Spillway passage survival of hatchery yearling and subyearling chinook salmon at Ice Harbor Dam, 2002

Fish Ecology Division

Northwest Fisheries Science Center

National Marine Fisheries Service

Seattle, Washington

by
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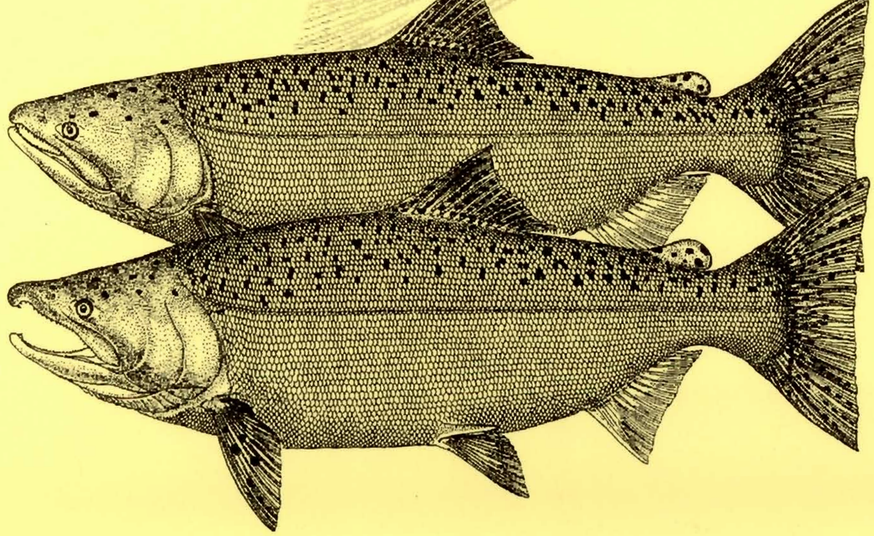
Douglas B. Dey

March 2005



Spillway Passage Survival of Hatchery Yearling and Subyearling Chinook Salmon at Ice Harbor Dam, 2002

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Report of research by

Fish Ecology Division
Northwest Fisheries Science Center
National Marine Fisheries Service
National Oceanic and Atmospheric Administration
2725 Montlake Boulevard East
Seattle, Washington 98112

to

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EXECUTIVE SUMMARY

In 2002, the National Marine Fisheries Service estimated relative survival for river-run hatchery yearling and subyearling chinook salmon *Oncorhynchus tshawytscha* passing through the spillway at Ice Harbor Dam on the Snake River. At the Lower Monumental Dam juvenile fish bypass/collection facility, yearling chinook salmon were collected and marked with either a PIT tag or both a radio tag and a PIT tag, and subyearling chinook salmon were marked with a PIT tag. After a 24-h holding period, treatment and reference groups were transported to Ice Harbor Dam and released. Treatment groups were released immediately upstream from all spillbays, and reference groups were released into the tailrace 0.5 km below Ice Harbor Dam under both day and night operations.

For PIT-tagged fish, relative spillway survival was estimated from detections at the juvenile bypass/detection facilities at McNary, John Day, and Bonneville Dams and from detections in the Columbia River estuary by the PIT-tag detector trawl. Nineteen paired replicates of yearling chinook salmon were released from 3 May to 4 June, and 13 paired replicates of subyearling chinook salmon were released from 28 June to 10 July.

For radio-tagged fish, relative spillway survival was estimated from detections at telemetry transects between Ice Harbor and John Day Dams; juvenile bypass/PIT-tag detection facilities at McNary, John Day, and Bonneville Dams; and from detections in the Columbia River estuary by the PIT-tag detector trawl. Eighteen paired replicates of yearling chinook salmon were released from 5 May to 4 June.

Relative spillway passage survival for hatchery yearling chinook salmon was estimated at 0.892 (95% CI, 0.840-0.944) for fish tagged with only a PIT-tag and 0.865 (95% CI, 0.833-0.897) for fish tagged with both a radio- and PIT-tag. Relative spillway survival was similar between daytime and nighttime operations for both PIT-tagged only (P = 0.929) and radio-tagged (P = 0.355) fish.

Relative spillway survival for PIT-tagged subyearling chinook salmon was 0.894 (95% CI, 0.856-0.932). Relative spillway passage survival was similar between daytime and nighttime releases for subyearling chinook salmon (P = 0.327). For both yearling and subyearling fish, only weak correlation was found between relative spillway survival and total dam discharge, spill volume, tailwater elevation, release date, fork length at tagging, and water temperature.

Tailrace egress was calculated as the elapsed time from release into the spillway at Ice Harbor Dam to detection at Goose Island (approximately 2 km downstream). Overall median tailrace egress time through this reach was 30 min.

Survival from the Ice Harbor Dam tailrace to McNary Dam for radio-tagged hatchery yearling chinook salmon was estimated at 0.749 (95% CI, 0.711-0.787). The study area was partitioned into three separate reaches: Ice Harbor to Sacajawea Park, Sacajawea Park to Port Kelley, and Port Kelley to McNary Dam. Among these reaches, estimated survival was lowest in the reach from Sacajawea Park to Port Kelley (0.860; 95% CI, 0.838- 0.882). The survival estimate through this reach was significantly lower ($P < 0.05$) than through the other two reaches.

Comparisons of survival estimates obtained using PIT and radiotelemetry tagging methodology resulted in no significant difference ($P = 0.382$). Travel times from release to McNary Dam were significantly different ($P < 0.05$) between all comparisons but were not likely to be biologically significant, with differences of less than 0.5 d.

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.

Spillway passage has long been considered the safest route for migrating juvenile salmonids at Snake and Columbia River hydroelectric projects. Holmes (1952) reported estimates of 96% (weighted average) to 97% (pooled) survival for Bonneville Dam spillway passage during the 1940s. A review of thirteen estimates of spillway passage mortality published through 1995 concluded that the most likely range in mortality for standard spillbays is 0 to 2% (Whitney et al. 1997). Similarly, 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; Smith et al. 1998). Pursuant to the National Marine Fisheries Service (NMFS-NOAA Fisheries) Biological Opinion (NMFS 2000), project operations at Ice Harbor Dam have relied on increased volumes of spill to maximize spillway passage by migrating juvenile salmonids.

The current spill program calls for daytime (0600 to 1800 PDT) spill volumes of 45 kcfs and nighttime spill volumes up to state and federal total dissolved gas limits, or 100% of total river flow. Under these operations, Eppard et al. (2000) estimated Ice Harbor fish passage efficiency (FPE) at 97%, with 81% FPE through the spillway for hatchery yearling chinook salmon during the 1999 spring migration. In 2000, the NMFS estimated spillway passage survival at 97.8% (SE = 0.020) and 88.5% (SE = 0.015) respectively for PIT-tagged hatchery yearling and subyearling chinook salmon passing Ice Harbor Dam under nighttime operations (Eppard et al. 2002). A second year of study was proposed for 2001 to validate the findings from 2000 at Ice Harbor Dam and to estimate survival during daytime operations. However, extremely low river flows resulted in less than one day of spill operation that year (Axel et al. 2003).

In 2002, we conducted a second year of survival evaluations for hatchery yearling and subyearling chinook salmon passing through the spillway at Ice Harbor Dam using passive integrated transponder (PIT) tags. To determine if radiotelemetry can confidently be used to estimate survival, we conducted a concurrent study to evaluate the application of radiotelemetry techniques for estimating spillway survival of hatchery yearling chinook salmon at Ice Harbor Dam. Specific objectives of this study were:

1) Estimate relative spillway passage survival for PIT-tagged and radio-tagged hatchery yearling chinook salmon under daytime and nighttime operations.

2) Partition reach survival between Ice Harbor and McNary Dams for radio-tagged hatchery yearling chinook salmon.

3) Determine tailrace egress times for radio-tagged hatchery yearling chinook salmon released into the spillway at Ice Harbor Dam.

4) Compare relative survival estimates and timing for PIT-tagged and radio-tagged hatchery yearling chinook salmon.

5) Estimate relative spillway passage survival for PIT-tagged hatchery subyearling chinook salmon during daytime and nighttime operations at Ice Harbor Dam.

Results of this study will be used to help management make decisions that will optimize survival for juvenile salmonids arriving at Ice Harbor Dam. This study addressed research needs outlined in SPE-W-00-1 of the U.S. Army Corps of Engineers, North Pacific Division, Anadromous Fish Evaluation Program.

METHODS

Study Area

The study area included a 118-km reach of the Snake and Columbia Rivers beginning at Ice Harbor Dam, continuing past McNary Dam, and ending at Crow Butte (Figure 1). Ice Harbor Dam, the first dam on the Snake River, is located 16 km above the confluence of the Snake and Columbia Rivers. McNary Dam, on the Columbia River, is located 470 km above the mouth of the Columbia River. For survival estimates of radio-tagged fish, the 68-km study area was further partitioned into three separate reaches: Ice Harbor Dam to Sacajawea Park at the mouth of the Snake River (reach 1), Sacajawea Park to Port Kelley (reach 2), and Port Kelley to McNary Dam (reach 3). Radiotelemetry receivers and multiple-element aerial antennas were used to establish detection transects between Ice Harbor Dam on the Snake River and Crow Butte on the Columbia River.

PIT-Tag Evaluations

Fish Collection and Tagging

For both yearling and subyearling hatchery chinook salmon, we collected and PIT-tagged river-run fish at the Lower Monumental Dam smolt collection facility in conjunction with the smolt monitoring program. Only chinook salmon not previously PIT tagged were used. Hatchery fish were identified by the absence of an adipose or pelvic fin or by the presence of a coded wire tag. Fish were anesthetized with tricaine methanesulfate (MS-222) and sorted and tagged in a recirculating anesthetic system. Fish for treatment and reference release groups were tagged simultaneously, and personnel were periodically rotated among tagging stations to minimize bias.

Fish were PIT tagged by hand (Prentice et al. 1990a,b,c) using individual syringes with a 12-gauge hypodermic needle. Used syringes were sterilized in ethyl alcohol for a minimum of 10 min before reloading with PIT tags. Yearling chinook were collected from 2 May through 3 June; subyearling chinook were collected from 27 June through 9 July. PIT-tagged fish were transferred from the smolt monitoring facility through a water-filled pipe to 568-L tanks mounted on trucks, where they were held for a minimum of 24 h with flow-through water to recover from anesthesia and for determination of post-tagging mortality. Maximum holding densities were 350 fish per tank for yearling chinook and 460 fish per tank for subyearling chinook. After the recovery period, trucks transported the fish to Ice Harbor Dam.

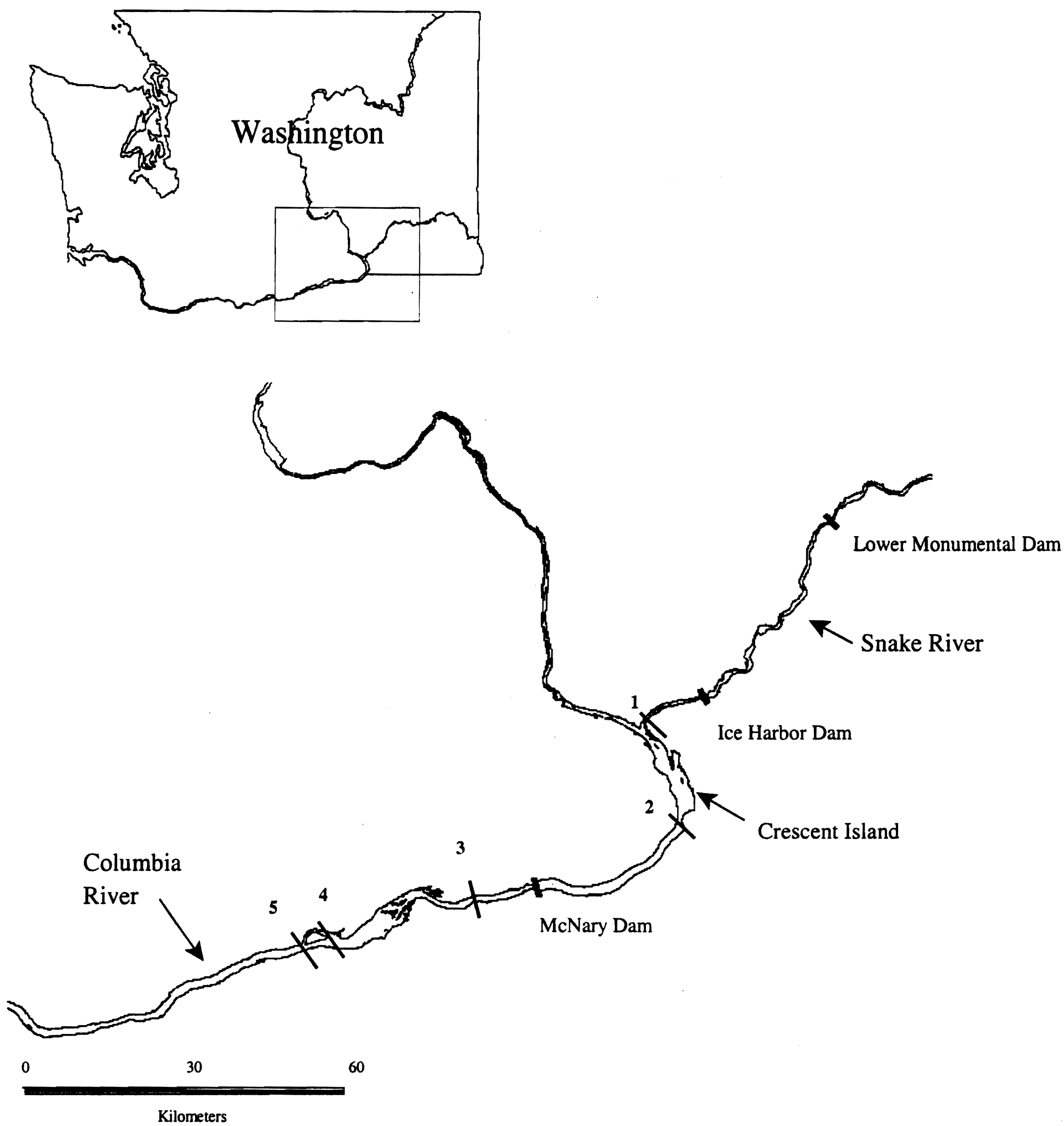

Figure 1. 2002 Study area showing location of radiotelemetry transects used for estimating spillway passage at Ice Harbor Dam. 1 = Mouth of the Snake River (Sacajawea Park); 2 = Port Kelley; 3 = Irrigon, OR; 4 = Crow Butte East; and 5 = Crow Butte West.

Releases

On arrival at Ice Harbor Dam, treatment groups were transferred from holding tanks via a 10.2-cm-diameter hose to a 935-L release tank. Release tanks were maneuvered with a mobile crane to the upstream side (forebay side) of individual spillbays, where fish were released at a depth of 3 m. Daytime groups were released immediately after transport from Lower Monumental Dam, while nighttime groups remained in tanks for an additional 9 h prior to release. Selection of spillbays for release was based on a 2-block design, where blocks were sequences of spillbays used during the first and second halves of the season. The sequence of spillbays used during the first half was randomly selected from the 10 available spillbays. This sequence was then used in reverse order during the second half of the season.

Reference (tailrace) groups were transferred to a 935-L tank mounted on an 8.5 × 2.4-m barge in the forebay of Ice Harbor Dam, transported to the tailrace and released mid-channel, water-to-water into the tailrace downstream of the stilling basin. To provide mixing of treatment and reference groups, treatment groups were released approximately 7 min prior to reference groups to allow time for fish to pass through the spillbay and stilling basin. This time interval was based on Ice Harbor Dam tailrace egress evaluations conducted in 1999 (Eppard et al. 2000).

For each release day, specific operating conditions were not requested; however, constant tailrace conditions (spill pattern, flow level, and powerhouse loading) were requested during both day and nighttime releases to provide a stable tailrace condition during releases. Project operations data were collected every 5 min, and the operations most closely corresponding to each release time were assigned to that treatment group.

Study Design and Data Analysis

A paired-release study design was used for estimating relative survival where groups of PIT-tagged fish were released at two sites, one upstream (treatment) and one downstream (reference) from the Ice Harbor Dam spillway. Individual fish records were downloaded for detections at juvenile bypass/detection facilities at McNary, John Day, and Bonneville Dams and the PIT-trawl towed array in the Columbia River estuary (PSMFC 1996). The single-release (SR) model (Cormack 1964; Jolly 1965; Seber 1965) was used to estimate survival and detection probabilities for individual release groups from Ice Harbor to McNary Dam, McNary to John Day Dam, and John Day to Bonneville Dam. Relative spillway passage survival was then expressed as the ratio of spillway (treatment) to tailrace (reference) survival estimates.

Average relative survival was calculated using weighted geometric means, where weights were inversely proportional to their respective sample variances (Burnham et al. 1987, p. 259). Because the variance of a survival probability estimate based on the SR model is a function of the estimate itself, lower survival estimates tend to have smaller estimated variance. Therefore, the inverse estimated absolute variance was not used in weighting, since this could result in a weighted mean that is biased toward these lower estimates (Muir et al. 2001, 2003).

The SR model was used for survival estimates for PIT-tagged yearling and subyearling chinook salmon. The SR model relies on two critical assumptions: A1) release groups have homogeneous passage distributions downstream (so that they encounter similar river conditions during passage), and A2) all fish in a given cohort had equal probabilities of detection and survival at a given site. Evaluations of model assumptions are presented in Appendix A.

Radiotelemetry Evaluations

Fish Collection and Tagging

Radio tags were purchased from Advanced Telemetry Systems Inc.,[1] had an expected battery life of 7 d and were pulse-coded for unique identification of individual fish. Each radio tag measured 17 mm in length by 6 mm in diameter and weighed 1.4 g in air.

River-run hatchery yearling chinook salmon were collected at the Lower Monumental Dam smolt collection facility from 4 May to 3 June. Only hatchery origin yearling chinook salmon not previously PIT tagged were used. Fish were anesthetized with tricaine methanesulfate (MS-222) and sorted in a recirculating anesthetic system. Fish for treatment and reference release groups were transferred through a water-filled 10.2-cm hose to a 935-L holding tank. Following collection and sorting, fish were transported to Ice Harbor Dam where they were maintained via flow-through river water and held for 24 h prior to radio tagging.

Fish were surgically implanted with radio tags using techniques described by Eppard et al. (2000). A PIT tag was also implanted in the body cavity of the fish during surgical procedures (Prentice et al. 1990a,b,c). Immediately following surgery tagged 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] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

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 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. Holding density did not exceed two fish per recovery container for radio-tagged yearling chinook salmon.

Releases

After the post-tagging recovery period of approximately 24 h, radio-tagged fish were moved in their recovery containers from the holding area to the release areas (Ice Harbor Dam spillway or tailrace). Treatment groups were transferred water-to-water from holding tanks to the PIT-tag release tank. Releases of radio-tagged fish began with the releases of PIT-tagged fish but were spread out over a 2-h period to avoid overloading the telemetry receivers with large numbers of radio tags passing the monitoring stations simultaneously.

Reference groups were transferred in their recovery containers to a 1,152-L tank mounted on an 8.5 × 2.4-m barge in the forebay of Ice Harbor Dam, transported to the tailrace and released mid-channel, water-to-water into the downstream section of the stilling basin. Project operations data were collected every 5 min, and the operations most closely corresponding to each release time were assigned to that treatment group.

Study Design and Data Analysis

A paired-release study design was used for estimating relative survival where groups of radio-tagged fish were released at two sites, one upstream (treatment) and one downstream (reference) from the Ice Harbor Dam spillway. Telemetry transects were located at Sacajawea Park on the Snake River mouth and at Port Kelley; McNary Dam; Irrigon, OR; and Crow Butte on the Columbia River (Figure 1). Based on detections of individual radio-tagged fish, the single-release model (Cormack 1964, Jolly 1965, Seber 1965) was used to estimate survival and probability of detection for individual release groups. Since radio-tagged fish were also tagged with a PIT tag, detections at the juvenile bypass/detection facilities 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.

Relative spillway passage survival was then expressed as the ratio of survival estimates for treatment fish to reference fish. Average relative survival was calculated using weighted geometric means. As described above for PIT-tagged yearling chinook salmon, weights were the inverse of the respective sample variances (Burnham et al. 1987; Muir et al. 2001, 2003).

Mixing tests for radio-tagged fish were not conducted due to the very high detection rates at downstream detection sites. Additionally, the large majority of all detections for both groups at most sites occurred during one or at most two days. Due to small release numbers and these very high detection rates, SR model assumptions could not be assessed using contingency tables because table cells for "not detected" fish were almost always zero or very small.

Reach survival for radio-tagged fish between Ice Harbor and McNary Dams was estimated using the single-release model. To estimate survival for reach 1, we used only radio-tagged fish released into the tailrace of Ice Harbor Dam. To estimate survival through reaches 2 and 3, we used all radio-tagged fish detected on the Sacajawea Park receivers. We used paired, two-tailed t-tests to compare survival between reaches.

Tailrace egress for fish passing through the spillway was calculated as the elapsed time between release just upstream of the spillway and first detection on the Goose Island detection line 2 km downstream of the dam.

Survival estimates between tagging methods (PIT and radiotelemetry) were compared with a t-test to assess the use of radiotelemetry for survival estimation. Travel time between tagging methods was compared using permutation tests on the difference between the two medians (Efron and Tibshirani 1993). Permutation tests evaluate the size of the difference between the observed medians relative to the distribution of all possible differences. The estimated distribution was constructed by:

1) pooling the two samples;
2) randomly permuting the pool into two groups the size of the original samples;
3) calculating the difference between the medians of the two permuted groups; and
4) repeating steps 2 and 3 a large number of times (e.g., 1,000).

A P-value for this test was the proportion of times the permuted differences were larger than the observed difference. This tested the use of radiotelemetry for assessing the migrational behavior of juvenile chinook salmon. Travel time comparisons were calculated from release (Ice Harbor Dam) to first PIT-tag detection within the juvenile bypass system at McNary Dam (68 km).

RESULTS

Yearling Chinook Salmon

PIT-Tag Evaluations

Fish Collection, Tagging, and Release--Yearling chinook salmon were collected and PIT tagged at Lower Monumental Dam on 19 d from 2 May to 3 June. Tagging began after 30% of the yearling chinook salmon had passed Lower Monumental Dam and was completed when 99% of these fish had passed (Figure 2). During respective daytime and nighttime operations, we released 6,128 and 5,886 PIT-tagged fish into the spillway and 6,160 and 6,160 into the tailrace at Ice Harbor Dam. Handling and tagging mortality for yearling chinook salmon was 0.6% overall. Overall mean fork lengths of fish released during daytime operations were 143.6 mm (SD = 11.6) for spillway releases and 145.9 mm (SD = 11.0) for tailrace releases (Table 1). Daytime releases occurred between 1226 and 1547 PDT and were made though spillbays discharging from 3.4 to 5.3 kcfs and open from 2.0 to 3.1 stops.

The U.S. Army Corps of Engineers, Walla Walla District operated Ice Harbor Dam based on the NMFS 2000 Biological Opinion (NMFS 2000) guidelines: project spill was 45 kcfs during daytime hours (0600-1800 PDT) and at or near 100% (up to the 120% total dissolved gas cap) during nighttime hours (1800-0600) for much of the study period (3 May-10 July; Appendix Figure B1). Daily total river flows were lower in 2002 than the daily average for the previous ten years (1992-2001), especially during the early part of May (Appendix Figure B2).

Ice Harbor Dam operations during daytime releases ranged from 44.3 to 98.0 kcfs total spill volume, or 34 to 77% of total project discharge; tailwater elevation was between 342.6 and 349.1 ft; and water temperatures ranged from 10.8 to 14.0°C (Appendix Table B1). Overall mean fork length for fish released during nighttime operations was 144.5 mm (SD = 11.4) for spillway releases and 146.6 mm (SD = 11.4) for tailrace releases (Table 2). Nighttime releases occurred between 2154 and 2321 PDT and were made though spillbays discharging from 3.4 to 12.0 kcfs and open from 2.0 to 8.0 stops. Ice Harbor Dam operations during nighttime releases ranged from 48.6 to 119.0 kcfs total spill volume, or 70.4 to 100% of total project discharge; tailwater elevation ranged from 341.2 to 348.2 ft; and water temperatures ranged from 10.6 to 13.8°C (Appendix Table B2).

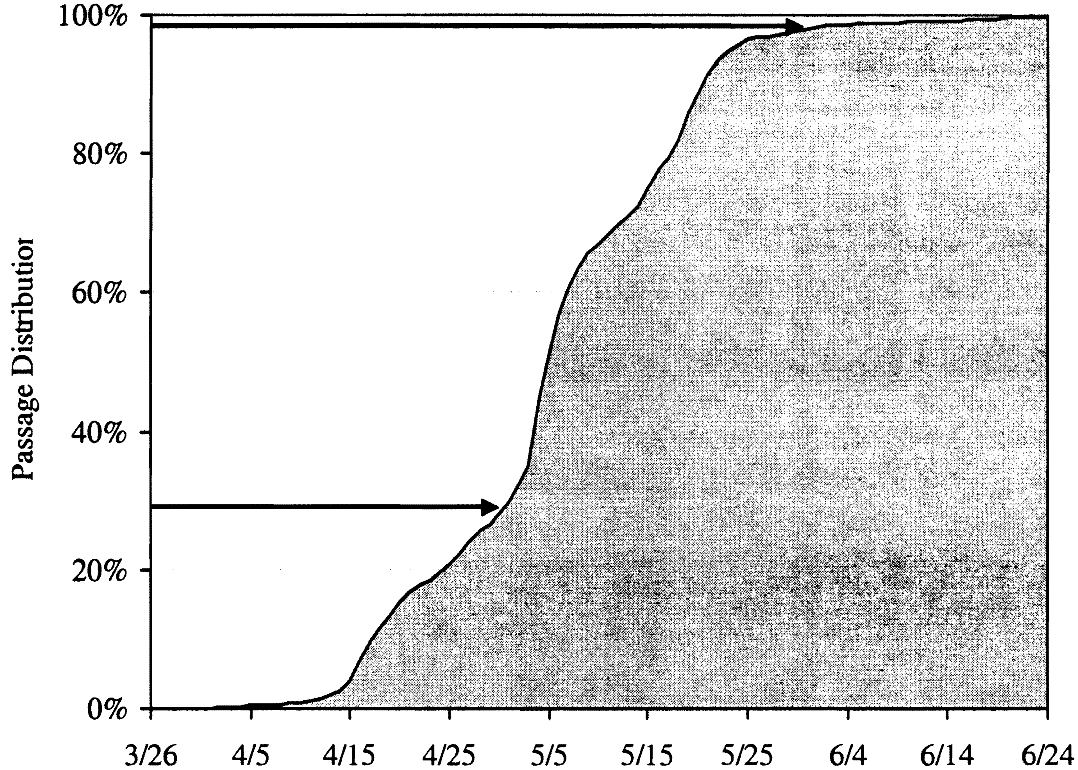

Figure 2. Cumulative passage distribution of yearling chinook salmon at Lower Monumental Dam during 2002. Arrows indicate beginning and ending release dates for tagged yearling chinook salmon to evaluate Ice Harbor Dam spillway survival, 2002.

Table 1. Sample size, mean, standard deviation (SD), and range of fork lengths (mm) for daytime releases of PIT-tagged hatchery yearling chinook salmon at Ice Harbor Dam, 2002.

	Spillway (treatment)*				Tailrace (reference)			
Release date	n	Mean fork length (mm)	SD	Range	n	Mean fork length (mm)	SD	Range
03 May	334	139.2	13.4	107-180	335	142.0	12.2	112-200
06 May	331	142.5	13.5	104-190	335	145.7	11.4	117-182
08 May	322	142.1	13.6	108-190	330	147.8	12.2	121-185
09 May	338	144.9	12.6	106-181	332	145.4	12.7	114-196
11 May	333	141.2	11.8	110-196	333	144.6	11.2	119-189
12 May	335	141.5	10.3	120-179	323	145.0	10.5	117-195
14 May	319	141.8	9.9	117-190	335	143.2	9.6	113-178
15 May	326	141.7	10.8	106-180	330	143.1	10.2	114-186
17 May	326	144.6	10.8	120-184	332	147.2	10.7	116-184
18 May	329	141.9	11.1	114-184	331	143.7	9.7	116-171
20 May	331	143.5	10.7	118-179	333	146.0	9.7	119-176
21 May	332	140.7	9.7	117-183	333	143.7	9.7	113-174
23 May	334	142.4	10.5	107-170	332	144.6	9.9	118-186
24 May	329	147.5	10.8	116-183	333	147.2	10.1	121-185
29 May	329	144.6	10.0	106-178	325	146.3	10.2	120-177
30 May	326	144.5	9.9	111-178	332	147.1	9.4	122-180
01 June	323	144.8	10.4	114-180	330	147.4	11.1	113-193
02 June	332	149.7	11.1	123-186	333	151.4	11.4	123-188
04 June	199	148.1	13.0	116-203	193	153.1	11.5	118-188
Overall	6,128	143.6	11.6	104-203	6,160	145.9	11.0	112-200

* PIT-tagged yearling chinook released to spillways had slightly larger average fork length than those released to the tailrace (<3 mm). Although we do not know the reason for the size discrepancy, it was not large enough to present a meaningful biological difference between the two treatments evaluated. No such discrepancy occurred among similar groups of radio-tagged yearling chinook or PIT-tagged subyearling chinook salmon, which were treated in the same manner for this study.

Table 2. Sample size, mean, standard deviation (SD), and range of fork lengths (mm) for PIT-tagged hatchery yearling chinook salmon with a known length at tagging and released during nighttime operations at Ice Harbor Dam, 2002.

	Spillway (treatment)				Tailrace (reference)			
Release date	n	Mean fork length (mm)	SD	Range	n	Mean fork length (mm)	SD	Range
03 May	336	139.1	12.8	107-182	332	148.6	12.3	91-186
06 May	333	144.8	13.0	107-183	334	144.1	12.0	109-192
08 May	234	142.1	12.8	115-181	332	147.9	12.8	100-197
09 May	336	145.4	11.4	117-187	335	146.9	13.1	111-204
11 May	332	141.8	11.1	120-178	332	141.8	11.3	98-183
12 May	299	144.1	11.9	117-185	335	144.7	11.1	111-182
14 May	325	143.1	10.6	116-192	328	144.7	9.9	118-185
15 May	329	141.6	10.3	105-177	332	144.0	11.1	116-186
17 May	261	145.7	11.1	116-178	331	147.7	11.8	110-200
18 May	264	142.6	12.1	108-182	333	144.3	10.6	115-177
20 May	332	147.9	11.8	117-186	331	147.8	10.5	116-182
21 May	333	144.2	10.3	118-180	333	146.4	11.0	120-186
23 May	336	145.5	9.9	120-180	335	146.1	10.2	117-179
24 May	332	147.0	10.6	106-198	329	149.2	10.1	121-185
29 May	323	144.9	9.8	110-177	330	145.2	9.1	120-178
30 May	331	145.9	9.4	113-187	328	146.7	10.0	118-186
01 June	325	145.2	9.9	122-183	334	147.0	10.0	111-177
02 June	253	147.4	11.2	118-180	253	153.6	11.9	126-192
04 June	272	147.9	12.7	107-190	263	151.5	12.1	110-187
Overall	5,886	144.5	11.4	105-198	6,160	146.6	11.4	91-204

Detection and Survival--Of the 24,661 PIT-tagged yearling chinook salmon released at Ice Harbor Dam, 11,270 (45.7% of those released) unique PIT-tags were detected at downstream locations on the Columbia River (Table 3). Detection probabilities at McNary Dam under daytime operations were similar between treatments, with overall estimates of 0.357 (SE = 0.039) for spillway and 0.346 (SE = 0.034) for tailrace releases (Table 4). Under nighttime operations, detection probabilities were 0.392 (SE = 0.042) for spillway releases and 0.383 (SE = 0.035) for tailrace releases. Variability in detection probabilities at McNary Dam was due to increased levels of spill as total river flows increased later in the study (Figure 3), and probably resulted in survival estimates for earlier groups having higher weight in weighted geometric means.

Survival estimates for individual release groups of PIT-tagged yearling chinook salmon that passed through the spillway at Ice Harbor Dam relative to those released in the tailrace ranged from 0.511 to 2.243 during daytime operations and from 0.609 to 1.521 during nighttime operations (Tables 5 and 6). The weighted geometric mean relative survival estimates were 0.895 (95% CI, 0.825-0.964) for daytime releases and 0.890 (95% CI, 0.812-0.968) for nighttime releases. There was no significant difference between daytime and nighttime relative spillway survival (paired t-test; $t = 0.09$, $P = 0.929$).

The overall estimate (weighted geometric mean) of spillway passage survival for PIT-tagged hatchery yearling chinook salmon was 0.892 (95% CI, 0.840-0.944). For yearling chinook salmon passing through the Ice Harbor Dam spillway, we found weak correlation between relative survival and total dam discharge, spill volume, tailwater elevation, release date, fork length at tagging, or water temperature (Appendix Figures C1-C6).

Table 3. First time detections at downstream PIT-tag detection sites with proportion of fish released for evaluating survival for hatchery yearling chinook salmon passing through the spillway at Ice Harbor Dam, 2002. Standard error shown in parenthesis.

Daytime Releases			
Detection site	Spillway	Tailrace	Total
McNary Dam	1,784 (0.290)	1,969 (0.319)	3,753 (0.305)
John Day Dam	437 (0.071)	514 (0.083)	951 (0.077)
Bonneville Dam	358 (0.058)	393 (0.064)	751 (0.061)
PIT-Trawl	25 (0.004)	44 (0.007)	69 (0.006)
Total	2,604 (0.423)	2,920 (0.474)	5,524 (0.448)
Nighttime Releases			
Detection site	Spillway	Tailrace	Total
McNary Dam	1,941 (0.315)	2,128 (0.345)	4,069 (0.330)
John Day Dam	450 (0.073)	484 (0.078)	934 (0.076)
Bonneville Dam	334 (0.054)	350 (0.057)	684 (0.055)
PIT-Trawl	32 (0.005)	27 (0.004)	59 (0.005)
Total	2,757 (0.447)	2,989 (0.484)	5,746 (0.466)

Table 4. Detection probabilities at McNary Dam for PIT-tagged hatchery yearling chinook salmon released during daytime and nighttime operations into the spillway and tailrace of Ice Harbor Dam, 2002. Standard errors are presented in parenthesis.

Release date	Daytime		Nighttime	
	Spillway	Tailrace	Spillway	Tailrace
03 May	0.582 (0.051)	0.641 (0.042)	0.621 (0.049)	0.599 (0.047)
06 May	0.575 (0.066)	0.446 (0.059)	0.487 (0.066)	0.474 (0.069)
08 May	0.498 (0.050)	0.517 (0.051)	0.440 (0.046)	0.504 (0.048)
09 May	0.502 (0.044)	0.479 (0.045)	0.432 (0.046)	0.567 (0.045)
11 May	0.467 (0.056)	0.488 (0.051)	0.455 (0.049)	0.408 (0.054)
12 May	0.501 (0.059)	0.387 (0.050)	0.504 (0.057)	0.453 (0.054)
14 May	0.388 (0.066)	0.339 (0.053)	0.659 (0.061)	0.385 (0.060)
15 May	0.440 (0.063)	0.470 (0.051)	0.459 (0.061)	0.502 (0.059)
17 May	0.414 (0.060)	0.451 (0.059)	0.630 (0.055)	0.569 (0.056)
18 May	0.434 (0.057)	0.430 (0.049)	0.507 (0.058)	0.440 (0.052)
20 May	0.277 (0.052)	0.317 (0.048)	0.377 (0.053)	0.427 (0.050)
21 May	0.319 (0.056)	0.289 (0.054)	0.322 (0.057)	0.402 (0.053)
23 May	0.467 (0.072)	0.219 (0.056)	0.575 (0.059)	0.344 (0.056)
24 May	0.367 (0.057)	0.305 (0.049)	0.294 (0.055)	0.402 (0.053)
29 May	0.141 (0.041)	0.187 (0.043)	0.234 (0.061)	0.159 (0.048)
30 May	0.063 (0.035)	0.079 (0.044)	0.164 (0.050)	0.226 (0.075)
01 June	0.132 (0.055)	0.180 (0.058)	0.104 (0.044)	0.196 (0.053)
02 June	0.182 (0.051)	0.179 (0.051)	0.083 (0.046)	0.075 (0.036)
04 June	0.040 (0.028)	0.175 (0.060)	0.104 (0.037)	0.137 (0.048)
Overall	0.357 (0.039)	0.346 (0.034)	0.392 (0.042)	0.383 (0.035)

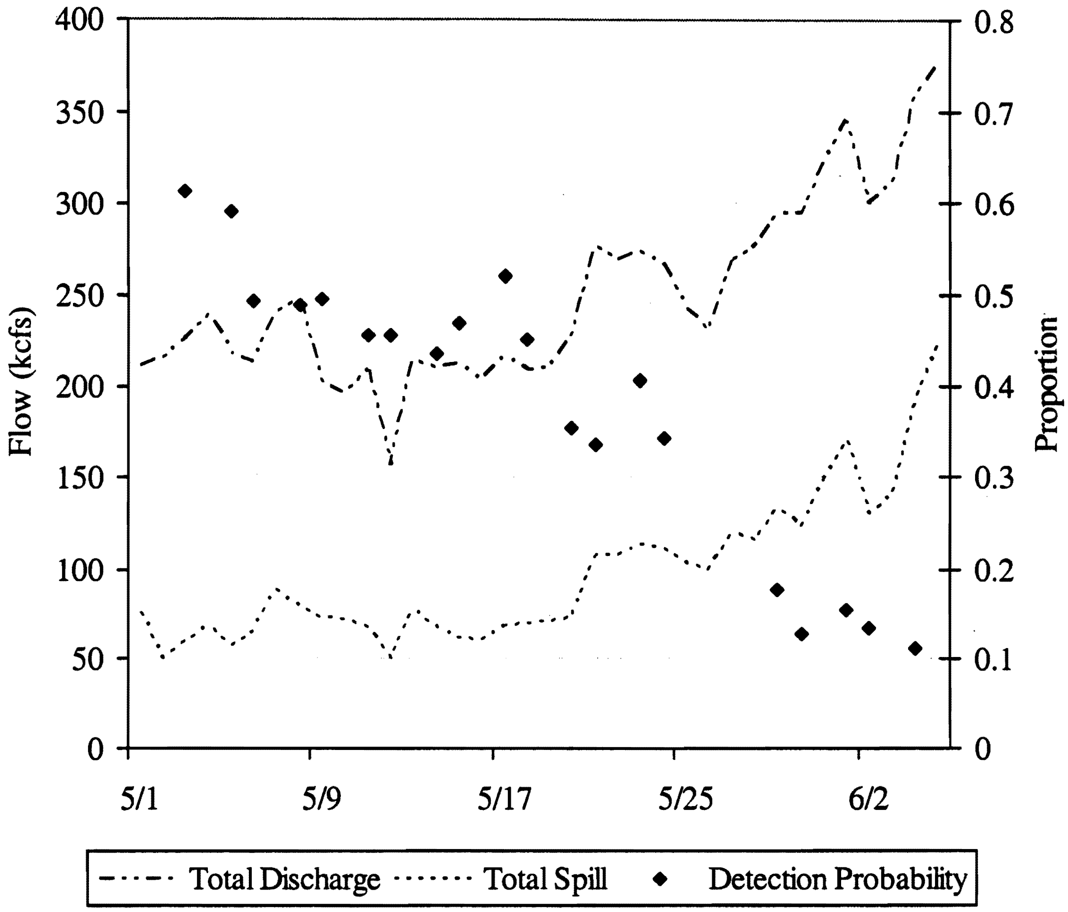

Figure 3. Total discharge, spill, and detection probabilities of PIT-tagged hatchery yearling chinook salmon at McNary Dam during the Ice Harbor Dam spillway survival study, 2002.

Table 5. Relative survival estimates for PIT-tagged hatchery yearling chinook salmon released during daytime operations into the spillway and tailrace of Ice Harbor Dam, 2002. Standard errors shown in parenthesis. The overall relative survival estimate is presented as a weighted geomean.

Release date	Daytime spillway releases (treatment)		Daytime tailrace releases (reference)		Relative survival
	n	Survival	n	Survival	
03 May	334	0.931 (0.067)	335	0.904 (0.045)	1.030 (0.090)
06 May	331	0.752 (0.081)	335	1.002 (0.112)	0.750 (0.116)
08 May	336	0.803 (0.064)	330	0.888 (0.074)	0.904 (0.104)
09 May	339	0.767 (0.052)	332	0.854 (0.059)	0.908 (0.088)
11 May	333	0.917 (0.095)	333	0.856 (0.073)	1.071 (0.144)
12 May	335	0.736 (0.075)	325	1.074 (0.118)	0.685 (0.103)
14 May	329	0.775 (0.106)	335	0.988 (0.135)	0.784 (0.152)
15 May	326	0.912 (0.112)	330	0.904 (0.080)	1.009 (0.153)
17 May	331	0.538 (0.063)	332	0.642 (0.072)	0.838 (0.136)
18 May	329	0.764 (0.085)	331	0.840 (0.069)	0.910 (0.126)
20 May	331	0.706 (0.116)	333	0.796 (0.100)	0.887 (0.183)
21 May	332	0.827 (0.125)	333	0.852 (0.151)	0.869 (0.190)
23 May	334	0.541 (0.075)	332	1.058 (0.245)	0.511 (0.138)
24 May	329	0.713 (0.095)	333	1.036 (0.145)	0.688 (0.133)
29 May	329	1.449 (0.388)	325	1.189 (0.243)	1.219 (0.411)
30 May	326	2.310 (1.542)	332	1.030 (0.538)	2.243 (1.901)
01 June	323	0.944 (0.367)	331	1.114 (0.357)	0.847 (0.427)
02 June	332	0.498 (0.111)	334	0.642 (0.159)	0.776 (0.258)
04 June	199	2.009 (1.298)	193	1.094 (0.338)	1.836 (1.315)
Pooled	6,158	0.942 (0.109)	6,164	0.940 (0.034)	0.895 (0.035)

Table 6. Relative survival estimates for PIT-tagged hatchery yearling chinook salmon released during nighttime operations into the spillway and tailrace of Ice Harbor Dam, 2002. Standard errors are shown in parenthesis. The overall relative survival estimate is presented as a weighted geomean.

Release date	Daytime spillway releases (treatment)		Daytime tailrace releases (reference)		Relative survival
	n	Survival	n	Survival	
03 May	336	0.891 (0.059)	333	0.994 (0.064)	0.896 (0.083)
06 May	333	0.738 (0.084)	334	0.899 (0.115)	0.820 (0.141)
08 May	335	0.889 (0.073)	335	0.911 (0.067)	0.975 (0.108)
09 May	336	0.794 (0.065)	335	0.737 (0.048)	1.077 (0.113)
11 May	332	0.764 (0.067)	333	0.992 (0.110)	0.770 (0.109)
12 May	331	0.694 (0.064)	336	0.987 (0.095)	0.703 (0.094)
14 May	327	0.684 (0.059)	329	1.123 (0.152)	0.609 (0.098)
15 May	330	0.889 (0.102)	332	0.898 (0.093)	0.989 (0.153)
17 May	329	0.591 (0.045)	332	0.790 (0.070)	0.748 (0.087)
18 May	335	0.757 (0.064)	333	0.847 (0.072)	0.893 (0.107)
20 May	334	0.972 (0.117)	333	0.782 (0.073)	1.242 (0.189)
21 May	334	0.945 (0.149)	333	0.835 (0.091)	1.131 (0.217)
23 May	336	0.537 (0.052)	335	0.765 (0.105)	0.701 (0.118)
24 May	334	0.753 (0.123)	329	0.825 (0.094)	0.912 (0.182)
29 May	323	1.080 (0.265)	330	1.203 (0.336)	0.897 (0.334)
30 May	333	0.763 (0.205)	328	0.681 (0.210)	1.120 (0.458)
01 June	326	1.239 (0.489)	334	0.856 (0.208)	1.447 (0.671)
02 June	253	1.066 (0.468)	253	1.207 (0.525)	0.883 (0.546)
04 June	272	0.633 (0.179)	263	0.416 (0.111)	1.521 (0.592)
Pooled	6,169	0.825 (0.041)	6,170	0.881 (0.043)	0.890 (0.039)

Radio-tag Evaluations

Fish Collection, Tagging, and Release--Yearling chinook salmon were collected and radio tagged at Lower Monumental Dam on 18 d from 4 May to 3 June. Tagging began after 30% of the yearling chinook salmon had passed Lower Monumental Dam and was completed when 99% of these fish had passed (Figure 4). During respective daytime and nighttime operations, we released 282 and 264 radio-tagged fish into the spillway and 270 and 267 into the tailrace at Ice Harbor Dam. Tagging mortality for yearling chinook salmon was 3.3% overall.

For daytime releases, overall mean fork length was 146.6 mm (SD = 9.8) for fish released to the spillway and 145.9 mm (SD = 13.4) for fish released to the tailrace (Table 7). Daytime releases occurred between 1328 and 1714 PDT and were made though spillbays discharging from 3.4 to 5.3 kcfs and open from 2.0 to 3.1 stops (Appendix Table B1). Ice Harbor Dam Project operations during daytime releases ranged from 44.3 to 98.0 kcfs total spill volume, or 34 to 77% of total project discharge; tailwater elevation was between 342.6 and 349.3 ft, and water temperatures ranged from 10.8 to 14.0°C.

For nighttime releases, overall mean fork length was 146.2 mm (SD = 9.9) for fish released to the spillway and 147.2 mm (SD = 13.1) for fish released to the tailrace (Table 8). Nighttime releases occurred between 2154 and 0054 PDT and were made through spillbays discharging from 3.4 to 13.5 kcfs and open from 2.0 to 8.0 stops. Ice Harbor Dam project operations during nighttime releases ranged from 48.6 to 119.0 kcfs total spill volume, or 70.4 to 100% of total project discharge; tailwater elevation was between 341.2 and 348.2 ft; and water temperatures ranged from 10.6 to 13.8°C (Appendix Table B2).

Detection and Survival--Of the 1,083 radio-tagged yearling chinook salmon released at Ice Harbor Dam, 957 (88.4% of those released) unique tags were detected at downstream telemetry transects on the Snake and Columbia Rivers. Of these, 956 (99.9%) were detected at Sacajawea Park. Detection probabilities at all transects were extremely high for both treatment and reference groups, ranging from 0.946 (SE = 0.016) at Port Kelly to 1.000 (SE = 0.000) at both Sacajawea Park and McNary Dam for daytime-released fish and from 0.915 (SE = 0.020) at Port Kelley to 1.000 (SE = 0.000) at Sacajawea Park and McNary Dam for nighttime-released fish (Tables 9 and 10).

Table 7. Sample size, mean, standard deviation (SD), and range of fork lengths (mm) for radio-tagged hatchery yearling chinook salmon (with a known length at tagging) released during daytime operations at Ice Harbor Dam, 2002.

Daytime releases, radio-tagged yearling chinook								
Release	Spillway releases (treatment)				Tailrace releases (reference)			
date	n	mean	SD	Range	n	mean	SD	Range
05 May	17	152.2	13.0	132-194	16	157.1	12.9	141-180
08 May	15	150.5	9.0	134-168	15	144.9	7.5	132-157
09 May	14	149.3	14.0	133-179	14	152.4	10.7	139-180
11 May	15	145.7	6.6	136-164	15	152.1	14.4	132-178
12 May	15	147.9	8.4	136-167	14	147.3	9.3	134-168
14 May	16	149.2	10.3	137-178	16	144.4	9.0	128-161
15 May	16	145.4	9.5	134-168	16	141.1	8.4	130-165
17 May	16	145.5	7.9	132-162	15	143.1	4.8	134-148
18 May	16	142.7	7.3	128-157	16	144.1	7.9	132-158
20 May	16	142.5	5.0	130-150	16	141.9	6.4	129-151
21 May	16	148.8	9.4	135-170	15	144.7	10.3	131-165
23 May	16	140.5	11.4	128-173	16	140.0	7.2	129-153
24 May	16	144.3	8.2	135-162	16	143.3	7.2	126-156
29 May	15	145.6	10.0	129-174	15	143.9	7.6	131-154
30 May	22	145.6	10.9	129-174	22	144.2	8.4	127-158
01 June	15	145.3	7.8	135-162	14	143.6	4.8	133-149
02 June	15	149.4	9.7	137-171	15	153.5	41.9	129-302
04 June	15	148.5	10.1	137-166	16	145.8	9.1	132-166
Overall	286	146.6	9.8	128-194	282	145.9	13.4	126-302

Table 8. Sample size, mean, standard deviation (SD), and range of fork lengths (mm) for radio-tagged hatchery yearling chinook salmon (with a known length at tagging) released during nighttime operations at Ice Harbor Dam, 2002.

Release date	Nighttime releases, radio-tagged yearling chinook							
	Spillway releases (treatment)				Tailrace releases (reference)			
	n	mean	SD	Range	n	mean	SD	Range
05 May	16	157.8	12.8	141-180	16	153.9	9.4	131-169
08 May	17	147.4	9.1	135-165	14	148.6	7.7	134-159
09 May	15	150.9	10.2	134-171	14	151.1	7.6	133-161
11 May	13	154.6	7.6	143-167	14	157.4	11.5	142-179
12 May	14	145.1	7.5	132-160	14	147.8	7.6	137-163
14 May	15	140.1	7.4	127-156	16	146.0	9.4	134-170
15 May	15	146.0	6.1	137-158	15	145.1	7.5	135-160
17 May	16	145.1	6.4	134-157	16	144.0	8.9	133-163
18 May	16	145.4	9.5	131-162	15	148.4	7.8	138-164
20 May	16	140.9	8.7	128-158	16	141.6	9.5	126-165
21 May	16	146.3	8.7	136-166	16	142.3	6.4	132-158
23 May	16	136.3	8.6	126-159	16	140.4	8.1	131-159
24 May	16	145.4	7.0	135-162	16	146.8	9.6	129-166
29 May	15	146.4	9.0	131-160	13	144.0	6.8	132-153
30 May	21	149.7	12.1	133-177	20	145.4	7.5	131-163
01 June	15	143.3	8.8	131-163	15	144.9	6.9	134-158
02 June	14	144.1	9.5	130-163	14	160.1	42.5	132-305
04 June	16	146.3	7.9	135-164	16	144.9	7.9	132-161
Overall	282	146.2	9.9	126-180	276	147.2	13.1	126-305

Table 9. Detection probabilities at radiotelemetry transects for daytime releases of radio-tagged hatchery yearling chinook salmon into the spillway and tailrace of Ice Harbor Dam, 2002. Standard errors are in parenthesis.

Daytime releases, radio-tagged yearling Chinook						
Release	Spillway (treatment)			Tailrace (reference)		
date	Sacajawea	Port Kelley	McNary Dam	Sacajawea	Port Kelley	McNary Dam
05 May	1.000 (0.000)	0.929 (0.069)	0.929 (0.069)	1.000 (0.000)	0.917 (0.080)	1.000 (0.000)
08 May	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)
09 May	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)
11 May	0.923 (0.074)	0.846 (0.100)	1.000 (0.000)	1.000 (0.000)	0.909 (0.087)	1.000 (0.000)
12 May	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	0.889 (0.105)	1.000 (0.000)
14 May	1.000 (0.000)	0.909 (0.087)	1.000 (0.000)	1.000 (0.000)	0.818 (0.116)	1.000 (0.000)
15 May	1.000 (0.000)	0.778 (0.139)	1.000 (0.000)	1.000 (0.000)	0.909 (0.087)	1.000 (0.000)
17 May	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)
18 May	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	0.917 (0.080)	1.000 (0.000)
20 May	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)
21 May	1.000 (0.000)	0.800 (0.126)	1.000 (0.000)	1.000 (0.000)	0.846 (0.100)	1.000 (0.000)
23 May	1.000 (0.000)	0.900 (0.095)	1.000 (0.000)	1.000 (0.000)	0.875 (0.117)	1.000 (0.000)
24 May	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)
29 May	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)
30 May	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)
01 June	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)
02 June	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	0.909 (0.087)	1.000 (0.000)
04 June	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)
Overall	0.995 (0.005)	0.095 (0.016)	0.993 (0.007)	1.000 (0.000)	0.946 (0.016)	1.000 (0.000)

Table 10. Detection probabilities at downstream radiotelemetry transects for nighttime releases of radio-tagged hatchery yearling chinook salmon into the spillway and tailrace of Ice Harbor Dam, 2002. Standard errors are in parenthesis.

	Nighttime releases, radio-tagged yearling chinook					
Release	Spillway (treatment)			Tailrace (reference)		
date	Sacajawea	Port Kelley	McNary Dam	Sacajawea	Port Kelley	McNary Dam
05 May	1.000 (0.000)	0.833 (0.108)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)
08 May	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)
09 May	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	0.923 (0.074)	1.000 (0.000)
11 May	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)
12 May	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	0.778 (0.139)	1.000 (0.000)
14 May	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	0.917 (0.080)	1.000 (0.000)
15 May	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	0.923 (0.074)	1.000 (0.000)
17 May	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)
18 May	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	0.917 (0.080)	1.000 (0.000)
20 May	1.000 (0.000)	0.900 (0.095)	1.000 (0.000)	1.000 (0.000)	0.800 (0.126)	1.000 (0.000)
21 May	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	0.727 (0.134)	1.000 (0.000)
23 May	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)
24 May	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)
29 May	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)
30 May	1.000 (0.000)	0.900 (0.095)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)
01 June	1.000 (0.000)	0.833 (0.152)	1.000 (0.000)	1.000 (0.000)	0.700 (0.145)	0.900 (0.095)
02 June	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	0.800 (0.126)	1.000 (0.000)
04 June	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	1.000 (0.000)	0.900 (0.095)	1.000 (0.000)
Overall	1.000 (0.000)	0.968 (0.014)	1.000 (0.000)	1.000 (0.000)	0.915 (0.020)	0.994 (0.006)

Survival estimates for individual release groups of radio-tagged yearling chinook salmon that passed through the spillway at Ice Harbor Dam relative to those released in the tailrace ranged from 0.600 to 1.000 during daytime operations and from 0.571 to 1.000 during nighttime operations (Tables 11 and 12). Weighted geometric mean relative survival was estimated at 0.848 (95% CI, 0.808-0.888) for daytime and 0.878 (95% CI, 0.828-0.928) for nighttime releases. No significant differences in relative survival estimates were found between daytime and nighttime spillway releases ($t = 0.94$, $P = 0.355$). The overall estimate (weighted geometric mean) of spillway passage survival for radio-tagged hatchery yearling chinook salmon was 0.865 (95% CI, 0.833-0.897). For radio-tagged fish passing through the Ice Harbor Dam spillway, we found only weak correlations between relative survival and total dam discharge, spill volume, tailwater elevation, release date, fork length at tagging, or water temperature (Appendix Figures C7-C12).

Partitioned Reach Survival--The reach from Ice Harbor Dam to McNary Dam was divided into three sections: Ice Harbor Dam to the mouth of the Snake River at Sacajawea Park (reach 1), Sacajawea Park to Port Kelley (reach 2), and Port Kelly to McNary Dam (reach 3). Survival of radio-tagged fish migrating through reach 1 and for the overall reach was estimated using detections only from fish released into the tailrace of Ice Harbor Dam. Survival through reaches 2 and 3 was estimated using detections at Sacajawea Park from all radio-tagged releases (spillway and tailrace releases). For the overall reach (Ice Harbor to McNary), survival was estimated at 0.749 (95% CI, 0.711-0.787). For individual reaches, survival estimates for radio-tagged fish were 0.961 through reach 1, 0.860 through reach 2, and 0.905 through reach 3 (Table 13).

Survival estimates through reach 2 were lower and significantly different from survival estimates through both reach 1 ($t = 7.43$, $P < 0.001$) and reach 3 ($t = 3.03$, $P = 0.005$). This may have been due in part to avian predation, primarily from Caspian Terns *Sterna caspia* that nest on Crescent Island, which is located within reach 2. Tags from 7.7% (n = 83) of the fish released at Ice Harbor Dam were recovered on Crescent Island (Table 14). Although the range of these birds appears to extend over the entire study area, 44.6% of the radio tags recovered on the island were last detected at Sacajawea Park, and 31.3% were last detected at Port Kelly (Table 15).

Table 11. Relative survival estimates for radio-tagged hatchery yearling chinook salmon released during daytime operations into the spillway and tailrace of Ice Harbor Dam, 2002. Standard errors are shown in parenthesis. The pooled relative survival estimate is presented as a weighted geometric mean.

	Daytime releases, radio-tagged yearling chinook				
	Spillway (treatment)		Tailrace (reference)		Relative survival
Release date	n	Survival	n	Survival	
05 May	17	1.000 (0.000)	16	1.000 (0.000)	1.000 (0.000)
08 May	15	0.867 (0.088)	13	1.000 (0.000)	0.967 (0.088)
09 May	12	1.000 (0.000)	14	1.000 (0.000)	1.000 (0.000)
11 May	15	0.867 (0.088)	15	1.000 (0.000)	0.967 (0.088)
12 May	15	0.733 (0.114)	13	0.846 (0.100)	0.866 (0.169)
14 May	16	0.688 (0.116)	14	1.000 (0.000)	0.688 (0.116)
15 May	16	0.813 (0.098)	16	1.000 (0.000)	0.813 (0.098)
17 May	15	0.733 (0.114)	15	1.000 (0.000)	0.733 (0.114)
18 May	16	0.875 (0.083)	15	0.933 (0.064)	0.938 (0.110)
20 May	16	0.813 (0.098)	16	1.000 (0.000)	0.813 (0.098)
21 May	16	0.813 (0.098)	15	1.000 (0.000)	0.813 (0.098)
23 May	15	0.867 (0.088)	15	0.933 (0.064)	0.929 (0.114)
24 May	16	0.688 (0.116)	14	0.857 (0.094)	0.803 (0.161)
29 May	15	0.933 (0.064)	15	1.000 (0.000)	0.933 (0.064)
30 May	22	0.636 (0.103)	19	0.895 (0.070)	0.711 (0.128)
01 June	15	0.733 (0.114)	14	0.929 (0.069)	0.789 (0.136)
02 June	15	0.600 (0.126)	15	0.867 (0.088)	0.692 (0.161)
04 June	15	0.800 (0.103)	16	1.000 (0.000)	0.800 (0.103)
Pooled	282	0.803 (0.027)	270	0.959 (0.014)	0.848 (0.020)

Table 12. Relative survival estimates for radio-tagged hatchery yearling chinook salmon released during nighttime operations into the spillway and tailrace of Ice Harbor Dam, 2002. Standard errors are shown in parenthesis. The pooled relative survival estimate is presented as a weighted geometric mean.

	Nighttime releases, radio-tagged yearling chinook				
	Spillway (treatment)		Tailrace (reference)		Relative
Release date	n	Survival	n	Survival	survival
05 May	15	0.933 (0.064)	16	0.750 (0.108)	1.244 (0.198)
08 May	17	0.824 (0.092)	14	1.000 (0.000)	0.824 (0.092)
09 May	15	0.933 (0.064)	14	1.000 (0.000)	0.933 (0.064)
11 May	13	1.000 (0.000)	14	1.000 (0.000)	1.000 (0.000)
12 May	12	0.667 (0.136)	13	0.846 (0.100)	0.788 (0.186)
14 May	16	0.813 (0.098)	15	0.933 (0.064)	0.871 (0.121)
15 May	13	0.692 (0.128)	15	0.933 (0.064)	0.742 (0.146)
17 May	16	0.875 (0.083)	16	0.938 (0.061)	0.933 (0.107)
18 May	15	0.600 (0.126)	15	1.000 (0.000)	0.600 (0.126)
20 May	16	0.875 (0.083)	16	1.000 (0.000)	0.875 (0.083)
21 May	15	0.933 (0.064)	14	1.000 (0.000)	0.933 (0.064)
23 May	15	0.867 (0.088)	15	1.000 (0.000)	0.867 (0.088)
24 May	15	0.867 (0.088)	14	1.000 (0.000)	0.867 (0.088)
29 May	15	0.867 (0.088)	13	1.000 (0.000)	0.867 (0.088)
30 May	17	0.706 (0.111)	18	0.944 (0.054)	0.748 (0.125)
01 June	10	0.700 (0.145)	15	1.000 (0.000)	0.700 (0.145)
02 June	14	0.571 (0.132)	14	1.000 (0.000)	0.571 (0.132)
04 June	15	0.867 (0.088)	16	1.000 (0.000)	0.867 (0.088)
Pooled	264	0.811 (0.029)	267	0.964 (0.016)	0.878 (0.025)

Table 13. Survival estimates for partitioned reaches between Ice Harbor and McNary Dams, 2002 (standard errors in parenthesis). Ice Harbor Dam to Sacajawea Park based on tailrace released fish. Sacajawea to Port Kelly and Port Kelly to McNary Dam based on all fish detected at Sacajawea Park.

Date	n	Ice Harbor Dam to Sacajawea Park	n	Sacajawea Park to Port Kelley	Port Kelly to McNary Dam
05 May	32	0.875 (0.058)	22	0.869 (0.074)	0.889 (0.074)
06 May	---	---	52	0.987 (0.020)	0.938 (0.037)
07 May	---	---	28	0.968 (0.018)	0.905 (0.064)
08 May	27	1.000 (0.000)	20	0.950 (0.030)	0.882 (0.078)
09 May	28	1.000 (0.000)	53	0.906 (0.040)	0.813 (0.056)
10 May	---	---	35	0.857 (0.059)	1.000 (0.000)
11 May	29	1.000 (0.000)	24	0.972 (0.043)	0.857 (0.076)
12 May	26	0.846 (0.071)	48	0.855 (0.051)	0.950 (0.034)
13 May	---	---	23	0.880 (0.072)	0.889 (0.074)
14 May	29	0.966 (0.034)	22	0.909 (0.061)	1.000 (0.000)
15 May	31	0.968 (0.032)	58	0.869 (0.046)	0.913 (0.042)
16 May	---	---	25	0.842 (0.074)	0.950 (0.049)
17 May	31	0.968 (0.032)	26	0.885 (0.063)	0.870 (0.070)
18 May	30	0.967 (0.033)	56	0.804 (0.053)	0.977 (0.022)
19 May	---	---	25	0.926 (0.055)	0.864 (0.073)
20 May	32	1.000 (0.000)	29	0.793 (0.075)	1.000 (0.000)
21 May	29	1.000 (0.000)	53	0.870 (0.052)	0.846 (0.058)
22 May	---	---	33	0.854 (0.063)	0.958 (0.041)
23 May	30	0.967 (0.033)	25	0.777 (0.089)	0.824 (0.092)
24 May	28	0.929 (0.049)	53	0.792 (0.056)	0.805 (0.095)
25 May	---	---	27	0.852 (0.068)	0.957 (0.043)
29 May	28	1.000 (0.000)	29	0.931 (0.047)	0.889 (5.560)
30 May	37	0.919 (0.045)	56	0.768 (0.056)	0.860 (0.053)
31 May	---	---	30	0.871 (0.063)	0.880 (0.065)
01 June	29	0.966 (0.034)	24	0.875 (0.068)	1.000 (0.000)
02 June	29	0.931 (0.047)	41	0.872 (0.058)	0.870 (0.062)
03 June	---	---	25	0.686 (0.094)	0.933 (0.064)
04 June	32	1.000 (0.000)	25	0.920 (0.054)	0.783 (0.086)
05 June	---	---	31	0.843 (0.067)	0.880 (0.065)
Pooled	537	0.961 (0.008)	998	0.860 (0.011)	0.905 (0.010)

Table 14. Minimum estimates of avian predation with percent of daily release groups for radio-tagged hatchery yearling chinook salmon released at Ice Harbor Dam based on the recovery of radio and/or PIT tags from Crescent Island, 2002.

	Radio-tagged yearling chinook									
	Daytime releases				Nighttime releases					
Release	Spillway		Tailrace		Spillway		Tailrace		Daily Total	
date	n	Percent	n	Percent	n	Percent	n	Percent	n	Percent
05 May	--		1	(6.3)	--		--		1	(1.6)
08 May	1	(6.7)	3	(23.1)	1	(5.9)	--		5	(8.5)
09 May	--		--		--		--		--	
11 May	--		--		1	(7.7)	--		1	(1.8)
12 May	--		--		--		--		--	
14 May	--		--		--		--		--	
15 May	1	(6.3)	--		--		1	(6.7)	2	(3.3)
17 May	1	(6.7)	--		--		1	(6.3)	2	(3.2)
18 May	--		1	(6.7)	1	(6.7)	--		2	(3.3)
20 May	2	(12.5)	2	(12.5)	1	(6.3)	1	(6.3)	6	(9.4)
21 May	3	(18.8)	1	(6.7)	--		1	(7.1)	5	(8.3)
23 May	1	(6.7)	1	(6.7)	4	(26.7)	2	(13.3)	8	(13.3)
24 May	1	(6.3)	2	(14.3)	1	(6.7)	--		4	(6.8)
29 May	4	(26.7)	--		1	(6.7)	3	(23.1)	8	(13.8)
30 May	2	(9.1)	3	(15.8)	1	(5.9)	2	(11.1)	8	(10.5)
01 June	5	(33.3)	2	(14.3)	4	(40.0)	2	(13.3)	13	(24.1)
02 June	3	(20.0)	3	(20.0)	1	(7.1)	3	(21.4)	10	(17.2)
04 June	2	(13.3)	1	(6.3)	1	(6.7)	4	(25.0)	8	(12.9)
Totals	26	(9.2)	20	(7.4)	17	(6.4)	20	(7.5)	83	(7.7)

Table 15. Location of last radio-tag detection for hatchery yearling chinook salmon released into the spillway or tailrace of Ice Harbor Dam and whose tags were recovered on Crescent Island, 2002.

Location of last detection	Number recovered	Percent recovered
Goose Island	18	21.7
Sacajawea Park	37	44.6
Port Kelley	26	31.3
McNary Dam	1	1.2
Crow Butte	1	1.2

Tailrace Egress--Tailrace egress is defined as the elapsed time in minutes from release into the spillway at Ice Harbor Dam to the first detection at Goose Island approximately 2 km downstream from the dam. Median tailrace egress for all radio-tagged fish was 30 min (16 and 152 min for the 10^{th} and 90^{th} percentiles, respectively). Fish released during nighttime operations had slightly faster median egress time (27 min) than fish released during daytime operations (32 min). Fish released through Spillbays 9 and 10 had the longest median egress time (46 and 48 min, respectively, for fish released during both daytime and nighttime operations) compared to fish released through the other bays (Figure 5).

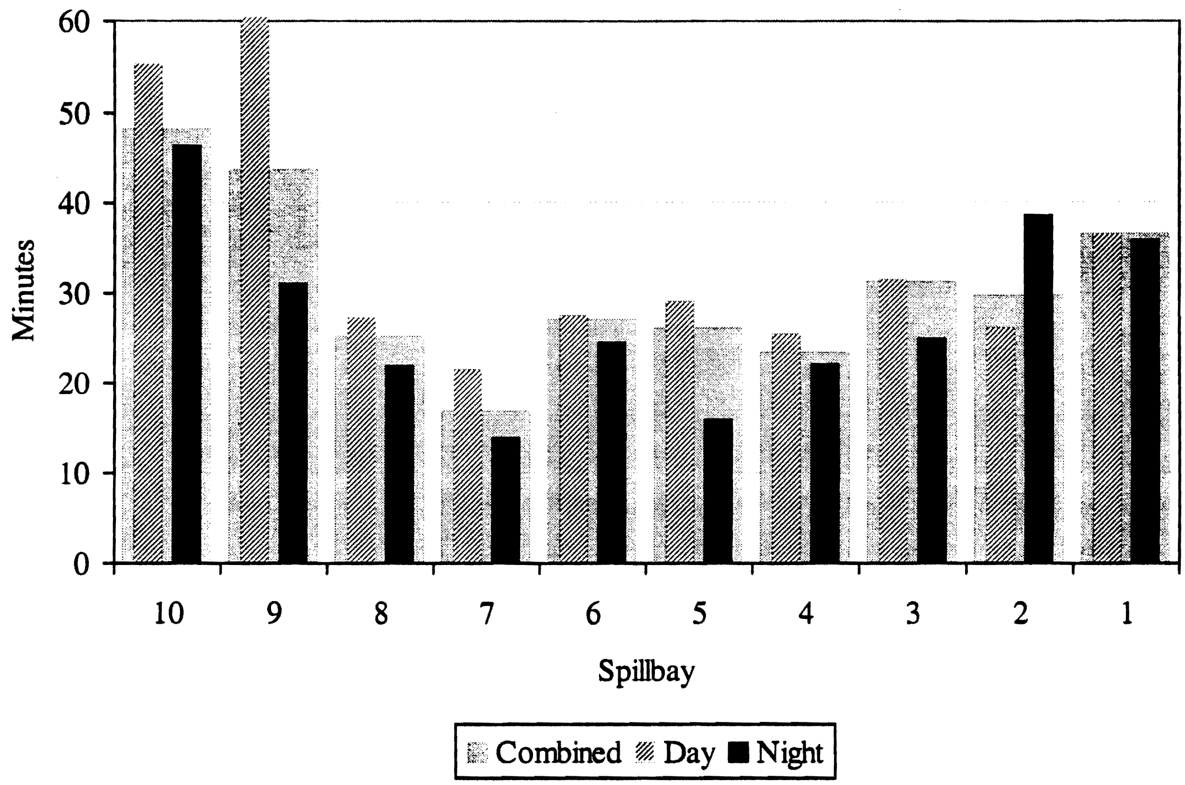

Figure 5. Median tailrace egress times in minutes for radio-tagged hatchery yearling chinook salmon released into the spillway during daytime and nighttime operations at Ice Harbor Dam, 2002.

PIT- and Radio-tag Comparison

A statistical comparison between relative spillway passage survival estimates obtained using PIT-tag and radio-tag methodologies indicated they were not significantly different ($t = 0.88$, $P = 0.382$). A comparison of median travel times from release to McNary Dam showed a statistically significant difference for all groups (spillway/day, spillway/night, tailrace/day, and tailrace/night; Table 16) where radio-tagged fish traveled slightly slower than their PIT-tagged counterparts. However, differences were measured in tenths of days and were not likely to have been biologically significant. Based on recovery of PIT tags from Crescent Island, a minimum of 2.1% of the PIT-tagged fish released at Ice Harbor Dam in 2002 was taken by avian predators, compared to 7.7% of the radio-tagged fish released. The majority of tags for both methodologies were taken from later release groups (Figure 6).

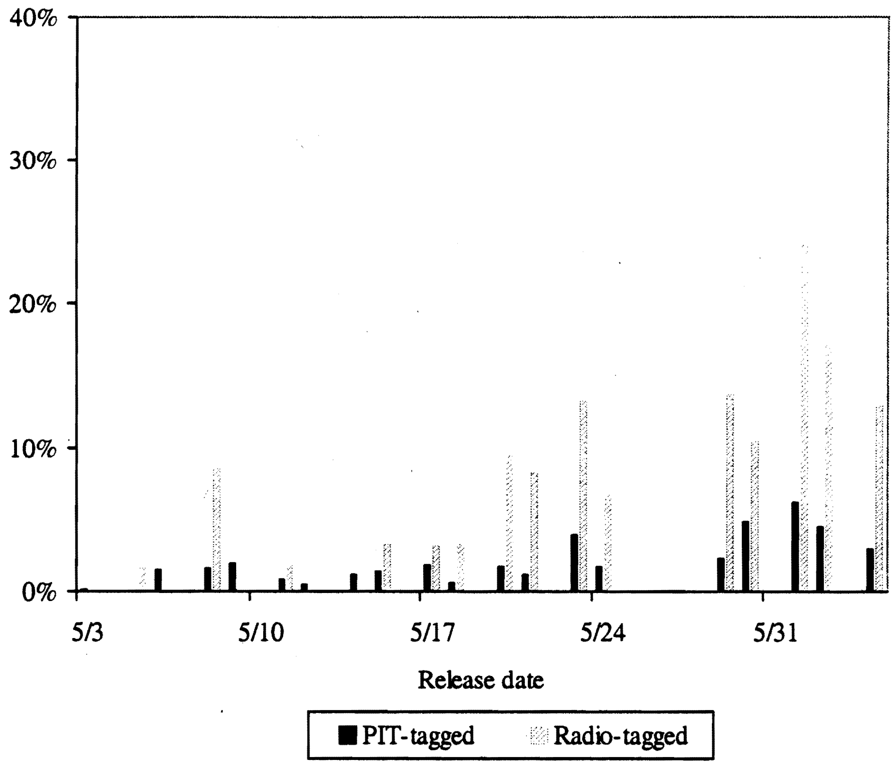

Figure 6. Percent of tags (both PIT and radio) released into the spillway or tailrace of Ice Harbor Dam and subsequently recovered from Crescent Island, 2002.

Table 16. Comparison of median travel times (in days) from release into the spillway and tailrace of Ice Harbor Dam to first PIT-tag detection at McNary Dam for PIT- and radio-tagged hatchery yearling chinook salmon, 2002.

Release location and time	Travel time (d): Radio-tagged yearling chinook		Travel time (d): PIT-tagged yearling chinook		*P*-value
	n	Median	n	Median	
Spillway Day	66	2.3	1,798	2.0	0.012
Spillway Night	61	2.3	1,949	1.9	0.034
Tailrace Day	76	2.0	1,953	1.9	0.010
Tailrace Night	85	2.0	2,157	1.8	0.020
Combined	288	2.1	7,857	1.9	0.002

Subyearling Chinook Salmon

Fish Collection, Tagging, and Release

Subyearling chinook salmon were collected and PIT tagged at Lower Monumental Dam on 13 d from 27 June to 9 July. Tagging began after 22% of the subyearling chinook salmon had passed Lower Monumental Dam and was completed when 53% of these fish had passed (Figure 7). We released 7,561 and 6,766 PIT-tagged fish into the spillway and 6,663 and 6,507 into the tailrace at Ice Harbor Dam during daytime and nighttime operations, respectively.

Handling and tagging mortality for yearling chinook salmon was 0.9% overall. For daytime releases, overall mean fork length was 111.5 mm (SD = 10.9) for fish released to the spillway and 112.4 mm (SD = 10.9) for fish released to the tailrace (Table 17). Daytime releases occurred between 1440 and 1600 PDT and were made though spillbays discharging from 3.4 to 5.3 kcfs and open from 2.0 to 3.1 stops. Ice Harbor Dam operations during daytime releases ranged from 44.7 to 46.1 kcfs total spill volume, or 49 to 78% of total project discharge; tailwater elevation ranged from 342.4 to 345.7 ft, and water temperatures ranged from 16.2 to 19.1°C (Appendix Table B3).

For nighttime releases, overall mean fork length was 111.7 mm (SD = 10.6) for fish released to the spillway and 112.0 mm (SD = 10.8) for fish released to the tailrace (Table 18). Nighttime releases occurred between 2215 and 2350 PDT and were made though spillbays discharging from 3.4 to 10.1 kcfs and open from 2.0 to 6.0 stops. Ice Harbor Dam operations during daytime releases ranged from 30.2 to 84.8 kcfs total spill volume, or 100% of total project discharge; tailwater elevation ranged from 340.2 to 344.5 ft, and water temperatures ranged from 16.2 to 18.8°C (Appendix Table B4). Severe thunderstorms on the night of 7 July prevented the release of the tailrace reference group; therefore, this group was omitted from detection and survival analyses.

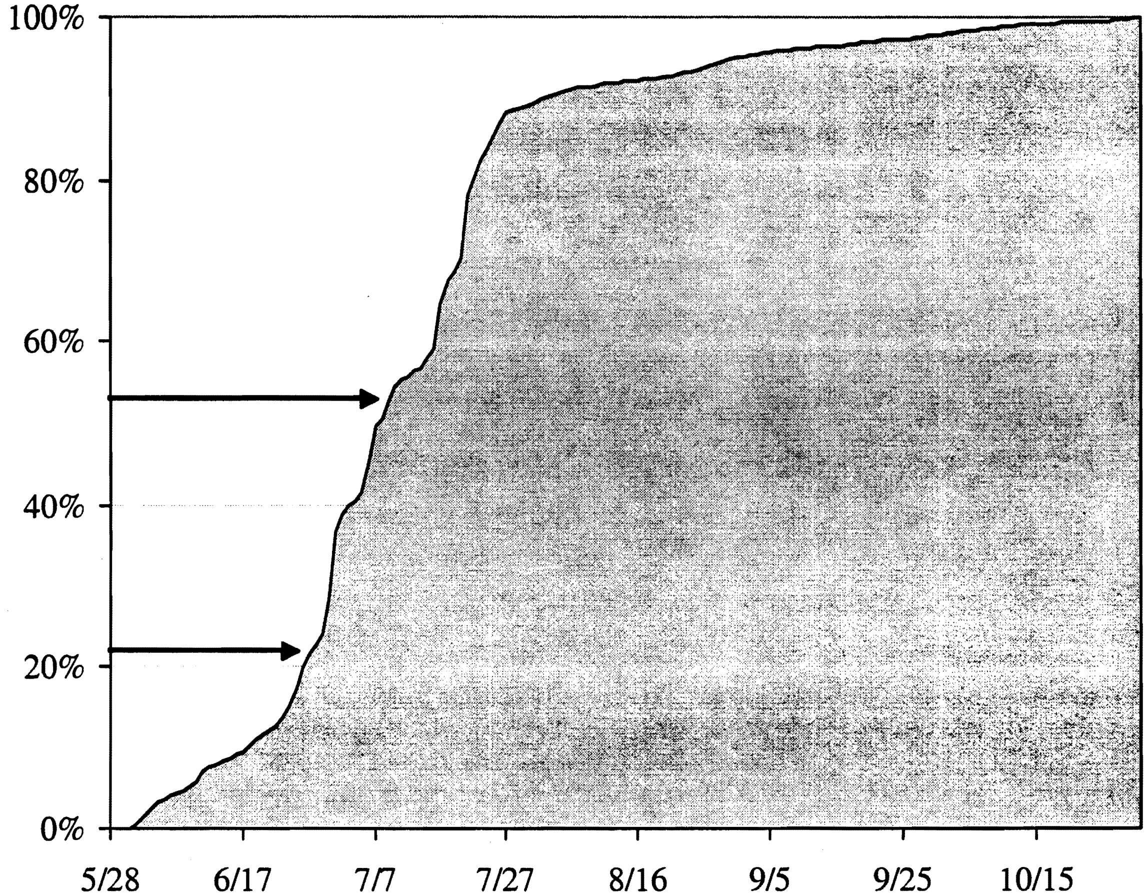

Figure 7. Cumulative passage distribution of subyearling chinook salmon at Lower Monumental Dam during 2002. Arrows indicate beginning and ending release dates for PIT-tagged hatchery subyearling chinook salmon to evaluate Ice Harbor Dam spillway survival, 2002.

Table 17. Sample size, mean, standard deviation (SD), and range of fork lengths (mm) for PIT-tagged subyearling chinook salmon (with a known length at tagging) released during daytime operations at Ice Harbor Dam to evaluate spillway survival, 2002.

Release date	Spillway (treatment)				Tailrace (reference)			
	n	Mean fork length (mm)	SD	Range	n	Mean fork length (mm)	SD	Range
28 June	413	103.2	11.7	79-137	401	104.8	12.0	78-144
29 June	317	102.4	13.5	73-139	314	108.4	14.7	79-212
30 June	415	106.6	14.5	78-151	415	110.6	13.5	81-152
01 July	349	117.0	14.5	84-157	350	117.9	14.3	75-149
02 July	658	113.7	11.4	76-151	462	112.7	12.9	71-155
03 July	692	110.2	10.9	79-172	398	115.5	11.7	77-152
04 July	598	113.4	9.6	63-158	565	112.4	9.8	88-156
05 July	768	113.4	8.9	83-172	749	113.0	9.2	78-171
06 July	783	114.2	8.6	85-162	726	113.6	9.4	86-156
07 July	595	112.8	7.6	92-150	592	112.5	8.6	81-149
08 July	776	114.5	7.9	80-154	707	110.3	7.5	84-156
09 July	409	108.8	7.3	87-149	448	114.3	8.1	85-156
10 July	302	108.9	7.3	92-148	347	115.2	7.6	91-151
Overall	7,075	111.5	10.9	63-172	6,474	112.4	10.9	71-212

Table 18. Sample size, mean, standard deviation (SD), and range of fork lengths (mm) for PIT-tagged subyearling chinook salmon (with a known length at tagging) released during nighttime operations at Ice Harbor Dam to evaluate spillway survival, 2002. (Note: Severe weather conditions prevented the tailrace release on 07 July.)

Release date	Spillway (treatment)				Tailrace (reference)			
	n	Mean fork length (mm)	SD	Range	n	Mean fork length (mm)	SD	Range
28 June	445	100.3	10.7	71-145	457	103.1	11.8	78-139
29 June	209	102.0	11.6	81-159	211	106.0	12.1	84-158
30 June	384	106.1	13.4	76-141	385	110.4	13.3	77-146
01 July	323	111.5	13.8	76-147	350	115.4	14.6	80-148
02 July	690	114.5	12.9	80-180	612	114.7	11.7	83-155
03 July	762	112.0	12.1	78-281	542	113.2	11.9	82-230
04 July	696	114.7	8.8	87-155	697	112.8	10.6	82-163
05 July	777	114.4	9.0	81-168	818	112.3	9.6	83-186
06 July	781	114.2	7.7	85-146	774	112.8	8.4	83-152
07 July	1,392	112.7	7.5	88-152				
08 July	797	114.7	7.9	84-158	808	110.1	6.6	86-150
09 July	443	108.9	7.1	91-155	446	115.4	7.6	94-161
10 July	309	107.2	6.4	72-131	310	115.0	8.3	86-160
Overall	8,008	111.7	10.6	71-281	6,410	112.0	10.8	77-230

Detection and Survival

Of the 27,587 PIT-tagged hatchery subyearling chinook salmon released at Ice Harbor Dam for estimation of spillway passage survival, unique PIT-tags were detected at downstream locations on the Columbia River for 15,092 (54.7%; Table 19). Detection probabilities at McNary Dam for daytime release groups were similar between treatments, with overall estimates of 0.536 (SE = 0.012) and 0.545 (SE = 0.012) for spillway and tailrace releases, respectively (Table 20).

For nighttime releases, overall detection probabilities were 0.565 (SE = 0.013) and 0.546 (SE = 0.013) for spillway and tailrace released fish, respectively. Similar to the yearling chinook salmon released in the spring, detection probabilities at McNary Dam were affected by the overall amount of spill. As total river flows and total spill volume decreased, detection probabilities increased (Figure 8).

Survival estimates for individual release groups of PIT-tagged subyearling chinook salmon that passed through the spillway at Ice Harbor Dam relative to those released into the tailrace ranged from 0.757 to 1.333 and 0.695 to 1.144 during daytime and nighttime operations, respectively (Table 21 and 22). The weighted geometric mean relative survival estimates were 0.876 (95% CI, 0.828-0.924) and 0.915 (95% CI, 0.855-0.975) for daytime and nighttime released fish, respectively. There was no significant difference between daytime and nighttime relative spillway survival ($t = 1.00$, $P = 0.327$). The overall estimate (weighted geometric mean) of spillway passage survival for PIT-tagged hatchery subyearling chinook salmon was 0.894 (95% CI, 0.856-0.932). For subyearling chinook salmon passing through the Ice Harbor Dam spillway, no significant correlation was found between relative survival and total dam discharge, spill volume, tailwater elevation, release date, fork length at tagging, or water temperature (Appendix Figures C13-C18).

Table 19. First time detections at downstream PIT-tag detection sites with proportion of fish released for evaluating survival for hatchery subyearling chinook salmon passing through the spillway at Ice Harbor Dam, 2002. Standard error shown in parenthesis.

Detection site	Spillway	Tailrace	Total
		Daytime releases	
McNary Dam	3,187 (0.422)	3,156 (0.474)	6,343 (0.446)
John Day Dam	463 (0.061)	485 (0.073)	948 (0.067)
Bonneville Dam	323 (0.043)	342 (0.051)	665 (0.047)
PIT-Trawl	5 (0.001)	4 (0.001)	9 (0.001)
Total	3,910 (0.517)	3,917 (0.588)	7,827 (0.550)
		Nighttime releases	
McNary Dam	2,979 (0.440)	3,052 (0.463)	6,301 (0.541)
John Day Dam	360 (0.053)	378 (0.057)	738 (0.055)
Bonneville Dam	265 (0.039)	323 (0.049)	588 (0.044)
PIT-Trawl	1 (0.000)	6 (0.001)	7 (0.001)
Total	3,565 (0.527)	3,700 (0.561)	7,265 (0.544)

Table 20. Detection probabilities at McNary Dam for PIT-tagged hatchery subyearling chinook salmon released during daytime and nighttime operations into the spillway and tailrace of Ice Harbor Dam, 2002. Standard errors are presented in parenthesis.

Release date	Daytime		Nighttime	
	Spillway	Tailrace	Spillway	Tailrace
28 June	0.582 (0.051)	0.450 (0.051)	0.501 (0.048)	0.515 (0.053)
29 June	0.575 (0.066)	0.473 (0.054)	0.308 (0.074)	0.331 (0.064)
30 June	0.498 (0.050)	0.379 (0.055)	0.382 (0.058)	0.295 (0.048)
01 July	0.502 (0.044)	0.254 (0.053)	0.423 (0.053)	0.490 (0.055)
02 July	0.467 (0.056)	0.291 (0.040)	0.449 (0.039)	0.320 (0.040)
03 July	0.501 (0.059)	0.382 (0.050)	0.647 (0.037)	0.530 (0.046)
04 July	0.388 (0.066)	0.592 (0.043)	0.587 (0.043)	0.560 (0.042)
05 July	0.440 (0.063)	0.689 (0.031)	0.611 (0.034)	0.604 (0.030)
06 July	0.414 (0.060)	0.635 (0.028)	0.614 (0.033)	0.671 (0.028)
07 July	0.434 (0.057)	0.585 (0.032)		
08 July	0.277 (0.052)	0.611 (0.034)	0.728 (0.040)	0.713 (0.038)
09 July	0.319 (0.056)	0.671 (0.046)	0.570 (0.065)	0.513 (0.055)
10 July	0.467 (0.072)	0.501 (0.059)	0.633 (0.056)	0.581 (0.060)
Overall	0.536 (0.012)	0.545 (0.012)	0.565 (0.013)	0.546 (0.013)

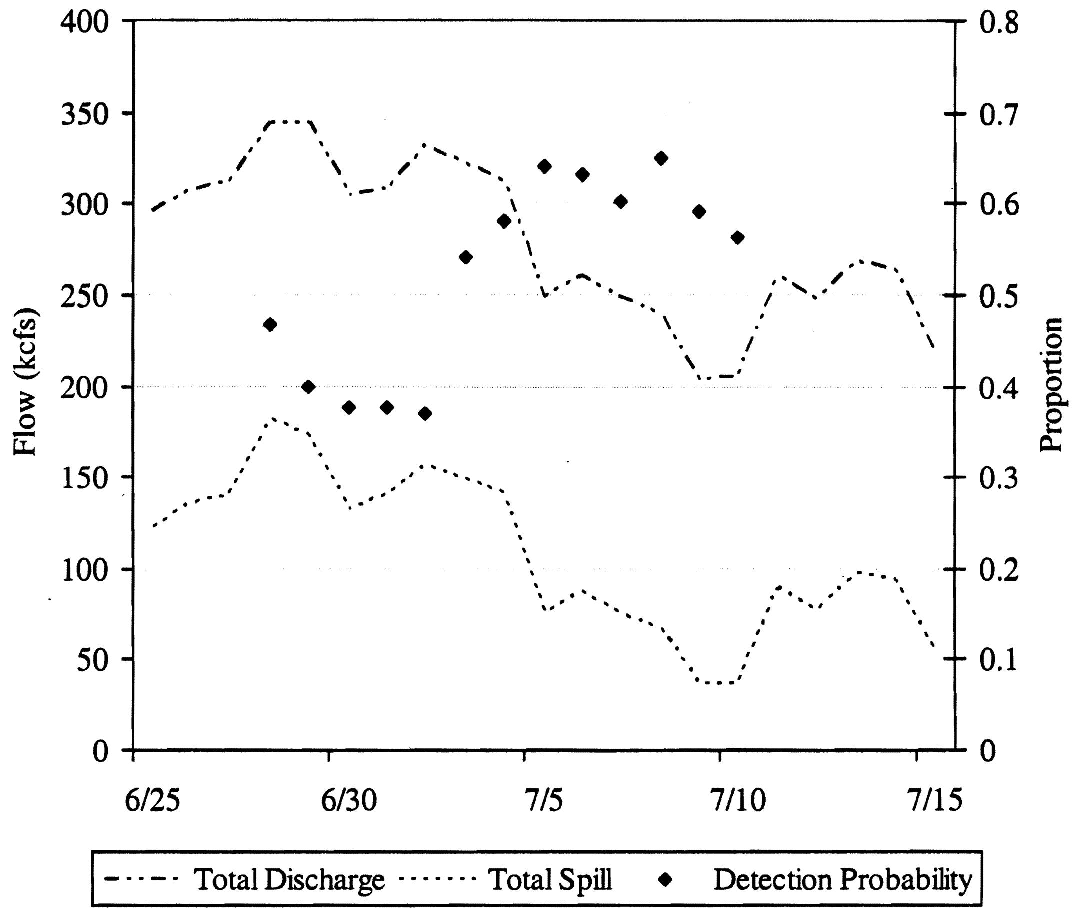

Figure 8. Total discharge, spill, and detection probabilities of PIT-tagged hatchery subyearling chinook salmon at McNary Dam during the Ice Harbor Dam spillway survival study, 2002.

Table 21. Relative survival estimates for PIT-tagged hatchery subyearling chinook salmon released during daytime operations into the spillway and tailrace of Ice Harbor Dam, 2002. Standard errors are shown in parenthesis. The overall relative survival estimate is presented as a weighted geomean.

	Daytime releases, subyearling chinook				
Release	Spillway (treatment)		Tailrace (reference)		Relative
date	n	Survival	n	Survival	survival
28 June	447	0.802 (0.075)	445	0.728 (0.072)	1.101 (0.150)
29 June	317	0.679 (0.081)	614	0.849 (0.083)	0.799 (0.123)
30 June	415	0.688 (0.082)	415	0.864 (0.111)	0.796 (0.140)
01 July	349	4.096 (0.164)	350	0.822 (0.152)	1.333 (0.317)
02 July	757	0.792 (0.067)	462	1.046 (0.124)	0.757 (0.110)
03 July	800	0.802 (0.052)	398	1.016 (0.118)	0.789 (0.105)
04 July	699	0.729 (0.044)	628	0.851 (0.055)	0.856 (0.076)
05 July	818	0.679 (0.032)	797	0.792 (0.032)	0.857 (0.053)
06 July	784	0.811 (0.041)	757	0.919 (0.033)	0.882 (0.055)
07 July	595	0.840 (0.042)	592	1.004 (0.043)	0.836 (0.055)
08 July	778	0.888 (0.059)	709	0.947 (0.045)	0.937 (0.077)
09 July	453	0.759 (0.064)	449	0.930 (0.056)	0.816 (0.085)
10 July	349	0.941 (0.087)	347	0.842 (0.085)	1.117 (0.153)
Pooled	7,561	0.808 (0.032)	6,663	0.893 (0.026)	0.876 (0.024)

Table 22. Relative survival estimates for PIT-tagged hatchery subyearling chinook salmon released during nighttime operations into the spillway and tailrace of Ice Harbor Dam, 2002. Standard errors are shown in parenthesis. The overall relative survival estimate is presented as a weighted geomean.

Release date	Nighttime releases, subyearling chinook				Relative survival
	Spillway (treatment)		Tailrace (reference)		
	n	Survival	n	Survival	
28 June	459	0.776 (0.065)	457	0.908 (0.084)	0.854 (0.107)
29 June	209	0.911 (0.194)	211	0.922 (0.150)	0.988 (0.265)
30 June	384	0.747 (0.100)	385	0.755 (0.108)	0.989 (0.194)
01 July	347	0.926 (0.090)	350	0.784 (0.079)	1.053 (0.156)
02 July	746	0.851 (0.064)	612	1.223 (0.136)	0.695 (0.093)
03 July	795	0.726 (0.039)	595	0.952 (0.076)	0.762 (0.073)
04 July	696	0.692 (0.047)	698	0.725 (0.049)	0.954 (0.091)
05 July	799	0.780 (0.040)	858	0.904 (0.038)	0.862 (0.057)
06 July	781	0.830 (0.039)	798	0.870 (0.030)	0.954 (0.056)
08 July	797	0.744 (0.039)	877	0.761 (0.039)	0.977 (0.072)
09 July	443	0.747 (0.081)	446	0.846 (0.083)	0.882 (0.129)
10 July	310	0.925 (0.073)	310	0.808 (0.076)	1.144 (0.141)
Pooled	6,766	0.796 (0.021)	6,597	0.872 (0.038)	0.915 (0.030)

DISCUSSION

For PIT-tagged hatchery yearling chinook salmon at Ice Harbor Dam in 2002, the overall estimate of relative spillway passage survival (0.892) was lower than the estimate in 2000 (0.978). Weak correlations were found between relative survival estimates and environmental conditions in both studies. However, the strongest of these correlations indicated a relationship between spillway survival and total river flow, spill volume, and tailwater elevation, where survival was lower when total river flows were low.

For PIT-tagged hatchery subyearling chinook salmon, overall estimates of relative spillway passage survival were comparable between 2000 and 2002, at 0.885 and 0.894, respectively. Lower survival estimates for summer migrants have been attributed to higher predation rates created by unfavorable environmental conditions (i.e., low flows, low turbidity, and higher water temperatures). Increases in water temperature have been shown to increase the digestion and consumption rates of northern pikeminnow (Falter 1969; Steigenberger and Larkin 1974; Beyer et al. 1988; Vigg 1988). Decreases in turbidity and flow may increase capture efficiency of predators (Gray and Rondorf 1986) and increase exposure time when predator consumption rates are higher (Beamesderfer et al. 1990; Rieman et al. 1991).

River flows in early spring 2002 (1-17 May) were considerably lower than the 10-year average and were 20% lower than flows in 2000 during the same period (average daily flows of 85.1 and 68.4 kcfs for 2000 and 2002, respectively). These early spring flows in 2002 were only16% higher than average flows during summer releases (68.4 and 57.3 kcfs for spring and summer, respectively). Although average daily flows in early May were low and similar to historic summer flows, the average water temperature during spring releases was 5°C lower than the average during summer releases. These lower water temperatures likely resulted in reduced digestion and consumption rates by predators.

Additionally, fish passing the spillway at Ice Harbor Dam exited the tailrace relatively quickly (median egress times of 30 min from release to detection at Goose Island, 2 km downstream of the dam). Based on recovery of PIT tags from Crescent Island, rates of predation by terns and sea gulls (*Larus* spp). were higher in the latter part of May, when relative survival estimates were also higher. Combined with decreased consumption rates, and therefore reduced predation under lower water temperatures, this may indicate that some other factor is influencing spillway passage survival at low total river flows.

Survival for yearling chinook salmon from release 5 km above Ice Harbor Dam to McNary Dam was estimated at 0.724 in 2001 (Axel et al. 2003). Survival through the reach between Sacajawea Park and Port Kelley was lowest (0.860), likely due to avian predation. Crescent Island, located within this reach, harbors the second largest Caspian tern colony in North America (>600) and large populations of gulls (>39,000; Collis et al. 2002). Birds from this island consumed nearly 8% of radio-tagged fish and just over 2% of the PIT-tagged fish released at Ice Harbor Dam. Tag-detection percentage on avian colonies is a minimum estimate of loss due to bird predation because not all tags taken by birds are deposited on a colony, and not all deposited tags are detected (Collis et al. 2001; Ryan et al. 2001)

Hockersmith et al. (2003) found that during migrations of moderate duration (<6 d) the presence of a sham radio tag, whether surgically or gastrically implanted, had little effect on performance or survival compared with the presence of a PIT tag. A comparison of relative spillway passage survival estimates obtained using PIT-tag and radio-tag methodology resulted in no significant difference between survival estimates. Analysis of travel time from Ice Harbor to McNary Dam revealed significant differences, but these were less than 0.5 d for all treatments.

Based on recovery of radio and PIT tags from Crescent Island, radio-tagged fish may be more susceptible to avian predation (7.7 and 2.1% for radio- and PIT-tagged yearling chinook salmon, respectively). Perry et al. (2001) concluded that the presence of a radio tag may make juvenile chinook salmon less buoyant than their untagged counterparts, causing them to expend more energy to maintain their position in the water column. They concluded that due to this reduced buoyancy, radio-tagged fish may reside at a shallower depth than non-tagged fish in order to reduce energy expenditure and remain in a suitable range of buoyancy.

Due to high detection probabilities, mobility of detection equipment, and reduced sample size numbers (and thus reduced impact to the resource), radiotelemetry is proving to be a very useful tool for estimating survival of juvenile salmonids. Based on the results of this study, we concluded that radiotelemetry is a technically valid and practical tool for estimating relative survival of migrating juvenile salmonids. Using a paired-release study design should minimize any bias associated with increased vulnerability to avian predation and other mortality factors, in that the treatment and reference groups would be similarly affected.

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APPENDIX A: Tests of Model Assumptions

Methods

The single-release model assumed that all fish in a given cohort had equal probability of detection at a given site and that treatment and paired reference groups had similar survival through common reaches (e.g., for spillway- and tailrace- released fish this was the reach downstream of the tailrace release location). If these paired groups were evenly mixed and traveled together through downstream reaches, we determined the assumptions were not violated. We tested the second assumption with χ^2 tests on $r \times c$ contingency tables, where r was the number of rows of daily detection totals at a given detection site, and $c = 2$ for the columns of spillway and tailrace. The *P*-values for these tests were calculated using Monte Carlo approximations to exact methods with Statxact (Mehta and Patel 1992). *P*-values based on asymptotic normal theory were not used due to the sparse nature of the tails of the detection distributions (i.e., many values of zero and small detection numbers).

We did not have appropriate data with which to objectively determine the level of bias that may have resulted from violations of SR model assumptions. However, when violations were indicated, we assessed the general magnitude of the violations and qualitatively determined the potential effects on study results.

A further model assumption was that detection and survival probabilities downstream from detection sites were not conditional on PIT-tag detection at upstream sites. That is, that detection and survival downstream from a detection site is not dependent on one or more prior detection events. We assessed this assumption using the methods of Burnham et al. (1987). Using contingency tables of the totals in various detection-history categories, we calculated χ^2 tests for each temporal group and overall. If goodness-of-fit tests for a series of temporal groups resulted in more significant tests than expected by chance ($\alpha = 0.05$), we examined the appropriate tables to determine the nature of the violation and to see if there was consistency in the pattern of the violation. We did not evaluate contingency table tests where expected values of table cells were less than 1.0, as no inference regarding the assumptions was possible from such tables. In 2×3 tables with one column of zeros, a reduced (2×2) table was tested.

For the four detection sites used in this study (release at Ice Harbor Dam, detection at John Day Dam, Bonneville Dam, and the estuary PIT Trawl), two of Burnham et al.'s (1987) tests were applicable, Test 2.C2 and Test 3.SR3. Tests 2.C3, 3.SM3, and 3.SR4 were theoretically applicable but could not be used due to the small numbers of detections with the estuary PIT Trawl of both yearling and subyearling fish.

Test 2.C2 was based on the contingency table:

Test 2.C2	First site detected below McNary Dam		
df = 2 or 1 (if Trawl = 0)	John Day Dam	Bonneville Dam	Trawl
Not detected at McNary Dam	n_{11}	n_{12}	n_{13}
Detected at McNary Dam	n_{21}	n_{22}	n_{23}

If the assumptions were met, the counts at downstream sites for fish detected at McNary Dam should be in constant proportion to those for fish not detected (i.e., n_{11}/n_{21} and n_{12}/n_{22}, and n_{13}/n_{23} should be equal). If there were no detections at the estuary PIT trawl, the table was reduced to a 2 × 2 table. Test 3.SR3 was based on the contingency table:

Test 3.SR3	Detected again at Bonneville Dam or PIT Trawl?	
df = 1	YES	NO
Detected at John Day Dam Not detected at McNary Dam	n_{11}	n_{12}
Detected at John Day Dam Detected at McNary Dam	n_{21}	n_{22}

If the assumptions were met, the numbers detected at Bonneville Dam and in the PIT trawl should be in constant proportion for fish "detected at John Day and McNary Dams" vs. "detected at John Day Dam but not detected at McNary Dam."

Results

PIT Tagged Hatchery Yearling Chinook Salmon

Distributions of PIT-tagged hatchery yearling chinook salmon passing McNary Dam were compared for spillway and tailrace releases. In 14 of 38 tests, *P*-values were <0.05, indicating a significant lack of mixing between spillway and tailrace-released paired cohorts (Appendix Table A1). Although fish passed McNary Dam over several days (by cohort), the majority passed within 2-4 d (the span was shorter for later releases; Appendix Figures D1-D14). Lack of mixing was evidenced by tailrace groups passing ahead of the spillway fish (median travel time 1.9 vs. 2.0 d, respectively, for daytime released fish, and 1.8 vs. 1.9 d for night-released fish) with mildly protracted "tails" in some cases (Appendix Table A2).

Tests for John Day and Bonneville Dams had 5 and 1, respectively, of 38 tests with *P*-values <0.05 (Appendix Tables A3-A4). Passage distributions were similar to those at McNary Dam, but more protracted, and paired cohorts appeared to be somewhat mixed. Although these tests indicated a lack of mixing at McNary and John Day Dams, the differences in passage distributions were of short enough duration (i.e., less that a day delay for spillway-released fish) that the relative spillway-to-tailrace survival estimates were most likely minimally biased with respect to relative spillway passage survival.

The results of Test 2C.2 had *P*-values <0.05 in 4 of 36 calculable tests for daytime spillway- and tailrace-released fish, indicating some violations of the assumption that PIT-tag detection history at McNary Dam did not affect detection at downstream sites. Tests for night-released fish had no *P*-values <0.05 of 38 calculable tests, indicating no violations of the assumption. Violations to this assumption for daytime released fish were likely caused by detections systems selecting for smaller fish and a positive, albeit weaker, relationship between fish length at tagging and survival probabilities (i.e., larger fish generally have greater survival probabilities; Zabel et al. in review).

Further research is needed to investigate the causes of assumption violations, their effect on the accuracy of survival estimates, and potential remedial measures. Given current knowledge of these issues, we believe that the violations of assumptions have only a small effect on the single-release model survival estimates interpreted as average survival probability for the group, and we report estimates from the single-release model for all release groups. The results of Test 3.Sr3 had *P*-values <0.05 in 1 of 27 calculable tests for day-released PIT-tagged fish and in 2 of 25 calculable tests for night-released fish, indicating no meaningful violation of this model assumption.

Appendix Table A1. Test of homogeneity in passage distributions at McNary Dam for PIT-tagged hatchery yearling chinook salmon released to the spillway and tailrace of Ice Harbor Dam, 2002. Shaded cells indicate significant differences in passage timing among tests (P <0.05).

	Daytime			Nighttime		
Release date	χ^2	Degrees of freedom	P	χ^2	Degrees of freedom	P
03 May	7.08	9	0.697	10.01	9	0.326
06 May	4.90	7	0.715	7.89	6	0.591
08 May	6.61	6	0.375	12.72	6	0.027
09 May	15.61	9	0.031	20.57	6	0.000
11 May	10.88	6	0.050	1.14	4	0.979
12 May	9.75	4	0.037	17.27	6	0.001
14 May	14.98	5	0.004	6.90	6	0.265
15 May	4.01	5	0.607	9.68	7	0.142
17 May	10.30	6	0.062	3.41	4	0.537
18 May	11.13	5	0.024	6.42	5	0.246
20 May	7.56	3	0.043	5.51	4	0.235
21 May	4.90	3	0.168	6.47	3	0.080
23 May	7.83	3	0.042	22.89	6	<0.001
24 May	13.86	5	0.004	4.84	5	0.429
29 May	3.88	4	0.461	17.52	5	0.001
30 May	5.00	5	0.449	1.63	4	0.866
01 June	7.15	3	0.036	3.83	4	0.463
02 June	3.92	3	0.278	1.14	2	0.645
04 June	0.78	2	0.999	1.42	2	0.688

Appendix Table A2. Travel time (d) distribution for groups of PIT-tagged hatchery yearling chinook salmon released into the spillway and tailrace of Ice Harbor Dam and detected by the full-flow bypass PIT-tag detector at McNary Dam, 2002.

Release date	Daytime						Nighttime					
	Spillway			Tailrace			Spillway			Tailrace		
	10%	50%	90%	10%	50%	90%	10%	50%	90%	10%	50%	90%
03 May	1.8	2.7	4.6	1.9	2.6	4.0	1.7	2.6	4.3	1.7	2.5	4.1
06 May	1.8	2.3	4.0	1.7	2.1	4.3	1.6	2.4	3.9	1.6	2.3	3.8
08 May	2.0	2.5	4.2	1.8	2.3	3.6	1.7	2.5	4.4	1.7	2.2	3.7
09 May	1.8	2.5	3.9	1.6	2.2	3.3	1.6	2.3	3.7	1.5	1.9	2.7
11 May	1.6	2.1	3.6	1.5	1.9	2.8	1.5	2.2	3.2	1.6	2.2	3.1
12 May	1.8	2.1	3.0	1.6	1.9	2.9	1.5	1.8	2.8	1.4	1.7	2.4
14 May	1.6	2.1	3.0	1.5	2.0	2.8	1.6	1.9	2.9	1.5	1.8	2.7
15 May	1.3	1.9	2.8	1.4	1.8	2.4	1.5	1.9	3.2	1.4	1.7	2.6
17 May	1.7	2.1	3.1	1.4	2.0	3.0	1.6	2.0	2.8	1.6	2.0	3.0
18 May	1.5	2.0	2.8	1.4	1.9	2.7	1.6	2.0	3.2	1.5	1.9	2.7
20 May	1.3	1.7	2.7	1.3	1.7	2.1	1.3	1.6	2.5	1.1	1.5	2.2
21 May	1.3	1.7	2.6	1.1	1.5	2.1	1.1	1.5	2.4	1.1	1.4	2.2
23 May	1.3	1.9	2.8	1.2	1.7	2.3	1.5	2.1	2.8	1.3	1.6	2.5
24 May	1.4	1.8	2.6	1.3	1.7	2.0	1.2	1.6	2.8	1.1	1.5	2.5
29 May	1.1	1.6	2.6	1.1	1.6	2.2	1.1	1.6	3.0	1.2	1.5	1.7
30 May	1.2	1.8	3.7	1.1	1.7	2.6	1.1	1.6	2.6	1.0	1.5	2.5
01 June	1.1	1.7	2.0	1.1	1.5	1.9	1.0	1.5	1.7	1.1	1.4	2.1
02 June	1.0	1.6	2.1	1.0	1.4	1.8	1.0	1.3	2.1	0.9	1.3	1.9
04 June	1.1	1.6	1.8	1.0	1.7	2.1	1.0	1.3	1.7	1.0	1.5	1.7
Overall	1.5	2.0	3.1	1.3	1.9	2.9	1.4	1.9	3.2	1.3	1.7	2.8

Appendix Table A3. Test of homogeneity of John Day Dam passage distributions for groups of PIT-tagged hatchery yearling chinook salmon released into the spillway and tailrace of Ice Harbor Dam, 2002. Shaded cells indicate significant differences in passage timing among tests (P <0.05).

	Daytime			Nighttime		
Release date	χ^2	Degrees of freedom	P	χ^2	Degrees of freedom	P
03 May	7.73	10	0.715	8.90	11	0.699
06 May	8.67	8	0.373	8.57	8	0.377
08 May	13.95	7	0.031	13.22	9	0.104
09 May	8.51	6	0.183	7.03	8	0.587
11 May	4.54	5	0.520	8.20	6	0.187
12 May	14.82	6	0.008	2.69	4	0.776
14 May	10.30	5	0.036	7.37	6	0.268
15 May	3.69	6	0.834	8.77	5	0.063
17 May	1.80	4	0.788	6.57	5	0.246
18 May	7.78	6	0.240	7.41	5	0.172
20 May	3.40	5	0.735	4.73	4	0.344
21 May	6.17	5	0.288	10.00	4	0.026
23 May	1.07	3	0.859	6.51	6	0.338
24 May	9.13	6	0.114	2.90	4	0.641
29 May	2.45	3	0.529	4.45	4	0.392
30 May	4.99	4	0.343	3.41	3	0.405
01 June	3.42	4	0.506	6.67	3	0.062
02 June	2.81	3	0.431	10.11	3	0.011
04 June	2.02	4	0.999	4.67	3	0.160

Appendix Table A4. Test of homogeneity of Bonneville Dam passage distributions for groups of PIT-tagged hatchery yearling chinook salmon released into the spillway and tailrace of Ice Harbor Dam, 2002. Shaded cells indicate significant differences in passage timing among tests (P <0.05).

	Daytime			Nighttime		
Release date	χ^2	Degrees of freedom	P	χ^2	Degrees of freedom	P
03 May	9.60	10	0.509	10.81	9	0.269
06 May	12.87	8	0.075	5.72	7	0.702
08 May	4.60	5	0.517	4.52	7	0.801
09 May	8.05	8	0.467	5.55	8	0.781
11 May	3.16	5	0.789	5.90	6	0.444
12 May	4.06	5	0.581	4.31	5	0.564
14 May	6.12	6	0.449	3.87	3	0.309
15 May	7.67	5	0.132	8.83	5	0.073
17 May	4.12	6	0.767	3.80	5	0.662
18 May	4.22	4	0.415	1.27	3	0.781
20 May	2.02	4	0.802	3.06	4	0.602
21 May	5.33	4	0.239	4.38	4	0.337
23 May	4.68	5	0.511	7.86	6	0.220
24 May	3.02	4	0.647	3.88	5	0.659
29 May	6.36	4	0.156	1.18	3	0.871
30 May	8.22	3	0.027	1.77	4	0.894
01 June	5.26	5	0.486	1.21	3	0.782
02 June	4.32	5	0.546	2.22	3	0.599
04 June	0.99	3	0.928	3.13	3	0.357

PIT-tagged Hatchery Subyearling Chinook Salmon

Mixing tests for PIT-tagged hatchery subyearling chinook salmon passing McNary Dam resulted in 19 of 25 tests with *P* values <0.05, with many highly significant differences (*P* <0.001; Appendix Table A5). The reason for lack of mixing was the same as detailed for PIT-tagged yearling chinook salmon, but was more pronounced. Passage distributions were spread over a period as long as 3 weeks, but with most fish passing in 4-5 d (Appendix Figures D15-B33). Tailrace releases were somewhat faster than spillway releases in getting to the dam (median travel time 2.1 vs. 2.9 d, respectively, for daytime releases; 2.4 vs. 2.6 d for nighttime releases) with quite protracted distributions in some cases (the difference in 90th percentile passage was 2.1 d for daytime and 0.8 d for nighttime releases; Appendix Table A6).

Tests of mixing at John Day and Bonneville Dams produced 9 and 7 results, respectively (of 25 tests each) with *P*-values <0.05 (Appendix Tables A7-A8). Passage distributions and lack of mixing were similar to those at McNary Dam. We are unsure of the level and direction of bias in the relative survival estimates that may have occurred due to lack of mixing. However, we did not see any strong trends in survival estimates through time; thus a meaningful biological impact due to lack of mixing was not likely.

The results of Test 2C.2 had *P*-values <0.05 in 7 of 26 tests for daytime spillway and tailrace releases, indicating a violation of the assumption that PIT-tag detection history at McNary Dam did not affect detection at downstream sites. Similar to the spring work, these violations were likely caused by detection systems selecting for smaller fish and a positive, albeit weaker, relationship between fish length at tagging and survival probabilities (i.e., larger fish generally have greater survival probabilities; Zabel et al. in review). Tests for night-released fish had *P*-values <0.05 in 3 of 25 tests, also indicating a violation of the assumption.

The results of Test 3.Sr3 had *P*-values <0.05 in only 2 of 24 calculable tests for daytime and nighttime releases, indicating no violation of the assumption that PIT-tag detection does not affect the probability of subsequent detection or survival.

Appendix Table A5. Tests of homogeneity of McNary Dam passage distributions for groups of PIT-tagged hatchery subyearling chinook salmon released into the spillway and tailrace of Ice Harbor Dam. Shaded cells indicate significant differences in passage timing among tests ($\alpha = 0.05$).

Release date	Release time	χ^2	Degrees of freedom	P
28-Jun	Day	24.07	18	0.114
	Night	19.05	17	0.326
29-Jun	Day	28.72	15	0.006
	Night	14.17	14	0.448
30-Jun	Day	24.35	17	0.065
	Night	20.52	11	0.020
1-Jul	Day	49.99	15	<0.001
	Night	17.12	9	0.028
2-Jul	Day	40.15	12	<0.001
	Night	23.96	10	0.002
3-Jul	Day	83.53	14	<0.001
	Night	37.79	11	<0.001
4-Jul	Day	111.20	16	<0.001
	Night	60.46	11	<0.001
5-Jul	Day	199.80	17	<0.001
	Night	61.55	12	<0.001
6-Jul	Day	130.50	13	<0.001
	Night	55.89	13	<0.001
7-Jul	Day	155.80	11	<0.001
	Night	NA		
8-Jul	Day	100.90	11	<0.001
	Night	41.79	9	<0.001
9-Jul	Day	68.50	9	<0.001
	Night	11.45	7	0.089
10-Jul	Day	11.80	9	0.201
	Night	18.49	9	0.011

Appendix Table A6. Travel time (days) distribution for groups of PIT-tagged hatchery subyearling chinook salmon released into the spillway and tailrace of Ice Harbor Dam and detected at McNary Dam, 2002.

Release date	Daytime releases						Nighttime releases					
	Spillway			Tailrace			Spillway			Tailrace		
	10%	50%	90%	10%	50%	90%	10%	50%	90%	10%	50%	90%
28 June	1.7	2.9	9.1	1.7	2.7	8.7	1.6	3.2	10.5	1.5	2.5	8.9
29 June	1.6	3.5	9.7	1.2	2.0	6.6	1.4	3.4	9.7	1.3	2.6	6.9
30 June	1.8	3.2	9.0	1.6	2.3	6.9	1.5	2.7	6.1	1.2	2.0	5.5
01 July	1.8	3.6	9.7	1.1	2.0	5.3	1.5	2.4	5.1	1.4	1.7	5.2
02 July	1.7	2.8	6.7	1.2	1.9	3.9	1.5	2.3	4.6	1.5	2.0	3.9
03 July	2.0	3.0	6.1	1.3	1.9	5.1	2.0	2.7	4.6	1.8	2.4	3.7
04 July	1.8	3.0	6.3	1.4	2.1	3.8	2.0	2.7	4.6	1.7	2.4	3.7
05 July	2.3	3.6	6.7	1.6	2.3	3.8	2.2	3.1	4.9	1.8	2.6	4.2
06 July	2.0	3.0	5.2	1.7	2.3	3.6	2.1	2.7	4.5	1.9	2.4	3.6
07 July	1.9	2.7	4.7	1.4	1.9	3.1						
08 July	1.8	2.7	4.7	1.4	2.1	3.3	2.1	2.6	4.3	1.9	2.4	3.7
09 July	1.7	2.7	4.9	1.4	1.9	3.3	1.7	2.4	4.2	1.6	2.3	3.8
10 July	1.5	2.2	3.6	1.6	2.5	4.0	1.6	2.2	3.4	1.7	2.4	4.4
Overall	1.8	2.9	6.0	1.4	2.1	3.9	1.8	2.6	4.9	1.6	2.4	4.1

Appendix Table A7. Tests of homogeneity of John Day Dam passage distributions for groups of PIT-tagged hatchery subyearling chinook salmon released into the spillway and tailrace of Ice Harbor Dam. Shaded cells indicate significant differences in passage timing among tests ($\alpha = 0.05$).

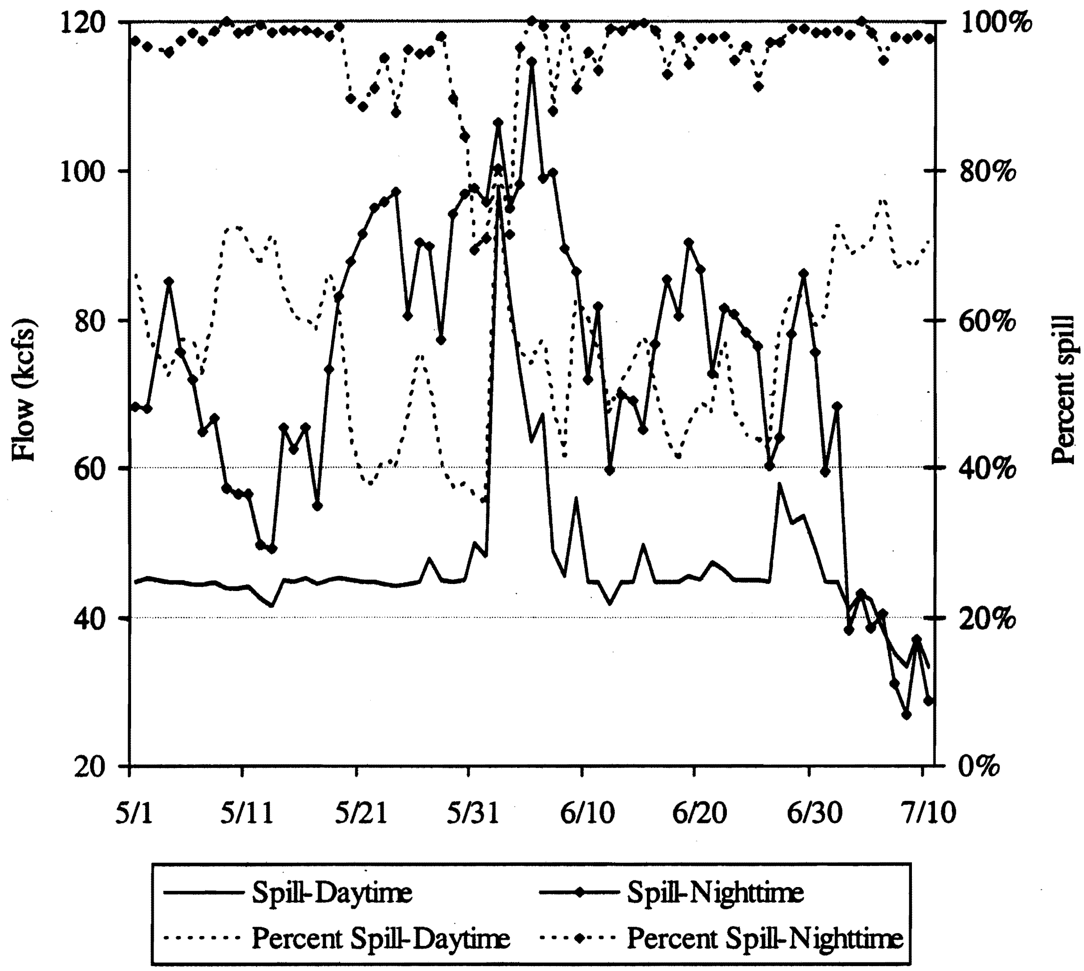
Release date	Release time	χ^2	Degrees of freedom	P
28-Jun	Day	20.89	13	0.055
	Night	13.79	17	0.682
29-Jun	Day	21.44	14	0.048
	Night	12.96	14	0.613
30-Jun	Day	10.48	11	0.531
	Night	20.46	15	0.106
1-Jul	Day	14.36	10	0.115
	Night	7.88	9	0.608
2-Jul	Day	30.65	13	0.001
	Night	9.55	10	0.507
3-Jul	Day	39.28	12	<0.001
	Night	20.43	12	0.026
4-Jul	Day	26.83	12	0.002
	Night	11.45	9	0.222
5-Jul	Day	36.52	14	0.001
	Night	15.14	7	0.020
6-Jul	Day	16.99	9	0.024
	Night	10.31	7	0.147
7-Jul	Day	34.08	8	<0.001
	Night			
8-Jul	Day	32.89	7	<0.001
	Night	5.92	5	0.325
9-Jul	Day	10.35	5	0.059
	Night	7.93	6	0.237
10-Jul	Day	13.50	9	0.090
	Night	8.10	5	0.145

Appendix Table A8. Tests of homogeneity of Bonneville Dam passage distributions for groups of PIT-tagged hatchery subyearling chinook salmon released into the spillway and tailrace of Ice Harbor Dam. Shaded cells indicate significant differences in passage timing among tests ($\alpha = 0.05$).

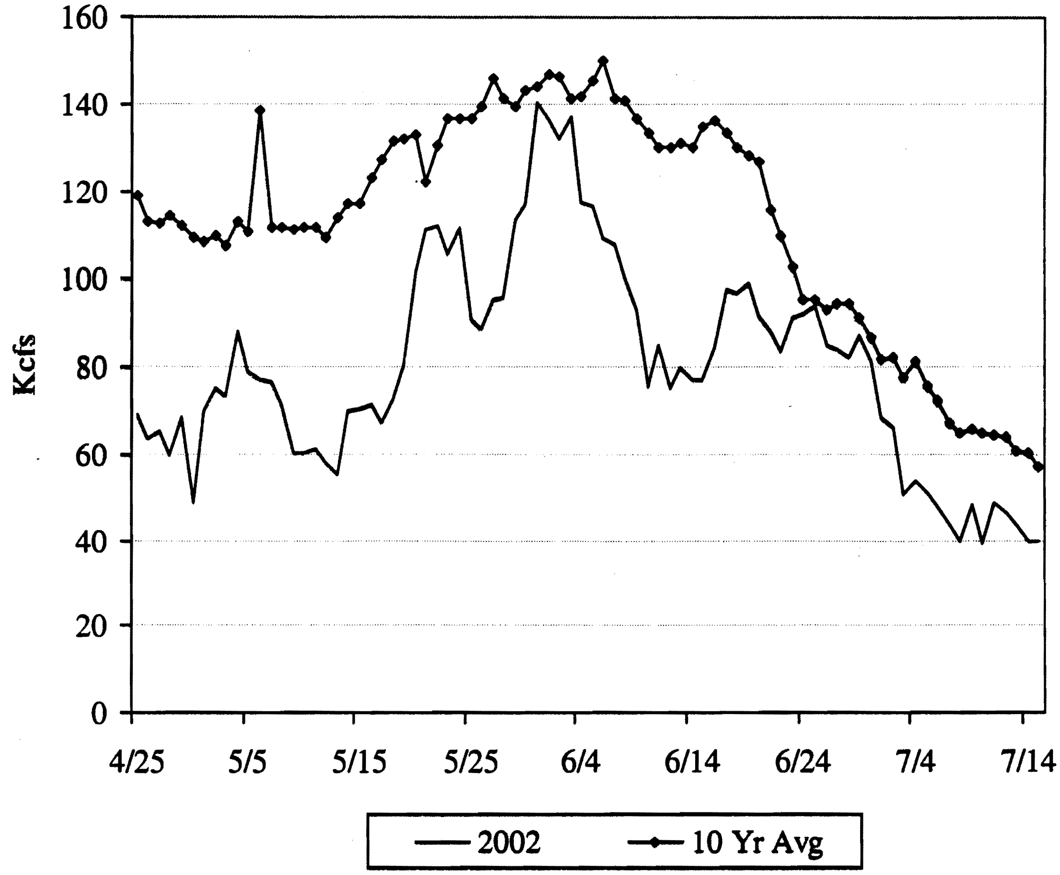
Release date	Release time	χ^2	Degrees of freedom	P
28-Jun	Day	16.30	14	0.282
	Night	17.07	17	0.477
29-Jun	Day	13.28	11	0.252
	Night	13.43	11	0.231
30-Jun	Day	11.88	12	0.487
	Night	17.29	11	0.054
1-Jul	Day	30.52	12	0.001
	Night	9.58	10	0.506
2-Jul	Day	21.50	12	0.018
	Night	16.56	11	0.064
3-Jul	Day	27.92	10	0.001
	Night	10.07	10	0.433
4-Jul	Day	29.73	11	0.001
	Night	5.85	6	0.447
5-Jul	Day	21.04	11	0.011
	Night	9.39	7	0.211
6-Jul	Day	19.35	9	0.008
	Night	8.20	8	0.417
7-Jul	Day	23.19	7	0.001
	Night	NA		
8-Jul	Day	10.15	7	0.168
	Night	6.35	5	0.281
9-Jul	Day	5.35	6	0.539
	Night	3.39	5	0.694
10-Jul	Day	6.67	5	0.250
	Night	8.95	5	0.083

APPENDIX B:

Ice Harbor Dam Operations



Appendix Figure B1. Spill operations at Ice Harbor Dam during the hatchery yearling and subyearling spillway passage survival study, 2002.



Appendix Figure B2. Daily average total river flows at Ice Harbor Dam during the 2002 spillway passage survival evaluation and the 10-year average (1992-2001) over the same time period.

Appendix Table B1. Ice Harbor Dam operations and discharge conditions during daytime releases of radio- and PIT-tagged hatchery yearling chinook salmon, 2002 (operations data were not available for 03 May).

Release Day	Release Spillbay Bay	Gate	kcfs	Spillway (kcfs)	Powerhouse (kcfs)	Total Discharge (kcfs)	Tailwater Elevation (ft)	Water Temperature (°C)
03 May	7							10.8
06 May	7	3.0	5.1	44.3	29.1	73.5	343.7	10.8
08 May	2	3.0	5.2	45.0	34.4	79.4	344.2	10.8
09 May	4	3.0	5.2	45.2	20.2	65.4	342.6	10.8
11 May	6	3.0	5.1	44.8	22.6	67.4	343.1	11.2
12 May	10	2.0	3.5	45.1	26.2	71.3	342.9	11.5
14 May	1	2.0	3.5	44.9	29.8	74.7	343.6	11.8
15 May	8	2.1	3.6	44.7	22.5	67.2	343.3	11.8
17 May	3	3.0	5.1	44.5	32.4	76.9	344.0	11.8
18 May	5	3.1	5.2	45.0	22.5	67.5	342.9	11.9
20 May	7	3.1	5.3	45.0	69.6	114.6	347.0	11.6
21 May	9	2.0	3.5	44.9	76.1	120.9	347.7	11.5
23 May	2	3.0	5.2	44.6	50.8	95.3	345.7	12.2
24 May	4	3.0	5.1	44.4	63.2	107.6	346.7	12.2
29 May	6	3.0	5.1	44.7	71.9	116.6	347.6	12.2
30 May	8	2.3	4.0	44.9	79.1	124.0	348.0	11.7
01 June	10	2.1	3.5	48.6	88.4	137.0	349.1	12.6
02 June	1	2.0	3.4	98.0	31.4	129.3	347.5	13.1
04 June	9	3.1	5.2	58.1	49.4	107.5	347.5	14.0

Appendix Table B2. Ice Harbor Dam operations and discharge conditions during nighttime releases of PIT- and radio-tagged hatchery yearling chinook salmon, 2002 (operations data were not available for 03 May).

Release Day	Release Spillbay Bay	Gate	kcfs	Spillway (kcfs)	Powerhouse (kcfs)	Total Discharge (kcfs)	Tailwater Elevation (ft)	Water Temperature (°C)
06 May	7	4.0	6.8	59.9	0.0	59.9	342.2	10.7
08 May	2	3.8	6.5	48.6	0.0	48.6	341.2	10.6
09 May	4	4.9	8.3	72.6	0.0	72.6	342.8	10.7
11 May	6	3.8	6.5	59.0	0.0	59.0	341.8	11.2
12 May	10	2.0	3.5	50.1	0.0	50.1	341.3	11.4
14 May	1	2.0	3.5	69.8	0.0	69.8	342.9	11.8
15 May	8	5.1	8.6	75.5	0.0	75.5	342.9	11.7
17 May	3	5.0	8.5	75.0	0.0	75.0	342.9	11.7
18 May	5	6.1	10.2	90.6	0.0	90.6	344.2	11.8
20 May	7	7.1	12.0	101.9	10.1	112.0	346.1	11.6
21 May	9	7.0	11.8	101.7	0.0	101.7	345.1	11.6
23 May	2	7.1	11.9	101.6	0.0	101.6	345.0	12.2
24 May	4	7.0	11.8	97.3	4.4	101.7	345.7	12.4
29 May	6	7.0	11.7	101.8	3.3	105.1	345.8	11.9
30 May	8	7.0	11.8	102.1	32.1	134.2	347.8	11.7
01 June	10	2.0	3.4	114.1	24.0	138.1	348.2	12.7
02 June	1	2.0	3.4	97.5	31.6	129.1	347.5	13.2
04 June	9	8.0	13.5	119.0	0.0	119.0	346.7	13.8

Appendix Table B3. Ice Harbor Dam operations and discharge conditions during daytime releases of PIT-tagged hatchery subyearling chinook salmon, 2002.

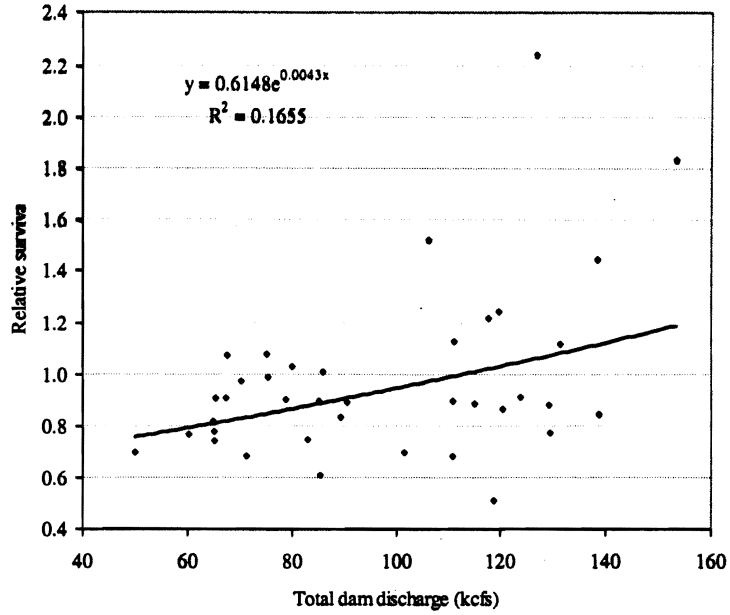
	Release spillbay							
Release Day	Bay	Gate	kcfs	Spillway (kcfs)	Powerhouse (kcfs)	Total discharge (kcfs)	Tailrace elevation (ft)	Water temperature (°C)
28 June	4	3.0	5.2	44.9	42.7	87.6	345.7	16.2
29 June	6	3.0	5.1	44.7	39.8	84.5	345.0	16.3
30 June	8	2.0	3.5	45.0	46.1	91.1	345.6	16.3
01 July	10	2.1	3.5	45.0	19.1	64.1	343.9	16.4
02 July	1	2.0	3.4	44.8	22.9	67.7	343.4	16.7
02 July	2	3.0	5.1	44.8	22.9	67.7	343.4	16.7
03 July	9	2.0	3.5	44.7	29.4	74.1	344.2	16.8
03 July	7	3.0	5.1	44.7	29.4	74.1	344.2	16.8
04 July	5	3.0	5.2	45.1	32.8	77.9	344.5	17.1
04 July	3	3.0	5.2	45.1	32.9	78.0	344.5	17.1
05 July	2	3.0	5.1	45.0	23.3	68.3	343.7	17.3
05 July	10	2.0	3.4	44.8	23.0	67.8	343.5	17.3
06 July	8	2.1	3.5	45.1	12.5	57.6	342.7	17.4
06 July	6	3.1	5.2	45.1	12.5	57.6	342.4	17.4
07 July	4	3.0	5.2	45.0	23.7	68.7	343.4	17.8
07 July	3	3.1	5.2	45.0	23.7	68.7	343.4	17.9
08 July	5	3.0	5.2	45.3	27.3	72.6	343.8	18.0
08 July	7	3.1	5.3	45.3	22.4	67.7	343.6	18.0
09 July	9	2.1	3.5	45.5	39.7	85.2	344.4	18.7
10 July	1	2.2	3.8	46.1	19.4	65.5	342.8	19.1

Appendix Table B4. Ice Harbor Dam operations and discharge conditions during nighttime releases of PIT-tagged hatchery subyearling chinook salmon, 2002.

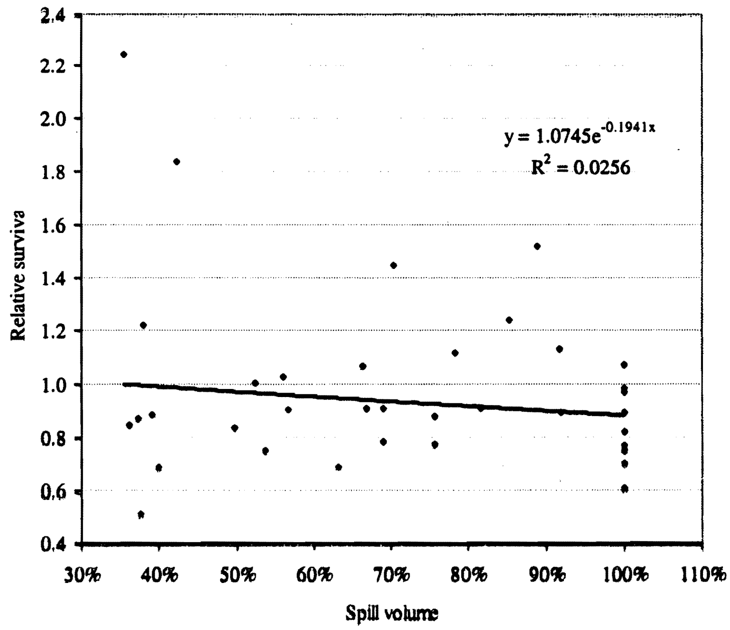
	Release Spillbay			Spillway (kcfs)	Powerhouse (kcfs)	Total Discharge (kcfs)	Tailwater Elevation (ft)	Water Temperature (°C)
	Bay	Gate	kcfs					
30 June	8	5.0	8.5	84.8	0.0	84.8	344.3	16.2
01 July	10	2.1	3.5	54.9	0.0	54.9	340.9	16.3
02 July	1	5.0	8.4	69.8	0.0	69.8	344.0	16.6
02 July	2	2.0	3.4	69.7	0.0	69.7	343.7	16.6
03 July	9	3.0	5.2	55.2	0.0	55.2	342.2	16.7
03 July	7	3.0	5.1	55.2	0.0	55.2	342.2	16.7
04 July	5	2.1	3.7	40.4	0.0	40.4	340.8	17.1
04 July	3	3.0	5.2	40.3	0.0	40.3	340.7	17.1
05 July	2	3.0	5.1	45.0	0.0	45.0	341.6	17.2
05 July	10	2.0	3.5	45.0	0.0	45.0	341.4	17.2
06 July	8	2.1	3.5	39.9	0.0	39.9	341.1	17.3
06 July	6	2.1	3.5	39.9	0.0	39.9	341.0	17.3
07 July	4	3.0	5.1	39.5	0.0	39.5	340.9	17.8
07 July	3	3.0	5.2	39.8	0.0	39.8	340.9	17.8
08 July	5	2.0	3.4	30.2	0.0	30.2	340.3	18.2
08 July	7	2.0	3.4	30.2	0.0	30.2	340.2	18.2
09 July	9	4.1	7.0	62.0	0.0	62.0	342.3	18.8
10 July	1	2.0	3.5	40.2	0.0	40.2	340.9	18.8

APPENDIX C:

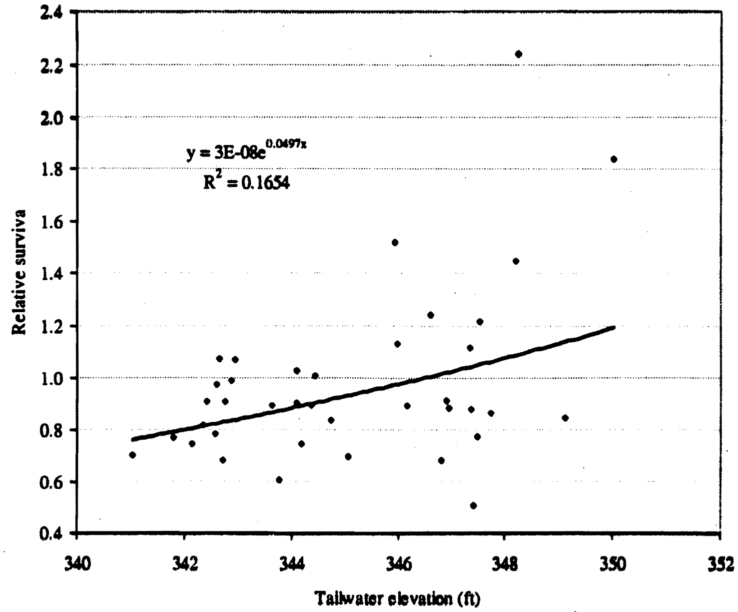
Correlations of Relative Spillway Passage Survival vs. Environmental Conditions at Time of Release



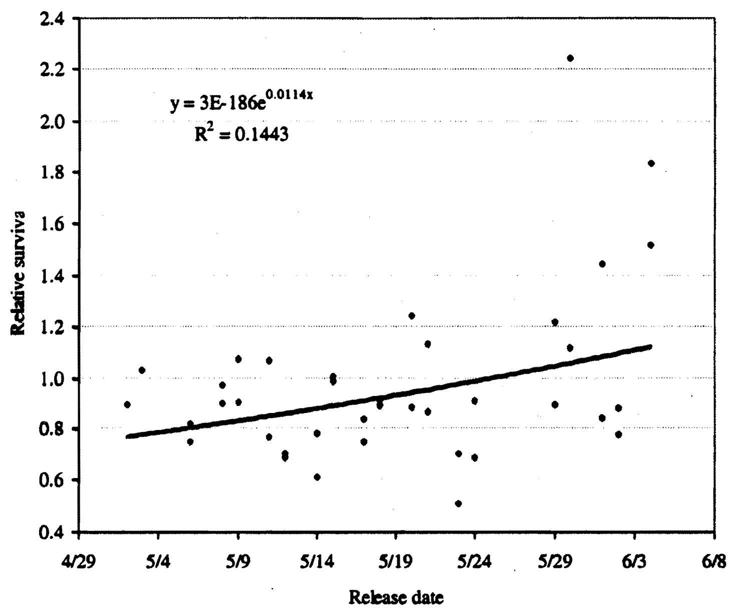
Appendix Figure C1. Estimated relative spillway survival by total dam discharge at time of release for PIT-tagged hatchery yearling chinook salmon released at Ice Harbor Dam, 2002 ($P = 0.011$)



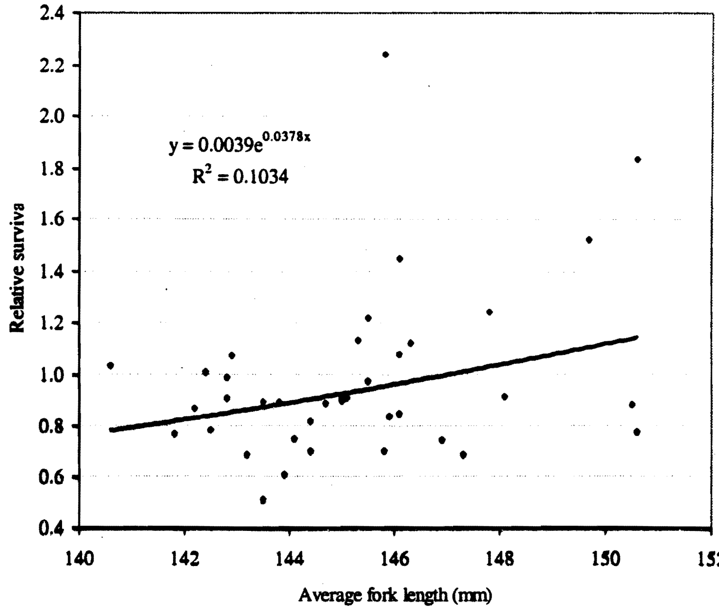
Appendix Figure C2. Estimated relative spillway survival by spill volume (presented as a percent of total dam discharge) at time of release for PIT-tagged hatchery yearling chinook salmon released at Ice Harbor Dam, 2002 ($P = 0.337$).



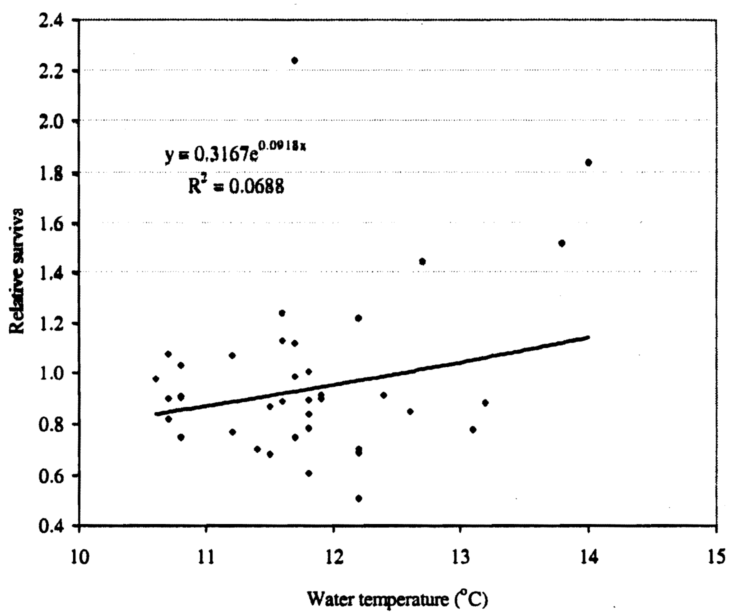
Appendix Figure C3. Estimated relative spillway survival by tailwater elevation (presented as feet above mean sea level) at time of release for PIT-tagged hatchery yearling chinook salmon released at Ice Harbor Dam, 2002 ($P = 0.011$).



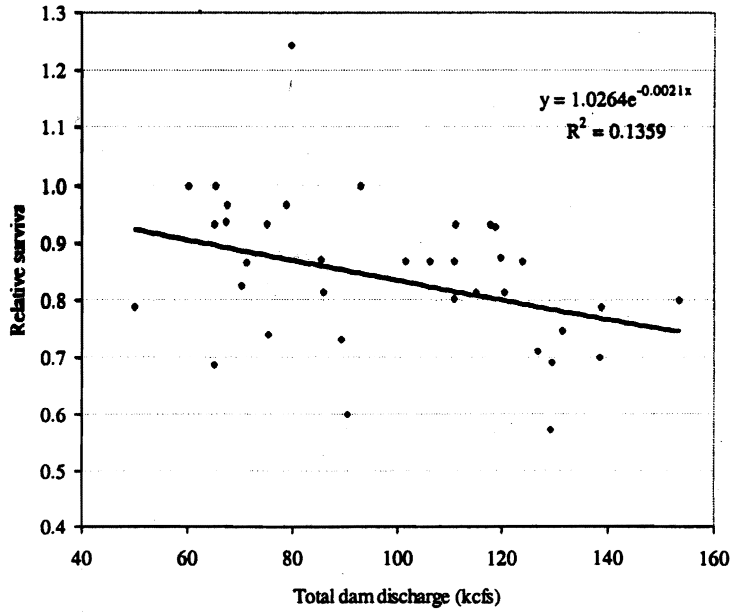
Appendix Figure C4. Estimated relative spillway survival by release date for PIT-tagged hatchery yearling chinook salmon released at Ice Harbor Dam, 2002 ($P = 0.019$).



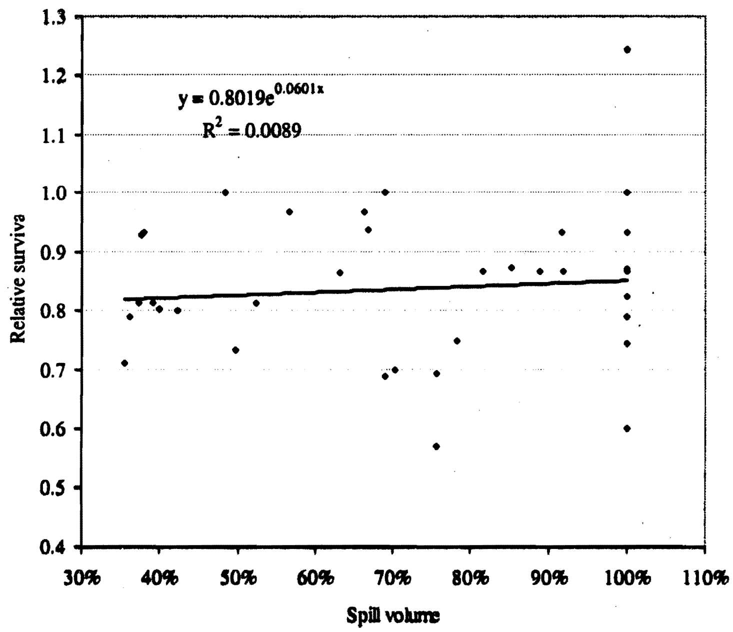
Appendix Figure C5. Estimated relative spillway survival by average fork length (mm) at tagging for PIT-tagged hatchery yearling chinook salmon released at Ice Harbor Dam, 2002 ($P = 0.049$).



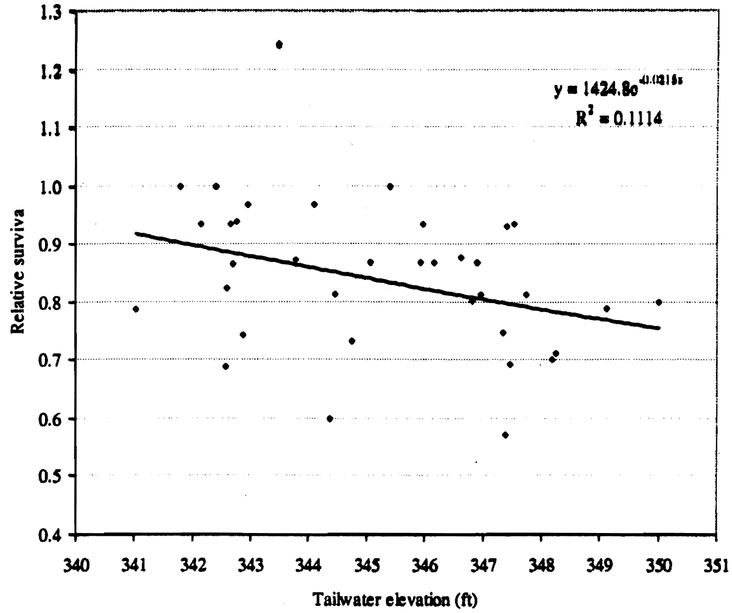
Appendix Figure C6. Estimated relative spillway survival by average water temperature (°C) at release for PIT-tagged hatchery yearling chinook salmon released at Ice Harbor Dam, 2002 ($P = 0.112$).



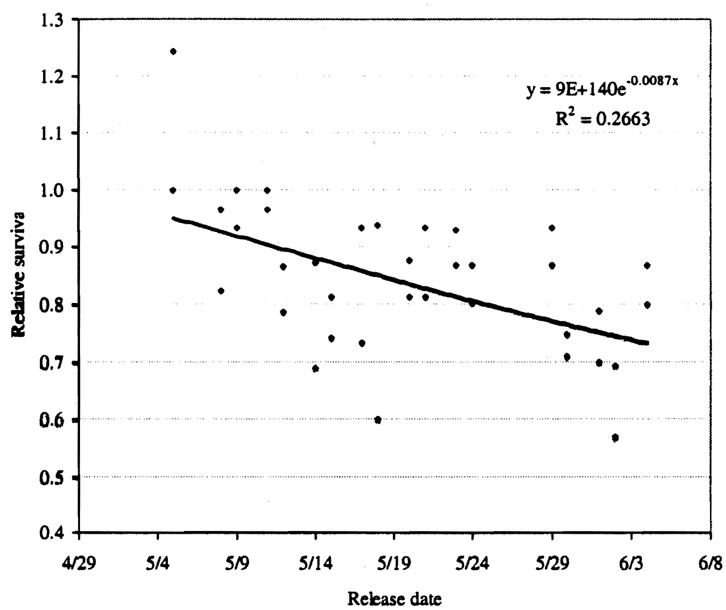
Appendix Figure C7. Estimated relative spillway survival by total dam discharge at time of release for radio-tagged hatchery yearling chinook salmon released at Ice Harbor Dam, 2002 ($P = 0.027$).



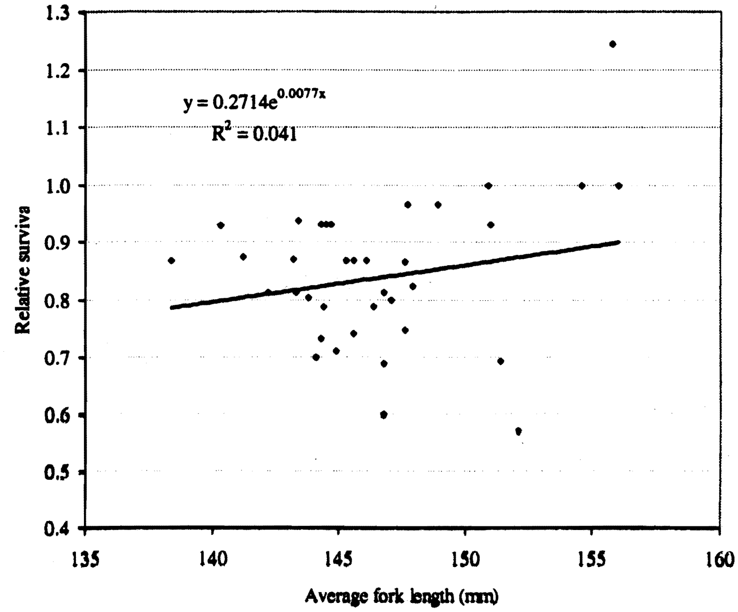
Appendix Figure C8. Estimated relative spillway survival by spill volume (presented as a percent of total dam discharge) at time of release for radio-tagged hatchery yearling chinook salmon released at Ice Harbor Dam, 2002 ($P = 0.585$).



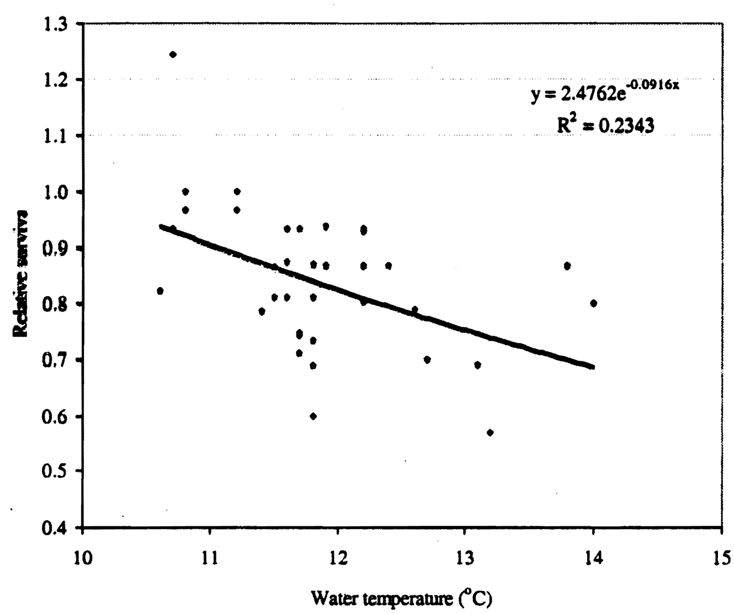
Appendix Figure C9. Estimated relative spillway survival by tailwater elevation (presented as feet above mean sea level) at time of release for radio-tagged hatchery yearling chinook salmon released at Ice Harbor Dam, 2002 ($P = 0.047$).



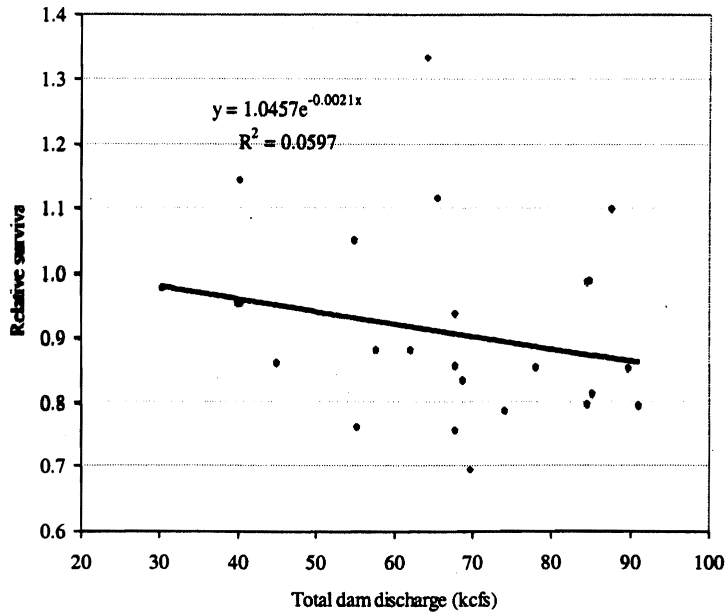
Appendix Figure C10. Estimated relative spillway survival by release date for radio-tagged hatchery yearling chinook salmon released at Ice Harbor Dam, 2002 ($P = 0.001$).



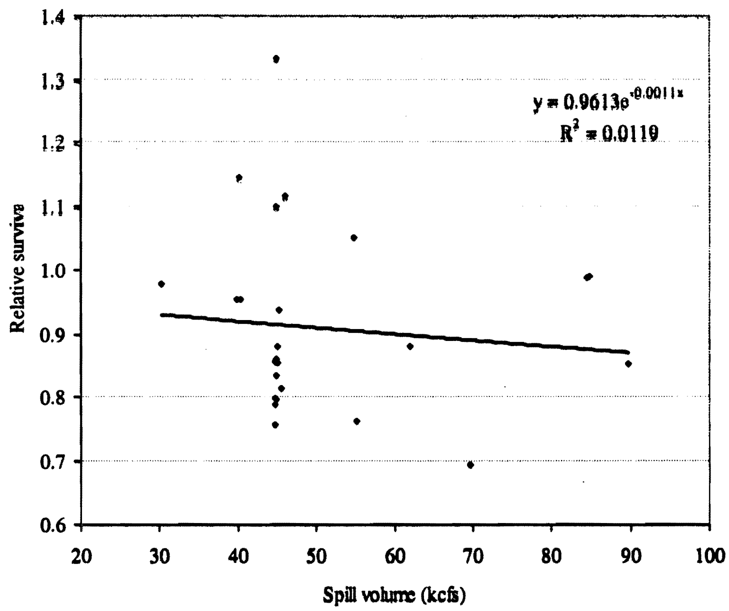
Appendix Figure C11. Estimated relative spillway survival by average fork length (mm) at tagging for radio-tagged hatchery yearling chinook salmon released at Ice Harbor Dam, 2002 ($P = 0.236$).



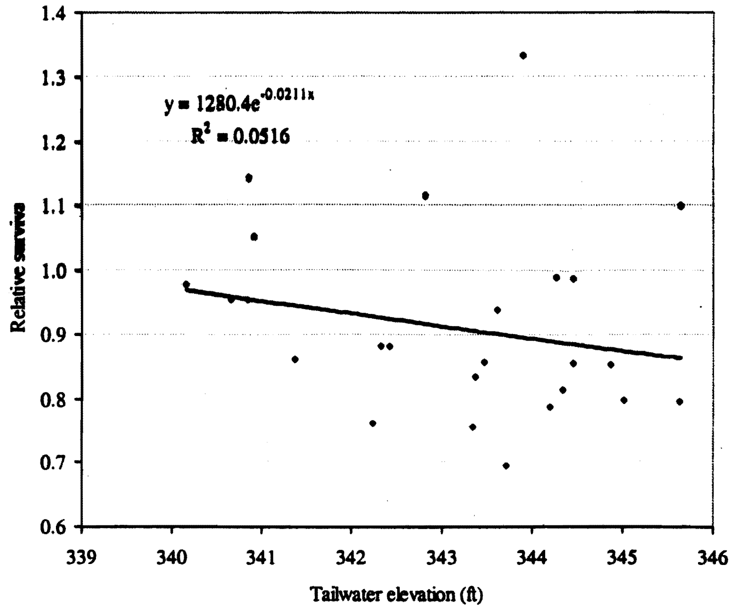
Appendix Figure C12. Estimated relative spillway survival by average water temperature (°C) at release for radio-tagged hatchery yearling chinook salmon released at Ice Harbor Dam, 2002 ($P = 0.003$).



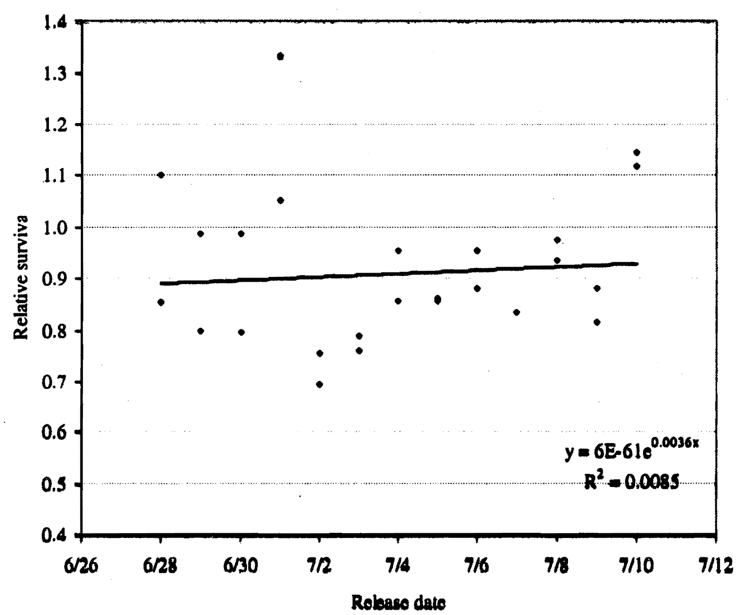
Appendix Figure C13. Estimated relative spillway survival by total dam discharge at time of release for PIT-tagged hatchery subyearling chinook salmon released at Ice Harbor Dam, 2002 ($P = 0.239$).



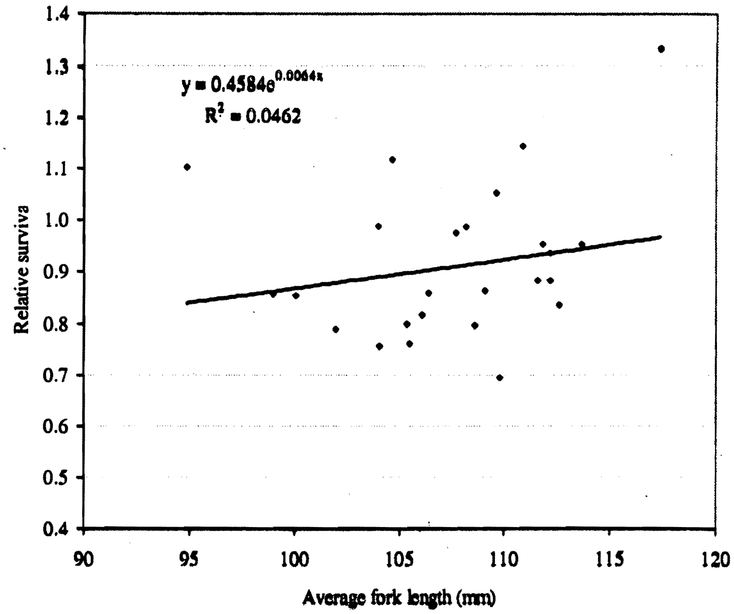
Appendix Figure C14. Estimated relative spillway survival by total spill volume at time of release for PIT-tagged hatchery subyearling chinook salmon released at Ice Harbor Dam, 2002 ($P = 0.604$).



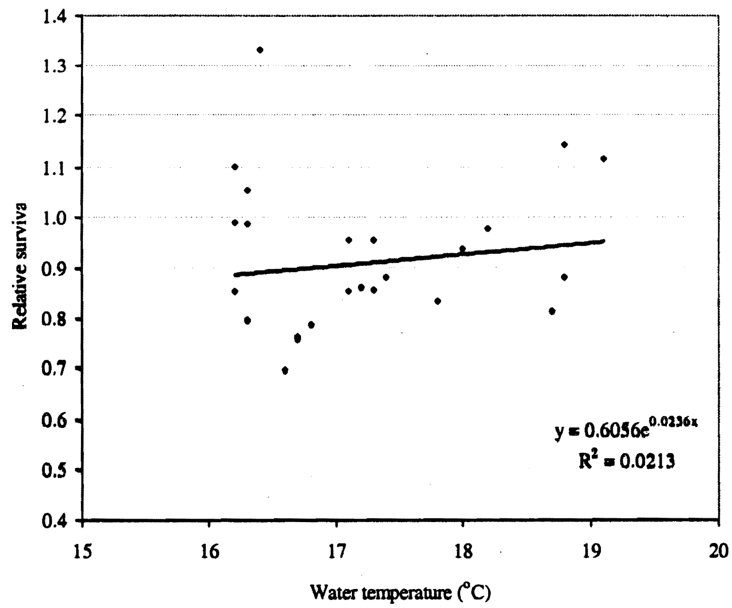
Appendix Figure C15. Estimated relative spillway survival by tailwater elevation (presented at mean feet above sea level) at time of release for PIT-tagged hatchery subyearling chinook salmon released at Ice Harbor Dam, 2002 ($P = 0.275$).



Appendix Figure C16. Estimated relative spillway survival by release date for PIT-tagged hatchery subyearling chinook salmon released at Ice Harbor Dam, 2002 ($P = 0.661$).



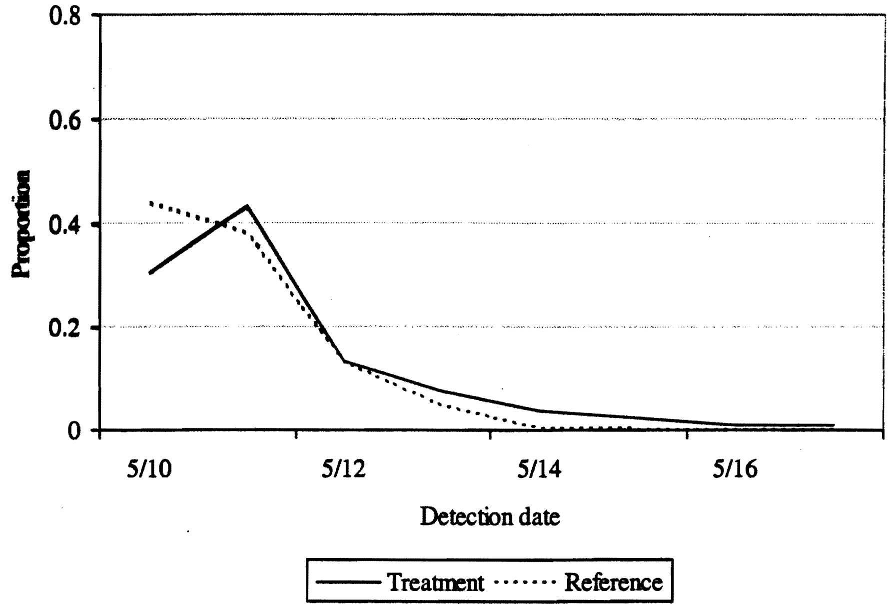
Appendix Figure C17. Estimated relative spillway survival by average fork length (mm) at tagging for PIT-tagged hatchery subyearling chinook salmon released at Ice Harbor Dam, 2002 ($P = 0.302$).



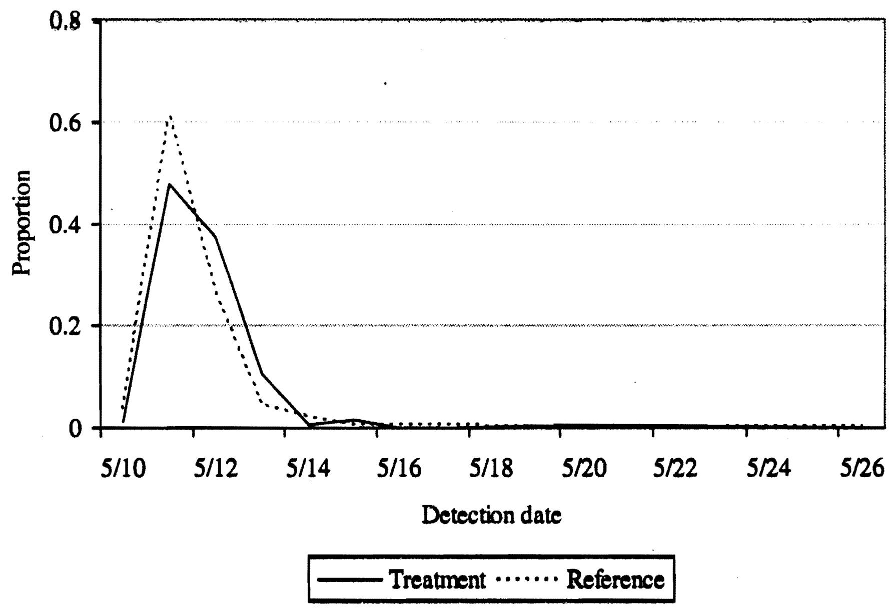
Appendix Figure C18. Estimated relative spillway survival by average water temperature (°C) at release for PIT-tagged hatchery subyearling chinook salmon released at Ice Harbor Dam, 2002 ($P = 0.487$).

APPENDIX D:

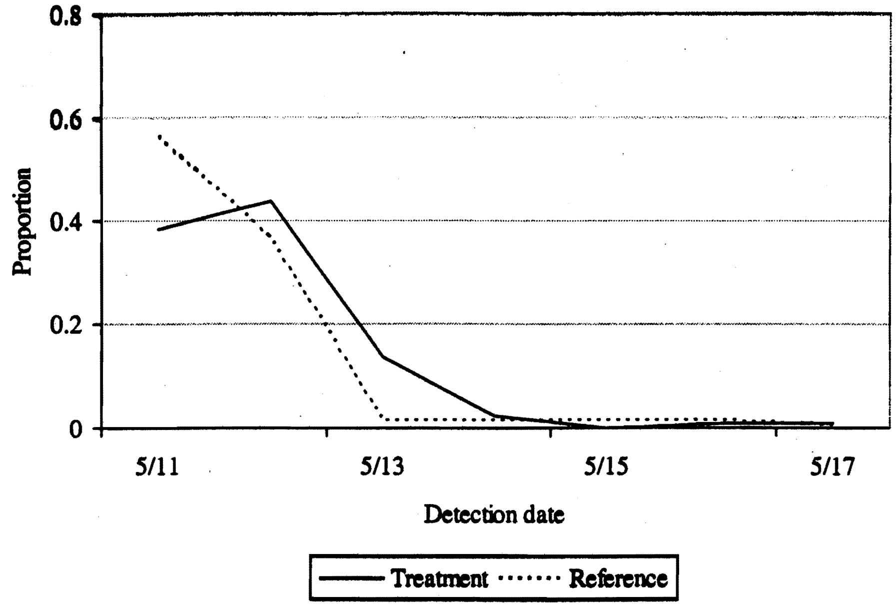
McNary Dam Passage Distributions for Release Groups with Significantly Different Passage Timing



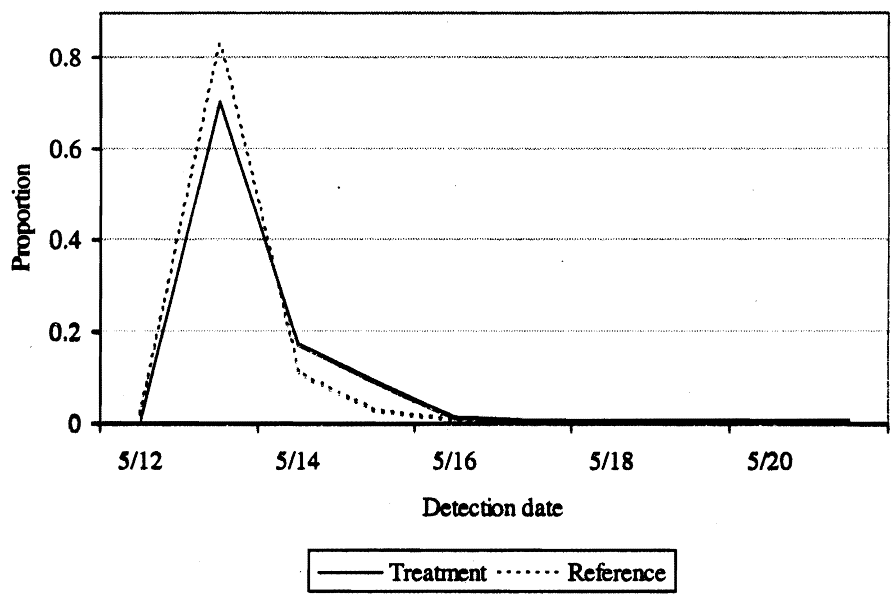
Appendix Figure D1. Passage distribution at McNary Dam for PIT-tagged hatchery yearling chinook salmon released during nighttime operations at Ice Harbor Dam on 08 May 2002.



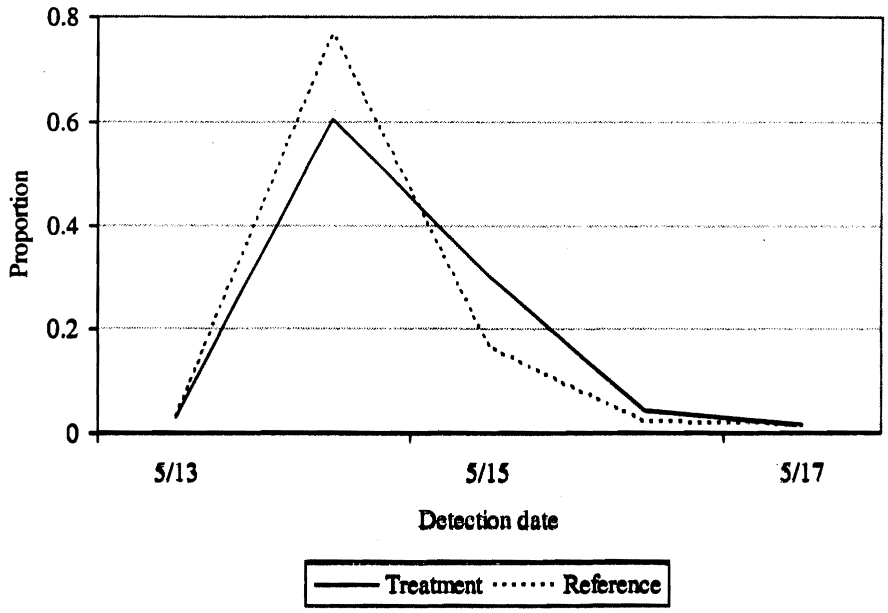
Appendix Figure D2. Passage distribution at McNary Dam for PIT-tagged hatchery yearling chinook salmon released during daytime operations at Ice Harbor Dam on 09 May 2002.



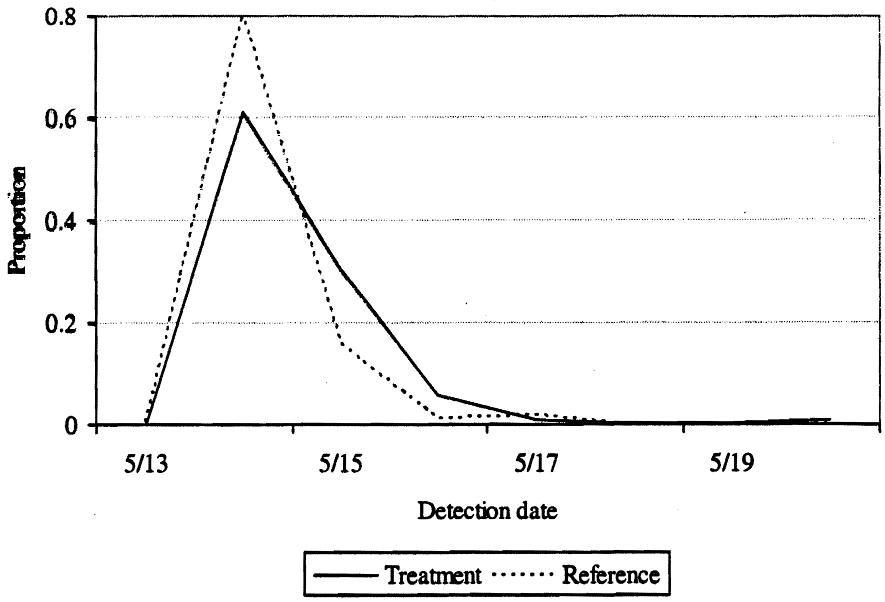
Appendix Figure D3. Passage distribution at McNary Dam for PIT-tagged hatchery yearling chinook salmon released during nighttime operations at Ice Harbor Dam on 09 May 2002.



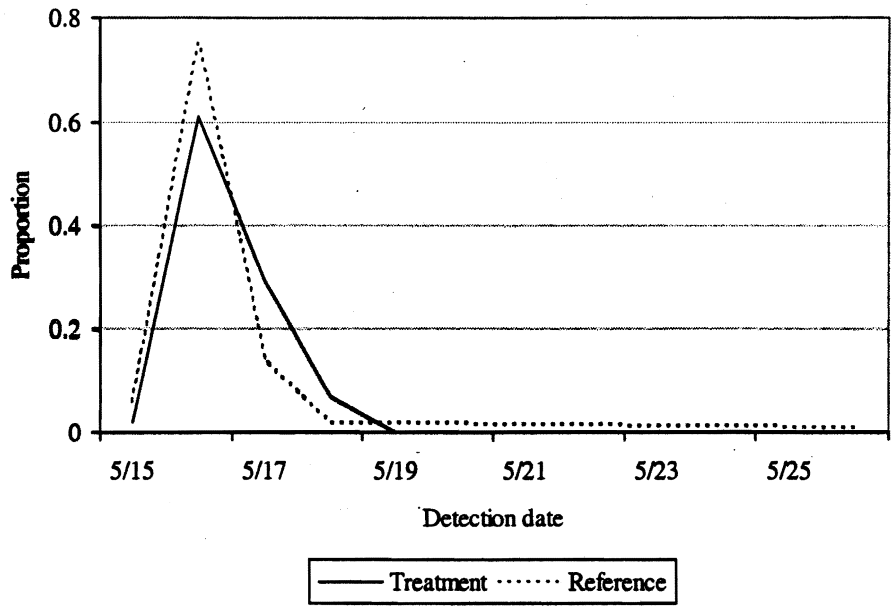
Appendix Figure D4. Passage distribution at McNary Dam for PIT-tagged hatchery yearling chinook salmon released during daytime operations at Ice Harbor Dam on 11 May 2002.



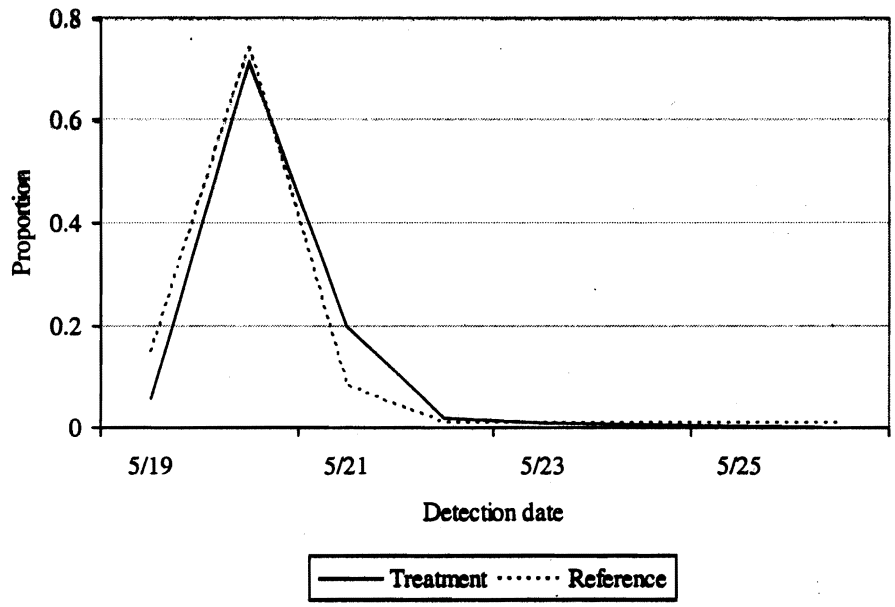
Appendix Figure D5. Passage distribution at McNary Dam for PIT-tagged hatchery yearling chinook salmon released during daytime operations at Ice Harbor Dam on 12 May 2002.



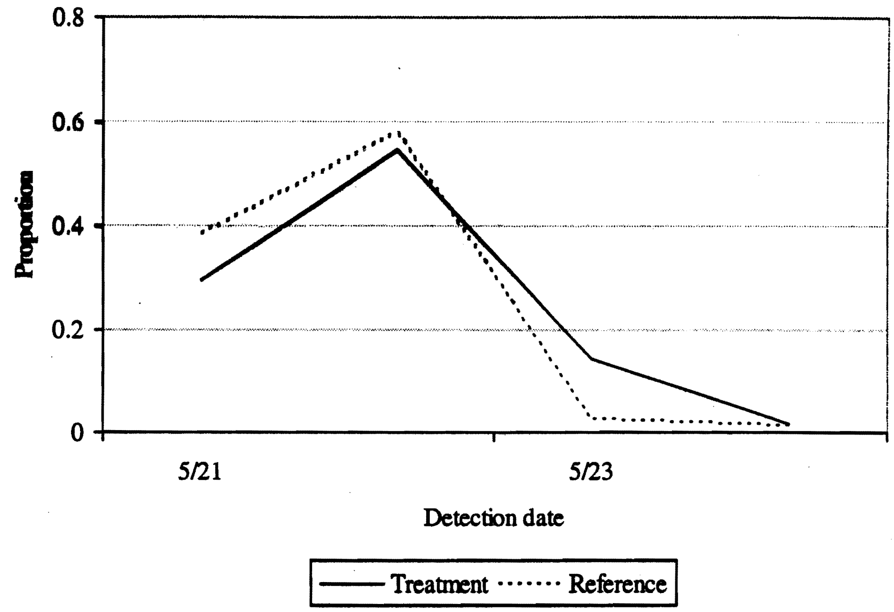
Appendix Figure D6. Passage distribution at McNary Dam for PIT-tagged hatchery yearling chinook salmon released during nighttime operations at Ice Harbor Dam on 12 May 2002.



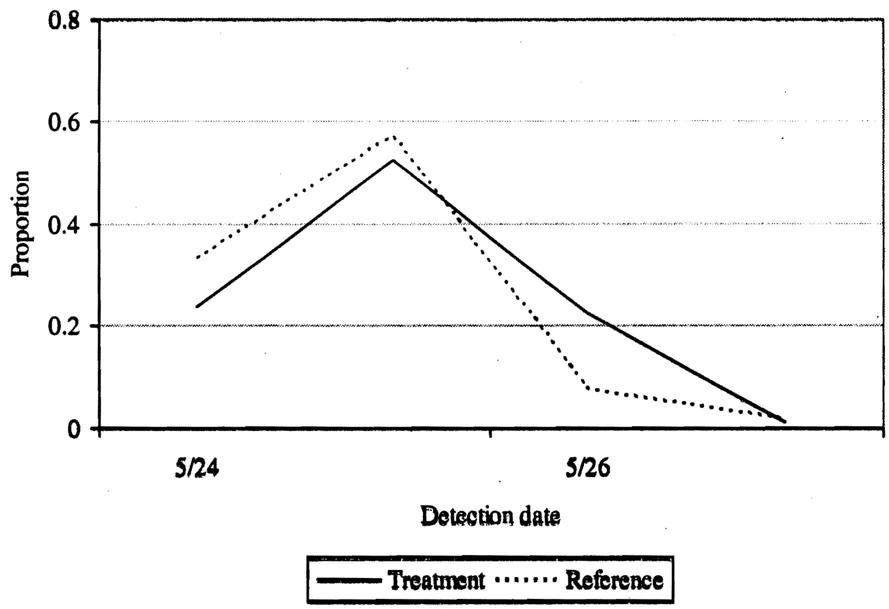
Appendix Figure D7. Passage distribution at McNary Dam for PIT-tagged hatchery yearling chinook salmon released during daytime operations at Ice Harbor Dam on 14 May 2002.



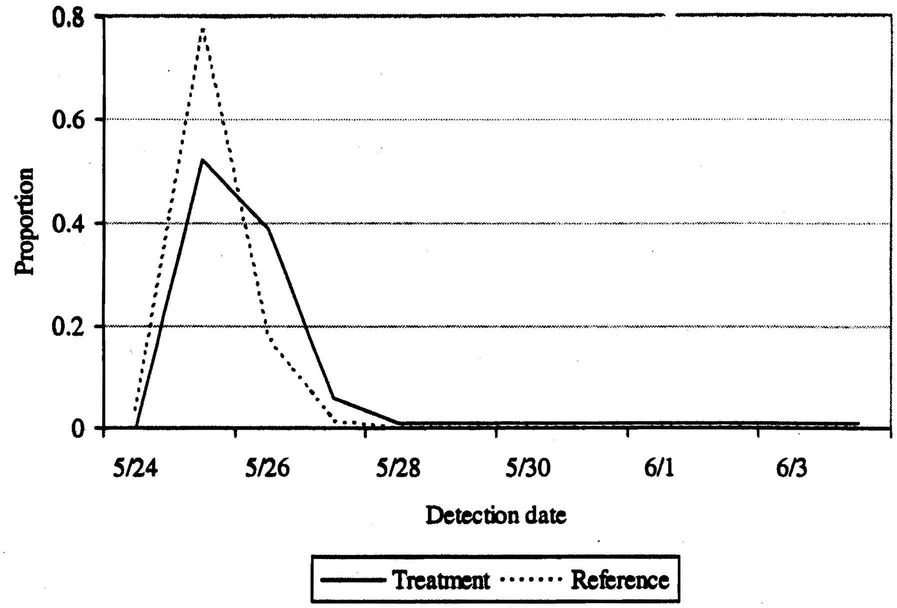
Appendix Figure D8. Passage distribution at McNary Dam for PIT-tagged hatchery yearling chinook salmon released during daytime operations at Ice Harbor Dam on 18 May 2002.



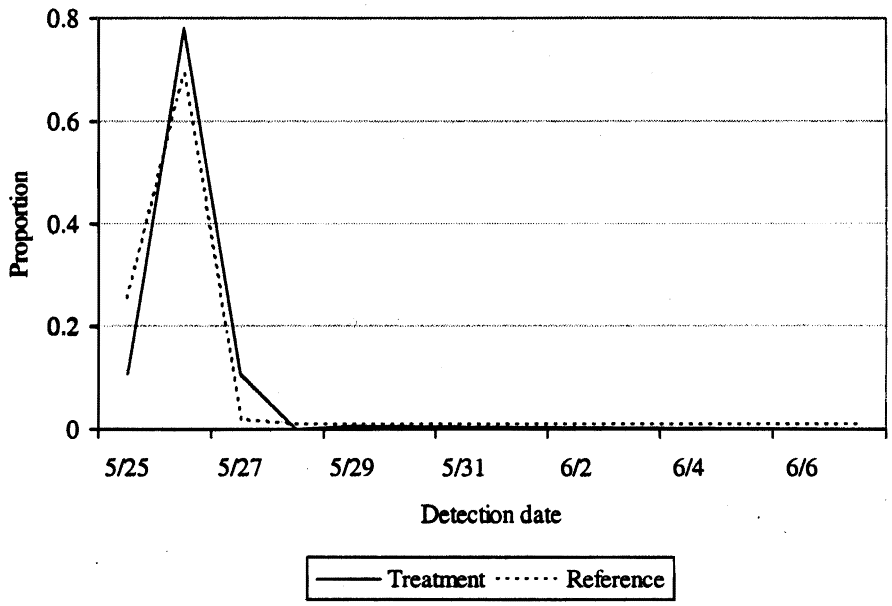
Appendix Figure D9. Passage distribution at McNary Dam for PIT-tagged hatchery yearling chinook salmon released during daytime operations at Ice Harbor Dam on 20 May 2002.



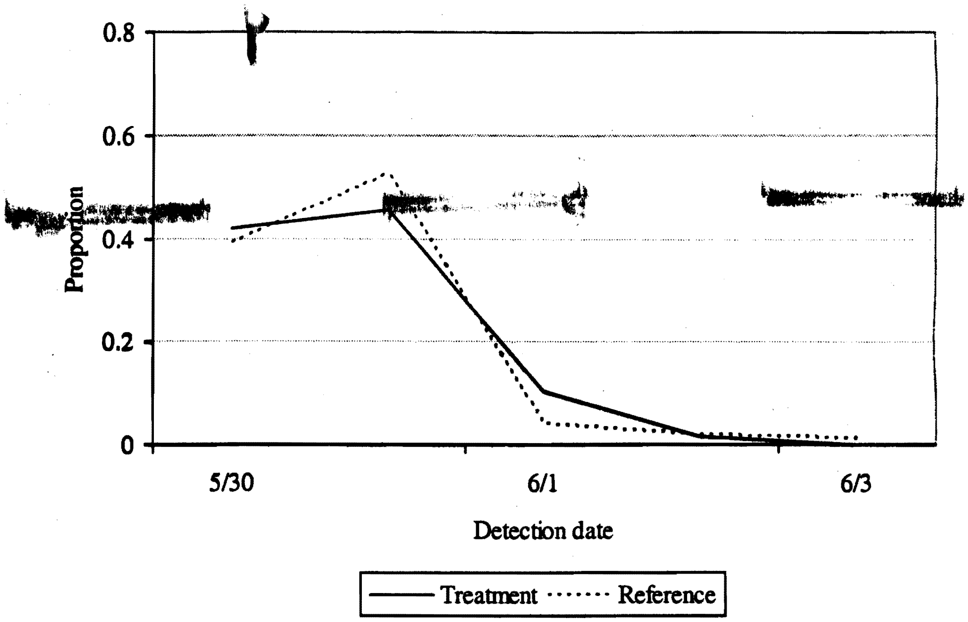
Appendix Figure D10. Passage distribution at McNary Dam for PIT-tagged hatchery yearling chinook salmon released during daytime operations at Ice Harbor Dam on 23 May 2002.



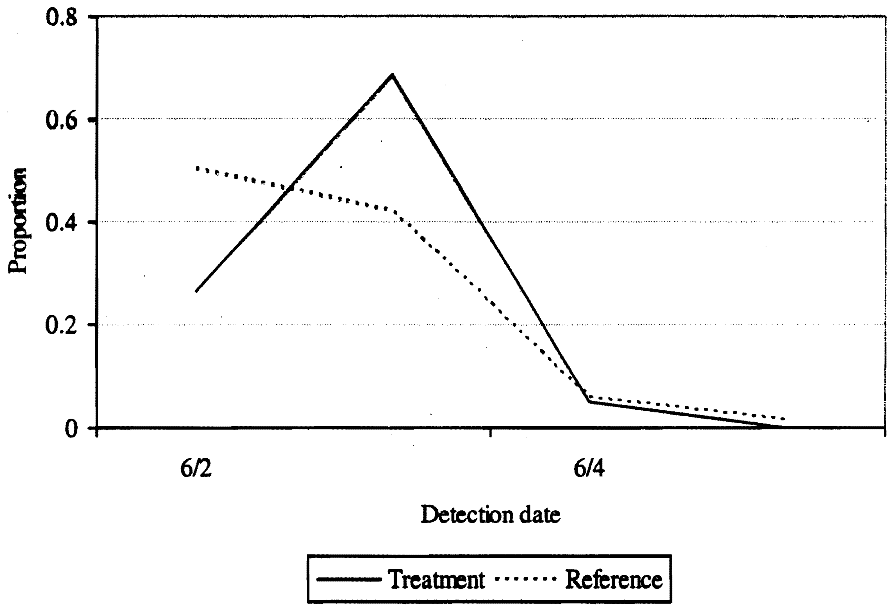
Appendix Figure D11. Passage distribution at McNary Dam for PIT-tagged hatchery yearling chinook salmon released during nighttime operations at Ice Harbor Dam on 23 May 2002.



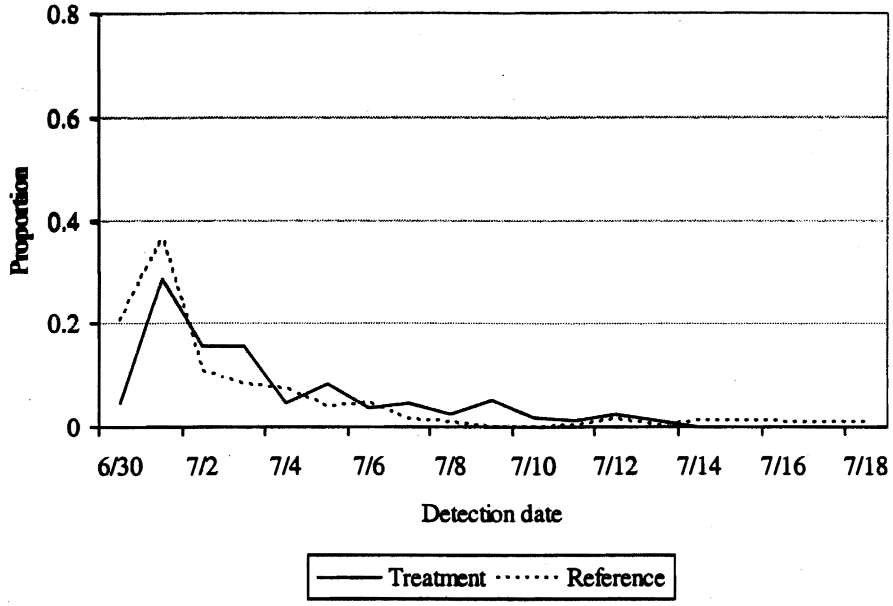
Appendix Figure D12. Passage distribution at McNary Dam for PIT-tagged hatchery yearling chinook salmon released during daytime operations at Ice Harbor Dam on 24 May 2002.



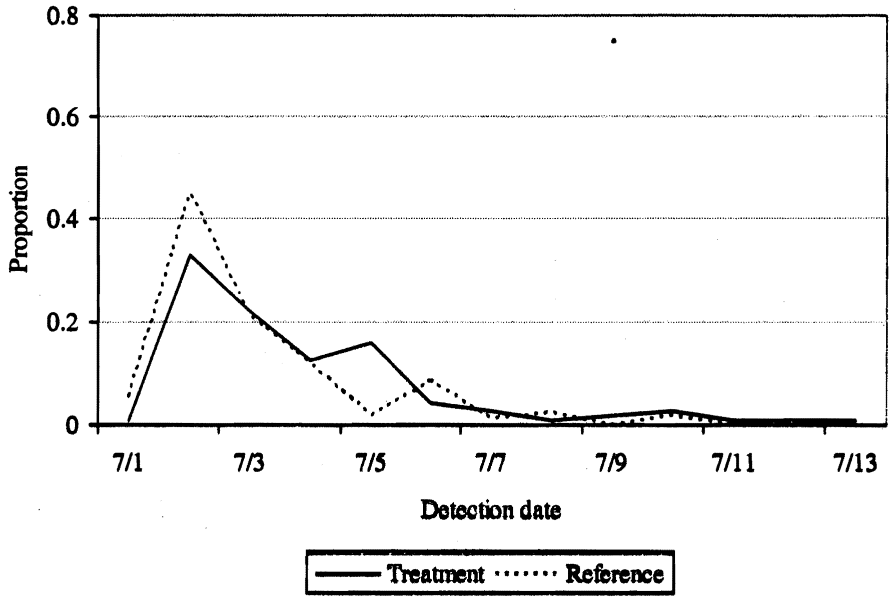
Appendix Figure D13. Passage distribution at McNary Dam for PIT-tagged hatchery yearling chinook salmon released during nighttime operations at Ice Harbor Dam on 29 May 2002.



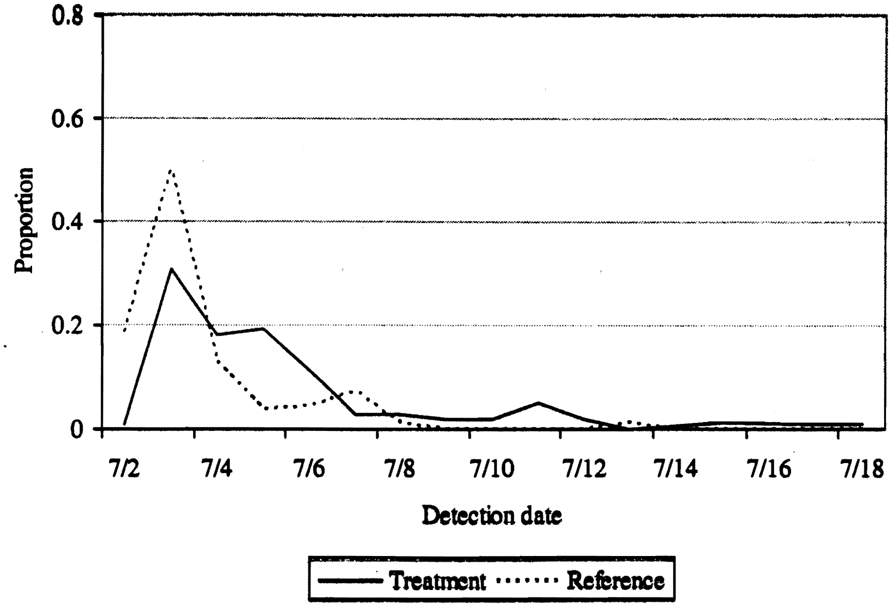
Appendix Figure D14. Passage distribution at McNary Dam for PIT-tagged hatchery yearling chinook salmon released during daytime operations at Ice Harbor Dam on 01 June 2002.



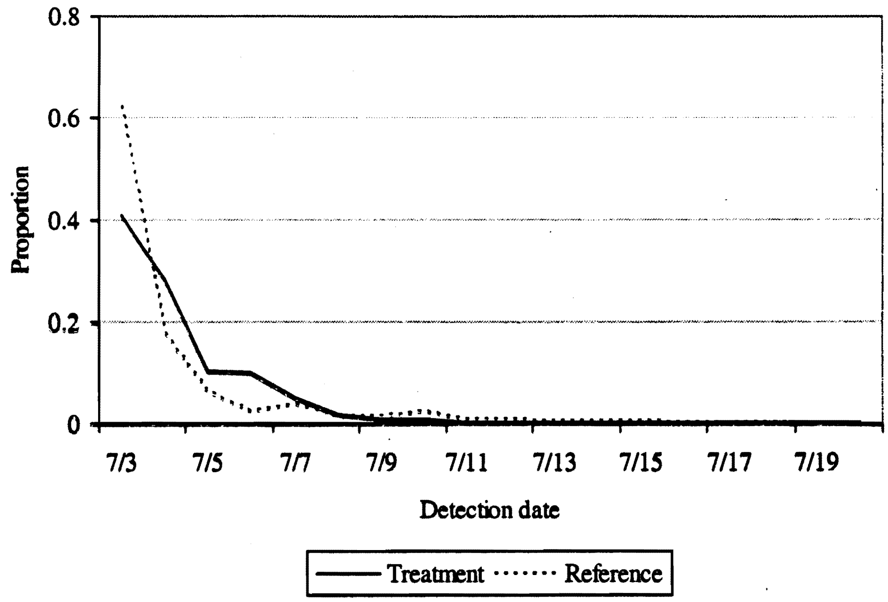
Appendix Figure D15. Passage distribution at McNary Dam for PIT-tagged hatchery subyearling chinook salmon released during daytime operations at Ice Harbor Dam on 29 June 2002.



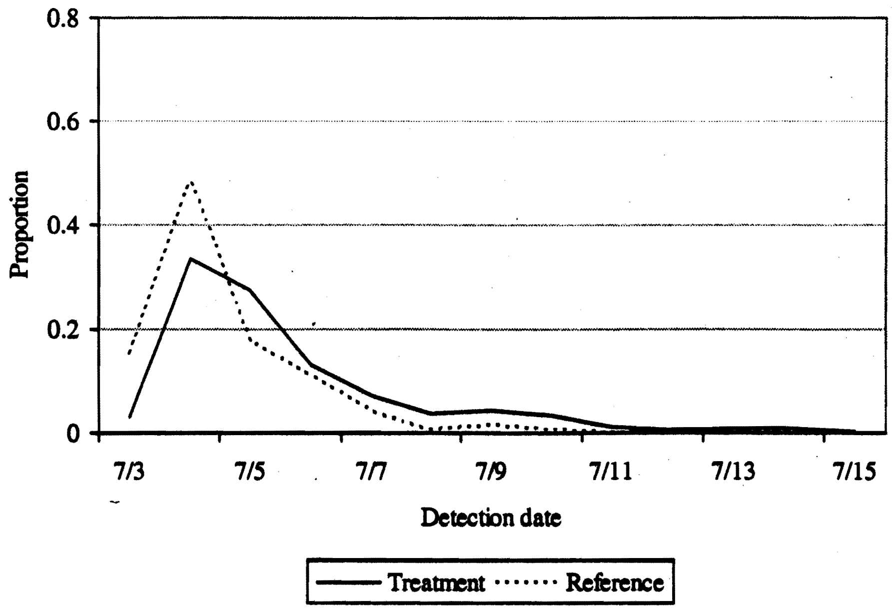
Appendix Figure D16. Passage distribution at McNary Dam for PIT-tagged hatchery subyearling chinook salmon released during nighttime operations at Ice Harbor Dam on 30 June 2002.



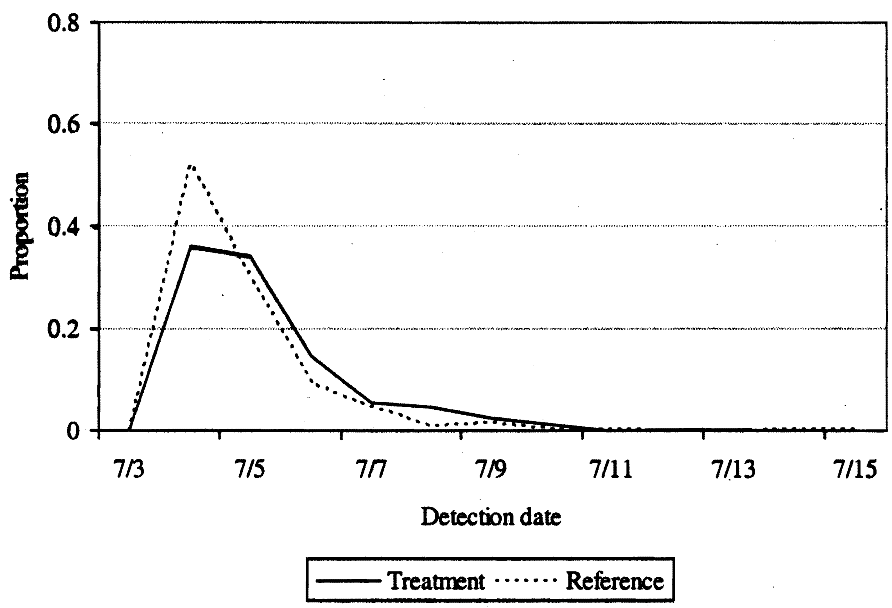
Appendix Figure D17. Passage distribution at McNary Dam for PIT-tagged hatchery subyearling chinook salmon released during daytime operations at Ice Harbor Dam on 01 July 2002.



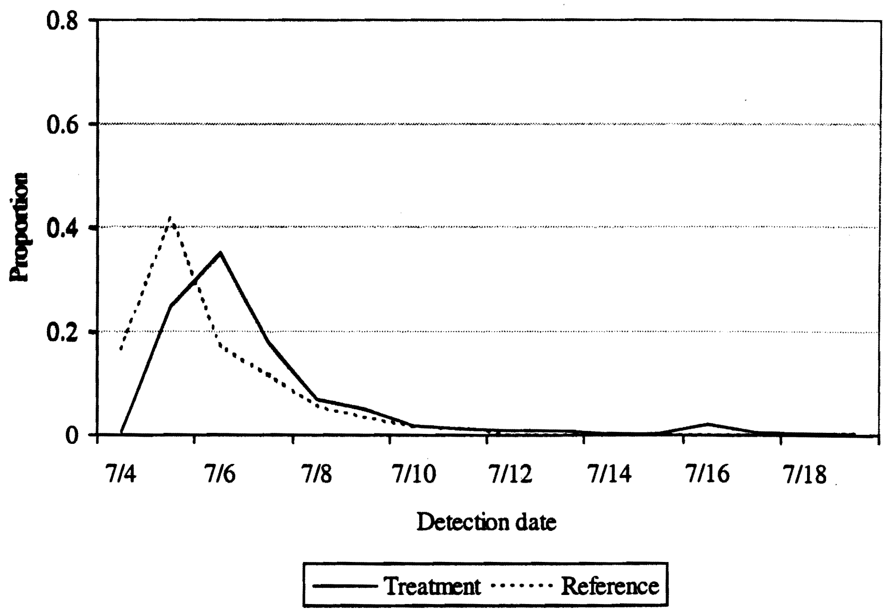
Appendix Figure D18. Passage distribution at McNary Dam for PIT-tagged hatchery subyearling chinook salmon released during nighttime operations at Ice Harbor Dam on 01 July 2002.



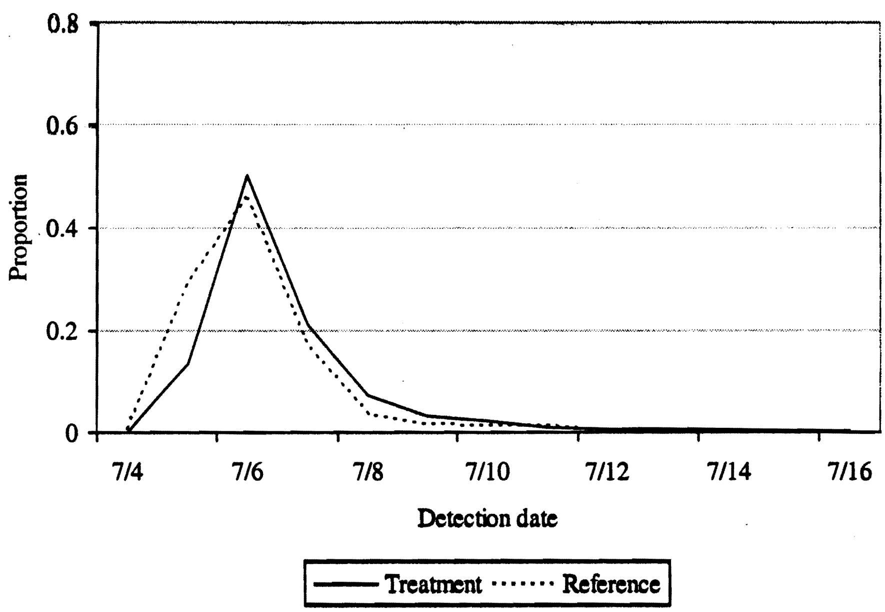
Appendix Figure D19. Passage distribution at McNary Dam for PIT-tagged hatchery subyearling chinook salmon released during daytime operations at Ice Harbor Dam on 02 July 2002.



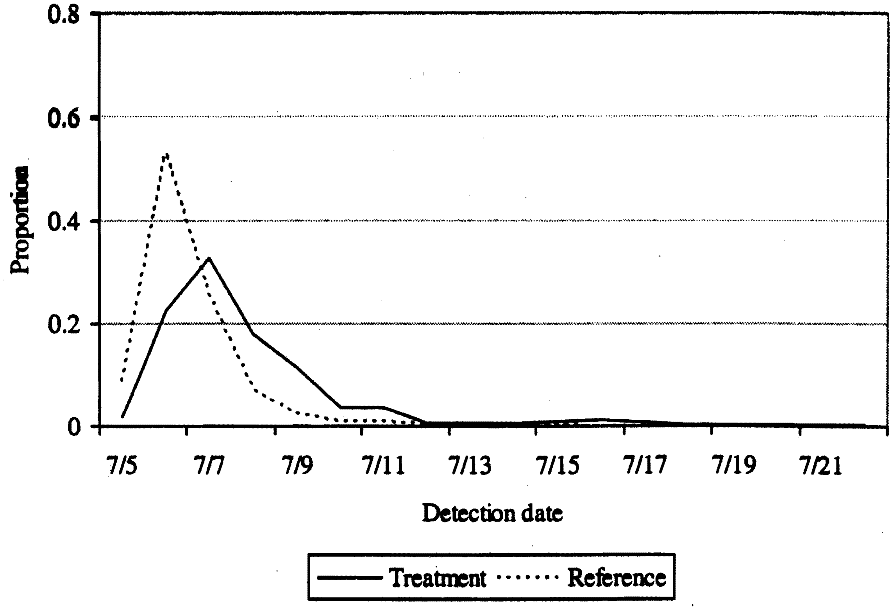
Appendix Figure D20. Passage distribution at McNary Dam for PIT-tagged hatchery subyearling chinook salmon released during nighttime operations at Ice Harbor Dam on 02 July 2002.



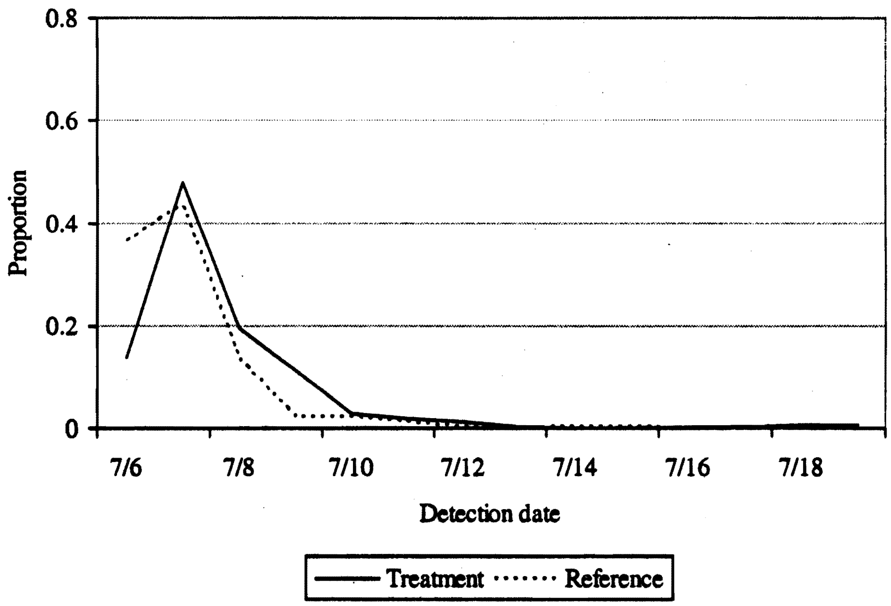
Appendix Figure D21. Passage distribution at McNary Dam for PIT-tagged hatchery subyearling chinook salmon released during daytime operations at Ice Harbor Dam on 03 July 2002.



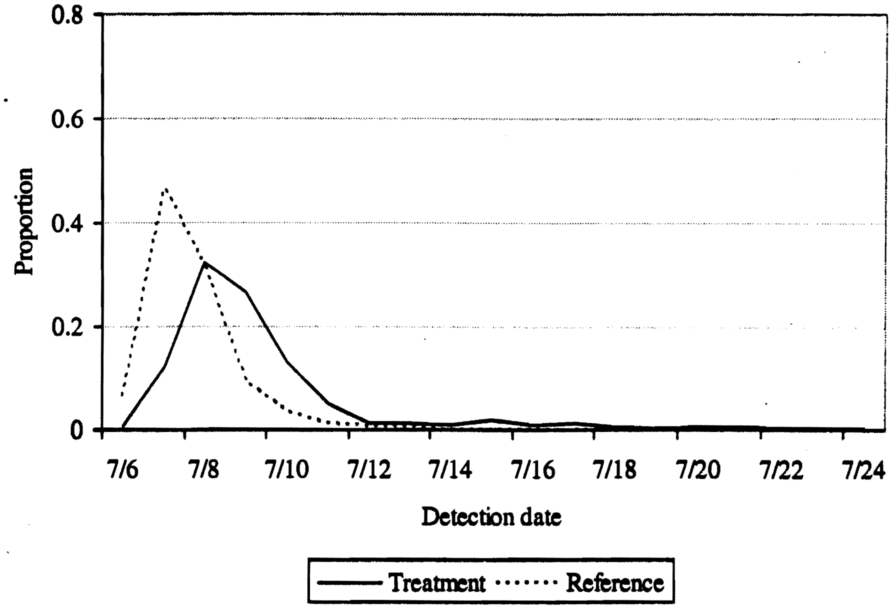
Appendix Figure D22. Passage distribution at McNary Dam for PIT-tagged hatchery subyearling chinook salmon released during nighttime operations at Ice Harbor Dam on 03 July 2002.



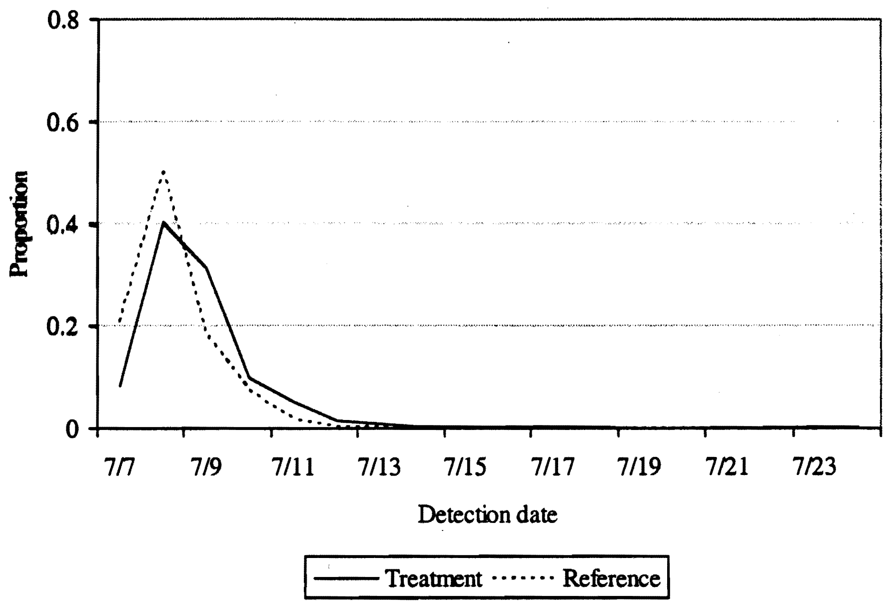
Appendix Figure D23. Passage distribution at McNary Dam for PIT-tagged hatchery subyearling chinook salmon released during daytime operations at Ice Harbor Dam on 04 July 2002.



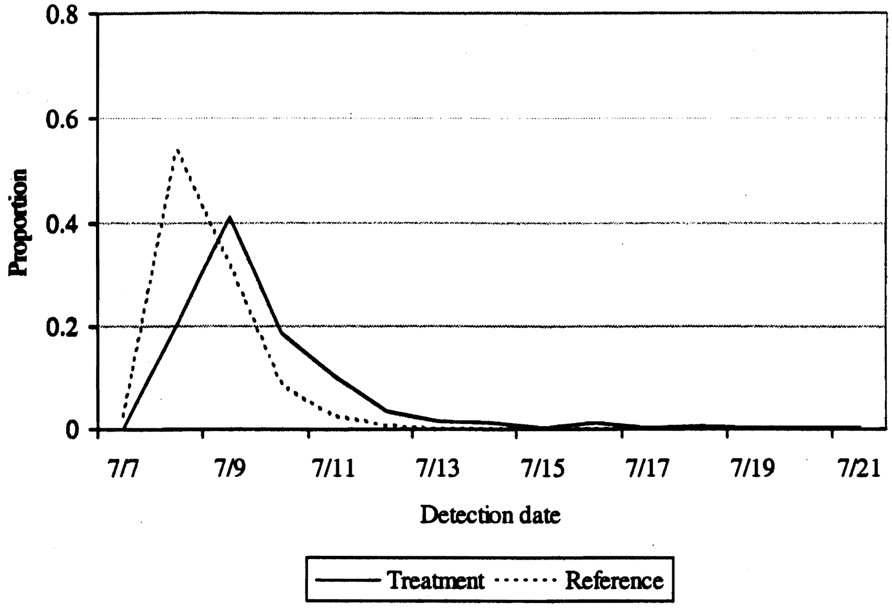
Appendix Figure D24. Passage distribution at McNary Dam for PIT-tagged hatchery subyearling chinook salmon released during nighttime operations at Ice Harbor Dam on 04 July 2002.



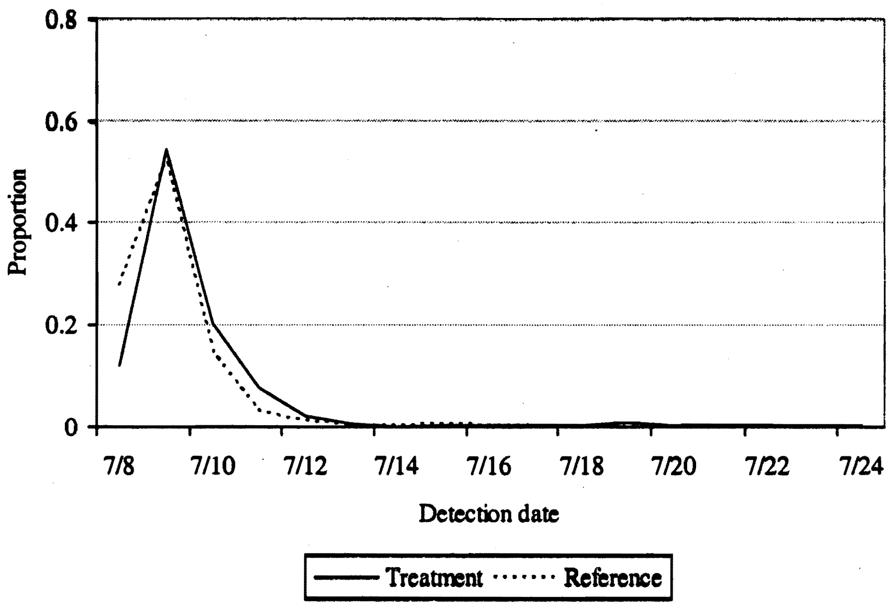
Appendix Figure D25. Passage distribution at McNary Dam for PIT-tagged hatchery subyearling chinook salmon released during daytime operations at Ice Harbor Dam on 05 July 2002.



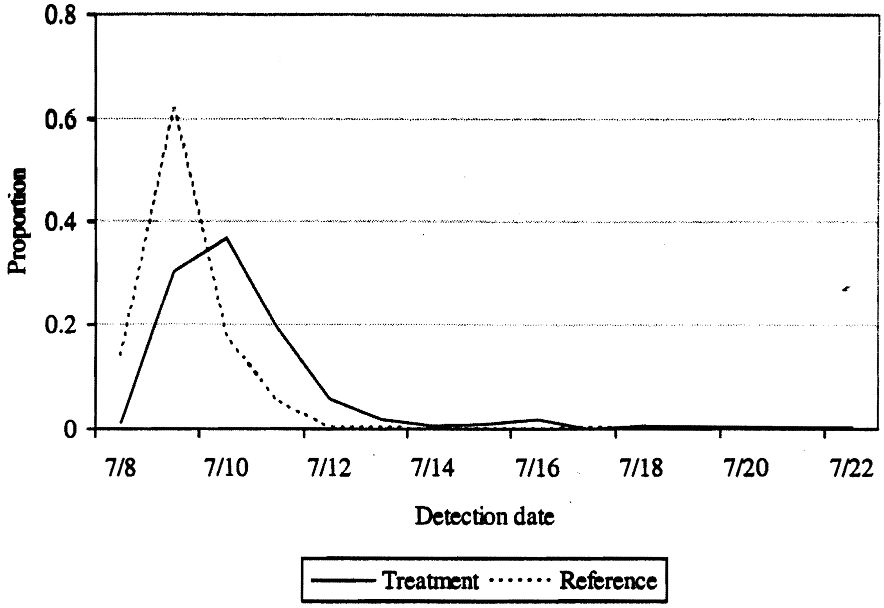
Appendix Figure D26. Passage distribution at McNary Dam for PIT-tagged hatchery subyearling chinook salmon released during nighttime operations at Ice Harbor Dam on 05 July 2002.



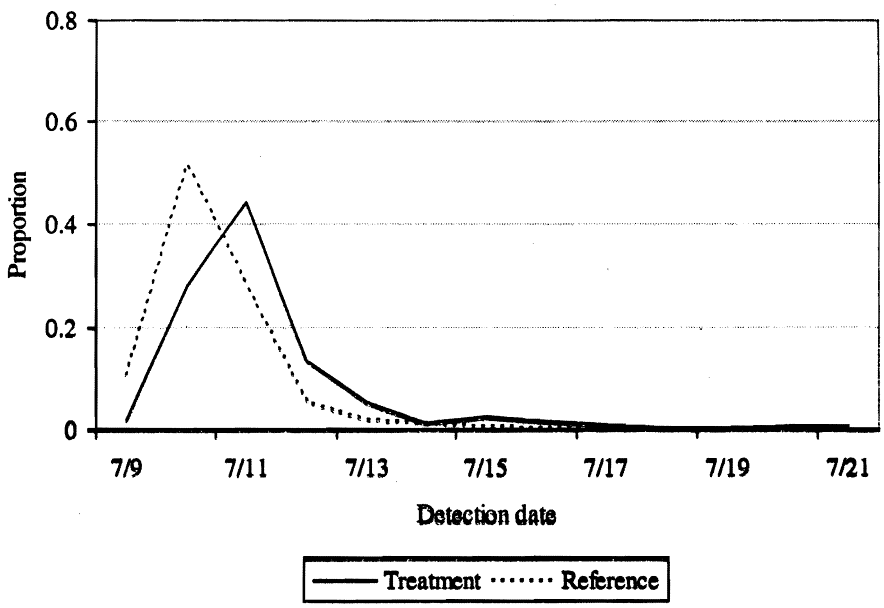
Appendix Figure D27. Passage distribution at McNary Dam for PIT-tagged hatchery subyearling chinook salmon released during daytime operations at Ice Harbor Dam on 06 July 2002.



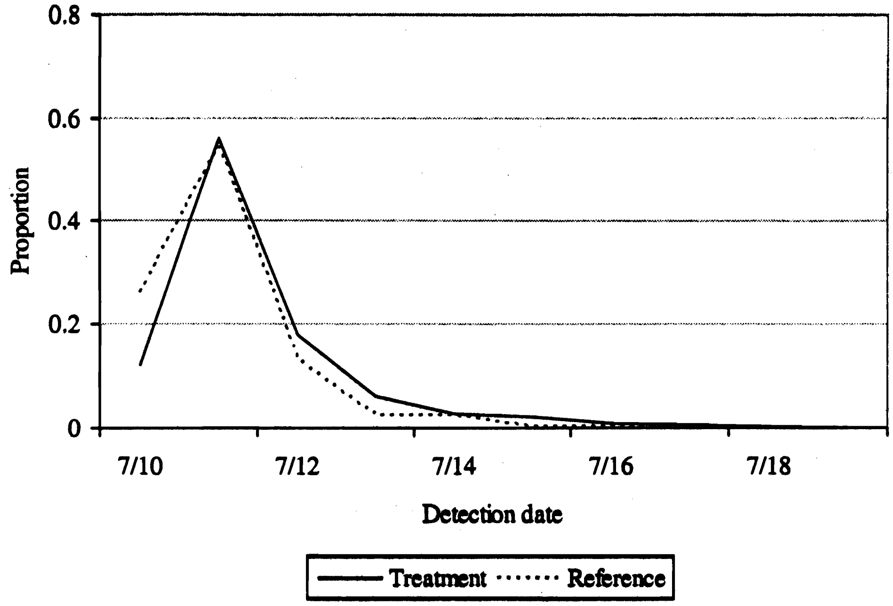
Appendix Figure D28. Passage distribution at McNary Dam for PIT-tagged hatchery subyearling chinook salmon released during nighttime operations at Ice Harbor Dam on 06 July 2002.



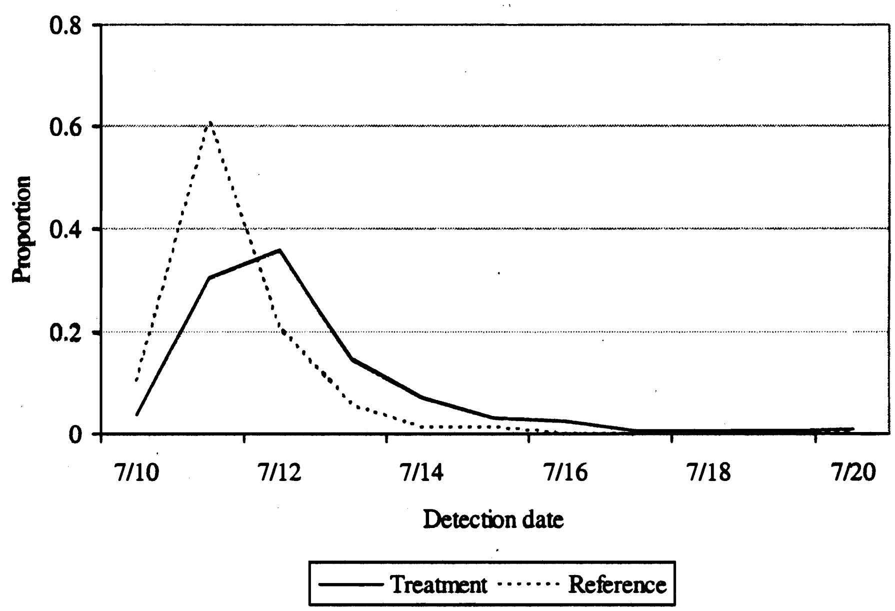
Appendix Figure D29. Passage distribution at McNary Dam for PIT-tagged hatchery subyearling chinook salmon released during daytime operations at Ice Harbor Dam on 07 July 2002.



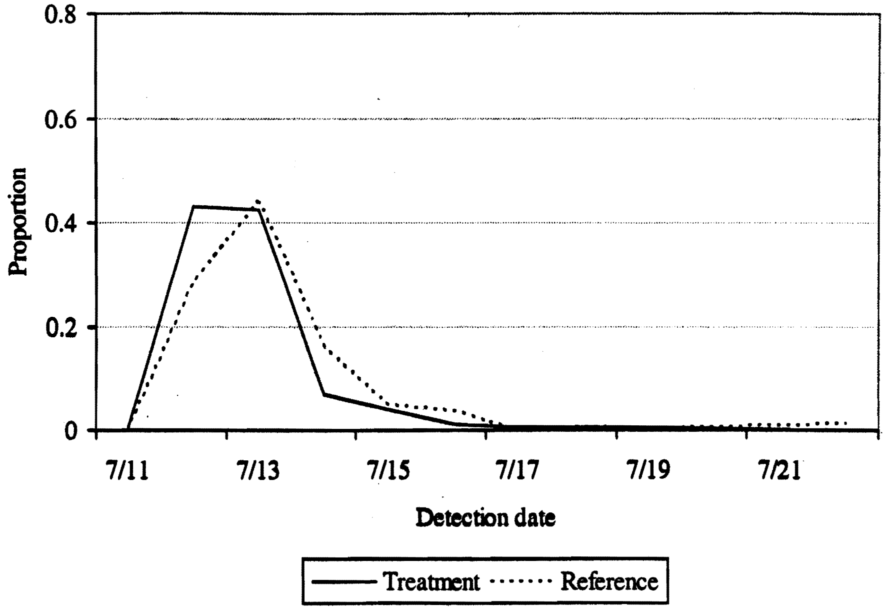
Appendix Figure D30. Passage distribution at McNary Dam for PIT-tagged hatchery subyearling chinook salmon released during daytime operations at Ice Harbor Dam on 08 July 2002.



Appendix Figure D31. Passage distribution at McNary Dam for PIT-tagged hatchery subyearling chinook salmon released during nighttime operations at Ice Harbor Dam on 08 July 2002.



Appendix Figure D32. Passage distribution at McNary Dam for PIT-tagged hatchery subyearling chinook salmon released during daytime operations at Ice Harbor Dam on 09 July 2002.



Appendix Figure D33. Passage distribution at McNary Dam for PIT-tagged hatchery subyearling chinook salmon released during nighttime operations at Ice Harbor Dam on 10 July 2002.