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Fish Ecology Division

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Seattle, Washington

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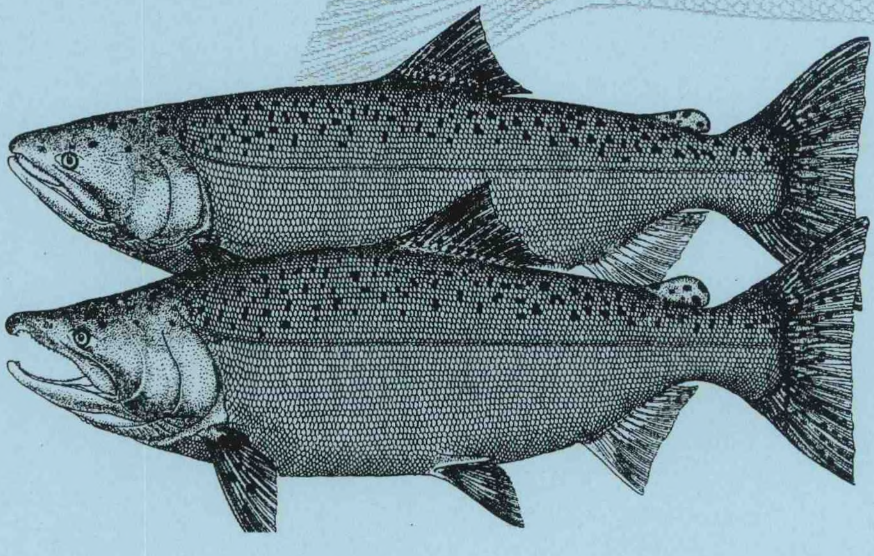

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Report of research by

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EXECUTIVE SUMMARY

In 2008, we evaluated passage behavior, distribution, and survival of yearling Chinook salmon, steelhead, and subyearling Chinook salmon at Ice Harbor Dam. A central objective of these evaluations was to determine the effects of a removable spillway weir (RSW) used during two different spill operations. Study fish consisted of those collected and surgically tagged with both a radio transmitter and PIT tag for similar evaluations at Lower Monumental Dam. For the Ice Harbor evaluation, treatment groups consisted of fish released either 42 km above Lower Monumental Dam or into the tailrace of Lower Monumental Dam. These fish were regrouped by day of detection on the Ice Harbor forebay entry line, 600 m upstream from the dam. A total of 1,699 yearling Chinook salmon, 1,951 juvenile steelhead, and 2,314 subyearling Chinook salmon from these releases were obtained as treatment fish in this manner.

All yearling Chinook salmon and steelhead replicate groups were released during both day and night hours over 27 d from 28 April to 24 May. Subyearling Chinook salmon were released during day and night hours over 27 d from 8 June to 4 July. We planned to alternate project operational treatments 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). However, due to increased river flows, involuntary spill precluded a majority of the reduced spill treatments, and this resulted in a reduction of viable replicates for comparison. There was some ability to compare behavior and passage among spill treatments during the first 14 days of the study; however, the latter half of the study was obscured by project operations that exceeded the maximum of 40% spill required for the reduced spill treatments. Therefore, all operational treatments were ignored for analysis, and data was grouped into daily replicates.

Estimates of "dam survival" reported below include the entire "effect zone," that is, the immediate forebay, approximately 600 m upstream, the concrete, and the tailrace to the nearest survival transect located 5 km or further downstream (Peven et al. 2005). Ice Harbor Dam over the years has had some of the highest levels of mortality observed in forebays of dams due to the proximity of avian predator colonies. As a result, while concrete survival is fairly high across all routes, dam survival is continually lower than at most other dams as a result of high levels of forebay predation.

Yearling Chinook salmon—Median forebay delay for yearling Chinook salmon passing Ice Harbor Dam was 1.7 h. Overall passage distribution for yearling Chinook salmon was 71.0% through the spillway (28.3% of which passed over the RSW), 23.9% through the juvenile bypass, and 5.2% through turbines (Table 1).

For yearling Chinook salmon during spring operations, overall fish passage efficiency was 94.8% (95% CI, 94.1-97.6), fish guidance efficiency was 82.2%

Table 1. Dam operations, passage behavior, and survival for radio-tagged yearling and subyearling Chinook and juvenile steelhead at Ice Harbor Dam, 2008.

			Pooled results		
			Yearling Chinook salmon	Juvenile steelhead	Subyearling Chinook salmon
Operating conditions (average)	Discharge				
	Project (kcfs)		112.0	112.0	110.4
	Spill kcfs (%)		62.4 (56)	62.4 (56)	57.3 (52)
	RSW kcfs (%)		8.0 (7)	8.0 (7)	8.1 (7)
	Training flow kcfs (%)		54.4 (49)	54.4 (49)	53.1 (48)
	Tailwater elevation (ft msl)		346.4	346.4	346.5
	Water temperature (°C)		10.9	10.9	14.5
	Secchi depth (m)		N/A	N/A	N/A
Passage-route distribution and percentile	Juvenile bypass		379 (23.9)	275 (15.0)	583 (27.8)
	Turbines	Unit 1	20 (1.3)	4 (0.2)	14 (0.7)
		Unit 2	22 (1.4)	2 (0.1)	8 (0.4)
		Unit 3	25 (1.6)	7 (0.4)	16 (0.8)
		Unit 4	0 (0.0)	3 (0.2)	16 (0.8)
		Unit 5	15 (0.9)	6 (0.3)	15 (0.7)
		Unit 6	0 (0.0)	0 (0.0)	12 (0.6)
		Turbines combined	82 (5.2)	22 (1.2)	81 (3.9)
	Spillways	Spill bay 1	5 (0.3)	7 (0.4)	0 (0.0)
		RSW	449 (28.3)	819 (44.7)	560 (26.7)
		Spill bay 3	135 (8.5)	144 (7.9)	110 (5.3)
		Spill bay 4	95 (6.0)	95 (5.2)	110 (5.3)
		Spill bay 5	124 (7.8)	129 (7.0)	140 (6.7)
		Spill bay 6	81 (5.1)	92 (5.0)	149 (7.1)
		Spill bay 7	84 (5.3)	83 (4.5)	106 (5.1)
		Spill bay 8	63 (4.0)	76 (4.1)	95 (4.5)
		Spill bay 9	51 (3.2)	57 (3.1)	102 (4.9)
		Spill bay 10	41 (2.6)	35 (1.9)	58 (2.8)
		Spillways combined	1,128 (71.0)	1,537 (83.8)	1,430 (68.3)
		Training spill	679 (42.7)	718 (39.1)	870 (41.5)
	Unknown route		2.0	1.6	2.0
Passage metric	Median forebay delay (h)		1.7	3.0	1.5
	Fish passage efficiency FPE (%)		94.8	98.8	96.1
	Spillway passage efficiency SPE (%)		71.0	83.8	68.3
	Spillway passage effectiveness SPS (%)		1.27	1.50	1.32
	Surface outlet effectiveness SOS (%)		3.99	6.30	3.67
	Training spill effectiveness		0.88	0.80	0.86
	Fish guidance efficiency FGE (%)		82.2	92.6	87.8
	Median tailrace egress (min)		8.4	8.1	8.6
Survival (%) 95% CI	Dam (forebay BRZ to tailrace)		0.925 (0.905-0.944)	0.927 (0.909-0.946)	0.862 (0.846-0.878)
	Concrete (all fish passing the dam)		0.966 (0.955-0.978)	0.970 (0.959-0.981)	0.933 (0.919-0.947)
	Spillway (through spillway)		0.966 (0.953-0.978)	0.973 (0.962-0.985)	0.942 (0.926-0.958)
	Removable spillway weir (RSW)		0.953 (0.927-0.979)	0.970 (0.954-0.986)	0.920 (0.891-0.948)
	Juvenile bypass system (JBS)		0.977 (0.954-1.000)	0.971 (0.947-0.996)	0.929 (0.903-0.956)
	Turbine		0.943 (0.889-0.996)	---	0.778 (0.685-0.870)

(80.5-88.9), and spillway passage efficiency was 71.0% (67.1-79.2). Overall surface outlet efficiency for the RSW was 28.3% (24.9-33.5). Mean spillway passage effectiveness was 1.27:1, and mean surface outlet effectiveness was 3.99:1. Training spill effectiveness was measured at 0.88:1.

Yearling Chinook passage survival was estimated at 0.966 (0.953-0.978) through the spillway, 0.953 (0.927-0.979) through the RSW, and 0.925 (0.905-0.944) through the dam. Survival was estimated at 0.977 (0.954-1.000) through the juvenile bypass system and 0.943 (0.889-0.996) through the turbines. Concrete survival, or the survival estimate for all fish that passed the project, was 0.966 (0.955-0.978).

Juvenile Steelhead—Median forebay delay for juvenile steelhead at Ice Harbor Dam was nearly twice that observed for yearling Chinook at 3.0 h. Overall passage distribution for juvenile steelhead was 83.8% through the spillway (44.7% of which passed over the RSW), 15.0% through the juvenile bypass, and 1.2% through turbines (Table 1).

Juvenile steelhead fish passage efficiency during similar operations was 98.8% (95% CI, 98.4-99.6), fish guidance efficiency was 92.6% (86.0-96.7), and spillway passage efficiency was 83.8% (80.4-88.8). Surface outlet efficiency was 44.7% (35.1-51.3). Mean spillway passage effectiveness was 1.50:1, while mean surface outlet effectiveness was 6.30:1. Training spill effectiveness was measured at 0.80:1.

Passage survival for juvenile steelhead was estimated at 0.973 (0.962-0.985) for the spillway, 0.970 (0.954-0.986) for the RSW, 0.971 (0.947-0.996) for the juvenile bypass system, and 0.927 (0.909-0.946) for the dam. Concrete survival was 0.970 (0.959-0.981). Insufficient numbers of tagged fish (22) passed through the turbines to estimate survival.

Subyearling Chinook salmon—Median forebay delay for subyearling Chinook salmon passing Ice Harbor Dam was 1.5 h. Overall passage distribution for subyearling Chinook salmon was 68.3% through the spillway (26.7% of which passed over the RSW), 27.8% through the juvenile bypass, and 3.9% through turbines (Table 1).

Fish passage efficiency for subyearling Chinook salmon was 96.1% (95% CI, 95.6-97.5), fish guidance efficiency was 87.8% (81.7-90.7), and spillway passage efficiency was 68.3% (64.4-76.5). Surface outlet efficiency for the RSW was 26.7% (23.0-32.9). Mean spillway passage effectiveness was 1.32:1, and mean surface outlet effectiveness was 3.67:1. Training spill effectiveness was measured at 0.86:1.

Passage survival for subyearling Chinook salmon was estimated at 0.942 (0.926-0.958) through the spillway, 0.920 (0.891-0.948) through the RSW, and 0.862 (0.846-0.878) through the dam. The estimate for bypass survival was 0.929 (0.903-0.956), while turbine survival measured 0.778 (0.685-0.870). Concrete survival was 0.933 (0.919-0.947).

CONTENTS

INTRODUCTION

A primary focus of recovery efforts for depressed stocks of Pacific salmon *Oncorhynchus* spp. and steelhead *O. mykiss* has been assessing and improving fish passage conditions at dams. 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). Project operations at Lower Granite, Little Goose, and Lower Monumental Dams utilize a combination of voluntary spill and collection of fish for transportation to improve passage survival of juvenile salmonids. These mitigation efforts were employed pursuant to Biological Opinions issued by the National Marine Fisheries Service in 2000 (NMFS 2000) and in subsequent years. Since Ice Harbor Dam is not equipped with transportation facilities, passage survival improvement relies on increasing the proportion of fish that pass via 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 pressures, providing more efficient and less stressful passage conditions. In contrast, traditional spill bay gates, which open 15.2 m below the water surface at the face of the dam, create high water pressure and high velocity. An RSW was installed at Lower Granite Dam in 2001, at Ice Harbor Dam in 2005, and at Lower Monumental Dam prior to the 2008 spring juvenile migration. A temporary spillway weir (similar to the RSW) was installed at Little Goose Dam prior to the 2009 migration. Thus surface passage routes are available at all lower Snake River dams.

Previous studies at Ice Harbor Dam have shown the majority of spring migrants pass through the spillway (Eppard et al. 2000, 2005a, b; Axel et al. 2006). In 2004 and 2005, we evaluated passage behaviour, distribution, and survival of yearling Chinook salmon *O. tshawytscha* and juvenile steelhead associated with two dam operational conditions: 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 from these studies 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 (spill bay 2).

In 2006, we again utilized radiotelemetry to determine variations in behavior, passage distribution, and survival of yearling Chinook salmon and juvenile steelhead during two different operational conditions: BiOp spill, meaning spill levels of 45 kcfs during the day and spill to the gas cap at night; and reduced spill, with 30-40% of total 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. During 2006, flows were high, with Snake River flow volume measuring higher than the 10-year average throughout the study period (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 during spring, which in effect collected and passed more fish (Axel et al. 2008). Likewise, the percentage of total flow through the RSW increased 7% over 2006 during summer 2007. Approximately 21% of total river flow was available to attract subyearling Chinook salmon to approach and utilize the surface passage route (Ogden et al. 2008). This resulted in nearly 74% of tagged subyearlings using the RSW to pass the project during reduced spill treatments. Overall, there has been no significant difference in survival between species, project operation treatments, or flow years at Ice Harbor Dam.

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 spill bays numbered 1 to 10 from south to north. Spill bay flow is metered by operation of Tainter gates, with the exception of the RSW bay (spill bay 2), where flow is regulated exclusively by forebay pool elevation. The spillway crest for conventional spill bays is located at an elevation of 119.2 m, while the RSW spills water at an elevation of 129.5 m. The powerhouse measures 204.5 m long, and each of its six turbine unit intakes is outfitted with standard length submerged traveling screens (STS), which diverts downstream-migrating salmonids into the JBS. The STSs are deployed at an elevation of 106.7 m, and all fish not diverted by the screens will pass through a 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 26 April to 22 May. We chose only fish that did not have any gross injury or deformity, were not previously PIT tagged, and were at least 110 mm in length and 12 g in weight. River-run subyearling Chinook salmon were collected from 6 June to 1 July and were at least 100 mm in length and 10 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. After 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 at 30 MHz for unique identification of

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

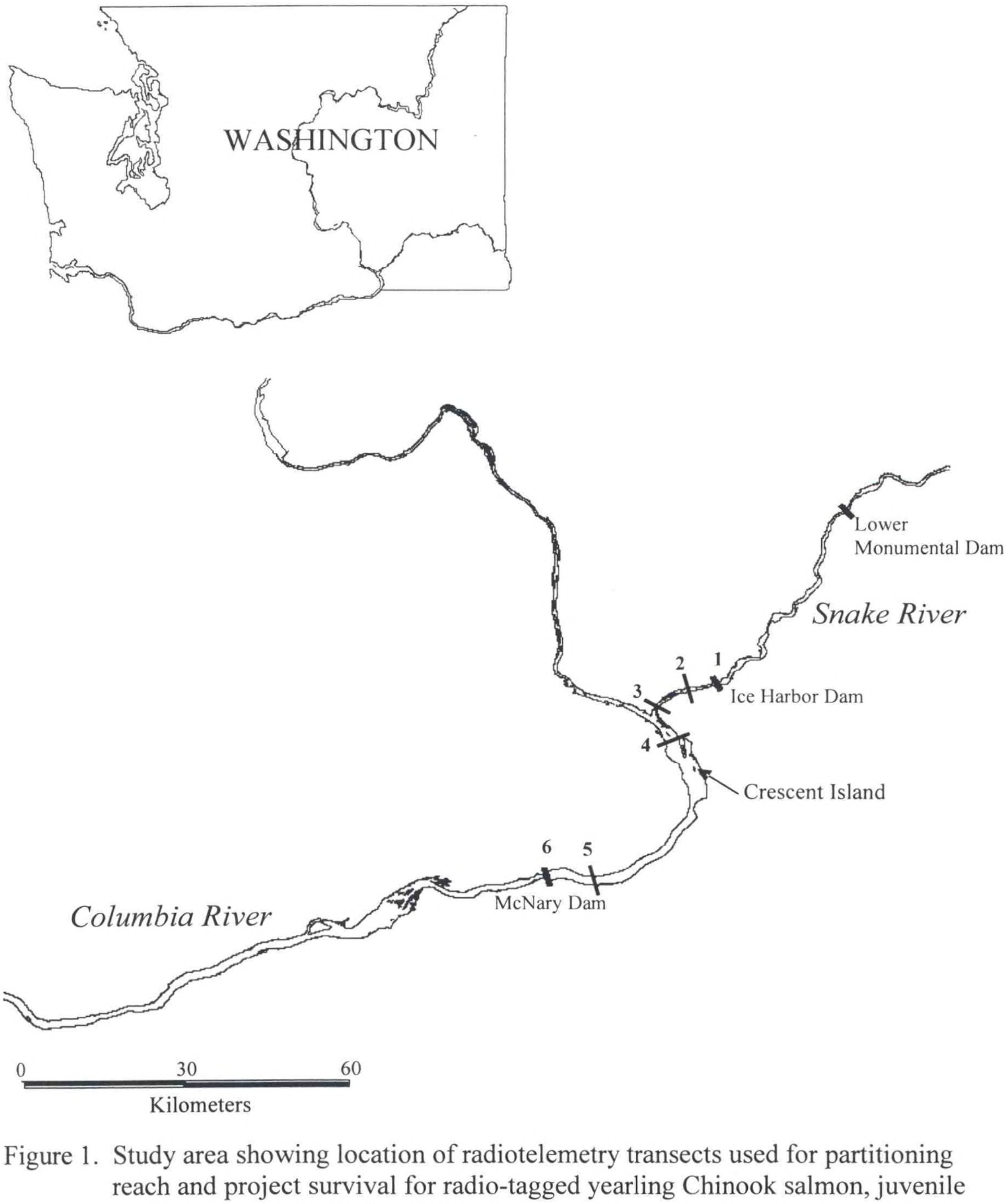

Figure 1. Study area showing location of radiotelemetry transects used for partitioning reach and project survival for radio-tagged yearling Chinook salmon, juvenile steelhead, and subyearling Chinook salmon between Lower Monumental and McNary Dams, 2008. (Note: 1 = Ice Harbor Dam forebay; 2 = Goose Island; 3 = Sacajawea State Park; 4 = Burbank Railroad Bridge; 5 = McNary Beach; and 6 = McNary Dam forebay.)

individual fish. Each radio tag measured 13.4 mm in length by 5.5 mm in diameter and had an average height of 3.6 mm and weight of 0.8 g in air. Average total volume for the tag was 265 mm^3.

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 JBS passage survival.

Immediately following tagging, fish were placed into a 19-L bucket (2 fish per bucket) 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 deep) 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 9.1 and 12.0°C for the spring study, and between 11.0 and 15.8°C for the summer study.

After the post-tagging recovery period, holding tanks with buckets containing radio-tagged fish were moved to the tailrace release areas at Little Goose and Lower Monumental Dam. All holding tanks were aerated with oxygen during transport to release locations. Little Goose tailrace 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.

At Lower Monumental Dam, fish were released into the tailrace about 1 km below the dam. Daytime releases to the tailrace were made between 0900 and 1500 and nighttime releases between 2100 and 0300 PDT. Both day and night releases were made in 24 gro ups of approximately 21 fish. In conjunction with tailrace releases, treatment fish for Lower Monumental Dam were released 42 km upstream from the dam near Little Goose Dam. These releases were made from 0900 to 1000 and from 1400 to 1500 PDT during the daytime; both releases were made in 24 groups of about 25 fish. Temperatures during these releases ranged from 8.6 to 11.9°C.

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 21 fish during both daytime (0900-1500 PDT) and nighttime (2100-0300) periods. Juvenile steelhead were released 42 km upstream from Lower Monumental Dam in 24 groups of approximately 25 fish during both daytime release periods (0900-1000 and 1400-1500).

Subyearling Chinook salmon—As described above for yearling Chinook salmon, subyearling Chinook salmon 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 43 fish during both daytime (0900-1500 PDT) and nighttime (2100-0300) periods. Fish were released 42 km upstream from Lower Monumental Dam in 24 groups of approximately 49 fish during daytime (0900-1000 and 1400-1500) release periods. Temperatures during these releases ranged from 11.0 to 16.0°C.

Survival Estimates

Estimates of survival for 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 the tailrace exit, located 1 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.

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

Dam Survival: Survival estimate for fish that passed through the entire "effect zone". The "effect zone" is the reach from approximately 600 m upstream to approximately 5 km downstream from the dam.

Spillway Survival: Survival estimate for fish that passed through the spillway.

RSW Survival: Survival estimate for fish that passed via the RSW.

Training Flow Survival: Survival estimate for fish that passed through the spillway (not including the RSW).

Bypass Survival: Survival estimate for fish that passed via the juvenile bypass system.

Concrete Survival: Ratio of the survival estimate for fish that passed via all passage routes combined (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 (BRZ) of Ice Harbor Dam. These groups were used for estimates of dam survival, with replicates composed of fish detected on the same date.

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 date of passage. Subsequent downstream detections at Goose Island and below were used for dam, spillway, and concrete survival estimation (Figure 1). We used the same criteria for the remaining 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 Delay

Forebay delay was determined for fish that had been released upstream from Ice Harbor Dam using the following criteria; detected entering the forebay, in a passage route, in the immediate tailrace in the stilling basin, turbine draft tube, or tailrace exit receivers. Arrival into the forebay was based on the first time a fish was detected on the forebay entry line at the upstream end of the BRZ at Ice Harbor Dam (approximately 600 m upstream from the dam). Delay 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.

Overall tailrace egress time was characterized by constructing means and 95% confidence intervals (i.e. means +- $t_{(0.05,\, n-1)}$ standard errors, where t was the t-value, given n-1 degrees of freedom and $\alpha = 0.05$) for the 10^{th}, 50^{th}, and 90^{th} percentiles of the egress time distributions. Replicates were grouped by dam passage day.

Passage Route Distribution

Approach distributions were based on first detection at either underwater dipole spillway antennas (Beeman et al. 2004) or on stripped coaxial underwater antennas (Knight et al. 1977) on the STSs. Route of passage was based on the last time a fish was detected on a passage route antenna (Figure 2) and was assigned only to fish that were subsequently detected in the tailrace on the stilling basin, turbine draft tube, or tailrace exit receivers. For analysis of passage route distributions, we included only fish that had been released upstream from Ice Harbor Dam, detected in the forebay, detected again in a passage route, and detected a third time in the immediate tailrace either on the stilling basin, turbine draft tube, or a tailrace exit receiver.

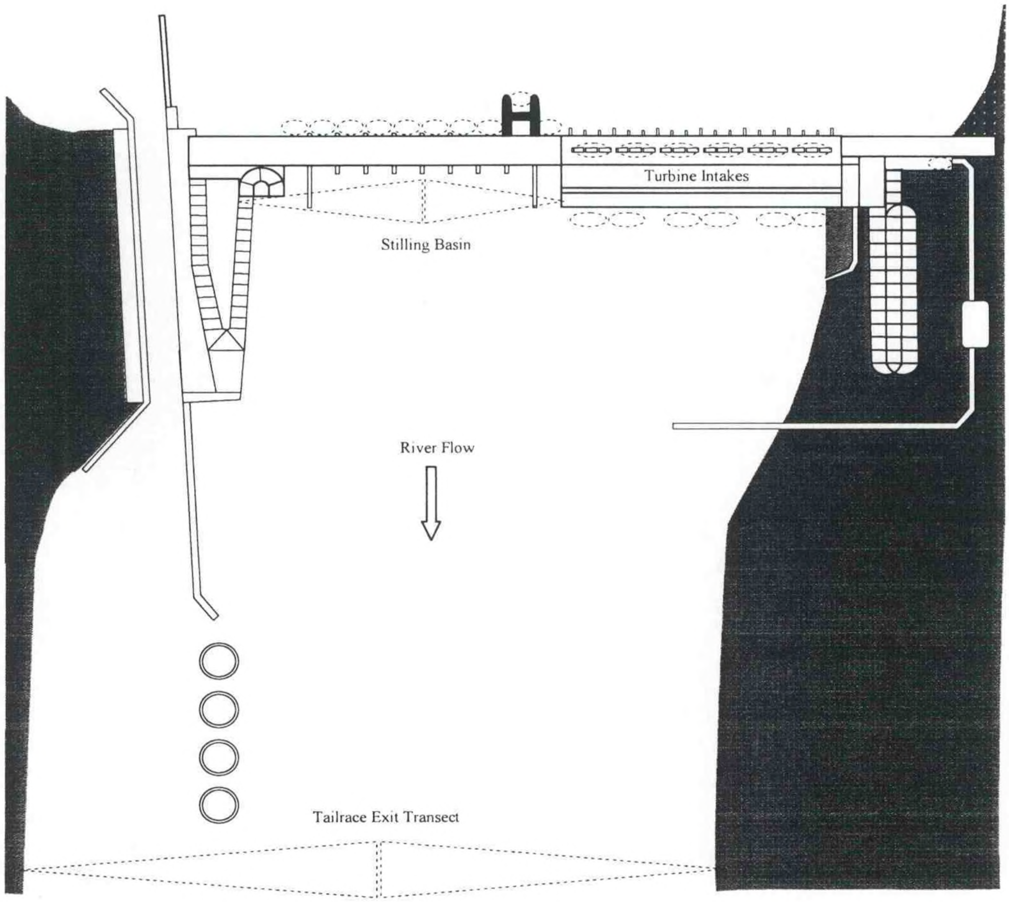

Figure 2. Plan view of Ice Harbor Dam showing approximate radiotelemetry detection zones for evaluation of passage behavior and survival at Ice Harbor Dam in 2008. Note: Dashed ovals represent underwater antennas. Dashed triangles represent aerial antennas.

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 6.1 and 12.2 m. Pre-season range testing showed this configuration effectively monitored the entire spill bay with no gaps. In addition, we mounted aerial loop antennas to the handrail of the RSW in order to ensure we detected all fish that passed over the RSW. We used armored co-axial cable, stripped at the end, to detect radio-tagged fish passingthrough 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:

Spillway passage efficiency (SPE): Total number of fish passing the spillway divided by total number passing the dam.

Spillway passage effectiveness (SPS): Proportion of fish passing the spillway divided by proportion of water spilled.

Fish passage efficiency (FPE): Number of fish passing the dam via non-turbine routes divided by total number passing the dam.

Fish guidance efficiency (FGE): 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).

Surface outlet efficiency (SOE): Number of fish passing through a surface flow route (RSW) divided by the total number of fish passing the dam.

Surface outlet effectiveness (SOS): Proportion of fish passing through a surface flow route (RSW) divided by the proportion of water passing through the same route.

Tailrace Egress

For analysis of tailrace egress, we included only fish that had been released upstream from Ice Harbor Dam, detected in the forebay, detected again in a passage route, and detected a third time in the immediate tailrace either on the stilling basin, turbine draft tube, or a tailrace exit receiver. 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. Overall tailrace egress time was characterized by constructing means and 95% confidence intervals (i.e. means +- $t_{(0.05,\, n\text{-}1)}$ standard errors, where t was the t-value, given n-1 degrees of freedom and $\alpha = 0.05$) for the 10^{th}, 50^{th}, and 90^{th} percentiles of the egress time distributions. Replicates were grouped by dam passage day.

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 (S. Sebring, NMFS, personal communication; also see Ryan et al. 2001) 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 27 d from 26 April to 22 May. Collection and tagging began after approximately 2.1% of the yearling Chinook salmon and 1.0% of the juvenile steelhead had passed Lower Monumental Dam. For both species, collection was completed when more than 87% of these fish had passed (Figure 3). Overall mean fork length for the 2,163 yearling Chinook salmon that were tagged and released was 142.4 mm (SD = 12.8, Table 2) and overall mean weight was 28.8 g (SD = 8.3, Table 3). Overall mean fork length for the 2,181 steelhead tagged and released was 207.1 mm (SD = 21.8, Table 4) and overall mean weight was 79.2 g (SD = 25.2, Table 5).

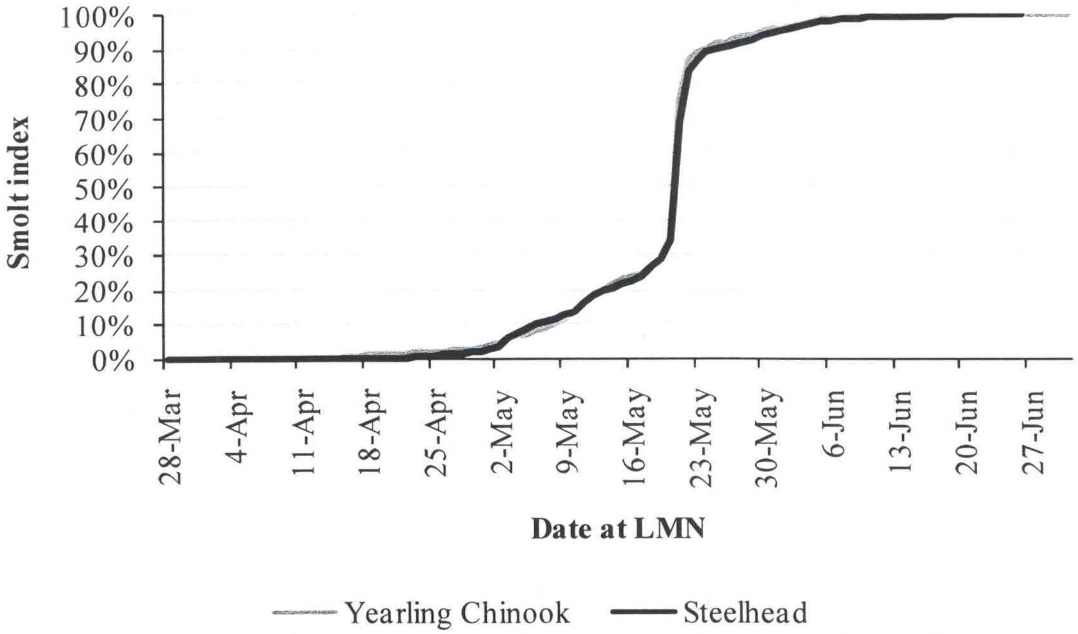

Figure 3. Percentage of yearling Chinook salmon and juvenile steelhead index estimated at Lower Monumental Dam during 2008.

Table 2. Sample size, range, mean, and standard deviation (SD) of fork lengths (mm) for radio-tagged, yearling Chinook salmon released above Ice Harbor Dam to evaluate passage behavior and survival, 2008.

2008		Yearling Chinook salmon length (FL mm)			
Tag date	n	Min.	Max.	Mean	SD
27 April	30	124	184	145.0	14.6
28 April	47	106	168	137.9	16.1
29 April	66	106	167	139.8	14.6
30 April	85	112	186	142.8	14.8
1 May	89	115	171	137.8	15.2
2 May	87	113	189	147.2	16.6
3 May	86	111	195	146.2	17.8
4 May	85	113	193	147.3	17.9
5 May	91	118	187	142.2	14.2
6 May	90	111	188	139.4	13.8
7 May	97	117	181	143.7	12.0
8 May	92	112	185	138.3	13.2
9 May	97	114	183	140.6	12.8
10 May	92	114	182	142.9	13.4
11 May	96	122	188	145.1	10.5
12 May	96	122	163	141.6	9.1
13 May	95	118	169	138.2	9.5
14 May	95	121	166	143.1	9.6
15 May	93	115	173	140.0	10.4
16 May	92	122	163	143.1	9.2
17 May	93	120	168	143.2	9.0
18 May	94	121	176	143.7	10.0
19 May	96	118	160	141.6	8.9
20 May	96	123	162	143.1	8.8
21 May	43	122	164	143.3	9.5
22 May	40	129	163	146.4	8.2
Overall	2,163	106	195	142.4	12.8

Table 3. Sample size, range, mean, and standard deviation (SD) of weights (grams) for radio-tagged, yearling Chinook salmon released above Ice Harbor Dam to evaluate passage behavior and survival, 2008.

2008		Yearling Chinook salmon weight (g)			
Tag date	n	Min.	Max.	Mean	SD
27 April	30	20	64	33.1	10.6
28 April	47	13	47	28.2	9.4
29 April	66	12	50	29.5	9.1
30 April	85	15	64	31.1	10.1
1 May	89	15	52	27.8	9.6
2 May	87	15	55	30.5	10.3
3 May	86	15	72	33.6	12.2
4 May	85	15	78	33.6	12.7
5 May	91	16	61	29.7	9.1
6 May	90	17	64	29.8	9.2
7 May	97	17	57	29.5	8.2
8 May	92	15	57	26.6	8.1
9 May	97	15	57	27.9	8.0
10 May	92	16	57	28.9	8.5
11 May	96	16	59	29.4	7.2
12 May	96	16	47	28.1	5.9
13 May	95	17	50	27.4	6.3
14 May	95	17	56	28.4	6.4
15 May	93	16	50	26.4	6.1
16 May	92	18	43	27.6	5.5
17 May	93	16	45	27.0	5.6
18 May	94	16	52	27.1	6.1
19 May	96	16	39	27.6	5.1
20 May	96	17	40	26.0	4.9
21 May	43	19	38	27.8	5.2
22 May	40	20	42	28.5	5.3
Overall	2,163	12	78	28.8	8.3

Table 4. Sample size, range, mean, and standard deviation (SD) of fork lengths (mm) for radio-tagged, juvenile steelhead released above Ice Harbor Dam to evaluate passage behavior and survival, 2008.

2008		Juvenile steelhead length (FL mm)			
Tag date	n	Min.	Max.	Mean	SD
27 April	34	187	239	213.8	13.3
28 April	45	173	282	213.1	19.4
29 April	70	165	261	206.2	17.3
30 April	88	162	235	193.5	13.5
1 May	86	168	209	192.3	9.0
2 May	89	177	273	201.2	15.5
3 May	87	162	246	203.8	17.5
4 May	87	164	259	200.9	17.2
5 May	98	156	240	197.9	15.1
6 May	95	155	267	198.3	18.6
7 May	97	147	260	197.6	20.7
8 May	96	154	253	200.6	23.5
9 May	96	143	222	187.5	14.3
10 May	94	146	278	205.5	25.9
11 May	89	148	267	220.7	23.6
12 May	99	153	254	207.2	25.0
13 May	97	135	253	206.8	24.4
14 May	95	150	250	209.1	23.1
15 May	96	156	249	210.7	21.1
16 May	98	153	249	214.7	20.8
17 May	90	162	253	218.6	18.6
18 May	94	172	256	220.5	17.8
19 May	90	182	253	222.6	17.0
20 May	87	188	264	224.2	17.6
21 May	44	167	258	221.9	18.2
22 May	40	189	248	220.4	16.3
Overall	2,181	135	282	207.1	21.8

Table 5. Sample size, range, mean, and standard deviation (SD) of weights (grams) for radio-tagged, juvenile steelhead released above Ice Harbor Dam to evaluate passage behavior and survival, 2008.

2008		Juvenile steelhead weight (g)			
Tag date	n	Min.	Max.	Mean	SD
27 April	34	59	120	89.5	16.0
28 April	45	46	197	90.7	26.3
29 April	70	44	158	80.9	22.0
30 April	88	38	123	65.8	14.6
1 May	86	39	86	64.0	9.1
2 May	89	46	169	69.0	15.6
3 May	87	37	137	78.3	21.1
4 May	87	41	140	73.0	20.3
5 May	98	32	117	68.3	16.3
6 May	95	35	172	75.9	22.0
7 May	97	26	146	69.2	22.2
8 May	96	31	150	73.2	26.9
9 May	96	26	84	55.8	11.6
10 May	94	26	189	77.9	30.4
11 May	89	25	178	96.4	30.2
12 May	99	31	149	79.0	28.6
13 May	97	22	142	83.8	28.8
14 May	95	29	160	81.5	28.7
15 May	96	30	135	79.3	24.9
16 May	98	27	147	86.3	24.3
17 May	90	32	146	91.7	22.9
18 May	94	40	136	91.1	22.9
19 May	90	52	147	98.5	23.3
20 May	87	48	147	92.0	22.5
21 May	44	38	131	90.7	20.9
22 May	40	56	136	88.1	20.5
Overall	2,181	22	197	79.2	25.2

Unmarked subyearling Chinook salmon were collected, radio tagged, and PIT tagged at Lower Monumental for 27 d from 6 June to 2 July. Collection and tagging began after approximately 13% of the subyearling Chinook salmon had passed Lower Monumental Dam and was completed when more than 85% of these fish had passed (Figure 4). Overall mean fork length for 4,433 subyearling Chinook salmon was 108.1 mm (SD = 5.3, Table 6) and overall mean weight was 13.1 g (SD = 2.2, Table 7).

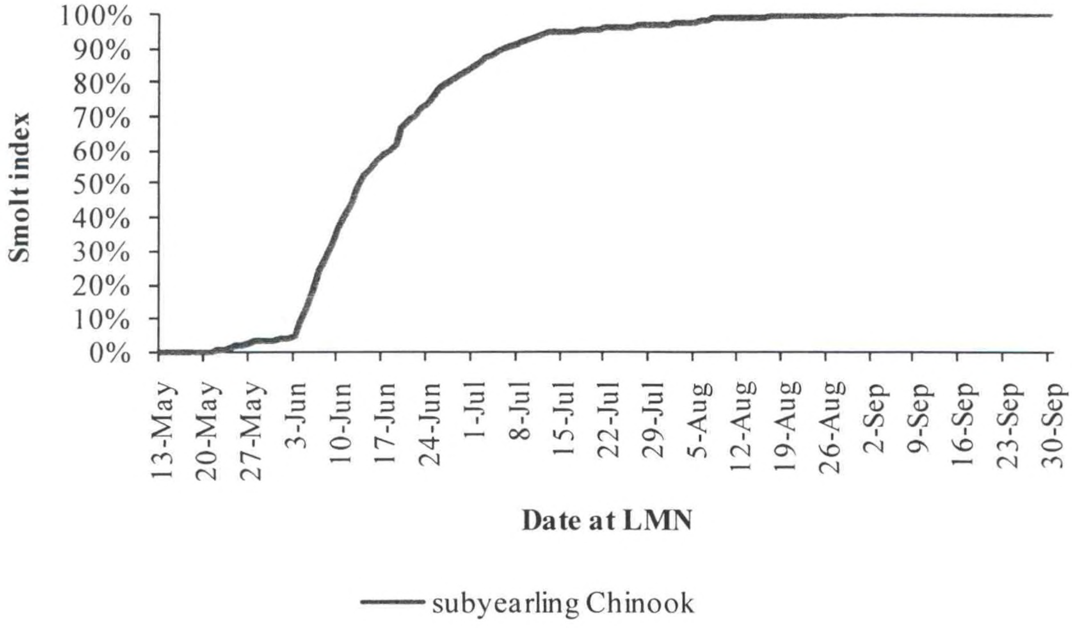

Figure 4. Percentage of subyearling Chinook salmon index estimated at Lower Monumental Dam during 2008.

Table 6. Sample size, range, mean, and standard deviation (SD) of fork lengths (mm) for radio-tagged, subyearling Chinook salmon released above Ice Harbor Dam to evaluate passage behavior and survival, 2008.

2008		Subyearling Chinook salmon length (FL mm)			
Tag date	n	Min.	Max.	Mean	SD
7 June	86	101	124	109.6	4.5
8 June	88	100	120	108.2	4.3
9 June	173	100	132	107.5	5.0
10 June	174	100	124	107.8	3.9
11 June	193	100	119	106.9	4.3
12 June	193	100	123	105.8	4.7
13 June	188	100	127	107.7	5.0
14 June	194	100	126	106.7	4.8
15 June	195	100	124	107.1	4.8
16 June	195	100	118	105.6	4.0
17 June	195	100	127	107.1	5.1
18 June	195	100	125	107.8	5.3
19 June	194	100	123	107.3	5.4
20 June	190	100	132	108.7	5.0
21 June	193	101	124	109.6	5.0
22 June	195	100	127	107.9	5.2
23 June	194	100	123	108.4	4.2
24 June	193	100	126	109.4	5.9
25 June	195	100	128	109.0	6.4
26 June	194	100	133	109.9	5.8
27 June	174	100	135	110.1	6.2
28 June	176	100	130	108.1	5.8
29 June	168	100	125	108.6	5.5
30 June	160	100	131	109.8	6.6
1 July	70	100	144	108.5	8.4
2 July	68	100	137	108.3	7.5
Overall	4,433	100	144	108.1	5.3

Table 7. Sample size, range, mean, and standard deviation (SD) of weights (grams) for radio-tagged, subyearling Chinook salmon released above Ice Harbor Dam to evaluate passage behavior and survival, 2008.

2008		Subyearling Chinook salmon weight (g)			
Tag date	n	Min.	Max.	Mean	SD
7 June	86	11	20	13.6	1.8
8 June	88	10	17	13.2	1.7
9 June	173	10	25	12.8	2.1
10 June	174	10	19	12.8	1.5
11 June	193	10	18	12.5	1.6
12 June	193	10	20	12.9	1.9
13 June	188	10	22	12.9	2.0
14 June	194	10	20	12.7	1.9
15 June	195	10	19	12.5	1.8
16 June	195	10	19	12.4	1.8
17 June	195	10	20	12.4	1.9
18 June	195	10	20	12.8	2.0
19 June	194	10	20	12.9	2.1
20 June	190	10	20	12.9	1.9
21 June	193	10	18	13.2	1.8
22 June	195	10	20	12.7	2.0
23 June	194	10	19	13.2	1.7
24 June	193	10	21	13.2	2.2
25 June	195	10	23	13.6	2.6
26 June	194	10	26	13.8	2.5
27 June	174	10	27	13.9	2.8
28 June	176	10	23	13.5	2.5
29 June	168	10	21	13.1	2.2
30 June	160	10	25	13.8	2.9
1 July	70	10	35	13.6	4.3
2 July	68	10	29	13.9	3.5
Overall	4,433	10	35	13.1	2.2

Dam Operations

The 2007 voluntary spill program attempted to follow 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 spill volume (30-40% of total flow volume), with both treatments utilizing the RSW. The spill program pattern also 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, leading to potentially higher survival. However, due to high river flows, involuntary spill precluded a majority of the reduced spill treatments, resulting in a reduction of viable replicates for comparison. While there was some ability to compare behavior and passage during the first 14 days of the spring study, the latter half of the study and the entire summer study were obscured by project operations exceeding the maximum of 40% spill required for reduced spill treatments.

Mean spill volume was 65.9 thousand cubic feet per second (kcfs) during spring (56% of the total river flow) and 53.8 kcfs (56%) during summer. Mean flow through turbines and spill bays for both the spring and summer are shown in Figure 5.

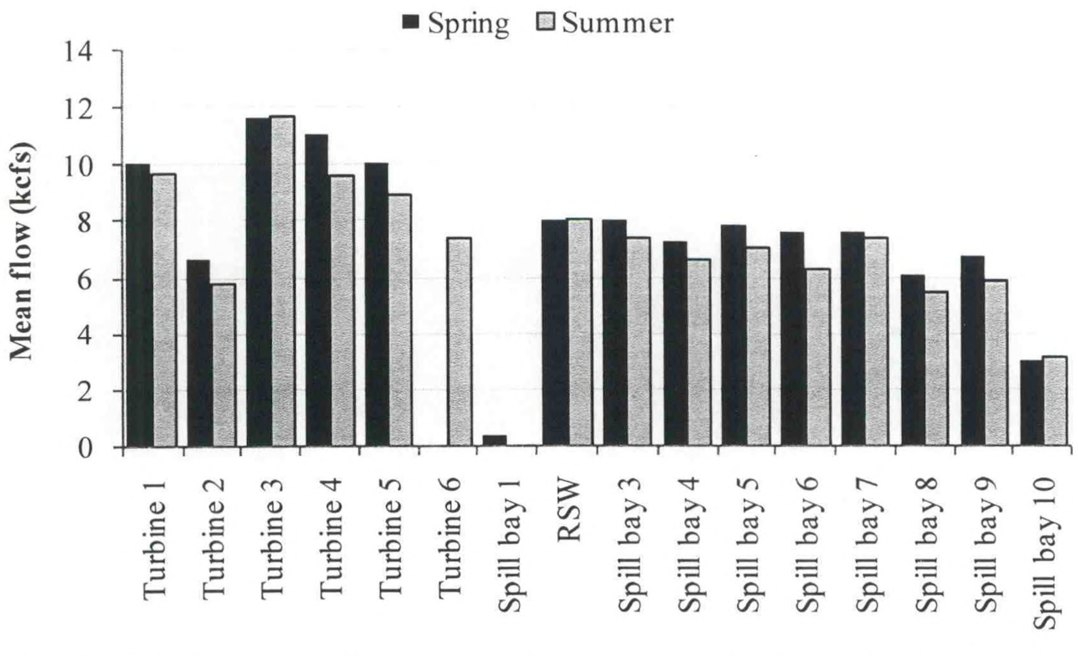

Figure 5. Mean flow (kcfs) for the powerhouse and spillway for radio-tagged yearling Chinook salmon (spring), juvenile steelhead (spring), and subyearling Chinook salmon (summer) arriving at Ice Harbor Dam, 2008.

Mean daily total discharge was 113.6 kcfs (range 60.7-198.2 kcfs) during the spring study and 110.4 kcfs during the summer study (range 62.9-142.5 kcfs). Mean percentages of spill during spring and summer evaluations are shown in Figures 6 and 7, respectively. Mean daily flows (kcfs) for each turbine unit and spill bay are shown for the respective spring and summer study periods in Tables 8 and 10. Mean daily gate openings (stops) by spill bay are shown in Table 9 for the spring study and Table 11 for the summer study period.

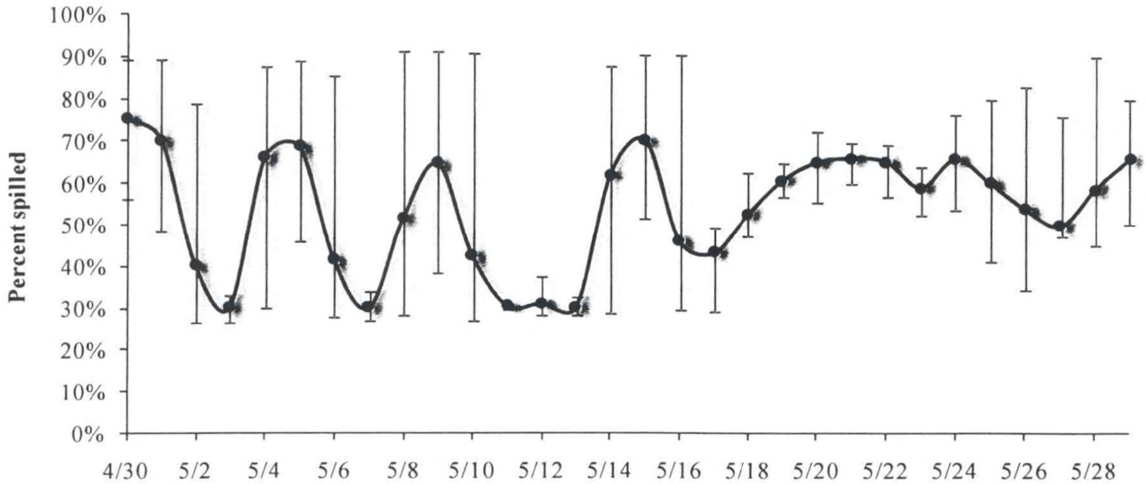

Figure 6. Mean daily spill percentage and range for radio-tagged yearling Chinook salmon and juvenile steelhead arriving during spring operations at Ice Harbor Dam, 2008.

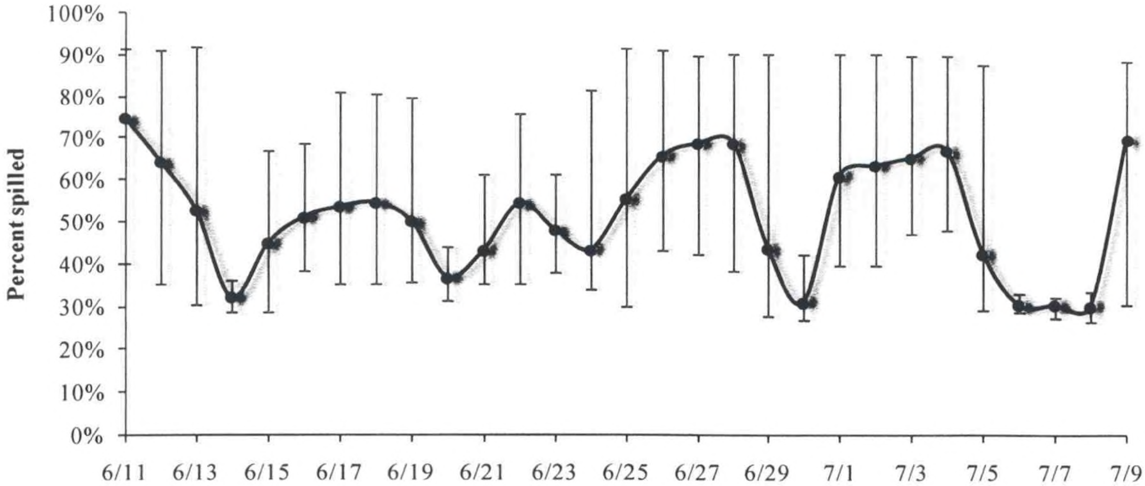

Figure 7. Mean daily spill percentage and range for radio-tagged subyearling Chinook salmon arriving during summer operations at Ice Harbor Dam, 2008.

Table 8. Average daily flow (kcfs) by turbine unit and spill bay at Ice Harbor Dam during spring spill operations, 2008.

	Turbines—spring 2008						Spill bays—spring 2008									
Date	1	2	3	4	5	6	1	RSW	3	4	5	6	7	8	9	10
29 Apr	3.1	0.0	9.4	3.2	2.4	0.0	0.0	8.0	0.0	9.8	2.3	8.5	7.7	4.3	4.6	3.7
30 Apr	5.8	0.0	10.0	2.0	0.0	0.0	0.0	8.0	1.8	10.1	4.6	8.5	8.4	5.3	5.3	3.4
1 May	4.5	0.0	9.6	4.7	4.3	0.0	0.0	8.0	1.4	9.7	3.0	8.5	7.3	4.2	4.5	3.2
2 May	8.1	2.2	10.1	9.3	8.3	0.0	0.0	8.0	3.5	1.7	0.0	2.6	1.4	1.6	2.0	2.0
3 May	10.9	0.0	11.1	12.9	10.1	0.0	0.0	8.0	6.3	0.0	0.0	0.4	0.6	0.7	1.7	1.7
4 May	6.0	0.0	9.9	4.6	0.0	0.0	0.0	8.0	0.0	8.0	2.4	6.7	7.1	4.1	4.1	3.2
5 May	5.2	2.4	9.1	4.8	3.7	0.0	0.0	8.0	2.4	9.8	2.5	8.4	7.3	4.3	4.6	3.5
6 May	9.0	8.3	10.9	10.7	10.7	0.0	0.0	8.0	6.6	2.1	2.5	2.6	2.6	1.9	2.0	2.4
7 May	11.4	11.0	11.5	13.6	13.5	0.0	0.0	8.0	8.3	0.0	5.4	0.3	0.6	0.8	1.0	1.7
8 May	9.7	5.5	12.1	11.6	11.7	0.0	0.0	8.0	4.7	8.5	6.0	7.5	7.2	4.5	4.8	3.0
9 May	6.9	3.7	11.3	7.7	7.2	0.0	0.0	8.0	3.2	10.1	4.6	9.6	8.8	6.1	6.0	3.3
10 May	10.4	7.6	12.4	12.4	12.2	0.0	0.0	8.0	8.9	2.2	7.8	2.0	1.9	3.2	3.2	2.2
11 May	11.1	10.8	11.2	13.4	13.3	0.0	0.0	8.0	8.3	0.0	8.3	0.0	0.0	0.0	0.0	1.6
12 May	12.0	10.9	12.2	12.4	14.5	0.0	0.0	8.0	8.3	0.0	7.3	0.0	0.1	1.0	1.2	2.3
13 May	11.2	10.8	11.2	13.1	13.3	0.0	0.0	8.0	8.4	0.0	6.4	0.2	0.4	0.7	0.8	1.0
14 May	6.3	2.2	10.5	6.3	5.3	0.0	0.0	8.0	1.7	7.9	3.5	7.5	6.6	3.1	3.1	3.1
15 May	5.4	0.0	10.5	7.2	0.9	0.0	0.0	8.0	2.0	10.3	4.6	8.7	8.7	5.3	5.3	3.5
16 May	10.1	8.7	12.1	12.2	12.1	0.0	0.0	8.0	9.1	2.2	9.7	1.9	2.8	3.7	4.0	3.1
17 May	12.4	11.3	12.4	15.2	15.0	0.0	0.0	8.0	9.7	0.0	9.0	6.3	7.0	3.0	7.1	3.1
18 May	13.2	11.3	13.2	16.1	16.0	0.0	0.0	8.0	10.2	8.3	10.5	10.2	9.8	8.3	9.8	3.5
19 May	13.8	11.0	13.8	16.7	16.8	0.0	1.2	8.0	14.9	14.9	14.5	13.8	13.9	13.8	13.8	3.4
20 May	13.3	11.1	13.2	15.4	15.4	0.0	3.3	8.1	17.1	16.9	16.7	16.5	16.0	15.9	15.7	3.5
21 May	13.2	11.3	13.3	14.6	14.6	0.0	3.1	8.1	16.9	16.8	16.8	16.8	16.6	16.4	16.2	3.5
22 May	13.2	11.1	13.4	14.4	14.5	0.0	2.3	8.1	16.5	16.3	16.4	16.0	16.0	15.9	15.3	3.4
23 May	13.1	11.2	13.2	14.3	14.4	0.0	0.0	8.1	12.3	12.3	12.3	12.1	12.0	12.0	11.6	3.5
24 May	11.4	5.2	11.6	12.6	8.5	0.0	0.0	8.1	12.9	12.3	12.2	11.4	11.2	11.2	11.2	3.5
25 May	12.4	6.1	12.4	11.9	8.8	0.0	0.0	8.1	7.9	11.0	9.9	10.2	10.1	8.8	8.9	3.4
26 May	12.7	8.8	12.8	12.5	11.7	0.0	0.0	8.0	10.7	4.0	10.3	6.6	9.5	6.2	9.5	3.5
27 May	13.3	10.8	13.3	14.5	14.6	0.0	0.0	8.0	10.2	0.5	10.2	9.9	10.0	3.9	10.0	3.5
28 May	11.7	8.0	13.1	11.5	10.8	0.0	0.0	8.0	11.4	5.5	11.3	9.5	10.7	6.9	10.6	3.5
29 May	11.8	5.9	11.7	12.9	8.8	0.0	0.0	8.0	12.7	12.5	12.2	12.1	11.8	11.4	11.2	3.5

Table 9. Average gate openings (stops) by spill bay at Ice Harbor Dam during spring spill operations, 2008.

	Spill bays—spring 2008									
Date	1	RSW	3	4	5	6	7	8	9	10
29 Apr	0.0	4.8	0.0	5.9	1.3	5.1	4.6	2.6	2.7	2.2
30 Apr	0.0	4.8	1.1	6.0	2.7	5.1	5.0	3.1	3.1	2.0
1 May	0.0	4.8	0.8	5.8	1.8	5.1	4.3	2.5	2.7	1.9
2 May	0.0	4.8	2.1	1.0	0.0	1.5	0.8	0.9	1.2	1.2
3 May	0.0	4.8	3.7	0.0	0.0	0.2	0.4	0.4	1.0	1.0
4 May	0.0	4.8	0.0	4.8	1.4	4.0	4.2	2.4	2.4	1.9
5 May	0.0	4.8	1.4	5.9	1.5	5.0	4.3	2.6	2.7	2.0
6 May	0.0	4.8	3.9	1.2	1.5	1.5	1.5	1.1	1.2	1.4
7 May	0.0	4.8	5.0	0.0	3.2	0.2	0.3	0.4	0.6	1.0
8 May	0.0	4.8	2.8	5.1	3.6	4.5	4.3	2.7	2.8	1.8
9 May	0.0	4.8	1.9	6.1	2.8	5.7	5.3	3.6	3.6	1.9
10 May	0.0	4.8	5.3	1.3	4.6	1.2	1.1	1.9	1.9	1.3
11 May	0.0	4.8	5.0	0.0	4.9	0.0	0.0	0.0	0.0	1.0
12 May	0.0	4.8	5.0	0.0	4.3	0.0	0.0	0.6	0.7	1.4
13 May	0.0	4.8	5.0	0.0	3.8	0.1	0.2	0.4	0.4	0.5
14 May	0.0	4.8	1.0	4.7	2.1	4.5	3.9	1.8	1.8	1.8
15 May	0.0	4.8	1.2	6.1	2.7	5.2	5.2	3.2	3.1	2.0
16 May	0.0	4.8	5.5	1.3	5.8	1.1	1.7	2.2	2.4	1.8
17 May	0.0	4.8	5.8	0.0	5.4	3.8	4.2	1.8	4.2	1.8
18 May	0.0	4.8	6.1	5.0	6.3	6.1	5.9	5.0	5.9	2.0
19 May	0.7	4.8	9.0	9.0	8.8	8.4	8.4	8.3	8.3	2.0
20 May	1.9	4.8	10.4	10.3	10.2	10.0	9.7	9.6	9.5	2.1
21 May	1.8	4.8	10.3	10.2	10.2	10.2	10.1	9.9	9.9	2.1
22 May	1.3	4.8	10.0	9.9	9.9	9.7	9.7	9.7	9.3	2.0
23 May	0.0	4.8	7.4	7.4	7.4	7.3	7.2	7.2	7.0	2.1
24 May	0.0	4.8	7.8	7.4	7.4	6.8	6.7	6.8	6.8	2.1
25 May	0.0	4.8	4.8	6.6	6.0	6.1	6.1	5.3	5.3	2.0
26 May	0.0	4.8	6.4	2.4	6.2	3.9	5.7	3.7	5.7	2.0
27 May	0.0	4.8	6.1	0.3	6.1	5.9	6.0	2.3	6.0	2.0
28 May	0.0	4.8	6.8	3.3	6.8	5.7	6.4	4.1	6.4	2.0
29 May	0.0	4.8	7.6	7.5	7.3	7.3	7.1	6.8	6.7	2.1

Table 10. Average daily flow (kcfs) by turbine unit and spill bay at Ice Harbor Dam during summer spill operations, 2008.

	Turbines—summer 2008						Spill bays—summer 2008									
Date	1	2	3	4	5	6	1	RSW	3	4	5	6	7	8	9	10
11 Jun	6.2	3.6	11.9	5.0	4.9	0.0	0.0	8.1	10.7	13.1	11.4	12.5	11.6	10.8	10.8	3.3
12 Jun	9.2	4.7	12.2	7.1	6.0	7.8	0.0	8.1	6.8	10.9	10.0	9.8	9.8	9.5	9.3	3.3
13 Jun	10.0	8.1	12.4	10.4	10.2	10.8	0.0	8.1	11.0	4.1	10.9	4.1	10.5	6.1	8.4	3.4
14 Jun	13.2	11.2	13.3	14.4	14.6	14.5	0.0	8.1	9.4	0.0	8.7	0.0	2.4	3.3	3.3	3.3
15 Jun	11.2	6.0	11.2	12.3	10.6	12.2	0.0	8.1	4.2	8.0	6.1	7.1	7.0	4.2	4.2	3.2
16 Jun	9.9	5.1	10.7	12.5	7.0	12.4	0.0	8.1	4.6	10.0	4.6	9.2	9.1	6.6	5.8	3.4
17 Jun	12.8	6.2	12.8	8.9	7.9	10.7	0.0	8.1	5.5	11.0	7.5	9.8	9.8	6.7	6.3	3.8
18 Jun	12.9	5.2	12.9	9.0	7.9	13.5	0.0	8.1	6.8	11.4	8.4	10.3	10.2	7.9	8.3	3.9
19 Jun	12.3	7.9	12.2	10.0	10.1	13.3	0.0	8.1	10.9	4.4	11.0	4.1	10.9	6.3	9.0	3.4
20 Jun	13.4	11.3	13.5	14.7	14.7	14.7	0.0	8.1	9.9	0.0	9.9	1.4	5.8	3.4	6.7	3.4
21 Jun	12.7	8.7	12.7	14.0	14.0	13.9	0.0	8.1	4.6	7.8	9.1	6.9	9.1	4.1	4.8	3.4
22 Jun	11.4	4.6	11.4	11.4	11.5	12.5	0.0	8.1	7.6	10.3	9.7	9.8	9.6	8.3	7.8	3.4
23 Jun	12.4	8.8	12.5	13.5	13.6	13.5	0.0	8.1	9.8	5.9	10.1	6.0	9.5	6.7	8.7	3.4
24 Jun	12.8	10.4	12.8	13.3	13.3	13.3	0.0	8.1	5.8	6.8	9.4	6.3	8.9	5.2	5.3	3.3
25 Jun	11.2	5.1	11.9	9.0	6.7	9.9	0.0	8.1	10.6	6.7	10.6	6.4	7.6	7.6	7.5	3.4
26 Jun	8.1	0.0	11.1	6.8	4.3	7.0	0.0	8.1	10.7	7.3	10.7	7.4	10.8	8.1	8.1	3.4
27 Jun	8.2	4.1	11.0	4.6	4.5	0.0	0.0	8.1	7.0	10.7	6.6	9.7	9.8	7.9	7.6	3.4
28 Jun	7.6	3.8	11.1	5.0	5.0	0.9	0.0	8.1	6.6	10.3	6.6	9.8	9.8	7.6	7.4	3.3
29 Jun	9.1	8.5	11.6	10.0	10.0	9.2	0.0	8.1	9.2	2.6	8.8	2.7	2.7	3.5	4.0	2.9
30 Jun	11.6	11.2	11.5	12.7	12.6	12.6	0.0	8.1	8.8	0.0	8.8	0.0	0.4	1.6	2.1	2.7
1 Jul	7.7	6.6	10.2	6.6	6.6	3.7	0.0	8.1	5.2	10.2	5.2	9.3	9.8	6.1	6.1	3.5
2 Jul	8.0	3.5	11.2	7.5	5.7	2.9	0.0	8.1	5.3	10.8	5.4	9.8	9.8	6.5	6.5	3.5
3 Jul	9.5	0.0	11.3	6.8	5.3	0.0	0.0	8.1	4.6	10.6	5.1	9.5	9.5	6.3	6.3	3.5
4 Jul	6.9	0.0	11.0	6.7	5.5	0.0	0.0	8.1	3.7	10.2	4.7	8.7	8.7	5.8	5.9	3.5
5 Jul	8.4	8.9	10.3	9.2	9.1	0.0	0.0	8.1	7.7	2.1	2.1	2.8	2.9	3.0	3.1	2.2
6 Jul	10.7	4.8	10.7	11.7	11.7	0.0	0.0	8.1	8.3	0.0	0.0	0.8	0.6	0.8	1.2	1.7
7 Jul	11.1	2.3	10.6	11.4	11.5	0.0	0.0	8.1	8.3	0.0	0.0	0.1	0.5	0.9	0.9	1.6
8 Jul	2.7	7.9	10.4	11.5	11.4	3.2	0.0	8.1	8.0	0.0	0.0	0.5	0.6	0.7	0.8	1.7
9 Jul	0.0	0.0	11.7	3.3	2.5	0.0	0.0	8.1	1.7	7.9	2.2	7.4	7.0	3.9	4.2	3.0

Table 11. Average gate openings (stops) by spill bay at Ice Harbor Dam during summer spill operations, 2008.

	Spill bays—summer 2008									
Date	1	RSW	3	4	5	6	7	8	9	10
11 Jun	0.0	4.8	6.5	7.9	6.9	7.6	7.0	6.5	6.5	2.0
12 Jun	0.0	4.8	4.1	6.5	6.0	5.9	5.9	5.7	5.6	1.9
13 Jun	0.0	4.8	6.6	2.4	6.5	2.4	6.3	3.6	5.0	2.0
14 Jun	0.0	4.8	5.6	0.0	5.2	0.0	1.4	2.0	1.9	1.9
15 Jun	0.0	4.8	2.5	4.8	3.7	4.2	4.2	2.5	2.5	1.9
16 Jun	0.0	4.8	2.8	6.0	2.8	5.5	5.5	3.9	3.4	2.0
17 Jun	0.0	4.8	3.3	6.6	4.5	5.8	5.8	4.0	3.7	2.2
18 Jun	0.0	4.8	4.1	6.8	5.0	6.1	6.1	4.7	5.0	2.3
19 Jun	0.0	4.8	6.5	2.6	6.6	2.4	6.5	3.7	5.4	2.0
20 Jun	0.0	4.8	5.9	0.0	5.9	0.8	3.5	2.0	4.0	2.0
21 Jun	0.0	4.8	2.7	4.7	5.4	4.1	5.4	2.5	2.8	2.0
22 Jun	0.0	4.8	4.6	6.2	5.8	5.8	5.8	5.0	4.6	2.0
23 Jun	0.0	4.8	5.9	3.5	6.0	3.6	5.7	4.0	5.2	2.0
24 Jun	0.0	4.8	3.4	4.0	5.6	3.8	5.3	3.1	3.1	2.0
25 Jun	0.0	4.8	6.4	4.0	6.3	3.8	4.5	4.5	4.5	2.0
26 Jun	0.0	4.8	6.4	4.4	6.4	4.4	6.5	4.9	4.9	2.0
27 Jun	0.0	4.8	4.2	6.4	4.0	5.8	5.9	4.8	4.5	2.0
28 Jun	0.0	4.8	4.0	6.2	4.0	5.9	5.9	4.5	4.4	2.0
29 Jun	0.0	4.8	5.5	1.6	5.2	1.6	1.6	2.1	2.4	1.7
30 Jun	0.0	4.8	5.3	0.0	5.2	0.0	0.2	1.0	1.2	1.6
1 Jul	0.0	4.8	3.1	6.1	3.1	5.6	5.9	3.7	3.7	2.0
2 Jul	0.0	4.8	3.2	6.5	3.2	5.9	5.9	3.9	3.8	2.1
3 Jul	0.0	4.8	2.8	6.4	3.1	5.7	5.7	3.7	3.7	2.1
4 Jul	0.0	4.8	2.2	6.1	2.8	5.2	5.2	3.5	3.5	2.0
5 Jul	0.0	4.8	4.6	1.2	1.2	1.7	1.7	1.8	1.8	1.3
6 Jul	0.0	4.8	4.9	0.0	0.0	0.5	0.4	0.4	0.7	1.0
7 Jul	0.0	4.8	4.9	0.0	0.0	0.0	0.3	0.5	0.5	1.0
8 Jul	0.0	4.8	4.8	0.0	0.0	0.3	0.3	0.4	0.4	1.0
9 Jul	0.0	4.8	1.0	4.7	1.3	4.4	4.2	2.3	2.5	1.8

Survival Estimates

Yearling Chinook Salmon—During spring spill operations, survival was estimated at 0.966 (0.953-0.978) through the spillway and 0.953 (0.927-0.979) through the RSW. Dam survival was estimated at 0.925 (0.905-0.944). Survival was estimated at 0.977 (0.954-1.000) through the juvenile bypass system and 0.943 (0.889-0.996) through the turbines. Concrete survival, or the survival estimate for all fish that passed the project, was 0.966 (0.955-0.978).

Juvenile Steelhead—During spring spill operations, spillway passage survival was 0.973 (0.962-0.985), RSW survival was 0.970 (0.954-0.986), juvenile bypass system survival was 0.971 (0.947-0.996), and dam survival was 0.927 (0.909-0.946). Concrete survival was 0.970 (0.959-0.981). Insufficient numbers of tagged fish (22) passed through the turbines to estimate survival.

Subyearling Chinook Salmon—During summer spill operations, survival was estimated at 0.942 (0.926-0.958) through the spillway and 0.920 (0.891-0.948) through the RSW. Dam survival was estimated at 0.862 (0.846-0.878). Survival was estimated at 0.929 (0.903-0.956) for the juvenile bypass system and 0.778 (0.685-0.870) for the turbines. Concrete survival was estimated at 0.933 (0.919-0.947).

Passage Behavior and Timing

Travel, Arrival, and Passage Timing

At the forebay entrance telemetry transect at Ice Harbor Dam, we detected 1,699 radio-tagged yearling Chinook salmon, 1,951 juvenile steelhead, and 2,314 subyearling Chinook salmon released for evaluations 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, 93 and 50 km upstream from Ice Harbor Dam, respectively (Table 12).

For yearling Chinook salmon approaching Ice Harbor Dam during spring operations, 1,150 (73%) were first detected approaching in front of the spillway, and 416 (27%) in front of the powerhouse (Figure 8). Steelhead approach during the same operations were somewhat similar to yearling Chinook with the largest percentage of first contacts at the spillway; 1,578 (86%) were first detected approaching in front of the spillway, and 250 (14%) in front of the powerhouse. A majority of both species were attracted to the vicinity of the RSW with approximately 18% first detected at the RSW. However, yearling Chinook salmon displayed a slightly stronger tendency toward the powerhouse, especially as turbine loads increased with higher river flows.

Table 12. Travel time (days) from release into the forebay (93 km upstream) or tailrace (50 km upstream) of Lower Monumental Dam to detection at the forebay entry transect at Ice Harbor Dam for radio-tagged hatchery yearling Chinook salmon, juvenile steelhead, and subyearling Chinook salmon, 2008.

	Travel time (d)					
	Yearling Chinook		Steelhead		Subyearling Chinook	
	Release location at Lower Monumental Dam					
	Forebay	Tailrace	Forebay	Tailrace	Forebay	Tailrace
N	861	838	1,023	928	1,020	1,294
Min	1.2	0.5	1.0	0.5	1.9	0.5
Percentile						
10th	1.7	0.8	1.6	0.7	2.7	1.3
20th	2.2	1.1	2.0	0.9	3.0	1.7
30th	2.6	1.2	2.1	1.0	3.4	1.6
40th	2.9	1.4	2.3	1.1	3.7	1.8
50th	3.2	1.5	2.6	1.2	3.9	2.0
60th	3.5	1.7	2.8	1.3	4.2	2.2
70th	3.9	1.9	3.0	1.4	4.6	2.4
80th	4.3	2.2	3.2	1.6	5.0	2.8
90th	5.2	2.7	3.8	1.9	5.8	3.3
Max	8.0	6.7	7.6	8.0	8.1	7.7
Travel time > 8 d	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 (0.0%)	0 (0.0%)

Subyearling Chinook salmon approached Ice Harbor Dam similar to both yearling Chinook salmon and steelhead (Figure 9) with 1,801 (78%) first detected at the spillway and 522 (22%) detected in front of the powerhouse. The RSW attracted the largest proportion of subyearlings, similar to spring results.

Arrival timing of yearling Chinook salmon at the forebay entrance line of Ice Harbor Dam and subsequent passage distribution measured consistently between 3 and 6% across all hours of the day (Figure 10). Juvenile steelhead arrival distribution was more heavily weighted during daytime hours with passage timing distribution offset due to some forebay delay (Figure 10). Subyearling Chinook salmon demonstrated somewhat similar trends for both arrival and passage timing distributions as were observed for yearling Chinook salmon (Figure 10).

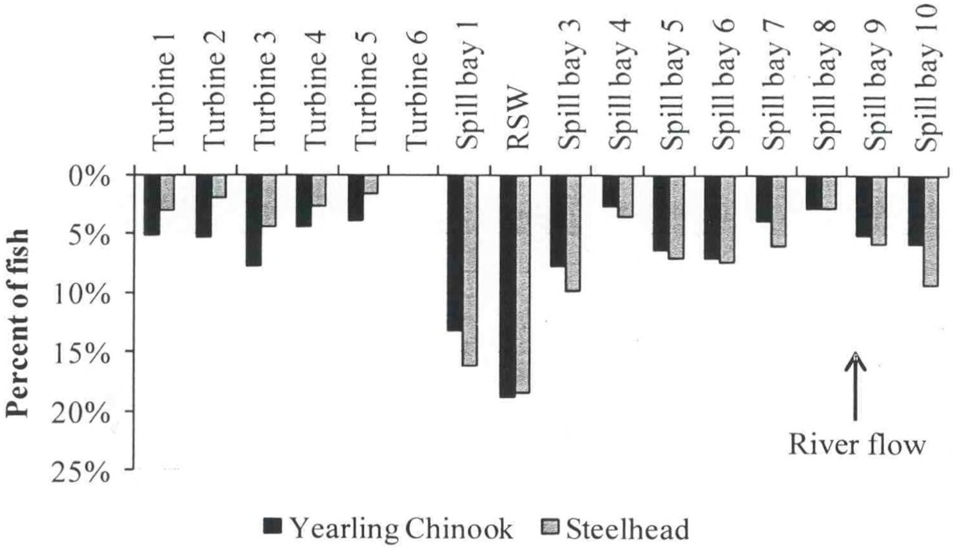

Figure 8. First approach location (percent) of radio-tagged yearling Chinook salmon and steelhead at Ice Harbor Dam during spring operations, 2008.

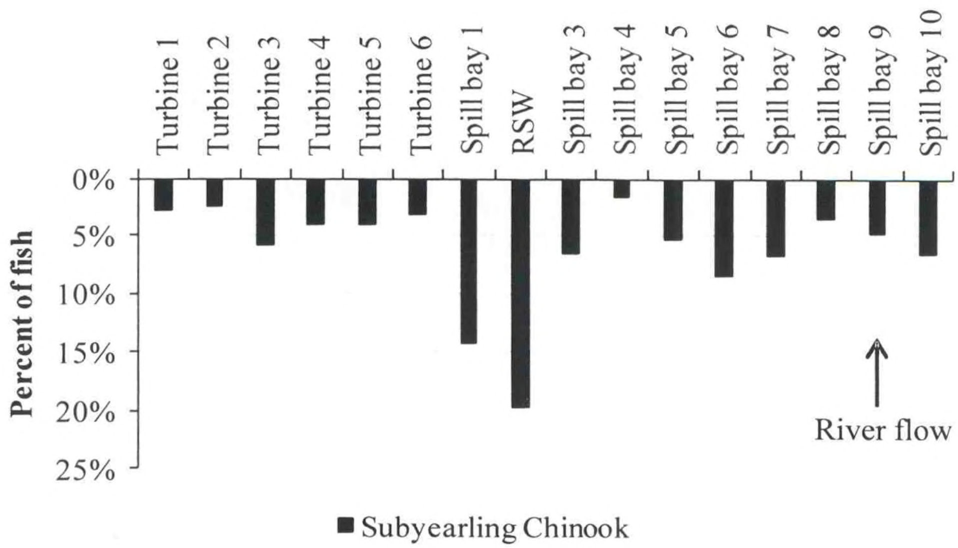

Figure 9. First approach location (percent) of radio-tagged subyearling Chinook salmon at Ice Harbor Dam during summer operations, 2008.

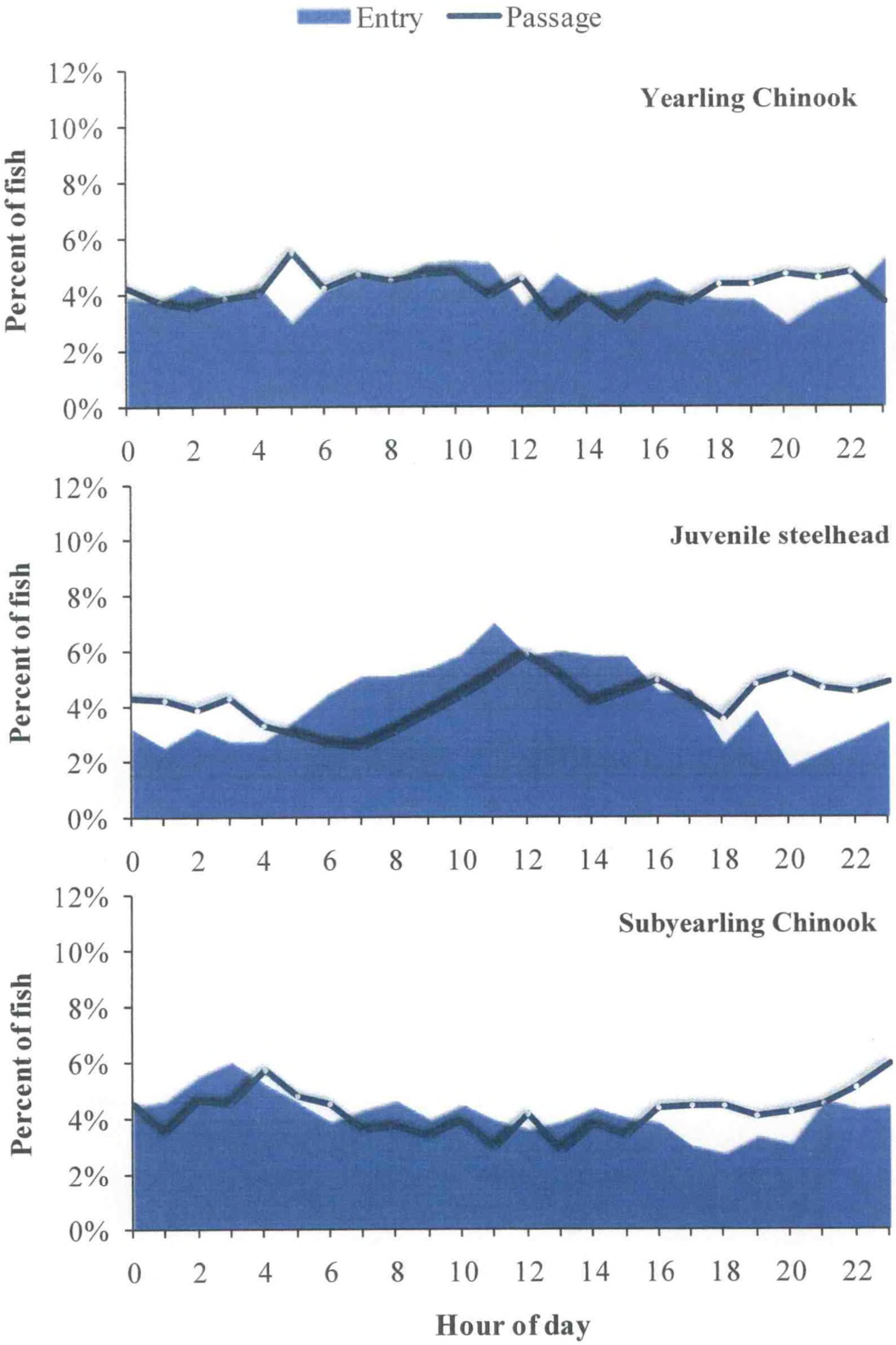

Figure 10. Percent of radio-tagged fish arriving and passing Ice Harbor Dam by hour of day during spring operations for yearling Chinook salmon and steelhead and during summer operations for subyearling Chinook salmon, 2008.

Forebay Delay

Forebay delay was measured for 1,593 yearling Chinook salmon, 1,834 steelhead, and 1,511 subyearling Chinook salmon based on two criteria: fish were detected at the entry line in the forebay and were subsequently determined to have a valid passage time.

For yearling Chinook salmon, median forebay delay of fish that passed through the JBS (4.5 h, 95% CI 3.5-5.5 h; Table 13) was significantly longer than those of fish that passed through the RSW (2.0 h, 1.5-2.6 h; $P < 0.0001$) or spillway (1.6 h, 1.2-1.9 h; $P < 0.0001$). In contrast, forebay delay of yearling Chinook that passed via turbines (2.2 h, no CI calculated) was shorter, although not significantly different, than that of those passing via the JBS ($P = 0.0580$).

For steelhead, median forebay delay (3.4 h, 95% CI 2.6-4.1 h; Table 13) was significantly different ($P < 0.0001$) than yearling Chinook salmon (1.8 h; 95% CI 1.5-2.1) that passed during similar spring operations. Median forebay residence time for steelhead that passed through the JBS (6.5 h, 95% CI 4.8-8.2 h) was significantly longer than for those passing either through the RSW (3.1 h, 2.4-3.8 h; $P = 0.0002$) or spillway (3.8 h, 2.7-5.0 h; $P = 0.0085$). Median forebay delay for steelhead that passed via turbines was not significantly shorter than that of turbine passed fish (6.0 h; no CI calculated; $P = 0.4551$).

Subyearling Chinook salmon had median forebay residence timing that was similar to that of yearling Chinook salmon (1.9 h, 95% CI 1.6-2.1 h; Table 13). However, these fish passed during summer, when conditions differed slightly from those during spring. Median forebay delay of subyearling Chinook salmon that passed through the JBS (3.2 h, 95% CI 2.4-4.0 h) was significantly different than that of cohorts passing either through the RSW (2.1 h, 1.8-2.4 h; $P = 0.0097$), spillway (1.4 h, 1.2-1.5 h; $P < 0.0001$), or turbine (1.7 h, no CI calculated; $P = 0.0074$).

Table 13. Forebay delay (h) by passage route distribution (percentile) between forebay entry and passage at Ice Harbor Dam for radio-tagged hatchery yearling and subyearling Chinook salmon and steelhead, 2008.

	Forebay delay (h)				
Passage percentile	Overall	JBS	Spillway	RSW	Turbine
	Yearling Chinook salmon				
N	1,589	379	679	449	82
10th	0.8	1.0	0.7	0.7	0.8
20th	1.0	1.4	0.8	1.0	0.9
30th	1.2	1.9	1.0	1.2	1.1
40th	1.4	2.9	1.2	1.6	1.4
50th	1.8	4.5	1.6	2.0	2.2
60th	2.5	6.5	1.8	2.7	3.4
70th	3.8	9.4	2.7	4.3	5.4
80th	6.6	14.7	5.4	7.3	10.2
90th	13.8	28.1	9.7	15.9	14.2
95th	20.8	28.8	10.7	20.9	25.9
minimum	0.3	0.6	0.3	0.3	0.4
mean	5.0	9.0	2.9	4.7	6.1
median	1.8	4.5	1.6	2.0	2.2
mode	0.6	1.3	0.6	0.9	0.8
maximum	95.5	95.5	87.5	61.7	38.5
SD	9.0	13.0	5.9	7.4	8.7
	Juvenile steelhead				
N	1,834	275	718	819	22
10th	1.0	1.4	1.0	1.0	0.9
20th	1.4	2.4	1.3	1.3	1.2
30th	1.9	3.3	1.8	1.8	2.0
40th	2.5	4.7	2.6	2.3	2.6
50th	3.4	6.5	3.8	3.1	6.0
60th	4.5	9.3	4.9	4.2	7.7
70th	6.2	15.2	6.6	5.5	10.6
80th	8.6	28.5	9.2	7.5	13.7
90th	15.6	42.5	17.7	12.5	20.6
95th	22.5	45.0	17.4	20.2	36.8
minimum	0.3	0.6	0.3	0.3	0.8
mean	6.8	14.4	5.4	5.3	9.4
median	3.4	6.5	3.8	3.1	6.0
mode	0.6	2.3	0.6	1.5	0.8
maximum	276.6	276.6	114.8	63.3	39.0
SD	14.3	30.9	8.8	6.7	11.1
	Subyearling Chinook				
N	2,094	583	870	560	81
10th	0.8	1.1	0.8	0.8	0.8
20th	1.0	1.5	0.9	1.0	1.0
30th	1.2	2.0	1.0	1.3	1.2
40th	1.5	2.6	1.1	1.6	1.3
50th	1.9	3.2	1.4	2.1	1.7

Table 13. Continued.

Passage percentile	Forebay delay (h)				
	Overall	JBS	Spillway	RSW	Turbine
	Subyearling Chinook (continued)				
60^{th}	2.4	4.3	1.6	2.7	2.6
70^{th}	3.3	6.6	2.1	3.5	3.2
80^{th}	5.4	10.0	2.9	5.8	5.3
90^{th}	9.3	18.7	5.6	9.7	7.7
95^{th}	14.7	23.6	8.6	11.6	10.5
minimum	0.4	0.7	0.4	0.4	0.7
mean	4.1	6.5	2.6	4.0	3.4
median	1.9	3.2	1.4	2.1	1.7
mode	0.8	1.5	0.8	0.8	0.8
maximum	104.0	104.0	61.4	91.4	16.9
sd	7.3	10.4	4.7	6.5	3.5

Passage Route Distribution

During spring, the overall passage distribution for yearling Chinook salmon was 71.0% through the spillway (28.3% of which passed over the RSW), 23.9% through the juvenile bypass, and 5.2% through turbines (Table 1). Less than 2.0% (33) of these fish passed the project by an unknown route, and an additional 77 fish entered the forebay but did not pass the project.

Overall passage distribution for juvenile steelhead was 83.8% through the spillway (44.7% of which passed over the RSW), 15.0% through the juvenile bypass, and 1.2% through turbines (Table 1). Less than 1.7% (31) of the fish passed the project by an unknown route, and an additional 86 fish entered the forebay but did not pass the project. Horizontal spillway distributions during spring operations for yearling Chinook salmon and steelhead are shown in Figure 13.

Overall passage distribution for subyearling Chinook salmon was 68.3% through the spillway (26.7% of which passed over the RSW), 27.8% through the juvenile bypass, and 3.9% through turbines (Table 1). Horizontal spillway distributions during summer operations for subyearling Chinook salmon are shown in Figure 14.

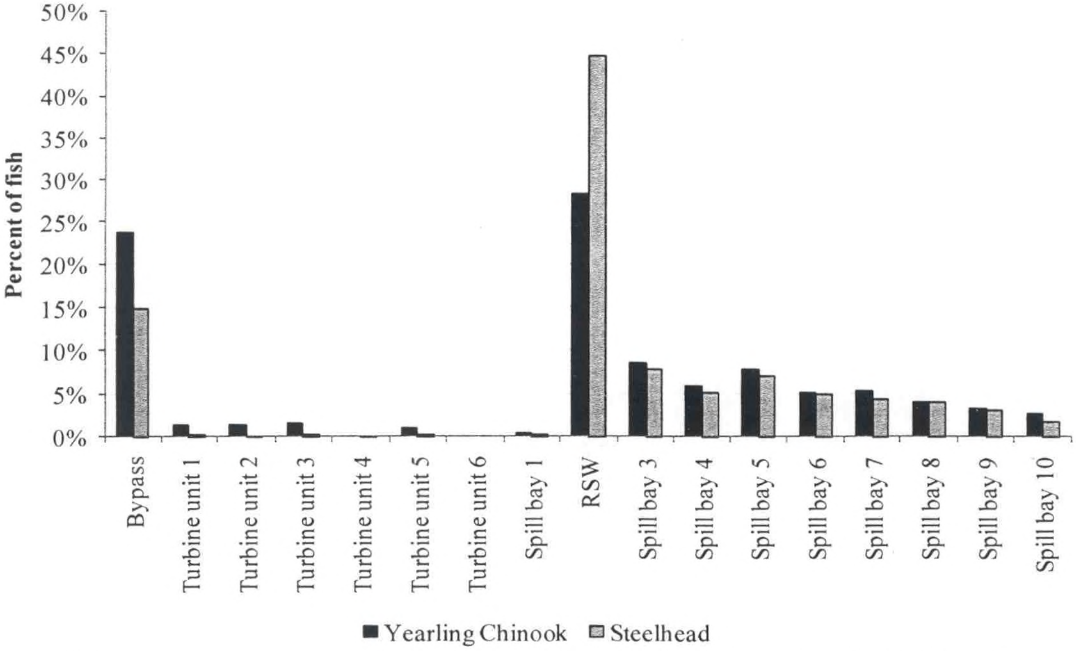

Figure 13. Horizontal passage distribution of radio-tagged yearling Chinook salmon and steelhead during spring operations at Ice Harbor Dam, 2008.

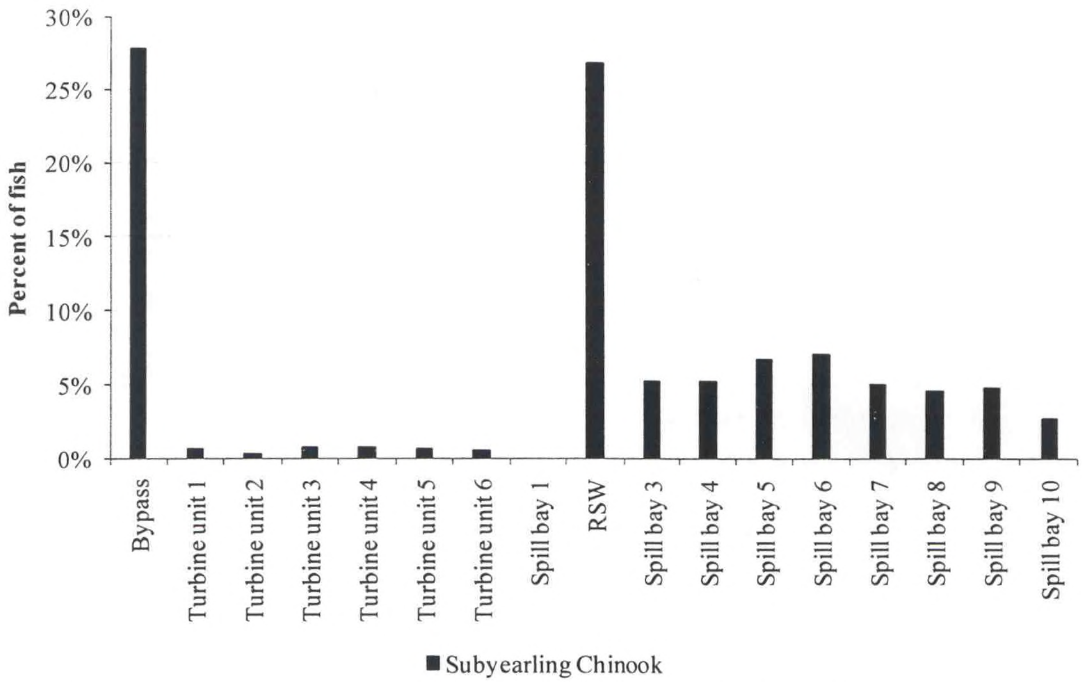

Figure 14. Horizontal passage distribution of radio-tagged subyearling Chinook salmon during summer operations at Ice Harbor Dam, 2008.

Fish Passage Metrics

For yearling Chinook salmon during spring operations, overall fish passage efficiency was 94.8% (95% CI, 94.1-97.6), fish guidance efficiency was 82.2% (80.5-88.9), and spillway passage efficiency was 71.0% (67.1-79.2; Table 14). Overall surface outlet efficiency for the RSW was 28.3% (24.9-33.5). Mean spillway passage effectiveness was 1.27:1 and mean surface outlet effectiveness was 3.99:1. Training spill effectiveness was measured at 0.88:1.

Juvenile steelhead fish passage efficiency during similar operations was 98.8% (95% CI, 98.4-99.6), fish guidance efficiency was 92.6% (95% CI, 86.0-96.7), and spillway passage efficiency was 83.8% (80.4-88.8; Table 15). Surface outlet efficiency was 44.7% (35.1-51.3). Mean spillway passage effectiveness was 1.50:1 while mean surface outlet effectiveness was 6.30:1. Training spill effectiveness was measured at 0.80:1.

Fish passage efficiency for subyearling Chinook salmon was 96.1% (95% CI, 95.6-97.5), fish guidance efficiency was 87.8% (81.7-90.7), and spillway passage efficiency was 68.3% (64.4-76.5; Table 16). Surface outlet efficiency for the RSW was 26.7% (23.0-32.9). Mean spillway passage effectiveness was 1.32:1 and mean surface outlet effectiveness was 3.67:1. Training spill effectiveness was measured at 0.86:1.

We have been evaluating fish passage at Ice Harbor Dam with respect to operation of an RSW for 3 years. As a result, we have data from a large number of fish that have passed under variable levels of percent spill. Regressions were plotted for percentage of fish that passed vs. percentage of spill for yearling Chinook salmon (n = 4,876), juvenile steelhead (n = 4,470), and subyearling Chinook salmon (n = 4,095; Figure 15). Results identified various operating points, in terms of percent spill, where project operation might influence fish passage distribution. For yearling Chinook salmon, spill percentages greater than 40% seemed to shift fish away from the powerhouse, but levels higher than 48% appeared to decrease the effectiveness of the RSW. Similar respective beneficial and detrimental operating points were identified at approximately 39 and 55% spill for steelhead, and 51 and 63% spill for subyearling Chinook.

Table 14. Passage distribution and fish passage metrics for radio-tagged yearling Chinook salmon passing Ice Harbor Dam during spring operations, 2008.

		Yearling Chinook salmon							
	Mean spill	Passage route					Fish passage metrics		
Date	(kcfs)	Spillway	RSW	Bypass	Turbine	Total	Spill efficiency	FPE	FGE
1 May	49.9	3	1			4	1.000	1.000	
2 May	22.8	3	4	3		10	0.700	1.000	1.000
3 May	19.5	3	11	8	2	24	0.583	0.917	0.800
4 May	43.7	23	15	4		42	0.905	1.000	1.000
5 May	50.8	26	23	8	2	59	0.831	0.966	0.800
6 May	30.6	16	20	19	2	57	0.632	0.965	0.905
7 May	26.2	14	23	33	10	80	0.463	0.875	0.767
8 May	54.0	30	26	28	8	92	0.609	0.913	0.778
9 May	59.8	37	18	8	1	64	0.859	0.984	0.889
10 May	39.5	24	9	24	1	58	0.569	0.983	0.960
11 May	26.2	17	20	16	2	55	0.673	0.964	0.889
12 May	28.2	11	28	28	2	69	0.565	0.971	0.933
13 May	25.8	14	27	17	2	60	0.683	0.967	0.895
14 May	44.3	36	15	11	1	63	0.810	0.984	0.917
15 May	56.3	46	18	3	1	68	0.941	0.985	0.750
16 May	44.4	24	33	17	3	77	0.740	0.961	0.850
17 May	53.3	26	37	27	5	95	0.663	0.947	0.844
18 May	78.6	38	30	25	7	100	0.680	0.930	0.781
19 May	112.2	56	17	23	3	99	0.737	0.970	0.885
20 May	129.8	61	20	17	4	102	0.794	0.961	0.810
21 May	131.3	54	16	21	7	98	0.714	0.929	0.750
22 May	126.1	61	15	8	4	88	0.864	0.955	0.667
23 May	96.2	22	10	18	13	63	0.508	0.794	0.581
24 May	94.0	21	11	6	1	39	0.821	0.974	0.857
25 May	78.2	10	2	6	1	19	0.632	0.947	0.857
26 May	68.3	1				1	1.000	1.000	
27 May	66.1	1				1	1.000	1.000	
28 May	77.4	1		1		2	0.500	1.000	1.000
Totals		**679**	**449**	**379**	**82**	**1,589**	**0.710**	**0.948**	**0.822**

Table 15. Passage distribution and fish passage metrics for radio-tagged juvenile steelhead passing Ice Harbor Dam during spring operations, 2008.

		Juvenile steelhead							
	Mean spill	Passage route					Fish passage metrics		
Date	(kcfs)	Spillway	RSW	Bypass	Turbine	Total	Spill efficiency	FPE	FGE
1 May	49.9	12	12			24	1.000	1.000	
2 May	22.8	5	37	1		43	0.977	1.000	1.000
3 May	19.5	4	29	10	1	44	0.750	0.977	0.909
4 May	43.7	19	41	7	1	68	0.882	0.985	0.875
5 May	50.8	37	51	1		89	0.989	1.000	1.000
6 May	30.6	14	64	5	1	84	0.929	0.988	0.833
7 May	26.2	23	68	19	4	114	0.798	0.965	0.826
8 May	54.0	52	37	12		101	0.881	1.000	1.000
9 May	59.8	37	41	1	1	80	0.975	0.988	0.500
10 May	39.5	20	36	13		69	0.812	1.000	1.000
11 May	26.2	15	32	19		66	0.712	1.000	1.000
12 May	28.2	22	44	21	1	88	0.750	0.989	0.955
13 May	25.8	16	27	17		60	0.717	1.000	1.000
14 May	44.3	19	36	6	4	65	0.846	0.938	0.600
15 May	56.3	43	29	4		76	0.947	1.000	1.000
16 May	44.4	16	46	17	1	80	0.775	0.988	0.944
17 May	53.3	41	51	31	1	124	0.742	0.992	0.969
18 May	78.6	47	35	16	1	99	0.828	0.990	0.941
19 May	112.2	72	22	13	3	110	0.855	0.973	0.813
20 May	129.8	53	16	10	1	80	0.863	0.988	0.909
21 May	131.3	52	23	9		84	0.893	1.000	1.000
22 May	126.1	46	13	10	1	70	0.843	0.986	0.909
23 May	96.2	21	18	15	1	55	0.709	0.982	0.938
24 May	94.0	20	8	13		41	0.683	1.000	1.000
25 May	78.2	8	3	5		16	0.688	1.000	1.000
26 May	68.3	2				2	1.000	1.000	
27 May	66.1					0			
28 May	77.4					0			
29 May	95.4	2				2	1.000	1.000	
Totals		**718**	**819**	**275**	**22**	**1,834**	**0.838**	**0.988**	**0.926**

Table 16. Passage distribution and fish passage metrics for radio-tagged subyearling Chinook salmon passing Ice Harbor Dam during summer operations, 2008.

	Subyearling Chinook salmon								
	Mean spill	Passage route					Fish passage metrics		
Date	(kcfs)	Spillway	RSW	Bypass	Turbine	Total	Spill efficiency	FPE	FGE
11 Jun	92.2	21		1	1	23	0.913	0.957	0.500
12 Jun	77.5	37	11	17	3	68	0.706	0.956	0.850
13 Jun	66.5	32	18	30	4	84	0.595	0.952	0.882
14 Jun	38.4	13	11	24	4	52	0.462	0.923	0.857
15 Jun	52.2	14	17	24	2	57	0.544	0.965	0.923
16 Jun	61.5	21	18	30	1	70	0.557	0.986	0.968
17 Jun	68.5	25	12	13	2	52	0.712	0.962	0.867
18 Jun	75.3	45	11	18	5	79	0.709	0.937	0.783
19 Jun	67.9	36	16	18	1	71	0.732	0.986	0.947
20 Jun	48.5	20	18	44	3	85	0.447	0.965	0.936
21 Jun	57.9	27	28	39	5	99	0.556	0.949	0.886
22 Jun	74.6	46	29	20	3	98	0.765	0.969	0.870
23 Jun	68.2	38	25	47	7	117	0.538	0.940	0.870
24 Jun	59.1	23	28	25	5	81	0.630	0.938	0.833
25 Jun	68.4	44	23	30	2	99	0.677	0.980	0.938
26 Jun	74.5	62	18	6	4	90	0.889	0.956	0.600
27 Jun	70.9	68	31	12	2	113	0.876	0.982	0.857
28 Jun	69.6	38	19	11	4	72	0.792	0.944	0.733
29 Jun	44.7	28	24	30	7	89	0.584	0.921	0.811
30 Jun	32.5	12	30	56	6	104	0.404	0.942	0.903
1 Jul	63.6	38	37	22	5	102	0.735	0.951	0.815
2 Jul	65.7	60	30	19	2	111	0.811	0.982	0.905
3 Jul	63.6	62	33	15		110	0.864	1.000	1.000
4 Jul	59.3	39	25	8	2	74	0.865	0.973	0.800
5 Jul	34.0	16	27	14	1	58	0.741	0.983	0.933
6 Jul	21.5	4	14	9		27	0.667	1.000	1.000
7 Jul	20.4	1	4			5	1.000	1.000	
8 Jul	20.3		1			1	1.000	1.000	
9 Jul	45.3		2	1		3	0.667	1.000	1.000
Totals		**870**	**560**	**583**	**81**	**2,094**	**0.683**	**0.961**	**0.878**

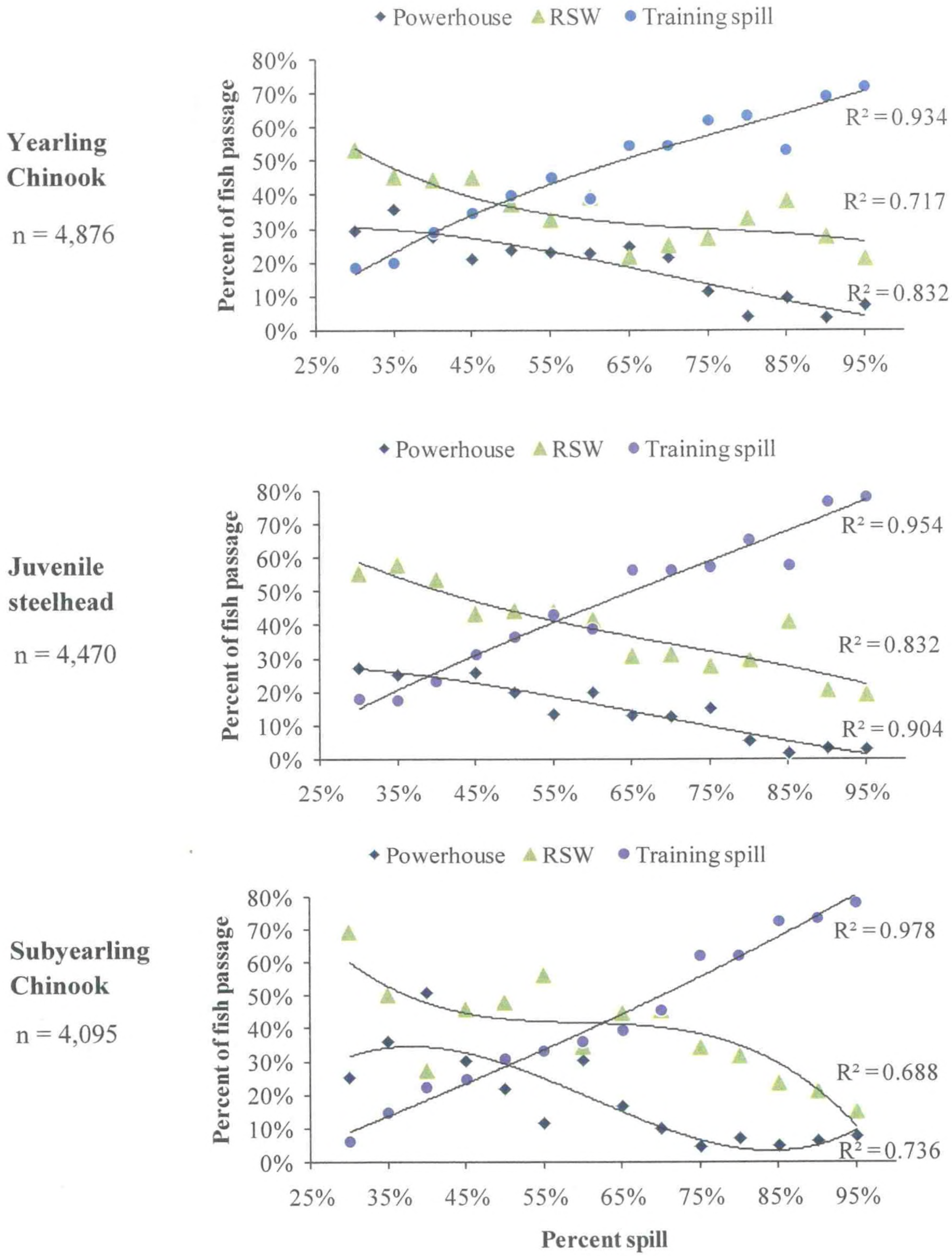

Figure 15. Percent of radio-tagged yearling Chinook, steelhead, and subyearling Chinook salmon passing through the powerhouse, RSW, and training spill during varying levels of percent spill at Ice Harbor Dam, 2006-2008.

Tailrace Egress

Tailrace egress was measured for 1,430 yearling Chinook salmon, 1,697 steelhead, and 1,628 subyearling Chinook salmon based on two inclusion criteria: fish were determined to have a valid passage time and were also subsequently detected at the tailrace exit line. Median tailrace egress of steelhead (8.1 min) was significantly different (P = 0.766) from that of yearling Chinook salmon (8.4 min) that passed during similar spring operations (Table 17). Subyearling Chinook salmon had slightly longer tailrace egress (8.6 min) compared to yearling Chinook salmon, though this was during summer conditions which differed slightly to spring conditions. Percentile distribution by date for tailrace egress for radio-tagged hatchery yearling Chinook salmon, juvenile steelhead, and subyearling Chinook salmon is shown in Table 18-20, respectively.

Table 17. Sample size, percentile distribution, minimum, mean, median, mode, and maximum tailrace egress (minutes) from passage time at Ice Harbor Dam to the tailrace exit for radio-tagged hatchery yearling Chinook salmon, 2008.

	Tailrace egress (min)		
Passage percentile	Yearling Chinook	Steelhead	Subyearling Chinook
N	1,430	1,697	1,628
10th	4.4	4.4	4.6
20th	5.6	5.4	5.8
30th	6.5	6.4	6.7
40th	7.4	7.2	7.6
50th	8.4	8.1	8.6
60th	9.4	9.2	9.9
70th	11.0	10.5	11.8
80th	14.1	13.2	15.3
90th	28.1	25.0	31.3
95th	55.7	52.0	123.6
minimum	0.7	0.9	1.4
mean	46.0	42.0	99.3
median	8.4	8.1	8.6
mode	7.8	6.4	6.5
maximum	9,043.6	8,390.2	8,546.7

Table 18. Percentile distribution by date for tailrace egress (minutes) from passage time at Ice Harbor Dam to the tailrace exit for radio-tagged hatchery yearling Chinook salmon, 2008.

Replicate			Tailrace egress percentile (min) for Yearling Chinook salmon								
date	day	n	10th	20th	30th	40th	50th	60th	70th	80th	90th
5/1	122										
5/2	123	9		10.4	10.7	12.5	15.1	55.5	80.4		
5/3	124	23	5.7	6.4	7.6	8.6	11.3	13.5	15.8	23.9	97.2
5/4	125	41	4.6	6.9	8.1	8.5	9.7	11.2	14.3	22.3	54.2
5/5	126	58	6.1	7.8	8.3	9.2	10.9	12.3	14.6	16.5	40.6
5/6	127	55	4.3	5.7	6.6	7.9	8.4	9.8	13.6	17.4	40.2
5/7	128	75	3.4	4.6	6.4	7.6	8.0	8.7	10.3	12.2	17.6
5/8	129	74	4.9	6.3	6.9	8.3	9.3	10.4	14.3	20.5	37.6
5/9	130	56	4.7	5.4	6.1	7.4	8.2	8.7	10.3	16.3	40.7
5/10	131	52	3.7	4.9	5.3	5.9	6.2	7.9	9.0	12.7	28.1
5/11	132	46	3.4	4.6	5.3	7.1	7.8	8.5	9.1	12.3	24.4
5/12	133	62	3.6	4.7	5.4	5.9	7.5	7.8	10.8	15.0	29.3
5/13	134	58	4.4	6.1	7.0	7.4	8.2	9.7	10.5	13.5	25.9
5/14	135	62	5.6	6.8	7.7	8.8	9.8	11.1	15.9	27.4	48.1
5/15	136	64	5.4	6.7	7.1	7.6	9.1	12.2	19.8	28.7	42.7
5/16	137	71	4.6	5.6	7.2	8.6	9.5	10.3	13.7	17.9	46.4
5/17	138	85	4.6	5.9	6.7	8.1	9.6	10.3	11.0	12.1	15.1
5/18	139	81	5.1	6.0	7.1	8.4	9.4	10.4	11.5	13.9	21.3
5/19	140	82	4.0	5.2	5.9	6.8	7.3	8.1	9.7	11.2	14.2
5/20	141	94	3.5	4.3	5.4	6.3	6.8	7.6	8.5	10.2	14.0
5/21	142	88	4.1	4.8	5.4	6.2	6.7	7.1	8.4	8.9	12.1
5/22	143	73	2.6	3.9	5.9	6.2	7.0	7.6	9.7	17.2	26.3
5/23	144	63	4.3	6.2	7.6	8.5	9.4	10.2	10.9	12.9	14.2
5/24	145	36	6.1	7.3	8.4	8.8	9.2	9.5	10.5	12.9	16.2
5/25	146	22	5.4	6.4	6.6	7.0	7.5	10.5	12.2	13.7	26.3
Total		*1,430*									
Mean			**4.5**	5.9	6.9	7.8	**8.8**	11.6	14.8	16.1	**31.9**
SE			**0.2**	0.3	0.3	0.3	**0.4**	1.9	2.9	1.1	**4.0**
95 % CI			**4.1-4.9**	5.4-6.5	6.3-7.4	7.2-8.4	**8.0-9.6**	7.6-15.6	8.8-20.8	13.8-18.4	**23.6-40.1**

Table 19. Percentile distribution by date for tailrace egress (minutes) from passage time at Ice Harbor Dam to the tailrace exit for radio-tagged juvenile steelhead, 2008.

Replicate			Tailrace egress percentile (min) for Steelhead								
date	day	n	10th	20th	30th	40th	50th	60th	70th	80th	90th
5/1	122	14	2.7	3.9	5.9	7.0	8.5	9.3	20.4	33.1	58.9
5/2	123	29	5.0	6.7	8.2	9.6	9.8	13.8	15.7	17.7	52.5
5/3	124	44	6.1	6.4	7.6	9.3	11.0	13.4	16.7	20.0	48.0
5/4	125	68	5.1	7.1	8.0	8.5	9.2	10.8	13.9	21.6	51.2
5/5	126	88	4.7	5.8	6.7	7.7	8.7	9.8	13.4	18.5	26.4
5/6	127	84	4.0	5.3	5.9	6.6	7.2	8.2	9.4	10.8	16.6
5/7	128	112	4.6	5.7	6.5	7.5	8.3	9.3	10.4	12.4	32.4
5/8	129	98	4.9	6.1	7.1	8.2	9.2	10.5	12.5	19.1	35.0
5/9	130	70	4.7	5.6	6.5	7.2	8.4	9.8	11.2	18.9	22.5
5/10	131	63	4.1	5.4	6.1	6.7	7.2	7.6	8.6	11.4	18.5
5/11	132	54	3.7	4.3	5.2	5.8	6.5	7.3	7.9	9.4	15.8
5/12	133	81	4.0	5.2	5.9	6.9	7.9	8.6	9.1	12.6	31.6
5/13	134	59	4.2	5.0	6.0	6.6	7.3	8.9	11.1	14.7	71.8
5/14	135	62	5.7	6.9	8.2	9.3	10.4	11.3	15.5	17.8	30.5
5/15	136	73	5.0	6.4	7.3	8.6	9.6	11.9	14.3	19.8	26.0
5/16	137	76	4.9	5.4	6.2	6.8	8.0	8.7	9.7	12.3	18.3
5/17	138	119	4.3	5.9	6.7	7.2	7.9	9.2	10.2	11.4	14.0
5/18	139	80	4.0	5.5	5.9	7.0	7.8	8.7	9.4	10.4	13.5
5/19	140	100	3.7	4.9	5.9	6.4	7.1	8.1	9.5	10.7	16.5
5/20	141	74	3.3	4.0	4.8	5.8	7.3	8.6	9.6	12.9	35.7
5/21	142	73	3.2	4.4	5.4	6.5	8.0	8.7	9.8	13.4	35.3
5/22	143	63	2.9	4.1	4.6	5.4	6.1	7.0	7.8	8.6	12.2
5/23	144	54	4.3	6.4	7.0	7.8	8.5	9.2	10.4	12.2	14.5
5/24	145	40	4.4	4.9	5.8	8.2	9.4	10.2	11.1	12.9	29.8
5/25	146	19	4.6	5.4	6.7	7.3	8.3	9.4	11.3	25.2	48.6
Total		*1,697*									
Mean			**4.3**	5.5	6.4	7.3	**8.3**	9.5	11.6	15.5	**31.0**
SE			**0.2**	0.2	0.2	0.2	**0.2**	0.3	0.6	1.1	**3.2**
95 % CI			**4.0-4.7**	5.1-5.8	6.0-6.8	6.9-7.8	**7.8-8.8**	8.8-10.2	10.3-12.8	13.2-17.8	**24.4-37.7**

Table 20. Percentile distribution by date for tailrace egress (minutes) from passage time at Ice Harbor Dam to the tailrace exit for radio-tagged hatchery subyearling Chinook salmon, 2008.

Replicate			Tailrace egress percentile (min) for subyearling Chinook salmon								
date	day	n	10th	20th	30th	40th	50th	60th	70th	80th	90th
6/11	163	12	3.5	4.6	5.1	5.6	6.5	11.2	15.7	25.5	41.7
6/12	164	40	4.6	6.0	7.6	8.3	11.0	11.7	14.8	26.4	262.0
6/13	165	54	4.5	5.3	6.1	7.0	7.9	9.8	12.8	19.0	45.7
6/14	166	32	4.0	4.9	5.2	5.7	6.2	6.5	6.9	8.2	9.9
6/15	167	28	5.7	6.8	7.6	8.5	8.8	10.4	12.6	14.2	25.3
6/16	168	14	5.3	7.7	10.8	11.4	14.3	17.9	19.7	34.0	157.4
6/17	169	26	2.7	4.7	5.9	6.8	7.3	7.5	10.0	11.2	23.3
6/18	170	22	5.1	6.4	6.9	7.4	7.6	8.2	9.1	11.7	
6/19	171	3	5.7	5.7	6.2	7.2	8.3	8.5	8.8	8.9	8.9
6/20	172	54	5.2	6.1	6.8	7.4	8.5	9.4	11.5	15.5	322.2
6/21	173	97	5.0	5.8	6.5	7.4	8.1	9.0	10.1	11.1	19.3
6/22	174	90	4.3	5.2	6.1	6.9	8.1	10.3	12.3	17.8	62.6
6/23	175	102	4.3	5.1	6.3	7.1	8.1	8.9	9.6	11.5	14.7
6/24	176	64	4.0	6.5	7.7	8.1	9.7	11.0	12.8	20.3	118.0
6/25	177	91	4.1	4.9	5.8	6.8	8.0	9.2	11.7	15.5	28.4
6/26	178	90	4.6	5.6	6.5	7.9	9.2	10.3	12.2	20.3	77.7
6/27	179	110	4.6	5.8	6.7	7.6	9.0	10.3	12.3	17.7	27.3
6/28	180	70	4.1	5.5	7.3	8.1	10.5	12.1	13.6	17.1	34.1
6/29	181	73	4.2	6.3	7.0	7.8	8.3	9.3	12.1	17.5	117.2
6/30	182	101	5.0	6.4	6.8	7.3	8.2	8.9	9.7	11.6	16.2
7/1	183	92	4.9	6.4	7.4	8.2	9.4	11.0	12.4	15.2	20.0
7/2	184	107	4.7	6.3	7.1	8.2	9.4	11.5	13.2	15.7	37.9
7/3	185	102	4.2	6.0	6.5	7.5	8.7	10.3	12.7	15.5	26.0
7/4	186	71	4.9	5.7	6.3	7.4	8.7	10.9	12.7	16.3	24.3
7/5	187	52	4.4	5.8	6.7	8.5	9.7	11.7	16.1	51.0	136.7
7/6	188	23	5.9	7.2	7.9	8.7	9.4	10.0	11.1	18.0	64.4
7/7	189	5					9.0				
7/8	190	1									
7/9	191	2									
Total		*1,628*									
Mean			**4.6**	5.9	6.8	7.6	**8.8**	10.2	12.2	17.9	**68.8**
SE			**0.1**	0.1	0.2	0.2	**0.3**	0.4	0.5	1.7	**15.9**
95 % CI			**4.3-4.9**	5.6-6.2	6.4-7.2	7.2-8.1	**8.2-9.4**	9.4-11.1	11.1-13.2	14.4-21.5	**36.1-101.6**

Avian Predation

Recovery efforts on the Crescent Island tern colony produced 60 radio tags from juvenile steelhead that had volitionally entered the forebay of Ice Harbor Dam. This number represented 3.1% of the fish used for the evaluation. We recovered radio tags from 16 yearling Chinook salmon that had volitionally entered the forebay of Ice Harbor Dam, representing approximately 0.9% of the fish used for this evaluation. We also recovered 51 radio tags from subyearling Chinook salmon, the highest number of radio tags from this species that we have seen on Crescent Island. These recoveries represented 2.2% of the fish used for this evaluation.

For fish with radio tags recovered on the tern colony, we plotted the last known detection transect on which they were detected in order to determine where the "kill zone" might be located. Both juvenile steelhead and subyearling Chinook salmon were most vulnerable when they left the tailrace of Ice Harbor Dam and entered the confluence of the Snake and Columbia Rivers (Figure 18). Yearling Chinook were taken at a much lower level than the other two species.

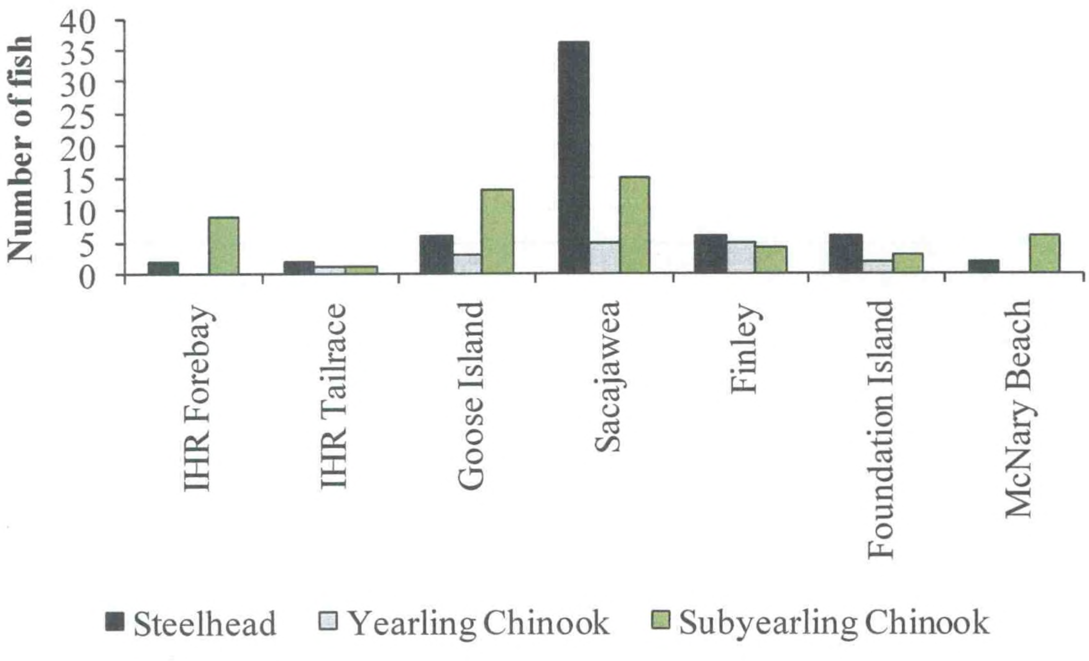

Figure 18. Percentage of radio-tagged juvenile steelhead, yearling Chinook, and subyearling Chinook salmon migrants with their last known telemetry detection site before avian predation event, 2008.

DISCUSSION

Overall, the RSW at Ice Harbor Dam continues to be extremely effective in passing more fish with less water than operations without the RSW. Survival estimates were high and not significantly different from previous years with varying levels of flow. During spring 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 (Axel et al. 2008). This occurred because flow through the RSW is predetermined based on the minimum operating pool level at Ice Harbor Dam, which results in a higher percentage of total river flow through the RSW during years of lower flow.

This factor, as well as the overall percentage of spill for the project, may have a large determining factor in first-approach and passage distributions for yearling Chinook salmon, juvenile steelhead, and subyearling Chinook salmon. During 2008, we observed a high-flow year which resulted in large amounts of involuntary spill while the percentage of flow over the surface outlet measured its lowest levels since it was installed. Consequently, first approaches at the RSW were considerably reduced and subsequent surface outlet efficiency was lower than in recent years.

Forebay delay in 2008 was slightly longer than those found in 2006 and 2007 for both species under each spill treatment (Axel et al. 2007). Median forebay delay for yearling Chinook salmon during the high flows of 2006 was 1.8 h for reduced spill and 1.1 h for 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 delays of 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 results in wandering behavior, while fish were likely deciding on which flow queue to follow. Although a difference in delay of minutes does not suggest a major biological significance, it does provide increased exposure to predators. When spill is adequately provided, forebay delays can be reduced. Predators, both avian and picivorous, have long exploited this holding area for migrating juveniles, making the forebay one of the highest areas of smolt loss to predation (Poe et al. 1991; Beamesderfer and Rieman 1991; Antolos et al. 2005). Concerns remain regarding the high level of mortality in the forebay at Ice Harbor Dam, which are some of the highest measured levels of mortality within the Columbia River Basin, and which have reduced Ice Harbor Dam survival. The Crescent Island Caspian Tern and the Foundation Island Double-Breasted Cormorant *Phalacrocorax auritas* colonies have played a major role in this. Discussions are ongoing for mitigation of this issue.

Passage efficiency for steelhead, yearling Chinook, and subyearling Chinook salmon passing through the powerhouse, RSW, and training spill were examined over the last three years as a function of the percent spill during the time of passage. Our results suggest a correlation exists between the percentage of spill and the number of fish that utilize the powerhouse. There also exists a point of diminishing returns, where additional spill reduces the overall effectiveness of the RSW, as well as the spillway as a whole. While there are some differences between species, spill percentages greater than 30% pass the majority of the fish through the spillway. However, when spill exceeds 40%, the effectiveness of a surface outlet begins to decline, although the amount of fish approaching and passing through the JBS and turbines declines much more.

Successive evaluations conducted since 2005 have shown the ability of the RSW to modify and improve fish passage, particularly for forebay residence, at Ice Harbor Dam. The surface outlet has added some flexibility with respect to project operations, which allows for high passage survival estimates of juvenile steelhead, yearling Chinook salmon, and subyearling Chinook salmon even during periods of low river flows.

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 and spill bays during periods of increased turbine loading. Operation of this spill bay 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 yearling Chinook salmon, juvenile steelhead, and subyearling Chinook salmon released above Ice Harbor Dam. 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 1,699 radio-tagged yearling Chinook salmon detected at Ice Harbor Dam, 1,574 (92.6% of those observed) were detected either at or below the primary survival transect at Goose Island. Detection probability for fish used in survival analysis at Ice Harbor Dam was 0.983 overall (Appendix Table A1).

Of the 1,951 radio-tagged juvenile steelhead detected at Ice Harbor Dam, 1,817 (93.1% of those observed) were detected either at or below the primary survival transect. Detection probability for fish used in survival analysis at Ice Harbor Dam was 0.977 overall (Appendix Table A1).

Of the 2,314 radio-tagged subyearling Chinook salmon detected at Ice Harbor Dam, 1,998 (86.3% of those observed) were detected either at or below the primary survival transect. Detection probability for fish used in survival analysis at Ice Harbor Dam was 0.984 overall (Appendix Table A1).

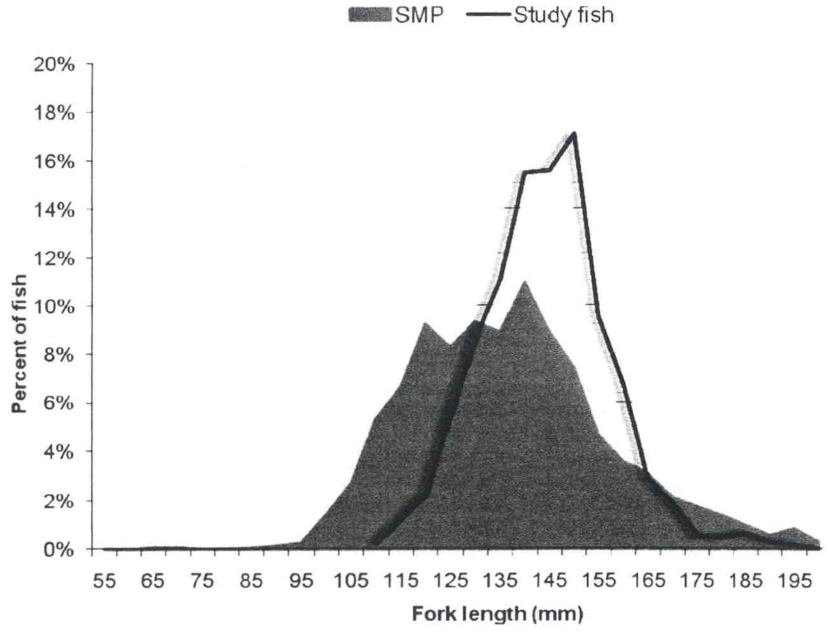
Appendix Table A1. Treatment fish released above Ice Harbor Dam and detected at or below the primary survival transect. These detections were used for evaluating survival of yearling and subyearling Chinook salmon and steelhead at Ice Harbor Dam, 2008.

Species	Detected at Goose Island	Detected at or below Goose Island	Detection probability
Yearling Chinook salmon	1,547	1,574	0.983
Juvenile steelhead	1,776	1,817	0.977
Subyearling Chinook salmon	1,966	1,998	0.984

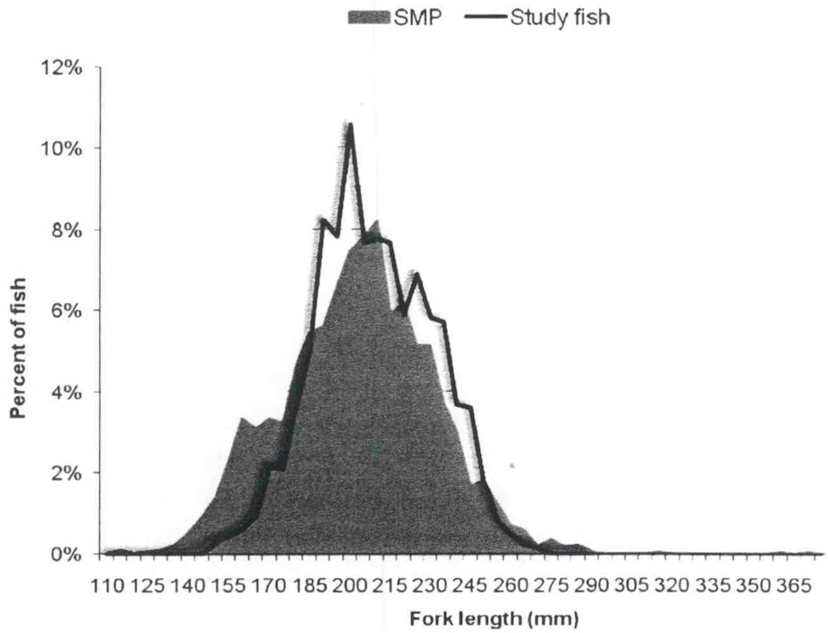
A2. Individuals tagged for the study are a representative sample of the population of interest.

Unmarked yearling Chinook salmon and juvenile steelhead were collected at Lower Monumental for 27 d from 27 April to 23 May. Collection and tagging began after approximately 2.1% of the yearling Chinook salmon and 1.0% of the juvenile steelhead had passed Lower Monumental Dam and was completed when more than 87% of these fish had passed. Overall mean fork length for yearling Chinook salmon was 142.4 mm (SD = 12.8) and overall mean weight was 28.8 g (SD = 8.3). Overall mean fork length for steelhead was 207.1 mm (SD = 21.8) and overall mean weight was 79.2 g (SD = 25.2). Appendix Figures A2a and A2b display comparisons between smolt monitoring data (SMP) and fish used for this study.

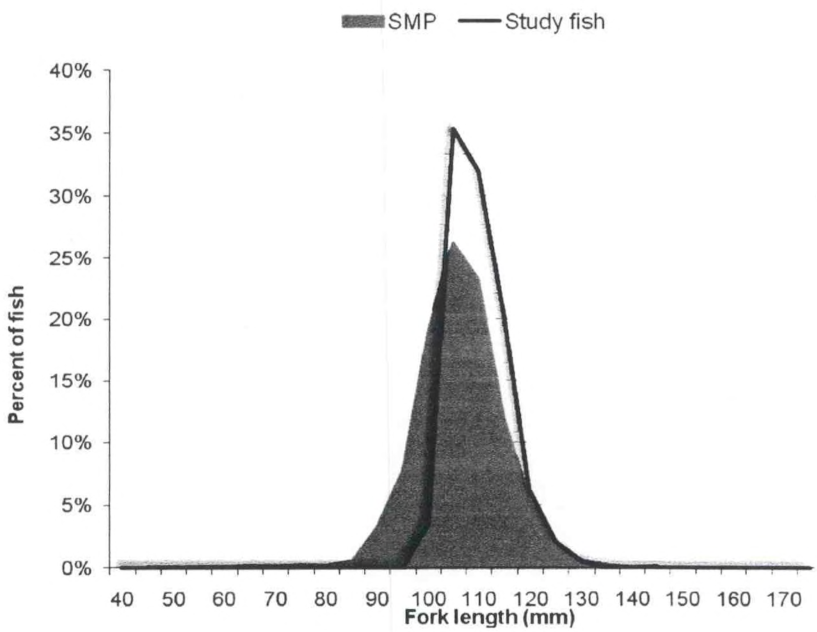
Unmarked subyearling Chinook salmon were collected at Lower Monumental for 27 d from 6 June to 2 July. Collection and tagging began after approximately 13% of the subyearling Chinook salmon had passed Lower Monumental Dam and was completed when more than 85% of these fish had passed. Overall mean fork length for subyearling Chinook salmon was 142.4 mm (SD = 12.8) and overall mean weight was 28.8 g (SD = 8.3). Appendix Figure A2c displays comparisons between smolt monitoring data (SMP) and fish used for this study.



Appendix Figure A2a. Size distribution for SMP collection of yearling Chinook salmon and those tagged for evaluations at Ice Harbor Dam, 2008.



Appendix Figure A2b. Size distribution for SMP collection of juvenile steelhead and those tagged for evaluations at Ice Harbor Dam, 2008.



Appendix Figure A2c. Size distribution for SMP collection of subyearling Chinook salmon and those tagged for evaluations at Ice Harbor Dam, 2008.

A3. The tag and/or tagging method does not significantly affect the subsequent behavior or survival of the marked individual.

Assumption A3 was not tested for validation in this study. 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.

A4. 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 2 (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 69 radio transmitters throughout the spring 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. No tags failed prior to the preprogrammed shut-down after 10 d (Appendix Table A2). Maximum median travel time from release to Ice Harbor Dam was 3.9 d overall, with less than 1% of the fish overall taking 8 days or more to reach Ice Harbor Dam (Table 12).

Appendix Table A2. Frequency of days tags lasted in tag life testing, 2008.

Tag life (d)	Number of tags	Percent of tags (%)
1	0	0
2	0	0
3	0	0
4	0	0
5	0	0
6	0	0
7	0	0
8	0	0
9	0	0
10	69	100

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).

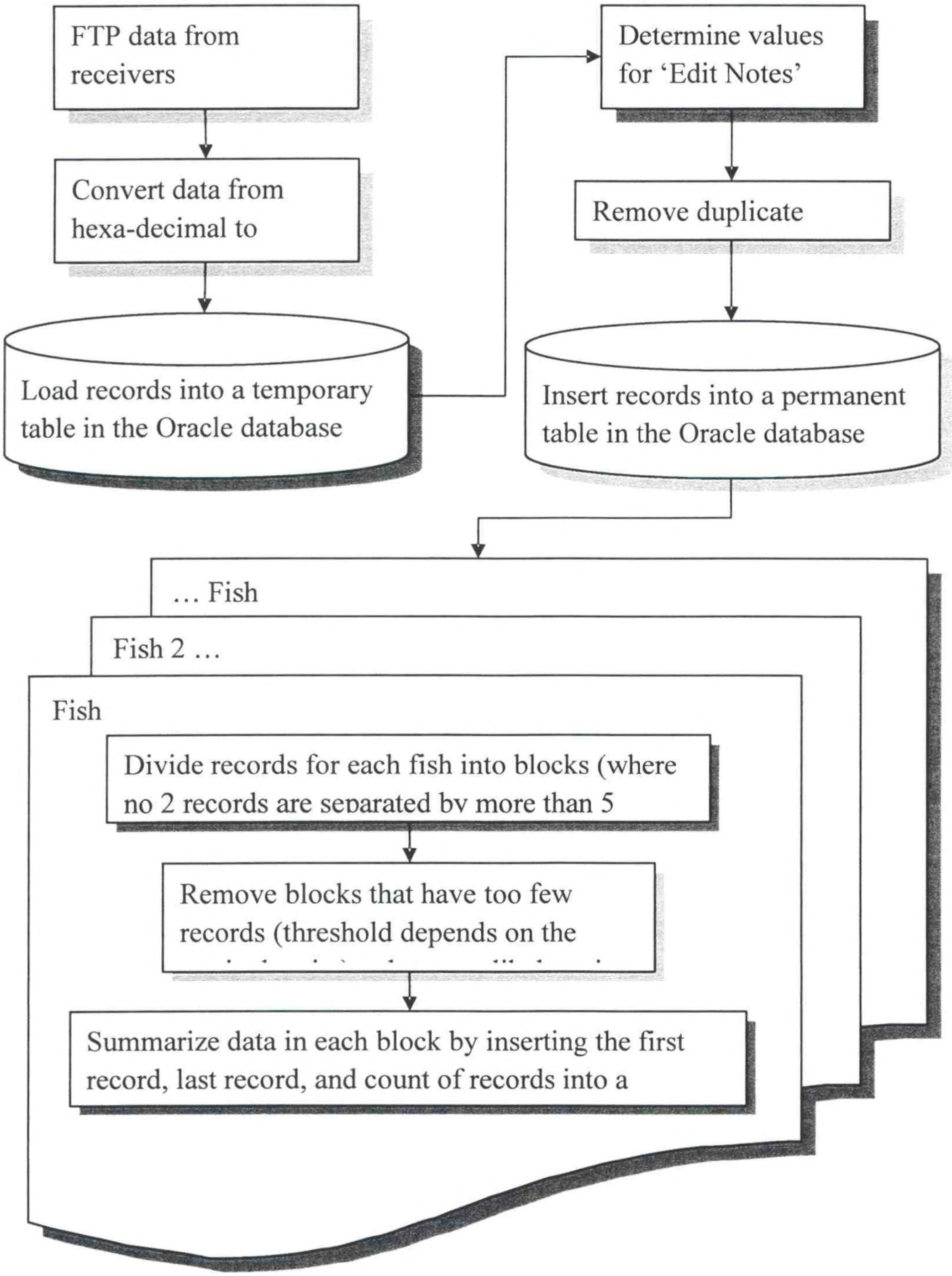
Gt end_time: Assigned to records occurring after the end time on a tag (they run for 10 days once activated).

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 min).

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, steelhead, and subyearling Chinook salmon, 2008.

APPENDIX C

Detection history data for yearling Chinook salmon, juvenile steelhead, and subyearling Chinook salmon

Appendix Table C1. Detection histories of radio-tagged fish released above Ice Harbor Dam to evaluate ***dam*** passage survival during spring operations for Chinook salmon and steelhead and during summer operations for subyearling Chinook salmon, 2008. Arrays are shown in Figure 1. Detection histories are 1 = detected, 0 = not detected.

Releases (n)	Detection history: Primary survival array	Detection history: Post primary array	n
	Yearling Chinook salmon		
Treatment group (1,699)	0	0	132
	1	0	239
	0	1	20
	1	1	1,308
	Juvenile steelhead		
Treatment group (1,951)	0	0	145
	1	0	270
	0	1	30
	1	1	1,506
	Subyearling Chinook salmon		
Treatment group (2,314)	0	0	324
	1	0	717
	0	1	24
	1	1	1,249

Appendix Table C2. Detection histories of radio-tagged fish released above Ice Harbor Dam to evaluate ***concrete*** passage survival during spring operations for Chinook salmon and steelhead and during summer operations for subyearling Chinook salmon, 2008. Arrays are shown in Figure 1. Detection histories are 1 = detected, 0 = not detected.

	Detection history: Primary survival array	Detection history: Post primary array	n
	Yearling Chinook salmon		
Treatment group (1,622)	0	0	55
	1	0	239
	0	1	20
	1	1	1,308
	Juvenile steelhead		
Treatment group (1,865)	0	0	60
	1	0	270
	0	1	29
	1	1	1,506
	Subyearling Chinook salmon		
Treatment group (908)	0	0	148
	1	0	717
	0	1	24
	1	1	1,249

Appendix Table C3. Detection histories of radio-tagged fish released above Ice Harbor Dam to evaluate ***spillway*** passage survival during spring operations for Chinook salmon and steelhead and during summer operations for subyearling Chinook salmon, 2008. Arrays are shown in Figure 1. Detection histories are 1 = detected, 0 = not detected.

	Detection history		
	Primary survival array	Post primary array	n
	Yearling Chinook salmon		
Treatment group (1,128)	0	0	40
	1	0	162
	0	1	13
	1	1	913
	Juvenile steelhead		
Treatment group (1,537)	0	0	46
	1	0	227
	0	1	18
	1	1	1,246
	Subyearling Chinook salmon		
Treatment group (1,430)	0	0	86
	1	0	473
	0	1	15
	1	1	856

Appendix Table C4. Detection histories of radio-tagged fish released above Ice Harbor Dam to evaluate passage survival through the ***JBS*** during spring operations for Chinook salmon and steelhead and during summer operations for subyearling Chinook salmon, 2008. Arrays are shown in Figure 1. Detection histories are 1 = detected, 0 = not detected.

	Detection history		
	Primary survival array	Post primary array	n
	Yearling Chinook salmon		
Treatment group (379)	0	0	9
	1	0	55
	0	1	5
	1	1	310
	Juvenile steelhead		
Treatment group (275)	0	0	14
	1	0	35
	0	1	8
	1	1	218
	Subyearling Chinook salmon		
Treatment group (583)	0	0	45
	1	0	194
	0	1	6
	1	1	338

Appendix Table C5. Detection histories of radio-tagged fish released above Ice Harbor Dam to evaluate ***turbine*** passage survival during spring operations for Chinook salmon and steelhead and during summer operations for subyearling Chinook salmon, 2008. Arrays are shown in Figure 1. Detection histories are 1 = detected, 0 = not detected.

	Detection history		
	Primary survival array	Post primary array	n
	Yearling Chinook salmon		
Treatment group (82)	0	0	5
	1	0	17
	0	1	1
	1	1	59
	Juvenile steelhead		
Treatment group (22)	0	0	0
	1	0	5
	0	1	0
	1	1	17
	Subyearling Chinook salmon		
Treatment group (81)	0	0	17
	1	0	28
	0	1	1
	1	1	35

Appendix Table C6. Detection histories of radio-tagged fish released above Ice Harbor Dam to evaluate ***RSW*** passage survival during spring operations for Chinook salmon and steelhead and during summer operations for subyearling Chinook salmon, 2008. Arrays are shown in Figure 1. Detection histories are 1 = detected, 0 = not detected.

	Detection history		
	Primary survival array	Post primary array	n
Treatment group (449)	yearling Chinook salmon		
	0	0	22
	1	0	66
	0	1	8
	1	1	353
Treatment group (819)	Juvenile steelhead		
	0	0	31
	1	0	124
	0	1	12
	1	1	652
	subyearling Chinook salmon		
Treatment group (560)	0	0	47
	1	0	177
	0	1	6
	1	1	330