Relative survival estimates for PIT-tagged juvenile chinook salmon

passing through turbines, collection channels, and spillways at Ice Harbor Dam, 2003

Fish Ecology Division

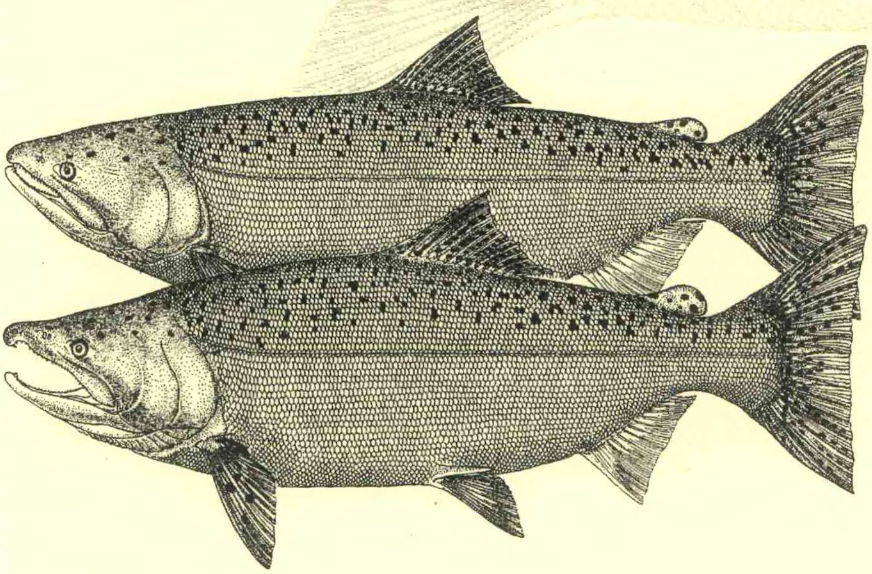
Northwest Fisheries Science Center

National Marine Fisheries Service

Seattle, Washington

by
Randall F. Absolon, Benjamin P. Sandford,
M. Brad Eppard, Dean A. Brege, Ken W. McIntyre,
Eric E. Hockersmith, and Gene M. Matthews

July 2005



Relative Survival Estimates for PIT-tagged Juvenile Chinook Salmon Passing through Turbines, Collection Channels, and Spillways at Ice Harbor Dam, 2003

Randall F. Absolon, Benjamin P. Sandford, M. Brad Eppard, Dean A. Brege,
Ken W. McIntyre, Eric E. Hockersmith, and Gene M. Matthews

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 98112-2097

to

Walla Walla District
Northwestern Division
U.S. Army Corps of Engineers
201 North 3rd
Walla Walla, Washington 99362-1876
Contract W68SBV92844866

July 2005

EXECUTIVE SUMMARY

Survival of juvenile salmonids through turbines at hydroelectric projects on the Columbia River has long been lower than desired. While other routes past hydroelectric projects, such as spillways and bypass systems, typically result in higher survival rates for juvenile salmonids, improving turbine survival could offer great benefits, especially in low flow years such as 2001. Studies to estimate turbine survival under current and potential operating conditions need to be undertaken. This study addresses turbine survival under the National Marine Fisheries Service Biological Opinion for the Federal Columbia River Power System and the Northwest Fisheries Science Center Salmon Research Plan.

There were two objectives for this study. The first was to evaluate relative survival of yearling hatchery Chinook salmon released into the collection channel and two turbine units at Ice Harbor Dam. This evaluation was conducted with river-run hatchery yearling Chinook salmon collected and PIT tagged at Little Goose Dam. At Ice Harbor Dam, releases were made to the collection channel, to turbine slots 1A and 3A, and to the tailrace about 1 km downstream from the dam. A total of 37 releases were made, with about 350 fish in each release group. For hatchery yearling Chinook salmon, point estimates of relative survival through the turbines and collection channel were 0.871 and 0.975, respectively. Relative survival through individual turbines was estimated at 0.888 for turbine unit 1A and 0.855 for turbine unit 3A.

The second objective was to evaluate relative survival of hatchery subyearling Chinook salmon released to the spillway, collection channel, and a turbine unit. This evaluation used river-run hatchery subyearling Chinook salmon collected and PIT tagged at Lower Monumental Dam. Twenty-four releases of approximately 525 fish per group were made at Ice Harbor Dam, with groups released into spillway slots 2-4, into the collection channel adjacent to turbine slot 6B, into turbine slot 1A, and into the tailrace about 1 km downstream from the dam. Releases were made in alternating 2-d blocks of spill and no spill, and spill volume was distributed among 2-3 spillbays (bulk pattern) rather than evenly across the spillway (BiOp pattern).

Point estimates of relative survival for hatchery subyearling Chinook salmon released into turbine units, the spillway, and the collection channel were 0.893, 0.964, and 0.997, respectively. Relative survival of subyearling Chinook salmon through spillways was estimated at 0.964 under the bulk spill pattern; this was higher than the estimates obtained in 2000 (0.885) and 2002 (0.894) under the BiOp spill patterns.

CONTENTS

EXECUTIVE SUMMARY iii

INTRODUCTION 1

OBJECTIVE 1: Evaluate Relative Survival of Yearling Chinook Salmon through the Turbines and Collection Channel 3
- Methods 3
- Statistical Analysis 4
- Results and Discussion 6

OBJECTIVE 2: Evaluate Relative Survival of Subyearling Chinook Salmon through the Spillway, Collection Channel, and Turbines 11
- Methods 11
- Statistical Analysis 13
- Results and Discussion 13

CONCLUSIONS 19

ACKNOWLEDGMENTS 20

REFERENCES 21

APPENDIX: Data Tables 25

INTRODUCTION

Survival of juvenile salmonids through turbines of hydroelectric projects on the Columbia River has long been lower than desired. While other routes past hydroelectric projects, such as spillways and bypass systems, typically result in higher survival rates for juvenile salmonids, improving turbine survival could offer great benefits, especially in low flow years such as 2001. Studies that estimate turbine survival under current and potential operating conditions need to be undertaken. This study addresses turbine survival under the National Marine Fisheries Service Biological Opinion for the Federal Columbia River Power System and the Northwest Fisheries Science Center Salmon Research Plan (NWFSC 2002).

There were two objectives for this study. The first was to evaluate relative survival of hatchery yearling Chinook salmon *Oncorhynchus tshawytscha* released into the collection channel and turbine units at Ice Harbor Dam. The second was to evaluate the relative survivals of subyearling Chinook salmon released into the spillway, collection channel, and turbine units at the dam.

OBJECTIVE 1: Evaluate Relative Survival of Yearling Chinook Salmon through the Turbines and Collection Channel

Methods

To estimate relative survival of juvenile yearling Chinook salmon through turbines and the collection channel at Ice Harbor Dam, we released groups of PIT-tagged hatchery yearling Chinook salmon into two turbine units, the collection channel, and the tailrace about 1 km downstream from the dam. River-run hatchery yearling Chinook salmon used in this study were collected at the Little Goose Dam juvenile fish facility by increasing the sample rate on the "A" (small fish) side of the juvenile collection system.

We operated two PIT-tagging stations (Prentice et al. 1990), with each station tagging into the same transport tank to eliminate any potential bias introduced by tagging differences between personnel. Fish were tagged into eight transport tanks on a trailer. To minimize bias from different fish holding time in each tank, we frequently rotated stations among the tanks, adding fish to each tank both earlier and later in the tagging session. We varied the location and diel release period on a daily basis to further minimize potential bias. Because of concerns with trying to keep tag files and tank delivery correct it was decided not to use a more randomized tagging sequence.

After tagging, fish were transported to Ice Harbor Dam and held on the intake deck with a supply of flow-through river water for 16 to 24 h prior to release. Water supply and temperature were continuously monitored while fish were being held. Immediately prior to release, we inspected tanks and removed any dead fish and loose tags.

Reference-release fish were transferred water-to-water via a 7.6-cm hose from the tagging tank to the release tank on a barge. Fish were then transported below Ice Harbor Dam and released at a time estimated to coincide with the passage of test groups released at the powerhouse based on the results of previous radio tag studies. To ensure fish were handled in the same manner, all test groups were also transferred water-to-water to another tank prior to release. The collection channel group was released through a 7.6-cm hose into the collection channel adjacent to turbine slot 6B. Turbine groups were released into slots 1A and 3A through a 7.6-cm hose which terminated in the center of the downstream edge of the submersible traveling screen (STS) frame. After each release, hoses were flushed to ensure all fish exited the hose and were released in the desired location.

Groups of approximately 350 fish each were released into the collection channel and turbine units 1A and 3A. These turbine units were selected because they are the priority units at Ice Harbor Dam and were consequently more likely to be on line when releases were made. The "A" slots of these units were selected because they have the highest flows of the three slots and thus would be expected to indicate the "worst case" conditions for juvenile salmonids. The reference-release site was approximately 1 km downstream from Ice Harbor Dam where fish were released from tanks carried on a barge. Releases were made both morning and evening on 20 d, from 29 April to 24 May. Median release time was 1053 PDT for morning releases and 1917 PDT for evening releases. Approximately equal numbers of fish were released in both the morning and evening each release day.

Releases to the collection channel and downstream reference site were made every release period; however, releases to turbine slots 1A and 3A were made only when those units were running. On many occasions only one of the two turbine units was running. In these cases, both tanks of fish designated for turbine release were released into the turbine unit that was running.

Statistical Analysis

The single-release model (Cormack 1964; Jolly 1965; Seber 1965) was used to estimate relative survival to McNary Dam tailrace for releases of yearling Chinook salmon at Ice Harbor Dam. Survival estimates were based on downstream PIT detections of study fish from McNary, John Day, and Bonneville Dams, as well as from the pair-trawl detection system in the estuary. The single-release model produces unbiased estimates if model assumptions are met (Zabel et al. 2002; Smith et al. 2003), particularly the assumption that detection and survival probabilities are not influenced by previous detections upstream.

We evaluated whether this assumption was met by testing the goodness-of-fit of observed data to the single-release model using the methods of Burnham et al. (1987). We constructed contingency tables of observed detections in each detection-history category and compared them with the expected values using chi-square goodness-of-fit tests (Table 1). We tested each daily release group and the groups overall. If more significant differences between observed and expected values were found than would be expected by chance, we examined the data to determine the nature of the violation and to see if there was consistency in the pattern of the violation.

Table 1. Chi-square contingency tables constructed for testing goodness-of-fit of the single-release model (used to estimate relative survival) to observed detection data (Burnham et al. 1987).

Test 2.C2	First site detected below McNary Dam	
df = 2	John Day Dam	Bonneville Dam
Not detected at McNary Dam	n_{11}	n_{12}
Detected/bypassed at McNary Dam	n_{21}	n_{22}

Test 3.SR3	Detected again at Bonneville Dam?	
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}

For the data encompassing release at Ice Harbor Dam and possible detection at McNary, John Day, and Bonneville Dams, we used the applicable tests presented by Burnham et al. (1987; Test 2.C2 and Test 3.SR3).

If the assumptions were met for Test 2.C2, the ratio of detected and non-detected fish at McNary Dam would be in constant proportion to ratios of detected and non-detected fish at John Day and Bonneville Dam (i.e., n_{11}/n_{12} and n_{21}/n_{22} should be equal). If the assumptions were met for Test 3.SR3, then for fish detected at Bonneville Dam, ratios of fish detected at John Day but not detected at McNary would be constant with ratios of fish detected at both John Day and McNary Dam.

Survival estimates were calculated using SURPH v. 2.1 (Survival Under Proportional Hazards) analytical software (Smith et al. 1994; Lady et al. 2001).

Weighted geometric mean relative survival was calculated by treatment using inverse relative variance for the weights (Muir et al. 2003, Ferguson et al. In prep), the geometric average is the same as the back-transformed arithmetic average of the log-transformed estimates. Ratios of binomial proportions are typically well-approximated by a log-normal distribution. This transformation also works to stabilize the variance (Snedecor and Cochran, 1980). Standard errors were calculated on the log-scale using the empirical replicate variablilty. Confidence intervals (95%) for each weighted mean survival estimate were made on the log scale, and the endpoints back-transformed.

We tested the assumption of mixing between treatment and reference groups (i.e., homogeneity of passage distributions at McNary Dam) with chi-square tests for each release date, using a Monte Carlo approximation of the exact method to calculate P-values (Mehta and Patel 1992). Significance was established at $P < 0.10$. Relative survival estimates for groups identified as not mixed were compared to those of mixed groups using a two-sample t-test.

Correlation coefficients were calculated for the relative survival estimates in independent variables (tailwater elevation, total river volume, spill volume, and water temperature), and stepwise linear regressions were conducted to evaluate the predictive potential of log-transformed survival ratios.

Results and Discussion

A total of 49,742 hatchery yearling Chinook salmon were released during this study. Of these, 12,528 were released into the collection channel; 9,985 were released into Turbine Slot 1A; 14,458 were released into Turbine Slot 3A; and 12,771 were released as reference groups downstream from Ice Harbor Dam. The numbers of fish released into turbine unit 1 in the morning and evening were 6,588 and 3,397, respectively. Fewer fish were released into turbine unit 1 because it was often not running during the evening release periods; when this occurred, the fish planned for release in turbine unit 1 were released into turbine unit 3. We released a total of 5,988 and 8,470 fish into turbine unit 3 during morning and evening releases, respectively. Totals of 6,111 and 6,417 fish were released into the collection channel during morning and evening releases, respectively. Totals of 6,360 and 6,411 fish were released as downstream reference fish during morning and evening releases, respectively.

A total of 25,976 unique tags (52.2 percent of released tagged fish) were detected by at least one of the downstream PIT-tag detection systems (Appendix Table 1).

In testing the detection data for goodness-of-fit to the single-release model, we found more significant differences in general than would be expected by chance for yearling Chinook salmon released in the spring of 2003. This indicated a violation of the assumption that downstream PIT-tag detection was independent of previous detection (Appendix Table 2). However, in nearly every case, the violation occurred because too few fish detected and bypassed at McNary Dam were subsequently detected at Bonneville Dam. This pattern indicated higher detection rates at Bonneville for fish detected at McNary Dam than for those not detected at McNary. Unfortunately, the degree of the violation and effect of the resultant bias on survival estimates are unknown and difficult to quantify. One mitigating factor was that the violation occurred in both treatment and reference (tailrace) groups, and we assumed the biases "cancelled" each other in the relative survival estimates. For Test 3.SR3, no violations of this assumption were found; the number of individual significant tests was no more than would be expected by chance (Appendix Table 3).

Point estimates of relative survival were 0.888 (95% CI, 0.840-0.939) for releases to turbine unit 1A, 0.855 (0.812-0.900) for releases to turbine unit 3A, and 0.975 (0.931-1.022) for releases to the collection channel. Combined turbine relative survival was 0.871 (0.832-0.913). Relative survival estimates for individual releases ranged from 0.774 to 1.230 through turbine unit 1A, from 0.723 to 1.085 through turbine unit 3A, and from 0.820 to 1.166 through the collection channel (Appendix Table 4).

During the release period of the study, total river flow ranged from 1,606 to 3,104 m^3/sec (56,700-109,600 ft^3/sec), and spill ranged from 827 to 2,815 m^3/sec (29,200-99,400 ft^3/sec; Appendix Table 5). Turbine loading ranged from 64.7 to 95.5 MW (9,100-13,100 cfs) for turbine unit 1 and from 59.1 to 96.4 MW (8,600-13,300 cfs) for turbine unit 3 during spring releases (Appendix Table 5).

Combined median travel time for all release groups from Ice Harbor Dam to McNary, John Day, and Bonneville Dams, and the pair-trawl detection system at Jones Beach was 2.1, 5.8, 7.9, and 9.7 d, respectively (Table 2).

Average median travel time from release to detection at McNary Dam, was 2.0 d for releases 1 km downstream from the tailrace (reference fish) and 2.2 d for releases to the collection channel, turbine unit 1, and turbine unit 3. Little difference in travel time was noted between day and night releases (Table 3). The shorter travel times for tailrace groups was expected because their distance traveled was shorter.

Table 2. Shortest, median, and longest travel times and the number of yearling Chinook salmon detected from all release groups combined. Travel time is from release at Ice Harbor Dam to detection at McNary, John Day, and Bonneville Dams and the pair-trawl detection system at Jones Beach.

Location		Travel time (d)	Number of fish
McNary Dam	Shortest	1.0	
	Median	2.1	17,801
	Longest	51.6	
John Day Dam	Shortest	2.7	
	Median	5.8	9,916
	Longest	48.5	
Bonneville Dam	Shortest	4.7	
	Median	7.9	4,977
	Longest	45.4	
Jones Beach	Shortest	4.6	
	Median	9.7	869
	Longest	29.1	

Table 3. Median travel times (in days), for yearling Chinook salmon from time of release at Ice Harbor Dam to detection at McNary Dam, by release date, location, and diel period.

	1 km downstream from tailrace			Collection channel			Turbine unit 1			Turbine unit 3		
Rel. date	Day	Night	Comb.	Day	Night	Comb.	Day	Night	Comb.	Day	Night	Comb.
4/29	2.3	2.5	2.4	3.0	2.8	2.9	3.0	--	3.0	2.5	2.7	2.7
4/30	2.5	2.5	2.5	3.1	2.6	2.7	3.1	2.7	2.9	3.0	2.8	2.8
5/1	2.3	2.4	2.3	2.5	2.4	2.5	2.7	2.5	2.6	2.7	2.5	2.5
5/2	2.4	2.0	2.3	3.0	2.5	2.6	2.5	--	2.5	2.8	2.5	2.6
5/3	2.0	1.8	1.9	2.2	2.0	2.1	2.2	--	2.2	--	2.0	2
5/6	2.0	2.0	2.0	2.5	2.3	2.4	2.5	--	2.5	2.5	2.5	2.5
5/7	2.4	2.2	2.3	2.5	2.4	2.5	3.0	--	3	2.6	2.3	2.5
5/8	1.9	2.0	1.9	2.1	1.9	2.0	2.1	2.1	2.1	2.2	2.1	2.1
5/9	2.1	1.9	2.0	2.3	2.0	2.1	2.3	2.1	2.3	2.2	2.1	2.2
5/10	2.3	1.9	2.1	2.2	2.0	2.1	2.3	2.1	2.3	2.2	2.1	2.1
5/13	1.8	1.9	1.8	2.1	1.9	2.0	2.0	--	2	2.2	1.9	2.1
5/14	1.8	1.6	1.7	1.8	1.8	1.8	1.9	--	1.9	1.8	1.8	1.8
5/15	1.7	1.6	1.7	1.8	1.7	1.8	1.8	--	1.8	1.8	1.9	1.9
5/16	1.7	1.6	1.6	1.8	1.8	1.8	1.9	1.7	1.8	1.8	1.7	1.8
5/17	1.8	1.6	1.7	1.9	1.7	1.8	2.0	--	1.9	1.9	--	1.9
5/20	1.8	1.8	1.8	1.9	1.9	1.9	1.9	1.9	1.9	2.0	--	2.0
5/21	1.8	1.7	1.7	1.9	1.9	1.9	1.9	--	1.9	1.9	1.9	1.9
5/23	1.9	1.7	1.8	2.0	1.8	1.9	2.0	--	2	2.0	1.9	1.9
5/24	1.9	--	1.9	--	--	--	2.0	--	2	2.0	--	2.0
Avg:	2.0	1.9	2.0	2.2	2.1	2.2	2.3	2.2	2.2	2.2	2.2	2.2

Travel time tended to decrease over the study period, but did not correlate to tailwater elevation, total river flow, or river temperature. There were also no strong correlations between relative survival estimates and release date, tailwater elevation, total river flow, river temperature, or turbine unit 3 load (Appendix Table 6). We selected turbine unit 3 load for the comparison because that unit was operated more frequently than turbine unit 1, so more data were available.

We used chi-square tests to determine if release groups were mixed upon arrival at McNary, John Day, and Bonneville Dams (there was insufficient data from the pair-trawl detection system to evaluate mixing). Results of these tests showed that most releases were mixed on arrival at McNary Dam (Appendix Table 7). Among releases that were not mixed, the tailrace group arrived earlier than the collection channel and turbine groups in every instance except one, when none of the groups were mixed.

Most of the groups arriving at John Day and Bonneville Dams were also mixed. However, because there were fewer detections at these dams, results were less reliable and varied considerably from those seen at McNary Dam. The results indicated that some releases that had been mixed at McNary Dam were not mixed at John Day or Bonneville Dams. This was likely due to the smaller detection numbers at downstream dams, resulting in sparse and/or patchy data.

Therefore, we did not consider these results as an indication that SR model assumptions had been violated. Little difference between mixed and unmixed groups was evident in detection timing at McNary Dam (Appendix Table 8).

OBJECTIVE 2: Evaluate Relative Survival of Subyearling Chinook Salmon through the Spillway, Collection Channel, and Turbines

Methods

To estimate relative survival of juvenile subyearling Chinook salmon through passage routes at Ice Harbor Dam, we released groups of PIT-tagged fish to the spillway, collection channel, and turbines. Groups of reference fish were also released to the tailrace, about 1-km downstream from the dam. Releases were river-run hatchery subyearling Chinook salmon collected at Lower Monumental Dam by increasing the sample rate on the "A" side (small fish side) of the juvenile collection system.

Two PIT-tagging stations were utilized, each tagging into a separate tank. Fish were routed directly from the tagging station to the transport tank. The release location and diel release period of the tanks was varied daily to minimize any potential bias between personnel. Tanks were initially filled from front to back on the trailer and then more fish added to each tank depending on fish numbers to minimize any potential bias due to tank tagging order. It was decided not to further randomize the tagging because of concerns with maintaining the integrity of the tagging data.

After tagging, fish were transported to Ice Harbor Dam, where they were held on the intake deck with a supply of flow-through river water for 16-24 h prior to release. Water supply and temperature were continuously monitored while fish were being held. Immediately prior to release, tanks were inspected, and any dead fish and loose tags were removed.

Ice Harbor Dam was operated in two-day blocks during the test period: two days of no spill were alternated with two days spill. This block pattern was established for other research projects conducted during the same time period as this study. Spill volumes were in accordance with those recommended in the 2000 Federal Columbia River Power System Biological Opinion (BiOp; NMFS 2000), although the spill pattern differed. While the BiOp calls for spill to be spread evenly across all 10 spillbays, spill was concentrated into 2 to 4 spillbays for this evaluation. This spill pattern (referred to as "bulk spill") was used in an attempt to increase relative survival over that found using BiOp spill pattern in 2000 and 2002 (Eppard et al. 2002, 2005).

During two-day periods of no spill, releases were made into the turbine unit, collection channel, and tailrace during both morning and evening. During two-day periods of spill, morning releases were made into the spillway, collection channel, turbine unit, and tailrace. However, because the BiOp calls for 100% spill during evening, evening releases during periods of spill were made only to the spillway and tailrace.

On a few occasions near the end of the test period, we could not obtain sufficient numbers of fish for tagging. When that occurred, either a morning or an evening release was omitted.

Releases were made on fifteen days from 24 June through 12 July. Approximately equal numbers of fish were released in both the morning and evening each release day. The median release time was 1053 PDT for morning releases and 1912 PDT for evening releases.

Groups of approximately 500 fish each were released into the spillbays, collection channel, turbine unit 1A, and at a reference release site approximately 1-km downstream from Ice Harbor Dam. Spillbay releases were made into each open spillbay, with the total number of fish released similar to the other release locations.

Spillway releases were made in the same manner as in 2000 and 2002 for this study (Eppard et al. 2002, 2005). A crane lowered the release tank close to the surface in the center of the spillbay within 3 m of the upstream face of the dam. High water velocity in the spillway at the higher spillbay openings prevented the weighted release hose from being placed deeper than approximately 2 m below water level. The tank was watched at the time of release to ensure all fish had exited during the release.

Collection channel and turbine release groups were transferred to a release tank and released through a 7.6-cm hose. After these releases, the hoses were flushed to ensure all fish exited the hose into the release location.

Fish for reference releases were transferred water-to-water via a 7.6-cm hose from the tagging tank to a tank on the barge. They were then transported and released approximately 1-km downstream from Ice Harbor Dam in the same location used for the spring reference releases. Fish were released at a time estimated to coincide with the passage of test groups released at the powerhouse. To ensure fish were handled the same manner, all test groups were also transferred water-to-water to another tank prior to release.

Statistical Analysis

The complete capture history protocol of Burnham et al. (1987) was used to estimate survival by applying the single-release model (Cormack 1964, Jolly 1965, Seber 1965, Skalski et al. 1998) independently to each release group. The same tests, 2.C2 and 3.SR3, and methodology described for Objective 1 were used for this analysis of detection data. Analyses were conducted using SURPH statistical software developed at the University of Washington (Smith et al. 1994; Lady et al. 2001).

Correlation coefficients were calculated for the relative survival estimates of independent variables (tailwater elevation, total river volume, spill volume, and water temperature), and stepwise linear regressions were conducted to evaluate the predictive potential of log-transformed survival ratios.

We tested the assumption of mixing between treatment and reference groups (i.e., homogeneity of passage distributions at McNary Dam) with chi-square tests for each release date, using a Monte Carlo approximation of the exact method to calculate P-values (Mehta and Patel 1992). Significance was established at $P < 0.10$. Relative survival estimates for groups identified as not mixed were compared to those of mixed groups using a two-sample t-test.

Results and Discussion

A total of 33,709 hatchery subyearling Chinook salmon were released. Of these, 7,315 were released into the spillway, 6,872 into the collection channel, 6,934 into turbine units and 12,588 were released 1 km downstream from Ice Harbor Dam. A total of 22,312 unique tags (66.2% of released fish) were detected by at least one downstream PIT-tag detection system (Appendix Table 9).

In testing for goodness-of-fit of detection data to the single-release model, we found that in general, for subyearling Chinook salmon, only a few results of Test 2.C2 indicated a violation of the assumption that one detection affected subsequent detection or survival probabilities (Appendix Table 10). Thus, there was little evidence of bias in survival estimates or of violations of model assumptions overall. No violations of assumptions were found using Test 3.SR.3; the number of significant tests between observed and expected values was no more than expected by chance (Appendix Table 11).

Collection channel and turbine releases were conducted daily from 24 June-4 July. Spill releases were made in 2-day on/2-day off blocks from 24 June-4 July and three additional releases were made from 9-12 July. Because of this temporally unbalanced design, analysis with all three treatments did not incorporate release date as a factor. This unbalanced design was due to an insufficient number of fish that were available for tagging, and the decision was made to bolster the precision of the spillway release location.

Point estimates of relative survival (95% CI) were 0.964 (0.905-1.026) for spillway fish, 0.997 (0.959-1.036) for collection-channel fish, and 0.893 (0.849-0.941) for turbine fish. Relative survival estimates ranged from 0.888 to 1.213 for spillway fish, from 0.824 to 1.063 for turbine fish, and 0.873 to 1.098 for collection-channel fish (Appendix Table 12).

Under the "no spill" condition, point estimates of relative survival were 0.999 (95% CI, 0.948-1.052) for collection-channel groups and 0.886 (0.799-0.982) for turbine groups. Under spill conditions, the point estimates of relative survival were 0.992 (0.897-1.097) and 0.910 (0.854-0.970) for the collection channel and turbines, respectively (Appendix Table 12).

In 2003, relative survival of subyearling Chinook salmon through the spillways was estimated at 0.964 (95%CI, 0.905-1.026) under bulk spill; this was higher than estimates obtained in 2000 and 2002, which used the same release methods under BiOp spill patterns. Those estimates were 0.885 (0.856-0.915) in 2000 and 0.894 (0.856-0.932) in 2002 (Eppard et al. 2002, 2005).

Total river flow ranged from 292 to 2,294 m^3/sec (10,300-81,000 ft^3/sec), and average spill ranged from 0 to 1,274 m^3/sec (0-45,000 ft^3/sec) during the study period (Appendix Table 13). No strong correlations between relative survival and release date, tailwater elevation, total river flow, and river temperature were noted for any of the three treatment release locations. In addition, no strong correlations between travel time and release date, tailwater elevation, total river flow, or river temperature were noted (Appendix Table 14).

Combined median travel times for all release groups from Ice Harbor Dam to McNary, John Day, and Bonneville Dams were 2.5, 6.4, and 8.5 d, respectively. Travel times ranged from 1.1 to 40.6 d from Ice Harbor Dam to McNary Dam, from 3.7 to 38.5 d to John Day Dam, and from 5.5 to 34.1 d to Bonneville Dam (Table 4). Average median travel time from time of release to detection at McNary Dam was 2.4 d for tailrace releases, 2.5 d for collection-channel releases, 2.6 d for spillway releases, and 2.5 d for turbine releases. As occurred during the spring study, little difference was noted between day and night releases (Table 5).

Table 4. Shortest, median, and longest travel times and the numbers of subyearling Chinook salmon detected from all release groups combined. Travel times are from release at Ice Harbor Dam to detection at McNary, John Day, and Bonneville Dams.

Location		Travel time (d)	Number of fish
McNary Dam	Shortest	1.1	
	Median	2.5	21,102
	Longest	40.6	
John Day Dam	Shortest	3.7	
	Median	6.4	2,715
	Longest	38.5	
Bonneville Dam	Shortest	5.5	
	Median	8.5	2,701
	Longest	34.1	

Table 5. Median travel times (in days), of subyearling Chinook salmon from time of release at Ice Harbor Dam to detection at McNary Dam, by release date, location, and diel period.

Rel. date	1 km downstream from tailrace			Collection channel			Spillway			Turbine		
	Day	Night	Comb.	Day	Night	Comb.	Day	Night	Comb.	Day	Night	Comb.
6/24	2.2	2.3	2.2	2.5	--	2.5	2.5	2.6	2.5	2.5	--	2.5
6/25	2.9	--	2.9	2.9	--	2.9	2.5	2.7	2.5	2.9	--	2.9
6/26	2.5	2.4	2.5	2.5	2.5	2.5	--	--	--	2.7	2.5	2.6
6/27	2.3	2.5	2.5	2.6	2.6	2.6	--	--	--	2.5	2.6	2.6
6/28	2.2	2.5	2.4	2.3	--	2.3	2.3	2.6	2.5	2.3	--	2.3
6/29	2.1	2.1	2.1	2.2	--	2.2	2.2	2.4	2.3	2.2	--	2.2
6/30	2.2	2.1	2.2	2.2	2.1	2.2	--	--	--	2.2	2.2	2.2
7/1	2.2	2.6	2.5	2.5	2.6	2.5	--	--	--	2.2	2.6	2.4
7/2	2.4	--	2.4	--	--	--	2.6	--	2.6	--	--	--
7/3	2.1	2	2.1	2.2	--	2.2	2.2	2.3	2.2	2.2	--	2.2
7/4	2.5	--	2.5	2.7	--	2.7	--	--	--	2.8	--	2.8
7/9	2.2	--	2.2	--	--	--	2.3	--	2.3	--	--	--
7/11	3.9	--	3.9	--	--	--	3.9	--	3.9	--	--	--
7/12	--	2.5	2.5	--	--	--	--	2.5	2.5	--	--	--
Avg:	2.4	2.3	2.4	2.5	2.5	2.5	2.6	2.5	2.6	2.4	2.5	2.5

We used a chi-square test to determine if release groups were mixed upon arrival at McNary, John Day, and Bonneville Dams. Results showed that just over half of the releases were mixed on arrival at McNary Dam (Appendix Table 15). Among releases that were not mixed on arrival at McNary Dam, the tailrace group arrived earlier than other groups in every instance except one, in which the turbine group arrived later than the tailrace and collection-channel groups. All release groups were mixed on arrival at the downstream dams except one group at John Day and a separate group at Bonneville Dam.

Results of these mixing tests indicate that when differences in arrival to McNary Dam were noted, it was generally because tailrace fish arrived less than a day earlier than turbine or collection-channel fish. Therefore, it is doubtful that the level of non-mixing for these groups resulted in violations of model assumptions. As was the case with the spring releases, little difference between mixed and unmixed groups was evident in detection timing at McNary Dam (Appendix Table 16).

CONCLUSIONS

1. Relative survival estimates for hatchery yearling Chinook salmon were 0.871 and 0.975 through the Ice Harbor Dam turbine units and collection channel, respectively.

2. Relative survival estimates for hatchery subyearling Chinook salmon for spill and no-spill blocks combined were 0.893, 0.964, and 0.997 through the turbine units, spillway, and collection channel, respectively.

3. Relative survival estimates for subyearling Chinook salmon during the no-spill condition were 0.886 and 0.999 for the turbine units and collection channel, respectively.

4. Relative survival estimates for subyearling Chinook salmon during the spill condition were 0.910 and 0.992 for the turbine units and collection channel, respectively.

5. The bulk spill pattern evaluated in 2003 provided higher point estimates of relative survival than were observed in 2000 and 2002 under the BiOp spill pattern.

ACKNOWLEDGMENTS

We express our appreciation to all who assisted with this research. In particular, we thank personnel of the U.S. Army Corps of Engineers Walla Walla District, including Mark Smith and Marvin Shutters; Mark Plummer at Ice Harbor Dam; John Bailey at Little Goose Dam; Bill Spurgeon at Lower Monumental Dam; and all Operations personnel at Ice Harbor Dam. Ann Setter, Ben Clemens, and the staff of the Oregon Department of Fish and Wildlife at Little Goose Dam provided valuable assistance collecting the spring study fish. Monty Price, Sharon Lind, and the Washington Department of Fish and Wildlife staff provided valuable assistance collecting the summer study fish at Lower Monumental Dam. The Argus Security personnel at Ice Harbor Dam also provided valuable assistance both by letting us on and off of the project and by transporting personnel to our fish holding area. We also greatly appreciate the assistance of NMFS personnel including Thomas Ruehle, Ronald Marr, William Ryan, Steven Brewer, Galen Wolf, Scott Shields, and Scott Davidson, who were involved throughout the study period. Without the efforts of all of the above people and the temporary personnel hired for the project, the study would not have been successful.

REFERENCES

Absolon, R. F., E. M. Dawley, B. P. Sandford, J. W. Ferguson, and D. A. Brege. 2002. Relative survival of juvenile salmon passing through the spillway of The Dalles Dam, 1997-2000. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Portland District, Portland, Oregon.

Burnham, K. P., D. R. Anderson, G. C. White, C. Brownie, and K. H. Pollock. 1987. Design and analysis methods for fish survival experiments based on release-recapture. American Fisheries Society Monograph 5, Bethesda MD.

Cormack, R. M. 1964. Estimates of survival from sightings of marked animals. Biometrika 51:429-438.

Eppard, M. B., E. E. Hockersmith, G. A. Axel, and B. P. Sandford. 2002. Spillway survival for hatchery yearling and subyearling chinook salmon passing Ice Harbor Dam, 2000. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington.

Eppard, M. B., B. P. Sandford, E. E. Hockersmith, G. A. Axel, and D. B Dey. 2005. Spillway passage survival of hatchery yearling and subyearling chinook salmon at Ice Harbor Dam, 2002. Report of the National Marine Fisheries Service to the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, Washington.

Ferguson, J. W., R. F. Absolon, T. J. Carlson, and B. P. Sandford. In prep. Evidence of delayed mortality in juvenile pacific salmon passing through turbines at Columbia River Dams.

Jolly, G. M. 1965. Explicit estimates from capture-recapture data with both death and immigration-stochastic model. Biometrika 52:225-247.

Mehta, C., and N. Patel. 1992. Statxact user's manual. Cytel Software Corp., Cambridge MA.

Muir, W. D., S. G. Smith, R. W. Zabel, D. M. Marsh, and J. G. Williams. 2003. Survival estimates for the passage of spring-migrating juvenile salmonids through Snake and Columbia River dams and reservoirs, 2002. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland Oregon.

NMFS (National Marine Fisheries Service). 2004. Endangered Species Act – Section 7 Consultation, Biological Opinion–on remand. Consultation on Remand for Operation of the Columbia River Power System and 19 Bureau of Reclamation Projects in the Columbia Basin (Revised and reissued pursuant to court order, NWF v. NMFS, Civ.No.01-640-RE (D. Oregon)). Available www.salmonrecovery.gov/R_biop_final.shtml (July 2005).

NWFSC (Northwest Fisheries Science Center). 2002. A salmon research plan, volume II: implementing the research required to answer the ten key questions. National Marine Fisheries, Northwest Fisheries Science Center, Seattle. Available www.nwfsc.noaa.gov/publications/ researchplans (January 2005).

PSMFC (Pacific States Marine Fisheries Commission). 1996. The Columbia Basin PIT Tag Information System (PTAGIS). PSMFC, Gladstone, Oregon. Available www.psmfc.org.pittag (October 2003).

Prentice, E. F., T. A. Flagg, C. S. McCutcheon, D. F. Brastow, and D. C. Cross. 1990. Equipment, methods, and an automated data-entry station for PIT tagging. Pages 335-340 *in* N. C. Parker et al., editors. Fish-marking techniques. American Fisheries Society Symposium 7.

Seber, G. A. F. 1965. A note on the multiple recapture census. Biometrika 52:249-259.

Skalski, J. R., S. G. Smith, R. N. Iwamoto, J. G. Williams, and A. Hoffmann. 1998. Use of passive integrated transponder tags to estimate survival of migrant juvenile salmonids in the Snake and Columbia Rivers. Canadian Journal of Fisheries and Aquatic Sciences 55:1484-1493.

Smith, S. G., J. R. Skalski, W. Sclechte, A. Hoffmann, and V. Cassen. 1994. Statistical survival analysis of fish and wildlife tagging studies. SURPH.1 Manual. Center for Quantitative Science, University of Washington, Seattle.

Snedecor and Cochran. 1980. Statistical Methods. Seventh Edition. Iowa State University Press. Ames, Iowa. 507 p.

Lady, J., P. Westhagen, and J. R. Skalski. 2001. Surph 2.1 user manual: Survival under proportional hazards. U.S. Department of Energy, Bonneville Power Administration, Division of Fish and Wildlife. Portland, Oregon. Available www.cbr.washington.edu/ analysis.html (January 2005).

Smith, S. G., W. D. Muir, R. W. Zabel, D. M. Marsh, R. A. McNatt, J. G. Williams, and J. R. Skalski. 2003. Survival estimates for the passage of spring-migrating juvenile salmonids through Snake and Columbia River dams and reservoirs, 2003. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland, Oregon.

Zabel, R. W., S. G. Smith, W. D. Muir, D. M. Marsh, J. G. Williams, and J. R. Skalski. 2002. Survival estimates for the passage of spring-migrating juvenile salmonids through Snake and Columbia River dams and reservoirs, 2001. Report of the National Marine Fisheries Service to the Bonneville Power Administration, Portland, Oregon.

APPENDIX

Data Tables

Appendix Table 1. Detections, for yearling Chinook salmon at each recovery site, separated by release dates, release times and release locations during spring 2003 at Ice Harbor Dam. Totals are for unique tag observations; multiple observations of a tag are not counted.

Yearling Chinook salmon--Spring 2003							
			Detections				
Tag date	Release date	Release number	McNary Dam	John Day Dam	Bonneville Dam	Jones Beach Trawl	Total
Daytime tailrace releases							
4/28	4/29	339	162	57	30	5	210
4/29	4/30	309	110	69	27	5	164
4/30	5/1	348	125	78	44	9	195
5/1	5/2	182	78	36	16	5	106
5/2	5/3	400	146	71	42	7	212
5/5	5/6	399	138	67	48	9	209
5/6	5/7	343	130	54	30	5	175
5/7	5/8	350	143	59	38	4	193
5/8	5/9	494	160	113	43	11	257
5/9	5/10	249	50	53	36	6	116
5/12	5/13	198	73	42	27	3	116
5/13	5/14	497	163	131	57	7	275
5/14	5/15	489	166	121	58	11	279
5/15	5/16	398	132	109	56	12	235
5/16	5/17	288	81	78	37	3	163
5/19	5/20	346	102	76	38	5	176
5/20	5/21	349	148	69	52	7	209
5/21-22	5/23	140	57	52	13	3	84
5/23	5/24	242	75	94	30	9	152
Nighttime tailrace releases							
4/28	4/29	376	160	53	27	3	200
4/29	4/30	391	160	66	34	6	216
4/30	5/1	241	118	44	27	5	153
5/1	5/2	192	88	33	19	3	118
5/2	5/3	494	248	64	42	8	297
5/5	5/6	397	185	49	38	5	223
5/6	5/7	347	159	64	30	7	194
5/7	5/8	295	123	54	32	9	163
5/8	5/9	398	141	68	44	10	211
5/9	5/10	247	87	41	28	4	126
5/12	5/13	240	81	54	28	2	121
5/13	5/14	493	181	129	54	9	287
5/14	5/15	399	109	114	49	6	210
5/15	5/16	497	138	145	52	13	265
5/16	5/17	347	97	78	44	9	178
5/19	5/20	397	127	94	52	10	215
5/20	5/21	391	149	94	62	8	222
5/21-22	5/23	269	135	106	29		186

Appendix Table 1. Continued.

Yearling Chinook salmon--Spring 2003							
			Detections				
Tag date	Release date	Release number	McNary Dam	John Day Dam	Bonneville Dam	Jones Beach Trawl	Total
Daytime turbine 1A releases							
4/28	4/29	327	120	44	21	2	154
4/29	4/30	316	115	39	28	2	150
4/30	5/1	393	142	57	41	3	192
5/1	5/2	189	56	25	18	3	82
5/2	5/3	394	189	55	33	8	211
5/2	5/3	400	131	63	35	11	185
5/5	5/6	396	136	45	38	11	184
5/6	5/7	107	29	11	9	3	42
5/7	5/8	399	152	63	34	10	218
5/8	5/9	493	141	98	37	7	218
5/9	5/10	250	49	35	20	3	90
5/12	5/13	200	58	45	18	4	95
5/13	5/14	493	156	114	48	12	248
5/14	5/15	491	152	122	56	8	252
5/15	5/16	396	124	97	41	10	204
5/16	5/17	345	102	71	26	8	159
5/19	5/20	352	114	73	44	6	181
5/20	5/21	347	119	86	46	6	194
5/21-22	5/23	150	52	43	12		83
5/23	5/24	150	49	51	15	1	90
Nighttime turbine 1A releases							
4/29	4/30	376	139	44	20	9	174
4/30	5/1	336	141	60	24	8	186
5/7	5/8	345	116	54	26	6	161
5/8	5/9	397	111	80	33	5	179
5/12	5/13	249	83	43	25	5	118
5/15	5/16	500	144	123	58	11	253
5/16	5/17	247	63	54	14	2	107
5/16	5/17	248	79	61	31	4	133
5/19	5/20	399	121	76	42	7	187
5/19	5/20	300	86	60	33	2	141

Appendix Table 1. Continued.

Yearling Chinook salmon--Spring 2003							
			Detections				
Tag date	Release date	Release number	McNary Dam	John Day Dam	Bonneville Dam	Jones Beach Trawl	Total
Daytime turbine 3A releases							
4/28	4/29	337	125	43	30	4	162
4/29	4/30	315	96	51	23	5	135
4/30	5/1	342	124	54	38	6	170
5/1	5/2	186	65	34	8		85
5/5	5/6	397	137	58	34	7	186
5/6	5/7	345	130	41	31	7	175
5/7	5/8	349	133	49	28	3	166
5/8	5/9	496	165	100	36	4	224
5/9	5/10	304	93	47	26	4	140
5/12	5/13	199	72	46	19	3	105
5/13	5/14	495	151	97	42	7	228
5/14	5/15	486	153	110	49	6	237
5/15	5/16	400	106	96	41	11	191
5/16	5/17	341	94	80	33	6	171
5/19	5/20	350	99	57	51	5	166
5/20	5/21	348	118	89	35	4	180
5/21-22	5/23	149	55	50	18	1	85
5/23	5/24	149	50	55	13		89
Nighttime turbine 3A releases							
4/28	4/29	357	120	58	20	6	157
4/28	4/29	367	127	52	32	4	170
4/29	4/30	386	128	61	22	6	179
4/30	5/1	347	141	50	37	4	180
5/1	5/2	143	62	17	10	2	75
5/2	5/3	489	294	53	44	11	269
5/5	5/6	390	162	50	35	7	199
5/5	5/6	390	139	47	24	7	187
5/6	5/7	339	143	52	35	7	183
5/6	5/7	346	140	49	24	9	173
5/7	5/8	299	110	56	21	3	150
5/8	5/9	399	121	62	23	8	175
5/9	5/10	247	71	34	18	7	101
5/12	5/13	248	84	43	19	4	113
5/13	5/14	497	184	96	44	6	244
5/13	5/14	492	177	86	46	10	244
5/14	5/15	400	122	80	38	10	188
5/14	5/15	395	113	105	41	3	195
5/15	5/16	497	148	129	56	8	250
5/20	5/21	348	131	70	37	6	179
5/20	5/21	397	139	75	49	2	201
5/21-22	5/23	348	145	104	35	7	198
5/21-22	5/23	349	143	100	36	6	203

Appendix Table 1. Continued.

			Yearling Chinook salmon--Spring 2003				
			Detections				
Tag date	Release date	Release number	McNary Dam	John Day Dam	Bonneville Dam	Jones Beach Trawl	Total
Daytime collection-channel releases							
4/28	4/29	329	132	56	24	5	170
4/29	4/30	323	125	48	47	2	180
4/30	5/1	340	127	61	33	2	184
5/1	5/2	186	62	29	15	4	86
5/2	5/3	392	153	53	26	8	196
5/5	5/6	399	147	70	54	13	212
5/6	5/7	343	155	56	33	4	192
5/7	5/8	344	151	62	30	6	190
5/8	5/9	399	138	68	36	9	195
5/9	5/10	250	58	43	44	3	113
5/12	5/13	200	73	40	21	4	107
5/13	5/14	494	179	140	48	9	287
5/14	5/15	492	174	131	54	9	287
5/15	5/16	397	115	120	51	8	223
5/16	5/17	335	98	92	37	6	176
5/19	5/20	347	105	67	33	5	173
5/20	5/21	346	121	63	51	2	177
5/21-22	5/23	195	77	71	31	4	125
Nighttime collection-channel releases							
4/28	4/29	361	138	43	19	2	173
4/29	4/30	374	133	51	28	5	178
4/30	5/1	244	112	40	33	3	146
5/1	5/2	145	70	25	11	3	86
5/1	5/2	189	86	37	18	6	113
5/2	5/3	489	243	64	49	9	299
5/5	5/6	396	183	55	45	7	234
5/6	5/7	349	172	42	37	7	209
5/7	5/8	297	126	44	14	1	159
5/8	5/9	397	127	84	28	12	195
5/9	5/10	250	74	44	22	5	116
5/12	5/13	199	70	39	18	6	104
5/13	5/14	490	202	124	52	10	293
5/14	5/15	399	144	112	53	11	228
5/15	5/16	496	147	151	65	13	283
5/16	5/17	301	110	69	47	7	181
5/19	5/20	393	139	87	43	2	207
5/20	5/21	415	187	104	58	5	256
5/21-22	5/23	233	116	73	29	6	155

Appendix Table 2. Results of Burnham Test 2.C2 for PIT-tagged yearling Chinook salmon released in the collection channel, turbine, or tailrace of Ice Harbor Dam, spring 2003.

	Collection channel		Turbine		Tailrace	
Release date	$\chi2$	*P*	$\chi2$	*P*	$\chi2$	*P*
4/29/03	0.19	0.666	5.66	0.017	0.69	0.408
4/30/03	1.22	0.269	0.60	0.440	0.85	0.357
5/1/03	0.35	0.555	0.70	0.404	4.01	0.045
5/2/03	0.31	0.580	0.35	0.553	0.05	0.828
5/3/03	0.67	0.414	0.05	0.819	2.44	0.118
5/6/03	2.85	0.091	0.21	0.644	2.58	0.108
5/7/03	2.99	0.084	1.92	0.166	0.12	0.729
5/8/03	0.00	0.960	0.28	0.594	1.65	0.199
5/9/03	1.90	0.168	0.00	0.975	0.00	0.964
5/10/03	4.18	0.041	4.72	0.030	6.29	0.012
5/13/03	0.08	0.772	2.81	0.094	0.05	0.827
5/14/03	0.00	0.996	0.03	0.857	0.08	0.779
5/15/03	0.49	0.484	0.00	0.977	0.68	0.410
5/16/03	0.51	0.476	1.05	0.305	0.02	0.883
5/17/03	0.03	0.871	0.41	0.524	0.92	0.337
5/20/03	0.06	0.808	0.53	0.466	0.38	0.536
5/21/03	3.78	0.052	3.17	0.075	7.00	0.008
5/23/03	0.00	0.957	4.17	0.041	1.14	0.285
5/24/03			3.21	0.073	0.21	0.650
Total	19.60 (18 df)	0.356	29.88 (19 df)	0.050	29.16 (19 df)	0.064

Appendix Table 3. Results of Burnham Test 3.SR3 for PIT-tagged yearling Chinook salmon released in the collection channel, turbine, and tailrace at Ice Harbor Dam, spring 2003.

	Collection channel		Turbine		Tailrace	
Release date	$\chi 2$	*P*	$\chi 2$	*P*	$\chi 2$	*P*
4/29/03	0.00	0.976	3.52	0.061	3.52	0.061
4/30/03	1.22	0.270	1.38	0.241	1.38	0.241
5/1/03	0.43	0.512	0.00	0.978	0.00	0.978
5/2/03	0.74	0.389	0.76	0.384	0.76	0.384
5/3/03	0.46	0.500	0.38	0.537	0.38	0.537
5/6/03	0.07	0.795	0.24	0.622	0.24	0.622
5/7/03	0.25	0.616	0.02	0.883	0.02	0.883
5/8/03	0.01	0.935	0.00	0.987	0.00	0.987
5/9/03	1.67	0.196	1.18	0.278	1.18	0.278
5/10/03	0.45	0.503	0.26	0.262	0.26	0.262
5/13/03	0.79	0.373	3.84	0.050	3.84	0.050
5/14/03	0.01	0.913	0.93	0.336	0.93	0.336
5/15/03	0.68	0.410	0.51	0.476	0.51	0.476
5/16/03	0.04	0.842	0.45	0.502	0.45	0.502
5/17/03	0.05	0.820	2.62	0.106	2.62	0.106
5/20/03	0.63	0.429	1.02	0.312	1.02	0.312
5/21/03	0.41	0.520	1.07	0.300	1.07	0.300
5/23/03	0.07	0.788	0.74	0.388	0.74	0.388
5/24/03			0.88	0.348	0.88	0.348
Total	7.98	0.979	20.80	0.348	20.60	0.360

Appendix Table 4. Relative survival estimates to McNary Dam for yearling Chinook salmon released into the Ice Harbor Dam collection channel, turbine unit 1A, turbine unit 3A, and combined turbine units using CJS and SURPH methodologies, spring 2003.

Release date	Turbine unit 1A	Turbine unit 3A	Collection channel	Combined turbines
4/29	0.784	0.751	0.820	0.759
4/30	0.837	0.790	1.004	0.816
5/1	0.901	0.808	1.072	0.853
5/2	0.834	0.793	0.865	0.811
5/3	0.812	0.752	0.968	0.790
5/6	0.940	0.919	0.936	0.923
5/7	0.883	1.085	1.166	1.067
5/8	1.230	0.925	1.081	1.066
5/9	0.774	0.723	0.850	0.749
5/10	0.893	0.875	0.863	0.878
5/13	0.907	0.915	1.002	0.913
5/14	0.844	0.801	0.975	0.815
5/15	0.881	0.799	0.980	0.822
5/16	0.925	0.873	1.031	0.899
5/17	0.789	1.033	0.969	0.849
5/20	0.831	0.972	0.954	0.859
5/21	1.038	0.844	0.881	0.886
5/23	0.966	0.891	1.066	0.900
5/24	0.982	0.930		0.956
Weighted geometric mean	0.888	0.855	0.975	0.871

Appendix Table 5. Times and conditions by release location during morning and evening releases of yearling Chinook salmon at Ice Harbor Dam, spring 2003.

Turbine unit 1A								
Release date	Time (PDT)	Tailwater elevation (ft)	Unit 1 load (MW)	Unit 1 flow (kcfs)	Total powerhouse (kcfs)	Total spill (kcfs)	Total river flow (kcfs)	River temp (°C)
Morning								
4/29	11:00	344.50	95.5	13.1	42.6	45.2	87.8	10.78
4/30	11:01	344.30	93.1	12.8	41.5	41.5	83.0	10.56
5/1	9:56	343.16	79.1	10.6	34.9	34.8	69.7	10.89
5/2	10:44	342.82	87.9	11.7	23.4	44.7	68.1	11.44
5/3	9:36	341.91	89.2	11.9	11.9	44.8	56.7	11.17
5/3	9:51	341.85	89.4	11.9	11.9	44.8	56.7	11.17
5/6	9:55	344.4	88.1	12.1	39.3	45.1	84.4	10.78
5/7	9:54	344.29	85.8	11.7	38.4	44.7	83.1	10.83
5/8	9:33	344.03	88.4	12.0	39.7	40.3	80.0	11.00
5/9	9:18	344.49	64.7	9.1	41.7	40.0	81.7	10.78
5/10	12:55	344.29	86.8	11.8	39.1	45.2	84.3	11.33
5/13	12:25	343.35	78.5	10.7	34.9	34.3	69.2	11.83
5/14	12:34	345.31	72.2	10.0	45.8	45.0	90.8	11.61
5/15	12:17	344.46	85.9	11.7	38.4	45.1	83.5	11.78
5/16	12:27	345.63	78.4	10.8	49.8	50.0	99.8	11.44
5/17	12:38	344.97	69.2	9.6	44.9	44.9	89.8	11.33
5/20	12:04	345.22	75.4	10.4	48.4	45.4	93.8	
5/21	8:32	344.14	88.7	12.1	39.7	41.5	81.2	11.94
5/23	8:24	344.63	71.2	9.8	43.6	45.2	88.8	12.28
5/24	8:19	345.28	74.9	10.3	48.1	50.3	98.4	12.28
Evening								
4/30	20:20	344.86	68.2	9.5	43.5	44.7	88.2	10.94
5/1	20:18	344.55	69.8	9.7	44.6	44.8	89.4	11.56
5/8	19:23	344.46	89.1	12.2	39.8	40.3	80.1	10.78
5/9	19:10	343.51	86.0	11.6	37.9	34.2	72.1	11.00
5/13	19:10	343.22	78.3	10.6	34.8	34.4	69.2	12.06
5/16	19:06	345.46	72.2	10.0	47.4	49.9	97.3	11.50
5/17	18:56	346.62	86.5	12.2	55.2	54.4	109.6	11.39
5/17	18:57	346.62	86.5	12.2	55.2	54.4	109.6	11.39
5/20	18:56	343.29	72.6	9.9	32.6	34.1	66.7	12.61
5/20	18:57	343.29	72.6	9.9	32.6	34.1	66.7	12.61

Appendix Table 5. Continued.

Turbine unit 3A								
Release date	Time (PDT)	Tailwater elevation (ft)	Unit 3 load (MW)	Unit 3 flow (kcfs)	Total powerhouse (kcfs)	Total spill (kcfs)	Total river flow (kcfs)	River temp (°C)
Morning								
4/29	10:35	344.37	95.0	13.0	42.5	45.2	87.7	10.78
4/30	10:36	344.31	91.6	12.6	41.3	41.5	82.8	10.56
5/1	9:44	343.19	69.4	9.4	30.9	31.9	62.8	10.89
5/2	10:31	342.83	87.8	11.7	23.4	44.7	68.1	11.44
5/6	9:37	344.41	87.9	12.1	39.3	45.1	84.4	10.78
5/7	9:40	344.28	85.1	11.6	38.4	44.6	83.0	10.83
5/8	9:18	343.91	88.6	12.0	39.3	40.3	79.6	10.56
5/9	9:04	344.36	64.0	9.1	41.3	40.0	81.3	10.78
5/10	12:44	344.35	88.4	12.0	39.0	45.2	84.2	11.33
5/13	12:15	343.45	77.9	10.6	34.7	34.7	69.4	11.83
5/14	12:21	345.39	71.5	9.9	46.0	45.0	91.0	11.67
5/15	12:04	344.55	85.8	11.7	38.5	45.1	83.6	11.78
5/16	12:16	345.55	80.2	11.0	49.8	50.0	99.8	11.44
5/17	12:25	344.92	69.5	9.6	44.5	44.9	89.4	11.28
5/20	11:51	345.33	75.3	10.4	48.4	44.6	93.0	
5/21	8:21	344.18	90.2	12.3	39.9	41.5	81.4	11.89
5/23	8:12	344.32	96.4	13.3	43.3	45.2	88.5	12.28
5/24	8:07	344.27	69.6	9.5	45.0	50.1	95.1	12.78
Evening								
4/29	20:25	342.93	67.6	9.3	9.3	60.0	69.3	10.28
4/29	20:37	342.88	67.8	9.2	9.2	60.0	69.2	10.33
4/30	20:02	344.70	71.7	10.0	43.5	44.7	88.2	10.94
5/1	20:00	343.97	89.3	12.1	39.9	37.0	76.9	11.56
5/2	19:38	342.88	70.0	9.5	9.5	59.9	69.4	11.11
5/3	18:33	343.17	70.8	9.6	9.6	60.0	69.6	11.17
5/6	20:00	342.97	71.0	9.6	9.6	55.1	64.7	10.83
5/6	20:01	342.97	71.0	9.6	9.6	55.1	64.7	10.83
5/7	19:25	342.64	71.4	9.7	9.7	49.2	58.9	10.61
5/7	19:26	342.64	71.4	9.7	9.7	49.2	58.9	10.61
5/8	19:10	344.55	89.8	12.4	40.1	40.3	80.4	10.78
5/9	18:58	343.45	80.5	10.9	36.0	34.2	70.2	11.00
5/10	19:12	342.50	65.6	9.1	9.1	54.5	63.6	10.89
5/13	18:54	342.92	67.5	9.2	30.7	34.4	65.1	12.06
5/14	18:51	344.51	70.1	9.7	9.7	75.1	84.8	11.67
5/14	19:01	344.54	68.6	9.5	9.5	75.1	84.6	11.67
5/15	20:01	344.70	59.5	8.6	8.6	94.2	102.8	11.78
5/157	20:14	345.21	59.1	8.6	8.6	99.4	108.0	11.78
5/16	18:47	345.55	70.5	9.8	45.4	44.9	90.3	11.50
5/21	19:00	345.06	69.1	9.6	45.0	43.1	88.1	12.11
5/21	19:01	345.06	69.1	9.6	45.0	43.1	88.1	12.11
5/23	19:05	344.37	76.5	10.6	10.6	87.8	98.4	12.44
5/23	19:06	344.37	76.5	10.6	10.6	87.8	98.4	12.44

Appendix Table 5. Continued.

Release date	Time (PDT)	Tailwater elevation (ft)	Total powerhouse (kcfs)	Total spill (kcfs)	Total river flow (kcfs)	River temp (°C)
			Collection channel			
Morning						
4/29	9:51	343.84	31.6	45.1	76.7	10.83
4/30	10:15	344.37	41.2	41.5	82.7	10.44
5/1	9:31	343.17	34.3	34.8	69.1	10.89
5/2	10:14	342.88	23.7	44.7	68.4	11.72
5/3	9:17	342.09	11.9	44.8	56.7	11.17
5/6	9:22	344.47	39.2	45.1	84.3	10.78
5/7	9:28	344.33	38.1	44.7	82.8	10.61
5/8	9:00	343.28	36.0	35.1	71.1	10.56
5/9	8:47	344.20	41.6	40.0	81.6	10.78
5/10	12:34	344.47	38.6	45.2	83.8	11.33
5/13	12:06	343.66	34.8	34.7	69.5	11.83
5/14	12:10	345.53	45.6	45.0	90.6	11.67
5/15	11:54	344.65	38.6	45.1	83.7	11.78
5/16	12:04	344.96	47.9	50.0	97.9	11.44
5/17	12:12	344.87	44.3	43.9	88.2	11.28
5/20	11:40	345.01	48.5	44.6	93.1	
5/21	8:09	344.31	39.8	41.5	81.3	11.89
5/23	8:01	344.17	37.9	45.2	83.1	12.28
Evening						
4/29	19:57	342.45	9.5	59.9	69.4	10.28
4/30	19:35	344.29	43.0	37.3	80.3	10.94
5/1	19:43	344.12	37.8	37.0	74.8	11.56
5/2	20:13	343.55	9.7	75.7	85.4	11.11
5/2	20:23	343.71	9.5	75.7	85.2	11.11
5/3	18:19	343.37	9.4	60.0	69.4	11.22
5/6	19:42	343.16	9.6	54.7	64.3	10.83
5/7	19:06	342.75	9.7	49.1	58.8	10.61
5/8	18:58	344.69	40.1	40.2	80.3	10.78
5/9	18:48	343.41	34.8	34.2	69.0	11.00
5/10	19:01	342.63	9.1	54.5	63.6	10.89
5/13	18:41	343.07	30.2	29.2	59.4	12.06
5/14	18:39	344.38	9.7	75.1	84.8	11.67
5/15	18:47	343.17	8.7	60.1	68.8	11.78
5/16	18:36	345.37	45.2	45.0	90.2	11.50
5/17	18:31	346.51	54.8	54.7	109.5	11.39
5/20	18:38	343.57	32.8	34.4	67.2	12.61
5/21	18:45	344.99	43.7	43.2	86.9	12.11
5/23	18:43	344.05	13.0	69.7	82.7	12.44

Appendix Table 6. Results of yearling Chinook salmon relative survival analysis and analysis of travel time correlation from release at Ice Harbor Dam to detection at McNary Dam, spring 2003.

Collection channel--spring				
	Relative survival correlations			
N = 35	Relative survival	Date	Tailwater elevation	Total river flow
Date	0.337			
Tailwater elevation	0.374	0.473		
Total river flow	0.280	0.406	0.928	
River temperature	0.081	0.748	0.216	0.127
Stepwise regression: diel factor included in all models; F-to-enter = 4 F-to-remove = 4				
Step	1	2		
Constant	96.49	-1141.65		
Diel	3.7	4.5		
t	1.35	1.75		
P	0.186	0.089		
Tailwater		3.6		
t		2.63		
P		0.013		
S	8.18	7.53		
R^2 (adj)	2.36	17.16		
	Travel time correlations			
N = 35	Travel time	Date	Tailwater elevation	Total river flow
Date	-0.808			
Tailwater elevation	-0.380	0.473		
Total river flow	-0.274	0.406	0.928	
River temperature	-0.573	0.748	0.216	0.127
Stepwise regression: diel factor included in all models; F-to-enter = 4 F-to-remove = 4				
Step	1	2		
Constant	2.276	7.799		
Diel	-0.199	-0.174		
t	-1.53	-2.34		
P	0.136	0.026		
Date		-0.0426		
t		-8.3		
P		0		
S	0.385	0.22		
R^2 (adj)	3.77	68.53		

Appendix Table 6. Continued.

Combined turbines--spring					
	Relative survival correlations				
	Relative survival	Date	Tailwater elevation	Total river flow	River temp.
Date	0.390				
Tailwater elevation	0.235	0.500			
Total river flow	0.177	0.473	0.939		
River temperature	0.086	0.702	0.192	0.238	
Turbine unit 3 load	-0.071	-0.194	0.124	0.101	-0.191

Stepwise regression: survival versus date, diel, tailwater, total river flow, river temperature and turbine unit 3 load; F-to-enter = 4 F-to-remove = 4
Response is relative survival on 5 predictors, with N=36
N (cases with missing observations)=1, N (all cases)=37

Step	1	2
Constant	88.01	56.76
Diel	-0.1	-0.1
t	-0.06	-0.06
P	0.951	0.954
Date		0.24
t		2.21
P		0.034
S	5.08	4.81
R^2 (adj)	0	7.62

Appendix Table 6. Continued.

Combined turbines--spring

	Travel time correlations				
	Travel time	Date	Tailwater elevation	Total river flow	River temp.
Date	-0.821				
Tailwater elevation	-0.335	0.500			
Total river flow	-0.293	0.473	0.939		
River temperature	-0.629	0.702	0.192	0.238	
Turbine unit 3 load	0.268	-0.194	0.124	0.101	-0.191

Stepwise regression: travel time versus date, diel, tailwater elevation, total river flow, river temperature, and turbine unit 3 load; F-to-enter = 4 F-to-remove = 4
Response is travel time on 5 predictors, with N=36
N (cases with missing observations)=1; N (all cases)=37

Step	1	2
Constant	2.256	7.468
Diel	-0.122	-0.124
t	-1.02	-1.91
P	0.316	0.065
Date		-0.04
t		-9.08
P		0.00
S	0.36	0.195
R^2 (adj)	0.11	70.58

Appendix Table 7. Tests of homogeneity for McNary, John Day and Bonneville Dam passage distributions for groups of PIT-tagged yearling Chinook salmon released into the collection channel, turbines, and tailrace at Ice Harbor Dam, spring 2003. D = daytime release, N = evening release.

McNary Dam					
Release date	Diel period	χ^2	df	*P*	Result*
4/29	D	44.1	22	0.0010	Tailrace early
	N	39.7	20	0.0014	Tailrace early
4/30	D	27.3	20	0.2796	Mixed
	N	25.9	20	0.1257	Mixed
5/1	D	37.4	22	0.0093	Tailrace early
	N	22.3	16	0.1089	Mixed
5/2	D	19.9	18	0.3215	Mixed
	N	30.6	20	0.0293	Tailrace early
5/3	D	30.6	24	0.1035	Mixed
	N	35.0	22	0.0130	All different
5/6	D	41.5	18	0.0004	Tailrace early
	N	18.9	10	0.0369	Tailrace early
5/7	D	30.0	26	0.2076	Mixed
	N	11.7	16	0.8394	Mixed
5/8	D	18.7	16	0.2598	Mixed
	N	15.4	14	0.3221	Mixed
5/9	D	26.1	18	0.0715	Tailrace early
	N	12.7	12	0.3921	Mixed
5/10	D	12.2	18	0.8902	Mixed
	N	16.6	16	0.3796	Mixed
5/13	D	16.6	14	0.2610	Mixed
	N	12.3	14	0.6314	Mixed
5/14	D	15.7	18	0.6390	Mixed
	N	18.5	12	0.0713	Tailrace early
5/15	D	21.1	14	0.0710	Tailrace early
	N	10.7	10	0.3795	Mixed
5/16	D	23.7	14	0.0211	Tailrace early
	N	29.3	14	0.0042	Tailrace early
5/17	D	14.8	16	0.5558	Mixed
	N	4.5	8	0.8302	Mixed
5/20	D	26.0	18	0.0514	Tailrace early
	N	22.6	18	0.1628	Mixed
5/21	D	19.3	16	0.2351	Mixed
	N	23.8	18	0.1140	Mixed
5/23	D	12.8	14	0.5804	Mixed
	N	15.9	14	0.3025	Mixed
5/24	D	9.2	5	0.0625	Tailrace early

Appendix Table 7. Continued.

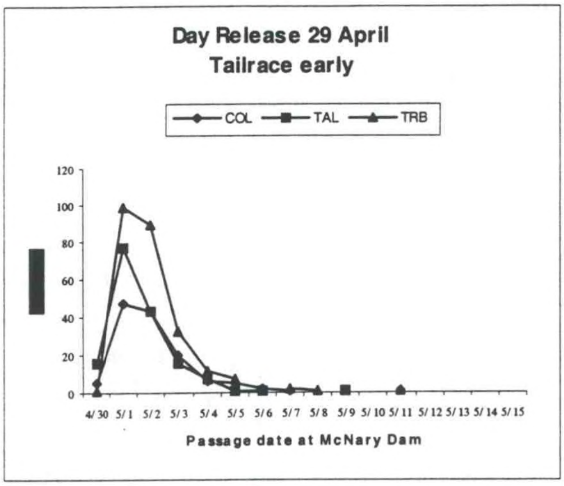
John Day Dam					
Release date	Diel period	χ^2	df	P	Result*
4/29	D	18.6	22	0.7342	Mixed
	N	27.4	32	0.7565	Mixed
4/30	D	27.6	26	0.3639	Mixed
	N	17.9	24	0.8843	Mixed
5/1	D	19.7	26	0.9034	Mixed
	N	21.2	20	0.3837	Mixed
5/2	D	23.4	22	0.3740	Mixed
	N	13.7	24	0.9768	Mixed
5/3	D	48.5	26	0.0017	All different
	N	20.3	24	0.7478	Mixed
5/6	D	41.2	32	0.0592	Tailrace early
	N	28.1	20	0.0729	Turbine late
5/7	D	28.4	24	0.1774	Mixed
	N	6.9	14	0.9595	Mixed
5/8	D	34.5	20	0.0101	Tailrace early
	N	21.3	24	0.6755	Mixed
5/9	D	26.4	26	0.4454	Mixed
	N	11.0	16	0.8679	Mixed
5/10	D	21.0	18	0.2595	Mixed
	N	29.6	20	0.0246	Turbine late
5/13	D	25.2	18	0.0965	Tailrace early
	N	19.1	20	0.5461	Mixed
5/14	D	18.0	22	0.7595	Mixed
	N	27.8	22	0.1343	Mixed
5/15	D	27.6	24	0.2452	Mixed
	N	23.5	22	0.3598	Mixed
5/16	D	12.6	18	0.8510	Mixed
	N	24.8	22	0.2793	Mixed
5/17	D	13.2	16	0.6981	Mixed
	N	8.5	12	0.7614	Mixed
5/20	D	24.4	12	0.0113	Turbine late
	N	16.5	16	0.4060	Mixed
5/21	D	25.2	22	0.2761	Mixed
	N	23.7	18	0.1204	Mixed
5/23	D	7.5	12	0.9065	Mixed
	N	10.7	18	0.9505	Mixed
5/24	D	7.5	5	0.1695	Mixed

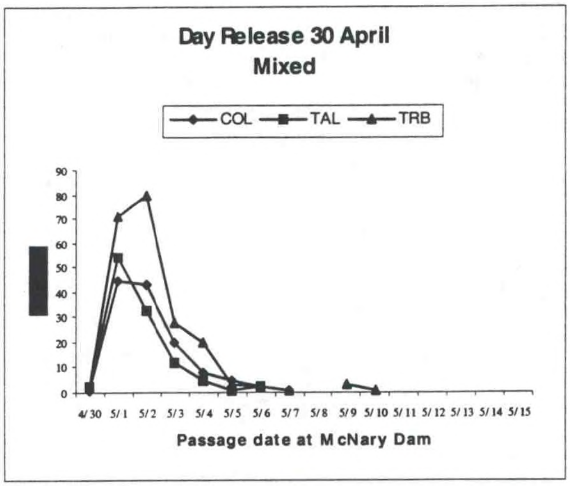
Appendix Table 7. Continued.

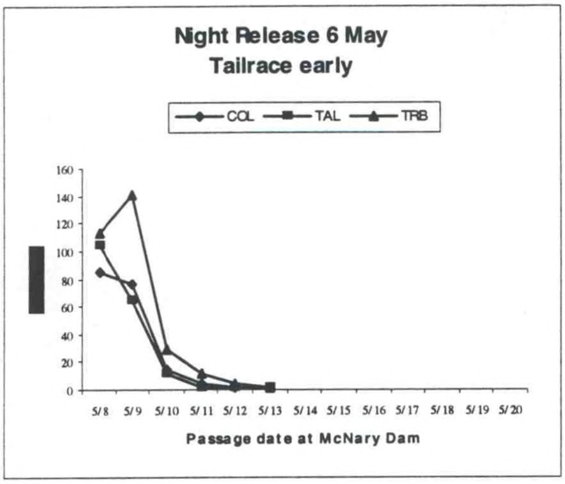
Bonneville Dam					
Release date	Diel period	χ^2	df	P	Result*
4/29	D	22.1	24	0.6189	Mixed
	N	34.0	22	0.0303	Tailrace early
4/30	D	27.6	24	0.2583	Mixed
	N	15.1	24	0.9803	Mixed
5/1	D	37.6	28	0.0727	Tailrace early
	N	20.0	24	0.7664	Mixed
5/2	D	17.7	22	0.8178	Mixed
	N	12.8	18	0.8753	Mixed
5/3	D	20.9	18	0.2827	Mixed
	N	17.0	20	0.7009	Mixed
5/6	D	21.9	22	0.4756	Mixed
	N	18.8	18	0.4070	Mixed
5/7	D	17.7	16	0.3263	Mixed
	N	15.7	16	0.5015	Mixed
5/8	D	14.9	14	0.3888	Mixed
	N	17.4	14	0.2248	Mixed
5/9	D	29.2	14	0.0038	Tailrace early
	N	7.5	10	0.7253	Mixed
5/10	D	25.2	18	0.0800	Turbine late
	N	13.5	12	0.3173	Mixed
5/13	D	9.9	16	0.9408	Mixed
	N	8.6	14	0.9165	Mixed
5/14	D	14.8	18	0.7141	Mixed
	N	14.9	18	0.7203	Mixed
5/15	D	21.2	20	0.3710	Mixed
	N	24.6	18	0.1037	Mixed
5/16	D	36.7	18	0.0014	All different
	N	12.8	16	0.7223	Mixed
5/17	D	24.5	16	0.0358	Tailrace early
	N	11.8	8	0.1621	Mixed
5/20	D	11.1	12	0.5326	Mixed
	N	13.2	14	0.5332	Mixed
5/21	D	20.2	18	0.2824	Mixed
	N	13.1	18	0.9194	Mixed
5/23	D	19.1	14	0.1236	Mixed
	N	20.1	12	0.0506	Turbine late
5/24	D	6.5	4	0.1596	Mixed

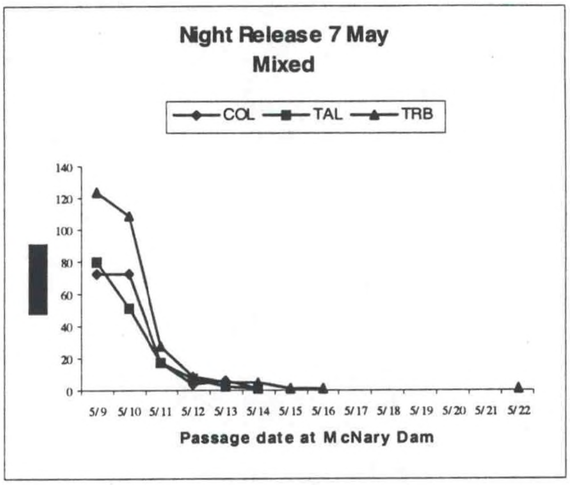
* P>0.10, interpreted as being consistent with the assumption of mixing.

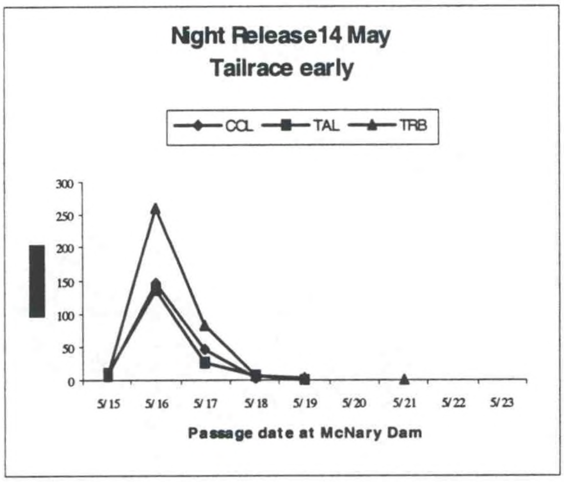
Appendix Table 8. Graphs of selected release groups of mixed and unmixed yearling Chinook salmon released at Ice Harbor Dam as determined by chi-square testing.

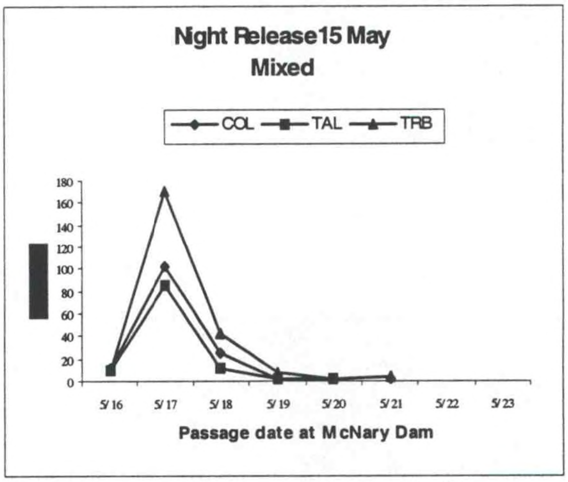












Appendix Table 9. Detections for subyearling Chinook salmon at each recovery site, separated by release dates, release times, and release locations during summer 2003 at Ice Harbor Dam. Totals are for unique tag observations; multiple observations of a tag are not counted.

Subyearling Chinook salmon--Summer 2003						
Daytime tailrace releases						
			Detections			
Tag date	Release date	Release number	McNary Dam	John Day Dam	Bonneville Dam	Total
6/23	6/24	521	337	28	72	365
6/24	6/25	646	411	53	73	440
6/25	6/26	947	664	103	81	697
6/26	6/27	374	240	42	44	260
6/27	6/28	415	291	25	39	310
6/28	6/29	382	308	32	28	314
6/29	6/30	495	355	47	42	372
6/30	7/1	192	123	21	18	129
7/1	7/2	338	198	29	30	209
7/2	7/3	526	322	26	29	333
7/3	7/4	786	409	71	66	441
7/7-8	7/9	410	224	16	24	232
7/9	7/11	374	211	29	23	232
Nighttime tailrace releases						
6/23	6/24	515	335	14	71	358
6/24	6/25	648	432	48	66	463
6/25	6/26	946	669	122	87	703
6/26	6/27	455	285	47	34	302
6/27	6/28	427	304	29	26	312
6/28	6/29	384	272	41	30	283
6/29	6/30	494	346	60	37	365
6/30	7/1	194	118	13	13	124
7/2	7/3	528	326	36	38	341
7/10-11	7/12	922	551	47	35	571
7/12	7/12	669	378	39	34	397

Appendix Table 9. Continued.

Subyearling Chinook salmon--Summer 2003						
Daytime turbine releases						
			Detections			
Tag date	Release date	Release number	McNary Dam	John Day Dam	Bonneville Dam	Total
6/23	6/24	521	290	23	67	321
6/24	6/25	596	357	51	55	384
6/25	6/26	1,025	629	79	78	656
6/26	6/27	396	230	50	28	249
6/27	6/28	317	192	21	17	201
6/28	6/29	234	148	20	12	153
6/29	6/30	498	305	43	36	317
6/30	7/1	230	118	20	19	128
7/2	7/3	328	183	21	23	193
7/3	7/4	774	352	63	61	398
Nighttime turbine releases						
6/25	6/26	890	543	94	70	569
6/26	6/27	395	218	41	21	238
6/29	6/30	532	302	31	24	314
6/30	7/1	198	91	11	15	101

Appendix Table 9. Continued.

Subyearling Chinook salmon--Summer 2003						
Daytime collection-channel releases						
			Detections			
Tag date	Release date	Release number	McNary Dam	John Day Dam	Bonneville Dam	Total
6/23	6/24	522	321	24	68	353
6/24	6/25	597	390	45	60	415
6/25	6/26	1,005	669	84	78	696
6/26	6/27	376	252	48	30	268
6/27	6/28	324	236	21	20	240
6/28	6/29	225	168	28	21	176
6/29	6/30	492	367	51	31	381
6/30	7/1	225	126	21	13	135
7/2	7/3	323	210	27	23	218
7/3	7/4	709	386	77	71	426
Nighttime collection-channel releases						
6/25	6/26	899	899	100	85	678
6/26	6/27	453	453	46	44	318
6/29	6/30	531	531	53	41	381
6/30	7/1	191	191	21	11	110

Appendix Table 9. Continued.

Tag date	Release date	Spillbay	Release number	Detections: McNary Dam	Detections: John Day Dam	Detections: Bonneville Dam	Total
Subyearling Chinook salmon--Summer 2003							
Daytime spillway releases							
6/23	6/24	2	196	124	9	32	136
		3	202	129	13	30	138
		4	203	111	7	24	122
6/24	6/25	2	224	140	13	20	152
		3	222	147	18	33	159
		4	224	146	14	19	149
6/27	6/28	2	110	70	5	4	72
		2	124	77	8	9	81
		3	131	96	6	7	99
6/28	6/29	2	89	69	7	2	69
		3	89	65	9	2	67
		4	88	67	7	2	68
7/1	7/2	2	90	57	5	11	62
		2	95	60	8	9	65
		3	116	75	9	10	79
7/2	7/3	3	108	61	7	4	64
		3	109	68	7	8	68
		2	120	78	7	13	80
7/7-8	7/9	2	155	82	7	10	85
		3	124	79	8	8	84
		4	125	70	10	5	75
7/9	7/11	2	143	81	7	7	85
		3	118	69	7	4	74
		3	118	53	4	4	58
Nighttime spillway releases							
6/23	6/24	2	227	120	11	24	131
		3	225	132	18	12	139
		4	176	118	14	17	123
6/24	6/25	2	250	151	32	35	170
		3	225	149	24	28	156
		3	243	158	16	24	168
6/27	6/28	4	109	76	8	5	80
		3	110	72	8	4	76
		2	115	78	5	7	81
6/28	6/29	4	89	56	9	2	59
		3	105	66	11	6	69
		2	104	71	9	8	74
7/2	7/3	2	117	74	7	5	76
		3	109	58	5	7	59
		3	119	76	9	7	78
7/10-11	7/12	2	660	378	34	33	399
		3	319	184	21	15	190
7/12	7/12	2	461	264	22	13	275
		3	229	144	18	10	148

Appendix Table 10. Results of Test 2.C2 for PIT-tagged subyearling Chinook salmon released into the collection channel, spillway, tailrace, and turbine of Ice Harbor Dam, summer 2003.

	Collection channel		Spillway		Tailrace		Turbine	
Release date	$\chi2$	*P*	$\chi2$	*P*	$\chi2$	*P*	$\chi2$	*P*
6/25/03	2.28	0.131	5.84	0.016	3.67	0.055	1.47	0.226
6/26/03	1.09	0.296	0.56	0.454	3.97	0.046	0.45	0.501
6/27/03	2.28	0.131	--	--	0.35	0.552	0.60	0.437
6/28/03	2.78	0.095	--	--	0.01	0.941	0.90	0.343
6/29/03	0.80	0.370	1.46	0.228	3.10	0.078	0.56	0.455
6/30/03	2.17	0.141	0.32	0.573	1.58	0.209	1.92	0.166
7/1/03	2.37	0.124	--	--	0.24	0.625	0.71	0.398
7/2/03	0.19	0.664	--	--	0.50	0.478	1.00	0.316
7/3/04	--	--	1.19	0.276	0.38	0.539	1.85	0.174
7/4/03	4.97	0.026	1.82	0.178	0.78	0.378	0.09	0.770
7/5/03	6.73	0.009	--	--	0.40	0.525	--	--
7/10/03	--	--	0.49	0.484	0.26	0.611	--	--
7/11/03	--	--	0.20	0.653	1.40	0.237	--	--
7/13/03	--	--	0.16	0.688	1.73	0.188	--	--
Total	25.66	0.004	12.03	0.212	18.37	0.191	9.55	0.480

Appendix Table 11. Results of Test 3.SR3 for PIT-tagged subyearling Chinook salmon released in the collection channel, spillway, tailrace, and turbine of Ice Harbor Dam, summer 2003. Values of "NA" imply test was not calculable due to expected values less than one in at least one cell of the contingency table.

	Collection channel		Spillway		Tailrace		Turbine	
Release date	$\chi 2$	*P*	$\chi 2$	*P*	$\chi 2$	*P*	$\chi 2$	*P*
6/25/03	0.61	0.437	1.31	0.253	NA		0.12	0.726
6/26/03	12.66	0.000	1.52	0.218	0.08	0.772	NA	
6/27/03	0.75	0.386	--	--	0.48	0.490	0.24	0.622
6/28/03	3.37	0.066	--	--	3.80	0.051	0.42	0.516
6/29/03	NA		0.02	0.886	0.03	0.859	NA	
6/30/03	0.28	0.595	NA		0.69	0.405	NA	
7/1/03	0.10	0.748	--	--	1.17	0.280	0.13	0.720
7/2/03	2.01	0.156	--	--	2.24	0.134	0.25	0.619
7/3/04	--	--	0.01	0.907	NA		--	--
7/4/03	NA		NA		NA		NA	
7/5/03	0.28	0.599	--	--	0.00	0.970	0.08	0.783
7/10/03	--	--	NA		NA		--	--
7/11/03	--	--	NA		0.01	0.917	--	--
7/13/03	--	--	0.48	0.487	0.56	0.453	--	--
Total	20.06	0.010	3.34	0.647	9.06	0.526	1.24	0.975

Appendix Table 12. Relative survival estimates to McNary Dam for subyearling Chinook salmon released into the collection channel, spillway, and turbine units 1A and 3A at Ice Harbor Dam, summer 2003. Estimates used the single-release model and SURPH statistical software.

Release date	Collection channel	Spillway	Turbines
		Spill blocks	
6/24	1.090	0.902	0.967
6/25	0.988	0.960	0.924
6/28	0.873	1.003	0.850
6/29	1.040	0.955	0.860
7/2	*	1.213	*
7/3	1.018	0.888	0.933
7/9	*	1.152	*
7/10	*	0.918	*
7/12	*	0.997	*
Weighted geomean (spill)	0.992	0.964	0.910
		No-spill blocks	
6/26	0.972		0.858
6/27	1.014		0.958
6/30	1.007		0.824
7/1	0.969		0.922
7/4	1.098		1.063
Weighted geomean (no spill)	0.999		0.886
Weighted geomean overall	0.997	0.964	0.893

* Insufficient numbers of fish were available to form a replicate for release.

Appendix Table 13. Times and conditions by release location during morning and evening releases of subyearling Chinook salmon at Ice Harbor Dam, summer 2003.

Release date	Time (PDT)	Tailwater elevation (ft)	Unit 1 load (MW)	Unit 1 flow (kcfs)	Total powerhouse (kcfs)	Total spill (kcfs)	Total river flow (kcfs)	River temp (°C)
				Turbine				
Morning								
6/24	9:45	343.57	63.6	9.0	29.9	45.0	74.9	16.56
6/25	9:34	340.33	64.8	8.8	8.8	30.7	39.5	16.72
6/26	9:00	339.37	102.6	13.5	13.5	0	13.5	17.83
6/27	10:43							18.22
6/28	10:57	339.40	69.9	9.3	9.3	20.3	29.6	18.17
6/29	11:32	341.37	89.9	11.9	11.9	35.1	47.0	18.33
6/30	10:49	342.06	72.4	9.8	44.4	0	44.4	18.06
7/1	11:02	342.75	89.8	12.1	55.3	0	55.3	19.11
7/3	11:37	340.30	64.0	8.8	8.8	25.1	33.9	18.5
7/4	11:05	340.85	96.5	12.7	25.4	0	25.4	18.28
Evening								
6/26	19:06	343.60	99.0	13.6	61.3	0	61.3	20.72
6/27	19:09							20.33
6/30	18:51	342.30	70.4	9.6	44.0	0	44.0	18.61
7/1	18:42	342.39	81.8	10.9	49.9	0	49.9	18.67
				Collection channel				
Morning								
6/24	11:17	343.68			30.0	45.0	75.0	16.50
6/25	9:17	340.51			9.0	30.7	39.7	16.83
6/26	8:49	339.30			10.3	0	10.3	17.83
6/27	11:09							18.22
6/28	10:44	339.48			9.2	20.3	29.5	18.17
6/29	11:20	341.31			12.0	35.1	47.1	18.89
6/30	10:36	342.07			44.1	0	44.1	18.06
7/1	11:22	343.19			55.8	0	55.8	19.11
7/3	11:22	340.23			8.8	25.1	33.9	18.56
7/4	11:27	340.83			26.2	0	26.2	18.28
Evening								
6/26	18:53	343.62			60.7	0	60.7	20.72
6/27	18:57							20.33
6/30	18:37	342.25			44.2	0	44.2	18.61
7/1	18:30	342.36			49.8	0	49.8	18.67

Appendix Table 13. Continued.

Rel. date	Time (PDT)	Bay	Tailwater elevation (ft)	Gate 2 position (stops)	Gate 2 flow (kcfs)	Gate 3 position (stops)	Gate 3 flow (kcfs)	Gate 4 position (stops)	Gate 4 flow (kcfs)	Total powerhouse (kcfs)	Total spill (kcfs)	Total flow (kcfs)	River temp (°C)
						Spillway							
Morning													
6/24	9:01	2	343.64	9.0	15.1	9.0	15.0	9.0	15.0	28.9	45.1	74.0	16.56
6/24	9:12	3	343.54	9.0	15.0	9.0	15.0	9.0	15.0	27.9	45.0	72.9	16.56
6/24	9:27	4	343.43	9.0	15.0	9.0	15.0	9.0	15.0	29.6	45.0	74.6	16.56
6/25	8:27	2	340.09	6.0	10.2	6.1	10.3	6.0	10.2	8.7	30.7	39.4	16.83
6/25	8:51	3	340.16	6.0	10.2	6.1	10.3	6.0	10.1	8.7	30.6	39.3	16.83
6/25	9:04	4	340.18	6.0	10.2	6.1	10.3	6.0	10.2	8.7	30.7	39.4	16.83
6/28	10:12	2	339.51	6.0	10.1	6.0	10.2	0	0	9.2	20.3	29.5	17.56
6/28	10:27	3	339.81	6.0	10.1	6.0	10.2	0	0	9.2	20.3	29.5	17.56
6/29	10:34	2	341.27	7.0	11.7	7.0	11.7	7.0	11.7	10.5	35.1	45.6	18.89
6/29	10:54	3	341.22	7.0	11.7	7.0	11.7	7.0	11.7	10.5	35.1	45.6	18.89
6/29	11:04	4	341.25	7.0	11.7	7.0	11.7	7.0	11.7	11.3	35.1	46.4	18.89
7/2	10:43	2	339.50	5.7	9.6	5.6	9.4	0	0	9.2	19.0	28.2	18.44
7/2	11:04	3	339.73	5.7	9.6	5.6	9.4	0	0	9.2	19.0	28.2	18.44
7/3	10:53	3	340.27	7.9	13.3	7.0	11.8	0	0	8.8	25.1	33.9	18.56
7/3	11:11	2	340.45	7.9	13.3	7.0	11.8	0	0	8.8	25.1	33.9	18.56
7/9	11:20	2	340.40	7.0	11.7	6.0	10.1	5.7	9.6	8.5	31.4	39.9	19.78
7/9	11:07	3	340.51	7.0	11.7	6.0	10.1	5.7	9.6	8.5	31.4	39.9	19.78
7/9	10:56	4	340.20	7.0	11.7	6.0	10.1	5.7	9.6	8.5	31.4	39.9	19.78
7/11	10:10	2	340.14	8.0	13.4	7.0	11.8	0	0	8.7	25.2	33.9	19.67
7/11	10:31	3	340.17	8.0	13.3	7.0	11.8	0	0	8.7	25.1	33.8	19.67
Evening													
6/24	19:59	2	344.26	8.0	13.4	8.1	13.5	7.2	12.1	28.3	50.9	79.2	16.61
6/24	19:47	3	344.32	8.0	13.4	8.1	13.5	7.2	12.1	30.1	50.9	81.0	16.61
6/24	19:35	4	344.37	8.0	13.4	8.1	13.5	7.2	12.1	30.2	50.9	81.1	16.61
6/25	19:30	2	340.50	9.0	15.0	8.1	13.5	3.7	5.1	8.7	38.6	47.3	16.83
6/25	19:14	3	340.67	9.0	15.0	9.0	15.0	0	0	8.9	30.0	38.9	16.83
6/28	19:18	4	342.00	9.0	14.9	9.0	14.9	9.0	14.9	9.1	44.7	53.8	17.50
6/28	19:30	3	341.90	9.0	14.9	9.0	14.9	9.0	14.9	9.1	44.7	53.8	17.50
6/28	19:38	2	341.86	9.0	14.9	9.0	14.9	9.0	14.9	9.1	44.7	53.8	17.50
6/29	19:14	4	341.49	7.0	11.7	7.0	11.7	7.0	11.7	10.5	35.1	45.6	18.22
6/29	19:27	3	341.43	7.0	11.7	7.0	11.7	7.0	11.7	10.5	35.1	45.6	18.22
6/29	19:43	2	341.36	7.0	11.7	7.0	11.7	7.0	11.7	10.5	35.1	45.6	18.22
7/3	19:48	2	340.65	7.9	13.3	7.0	11.8	0	0	8.8	25.1	33.9	18.50
7/3	19:07	3	340.40	7.9	13.3	7.0	11.8	0	0	8.9	25.1	34.0	18.50
7/12	19:42	2	340.62	9.0	14.9	9.0	14.9	0	0	9.0	29.8	38.8	19.83
7/12	19:11	3	340.75	9.0	14.9	9.0	14.9	0	0	9.0	29.8	38.9	19.83

Appendix Table 14. Results of subyearling Chinook salmon relative survival analysis and analysis of travel time correlation from release at Ice Harbor Dam to detection at McNary Dam, summer 2003.

Collection channel--Summer				
	Relative survival correlations			
N = 12	Relative survival	Date	Tailwater elevation	Total river flow
Date	0.042			
Tailwater elevation	-0.306	-0.092		
Total river flow	-0.267	-0.257	0.911	
River temperature	0.093	0.239	0.290	0.102
Stepwise regression: diel factor included in all models; F-to-enter = 4 F-to-remove = 4				
Step	1			
Constant	99.23			
Diel	-3			
t	-0.76			
P	0.467			
S	5.94			
R^2 (adj)	0.00			
	Travel time correlations			
N = 12	Travel time	Date	Tailwater elevation	Total river flow
Date	-0.335			
Tailwater elevation	-0.146	-0.092		
Total river flow	-0.178	-0.257	0.911	
River temperature	-0.206	0.239	0.290	0.102
Stepwise regression: diel factor included in all models; F-to-enter = 4 F-to-remove = 4				
Step	1			
Constant	2.429			
Diel	-0.02			
t	-0.10			
P	0.922			
S	0.258			
R^2 (adj)	0.00			

Appendix Table 14. Continued.

Combined turbines--Summer				
	Relative survival correlations			
N = 12	Relative survival	Date	Tailwater elevation	Total river flow
Date	-0.162			
Tailwater elevation	-0.385	-0.113		
Total river flow	-0.280	-0.314	0.904	
River temperature	-0.197	0.210	0.334	0.108
Stepwise regression: diel factor included in all models; F-to-enter = 4 F-to-remove = 4				
Step	1			
Constant	87.32			
Diel	-5.4			
t	-1.72			
P	0.115			
S	4.72			
R^2 (adj)	15.22			
	Travel time correlations			
N = 12	Travel time	Date	Tailwater elevation	Total river flow
Date	-0.299			
Tailwater elevation	-0.218	-0.113		
Total river flow	-0.251	-0.314	0.904	
River temperature	-0.172	0.21	0.334	0.108
Stepwise regression: diel factor included in all models; F-to-enter = 4 F-to-remove = 4				
Step	1			
Constant	2.427			
Diel	0.01			
t	0.05			
P	0.959			
S	0.266			
R^2 (adj)	0.00			

Appendix Table 14. Continued.

Spillway--Summer				
	Relative survival correlations			
N = 14	Relative survival	Date	Tailwater elevation	Total river flow
Date	0.336			
Tailwater elevation	-0.502	-0.479		
Total river flow	-0.448	-0.515	0.990	
River temperature	0.319	0.944	-0.503	-0.544
Stepwise regression: diel factor included in all models; F-to-enter = 4 F-to-remove = 4				
Step	1			
Constant	98.71			
Diel	-3.6			
t	-1.14			
P	0.275			
S	5.82			
R^2 (adj)	2.32			
	Travel time correlations			
N = 12	Travel time	Date	Tailwater elevation	Total river flow
Date	0.351			
Tailwater elevation	-0.053	-0.479		
Total river flow	-0.058	-0.515	0.99	
River temperature	0.204	0.944	-0.503	-0.544
Stepwise regression: diel factor included in all models; F-to-enter = 4 F-to-remove = 4				
Step	1			
Constant	2.569			
Diel	-0.05			
t	-0.21			
P	0.837			
S	0.424			
R^2 (adj)	0.00			

Appendix Table 15. Tests for homogeneity for McNary, John Day, and Bonneville Dams passage distributions for groups of PIT-tagged subyearling Chinook salmon released into the spillway, collection channel, turbines, and tailrace at Ice Harbor Dam, 2003. D = daytime release, N = evening release. Col = collection channel, Spl = spillway, Tal = tailrace, and Trb = turbine releases.

McNary Dam						
Release date	Diel period	Release groups	χ^2	df	*P*	Result*
6/24	D	Col, Spl, Tal, Trb	70.8	42	0.0007	Tailrace early
	N	Spl, Tal	40.5	10	<0.0001	Tailrace early
6/25	D	Col, Spl, Tal, Trb	78.4	45	0.0002	Tailrace early
	N	Spl, Tal	13.2	12	0.3300	Mixed
6/26	D	Col, Tal, Trb	45.9	36	0.0704	Turbine late
	N	Col, Tal, Trb	35.5	24	0.0242	Tailrace early
6/27	D	Col, Tal, Trb	22.7	18	0.1565	Mixed
	N	Col, Tal, Trb	19.8	18	0.2975	Mixed
6/28	D	Col, Spl, Tal, Trb	25.2	21	0.2186	Mixed
	N	Spl, Tal	29.6	6	<0.0001	Tailrace early
6/29	D	Col, Spl, Tal, Trb	61.1	30	0.0001	Tailrace early
	N	Spl, Tal	10.8	6	0.0528	Tailrace early
6/30	D	Col, Tal, Trb	16.6	18	0.5725	Mixed
	N	Col, Tal, Trb	12.0	12	0.4502	Mixed
7/1	D	Col, Tal, Trb	7.9	12	0.7970	Mixed
	N	Col, Tal, Trb	10.0	12	0.6605	Mixed
7/2	D	Spl, Tal	7.8	7	0.3566	Mixed
7/3	D	Col, Spl, Tal, Trb	31.6	24	0.1030	Mixed
	N	Spl, Tal	17.0	8	0.0129	Tailrace early
7/4	D	Col, Tal, Trb	32.7	18	0.0094	Tailrace early
7/9	D	Spl, Tal	8.6	11	0.7263	Mixed
7/10	D	Spl, Tal	11.2	13	0.6609	Mixed
7/12	N	Spl, Tal	35.1	17	0.0025	Tailrace early

Appendix Table 15. Continued.

John Day Dam						
Release date	Diel period	Release groups	χ^2	df	*P*	Result*
6/24	D	Col, Spl, Tal, Trb	36.4	39	0.6556	Mixed
	N	Spl, Tal	12.1	10	0.2722	Mixed
6/25	D	Col, Spl, Tal, Trb	61.6	45	0.0143	Tailrace late
	N	Spl, Tal	10.4	12	0.6962	Mixed
6/26	D	Col, Tal, Trb	28.4	28	0.4351	Mixed
	N	Col, Tal, Trb	26.5	24	0.2927	Mixed
6/27	D	Col, Tal, Trb	21.3	24	0.7566	Mixed
	N	Col, Tal, Trb	12.7	14	0.5840	Mixed
6/28	D	Col, Spl, Tal, Trb	33.5	27	0.1608	Mixed
	N	Spl, Tal	5.9	8	0.8341	Mixed
6/29	D	Col, Spl, Tal, Trb	27.1	27	0.4703	Mixed
	N	Spl, Tal	2.3	6	0.9531	Mixed
6/30	D	Col, Tal, Trb	21.4	16	0.1226	Mixed
	N	Col, Tal, Trb	19.7	20	0.4959	Mixed
7/1	D	Col, Tal, Trb	9.4	16	0.9687	Mixed
	N	Col, Tal, Trb	11.0	14	0.8019	Mixed
7/2	D	Spl, Tal	4.1	7	0.8350	Mixed
7/3	D	Col, Spl, Tal, Trb	30.6	27	0.2352	Mixed
	N	Spl, Tal	2.2	6	0.9549	Mixed
7/4	D	Col, Tal, Trb	32.1	22	0.0379	Col channel late
7/9	D	Spl, Tal	5.7	7	0.7250	Mixed
7/10	D	Spl, Tal	5.7	7	0.6690	Mixed
7/12	N	Spl, Tal	13.7	18	0.8161	Mixed

Appendix Table 15. Continued.

Bonneville Dam						
Release date	Diel period	Release groups	χ^2	df	*P*	Result*
6/24	D	Col, Spl, Tal, Trb	30.3	33	0.6400	Mixed
	N	Spl, Tal	25.2	10	0.0010	Tailrace early
6/25	D	Col, Spl, Tal, Trb	34.2	39	0.7618	Mixed
	N	Spl, Tal	9.5	8	0.2834	Mixed
6/26	D	Col, Tal, Trb	19.7	24	0.7863	Mixed
	N	Col, Tal, Trb	17.8	28	0.9899	Mixed
6/27	D	Col, Tal, Trb	24.0	18	0.0946	Mixed
	N	Col, Tal, Trb	14.7	18	0.6862	Mixed
6/28	D	Col, Spl, Tal, Trb	26.2	27	0.5378	Mixed
	N	Spl, Tal	14.0	9	0.0636	Mixed
6/29	D	Col, Spl, Tal, Trb	19.3	21	0.5955	Mixed
	N	Spl, Tal	8.5	7	0.3078	Mixed
6/30	D	Col, Tal, Trb	14.2	18	0.7946	Mixed
	N	Col, Tal, Trb	20.2	18	0.3242	Mixed
7/1	D	Col, Tal, Trb	11.6	14	0.7122	Mixed
	N	Col, Tal, Trb	13.6	14	0.5390	Mixed
7/2	D	Spl, Tal	1.6	5	0.9538	Mixed
7/3	D	Col, Spl, Tal, Trb	40.4	24	0.0067	All different
	N	Spl, Tal	9.3	8	0.3266	Mixed
7/4	D	Col, Tal, Trb	20.6	22	0.5840	Mixed
7/9	D	Spl, Tal	4.9	6	0.6477	Mixed
7/10	D	Spl, Tal	9.8	6	0.1029	Mixed
7/12	N	Spl, Tal	14.7	12	0.2102	Mixed

* $P>0.10$, interpreted as being consistent with the assumption of mixing.

Appendix Table 16. Graphs of selected subyearling Chinook salmon unmixed and mixed release groups as determined by chi-square tests.