Effects of spill on the passage of hatchery yearling chinook salmon at Ice Harbor Dam, 1999

Fish Ecology Division

Northwest Fisheries Science Center

National Marine Fisheries Service

Seattle, Washington

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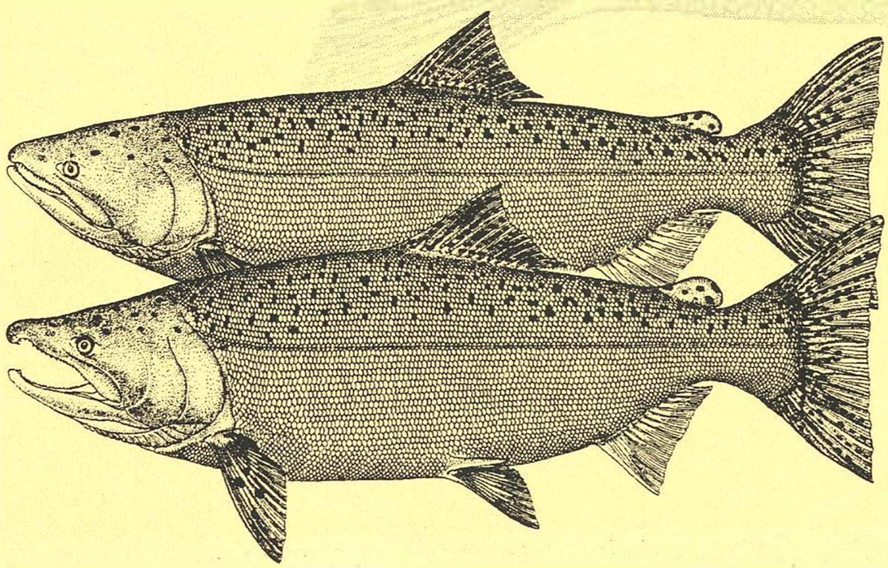
October 2000



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Report of Research

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EXECUTIVE SUMMARY

In recent years, spill has been utilized increasingly to expedite the migration rates of juvenile salmonids past Columbia and Snake River hydroelectric dams and to reduce the proportion of smolts passing through turbines. However, high spill volumes at Ice Harbor Dam on the Snake River produce an eddy in the tailrace of the dam. This eddy can potentially cause delays for migrating salmonids and expose them to increased total dissolved gas levels, often above state and federal water quality standards deemed safe for aquatic organisms. Testing has shown that operating only Turbine Unit 3 during high spill levels helped dissipate the eddy formed in the tailrace of Ice Harbor Dam, potentially decreasing tailrace residence times for juvenile salmonids passing the dam.

The primary objectives of this study were to determine tailrace residence times, spill efficiency, spill effectiveness, and fish passage efficiency for radio-tagged hatchery yearling chinook salmon (*Oncorhynchus tshawytscha*) passing Ice Harbor Dam under moderate and high spill conditions.

Spill levels at Ice Harbor Dam during this study were as high as 45% of total river flow during the day (0600 to 1800 h) and up to 100% spill at night (1800 to 0600 h). From 22 April to 25 May, we released 990 surgically radio-tagged hatchery yearling chinook salmon into the tailrace of Lower Monumental Dam (51 km upstream from Ice Harbor Dam) on the Snake River. Data were collected on 896 (91% of those released) radio-tagged fish at Ice Harbor Dam.

Median tailrace residence times were 2.7, 5.7, and 7.3 minutes for radio-tagged fish that passed Ice Harbor Dam through the spillway, bypass system, or turbines, respectively, during daytime hours. During nighttime hours and 100% spill, median tailrace residence time was 3 minutes for fish that passed through the spillway. During high spill and with Turbine Unit 3

operating, median tailrace residence time was 2.6 minutes for fish that passed through the spillway.

Based on the 896 radio-tagged fish that were detected in the study area, passage distribution was 80, 8, and 3% for fish passing through the spillway, bypass system, and turbine units, respectively. Eight percent passed the dam but were not detected on a passage route receiver and one percent were detected in the forebay but never downstream from Ice Harbor Dam. Respective spill efficiency, spill effectiveness, and fish passage efficiency for radio-tagged fish passing Ice Harbor Dam was 82.6%, 1.8:1, and 96.1% during daytime hours and 93.2%, 1:1, and 97.8% during nighttime hours.

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INTRODUCTION

In recent years, spill has been utilized increasingly to expedite the migration rates of juvenile salmonids past hydroelectric dams and to reduce the proportion of smolts passing through turbines where survival is lower (Iwamoto et al. 1994; Muir et al. 1995, 1996). The present spill program at Ice Harbor Dam, as prescribed by the National Marine Fisheries Service (NMFS) in its Biological Opinion (1995), was designed to increase fish passage efficiency (FPE), spill efficiency, and survival as well as alleviate migrational delays associated with passage at the dam. However, high spill volumes at Ice Harbor Dam produce an eddy in the tailrace of the dam potentially causing delays for migrating salmonids and exposing them to increased total dissolved gas (TDG) levels, often above state and federal water quality standards deemed safe for aquatic organisms. The potential survival benefits for juvenile salmonids from increased spill volumes can be offset by mortality caused by elevated TDG levels (Cramer 1995, 1996). Testing at the U.S. Army Corps of Engineers (COE) Waterways Experiment Station showed that operating only Turbine Unit 3 at Ice Harbor Dam during high spill levels helped to alleviate the eddy directly downstream from the powerhouse, possibly decreasing tailrace residence times for migrating juvenile salmonids.

Spill efficiency, spill effectiveness, and FPE as used in this report are defined as follows:

Spill efficiency	=	Number of fish passing the dam via the spillway divided by the total number of fish passing the dam.
Spill effectiveness	=	The proportion of fish passing the dam via the spill divided by the proportion of water spilled.
Fish passage efficiency	=	The number of fish passing the dam in non-turbine routes divided by total project passage.

Giorgi et al. (1988) reported that spill effectiveness was near 2:1 for radio-tagged yearling chinook salmon at 20% spill levels and 1.5:1 at 40% spill levels at Lower Granite Dam. Eppard et al. (1998) reported that spill efficiency, spill effectiveness, and FPE were 89%, 2.3:1, and 100% at less than 40% spill and 87%, 1.2:1, and 88% at greater than 60% spill, respectively, for radio-tagged hatchery subyearling fall chinook salmon at Ice Harbor Dam.

OBJECTIVES

Objective 1

Determine tailrace residence times for radio-tagged hatchery yearling chinook salmon passing Ice Harbor Dam under varying operational conditions.

Objective 1.1. Determine the proportion of radio-tagged fish passing through the spillway, juvenile bypass system, and turbines at Ice Harbor Dam under varying operational conditions.

Objective 1.2. Determine the influence of route of passage on tailrace residence times.

Objective 2

Determine spill efficiency and effectiveness for radio-tagged hatchery yearling chinook salmon passing Ice Harbor Dam under varying operational conditions.

Objective 2.1 Determine the proportion of radio-tagged fish passing through the spillway, juvenile bypass system, and turbines at Ice Harbor Dam under varying operational conditions.

Objective 2.2 Relate time and route of passage of radio-tagged fish to existing spill conditions.

Objective 3

Compare timing of radio/PIT-tagged fish vs. PIT-tagged only fish between Lower Monumental and McNary Dams.

METHODS

Study Area

Ice Harbor Dam, the first dam on the Snake River, is located 15.5 km upstream from the confluence of the Snake and Columbia Rivers. The study area included Ice Harbor Dam and the immediate forebay and tailrace about 1 km above and below the dam (Fig. 1).

Radio Tags

Radio tags, purchased from Advanced Telemetry Systems Inc.,[1] had an expected battery life of about 7 days and were pulse-coded for unique identification of individual fish. Each radio tag measured 17 mm in length by 7 mm in diameter and weighed 1.4 g in air. A PIT tag was encapsulated in each radio tag.

Test Fish and Tagging Protocol

Fish used in this study were river-run hatchery yearling chinook salmon collected from 21 April through 25 May at the juvenile collection facility at Lower Monumental Dam. Anesthetized fish were removed from the sample and allowed to recover in a 113.5-L container with aeration and flow-through water 24 hours prior to tagging. Study fish were measured and their condition noted. Fish that were injured and/or heavily descaled were rejected and released into the COE transportation raceways. Test fish ranged from 124 to 231 mm in length (median 141 mm) and 16 to 125 g in weight (median 27 g).

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

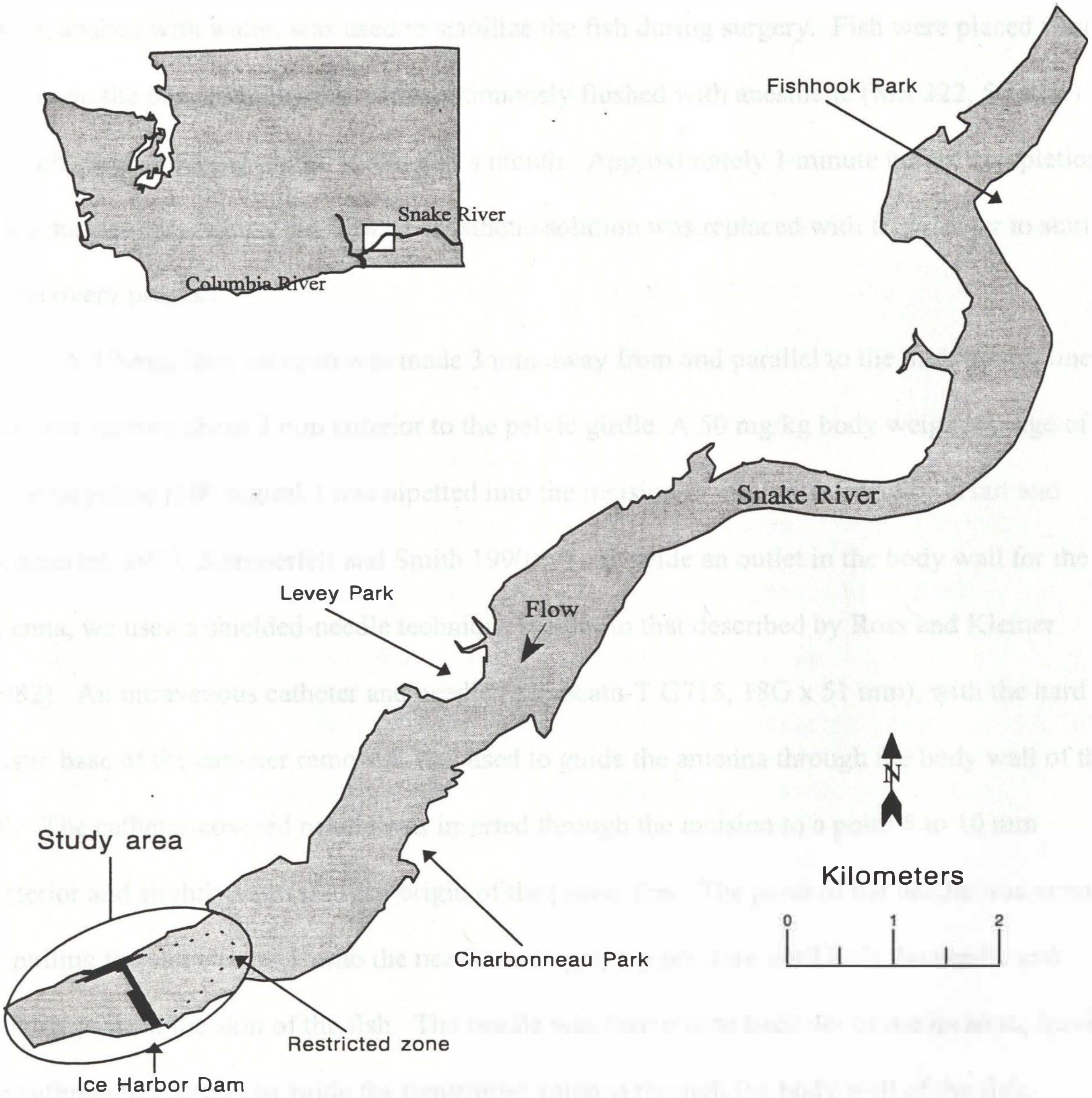

Figure 1. Study area showing location of Ice Harbor Dam on the Snake River, Washington.

Fish were radio tagged using surgical techniques similar to those described by Moore et al. (1990), but modified for use with smaller fish. A soft foam pad with a groove cut in the center, soaked with water, was used to stabilize the fish during surgery. Fish were placed ventral side up on the pad, and the gills were continuously flushed with anesthetic (MS 222, 50 ppm) fed through surgical tubing placed in the fish's mouth. Approximately 1 minute before completion of the surgical procedure, the flow of anesthetic solution was replaced with fresh water to start the recovery process.

A 10-mm long incision was made 3 mm away from and parallel to the mid-ventral line of each fish starting about 3 mm anterior to the pelvic girdle. A 50 mg/kg body weight dosage of oxytetracycline (100 mg/mL) was pipetted into the incision to minimize infection (Hart and Summerfelt 1975, Summerfelt and Smith 1990). To provide an outlet in the body wall for the antenna, we used a shielded-needle technique similar to that described by Ross and Kleiner (1982). An intravenous catheter and needle (Abbocath-T G715, 18G x 51 mm), with the hard plastic base of the catheter removed, was used to guide the antenna through the body wall of the fish. The catheter-covered needle was inserted through the incision to a point 5 to 10 mm posterior and slightly ventral to the origin of the pelvic fins. The point of the needle was exposed by pulling the catheter back onto the needle and applying pressure until both the needle and catheter pierced the skin of the fish. The needle was then pulled back out of the incision, leaving the catheter in position to guide the transmitter antenna through the body wall of the fish.

The transmitter was inserted into the abdominal cavity by threading the antenna through the incision end of the catheter. Both the antenna and catheter were gently pulled in the posterior direction while the transmitter was simultaneously inserted into the incision. This allowed the transmitter to lie in a horizontal position directly under the incision. The incision was closed with 2-3 simple, interrupted absorbable sutures (Ethicon coated vicryl braided, 5-0 taper FS-2 needle).

Individual radio-tagged fish were placed in a 19-L recovery container with aeration for approximately 5 minutes in order to recover from the effects of MS 222. Recovery containers were perforated with 1.3-cm-diameter holes in the top 18 cm of the container to facilitate water exchange during holding and transport. When fish regained equilibrium, recovery containers were covered with a lid and placed into 2.4 by 0.6 by 0.5 m troughs on a 1-ton flatbed truck. The troughs were supplied with flow-through water while fish were held overnight prior to release.

Release Protocol

We maintained a post-tagging recovery time of 20 to 24 hours. The morning after tagging, fish were transported and released into the juvenile fish bypass system flume downstream from the primary dewatering facility during primary bypass mode at Lower Monumental Dam. In this way, study fish, like the population they represent, were naive to Ice Harbor Dam. Prior to release, mortalities were removed from the buckets and recorded.

Monitoring of Radio-Tagged Fish

Radiotelemetry receivers and antennas were installed at Ice Harbor Dam to monitor the forebay, tailrace, and all routes of passage available to migrating juvenile salmonids (Fig. 2). A study-area entrance line (about 1 km upstream from the dam) monitored entrance into the study area by radio-tagged fish. The forebay in front of the powerhouse and spillway was monitored to determine approach patterns at the dam. Monitored passage routes included the juvenile fish

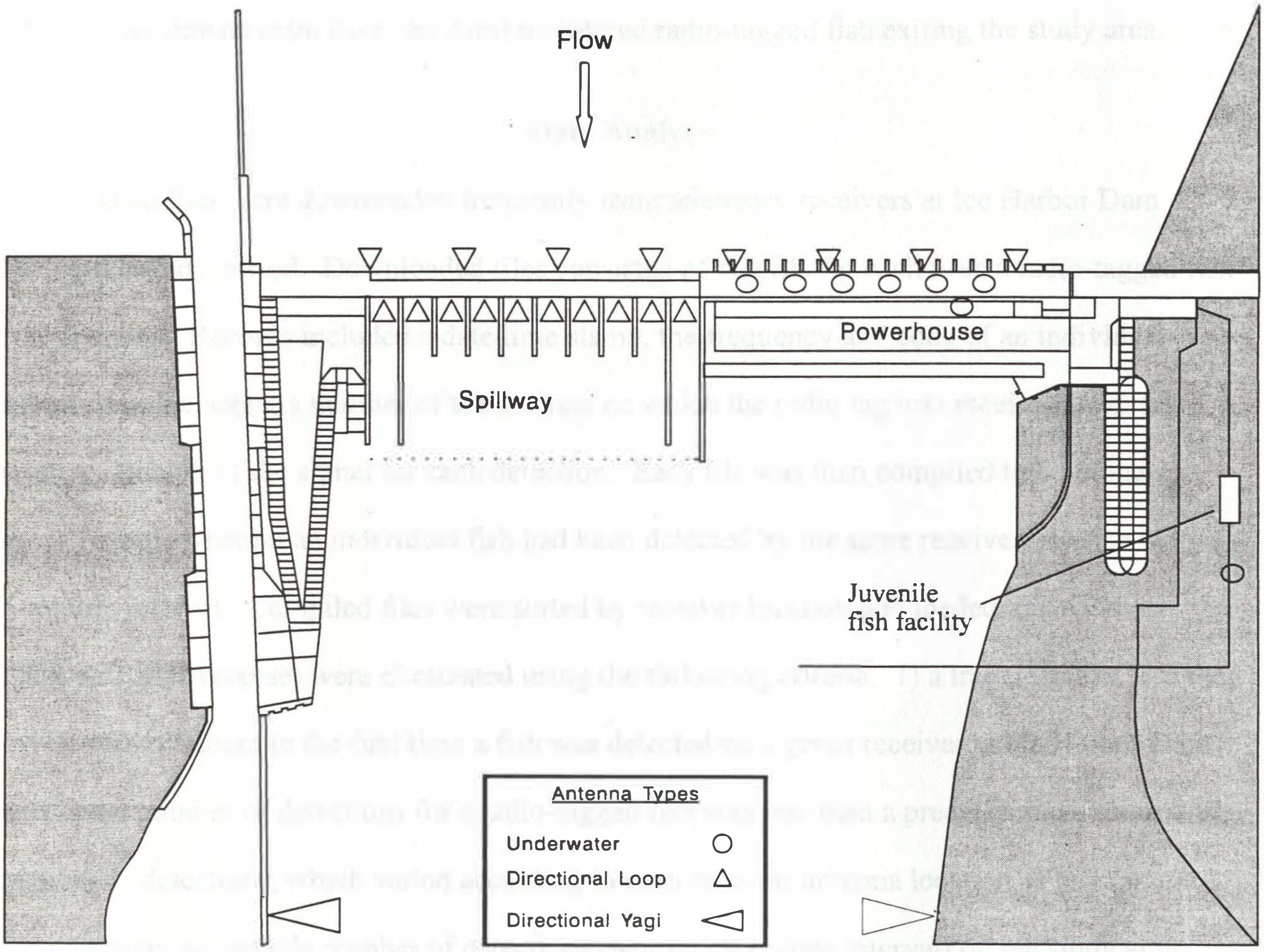

Figure 2. Ice Harbor Dam with locations of telemetry receivers and types of antennas (study-area entrance and exit lines are not shown). Symbol direction indicates the primary detection area of a given antenna.

bypass system, individual spillbays, and gatewells. A tailrace exit line (about 360 m downstream from the dam) was established to determine tailrace residence times. A study-area exit line (about 1 km downstream from the dam) monitored radio-tagged fish exiting the study area.

Data Analysis

Data files were downloaded frequently from telemetry receivers at Ice Harbor Dam during the study period. Downloaded files consisted of records for each time a radio-tagged fish was detected. Records included a date/time stamp, the frequency and code of an individual transmitter, the antenna number of the antenna on which the radio tag was received, and the relative strength of the signal for each detection. Each file was then compiled to combine and count records wherein an individual fish had been detected by the same receiver/antenna within a 5-minute interval. Compiled files were sorted by receiver location and loaded to a database. False detections (noise) were eliminated using the following criteria: 1) a travel time of less than 0.5 day from release to the first time a fish was detected on a given receiver at Ice Harbor Dam and 2) the number of detections for a radio-tagged fish was less than a predetermined minimum number of detections, which varied according to each receiver/antenna location. For example, the minimum acceptable number of detections (within a 5-minute interval) on the study area entrance and exit line receivers was 10. Finally, data from all sites were examined for chronological progression through the study area for individual radio-tagged fish. Criteria for acceptable chronological progression through the study area are described in Table 1.

Confidence intervals for median tailrace residence times as well as comparisons between differences in median residence times for groups passing through each route of passage were calculated using bootstrap techniques (Efron and Tibshirani 1993). The median was chosen

Table 1. Chronological progression criteria used in analyzing radio-tag data at Ice Harbor Dam, 1999.

Order	Detection areas	Criteria description
1	Study area entrance	First time detection in the forebay of the dam.
2	Dam approach	First time detection at the dam.
3	Passage route	Last record on a passage route monitor (i.e., spillway, bypass system, or turbine unit).
4	Tailrace exit	Last detection on the tailrace receivers.
5	Study area exit	Last detection on the study area exit receivers.

as the best estimator of central tendency for travel time data as the distributions of travel times are usually somewhat normally distributed but can have very long right tails (stragglers). Bootstrap confidence intervals for median travel times and comparisons between median travel times for fish experiencing different passage routes were calculated using the following approach: 1) A bootstrap "resample" of the same size as the original sample was taken with replacement for a particular group; 2) For single groups, the median of the resample was calculated. For comparison groups, the difference between the two resampled medians was calculated; 3) The process was repeated 1,000 times resulting in a "bootstrap distribution" of the original median (or difference of medians); 4) the 2.5 and 97.5 percentiles of this distribution (i.e., the 25th smallest and largest estimates) were chosen as the endpoints for the 95% confidence interval; 5) For comparison groups, the medians of the two groups were deemed significantly different if the 95% confidence interval on the difference of the medians did not include zero.

The relationship between spill proportion, spill efficiency, spill effectiveness, and fish passage efficiency were explored using linear regression.

Median travel time differences between radio-tagged and PIT-tagged fish from Lower Monumental Dam to McNary Dam were compared using analysis of covariance with tag-type as a factor and release date as a covariate. Only days when both tag-types were released were included. Significance was set at $\alpha = 0.05$.

RESULTS AND DISCUSSION

During the study period, spill volumes ranged from 32 to 100% of total river flow. Average daytime spill (0600-1800) was 53.9 kcfs or 45% of total river flow, while average nighttime spill (1800-0600) was 94.2 kcfs or 80.8% of total river flow (Fig. 3).

We released 990 radio-tagged hatchery yearling chinook salmon into the tailrace of Lower Monumental Dam (Table 2). Of these, 896 (91%) entered into the study area at Ice Harbor Dam. Approach patterns were recorded for 817 fish. During daytime hours, 185 (51%) fish approached at the spillway vs. 175 (49%) at the powerhouse. During nighttime hours, 357 (66%) approached at the spillway vs. 100 (34%) at the powerhouse (Fig. 4).

Overall and diel distributions for each passage route were determined using all radio-tagged fish that entered the study area and that were recorded as passing Ice Harbor Dam. Based on the 896 radio-tagged fish that entered the study area, overall passage distribution by route was 723 (80%) fish via the spillway, 70 (8%) via the juvenile bypass system, and 24 (3%) via the turbines (69 fish were recorded both upstream and downstream from the dam but their passage route was unknown; 10 were only detected upstream from the dam and their passage was undetermined). Diel passage distribution by route was 297 (83%), 49 (14%), and 14 (4%) for radio-tagged fish passing via the spillway, juvenile bypass system, and turbines, respectively, for the 360 fish that passed the dam during the day and 426 (93%) fish via the spillway, 21 (5%) via the juvenile bypass system, and 10 (2%) via the turbines for the 457 fish that passed during the night (Fig. 5).

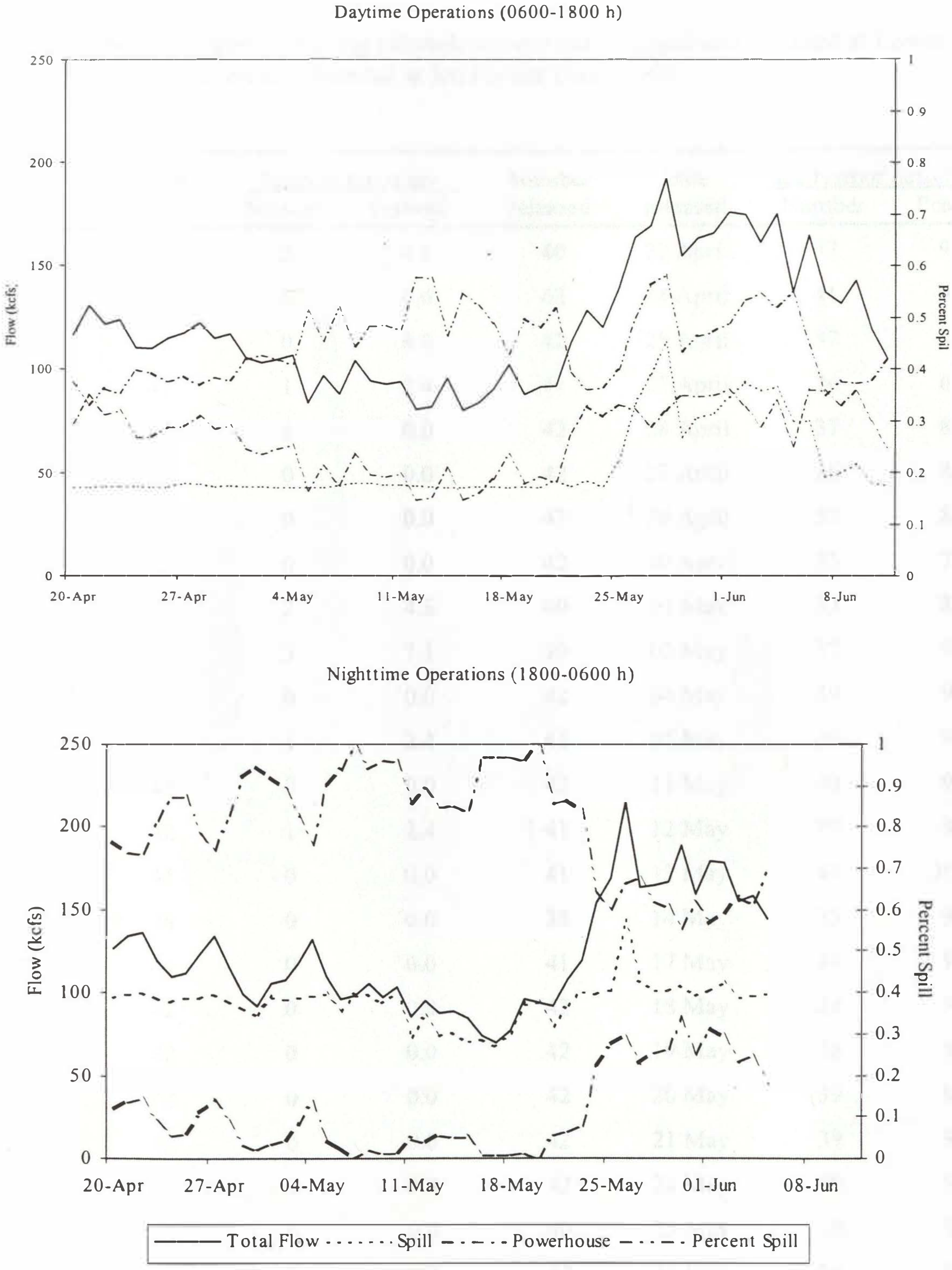

Figure 3. Average daytime (0600 - 1800 h) and nighttime (1800 - 0600) river flow data from 20 April to 11 June at Ice Harbor Dam, 1999.

Table 2. Number of hatchery yearling chinook salmon radio tagged and released at Lower Monumental Dam and detected at Ice Harbor Dam, 1999.

Group number	Number tagged	Tagging mortality		Number released	Date released	Ice Harbor detections	
		Number	Percent			Number	Percent
2	42	2	4.8	40	23 April	37	92.5
3	42	0	0.0	42	24 April	41	97.6
4	42	0	0.0	42	25 April	37	88.1
5	42	1	2.4	41	27 April	26	63.4
6	42	0	0.0	42	28 April	37	88.1
1	42	0	0.0	42	22 April	36	85.7
7	42	0	0.0	42	29 April	37	88.1
8	42	0	0.0	42	30 April	33	78.6
9	42	2	4.8	40	01 May	33	82.5
10	42	3	7.1	39	02 May	37	94.9
11	42	0	0.0	42	04 May	39	92.9
12	42	1	2.4	41	05 May	39	95.1
13	42	0	0.0	42	11 May	40	95.2
14	42	1	2.4	41	12 May	39	95.1
15	41	0	0.0	41	13 May	41	100.0
16	38	0	0.0	38	14 May	35	92.1
17	41	0	0.0	41	17 May	39	95.1
18	42	0	0.0	42	18 May	39	92.9
19	42	0	0.0	42	19 May	38	90.5
20	42	0	0.0	42	20 May	39	92.9
21	42	0	0.0	42	21 May	39	92.9
22	42	0	0.0	42	24 May	40	95.2
23	40	0	0.0	40	25 May	39	97.5
24	42	0	0.0	42	26 May	36	85.7
Total	**1000**	**10**	**1.0**	**990**		**896**	**90.6**

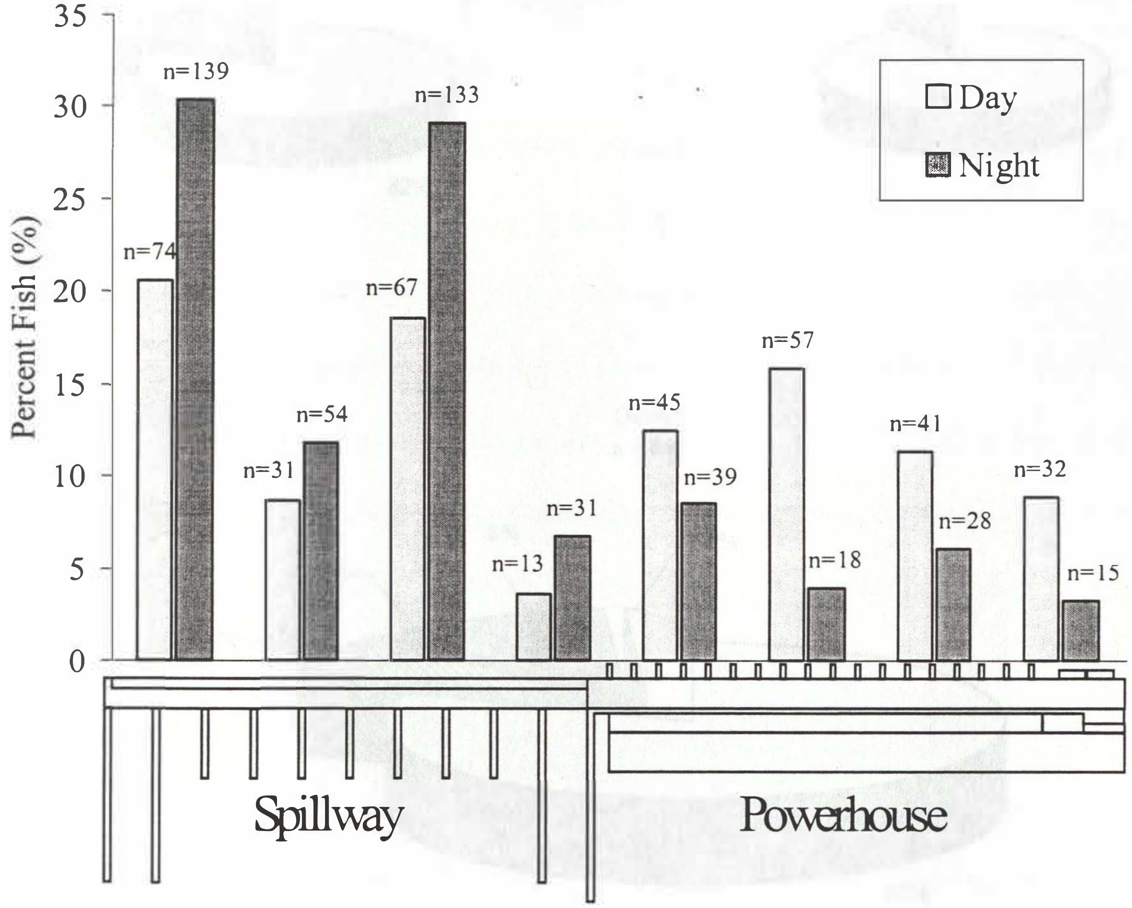

Figure 4. Approach patterns by diel period of radio-tagged hatchery yearling chinook salmon at Ice Harbor Dam, 1999.

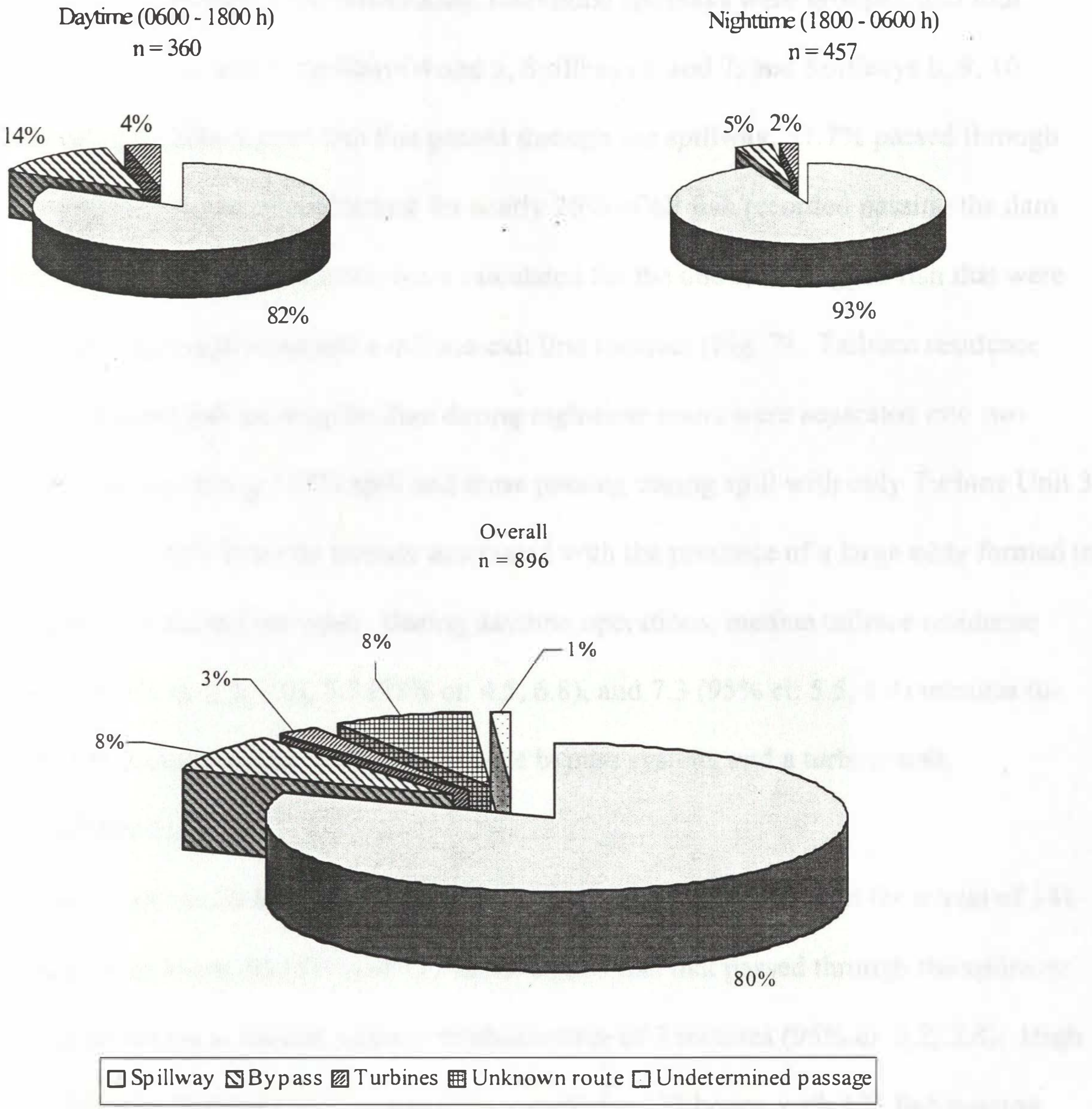

Figure 5. Overall and diel passage route distribution for radio-tagged hatchery yearling chinook salmon at Ice Harbor Dam, 1999.

For spillway passage route distribution, individual spillbays were grouped into four sections: Spillbays 1, 2, and 3; Spillbays 4 and 5; Spillbays 6 and 7; and Spillbays 8, 9, 10 (Fig. 6). Of the 723 radio-tagged fish that passed through the spillway, 31.7% passed through Section S2 (Spillbays 4 and 5) accounting for nearly 26% of all fish recorded passing the dam.

Median tailrace residence times were calculated for the 680 radio-tagged fish that were recorded on both a passage route and a tailrace-exit line receiver (Fig. 7). Tailrace residence times for radio-tagged fish passing the dam during nighttime hours were separated into two groups: those passing during 100% spill and those passing during spill with only Turbine Unit 3 operating. Delayed exits from the tailrace associated with the presence of a large eddy formed in front of the powerhouse did not exist. During daytime operations, median tailrace residence times were 2.7 (95% ci: 2.5, 3.0), 5.7 (95% ci: 4.5, 6.8), and 7.3 (95% ci: 5.5, 8.4) minutes for radio-tagged fish passing via the spillway, juvenile bypass system, and a turbine unit, respectively (Table 3).

From 23 April to 23 May, Ice Harbor Dam was operated at 100% spill for a total of 141 hours. During these hours, 95 (81%) of 117 radio-tagged fish that passed through the spillway were recorded as having a median tailrace residence time of 3 minutes (95% ci: 2.2, 3.8). High spill levels with only Turbine Unit 3 operating occurred for 133 hours, with 173 fish passing through the spillway. Median tailrace residence time for these fish was 2.6 minutes (95% ci: 2.4, 3.3). Overall median tailrace residence time was 2.8 minutes (95% ci: 2.6, 3.1) for 680 (83%) of the 817 fish recorded as passing Ice Harbor Dam during the study (Table 4).

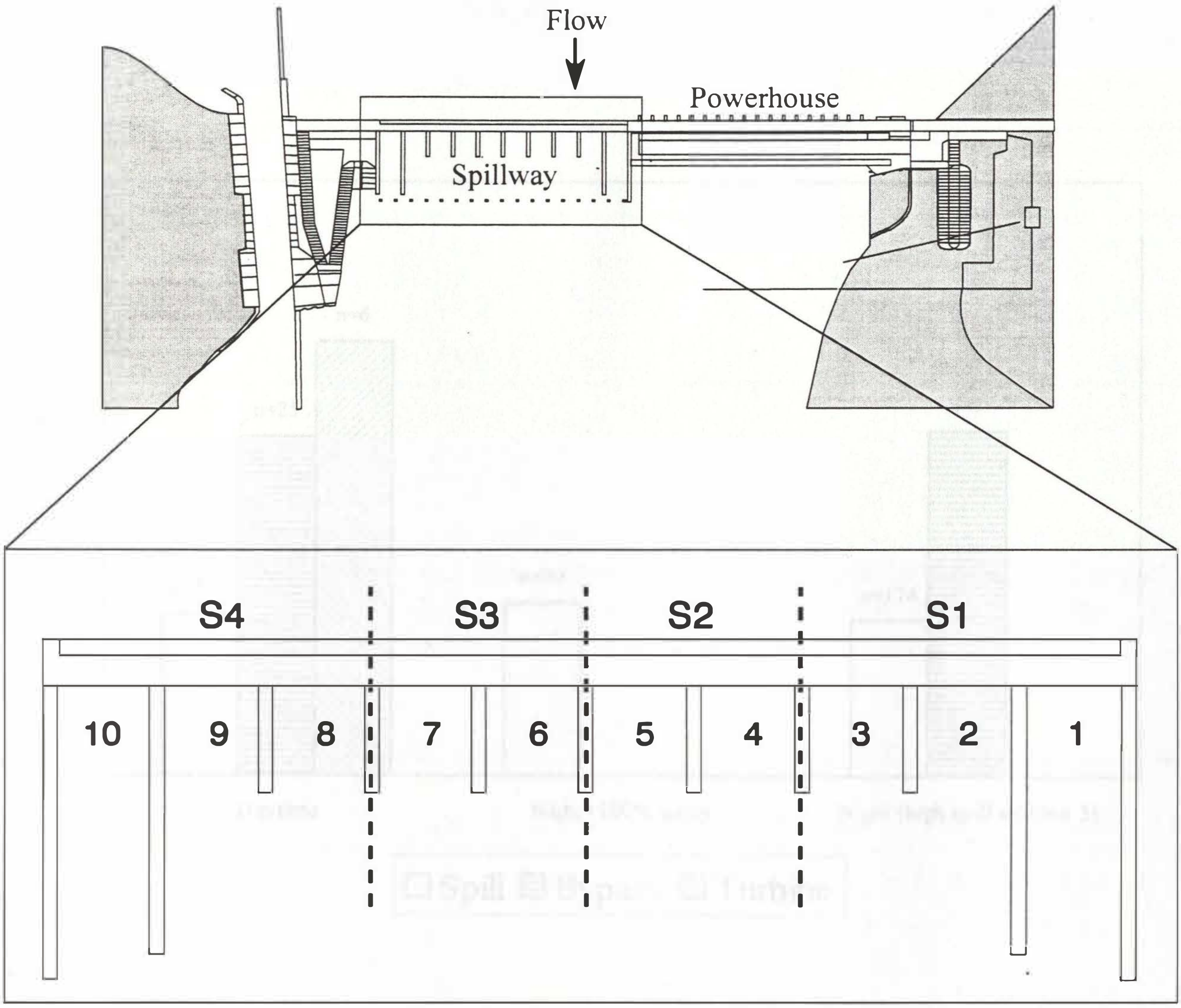

Figure 6. Ice Harbor Dam spillway showing four spillbay groupings used to evaluate passage route distribution, 1999.

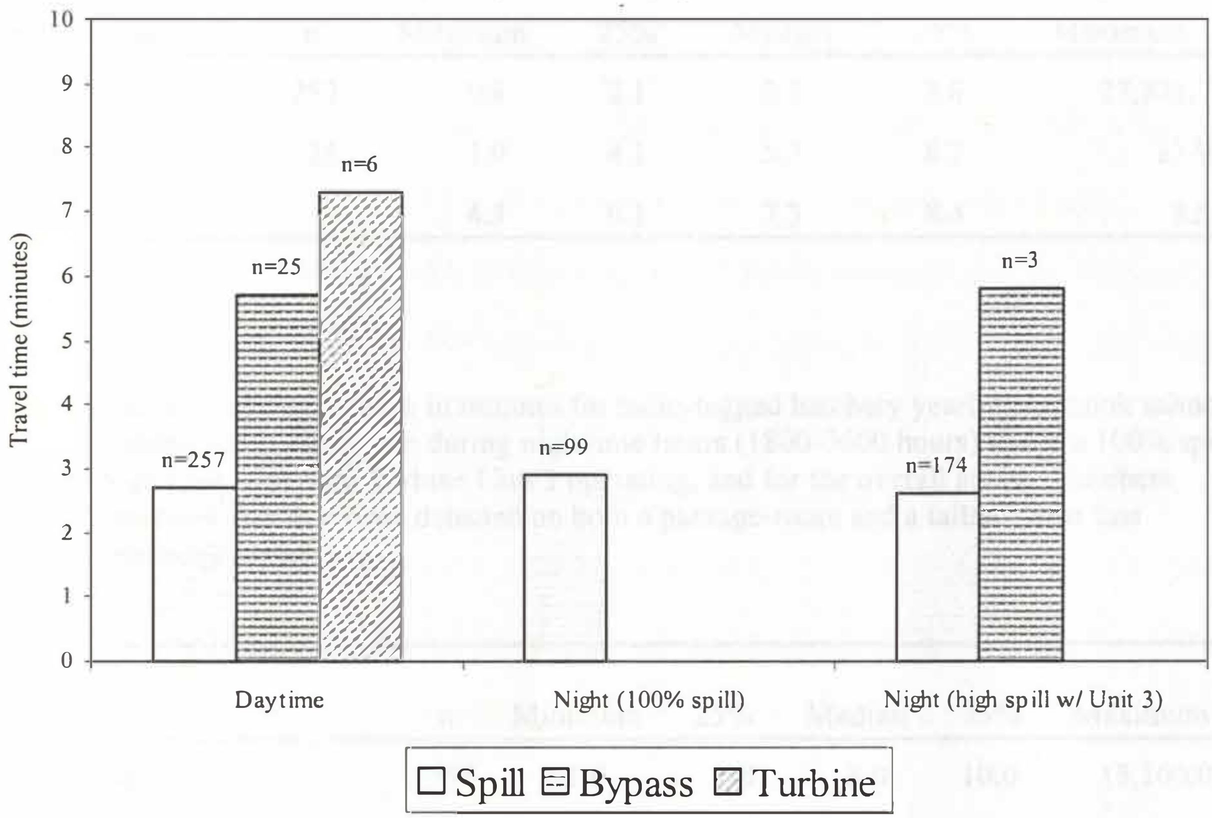

Figure 7. Median tailrace egress times for radio-tagged hatchery yearling chinook salmon passing Ice Harbor Dam, 1999.

Table 3. Tailrace residence times in minutes for radio-tagged hatchery yearling chinook salmon passing Ice Harbor Dam during daytime hours (0600-1800 hours). Numbers represent fish that were detected on both a passage-route and a tailrace-exit line telemetry receiver.

Passage route	n	Minimum	25%	Median	75%	Maximum
Spill	257	0.8	2.1	2.7	3.8	27,801.7
Bypass	25	1.0	4.1	5.7	8.7	23.9
Turbine	6	4.3	6.1	7.3	8.4	8.5

Table 4. Tailrace residence times in minutes for radio-tagged hatchery yearling chinook salmon passing Ice Harbor Dam during nighttime hours (1800-0600 hours) under a 100% spill, high spill with only Turbine Unit 3 operating, and for the overall study. Numbers represent fish that were detected on both a passage-route and a tailrace-exit line telemetry receiver.

Condition	n	Minimum	25%	Median	75%	Maximum
100% spill	95	1.0	1.8	3.0	10.0	13,100.0
High spill w/ Unit 3 only	173	0.4	1.9	2.6	15.0	17,507.3
Overall	680	0.3	1.9	2.8	5.8	27,801.7

Differences in tailrace residence time between groups of fish based on passage route selection were calculated. Radio-tagged fish that passed through a turbine remained in the tailrace longer than fish that passed through the juvenile bypass system or through the spillway (medians of 8.0, 5.4, and 2.7 minutes for turbine, bypass, and spillway, respectively) and fish that passed the dam through the juvenile bypass system remained in the tailrace longer than fish that passed via the spillway (Table 5). Differences were statistically significant; however, due to overall median tailrace residence times, differences may not be biologically significant.

High spill levels at Ice Harbor Dam accomplished the objective of increased FPE and spill efficiency as outlined in the NMFS Biological Opinion (1995) by guiding the majority of fish to the spillway; however, these same benefits existed at moderate spill levels. Spill efficiency, spill effectiveness, and FPE for radio-tagged fish passing Ice Harbor Dam during this study are outlined in Table 6 for overall passage and by diel period. Spill efficiency increased from 69 to 98% with an increase in the proportion of water spilled (Fig. 8), spill effectiveness decreased from 2:1 to 1:1 with increased spill (Fig. 9), and FPE increased from 91 to 99% with increased spill (Fig. 10).

Travel times from the study-area entrance line to passage, from passage to the study-area exit line, and from the study-area entrance line to exit from the study area were calculated for 612 radio-tagged fish that were detected on the study-area entrance line. Of these, 580 (95%) were detected on both the study-area entrance line and on a passage-route telemetry receiver. These 580 fish had a median travel time/forebay residence time of 1.3 hours. Of the same 612 fish, 534 (87%) were detected by a passage-route and study-area exit line receiver with a median travel time from passage to study-area exit line of 0.4 hours; and 561 (92%) fish were detected

Table 5. Tailrace residence times by passage route for all radio-tagged hatchery yearling chinook salmon detected on a passage route and tailrace-exit receiver.

Passage route	n	Minimum	25%	Median	75%	Maximum
Spillway	630	0.3	1.9	2.7	4.9	27,801.7
Bypass system	42	1.0	4.4	5.4	6.8	29.4
Turbine units	8	4.3	6.8	8.0	8.5	20.9

Table 6. Average percent spill, spill efficiency, spill effectiveness, and fish passage efficiency for radio-tagged hatchery yearling chinook salmon at Ice Harbor Dam, 1999.

	Day	Night	Combined
Average percent spill	45.0	80.8	61.8
Spill efficiency (%)	82.6	93.2	88.5
Spill effectiveness	1.8:1	1.1:1	1.5:1
Fish Passage Efficiency (%)	96.1	97.8	97.1

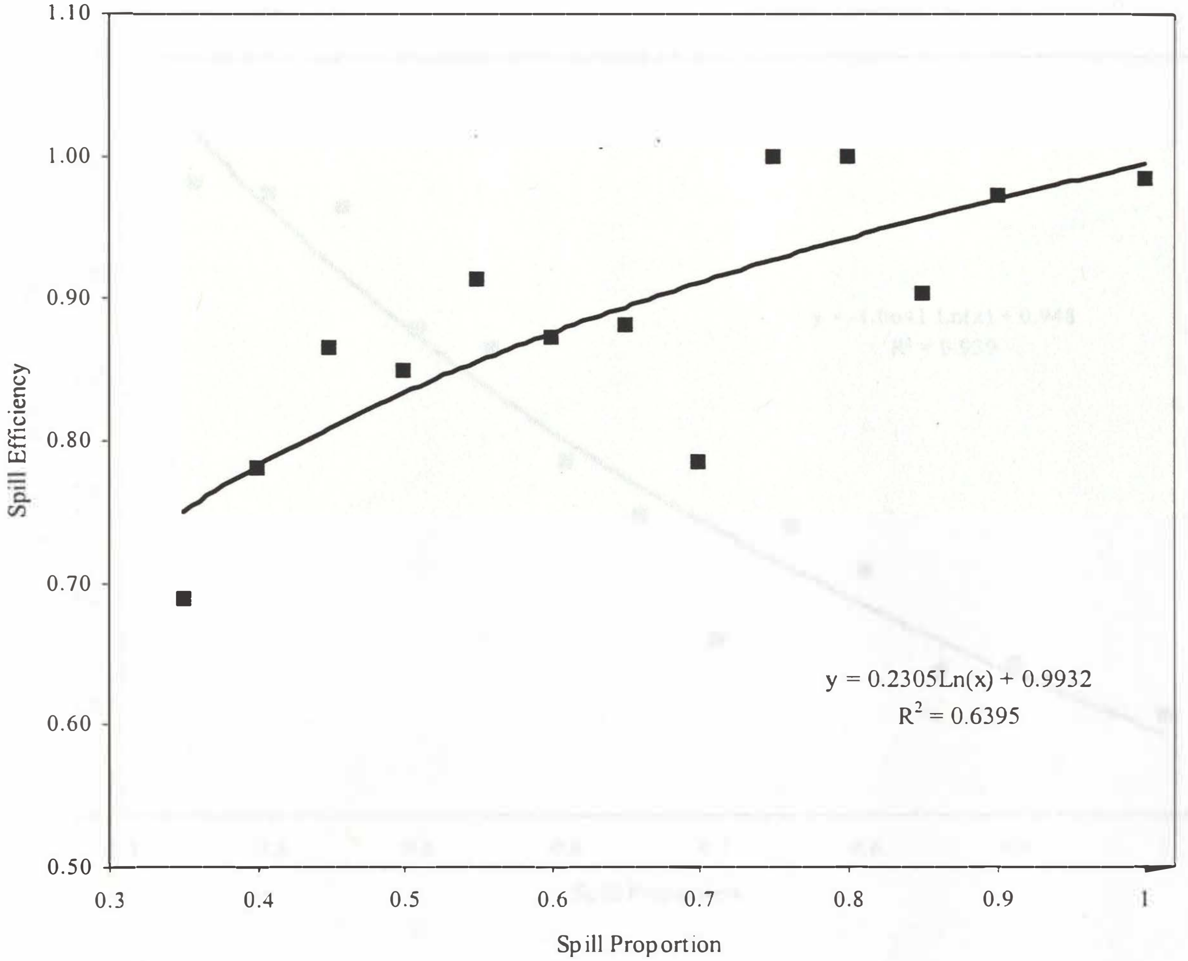

Figure 8. Spill Efficiency curve based on radio-tagged hatchery yearling chinook salmon passing Ice Harbor Dam, 1999.

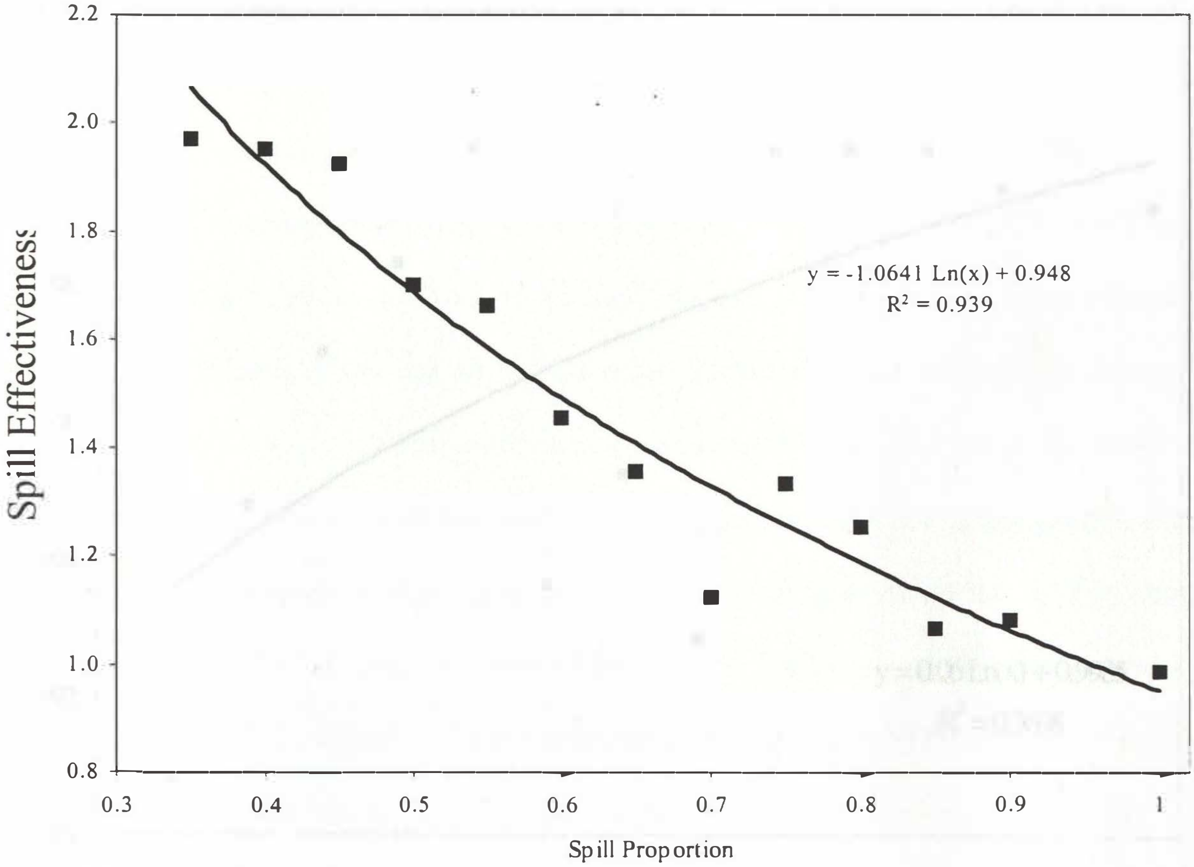

Figure 9. Spill effectiveness curve for radio-tagged hatchery yearling chinook salmon passing Ice Harbor Dam, 1999.

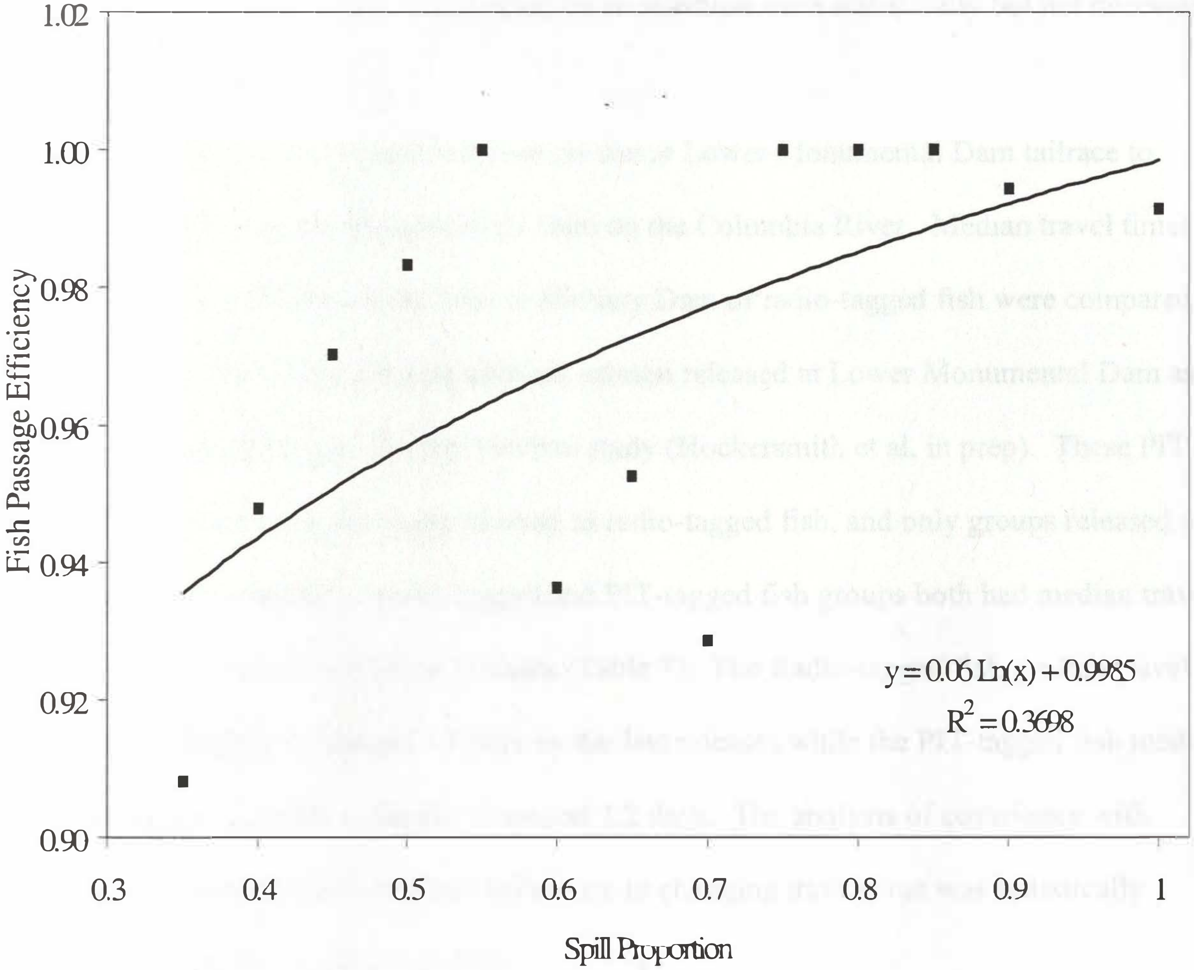

Figure 10. Fish passage efficiency curve based on radio-tagged hatchery yearling chinook salmon passing Ice Harbor Dam, 1999.

by the study-area entrance line and by the study-area exit line receivers with a median travel time of 1.9 hours through the entire study area. Similar to tailrace residence times, differences in travel time between groups based on passage-route selection were statistically but not necessarily biologically significant.

Travel time was also calculated from release at Lower Monumental Dam tailrace to detection by the PIT-tag system at McNary Dam on the Columbia River. Median travel times from release at Lower Monumental Dam to McNary Dam of radio-tagged fish were compared to those of PIT-tagged hatchery yearling chinook salmon released at Lower Monumental Dam as part of the juvenile fish bypass facility survival study (Hockersmith et al. in prep). These PIT-tagged fish were released in the same location as radio-tagged fish, and only groups released on the same day were compared. Radio-tagged and PIT-tagged fish groups both had median travel times around 4.5 days for the earliest releases (Table 7). The Radio-tagged fish median travel times decreased slightly to around 4.0 days by the last releases while the PIT-tagged fish median travel times decreased more markedly to around 3.2 days. The analysis of covariance with release day as a covariate indicated this difference in changing travel time was statistically significant (F = 5.6; df = 1,14; P = 0.032).

Table 7. Median travel time and travel rate of radio-tagged vs. PIT-tagged hatchery yearling chinook salmon from release at Lower Monumental Dam to detection at McNary Dam, 1999 (Note: travel time analysis based on PIT-tag detections at McNary Dam).

	Travel time (days)		Travel rate (km/day)	
Date	Radio-tagged	PIT-tagged	Radio-tagged	PIT-tagged
03 May	4.5	4.4	26.7	27.1
04 May	4.5	4.5	26.3	26.5
10 May	4.2	4.0	28.0	29.7
11 May	4.2	3.9	28.1	30.9
12 May	4.2	3.9	28.2	30.8
13 May	4.9	3.9	24.3	30.3
16 May	4.3	3.5	27.7	34.1
17 May	3.7	3.1	32.1	39.0
18 May	4.1	3.3	29.1	35.6

RECOMMENDATIONS

High spill volumes at Ice Harbor Dam provide several benefits to juvenile salmonids (including high spill efficiency and FPE); however, they also increase TDG levels in the tailrace, which may decrease survival for fish that pass Ice Harbor Dam. Latent effects on survival due to passage through the spillway under high spill conditions are unknown at Ice Harbor Dam, and studies to determine these effects should be conducted.

Although moderate and high spill volumes were evaluated in this study, low spill volumes were not. This study should be repeated at Ice Harbor Dam to evaluate the effects of low spill-levels and should be repeated at other hydroelectric projects on the Snake and Columbia Rivers to evaluate low-to-high spill levels.

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