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Fish Ecology Division

Northwest Fisheries Science Center

National Marine Fisheries Service

Seattle, Washington

by
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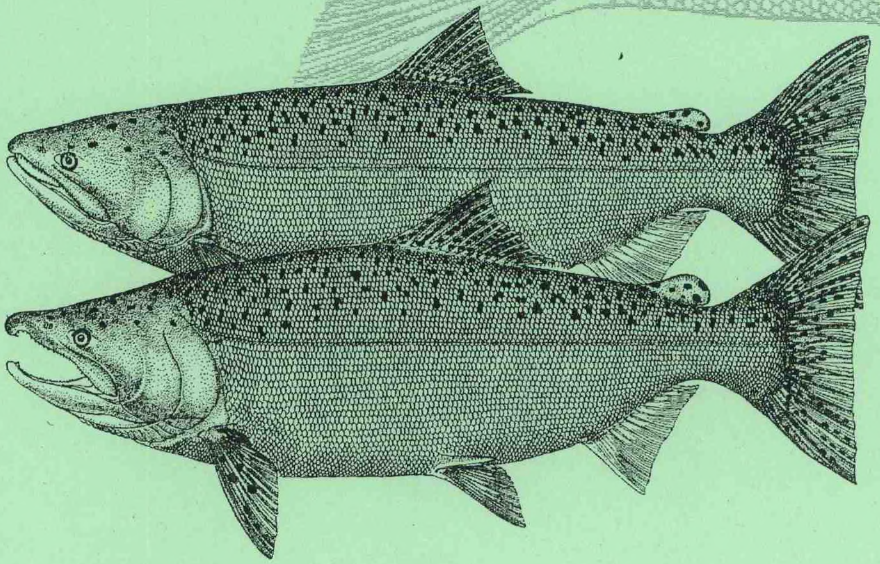

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Gordon A. Axel, Eric E. Hockersmith, Darren A. Ogden, Brian J. Burke, Kinsey E. Frick, and Benjamin P. Sandford

Report of research by

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Northwest Fisheries Science Center
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National Oceanic and Atmospheric Administration
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EXECUTIVE SUMMARY

In 2005, we evaluated behavior and passage distribution of yearling Chinook salmon and steelhead and estimated survival to ascertain the effects of a recently installed removable spillway weir (RSW) at Ice Harbor Dam. Fish were collected, PIT tagged, and surgically tagged with a radio transmitter at Lower Monumental Dam. We released 1,402 and 1,561 radio-tagged yearling Chinook salmon to the respective tailraces of Lower Monumental and Ice Harbor Dams, and an additional 1,886 fish were released into spill bays 7 and 8 at Lower Monumental Dam. We released 1,603 and 1,570 radio-tagged steelhead to the respective tailraces of Lower Monumental and Ice Harbor Dams.

Fish were released during day and night operations for 26 d from 3 to 28 May. Project operations at Ice Harbor Dam consisted of 2-d random blocks alternating between bulk spill and RSW operations. Mean spill discharge was nearly three times higher during bulk spill (85.8 kcfs) than during RSW spill (32.8 kcfs). Mean spill percentage during bulk and RSW spill treatments was 82 and 34%, respectively.

Median forebay residence time for yearling Chinook salmon passing Ice Harbor Dam was about 1 h longer for study fish approaching during RSW spill operations (2.3 h) than for those approaching during bulk spill (1.4 h). The overall passage distribution at Ice Harbor Dam during RSW spill for radio-tagged yearling Chinook salmon was 76.8% through the spillway (28.9% of which passed through the RSW), 15.5% through the juvenile bypass, 6.6% through turbines, and 1.1% through undetermined passage routes (Table 1).

During bulk spill, 97.4% passed via the spillway, 1.1% through the juvenile bypass, 0.4% through turbines, and 1.2% through undetermined passage routes. Fish passage efficiency (FPE) was 99.6% during bulk spill and 93.3% during RSW spill. Fish guidance efficiency (FGE) was 72.2% during bulk spill and 70.0% during RSW spill. Spill efficiency was 98.5% under bulk spill operations and 77.6% during RSW spill. Spill efficiency for the RSW was 28.9%. Mean spill effectiveness was 1.2:1 for bulk spill and 2.3:1 during RSW spill. Mean RSW spill effectiveness was 3.2:1.

Spillway passage survival was 0.97 (95% CI, 0.95-0.99) under bulk spill and 0.96 (95% CI, 0.94-0.98) during RSW operations with training spill. During RSW operations, estimated spillway passage survival was 0.97 (95% CI, 0.94-1.00) through the RSW spill bay and 0.95 (95% CI, 0.93-0.98) through the remaining spill bays combined (training spill passage survival). Relative dam survival was 0.93 (95% CI, 0.91-0.95) during bulk

Table 1. Final study results of conditions, passage behavior, and relative survival for radio-tagged yearling Chinook salmon at Ice Harbor Dam under two operations, 2005 (95% CI in parentheses).

	Forebay conditions	
	RSW on	Bulk spill/RSW off
Conditions		
Average project discharge (kcfs)	96	105
Average spill discharge (kcfs)	33 (34%)	86 (82%)
Average RSW discharge (kcfs)	9 (9%)	---
Average training flow discharge (kcfs)	24 (25%)	---
Average tailwater elevation (ft msl)	345.5	345.3
Average water temperature (°C)	12.5	12.6
Average Secchi depth (m)	1.1	1.0
Passage metric		
Median forebay delay (h)	2.3	1.4
Spillway passage (%)	77	97
JBS passage (%)	16	1
Turbine passage (%)	7	<1
RSW passage (%)	29	---
Unknown route (%)	1	1
FPE (%)	93.3	99.6
Spill efficiency (%)	77.6	98.5
Spill effectiveness	2.27	1.19
RSW effectiveness	3.15	---
FGE (%)	70.0	72.2
Median tailrace egress (min)	2.8	3.0
Relative survival		
Relative dam survival (%)	94.5 (92.5-96.5)	92.8 (90.7-95.0)
Relative concrete survival (%)	96.1 (94.2-98.1)	96.8 (94.9-98.8)
Relative spillway survival (%)	95.8 (93.7-97.9)	97.1 (95.2-99.0)
Relative RSW survival (%)	97.0 (94.2-99.9)	---
Relative training spill survival (no RSW) (%)	95.1 (92.6-97.6)	---
Relative JBS survival (%)	99.7 (96.8-102.7)	---

spill and 0.94 (95% CI, 0.92-0.96) during RSW spill operations. Project operations during the time that the RSW was spilling directed a larger portion of fish toward the powerhouse, and this enabled us to measure bypass survival, which was 1.00 (95% CI, 0.97-1.03).

Insufficient numbers of tagged fish passed through the powerhouse during bulk spill operations to estimate survival through turbines or the juvenile bypass system. Concrete survival, or survival estimated for all study fish that passed the project, was 0.97 (95% CI, 0.95-0.99) during bulk spill and 0.96 (95% CI, 0.94-0.98) during RSW spill operations.

Median forebay residence time for juvenile steelhead passing Ice Harbor Dam was slightly longer for study fish approaching during RSW spill operations (1.9 h) than for those approaching during bulk spill (1.5 h). The overall passage distribution at Ice Harbor Dam during RSW operation was 76.1% through the spillway (46.7% of which passed through the RSW), 20.4% through the juvenile bypass, 2.3% through turbines, and 1.1% through undetermined passage routes (Table 2). During bulk spill, 96.0% passed via the spillway, 2.2% through the juvenile bypass, 0.8% through turbines; and 1.0% through undetermined passage routes. FPE was 99.2% during bulk spill and 97.8% during RSW spill. FGE was 73.7% during bulk spill and 90.6% during RSW spill. Spill efficiency was 96.9% under bulk spill operations and 77.0% during RSW spill. Spill efficiency for the RSW was 46.7%. Mean spill effectiveness was 1.2:1 for bulk spill and 2.2:1 during RSW spill. Mean RSW spill effectiveness was 5.1:1.

Spillway passage survival was 1.00 (95% CI, 0.97-1.03) under bulk spill operations and 0.98 (95% CI, 0.95-1.01) during RSW operations with training spill. During RSW operations, estimated survival was 0.99 (95% CI, 0.95-1.02) through the RSW spill bay and 0.97 (95% CI, 0.93-1.02) through all other spill bays combined (i.e., survival during training spill). Relative dam survival during bulk spill was 0.93 (95% CI, 0.90-0.96) and 0.91 (95% CI, 0.88-0.94) during RSW operations. Insufficient numbers of tagged steelhead passed through the powerhouse to estimate survival through turbines or the juvenile bypass system. Concrete survival was 0.99 (95% CI, 0.97-1.02) during bulk spill and 0.97 (95% CI, 0.95-1.00) during RSW spill operations.

Table 2. Final study results of conditions, passage behavior, and relative survival for radio-tagged juvenile steelhead at Ice Harbor Dam under two operations, 2005 (95% CI in parentheses).

	Forebay conditions	
	RSW on	Bulk spill/RSW off
Operating conditions		
Average project discharge (kcfs)	96	105
Average spill discharge (kcfs)	33 (34%)	86 (82%)
Average RSW discharge (kcfs)	9 (9%)	---
Average training flow discharge (kcfs)	24 (25%)	---
Average tailwater elevation (ft msl)	345.5	345.3
Average water temperature (°C)	12.5	12.6
Average Secchi depth (m)	1.1	1.0
Passage metric		
Median forebay delay (h)	1.9	1.5
Spillway passage (%)	76	96
JBS passage (%)	20	2
Turbine passage (%)	2	1
RSW passage (%)	47	---
Unknown route (%)	1	1
FPE (%)	97.8	99.2
Spill efficiency (%)	77.0	96.9
Spill effectiveness	2.24	1.17
RSW effectiveness	5.09	---
FGE (%)	90.6	73.7
Median tailrace egress (min)	2.5	3.1
Relative survival (95% CI)		
Relative dam survival (%)	90.8 (87.7-93.9)	93.2 (90.0-96.4)
Relative concrete survival (%)	97.3 (94.6-100.1)	99.3 (96.5-102.1)
Relative spillway survival (%)	98.0 (95.1-101.0)	100.0 (97.2-1.027)
Relative RSW survival (%)	98.5 (95.0-102.0)	---
Relative training spill survival (no RSW) (%)	97.3 (92.9-101.6)	---
Relative JBS survival (%)	101.5 (97.6-105.5)	---

CONTENTS

INTRODUCTION

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

The spillway has long been considered the safest passage route for migrating juvenile salmonids at Columbia and Snake River dams. Holmes (1952) reported survival estimates of 96 (weighted average) to 97% (pooled) for fish passing Bonneville Dam spillway during the 1940s. A review of 13 estimates of spillway mortality published through 1995 concluded that the most likely mortality rates for fish passing standard spill bays range from 0 to 2% (Whitney et al. 1997). Similarly, recent survival studies on juvenile salmonid passage through various routes at dams on the lower Snake River have indicated that survival was highest through spillways, followed by bypass systems, then turbines (Iwamoto et al. 1994; Muir et al. 1995a,b, 1996, 1998, 2001; Smith et al. 1998).

Pursuant to the National Marine Fisheries Service (NMFS) Biological Opinion (NMFS 2000), project operations at Lower Monumental Dam have relied on a combination of voluntary spill to improve hydrosystem passage survival and collection of fish for transportation to improve smolt-to-adult return rates for migrating juvenile salmonids. Efforts to improve juvenile salmonid passage and survival at Ice Harbor Dam have focused on increasing the proportion of fish passing via voluntary spill.

Surface collection and bypass systems have been identified as a viable alternative for increasing survival and FPE for migrating juvenile salmonids at hydroelectric dams on the Snake and Columbia Rivers. Studies to evaluate a removable spillway weir (RSW) that was installed at Lower Granite Dam in 2001 have indicated that the RSW is an effective and safe means of passing juvenile migrant 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 using only 8.5% of total discharge. In 2003, passage effectiveness ratios were 8.3-9.9:1 through the RSW, and survival for radio-tagged fish passing through the RSW was estimated at 98% (±2.3%).

Juvenile anadromous salmonids in Columbia River Basin generally migrate in the upper 3 to 6 m of the water column. However, at dams on the lower Columbia and Snake Rivers, fish must dive to depths of 15 to 18 m in order to enter juvenile passage routes such as turbine intakes and gated spill bays. Engineers and biologists from the USACE developed the RSW to provide surface-oriented spillway passage. The RSW is attached to the upstream face of a spill bay on a traditional spillway, allowing juvenile salmonids to pass the spillway near the water surface under lower accelerations and lower pressures. This provides a more efficient and less stressful spillway passage route. The design of the RSW is different from existing spill bays, whose gates open 15 m below the water surface at the face of the dam and pass juvenile fish under high pressure and high velocities. In the lower Snake River, RSWs were installed at Lower Granite Dam in 2001 and at Ice Harbor Dam in 2005. An RSW is scheduled for installation at Lower Monumental Dam prior to the spring 2007 juvenile migration.

Previous studies at Ice Harbor Dam have shown that the majority of spring migrants pass through the spillway (Eppard et al. 2005a,b; Axel et al. 2006) largely due to high spill levels. In 2004, we evaluated juvenile yearling Chinook salmon and steelhead behavior, passage distribution, and survival associated with two different dam operations: bulk spill to the maximum allowable total dissolved gas level using large spill openings vs. flat spill utilizing more bays at lower gate openings. Results indicated much superior passage metrics and survival estimates for fish passing during the bulk spill treatments (Axel et al. 2006, Eppard et al. 2006).

During 2005, we utilized radiotelemetry to determine variations in behavior, passage distribution, and survival of juvenile yearling Chinook salmon and steelhead during two different operational conditions: a bulk spill pattern, with volume increased to the maximum dissolved gas level and with no RSW vs. an RSW spill pattern, consisting of a reasonable level of "training spill," or water spilled through the spillway containing the RSW to guide fish toward that spillway.

METHODS

Study Area

The study area included the 119-km reach of the Snake and Columbia Rivers from Lower Monumental Dam, located at river kilometer (rkm) 589 on the lower Snake River, to McNary Dam on the lower Columbia River (Figure 1). McNary Dam, the fourth dam on the Columbia River, is located at rkm 470. The focal point of the study is Ice Harbor Dam located at rkm 538 on the lower Snake River.

Fish Collection, Tagging, and Release

River-run juvenile yearling Chinook salmon and steelhead were collected at the Lower Monumental Dam smolt collection facility from 2 to 26 May. We also collected fish from the Little Goose Dam smolt collection facility in order to maintain sample sizes because numbers of fish arriving at the Lower Monumental collection facility decreased during the collection period. We chose fish that did not have any gross injury or deformity and that were at least 120 mm in length and 15 g in weight. Only fish that were not previously PIT tagged were used. Fish were anesthetized with tricaine methanesulfate and sorted in a recirculating anesthetic system. Fish for treatment and reference release groups were transferred through a water-filled 10.2-cm hose to a 935-L holding tank. Following collection and sorting, fish were maintained via flow-through river water and held for 24 h prior to radio transmitter implantation.

Radio tags were purchased from Advanced Telemetry Systems Inc.,[1] had a user-defined tag life of 10 d, and were pulse-coded for unique identification of individual fish at 30 MHz. Each radio tag measured 14 mm in length by 6 mm in diameter and weighed 0.9 g in air.

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. Immediately following tagging, fish were placed into a 19-L recovery container (2 fish per container) with aeration until recovery from the anesthesia. Recovery containers were then closed and transferred to a 1,152-L holding tank designed to accommodate up to 28 containers. Fish holding containers were perforated with 1.3-cm holes in the top 30.5 cm of the container to allow an exchange of

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

water during holding. All holding tanks were supplied with flow-through water during tagging and holding and were aerated with oxygen during transportation to release locations. After tagging, fish were held a minimum of 24 h with flow-through water for recovery and determination of post-tagging mortality. Pre- and post-tagging temperatures at Lower Monumental Dam ranged between 11.3 and 12.7°C.

After the post-tagging recovery period, radio-tagged fish were moved in their recovery containers from the holding area to release areas (Lower Monumental Dam and Ice Harbor Dam tailraces). Release groups were transferred from holding tanks to a release tank mounted on an 8.5 × 2.4-m barge, transported to the release location, and released mid-channel water-to-water.

Yearling Chinook Salmon

Daytime releases of yearling Chinook salmon at Ice Harbor Dam occurred between 0900 and 1700 PDT, and nighttime releases were made between 2030 and 0500 PDT. We released 25 groups of approximately 31 fish during both day and night into the tailrace of Ice Harbor Dam. A total of 1,561 radio-tagged fish were released into the tailrace of Ice Harbor Dam. Release temperatures in the tailrace of Ice Harbor ranged between 11.8 and 13.2°C.

For a separate evaluation of survival during the same study period (3-27 May), we released 25 groups of approximately 56 fish into the tailrace of Lower Monumental Dam between 0900 and 1400 PDT. In conjunction with these releases, 23 groups of approximately 41 fish were released into both spill bays 7 and 8. These fish were also used for survival estimates at Ice Harbor Dam, given that their tags had adequate battery life remaining in order to pass through the Ice Harbor study area, and that data from these fish would the bolster sample sizes, increasing the precision of survival estimates. A total of 3,288 radio-tagged fish were released at Lower Monumental Dam. Release temperatures ranged between 11.5 and 13.0°C.

Juvenile Steelhead

For survival evaluations at Lower Monumental Dam, we released 25 groups of approximately 64 fish into the tailrace between 0900 and 1400 PDT. As with yearling Chinook salmon, we used these releases for survival estimates at both Lower Monumental and Ice Harbor Dam. A total of 1,603 radio-tagged fish were released into the tailrace of Lower Monumental Dam.

At Ice Harbor Dam, daytime releases of juvenile steelhead occurred between 0900 and 1700, and nighttime releases were made between 2030 and 0500. We released twenty-five groups of approximately 31 fish during both day and night into the tailrace of Ice Harbor Dam. A total of 1,570 radio-tagged fish were released into the tailrace of Ice Harbor Dam.

Survival Estimates

Estimates of survival from the tailrace of Lower Monumental Dam to the forebay of Ice Harbor Dam were made based on detection histories using the single-release (SR) model (Cormack 1964; Jolly 1965; Seber 1965). Survival estimates for the model use recapture records (in this case, detections) of single release groups. These estimates consider the probability that a tagged fish may pass the downstream boundary of the area in question without being detected. Thus, 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. For this purpose, we used data from detections at Goose Island, located 2 km below Ice Harbor Dam.

Previous studies indicated that dead, radio-tagged fish released at Ice Harbor Dam are not detected at the downstream survival transects (Axel et al. 2003); therefore, we could safely assume that fish detected at each transect did not die as a result of passage at Ice Harbor Dam. In order to ensure that this was the case in our observations, we released an additional number of dead, radio-tagged yearling Chinook and juvenile steelhead into the tailrace of Ice Harbor Dam under the two operating conditions tested.

Additional survival estimates provided for this evaluation were defined as follows:

Relative Dam Survival: Ratio of survival estimates for groups passing through the "effect zone," between the forebay (approximately 500 ft upstream) and the tailrace (approximately 1000 ft downstream) of the dam vs. those of groups released to the tailrace.

Relative Spillway Survival: Ratio of survival estimates for groups passing through the spillway vs. those released to the tailrace

Relative RSW Survival: Ratio of survival estimates between groups passing the dam through the RSW vs. those of groups released to the tailrace

Relative Training Flow Survival: Ratio of survival estimates for groups passing through the spillway (not including the RSW) vs. those for groups released to the tailrace while the RSW was operating

Relative Bypass Survival: Ratio of survival estimates for groups passing through the bypass system vs. those of groups released to the tailrace

Relative Concrete Survival: Ratio of survival estimates for groups passing through all routes of passage combined vs. those of groups released to the tailrace (forebay loss was not included in this estimate)

For estimates of dam survival through Ice Harbor Dam, we created temporal release groups, that is, treatment replicate groups that were composed of fish detected arriving at the dam during the same operation treatment block. Arriving fish were those detected at the telemetry transect located at the upstream edge of the Boat Restricted Zone (BRZ). These temporal release groups were then paired with reference groups released to the tailrace of Ice Harbor Dam during the same period. The ratio of pooled survival estimates for treatment to reference fish provides the relative survival estimate for the dam.

Relative spillway survival estimates used fish with detections on a spillway receiver and at least one subsequent detection on a stilling basin or tailrace receiver. This validated the assumption that a fish last detected on a spillway receiver actually passed the dam via the spillway. Spillway fish were grouped by spill treatment (RSW or bulk spill), and paired with reference fish released during that particular treatment block. Subsequent downstream detections at Sacajawea State Park and below were used for both dam and spillway survival estimation (Figure 1). We used the same criteria for the remaining relative survival estimates as well.

Key assumptions underlying the SR model must be met in order to obtain unbiased estimates of survival through specific reaches or areas. One such assumption is that radiotelemetry detection at a given site does not affect subsequent detection probabilities downstream from that site. Tests of model assumptions are presented in Appendix A. For a 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).

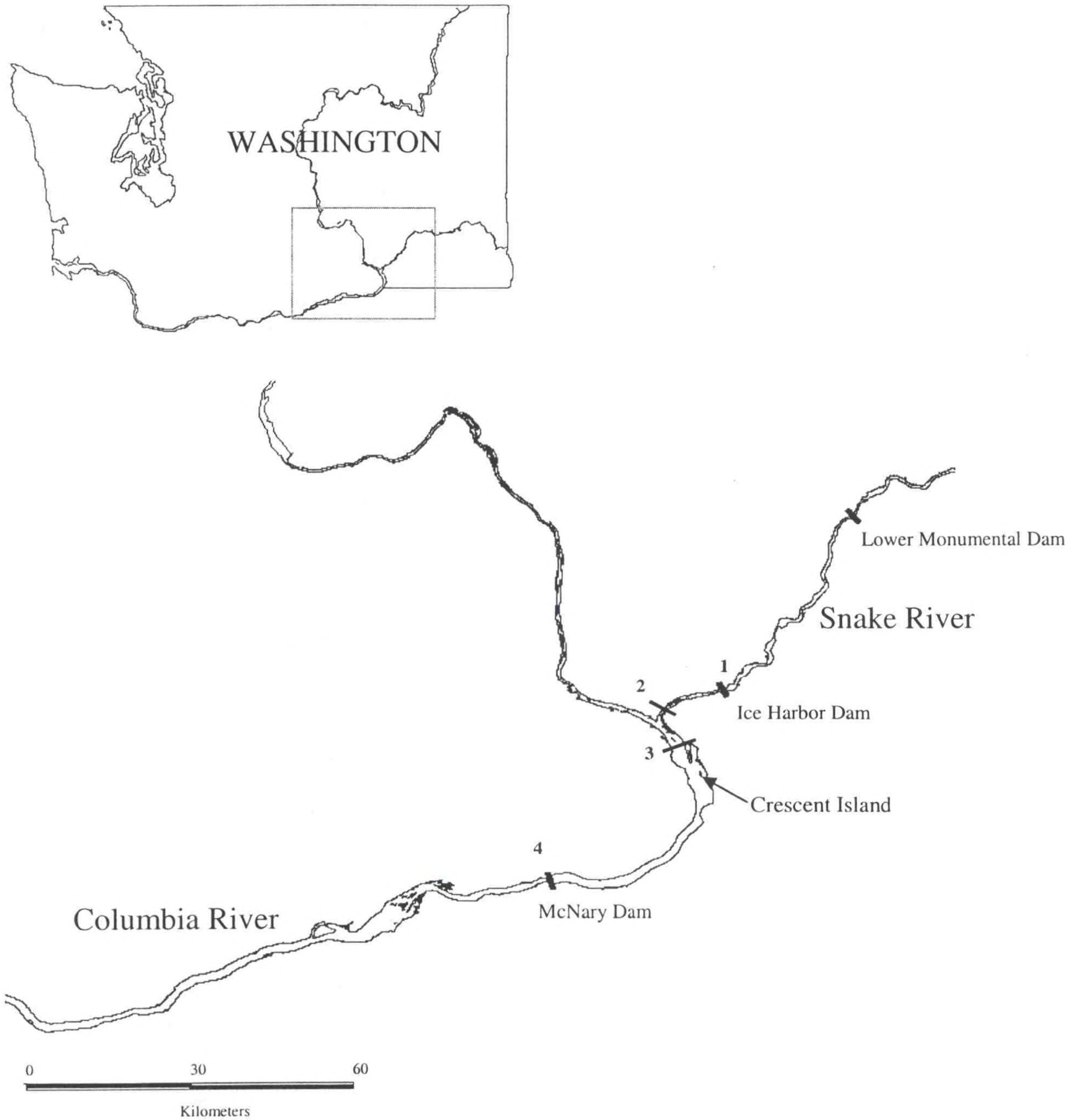

Figure 1. Study area showing location of radiotelemetry transects used for estimating partitioned reach survival for radio-tagged juvenile steelhead between Lower Monumental and McNary Dams, 2005. (Note: 1 = Ice Harbor Dam forebay; 2 = Sacajawea State Park; 3 = Burbank Railroad Bridge; and 4 = McNary Dam forebay.)

Passage Behavior and Timing

Travel, Arrival, and Passage Timing

Travel time was measured as the time from release to first detection at the entrance line of the next dam downstream. The first detection on the entrance line at Ice Harbor Dam was also used to determine arrival times at the project. Passage timing was determined by using the last detection in a passage route, and only fish with a subsequent detection in the stilling basin or immediate tailrace were used to calculate passage timing.

Forebay Residence Time

Forebay residence time at Ice Harbor Dam was measured from the first detection on the forebay entrance line to either the last detection during spillway passage or the first detection on a fish guidance screen. We compared forebay residence and tailrace egress times between temporal treatment groups using paired *t*-tests on the 50th and 90th passage percentiles.

Passage Route Distribution

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

We also placed two loop antennas on the hand rail at the collection channel exit located upstream from the juvenile bypass pipe. Fish that were detected on the fish guidance screen telemetry antennas but were not subsequently detected on the PIT-detection system or the telemetry monitor located in the collection channel were designated as 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 evaluations prior to 2000 (e.g., FGE was formerly calculated based on the percentage of fish caught in gatewells and fyke nets). Fish-passage metrics used for this evaluation were defined as follows:

Spill efficiency: Total number of fish passing the spillway divided by total number passing the dam

Spill effectiveness: Proportion of fish passing the spillway divided by proportion of water spilled

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

Fish guidance efficiency: Number of fish guided into the bypass system divided by total number passing via the powerhouse (i.e., the combined total for bypass system and turbine passage)

Tailrace Egress

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

Avian Predation

Predation from the Caspian Tern colony on Crescent Island, located 12.9 km downstream from the Snake River mouth (Figure 1), was measured by physical recovery of radio tags deposited on the island and by PIT-tag detection. Radio tags and PIT tags were recovered on the tern colony at Crescent Island during August 2005, after the birds had left the island. We physically recovered radio transmitters that were visible on the island and 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 NMFS and Real Time Research, Inc. (B. Ryan, NMFS, personal communication; see also Ryan et al. 2001; 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 and Little Goose Dam for 25 d from 2 May to 27 May. Tagging began after approximately 40% of the yearling Chinook salmon and 14% of the steelhead juvenile migrants had passed Lower Monumental Dam. Tagging was completed when 97% of both species had passed (Figure 2). Overall mean fork length was 143 mm for yearling Chinook and 203 mm for steelhead. This compared closely with the mean length of the unclipped run-at-large sampled at the smolt collection facility (139 mm for yearling Chinook and 197 mm for steelhead). Overall handling and tagging mortality was 2.2% for both species combined.

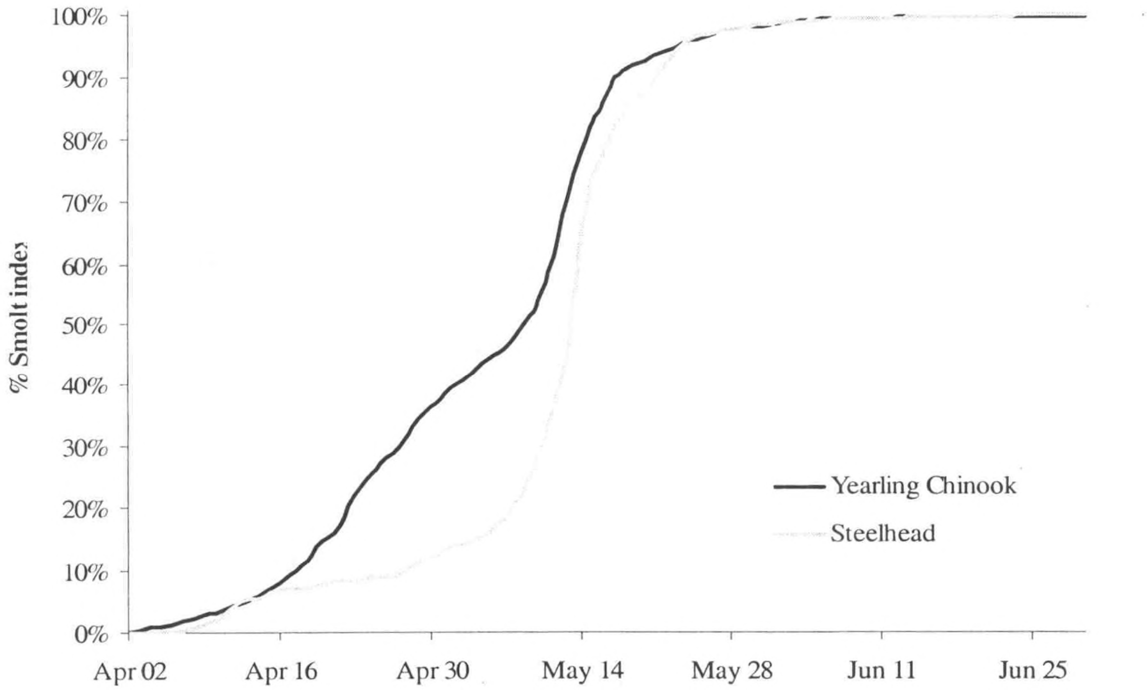

Figure 2. Percentage of juvenile steelhead and yearling Chinook salmon index estimated at Lower Monumental Dam during 2005. The shaded area depicts the tagging period and portion of the run targeted for tagging.

Dam Operations

Based on results from the 2004 spillway survival evaluation, the 2005 voluntary spill program followed a 2-d random block design, with a high volume of spill discharged in a bulk spill pattern as one block, and a lower volume of bulk spill utilizing the RSW as the second block. The "bulk" pattern typically utilized 6 or more spill bays with spillway gates for each bay are open at least 5 stops. Median spill volume during bulk spill was 91.4 thousand cubic feet per second (kcfs) while the median spill volume during RSW operation was 29.6 kcfs. Mean flow for each operation block is displayed in Figure 3. Mean daily total discharge during the study was 88.6 kcfs, ranging from 48.7 to 136.9 kcfs (Figure 4). Tables 3 and 4 display mean flow (kcfs) for each turbine unit and spill bay and mean gate openings (stops) by spill bay during the operational treatment blocks, respectively.

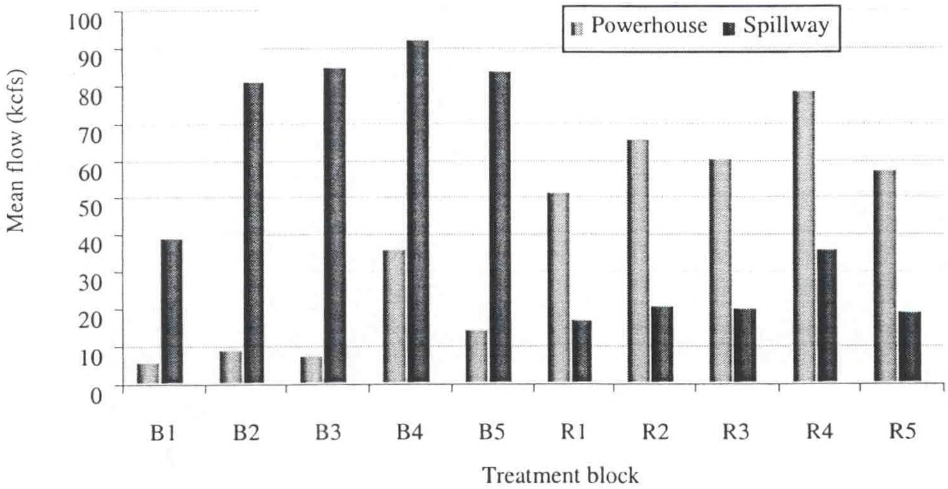

Figure 3. Mean flow (kcfs) for each treatment block for radio-tagged yearling Chinook salmon and juvenile steelhead arriving at Ice Harbor Dam, 2005.

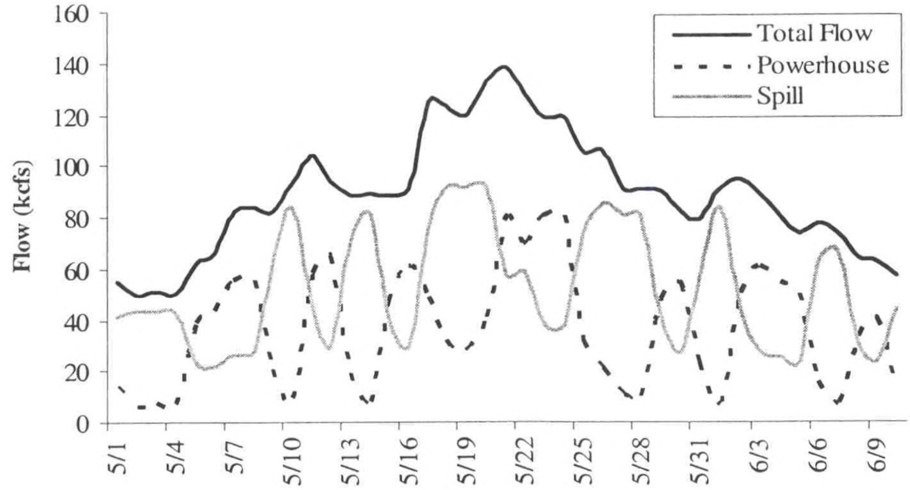

Figure 4. Mean daily project operations (kcfs) for radio-tagged yearling Chinook salmon and juvenile steelhead arriving at Ice Harbor Dam, 2005.

Table 3. Average flow (kcfs) by turbine unit and spillbay at Ice Harbor Dam during bulk (B) and RSW (R) spill operational test blocks, 2005.

		Average flow (kcfs)															
	Test	Turbines						Spill bays									
Date	block	1	2	3	4	5	6	1	RSW	3	4	5	6	7	8	9	10
May 4-5	B1	5.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.6	3.6	8.4	1.4	7.3	0.0	6.2	1.9
May 9-11	B2	6.8	0.0	1.5	0.0	0.0	0.0	5.8	0.0	10.9	11.5	11.5	11.6	11.6	4.5	11.4	1.7
May 13-15	B3	6.8	0.0	0.0	0.0	0.0	0.0	10.0	0.0	11.3	11.3	11.4	11.5	11.6	4.8	10.8	1.7
May 17-21	B4	11.0	0.0	11.1	3.8	0.0	9.3	10.0	0.0	11.7	11.6	11.7	11.6	11.6	10.0	11.7	1.7
May 25-29	B5	7.9	0.0	4.0	0.2	0.4	1.0	8.1	0.0	11.2	11.2	11.3	11.2	11.5	5.8	11.0	1.7
May 5-9	R1	11.4	0.2	11.6	12.1	3.1	12.3	4.9	8.9	8.1	0.0	0.0	0.0	0.0	0.0	1.6	1.7
May 11-13	R2	11.3	7.0	11.3	12.7	9.3	13.3	7.2	8.6	8.4	0.0	0.9	0.0	0.0	0.0	1.7	1.7
May 15-17	R3	11.8	0.7	11.8	13.5	8.2	13.8	7.8	8.8	8.4	0.0	0.2	0.0	0.0	0.0	1.7	1.7
May 21-25	R4	12.2	11.1	12.1	14.5	13.4	14.5	8.6	8.9	8.6	0.9	8.2	0.9	2.7	0.8	2.5	1.9
May 29-30	R5	11.3	0.0	11.4	13.4	7.2	13.3	6.7	8.8	8.4	0.1	0.1	0.1	0.1	0.0	1.7	1.7

Table 4. Average gate openings (stops) by spill bay at Ice Harbor Dam during bulk and RSW spill operational test blocks, 2005. RSW gate openings do not indicate relative volume of water passing, as compared to conventional gated spill.

	Test	Spill bays									
Date	block	1	RSW	3	4	5	6	7	8	9	10
May 4-5	B1	0.0	0.0	5.7	2.1	4.9	0.8	4.3	0.0	3.7	1.1
May 9-11	B2	3.4	0.0	6.5	6.8	6.8	6.9	6.9	2.7	6.8	1.0
May 13-15	B3	5.9	0.0	6.7	6.7	6.7	6.8	6.9	2.8	6.4	1.0
May 17-21	B4	5.9	0.0	6.9	6.9	6.9	6.9	6.9	5.9	6.9	1.0
May 25-29	B5	4.8	0.1	6.7	6.7	6.7	6.6	6.8	3.4	6.5	1.0
May 5-9	R1	2.9	7.4	4.8	0.0	0.0	0.0	0.0	0.0	1.0	1.0
May 11-13	R2	4.2	7.4	5.0	0.0	0.5	0.0	0.0	0.0	1.0	1.0
May 15-17	R3	4.6	7.4	4.9	0.0	0.1	0.0	0.0	0.0	1.0	1.0
May 21-25	R4	5.1	8.6	5.1	0.6	4.8	0.6	1.6	0.5	1.4	1.1
May 29-30	R5	4.0	8.4	4.9	0.0	0.0	0.0	0.0	0.0	1.0	1.0

Survival Estimates

Yearling Chinook Salmon

Spillway passage survival was 0.97 (95% CI, 0.95-0.99) under bulk spill operations and 0.96 (95% CI, 0.94-0.98) during RSW spill. During RSW deployment, estimated survival was 0.97 (95% CI, 0.94-1.00) through the RSW spill bay and 0.95 (95% CI, 0.93-0.98) through all other spill bays combined (training spill survival). Relative dam survival was 0.93 (95% CI, 0.91-0.95) during bulk spill and 0.94 (95% CI, 0.92-0.96) during RSW spill operations. Project operations during the time that the RSW was spilling directed a larger portion of fish toward the powerhouse enabling us to measure bypass survival which was 1.00 (95% CI, 0.97-1.03). Insufficient numbers of tagged fish passed through the powerhouse during bulk spill operations to estimate survival through turbines or the juvenile bypass system. Concrete survival, the survival estimate for all fish that passed the project, was 0.97 (95% CI, 0.95-0.99) during bulk spill and 0.96 (95% CI, 0.94-0.98) during RSW spill operations. We estimated pool survival between the tailrace of Lower Monumental Dam and the forebay of Ice Harbor Dam to be 0.89 (95% CI, 0.87–0.90).

Juvenile Steelhead

Spillway passage survival was 1.00 (95% CI, 0.97-1.03) under bulk spill operations and 0.98 (95% CI, 0.95-1.01) during RSW spill. RSW survival was 0.99 (95% CI, 0.95-1.02) with training spill survival estimated at 0.97 (95% CI, 0.93-1.02). Relative dam survival was 0.93 (95% CI, 0.90-0.96) during bulk spill and 0.91 (95% CI, 0.88-0.94) during RSW operations. Insufficient numbers of tagged steelhead passed through the powerhouse to estimate survival through turbines or the juvenile bypass system. Concrete survival during bulk and RSW spill operations was 0.99 (95% CI, 0.97-1.02) and 0.97 (95% CI, 0.95-1.00), respectively.

Latent Mortality Analysis

As detailed in Methods above, estimates of Ice Harbor project and passage route survival for radio-tagged yearling Chinook salmon and steelhead were constructed using the Cormack-Jolly-Seber single-release model (CJS). Estimates were generated for fish passing the dam (treatment) and released in the tailrace (reference) and the ratio of these was used to estimate the specific survival component through the project or through each passage route (i.e. spillway, RSW, turbine, and juvenile bypass system). The data used in generating these estimates was obtained from radio-telemetry detections downstream of Ice Harbor Dam at Sacajawea Park, just below the confluence of the Snake and Columbia

Rivers at the Burbank Railroad Bridge, and in the forebay of McNary Dam. Detections at Sacajawea Park were used as the primary "detection array" or "recapture period" and all detections downstream of this location were used as the secondary "detection array" in the CJS model.

The CJS model was used to estimate project survival from detections at the forebay entry line above Ice Harbor Dam to Sacajawea Park and to estimate passage survival from detection at the upstream end of each route to Sacajawea Park. Similarly, the survival of reference fish was estimated from fish released to the tailrace and detected at Sacajawea Park. Therefore, the ratio of survival estimates for treatment to reference fish produced appropriate estimates of project-specific survival (i.e. forebay to tailrace), or passage-route-specific survival (i.e. passage route to tailrace), *if* the "treatment effect" was fully expressed before fish passed Sacajawea Park. If fish were injured due to passage through a particular route and survived below Sacajawea Park before dying, then the model would underestimate the "true" treatment effect.

We examined whether this bias occurred by making similar ratio estimates using data only downstream of Sacajawea Park. If the bias occurred, these ratios would yield lower survival estimates than the original estimates. We did not make such estimates based on detections at the Burbank Railroad Bridge, as that location was quite close to Sacajawea Park. This left two options. One was to use radiotelemetry detections only from the forebay of McNary Dam, and the other was to use these detections in conjunction with PIT-tag detections at John Day and/or Bonneville Dams. The second option was not pursued primarily due to the relatively small numbers of downstream PIT-tag detections, as well as the possible violation of assumptions due to using two different tagging methodologies.

Therefore, we assessed survival estimates using only detections in the McNary Dam forebay. The proportions detected there were products of the estimates of "Survival from release to McNary forebay" *and* "detection at the McNary forebay." We assumed that the detection probability was similar between treatment and reference fish (assessed elsewhere in this report), and therefore, the ratio of the treatment to reference detection proportions was an estimate of passage route-to-tailrace survival. (Note that project survival could be estimated similarly, but we did not make those estimates under the assumption that the potential bias we were assessing would most likely occur for injury/mortality in passage routes rather than in the Ice Harbor Dam forebay.)

Weighted geometric means (as described in the report) of survival for each passage route under both dam operation conditions were compared between the Sacajawea Park-based and McNary Dam forebay-based approaches. We compared the estimates using *t*-tests under the null hypothesis that there was no difference between survival estimates derived from detections in McNary forebay and those derived from detections at Sacajawea Park. Since the study was not designed to evaluate these different approaches, only substantial differences would be expected to be significant ($\alpha = 0.05$).

Differences between Ice Harbor Dam passage-route survival estimates using these two approaches were fairly small (Table 5) for both radio-tagged yearling Chinook salmon and steelhead. In fact, the McNary forebay estimates were sometimes higher. There was little evidence to suggest that Ice Harbor Dam passage mortality was not expressed until after the fish had passed Sacajawea Park. It appears that Sacajawea Park is adequate as the primary detection location for radio-telemetry survival studies at Ice Harbor Dam.

Table 5. Weighted geometric means of survival for each passage route under both treatments were compared between the Sacajawea Park-based and McNary Dam forebay-based survival transects for radio-tagged yearling Chinook salmon and juvenile steelhead, 2005.

Test group	Passage route	Estimated mean relative survival: Ice Harbor to Sacajawea Park	SE	Ice Harbor to McNary Dam (Rel Rec)	SE	Difference	SE	*t*	*P*
		Yearling Chinook							
Bulk	Spill	0.97	0.02	0.93	0.02	0.04	0.03	1.41	0.21
	All	0.97	0.02	0.93	0.02	0.04	0.03	1.41	0.21
RSW on	Bypass	1.01	0.01	1.03	0.03	-0.02	0.03	0.63	0.55
	RSW	0.97	0.01	0.98	0.07	-0.01	0.07	0.14	0.89
	Spill	0.96	0.01	0.95	0.05	0.01	0.05	0.20	0.85
	RSW & Spill	0.96	0.01	0.95	0.05	0.01	0.05	0.20	0.85
	All	0.96	0.01	0.95	0.05	0.01	0.05	0.20	0.85
		Steelhead							
Bulk	Spill	1.00	0.02	0.98	0.12	0.02	0.12	0.16	0.87
	All	1.00	0.02	0.98	0.11	0.02	0.11	0.18	0.86
RSW on	Bypass	1.04	0.03	1.00	0.02	0.04	0.04	1.11	0.31
	RSW	0.99	0.01	1.00	0.05	-0.01	0.05	0.20	0.85
	Spill	0.98	0.02	0.96	0.06	0.02	0.06	0.32	0.76
	RSW & Spill	0.98	0.01	0.97	0.04	0.01	0.04	0.24	0.82
	All	0.98	0.02	0.96	0.04	0.02	0.04	0.45	0.67

Passage Behavior and Timing

Travel, Arrival, and Passage Timing

We detected 2,778 radio-tagged yearling Chinook salmon and 1,407 steelhead released at Lower Monumental Dam that approached the forebay of Ice Harbor Dam. We detected 1,082 radio-tagged yearling Chinook salmon and 1,013 steelhead released into the tailrace of Ice Harbor Dam that approached the forebay of McNary Dam. Travel times and migration rates were calculated for each reach (Tables 6 and 7).

For both yearling Chinook and steelhead, the first approach under a bulk spill treatment was primarily at the spillway, with very few fish being directed towards the powerhouse (Figures 5 and 6). During RSW treatments, the amount of flow through the spillway was greatly reduced and shifted to the powerhouse, which resulted in higher percentages of fish approaching the powerhouse and spill bay 1.

Hours of arrival and passage at Ice Harbor Dam were fairly consistent throughout both treatments of the study. Yearling Chinook salmon approached and passed during all hours of the day, while juvenile steelhead approached and passed primarily during the daylight hours. We plotted the percent of each species approaching and passing during both treatments and saw some interesting trends. Steelhead approached the project between 0500 and 2200 PST under both treatments, with passage slightly later, signifying relatively consistent short delays (Figures 7 and 8). Yearling Chinook arrived at Ice Harbor Dam across all hours, and during the bulk spill treatment, displayed similar results where passage trends suggest relatively low delay in the forebay (Figure 9). During the RSW treatment, we observed an irregular relationship between the arrival and passage plots which suggest some indifference in choosing a passage route, resulting in possibly longer delay times (Figure 10).

Table 6. Travel time and migration rate for radio-tagged juvenile steelhead and yearling Chinook released in the spillway and tailrace of Lower Monumental Dam and detected at the forebay entrance of Ice Harbor Dam, 2005.

Lower Monumental Dam to Ice Harbor Dam										
			Travel time (d)				Migration rate (km/h)			
	Released	Detected	Min	Max	Mean	SD	Min	Max	Mean	SD
Steelhead										
Tailrace	1,603	1,407	0.7	5.5	1.4	0.5	0.4	3.1	1.6	0.5
Yearling Chinook										
Spillway	1886	1407	0.8	6.6	1.8	0.7	0.3	2.8	1.3	0.4
Tailrace	1402	1249	0.7	5.6	1.6	0.6	0.4	3.0	1.6	0.5

Table 7. Travel time and migration rate for radio-tagged juvenile steelhead and yearling Chinook released in the tailrace of Ice Harbor Dam and detected at the forebay entrance of McNary Dam, 2005.

Ice Harbor Dam to McNary Dam										
			Travel time (d)				Migration rate (km/h)			
	Released	Detected	Min	Max	Mean	SD	Min	Max	Mean	SD
Steelhead										
Day			0.4	8.5	1.6	1.1	0.3	7.4	2.1	0.8
Night			0.4	7.5	1.5	0.7	0.4	7.4	2.0	0.6
Chinook										
Day			0.4	7.3	1.9	0.7	0.4	6.5	1.7	0.4
Night			0.4	6.8	1.7	0.6	0.4	7.8	1.9	0.4

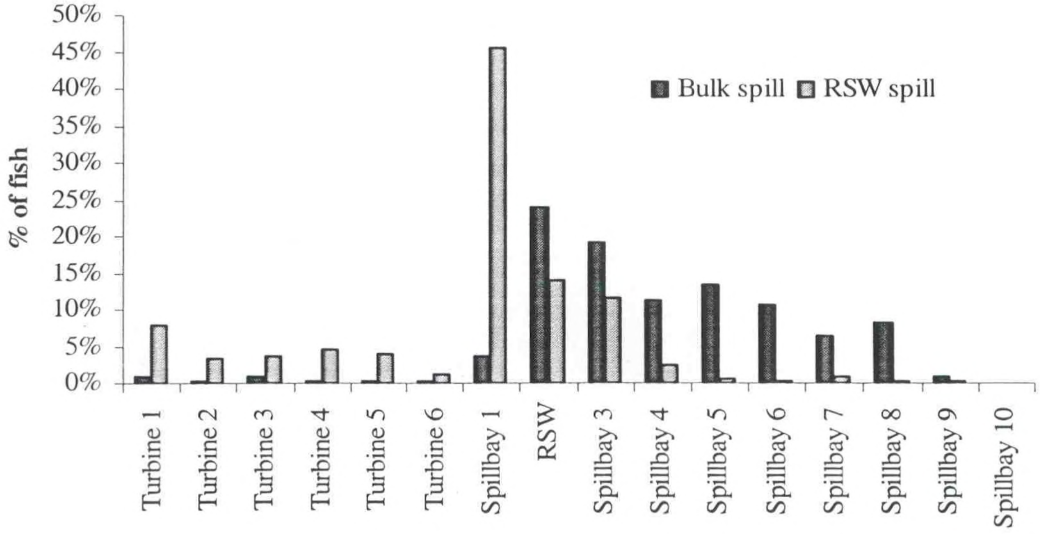

Figure 5. Percent of radio-tagged yearling Chinook salmon with first approach location at Ice Harbor Dam during two spill treatments, 2005.

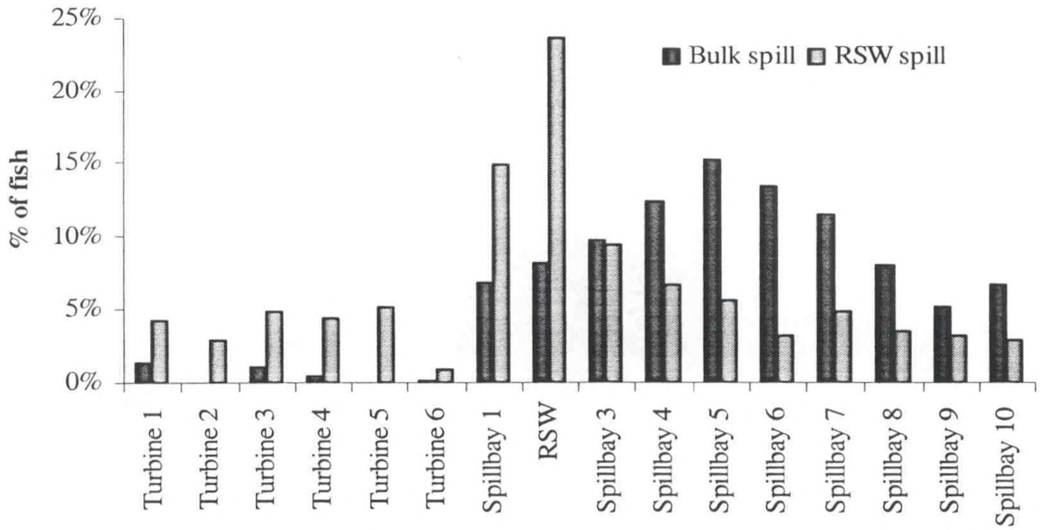

Figure 6. Percent of radio-tagged juvenile steelhead with first approach location at Ice Harbor Dam during two spill treatments, 2005.

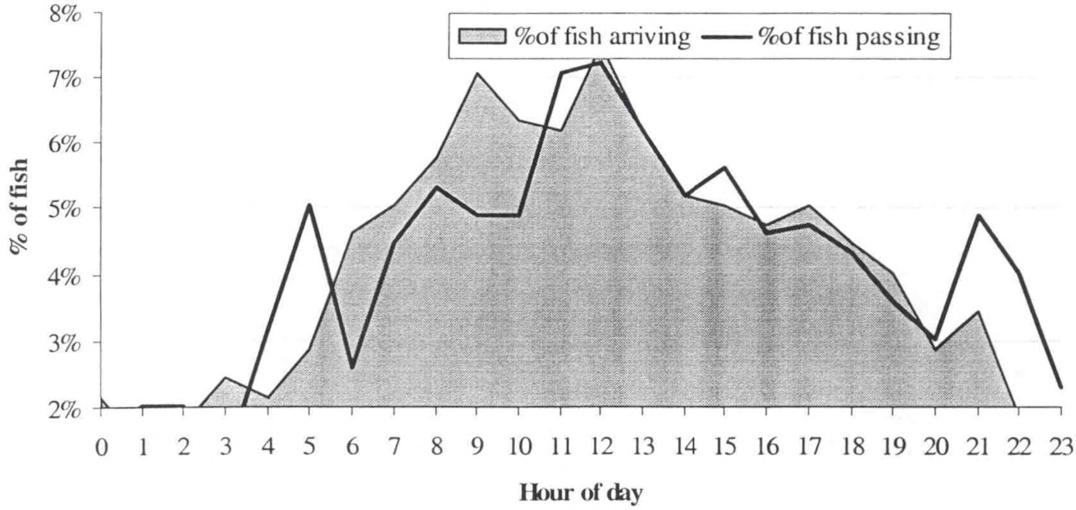

Figure 7. Percent of radio-tagged juvenile steelhead arriving and passing Ice Harbor Dam during RSW spill treatments, 2005.

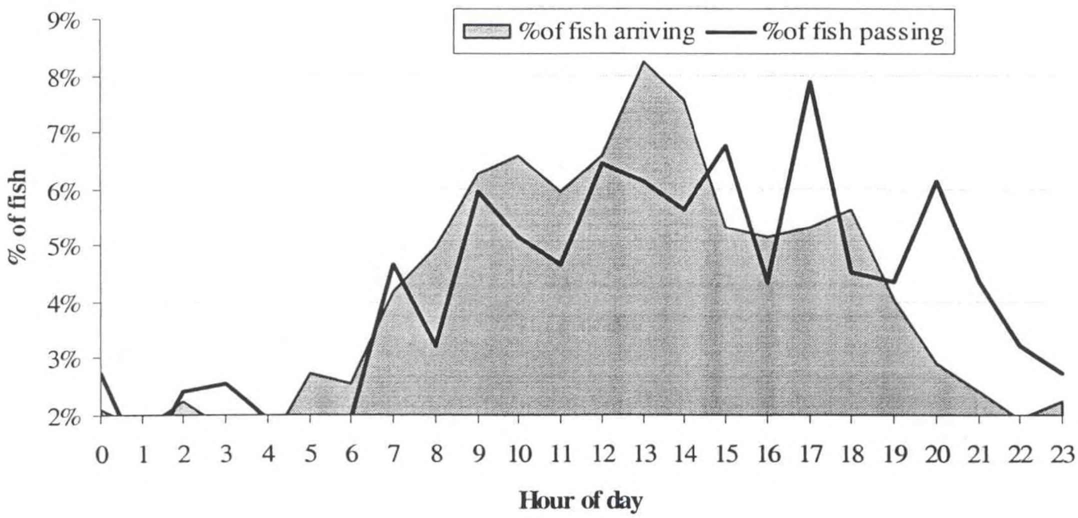

Figure 8. Percent of radio-tagged juvenile steelhead arriving and passing Ice Harbor Dam during bulk spill treatments, 2005.

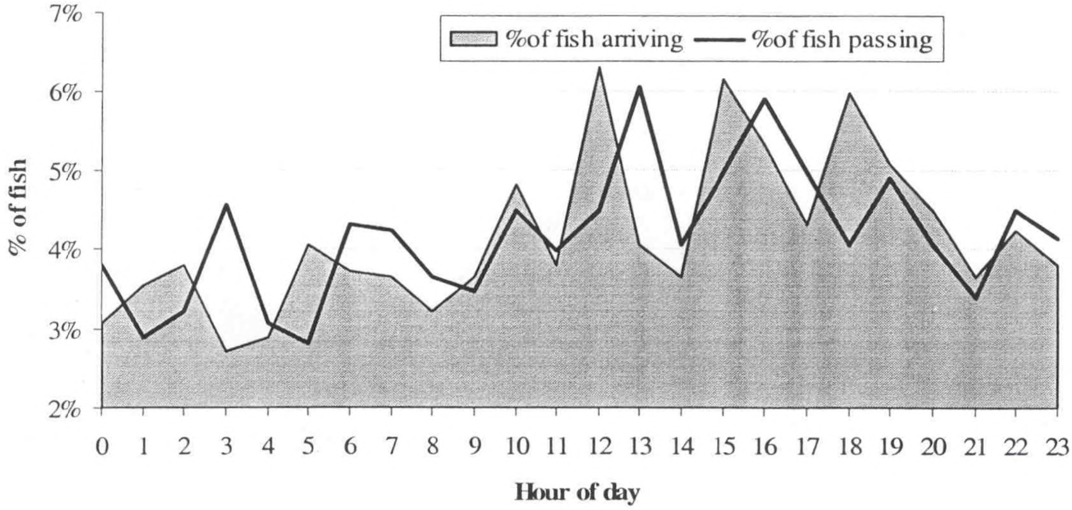

Figure 9. Percent of radio-tagged yearling Chinook salmon arriving and passing Ice Harbor Dam during bulk spill treatments, 2005.

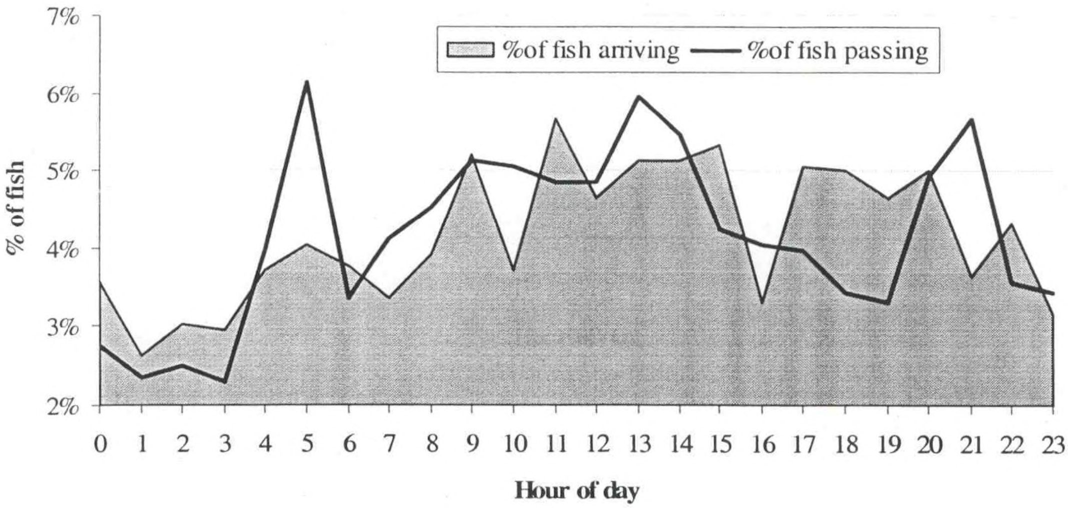

Figure 10. Percent of radio-tagged yearling Chinook salmon arriving and passing Ice Harbor Dam during RSW spill treatments, 2005.

Forebay Residence Time

Median forebay residence time was slightly longer for yearling Chinook salmon passing during RSW spill operations (2.3 h) than for those that passed during bulk spill (1.4 h; Figure 11); however, the difference was not statistically significant ($P = 0.163$) based on comparisons between spill conditions using paired *t*-tests on the 50th percentiles of the temporal replicate treatment groups (Figure 12). The two treatments displayed no statistically significant results as forebay residence times approach the 90th percentile ($P = 0.504$; Figure 13).

Median forebay residence time was longer for juvenile steelhead passing during RSW spill operations (1.9 h) than for those that passed during bulk spill (1.5 h; Figure 14); however, the difference was not statistically significant ($P = 0.592$) in comparisons between spill conditions using paired *t*-tests on the 50th percentiles of the temporal replicate treatment groups (Figure 15). The two treatments displayed similar results as forebay residence times approach the 90th percentile ($P = 0.855$; Figure 16).

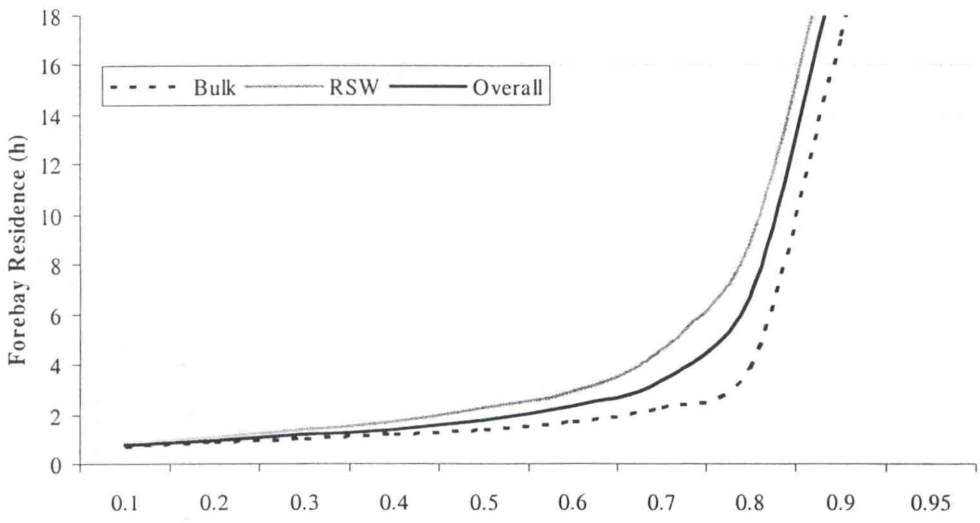

Figure 11. Forebay residence time versus the cumulative percent of radio-tagged yearling Chinook salmon passing Ice Harbor Dam under two different spill treatments, 2005.

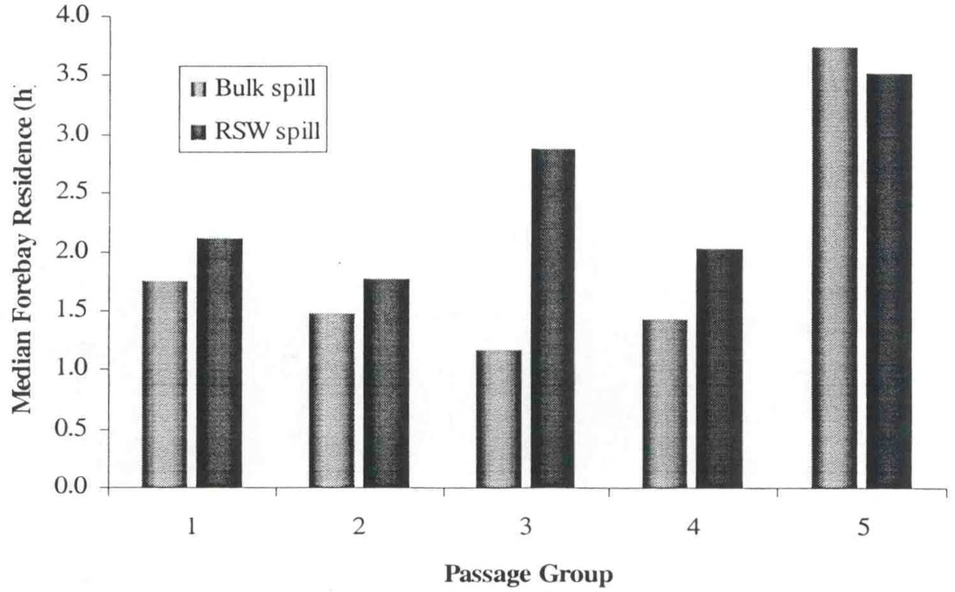

Figure 12. Paired 50th percentiles of forebay residence of radio-tagged yearling Chinook passing Ice Harbor Dam under two different spill treatments, 2005.

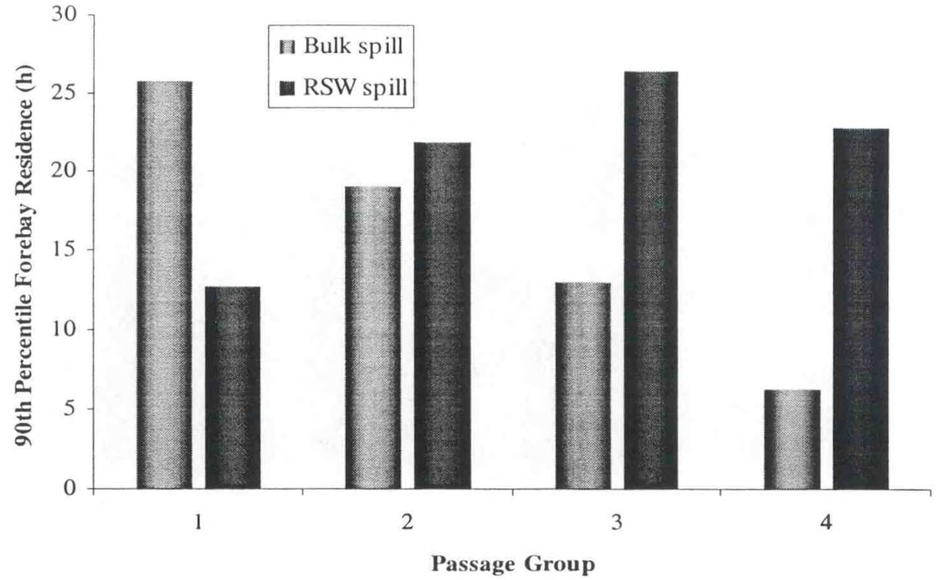

Figure 13. Paired 90th percentiles of forebay residence for radio-tagged yearling Chinook salmon passing Ice Harbor Dam under two different spill treatments, 2005.

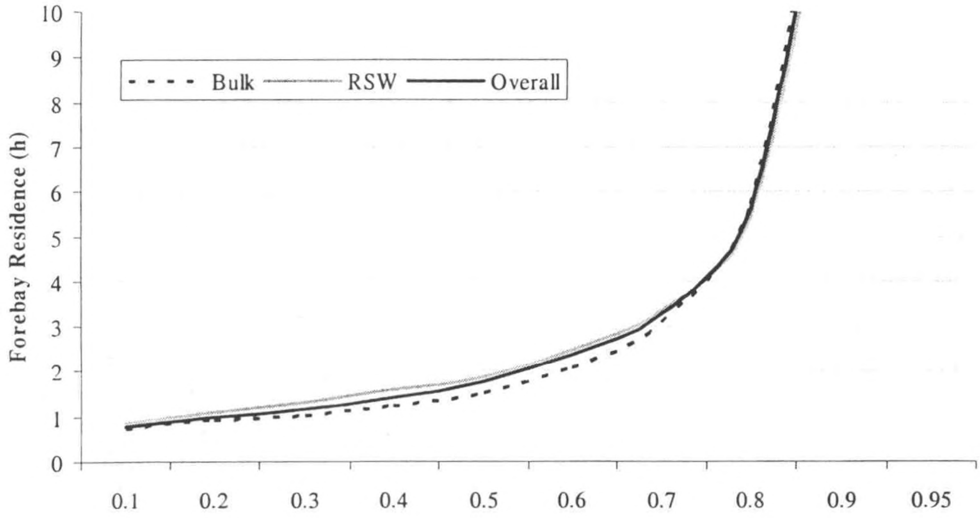

Figure 14. Forebay residence time versus the cumulative percent of radio-tagged juvenile steelhead passing Ice Harbor Dam under two different spill treatments, 2005.

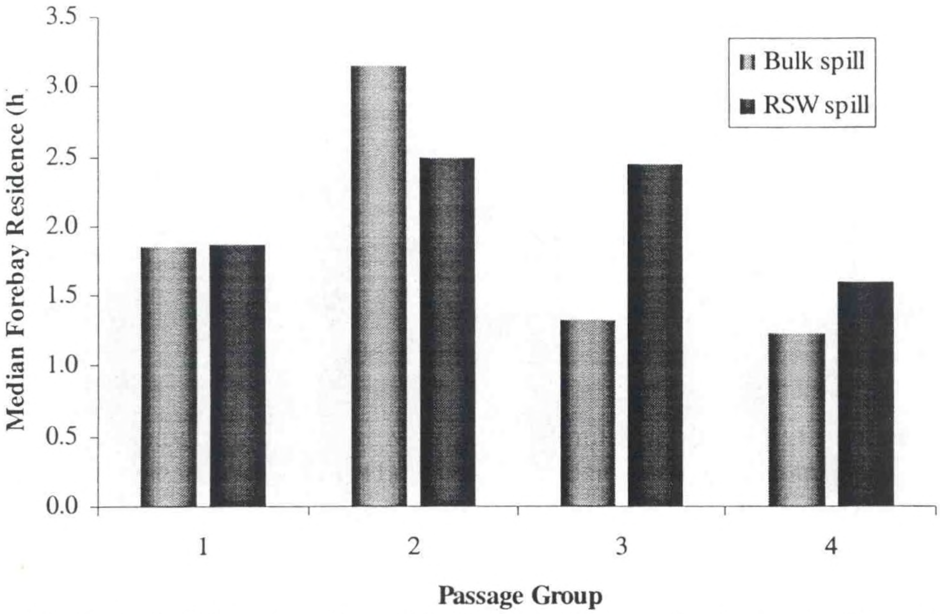

Figure 15. Paired 50th percentiles of forebay residence of radio-tagged juvenile steelhead passing Ice Harbor Dam under two different spill treatments, 2005.

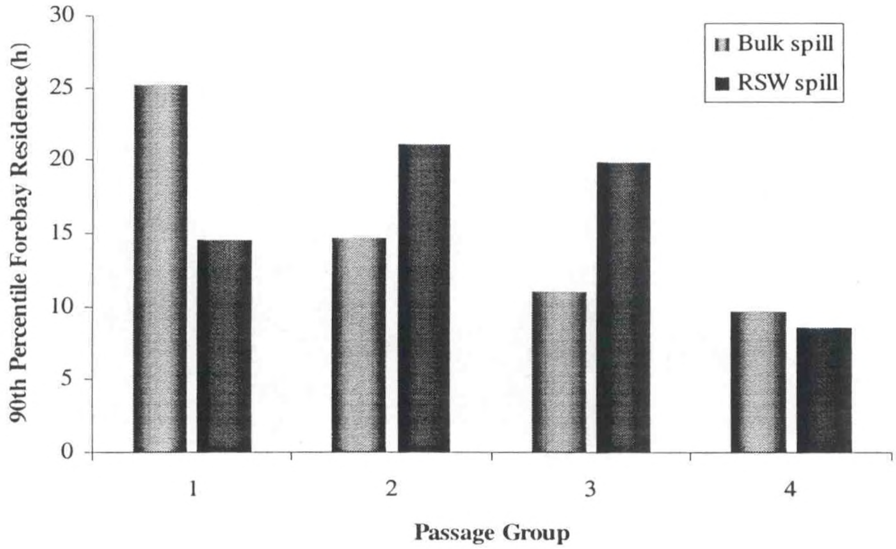

Figure 16. Paired 90th percentiles of forebay residence for radio-tagged juvenile steelhead passing Ice Harbor Dam under two different spill treatments, 2005.

Passage Route Distribution

During RSW spill treatments, overall passage distribution for radio-tagged yearling Chinook salmon was 76.8% (1,145) through the spillway (28.9% (431)of which passed through the RSW bay), 15.5% (231) through the juvenile bypass, and 6.6% (99) through turbine routes. Less than 1% (16) of these fish passed the project by an unknown route, and an additional 25 fish entered the forebay but did not pass the project. During bulk spill treatments 97.4% (1,180) of the fish passed via the spillway, with 1.1% (13) passing through the juvenile bypass system and 0.4% (5) passing through the turbine units. Less than 1% (14) of these fish passed the project by an unknown route, and an additional 51 fish entered the forebay but did not pass the project. Horizontal passage distribution during both spill treatments is shown in Figure 17.

Yearling Chinook salmon exhibited an unexpectedly higher proportion of passage through spill bay 1 during RSW operation. During midday, a higher percentage of yearling Chinook salmon passed through spill bay 1 than through the RSW (Figure 18). Further examination reveals that the mean powerhouse discharge was increasing during this time period, which may have resulted in more flow being directed downward towards spill bay 1 (Figure 19).

Overall passage distribution for radio-tagged juvenile steelhead was 88.1% through the spillway, 8.6% through the juvenile bypass, and 0.4% through turbines. Approximately 1.0% (13) of these fish passed the project by an unknown route, and an additional 85 fish entered the forebay but did not pass the project. During bulk spill treatments 97% (599) of the fish passed via the spillway with the other 2% (14) going through the bypass system and 1% (5) through the turbines. For the periods of RSW spill 47% (330) of the fish passed via the RSW, 30% (206) through the training spill, 21% (144) through the bypass system, and 2% (15) through the turbines. Horizontal spillway distribution during both spill treatments is shown in Figure 20.

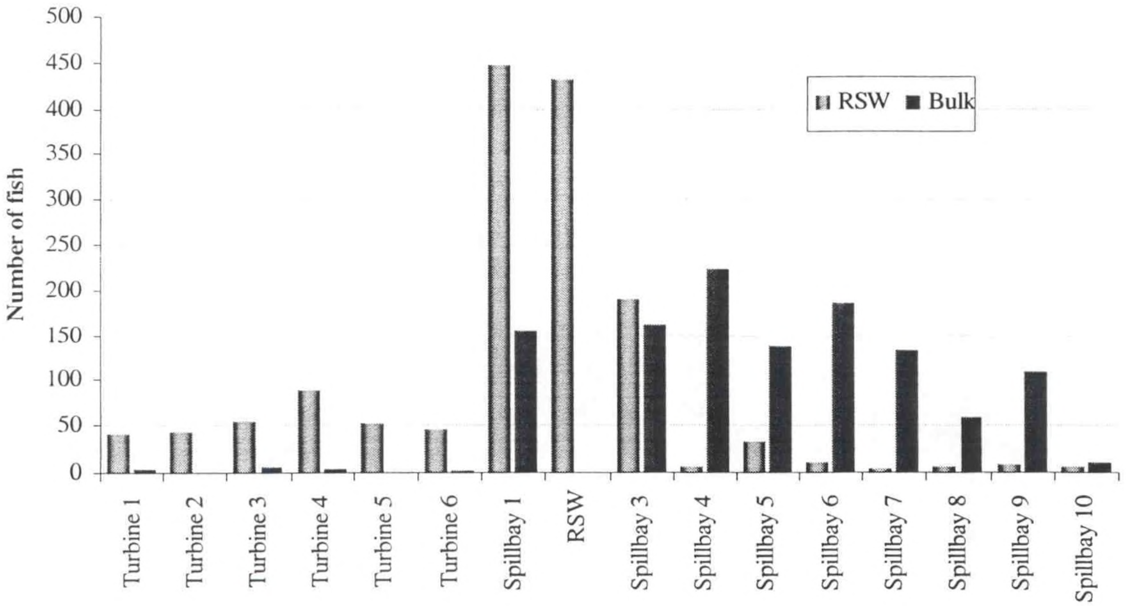

Figure 17. Horizontal passage distribution of radio-tagged juvenile yearling Chinook salmon during both spill treatments at Ice Harbor Dam, 2005.

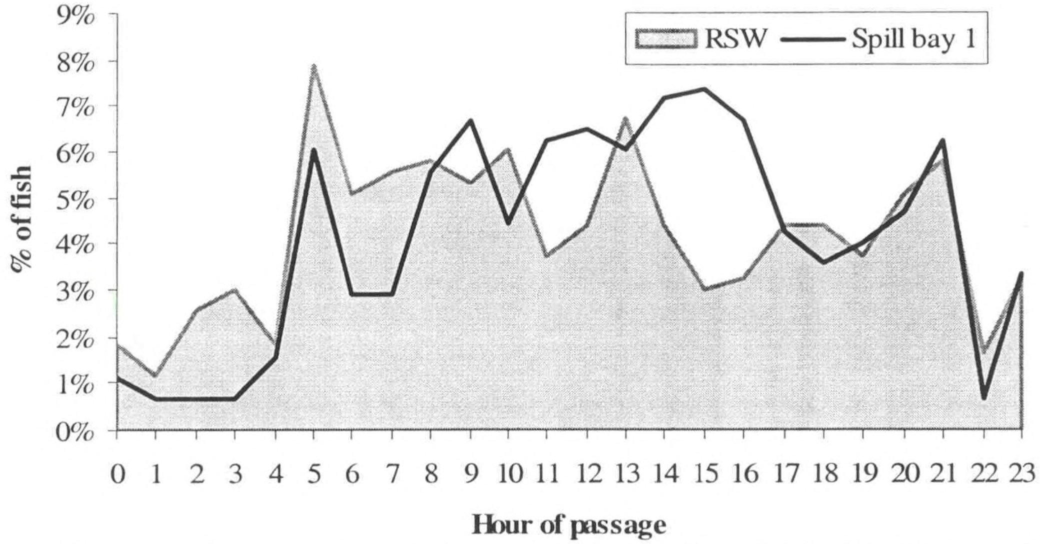

Figure 18. Hour of passage through the Removable Spillway Weir (RSW) and spill bay 1 during RSW spill treatments for radio-tagged yearling Chinook salmon at Ice Harbor Dam, 2005.

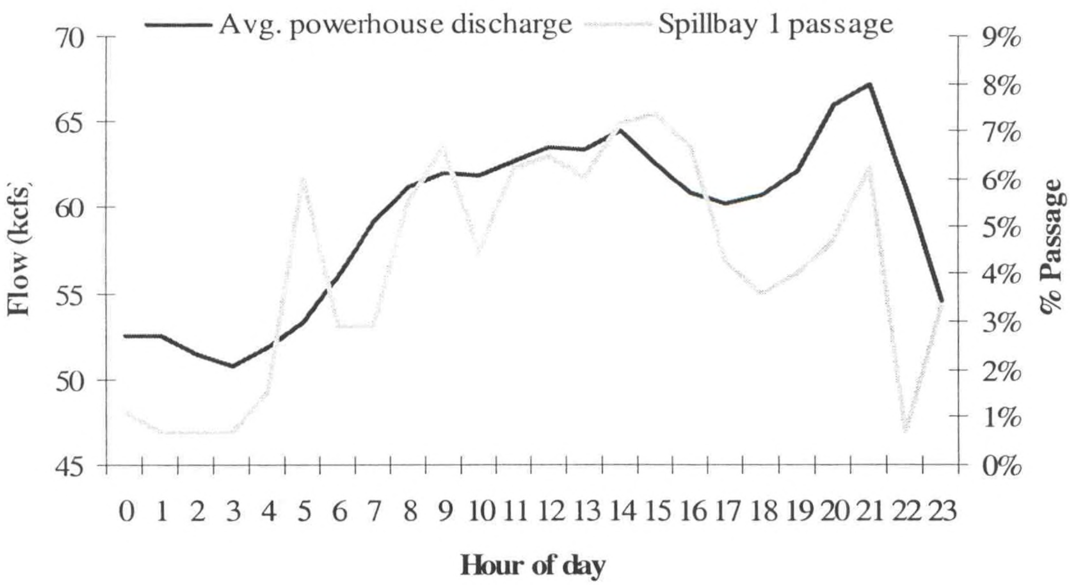

Figure 19. Hour of passage through spill bay 1 during RSW spill treatments for radio-tagged yearling Chinook salmon and mean powerhouse discharge at Ice Harbor Dam, 2005.

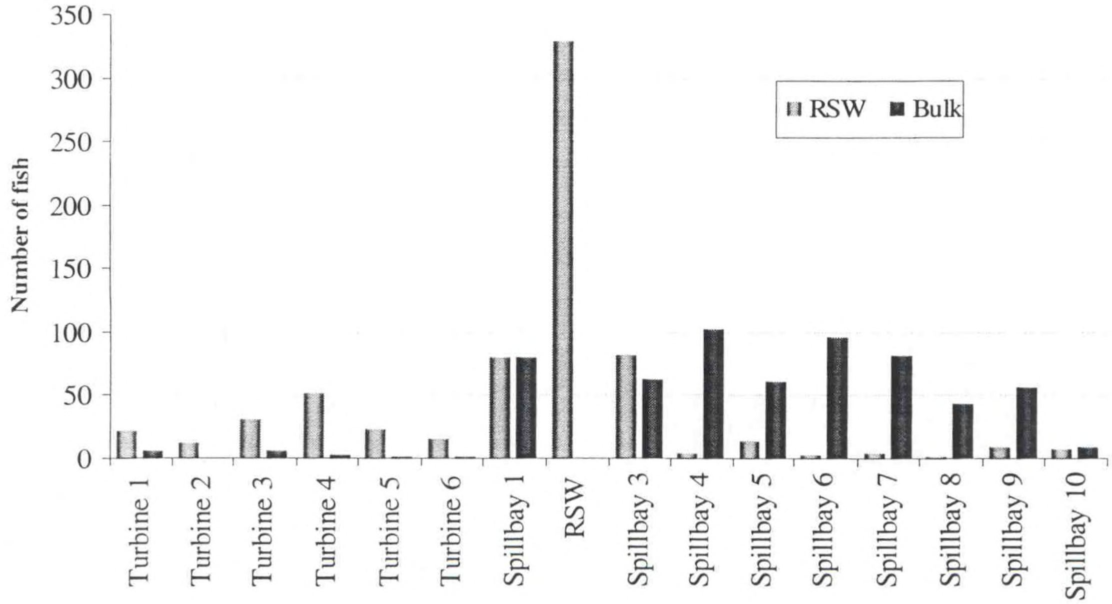

Figure 20. Horizontal passage distribution of radio-tagged juvenile steelhead during two spill treatments at Ice Harbor Dam, 2005.

Fish Passage Metrics

Fish passage efficiency for yearling Chinook salmon was 100% during bulk spill and 93% during RSW spill (Table 8). Fish guidance efficiency was 72% during bulk spill and 70% during RSW spill. Spill efficiency was 99% under bulk spill operations and 78% during RSW spill. Mean spill effectiveness was 1.2:1 for bulk spill and 2.3:1 for RSW spill, with RSW effectiveness measured at 3.2:1.

Fish passage efficiency for steelhead was 99% during bulk spill and 98% during RSW spill (Table 9). Fish guidance efficiency was 100% during bulk spill and 91% during RSW spill. Spill efficiency was 98% during bulk spill operations and 77% during RSW spill. Mean spill effectiveness was 1.2:1 for bulk spill and 2.1:1 for RSW spill, with RSW effectiveness measured at 5.1:1.

Table 8. Passage distribution and fish passage metrics for radio-tagged yearling Chinook salmon passing Ice Harbor Dam during bulk and RSW spill treatments, 2005.

			Passage route				Fish passage metrics		
Date	Spill treatment	Mean spill (kcfs)	Spillway	Bypass	Turbine	Total	Spill efficiency	FPE	FGE
May 9-11	Bulk 1	80.4	257	5	0	262	0.98	1.00	1.00
May 13-15	Bulk 2	84.3	244	1	1	246	0.99	1.00	0.50
May 17-21	Bulk 3	91.6	347	6	4	357	0.97	0.99	0.60
May 25-29	Bulk 4	83.0	324	1	0	325	1.00	1.00	1.00
May 31-June 2	Bulk 5	77.5	10	0	0	10	1.00	1.00	NA
	Totals		*1182*	*13*	*5*	*1200*	*0.99*	*1.00*	*0.72*
May 5-9	RSW 1	25.3	415	73	20	508	0.82	0.96	0.78
May 12-13	RSW 2	28.5	193	36	19	248	0.78	0.92	0.65
May 15-17	RSW 3	28.6	175	23	8	206	0.85	0.96	0.74
May 21-25	RSW 4	44.1	268	97	49	414	0.65	0.88	0.66
May 29-31	RSW 5	27.5	91	2	3	96	0.95	0.97	0.40
	Totals		*1142*	*231*	*99*	*1472*	*0.78*	*0.93*	*0.70*

Table 9. Passage distribution and fish passage metrics for radio-tagged juvenile steelhead passing Ice Harbor Dam during bulk and RSW spill treatments, 2005.

			Passage route				Fish passage metrics		
Date	Spill treatment	Mean spill (kcfs)	Spillway	Bypass	Turbine	Total	Spill efficiency	FPE	FGE
May 9-11	Bulk 1	80.4	136	1	1	138	0.99	0.99	0.50
May 13-15	Bulk 2	84.3	107	0	1	108	0.99	0.99	0.00
May 17-21	Bulk 3	91.6	137	9	2	148	0.93	0.99	0.82
May 25-29	Bulk 4	83.0	222	4	1	227	0.98	1.00	0.80
May 31-June 2	Bulk 5	77.5	0	0	0	0	NA	NA	NA
	Totals		*602*	*14*	*5*	*621*	*0.98*	*0.99*	*1.00*
May 5-9	RSW 1	25.3	225	34	4	263	0.86	0.98	0.89
May 12-13	RSW 2	28.5	103	17	2	122	0.84	0.98	0.89
May 15-17	RSW 3	28.6	67	33	3	103	0.65	0.97	0.92
May 21-25	RSW 4	44.1	132	60	6	198	0.67	0.97	0.91
May 29-31	RSW 5	27.5	6	0	0	6	1.00	1.00	NA
	Totals		*533*	*144*	*15*	*692*	*0.77*	*0.98*	*0.91*

Tailrace Egress

Median egress was longer for yearling Chinook salmon that passed during bulk spill (3.1 min) than for those that passed during RSW spill operations (2.8 min; Figure 21). This difference was found to be non-significant ($P = 0.246$) in comparisons of egress time between spill treatments using paired *t*-tests on the 50th percentiles of temporal replicate treatment groups (Figure 22). However, the difference between the two treatments became highly significant as tailrace egress times approach the 90th percentile ($P = 0.001$; Figure 23).

Median tailrace egress was longer for juvenile steelhead that passed during bulk spill operations (3.1 min) than for those that passed during RSW spill (2.5 min; Figure 24). This difference was found to be significant ($P = 0.060$) in comparisons of egress time between spill treatments using paired *t*-tests on the 50th percentiles of temporal replicate treatment groups (Figure 25). The difference between the two treatments became non-significant as tailrace egress times approach the 90th percentile ($P = 0.340$; Figure 26).

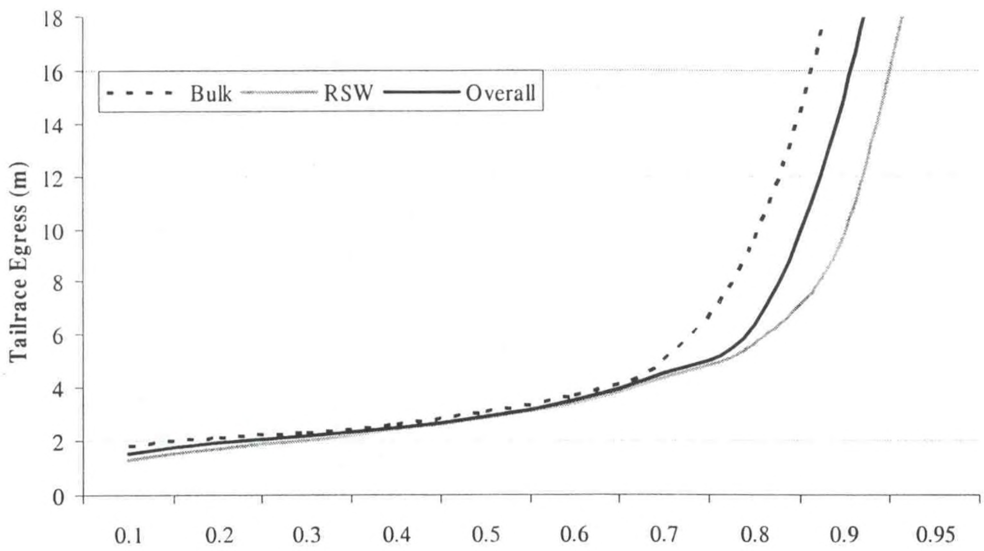

Figure 21. Tailrace egress of radio-tagged yearling Chinook salmon during two different spill treatments at Ice Harbor Dam, 2005.

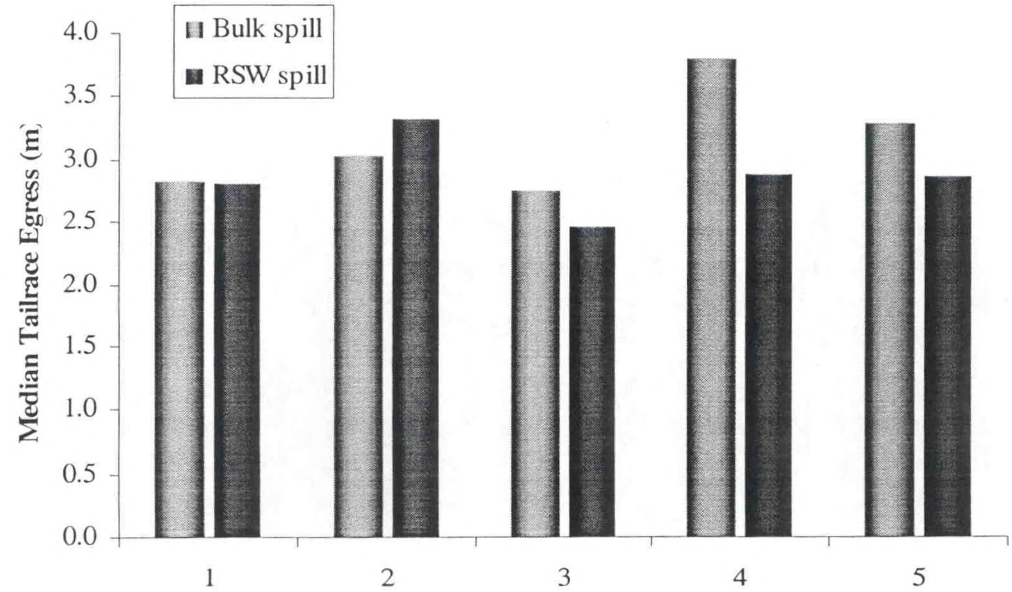

Figure 22. Paired 50th percentile of tailrace egress of radio-tagged yearling Chinook salmon at Ice Harbor Dam under two different spill treatments, 2005.

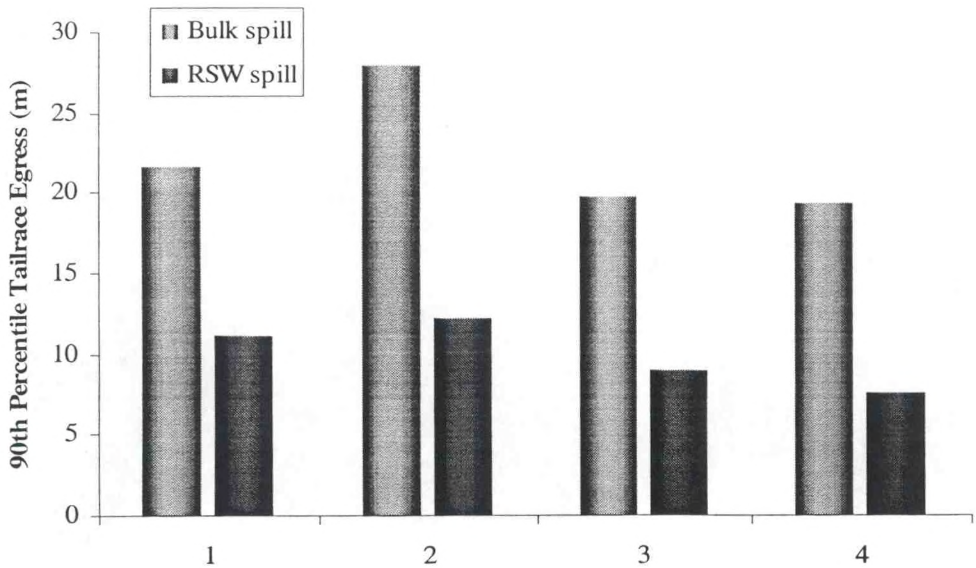

Figure 23. Paired 90th percentile of tailrace egress of radio-tagged yearling Chinook salmon at Ice Harbor Dam under two different spill treatments, 2005.

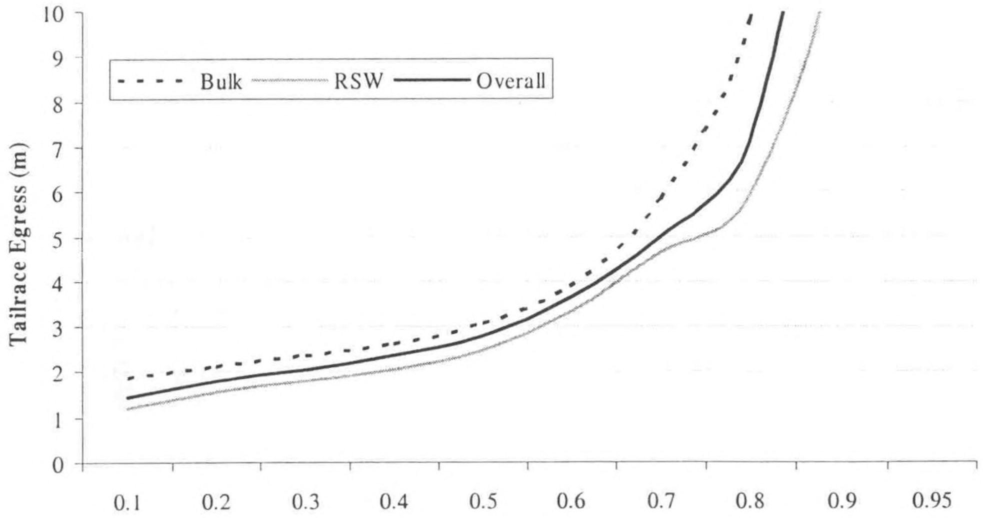

Figure 24. Tailrace egress of radio-tagged juvenile steelhead during two different spill treatments at Ice Harbor Dam, 2005.

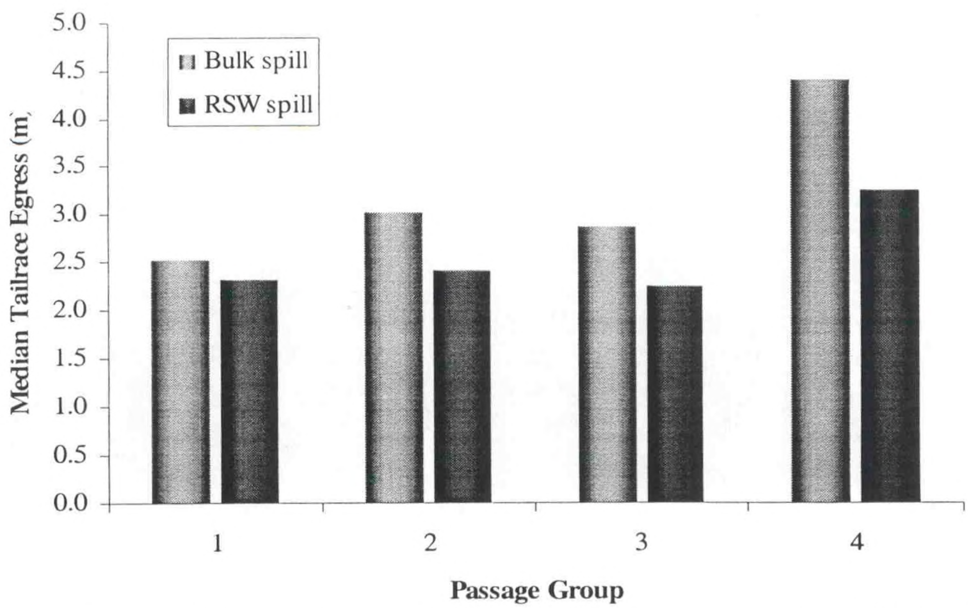

Figure 25. Paired 50th percentile of tailrace egress of radio-tagged juvenile steelhead at Ice Harbor Dam under two different spill treatments, 2005.

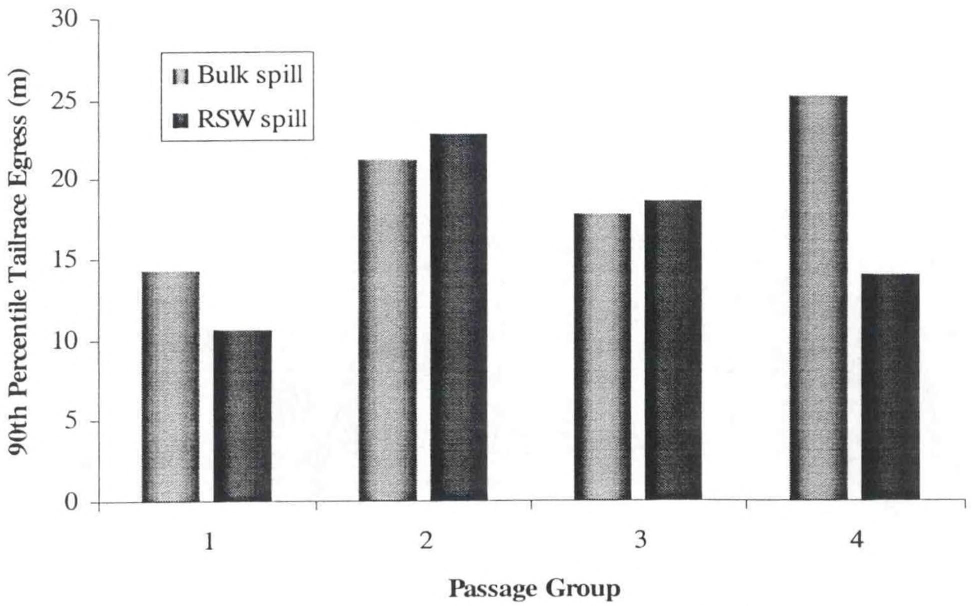

Figure 26. Paired 90th percentile of tailrace egress of radio-tagged juvenile steelhead at Ice Harbor Dam under two different spill treatments, 2005.

Avian Predation

We initiated a recovery effort for radio tags that were deposited on Crescent Island after the Caspian Tern colony had left the island for the season. We recovered tags by means of physical recovery and PIT-tag detection. There is an ongoing monitoring effort to recover PIT tags from the active Caspian Tern colonies in the region conducted by NOAA Fisheries Service and by the Columbia Bird Research group. In total, 419 juvenile steelhead mortalities were recorded within the tern colony representing approximately 13.2% of the steelhead we released into the Snake River. We recovered 83 yearling Chinook salmon tags which accounted for 1.7% of the population we released.

We plotted the last known detection transect where the fish was seen in order to ascertain where the largest "kill zone" might be located. According to the data, both juvenile steelhead and yearling Chinook salmon are most at risk when they enter the confluence of the Columbia and Snake Rivers (Figures 27 and 28). Their potential for predation increases as they continue on towards Crescent Island.

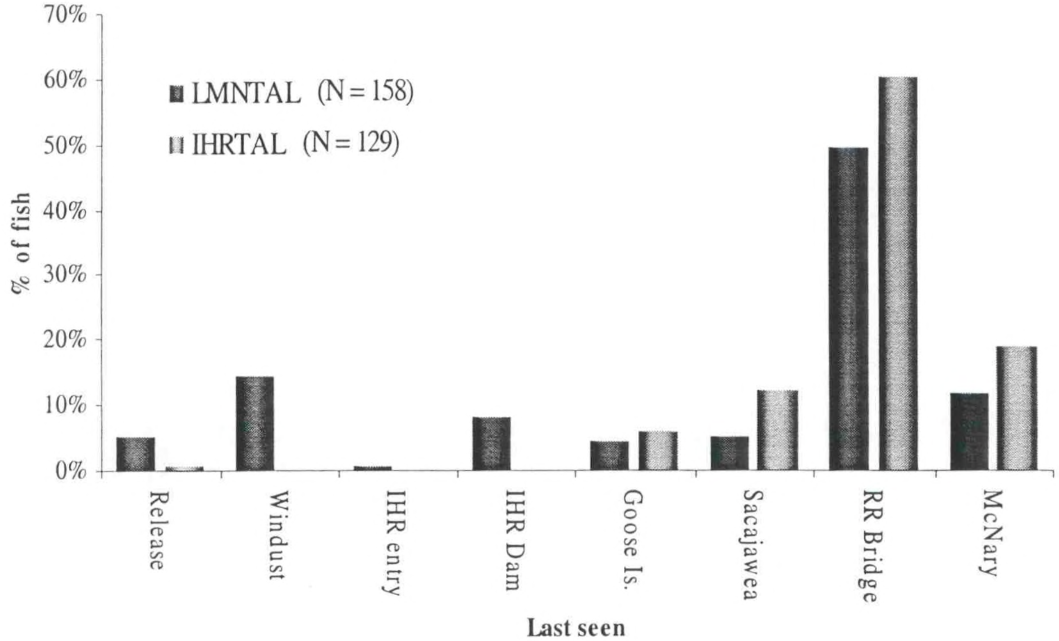

Figure 27. Percentage of radio-tagged juvenile steelhead and their last known location before predation event by Caspian Terns, 2005.

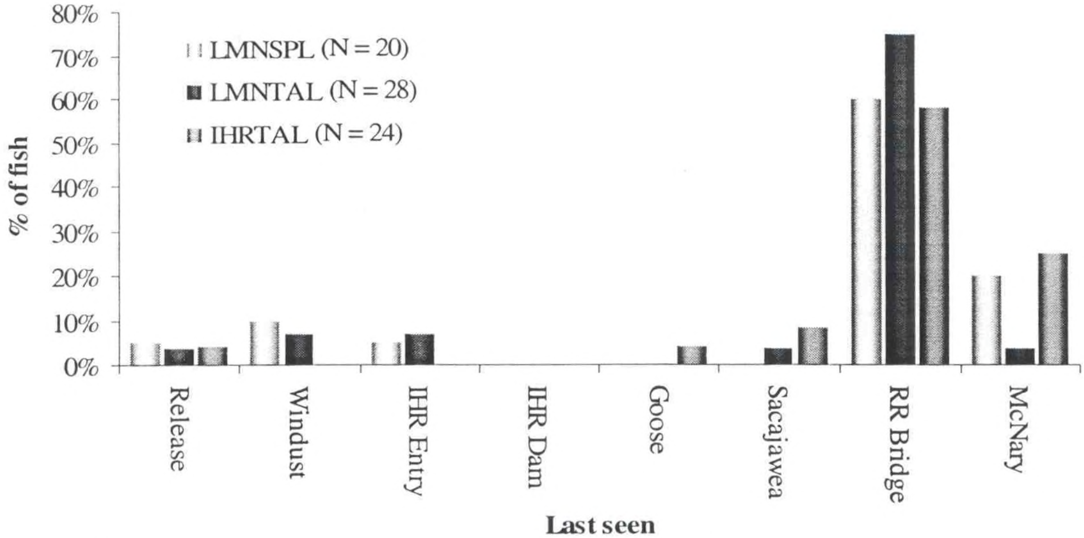

Figure 28. Percentage of radio-tagged yearling Chinook salmon and their last known location before predation event by Caspian Terns, 2005.

DISCUSSION

During the planning phase of this study, we expected to begin collection and tagging after the 20th percentile of the yearling Chinook salmon and juvenile steelhead migration had passed the dam and to continue until the 75th percentile had passed. This target tagging period was based on the 9-year average of passage distribution observed at Lower Monumental Dam. However, as a result of higher flows and a regional management decision to collect and transport a large majority of the fish, we were not able to begin tagging until the 40th percentile of the yearling Chinook migration had already passed the dam. We were still able to tag the bulk of the run, and the average size of the fish tagged was consistent with that of the run-at-large which provided estimates that were reasonably representative of unmarked juvenile spring migrants.

One major goal of this study was to distribute our releases of radio-tagged fish over time in order to have equal numbers of fish arriving and passing Ice Harbor Dam volitionally throughout both spill treatments and to match those fish up with the controls released in the tailrace. For steelhead, the hour of arrival and passage at Ice Harbor Dam was fairly consistent during the study. We observed a trend for both spill treatments wherein steelhead arrived in the forebay primarily during daylight hours and passed relatively quickly. Yearling Chinook salmon had a tendency to arrive fairly equally across all hours of the day, with the least amount of delay occurring with bulk spill. During RSW treatments we observed a lag in passage which was likely due to increasing powerhouse discharge as a result of power-peaking operations. First approach data also suggests that by increasing the turbine loads, project operations provided a larger flow-net which pulled fish away from the spillway.

The variation of spill treatment blocks did have an effect on passage distribution and fish passage metrics at Ice Harbor Dam. During RSW spill treatments, mean spill was reduced by virtually 50%. Spill efficiency decreased as a result of a larger proportion of fish passing through the powerhouse. A better comparison between the two spill treatments might have been obtained by operating the project with similar spill discharge between the alternating bulk and RSW spill patterns.

Previous studies have shown that the majority of juvenile yearling Chinook salmon pass through the spillway, with relatively few entering either powerhouse route (Eppard et al. 2000). Yearling Chinook salmon displayed behavior which suggested the possibility of confusion as they approached the RSW. Many had first approaches at the RSW but chose to pass through spill bay 1, which is located at depths similar to the possibly overwhelming flow-net created by the turbine loading. Since juvenile steelhead typically travel slightly higher in the water column than yearling Chinook, this may explain why a much smaller percentage passed at depth through spill bay 1 and the RSW effectiveness exceeded 5:1.

There was a tendency for forebay residence times to decrease during the bulk spill operations, but this may have been attributable to the decreased flow through the spillway during RSW operation. Tailrace egress was longer for fish that passed during bulk spill operations. This was a result of a large eddy which develops in the tailrace with a larger proportion of the river being spilled and very few turbine units being operated. However, the differences were not statistically significant for the 50th percentile of fish, and the mean differences were less than 2 min and were probably not biologically significant.

Survival estimates indicate that a large portion of the mortality associated with migrating juvenile steelhead appears to occur prior to passage at Ice Harbor Dam and between the mouth of the Snake River and Port Kelley. We can effectively attribute 13.2% of our juvenile steelhead mortality to the Caspian Tern colony on Crescent Island and 1.7% of our yearling Chinook salmon, although this is a minimum estimate since tags are also deposited elsewhere.

Steelhead are particularly susceptible to predation by birds; Collis et al. (2001) found that greater than 15% of the PIT-tagged steelhead entering the Columbia River estuary in 1998 were later found on Rice Island, which at the time was the home of the largest Caspian Tern colony in western North America. Crescent Island harbors the second largest Caspian Tern colony in western North America and large populations of gulls while nearby islands support burgeoning populations of cormorants and pelicans.

About 476 breeding pairs attempted to nest at the Crescent Island tern colony in 2004, approximately 10% fewer pairs than in 2004. Based on preliminary estimates, nesting success at the Crescent Island tern colony was reduced this year (0.55 fledglings raised per breeding pair) (Roby et al. 2006). This may have helped to reduce the overall predation on spring migrants and particularly juvenile steelhead that was observed in 2004. The last detection of radio-tagged fish subsequently found on Crescent Island indicated that, at a minimum, terns foraged from the tailrace of Lower Monumental Dam to the forebay of McNary Dam, a distance of nearly 120 km.

The high percentage of fish transported had another important consequence: the overall abundance of Snake River juvenile salmonids below Lower Monumental Dam was low as in previous years and the majority of these fish were PIT-tagged. This may have influenced predator/prey dynamics for the tagged fish and had a large influence on their survival. Extended travel times due to lower flows may have contributed to poor survival of juvenile salmonids by increasing their exposure time to predators and by extending their residence in reservoirs to periods with higher temperatures when predators were more active (Vigg and Burley 1991).

Overall, it appears that the RSW was extremely effective in passing more fish with less water, particularly for juvenile steelhead. Survival estimates were not different between treatments and the RSW provided very high survival estimates.

RECOMMENDATIONS

We recommend a reduction in spill through spill bay 1 at Ice Harbor dam to determine if that will allow more yearling Chinook salmon to be directed through the RSW. With high survival estimates achieved, we should attempt to further increase passage metrics resulting in fewer turbine passed fish as spill levels are decreased. We also suggest a continued effort to evaluate juvenile steelhead survival in the lower Snake River to identify areas of avian predation. It is becoming apparent that the Crescent Island Caspian Tern colony is targeting Snake River juvenile steelhead at a much higher rate than other salmonids, including Mid-Columbia juvenile steelhead. We need to continue monitoring tern predation and consider alternatives to improve steelhead migration through the McNary pool.

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APPENDIX A

Evaluation of Study Assumptions

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

A1. All tagged fish have similar probabilities of detection at a detection location.

Of the 2,752 radio-tagged yearling Chinook salmon detected at Ice Harbor Dam, 2,504 (91.0% of those observed) were detected either at or below the Sacajawea survival transect. Of the 1,561 radio-tagged yearling Chinook salmon released into the tailrace of Ice Harbor Dam, 1,505 (96.4% of those released) were detected either at or below Sacajawea. The detection probability for fish used in survival analysis at Ice Harbor Dam was 0.940 overall (Appendix Table A1a). With detection probabilities at or near 94% for all fish, there was likely no disparity between detection probabilities of treatment and reference groups.

Appendix Table A1a. Detections at and below Ice Harbor Dam and detection probabilities at Ice Harbor Dam for evaluating survival of hatchery yearling Chinook salmon passing through Ice Harbor Dam, 2005.

Release group	Release location	Detection at Sacajawea	Detection at or below Sacajawea	Detection probability
Treatment	Above IHR Dam	2,319	2,504	0.926
Reference	IHR Dam Tailrace	1,449	1,505	0.963
Totals		3,768	4,009	0.940

Of the 1,415 radio-tagged juvenile steelhead detected at Ice Harbor Dam, 1,222 (86.4% of those observed) were detected either at or below the Sacajawea survival transect. Of the 1,570 radio-tagged juvenile steelhead released into the tailrace of Ice Harbor Dam, 1,450 (92.4% of those released) were detected either at or below Sacajawea. The detection probability for fish used in survival analysis at Ice Harbor Dam was 0.921 overall (Appendix Table A1b). With detection probabilities at or near 92% for all fish, there was likely no disparity between detection probabilities of treatment and reference groups.

Appendix Table A1b. Detections at and below Ice Harbor Dam and detection probabilities at Ice Harbor Dam for evaluating survival of juvenile steelhead passing through Ice Harbor Dam, 2005.

Release group	Release location	Detection at Sacajawea	Detection at or below Sacajawea	Detection probability
Treatment	Above IHR Dam	1,129	1,222	0.924
Reference	IHR Dam Tailrace	1,331	1,450	0.918
Totals		2,460	2,672	0.921

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

To test that treatment and reference fish mixed evenly and traveled together downstream, we evaluated mixing of release groups at the Sacajawea survival transect by using contingency tables (chi-square goodness-of-fit) to test for differences in arrival distributions. The treatment fish at Ice Harbor Dam were paired with the release reference fish by the project operations at the time of treatment fish passage. *P*-values were calculated using the Monte Carlo approximation of the exact method described in the StatXact software user manual (Mehta and Patel 1992; $\alpha < 0.05$).

Test of homogeneity of arrival distributions at Ice Harbor Dam were similar for treatment and reference groups in 3 of the 8 paired treatment groups for yearling Chinook salmon (Appendix Tables A2a) and 3 of the 8 paired treatment groups for juvenile steelhead (Appendix Tables A2b). There were more significant tests than expected if all groups were generally mixed (for $\alpha = 0.05$ level we would expect 1 out of 20 tests not to be mixed). However, in general the differences between arrival times at Sacajawea were less than 1 d. Since our survival estimates were pooled over the treatment period, and the bulk of distributions generally occurred over a 2-3 d period, it is reasonable to conclude that the survival estimates were not significantly biased by violation of the assumption regarding mixing through the common reach. The arrival distributions for those releases which were not mixed are plotted in Appendix Figures B1 through B6.

Appendix Table A2a. Test of homogeneity of arrival timing at the Sacajawea survival transect for treatment (regrouped at Ice Harbor Dam forebay) and reference groups (tailrace) of radio-tagged hatchery yearling Chinook salmon used for estimating survival at Ice Harbor Dam. The treatment fish at Ice Harbor Dam were paired with the reference fish according to project operations at the time of passage. Shaded cells indicate significant differences in passage timing among tests ($\alpha = 0.05$).

Treatment group	χ^2	Degrees of freedom	*P*
Bulk 1	6.54	6	0.360
Bulk 2	5.56	6	0.499
Bulk 3	29.75	8	<0.001
Bulk 4	24.24	5	<0.001
RSW 1	20.58	6	0.001
RSW 2	4.84	3	0.156
RSW 3	9.00	4	0.043
RSW 4	29.02	5	<0.001

Appendix Table A2b. Test of homogeneity of arrival timing at the Sacajawea survival transect for treatment (regrouped at Ice Harbor Dam forebay) and reference groups (tailrace) of radio-tagged juvenile steelhead used for estimating survival at Ice Harbor Dam. The treatment fish at Ice Harbor Dam were paired with the reference fish according to project operations at the time of passage. Shaded cells indicate significant differences in passage timing among tests ($\alpha = 0.05$).

Treatment group	χ^2	Degrees of freedom	*P*
B1	6.44	4	0.109
B2	8.45	3	0.024
B3	13.47	5	0.014
B4	6.20	7	0.542
R1	15.95	5	0.004
R2	12.21	4	0.007
R3	5.63	5	0.276
R4	20.84	7	0.002

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

Unmarked yearling Chinook salmon and juvenile steelhead were collected at Lower Monumental and Little Goose Dam for 25 d from 2 May to 27 May. Tagging began after approximately 40% of the yearling Chinook salmon and 14% of the juvenile steelhead had passed Lower Monumental Dam and was completed when 97% of these fish had passed (Figure 2). Overall mean fork length for yearling Chinook and steelhead was 143 mm (SD = 11.0) and 203 mm (SD = 26.0), respectively. This compared closely with the mean length of the unclipped yearling Chinook and steelhead run-at-large sampled at the smolt collection facility (139 mm and 197 mm, respectively).

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

Assumption A4 was not tested for validation in this study. However, the effects of radio tagging on survival, predation, growth, and swimming performance of juvenile salmonids have previously been evaluated by Adams et al. (1998a, b) and Hockersmith et al. (2003). From their conclusions, we assumed that behavior and survival were not significantly affected over the length of our study area.

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

We released 35 dead radio-tagged hatchery yearling Chinook salmon and 45 juvenile steelhead into the tailrace of Ice Harbor Dam to test Assumption A5 (Appendix Table A3). The distance between release at Ice Harbor Dam and the first downstream telemetry array used to estimate survival (Ice Harbor Dam) was 16 km. Similar to the findings of Axel et al. (2003), none of our dead, radio-tagged fish were subsequently detected at telemetry transects which were used for estimating survival.

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

	Yearling Chinook	Steelhead
Number of dead fish released	35	45
Proportion of fish released which were dead	2.2%	2.8%
Number detected at Sacajawea	0	0
Number detected below Sacajawea	0	0

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

All transmitters were checked upon receipt from the manufacturer, prior to implantation into a fish and prior to release, to ensure that the transmitter was functioning properly. A total of 8,220 tags were implanted in hatchery yearling Chinook salmon and steelhead of which 78 (0.9%) were not working 24 h after tagging. All fish with tags that were not functioning properly were excluded from the study.

In addition, a total of 108 radio transmitters throughout the study were tested for tag life by allowing them to run in river water and checking them daily to determine if they functioned for the predetermined period of time. Nineteen tags (17%) failed prior to the preprogrammed shut-down after 10 d (Appendix Table A4). Of these only 1 (0.9%) failed in less than 7 d. Median travel time from release to Ice Harbor Dam was 1.6 d overall with less than 1% of the fish taking 5 d or more to reach Ice Harbor Dam (Appendix Table A5). Although we documented transmitters failures during our study the short travel times to our survival line and the relatively low failure rate were such that they would not have significantly changed our findings.

Appendix Table A4. Number of days tags lasted in tag life testing.

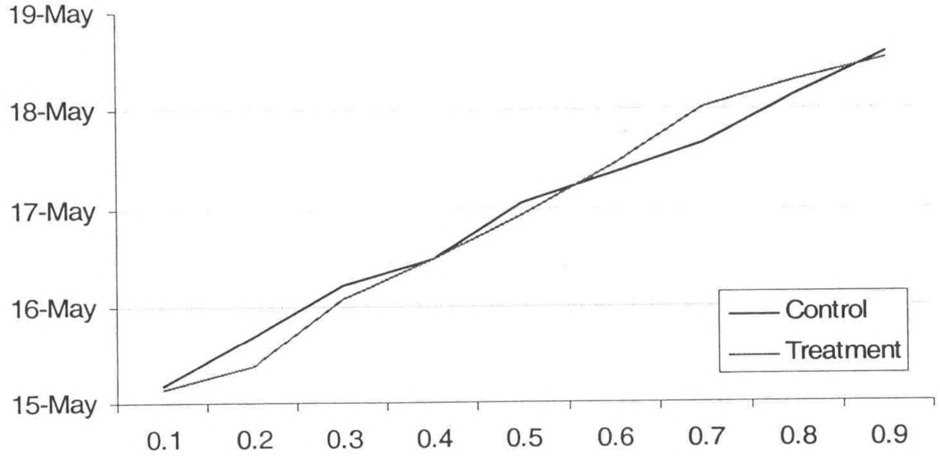
	Tag life	
N	days	(%)
0	1	0
0	2	0
0	3	0
0	4	0
0	5	0
1	6	1
1	7	1
3	8	3
14	9	13
89	10	82

Appendix Table A5. Travel time (days) from release to detection at 1st survival array below Ice Harbor Dam for radio-tagged, hatchery yearling Chinook salmon released into the spillway and tailrace and steelhead released into the tailrace of Lower Monumental Dam, 2005.

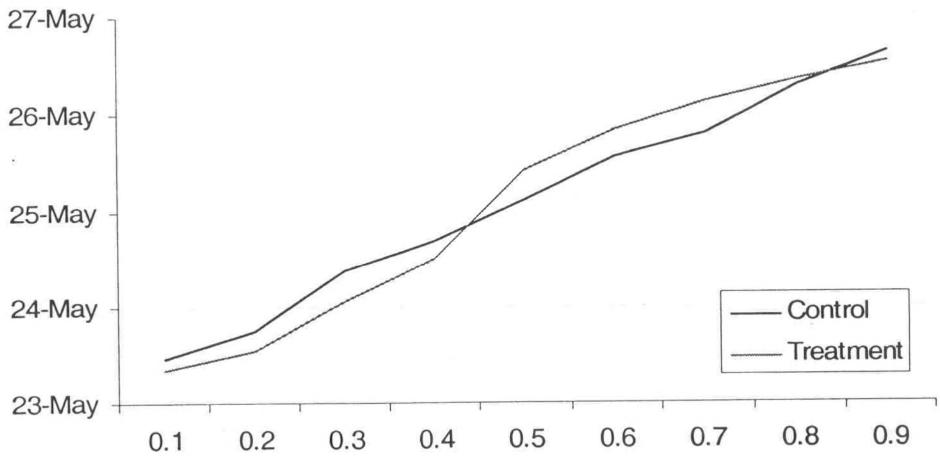
	Travel time (d)		
	Yearling Chinook		Steelhead
Percentile	Spillbays 7 & 8	Tailrace	Tailrace
N	1,277	1,025	1,131
Min	0.9	0.9	0.8
10	1.3	1.2	1.1
20	1.5	1.3	1.2
30	1.6	1.4	1.3
40	1.8	1.6	1.4
50	2.0	1.7	1.5
60	2.1	1.9	1.7
70	2.3	2.1	1.9
80	2.5	2.3	2.0
90	3.1	2.7	2.3
Max	7.7	7.5	7.8
Travel time > 6 d	7 (0.5%)	2 (0.2%)	3 (0.3%)

APPENDIX B

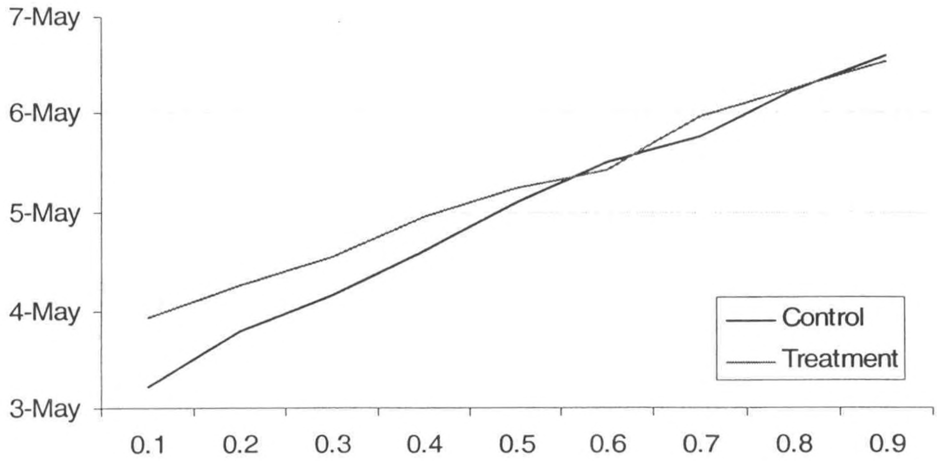
Ice Harbor Dam Arrival Distributions for Treatment and Reference Release Groups with Significantly Different Travel Timing



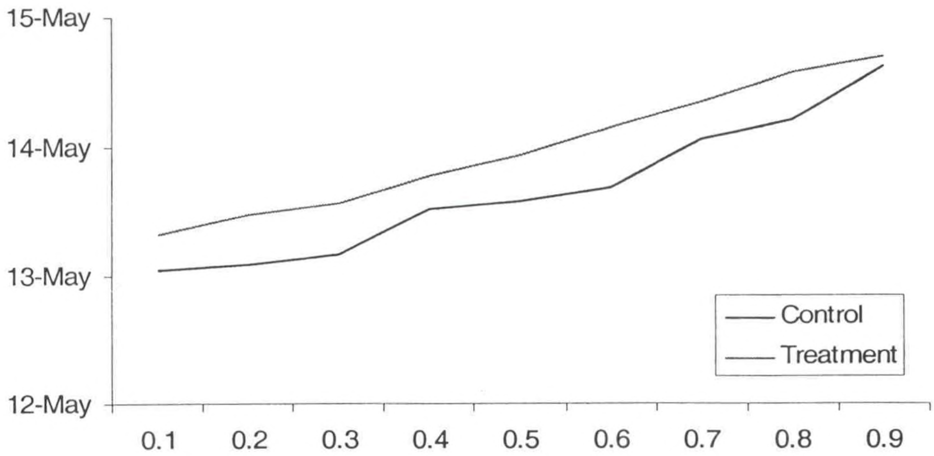
Appendix Figure B1. Arrival distribution at Sacajawea for treatment yearling Chinook salmon passing Ice Harbor Dam and reference fish released into the tailrace during the 3rd bulk treatment operation.



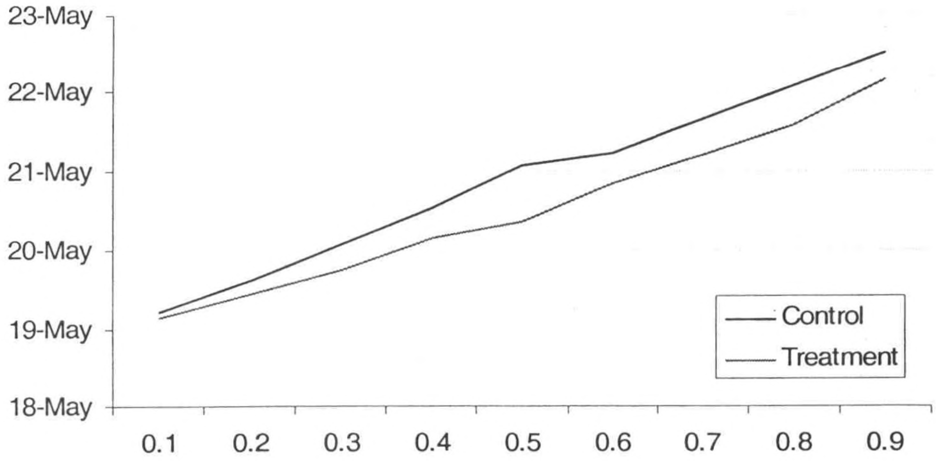
Appendix Figure B2. Arrival distribution at Sacajawea for treatment yearling Chinook salmon passing Ice Harbor Dam and reference fish released into the tailrace during the 4th bulk treatment operation.



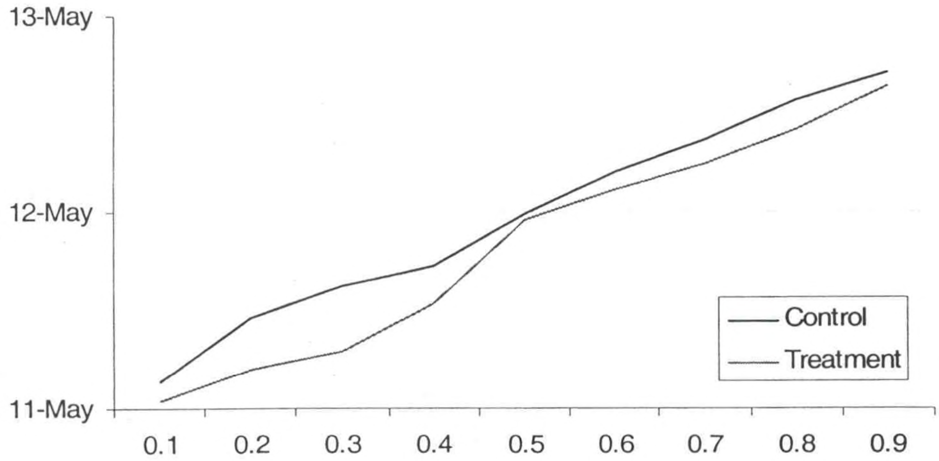
Appendix Figure B3. Arrival distribution at Sacajawea for treatment yearling Chinook salmon passing Ice Harbor Dam and reference fish released into the tailrace during the 1st RSW treatment operation.



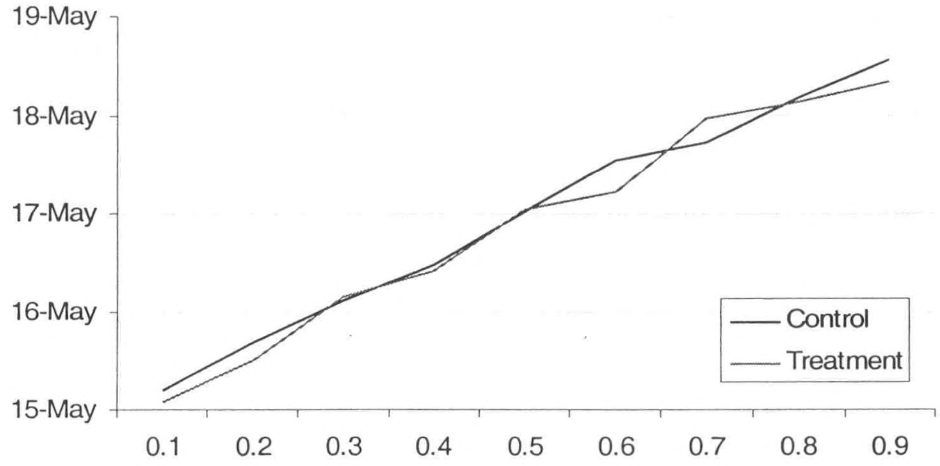
Appendix Figure B4. Arrival distribution at Sacajawea for treatment yearling Chinook salmon passing Ice Harbor Dam and reference fish released into the tailrace during the 3rd RSW treatment operation.



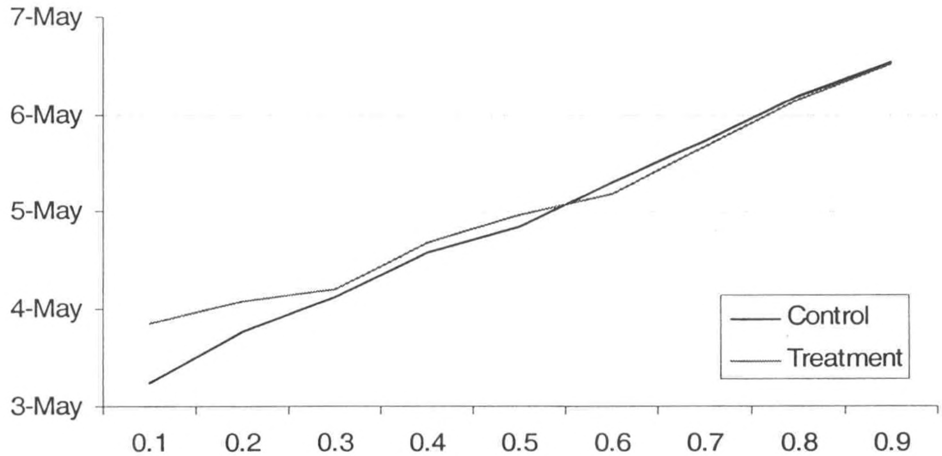
Appendix Figure B5. Arrival distribution at Sacajawea for treatment yearling Chinook salmon passing Ice Harbor Dam and reference fish released into the tailrace during the 4th RSW treatment operation.



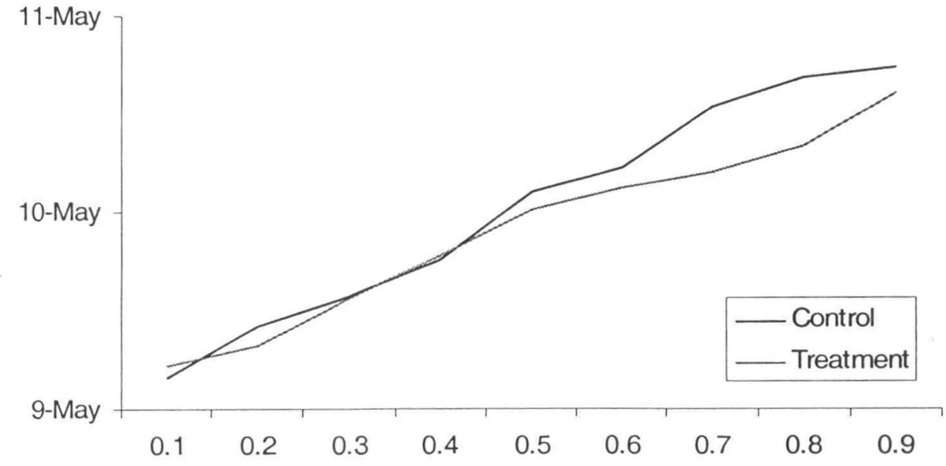
Appendix Figure B6. Arrival distribution at Sacajawea for treatment juvenile steelhead passing Ice Harbor Dam and reference fish released into the tailrace during the 2nd bulk treatment operation.



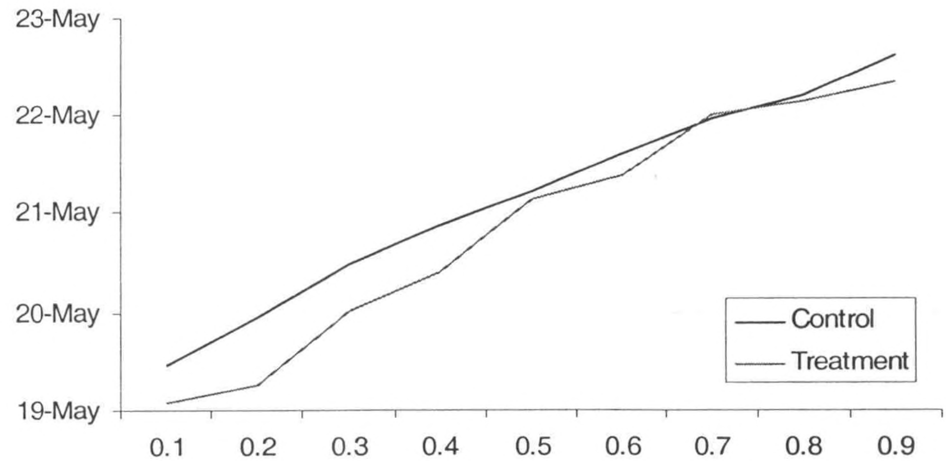
Appendix Figure B7. Arrival distribution at Sacajawea for treatment juvenile steelhead passing Ice Harbor Dam and reference fish released into the tailrace during the 3rd bulk treatment operation.



Appendix Figure B8. Arrival distribution at Sacajawea for treatment juvenile steelhead passing Ice Harbor Dam and reference fish released into the tailrace during the 1st RSW treatment operation.



Appendix Figure B9. Arrival distribution at Sacajawea for treatment juvenile steelhead passing Ice Harbor Dam and reference fish released into the tailrace during the 2nd RSW treatment operation.



Appendix Figure B10. Arrival distribution at Sacajawea for treatment juvenile steelhead passing Ice Harbor Dam and reference fish released into the tailrace during the 4th RSW treatment operation.

APPENDIX C

Telemetry Data processing and Reduction Flowchart

Overview

The database stores the data collected for the Juvenile Salmon Radiotelemetry Project in the Fish Ecology Division at the NOAA Fisheries Northwest Fisheries Science Center. This project tracks the migration routes and passage of juvenile salmon and steelhead past dams within the Columbia and Snake Rivers using a network of radio receivers to record signals emitted from radio transmitters ("tags") implanted into the fish. Special emphasis is placed on the routes of passage, and survival for individual routes at the various hydroelectric dams on the lower Columbia and Snake Rivers. The 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-min 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 chan=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.

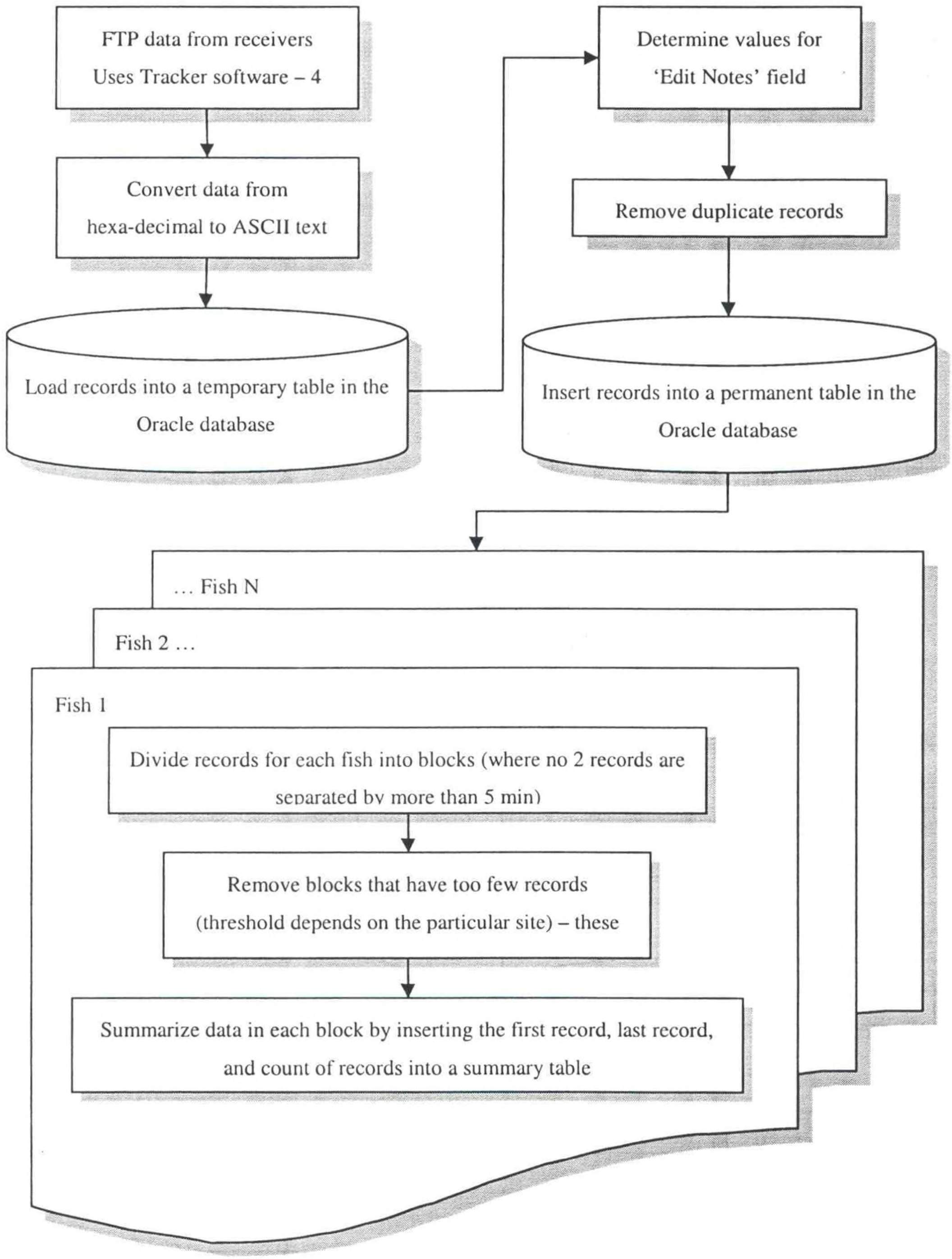
- Invalid Antenna: Denotes an observation attributed to an invalid (non-existent) antenna. These are most likely due to electronic noise within the receiver.
- Lt start time: Assigned to records occurring prior to the time a tag was activated (its start time).
- Gt end_time: Assigned to records occurring after the end time on a tag (they run for 10 d once activated).
- Gt 40 recs: Denotes tags that registered more than 40 records per min on an individual receiver. This is not possible as the tags emit a signal every 2 seconds (30/min). 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 the 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 C. Flowchart of telemetry data processing and reduction used in evaluating behavior and survival at Ice Harbor Dam for yearling Chinook salmon and steelhead, 2005.