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Fish Ecology Division

Northwest Fisheries Science Center

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Seattle, Washington

by
Gordon A. Axel, Eric E. Hockersmith, Brian J. Burke,
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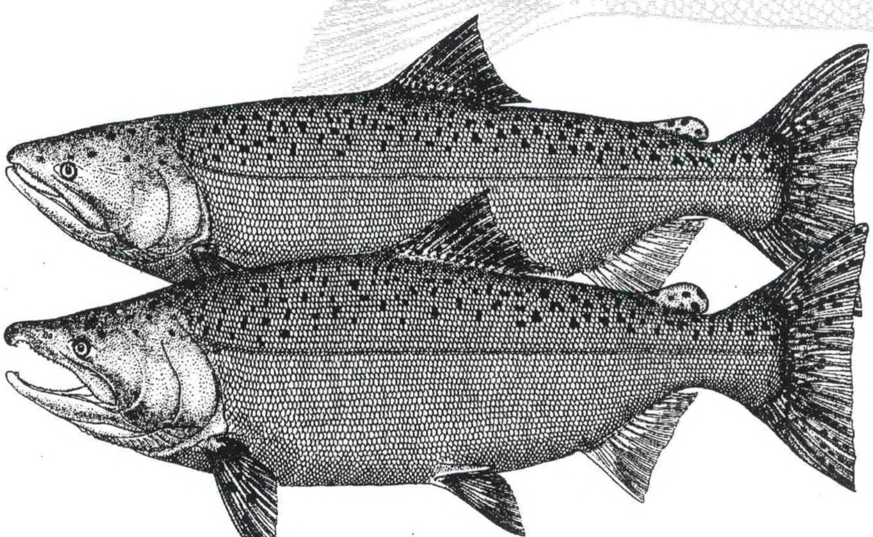

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Report of research by

Fish Ecology Division
Northwest Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
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EXECUTIVE SUMMARY

In 2007, we evaluated behavior, passage distribution, and survival of yearling Chinook salmon and steelhead at Ice Harbor Dam to determine effects of the recently installed removable spillway weir (RSW) during two different spill operations. A portion of study fish were those collected and surgically tagged with both a radio transmitter and PIT tag for similar evaluations at Lower Monumental Dam. Treatment groups for the Ice Harbor evaluation were the 663 yearling Chinook salmon and 665 juvenile steelhead released 5 km above Lower Monumental Dam and the additional 635 yearling Chinook and 646 juvenile steelhead released into the tailrace of Lower Monumental Dam.

Reference groups were collected and tagged at Ice Harbor Dam and released to the tailrace. A total of 833 yearling Chinook salmon and 876 juvenile steelhead were released as reference groups. All replicates were released during both day and night hours over 26 d from 2 to 27 May. Project operations at Ice Harbor Dam were alternated in 2-d random blocks between BiOp spill (45 kcfs during the day and spill to the dissolved gas limit at night) and reduced spill (30-40% of total flow volume). Both operations were evaluated with the RSW operating continuously.

Yearling Chinook salmon--Median forebay residence time for yearling Chinook salmon passing Ice Harbor Dam was slightly longer for fish that approached during reduced spill operations (2.0 h) than for those that approached during BiOp spill (1.5 h). During reduced spill, overall passage distribution for yearling Chinook salmon was 75.0% through the spillway, 16.3% through the juvenile bypass, and 8.7% through turbines, with less than 0.6% of the fish having undetermined passage routes (Table 1). During BiOp spill, 93.3% of yearling Chinook passed via the spillway, 4.6% through the juvenile bypass, and 2.1% through the turbines, with less than 0.6% having undetermined passage routes.

During respective reduced and BiOp spill operations, fish passage efficiency was 91.4 and 97.9%, fish guidance efficiency was 65.4 and 68.6%, spill efficiency was 75.0 and 93.3%, and spill efficiency for the RSW was 59.0 and 42.0%. Mean spill effectiveness was 2.43:1 for reduced spill and 1.36:1 during BiOp spill, and mean RSW effectiveness was 5.51:1 for reduced spill and 4.16:1 for BiOp spill. Training spill effectiveness measured less than 1:1 under both spill treatments.

During reduced and BiOp spill operations, respectively, passage survival was estimated at 0.97 (95% CI, 0.93-1.01) and 0.96 (0.92-0.99) through the spillway and 0.95 (0.91-1.00) and 0.95 (0.90-1.00) through the RSW. Relative dam survival was estimated at 0.94 (0.90-0.98) during reduced spill and 0.92 (0.88-0.96) during BiOp spill treatments. Numbers of fish passing via the powerhouse were insufficient to estimate survival through turbines. Concrete survival, or the survival estimate for all fish that passed the project, was 0.95 (0.91-0.99) during reduced spill and 0.96 (0.92-0.99) during BiOp spill operations.

Table 1. Operating conditions, passage behavior, and relative survival for radio-tagged yearling Chinook salmon at Ice Harbor Dam under two operations, 2007.

		Reduced Spill	BiOp Spill
Operating conditions (average)	Discharge (kcfs)		
	Project	74.5	78.9
	Spill (%)	23.0 or 31	54.0 or 68
	RSW (%)	8.0 or 11	8.0 or 10
	Training flow (%)	15.0 or 20	46.0 or 58
	Tailwater elevation (ft msl)	343.8	343.8
	Water temperature (°C)	12.9	12.7
	Secchi depth (m)	N/A	N/A
Passage route distribution (%)	Juvenile bypass	16.3	4.6
	Turbines		
	Unit 1	0.8	--
	Unit 2	1.2	0.6
	Unit 3	1.4	0.4
	Unit 4	3.3	0.8
	Unit 5	2.0	0.4
	Unit 6	--	--
	Turbines combined	8.7	2.1
	Spillway		
	Spill bay 1	--	--
	Spill bay 3	8.2	0.2
	Spill bay 4	--	11.5
	Spill bay 5	6.1	4.0
	Spill bay 6	--	11.3
	Spill bay 7	0.6	9.7
	Spill bay 8	0.4	9.4
	Spill bay 9	0.4	2.9
	Spill bay 10	0.4	2.5
	Overall spillway passage	75.0	93.3
	RSW	59.0	42.0
	Training spill passage	16.0	51.3
	Unknown route	<0.6	<0.6
Passage metric	Median forebay delay (h)	2.0	1.5
	Fish passage efficiency (%)	91.4	97.9
	Spill efficiency (%)	75.0	93.3
	Spill effectiveness	2.43	1.36
	RSW effectiveness	5.51	4.16
	Training spill effectiveness	0.80	0.88
	Fish guidance efficiency (%)	65.4	68.6
	Median tailrace egress (min)	9.6	9.6
Relative survival estimate and 95% CI (%)	Dam survival (forebay BRZ to tailrace)	0.94 (0.90-0.98)	0.92 (0.88-0.96)
	Concrete survival (all fish passing the dam)	0.95 (0.91-0.99)	0.96 (0.92-0.99)
	Spillway survival (fish passing through the spillway)	0.97 (0.93-1.01)	0.96 (0.92-0.99)
	RSW survival	0.95 (0.91-1.00)	0.95 (0.90-1.00)
	JBS survival (fish passing only through the JBS)	0.95 (0.88-1.02)	0.93 (0.78-1.07)

Juvenile Steelhead--Median forebay residence time for juvenile steelhead at Ice Harbor Dam was slightly longer for fish that approached during reduced spill operations (1.8 h) than for those that approached during BiOp spill (1.7 h). Overall passage distribution for juvenile steelhead during reduced spill treatments was 86.2% through the spillway, 11.9% through the juvenile bypass, and 2.0% through turbines, with less than 0.5% of fish having undetermined passage routes (Table 2). During BiOp spill, 95.2% of juvenile steelhead passed via the spillway, 3.8% through the juvenile bypass, and 1.0% through the turbines, with less than 0.5% having undetermined passage routes.

During reduced spill and BiOp spill respectively, fish passage efficiency was 98.0 and 99.0%, fish guidance efficiency was 85.7 and 80.0%, spill efficiency was 86.2 and 95.2%, and RSW spill efficiency was 74.1 and 53.2%. Mean spill effectiveness was 2.78:1 for reduced and 1.39:1 for BiOp spill. Mean RSW effectiveness was 6.92:1 for reduced and 5.27:1 for BiOp spill. Training spill effectiveness was less than 1:1 under both treatments.

During reduced and BiOp spill, respectively, spillway passage survival was 0.97 (95% CI, 0.93-1.02) and 0.97 (0.92-1.02), RSW survival was 0.97 (0.92-1.02) and 0.98 (0.92-1.04), and relative dam survival was 0.94 (0.89-0.99) and 0.93 (0.87-0.98). Insufficient numbers of tagged fish passed through the powerhouse to estimate survival through turbines. Concrete survival was 0.97 (0.93-1.02) during reduced spill and 0.96 (0.91-1.01) during BiOp spill operations.

Table 2. Operating conditions, passage behavior, and relative survival of radio-tagged juvenile steelhead at Ice Harbor Dam under two operations, 2007.

		Reduced Spill	BiOp Spill
Operating conditions (average)	Discharge (kcfs)		
	Project	74.5	78.9
	Spill (%)	23.0 or 31	54.0 or 68
	RSW (%)	8.0 or 11	8.0 or 10
	Training flow (%)	15.0 or 20	46.0 or 58
	Tailwater elevation (ft msl)	343.8	343.8
	Water temperature (°C)	12.9	12.7
	Secchi depth (m)	N/A	N/A
Passage route distribution (%)	Juvenile bypass	11.9	3.8
	Turbines		
	Unit 1	0.2	0.5
	Unit 2	0.7	--
	Unit 3	0.2	0.5
	Unit 4	0.9	--
	Unit 5	--	--
	Unit 6	--	--
	Turbines combined	2.0	1.0
	Spillway		
	Spill bay 1	--	--
	Spill bay 3	7.5	0.7
	Spill bay 4	--	11.3
	Spill bay 5	3.6	3.8
	Spill bay 6	--	6.0
	Spill bay 7	--	7.7
	Spill bay 8	0.2	5.8
	Spill bay 9	--	3.8
	Spill bay 10	0.7	2.9
	Overall spillway passage	86.2	95.2
	RSW	74.1	53.2
	Training spill passage	12.0	42.0
	Unknown route	<0.5	<0.5
Passage metric	Median forebay delay (h)	1.8	1.7
	Fish passage efficiency (%)	98.0	99.0
	Spill efficiency (%)	86.2	95.2
	Spill effectiveness	2.78	1.39
	RSW effectiveness	6.92	5.27
	Training spill effectiveness	0.60	0.72
	Fish guidance efficiency (%)	85.7	80.0
	Median tailrace egress (min)	8.4	9.7
Relative survival estimate and 95% CI (%)	Dam survival (forebay BRZ to tailrace)	0.94 (0.89-0.99)	0.93 (0.87-0.98)
	Concrete survival (all fish passing the dam)	0.97 (0.93-1.02)	0.96 (0.91-1.01)
	Spillway survival (fish passing through the spillway)	0.97 (0.93-1.02)	0.97 (0.92-1.02)
	RSW survival	0.97 (0.92-1.02)	0.98 (0.92-1.04)
	JBS survival (fish passing only through the JBS)	--	--

CONTENTS

INTRODUCTION

The Columbia and Snake River Basins have 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 warrant listing under the U.S. Endangered Species Act of 1973 (NMFS 1991, 1992, 1998, 1999). Anthropogenic factors 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 spill bays 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 (Muir et al. 2001). Pursuant to the National Marine Fisheries Service (NMFS) 2000 Biological Opinion (BiOp) (NMFS 2000), project operations at Lower Granite, Little Goose, and Lower Monumental Dams have relied on a combination of voluntary spill and collection of fish for transportation to improve passage survival of juvenile salmonids. At Ice Harbor Dam, effort to improve passage survival has focused on voluntary spill operations to increase the proportion of fish that pass via the spillways.

Surface collection and bypass systems have been identified as a viable alternative for increasing survival and fish passage efficiency (FPE) for migrating juvenile salmonids at hydroelectric dams on the Snake and Columbia Rivers. At Wells Dam on the Columbia River, the spillway (located over the turbine units) passes 90% of the juvenile fish while spilling just 7% of the total discharge (Whitney et al. 1997). Studies evaluating a removable spillway weir (RSW) installed at Lower Granite Dam in 2001 have shown the RSW to be an effective and safe means of passing migrating juvenile salmonids (Anglea et al. 2003; Plumb et al. 2003, 2004). In 2002, the RSW at Lower Granite Dam passed 56–62% of radio-tagged fish while spilling only 8.5% of total discharge. In 2003, passage effectiveness ratios were 8.3-9.9:1 through the Lower Granite Dam RSW, with survival estimated at 98% (±2.3%).

Juvenile anadromous salmonids in the Columbia River Basin generally migrate in the upper 3 to 6 m of the water column (Johnson et al. 2000; Beeman and Maule 2006). However, fish must sound (dive) to depths of 15-18 m to enter existing juvenile fish passage routes at lower Columbia and Snake River dams. Engineers and biologists from the USACE developed the RSW to provide a surface-oriented spillway passage route.

The RSW uses a traditional spillway and is attached to the upstream face of a spill bay. It allows juvenile salmon and steelhead to pass the dam near the water surface under lower accelerations and lower pressures, providing more efficient and less stressful passage conditions. In contrast, traditional spill bay gates open 15.2 m below the water surface at the face of the dam, passing juvenile fish under high water pressure and velocity. RSWs were installed at Lower Granite Dam in 2001 and at Ice Harbor Dam in 2005. An RSW is scheduled for installation at Lower Monumental Dam prior to the 2008 spring juvenile migration.

Previous studies at Ice Harbor Dam have shown that the majority of spring migrants pass through the spillway (Eppard et al. 2000, 2005a,b; Axel et al. 2006). In 2004, we evaluated yearling Chinook salmon *O. tshawytscha* and juvenile steelhead behaviour, passage distribution, and survival associated with two dam operations: bulk spill and flat spill. Bulk spill is obtained by using wide gate openings at fewer spill bays, with spill volume limited only by restrictions on dissolved gas levels in the tailrace (the gas cap). Flat spill uses narrow gate openings at more spill bays. Results indicated improved passage metrics and survival estimates for fish passing during bulk spill treatments (Axel et al. 2006; Eppard et al. 2005c).

In 2005, the first year of RSW evaluation at Ice Harbor Dam, estimates of fish passage survival through the RSW were high. However, an avoidance problem was also observed, wherein a higher proportion of yearling Chinook salmon passed through spill bay 1 than through the RSW spill bay.

During 2006, we utilized radiotelemetry to determine variations in behavior, passage distribution, and survival of yearling Chinook salmon and juvenile steelhead during two different operating conditions: BiOp spill, or spill levels of 45 kcfs during the day and spill to the gas cap at night, and reduced spill, meaning 30-40% of flow volume spilled. Both were evaluated with the RSW operating continuously. Also during 2006, regional managers agreed to close spill bay 1, given the behavior observed in 2005. This was intended to draw juvenile migrants away from the powerhouse and pass them through the RSW or safer spill bays, where survival estimates were higher. Results indicated that fish were successfully shifted toward the RSW and spillway, with fewer fish utilizing the powerhouse.

Very low river flows during 2007 were in complete contrast to the high river flows during 2006. Thus we designed the evaluation in 2007 to be similar to that of 2006; this provided an opportunity to examine results from comparable evaluations under considerably different river conditions.

METHODS

Study Area

The study area encompassed a 119-km reach of river, from Lower Monumental Dam (rkm 589) on the lower Snake River to McNary Dam (rkm 470) on the lower Columbia River (Figure 1). The focal point of the study was Ice Harbor Dam (rkm 538) on the lower Snake River in southeast Washington State, the first dam upstream from its confluence with the Columbia River.

Ice Harbor Dam has three major juvenile passage routes: the spillway, turbines, and a juvenile bypass system (JBS). The spillway is 179.8 m long and consists of 10 spillbays numbered 1 to 10 from south to north. Spillbay flow is metered by operation of Tainter gates with the exception of the RSW bay (bay 2), where flow is regulated exclusively by forebay pool elevation. The spillway crest for conventional bays is located at an elevation of 119.2 m, while the RSW spills water at 129.5 m of elevation. The powerhouse measures 204.5 m long, and each turbine unit intake is outfitted with standard length submerged traveling screens (STS), which divert downstream-migrating salmonids into the JBS. The screens are deployed at an elevation of 106.7 m, and all fish not diverted pass through the turbine. Turbine units are numbered 1 to 6 from south to north, where the junction between the powerhouse and the spillway is located.

Fish Collection, Tagging, and Release

River-run yearling Chinook salmon and juvenile steelhead were collected at the Lower Monumental Dam smolt collection facility from 1 to 26 May. We chose fish that did not have any gross injury or deformity, were not previously PIT tagged, and were at least 115 mm in length and 12 g in weight. 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. Following collection and sorting, fish were maintained via flow-through river water and held for 20 h prior to radio transmitter implantation.

Radio tags were purchased from Advanced Telemetry Systems Inc.,[1] had a user defined tag life of 10 d, and were pulse-coded for unique identification of individual fish at 30 MHz. Each radio tag measured 12 mm in length by 5 mm in diameter and weighed 0.7 g in air. Average total volume for the tag was 232 mm^3.

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

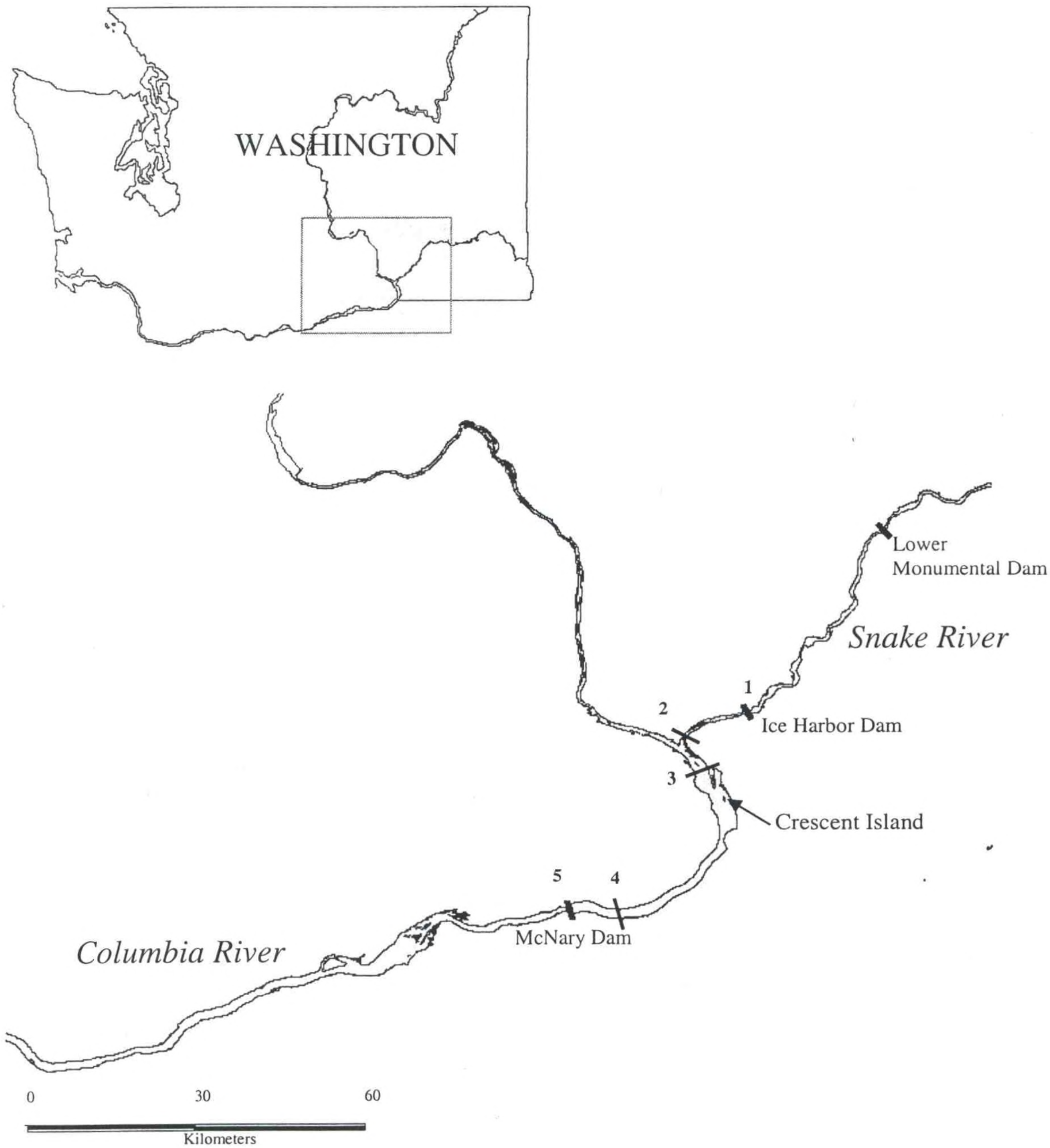

Figure 1. Study area showing location of radiotelemetry transects used for partitioning reach and project survival for radio-tagged yearling Chinook salmon and juvenile steelhead between Lower Monumental and McNary Dams, 2007. (Note: 1 = Ice Harbor Dam forebay; 2 = Sacajawea State Park; 3 = Burbank Railroad Bridge; 4 = McNary Beach; and 5 = McNary Dam forebay.)

Fish were surgically tagged with radio transmitters using techniques described by Adams et al. (1998a,b). Each fish also received a PIT tag before the incision was closed in order to monitor radio-tag performance. Detections from the PIT tag also ensured that study fish that passed through the Lower Monumental Dam juvenile fish bypass system were returned to the river so that they could be used in estimates of survival through the JBS.

Immediately following tagging, fish were placed into a 19-L bucket (2 fish per container) with aeration until recovery from the anesthesia. Buckets were then closed and placed into a large holding tank (1.49-m wide, 2.48-m long, 0.46-m depth) that could accommodate up to 28 buckets, and into which flow-through water was applied during tagging and holding. Fish holding buckets were perforated with 1.3-cm holes in the top 30.5 cm of the container to allow an exchange of water during holding. After tagging, fish were held a minimum of 24 h with flow-through water for recovery and determination of post-tagging mortality. Pre- and post-tagging temperatures at Lower Monumental Dam ranged between 11.0 and 14.2°C.

After the post-tagging recovery period, holding tanks with buckets containing radio-tagged fish were moved to release areas (Lower Monumental and Ice Harbor Dam tailraces). All holding tanks were aerated with oxygen during transport to release locations. Lower Monumental forebay release groups were transferred from holding tanks to a release tank mounted on an 8.5- by 2.4-m barge, transported to the release location, and released mid-channel water-to-water. Tailrace release groups were transferred to holding tanks mounted on a truck, transported to the release location, and released a minimum of 7.6 m from the bank into the river through a release flume.

Yearling Chinook salmon—Yearling Chinook salmon released for evaluations of survival at Lower Monumental Dam were also used for evaluations of survival at Ice Harbor Dam, as their tags had adequate battery life to remain active while passing through our study area. These additional fish bolstered the sample sizes to increase precision of survival estimates for evaluations at Ice Harbor Dam.

At Lower Monumental Dam, reference fish were released into the tailrace about 1 km below the dam. Daytime releases to the tailrace were made between 1000 and 1500 and nighttime releases between 2200 and 0300 PDT. Both day and night releases were made in 24 groups of approximately 13 fish. In conjunction with reference releases, treatment fish at Lower Monumental Dam were released 5 km upstream from the dam. Treatment releases were made from 0900 to 1000 during daytime and from 2100 to 2200 PDT at night; both day and nighttime releases were made in 24 groups of about 14 fish. Temperatures during these releases ranged from 11.0 to 14.2°C.

Yearling Chinook salmon tagged for evaluation at Ice Harbor Dam were released into the tailrace in 25 groups of approximately 17 fish per group . Daytime releases were made between 0900 and 1530 PDT and nighttime releases between 2030 and 0500. Temperatures during these releases ranged from 11.2 to 14.4°C. In total, 1,298 radio-tagged Yearling Chinook salmon were released at Lower Monumental Dam and 833 were released to the tailrace of Ice Harbor Dam.

Juvenile steelhead—As described above for Yearling Chinook salmon, juvenile steelhead tagged for evaluations of survival at Lower Monumental Dam were also used for evaluations at Ice Harbor Dam. Releases to the tailrace of Lower Monumental Dam were made in 24 groups of approximately 13 fish during both daytime (1000-1500 PDT) and nighttime (2200-0300) periods. Juvenile steelhead were released 5 km upstream from Lower Monumental Dam in 24 groups of approximately 14 fish during both daytime (0900-1000) and nighttime (2100-2200) release periods.

At Ice Harbor Dam, juvenile steelhead were released during the daytime between 0900 and 1530 PDT and during nighttime between 2030 and 0500 PDT. Both day and night releases were made into the tailrace of Ice Harbor Dam in 25 groups of approximately 17 fish each. In total, 1,311 radio-tagged juvenile steelhead were released at Lower Monumental Dam and 876 released into the tailrace of Ice Harbor Dam.

Survival Estimates

Estimates of survival from the tailrace of Lower Monumental Dam to the forebay of Ice Harbor Dam, were made based on detection histories using the single-release (SR) model (Cormack 1964; Jolly 1965; Seber 1965). The SR model uses recapture records (in this case, detections) from a single release group to estimate survival, considering the probability that a tagged fish may pass the downstream boundary of the area in question without being recaptured (detected). In order to separate the probability of detection from that of survival, the model requires detections of at least some fish downstream from the area of interest. To evaluate detection probabilities, we used detections at Goose Island, located 2 km below Ice Harbor Dam.

Previous studies indicated that dead, radio-tagged fish released at Ice Harbor Dam were not detected at downstream survival transects (Axel et al. 2003); therefore, we assumed that fish detected at each transect were alive after passage at Ice Harbor Dam. To verify this, we released dead, radio-tagged yearling Chinook salmon and juvenile steelhead into the tailrace during varying spill operations.

Survival was estimated for this evaluation through additional areas as follows:

Relative Dam Survival: Ratio of the survival estimate for fish that passed through the entire "effect zone" to that of fish released to the tailrace. The "effect zone" is the reach from approximately 500 ft upstream to approximately 1000 ft downstream from the dam.

Relative Spillway Survival: Ratio of the survival estimate for fish that passed through the spillway to that of fish released into the tailrace.

Relative RSW Survival: Ratio of the survival estimate for fish that passed via the RSW to that of fish released into the tailrace.

Relative Training Flow Survival: Ratio of the survival estimate for fish that passed through the spillway (not including the RSW) to that of fish released into the tailrace while the RSW was operating.

Relative Bypass Survival: Ratio of the survival estimate for fish that passed via the juvenile bypass system to that of fish into the tailrace.

Relative Concrete Survival: Ratio of the survival estimate for fish that passed via all passage routes combined to that of fish released into the tailrace (forebay loss was not included in the estimate).

To create replicate groups from fish released at Lower Monumental Dam, we grouped fish according to time of arrival at the telemetry transect on the upstream edge of the Boat Restricted Zone of Ice Harbor Dam. These groups were used for estimates of dam survival, with replicates composed of fish detected during the same period (block) of dam operation. Treatment replicates were paired with reference groups released into the tailrace of Ice Harbor Dam during the same period. Ratios of pooled survival estimates for treatment to reference fish provided the relative survival estimate for the dam.

For estimates of spillway survival, we used only fish that were detected on a spillway receiver and subsequently detected on a stilling basin or tailrace receiver. This verified that fish last detected on a spillway receiver had actually passed the dam via the spillway. Spillway fish were grouped by spill treatment (reduced or BiOp spill), and paired with reference fish released during that particular treatment block. Subsequent downstream detections at Sacajawea State Park and below were used for both dam and spillway survival estimation (Figure 1). We used the same criteria for the remaining relative survival estimates as well.

Key assumptions of the SR model must be valid if the model is to produce unbiased estimates of survival through specific reaches or areas. One such assumption was that radiotelemetry detection at a given site did not affect subsequent detection probabilities downstream from that site. Tests of model assumptions are presented in Appendix A. For more detailed discussion of the SR model and its associated tests of assumption, see Iwamoto et al. (1994), Zabel et al. (2002), and Smith et al. (2003).

Passage Behavior and Timing

Travel, Arrival, and Passage Timing

Travel time was measured as the time from release at Lower Monumental Dam to first detection at the forebay entrance transect at Ice Harbor Dam (the next dam downstream). First detection at the entrance transect at Ice Harbor Dam was also used to determine arrival time at the project. Passage timing was determined by using the last detection in a passage route, using only fish with a subsequent detection in the stilling basin or immediate tailrace.

Forebay Residence Time

Forebay residence time at Ice Harbor Dam was measured as time from first detection on the forebay entrance transect to either last detection during spillway passage or first detection on a fish guidance screen in a turbine unit or gatewell. We compared forebay residence and tailrace egress time between treatments using paired t-tests on the 50th and 90th passage percentiles of treatment replicate groups ($P < 0.05$).

Passage Route Distribution

To determine route of passage for individual fish at Ice Harbor Dam, we monitored the spillway, STS, and JBS. Each spillway was monitored by four underwater dipole antennas. Two antennas were installed along each of the two pier noses of each spill bay at depths of 20 and 40 ft. Pre-season range testing showed that this configuration effectively monitored the entire spill bay. In addition, we mounted aerial loop antennas to the handrail of the RSW and the downstream pier noses in the tailrace in order to ensure that we detected all fish that passed over the RSW. We used armored co-axial cable, stripped at the end, to detect radio-tagged fish passing through the turbine unit and JBS. These antennas were attached on both ends of the downstream side of the STS support frame located within each slot of the turbine intake.

We also placed two loop antennas on the hand rail at the collection channel exit located upstream from the JBS pipe. Fish that were detected on STS telemetry antennas, but were not subsequently detected on the PIT-detection system or the telemetry monitor located in the collection channel were designated turbine-passed fish.

Fish Passage Metrics

The standard fish-passage metrics of spill efficiency, spill effectiveness, fish passage efficiency (FPE), and fish guidance efficiency (FGE) were also evaluated at Ice Harbor Dam using radiotelemetry detections in the locations used for passage route evaluation (described above). However, the method of calculating these metrics using radiotelemetry differs from those used in previous evaluations (e.g., FGE was formerly calculated based on the percentage of fish caught in gatewells and fyke nets). Fish-passage metrics used for this evaluation were defined as follows:

Spill efficiency: Total number of fish passing the spillway divided by total number passing the dam.
Spill effectiveness: Proportion of fish passing the spillway divided by proportion of water spilled.
Fish passage efficiency: Number of fish passing the dam via non-turbine routes divided by total number passing the dam.
Fish guidance efficiency: Number of fish guided into the bypass system divided by total number passing via the powerhouse (i.e., the combined total for bypass system and turbine passage).

Tailrace Egress

Tailrace egress was measured from the last known detection through the project (spillway, turbine, or JBS) to the last known detection at the telemetry transect located approximately 1 km downstream from Ice Harbor Dam. Hypothesis testing to compare specific cohorts was conducted using the same methodology as that described above for comparing forebay residence time.

Avian Predation

Predation by Caspian terns *Hydoprogne caspia* from the colony on Crescent Island, located 12.9 km downstream from the Snake River mouth (Figure 1), was measured by physical recovery of radio tags and detection of PIT tags deposited on the island during August 2007 (after the birds had left the island). We used radio-tag serial numbers to identify individual tagged fish. PIT-tag detections and physical recovery of radio transmitters at Crescent Island were provided by other NMFS researchers and Real Time Research, Inc. (A. Evans, Real Time Research, Inc., personal communication).

RESULTS

Fish Collection, Tagging, and Release

Unmarked yearling Chinook salmon and juvenile steelhead were collected, radio tagged, and PIT tagged at Lower Monumental for 26 d from 1 to 26 May. Tagging began after approximately 2.5% of the yearling Chinook salmon and 0.4% of the juvenile steelhead had passed Lower Monumental Dam and was completed when more than 95% of these fish had passed (Figure 2). Overall mean fork length was 145 mm for tagged yearling Chinook and 220 mm for tagged steelhead, and respective mean weights were 26 and 86 g. Post-surgical mortality during the study was 1.0% for yearling Chinook salmon and 0.5% for juvenile steelhead, while respective collection mortality rates were 1.2 and 1.0%.

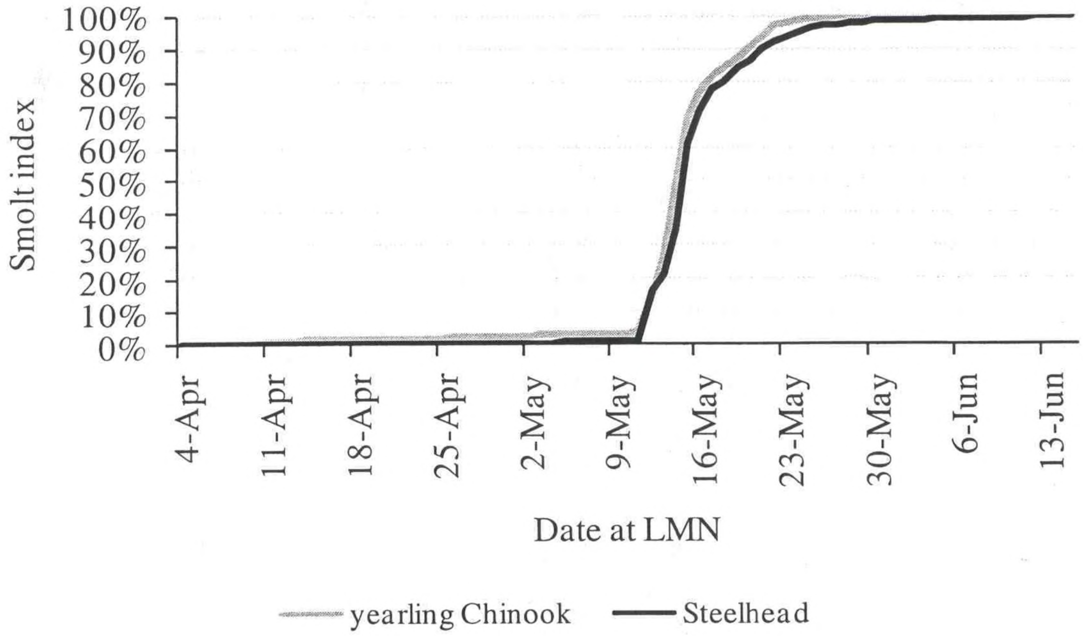

Figure 2. Percentage of juvenile steelhead and yearling Chinook salmon index estimated at Lower Monumental Dam during 2007.

Dam Operations

The 2007 voluntary spill program followed a 2-d random block design with two spill treatments; a high spill discharge in a BiOp spill operation (45 kcfs during the day and spill to the gas cap at night) and a reduced volume of spill (30-40% of flow volume), with both treatments utilizing the RSW. The spill pattern attempted to utilize spillway gates for each bay that were open at least 5 stops where feasible in order to allow for larger gate openings and potentially higher survival. Median spill volume was 54.0 thousand cubic feet per second (kcfs) during BiOp treatments and 23.0 kcfs during reduced spill. Mean flow through turbines and spill bays for each treatment are shown in Figure 3. Mean daily total discharge during the study was 78.9 kcfs for the BiOp spill treatments, ranging from 32.1 to 118.9 kcfs, and 74.5 kcfs for the reduced spill ranging from 35.7 to 115.6 kcfs. Mean daily river flow and percentage of spill during the spring evaluation, with treatment blocks identified, are shown in Figure 4 with mean hourly percent spill by treatment shown in Figure 5. Mean flow (kcfs) for each turbine unit and spill bay, and mean gate openings (stops) by spill bay during the operational treatment blocks are shown in Tables 3 and 4, respectively.

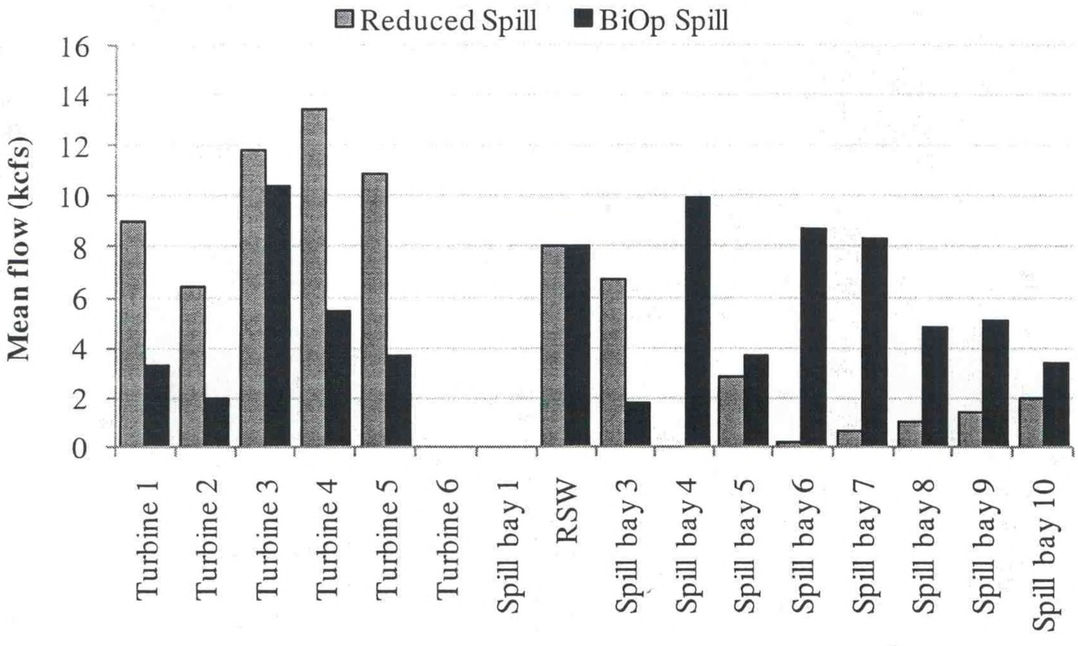

Figure 3. Mean flow (kcfs) for each treatment for radio-tagged yearling Chinook salmon and juvenile steelhead arriving at Ice Harbor Dam, 2007.

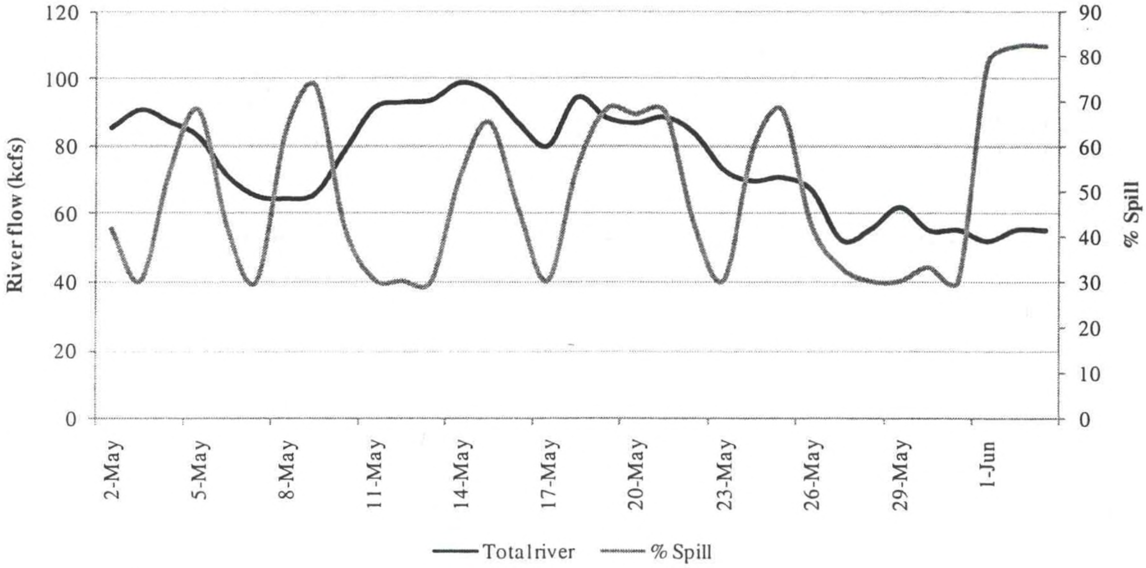

Figure 4. Mean daily river flow (kcfs) and spill percentage for radio-tagged yearling Chinook salmon and juvenile steelhead arriving at Ice Harbor Dam, 2007.

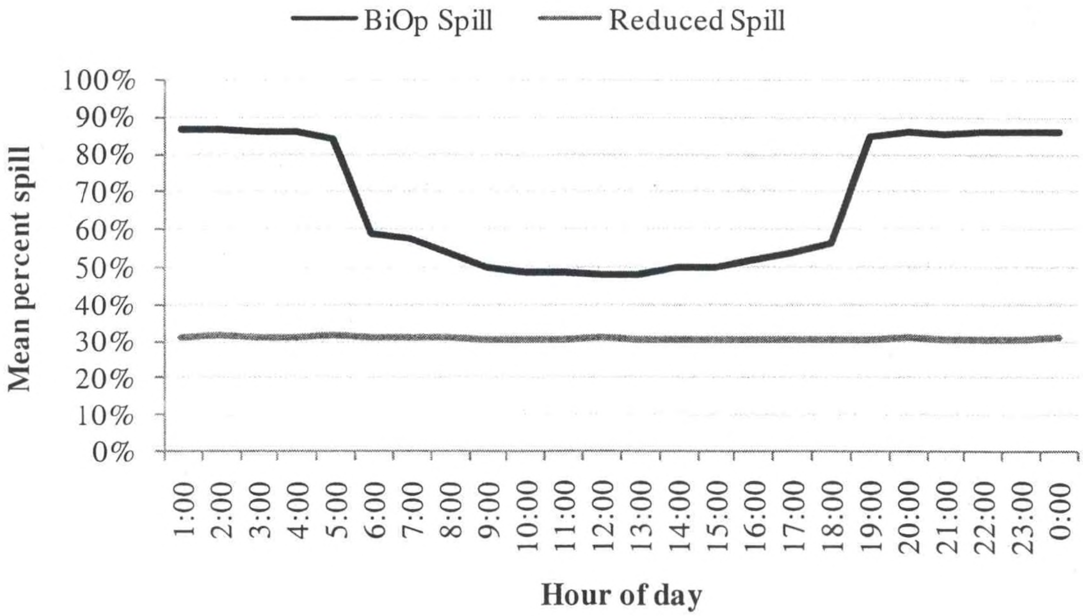

Figure 5. Mean hourly percent spill by treatment for radio-tagged yearling Chinook salmon and juvenile steelhead arriving at Ice Harbor Dam, 2007.

Table 3. Average flow (kcfs) by turbine unit and spill bay at Ice Harbor Dam during reduced and BiOp spill operation blocks, 2007.

	Test	Turbines						Spill bays									
Date	Block	1	2	3	4	5	6	1	RSW	3	4	5	6	7	8	9	10
May 2-4	Reduced 1	11.9	9.9	12.0	13.8	14.2	0.1	0.0	8.1	8.4	0.0	5.2	0.2	0.4	0.9	1.8	1.8
May 6-8	Reduced 2	10.9	0.9	11.1	13.0	9.5	0.0	0.0	8.1	6.3	0.0	0.0	0.1	1.0	1.1	1.6	1.8
May 10-12	Reduced 3	11.8	9.3	11.8	14.1	13.0	0.0	0.0	8.1	7.7	0.0	5.3	0.3	0.5	1.1	1.5	2.0
May 12-14	Reduced 4	12.7	11.6	12.8	15.1	14.4	0.0	0.0	8.1	7.8	0.0	7.0	0.0	0.2	1.3	1.7	2.7
May 16-18	Reduced 5	0.0	12.9	13.0	15.6	15.7	0.0	0.0	8.1	8.8	0.0	4.2	0.1	0.6	1.6	1.7	2.2
May 22-24	Reduced 6	0.0	11.5	12.2	14.6	14.6	0.0	0.0	8.1	8.0	0.0	3.1	0.2	0.5	0.5	1.0	2.1
May 26-28	Reduced 7	10.6	0.0	10.8	10.0	8.4	0.0	0.0	7.9	5.8	0.0	0.0	0.3	0.5	0.9	1.0	1.9
May 28-30	Reduced 8	11.0	0.9	11.0	11.9	4.4	0.0	0.0	7.9	3.4	0.0	0.0	0.4	1.2	1.4	1.4	1.7
May 4-6	BiOp 1	6.0	0.0	10.4	7.2	5.7	0.0	0.0	8.1	1.2	10.0	4.5	8.4	8.3	5.4	5.5	3.5
May 8-10	BiOp 2	5.1	0.0	10.5	2.9	0.0	0.0	0.0	8.1	0.0	9.8	3.7	8.4	7.5	3.9	4.8	3.5
May 14-16	BiOp 3	6.4	3.6	10.8	7.4	6.6	0.0	0.0	8.1	3.4	10.1	4.6	8.8	8.8	5.8	5.8	3.5
May 18-20	BiOp 4	0.0	5.5	10.3	7.1	7.1	0.0	0.0	8.1	4.5	10.2	4.8	9.8	9.3	6.4	6.0	3.3
May 20-22	BiOp 5	0.0	5.0	10.8	7.7	6.6	0.0	0.0	8.1	1.8	10.1	4.5	8.5	8.5	4.9	5.4	3.5
May 24-26	BiOp 6	4.3	0.9	10.6	6.2	1.8	0.0	0.0	8.1	0.5	9.8	2.8	8.6	7.9	3.8	4.2	3.4

Table 4. Average gate openings (stops) by spill bay at Ice Harbor Dam during reduced and BiOp spill operation blocks, 2007.

Date	Test Block	Spill bay 1	RSW	Spill bay 3	Spill bay 4	Spill bay 5	Spill bay 6	Spill bay 7	Spill bay 8	Spill bay 9	Spill bay 10
May 2-4	Reduced 1	0.0	4.8	5.0	0.0	3.1	0.1	0.2	0.5	1.0	1.1
May 6-8	Reduced 2	0.0	4.8	3.8	0.0	0.0	0.1	0.6	0.7	1.0	1.0
May 10-12	Reduced 3	0.0	4.8	4.6	0.0	3.2	0.2	0.3	0.6	0.9	1.2
May 12-14	Reduced 4	0.0	4.8	4.6	0.0	4.2	0.0	0.1	0.7	1.0	1.6
May 16-18	Reduced 5	0.0	4.8	5.3	0.0	2.5	0.1	0.4	0.9	1.0	1.3
May 22-24	Reduced 6	0.0	4.8	4.7	0.0	1.8	0.1	0.3	0.3	0.6	1.2
May 26-28	Reduced 7	0.0	4.7	3.5	0.0	0.0	0.2	0.3	0.5	0.6	1.1
May 28-30	Reduced 8	0.0	4.7	2.1	0.0	0.0	0.2	0.7	0.8	0.8	1.0
May 4-6	BiOp 1	0.0	4.8	0.7	6.0	2.7	5.0	5.0	3.2	3.3	2.1
May 8-10	BiOp 2	0.0	4.8	0.0	5.8	2.2	5.0	4.5	2.3	2.8	2.0
May 14-16	BiOp 3	0.0	4.8	2.0	6.1	2.8	5.3	5.3	3.4	3.5	2.1
May 18-20	BiOp 4	0.0	4.8	2.7	6.1	2.9	5.9	5.5	3.8	3.6	2.0
May 20-22	BiOp 5	0.0	4.8	1.1	6.0	2.7	5.1	5.1	2.9	3.2	2.0
May 24-26	BiOp 6	0.0	4.8	0.3	5.9	1.6	5.1	4.7	2.2	2.5	2.0

Survival Estimates

Yearling Chinook Salmon

For reduced and BiOp spill operations, respectively, spillway passage survival was 0.97 (95% CI, 0.93-1.01) and 0.96 (0.92-0.99), RSW survival was 0.95 (0.91-1.00) and 0.95 (0.90-1.00), relative dam survival was 0.94 (0.90-0.98) and 0.92 (0.88-0.96), and JBS survival was 0.95 (0.88-1.02) and 0.93 (0.78-1.07; Table 1). Insufficient numbers of tagged fish passed through the powerhouse to estimate survival through turbines. Concrete survival, or the survival estimate for all fish that passed the project, was 0.95 (0.91-0.99) during reduced spill and 0.96 (0.92-0.99) during BiOp spill operations. No comparison of survival between reduced and BiOp spill operations resulted in a significant difference for any of the passage routes analyzed.

Juvenile Steelhead

During the respective reduced and BiOp spill treatments, spillway passage survival was 0.97 (95% CI, 0.93-1.02) and 0.97 (0.92-1.02), RSW survival was 0.97 (0.92-1.02) and 0.98 (0.92-1.04), relative dam survival was 0.94 (0.89-0.96) and 0.93 (0.87-0.98), and JBS survival was 0.98 (0.88-1.09) and 0.91 (0.69-1.13; Table 2). Insufficient numbers of tagged fish passed through the powerhouse to estimate survival through turbines. Concrete survival, or the survival estimate for all fish that passed the project, was 0.97 (0.93-1.02) during reduced spill and 0.96 (0.91-1.01) during BiOp spill operations. No comparison of survival between reduced and BiOp spill operations resulted in a significant difference for any of the passage routes analyzed.

Passage Behavior and Timing

Travel, Arrival, and Passage Timing

At the forebay entrance telemetry transect of Ice Harbor Dam, we detected 1,042 radio-tagged yearling Chinook salmon and 1,013 juvenile steelhead released at Lower Monumental Dam. Travel time was calculated for each species from their respective release sites in the forebay or tailrace of Lower Monumental Dam (Table 5).

Table 5. Travel time (days) from release into the forebay or tailrace of Lower Monumental Dam to detection at the forebay entry transect at Ice Harbor Dam for radio-tagged hatchery yearling Chinook salmon and juvenile steelhead, 2007.

	Travel time (d)			
	Yearling Chinook		Steelhead	
	Release location at Lower Monumental Dam			
	Forebay	Tailrace	Forebay	Tailrace
N	502	540	450	563
Min	0.9	0.5	0.8	0.8
Percentile				
10th	1.6	1.1	1.9	1.0
20th	1.9	1.2	2.1	1.1
30th	2.0	1.3	2.3	1.2
40th	2.1	1.3	2.7	1.2
50th	2.1	1.4	2.9	1.3
60th	2.2	1.5	3.1	1.4
70th	2.4	1.6	3.3	1.5
80th	2.7	1.8	3.9	1.7
90th	3.0	2.0	4.7	1.9
Max	6.2	3.5	8.2	4.6
Travel time > 6 d	1 (0.1%)	0 (0.0%)	16 (3.5%)	0 (0.0%)

For both species under the BiOp treatment, first approach was primarily at the spillway, with very few fish directly approaching the powerhouse (Figures 6 and 7). During reduced spill treatments, flow through the spillway was reduced and shifted to the powerhouse, which resulted in slightly higher percentages of fish approaching the powerhouse.

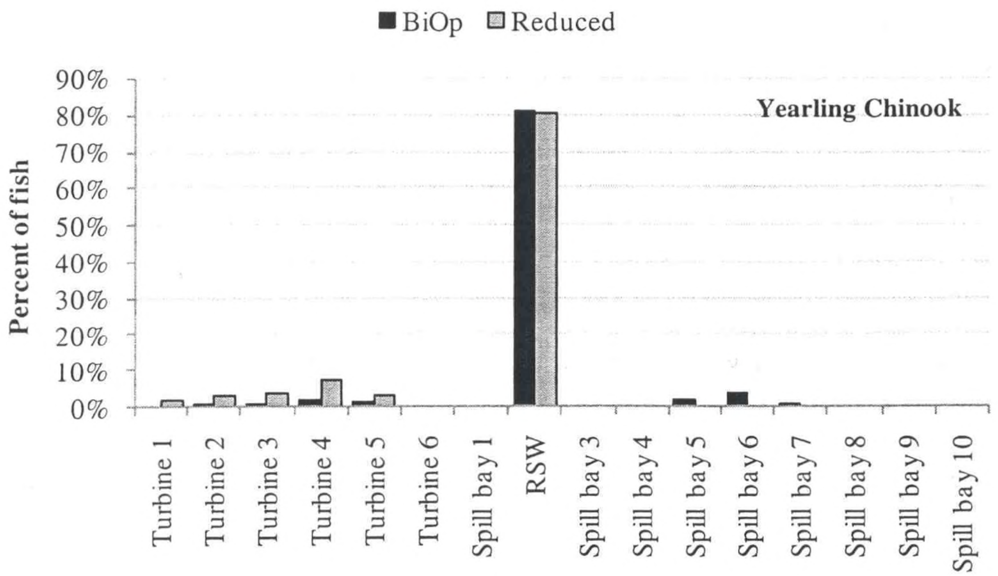

Figure 6. First approach location (percent) of radio-tagged yearling Chinook salmon at Ice Harbor Dam during two spill treatments, 2007.

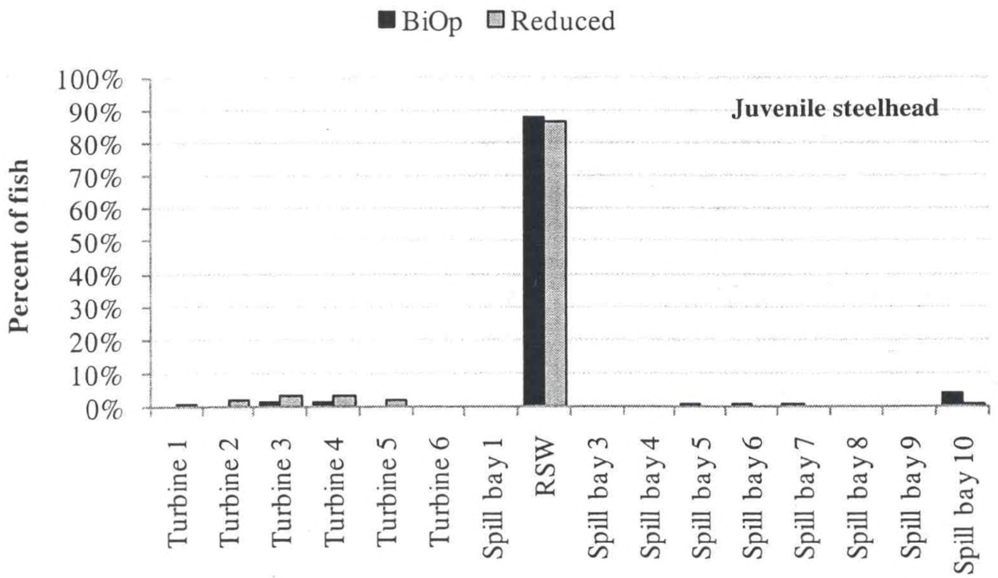

Figure 7. First approach location (percent) of radio-tagged juvenile steelhead at Ice Harbor Dam during two spill treatments, 2007.

We also observed a difference between the two species in the percentage of fish approaching the immediate forebay under the different spill treatments (Figure 8). Steelhead entered the forebay area much more readily under reduced spill treatments, while yearling Chinook had higher percentages approaching during BiOp spill. Both species were released into the tailrace of Lower Monumental Dam at the same time during both day and night.

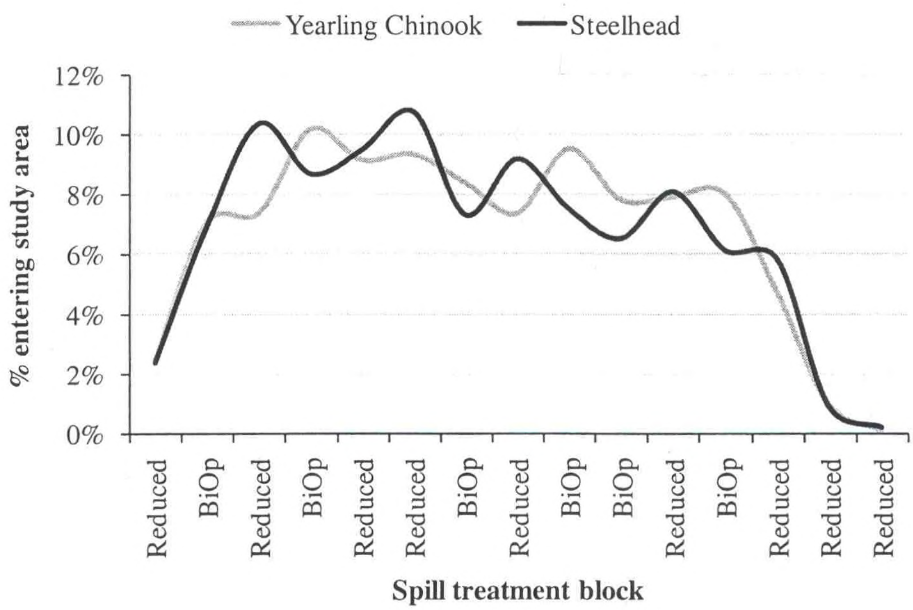

Figure 8. Percent of radio-tagged yearling Chinook salmon entering the forebay of Ice Harbor Dam during reduced and BiOp spill treatments, 2007.

Arrival and passage numbers at Ice Harbor Dam tended to be higher during daylight hours, particularly for steelhead. During BiOp spill treatments, spill levels were lower during daylight hours, which may have allowed steelhead to find the surface flow more easily. Numbers of yearling Chinook arriving were fairly consistent throughout both treatments of the study with anywhere from 2-9% arriving at all hours of the day (Figures 9-12).

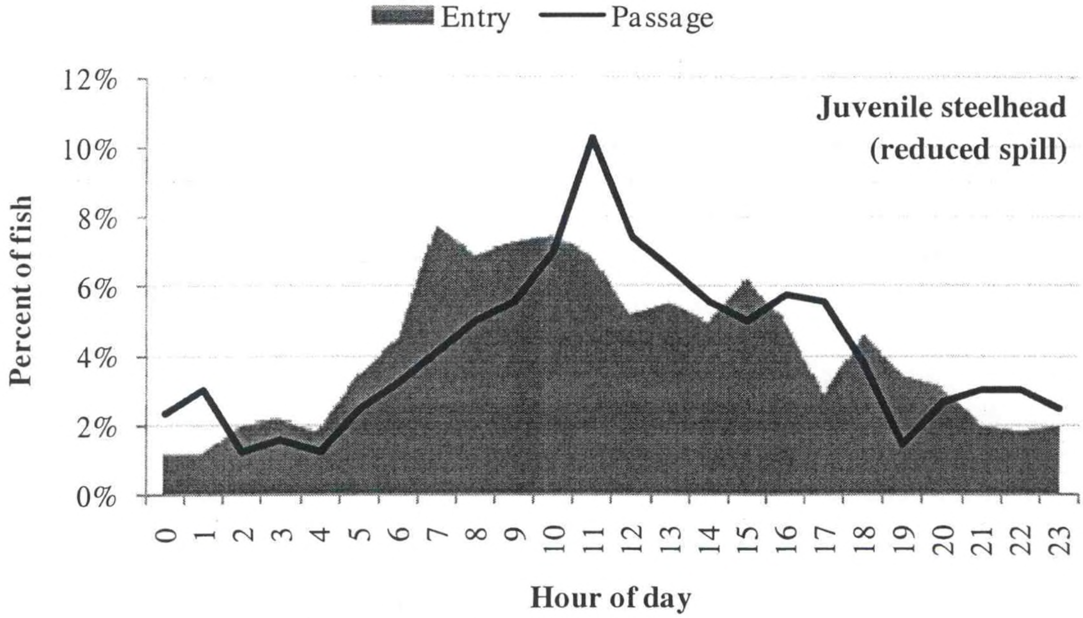

Figure 9. Percent of radio-tagged juvenile steelhead arriving and passing Ice Harbor Dam during reduced spill treatments, 2007.

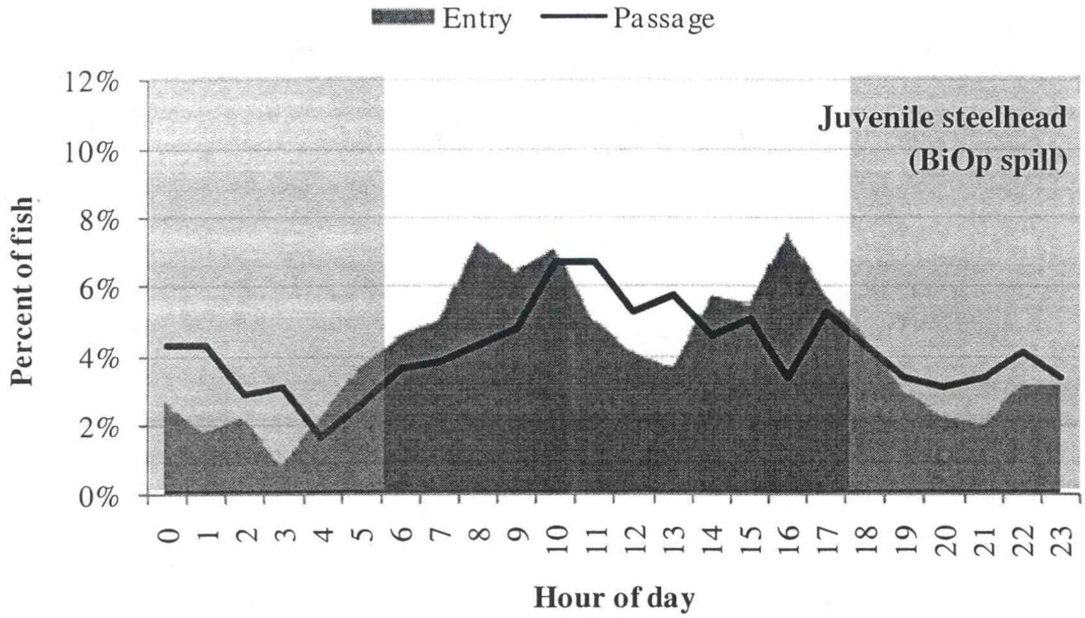

Figure 10. Percent of radio-tagged juvenile steelhead arriving and passing Ice Harbor Dam during BiOp spill treatments with shaded areas representing time periods of increased spill percentages, 2007.

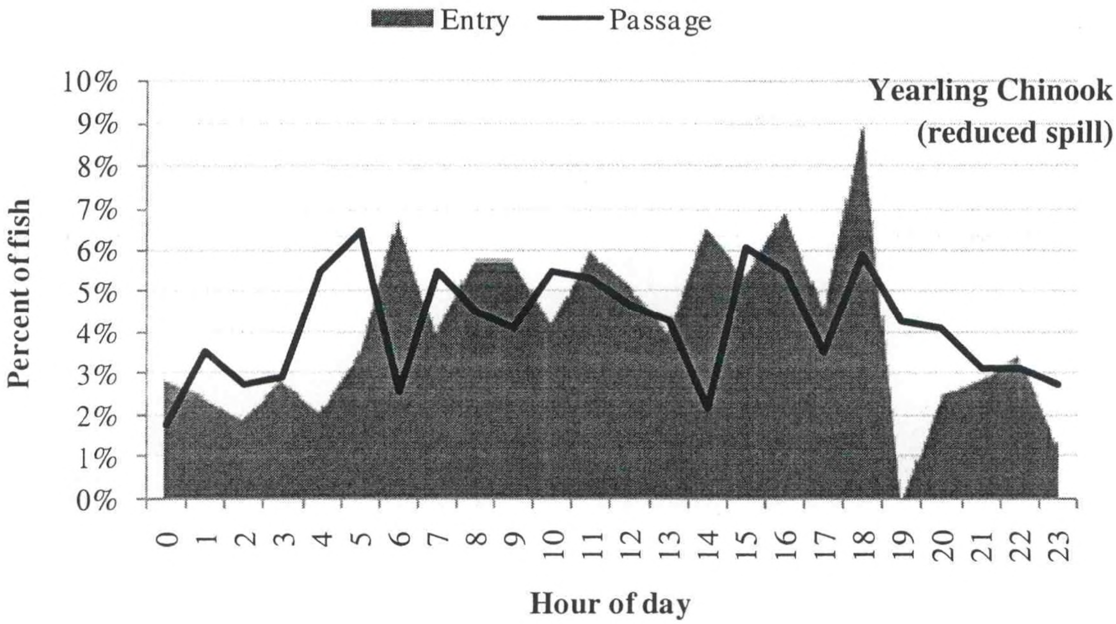

Figure 11. Percent of radio-tagged yearling Chinook salmon arriving and passing Ice Harbor Dam during reduced spill treatments, 2007.

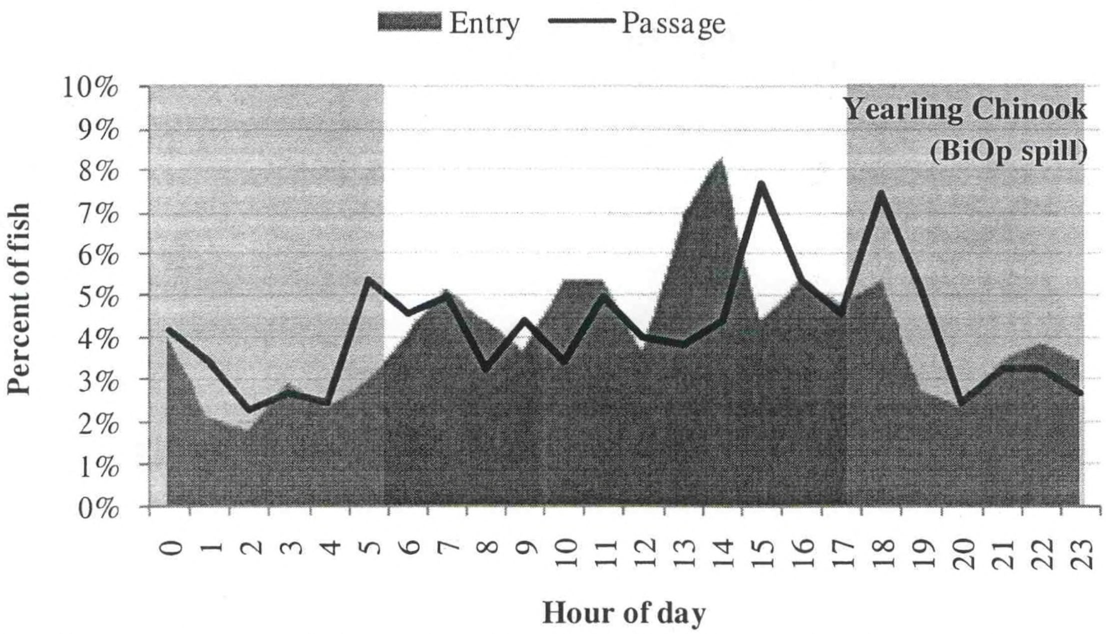

Figure 12. Percent of radio-tagged yearling Chinook salmon arriving and passing Ice Harbor Dam during BiOp spill treatments with shaded areas representing time periods of increased spill percentages, 2007.

Forebay Residence Time

Median forebay residence time for replicate treatment groups overall was not significantly different ($P = 0.146$) for yearling Chinook salmon that passed during reduced spill (2.0 h) vs. BiOp spill (1.5 h; Figure 13) operations. For juvenile steelhead that passed during reduced spill operations, median forebay residence time (1.8 h) was not significantly different ($P = 0.100$) from those that passed during BiOp spill (1.7 h; Figure 13) based on the 50th percentiles of all replicate treatment groups.

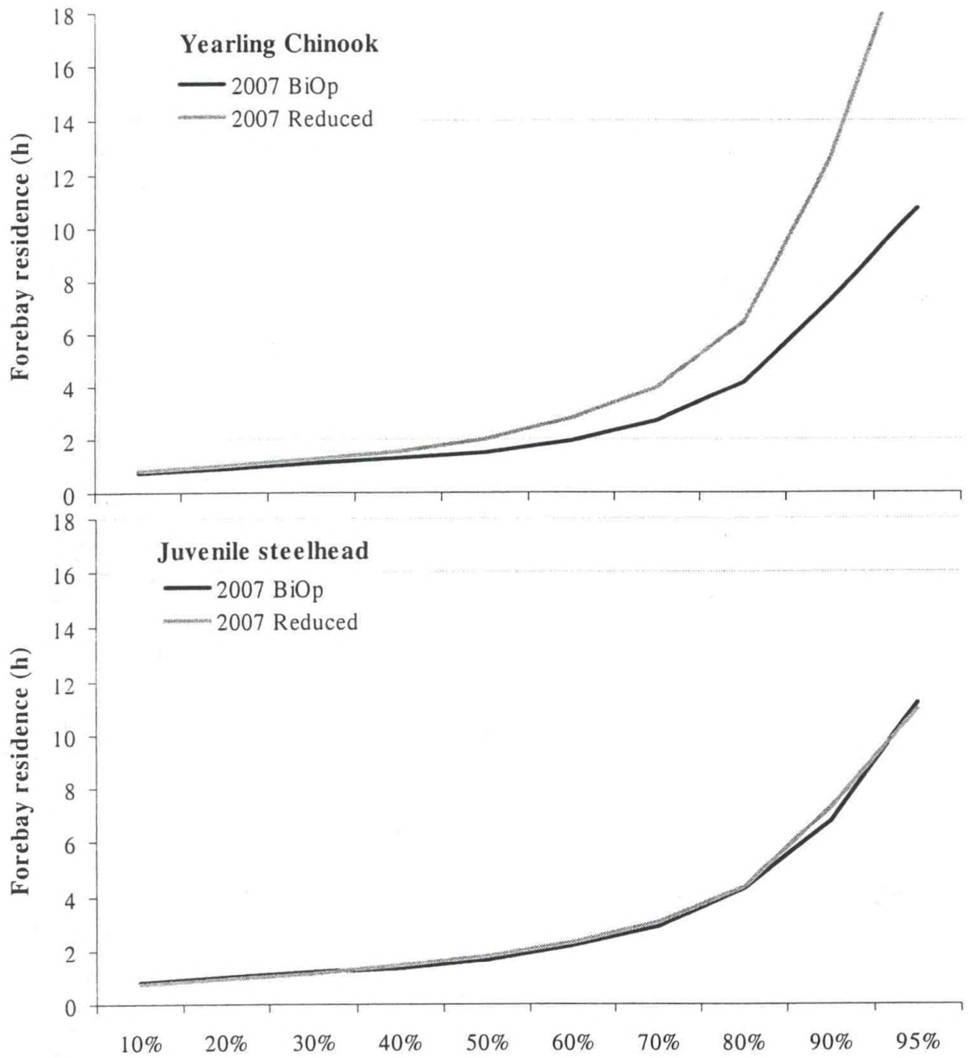

Figure 13. Forebay residence time by percentile of radio-tagged yearling Chinook (upper panel) and juvenile steelhead passing Ice Harbor Dam under two different spill treatments, 2007.

Passage Route Distribution

During reduced spill, overall passage distribution for yearling Chinook salmon was 75.0% through spillway (59.0% of which passed through the RSW bay), 16.3% through the JBS, and 8.6% through turbine routes (Table 1). Less than 0.8% (4) of the fish passed the project by an unknown route, and an additional 9 fish entered the forebay but did not pass the project. During BiOp spill treatments passage distribution was 93.3% through the spillway (42.0% of which passed through the RSW bay), 4.6% through the JBS, and 2.1% through turbine routes. Less than 0.4% (2) passed the project by an unknown route, and an additional 15 fish entered the forebay but did not pass the project. Horizontal spillway distributions during each spill treatment in comparison to 2006 results are shown in Figure 14.

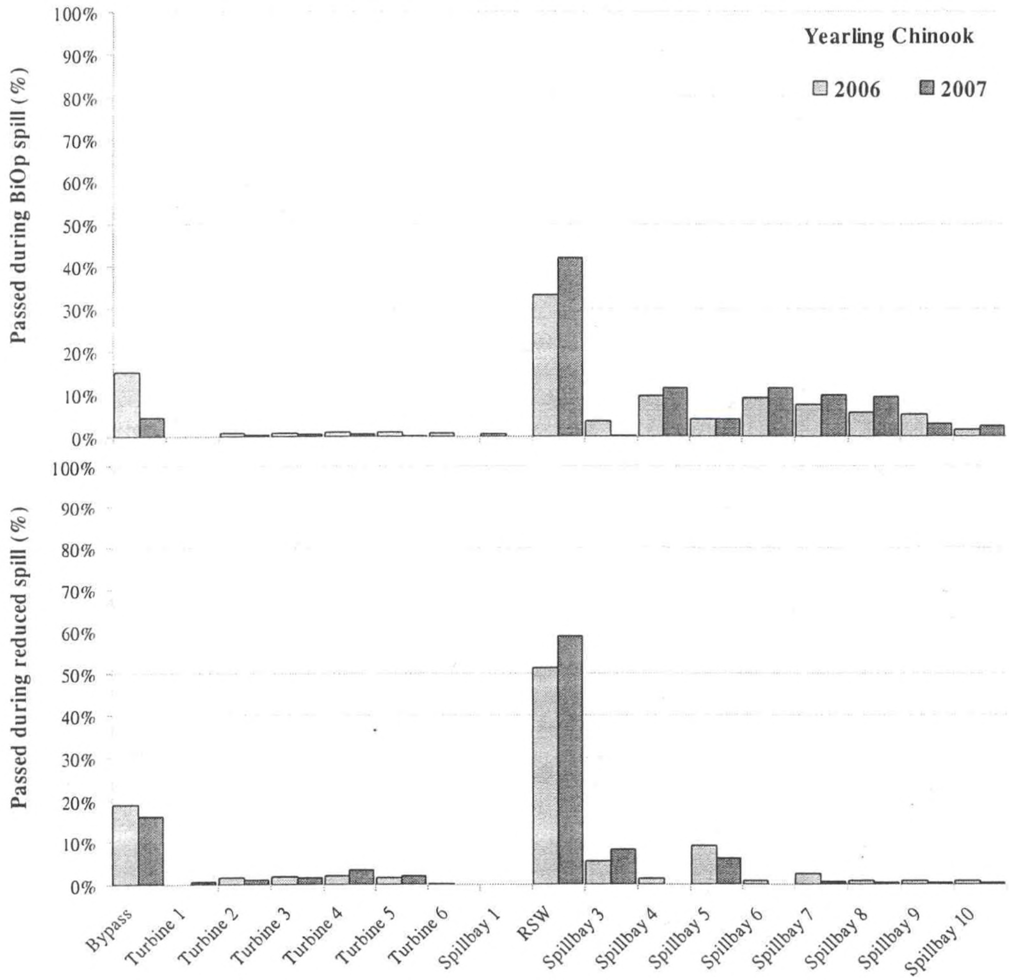

Figure 14. Horizontal passage distribution of radio-tagged yearling Chinook salmon during BiOp (upper panel) and reduced spill treatments at Ice Harbor Dam, 2006 and 2007.

During reduced spill, overall passage distribution for juvenile steelhead was 86.2% through spillways (74.1% of which passed through the RSW bay), 11.9% via the JBS, and 2.0% via turbine routes (Table 2). Less than 0.5% (2 fish) passed the project by an unknown route, and an additional 40 entered the forebay, but did not pass the project. During BiOp spill treatments 95.2% of juvenile steelhead passed via spillways (53.2% of which passed through the RSW bay), 3.8% via the JBS, and 1.0% through turbines. Less than 0.5% (3) passed the project by an unknown route. Horizontal spillway distributions during each spill treatment in comparison to 2006 results are shown in Figure 15.

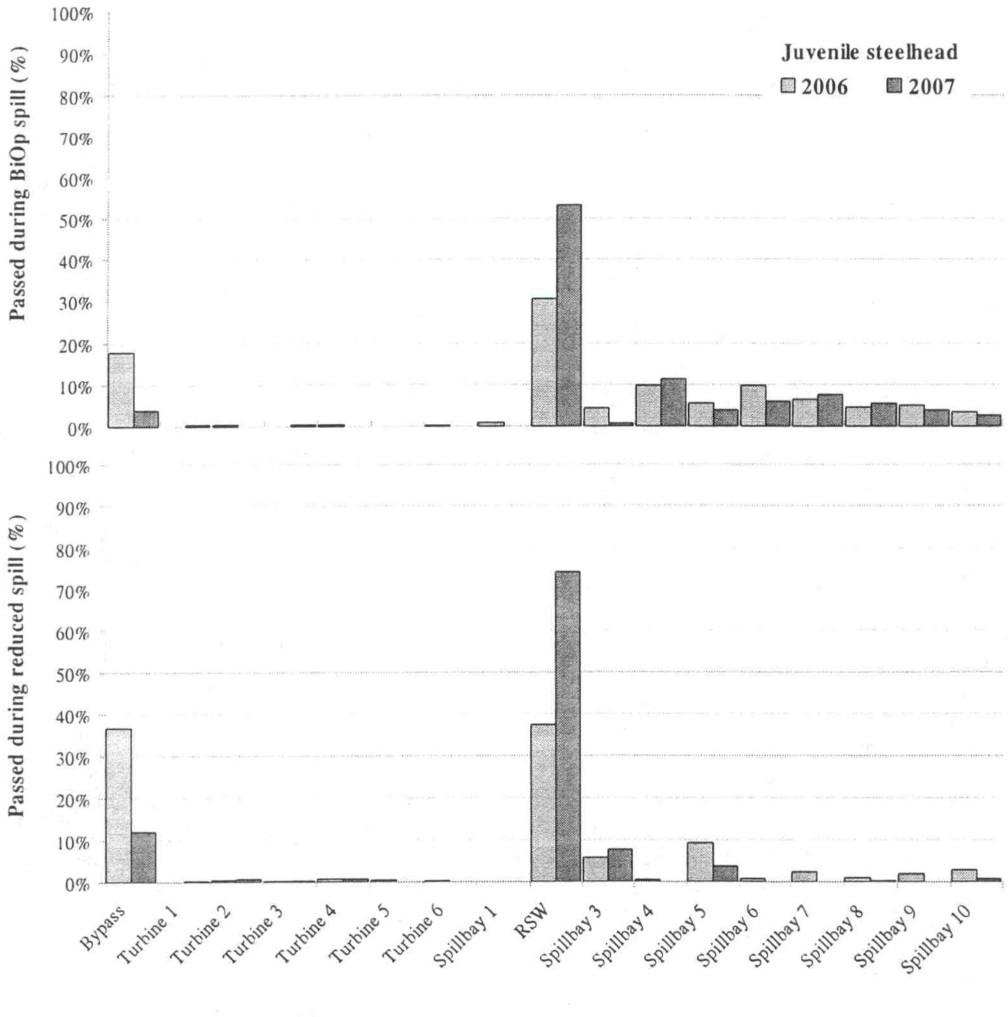

Figure 15. Horizontal passage distribution of radio-tagged juvenile steelhead during BiOp (upper panel) and reduced spill treatments at Ice Harbor Dam, 2006 and 2007.

Fish Passage Metrics

For yearling Chinook salmon during reduced and BiOp spill treatments, respectively, fish passage efficiency (FPE) was 91 (95% CI, 90-93%) and 98% (97-99%), fish guidance efficiency (FGE) was 65 (60-71%) and 69% (62-75%), and spill efficiency was 75 (71-79%) and 93% (91-96%;Table 6). Mean spill effectiveness during reduced spill treatments was 2.4:1 (2.3-2.5) for the spillway and 5.5:1 (5.2-5.8) for the RSW (Table 1). Mean spill effectiveness during BiOp spill treatments was 1.4:1 (1.3-1.4) for the spillway and 4.2:1 (3.9-4.4) for the RSW.

For juvenile steelhead during the respective reduced and BiOp spill treatments, fish passage efficiency (FPE) was 98 (95% CI, 97-99%) and 99% (98-100%), fish guidance efficiency (FGE) was 86 (81-91%) and 80% (75-85%), and spill efficiency was 86 (83-89%) and 95% (93-97%; Table 7). Mean spill effectiveness during reduced spill treatments was 2.8:1 (2.7-2.9) for the spillway and 6.9:1 (6.6-7.3) for the RSW (Table 2). Mean spill effectiveness during BiOp spill treatments was 1.4:1 (1.4-1.4) for the spillway and 5.3:1 (5.0-5.5) for the RSW.

Table 6. Passage distribution and fish passage metrics for radio-tagged yearling Chinook salmon passing Ice Harbor Dam during reduced and BiOp spill treatments, 2007.

			Passage route					Fish passage metrics		
Date	Spill treatment	Mean spill (kcfs)	Spillway	RSW	Bypass	Turbine	Total	Spill efficiency	FPE	FGE
May 2-4	Reduced Spill1	26.8	8	13	2	2	25	0.840	0.920	0.500
May 6-8	Reduced Spill2	20.0	10	58	6	4	78	0.872	0.949	0.600
May 10-12	Reduced Spill3	26.5	21	40	25	6	92	0.663	0.935	0.806
May 12-14	Reduced Spill4	28.9	20	46	13	16	95	0.695	0.832	0.448
May 16-18	Reduced Spill5	27.5	11	41	12	11	75	0.693	0.853	0.522
May 22-24	Reduced Spill6	23.5	9	55	19	1	84	0.762	0.988	0.950
May 26-31	Reduced Spill7	17.8	3	48	6	4	72	0.708	0.792	0.600
Totals			*82*	*301*	*83*	*44*	*510*	*0.751*	*0.914*	*0.654*
May 4-6	BiOp Spill1	55.0	37	31	2	4	74	0.919	0.946	0.333
May 8-10	BiOp Spill2	49.6	58	46	0	1	105	0.990	0.990	0.000
May 14-16	BiOp Spill3	59.0	39	35	9	2	85	0.871	0.976	0.818
May 18-20	BiOp Spill4	62.5	54	33	7	3	97	0.897	0.969	0.700
May 20-22	BiOp Spill5	55.3	41	37	3	1	82	0.951	0.988	0.750
May 24-26	BiOp Spill6	49.0	40	38	3	0	81	0.963	1.000	1.000
Totals			*269*	*220*	*24*	*11*	*524*	*0.933*	*0.979*	*0.686*

Table 7. Passage distribution and fish passage metrics for radio-tagged juvenile steelhead passing Ice Harbor Dam during reduced and BiOp spill treatments, 2007.

			Passage route					Fish passage metrics		
Date	Spill treatment	Mean spill (kcfs)	Spillway	RSW	Bypass	Turbine	Total	Spill efficiency	FPE	FGE
May 2-4	Reduced Spill 1	26.8	3	19	2	0	24	0.917	1.000	1.000
May 6-8	Reduced Spill 2	20.0	7	86	6	5	104	0.894	0.952	0.545
May 10-12	Reduced Spill 3	26.5	12	65	14	2	93	0.828	0.978	0.875
May 12-14	Reduced Spill 4	28.9	18	65	18	3	104	0.798	0.971	0.857
May 16-18	Reduced Spill 5	27.5	15	63	10	0	88	0.886	1.000	1.000
May 22-24	Reduced Spill 6	23.5	6	61	12	1	80	0.838	0.988	0.923
May 26-31	Reduced Spill 7	17.8	6	53	4	0	71	0.831	0.887	1.000
Totals			*67*	*412*	*66*	*11*	*556*	*0.862*	*0.980*	*0.857*
May 4-6	BiOp Spill 1	55.0	26	41	1	2	70	0.957	0.971	0.333
May 8-10	BiOp Spill 2	49.6	39	45	1	0	85	0.988	1.000	1.000
May 14-16	BiOp Spill 3	59.0	23	39	8	2	72	0.861	0.972	0.800
May 18-20	BiOp Spill 4	62.5	29	37	3	0	69	0.957	1.000	1.000
May 20-22	BiOp Spill 5	55.3	27	34	1	0	62	0.984	1.000	1.000
May 24-26	BiOp Spill 6	49.0	31	26	2	0	59	0.966	1.000	1.000
Totals			*175*	*222*	*16*	*4*	*417*	*0.952*	*0.990*	*0.800*

Tailrace Egress

Median egress times for juvenile yearling Chinook salmon were not significantly different ($P = 0.574$) when the 50th percentiles of temporal replicate treatment groups were compared between reduced spill operations (9.6 min) and BiOp spill operations (9.6 min). Median tailrace egress times for juvenile steelhead were not significantly different ($P = 0.108$) when the 50th percentiles of temporal replicate treatment groups were compared between reduced (9.7 min) and BiOp spill operations (8.4 min; Figure 16).

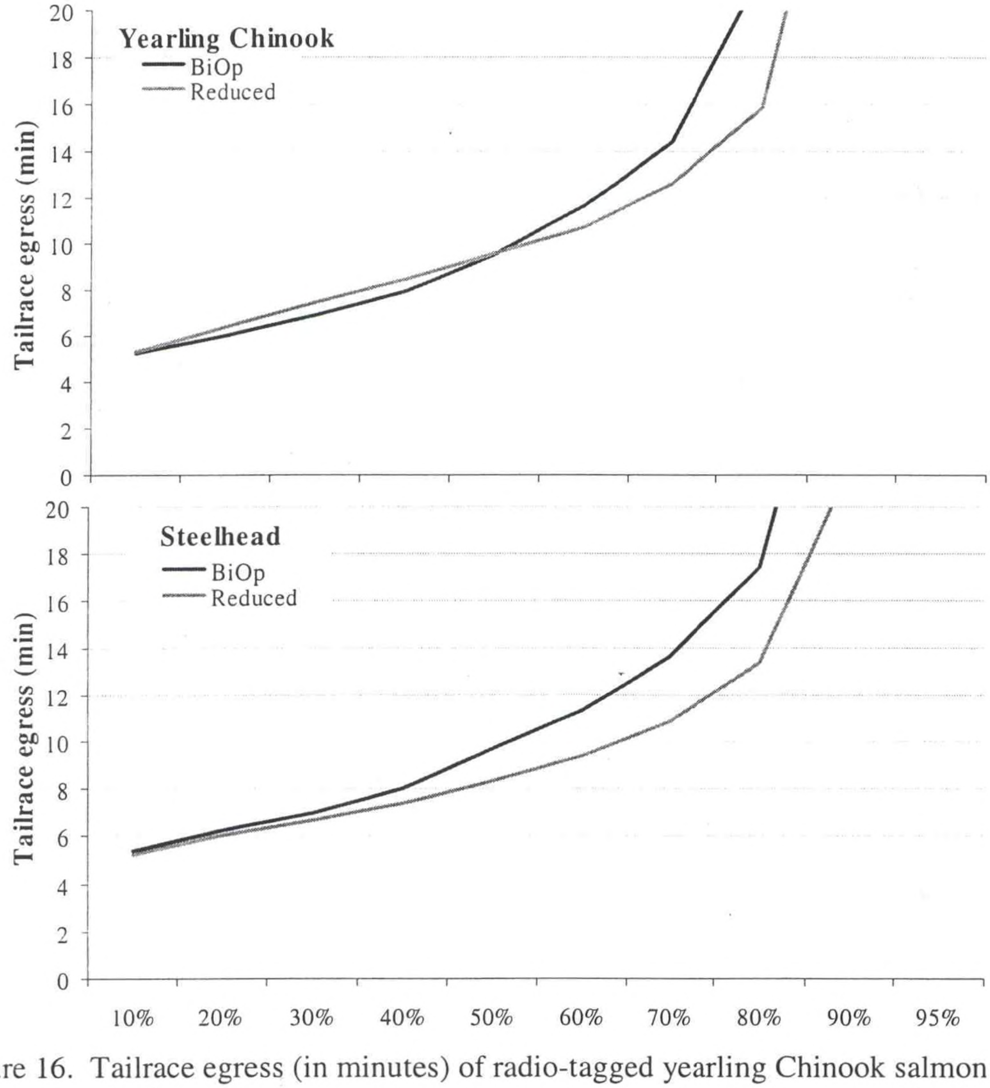

Figure 16. Tailrace egress (in minutes) of radio-tagged yearling Chinook salmon (upper panel) and juvenile steelhead passage during two different spill treatments at Ice Harbor Dam, 2007.

Avian Predation

Recovery efforts on the Crescent Island tern colony found 228 juvenile steelhead radio tags, representing approximately 6.1% of the steelhead we released into the Snake River. We recovered 55 yearling Chinook salmon radio tags, representing approximately 1.3% of the yearling Chinook salmon we released.

We plotted the last known detection transect where the fish were observed in order to determine where the "kill zone" might be located. Both juvenile steelhead and yearling Chinook salmon were most vulnerable when they entered the forebay of Ice Harbor Dam and near the confluence of the Snake and Columbia Rivers (Figure 17).

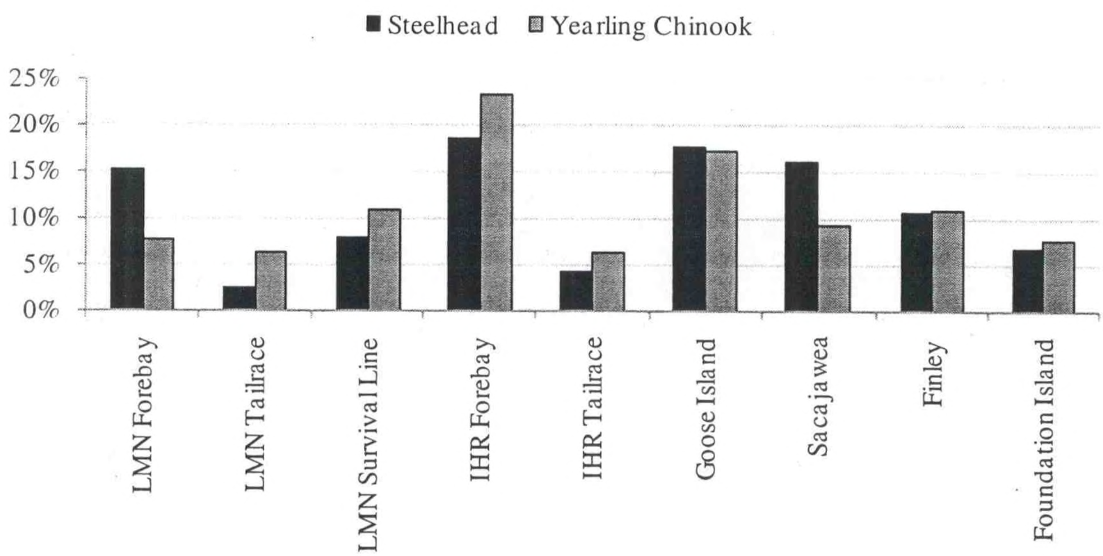

Figure 17. Percentage of radio-tagged yearling Chinook salmon and juvenile steelhead migrants with their last known telemetry detection site before avian predation event, 2007.

DISCUSSION

Overall, for the second consecutive year of evaluation, the RSW at Ice Harbor Dam was extremely effective in passing more fish with less water than operations without the RSW. Survival estimates were high and not significantly different between BiOp and reduced spill treatments. During 2006, we encountered a high-flow year, with flow volume measuring higher than the 10-year average for the Snake River throughout the study (Axel et al. 2007). In contrast, 2007 was a low-flow year, with flow volume below the 10-year average nearly every day of the study. However, the lower flows during 2007 resulted in a 4% increase over 2006 in the percentage of total flow through the RSW. This occurred because flow through the RSW was predetermined in both years so that the percentage of total river flow through the RSW would be greater in years of lower flow. This factor alone may have produced the increases in first approach and passage at the RSW for both yearling Chinook salmon and juvenile steelhead.

In 2006, first detections at the RSW were approximately 51% for yearling Chinook salmon and 61% for steelhead under both treatments (Axel et al. 2007). The proportion of total river flow through the RSW increased from 7% in 2006 to 11% in 2007, although mean discharge remained the same during both years at 8 kcfs. Consequently, fish approach distributions at the RSW increased dramatically for both yearling Chinook salmon (>80% first seen at the RSW) and juvenile steelhead (>86%) during the low flow year of 2007. Passage through the RSW for both species also increased as a result of more fish being drawn toward the surface passage route. However, not all fish that approached within 5 m of the RSW continued to pass over the RSW, and the reason for this is not clear. Overall passage distribution for 2006 through non-turbine routes was greater than 95% for yearling Chinook salmon and 98% for steelhead. In 2007, non-turbine passage routes accounted for greater than 92% of the yearling Chinook salmon and 98% of the steelhead.

The diel hour of arrival and passage at Ice Harbor Dam was comparatively consistent during the study for both yearling Chinook salmon and juvenile steelhead. Both species displayed similar patterns under both treatments, where approach and passage trends suggested relatively little delay in the forebay. Arrival and passage numbers at Ice Harbor Dam tended to be higher during daylight hours, particularly for steelhead. During BiOp spill treatments, daylight hours consisted of lower levels of spill, which may have allowed steelhead to find the surface flow more easily. Yearling Chinook salmon arrived in fairly consistent proportions throughout both spill operation treatments, with anywhere from 2 to 9% arriving during all hours of the day.

Median forebay delays in 2007 were similar to those found in 2006 for both species under each spill treatment (Axel et al. 2007). Median forebay residence time for yearling Chinook salmon during the high flows of 2006 was 1.8 h for reduced spill and

1.1 h BiOp spill. During 2007 we observed median forebay delays of 2.0 h for reduced and 1.5 h for BiOp spill. Results in 2006 for steelhead were similar to those of yearling Chinook salmon, with 1.8 h for reduced and 1.7 h for BiOp spill. Both species exhibited slightly longer delays of 5-10 min under the reduced spill treatments, most likely due to the increased flow through the powerhouse during reduced spill. Additional flow to the powerhouse resulted in some wandering behavior, while fish were likely deciding on which flow queue to follow. However, the differences in delay of minutes would likely have no biological significance.

First approach for both species under a BiOp treatment was primarily at the spillway with very few fish directly approaching the powerhouse. During reduced spill treatments, the amount of flow through the spillway was reduced and shifted to the powerhouse, which resulted in slightly higher percentages of fish approaching the powerhouse. We also observed a difference between the two species associated with the percentage of fish approaching the immediate forebay under the two different spill treatments. Steelhead entered the forebay area much more readily under reduced spill treatments, while yearling Chinook had higher percentages approached during BiOp spill.

The BiOp operating condition tended to direct more fish into the conventional bays rather than over the RSW. However this occurred to a lesser extent than was observed in 2006, and the distribution still favored the RSW. Steelhead passage through the JBS decreased considerably for both treatments, but most significantly under the reduced spill treatment. This behavior was most likely attributable to the increased percentage of flow over the RSW. With fish guidance efficiencies as high as they were, few fish of either species passed through the turbine intakes under increasing turbine loading conditions.

Overall, there was no difference in survival between species, project operation treatments, or flow years. Survival estimates were not different between flows or treatments. In fact, dam survival estimates, which included forebay losses, were slightly higher in 2007 for the reduced spill treatment, while forebay residence was slightly longer.

RECOMMENDATIONS

Continued preclusion of spillway 1 operation is recommended to help maximize the proportion of yearling Chinook salmon that will find and pass through the RSW during periods of increased turbine loading. Operation of this spillbay has been curtailed because of its tendency to increase confusion and delay passage of juvenile salmonids through spillway passage routes.

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APPENDIX A

Evaluation of Study Assumptions

We used a single-release model (Cormack 1964; Jolly 1965; Seber 1965) to estimate survival of radio-tagged juvenile Chinook salmon released above and below Ice Harbor Dam. Ratios of these survival estimates (treatment survival divided by reference survival) were calculated to determine relative survival. Evaluation of critical model and biological assumptions of the study are detailed below.

A1. All tagged fish have similar probabilities of downstream detection.

Of the 1,048 radio-tagged yearling Chinook salmon detected at Ice Harbor Dam, 937 (89.4% of those observed) were detected either at or below the primary survival transect at Sacajawea Park. Of 830 radio-tagged yearling Chinook salmon released into the tailrace of Ice Harbor Dam, 781 (94.1% of those released) were detected either at or below Sacajawea. Detection probability for fish used in survival analysis at Ice Harbor Dam was 0.991 overall (Appendix Table A1a). With detection probabilities at 99% for all fish, there was likely no disparity between detection probabilities of treatment and reference groups.

Of the 1,015 radio-tagged juvenile steelhead detected at Ice Harbor Dam, 937 (92.3% of those observed) were detected either at or below the primary survival transect at Sacajawea Park. Of the 874 radio-tagged juvenile steelhead released into the tailrace of Ice Harbor Dam, 781 (89.4% of those released) were detected either at or below Sacajawea. Detection probability for fish used in survival analysis at Ice Harbor Dam was 0.991 overall (Appendix Table A1b). With detection probabilities at 99% for all fish, there was likely no disparity between detection probabilities of treatment and reference groups.

Appendix Table A1a. Detections at and below Ice Harbor Dam and detection at Ice Harbor Dam for evaluating survival of yearling Chinook salmon passing through Ice Harbor, 2007.

Release group	Release location	Detection at Sacajawea	Detection at or below Sacajawea	Detection probability
Treatment	Above IHR Dam	929	937	0.992
Reference	IHR Dam tailrace	774	781	0.991
Totals		1,703	1,718	0.991

Appendix Table A1b. Detections at and below Ice Harbor Dam and detection at Ice Harbor Dam for evaluating survival of steelhead passing through Ice Harbor Dam, 2007.

Release group	Release location	Detection at Sacajawea	Detection at or below Sacajawea	Detection probability
Treatment	Above IHR Dam	840	849	0.990
Reference	IHR Dam tailrace	773	779	0.992
Totals		1,613	1,628	0.991

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

To test that treatment and reference fish mixed evenly and traveled together downstream, we evaluated mixing of release groups at Sacajawea and McNary Beach detection sites by comparing specific percentiles (10th, 50th, 90th). For these comparisons, we used a *t*-test with a 95% CI to assess differences in passage distributions. The treatment grouping (BiOp or reduced spill levels) was paired with the same grouping of reference fish.

Tests of homogeneity in passage distributions at Sacajawea were not statistically significantly different for yearling Chinook salmon between treatment and reference groups used to calculate relative survival estimates (Appendix Table A2a-A2b). Results were marginally significant for the 10th and 90th percentiles of juvenile steelhead (Appendix A2c-A2d), but this may have been a result of the 48-h treatment blocks. Average timing differences in passage between treatment and reference fish were less than 1 h for Chinook and around 2 h for steelhead overall. Average timing differences by treatment type were far smaller than the 2-d intervals of the treatment blocks.

Appendix Table A2a. Differences and subsequent tests of homogeneity of passage timing at the primary survival transect (16 km downstream of the dam) between treatment and reference groups (in hours) for radio-tagged yearling Chinook salmon used for estimating survival at Ice Harbor Dam during BiOp spill treatments, 2007.

		Timing difference (h) by passage percentile		
Block	N	10th	50th	90th
BiOp spill 1	116	-0.006	0.279	0.341
BiOp spill 2	160	0.037	0.346	0.037
BiOp spill 3	147	-0.054	0.129	-0.050
BiOp spill 4	154	-0.120	-0.407	-0.124
BiOp spill 5	144	-0.027	-0.264	-0.048
BiOp spill 6	119	-0.174	-0.225	0.056
Mean difference in timing (h)		-1.4	-0.6	0.9
t		-1.81	-0.18	0.53
df		5	5	5
P		0.130	0.861	0.618

Appendix Table A2b. Differences and subsequent tests of homogeneity of passage timing at the primary survival transect (16 km downstream of the dam) between treatment and reference groups (in hours) for radio-tagged yearling Chinook salmon used for estimating survival at Ice Harbor Dam during reduced spill treatments, 2007.

		Timing difference (h) by passage percentile		
Block	N	10th	50th	90th
Reduced spill 1	139	-0.105	-0.130	0.001
Reduced spill 2	149	-0.053	0.209	-0.015
Reduced spill 3	153	-0.139	-0.227	-0.183
Reduced spill 4	139	0.020	0.080	-0.133
Reduced spill 5	145	-0.063	0.047	0.179
Reduced spill 6	82	0.036	-0.024	0.042
Mean difference in timing (h)		-1.2	-0.2	-0.4
t		-1.81	-0.12	-0.35
df		5	5	5
P		0.130	0.907	0.742

Appendix Table A2c. Differences and subsequent tests of homogeneity of passage timing at the primary survival transect (16 km downstream of the dam) between treatment and reference groups (in hours) for radio-tagged juvenile steelhead used for estimating survival at Ice Harbor Dam during BiOp spill treatments, 2007.

		Timing difference (h) by passage percentile		
Block	N	10th	50th	90th
BiOp spill 1	132	-0.189	-0.278	-0.042
BiOp spill 2	139	0.050	0.287	-0.069
BiOp spill 3	120	-0.202	-0.247	-0.098
BiOp spill 4	128	-0.025	0.033	0.005
BiOp spill 5	125	-0.195	0.052	-0.008
BiOp spill 6	97	-0.160	-0.138	0.049
Mean difference in timing (h)		-2.9	-1.2	-0.7
t		-2.77	-0.55	-1.25
df		5	5	5
P		0.039	0.604	0.267

Appendix Table A2d. Differences and subsequent tests of homogeneity of passage timing at the primary survival transect (16 km downstream of the dam) between treatment and reference groups (in hours) for radio-tagged juvenile steelhead used for estimating survival at Ice Harbor Dam during reduced spill treatments, 2007.

		Timing difference (h) by passage percentile		
Block	N	10th	50th	90th
Reduced spill 1	165	-0.003	-0.014	-0.258
Reduced spill 2	149	-0.087	0.106	0.002
Reduced spill 3	155	-0.227	-0.141	-0.088
Reduced spill 4	150	-0.111	-0.190	-0.244
Reduced spill 5	132	-0.172	-0.117	-0.105
Reduced spill 6	76	-0.139	-0.519	-0.314
Mean difference in timing (h)		-3.0	-3.5	-4.0
t		-3.95	-1.69	-3.37
df		5	5	5
P		0.011	0.152	0.020

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

Unmarked yearling Chinook salmon and juvenile steelhead were collected at Lower Monumental for 26 d from 1 May to 26 May. Tagging began after approximately 2.5% of the yearling Chinook salmon and 0.4% of the juvenile steelhead had passed Lower Monumental Dam, and was completed when 97% of these fish had passed (Figure 2). Overall mean fork length for yearling Chinook and steelhead was 146 mm (SD = 11.3) and 220 mm (SD = 21.3), respectively. This compared closely with the mean length of the fin-clipped yearling Chinook and steelhead run-at-large sampled at the smolt collection facility (140 mm and 213 mm, respectively).

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

Assumption A4 was 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). From their conclusions, we assumed that behavior and survival were not significantly affected over the length of our study area.

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

We released 21 dead radio-tagged hatchery yearling Chinook salmon and 5 juvenile steelhead into the tailrace of Ice Harbor Dam to test Assumption A5 (Appendix Table A3). The low numbers were indicative of extremely low tagging mortality. The distance between release at Ice Harbor Dam and the first downstream telemetry array used to estimate survival (Ice Harbor Dam) was 16 km. Similar to the findings of Axel et al. (2003, 2006), none of our dead, radio-tagged fish were subsequently detected at telemetry transects which were used for estimating survival.

Appendix Table A3. Numbers of dead fish released and subsequently detected at and below the survival transect at Sacajawea for testing the assumption that fish that die as a result of passing through a passage route at Ice Harbor Dam are not subsequently detected on downstream survival arrays, 2007.

	Yearling Chinook	Steelhead
Number of dead fish released	21	5
Proportion of fish released which were dead	2.5%	0.6%
Number detected at Sacajawea	0	0
Number detected below Sacajawea	0	0

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

All transmitters were checked upon receipt from the manufacturer, prior to implantation into a fish and prior to release, to ensure that the transmitter was functioning properly. A total of 4,429 tags were implanted in hatchery yearling Chinook salmon and steelhead, of which 45 (1.0%) were not working 24 hours after tagging. All fish with tags that were not functioning properly were excluded from the study.

In addition, a total of 76 radio transmitters 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. Two tags (2.6%) failed prior to the preprogrammed shut-down after 10 d (Appendix Table A4). Both failed in less than 8 days. Maximum median travel time from release to Ice Harbor Dam was 2.9 days overall with less than 1% of the fish overall taking 6 days or more to reach Ice Harbor Dam (Table 5). Although we documented transmitter failures during our study, the short travel times to our survival transect and the relatively low failure rate were such that they would not have significantly changed our findings.

Appendix Table A4. Frequency of days tags lasted in tag life testing, 2007.

N	%	Tag life (d)
0	0	1
0	0	2
0	0	3
0	0	4
0	0	5
2	3	6
0	0	7
0	0	8
0	0	9
74	97	10

APPENDIX B

Telemetry Data processing and Reduction Flowchart

Overview

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

Database Inputs

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

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

Database Outputs

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

Processes

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

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

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

***Null*:** denotes a valid observation of a tag.

Not Tagged: Denotes an observation of a channel-code combination that was not in use at the time. Such values are likely due to radio-frequency noise being picked up at an antenna.

Noise Record: Denotes an observation where the code is equal to 995, 997, or 999. These are not valid records, and relate to radio-frequency noise being picked up at the antenna.

Beacon Record: Hits recorded on channel = 5, code = 575, which is being used to ensure proper functioning of the receivers. This combination does not indicate the presence of a tagged fish.

Invalid Record Date: Denotes an observation whose date/time is invalid (occurring before we started the database; prior to Jan. 1, 2004, or some time in the future). Due to improvements in the data loading process, such records are unlikely to arise.

Invalid Site: Denotes an observation attributed to an invalid (non-existent) site. These are typically caused by typographical errors in naming hex files at the receiver end. They should not be present in the database, since they should be filtered out during the data loading process.

Invalid Antenna: Denotes an observation attributed to an invalid (non-existent) antenna. These are most likely due to electronic noise within the receiver.

Lt start time: Assigned to records occurring prior to the time a tag was activated (its start time).

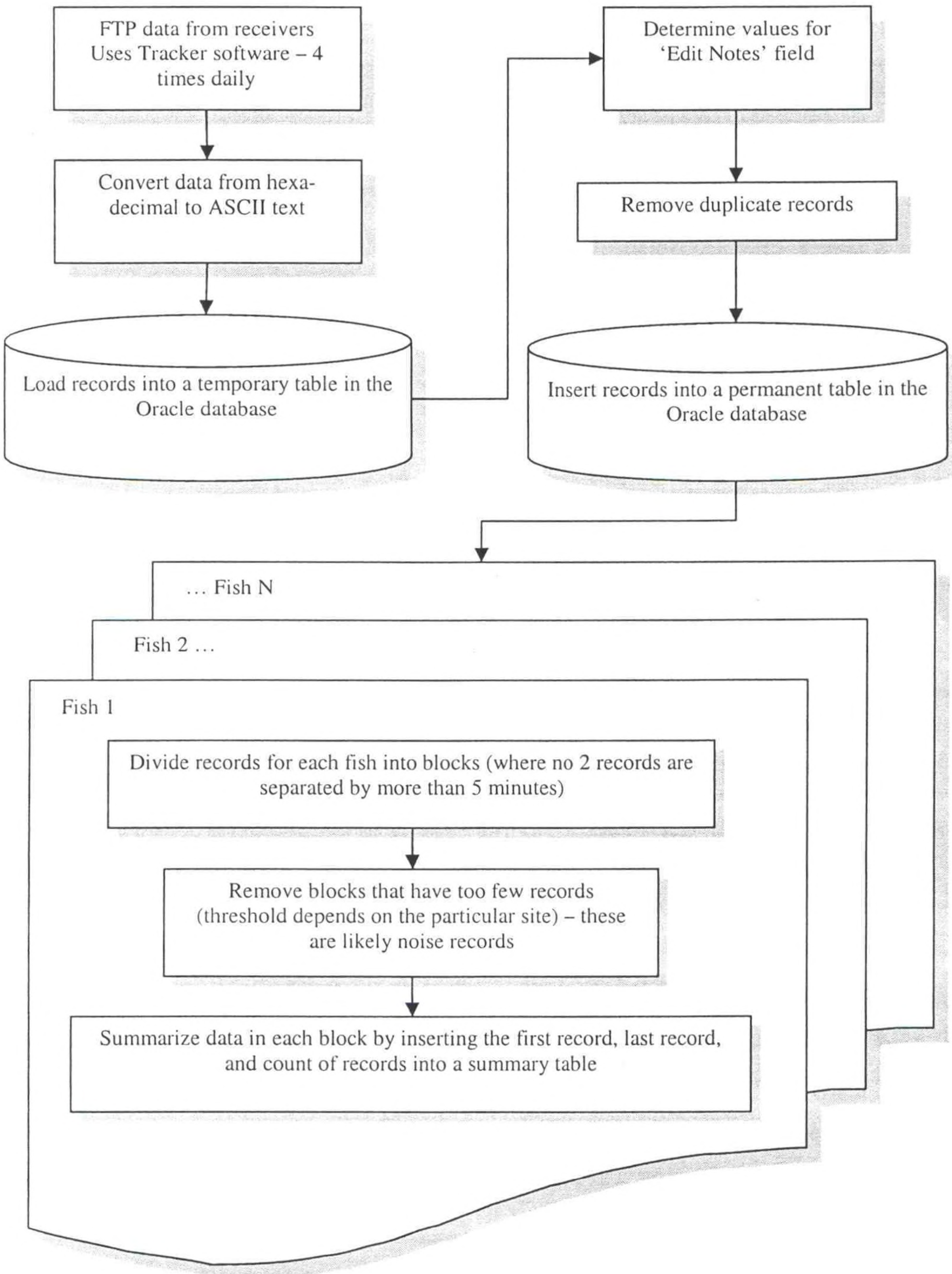
Gt end_time: Assigned to records occurring after the end time on a tag (they run for 10 days once activated).

Gt 40 recs: Denotes tags that registered more than 40 records per minute on an individual receiver. This is not possible as the tags emit a signal every 2 seconds (30/minute). Such patterns indicate noise.

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

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

Flow Chart



Appendix Figure B1. Flowchart of telemetry data processing and reduction used in evaluating behavior and survival at Ice Harbor Dam for yearling Chinook salmon and steelhead, 2007.

APPENDIX C

Detection histories for radio-tagged yearling Chinook salmon and juvenile steelhead passing Ice Harbor Dam

Appendix Table C1. Detection histories of radio-tagged yearling Chinook salmon released above (treatment) and below (reference) Ice Harbor Dam to evaluate dam passage survival for reduced spill treatment in 2007. The primary survival array was 16 km downstream from the dam, and additional downstream arrays are shown in Figure 1. Detection histories recorded as 1 detected, 0 = not detected.

	Detection history		
Releases (n)	Primary survival array	Post primary array	n
Treatment group (523)	0	0	57
	1	0	104
	0	1	3
	1	1	359
Reference group (430)	0	0	25
	1	0	5
	0	1	92
	1	1	308

Appendix Table C2. Detection histories of radio-tagged yearling Chinook salmon released above (treatment) and below (reference) Ice Harbor Dam to evaluate dam passage survival for BiOp spill treatment in 2007. The primary survival array was 16 km downstream from the dam, and additional downstream arrays are shown in Figure 1. Detection histories recorded as 1, detected; 0, not detected.

	Detection history		
	Primary survival array	Post primary array	n
Treatment group (541)			
	0	0	71
	1	0	100
	0	1	4
	1	1	366
Reference group (400)			
	0	0	24
	1	0	79
	0	1	2
	1	1	295

Appendix Table C3. Detection histories of radio-tagged steelhead released above (treatment) and below (reference) Ice Harbor Dam to evaluate dam passage survival for reduced spill treatment in 2007. The primary survival array was 16 km downstream from the dam, and additional downstream arrays are shown in Figure 1. Detection histories recorded as 1, detected; 0, not detected.

	Detection history		
	Primary survival array	Post primary array	n
Treatment group (579)			
	0	0	90
	1	0	114
	0	1	5
	1	1	370
Reference group (440)			
	0	0	49
	1	0	111
	0	1	3
	1	1	277

Appendix Table C4. Detection histories of radio-tagged steelhead released above (treatment) and below (reference) Ice Harbor Dam to evaluate dam passage survival for BiOp spill treatment in 2007. The primary survival array was 16 km downstream from the dam, and additional downstream arrays are shown in Figure 1. Detection histories recorded as 1, detected; 0, not detected.

	Detection history		
	Primary survival array	Post primary array	n
Treatment group (436)			
	0	0	76
	1	0	93
	0	1	4
	1	1	263
Reference group (434)			
	0	0	46
	1	0	99
	0	1	3
	1	1	286

Appendix Table C5. Detection histories of radio-tagged yearling Chinook salmon released above (treatment) and below (reference) Ice Harbor Dam to evaluate Concrete passage survival for reduced spill treatments in 2007. The primary survival array was 16 km downstream from the dam, and additional downstream arrays are shown in Figure 1. Detection histories recorded as 1, detected; 0, not detected.

	Detection history		
	Primary survival array	Post primary array	n
Treatment group (771)			
	0	0	79
	1	0	145
	0	1	6
	1	1	541
Reference group (430)			
	0	0	25
	1	0	5
	0	1	92
	1	1	308

Appendix Table C6. Detection histories of radio-tagged yearling Chinook salmon released above (treatment) and below (reference) Ice Harbor Dam to evaluate Concrete passage survival for BiOp spill treatments in 2007. The primary survival array was 16 km downstream from the dam, and additional downstream arrays are shown in Figure 1. Detection histories recorded as 1, detected; 0, not detected.

	Detection history		
	Primary survival array	Post primary array	n
Treatment group (958)			
	0	0	102
	1	0	188
	0	1	7
	1	1	661
Reference group (400)			
	0	0	24
	1	0	79
	0	1	2
	1	1	295

Appendix Table C7. Detection histories of radio-tagged steelhead released above (treatment) and below (reference) Ice Harbor Dam to evaluate concrete passage survival for reduced spill treatments in 2007. The primary survival array was 16 km downstream from the dam, and additional downstream arrays are shown in Figure 1. Detection histories recorded as 1, detected; 0, not detected.

	Detection history		
	Primary survival array	Post primary array	n
Treatment group (801)			
	0	0	99
	1	0	159
	0	1	6
	1	1	537
Reference group (440)			
	0	0	49
	1	0	111
	0	1	3
	1	1	277

Appendix Table C8. Detection histories of radio-tagged steelhead released above (treatment) and below (reference) Ice Harbor Dam to evaluate concrete passage survival for BiOp spill treatments in 2007. The primary survival array was 16 km downstream from the dam, and additional downstream arrays are shown in Figure 1. Detection histories recorded as 1, detected; 0, not detected.

	Detection history		
	Primary survival array	Post primary array	n
Treatment group (908)			
	0	0	119
	1	0	192
	0	1	9
	1	1	588
Reference group (434)			
	0	0	46
	1	0	99
	0	1	3
	1	1	286

Appendix Table C9. Detection histories of radio-tagged yearling Chinook salmon released above (treatment) and below (reference) Ice Harbor Dam to evaluate spillway passage survival for reduced spill treatments in 2007. The primary survival array was 16 km downstream from the dam, and additional downstream arrays are shown in Figure 1. Detection histories recorded as 1, detected; 0, not detected.

	Detection history		
	Primary survival array	Post primary array	n
Treatment group (602)			
	0	0	55
	1	0	105
	0	1	5
	1	1	437
Reference group (430)			
	0	0	25
	1	0	5
	0	1	92
	1	1	308

Appendix Table C10. Detection histories of radio-tagged yearling Chinook salmon released above (treatment) and below (reference) Ice Harbor Dam to evaluate spillway passage survival for BiOp spill treatments in 2007. The primary survival array was 16 km downstream from the dam, and additional downstream arrays are shown in Figure 1. Detection histories recorded as 1, detected; 0, not detected.

	Detection history		
	Primary survival array	Post primary array	n
Treatment group (789)			
	0	0	78
	1	0	148
	0	1	6
	1	1	557
Reference group (400)			
	0	0	24
	1	0	79
	0	1	2
	1	1	295

Appendix Table C11. Detection histories of radio-tagged steelhead released above (treatment) and below (reference) Ice Harbor Dam to evaluate spillway passage survival for reduced spill treatments in 2007. The primary survival array was 16 km downstream from the dam, and additional downstream arrays are shown in Figure 1. Detection histories recorded as 1, detected; 0, not detected.

	Detection history		
	Primary survival array	Post primary array	n
Treatment group (701)			
	0	0	84
	1	0	134
	0	1	2
	1	1	481
Reference group (440)			
	0	0	49
	1	0	111
	0	1	3
	1	1	277

Appendix Table C12. Detection histories of radio-tagged steelhead released above (treatment) and below (reference) Ice Harbor Dam to evaluate spillway passage survival for BiOp spill treatments in 2007. The primary survival array was 16 km downstream from the dam, and additional downstream arrays are shown in Figure 1. Detection histories recorded as 1, detected; 0, not detected.

	Detection history		
	Primary survival array	Post primary array	n
Treatment group (808)			
	0	0	104
	1	0	167
	0	1	5
	1	1	532
Reference group (434)			
	0	0	46
	1	0	99
	0	1	3
	1	1	286

Appendix Table C13. Detection histories of radio-tagged yearling Chinook salmon released above (treatment) and below (reference) Ice Harbor Dam to evaluate JBS passage survival for reduced spill treatments in 2007. The primary survival array was 16 km downstream from the dam, and additional downstream arrays are shown in Figure 1. Detection histories recorded as 1, detected; 0, not detected.

	Detection history		
	Primary survival array	Post primary array	n
Treatment group (83)			
	0	0	8
	1	0	21
	0	1	0
	1	1	54
Reference group (430)			
	0	0	25
	1	0	5
	0	1	92
	1	1	308

Appendix Table C14. Detection histories of radio-tagged yearling Chinook salmon released above (treatment) and below (reference) Ice Harbor Dam to evaluate JBS passage survival for BiOp spill treatments in 2007. The primary survival array was 16 km downstream from the dam, and additional downstream arrays are shown in Figure 1. Detection histories recorded as 1, detected; 0, not detected.

	Detection history		
	Primary survival array	Post primary array	n
Treatment group (24)			
	0	0	3
	1	0	5
	0	1	0
	1	1	16
Reference group (400)			
	0	0	24
	1	0	79
	0	1	2
	1	1	295

Appendix Table C15. Detection histories of radio-tagged steelhead released above (treatment) and below (reference) Ice Harbor Dam to evaluate JBS passage survival for reduced spill treatments in 2007. The primary survival array was 16 km downstream from the dam, and additional downstream arrays are shown in Figure 1. Detection histories recorded as 1, detected; 0, not detected.

	Detection history		
	Primary survival array	Post primary array	n
Treatment group (65)			
	0	0	8
	1	0	18
	0	1	2
	1	1	37
Reference group (440)			
	0	0	49
	1	0	111
	0	1	3
	1	1	277

Appendix Table C16. Detection histories of radio-tagged steelhead released above (treatment) and below (reference) Ice Harbor Dam to evaluate JBS passage survival for BiOp spill treatments in 2007. The primary survival array was 16 km downstream from the dam, and additional downstream arrays are shown in Figure 1. Detection histories recorded as 1, detected; 0, not detected.

	Detection history		
	Primary survival array	Post primary array	n
Treatment group (16)			
	0	0	3
	1	0	5
	0	1	0
	1	1	8
Reference group (434)			
	0	0	46
	1	0	99
	0	1	3
	1	1	286

Appendix Table C17. Detection histories of radio-tagged yearling Chinook salmon released above (treatment) and below (reference) Ice Harbor Dam to evaluate turbine passage survival for reduced spill treatments in 2007. The primary survival array was 16 km downstream from the dam, and additional downstream arrays are shown in Figure 1. Detection histories recorded as 1, detected; 0, not detected.

	Detection history		
	Primary survival array	Post primary array	n
Treatment group (45)			
	0	0	9
	1	0	10
	0	1	0
	1	1	26
Reference group (430)			
	0	0	25
	1	0	5
	0	1	92
	1	1	308

Appendix Table C18. Detection histories of radio-tagged yearling Chinook salmon released above (treatment) and below (reference) Ice Harbor Dam to evaluate turbine passage survival for BiOp spill treatments in 2007. The primary survival array was 16 km downstream from the dam, and additional downstream arrays are shown in Figure 1. Detection histories recorded as 1, detected; 0, not detected.

	Detection history		
	Primary survival array	Post primary array	n
Treatment group (11)			
	0	0	4
	1	0	2
	0	1	1
	1	1	4
Reference group (400)			
	0	0	24
	1	0	79
	0	1	2
	1	1	295

Appendix Table C19. Detection histories of radio-tagged steelhead released above (treatment) and below (reference) Ice Harbor Dam to evaluate turbine passage survival for reduced spill treatments in 2007. The primary survival array was 16 km downstream from the dam, and additional downstream arrays are shown in Figure 1. Detection histories recorded as 1, detected; 0, not detected.

	Detection history		
	Primary survival array	Post primary array	n
Treatment group (10)			
	0	0	1
	1	0	1
	0	1	0
	1	1	8
Reference group (440)			
	0	0	49
	1	0	111
	0	1	3
	1	1	277

Appendix Table C20. Detection histories of radio-tagged steelhead released above (treatment) and below (reference) Ice Harbor Dam to evaluate turbine passage survival for BiOp spill treatments in 2007. The primary survival array was 16 km downstream from the dam, and additional downstream arrays are shown in Figure 1. Detection histories recorded as 1, detected; 0, not detected.

	Detection history		
	Primary survival array	Post primary array	n
Treatment group (4)			
	0	0	1
	1	0	0
	0	1	1
	1	1	2
Reference group (434)			
	0	0	46
	1	0	99
	0	1	3
	1	1	286

Appendix Table C21. Detection histories of radio-tagged yearling Chinook salmon released above (treatment) and below (reference) Ice Harbor Dam to evaluate RSW passage survival for reduced spill treatments in 2007. The primary survival array was 16 km downstream from the dam, and additional downstream arrays are shown in Figure 1. Detection histories recorded as 1, detected; 0, not detected.

	Detection history		
	Primary survival array	Post primary array	n
Treatment group (300)			
	0	0	29
	1	0	56
	0	1	3
	1	1	212
Reference group (430)			
	0	0	25
	1	0	5
	0	1	92
	1	1	308

Appendix Table C22. Detection histories of radio-tagged yearling Chinook salmon released above (treatment) and below (reference) Ice Harbor Dam to evaluate RSW passage survival for BiOp spill treatments in 2007. The primary survival array was 16 km downstream from the dam, and additional downstream arrays are shown in Figure 1. Detection histories recorded as 1, detected; 0, not detected.

	Detection history		
	Primary survival array	Post primary array	n
Treatment group (220)			
	0	0	24
	1	0	33
	0	1	2
	1	1	161
Reference group (400)			
	0	0	24
	1	0	79
	0	1	2
	1	1	295

Appendix Table C23. Detection histories of radio-tagged steelhead released above (treatment) and below (reference) Ice Harbor Dam to evaluate RSW passage survival for reduced spill treatments in 2007. The primary survival array was 16 km downstream from the dam, and additional downstream arrays are shown in Figure 1. Detection histories recorded as 1, detected; 0, not detected.

	Detection history		
	Primary survival array	Post primary array	n
Treatment group (412)			
	0	0	50
	1	0	80
	0	1	2
	1	1	280
Reference group (440)			
	0	0	49
	1	0	111
	0	1	3
	1	1	277

Appendix Table C24. Detection histories of radio-tagged steelhead released above (treatment) and below (reference) Ice Harbor Dam to evaluate RSW passage survival for BiOp spill treatments in 2007. The primary survival array was 16 km downstream from the dam, and additional downstream arrays are shown in Figure 1. Detection histories recorded as 1, detected; 0, not detected.

	Detection history		
	Primary survival array	Post primary array	n
Treatment group (222)			
	0	0	27
	1	0	39
	0	1	0
	1	1	156
Reference group (434)			
	0	0	46
	1	0	99
	0	1	3
	1	1	286