Survival of Juvenile Salmonids through the Lower Monumental Dam Spillway, 2003

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Report of research by

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EXECUTIVE SUMMARY

In 2003, NOAA Fisheries estimated relative survival for radio-tagged, river-run, hatchery yearling chinook salmon passing through the spillway at Lower Monumental Dam on the Snake River. Fish were collected, gastrically implanted with a radio transmitter, and PIT tagged. We released 206 and 214 fish into spillbays 4 and 7 (treatment), respectively, and 427 to the tailrace (reference). Releases occurred during daytime operations for 26 days from 29 April to 6 June.

Relative spillway survival was estimated from detections of treatment and reference groups at a series of downstream telemetry transects between Lower Monumental Dam on the lower Snake River and John Day Dam on the lower Columbia River. Overall relative spillway survival was 0.900 (95% CI, 0.843-0.961).

Relative survival estimates were similar for releases into spillbays 4 and 7, at 0.896 (95% CI, 0.779-1.031) and 0.895 (95% CI, 0.724-1.106), respectively (t = 0.10; P = 0.9234). Powerhouse discharge, total river flow, and tailwater elevation at Lower Monumental Dam were highly correlated among themselves during releases. Spillway survival was significantly higher for releases from 24 May through 6 June (0.987; 95% CI, 0.922-1.058) than for releases from 29 April through 23 May (0.834; 95% CI, 0.777-0.896; z = 4.31; P = 0.001). After 23 May, average total river flow doubled, average powerhouse discharge increased threefold, and average tailwater elevation increased by 4 feet, whereas the volume spilled and spillway gate opening remained relatively constant compared to conditions before 24 May.

CONTENTS

INTRODUCTION

The Columbia and Snake River Basins historically produced some of the largest runs of Pacific salmon *Oncorhynchus* spp. and steelhead *O. mykiss* in the world (Netboy 1980). More recently, however, some stocks have decreased to levels that warranted listing under the U.S. Endangered Species Act of 1973 (NMFS 1991, 1992, 1998, 1999). Factors associated with human activities that have contributed to the decline and loss of some salmonid stocks include overfishing, hatchery practices, logging, mining, agricultural practices, and dam construction and operation (Nehlsen et al. 1991). A primary focus of recovery efforts for depressed stocks has been assessing and improving fish passage conditions at dams.

The spillway has long been considered the safest passage route for migrating juvenile salmonids at Columbia and Snake River dams. Holmes (1952) reported survival estimates of 96 (weighted average) to 97% (pooled) for fish passing Bonneville Dam spillway during the 1940s. A review of 13 estimates of spillway mortality published through 1995 concluded that the most likely mortality rate for fish passing standard spillbays ranges from 0 to 2% (Whitney et al. 1997). Similarly, recent survival studies on juvenile salmonid passage through various routes at dams on the lower Snake River have indicated that 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). Pursuant to the National Marine Fisheries Service (NMFS) 2000 Biological Opinion (NMFS 2000), project operations at Lower Monumental Dam have relied on a combination of voluntary spill and collection of fish for transportation to improve hydrosystem-passage survival for migrating juvenile salmonids.

The current spill program at Lower Monumental Dam calls for voluntary spill to state and federal total dissolved-gas level limits. In 2002, the U.S. Army Corps of Engineers (USACE) modified the spillway at Lower Monumental Dam by adding flow deflectors to the end bays in conjunction with a contract to repair damage to the stilling basin. With the addition of end-bay flow deflectors, new spill patterns using all eight bays were developed prior to the 2003 juvenile salmonid migration.

In 2003, we investigated spillway survival for hatchery yearling chinook at Lower Monumental Dam using radiotelemetry under the new spill pattern. Results of this study will be used to inform management decisions to optimize survival for juvenile salmonids arriving at the dam. This study addressed research needs outlined in SPE-W-00-1 of the U.S. Army Corps of Engineers, Northwestern Division, Anadromous Fish Evaluation Program.

METHODS

Study Area

The study area included a 354-km river reach from Lower Monumental Dam on the lower Snake River to Bonneville Dam on the lower Columbia River (Figures 1 and 2). Lower Monumental Dam, the second dam on the Snake River, is located 67 km above the confluence of the Snake and Columbia Rivers.

Tagging and Release Methodology

Radio Tags

Radio tags were purchased from Advanced Telemetry Systems Inc.,[1] had a user-defined shut-off after 7 days, and were pulse-coded for 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 05 June. Only hatchery-origin yearling chinook salmon not previously PIT tagged 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 randomly selected from the daily smolt monitoring sample and transferred through a water-filled, 10.2-cm hose to a 935-L holding tank. Following collection and sorting, fish were maintained via flow-through river water and held for 24 hours prior to radio tagging.

Fish were gastrically implanted with a radio transmitter using techniques described by Adams et al. (1998a). All radio-tagged fish were also PIT tagged by hand (Prentice et al. 1990c). Immediately following tagging, fish were placed into a 19-L, aerated recovery container (two fish per container) and held a minimum of 20 h for recovery and determination of post-tagging mortality and tag regurgitation. Recovery

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

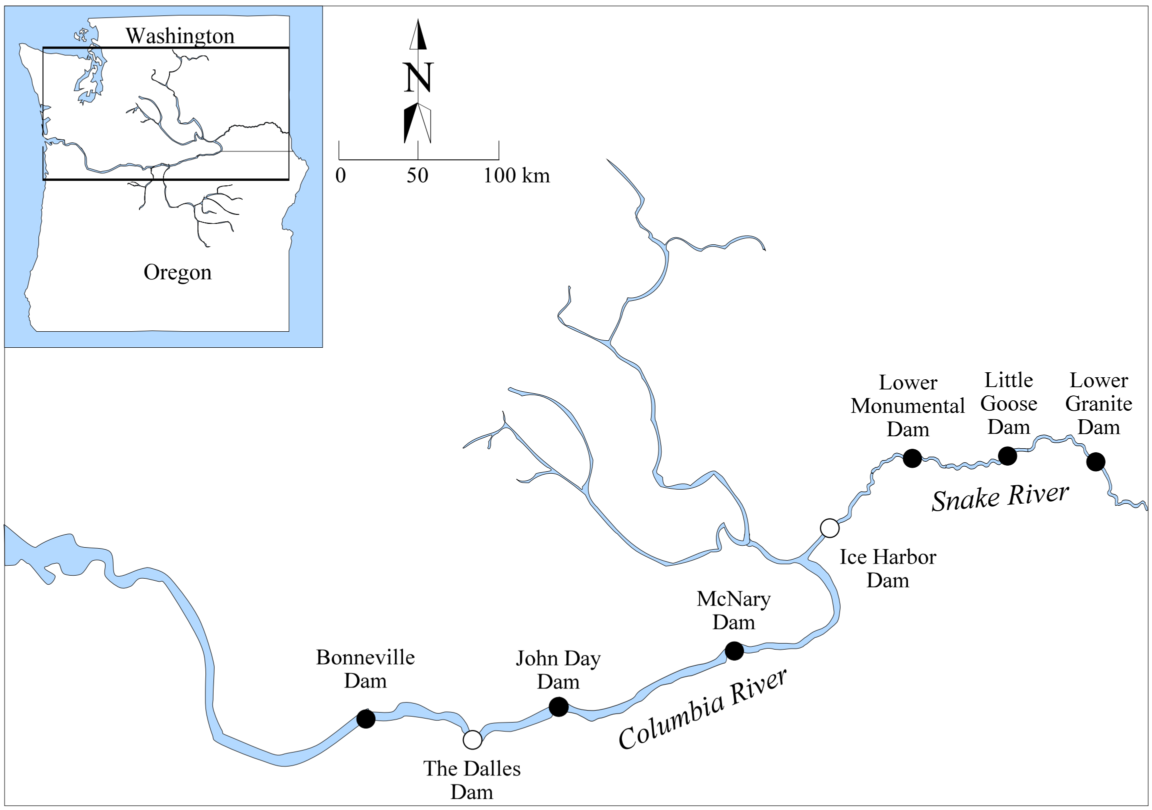

Figure 1. Study area showing locations of Snake and Columbia River hydroelectric dams with (●), and without (○) PIT-tag detection facilities and release site (Lower Monumental Dam).

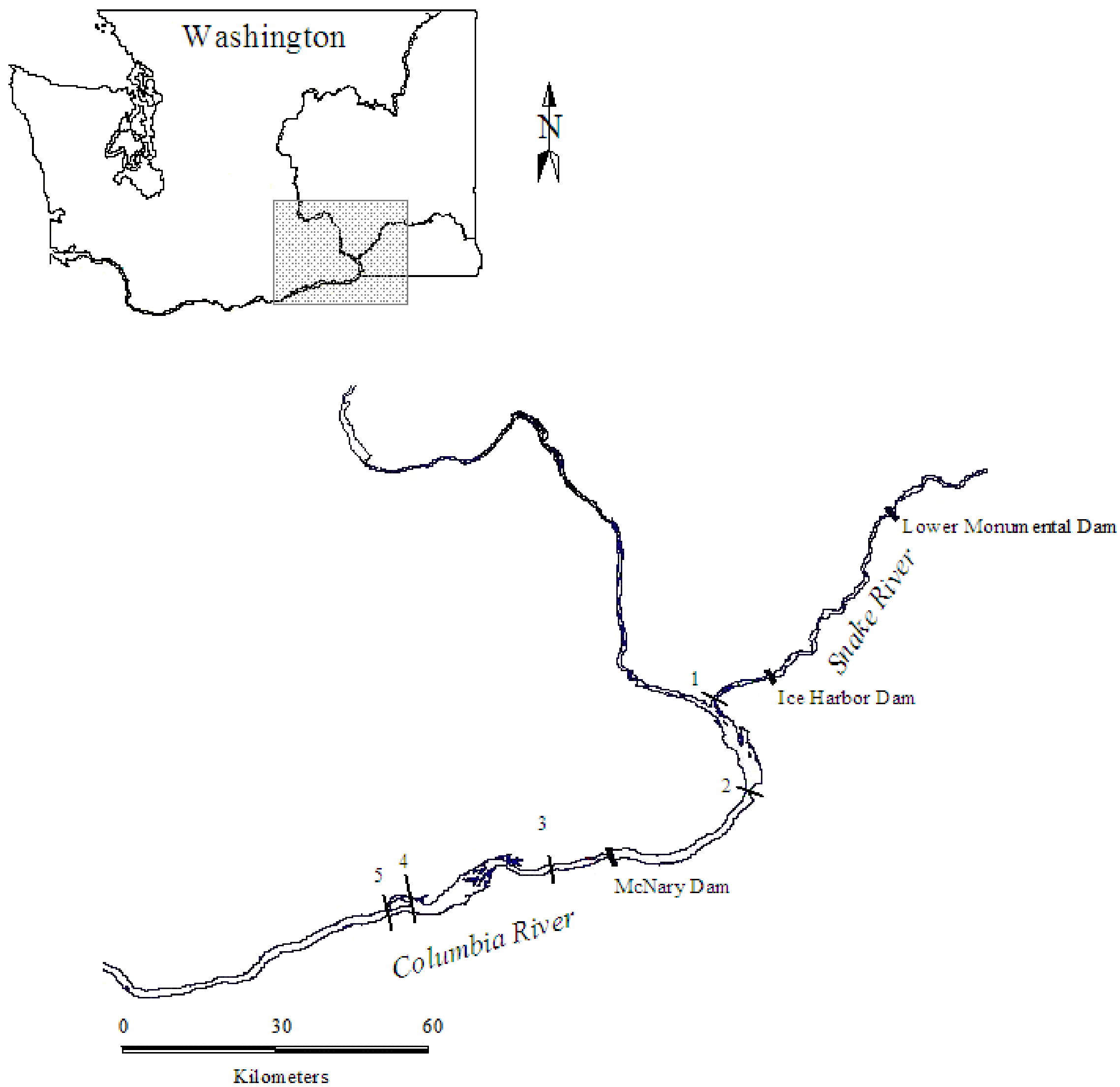

Figure 2. Detail of the study area showing locations of radiotelemetry transects used for estimating spillway passage survival at Lower Monumental Dam. Transects included: 1 = mouth of the Snake River; 2 = Port Kelley; 3 = Irrigon; OR, 4 = Crow Butte East; and 5 = Crow Butte West. The forebay, tailrace, and all routes of passage at both Ice Harbor and McNary Dams were also monitored.

containers were then closed and transferred to a 1,152-L holding tank designed to accommodate up to 28 containers. Fish holding containers were perforated with 1.3-cm holes in the top 30.5-cm of the container to allow an exchange of water during holding. All holding tanks were supplied with flow-through water during tagging and holding, and were aerated with oxygen during transportation to release locations.

Releases

After the post-tagging recovery period, fish were moved in their recovery containers from the holding area to release areas (Lower Monumental Dam spillway or tailrace). To provide mixing of treatment and reference groups, treatment groups were released approximately 7 min prior to reference groups to allow time for fish to pass through the spillbay and stilling basin. This time interval was chosen based on a tailrace-egress evaluation conducted in 1999 at Ice Harbor Dam (Eppard et al. 2000).

Treatment groups were transferred water-to-water from holding tanks to a release tank and released via a hose just upstream from the spillbays. We released approximately half of the treatment fish into spillbay 4 and half to spillbay 7 every release day except 3 and 4 May. On 3 May all treatment fish were released into spillbay 7 because of an excessive amount of woody debris in front of spillbay 4. All treatment fish were released into spillbay 4 on 4 May to balance the releases. Reference groups were transferred water-to-water from holding tanks to a release tank mounted on an 8.5 by 2.4-m barge, transported to the tailrace, and released mid-channel water-to-water into the downstream section of the stilling basin. For each release day, specific operating conditions were not requested. Project operations data were collected every 5 minutes; therefore the operational conditions assigned to each release group corresponded to conditions closest to time of release.

Data Analysis

Spillway survival was estimating using the single-release model (Cormack 1964; Jolly 1965; Seber 1965). Ratios of survival estimates were used for analyses where groups of tagged fish were released upstream ("treatment" numerator) and downstream ("reference" denominator) from the Lower Monumental Dam spillway. Estimates were based on detections of individual fish at telemetry transects on the Snake River at Ice Harbor Dam and the Snake River mouth and on the Columbia River at Port Kelley, McNary Dam, Irrigon, and Crow Butte (Figure 2). Since radio-tagged fish were also PIT tagged, we also used PIT-tag detections from the juvenile collection/detection facilities (Prentice 1990a,b) at McNary, John Day, and Bonneville Dam, as well as detections from the PIT-tag detection trawl towed in the Columbia River estuary. Capture histories of treatment and reference groups were partitioned into two periods for survival estimation: detection at Ice Harbor Dam and detection downstream from Ice Harbor Dam.

Weighted geometric means were used to average relative survival estimates, as these estimates are ratios of proportions, which can be assumed to be log-normally distributed (Snedecor and Cochran 1980). The geometric mean is equivalent to the back-transformed arithmetic mean of the log-transformed estimates. Weights were calculated using inverse relative variance (Zabel et al. 2001).

To evaluate mixing of release groups at Ice Harbor Dam, we used contingency tables (chi-square goodness-of-fit) to test for differences in arrival distributions among treatment and reference release groups. Comparisons of survival estimates between spillbays and between changes in conditions were evaluated using a z-test (< 0.05). Relationships between survival estimates and environmental conditions or project operations were analyzed using regression analysis. Study assumptions are outlined in Appendix E. At present, no formal analysis of adult returns of PIT-tagged fish used in this study is anticipated.

RESULTS

Fish Collection, Tagging, and Release

Yearling chinook salmon were collected, radio tagged, and PIT tagged at Lower Monumental Dam on 26 days from 28 April to 5 June. Tagging began after 30% of the yearling chinook salmon run had passed Lower Monumental Dam and was completed when 99% of the run had passed (Figure 3). Handling and tagging mortality for yearling chinook salmon was 4.9% overall, and tag loss due to regurgitation was 0.3%.

We released 206, 214, and 427 radio-tagged fish into spillbay 4, spillbay 7, and the tailrace of Lower Monumental Dam, respectively (Table 1). Overall mean fork lengths were 150.0, 149.0, and 150.0 mm for fish released into spillway 4, spillway 7, and the tailrace, respectively (Table 1). Respective overall mean weights were 30.6, 30.4, and 30.2 g for fish released into spillway 4, spillway 7, and the tailrace (Table 2). Releases occurred between 0925 and 1315 PDT and were made through spillbays discharging from 2.0 to 11.5 kcfs and open from 1.4 to 7.1 stops (feet) (Table 3 and Figure 4).

Lower Monumental Dam project operations during releases comprised 59.0 to 205.1 kcfs total project discharge; 29.2 to 121.6 kcfs powerhouse discharge; 23.8 to 85.3 kcfs total spill volume, or 18.6 to 51.3% of total project discharge; and tailwater elevation between 439.2 and 446.7 ft msl (Table 3 and Figure 5). Water temperature during releases ranged from 10.0 to 13.5°C.

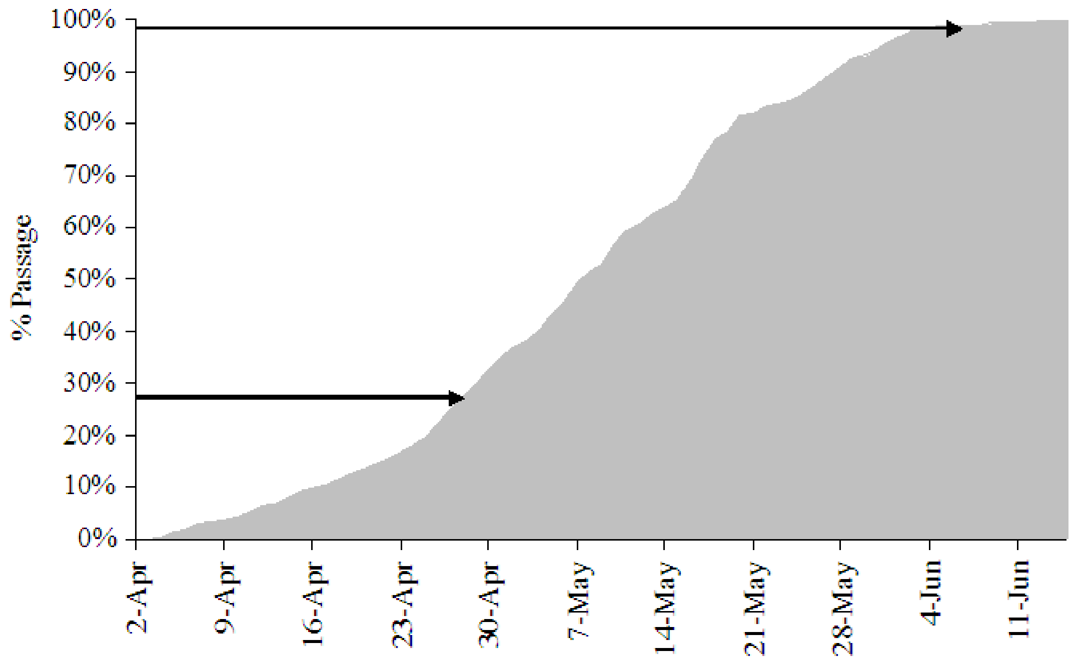

Figure 3. Cumulative passage distribution of hatchery yearling chinook salmon at Lower Monumental Dam during 2003. Arrows indicate beginning and ending release dates for radio-tagged yearling chinook salmon released to evaluate Lower Monumental Dam spillway survival, 2003.

Table 1. Sample size, mean fork length, standard deviation (SD), and range of fork lengths for radio-tagged, yearling chinook salmon released at Lower Monumental Dam to evaluate spillway survival, 2003.

	Spillbay 4				Spillbay 7				Tailrace			
Date	N	Mean length (mm)	SD	Range (mm)	N	Mean length (mm)	SD	Range (mm)	N	Mean length (mm)	SD	Range (mm)
29 Apr	6	151.7	10.6	140-167	7	146.7	3.1	143-152	12	149.5	9.8	138-175
30 Apr	7	152.0	9.4	142-166	7	147.6	10.3	139-170	9	149.8	8.1	138-165
01 May	7	153.6	7.6	145-166	2	146.0	9.9	139-153	13	151.2	7.6	139-165
02 May	4	156.5	11.6	143-170	6	147.2	8.4	138-163	14	159.4	13.9	143-187
03 May	18	154.3	11.7	142-185	—	—	---	---	16	150.4	6.7	142-166
04 May	---	---	---	---	15	156.3	13.3	139-184	16	153.6	9.0	144-178
05 May	7	152.1	9.9	140-169	8	154.1	11.2	146-180	20	152.5	9.3	136-170
09 May	10	150.7	9.7	133-168	9	148.7	6.0	139-156	18	149.2	5.9	141-161
10 May	6	147.8	5.4	142-156	7	149.3	8.2	141-162	17	149.8	4.5	141-160
11 May	8	153.4	5.8	144-162	10	151.7	10.2	140-175	12	149.8	7.0	136-161
12 May	5	148.4	8.5	137-157	7	147.4	4.9	138-153	13	150.2	9.2	139-174
13 May	5	148.8	4.2	144-154	6	149.3	5.6	143-158	13	148.6	4.2	144-157
14 May	8	154.0	8.9	144-171	7	147.4	5.2	143-157	14	149.0	7.0	138-169
15 May	8	148.6	8.3	141-162	9	150.4	4.3	145-158	12	148.3	6.3	141-159
19 May	8	141.9	3.5	137-146	9	152.0	11.4	140-178	17	151.8	5.9	143-163
20 May	9	146.1	5.7	138-156	11	143.7	5.6	135-156	19	145.5	5.8	137-160
21 May	7	151.1	10.0	140-165	5	147.4	6.0	140-156	21	149.1	7.1	142-178
22 May	4	149.5	3.0	146-152	8	153.6	21.0	137-204	15	151.9	8.2	140-174
23 May	6	153.3	7.8	144-166	9	151.3	9.4	140-170	19	146.1	6.2	138-160
24 May	11	149.5	5.1	139-159	10	143.5	3.7	138-149	20	155.4	17.1	139-220
25 May	6	152.7	7.9	141-161	4	142.3	6.6	135-151	17	147.0	6.3	138-165
29 May	11	150.6	6.1	143-162	8	150.1	8.3	137-160	16	147.1	4.5	141-156
30 May	13	147.1	6.3	137-157	13	150.8	8.6	139-172	22	150.5	7.5	139-165
31 May	9	150.4	6.8	142-164	10	151.6	8.4	138-167	25	153.6	10.5	140-179
01 Jun	10	147.0	6.4	139-162	13	148.2	7.5	137-159	14	149.9	6.3	141-161
06 Jun	13	149.0	6.4	140-164	14	147.9	4.9	140-158	23	148.0	7.2	138-174
Overall	206	150.0	8.0	133-146	214	149.0	9.1	135-204	427	150.0	8.6	136-220

Table 2. Sample size, mean weight, standard deviation (SD), and range of weights (g) for radio-tagged, yearling chinook salmon released at Lower Monumental Dam to evaluate spillway survival, 2003.

	Spillbay 4				Spillbay 7				Tailrace			
Date	N	Mean weight (g)	SD	Range (g)	N	Mean weight (g)	SD	Range (g)	N	Mean weight (g)	SD	Range (g)
29 Apr	6	31.9	7.8	26.4-42.0	7	29.2	2.7	25.2-33.0	12	30.3	7.0	25.1-49.5
30 Apr	7	32.8	6.7	26.4-42.1	7	30.1	7.2	25.3-46.1	9	30.6	6.1	25.0-40.1
01 May	7	34.3	8.2	26.1-47.9	2	29.3	5.9	25.1-33.4	13	30.1	4.5	25.7-40.5
02 May	4	35.9	9.7	25.8-47.8	6	29.0	5.4	25.3-39.7	14	37.2	10.0	26.4-59.2
03 May	18	33.0	8.7	25.7-55.2	—	—	—	---	16	30.9	5.5	25.0-44.9
04 May	---	—	—	—	15	35.0	9.6	25.4-59.6	16	31.9	7.8	25.0-58.0
05 May	7	31.6	7.5	25.2-43.1	8	32.4	8.8	25.8-52.6	20	32.2	7.1	25.2-51.9
09 May	10	30.9	6.2	25.2-45.1	9	28.0	2.7	25.1-33.3	18	29.1	3.8	25.3-38.4
10 May	6	27.0	2.7	25.1-32.2	7	29.8	5.7	25.2-41.0	17	29.8	3.1	26.1-37.3
11 May	8	31.5	4.1	25.1-38.1	10	30.7	8.1	25.1-51.9	12	28.6	3.0	25.1-34.4
12 May	5	30.2	4.1	25.5-35.7	7	29.2	3.1	25.2-34.1	13	31.0	7.7	25.3-52.5
13 May	5	28.7	2.7	25.7-32.0	6	30.3	4.5	27.4-39.3	13	28.8	3.8	25.2-35.2
14 May	8	31.2	6.0	25.0-42.9	7	27.8	2.7	25.1-31.4	14	29.2	4.5	25.0-41.6
15 May	8	30.2	5.8	25.7-40.1	9	29.6	4.2	25.1-37.4	12	29.3	4.3	25.2-39.0
19 May	8	26.1	0.7	25.3-27.0	9	30.5	7.2	26.1-48.4	17	29.7	3.1	25.4-36.3
20 May	9	27.9	2.5	25.1-32.6	11	28.6	4.7	25.1-40.2	19	28.4	3.5	25.0-38.6
21 May	7	29.9	5.2	25.3-38.9	5	29.6	4.8	25.5-36.8	21	29.2	6.0	25.2-54.5
22 May	4	27.7	2.4	25.6-31.2	8	35.0	20.6	25.7-85.7	15	30.3	5.1	25.1-46.1
23 May	6	32.2	8.0	25.7-46.4	9	30.6	8.1	25.5-50.1	19	28.3	2.3	25.2-33.1
24 May	11	28.8	3.7	25.0-39.0	10	26.8	1.8	25.0-31.2	20	30.8	4.6	25.2-43.9
25 May	6	32.4	5.8	26.3-41.4	4	26.7	0.9	25.8-27.5	17	28.5	3.9	25.1-40.0
29 May	11	30.4	4.5	25.0-38.6	8	29.9	3.1	25.5-35.3	16	28.2	2.4	25.0-32.6
30 May	13	29.9	3.6	25.4-35.6	13	32.1	5.7	25.2-45.6	22	30.5	5.5	25.2-45.2
31 May	9	30.7	5.7	25.7-43.9	10	33.0	5.9	25.5-44.5	25	33.7	8.7	25.2-57.7
01 Jun	10	30.0	4.4	25.3-40.5	13	30.7	4.2	25.2-37.6	14	30.8	4.1	25.3-38.1
06 Jun	13	30.1	5.4	25.4-41.0	14	28.7	3.2	25.0-35.6	23	28.4	3.6	25.0-42.5
Overall	206	30.6	5.8	25.0-55.2	214	30.4	6.9	25.0-85.7	427	30.2	5.6	25.0-59.2

Table 3. Discharge conditions for radio-tagged, hatchery yearling chinook salmon released into spillbays 4 and 7 to evaluate spillway survival at Lower Monumental Dam, 2003.

Release date	Release time (PDT)	Spillbay 4 kcfs	Spillbay 4 stops	Spillbay 7 kcfs	Spillbay 7 stops	Spillway (kcfs)	Powerhouse (kcfs)	Total Discharge (kcfs)	Tailwater elevation (ft)	Water temperature (°C)
29 Apr	09:25	4.5	3.0	4.5	3.0	39.7	47.8	87.5	440.3	10.4
30 Apr	11:10	4.5	3.0	4.5	3.0	34.9	41.5	76.4	439.8	10.5
01 May	11:05	4.5	3.0	4.5	3.0	34.7	43.4	78.1	440.2	10.5
02 May	10:25	2.8	2.0	4.5	3.0	33.6	31.9	65.5	439.5	10.7
03 May	11:40	2.8	2.0	---	---	29.8	29.2	59.0	439.4	10.4
04 May	10:50	---	---	4.3	2.9	29.8	29.3	59.1	439.2	10.3
05 May	12:55	2.0	1.4	4.3	2.9	31.3	31.4	62.7	439.5	10.1
09 May	10:20	4.2	2.8	4.3	2.9	33.6	33.1	66.7	439.2	10.3
10 May	10:20	4.3	2.9	4.3	2.9	38.1	37.7	75.8	440.0	10.6
11 May	10:10	4.3	2.9	4.3	2.9	40.7	38.6	79.3	440.2	10.8
12 May	10:50	2.7	1.9	4.5	3.0	32.1	32.9	65.0	439.5	10.7
13 May	10:40	4.5	3.0	4.3	2.9	40.4	45.0	85.4	440.1	10.9
14 May	09:50	4.5	3.0	4.3	2.9	35.5	47.6	83.1	440.3	10.9
15 May	11:25	4.5	3.0	4.5	3.0	35.3	43.7	79.0	440.3	11.1
19 May	10:20	4.3	2.9	4.5	3.0	39.9	49.6	89.5	440.5	11.3
20 May	10:20	4.3	2.9	4.3	2.9	39.5	49.1	88.6	440.4	11.4
21 May	10:25	4.3	2.9	4.2	2.8	38.5	47.3	85.8	440.4	11.6
22 May	11:05	4.3	2.9	4.2	2.8	37.1	40.8	77.9	440.6	12.1
23 May	10:25	4.3	2.9	4.3	2.9	31.9	52.1	84.0	440.1	11.9
24 May	11:30	2.7	1.9	4.2	2.8	29.2	93.0	122.2	442.9	12.0
25 May	13:15	2.4	1.7	2.5	1.8	23.8	104.0	127.8	442.9	11.8
29 May	10:05	2.7	1.9	4.3	2.9	29.8	97.7	127.5	443.3	13.5
30 May	10:30	4.3	2.9	6.2	4	48.6	121.6	170.2	444.9	12.6
31 May	10:25	10.0	6.2	11.5	7.1	85.3	119.8	205.1	446.7	12.2
01 Jun	11:05	5.5	3.6	6.2	4.0	54.8	118.0	172.8	445.3	12.6
06 Jun	09:35	2.7	1.9	2.8	2.0	25.4	96.5	121.9	442.9	13.5
Average	10.46	4.1	2.7	4.7	3.1	37.4	58.6	96.0	441.1	11.3

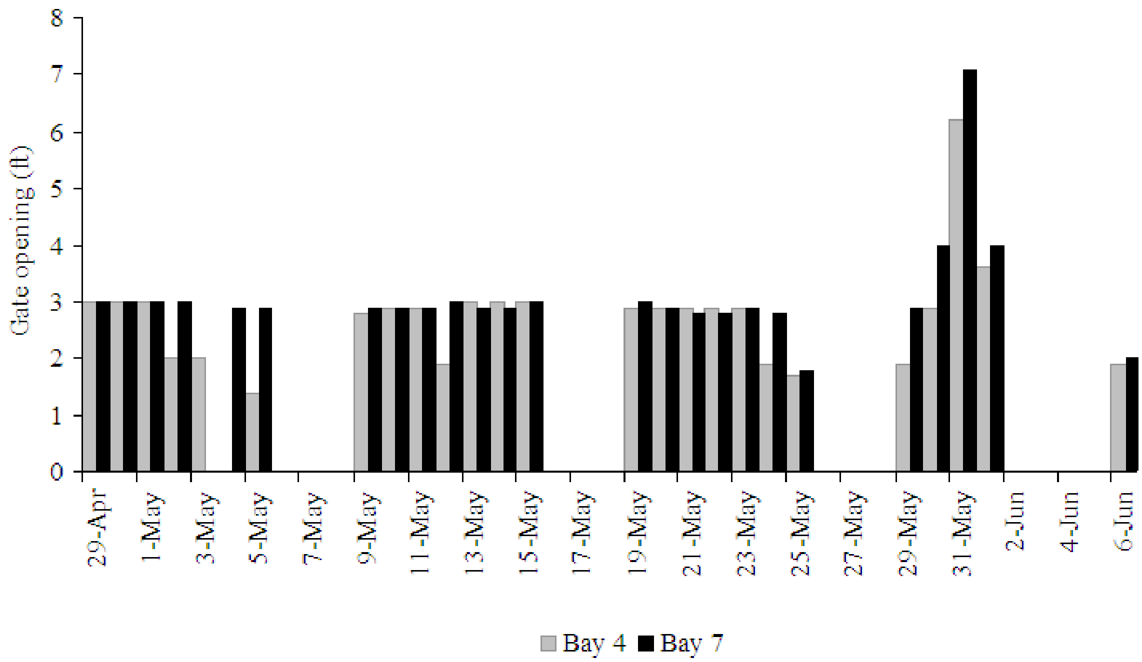

Figure 4. Spillbay gate openings during releases of radio-tagged, hatchery yearling chinook salmon into spillbays 4 and 7 at Lower Monumental Dam, 2003.

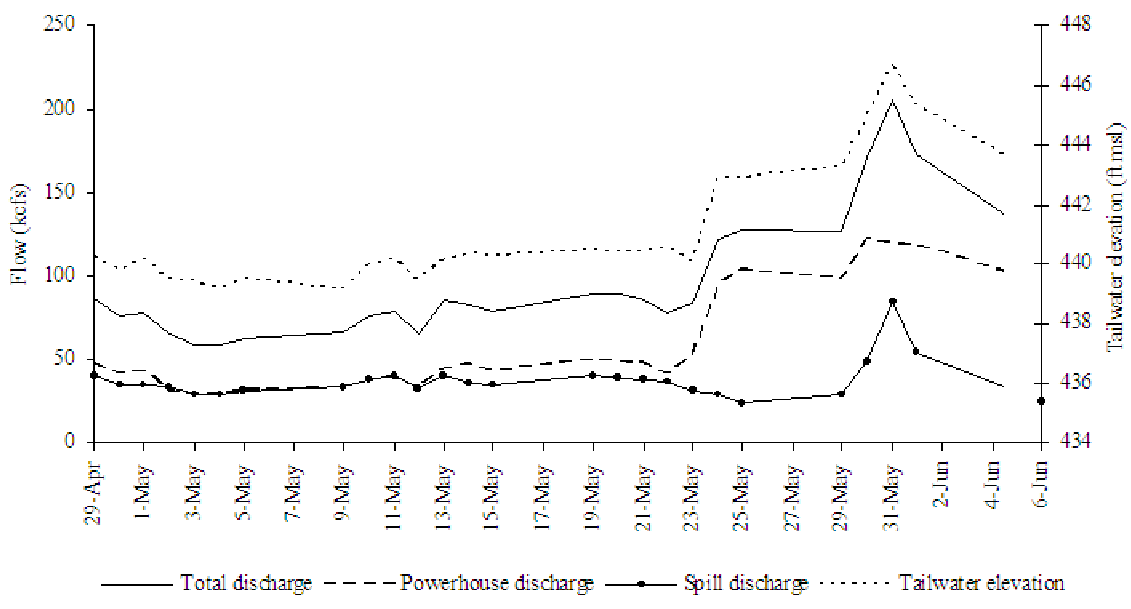

Figure 5. Snake River flow, powerhouse discharge, spillway discharge, and tailwater elevation during releases of radio-tagged, hatchery yearling chinook salmon released into spillbays 4 and 7 at Lower Monumental Dam, 2003.

Detection and Passage Distribution

Of the 847 radio-tagged yearling chinook salmon released at Lower Monumental Dam, 741 (87.5%) were detected at downstream telemetry sites or PIT-tag detection facilities (Table 4). Complete release and detection data by release date for treatment and reference groups are presented in Table 5. Temporal radiotelemetry detection distributions at Ice Harbor Dam were similar for treatment and reference groups for 24 of the 26 paired yearling chinook salmon releases (Table 6; Appendix Figures A1 and A2).

Two groups had significantly different temporal arrival distributions at Ice Harbor Dam; however, arrival timing generally varied by less than a day. These groups likely experienced similar conditions between release and arrival at Ice Harbor Dam, and the small difference in timing most likely had little effect on the survival estimates. Because the distributions appeared to differ only slightly, we concluded that the homogeneity test was sensitive enough to pick up differences that were too small to actually affect the survival analysis of treatment effects.

Relative Survival Estimates

Survival estimates for individual release groups of radio-tagged yearling chinook salmon that passed through the spillway at Lower Monumental Dam relative to those released in the tailrace ranged from 0.666 to 1.065 (Table 7). The weighted geometric mean relative survival estimate was 0.900 (SE 0.028; 95% CI, 0.843-96.1) overall for release groups in spillbays 4 and 7 combined. The weighted geometric mean relative survival estimate was 0.895 (SE 0.039; 95% CI 0.779-1.031) and 0.896 (SE 0.060; 95% CI, 0.724-1.106) for release groups in bays 4 and 7, respectively. Survival was not significantly different among releases into spillbays 4 and 7 ($t = 0.10$; $P = 0.923$; Appendix Table B1).

Table 4. First time detections at downstream telemetry and PIT-tag detection sites with proportion of fish released for evaluating survival for hatchery yearling chinook salmon passing through the spillway at Lower Monumental Dam, 2003.

Detection Site	Spillway	Tailrace	Total
Ice Harbor Dam	340 (0.810)	399 (0.934)	739 (0.872)
Below Ice Harbor Dam	1 (0.002)	1 (0.002)	2 (0.002)
Totals	341 (0.812)	400 (0.937)	741 (0.875)

Table 5. Complete release and detection data for radio-tagged, hatchery yearling chinook salmon for evaluation of the Lower Monumental Dam spillway survival including release location, numbers released, number and proportions detected, and proportion detected relative to tailrace reference groups (relative recovery).

	Spillway			Tailrace			
Date	Released	Detected	Proportion	Released	Detected	Proportion	Relative recovery
29 Apr	13	12	0.923	12	12	1.000	0.923
30 Apr	14	13	0.929	9	9	1.000	0.929
01 May	9	9	1.000	13	13	1.000	1.000
02 May	10	9	0.900	14	14	1.000	0.900
03 May	18	12	0.667	16	15	0.938	0.711
04 May	15	12	0.800	16	16	1.000	0.800
05 May	15	10	0.667	20	20	1.000	0.667
09 May	19	14	0.737	18	16	0.889	0.829
10 May	13	9	0.692	17	17	1.000	0.692
11 May	18	11	0.611	12	11	0.917	0.667
12 May	12	8	0.667	13	12	0.923	0.722
13 May	11	9	0.818	13	11	0.846	0.967
14 May	15	11	0.733	14	13	0.929	0.790
15 May	17	14	0.824	12	10	0.833	0.988
19 May	17	13	0.765	17	16	0.941	0.813
20 May	20	18	0.900	19	19	1.000	0.900
21 May	12	10	0.833	21	21	1.000	0.833
22 May	12	8	0.677	15	14	0.933	0.714
23 May	15	10	0.677	19	15	0.789	0.844
24 May	21	18	0.857	20	20	1.000	0.857
25 May	10	9	0.900	17	15	0.882	1.020
29 May	19	14	0.737	16	14	0.875	0.842
30 May	26	24	0.923	22	20	0.909	1.015
31 May	19	19	1.000	25	24	0.960	1.042
01 Jun	23	21	0.913	14	12	0.857	1.065
06 Jun	27	24	0.889	23	21	0.913	0.974
Overall	420	341	0.812	427	400	0.937	0.867

Table 6. Test of homogeneity of arrival at Ice Harbor Dam for treatment and reference groups of radio-tagged, hatchery yearling chinook salmon released on the same day at Lower Monumental Dam. Treatment release groups into spillbays 4 and 7 on the same day were pooled. Ice Harbor observations were grouped by quarter days (midnight to 6:00 am, etc.) since nearly all fish were detected in less than three days. *P*-values calculated using exact methods in Statxact (Mehta and Patel 1992). Shaded cells indicate significant differences in passage timing among tests ($\alpha = 0.05$).

Release date	χ^2	Degrees of freedom	*P*
29 April	10.27	7	0.1740
30 April	6.69	7	0.5649
01 May	1.13	4	0.9486
02 May	1.78	6	0.9999
03 May	7.26	7	0.4759
04 May	10.31	6	0.0783
05 May	16.27	11	0.1063
09 May	6.42	7	0.5959
10 May	8.28	6	0.2126
11 May	5.38	4	0.2442
12 May	9.03	6	0.2059
13 May	2.10	4	0.8636
14 May	6.15	3	0.1235
15 May	5.18	4	0.2885
19 May	6.67	6	0.3778
20 May	5.11	4	0.3251
21 May	1.25	3	0.8792
22 May	8.25	4	0.0679
23 May	13.53	5	0.0041
24 May	1.77	4	0.8616
25 May	0.60	2	0.8385
29 May	4.67	3	0.1750
30 May	2.93	3	0.4275
31 May	3.16	5	0.8300
01 June	1.43	4	0.9574
06 June	14.97	7	0.0120

Table 7. Estimated spillway survival for radio-tagged, hatchery yearling chinook salmon released into spillbays 4 and 7 (treatment) and the tailrace (reference) of Lower Monumental Dam, 2003. Treatment groups are combined releases into spillbays 4 and 7. The individual standard errors (in parenthesis) were from the single-release model and the relative survival variance estimates were calculated using the delta method (Mood et al. 1974).

Release date	Treatment survival	Reference survival	Relative survival
29 Apr	0.923 (0.074)	1.000 (0.000)	0.923 (0.074)
30 Apr	0.929 (0.069)	1.000 (0.000)	0.929 (0.069)
01 May	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)
02 May	0.900 (0.095)	1.000 (0.000)	0.900 (0.950)
03 May	0.667 (0.111)	0.938 (0.061)	0.711 (0.127)
04 May	0.800 (0.103)	1.000 (0.000)	0.800 (0.103)
05 May	0.667 (0.122)	1.000 (0.000)	0.667 (0.122)
09 May	0.737 (0.101)	0.889 (0.074)	0.829 (0.133)
10 May	0.692 (0.128)	1.000 (0.000)	0.692 (0.128)
11 May	0.611 (0.115)	0.917 (0.080)	0.666 (0.138)
12 May	0.667 (0.136)	0.923 (0.074)	0.723 (0.158)
13 May	0.818 (0.116)	0.846 (0.100)	0.967 (0.179)
14 May	0.733 (0.114)	0.929 (0.069)	0.789 (0.136)
15 May	0.824 (0.092)	0.833 (0.108)	0.989 (0.169)
19 May	0.765 (0.103)	0.941 (0.057)	0.813 (0.120)
20 May	0.900 (0.067)	1.000 (0.000)	0.900 (0.067)
21 May	0.833 (0.108)	1.000 (0.000)	0.833 (0.108)
22 May	0.667 (0.136)	0.933 (0.064)	0.715 (0.154)
23 May	0.667 (0.122)	0.789 (0.094)	0.845 (0.185)
24 May	0.857 (0.076)	1.000 (0.000)	0.857 (0.076)
25 May	0.900 (0.095)	0.882 (0.078)	1.020 (0.141)
29 May	0.789 (0.094)	0.875 (0.083)	0.902 (0.137)
30 May	0.923 (0.052)	0.909 (0.061)	1.015 (0.089)
31 May	1.000 (0.000)	0.960 (0.039)	1.042 (0.042)
01 Jun	0.913 (0.059)	0.857 (0.094)	1.065 (0.136)
06 Jun	0.889 (0.060)	0.913 (0.059)	0.974 (0.091)
weighted geomean			0.900 (0.028)

Correlations between Spillway Survival and Project Operation

High correlation was found among total river flow, powerhouse discharge, and tailwater elevation (Figure 6 and Appendix Table C1). Because of this, and the sequential relationship of these variables, we used total river flow to represent all three variables in a stepwise multiple regression analysis. The stepwise multiple regression procedure using total river flow, release date, spillway gate opening, or water temperature identified only total river flow as having a significant relationship to spillway survival ($P < 0.0001$; Appendix Table C2).

Correlations between survival and powerhouse discharge, river flow, and tailwater elevation were relatively high when compared to correlations between survival and percent spill, water temperature, release date, spillway gate opening, or spill volume (Figures 7-14). Total river flow, spill volume, powerhouse discharge, and tailwater elevation during releases were relatively constant from 29 April though 23 May (Table 3 and Figure 5). For releases from 29 April through 23 May, relative spillway survival was 0.834 (SE 0.026; 95% CI, 0.777-0.896).

On 24 May total river flow substantially increased at Lower Monumental Dam in response to the onset of spring run-off. Powerhouse discharge and tailwater elevations also increased during this time. For releases from 24 May through 6 June, relative spillway survival was 0.987 (SE 0.024; 95% CI, 0.922-1.058). Relative spillway survival was significantly higher ($z = 3.43$; $P = 0.001$) for releases when river flow, powerhouse discharge and tailwater elevation were higher (24 May through 6 June) than for releases when river flow, powerhouse discharge and tailwater elevation were lower (29 April though 23 May; Appendix Table D1). Validation and testing of study assumptions are presented in Appendix E.

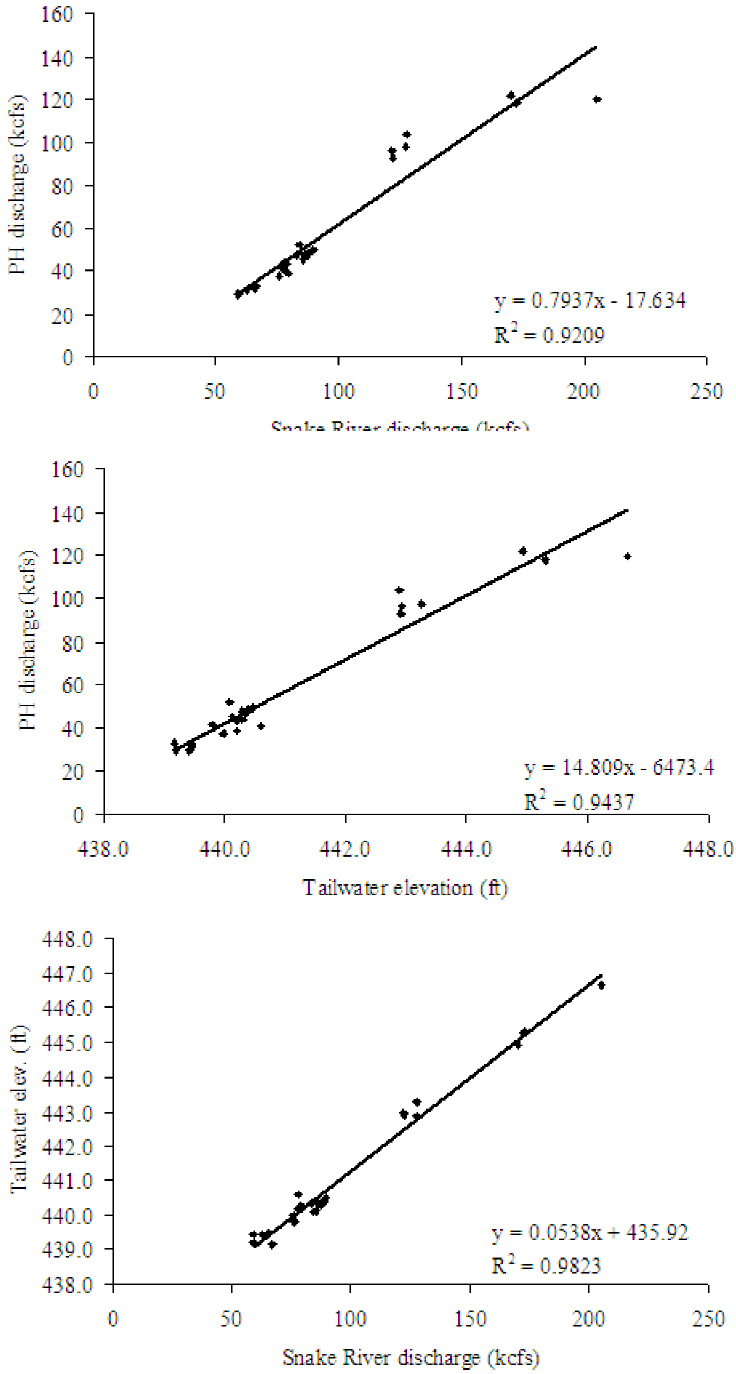

Figure 6. Relationships between Snake River flow, powerhouse discharge (PH), and tailwater elevation during releases of radio-tagged, hatchery yearling chinook salmon into spillbays 4 and 7 at Lower Monumental Dam, 2003.

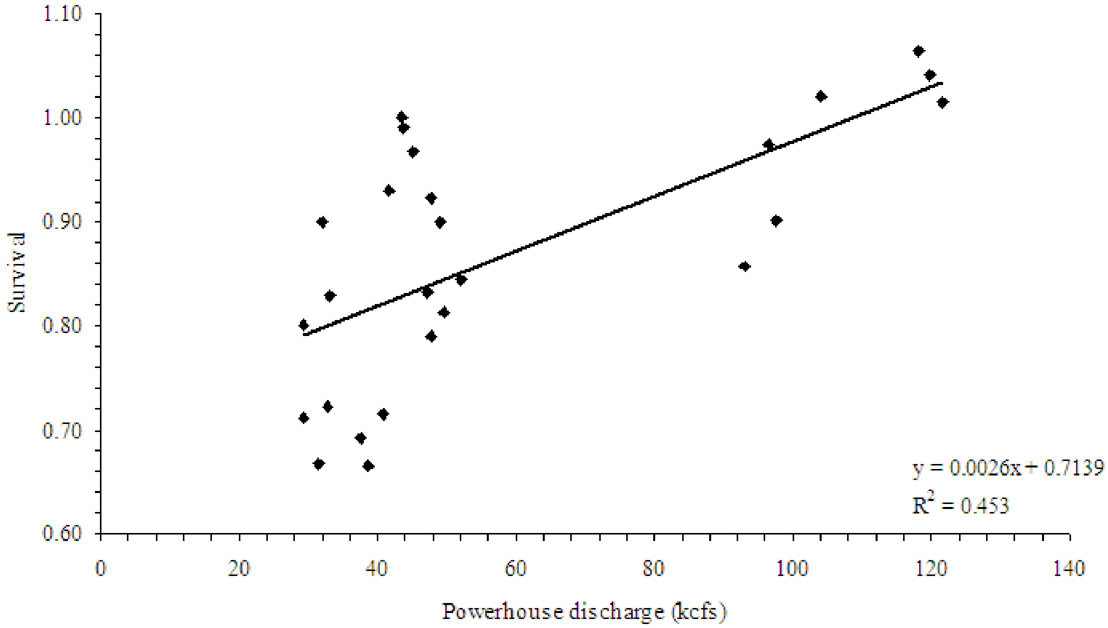

Figure 7. Relationships between estimated relative spillway survival and powerhouse discharge for groups of radio-tagged, hatchery yearling chinook salmon released into spillbays 4 and 7 at Lower Monumental Dam, 2003.

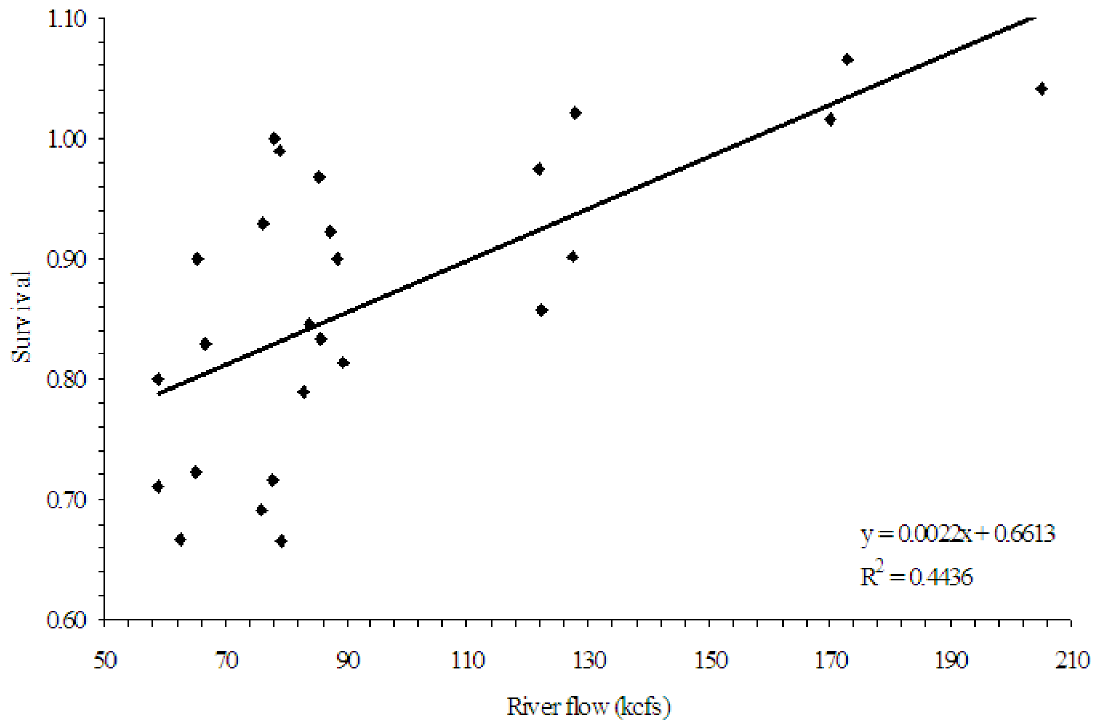

Figure 8. Relationships between estimated relative spillway survival and Snake River flow for groups of radio-tagged, hatchery yearling chinook salmon released into spillbays 4 and 7 at Lower Monumental Dam, 2003.

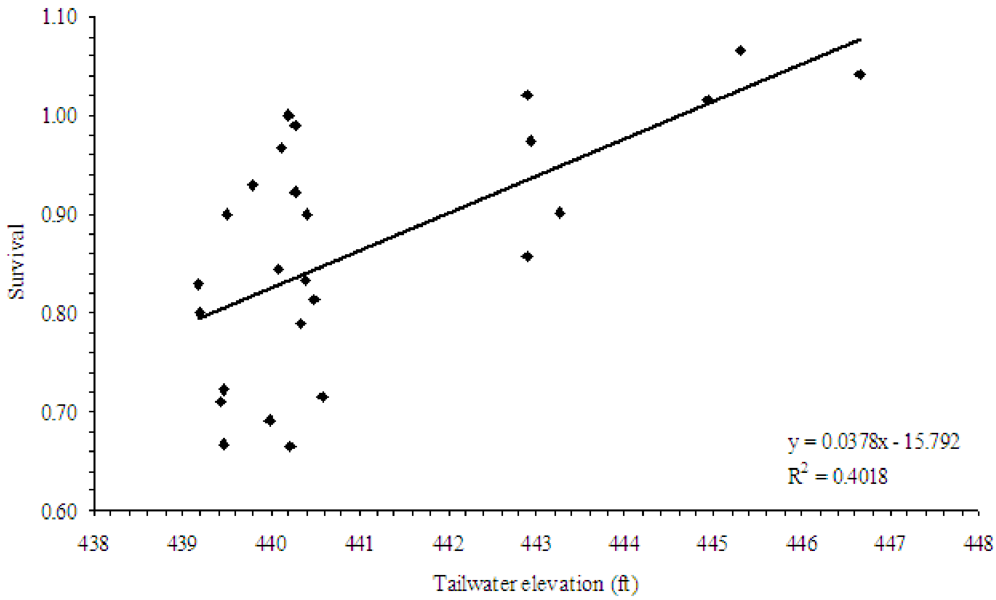

Figure 9. Relationships between estimated relative spillway survival and tailwater elevation for groups of radio-tagged, hatchery yearling chinook salmon released into spillbays 4 and 7 at Lower Monumental Dam, 2003.

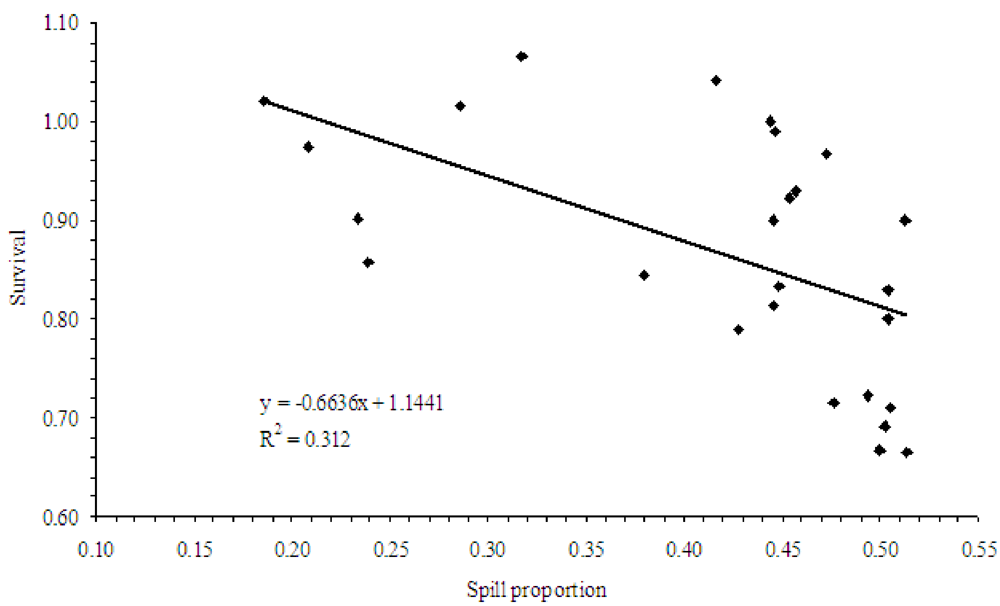

Figure 10. Relationships between estimated relative spillway survival and proportion spilled for groups of radio-tagged, hatchery yearling chinook salmon released into spillbays 4 and 7 at Lower Monumental Dam, 2003.

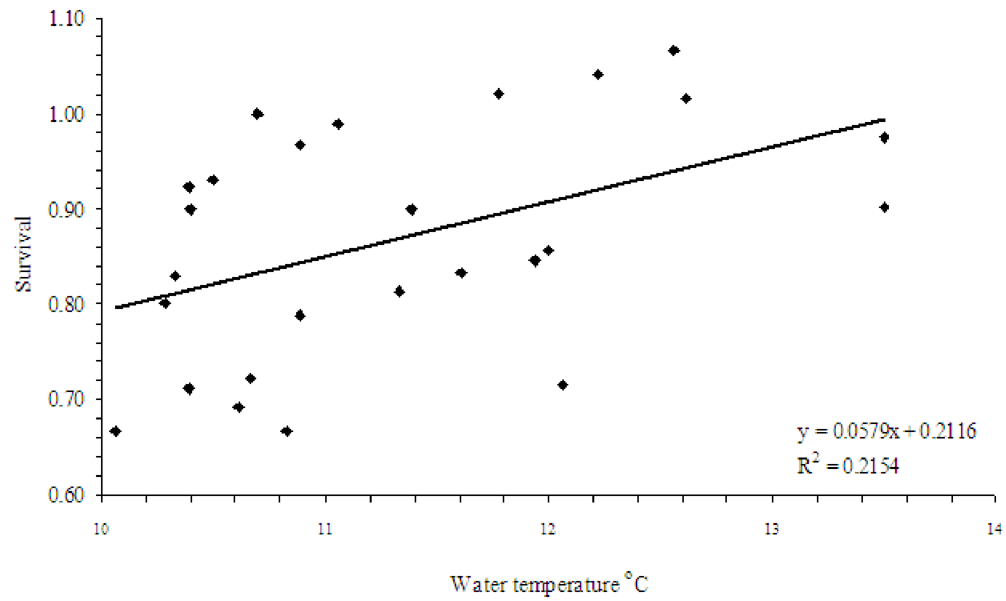

Figure 11. Relationships between estimated relative spillway survival and Snake River water temperature for groups of radio-tagged, hatchery yearling chinook salmon released into spillbays 4 and 7 at Lower Monumental Dam, 2003.

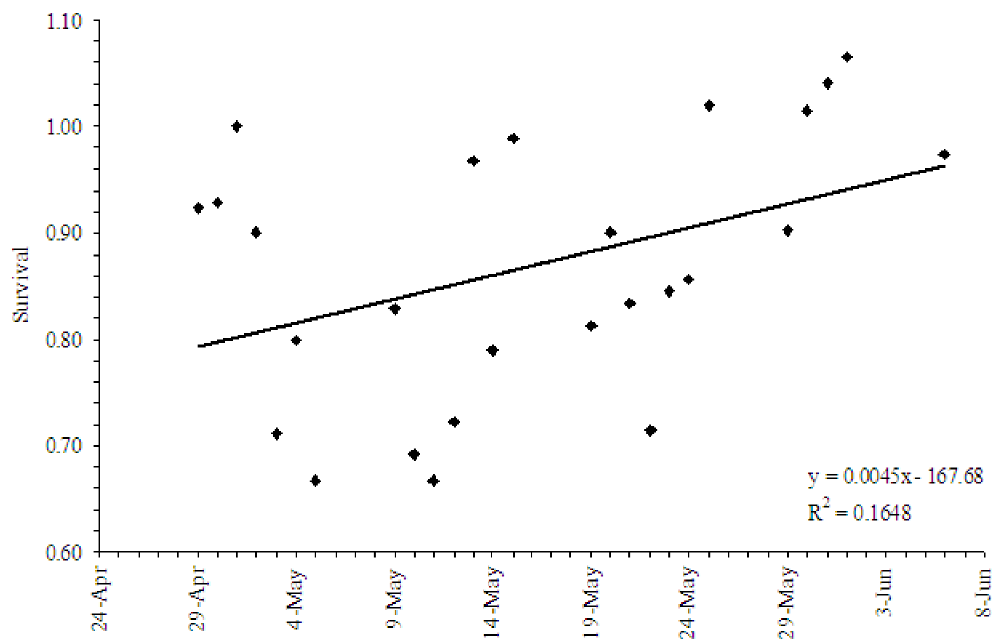

Figure 12. Relationships between estimated relative spillway survival and release date for groups of radio-tagged, hatchery yearling chinook salmon released into spillbays 4 and 7 at Lower Monumental Dam, 2003.

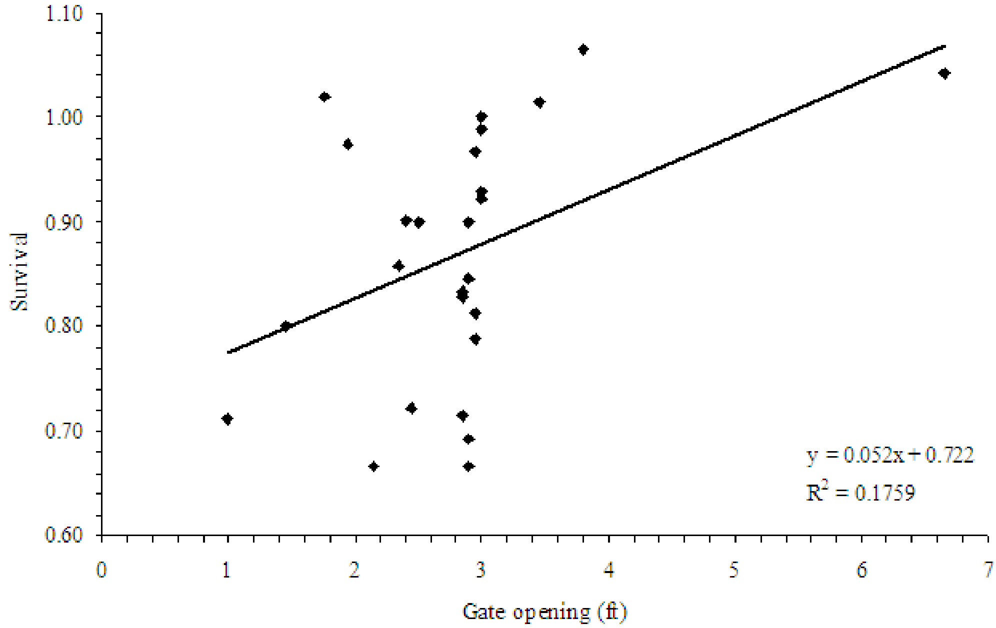

Figure 13. Relationships between estimated relative spillway survival and spillbay gate opening for groups of radio-tagged, hatchery yearling chinook salmon released into spillbays 4 and 7 at Lower Monumental Dam, 2003.

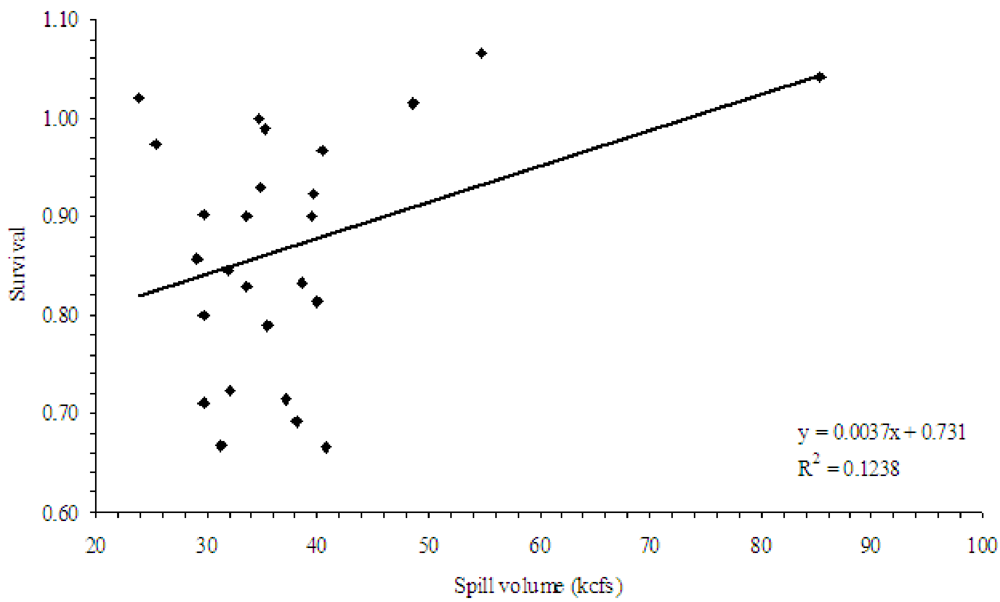

Figure 14. Relationships between estimated relative spillway survival and spillway discharge for groups of radio-tagged, hatchery yearling chinook salmon released into spillbays 4 and 7 at Lower Monumental Dam, 2003.

DISCUSSION

In general, among the various passage routes (spillway, bypass, or turbine) at lower Snake River Dams, spillway passage is considered to have the highest survival for juvenile salmonids (Muir et al. 2001). Higher survival for spillway passage is attributed to reduced passage delays and exposure to predators in the forebay and tailrace (Beamesderfer et al. 1990; Vigg et al. 1991). However, recent spillway survival studies at Ice Harbor Dam (Eppard et al. 2002), The Dalles Dam (Absolon et al. 2002; Dawley et al. 1998, 2000a,b) and Bonneville Dam (Normandeau Associates et al. 2003), found that spillway survival for juvenile fish can be inconsistent across years.

A reanalysis of juvenile salmonid survival studies by Bickford and Skalski (2000) also found high variability among spillway survival estimates. This is not surprising since the hydraulic conditions in the stilling basin and immediate tailrace can be highly variable across a range of project operations and total river flow. Our daily estimates of relative spillway survival at Lower Monumental Dam were also inconsistent across release dates (range 67 to 107%).

Previous evaluations of spillway survival at Lower Monumental Dam have seen considerable variation across species, runs, or years; this variation may have been species- or run-specific, or it may be related to differences in project operation. Long and Ossiander (1974) reported spillway passage survival of 97 to 110% for coho salmon released into spillbays with flow deflectors. Estimated survival of steelhead was 98% for releases into a spillbay with a flow deflector and 76% for releases into a spillbay without a flow deflector (Long et al. 1975). For subyearling chinook salmon released into a spillbay with a flow deflector, survival estimates were 83 to 84% (Long et al 1972).

For yearling chinook salmon, Muir et al. (1995a) estimated survival at 93% for releases into a spillbay with a flow deflector (spillbay 7) and 98% for releases into a spillbay without a flow deflector (spillbay 8) at Lower Monumental Dam. Our seasonal estimate of survival through spillbays with a flow deflector was slightly lower (90%) than Muir et al. (1995a) for yearling chinook. Estimated spillway survival was similar for releases into spillbays 4 and 7. We did not evaluate survival for fish passing through the other bays including the end spillbays (1 and 8).

Relationships between juvenile salmonid spillway survival and project operations (project and powerhouse discharge, spill volume, spill pattern, spillbay gate opening, and tailwater elevation) in the lower Snake and Columbia River Basins are not well understood. In addition, the indirect effects of spill operations on predation of smolts passing hydroelectric dams (i.e., increased vulnerability of smolts due to structures, back-eddies, or disorientation) remain critical uncertainties. Few spillway survival studies have identified relationships between survival and project operations because the range of project operations available to evaluate are often limited by lack of a power supply, regulations governing dam operations, or timing of the juvenile migration.

In a multi-year study of spillway survival trends at The Dalles Dam (1997-1999), relationships between passage survival for spring and summer migrants and changes in release date, river flow, spill volume, tailwater elevation, or temperature were not evident (Absolon et al. 2002, Dawley et al.1998, 2000a,b). Evaluations at Ice Harbor Dam during 2000, 2002, and 2003 have also been unable to identify relationships between spillway survival and release date, river flow, spill volume, tailwater elevation, or temperature for yearling or subyearling chinook salmon (Eppard et al. 2002, In prep.a,b).

Although our study was not designed to compare survival between two conditions, project operations at Lower Monumental Dam (due to the Snake River hydrograph) during 2003 and spillway survival were sufficiently different to allow comparison. Tailrace conditions during releases from 29 April to 23 May were substantially different compared to releases from 24 May to 6 June. Between the early period of the study and the latter period average total river flow doubled, powerhouse discharge increased threefold, and tailwater elevation increased by 4 feet, whereas the volume spilled and spillway gate opening remained relatively constant.

We observed significantly higher spillway survival (99% versus 83%) for fish groups released during periods of higher total river flow, powerhouse discharge, and tailwater elevation. However, because these variables were highly correlated among themselves, we were unable to determine their relative importance with regard to spillway survival. During 2000 at Ice Harbor Dam, Eppard et al. (2002) found higher spillway survival for spring migrants (98%) than for summer migrants (89%). Although they found weak relationships between spillway survival and project operations, survival estimates were lower for migrants during periods of lower total river flow, spill volume, and tailwater elevation.

During the late 1960s and early 1970s, high levels of spill at hydroelectric projects on the Snake and Columbia Rivers resulted in severe dissolved gas supersaturation problems and high mortalities of fish from gas bubble disease (Weitkamp and Katz 1980). To reduce plunging and associated air entrainment of spilled water, flow deflectors were installed on the spillway ogees at lower Snake and Columbia River dams (Smith 1974). Because flow deflectors are at a fixed elevation, spillway passed fish may come in contact with the flow deflector and become injured at lower tailwaters. The flow deflectors at Lower Monumental Dam for spillbays 2 through 7 are at elevation 434 ft msl and the end bays are at elevation 432 ft msl. During our study, spillway survival was significantly higher for releases when the average submergence of the flow deflectors was 10 ft compared to when the average submergence was 6 ft.

Muir et al (2001) did not find statistically significant differences in spillway survival when comparing releases of juvenile salmonids into spillbays with and without flow deflectors at Little Goose or Lower Monumental Dams. However, the point estimates of survival were higher for releases into spillbays without a flow deflector than with a flow deflector (100 vs. 97% at Little Goose Dam and 98 vs. 93% at Lower Monumental Dam, respectively).

Spillway survival evaluations at Ice Harbor Dam in 2000 (Eppard et al. 2002) and in our study indicate that under higher flow conditions and BiOp operations (NMFS 2000), spillway survival through spillbays with flow deflectors is high (97 to 100%.), whereas survival decreases to less than 90% under BiOp operations during lower flows such as those that occur in early spring and summer. Lower spillway survival at Lower Monumental Dam appears to be related to the tailrace conditions such as the depth of submergence of the flow deflectors or the hydraulic conditions near the deflector since survival was significantly higher during periods of higher total river flow and tailwater elevation. Larger spillbay gate openings may create tailrace conditions at the deflector similar to those under higher project discharges by increasing the submergence of the flow deflector because the volume and depth of water over the deflector is increased.

The results of our study indicated that passage survival through spillbays equipped with flow deflectors can vary widely over a range of operational conditions. This is not surprising, since the primary design criteria for the flow deflectors was dissolved gas abatement (particularly necessary during high river flow conditions) and not fish passage. While survival through spillbays with flow deflectors may be lower than for spillbays without flow deflectors (especially under lower tailwater conditions) the benefits of reduced dissolved gas levels for both adult and juvenile salmonids may offset reduced spillway survival for juvenile salmonids.

RECOMMENDATIONS

1. Model testing at the USACE Waterways Experiment Station should be conducted to examine Lower Monumental Dam project operations and hydraulic conditions in the stilling basin and immediate tailrace to determine conditions to optimize spillway survival. Model testing should also examine the relationships between hydraulic conditions and tailwater elevation or flow deflector submergence.
2. Lower Monumental Dam spillway survival should be evaluated for a second year to validate 2003 study findings.
3. Balloon-tag, spillway survival studies should be conducted to determine direct impacts of spillway passage at Lower Monumental Dam under low, medium, and high flow conditions.
4. Spillway survival at Lower Monumental Dam should be evaluated with juvenile steelhead and subyearling chinook salmon.

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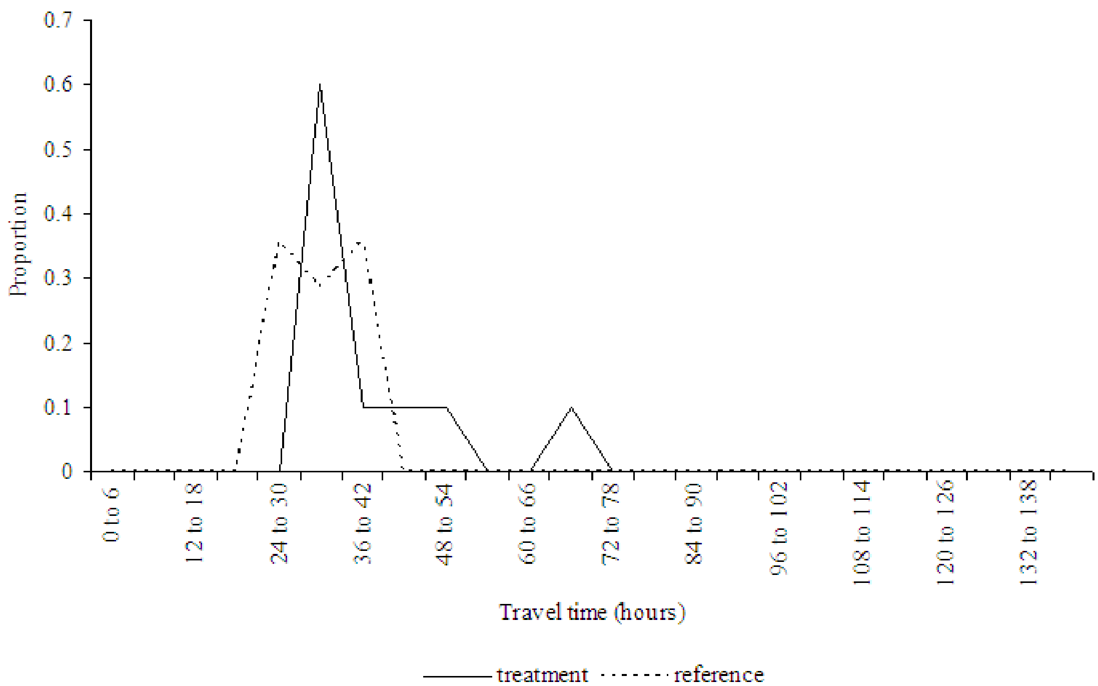
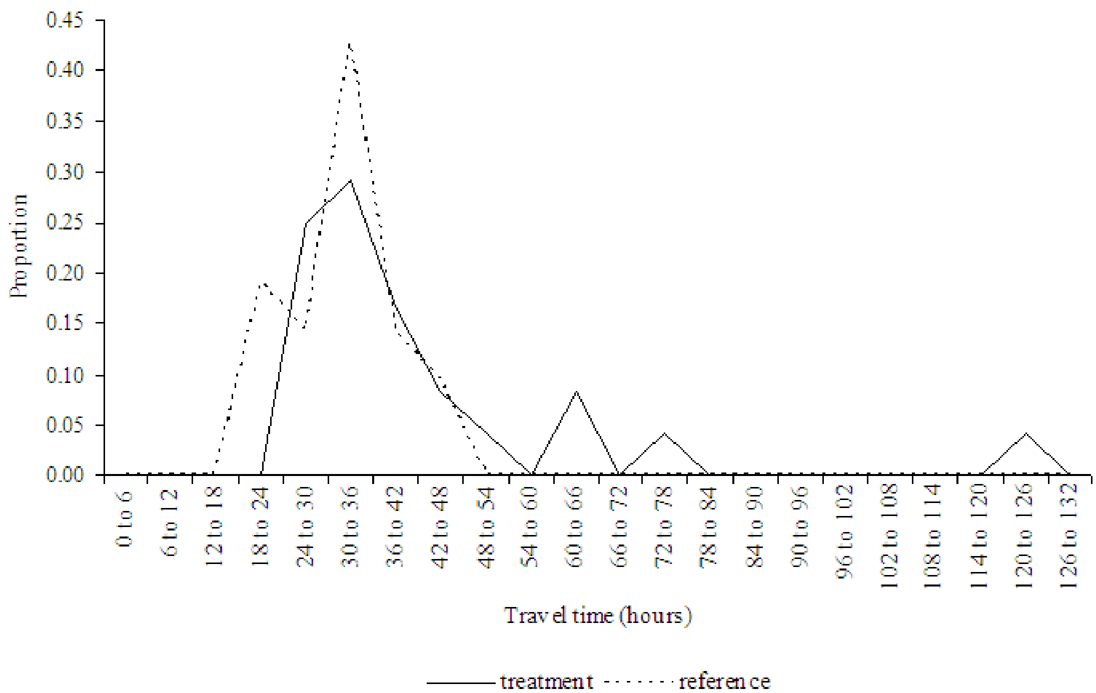
APPENDIX A: Ice Harbor Dam Arrival Distributions for Treatment and Reference Release Groups with Significantly Different Travel Timing



Appendix Figure A1. Arrival distribution at Ice Harbor Dam for radio-tagged, hatchery yearling chinook salmon released at Lower Monumental Dam on 23 May 2003.



Appendix Figure A2. Arrival distribution at Ice Harbor Dam for radio-tagged, hatchery yearling chinook salmon released at Lower Monumental Dam on 6 June 2003.

APPENDIX B: Comparison of Estimated Relative Survival among Spillbays

Appendix Table B. Spillway survival estimates for radio-tagged, hatchery yearling chinook salmon released into spillbay 4 and spillbay 7 at Lower Monumental Dam, 2003. Releases were grouped by week for survival estimation. Standard errors in parenthesis. Survival estimates for releases in spillbay 4 relative to spillbay 7 and *t*-test statistics (to test the null hypothesis that survival was equal between bays) are also shown.

	Estimated survival		
Release dates	Spillbay 4 (tailrace)	Spillbay 7 (tailrace)	Relative survival (Spillbay 4/Spillbay7)
29 April-5 May	0.806 (0.060)	0.854 (0.056)	0.943 (0.091)
9 May-15 May	0.887 (0.063)	0.688 (0.073)	1.289 (0.157)
19 May-25 May	0.857 (0.063)	0.857 (0.060)	1.000 (0.096)
29 May-6 June	0.982 (0.055)	1.004 (0.052)	0.978 (0.060)
Weighted geomean	0.896 (0.039)	0.895 (0.060)	1.009 (0.088)
			t = 0.10 df = 3 P = 0.9234

APPENDIX C: Stepwise Multiple Regression Analysis

Appendix Table C1. Correlation coefficients for total river flow, powerhouse discharge, and tailwater elevation at Lower Monumental Dam during releases of radio-tagged, hatchery yearling chinook salmon to evaluate spillway survival, 2003.

	Total river flow	Powerhouse discharge
Powerhouse discharge	0.960	
Tailwater elevation	0.990	0.972

Appendix Table C2. Stepwise multiple regression analysis of survival, total river flow, release date, water temperature, and gate opening during releases of radio-tagged, hatchery yearling chinook salmon to evaluate spillway survival at Lower Monumental Dam, 2003.

	Survival	Release date	Total river flow	Water temperature
Release date	0.406			
Total river flow	0.666	0.768		
Water temperature	0.460	0.927	0.734	
Gate opening	0.420	0.324	0.638	0.232

The final stepwise regression equation is
Survival = 0.6520 + 0.0022 Total river flow
$R^2 = 0.444$

APPENDIX D: Estimated Relative Survival for Releases during Low and High Total River Flow

Appendix Table D. Average and range of environmental and operational conditions during releases of radio-tagged, hatchery yearling chinook salmon into the spillway and the tailrace of Lower Monumental Dam, 2003. Survival and conditions are divided into releases during relatively low total river flow versus releases during relatively high total river flow. Standard errors are in parenthesis of survival estimates. Statistical *z*-test to test the null hypothesis that survival was equal between flow levels is also shown.

	29 April through 23 May		24 May through 6 June	
	Mean	Range	Mean	Range
Spillway survival	0.834 (0.026)	0.667-1.000	0.987 (0.024)	0.857-1.065
Total river flow (kcfs)	76.2	59-90	149.6	122-205
Powerhouse discharge (kcfs)	40.6	29-52	107.2	93-122
Spill volume (kcfs)	35.6	30-41	42.4	24-85
Spill (%)	47.0	38-51	26.9	19-42
Tailwater elevation (ft)	440.0	439-441	444.1	443-447
Bay 4 gate opening (ft)	2.7	1.4-3.0	2.9	1.7-6.2
Bay 7 gate opening (ft)	2.9	2.8-3.0	3.5	1.8-7.1
Average gate opening (ft)	2.8	2.0-3.0	3.2	1.8-6.7
Water temperature °C	10.9	10-12	12.6	12-14

z-test

$t = 3.43$

$P = 0.001$

APPENDIX E: Assumptions for Survival Estimation

Model Assumptions

We used a single-release model (Cormack 1964; Jolly 1965; Seber 1965) to estimate survival of radio-tagged juvenile chinook salmon released into the spillway and tailrace of Lower Monumental Dam. The ratios of these survival estimates (spillway survival divided by tailrace survival) were calculated to determine 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.

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

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.

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.

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

A7. Treatment fish which were released via hoses immediately upstream of spillbays 4 and 7 passed the dam through the intended spillbay.

Assumption Testing and Validation

Assumption A1

Radiotelemetry detection probabilities at Ice Harbor Dam were almost 100% with only two fish (one each from treatment and reference groups) detected downstream and not at Ice Harbor Dam. With detection probabilities at or near 100% for all fish there is no disparity between detection of treatment and reference groups.

Assumption A2

Treatment and corresponding reference groups were evenly mixed and traveled together through downstream reaches for 24 of 26 releases based on the results of chi-square homogeneity test. The visual assessment of treatment and reference groups for the two2 releases with significantly different temporal arrival distribution at Ice Harbor Dam indicated that these differences were small (less than 12 hours). The two tests with significantly different temporal distributions were unlikely to influence the survival analysis of treatment effects.

Assumptions A3-A5

Assumptions A3, A4, and A5 were not tested for validation in this study. However, the effects of radio tagging on survival, predation, growth, and swimming performance of juvenile salmonids have previously been evaluated by Adams et al. (1998a,b) and Hockersmith et al. (2003). The distance between our releases at Lower Monumental Dam and our first downstream array which was used to estimate survival (Ice Harbor Dam) was 51 km. Axel et al. (2003) reported that dead, radio-tagged fish released into the bypass systems at Ice Harbor and McNary Dams were not subsequently detected at telemetry transects which were more than 3.2 km downstream.

Assumption A6

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 not functioning properly were not used in the study. In addition, 84 radio transmitters from tagging mortalities or tag regurgitation 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 7days.

Assumption A7

Lower Monumental Dam PIT-tag detections were examined to determine if any of the treatment fish passed through the juvenile bypass system rather than the spillway. A total of 6 treatment fish passed Lower Monumental Dam through the juvenile bypass system rather than through the spillway (Appendix Table A1). These fish were removed from the analysis. The remainder of the treatment fish were assumed to have passed through the spillbay where they were released. We did not attempt to validate that spillway releases passed through the intended spillbay.

Appendix Table E. PIT-tag detections at Lower Monumental Dam of hatchery yearling chinook salmon released to evaluate spillway survival at Lower Monumental Dam, 2003.

Release date	Spillbay 4	Spillbay 7	Total
22 May	1	0	1
24 May	0	1	1
6 June	1	3	4
Total	2	4	6