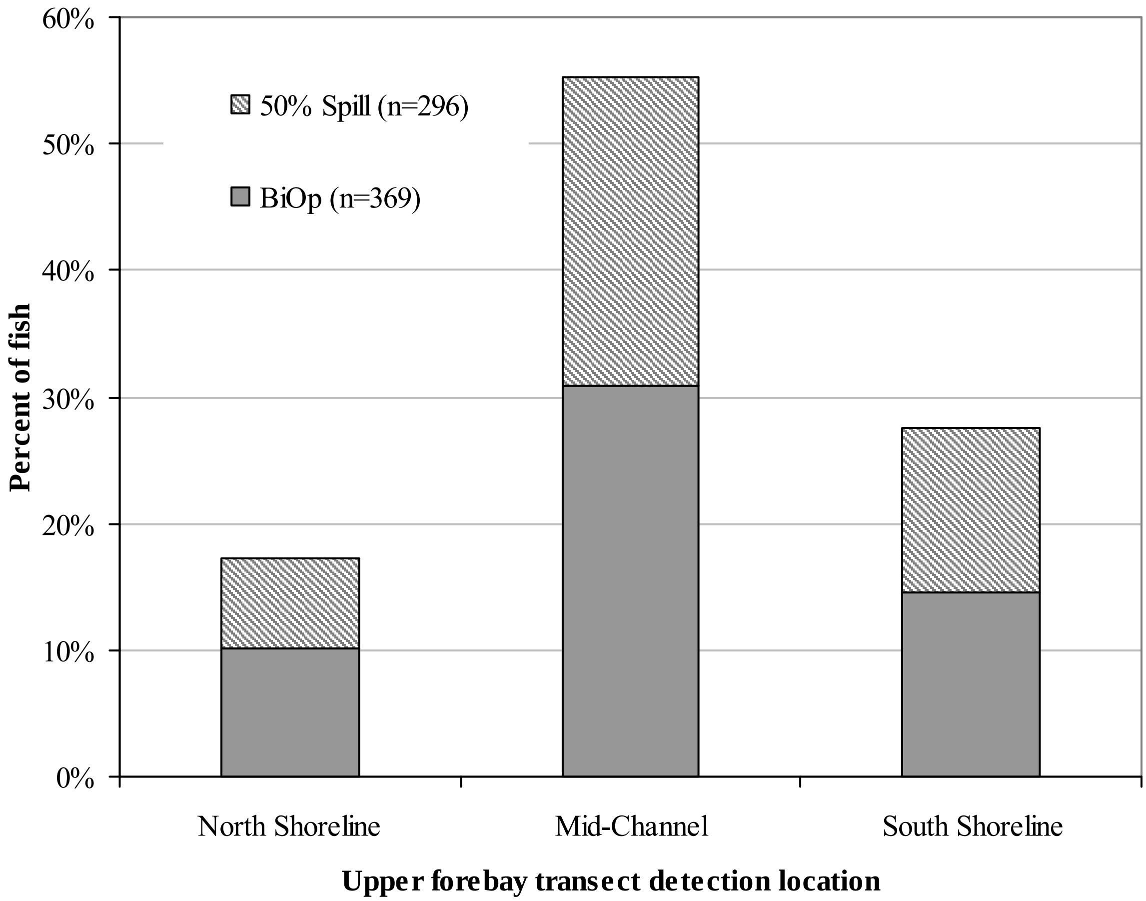
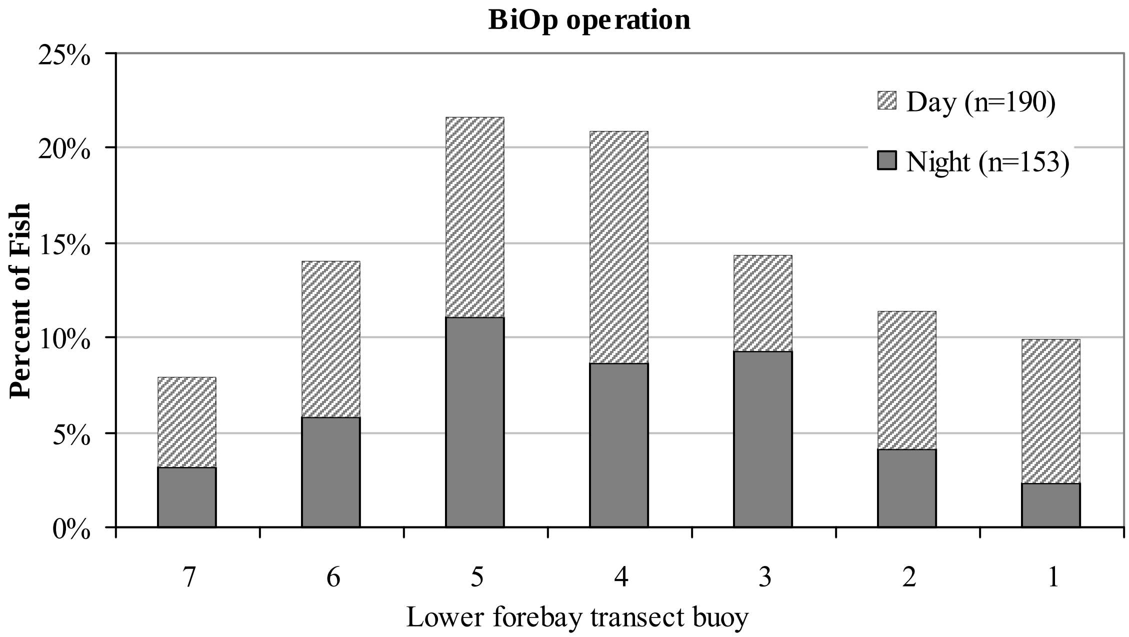


Figure 7. Horizontal distribution across the upper forebay of Ice Harbor Dam based on first detections on upper forebay transect receivers (see Figure 2), during 50% spill vs. BiOp spill operations, 2003.



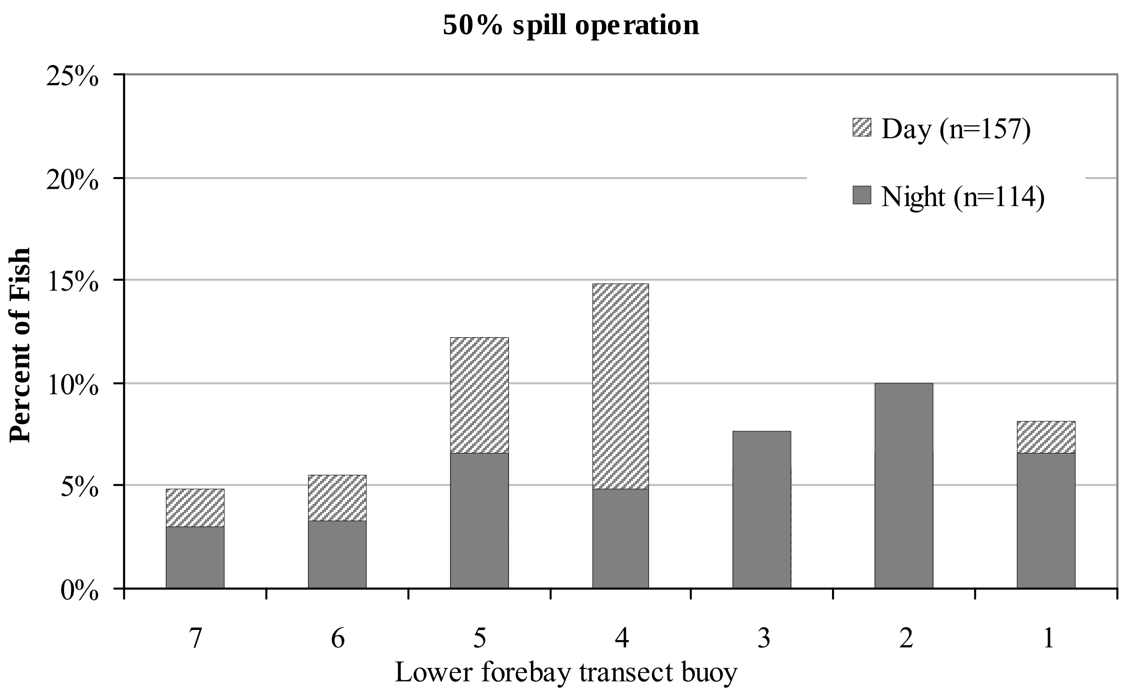


Figure 8. Horizontal distribution across the immediate forebay based on first detections on lower forebay transect buoys at Ice Harbor Dam, 2003 (Figure 3). Daytime and nighttime detections during both BiOp and 50% spill operations are shown.

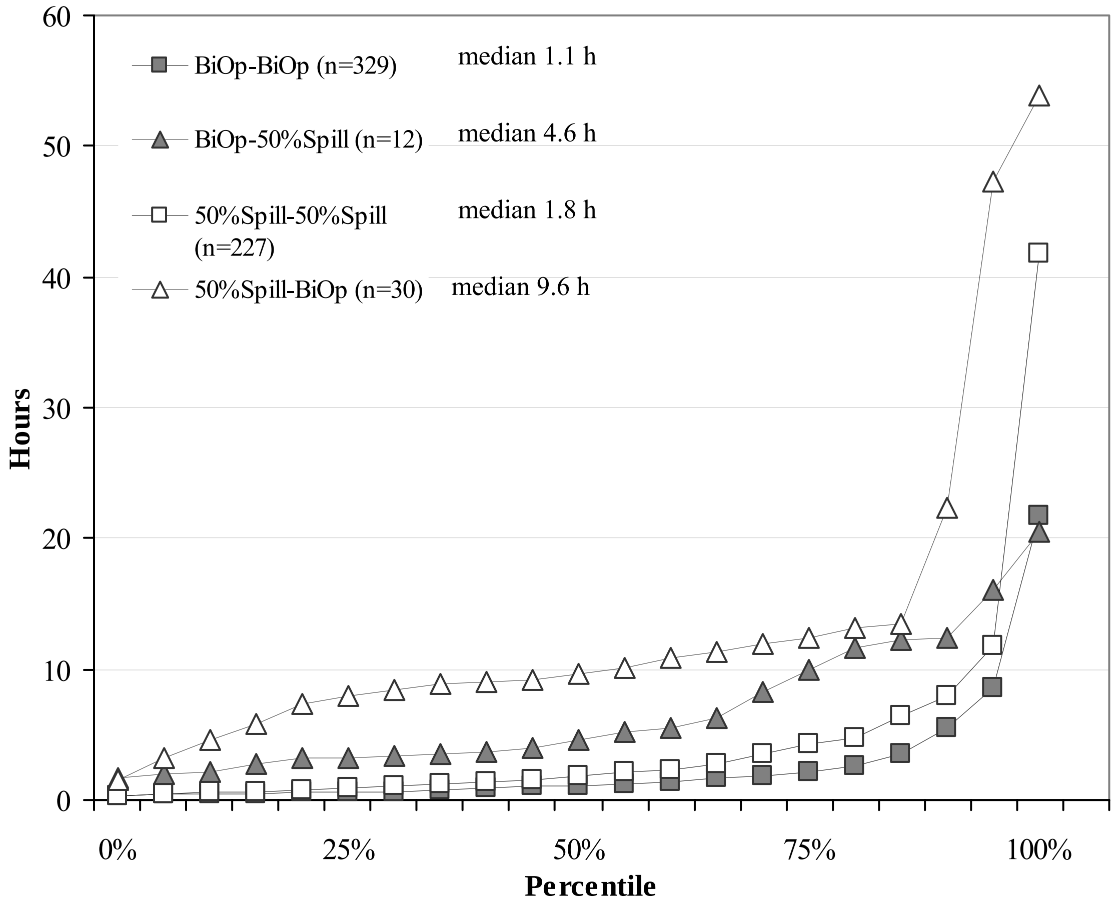


Figure 9. Distribution of forebay residence time from detection at the upper forebay transect to detection in a spillbay, turbine, or the juvenile bypass system of Ice Harbor Dam, 2003. Data is grouped by operating condition at the time of first detection in the upper forebay (BiOp or 50% spill) and by operating condition at the time of passage for radio-tagged hatchery yearling Chinook.

Passage Distribution and Metrics

Of the 847 radio-tagged fish released at Lower Monumental Dam, 746 (88.1%) were detected at or below Ice Harbor Dam and 670 (79.1%) were detected on a passage-route receiver at Ice Harbor Dam. The overall passage-route distribution for these fish was 594 (79.6%) through the spillway, 41 (5.5%) through the juvenile bypass system, and 35 (4.7%) through turbines. Eleven fish (1.8%) entered the forebay but were not recorded as passing the dam and 65 (8.7%) passed the dam but were never detected on a passage-route receiver.

Of the 670 radio-tagged fish detected on a passage-route receiver, 390 passed the project during BiOp conditions, with 210 (53.8%) of these fish passing during daytime hours and 180 (46.2%) passing during nighttime hours (Tables 4 and 5). Of the remaining 280 radio-tagged fish, 273 passed during 50% spill conditions, with 156 (57.1%) passing during daytime hours and 117 (42.9%) passing during nighttime hours. Seven fish passed the dam during operations we defined as other than BiOp or 50% spill conditions.

Most radio-tagged fish passed volitionally through the spillway during both BiOp and 50% spill operations at Ice Harbor Dam. Passage-route distribution during BiOp operations was 363 (93.1%) through the spillway, 17 (4.4%) through the juvenile bypass system, and 10 (2.6%) through turbines. Passage-route distribution during 50% spill was 224 (82.1%) through the spillway, 24 (8.8%) through the bypass system, and 25 (9.2%) through turbines.

Horizontal passage distribution through the spillway was similar between operations, with 63.4% of radio-tagged fish passing through Spillbays 1-5 during both BiOp and 50% spill (Figure 10). Problems associated with the telemetry receivers near Spillbays 3 and 4 may have led to inflation of passage numbers through Spillbay 2.

Of the 76 radio-tagged fish with known passage through either the juvenile bypass system or turbines, 69 (90.8%) passed when three or more turbine units were in operation. The proportion of these fish that passed through the juvenile bypass was 53.9% (41), while the proportion that passed through turbines was 46.1% (35). Horizontal passage distribution through powerhouse turbine units is presented in Figure 11.

Table 4. Passage-route distribution during testing at Ice Harbor Dam for radio-tagged hatchery yearling Chinook salmon, 2003.

	n	Bypass	50% Spill	Turbine
BioOp	390	4.1	93.1	2.8
50% spill	273	8.8	82.1	9.2
Overall	670	6.0	88.7	5.4

Table 5. Diel passage-route distribution for radio-tagged hatchery yearling Chinook salmon at Ice Harbor Dam, 2003.

	n	Bypass	50% Spill	Turbine
BioOp day	210	5.2	91.0	3.8
BiOp night	180	2.8	95.6	1.7
50% spill day	156	5.8	90.4	3.8
50% spill night	117	12.8	70.9	16.2

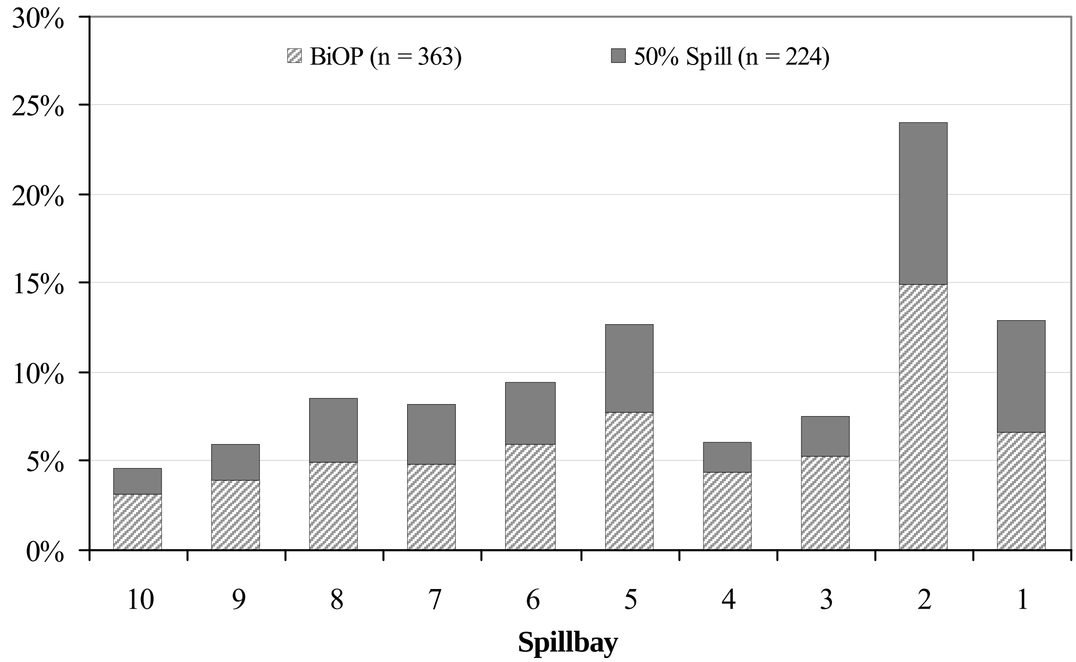


Figure 10. Horizontal passage distribution through the spillway for radio-tagged hatchery yearling Chinook salmon under BiOp and 50% spill operations at Ice Harbor Dam, 2003. Problems with the receiver monitoring Spillbays 3 and 4 likely inflated Spillbay 2 passage numbers; passage through Spillbays 3 and 4 was likely higher.

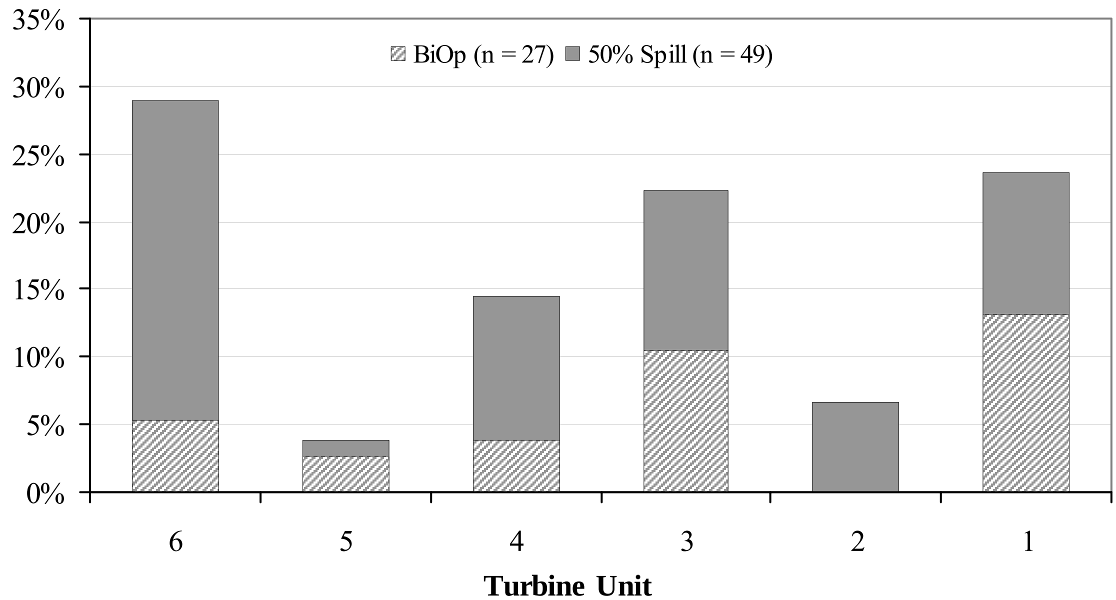


Figure 11. Horizontal passage distribution through turbines for radio-tagged hatchery yearling Chinook salmon under BiOp and 50% spill operations at Ice Harbor Dam, 2003.

Overall spill efficiency (SPE) for radio-tagged fish passing Ice Harbor Dam during BiOp operations was 93.4%; significantly higher than the 82.0% SPE during 50% spill (t = 3.25, P = 0.006; Table 6). During BiOp operations, SPE was not different between daytime and nighttime operations (t = 1.42, P = 0.178); however, during 50% spill operations, the nighttime estimate was higher than the daytime estimate, and the difference was significant (t = 4.19, P = 0.001).

The overall spill effectiveness (SPF) estimate for radio-tagged fish passing during BiOp operations was 1.4 and was significantly different from the 1.6 SPF estimate during 50% spill operations (t = 2.65, P = 0.020; Table 7). Spill effectiveness estimates for fish passing during daytime and nighttime hours were statistically different during both BiOp (t = 4.04, P = 0.001) and 50% spill (t = 4.30, P = 0.001) operations.

Overall fish passage efficiency (FPE) for radio-tagged fish passing Ice Harbor Dam during BiOp operations was 97.5%, significantly higher than the 90.0% FPE during the 50% spill operation (t = 2.51, P = 0.026; Table 8). During BiOp operations, FPE was not statistically different between daytime and nighttime operations (t = 1.16, P = 0.265); however, during 50% spill operations, the estimate for nighttime hours was higher than the estimate for daytime hours, and the difference was significant (t = 2.66, P = 0.020).

We did not calculate fish guidance efficiency because the number of radio-tagged fish (76) that passed through the powerhouse at Ice Harbor Dam during this study was too small to produce accurate estimates.

Table 6. Spill efficiency (SPE) estimates for radio-tagged hatchery yearling Chinook salmon passing during BiOp or 50% spill operations at Ice Harbor Dam, 2003. Overall estimates are shown with 95% confidence intervals in parenthesis.

Test block	Start	End	Daytime n	Daytime SPE (%)	Nighttime n	Nighttime SPE (%)	Combined n	Combined SPE (%)
				BiOp spill condition				
B01	04/28 05:00	04/30 04:55	0	--	0	--	0	--
B02	05/02 05:00	05/04 04:55	18	100.0	19	100.0	37	100.0
B03	05/06 05:00	05/08 04:55	35	85.7	19	89.5	54	87.0
B04	05/10 05:00	05/12 04:55	17	88.2	14	100.0	31	93.5
B05	05/14 05:00	05/16 04:55	9	100.0	33	100.0	42	100.0
B06	05/18 05:00	05/20 04:55	0	--	0	--	0	--
B07	05/22 05:00	05/24 05:55	39	92.3	28	100.0	67	95.5
B08	05/26 05:00	05/28 04:55	18	77.8	9	100.0	27	85.2
B09	05/30 10:00	06/01 12:55	53	92.5	34	82.4	87	88.5
B10	06/03 05:00	06/05 04:55	1	--	0	--	1	--
B11	06/07 05:00	06/09 04:55	19	94.7	24	100.0	43	97.7
B12	06/11 05:00	06/13 04:55	1	--	0	--	1	--
Overall SPE (95% CI)			210	91.4 (85.2-97.6)	180	96.5 (90.8-102.2)	390	93.4 (88.5-98.3)
				50% spill condition				
T01	04/30 05:00	05/02 04:55	13	100.0	7	57.1	20	85.0
T02	05/04 05:00	05/06 04:55	26	92.3	19	68.4	45	82.2
T03	05/08 05:00	05/10 04:55	5	--	1	--	6	--
T04	05/12 05:00	05/14 04:55	25	88.0	8	50.0	33	78.8
T05	05/16 05:00	05/18 04:55	12	100.0	15	73.3	27	85.2
T06	05/20 05:00	05/22 04:55	21	95.2	17	88.2	38	92.1
T07	05/24 06:00	05/26 04:55	29	89.7	30	76.7	59	83.1
T08	05/28 05:00	05/30 09:55	5	--	7	--	12	--
T09	06/01 13:00	06/03 04:55	19	78.9	12	50.0	31	67.7
T10	06/05 05:00	06/07 04:55	0	--	0	--	0	--
T11	06/09 05:00	06/11 04:55	1	--	1	--	2	--
T12	06/13 05:00	06/15 04:55	0	--	0	--	0	--
Overall SPE (95% CI)			156	92.0 (85.2-H98.9)	117	66.3 (52.9-79.6)	273	82.0 (75.1-88.9)

Table 7. Spill effectiveness (SPF) estimates for radio-tagged hatchery yearling Chinook salmon passing during BiOp or 50% spill operations at Ice Harbor Dam, 2003. Overall estimates are shown with 95% confidence intervals in parenthesis.

Test			Daytime		Nighttime		Combined	
block	Start	End	n	SPF	n	SPF	n	SPF
			BiOp spill condition					
B01	04/28 05:00	04/30 04:55	0	--	0	--	0	--
B02	05/02 05:00	05/04 04:55	18	1.4	19	1.1	37	1.2
B03	05/06 05:00	05/08 04:55	35	1.5	19	1.0	54	1.2
B04	05/10 05:00	05/12 04:55	17	1.5	14	1.1	31	1.3
B05	05/14 05:00	05/16 04:55	9	1.8	33	1.1	42	1.4
B06	05/18 05:00	05/20 04:55	0	--	0	--	0	--
B07	05/22 05:00	05/24 05:55	39	1.7	28	1.1	67	1.3
B08	05/26 05:00	05/28 04:55	18	1.7	9	1.5	27	1.5
B09	05/30 10:00	06/01 12:55	53	1.7	34	1.5	87	1.6
B10	06/03 05:00	06/05 04:55	1	--	0	--	1	--
B11	06/07 05:00	06/09 04:55	19	2.3	24	1.3	43	1.7
B12	06/11 05:00	06/13 04:55	1	--	0	--	1	--
Overall SPF (95% CI)			210	1.7 (1.5-1.9)	180	1.2 (1.0-1.4)	390	1.4 (1.3-1.6)
			50% spill condition					
T01	04/30 05:00	05/02 04:55	13	2.0	7	1.1	20	1.7
T02	05/04 05:00	05/06 04:55	26	1.8	19	1.4	45	1.6
T03	05/08 05:00	05/10 04:55	5	--	1	--	6	--
T04	05/12 05:00	05/14 04:55	25	1.8	8	1.0	33	1.6
T05	05/16 05:00	05/18 04:55	12	2.0	15	1.4	27	1.7
T06	05/20 05:00	05/22 04:55	21	1.9	17	1.7	38	1.8
T07	05/24 06:00	05/26 04:55	29	1.8	30	1.5	59	1.7
T08	05/28 05:00	05/30 09:55	5	--	7	--	12	--
T09	06/01 13:00	06/03 04:55	19	1.6	12	1.0	31	1.3
T10	06/05 05:00	06/07 04:55	0	--	0	--	0	--
T11	06/09 05:00	06/11 04:55	1	--	1	--	2	--
T12	06/13 05:00	06/15 04:55	0	--	0	--	0	--
Overall SPF (95% CI)			156	1.8 (1.7-2.0)	117	1.3 (1.1-1.6)	273	1.6 (1.5-1.8)

Table 8. Fish passage efficiency (FPE) estimates for radio-tagged hatchery yearling Chinook salmon passing during BiOp or 50% spill operations at Ice Harbor Dam, 2003. Overall spill efficiency estimates are presented with 95% confidence intervals in parenthesis.

Test block	Start	End	Daytime n	Daytime FPE (%)	Nighttime n	Nighttime FPE (%)	Combined n	Combined FPE (%)
				BiOp spill condition				
B01	04/28 05:00	04/30 04:55	0	--	0	--	0	--
B02	05/02 05:00	05/04 04:55	18	100.0	19	100.0	37	100.0
B03	05/06 05:00	05/08 04:55	35	85.7	19	94.7	54	88.9
B04	05/10 05:00	05/12 04:55	17	88.2	14	100.0	31	93.5
B05	05/14 05:00	05/16 04:55	9	100.0	33	100.0	42	100.0
B06	05/18 05:00	05/20 04:55	0	--	0	--	0	--
B07	05/22 05:00	05/24 05:55	39	97.4	28	100.0	67	98.5
B08	05/26 05:00	05/28 04:55	18	100.0	9	100.0	27	100.0
B09	05/30 10:00	06/01 12:55	53	100.0	34	97.1	87	98.9
B10	06/03 05:00	06/05 04:55	1	--	0	--	1	--
B11	06/07 05:00	06/09 04:55	19	100.0	24	100.0	43	1.000
B12	06/11 05:00	06/13 04:55	1	--	0	--	1	--
Overall FPE			210	96.4 (91.5-101.4)	180	99.0 (97.3-100.6)	390	97.5 (94.0-100.9)
				50% spill condition				
T01	04/30 05:00	05/02 04:55	13	100.0	7	57.1	20	85.0
T02	05/04 05:00	05/06 04:55	26	92.3	19	78.9	45	86.7
T03	05/08 05:00	05/10 04:55	5	--	1	--	6	--
T04	05/12 05:00	05/14 04:55	25	92.0	8	50.0	33	81.8
T05	05/16 05:00	05/18 04:55	12	100.0	15	73.3	27	85.2
T06	05/20 05:00	05/22 04:55	21	100.0	17	88.2	38	95.0
T07	05/24 06:00	05/26 04:55	29	96.6	30	96.7	59	96.6
T08	05/28 05:00	05/30 09:55	5	--	7	--	12	--
T09	06/01 13:00	06/03 04:55	19	100.0	12	100.0	31	100.0
T10	06/05 05:00	06/07 04:55	0	--	0	--	0	--
T11	06/09 05:00	06/11 04:55	1	--	1	--	2	--
T12	06/13 05:00	06/15 04:55	0	--	0	--	0	--
Overall FPE			156	97.3 (93.8-100.7)	117	77.8 (60.1-95.4)	273	90.0 (83.5-96.5)

Tailrace Behavior and Timing

Tailrace egress times for radio-tagged hatchery yearling Chinook salmon were calculated as elapsed time from detection on a passage route at Ice Harbor Dam to first detection at Goose Island, approximately 2 km downstream. For fish that passed through the spillway, median tailrace egress time was 0.36 h (95% CI, 0.34-0.37) during BiOp conditions and 0.37 h (95% CI, 0.36-0.40) during 50% spill conditions, and the difference was not significant (P = 0.188; Figure 12).

Spill volumes during daytime and nighttime hours can differ considerably during BiOp operations (Table 1). However, these diel changes in spill volume did not appear to impact tailrace egress time for radio-tagged fish. Median tailrace egress time during BiOp operation was 0.35 h (95% CI, 0.33-0.37) for fish that passed during daytime hours and 0.36 h (95% CI, 0.35-0.40) for fish that passed during nighttime hours; the difference was not significant (P = 0.108).

Tailrace egress time by passage route was 0.36 h (95% CI, 0.35-0.37) for fish passing through the spillway, 0.42 h (95% CI, 0.50-0.67) for fish passing through the juvenile bypass, and 0.68 h (95% CI, 0.60-0.75) for radio-tagged fish passing through the turbines. The difference in tailrace egress time between fish passing through the bypass system and those passing via turbines was significant (P = 0.002).

Median tailrace egress time for fish passing through the powerhouse (bypass system and turbine combined) was 0.59 h (95% CI, 0.50-0.67), and the difference in timing between these fish and fish that passed via the spillway was statistically significant (P = 0.002). However, this timing difference (less than one-half hour) was not likely to have been biologically meaningful. Tailrace egress timing for the 90th percentiles of each passage distribution by passage route was 0.7 h through the spillway, 0.7 h through the bypass system, and 1.2 h though turbines.

Below Ice Harbor Dam, the section of river between Eagle Island and the south shoreline was monitored to assess the proportion of radio-tagged fish that passed through this area. Of the 735 radio-tagged fish that passed Ice Harbor Dam, 53 were detected in the shallow area between Eagle Island and the south shoreline. Of these 53 fish, 38, 4, and 6 had passed through the spillway, bypass system, and turbines, respectively. Five fish detected in this area passed the dam through an unknown route. Of the 53 fish detected between Eagle Island and the south shoreline, 47 (88.7%) were subsequently detected on a downstream telemetry receivers.

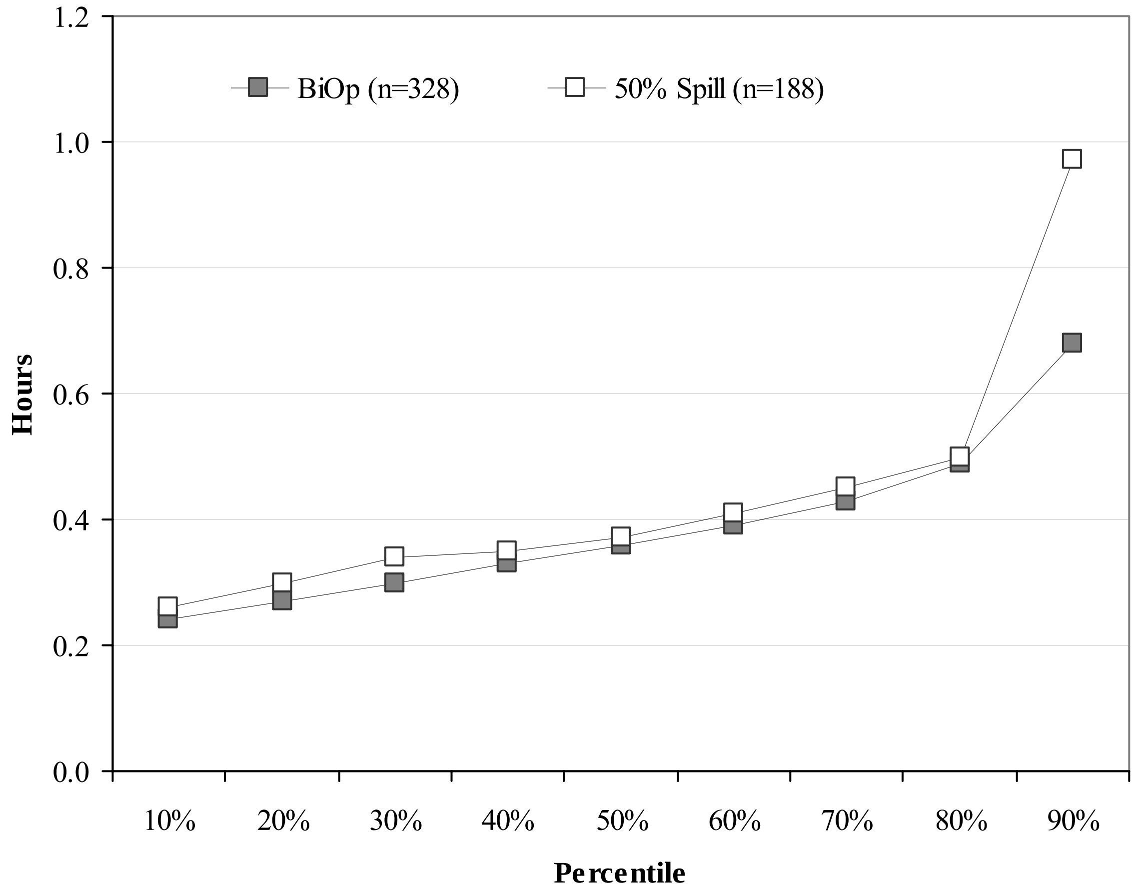


Figure 12. Tailrace egress timing for radio-tagged hatchery yearling Chinook salmon passing through the spillway at Ice Harbor Dam, 2003. Times are calculated as the elapsed time (in hours) from passage to first detection on the lower tailrace transect at Goose Island.

Detection and Survival

Of the 1,574 radio-tagged hatchery yearling Chinook salmon released for estimation of dam and spillway passage survival at Ice Harbor Dam, 1,457 (92.6%) were detected at downstream telemetry transects on the Snake and Columbia Rivers. Of these, 1,337 (91.8%) were detected at Sacajawea Park. Detection probabilities at downstream transects used for estimating survival were similar for both treatment and reference groups (Figure 13). Combined detection probabilities were 0.909 (SE = 0.008) at Sacajawea Park, 0.434 (SE = 0.014) at Port Kelley, and 0.975 (SE = 0.005) at McNary Dam.

Survival estimates for tailrace release groups of radio-tagged yearling Chinook salmon released into the upper tailrace of Ice Harbor Dam (R_1) relative to those released to the lower tailrace at Goose Island (R_2, Figure 2) ranged from 0.959 to 1.075 during BiOp operations (respective 95% CIs, 0.828-1.111; 0.968-1.195) and from 0.879 to 1.034 during 50% spill operations (95% CIs 0.737-1.050; 0.806-1.327; Table 9). The geometric mean relative survival was estimated at 0.999 (95% CI, 0.968-1.032) for fish released under the BiOp condition and 0.976 (95% CI, 0.940-1.014) for fish released under the 50% spill condition. There was no significant difference between relative survival estimates under the two operating conditions ($t = 0.96$, $P = 0.355$).

Additionally, survival estimates under both operating conditions combined were 0.971 (95% CI, 0.953-0.989) for the upper tailrace releases and 0.985 (95% CI, 0.969-1.001) for the lower tailrace releases at Goose Island. There was no significant difference between survival estimates for the upper and lower tailrace releases ($t = 1.16$, $P = 0.266$). Overall relative survival estimated for radio-tagged fish passing through the tailrace was 0.986 (95% CI, 0.962-1.010).

The upper and lower tailrace release groups were combined to form an overall reference group for estimates of relative spillway passage and dam survival. Survival estimates for groups of radio-tagged yearling Chinook salmon passing through the spillway of Ice Harbor Dam relative to those released to the tailrace ranged from 0.888 to 1.040 under BiOp operations (respective 95% CIs 0.775-1.018 and 0.942-1.147) and from 0.785 to 1.000 during 50% spill operations (95% CIs, 0.596-1.032 and 0.916-1.092; Table 10). The weighted geometric mean relative survival estimate was 0.952 (95% CI, 0.917-0.989) for fish passing under BiOp operations and 0.937 (95% CI, 0.890-0.988) for fish passing under 50% spill conditions. There was no significant difference between relative spillway passage survival estimates under the two operations ($t = 0.50$, $P = 0.628$).

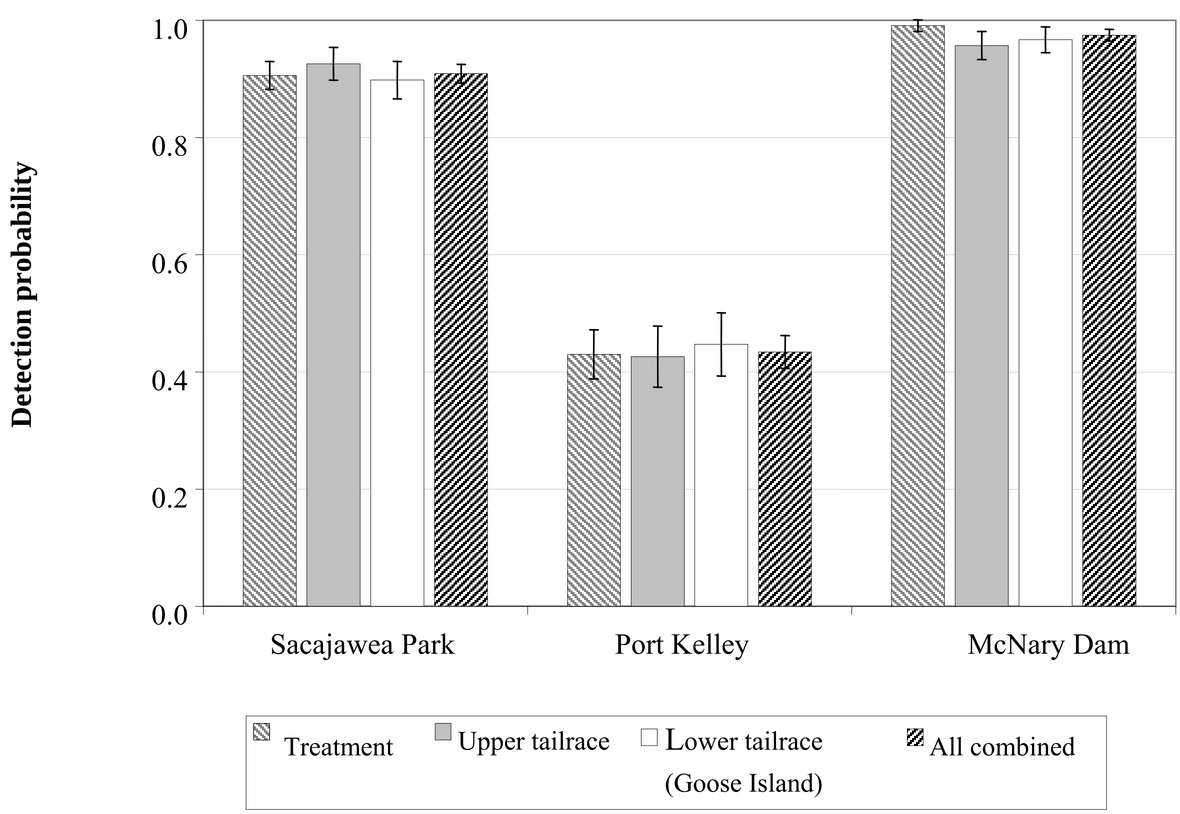


Figure 13. Detection probabilities (with 95% CIs) used for estimating spillway and dam passage survival for radio-tagged hatchery yearling Chinook salmon at Ice Harbor Dam, 2003. Treatment fish were those detected in the forebay of the dam; reference fish were released to the upper tailrace immediately below the dam or to the lower tailrace at Goose Island.

Table 9. Survival estimates for releases to the upper and lower tailrace of Ice Harbor Dam with relative survival for radio-tagged hatchery yearling Chinook salmon under BiOp and 50% spill operating conditions, 2003. Relative survival is (Standard errors in parenthesis; overall estimates are geometric means; test blocks without estimates represent periods when too few fish passed to allow survival estimation.

Test block	Upper tailrace	Lower tailrace (Goose Island)	Relative survival (upper/lower tailrace)
		BiOp condition	
B01	--	--	--
B02	0.967 (0.033)	1.000 (0.000)	0.967 (0.033)
B03	1.000 (0.000)	0.964 (0.040)	1.037 (0.043)
B04	0.962 (0.038)	0.963 (0.036)	0.999 (0.054)
B05	0.958 (0.055)	0.958 (0.053)	1.000 (0.080)
B06	--	--	--
B07	0.964 (0.052)	1.005 (0.050)	0.959 (0.070)
B08	1.002 (0.003)	0.932 (0.049)	1.075 (0.057)
B09	0.970 (0.030)	1.006 (0.006)	0.964 (0.030)
B10	--	--	--
B11	--	--	--
B12	--	--	--
Overall	0.975 (0.007)	0.975 (0.011)	0.999 (0.016)
		50% spill condition	
T01	0.952 (0.046)	1.000 (0.000)	0.952 (0.046)
T02	1.004 (0.004)	1.016 (0.013)	0.988 (0.013)
T03	--	--	--
T04	0.917 (0.080)	0.887 (0.079)	1.034 (0.129)
T05	1.017 (0.015)	1.017 (0.014)	1.000 (0.020)
T06	0.882 (0.078)	1.003 (0.004)	0.879 (0.078)
T07	0.995 (0.046)	0.970 (0.037)	1.026 (0.061)
T08	0.952 (0.046)	1.014 (0.014)	0.939 (0.047)
T09	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)
T10	--	--	--
T11	--	--	--
T12	--	--	--
Overall	0.965 (0.017)	0.988 (0.015)	0.976 (0.018)

Table 10. Spillway passage survival estimates with relative survival of radio-tagged hatchery yearling Chinook salmon passing Ice Harbor Dam under standard BiOp and 50% spill conditions, 2003. Standard errors in parenthesis; overall estimates are geometric means. Test blocks without estimates represent periods when too few fish passed to allow survival estimation.

Test block	Spillway	Combined tailrace	Relative survival (spillway/tailrace)
		BiOp condition	
B01	--	--	--
B02	0.871 (0.057)	0.981 (0.019)	0.888 (0.061)
B03	0.892 (0.061)	0.984 (0.020)	0.907 (0.065)
B04	0.931 (0.047)	0.962 (0.026)	0.968 (0.055)
B05	0.997 (0.029)	0.959 (0.038)	1.040 (0.051)
B06	--	--	--
B07	0.899 (0.040)	0.986 (0.036)	0.912 (0.052)
B08	0.924 (0.061)	0.968 (0.024)	0.955 (0.067)
B09	0.937 (0.028)	0.988 (0.015)	0.948 (0.032)
B10	--	--	--
B11	--	--	--
B12	--	--	--
Overall	0.920 (0.015)	0.975 (0.005)	0.952 (0.018)
		50% spill condition	
T01	0.765 (0.103)	0.975 (0.025)	0.785 (0.108)
T02	1.009 (0.044)	1.009 (0.006)	1.000 (0.044)
T03	--	--	--
T04	0.877 (0.077)	0.900 (0.057)	0.974 (0.105)
T05	0.839 (0.081)	1.018 (0.010)	0.824 (0.080)
T06	0.910 (0.060)	0.949 (0.039)	0.959 (0.074)
T07	0.899 (0.044)	0.979 (0.028)	0.918 (0.052)
T08	0.917 (0.080)	0.978 (0.025)	0.938 (0.085)
T09	0.850 (0.080)	1.000 (0.000)	0.850 (0.080)
T10	--	--	--
T11	--	--	--
T12	--	--	--
Overall	0.883 (0.025)	0.976 (0.013)	0.937 (0.024)

Point estimates of dam survival for groups of radio-tagged yearling Chinook salmon passing Ice Harbor Dam relative to those released into the tailrace ranged from 0.889 to 1.008 during BiOp operations (95% CIs, 0.782-1.010; 0.904-1.124) and from 0.718 to 0.978 during 50% spill operations (95% CIs, 0.588-0.877; 0.824-1.161; Table 11). The weighted geometric mean relative survival estimates were 0.948 (95% CI, 0.923-0.972) and 0.927 (95% CI, 0.875-0.983) for fish passing under BiOp and 50% spill conditions, respectively. There was no significant difference between relative spillway passage survival estimates (t = 0.68, P = 0.509) under the two operating conditions.

We found no evidence that critical assumptions of the single-release model were violated (Appendix A).

Table 11. Dam survival estimates with relative survival (treatment/reference) for radio-tagged hatchery yearling Chinook salmon passing Ice Harbor Dam under standard BiOp and 50% spill conditions, 2003. Standard errors in parenthesis; overall estimates are geometric means. Test blocks without estimates represent periods when too few fish passed to allow survival estimation.

Test block	Combined spillway, bypass, and turbine (treatment)	Combined tailrace (reference)	Relative survival
	BiOp condition		
B01	--	--	--
B02	0.872 (0.053)	0.981 (0.019)	0.889 (0.057)
B03	0.918 (0.037)	0.984 (0.020)	0.933 (0.042)
B04	0.903 (0.053)	0.962 (0.026)	0.939 (0.061)
B05	0.967 (0.036)	0.959 (0.038)	1.008 (0.055)
B06	--	--	--
B07	0.908 (0.037)	0.986 (0.036)	0.921 (0.050)
B08	0.905 (0.058)	0.968 (0.024)	0.935 (0.064)
B09	0.950 (0.024)	0.988 (0.015)	0.962 (0.028)
B10	--	--	--
B11	0.874 (0.050)	--	--
B12	--	--	--
Overall	0.912 (0.012)	0.975 (0.005)	0.948 (0.012)
	50% spill condition		
T01	0.800 (0.089)	0.975 (0.025)	0.821 (0.094)
T02	0.985 (0.035)	1.009 (0.006)	0.976 (0.035)
T03	--	--	--
T04	0.880 (0.051)	0.900 (0.057)	0.978 (0.084)
T05	0.867 (0.068)	1.018 (0.010)	0.852 (0.067)
T06	0.910 (0.053)	0.949 (0.039)	0.959 (0.068)
T07	0.886 (0.039)	0.979 (0.028)	0.905 (0.048)
T08	0.929 (0.069)	0.978 (0.025)	0.950 (0.075)
T09	0.718 (0.072)	1.000 (0.000)	0.718 (0.072)
T10	--	--	--
T11	--	--	--
T12	--	--	--
Overall	0.872 (0.029)	0.976 (0.013)	0.927 (0.027)

DISCUSSION

Operations at Ice Harbor Dam continue to be effective at passing migrating juvenile Chinook salmon while efficiently guiding fish away from turbines. Under both operating conditions evaluated in this study, radio-tagged fish entered the forebay and passed the dam quickly. Although median residence times were significantly different between BiOp and 50% spill operations, the difference of 0.7 h was not likely to have been biologically meaningful. Median forebay residence times in 2003 were similar to results from our 1999 study, wherein a majority of radio-tagged hatchery yearling Chinook salmon entered the forebay and passed the dam within 1.3 h under BiOp operations (Eppard et al. 2000).

Passage-route distribution for radio-tagged fish was dominated by spillway passage, with nearly 80% of radio-tagged fish detected in the forebay choosing the spillway for passage. Spill efficiency, spill effectiveness, and fish passage efficiency were all significantly different and higher under BiOp operations. However, fish passage efficiency, widely considered the most important of these metrics, was 90% or greater under both operations. A concurrent hydroacoustic study at Ice Harbor Dam yielded similar fish passage efficiency numbers of 95% for all species migrating past the dam (Moursund et al. 2004). Additionally, the 97.5% FPE results from this study closely matched those of our 1999 work, wherein FPE was estimated at 97.1% (Eppard et al. 2000).

Timing data for radio-tagged fish migrating through the tailrace under either BiOp or 50% spill operations indicated that little to no delay occurred for the large majority of fish (similar to results for passage through the forebay). Ninety percent of all radio-tagged fish passing through the spillway exited the tailrace in less than 1 h. Median travel time for radio-tagged fish through all routes of passage in 1999 was 0.4 h, a few minutes slower than fish in 2003. Radio-tagged fish passing through the turbines had significantly longer median egress time than fish passing through either the spillway and bypass system; however, these fish still exited in less than 1 h.

Based on both survival estimates and timing through the tailrace, predation on fish in the tailrace appeared to be minimal. A small proportion of the fish (7% or 53 fish) passing Ice Harbor Dam were guided along the south shoreline through the shallow waters between the shoreline and Eagle Island; all but six of these were subsequently detected on downstream telemetry transects.

We found no statistical difference between survival estimates for radio-tagged fish passing either through the spillway or the dam as a whole during BiOp or 50% spill operations. However, during BiOp operation, spillway passage survival estimated for radio-tagged fish that passed volitionally in 2003 was significantly higher (0.952, 95% CI, 0.917-0.989) than for fish that were released to the spillway in 2002 (0.865, 95% CI, 0.833-0.897; $t = 3.63$, $P = 0.001$).

In 2002, test fish were released through a hose at a depth of 2-3 m in the middle of each spillbay and approximately 15-20 m in front of the spillbay gate. Because fish were released this way over a short period of time, we were able to correlate project operations and environmental conditions at time of release to passage survival estimates. Weak trends indicated a relationship between total project discharge and survival where survival was lower at lower discharges (Eppard et al. 2005). In 2003, fish were released upstream from the dam and allowed to pass volitionally; because fish passed the spillway over a wider time period, and operations were so variable within a given test block, we were unable to correlate survival data with environmental conditions.

In a concurrent study of direct survival, Normandeau et al. (2004) reported survival estimates above 98% for all treatments. Injury rates, however, were higher for fish released during 50% spill compared to those released during 100% spill (BiOp night operation), indicating injuries were more prevalent at lower spill volumes. A third concurrent study released sensors approximating the size and mass of juvenile salmon (Carlson and Duncan 2003). Results indicated that injuries sustained as fish pass through a spillbay may be caused by adverse hydraulic conditions in the vicinity of the flow deflector. Sensor data indicated that where a fish passes vertically may affect its probability of injury and subsequent survival.

Normandeau et al. (2004) also found that injury rates were higher for fish released at a deeper release location (3 ft above the ogee) compared to fish released at a shallow location (7 ft above the ogee). Moursund et al. (2004) reported that the vertical distribution of most fish passing the dam was concentrated higher in the water column than the release locations used in the direct survival study (Normandeau et al. 2004), with the difference narrowing as spill volumes decreased and the spill gate was lowered.

Absolon et al. (2004) estimated relative spillway passage survival at 0.964 for PIT-tagged fall Chinook salmon released at Ice Harbor Dam during summer 2003 under a bulk spill condition (BiOp spill volume through fewer bays). This was significantly higher than the previous estimates of 0.885 in 2000 ($t = 2.24$, $P = 0.036$) and 0.894 in 2002 ($t = 2.72$, $P = 0.012$; Eppard et al. 2002, 2005). This higher relative spillway survival under the bulk spill pattern indicates that increased volume through individual spillbays may allow fish to pass over the ogee at a shallower depth, thus avoiding adverse hydraulic conditions near the flow deflector. We concluded that operating the Ice Harbor Dam spillway under a bulk spill pattern when total project discharge is low may increase survival of migrating juvenile salmonids passing the dam through that route.

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APPENDIX A:

Tests of Model Assumptions

Methods

The single-release model (Cormack 1964; Jolly 1965; Seber 1965) was used to estimate survival from Ice Harbor to Sacajawea, Port Kelley, and McNary Dam (for estimates of total dam survival, reference fish survival, spillway test fish survival, and survival of upper and lower tailrace releases). The SR model provides unbiased estimates if critical model assumptions are met, particularly assumption A1: that detection and survival probabilities are not influenced by previous detection upstream from the site of interest (Zabel et al. 2002; Smith et al. 2003).

We assessed the validity of assumption A1 using the methods of Burnham et al. (1987). We constructed χ^2 contingency tables of the total detections expected in each detection history category. Based on these tables, we tested goodness-of-fit for the actual detections of each temporal group and for the groups overall. A violation of the assumption was assumed if we found more significant differences between the expected and observed detections than would be expected by chance ($\alpha = 0.05$). In these cases, we examined the tables to determine whether the nature of the violation could be explained by a consistent pattern. We excluded any contingency table wherein the expected value in a cell was less than 1.0, as the test statistic did not sufficiently approximate the asymptotic χ^2 distribution in these cases.

For our data (a grouped cohort or release at Ice Harbor Dam, detection at Sacajawea, Port Kelley, McNary Dam, and downstream from McNary Dam), five of Burnham et al.'s (1987) goodness-of-fit tests were applicable: Tests 2.C2, 2.C3, 3.SR3, 2.Sm3, and Test 3.SR4. Test 2.C2 was based on the contingency table:

Test 2.C2	First site detected below Sacajawea		
df = 2	Port Kelley	McNary	Below McNary
Not detected at Sacajawea	n_{11}	n_{12}	n_{13}
Detected at Sacajawea	n_{21}	n_{22}	n_{23}

If assumption A1 was met, the counts for fish detected at Sacajawea should be in constant proportion to those for fish not detected (i.e., n_{11}/n_{21} and n_{12}/n_{22}, and n_{13}/n_{23} should be equal).

Test 2.C3 was based on the contingency table:

Test 2.C3	First site detected below Port Kelley	
df = 1	McNary Dam	Below McNary Dam
Not detected at Port Kelley	n_{11}	n_{12}
Detected at Port Kelley	n_{21}	n_{22}

Again, if assumption A1 was met, then numbers of fish detected at and below McNary Dam and previously detected at Port Kelley should be in constant proportion to those of fish not detected at Port Kelly (i.e., n_{11}/n_{21} and n_{12}/n_{22} should be equal).

Test 3.SR3 was based on the contingency table:

Test 3.SR3	Detected again at McNary Dam or below?	
df = 1	YES	NO
Detected at Port Kelley Not detected at Sacajawea	n_{11}	n_{12}
Detected at Port Kelley Detected at Sacajawea	n_{21}	n_{22}

If assumption A1 was met, counts of fish detected at McNary Dam or below McNary Dam vs. those of fish not detected should be in constant proportion between fish with detection histories "detected at Sacajawea and Port Kelley" and "detected at Port Kelley but not at Sacajawea."

Test 3.Sm3 was based on the contingency table:

Test 3.Sm3	Site first detected below Port Kelley	
df = 1	McNary Dam	Below McNary Dam
Detected at Port Kelley; not detected at Sacajawea	n_{11}	n_{12}
Detected at Port Kelley; detected at Sacajawea	n_{21}	n_{22}

This test is similar to Test 3.SR3, except that counts are for site of first detection downstream from Port Kelley. Again, the proportions will be similar if the model assumption is met.

The final test, Test 3.SR4, was based on the contingency table:

Test 3.SR4	Detected below McNary Dam?	
df = 1	YES	NO
Detected at McNary Dam, not detected previously	n_{11}	n_{12}
Detected at McNary Dam, also detected previously	n_{21}	n_{22}

If the model assumption is met, the detection history prior to detection at McNary Dam did not affect detection below McNary Dam, and detection/non-detection ratios would be in constant proportion.

A second assumption of the SR model, assumption A2, stipulates that survival and detection probabilities downstream from Goose Island are equitable among regrouped-test cohorts and reference releases. We examined the data for violations of this assumption by testing whether passage distributions were homogeneous between groups, or whether groups were “mixed” at downstream sites. This test used a $2 \times c$ contingency table, with two columns for the 2 groups and c rows for the number of days when fish were detected.

Again, we calculated χ^2 tests for each temporal group and if more significant differences between observed and expected data were found than would be expected by chance, we examined the table to determine the nature of the violation. We considered an additional test using three groups: spillway test groups, reference groups released in the upper tailrace (R_1), and reference groups release in the lower tailrace at Goose Island (R_2). However, the two-group test appropriately addressed our main concern, which was to examine whether the regrouped cohorts of spillway test fish were mixing with the entire cohort of reference fish (R1 and R2 combined).

Results

We found no statistical evidence that assumptions of the single-release model were violated in this study. Very few of the "Burnham tests" were calculable for any of the five groups of tests, the best being Test 2.C2 with only 28 of 80 calculable tests, and all the rest with 15 of 320 calculable tests. The was primarily due to very high detection proportions, particularly at McNary Dam, resulting in one or more of the cells with very small observed counts, and "expected counts" less than 1. For these data sets, we had very little power to test for differences in detection rates based on previous detection history. However, with such high detection rates, the tests are somewhat moot.

The results of the mixing tests indicated the test and reference fish were generally temporally mixed at Port Kelley (1 of 15 tests significant) and McNary Dam (4 of 15 tests significant, 3 of these the last 3 tests), but not at Sacajawea where 8 of 15 tests were significant (Appendix Tables A1-A3). Note that the 50% spill group 8 had a highly significant result at all three locations. This was due to few study fish in that cohort all passing Ice Harbor Dam "late" in the 2-d time period.

Study fish passed Ice Harbor Dam relatively "continuously," while reference groups were point source releases. Since Sacajawea 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. However, by the time all fish reached Port Kelley, and particularly McNary Dam, the distribution of reference fish appeared to have become more protracted, and cohorts were fairly well-mixed. Although there was some indication of a mixing violation at McNary Dam near the end of the study, the fish still were detected over a relatively short 3-d period.

Appendix Table A1. Mixing test results for Ice Harbor Dam study and reference cohorts to compare passage distributions at Sacajawea, 2003.

Test block	χ^2	Degrees of freedom	*P*-value
		BiOp condition	
B02	4.38	3	0.1943
B03	2.74	2	0.2786
B04	14.89	3	0.0008
B05	8.87	3	0.0166
B07	3.40	2	0.2082
B08	21.42	3	0.0001
B09	5.93	2	0.0538
		50% spill condition	
T01	9.11	2	0.0116
T02	2.59	3	0.4860
T04	5.41	3	0.1112
T05	3.26	2	0.1903
T06	9.57	2	0.0080
T07	10.61	2	0.0030
T08	21.15	1	<0.0001
T09	7.73	2	0.0081

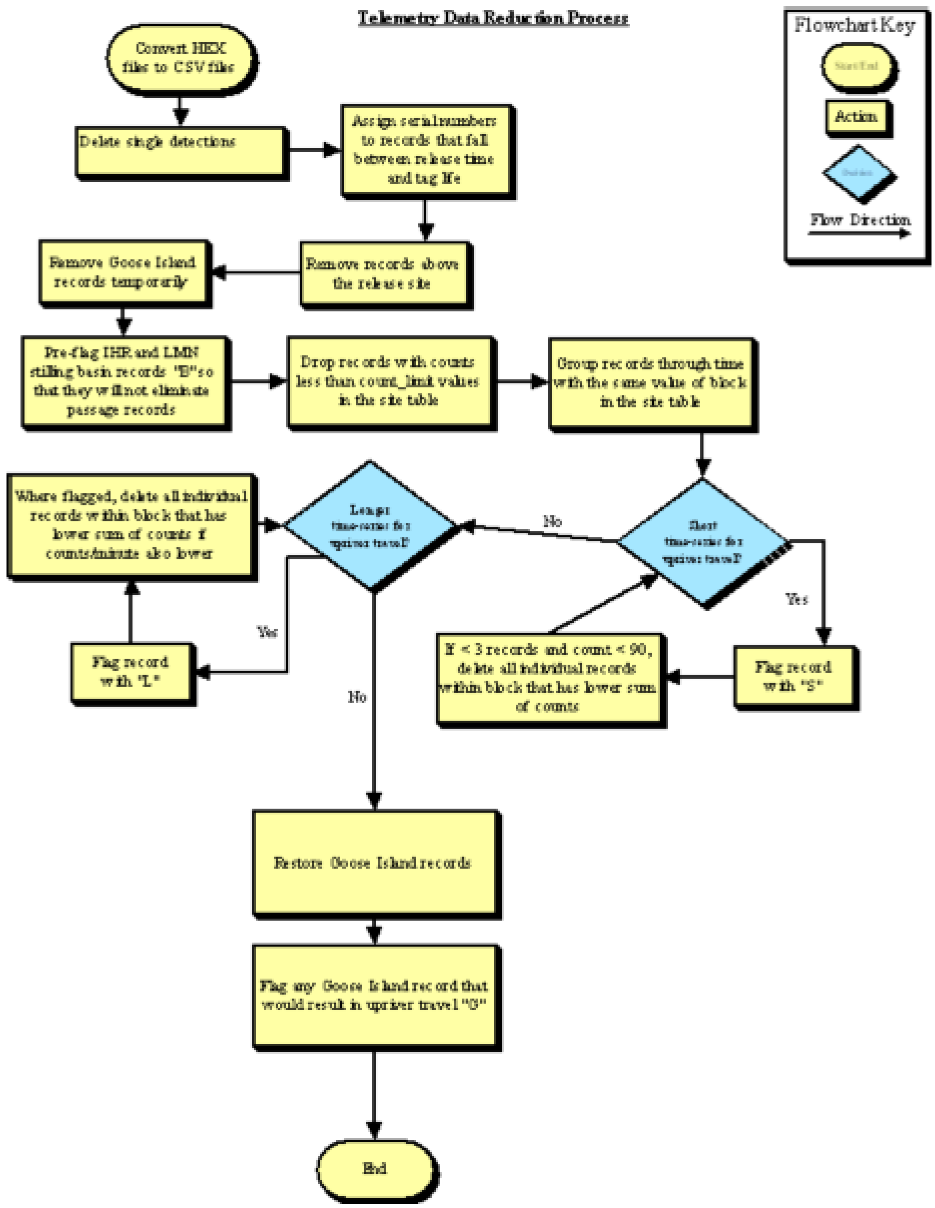
Appendix Table A2. Mixing test results for Ice Harbor Dam study and reference cohorts to compare passage distributions at Port Kelley, 2003.

Test block	χ^2	Degrees of freedom	*P*-value
		BiOp spill condition	
B02	2.03	2	0.5650
B03	3.98	5	0.7564
B04	0.08	1	0.9999
B05	5.44	3	0.1204
B07	0.38	2	0.9107
B08	0.47	3	0.9999
B09	1.73	4	0.8995
		50% spill condition	
T01	0.05	1	0.9999
T02	0.88	2	0.6780
T04	4.15	4	0.4278
T05	2.04	2	0.4924
T06	1.91	1	0.1527
T07	2.59	3	0.6650
T08	10.00	3	0.0160
T09	0.14	1	0.9999

Appendix Table A3. Mixing test results for Ice Harbor Dam study and reference cohorts to compare passage distributions at McNary, 2003.

Test block	χ^2	Degrees of freedom	P-value
		BiOp spill condition	
B02	2.76	3	0.4270
B03	4.01	4	0.4470
B04	1.79	4	0.8939
B05	3.60	4	0.5189
B07	1.37	2	0.5431
B08	9.27	2	0.0107
B09	1.12	4	0.9058
		50% spill condition	
T01	3.39	3	0.3336
T02	2.73	4	0.7209
T04	2.67	3	0.4641
T05	1.91	4	0.7681
T06	2.77	2	0.1803
T07	9.31	3	0.0155
T08	21.18	2	<0.0001
T09	6.81	2	0.0354

APPENDIX B: Telemetry Data Reduction



Appendix Figure B. Flowchart of telemetry data processing and reduction used in evaluating behavior and survival of yearling Chinook salmon at Ice Harbor Dam, 2003.