Partitioning Reach Survival for Steelhead between Lower Monumental and McNary Dams, 2004

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EXECUTIVE SUMMARY

In 2004, we estimated reach survival for juvenile steelhead *Oncorhynchus mykiss* between Lower Monumental Dam and McNary Dam in order to ascertain areas of loss more accurately. Fish were collected, PIT tagged, and surgically tagged with a radio transmitter at Lower Monumental Dam. We released 921 and 935 radio-tagged fish to the respective tailraces of Lower Monumental and Ice Harbor Dam. Fish were released during day and night operations for 20 d from 7 to 27 May.

We estimated pool survival between the tailrace of Lower Monumental Dam and the forebay of Ice Harbor Dam and partitioned the reach between Ice Harbor and McNary Dam reach into three smaller reaches. Ice Harbor pool survival was 0.841 (95% CI, 0.817–0.865). Pool survival estimates for the three smaller reaches were as follows: 0.944 (95% CI, 0.932-0.956) from the tailrace of Ice Harbor Dam to the mouth of the Snake River, 0.760 (95% CI, 0.736-0.784) from the mouth of the Snake River to Port Kelley, and 0.840 (95% CI, 0.814-0.866) from Port Kelley to the forebay of McNary Dam. At Ice Harbor Dam, relative dam survival was 0.870 (95% CI, 0.838–0.902).

Project operations at Ice Harbor Dam consisted of 2-d blocks alternating between bulk spill and flat spill. Spillway passage survival was 0.977 (95% CI, 0.948-1.007) under bulk spill operations and 0.977 (95% CI, 0.926-1.028) during flat spill. Insufficient numbers of tagged fish passed through the powerhouse to enable us to estimate survival through turbines or the juvenile bypass system.

Median forebay residence time for juvenile steelhead passing Ice Harbor Dam was nearly twice as long for radio-tagged fish approaching during flat spill operations (3.1 h) as it was for those approaching during bulk spill (1.8 h). Mean spill discharge was nearly twice as high during bulk spill as it was during flat spill. Overall passage distribution for radio-tagged Snake River juvenile steelhead was 88.1% through the spillway, 8.6% through the juvenile bypass, and 0.4% through turbines at Ice Harbor Dam, with 2.9% of the fish having undetermined passage routes.

During bulk spill treatments, 99% (348) of the fish passed via the spillway with the other 1% (5) going through the bypass system. For the periods of flat spill, 82% (240) of the fish passed via the spillway, 17% (50) through the bypass system, and 1% (2) through the turbines. Fish passage efficiency (FPE) was 100% during bulk spill and 99% during flat spill. Fish guidance efficiency (FGE) was 100% during bulk spill and 96% during flat spill. Spill efficiency was 99% under bulk spill operations and 82% during flat spill. Mean spill effectiveness was 1.00:1 for bulk spill and 1.08:1 during flat spill.

CONTENTS

INTRODUCTION

The Columbia and Snake River Basins have historically produced some of the largest runs of salmon *Oncorhynchus* spp. and steelhead *O. mykiss* in the world (Netboy 1980). More recently, however, some stocks have decreased to levels warranting listing under the U.S. Endangered Species Act of 1973 (NMFS 1991, 1992, 1998, 1999). Human activities contributing 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 hydroelectric projects and their reservoirs. Recent survival studies of juvenile salmonid passage through various routes at dams on the lower Snake River have indicated that among the different passage routes, 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).

Since the listing of Columbia River Basin salmonid stocks under the Endangered Species Act, juvenile salmonid passage behavior evaluations and project or route-specific survival estimates at Lower Monumental, Ice Harbor, and McNary Dams (Figure 1) have been conducted primarily with Chinook salmon. However, passage and survival estimates for juvenile steelhead are also essential for regional management in order to make decisions in the best interest of this species.

As part of a study funded by the Bonneville Power Administration (BPA), the National Marine Fisheries Service (NMFS) has provided annual survival estimates for river-run PIT-tagged juvenile salmonids migrating through the Lower Snake and Columbia River hydropower system. The study provides annual survival estimates for the reach of river from the tailrace of Lower Monumental Dam to the tailrace of McNary Dam. These estimates indicate that project survival for steelhead has been substantially lower in the reach from Lower Monumental to McNary Dam than in the reaches from Lower Granite to Little Goose Dam and Little Goose to Lower Monumental Dam (Zabel et al. 2002).

However, because Ice Harbor Dam does not have PIT-tag detection capability, the study has not been able to partition survival estimates between Lower Monumental and McNary Dams (Muir et al. 2001). Because the behavior and life history of juvenile steelhead are different, and in some ways more complex, than those of Chinook salmon, we proposed a pilot study to determine travel times, passage behavior, radiotelemetry detection probabilities, and survival between Lower Monumental and McNary Dams for juvenile steelhead. This information will assist in designing more comprehensive studies to evaluate behavior and survival in future years and will help inform management on strategies to optimize survival for juvenile steelhead between Lower Monumental and McNary Dams.

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 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 river kilometer 470.

Fish Collection, Tagging, and Release

River-run steelhead were collected at the Lower Monumental Dam smolt collection facility from 5 to 25 May. We chose fish that did not have any gross injury or deformity and that were at least 140 mm in length and 20 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 16 mm in length by 6 mm in diameter and weighed 1.3 g in air.

Fish were surgically tagged with radio transmitters using techniques described by Adams et al. (1998). 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 water during holding. All holding tanks were supplied with flow-through water during

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

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 11.9 and 13.4 ^{o}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. Two fish were released every 15 min in order to distribute releases over a period of 8 to 10 h.

Daytime releases occurred between 0920 and 1400 PDT. Nighttime releases were made between 1710 and 2250 PDT. We released twenty groups of approximately 20-25 fish. A total of 921 radio-tagged fish were released into the tailrace of Lower Monumental Dam. Release temperatures ranged between 11.9 and 13.4ºC. A total of 935 radio-tagged fish were released into the tailrace of Ice Harbor Dam. Release temperatures in the tailrace of Ice Harbor ranged between 12.5 and 13.4°C.

Survival Estimates

Estimates of pool 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, for survival estimates through the pool. We also used the SR model to estimate reach survival between Ice Harbor and McNary Dam using telemetry transects located at Sacajawea State Park (mouth of the Snake River), Port Kelley, the forebay of McNary Dam, and at Irrigon, OR. Previous studies indicated that dead, radio-tagged fish released at Ice Harbor Dam and also in the bypass system at McNary 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 or McNary Dam.

For estimates of dam survival through Ice Harbor Dam, we created temporal release groups, that is, treatment replicate groups were composed of fish detected on the same day at the telemetry transect located at the upstream edge of the Boat Restricted Zone. These temporal release groups were then paired with reference groups released in the tailrace of Ice Harbor Dam during the same period. The ratio of pooled survival estimates for treatment to reference fish provide the relative survival estimate for the dam.

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

Since radio-tagged fish were also tagged with a PIT tag, detections at the juvenile collection/detection facilities (Prentice 1990a,b) at McNary, John Day, and Bonneville Dams and with the PIT-trawl towed-array in the Columbia River estuary were also used for survival estimates.

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).

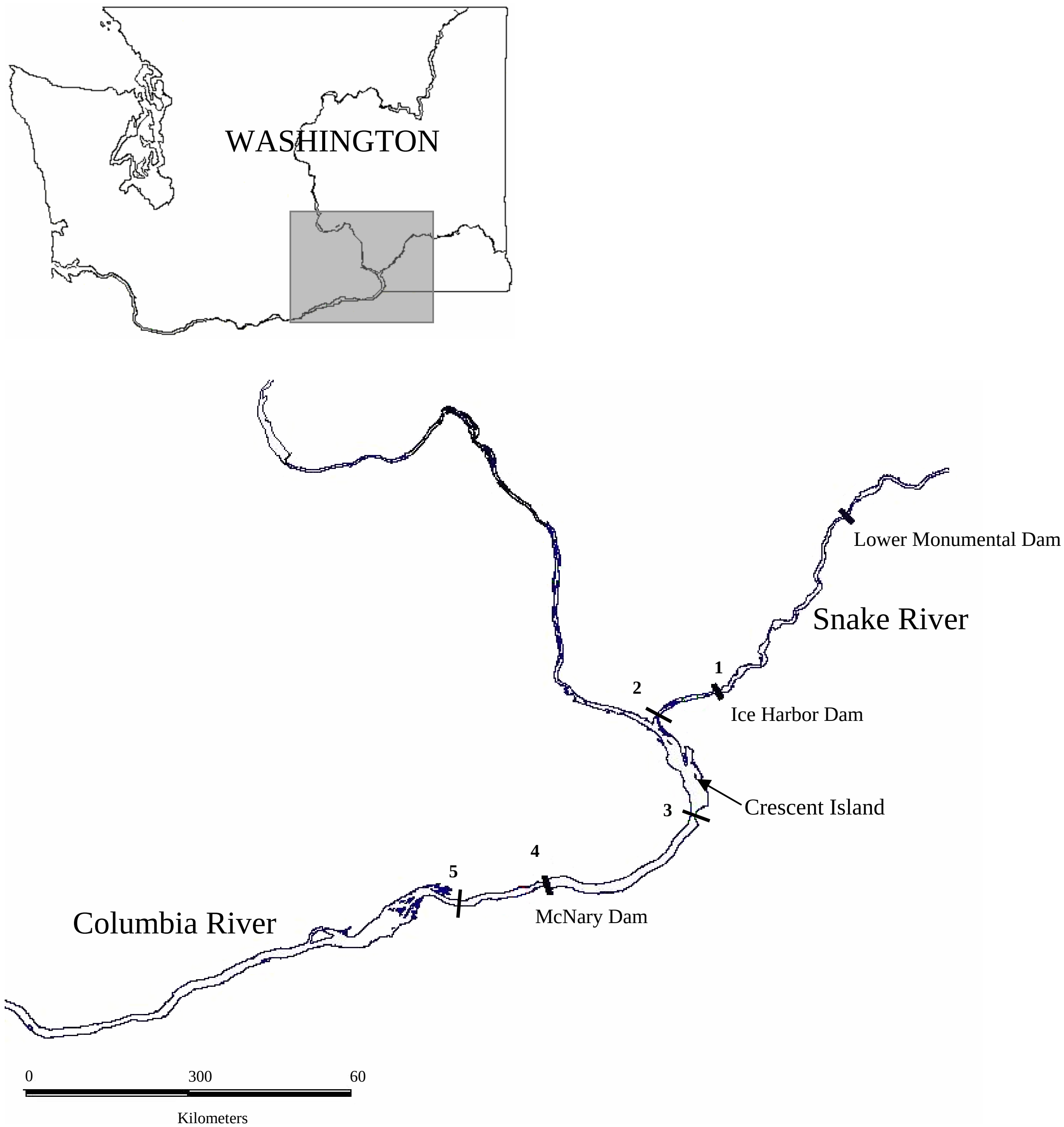

Figure 1. 2004 study area showing location of radiotelemetry transects used for estimating partitioned reach project survival for radio-tagged juvenile steelhead between Lower Monumental and McNary Dams. (Note: 1 = Ice Harbor Dam forebay; 2 = Sacajawea State Park; 3 = Port Kelly; 4 = McNary Dam forebay; and 5 = Irrigon, OR. The forebay, tailrace, and all routes of passage at McNary Dam were also monitored.)

Passage Behavior and Timing

Travel, Arrival, and Passage Timing

Travel time was measured as time from release to the 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 moving past a fish guidance screen into a turbine unit or gatewell. We compared forebay residence and tailrace egress times between treatments using paired *t*-tests on the 50th and 90th passage percentiles of the temporal treatment replicate groups.

Passage Route Distribution

To determine the route of passage individual fish used at Ice Harbor Dam, we monitored the spillway, standard traveling screens (STSs), and the bypass system. The spillway was monitored by four underwater dipole antennas in each spillbay. Two antennas were installed along each of the two pier noses of each spillbay at depths of 20 and 40 ft. Pre-season range testing showed that this configuration monitors the entire spillbay. 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 separator were designated turbine passed fish.

Fish Passage Metrics

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

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

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

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

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

Tailrace Egress

Tailrace egress was measured from the last known detection through the project (spillway, turbine, or 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 PIT-tag detection. Radio tags and PIT tags were recovered on the tern colony at Crescent Island during fall 2004 after the birds 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 juvenile steelhead were collected, radio tagged, and PIT tagged at Lower Monumental Dam for 20 d from 7 May to 27 May. Tagging began after 40% of the juvenile steelhead had passed Lower Monumental Dam and was completed when 73% of these fish had passed (Figure 2). Overall mean fork length was 195 mm and mean weight was 60 g for tagged fish (Table 1). This compared closely with the mean weight and length of the unclipped run-at-large sampled at the smolt collection facility (193 mm and 63.4 g). Handling and tagging mortality for juvenile steelhead was 0.6%.

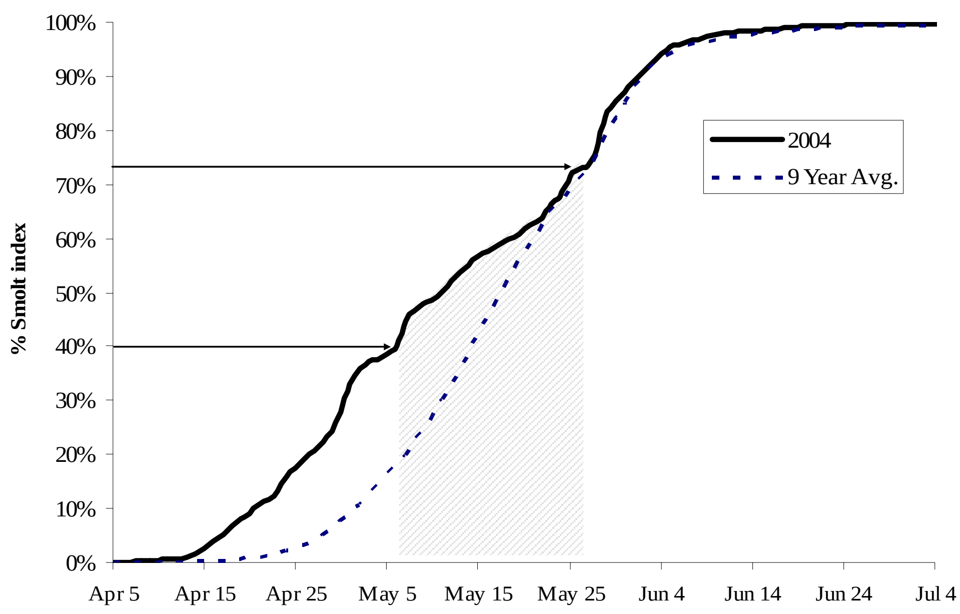

Figure 2. Percentage of juvenile steelhead smolt index estimated at Lower Monumental Dam during 2004. The shaded area depicts the tagging period and portion of the run targeted for tagging. The 9-year average (1996-2004) is also shown.

Table 1. Mean fork length and weight for radio-tagged juvenile steelhead and the untagged run-at-large.

	Tagged		Run-at-large	
	Weight (g)	Length (mm)	Weight (g)	Length (mm)
Min	19.7	140.0	10.9	110.0
Max	180.4	277.0	280.8	365.0
Mean	60.0	195.0	63.4	193.0

Dam Operations

Based on results from the 2003 spillway survival evaluation, the 2004 voluntary spill program followed a 4-d block design with 2 d of spill discharge volume in a “flat” spill operation (NMFS 2000) followed by 2 d of "bulk" spill operation. The flat spill operation passes water through all 10 spillbays, 24 h/d, while the “bulk” pattern typically utilizes fewer spillbays and spillway gates for each bay are open at least 5 stops (bulk spill operation was also 24 h/d). Mean spill during bulk spill was 70.9 thousand cubic feet per second (kcfs) while the mean spill volume during flat spill was 44.7 kcfs. Mean spill for each treatment group is displayed in Figure 3. Mean daily total discharge during the study was 87.5 kcfs, ranging from 61.3 to 139.3 kcfs (Figure 4). Tables 2 and 3 display mean spill (kcfs) and mean gate openings by spill bay during the block treatments, respectively.

Table 2. Average spill (kcfs) by spillbay at Ice Harbor Dam during bulk and flat spill operation blocks, 2004.

Operations block	Spillbay 1	Spillbay 2	Spillbay 3	Spillbay 4	Spillbay 5	Spillbay 6	Spillbay 7	Spillbay 8	Spillbay 9	Spillbay 10
B01	0.0	2.2	10.8	10.8	11.2	10.7	11.2	2.2	11.1	0.0
B02	0.0	1.6	10.5	7.8	11.2	3.6	10.6	1.6	9.5	0.0
B03	0.0	3.4	10.1	8.6	11.1	6.6	10.8	2.4	9.5	0.0
B04	0.0	5.6	11.1	11.5	11.8	11.3	11.6	5.4	11.3	0.0
B05	0.0	8.4	10.6	10.8	11.8	11.7	11.6	6.4	10.8	0.0
F01	4.3	5.1	4.6	4.2	4.3	4.3	4.4	4.2	4.9	4.3
F02	4.3	4.8	4.8	4.3	4.2	4.1	4.1	4.1	4.2	4.1
F03	4.2	4.8	4.8	4.1	4.2	4.2	4.2	4.2	4.2	4.2
F04	4.4	5.2	5.2	4.4	4.4	4.3	4.3	4.3	4.3	4.3
F05	4.3	5.1	4.3	4.2	4.3	4.3	5.1	4.3	5.1	4.3

Table 3. Average gate openings (stops) by spillbay at Ice Harbor Dam during bulk and flat spill operation blocks, 2004.

Operations block	Spillbay 1	Spillbay 2	Spillbay 3	Spillbay 4	Spillbay 5	Spillbay 6	Spillbay 7	Spillbay 8	Spillbay 9	Spillbay 10
B01	0.0	1.3	6.4	6.4	6.6	6.3	6.7	1.3	6.6	0.0
B02	0.0	1.0	6.3	4.6	6.6	2.1	6.3	0.9	5.6	0.0
B03	0.0	2.0	6.0	5.1	6.6	3.9	6.4	1.4	5.6	0.0
B04	0.0	3.3	6.6	6.8	7.0	6.7	6.9	3.2	6.7	0.0
B05	0.0	5.0	6.3	6.4	7.0	6.9	6.9	3.8	6.4	0.0
F01	2.5	3.0	2.7	2.5	2.5	2.5	2.6	2.4	2.9	2.5
F02	2.5	2.8	2.8	2.5	2.4	2.4	2.4	2.4	2.4	2.4
F03	2.5	2.8	2.9	2.4	2.5	2.5	2.4	2.5	2.5	2.4
F04	2.6	3.0	3.0	2.5	2.6	2.5	2.5	2.5	2.5	2.5
F05	2.5	3.0	2.5	2.5	2.5	2.5	3.0	2.5	3.0	2.5

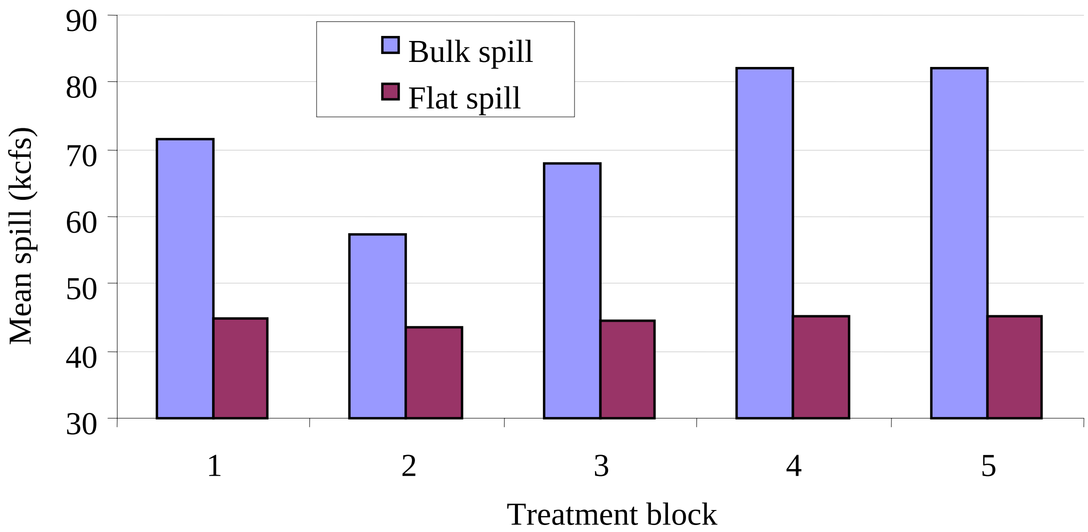

Figure 3. Mean spill (kcfs) for each treatment block for radio-tagged juvenile steelhead arriving at Ice Harbor Dam, 2004.

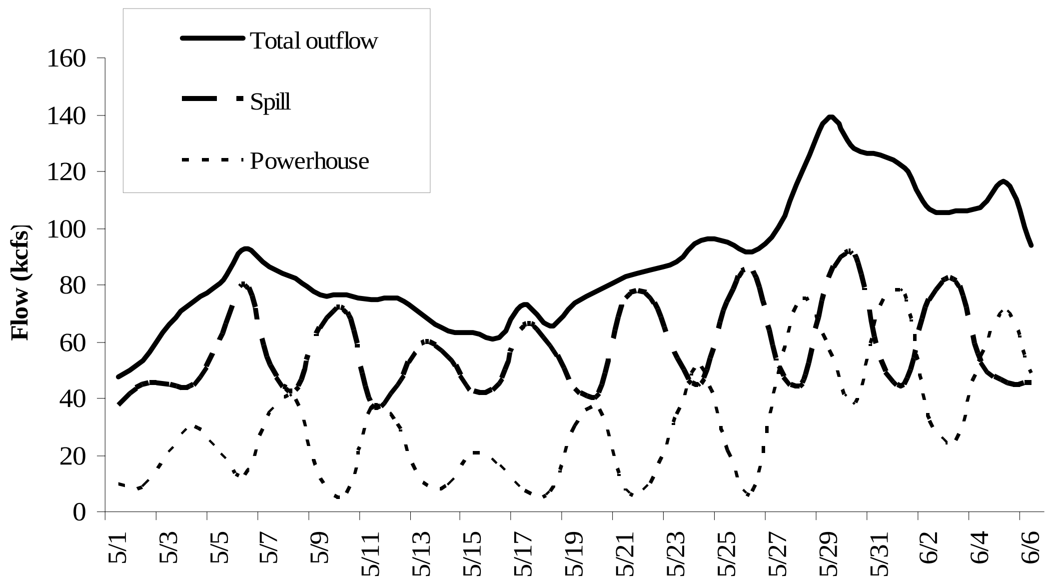

Figure 4. Mean daily project operations (kcfs) for radio-tagged juvenile steelhead arriving at Ice Harbor Dam, 2004.

Survival Estimates

Ice Harbor pool survival was estimated at 0.841 (95% CI, 0.817–0.865). Estimated survival through the partitioned reaches between Ice Harbor and McNary Dams were as follows: 0.944 (95% CI, 0.932-0.956) from the tailrace of Ice Harbor Dam to Sacajawea State Park, 0.760 (95% CI, 0.736-0.784) from Sacajawea to Port Kelley, and 0.840 (95% CI, 0.814-0.866) from Port Kelley to the forebay of McNary Dam.

Estimated dam survival at Ice Harbor Dam was 0.870 (95% CI, 0.838–0.902). Relative spillway survival was 0.977 (95% CI, 0.948-1.007) for bulk spill operations and 0.977 (95% CI, 0.926-1.028) for flat spill. As a result of varying forebay delay and the alternating project operations, regrouping of fish in order to analyze dam survival during the two spill treatments was virtually impossible. Insufficient numbers of fish passed through the powerhouse to enable us to estimate survival through the turbines or the juvenile bypass system.

Passage Behavior and Timing

Travel, Arrival, and Passage Timing

We detected 775 radio-tagged Snake River juvenile steelhead released into the tailrace of Lower Monumental Dam that approached the forebay of Ice Harbor Dam. We detected 469 radio-tagged Snake River juvenile 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 (Table 4 and 5).

Hours of arrival and passage at Ice Harbor Dam were fairly consistent throughout the study. The percentage of fish per hour entering the forebay of Ice Harbor Dam was slightly higher during daylight hours (3.7-7.6%) than during the night (1.8-3.7%; Figure 5). We observed a slight decline in fish passage from 0300 to 0600 and an increase from 2000 to 0100.

Table 4. Travel time and migration rate for radio-tagged juvenile steelhead released in the tailrace of Lower Monumental Dam and detected at the forebay entrance of Ice Harbor Dam, 2004.

Lower Monumental Dam										
			Travel time (d)				Migration rate (km/d)			
	Released	Detected	Min	Max	Mean	SD	Min	Max	Mean	SD
Day	472	384	0.6	9.4	1.6	0.6	0.2	3.5	1.4	0.4
Night	463	391	0.5	7.2	1.6	0.6	0.3	4.5	1.5	0.4
Total	935	775	0.5	9.4	1.6	0.6	0.2	4.5	1.4	0.4

Table 5. Travel time and migration rate for radio-tagged juvenile steelhead released in the tailrace of Ice Harbor Dam and detected at the forebay entrance of McNary Dam, 2004.

Ice Harbor Dam										
			Travel time (d)				Migration rate (km/d)			
	Released	Detected	Min	Max	Mean	SD	Min	Max	Mean	SD
Day	465	247	0.4	8.3	1.6	0.7	0.3	7.6	2.0	0.8
Night	456	222	0.4	8.2	1.5	0.6	0.3	7.3	2.1	0.6
Total	921	469	0.4	8.3	1.5	0.6	0.3	7.6	2.0	0.7

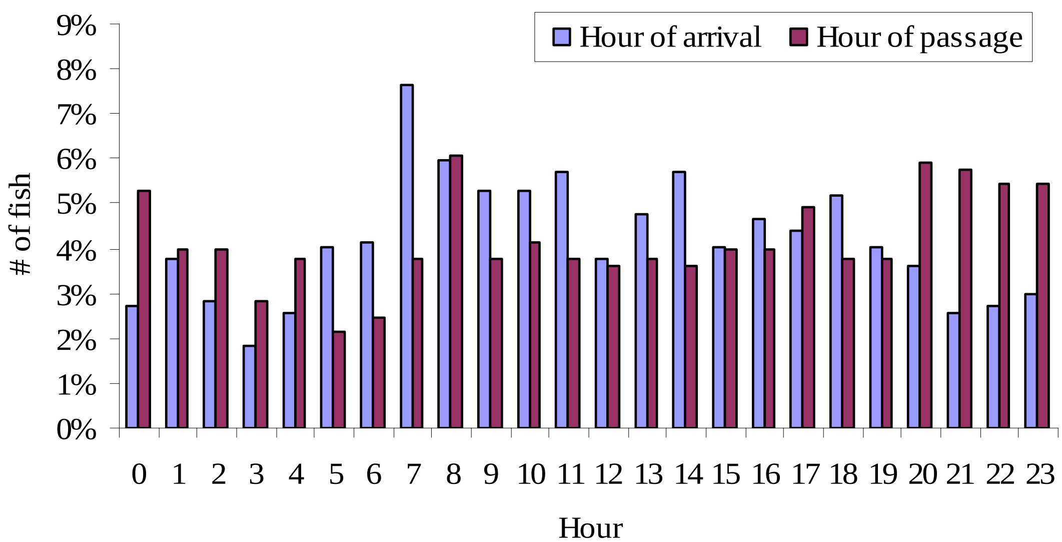

Figure 5. Hour of arrival and passage for radio-tagged juvenile steelhead at Ice Harbor Dam, 2004.

Forebay Residence Time

Median forebay residence time was longer for juvenile steelhead passing during flat spill operations (3.1 h) than for those that passed during bulk spill (1.8 h; Figure 6); however, the difference was not statistically significant (P = 0.065) in comparisons between spill conditions using paired *t*-tests on the 50th percentiles of the temporal replicate treatment groups (Figure 7). The difference between the two treatments became highly significant as forebay residence times approach the 90th percentile, with fish passing during bulk spill having shorter residence time (P = 0.017; Figure 8).

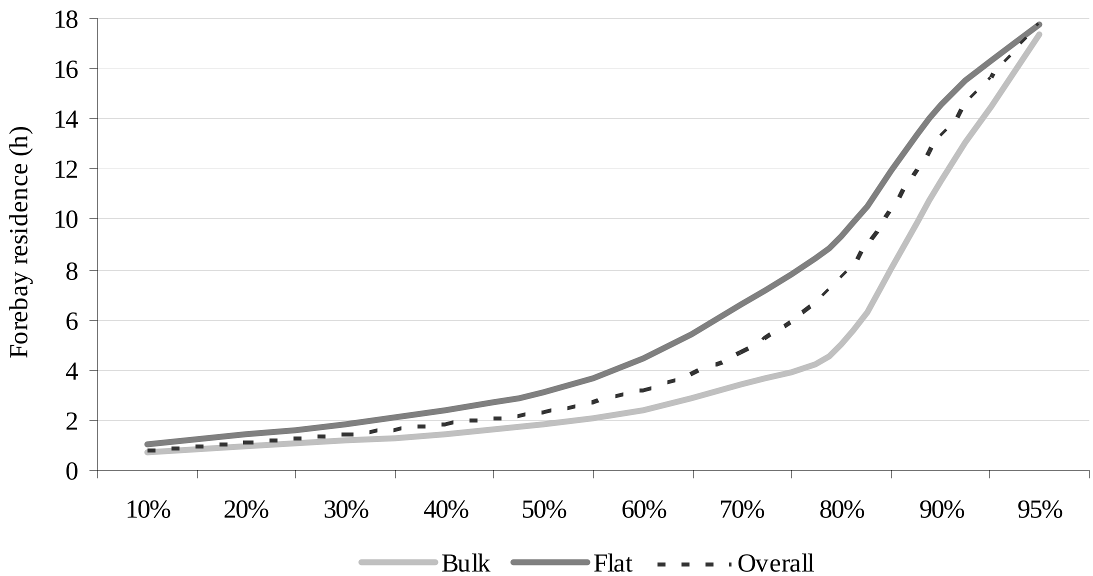

Figure 6. Forebay residence time versus the cumulative percent of radio-tagged juvenile steelhead passing Ice Harbor Dam under two different spill treatments, 2004.

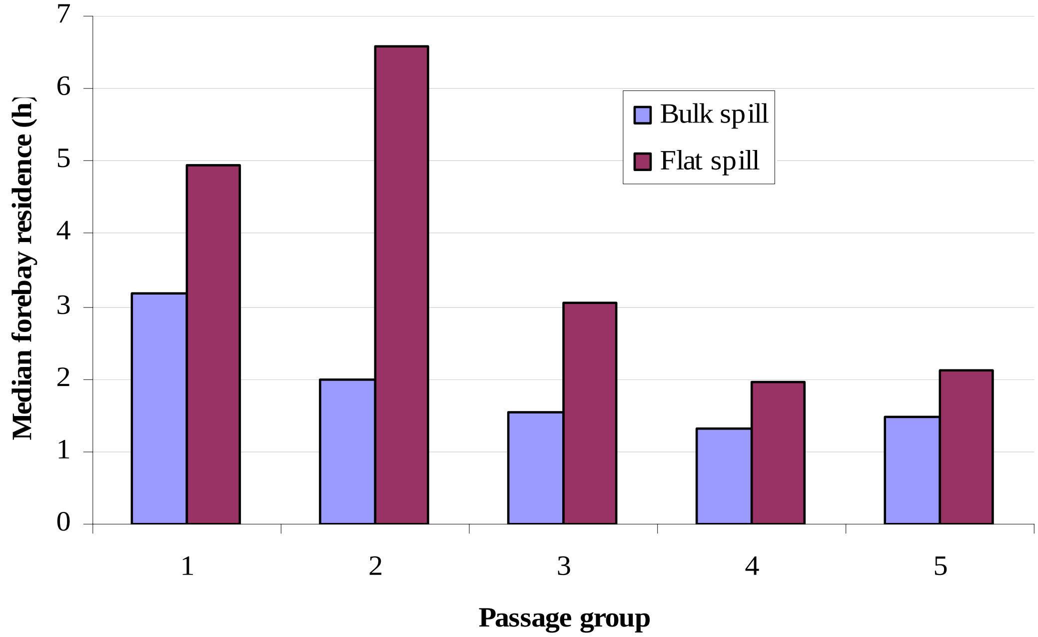

Figure 7. Paired 50th percentiles of forebay residence of radio-tagged juvenile steelhead passing Ice Harbor Dam under two different spill treatments, 2004.

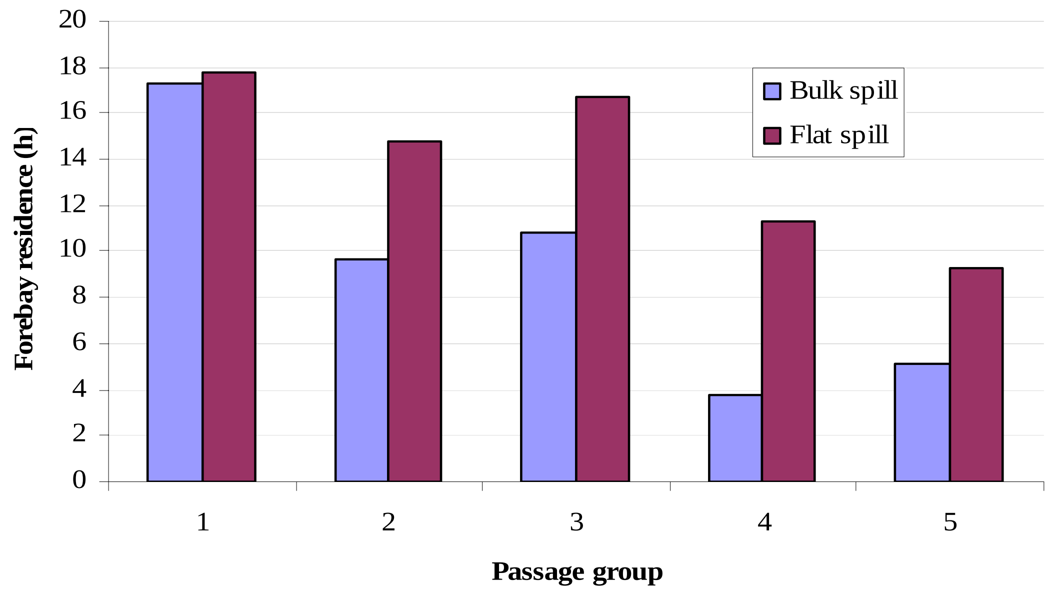

Figure 8. Paired 90th percentiles of forebay residence for radio-tagged juvenile steelhead passing Ice Harbor Dam under two different spill treatments, 2004.

Passage Route Distribution

Overall passage distribution for radio-tagged Snake River juvenile steelhead through spillway, bypass, and turbine routes was 88.1, 8.6, and 0.4%, respectively. Approximately 2.9% of the 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 99% (348) of the fish passed via the spillway with the other 1% (5) going through the bypass system. For the periods of flat spill 82% (240) of the fish passed via the spillway, 17% (50) through the bypass system, and 1% (2) through the turbines. Horizontal spillway distribution during both spill treatments is shown in Figure 9.

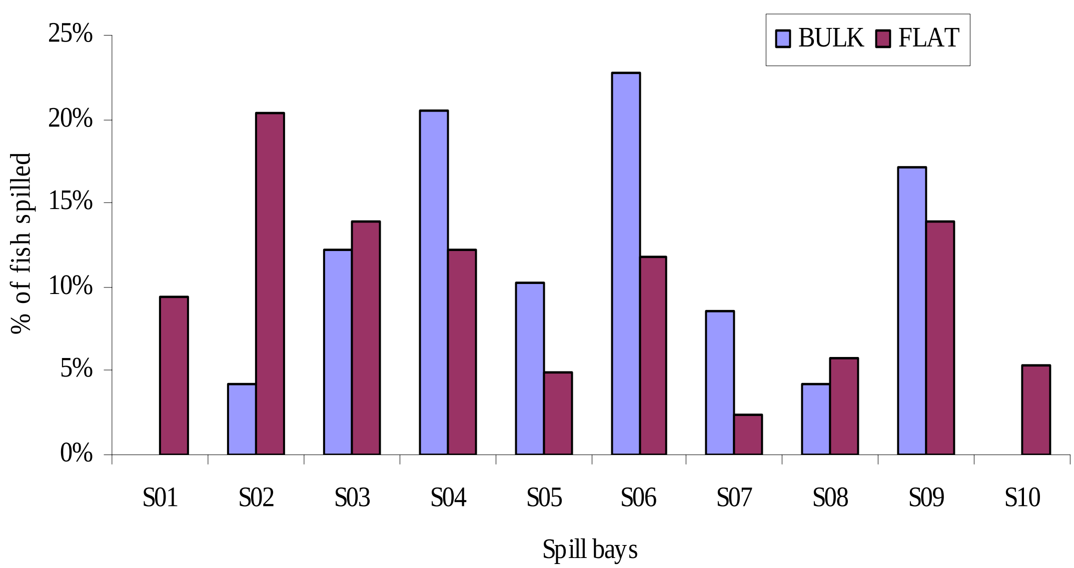

Figure 9. Horizontal spillway passage distribution of radio-tagged juvenile steelhead during both spill treatments at Ice Harbor Dam, 2004.

Fish Passage Metrics

Overall FPE at Ice Harbor Dam was 97%. Overall fish guidance efficiency (FGE) was 95% (95% CI 90-96%), with a minimum of 72% estimated by including fish with unknown passage routes as possible turbine passed fish. Overall spill efficiency was 91% (Table 6).

Fish passage efficiency was 100% during bulk spill and 99% during flat spill (Table 7). Fish guidance efficiency was 100% during bulk spill and 96% during flat spill. Spill efficiency was 99% under bulk spill operations and 82% during flat spill. Mean spill effectiveness was 1.00:1 for bulk spill and 1.08:1 for flat spill.

Table 6. Passage route distribution and spill efficiency by percent spill for radio-tagged juvenile steelhead at Ice Harbor Dam, 2004.

	Passage route				Spill efficiency
Spill (%)	Spill	Bypass	Turbine	Total	(%)
0.0-0.29	0	1	1	2	0.0
0.3-0.39	44	24	0	68	64.7
0.4-0.49	63	16	0	79	79.7
0.5-0.59	45	9	0	54	83.3
0.6-0.69	44	2	1	47	93.6
0.7-0.79	20	0	1	21	95.2
0.8-0.89	223	5	0	228	97.8
0.9-1.00	169	2	0	171	98.8
Overall	608	59	3	670	90.7
					SE = 0.10
					lo CI = 0.66
					hi CI = 1.15

Table 7. Passage distribution and fish passage metrics for radio-tagged juvenile steelhead passing Ice Harbor Dam during bulk and flat spill treatments, 2004.

			Passage route				Fish passage metrics		
Date	Spill treatment	Mean spill (kcfs)	Spillway	Bypass	Turbine	Total	Spill efficiency	FPE	FGE
May 9-11	Bulk 1	71.7	82	1		83	0.99	1.00	1.00
May 13-15	Bulk 2	57.3	71	1		72	0.99	1.00	1.00
May 17-19	Bulk 3	67.8	90			90	1.00	1.00	N/A
May 21-23	Bulk 4	82.0	60	1		61	0.98	1.00	1.00
May 25-27	Bulk 5	82.2	45	2		47	0.96	1.00	1.00
	Totals		348	5	0	353	0.99	1.00	1.00
May 11-13	Flat 1	44.9	45	10		55	0.82	1.00	1.00
May 15-17	Flat 2	43.6	55		2	57	0.96	0.96	0.00
May 19-21	Flat 3	44.5	31	4		35	0.89	1.00	1.00
May 23-25	Flat 4	45.0	60	9		69	0.87	1.00	1.00
May 27-29	Flat 5	45.3	49	27		76	0.64	1.00	1.00
	Totals		240	50	2	292	0.82	0.99	0.96

Tailrace Egress

Median tailrace egress was longer for juvenile steelhead passing during flat spill operations (4.4 min) versus those that passed during bulk spill (3.0 min; Figure 10). This difference was found to be highly significant ($P = 0.003$) in comparisons of egress time between spill treatments using paired *t*-tests on the 50th percentiles of temporal replicate treatment groups (Figure 11). The difference between the two treatments became non-significant as forebay residence times approach the 90th percentile ($P = 0.294$).

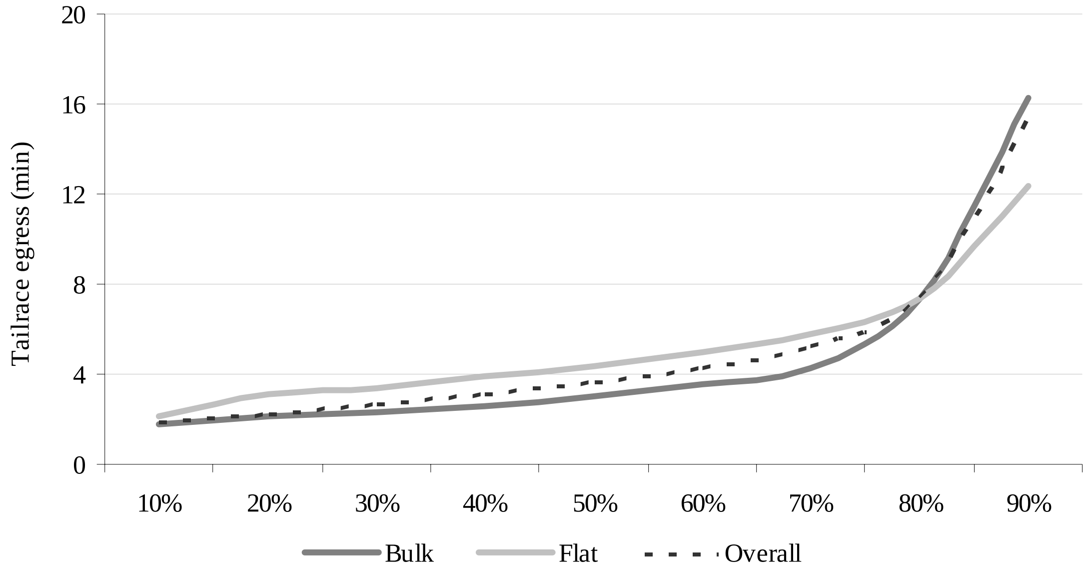

Figure 10. Tailrace egress of radio-tagged juvenile steelhead during two different spill treatments at Ice Harbor Dam, 2004.

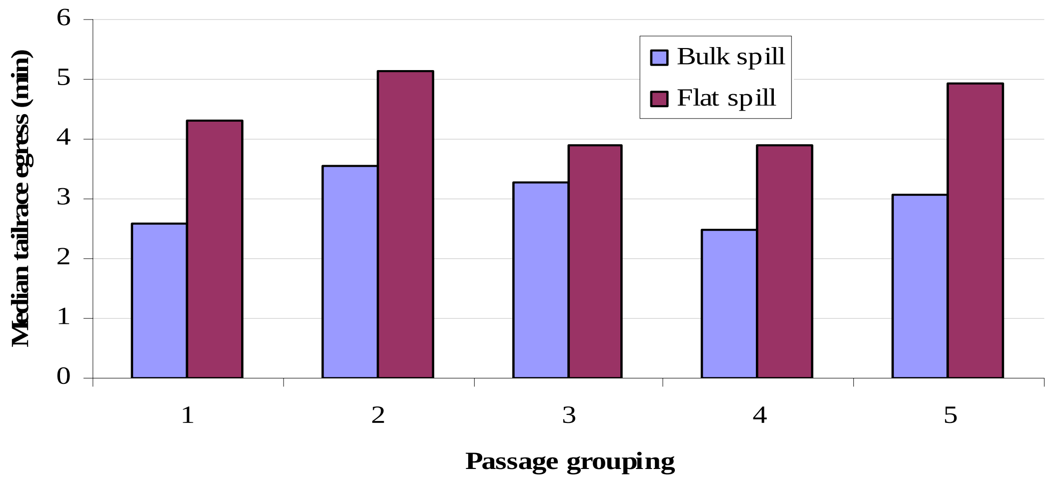

Figure 11. Paired 50th percentile of tailrace egress of radio-tagged juvenile steelhead at Ice Harbor Dam under two different spill treatments, 2004.

Avian Predation

After the Crescent Island Caspian Tern colony had left the island for the season, we initiated a recovery effort for radio tags that were deposited on the island. 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, 318 mortalities were recorded within the tern colony representing approximately 17% of the fish we released into the Snake River. Tern predation accounted for 20% of the fish we released into the tailrace of Lower Monumental Dam and 14% of the fish that were released into the tailrace of Ice Harbor Dam (Figure 12).

Queries of the PTAGIS database yielded a total of 23,316 PIT-tagged juvenile steelhead detected at Lower Monumental Dam and returned to the river rather than transported. Records of subsequent detection showed that 4,190 of these fish were found on the Crescent Island tern colony, representing 18% of the population. During a similar low flow year (2001), tern predation accounted for approximately 21% of the PIT-tagged juvenile steelhead returned to the river at Lower Monumental Dam (3,210 out of 15,242). Both years exhibited similar low turbidity measurements, and the increase in water clarity would have conferred an advantage in predation to the visually hunting Caspian Tern (Figure 13).

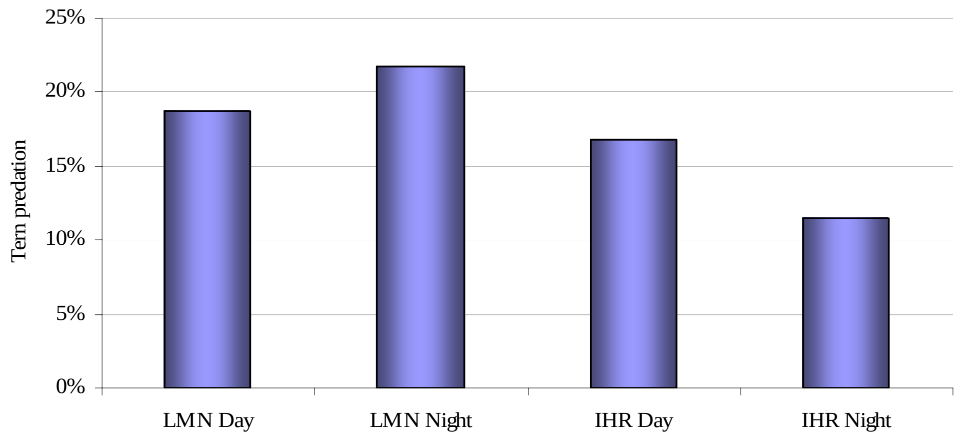

Figure 12. Percent of mortality attributed to tern predation of radio-tagged juvenile steelhead released into the tailraces of Lower Monumental and Ice Harbor Dams during both day and night, 2004.

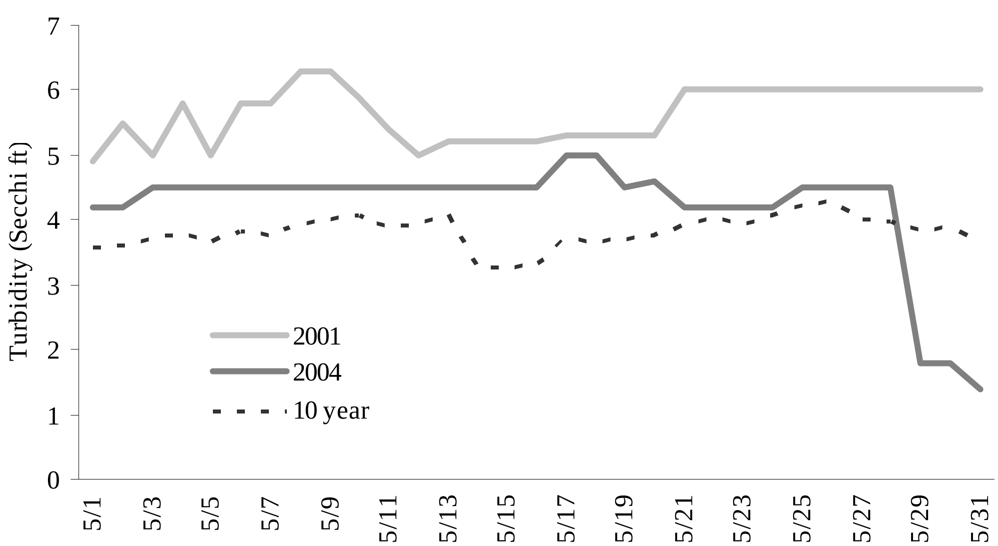

Figure 13. Turbidity in the forebay of Ice Harbor Dam during 2001 and 2004 and the 10-year average, 1994-2004 (measured by Secchi disk readings).

DISCUSSION

During the planning phase of this study, we expected to begin collection and tagging after the 20th percentile of the 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 passage distribution observed at Lower Monumental Dam. However, as a result of low flows and a regional management decision to collect and transport the majority of fish, we were not able to begin tagging until the 40th percentile of the steelhead migration had already passed the dam. We were still able to tag approximately the middle third of the run, and the average size of the fish tagged was consistent with that of the run-at-large, thus providing estimates that were reasonably representative of unmarked juvenile steelhead migrants.

One goal of this study was to distribute our releases of radio-tagged fish over time in order to have equal numbers of fish passing Ice Harbor Dam throughout any given 24-h period and to match those fish up with the controls released in the tailrace. The percentage of fish entering the forebay of Ice Harbor Dam was slightly higher during daylight hours. The hour of passage at Ice Harbor Dam was fairly consistent during the study. There was a slight decline in fish passage in the predawn hours and an increase at night, which was likely a result of changing operations at the project.

The variation of spill treatment blocks did have a small effect on passage distribution and fish passage metrics at Ice Harbor Dam. Spill efficiency decreased during the lower spill discharges experienced during flat spill. However, a more accurate comparison could be obtained by operating the project with similar spill discharge between the alternating bulk and flat spill patterns. Previous studies have shown that the majority of juvenile yearling Chinook salmon typically pass through the spillway, with relatively few entering either powerhouse route (Eppard et al. 2000). There was a tendency for forebay residence times to decrease during the bulk spill operations, but this may have been attributable to the increased flow through the spillway during bulk spill. Tailrace egress was longer for fish that passed during flat spill operations, but although the differences were statistically significant for the 50th percentile of fish, the mean differences were less than two minutes 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 17% of our total mortality to the Caspian Tern colony on Crescent Island, 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 530 breeding pairs attempted to nest at the Crescent Island tern colony in 2004, approximately 9% fewer pairs than in 2003. Based on preliminary estimates, nesting success at the Crescent Island tern colony was fair this year (0.62 fledglings raised per breeding pair), although slightly higher than productivity at this colony last year (Collis et al. 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 Irrigon, OR, a distance of nearly 130 km.

The high percentage of fish transported in 2001 and 2004 had another important consequence: the overall abundance of Snake River juvenile salmonids below Lower Monumental Dam was exceptionally low compared to previous years, and the majority of these fish were PIT-tagged. Only a small percentage of unmarked Snake River fish were subjected to the poor conditions faced by migrants passing downstream though the hydropower system. 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).

RECOMMENDATIONS

We recommend a continued effort to evaluate juvenile steelhead survival in the lower Snake River in order to identify areas of mortality. With the addition of a removable spillway weir at Ice Harbor Dam in 2005, we need to evaluate passage survival and the associated effects on juvenile steelhead behavior. It is also becoming apparent that the Crescent Island Caspian Tern colony is targeting juvenile steelhead at a much higher rate than other salmonids. 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 and Model Assumptions

We used the single-release (SR) model to estimate survival of radio-tagged juvenile steelhead from the tailrace of Lower Monumental Dam to the forebay of Ice Harbor Dam. We also used the SR model to estimate reach survival between Ice Harbor and McNary Dam using telemetry transects located at Sacajawea State Park (mouth of the Snake River), Port Kelley, the forebay of McNary Dam, and Irrigon, OR. Critical assumptions of the SR model were considered for this study, along with biological and statistical assumptions. These assumptions and their respective evaluations are detailed below.

A1. All tagged fish have the same probability of being detected at a detection location.

Radiotelemetry detection probabilities at Ice Harbor Dam were 100%, with all fish that were seen below Ice Harbor being detected on the forebay entrance receivers.

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

Collection and tagging of unmarked juvenile steelhead began after 40% of the juvenile steelhead had passed Lower Monumental Dam and was completed when 73% of these fish had passed (Figure 2). Therefore, we did not meet the goal of tagging during the 20th to 75th passage percentiles of the steelhead juvenile migration. However, the overall mean fork length and weight for tagged fish compared closely with the mean weight and length of the unclipped run-at-large sampled at the smolt collection facility during the tagging period.

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

Assumption A3 was not tested for validation in this study. However, previous evaluations have determine the effects of radio tagging on survival, predation, growth, and swimming performance of juvenile salmonids (Adams et al. 1998 a, b; Hockersmith et al. 2003).

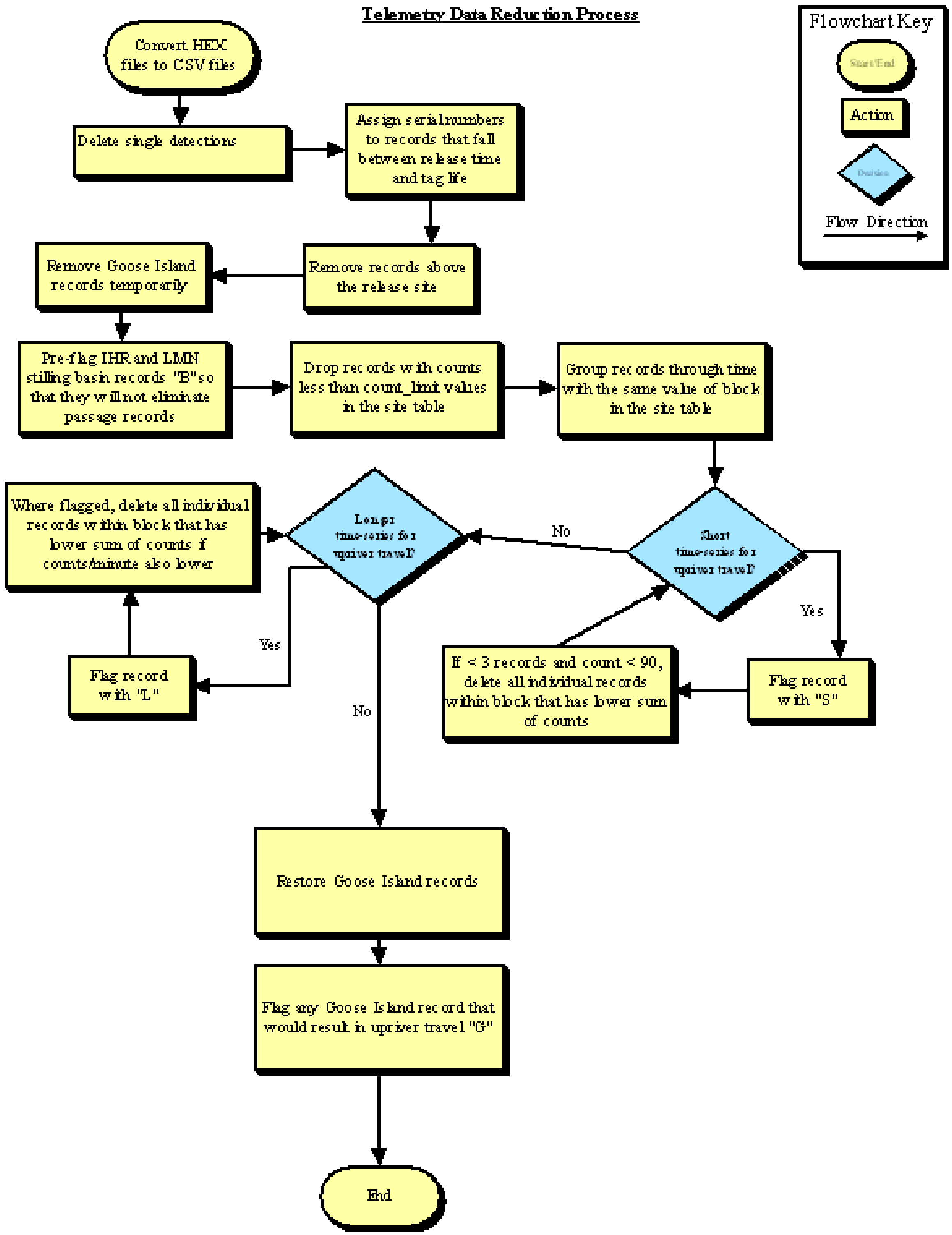
A4. Fish that die at either a project or passing through a passage route at a project are not subsequently detected at a downstream array which is used to estimate survival for the project or passage route.

Assumption A4 was not tested for validation in this study. The distance between Ice Harbor Dam and our first downstream detection array which was used for survival estimation (Irrigon) was 16 km. Axel et al. (2003) reported that dead radio-tagged fish released into the bypass systems at Ice Harbor Dam were not subsequently detected at telemetry transects which were more than 3.2 km downstream.

A5. 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 assure that the transmitter was functioning properly. Tags which were not functioning properly were not used in the study. In addition, a portion of the radio transmitters from tagging mortalities throughout the study were tested for tag life by allowing them to run in river water and checked daily to determine if they functioned for the predetermined period of time. None of the tags tested for tag life failed prior to the preprogrammed shut down after 10 d.

APPENDIX B


Telemetry Data Reduction Process
Flowchart Key
Start/End
Action
Decision
Flow Direction
Convert HEX files to CSV files
Delete single detections
Assign serial numbers to records that fall between release time and tag life
Remove records above the release site
Remove Goose Island records temporarily
Pre-flag IHR and LMN stilling basin records "B" so that they will not eliminate passage records
Drop records with counts less than count_limit values in the site table
Group records through time with the same value of block in the site table
Short time-series for upriver travel?
No
Yes
Flag record with "S"
If < 3 records and count < 90, delete all individual records within block that has lower sum of counts
Longer time-series for upriver travel?
Yes
Flag record with "L"
Where flagged, delete all individual records within block that has lower sum of counts if counts/minute also lower
No
Restore Goose Island records
Flag any Goose Island record that would result in upriver travel "G"
End