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Fish Ecology Division

Northwest Fisheries Science Center

National Marine Fisheries Service

Seattle, Washington

by

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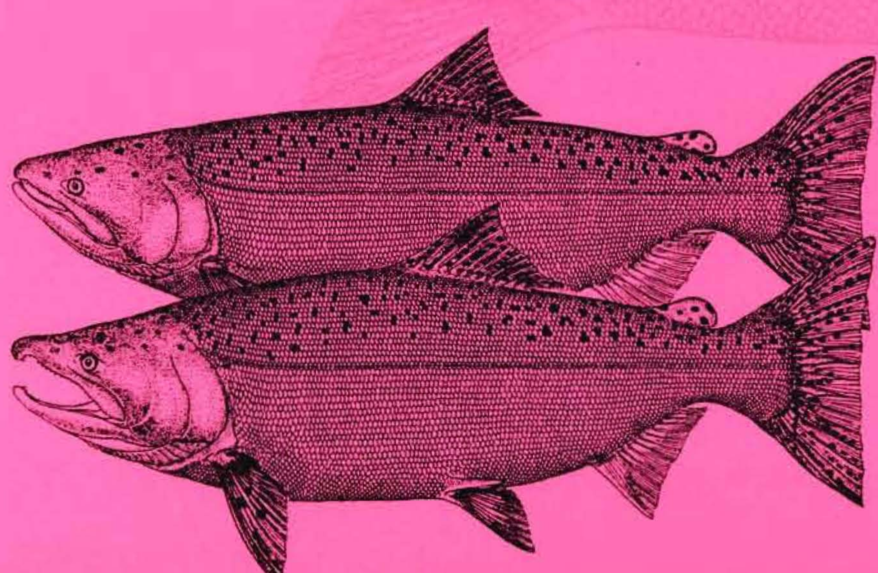

Spillway Survival for Hatchery Yearling and Subyearling Chinook Salmon Passing Ice Harbor Dam, 2000

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Report of research by

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EXECUTIVE SUMMARY

In 2000, the National Marine Fisheries Service (NMFS) 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. Fish were collected and marked with PIT tags at the Lower Monumental Dam smolt collection facility. After a 30-hour holding period, treatment and reference replicate groups were transported to Ice Harbor Dam and released. Treatment groups were released immediately upstream from Spillbay 3, 5, or 7, and reference groups were released into the tailrace 0.5 km below Ice Harbor Dam.

Relative survival was estimated from detections of individual PIT-tagged fish at juvenile collection/detection facilities at McNary, John Day, and Bonneville Dams and from detections in the Columbia River estuary by the NMFS PIT-tag detector trawl. Nineteen paired replicates of yearling chinook salmon were released from 5 to 31 May, and 15 paired replicates of subyearling chinook salmon were released from 31 May to 6 July.

Relative spillway survival for hatchery yearling and subyearling chinook salmon was 0.978 (95% CI, 0.941-1.018) and 0.885 (95% CI, 0.856-0.915), respectively. Relative survival estimates among spillbays were not statistically different for either hatchery yearling (range, 0.964-0.988, $P = 0.896$) or subyearling chinook salmon (range, 0.858-0.927, $P = 0.095$). Correlations between relative spillway survival and tailwater elevation, release date, spill proportion, total river flow, water temperature, fish size, or spillway gate position for both yearling and subyearling fish were weak.

CONTENTS

INTRODUCTION

In recent years, spill has been utilized increasingly to expedite the migration rates of juvenile salmonids past hydroelectric dams and to reduce the proportion of smolts passing through turbines, where survival is lower (Iwamoto et al. 1994, Muir et al. 2001). The current spill program prescribed by the NMFS in its Biological Opinion was designed to maximize spillway passage by migrating juvenile salmonids at hydroelectric dams. In recent years, project operations at Ice Harbor Dam have relied on increased volumes of spill to increase fish passage efficiency (FPE). Eppard et al. (2000) estimated Ice Harbor FPE at 97%, with 81% passage through the spillway for hatchery yearling chinook salmon during the 1999 spring migration.

Survival estimates for juvenile chinook salmon that migrate through reservoirs, hydroelectric projects, and free-flowing sections of the Snake and Columbia Rivers are essential for developing effective strategies to recover depressed stocks. Recent survival studies have evaluated passage through various routes at all dams on the lower Snake River except Ice Harbor Dam (Muir et al. 2001). These studies 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).

In 2000, we estimated survival for hatchery yearling and subyearling chinook salmon passing through the spillway at Ice Harbor Dam using passive integrated transponder (PIT) tags. In addition, we planned to conduct a concurrent study to evaluate the application of radiotelemetry techniques for estimating spillway survival of hatchery yearling chinook salmon at Ice Harbor Dam. The comparison of survival estimation techniques is needed to determine if radiotelemetry can confidently be used in survival studies at lower Columbia River projects where PIT-tag studies are not feasible due to insufficient detection capabilities downstream. However, due to malfunctions of radio transmitters, the telemetry portion of the study in 2000 was postponed until 2001.

Results of this study will be used to help make management decisions that will optimize survival for juvenile salmonids arriving at Ice Harbor Dam. This study addressed research needs outlined in SPE-W-00-5 of the U.S. Army Corps of Engineers, North Pacific Division, Anadromous Fish Evaluation Program.

METHODS

Tagging and Release Procedures

In 2000, we collected and tagged river-run hatchery yearling and subyearling chinook salmon with PIT tags at the Lower Monumental Dam smolt collection facility. Only adipose fin clipped hatchery yearling or subyearling chinook salmon not previously PIT tagged were used. Fish were preanesthetized with tricaine methanesulfonate (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.

Fish were PIT tagged by hand (Prentice et al. 1990a,c) using individual syringes with a 12-gauge hypodermic needle. Used syringes were sterilized in ethyl alcohol for a minimum of 10 minutes before reloading with tags. Tagging of yearling chinook salmon at Lower Monumental Dam began 4 May and continued through 31 May. Subyearling chinook salmon were collected and tagged from 31 May through 06 July.

PIT-tagged fish were transferred from the smolt monitoring facility through a water-filled pipe to 712-L tanks mounted on trucks. 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 30 hours with flow-through water for recovery and determination of post-tagging mortality. Holding density did not exceed 800 fish per tank.

After the post-tagging recovery period of approximately 24 hours, PIT-tagged fish were transported in recovery containers from Lower Monumental Dam to Ice Harbor Dam. At Ice Harbor Dam, treatment groups were released from tanks into Spillbay 3, 5, or 7 via a 10.2-cm-diameter hose (Fig. 1). Spillbay release selection was based on a randomized block design where blocks comprised three-day intervals and spillbay number was randomized within each block. Water was continuously added prior to, during, and after releases to ensure that all fish exited the hose.

Reference groups were transferred to a small barge in the forebay of Ice Harbor Dam, transported to the tailrace and released mid-channel water-to-water about 0.8 km downstream from the dam. To provide mixing of treatment and reference groups, the spillway group was released approximately 7 minutes prior to the reference release group

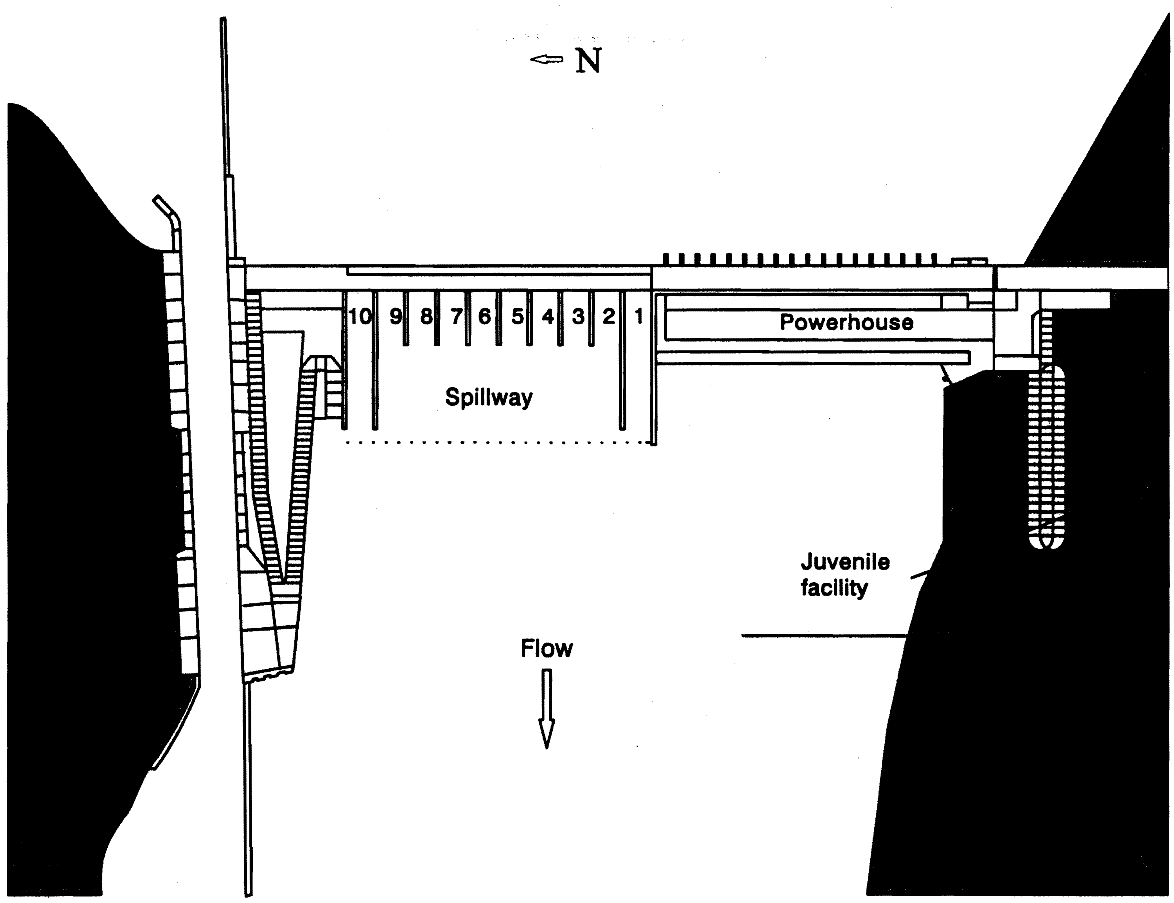

Figure 1. Overhead schematic of Ice Harbor Dam on the lower Snake River. Releases of PIT-tagged and radio-tagged hatchery yearling chinook salmon were made in the forebay directly in front of Spillbays 3, 5, and 7. Reference groups were released mid-channel about 0.8 km downstream of the dam.

to allow time for fish to pass through the tailrace. This time interval was based on Ice Harbor Dam tailrace egress evaluation conducted in 1999 (Eppard et al. 2000). Specific operating conditions for each release day were not requested; however, operating conditions (spill pattern, flow level, and powerhouse loading) were requested from 1800 until 2100 hours to ensure that tailrace conditions were stable during releases (releases were made between 1815 and 2030 PST during periods of spill). This data was not available.

Statistical Analyses

Sample sizes for releases were determined by evaluating data from PIT-tagged salmonids released into the Snake and Columbia Rivers in 1997, 1998, and 1999. The number of release groups per release location and number of fish per release group were calculated to maximize the ability to detect differences in spillway passage survival, within constraints imposed by the logistics of collecting, tagging, and transporting fish. For a given total number of fish used in the evaluation, similar statistical power could be attained with a range of combinations of total numbers of releases and numbers of fish per group. We designed the study to mark and release 18 groups of yearling chinook salmon and 20 groups of subyearling chinook salmon. Each release group comprised approximately 750 fish released into the spillway and 750 fish released into the tailrace (Appendix A).

A Paired-Release Model (Burnham et al. 1987) was used for analysis where groups of tagged fish were released at two sites, one upstream (treatment) and one downstream (reference) from the Ice Harbor spillway. The analysis was based on detections of individual PIT-tagged fish at the juvenile collection/detection facilities at McNary, John Day, and Bonneville Dams and with a detector trawl in the Columbia River estuary (PSMFC 1996). The detector trawl was not operated during most of the subyearling chinook migration; therefore, detections of subyearling chinook were not used in the survival analysis.

Relative survival for treatment releases was estimated as the ratio of treatment recovery proportions to reference recovery proportions. Differences in detection percentages among spillbays were evaluated using a weighted analysis of variance (ANOVA) with release location (spillbay) as the random factor. The weights were the inverses of the respective sample variances (Burnham et al. 1987).

Analysis was done on the natural log scale to normalize relative survival, and the log-scale means were back-transformed. Residuals were examined to assess the performance of the analysis.

To evaluate mixing of the release groups at downstream dams, we used contingency table tests (chi-square goodness-of-fit) to test for differences among distributions of daily detections at McNary, John Day, and Bonneville Dams. The relationship between survival estimates and environmental conditions and project operations were analyzed using regression analysis. At present, no formal analysis of adult returns of PIT-tagged fish used in this study is anticipated.

RESULTS

Spring Migration, Yearling Chinook Salmon

Fish Collection, Tagging, and Release

Yearling chinook salmon were collected and PIT tagged at Lower Monumental Dam on 20 days from 4 to 31 May (Table 1). Tagging began after 45% of the yearling chinook salmon had passed Lower Monumental Dam and was completed when 98% of these fish had passed. Handling and tagging mortality for yearling chinook salmon was 1.44% overall. We released 11,331 PIT-tagged fish into Spillbays 3, 5, or 7 at Ice Harbor Dam and 11,276 PIT-tagged fish into the Ice Harbor Dam tailrace over 19 days during May.

All release groups comprised fish collected and tagged 24 hours prior to release except the last release on 31 May, which comprised fish collected and tagged over a 48-hour period (30 to 31 May) due to the limited availability of target fish. Releases occurred from 1836 to 2026 PST. During the releases, spill levels ranged from 43.8 to 105.2 kcfs, or 71.5 to 100% of the total discharge; tailwater elevation ranged from 339.0 to 347.8 ft; and water temperature ranged from 11.7 to 14.4°C (Table 2).

Detection and Passage Distribution

Of the 22,607 yearling chinook salmon released at Ice Harbor Dam, 8,246 unique PIT-tags were detected at downstream locations on the Columbia River (Table 3). Temporal PIT-tag detection distributions at McNary Dam were similar for treatment and reference groups for 16 of the 19 paired yearling chinook salmon releases (Table 4 and Appendix B Figs. B1 and B2). Three groups had significantly different passage distributions at McNary Dam; however, their arrival timing generally varied by less than a day. These groups experienced similar passage conditions at downstream dams, and the small difference in timing most likely had little effect on the survival estimates. Because the distributions appeared to differ only slightly, we concluded that the homogeneity test was sensitive enough to pick up differences that were too small to actually affect the survival analyses of treatment effects.

Table 1. Number of hatchery yearling chinook salmon PIT tagged and released for the Ice Harbor spillway survival study, 2000.

Tag date	Spillway release groups			Tailrace release groups			Total		
	Tagged	Mortality	Released	Tagged	Mortality	Released	Tagged	Mortality	Released
4 May	750	23	727	744	27	717	1,494	50	1,444
5 May	643	5	638	639	18	621	1,282	23	1,259
8 May	601	2	599	599	6	593	1,200	8	1,192
9 May	746	4	742	728	13	715	1,474	17	1,457
10 May	698	5	693	699	9	690	1,397	14	1,383
11 May	698	6	692	699	15	684	1,397	21	1,376
12 May	673	3	670	675	3	672	1,348	6	1,342
15 May	353	1	352	351	2	349	704	3	701
16 May	200	0	200	197	0	197	397	0	397
17 May	377	5	372	376	1	375	753	6	747
18 May	850	12	838	850	22	828	1,700	34	1,666
19 May	567	2	565	564	2	562	1,131	4	1,127
22 May	755	19	736	753	12	741	1,508	31	1,477
22 May	751	36	715	750	9	741	1,501	45	1,456
23 May	751	5	746	749	9	740	1,500	14	1,486
24 May	480	1	479	477	1	476	957	2	955
25 May	558	2	556	556	5	551	1,114	7	1,107
26 May	750	23	727	749	18	731	1,499	41	1,458
30 May	155	1	154	133	1	132	288	2	286
31 May	131	1	130	162	1	161	293	2	291
Total	11,487	156	11,331	11,450	174	11,276	22,937	330	22,607

Table 2. Ice Harbor Dam operations and discharge conditions during releases of hatchery yearling chinook salmon for spillway survival evaluation, 2000.

Date	Time	Powerhouse (kcfs)	Spillway (kcfs)	Total discharge (kcfs)	Tailwater elevation (ft)	Temperature (°C)
05 May	1940	9.8	85.1	94.9	344.9	11.7
06 May	2004	0.0	69.5	69.5	342.8	11.7
09 May	1927	0.0	45.3	45.3	340.6	11.7
10 May	2014	0.0	90.1	90.1	343.7	11.7
11 May	1919	0.0	79.9	79.9	343.4	12.2
12 May	1916	0.0	79.6	79.6	343.5	12.2
13 May	1933	0.0	75.1	75.1	343.5	12.2
16 May	1937	0.0	43.8	43.8	339.0	12.2
17 May	1900	0.0	55.2	55.2	341.6	12.2
18 May	1902	0.0	59.1	59.1	341.8	12.2
19 May	1852	0.0	74.0	74.0	342.9	12.2
20 May	1910	9.6	94.9	104.5	345.7	12.2
23 May	1923	20.6	100.8	121.4	346.3	13.3
23 May	2026	40.3	101.1	141.4	347.8	13.3
24 May	1907	0.0	99.9	99.9	345.4	13.3
25 May	1856	0.0	90.4	90.4	344.4	14.4
26 May	1838	0.0	90.0	90.0	344.6	14.4
27 May	1836	0.0	105.2	105.2	345.7	14.4
31 May	1906	0.0	98.6	98.6	345.2	13.9
Average		4.2	80.9	85.2	343.8	12.7

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 of Ice Harbor Dam, 2000.

Detection site	Treatment	Reference	Total
McNary Dam	2,729 (0.241)	2,610 (0.231)	5,339 (0.236)
John Day Dam	303 (0.027)	373 (0.033)	676 (0.030)
Bonneville Dam	1,010 (0.089)	1,104 (0.098)	2,114 (0.094)
Detector trawl	50 (0.004)	67 (0.006)	117 (0.005)
Totals	4,092 (0.361)	4,154 (0.368)	8,246 (0.365)

Table 4. Test of homogeneity of McNary Dam passage distributions for groups of PIT-tagged hatchery yearling chinook salmon released into the tailrace and spillway at Ice Harbor Dam. Passage numbers grouped into day periods. *P* values calculated using a Monte Carlo approximation of the exact method. Shaded cells indicate significant differences in passage timing among tests (significance level $\alpha = 0.05$).

Release date	χ^2	Degrees of freedom	*P*
05 May	19.74	13	0.0585
06 May	8.64	9	0.4901
09 May	15.52	10	0.0830
10 May	12.95	9	0.1381
11 May	20.12	10	0.0150
12 May	31.61	11	0.0001
13 May	16.29	11	0.0697
16 May	9.32	7	0.1914
17 May	10.41	8	0.1923
18 May	9.91	10	0.4710
19 May	14.13	9	0.0790
20 May	11.28	6	0.0688
23 May	10.84	6	0.0765
24 May	10.37	6	0.0812
25 May	5.92	6	0.4327
26 May	2.25	7	0.9935
27 May	10.25	5	0.0537
31 May	9.67	7	0.1713

Relative Survival Estimates

Survival estimates for yearling chinook salmon that passed through the spillway at Ice Harbor Dam relative to those released in the tailrace ranged from 0.802 to 1.151 (Table 5). The weighted average relative survival estimate for the 19 releases was 0.978 (95% CI, 94.1-101.8). ANOVA showed no significant differences among release locations across Spillbays 3, 5, and 7 ($F = 0.11$, $P = 0.896$; Table 6). Given the sample size used and the observed variability, a true difference of 9% in survival among spillbays could be detected ($\alpha = 0.05$, $\beta = 0.20$). We did not identify a correlation between survival for yearling chinook salmon passing through the Ice Harbor Dam spillway and tailwater elevation, release date, spill proportion, total river flow, water temperature or fish size (Appendix Figs. D1-D6).

Summer Migration, Subyearling Chinook Salmon

Fish Collection, Tagging, and Release

Subyearling chinook salmon were PIT tagged at Lower Monumental Dam from 30 May through 6 July (Table 7). Tagging began after 5% of the subyearling chinook salmon had passed Lower Monumental Dam and was completed when 85% of these fish had passed. Handling and tagging mortality for subyearling chinook salmon was 10.08%. The majority of handling mortality for subyearling chinook salmon occurred on 26 June, when water flow to a truck containing 1,801 PIT-tagged fish was accidently shut off.

Handling and tagging mortality for subyearling chinook salmon excluding 26 June was 0.98%. We released 8,929 PIT-tagged fish into Spillbays 3, 5, or 7 at Ice Harbor Dam and 8,876 PIT-tagged fish into the Ice Harbor Dam tailrace over 15 days from late May through early July. All releases occurred approximately 24 hours after tagging, except release groups on 31 May; 2, 14, 16, and 20 June; and 6 July, which included fish collected and tagged over a 48-hour period due to the limited availability of target fish within a 24-hour period. Releases occurred from 1826 to 1906 PST (Table 8) with spill levels ranging from 30.4 to 98.6 kcfs or 93.8 to 100% of the total discharge. During the releases, tailwater elevation ranged from 340.3 to 345.1 ft and water temperature ranged from 13.9 to 17.2°C.

Table 5. Complete release and detection data for Ice Harbor Dam spillway survival study including release location, numbers released, numbers and proportions detected, and relative survival estimates for PIT-tagged hatchery yearling chinook salmon, 2000 (the standard error is provided for the pooled estimate).

	Tailrace			Spillway				
Release date	Released	Detected	Proportion	Spillbay	Released	Detected	Proportion	Relative survival
5 May	717	290	0.404	3	727	273	0.376	0.931
6 May	621	256	0.412	5	638	265	0.415	1.007
9 May	593	259	0.437	7	599	248	0.414	0.947
10 May	715	318	0.445	3	742	310	0.418	0.939
11 May	690	243	0.352	7	693	281	0.405	1.151
12 May	684	257	0.376	5	692	265	0.383	1.019
13 May	672	254	0.378	5	670	232	0.346	0.915
16 May	349	143	0.410	7	352	126	0.358	0.873
17 May	197	85	0.431	3	200	74	0.370	0.858
18 May	375	147	0.392	5	372	130	0.349	0.890
19 May	828	308	0.372	3	838	309	0.369	0.992
20 May	562	194	0.345	7	565	180	0.319	0.925
23 May	741	180	0.243	7	736	191	0.260	1.070
23 May	741	182	0.246	5	715	176	0.246	1.000
24 May	740	221	0.299	3	746	229	0.307	1.027
25 May	476	214	0.450	7	479	173	0.361	0.802
26 May	551	208	0.377	3	556	230	0.414	1.098
27 May	731	303	0.415	5	727	313	0.431	1.039
31 May	293	100	0.341	3	284	99	0.349	1.023
Overall	11,276	4,162	0.369		11,331	4,104	0.362	0.978 (0.020)*

* Pooled estimates are weighted averages of the independent estimates.

Table 6. Comparison of estimated relative survival probabilities for PIT-tagged hatchery yearling and subyearling chinook salmon tagged and released into Spillbays 3, 5, and 7 at Ice Harbor Dam, 2000. The estimates (provided by the Relative Recovery Model) were compared using ANOVA ($\alpha = 0.05$). Standard errors in parentheses. See Table 1 for numbers released.

	Spillbay 3	Spillbay 5	Spillbay 7	*P*
Yearling chinook salmon	0.981 (0.034)	0.988 (0.036)	0.964 (0.039)	0.896
Subyearling chinook salmon	0.927 (0.024)	0.865 (0.026)	0.858 (0.026)	0.095

Table 7. Number of hatchery subyearling fall chinook salmon PIT tagged at Lower Monumental Dam and released at Ice Harbor Dam as part of the spillway survival study.

	Spillway released groups			Tailrace released groups			Total		
Tag date	Tagged	Mortality	Released	Tagged	Mortality	Released	Tagged	Mortality	Released
30 May	140	3	137	123	4	119	263	7	256
31 May	168	1	167	120	2	118	288	3	285
01 June	65	3	62	64	4	60	129	7	122
02 June	49	0	49	47	2	45	96	2	94
13 June	24	5	19	23	1	22	47	6	41
14 June	238	2	236	238	3	235	476	5	471
15 June	466	4	462	466	5	461	932	9	923
16 June	312	2	310	311	2	309	623	4	619
19 June	30	1	29	31	0	31	61	1	60
20 June	242	1	241	243	1	242	485	2	483
21 June	580	3	577	581	5	576	1,161	8	1,153
22 June	894	5	889	895	8	887	1,790	13	1,777
23 June	900	12	888	900	3	897	1,799	15	1,784
24 June	744	8	736	743	3	740	1,487	11	1,476
25 June	881	8	873	885	3	882	1,766	11	1,755
26 June	901	901	0	900	900	0	1,801	1,801	0
27 June	900	6	894	900	6	894	1,800	12	1,788
28 June	838	14	824	838	7	831	1,676	21	1,655
29 June	441	8	433	441	10	431	882	18	864
30 June	824	11	813	824	21	803	1,648	32	1,616
05 July	168	3	165	168	2	166	336	5	331
06 July	127	2	125	127	0	127	254	2	252
Total	9,932	1,003	8,929	9,868	992	8,876	19,800	1,995	17,805

Table 8. Ice Harbor Dam operations and discharge conditions during releases of hatchery subyearling chinook salmon for spillway survival evaluation, 2000.

Date	Time	Powerhouse (kcfs)	Spillway (kcfs)	Total discharge (kcfs)	Tailwater elevation (ft)	Water temperature (°C)
31 May	1902	0.0	98.6	98.6	345.1	13.9
02 June	1906	0.0	80.2	80.2	343.6	13.9
14 June	1845	0.0	94.9	94.9	344.7	14.4
16 June	1847	0.0	80.0	80.0	343.7	15.0
20 June	1843	0.0	68.1	68.1	342.9	16.1
22 June	1842	0.0	67.4	67.4	343.0	16.7
23 June	1826	0.0	44.8	44.8	341.6	16.7
24 June	1839	0.0	45.2	45.2	340.9	16.7
25 June	1832	0.0	60.3	60.3	342.2	16.7
26 June	1834	0.0	54.9	54.9	341.6	16.7
28 June	1900	2.0	30.4	32.4	340.6	16.7
29 June	1852	0.0	35.1	35.1	340.3	16.7
30 June	1830	0.0	54.7	54.7	341.6	16.7
01 July	1844	0.0	40.0	40.0	340.5	17.2
06 July	1840	0.0	45.0	45.0	340.5	17.2
Average		0.1	60.0	60.1	342.2	16.1

Detection and Passage Distribution

From the 17,805 subyearling chinook salmon released at Ice Harbor Dam, 9,687 unique PIT-tags were detected at downstream locations on the Columbia River (Table 9). Temporal PIT-tag detection distributions at McNary Dam were similar for treatment and reference groups for only the first 5 of the 15 paired releases of subyearling chinook salmon (Table 10 and Appendix Figs. B3-B11). However, passage distributions at John Day Dam were similar for treatment and reference groups in 14 of the 15 paired releases of subyearling chinook salmon (Table 11).

The homogeneity test of passage distributions at McNary Dam was disproportionately affected by high detection rates at McNary Dam; therefore we concluded that the test was sensitive enough to pick up differences that were too small to actually affect the survival analyses of treatment effects.

Relative Survival Estimates

Survival estimates of subyearling chinook salmon that passed through the spillway at Ice Harbor Dam relative to those released in the tailrace ranged from 0.792 to 1.035 (Table 12). The weighted average relative survival estimates for the 15 releases was 0.885 (95% CI, 0.856-0.915). ANOVA showed no significant differences among spillbay release locations ($F = 2.88$, $P = 0.095$)(Table 6). Given the sample size used and the observed variability, a true difference in relative survival of 5.6% among spillbays could be detected ($\alpha = 0.05$ and $\beta = 0.20$). We did not identify a correlation between subyearling chinook salmon spillway passage survival and tailwater elevation, release date, spill proportion, total river flow, water temperature or fish size (Appendix Figs. D1-D6).

Table 9. 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 of Ice Harbor Dam.

Detection site	Treatment	Reference	Total
McNary Dam	4,323 (0.484)	4,840 (0.545)	9,163 (0.515)
John Day Dam	198 (0.022)	254 (0.029)	452 (0.025)
Bonneville Dam	42 (0.005)	30 (0.003)	72 (0.004)
Totals	4,563 (0.511)	5,124 (0.577)	9,687 (0.544)

Table 10. Tests of homogeneity of McNary Dam passage distributions for groups of PIT-tagged hatchery subyearling chinook salmon released into the tailrace and spillway at Ice Harbor Dam. Passage numbers by days. *P*-values were calculated using a Monte Carlo approximation of the exact method. Shaded cells indicate significant differences in passage timing among tests ($\alpha = 0.05$).

Release date	χ^2	Degrees of freedom	*P*
31 May	18.74	19	0.4980
02 June	20.20	17	0.2264
14 June	9.85	11	0.6047
16 June	13.84	11	0.1823
20 June	10.47	7	0.1250
22 June	53.25	12	<0.0001
23 June	197.50	17	<0.0001
24 June	147.40	15	<0.0001
25 June	28.21	12	0.0007
26 June	110.30	13	<0.0001
28 June	111.10	12	<0.0001
29 June	184.90	10	<0.0001
30 June	20.24	9	0.0068
01 July	50.37	11	<0.0001
06 July	39.54	9	<0.0001

Table 11. Tests of homogeneity of John Day Dam passage distributions for groups of PIT-tagged hatchery subyearling chinook salmon released into the tailrace and spillway at Ice Harbor Dam. Passage numbers by days. *P*-values calculated using a Monte Carlo approximation of the exact method. Shaded cells indicate significant differences in passage timing among tests ($\alpha = 0.05$).

Release date	χ^2	Degrees of freedom	*P*
31 May	17.83	17	0.4245
02 June	17.21	12	0.0720
14 June	4.22	5	0.5806
16 June	14.69	11	0.1222
20 June	6.78	5	0.2733
22 June	7.54	7	0.3733
23 June	11.04	8	0.1471
24 June	17.61	5	0.0015
25 June	10.30	7	0.1105
26 June	11.99	8	0.0942
28 June	10.70	10	0.3567
29 June	10.24	10	0.4290
30 June	9.99	6	0.0899
01 July	6.96	9	0.7978
06 July	8.07	6	0.2250

NOTE: Due to very small sample sizes, tests for Bonneville Dam passage distributions were not completed.

Table 12. Complete release and detection data for Ice Harbor Dam spillway survival study including release location, numbers released, numbers and proportions detected, and relative survival estimates for PIT-tagged hatchery subyearling chinook salmon, 2000 (the standard error is provided for the pooled estimate).

	Tailrace			Spillway				
Release date	Released	Detected	Proportion	Spillbay	Released	Detected	Proportion	Relative survival
31 May	237	88	0.371	3	304	111	0.365	0.984
2 June	105	46	0.438	7	111	42	0.378	0.863
14 June	257	80	0.311	3	255	82	0.322	1.035
16 June	770	269	0.349	5	772	237	0.307	0.880
20 June	273	164	0.601	7	270	147	0.544	0.905
22 June	576	345	0.599	3	577	340	0.589	0.983
23 June	887	637	0.718	5	889	565	0.636	0.886
24 June	897	604	0.673	7	888	499	0.562	0.835
25 June	740	458	0.619	5	736	361	0.490	0.792
26 June	882	453	0.514	3	873	435	0.498	0.969
28 June	894	553	0.619	7	894	493	0.551	0.890
29 June	831	476	0.573	3	824	422	0.512	0.894
30 June	431	251	0.582	5	433	231	0.533	0.916
1 July	803	506	0.630	3	813	443	0.545	0.865
6 July	293	194	0.662	7	290	154	0.531	0.802
Overall	8,876	5,124	0.577		8,929	4,562	0.511	0.885 (0.015)*

* Pooled estimates are weighted averages of the independent estimates.

DISCUSSION

Prior to this study, survival of juvenile salmonids passing through spillways at lower Snake and Columbia River dams has been evaluated, at least once, at all projects except Ice Harbor Dam, providing 28 estimates under a variety of conditions (Table 13). Our estimate of survival for yearling chinook salmon passing through the spillway at Ice Harbor Dam (97.8%) was similar to spillway survival estimates at Little Goose (102.1%)(Iwamoto et al. 1994) and Lower Monumental Dams (92.7 to 98.4%)(Muir et al. 1995a).

Previous studies of spillway survival for subyearling chinook salmon (summer migrants) have estimated survival from 75.2% at The Dalles Dam in 1998 (64% spill)(Dawley et al. 2000a) to 100% at The Dalles Dam in 1999 (30% spill)(Dawley et al. 2000b). Estimated survival for subyearling chinook passing through the spillways at lower Snake River dams has previously been evaluated only at Lower Monumental Dam (Long et al. 1972).

Our Ice Harbor Dam spillway survival estimate (88.5%) for subyearling chinook salmon was slightly higher than the estimates for Lower Monumental Dam (83.1 and 84.0%) and within the range of estimates observed at The Dalles Dam. Based on the results of our study, survival estimates for juvenile chinook salmon (both yearling and subyearling) were not significantly different among Spillbays 3, 5, and 7. We did not evaluate survival for fish passing through the end spillbays (1 and 10).

Pooled survival estimates for subyearling chinook salmon passing through the spillway at Ice Harbor Dam was 9.3% lower than estimates for yearling chinook salmon. Average volumes of spill and river discharge during subyearling chinook salmon releases were 26 and 29% lower than during yearling chinook salmon releases, respectively. Water temperature averaged 3.4°C warmer during the subyearling chinook salmon releases than during the yearling chinook salmon releases (16.1 and 12.7°C, respectively).

Environmental conditions in the summer including lower flows and lower tailrace elevations may have contributed to the lower survival for the summer versus spring migrants. However, environmental conditions experienced by summer migrants such as lower turbidity, lower flows, and higher temperatures favor higher predation rates. Increases in water temperature have been shown to increase digestion and consumption rates by northern pikeminnow (Falter 1969, Steigenberger and Larkin 1974, Beyer et al. 1988, Vigg et al. 1988). Decreases in turbidity and flow may increase capture efficiency

Table 13. Location, species and run type, study year, fish marking method, spillbay, test conditions, and survival estimates for spillway passage evaluation at hydroelectric projects on the lower Snake and Columbia Rivers.

Dam	Species and run type	Year	Method	Flow deflector	Location	Conditions (kcfs)	Survival	Reference
LGR[a]	Steelhead	1996	PIT tag	no	Bay 1	3.9	1.010	Smith et al. 1998
LGO	Steelhead	1997	PIT tag	no	Bay 1	4.9-10.0	1.004	Muir et al. 1998
LGO	Steelhead	1997	PIT tag	yes	Bay 3	4.9-10.0	0.972	Muir et al. 1998
LGO	Yearling chinook	1993	PIT tag	yes	Bay 3	3.8	1.021	Iwamoto et al. 1994
LMO	Coho	1973	Freeze brand	yes[b]	Bay 2	4.5	0.970	Long and Ossiander 1974
LMO	Coho	1973	Freeze brand	yes	Bay 4	4.5	1.100	Long and Ossiander 1974
LMO	Steelhead	1974	Freeze brand	yes	Bay 7	4.5	0.978	Long et al. 1975
LMO	Steelhead	1974	Freeze brand	no	Bay 8	4.5	0.755	Long et al. 1975
LMO	Subyearling chinook	1972	Freeze brand	yes[b]	Bay 2	13.1	0.831	Long et al. 1972
LMO	Subyearling chinook	1972	Freeze brand	yes[b]	Bay 2	2.8	0.840	Long et al. 1972
LMO	Yearling chinook	1994	PIT tag	yes	Bay 7	4.4-4.8	0.927	Muir et al. 1995a
LMO	Yearling chinook	1994	PIT tag	no	Bay 8	4.4-4.8	0.984	Muir et al. 1995a
MCN	Subyearling chinook	1955	Tattoo	no	NS[c]	NS	0.980	Schoeneman et al. 1961
MCN	Subyearling chinook	1956	Tattoo	no	NS	NS	1.000	Schoeneman et al. 1961
JDD	Subyearling chinook	1979	Freeze brand	no	Bay 16	4.3	0.965-1.187	Raymond and Sims 1980
TDA	Coho	1997	PIT tag	no	Varied	64% spill	0.870	Dawley et al. 1998

Table 13. Continued.

Dam	Species and run type	Year	Method	Flow deflector	Location	Conditions (kcfs)	Survival	Reference
TDA	Coho	1998	PIT tag	no	Varied	64% spill	0.890	Dawley et al. 2000a
TDA	Coho	1998	PIT tag	no	Varied	30% spill	0.970	Dawley et al. 2000a
TDA	Coho	1999	PIT tag	no	Varied	64% spill	0.930	Dawley et al. 2000b
TDA	Coho	1999	PIT tag	no	Varied	30% spill	0.960	Dawley et al. 2000b
TDA	Subyearling chinook	1997	PIT tag	no	Varied	64% spill	0.920	Dawley et al. 1998
TDA	Subyearling chinook	1998	PIT tag	no	Varied	64% spill	0.750	Dawley et al. 2000a
TDA	Subyearling chinook	1998	PIT tag	no	Varied	30% spill	0.890	Dawley et al. 2000a
TDA	Subyearling chinook	1999	PIT tag	no	Varied	64% spill	0.960	Dawley et al. 2000b
TDA	Subyearling chinook	1999	PIT tag	no	Varied	30% spill	1.000	Dawley et al. 2000b
BON	Subyearling chinook	1974	Freeze brand	no	Bay 11	13	0.958	Johnsen and Dawley 1974
BON	Subyearling chinook	1974	Freeze brand	yes	Bay 14	13	0.868	Johnsen and Dawley 1974
BON	Subyearling chinook	1989	CWT/Freeze brand	yes	Bay 5	6.8	0.960	Ledgerwood et al. 1990

a. LGR, Lower Granite Dam; LGO, Little Goose Dam; LMO, Lower Monumental Dam; MCN, McNary Dam; JDD, John Day Dam; TDA, The Dalles Dam; BON, Bonneville Dam.

b. Flow deflector included dentates

c. NS, not specified

d. CWT, coded-wire tag

of predators (Gray and Rondorf 1986) and increase exposure time when predator consumption rates are higher (Beamesderfer et al. 1990, Rieman et al. 1991). Increases in digestion and consumption rates and increases in capture efficiencies by predators due to changes in environmental conditions during the summer migration may have been the primary factor resulting in lower relative survival versus the spring migrants (97.8 and 88.5%, respectively). Survival estimates for spring migrants were 14 and 8% higher than those for summer migrants passing through the spillway at The Dalles Dam under 64 and 30% spill, respectively during 1998 (Dawley et al. 2000a). However, spillway passage survival during 1997 and 1999 at The Dalles Dam identified higher survival for summer migrants than spring migrants (Dawley et al. 1998 and 2000b).

Relationships between flow, water temperature, turbidity, juvenile salmonid survival and predation in the lower Snake and Columbia River Basins are not well understood. In addition, the effects of spill operations (spill volume, spill patterns, and spill duration) on predation of smolts passing hydroelectric dams (i.e., increased vulnerability of smolts due to structures, back-eddies, or disorientation) remain critical uncertainties. In a multi-year study of spillway-passage survival trends at The Dalles Dam (1997-1999), relationships between passage survival for spring and summer migrants and changes in date, river flow, spill volume, tailwater elevation, or temperature were not evident (Dawley et al.1998, 2000a,b) . However, nighttime releases had significantly higher survival than daytime releases.

Similar to The Dalles spillway survival evaluations, we were unable to identify any meaningful relationships between spillway survival and tailwater elevation, release date, spill proportion, total river flow, water temperature, fish size, or spillway gate position for yearling or subyearling chinook salmon passing through the Ice Harbor Dam spillway during 2000.

RECOMMENDATIONS

1. The Ice Harbor Dam relative spillway passage survival evaluation for spring and summer migrants should be repeated in order to verify the 2000 findings.

2. Model testing at the COE Waterways Experiment Station should be conducted to identify any tailrace hydraulic conditions that may have led to lower relative survival estimates for summer migrants compared to spring migrants.

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APPENDICES

APPENDICES

Appendix A: Sample Size Estimation

For hatchery yearling chinook salmon, sample sizes were determined by evaluating PIT-tag detection data for hatchery yearling chinook salmon released into the tailrace of Lower Monumental Dam in 1999 and for hatchery yearling chinook salmon released into the Snake River in 1997 and 1998. Detection probabilities for PIT-tagged hatchery yearling chinook salmon released into the tailrace of Lower Monumental Dam, and detected at least once at McNary, John Day, or Bonneville Dams was 43, 58, and 52.6% in 1997, 1998, and 1999, respectively.

For sample size calculations, we used a recovery rate of 50.5%, which is an average of the recovery rates for 1998, a low-flow, relatively low-spill year, and 1997, a typical high-spill year. For hatchery yearling chinook salmon we calculated an expected mean square error (MSE, defined below) of 0.000258 based on 1999 detections.

For hatchery subyearling chinook salmon, sample sizes were determined by evaluating PIT-tag detection data for subyearling chinook salmon released in the Hanford Reach of the Columbia River in 1998. Detection probabilities for PIT-tagged subyearling chinook salmon released into the Hanford Reach, and detected at least once at McNary, John Day, or Bonneville Dams was 30% in 1998. For sample size calculations, we calculated a recovery percentages of 30% and an expected MSE of 0.000278 which was based on 1998 detections.

Using releases of 750 fish per location, sample size was calculated by

$$b = \frac{8 \times 2 \times MSE}{d^2 \times p^2}$$

where

b = the number of 750-fish paired release groups.

8 = the square of the sum of the t-values corresponding to $\alpha = 0.05$ and $\beta = 0.20$.

MSE = the expected mean squared error term of the ANOVA.

d = the desired detectable difference (proportional change in recovery percentage).

p = the overall mean recovery proportion.

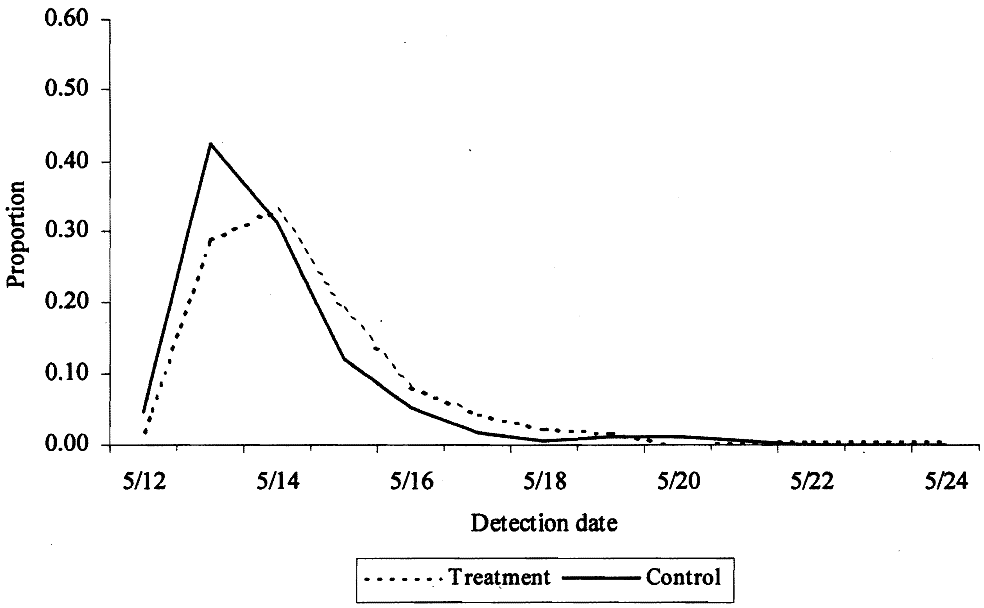
For hatchery yearling chinook salmon and detectable differences of 0.03, 0.04, or 0.05, the required number of 750-fish paired release groups is 18 (17.99 rounded to 18), 11 (10.1 rounded to 11), and 7 (6.4 rounded to 7), respectively (Appendix Table A1). To detect a 0.03 difference in recovery proportion between the release sites approximately 13,500 fish will be needed per release site, for a total of 27,000 hatchery yearling chinook salmon.

For hatchery subyearling chinook salmon and detectable differences of 0.03, 0.04, or 0.05, the required number of 750-fish paired release groups is 55 (54.9 rounded to 55), 31 (30.9 rounded to 31), and 20 (19.8 rounded to 20), respectively. To detect a 0.05 difference in recovery proportion between the release sites approximately 15,000 fish will be needed per release site, for a total of 30,000 hatchery subyearling chinook salmon.

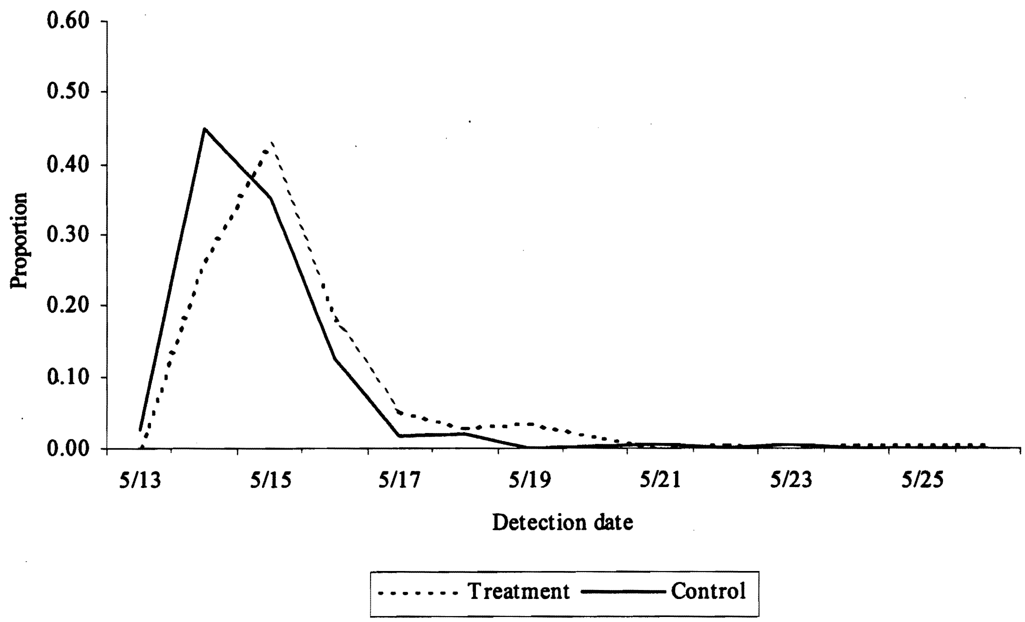
Appendix Table A1. The number of paired release groups (750 fish/group) of hatchery yearling and hatchery subyearling chinook salmon required per location (treatment and reference) and the total number of fish required (2 locations) for Ice Harbor Dam spillway survival evaluation.

Detectable difference	Recovery proportion	Number of release groups	Total number of fish required
Hatchery yearling chinook salmon			
3%	0.505	17.9	26,988
4%	0.505	10.1	15,180
5%	0.505	6.4	9,716
Hatchery subyearling chinook salmon			
3%	0.300	54.9	82,370
4%	0.300	30.9	46,333
5%	0.300	19.8	29,653

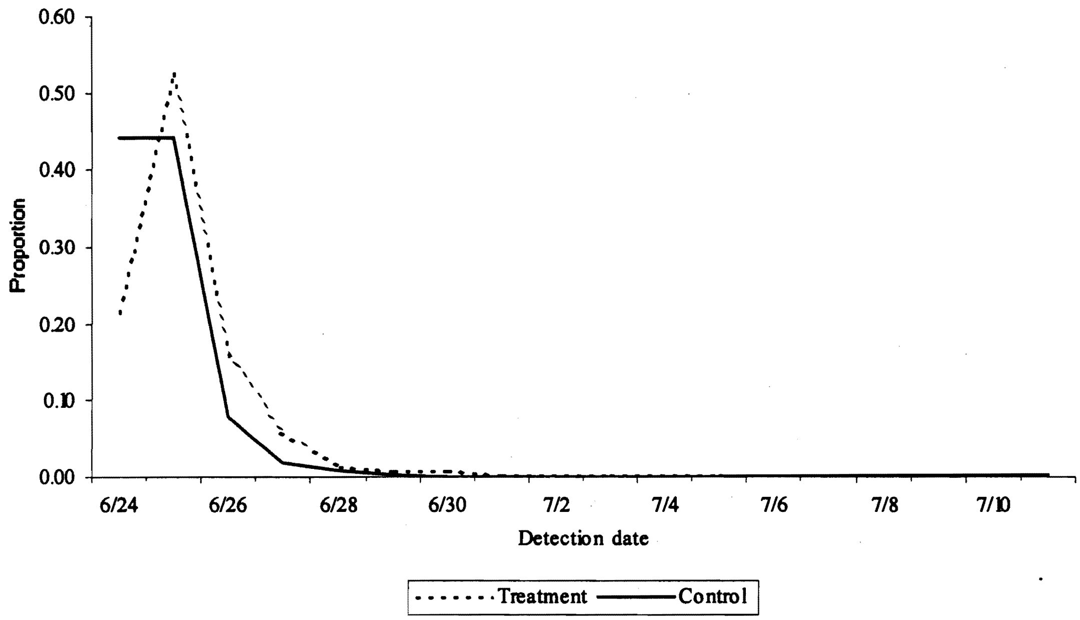
Appendix B: McNary Dam Passage Distributions for Release Groups with Significantly Different Passage Timing



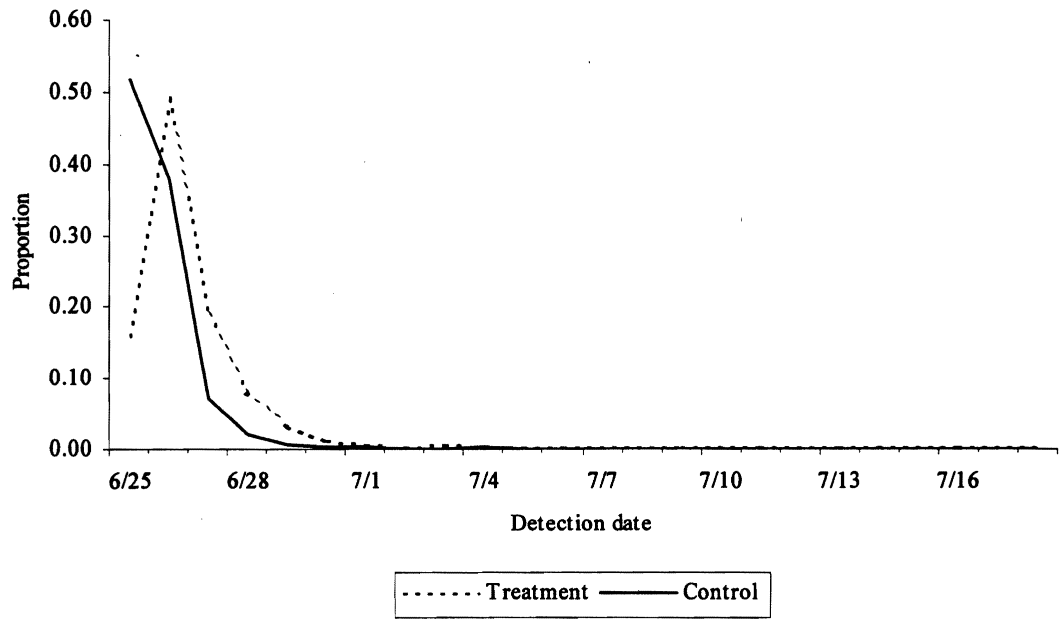
Appendix Figure B1. Passage distribution at McNary Dam for PIT-tagged hatchery yearling chinook salmon released at Ice Harbor Dam on 11 May 2000.



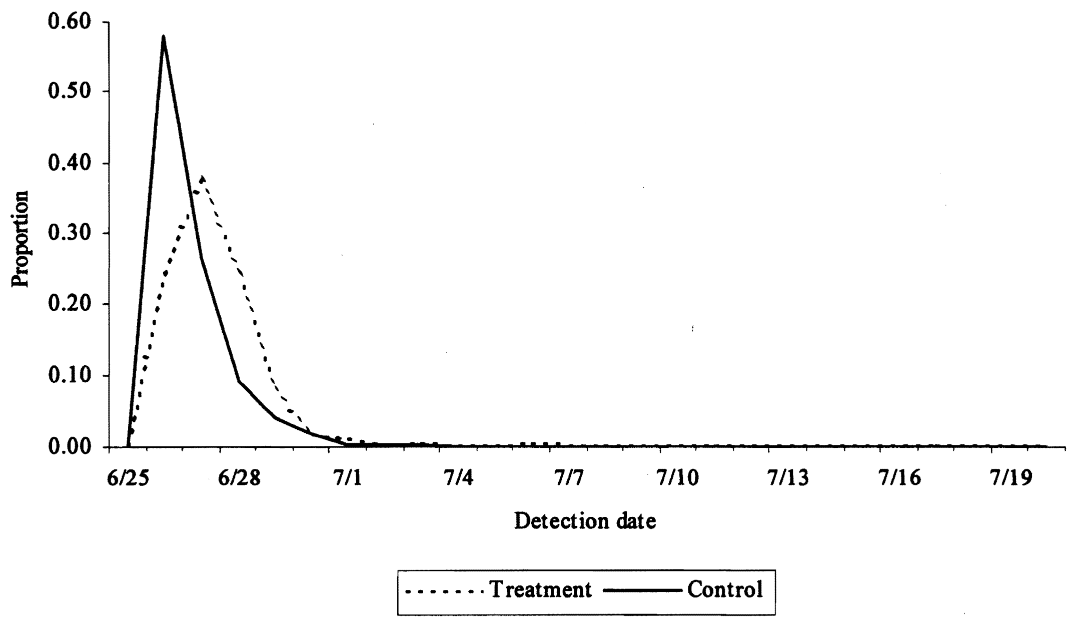
Appendix Figure B2. Passage distributions at McNary Dam for PIT-tagged hatchery yearling chinook salmon released at Ice Harbor Dam on 12 May 2000.



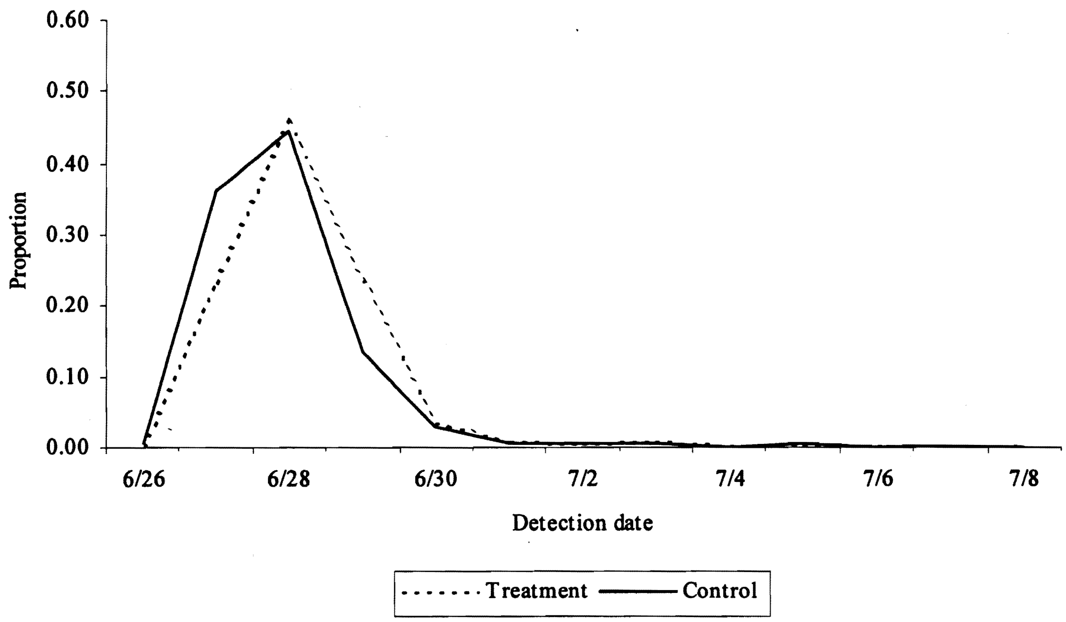
Appendix Figure B3. Passage distribution at McNary Dam for PIT-tagged hatchery subyearling chinook salmon released at Ice Harbor Dam on 22 June 2000.



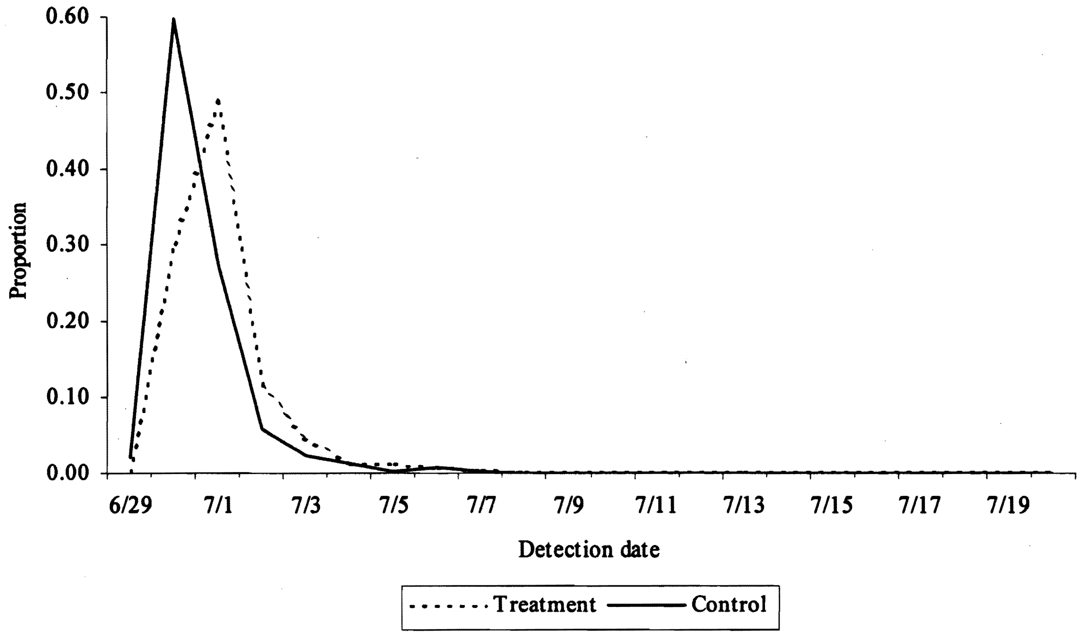
Appendix Figure B4. Passage distribution at McNary Dam for PIT-tagged hatchery subyearling chinook salmon released at Ice Harbor Dam on 23 June 2000.



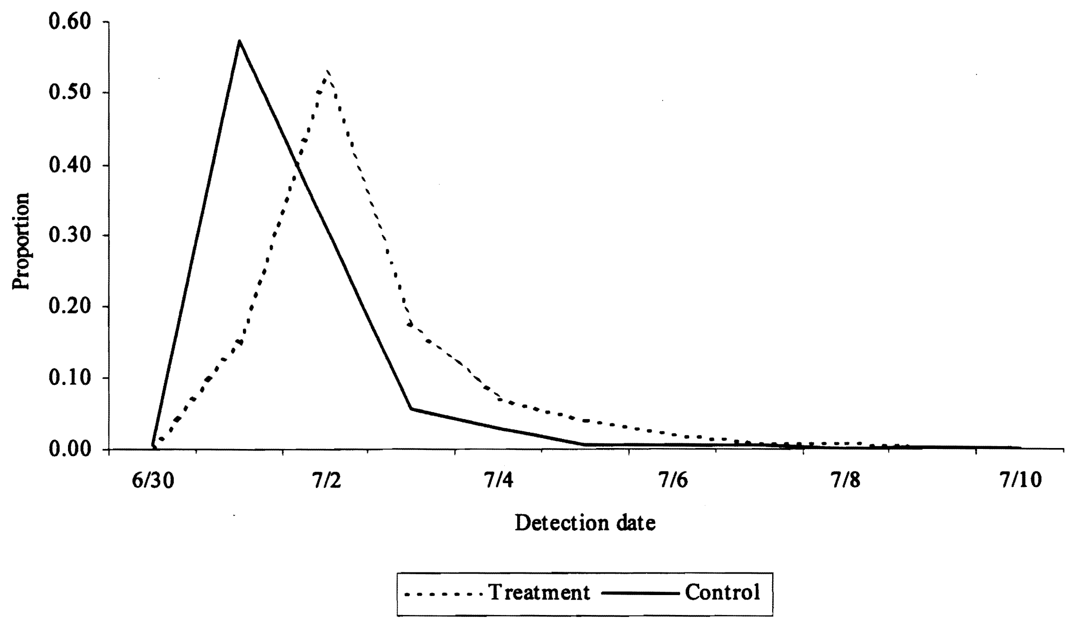
Appendix Figure B5. Passage distribution at McNary Dam for PIT-tagged hatchery yearling chinook salmon released at Ice Harbor Dam on 24 June 2000.



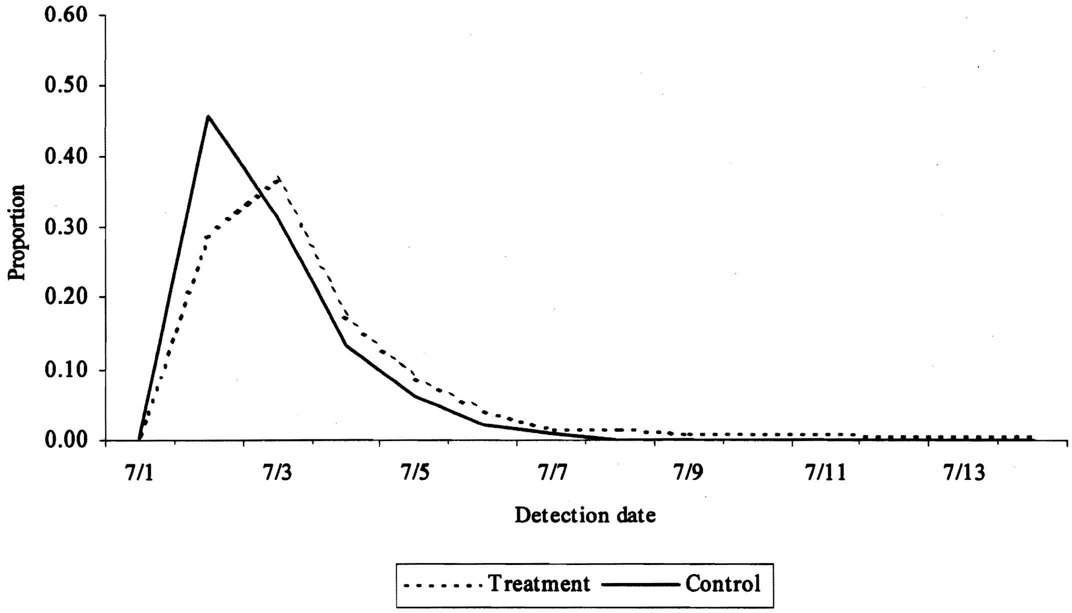
Appendix Figure B6. Passage distribution at McNary Dam for PIT-tagged hatchery subyearling chinook salmon released at Ice Harbor Dam on 25 June 2000.



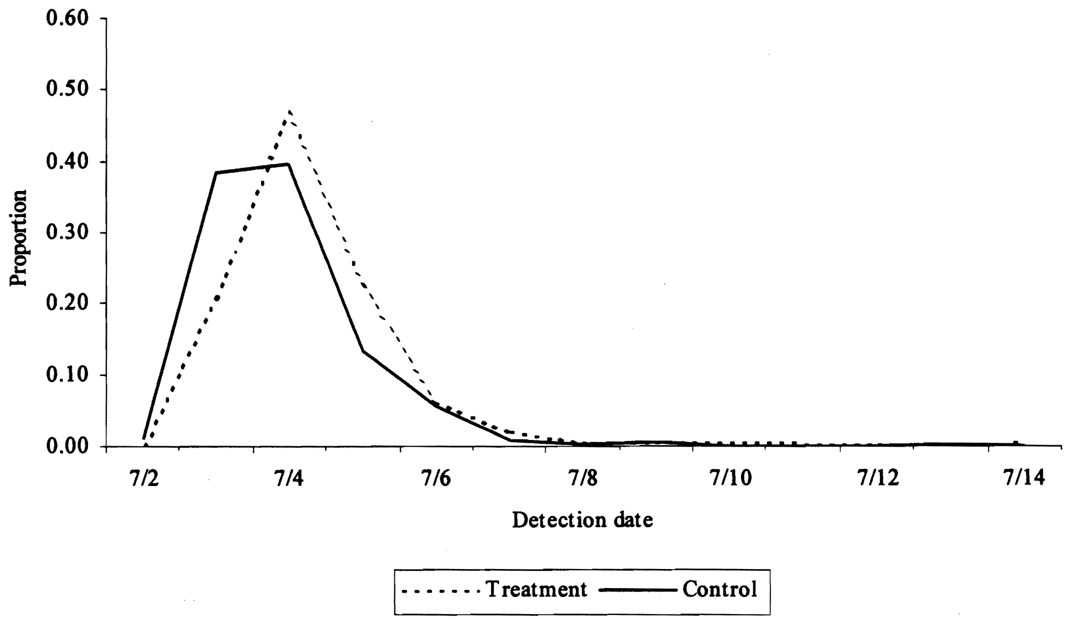
Appendix Figure B7. Passage distribution at McNary Dam for PIT-tagged hatchery subyearling chinook salmon released at Ice Harbor Dam on 28 June 2000.



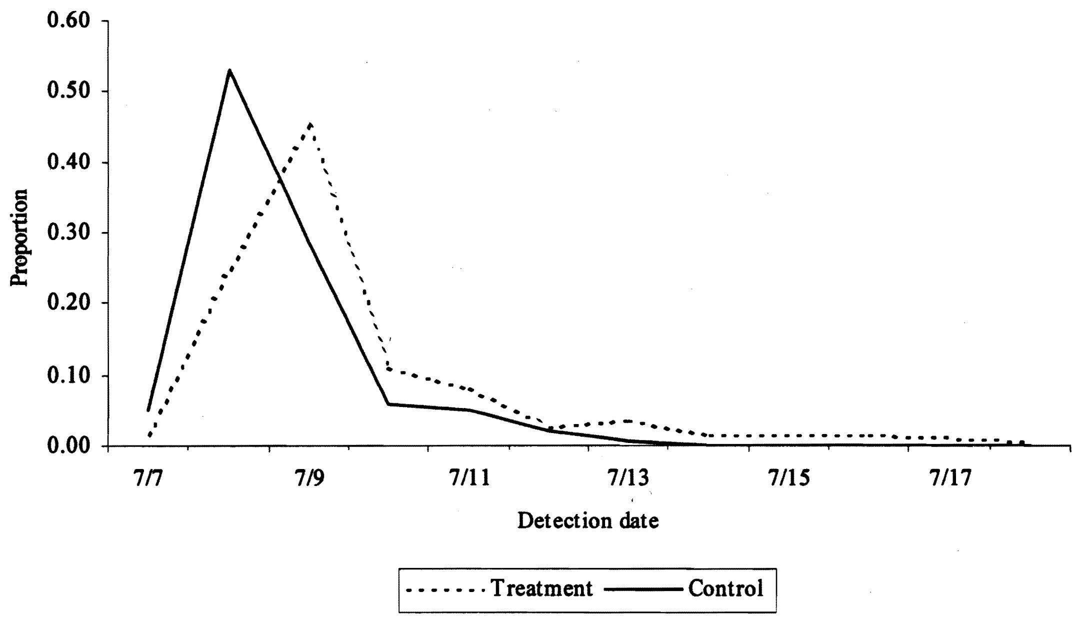
Appendix Figure B8. Passage distribution at McNary Dam for PIT-tagged hatchery subyearling chinook salmon released at Ice Harbor Dam on 29 June 2000.



Appendix Figure B9. Passage distribution at McNary Dam for PIT-tagged hatchery subyearling chinook salmon released at Ice Harbor Dam on 30 June 2000.



Appendix Figure B10. Passage distribution at McNary Dam for PIT-tagged hatchery subyearling chinook salmon released at Ice Harbor Dam on 01 July 2000.



Appendix Figure B11. Passage distribution at McNary Dam for PIT-tagged hatchery subyearling chinook salmon released at Ice Harbor Dam on 06 July 2000.

Appendix C: ANOVA for Estimated Relative Survival among Spillbays

Appendix Table C1. Relative weighted survival estimates (weights inverse of the respective sample variances) on the natural log scale (to normalize the relative survivals) and the back transformed means by release date and release location (spillbay) for hatchery yearling chinook salmon releases.

Release date	Spillbay	Log scale mean	Relative survival
5 May	3	-0.074	0.931
6 May	5	0.008	1.007
9 May	7	-0.053	0.947
10 May	3	-0.063	0.939
11 May	7	0.141	1.151
12 May	5	0.019	1.019
13 May	5	-0.088	0.915
16 May	7	-0.135	0.873
17 May	3	-0.154	0.858
18 May	5	-0.115	0.890
19 May	3	-0.009	0.992
20 May	7	-0.080	0.925
23 May	7	0.066	1.070
23 May	5	0.002	1.000
24 May	3	0.027	1.027
25 May	7	-0.219	0.802
26 May	3	0.092	1.098
27 May	5	0.038	1.039
31 May	3	0.021	1.023
Overall			
Spillbay 3		-0.0196	0.981
Spillbay 5		-0.0118	0.988
Spillbay 7		-0.0362	0.964

Appendix Table C2. Weighted ANOVA of relative survival with spillbay release location as a fixed factor for hatchery yearling chinook salmon releases.

Source	Degrees of freedom	Adjusted sum of squares	Adjusted mean square	*F*	*P*
Spillbay	2	0.317	0.159	0.11	0.896
Error	16	22.957	1.435		
Total	18	23.274			

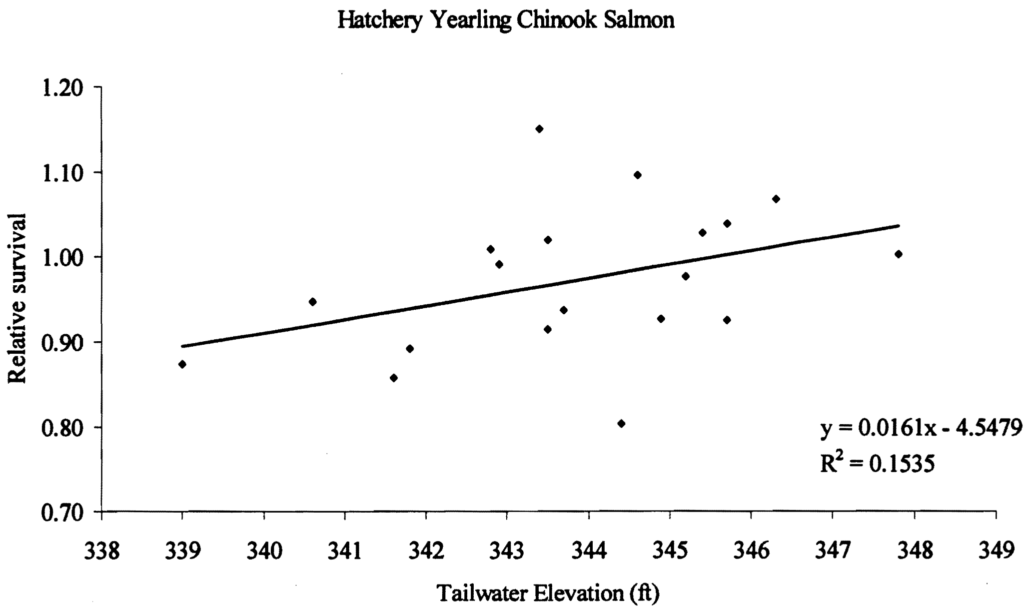
Appendix Table C3. Relative weighted survival estimates (weights inverse of the respective sample variances) on the natural log scale (to normalize the relative survivals) and the back transformed means by release date and release location (spillbay) for hatchery subyearling chinook salmon releases.

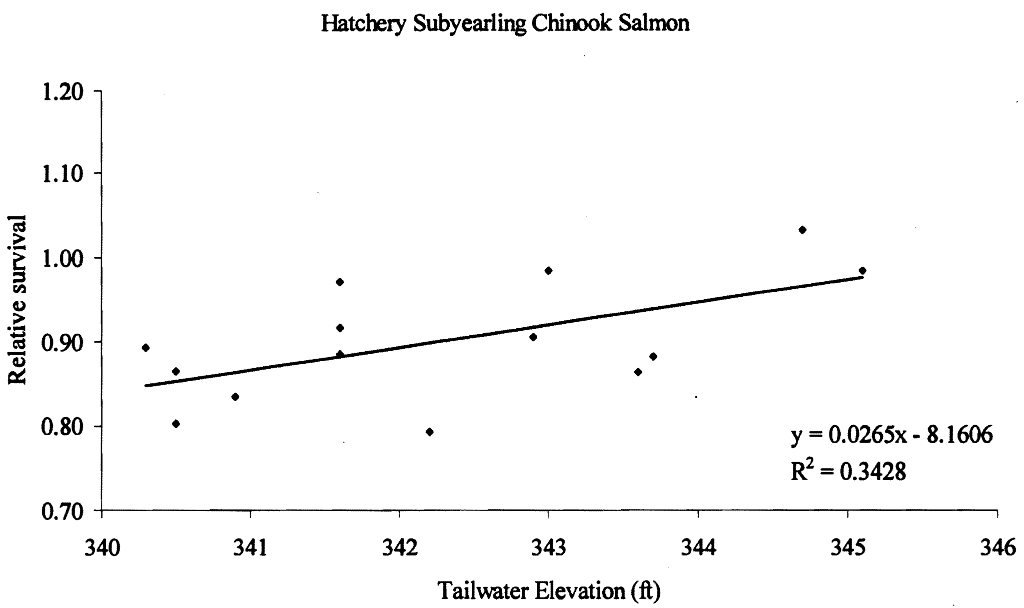
Release Date	Spillbay	Log scale mean	Relative survival
31 May	3	-0.017	0.984
2 June	7	-0.147	0.863
14 June	3	0.033	1.035
16 June	5	-0.129	0.880
20 June	7	-0.098	0.905
22 June	3	-0.016	0.983
23 June	5	-0.122	0.886
24 June	7	-0.181	0.835
25 June	5	-0.233	0.792
26 June	3	-0.030	0.969
28 June	7	-0.115	0.890
29 June	3	-0.112	0.894
30 June	5	-0.088	0.916
1 July	3	-0.145	0.865
6 July	7	-0.221	0.802
Overall			
Spillbay 3		-0.0759	0.927
Spillbay 5		-0.1448	0.865
Spillbay 7		-0.1530	0.858

Appendix Table C4. Weighted ANOVA of relative survival with spillbay release location as a fixed factor for hatchery subyearling chinook salmon releases.

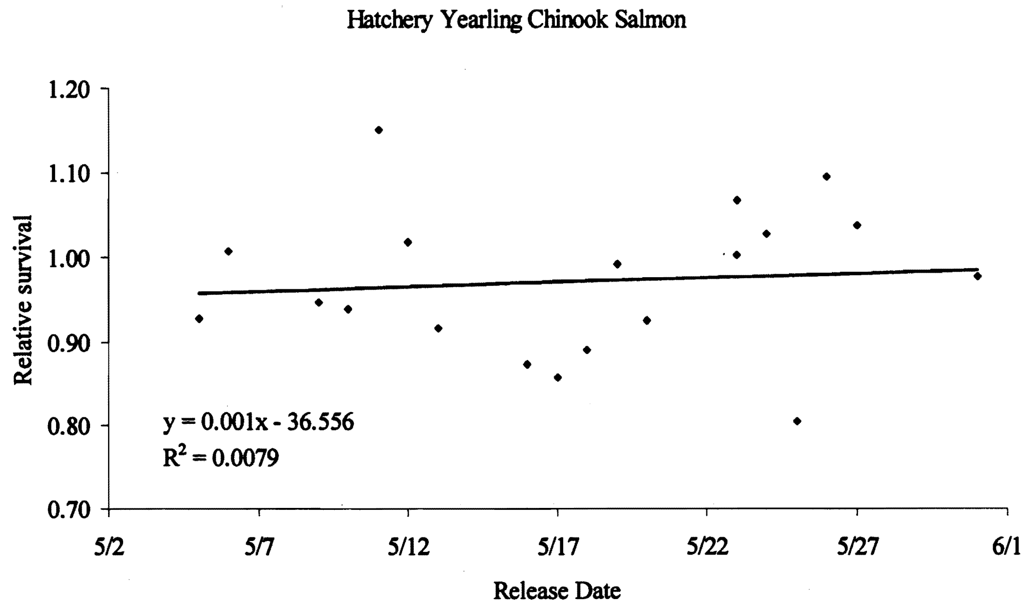
Source	Degrees of freedom	Adjusted sum of squares	Adjusted mean square	*F*	*P*
Spillbay	2	7.023	3.512	2.88	0.095
Error	16	14.618	1.218		
Total	18	21.642			

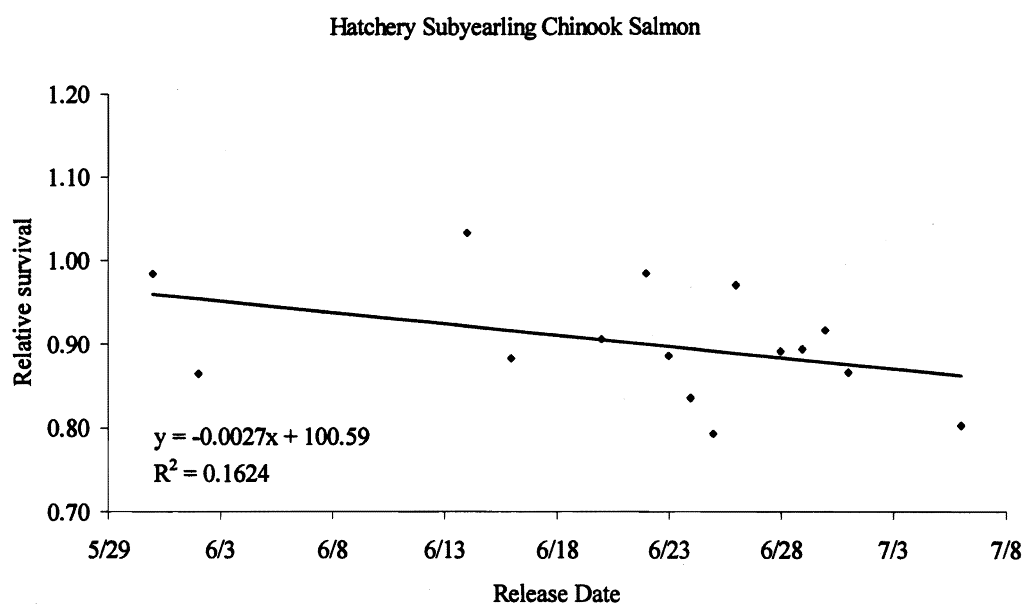
Appendix D: Correlations of Relative Spillway Passage Survival Versus Environmental Conditions at Time of Release



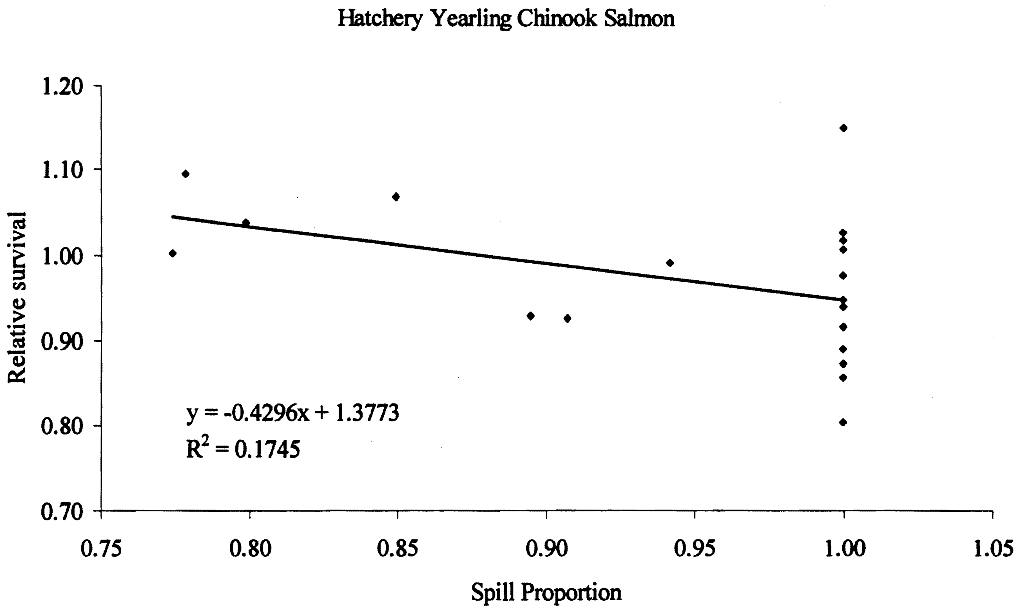


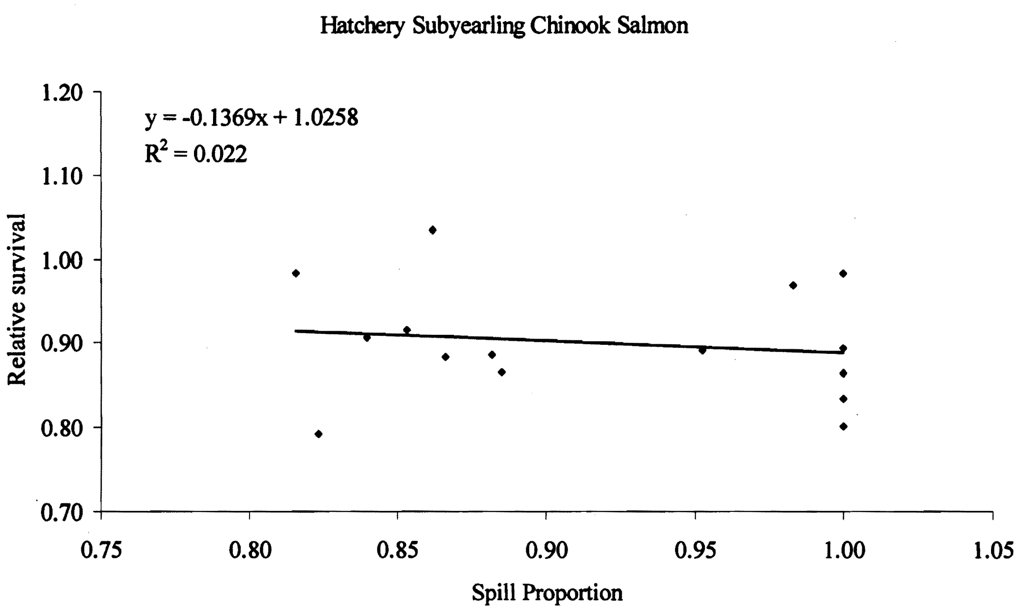
Appendix Figure D1. Estimated relative spillway passage survival by tailwater elevation at time of release for PIT-tagged hatchery yearling and subyearling chinook salmon released at Ice Harbor Dam, 2000.



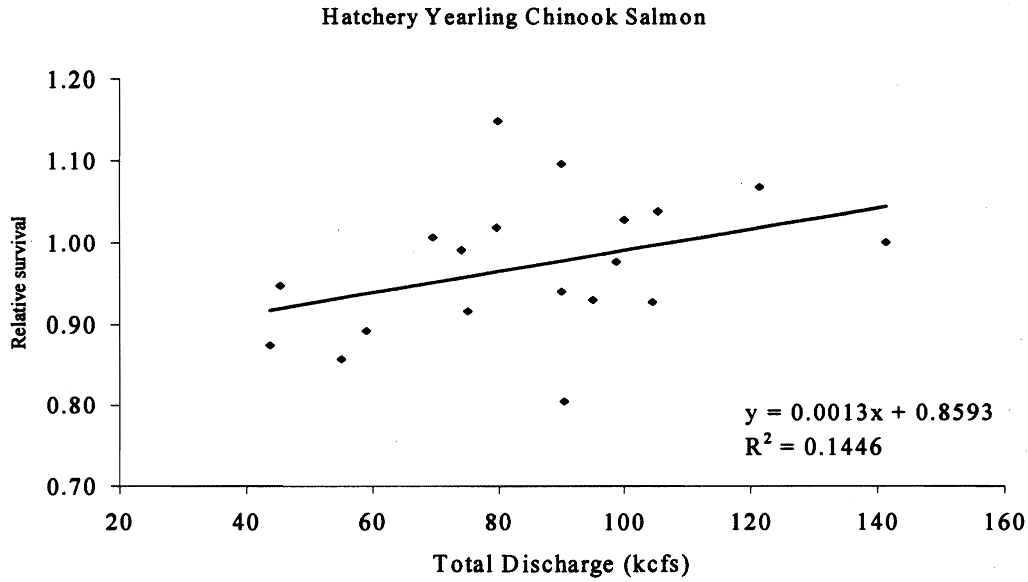


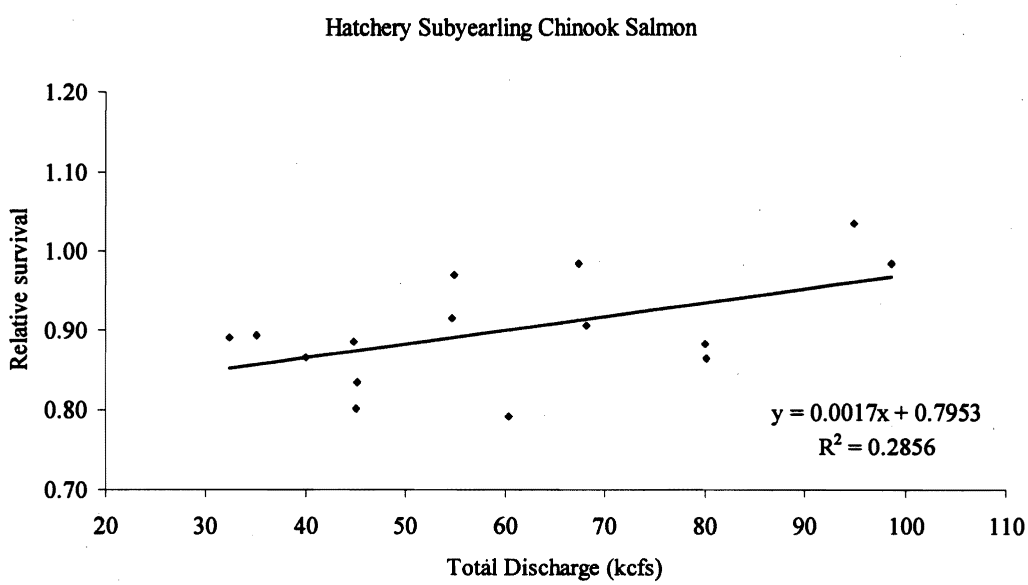
Appendix Figure D2. Estimated relative spillway passage survival by release date for PIT-tagged hatchery yearling and subyearling chinook salmon released at Ice Harbor Dam, 2000.



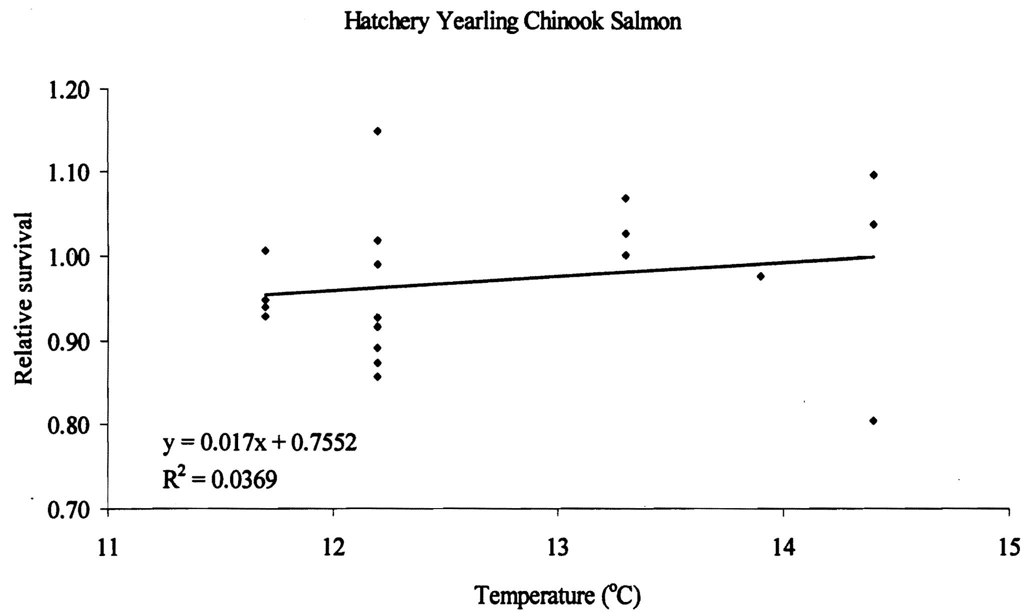


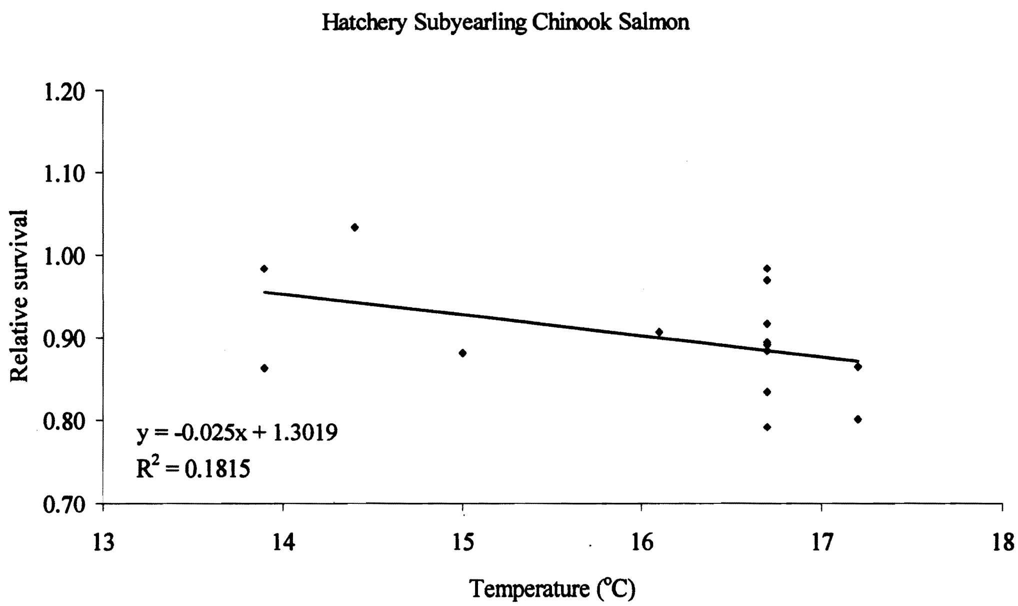
Appendix Figure D3. Estimated relative spillway passage survival by spill proportion for PIT-tagged hatchery yearling and subyearling chinook salmon released at Ice Harbor Dam, 2000.



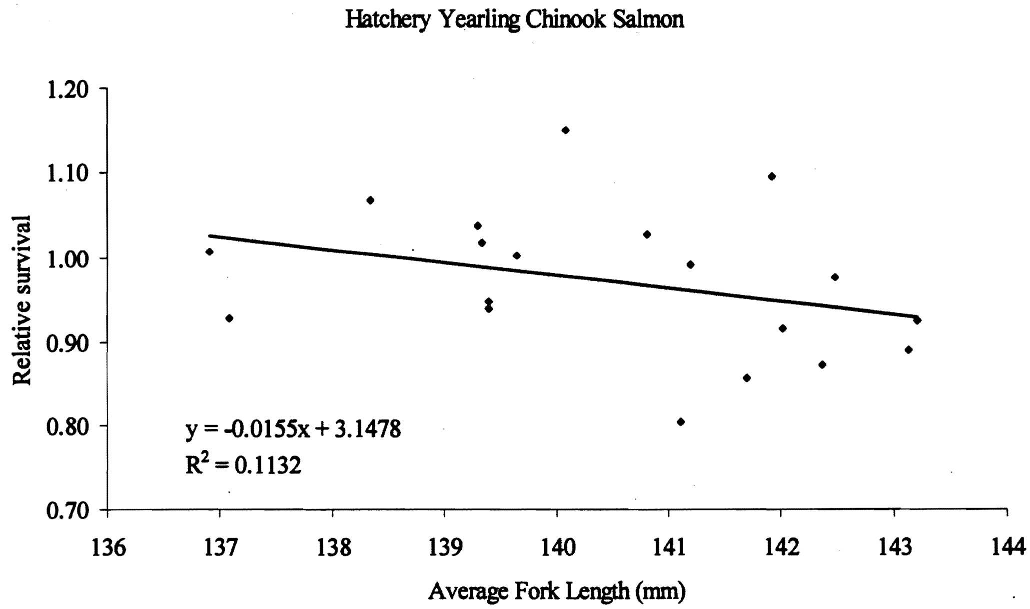


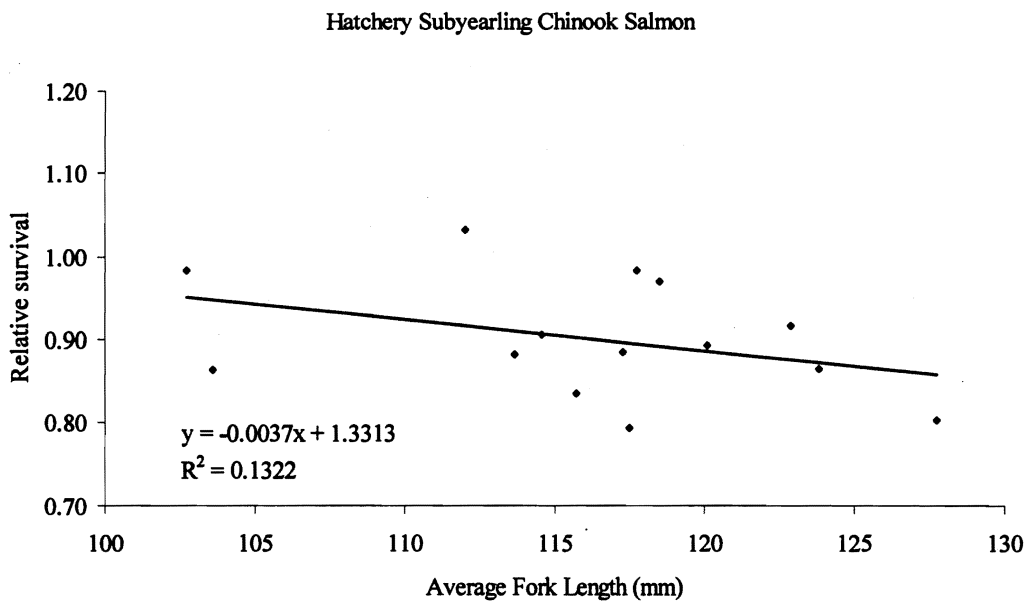
Appendix Figure D4. Estimated relative spillway passage survival by total dam discharge at time of release for PIT-tagged hatchery yearling and subyearling chinook salmon released at Ice Harbor Dam, 2000.



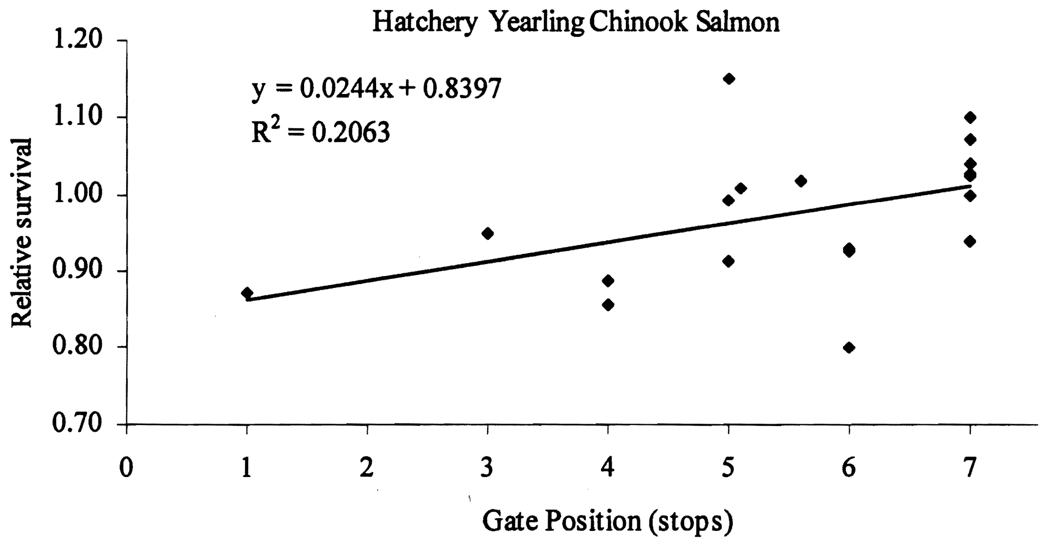


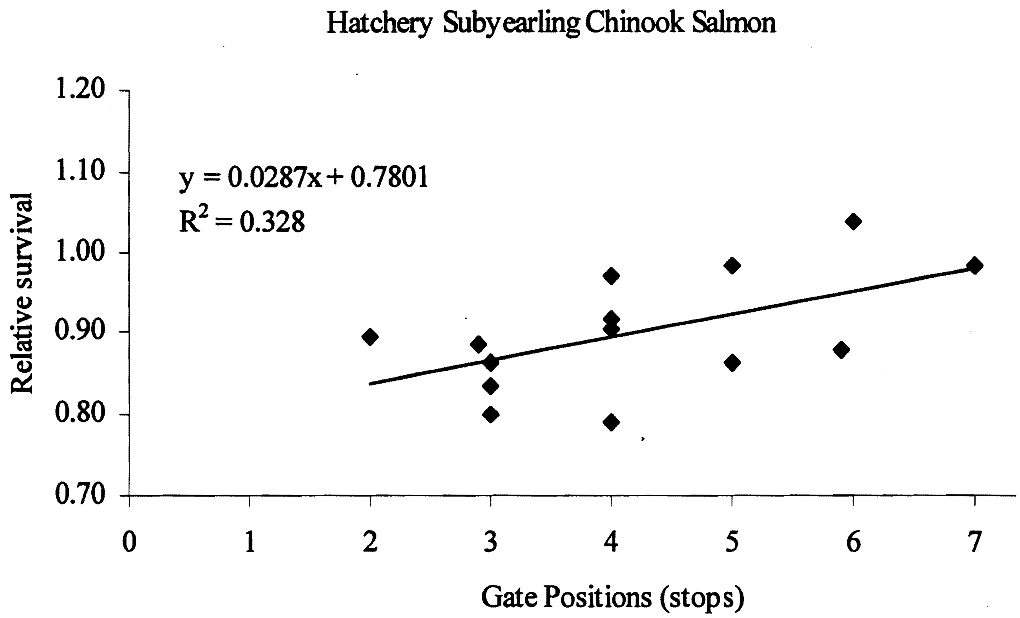
Appendix Figure D5. Estimated relative spillway passage survival by water temperature at time of release for PIT-tagged hatchery yearling and subyearling chinook salmon released at Ice Harbor Dam, 2000.





Appendix Figure D6. Estimated relative spillway passage survival by average fork length of each release group at time of tagging for PIT-tagged hatchery yearling and subyearling chinook salmon released at Ice Harbor Dam, 2000.





Appendix Figure D7. Estimated relative spillway passage survival by spillway gate position for each release group at time of release for PIT-tagged hatchery yearling and subyearling chinook salmon released at Ice Harbor Dam, 2000.