U.S. Army Corps of Engineers
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Survival estimates of migrant juvenile salmonids through The Dalles Dam using radio-telemetry, 2002.

Survival Estimates of migrant juvenile salmonids through The Dalles Dam using radio-telemetry, 2002.

Final Report of Research

Prepared by:

Timothy D. Counihan
Glen S. Holmberg
Christopher E. Walker
and
Jill M. Hardiman

United States Geological Survey
Western Fisheries Research Center
Columbia River Research Laboratory
Cook, WA 98605

Prepared for:

U.S. Army Corps of Engineers
Portland District
Planning and Engineering Division
Environmental Resources Branch
Robert Duncan Plaza
333 S.W. 1st Avenue
Portland, Oregon 97204-3495

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Executive Summary

During 2002, the USGS, Columbia River Research Laboratory evaluated survival of yearling and sub-yearling Chinook salmon at The Dalles Dam during 40% spill operations. These evaluations used a combination of site-specific releases through spill bays 4, 9, and 13 for yearling Chinook and spill bays 4 and 13 for sub-yearling Chinook and releases of radio-tagged fish in the tailraces of John Day dam and The Dalles Dam. The objective of these evaluations was to estimate and compare the survival probabilities of yearling and sub-yearling Chinook salmon through the spill bays (4, 9, and 13), ice and trash sluiceway, spillway, and turbines. The radio-tagged fish were interrogated using radio-telemetry systems at and below The Dalles Dam. The capture histories generated were then processed and analyzed using the paired release-recapture models of Burnham et al. (1987) for the site-specific releases and the Route Specific Survival Model for fish released above The Dalles Dam (Skalski et al. 2002).

Paired release recapture model – Spillway

Yearling Chinook salmon

We estimated that the survival of yearling Chinook salmon released through spillbay 4 at The Dalles Dam spillway during 2002 ranged from 0.85 to 1.06 with an average survival of 0.98 (± 0.029, 95% confidence interval). The estimated survival of yearling Chinook salmon released through spillbay 9 ranged from 0.85 to 1.06 with an average survival of 0.95 (± 0.033, 95% confidence interval), and spillbay 13 estimated survival ranged from 0.71 to 1.11 with an average survival of 0.92 (± 0.051, 95% confidence interval). The estimated survival for yearling Chinook salmon released though spillbay 4 was found to be significantly different than for spillbay 13 (Welch's variance weighted *ANOVA*, $P = 0.052$). Comparisons between spillbay 4 and spillbay 9 (*t-test*, $P = 0.25$) and between spillbay 9 and spillbay 13 (*t-test*, $P = 0.27$) did not indicate significant differences in the estimated survival of yearling Chinook releases through these spillbays.

Sub-yearling Chinook salmon

We estimated that the survival of sub-yearling Chinook salmon released through spillbay 4 at The Dalles Dam spillway during 2002 ranged from 0.91 to 1.10 with an average of 1.00 (± 0.026, 95% confidence interval). We also estimated that the survival of sub-yearling Chinook salmon released through spillbay 13 ranged from 0.75 to 1.13 with an average survival of 0.97 (± 0.048, 95% confidence interval). The estimated survival for sub-yearling Chinook salmon released though spillbay 4 was not found to be significantly different than for spillbay 13 (Welch's variance weighted *ANOVA*, $P = 0.20$).

Route Specific Survival Model

Yearling Chinook salmon

The survival of yearling Chinook salmon through The Dalles Dam spillway was estimated to be 0.882 (SE = 0.019; profile likelihood 95% confidence interval = [0.845, 0.920]) during 40% spill operations. For yearling Chinook passing the ice and trash sluiceway the estimated survival was 0.911 (SE = 0.036, profile likelihood 95% confidence interval [0.833, 0.974]) and for yearling Chinook passing via the powerhouse the estimated survival was 0.849 (SE = 0.023, profile likelihood 95% confidence interval [0.802, 0.894]). Yearling Chinook salmon dam survival was estimated to be 0.872 (SE = 0.021) during 40% spill operations at The Dalles Dam during 2002.

Sub-yearling Chinook salmon

The survival of sub-yearling Chinook salmon through The Dalles Dam spillway was estimated to be 0.906 (SE = 0.013; profile likelihood 95% confidence interval = [0.880, 0.934]) during 40% spill operations. For sub-yearling Chinook passing the ice and trash sluiceway the estimated survival was 0.907 (SE = 0.026, profile likelihood 95% confidence interval [0.854, 0.955]) and for sub-yearling Chinook passing via the powerhouse the estimated survival was 0.817 (SE = 0.016, profile likelihood 95% confidence interval [0.785, 0.850]). Sub-yearling Chinook salmon dam survival was estimated to be 0.872 (SE = 0.015) during 40% spill operations at The Dalles Dam during 2002.

Introduction

As anadromous juvenile salmonids migrate from freshwater rearing habitats to the ocean, they are vulnerable to a host of factors that affect their survival. Direct effects associated with dam passage (e.g., instantaneous mortality, injury, loss of equilibrium, etc.) and indirect effects (e.g., predation, disease, and physiological stress) contribute to the total mortality of seaward migrating salmonids. Many studies have been conducted to determine the effects of hydroelectric dams on the survival of salmonid migrants (Raymond 1979, Stier and Kynard 1986, Iwamato et al. 1994, Muir et al. 1995, Smith et al. 1998, Bickford and Skalski 2000). Giorgi et al. (2002) noted that survival of salmonid migrants is variable among projects and across species. Thus, studies designed to estimate project specific survival and route specific survival (i.e. through turbines, bypass areas, and spillways) of juvenile salmon are essential to identify sources of mortality. Based on this research and studies examining migrant salmonid behavior at dams in the Columbia River Basin, management actions are currently being implemented to improve the survival of juvenile salmonid migrants.

New fish marking techniques and the development and acceptance of new statistical methodologies (see: Leberton et al. 1992) have led scientists to reevaluate past techniques used to assess survival of migrant salmonids in the Columbia River Basin. The development of the passive integrated transponder (PIT) tag, allowed for the unique identification of fish (Prentice et al. 1990), and recent technological advancements in radio-telemetry equipment have decreased the size and increased the life of transmitters allowing for use with juvenile fish passage behavior and survival studies (Skalski et al. 2001 and 2002, Counihan et al. 2001 and 2002). Consequently, PIT-tag recoveries, radio telemetry capture histories, and release-recapture models (Burnham et al. 1987, Smith et al. 1996) have been used to assess the survival of migrant salmonid smolts through various reaches of the Columbia and Snake Rivers (Muir et al. 1995, Skalski et al. 1998b, Smith et al. 1998, Dawley et al. 1998, Skalski et al. 2001 and 2002). Results from studies examining simultaneous releases of PIT-tagged and radio-tagged fish in the Snake River and mid Columbia River suggest similar trends in survival between the two groups (Hockersmith et al. 2003). Further, concurrent releases of radio- and PIT-tagged yearling Chinook salmon at The Dalles Dam also indicate that estimates from the two tagging techniques provide comparable estimates (Counihan et al. 2001).

Although, the two techniques have comparable results there are important considerations with each method. The use of the PIT-tag technique relies on the availability of PIT-tag detectors at hydroelectric dams, which are not present at all locations in the Columbia River Basin (e.g. The Dalles Dam). The absence of PIT-tag detectors at certain projects and areas below Bonneville Dam has precluded or confounded survival estimation in some specific reaches of the Columbia River and limited the spatial scale over which survival estimates can be made. Further, the low detection probabilities associated with this technique requires that large numbers of fish be handled (although minimally) to obtain desired levels of precision in survival estimates (Skalski 1999b). Detection rates of marked fish affect the sample size required

for a given level of precision and thus, the reliability of survival estimates (Skalski 1992). The radio-telemetry technique offers high detection rates, observed in migrant salmonid studies at specific project sites and in-river sites in the lower Columbia River; suggesting that the numbers of fish necessary to generate survival estimates with similar or greater precision could be reduced using radio-tagged fish. Further, the flexibility of radio-telemetry system deployment at hydroelectric projects and in-river locations can increase the geographic area over which estimates are generated (e.g. areas below Bonneville Dam).

A primary objective of The National Marine Fisheries Service (NMFS) Federal Columbia River Power System (FCRPS) Biological Opinion is to increase survival of juvenile salmonid out migrants through the federal hydrosystem (NMFS 2000). The 2000 Biological opinion resulted in a spill program of up to 120% total dissolved gas (TDG), which was expected to provide a safer route of project passage than turbine passage. While there is a consensus that survival is greater for fish diverted from turbines, questions regarding the effectiveness of different spill patterns and other passage scenarios remain (Dawley et al. 1998). Normandeau Associates et al. (1996) expressed concerns that spillway survival at The Dalles Dam was lower than other dams. For example, in 2000 the survival through the spillway was estimated to be 92.7% (Counihan et al. 2001) whereas other dams average 98% (Ploskey et al. 2001). The Dalles Dam decreased spill passage survival under high spill conditions could be due to 1) a short stilling basin and shallow tailrace resulting in severe turbulence and lateral currents that may cause physical injury to migrant salmon; and 2) a large proportion of spillway-passed water moves through shallows and islands downstream where predation on salmonids by gulls (*Larus* spp.) and northern pikeminnow (*Ptychocheilus oregonensis*) may be substantially higher than at other dams. In recent years various levels and configurations of spill have been investigated to help increase survival and monitor survival, including routes of passage such as the ice and trash sluiceway.

During 1999, tests of the efficacy of different spill scenarios (64% and 30% spill levels) were conducted at The Dalles Dam. The motivation for these evaluations was to identify which spill scenario will increase fish passage efficiency and reduce predation of migrant juvenile salmonids by altering the hydraulic conditions in the forebay environment, shortening travel times through tailrace areas, and manipulating passage routes through tailrace areas to divert fish from areas with high predator densities. Survival studies by NMFS at The Dalles Dam during 1998-2000 and the USGS in 2000 indicated spillway survival at 30% spill (and 40% constant level for 2000) was typically higher than spillway survival at 64% spill and survival through the sluiceway was similar to the 30% spillway survival (Ploskey et al. 2001). These results indicate that high levels of spill can create conditions that cause unexpectedly high mortality during spill passage and that survival through preferred passage routes at The Dalles Dam is still lower than throughout the Columbia River dams. A result of these studies is the Fish Passage Plan in the 2000 Biological Opinion operating criteria now recommends 24-h spill at 40% spill level with the recommended operation of the ice and trash sluiceway as a surface bypass system for The Dalles Dam. Monitoring the survival of juvenile salmonids through The Dalles Dam will provide data that can be used to assess actions that increase or decrease

survival at The Dalles Dam and to help understand the factors causing mortality at this hydroelectric project.

During 2002, we evaluated the survival of yearling Chinook salmon through spillbays 4, 9, and 13 and sub-yearling Chinook through spillbays 4 and 13 at The Dalles Dam spillway during a 40% spill level. Additionally, we used radio-tagged yearling and sub-yearling Chinook salmon released at John Day Dam and the Route Specific Survival Model (RSSM, Skalski et al. 2002) to estimate survival probabilities of fish passing via the spillway, turbines, and ice and trash sluiceway.

Methods

Study area

To evaluate survival through The Dalles Dam spillway during the 2002 spring and summer out migration, we monitored radio-tagged juvenile salmonids released directly into spillbays 4, 9, and 13, and into the tailrace area immediately downstream of the spillway. To evaluate the route specific survival through other passage routes at The Dalles Dam, we monitored radio-tagged salmonids released upriver at John Day Dam (RKM 346.9) and in the tailrace of The Dalles Dam near the I-197 bridge. The study area extended from John Day Dam downriver to Bonneville Dam (Figure 1). Antenna arrays within the study area were located on The Dalles Dam (rkm 308.1), near the town of Lyle, WA (rkm 286.4), on the Hood River Bridge (rkm 273.2), and on Bonneville Dam (rkm 235.1). All detection arrays spanned the breadth of the river channel. The array at The Dalles Dam was set up so that passage route could be determined (Beeman et al. 2001a, Beeman et al. 2001b).

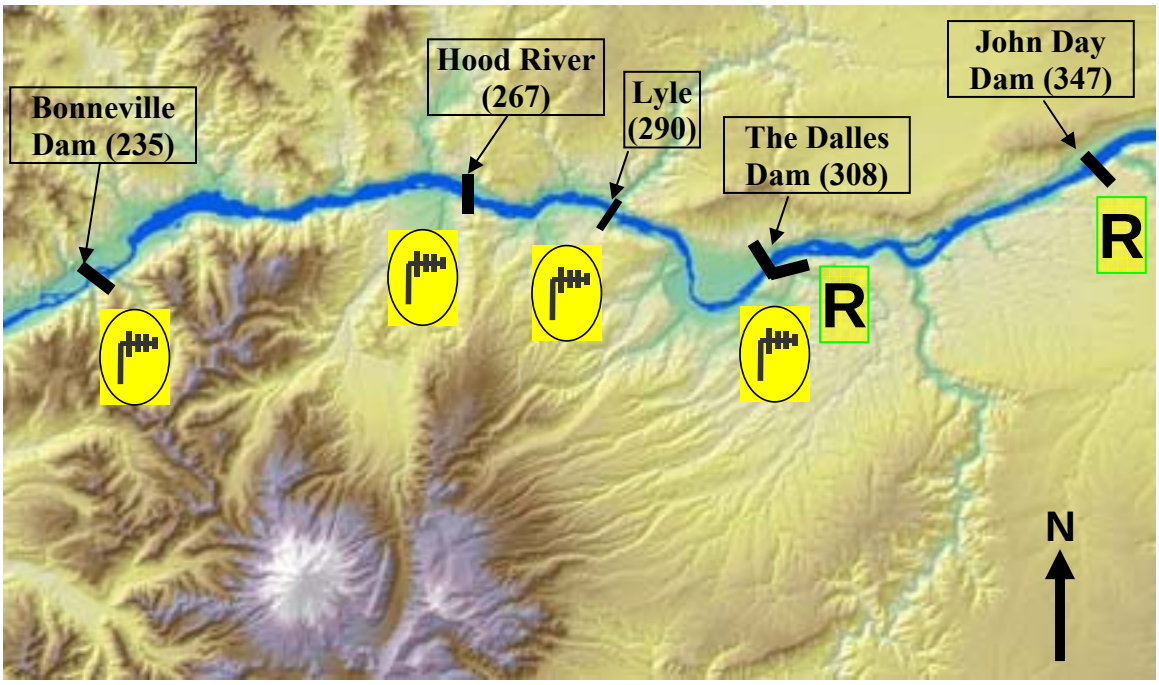

Figure 1. Release and detection locations for The Dalles Dam survival evaluation, during 2002. R = release locations, locations of radio telemetry arrays are shown as yellow ovals. River kilometers (rkm) are given in parentheses for each location.

The Dalles Dam

The Dalles Dam consists of a single powerhouse of 22 horizontal-axis turbine units, each with three intakes, and a spillway with 23 spillbays each controlled by a tainter gate (Figure 2). The powerhouse is oriented approximately perpendicular to the natural river thalweg. Openings in the dam at the water's surface above each turbine intake allow water and debris to flow into an ice and trash sluiceway. Water and debris flow to an outfall and plunge into the tailrace near the powerhouse outflow. Past research has shown a significant number of downstream migrants pass the dam through the Ice and Trash Sluiceway (Hansel, 1999). The river thalweg turns southeast abruptly in the powerhouse area, continues along the powerhouse tailrace and passes under the I-197 bridge near the Washington shore. A non-overflow wall connects the powerhouse and spillway. A navigation lock is located at the northwest end of the dam. The dam has two adult fish ladders, one between the spillway and navigational lock, the other at the east end of the powerhouse.

Figure 2. Aerial view of The Dalles Dam, 2002, looking upriver (northeast).

System antenna configuration

Antenna arrays used to monitor movements and passage location of radio-tagged fish released at John Day and The Dalles dams consisted of 4-element Yagi aerial antennas and dipole underwater antennas placed on the forebay and tailrace sides of the dam and in the Ice and trash Sluiceway (Figure 3). We placed 12 aerial antennas on the forebay spillbays, and 12 aerial antennas on the forebay turbine bays, and 8 aerial antennas on the non-overflow wall. Each aerial antenna monitoring the spillway and powerhouse was directed 45° away from the dam and provided coverage for two adjacent bays. A total of 90 underwater antennas were attached to the spillway forebay pier noses, 7 in the Ice and Trash Sluiceway, and 101 underwater antennas monitored the powerhouse forebay intakes. On the tailrace side, we placed 12 aerial antennas on the tailrace spillway and 12 on the powerhouse. A total of 92 underwater antennas were positioned in the spillway tailrace. We also set up 12 aerial antennas to cover the navigational lock and south spill. Detection range for aerial antennas was approximately 100 m but varied with depth of transmitter in the water column. Underwater antennas were used to monitor radio-tagged fish within 10 m of the turbine intakes, spillway tainter gates, spillway tailrace, and the Ice and Trash Sluiceway.

Antennas were connected to either an SRX-400 data logging telemetry receiver (Lotek Wireless, Newmarket, Ontario, Canada), a Digital Spectrum processor (Lotek Wireless), or a Multiprotocol Integrated Telemetry Acquisition System (MITAS; Grant Systems Engineering, King City, Ontario, Canada). Data logging devices stored detection histories for individual channel codes and were downloaded to a laptop computer every two to four days.

Figure 3. Locations of radio-telemetry antennas at The Dalles Dam during 2002. Yellow arrows represent aerial antennas and underwater antennas are represented as red dots. Schematic shows approximate locations.

Radio transmitters

We used pulse-coded transmitters (tags) manufactured by Lotek Engineering, Inc, (Newmarket, Ont.). Transmitters that operate at frequencies between 150.320 and 150.760 MHz used the Lotek Wireless "2000 code set", a pulse-coding scheme with 212 unique codes per frequency that allow each individual fish to be recognized. A radio signal was emitted every 2 seconds. Two sizes of these transmitters were used to accommodate the different sizes of the spring and summer migrants. Transmitters implanted in yearling Chinook salmon were 7.3 mm in diameter x 18.0 mm in length and weighed 1.4 g in air (Lotek Wireless model 3KM) and those implanted in sub-yearling Chinook salmon were 6.3 mm x 4.5 mm x 14.5 mm long and weighed 0.85 g in air (Lotek Wireless model NTC-3-1). Expected battery life was 8 days for the KM tags and 8 days in the NTC tag.

Converting radio signals into detection histories

Aerial and underwater antennas attached to data logging equipment will often record spurious radio signals or "noise" and designate them as such, or misinterpret other radio signals (e.g., from cars or trucks) and designate them with channel and code designations. After data collection, radio signals had to be interpreted and converted into detection histories. Some automated data processing was performed. For instance, signals designated as noise were removed through the use of code in the Statistical Analysis System (SAS) software and signals with time stamps recorded before the time of the release were also discarded. Minimum power thresholds were established. Detection data were then merged with release data, records were manually examined by two separate proofing staff and designated with a passage location and time, and then reconciled by a third staff member if any disagreement in either the time of passage or passage location were noted. Travel times to downriver locations, geographic ranking, and residence time at each of the arrays were considered when manually proofing the radio-telemetry records.

Fish tagging

Juvenile yearling and sub-yearling Chinook salmon to be radio tagged and released at John Day and The Dalles dams were collected from the juvenile collection and bypass facility at John Day Dam. Fish collected at John Day Dam were typically held at the collection facility for 12 to 24 h prior to tagging. Yearling and sub-yearling Chinook released at The Dalles Dam were collected at John Day Dam, held 12 to 24 h, then transported to The Dalles Dam. Fish transported to The Dalles Dam were tagged immediately and then held for 24 h after tagging.

Fish were considered suitable for tagging if they were free of injuries, severe descaling, external signs of gas bubble trauma, or other abnormalities. Transmitters were gastrically implanted in both species using the methods of Martinelli et al. (1998).

Release strategy

Releases made at John Day Dam were used to estimate the route specific survival at The Dalles Dam. Radio-tagged yearling and sub-yearling Chinook were released at John Day Dam from the juvenile bypass system and tailrace (Tables 1 – 2). To estimate survival through specific spillbays at The Dalles Dam, radio-tagged yearling Chinook were released into spillbays 4, 9, and 13 (Table 3) and sub-yearling Chinook were released into spillbays 4 and 13 (Table 4). Control fish were released in the The Dalles Dam tailrace either approximately 56 m downstream of spillbay 3 through a 0.1 m diameter flexible hose, or from a boat approximately 550 m downstream, beneath the I-197 Bridge. Releases of dead fish were made at the location 550 m downstream of The Dalles Dam beneath the I-197 Bridge. Releases into the tailrace were timed to coincide with the arrival of fish released from the spillbays. Approximately 20 fish were released at each location during 16 releases (Table 5).

Radio-tagged yearling and sub-yearling Chinook salmon were released through the spillbays at The Dalles Dam via a hose release mechanism. Platforms were built to support 0.8 m diameter circular tanks approximately 1 m above the parapet wall on the spillway deck. Flexible hose (0.1 m diameter) was connected to the lower end of the tank, extended over the parapet wall, and routed to the pier nose on the north side of each spillbay. The flexible hose was protected from damage by securing it inside a 0.16 m steel pipe fastened to the north pier nose wall. The steel pipe extended approximately 3 m above the forebay elevation to a position 1 m above the spillway crest. At its lower end, a sweeping 45° angle piece of conduit guided fish away from the pier nose where they encountered capture velocity and were pulled through the tainter gate. A submersible pump in the forebay supplied water to the release tank at a rate of 200 L/min.

Prior to releasing fish, the pumps were activated to fill the release tanks and eliminate any air pockets within the release hoses. A single radio-tagged fish was placed into each release tank. Fish generally exited the release tank within 5 to 10 s. Water from the submersible pump was simultaneously routed through the tank and hose system to ensure that fish exited the hose at the bottom. Fish were released from all four sites within several minutes of each other.

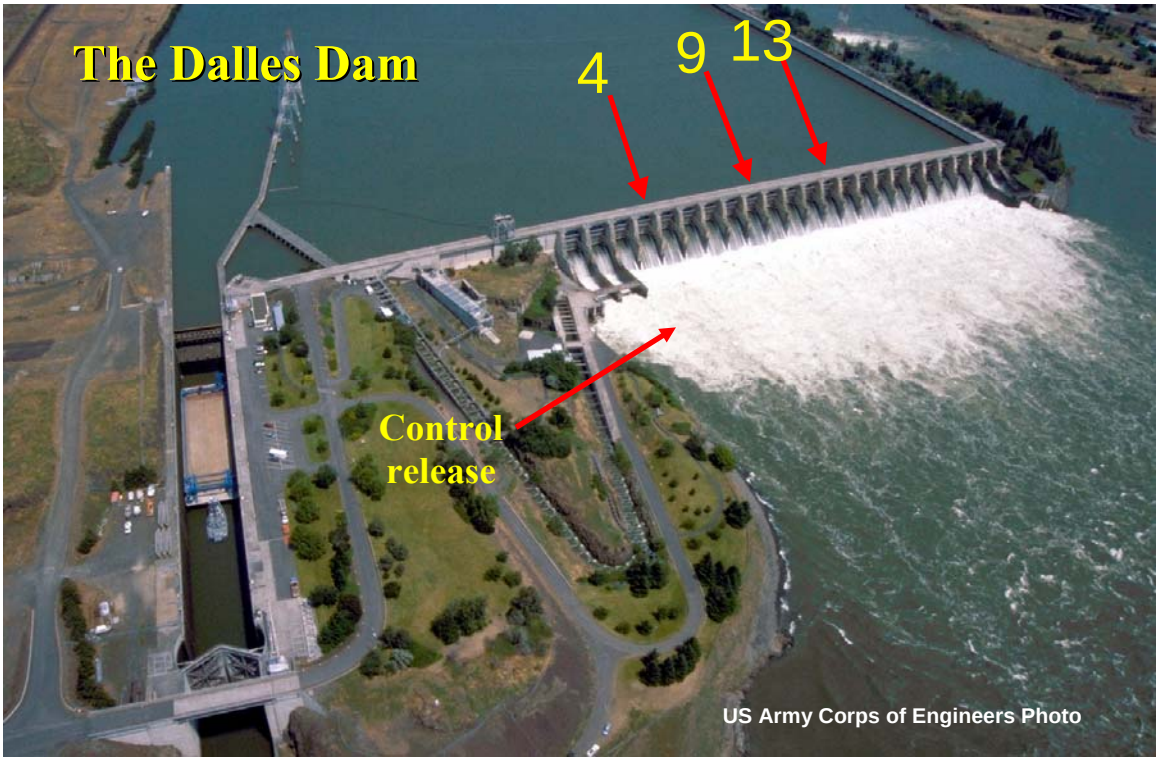

Figure 4. Spillbay release locations of yearling and sub-yearling Chinook salmon at The Dalles Dam, 2002.

Table 1. Release dates, numbers (N), and times for releases of yearling Chinook salmon from John Day Dam tailrace and juvenile bypass during spring 2002. Release times are the start of releases and include fish released up to 2 hours later.

Release	N	Date	Time
1	18	30 April	12:42
2	40	30 April	23:29
3	37	1 May	23:00
4	38	2 May	22:58
5	39	3 May	22:30
6	19	4 May	12:18
7	39	4 May	22:35
8	40	5 May	22:58
9	40	6 May	23:06
10	39	8 May	23:00
11	37	9 May	22:53
12	20	10 May	12:14
13	39	10 May	21:46
14	38	11 May	23:01
15	20	12 May	11:06
16	40	12 May	22:05
17	40	13 May	22:50
18	40	14 May	22:28
19	34	15 May	23:12
20	38	16 May	22:13
21	39	17 May	22:32
22	19	18 May	11:26
23	37	18 May	22:34
24	38	19 May	22:20
25	20	20 May	12:03
26	40	20 May	22:03
27	38	21 May	22:42
28	34	22 May	22:15
29	30	23 May	22:59
30	33	24 May	22:38
31	36	25 May	23:08
32	18	26 May	12:15
33	39	26 May	23:01
34	38	27 May	22:51
35	20	28 May	11:12
36	39	28 May	22:14
37	36	29 May	22:44
38	40	30 May	22:55
39	37	31 May	22:54
Overall:	1326		

Table 2. Release dates, numbers (N), and times for releases of sub-yearling Chinook salmon from John Day Dam tailrace and juvenile bypass during summer 2002. Release times are the start of releases and include fish released up to 2 hours later.

Release	N	Date	Time
1	112	21 June	23:19
2	108	22 June	23:23
3	107	24 June	00:33
4	109	25 June	00:03
5	59	25 June	11:32
6	108	25 June	23:29
7	45	26 June	12:11
8	109	27 June	00:18
9	48	27 June	11:52
10	111	27 June	23:12
11	46	28 June	11:27
12	120	29 June	01:09
13	51	29 June	11:11
14	98	29 June	23:27
15	53	30 June	11:39
16	97	30 June	22:48
17	48	1 July	12:05
18	99	1 July	22:42
19	44	2 July	11:01
20	75	2 July	23:04
21	32	3 July	11:08
22	81	3 July	22:58
23	38	4 July	11:40
24	102	4 July	22:42
25	41	5 July	11:29
26	115	5 July	22:34
27	35	6 July	11:03
28	83	6 July	23:23
29	31	7 July	11:02
30	112	7 July	23:35
31	34	8 July	11:49
32	92	8 July	22:51
33	40	9 July	11:32
34	81	9 July	22:51
35	44	10 July	12:05
36	81	10 July	23:22
37	42	11 July	11:08
38	82	11 July	23:01
39	39	12 July	11:21
40	79	12 July	22:49

Table 2 (Continued). Release dates, numbers (N), and times for releases of sub-yearling Chinook salmon from John Day Dam tailrace and juvenile bypass during summer 2002. Release times are the start of releases and include fish released up to 2 hours later.

Release	N	Date	Time
41	42	13 July	12:05
42	77	13 July	22:52
43	44	14 July	11:33
44	83	14 July	22:26
45	41	15 July	11:32
46	79	15 July	23:01
47	77	16 July	23:02
48	41	17 July	11:32
49	76	17 July	23:06
50	43	18 July	11:22
51	83	18 July	22:27
52	42	19 July	11:34
53	83	19 July	22:59
54	43	20 July	10:55
55	80	20 July	23:14
56	43	21 July	11:11
57	83	21 July	22:17
58	43	22 July	11:15
Overall:	4033		

Table 3. Release dates, numbers (N), and times for paired releases of yearling Chinook salmon at The Dalles Dam, spring 2002. Releases in the spillway were made into spillbays (SB) 4, 9, and 13 and tailrace releases were approximately 56 m (Control - Tailrace) and 550 m downstream (Control – I-197 bridge) of the spillway.

	Spillway					Control - Tailrace			Control – I-197 bridge		
	SB4	SB9	SB13								
Release	N	N	N	Date	Time	N	Date	Time	N	Date	Time
1	20	20	20	1 May	02:35	18	1 May	03:07	19	1 May	03:56
2	20	20	18	3 May	10:34	20	3 May	11:02	18	3 May	11:34
3	20	19	20	5 May	02:21	18	5 May	03:00	20	5 May	04:05
4	20	20	20	7 May	22:45	19	7 May	23:18	20	8 May	00:07
5	19	20	20	9 May	08:51	20	9 May	09:21	20	9 May	10:10
6	20	20	20	11 May	23:01	20	11 May	23:37	19	12 May	00:16
7	20	20	19	13 May	09:46	20	13 May	10:34	20	13 May	11:36
8	20	20	21	15 May	22:59	19	15 May	23:44	20	16 May	00:35
9	18	18	19	17 May	05:20	20	17 May	05:50	20	17 May	06:33
10	18	20	20	19 May	22:39	20	19 May	23:10	20	19 May	23:51
11	20	19	19	21 May	05:35	20	21 May	06:09	19	21 May	06:52
12	20	20	19	23 May	22:35	20	23 May	23:14	20	23 May	23:57
13	20	19	20	25 May	05:32	20	25 May	06:09	20	25 May	06:52
14	20	19	20	27 May	22:52	20	27 May	23:22	20	27 May	23:59
15	19	20	20	29 May	05:21	20	29 May	05:50	19	29 May	06:28
16	19	20	19	1 June	05:24	19	1 June	05:53	19	1 June	06:42
Overall:	313	314	314			313			313		

Table 4. Release dates, numbers (N), and times for paired releases of sub-yearling Chinook salmon at The Dalles Dam, summer 2002, through spillbays (SB) 4 and 13, and into the tailrace approximately 56 m downstream of the spillway.

	Spillway				Spillway Tailrace	
	SB4	SB13				
Release	N	N	Date	Time	N	Time
1	23	23	2 July	00:20	23	00:47
2	21	21	2 July	05:23	21	05:51
3[a]	17	16	3 July	22:47	17	23:10
4	25	24	5 July	22:38	24	23:07
5	25	24	6 July	05:13	24	05:41
6	24	25	8 July	06:13	25	06:44
7	25	25	9 July	22:12	25	22:45
8	22	18	11 July	22:50	22	23:12
9	25	24	12 July	04:53	24	05:28
10	18	18	13 July	22:35	18	23:00
11	23	25	14 July	04:31	24	04:59
12	25	25	15 July	23:12	24	23:49
13	25	24	16 July	05:08	23	05:35
14	25	25	17 July	22:18	25	22:43
15	25	24	18 July	05:01	25	05:29
16	24	25	19 July	22:33	25	23:13
17	22	25	20 July	05:29	25	06:02
18	26	25	21 July	23:13	24	23:53
19	25	24	22 July	05:21	24	05:49
Overall:	445	440			442	

a – During release 3, one fish was released into SB4 and one into SB13 after the tailrace release, at 23:30.

Statistical methods

Paired-release recapture model

We used the paired-release recapture models of Burnham et al. (1987) to estimate the survival of juvenile yearling Chinook salmon through spillbays 4, 9, and 13 and sub-yearling Chinook through spillbays 4 and 13 at The Dalles Dam.

Model assumptions

There are assumptions associated with using the single release and paired release-recapture (PR) model to estimate survival, some are biological and some pertain to the statistical models (Burnham et al. 1987, Skalski 1998, Skalski 1999a). The validity of some of the assumptions listed below can be evaluated using statistical tests and others can be met through careful consideration of fish collection, holding, tagging, and detection techniques. The assumptions are the following:

A1. Individuals marked for the study are a representative sample from the population of interest.

A2. Survival and capture probabilities are not affected by tagging or sampling (i.e., tagged animals have the same probabilities as untagged animals).

A3. All sampling events are "instantaneous" (i.e., sampling occurs over a short time relative to the length of the intervals between sampling events).

A4. The fate of each tagged individual is independent of the fate of all others.

A5. All individuals alive at a sampling location have the same probability of surviving until the end of that event.

A6. All tagged individuals alive at a sampling location have the same probability of being detected on that event.

A7. All tags are correctly identified and the status of fish (i.e., alive or dead) is correctly identified.

We conducted statistical tests to evaluate assumptions A5 and A6 using tests developed by Burnham et al. (1987). Burnham et al. (1987) presents a series of tests of assumptions named Test 2 that examine whether upstream or downstream detections affect downstream survival and/or detection. To examine whether upstream capture histories affect downstream survival and/or capture, Burnham et al. (1987) present a series of tests called Test 3.

Survival was estimated from paired releases by the expression:

$$\hat{S} = \frac{\hat{S}_{11}}{\hat{S}_{21}} \tag{1}$$

with a variance estimate based on the Delta method (Seber 1982) of:

$$\begin{aligned} \hat{Var}\left(\hat{S}_W\right) &\cong \left(\frac{\hat{S}_{11}}{\hat{S}_{21}}\right)^2 \left[\frac{Var\left(\hat{S}_{11}\right)}{\hat{S}_{11}^2} + \frac{Var\left(\hat{S}_{21}\right)}{\hat{S}_{21}^2}\right] \\ &\cong \hat{S}_W^2 \left[\hat{C}V\left(\hat{S}_{11}\right)^2 + \hat{C}V\left(\hat{S}_{21}\right)^2\right] \end{aligned} \tag{2}$$

where $\hat{S}_{11} =$ survival estimates for fish released above the project of interest and $\hat{S}_{22} =$ fish released below the project.

and where

$$\hat{C}V\left(\hat{\theta}\right) = \frac{\sqrt{Var\left(\hat{\theta}\right)}}{\theta}$$

In order to estimate S, the survival S_{11} is assumed to be of the form:

$$S_{11} = S \cong S_{21}$$

leading to the relationship

$$\frac{S_{11}}{S_{21}} = \frac{S \cdot S_{21}}{S_{21}} = S \tag{3}$$

The equality (3) suggests two additional assumptions for valid survival estimation using the paired release-recapture protocol.

A8. Survival in the upriver segment (S) is conditionally independent of survival in the lower river segment.

A9. Releases (R_1) and (R_2) have the same survival probability in the lower river segment (S_{21}).

The assumption of downstream mixing was tested at each downstream array. An R x C contingency table test of homogenous recoveries over time was performed using a table of the form:

		Release	
		R_1	R_2
Day of detections	1		
	2		
	3		
	⋮		
	D		

For each paired-release (R_1 and R_2), a chi-square test of homogeneity was performed at each downstream array. Tests were performed at $\alpha = 0.10$. Because there were multiple releases and tests across paired releases, the Type I error rates were adjusted for an overall experimental-wise error rate of $\alpha_{EW} = 0.10$ pertaining specifically to each paired-release recapture evaluation conducted at The Dalles Dam (Dunn-Sidak method, Sokal and Rohlf 1995).

Inferences regarding mixing will be largely based on the sequential use of likelihood ratio tests. In any given survival estimation scenario, a number of potential models will be generated and subsequently evaluated (Burnham et al. 1987, Leberton et al. 1992). Forward-sequential and reverse-sequential procedures will be used to find the most parsimonious statistical model that adequately describes the downstream survival and capture processes of the paired-release. The most efficient estimate of survival will be based on the statistical model for the paired releases that properly share all common parameters between release groups.

We evaluated t-tests to compare the estimated survival of yearling and sub-yearling Chinook salmon between spillbays 4, 9, and 13. The specific hypotheses tested were as follows:

<u>Yearling Chinook</u>

$$H_0 : S_{SPILLBAY\ 9} = S_{SPILLBAY\ 4}$$
$$H_A : S_{SPILLBAY\ 9} \neq S_{SPILLBAY\ 4}$$

$$H_0 : S_{SPILLBAY\ 13} = S_{SPILLBAY\ 4}$$
$$H_A : S_{SPILLBAY\ 13} \neq S_{SPILLBAY\ 4}$$

$$H_0 : S_{SPILLBAY\ 13} = S_{SPILLBAY\ 9}$$
$$H_A : S_{SPILLBAY\ 13} \neq S_{SPILLBAY\ 9}$$

Sub-yearling Chinook

$$H_0 : S_{SPILLBAY\ 13} = S_{SPILLBAY\ 4}$$
$$H_A : S_{SPILLBAY\ 13} \neq S_{SPILLBAY\ 4}$$

Bartlett's, Brown-Forsythe, and Levene's tests for equal variance were evaluated for each comparison and where suggested by the results of these tests, variance weighted t-tests were evaluated.

Estimable Parameters

The release and detection schemes used during 2002 allowed us to generate the survival and capture probabilities shown in Figure 4. The survival and capture probabilities shown in this schematic were generated for all of the site-specific paired releases at The Dalles Dam during 2002.

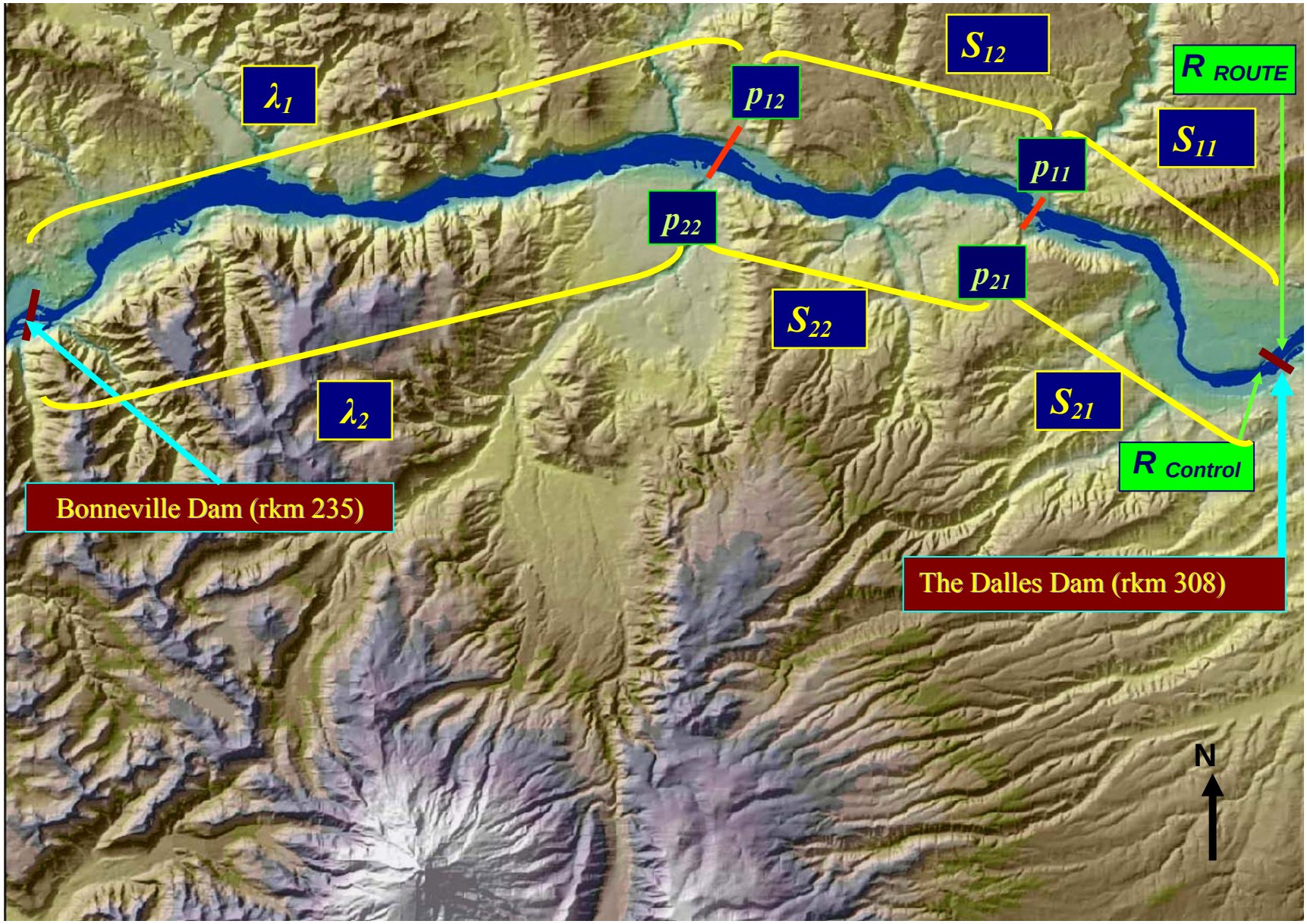

Figure 5. Schematic of estimable capture and survival probabilities (S = survival estimate, p = capture probability, and $\lambda = S \cdot p$) from site-specific releases (R_{ROUTE}) at The Dalles Dam and in The Dalles Dam tailrace. River kilometers (rkm) are given in parentheses for each dam location.

Route Specific Survival Model

Model Assumptions

The assumptions associated with the Route Specific Survival Model (RSSM) are described in detail in Skalski et. al. (2002) and are similar to those for the paired–release recapture model of Burnham et. al. (1987).

Assumptions of the RSSM are:

A1. Individuals marked for the study are a representative sample from the population of interest.

A2. Survival and capture probabilities are not affected by tagging or sampling (i.e., tagged animals have the same probabilities as untagged animals).

A3. All sampling events are "instantaneous" (i.e., sampling occurs over a short time relative to the length of the intervals between sampling events).

A4. The fate of each tagged individual is independent of the fate of all others.

A5. All tagged individuals alive at a sampling location have the same probability of surviving until the end of that event.

A6. All tagged individuals alive at a sampling location have the same probability of being detected.

A7. All tags are correctly identified and the status of fish (i.e., alive or dead) is correctly identified.

A8. Survival in the upriver segment (S) is conditionally independent of survival in the lower river segment.

A9. Both the upstream and downstream release groups within a paired release experience the same survival probability in the segment of the river that they travel together.

Skalski et. al. (2002) identified two additional assumptions are associated with the RSSM:

A10. Routes taken by the radio-tagged fish are known without error.

A11. Detections in the primary and secondary antenna arrays within a passage route are independent.

Skalski et al. (2002) suggest that assumption A10 can be qualitatively assessed by examining radio telemetry detection histories to determine whether inconsistencies in individual fish detection histories exist. Skalski et al. (2002) use an example of a situation where a radio-tagged fish is detected in the upstream array of a route and then in the downstream array of another route, resulting in uncertainty in the route taken. That is they used aerial antennas that monitored the tailrace area to help determine passage. Similar to the radio-telemetry system used in Skalski et al (2002), the double array we employed at The Dalles Dam consisted of aerial and underwater telemetry systems that interrogated fish in the immediate forebay area of each particular route, with the exception of the ice and trash sluiceway where underwater antennas were placed at two locations within the structure. However, while we did have a radio-telemetry system monitoring the tailrace area of each route, we did not consider detections in the tailrace when determining passage routes.

Typically, if fish were detected in one location and then moved across the dam face to another area, or moved out of the forebay and then approached the dam at another location, these movements were extensively documented with the aerial and/or underwater systems that were in place. In a few instances, a single radio-telemetry signal would be logged that would correspond to the signature of a released fish. However, we did not count these as sufficient to be tallied as valid detections. All data collected during 2002 were manually proofed and reconciled. We are confident that we satisfied this assumption.

Skalski et al. (2002) determined that while assumption A11 is necessary for valid estimation of in-route detection probabilities, the assumption cannot be empirically assessed with the data collected with this type of study. Rather, they suggest that the detection fields of the primary and secondary arrays should be located in a way that fish detected in one array does not have a higher or lower probability of being detected in the secondary array than the primary array. Further, they suggest that this is best accomplished by having independent receivers for each antenna array and by having the detection field of at least one array encompass the entire passage route. The arrays we deployed at the ice and trash sluiceway, spillway, and powerhouse conform to these requirements.

Parameter Estimation

The double radio-telemetry array systems that we deployed at The Dalles Dam allowed us to estimate route specific detection probabilities. In turn, these route specific detection probabilities can be incorporated into a statistical analysis that will extract route specific passage and survival (Skalski et. al. 2002). The following parameters were defined for the construction of the RSSM used at The Dalles Dam: S_{POOL}, survival from the release location at John Day Dam; G, conditional probability of guidance into the ice and trash sluiceway, given that fish were going to the powerhouse; P_{PH}, powerhouse primary array detection probability; ($q_{PH} = 1 - P_{PH}$); P'_{PH}, powerhouse secondary array detection probability; ($q_{PH} = 1-P'_{PH}$); P_{SPILL}, spillway primary array detection probability; ($q_{SPILL} = 1 - P_{SPILL}$); P'_{SPILL}, spillway secondary array detection probability;

(q_{SPILL} = 1 - P'_{SPILL}); P_{SLU}, sluiceway primary array detection probability; (q_{SLU} = 1 - P_{SLU}); P'_{SLU}, sluiceway secondary array detection probability; (q_{SLU} = 1 - P'_{SLU}); S_{PH}, powerhouse survival probability; S_{SPILL}, spillway survival probability, S_{SLU}, juvenile bypass survival probability, λ, joint probability of surviving and being detected at the arrays below The Dalles Dam. The releases made at John Day Dam (R_1) and the releases in The Dalles Dam tailrace (R_2) were interrogated at three arrays below The Dalles Dam, the furthest downriver being an array deployed on Bonneville Dam (Figure 1). A branching process was used to model the migration and survival of releases R_1 and R_2 (Figure 5). Additional details regarding the methodology used in the formulation of the RSSM and the estimation of the associated parameters can be found in Skalski et al. (2002). For the RSSM survival probabilities both standard errors and profile likelihood 95% confidence intervals are reported (Sklaski et al. 2002).

The route specific survival and passage probabilities can be combined using maximum likelihood estimation to estimate survival through the dam. The survival through The Dalles Dam was estimated from the expression

$$\hat{S}_{DAM\ldots} = (1-\hat{E})(1-\hat{G})\ \hat{S}_{PH} + (1-\hat{E})\hat{G}\,\hat{S}_{SLU} + \hat{E}\,\hat{S}_{SPILL}$$

The variance for the dam survival estimate was estimated using the delta method (Seber 1982, pp 7-9). All of the route specific survival and passage probabilities were estimated using the USER (User Specified Estimation Routine) developed at the University of Washington (Lady et al. 2003; see: http://www.cqs.washington.edu/paramEst/USER/).

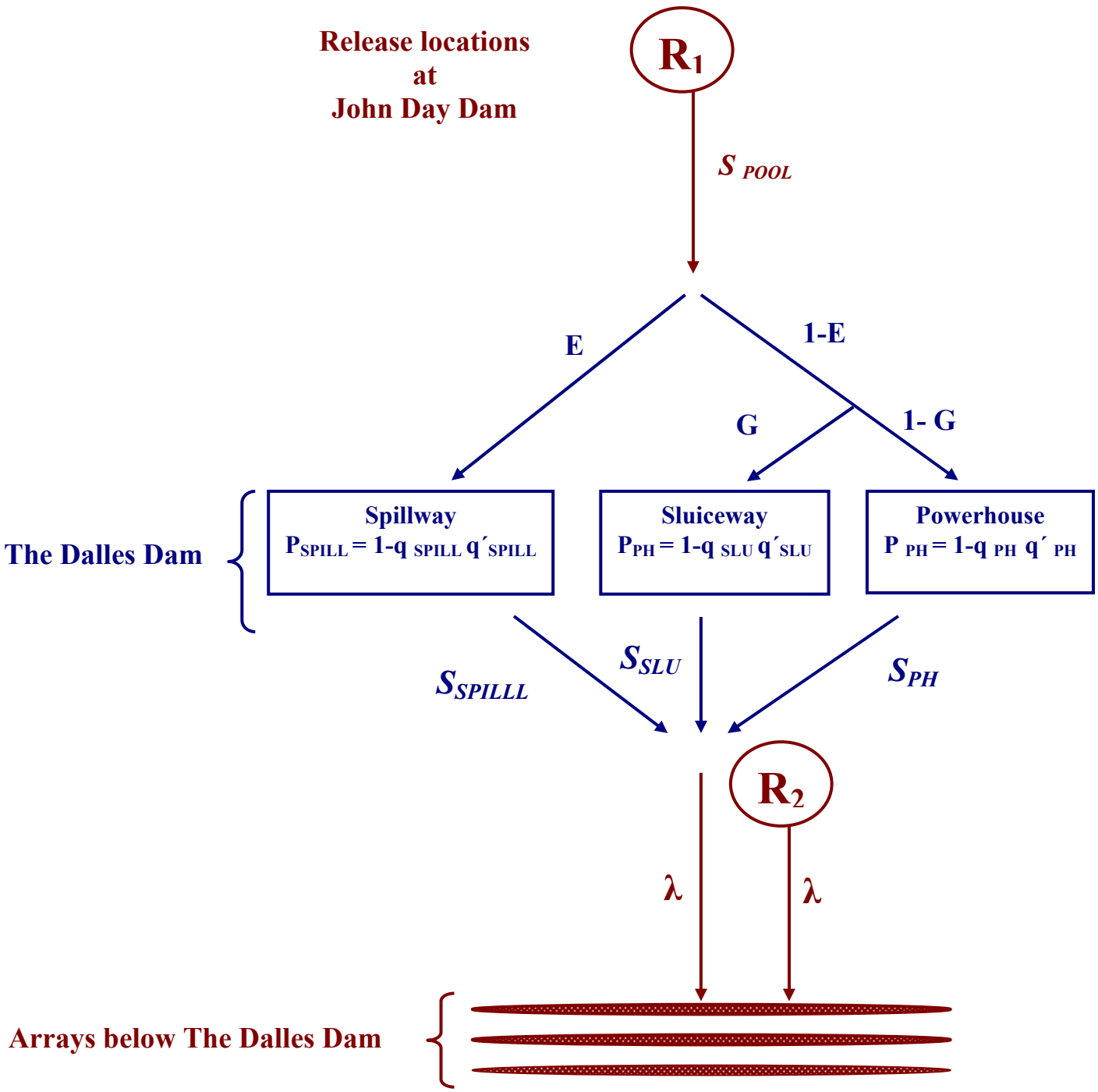

Figure 6. Schematic of route-specific passage and survival probabilities through The Dalles Dam for releases made at John Day Dam (rkm 347) and in the tailrace of The Dalles Dam (rkm 308).

Results

Spillway – Paired-release recapture model

Yearling Chinook salmon

Assumption tests

Burnham Tests

The results of the Burnham Tests 2 and 3 testing assumptions A5 and A6 for the yearling Chinook released into spillbays 4, 9, and 13 at The Dalles Dam spillway and their corresponding tailrace releases suggested that these assumptions were not violated although the results for Test 3 were in general inconclusive. The results of these tests can be found in Appendix 2.

Tests of the assumption of mixing of the treatment and control groups

The chi-square tests of homogeneity testing for the similarity in arrival times of paired releases of yearling Chinook salmon indicated that there were no significant differences in arrival times between the two release groups at the downstream radio-telemetry arrays (Appendix 3).

Releases of dead radio-tagged fish

No dead radio-tagged fish were detected at any of the radio-telemetry arrays downstream of The Dalles Dam.

Survival estimation

Spillbay 4

We estimated that the survival of yearling Chinook salmon released through spillbay 4 at The Dalles Dam spillway during 2002 ranged from 0.85 to 1.06 (Table 5). The average survival of yearling Chinook salmon released through spillbay 4 during the 2002 migration season was 0.98 (± 0.029, 95% confidence interval).

Spillbay 9

We estimated that the survival of yearling Chinook salmon released through spillbay 9 at The Dalles Dam spillway during 2002 ranged from 0.85 to 1.06 (Table 5). The average survival of yearling Chinook salmon released through spillbay 9 during the 2002 migration season was 0.95 (± 0.033, 95% confidence interval).

Spillbay 13

We estimated that the survival of yearling Chinook salmon released through spillbay 13 at The Dalles Dam spillway during 2002 ranged from 0.71 to 1.11 (Table 5). The average survival of yearling Chinook salmon released through spillbay 13 during the 2002 migration season was 0.92 (± 0.051, 95% confidence interval).

Table 5. The estimated survival (S) and standard error (SE) of yearling Chinook salmon released through spillbays 4, 9, and 13 at The Dalles Dam spillway during the 2002 spring migration season. The estimates presented are generated using the paired release-recapture models of Burnham et al. (1987). Control groups were released via a hose mechanism into The Dalles Dam tailrace approximately 56 m downstream of spillbay 3.

	Spillbay 4		Spillbay 9		Spillbay 13	
Release	S	SE	S	SE	S	SE
1	1.01	0.11	0.97	0.12	1.01	0.11
2	0.89	0.12	1.06	0.07	0.98	0.11
3	0.85	0.11	0.95	0.09	0.79	0.10
4	0.93	0.11	0.91	0.10	0.96	0.10
5	0.95	0.09	0.90	0.08	0.71	0.12
6	1.00	0.12	0.95	0.09	0.96	0.09
7	0.91	0.10	0.86	0.11	0.79	0.11
8	1.00	0.12	0.85	0.11	0.86	0.11
9	0.99	0.08	0.94	0.09	0.94	0.09
10	1.05	0.09	1.00	0.08	0.94	0.08
11	0.96	0.11	0.95	0.09	0.90	0.10
12	1.00	0.09	0.85	0.11	0.90	0.10
13	0.95	0.10	0.96	0.12	0.85	0.11
14	1.06	0.10	1.06	0.10	1.11	0.13
15	1.05	0.05	1.05	0.10	1.05	0.10
16	1.00	0.12	0.95	0.09	0.89	0.10

Comparisons of survival estimates between spillbays

The estimated survival for yearling Chinook salmon released though spillbay 4 was found to be significantly different than for spillbay 13 (Welch's variance weighted ANOVA, $P = 0.052$). Comparisons between spillbay 4 and spillbay 9 (t-test, $P = 0.25$) and between spillbay 9 and spillbay 13 (two tailed *t-test*, $P = 0.27$) did not indicate significant differences in the estimated survival of yearling Chinook releases through these spillbays.

Sub-yearling Chinook salmon

Assumption Tests

Burnham Tests

The results of the Burnham Tests 2 and 3 testing assumptions A5 and A6 for the sub-yearling Chinook released into spillbays 4 and 13 at The Dalles Dam spillway during 2002 did not indicate that these assumptions were violated. However, the results for Burnham Test 3 were largely inconclusive. The results of these tests can be found in Appendix 2.

Tests of the assumption of mixing of the treatment and control groups

The chi-square tests of homogeneity testing for the similarity in arrival times of paired releases of sub-yearling Chinook salmon indicated that there were no significant differences in arrival times between the two release groups at the downstream radio-telemetry arrays (Appendix 3).

Releases of dead radio-tagged fish

No dead radio-tagged fish were detected at any of the radio-telemetry arrays downstream of The Dalles Dam.

Survival estimation

Spillbay 4

We estimated that the survival of sub-yearling Chinook salmon released through spillbay 4 at The Dalles Dam spillway during 2002 ranged from 0.91 to 1.10 (Table 6). The average survival of sub-yearling Chinook salmon released through spillbay 4 during the 2002 migration season was 1.00 (± 0.026, 95% confidence interval).

Spillbay 13

We estimated that the survival of sub-yearling Chinook salmon released through spillbay 13 at The Dalles Dam spillway during 2002 ranged from 0.75 to 1.13 (Table 6). The average survival of sub-yearling Chinook salmon released through spillbay 13 during the 2002 migration season was 0.97 (± 0.048, 95% confidence interval).

Table 6. The estimated survival (S) and standard error (SE) of sub-yearling Chinook salmon released through spillbays 4, and 13 at The Dalles Dam spillway during the 2002 summer migration season. The estimates presented are generated using the paired release-recapture models of Burnham et al. (1987). Control groups were released via a hose mechanism into The Dalles Dam tailrace approximately 56 m downstream of spillbay 3.

	Spillbay 4		Spillbay 13	
Release	S	SE	S	SE
1	1.10	0.11	1.05	0.08
2	0.95	0.09	0.76	0.11
3	1.07	0.11	1.13	0.15
4	1.01	0.09	1.09	0.10
5	0.96	0.08	0.88	0.09
6	1.04	0.08	0.75	0.10
7	1.00	0.10	0.88	0.09
8	0.96	0.10	0.94	0.09
9	1.00	0.06	1.00	0.06
10	1.06	0.11	1.12	0.14
11	0.96	0.08	0.96	0.10
12	1.00	0.10	0.96	0.08
13	0.92	0.12	1.01	0.11
14	1.04	0.08	1.00	0.06
15	1.00	0.04	1.04	0.09
16	0.91	0.08	0.92	0.08
17	1.09	0.09	1.00	0.07
18	0.92	0.08	0.87	0.08
19	1.00	0.09	1.00	0.09

Comparisons of survival estimates between spillbays

The estimated survival for sub-yearling Chinook salmon released through spillbay 4 was not found to be significantly different than for spillbay 13 (Welch's variance weighted *ANOVA*, $P = 0.20$).

Route Specific Survival Model

Yearling Chinook salmon

Using capture histories generated from the detections of radio-tagged yearling Chinook salmon (Table 7), maximum likelihood estimates of the route-specific passage and survival probabilities were calculated for fish passing The Dalles Dam along with associated standard errors and profile likelihood 95% confidence intervals. The survival of yearling Chinook salmon through The Dalles Dam spillway was estimated to be 0.882 (SE = 0.019; profile likelihood 95% confidence interval = [0.845, 0.920]) (Figure 7). For yearling Chinook passing the ice and trash sluiceway the estimated survival was 0.911 (SE = 0.036, profile likelihood 95% confidence interval [0.833, 0.974]) and for yearling Chinook passing via the powerhouse at The Dalles Dam the estimated survival was 0.849 (SE = 0.023, profile likelihood 95% confidence interval [0.802, 0.894]) (Figure 7). Yearling Chinook salmon dam survival (see p. 23, this report) was estimated to be 0.872 (SE = 0.021).

Sub-yearling Chinook salmon

Using capture histories generated from the detections of radio-tagged sub-yearling Chinook salmon (Table 8), maximum likelihood estimates of the route-specific passage and survival probabilities were calculated for fish passing The Dalles Dam along with associated standard errors and profile likelihood 95% confidence intervals. The survival of sub-yearling Chinook salmon through The Dalles Dam spillway was estimated to be 0.906 (SE = 0.013; profile likelihood 95% confidence interval = [0.880, 0.934]) (Figure 8). For sub-yearling Chinook passing the ice and trash sluiceway the estimated survival was 0.907 (SE = 0.026, profile likelihood 95% confidence interval [0.854, 0.955]) and for sub-yearling Chinook passing via the powerhouse at The Dalles Dam the estimated survival was 0.817 (SE = 0.016, profile likelihood 95% confidence interval [0.785, 0.850]) (Figure 8). Sub-yearling Chinook salmon dam survival (see p. 23, this report) was estimated to be 0.872 (SE = 0.015).

Table 7. Counts of radio-tagged yearling Chinook salmon based on the releases from John Day Dam (R_1) and in the tailrace approximately 550 m downstream of The Dalles Dam, beneath the I-197 bridge (R_2) used in the route-specific survival model.

Release	Detection History [A]	Route	Counts	Within-route histories at The Dalles Dam [A] 11	01	10
R_1 = 1363	100		238			
	101		95			
	110	Spillway	90	363	172	42
	111		487			
	110	Powerhouse [B]	68	171	122	59
	111		284			
	110	Ice and trash	13	53	40	8
	111	sluiceway	88			
R_2 = 314	010		13			
	011		301			

[A] - Detection history recorded as: 1, detected; 0, not detected
[B] - Unguided passage

Table 8. Counts of radio-tagged sub-yearling Chinook salmon based on the releases from John Day Dam (R_1) and released in the tailrace approximately 56 m downstream of spillbay 3 through a 0.1 m diameter flexible hose (R_2) used in the route-specific survival model.

Release	Detection History [A]	Route	Counts	Within-route histories at The Dalles Dam [A] 11	01	10
R_1 = 4033	100		632			
	101		372			
	110	Spillway	262	1052	569	164
	111		1523			
	110	Powerhouse [B]	239	372	526	97
	111		756			
	110	Ice and trash	36	149	91	9
	111	sluiceway	213			
R_2 = 467	010		26			
	011		441			

[A] - Detection history recorded as: 1, detected; 0, not detected
[B] - Unguided passage

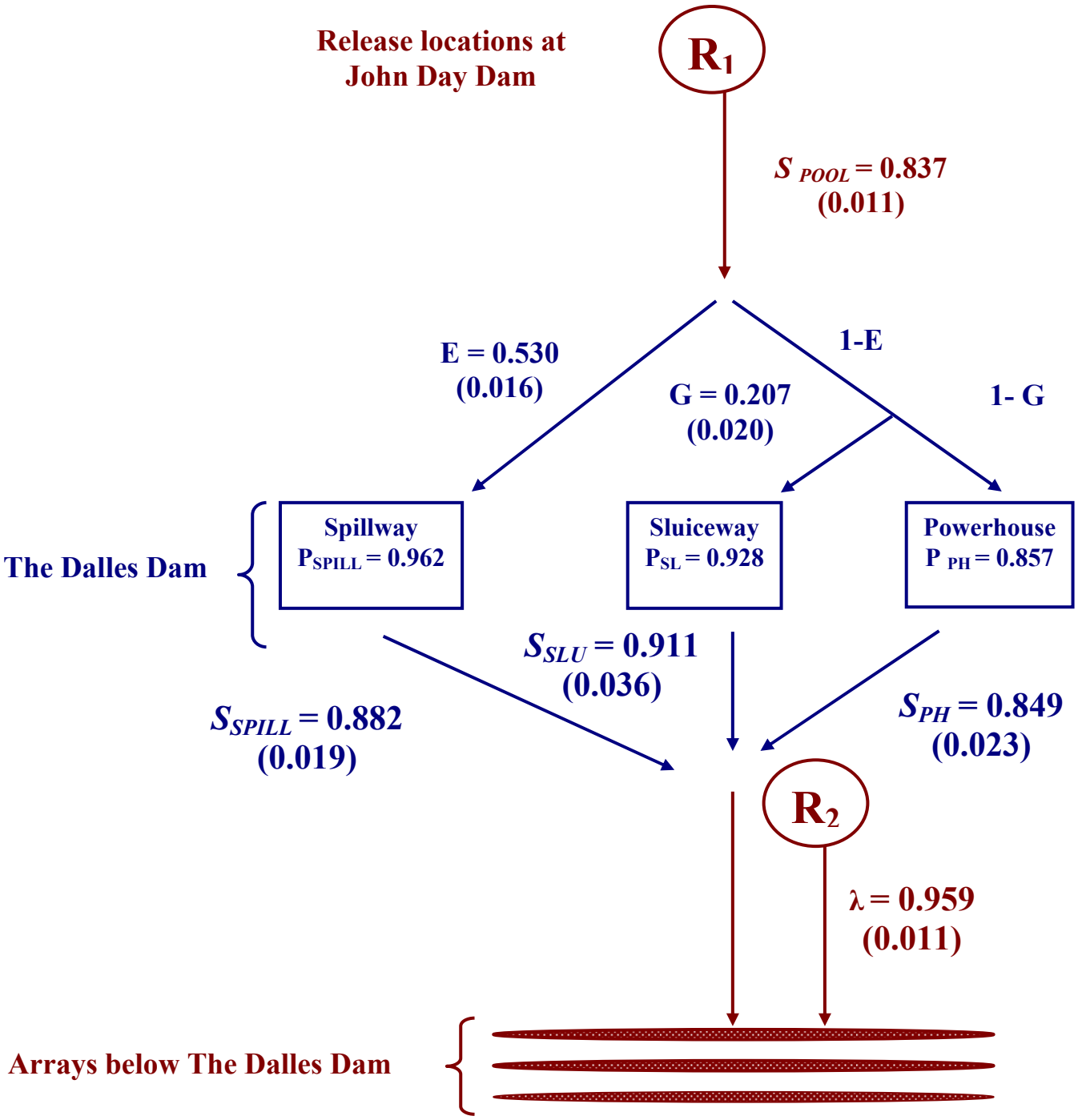

Figure 7. Schematic of estimated route-specific passage and survival probabilities for yearling Chinook salmon through The Dalles Dam during 2002. Estimated standard errors are in parentheses.

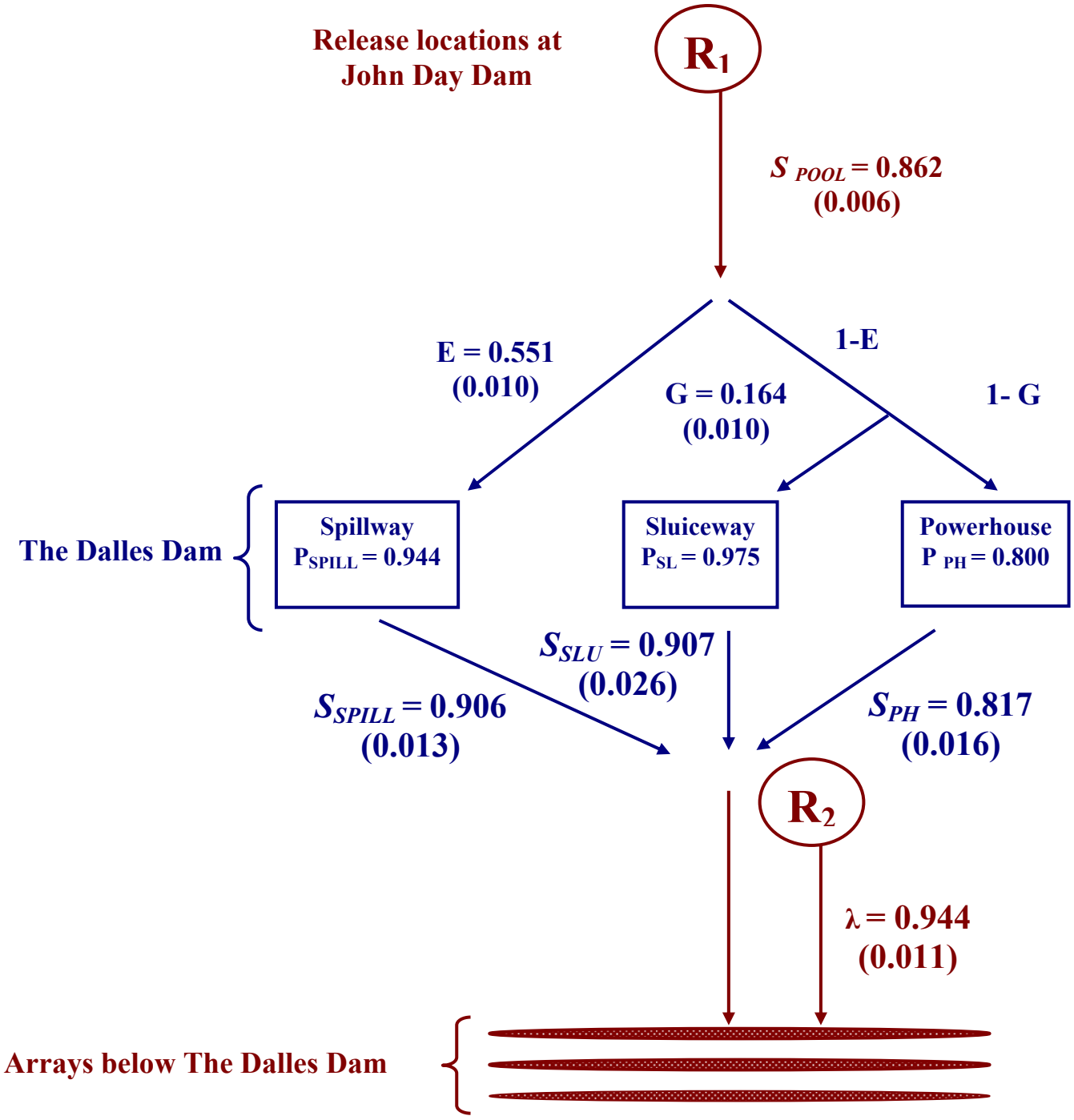

Figure 8. Schematic of estimated route-specific passage and survival probabilities for sub-yearling Chinook salmon through The Dalles Dam during 2002. Estimated standard errors are in parentheses.

Discussion

During 2002, we released radio-tagged yearling Chinook salmon into spillbays 4, 9, and 13 and radio-tagged sub-yearling Chinook salmon into spillbays 4 and 13 to evaluate potential differences in survival for fish passing via each spillbay during a 40% spill operation at The Dalles Dam. Our results suggest that survival was lowest for yearling Chinook salmon released through spillbay 13 (0.92 ± 0.051, 95% confidence interval). Similar results were found in a concurrent balloon tag study conducted by Normandeau Associates Inc. (Skalski et al. 2002) of yearling Chinook salmon survival estimates at The Dalles Dam in 2002. Skalski et al. (2002) also found that the estimated survival of yearling Chinook salmon was lowest for spillbay 13 (0.917; 90% confidence interval =0.889- 0.944), and higher for spillbay 9 (0.95; 90% confidence interval =0.932-0.979) and spillbay 4 (0.98; 90% confidence interval =0.955-0.99). Similarly, the estimated survival of radio-tagged yearling Chinook salmon was also higher for spillbay 9 (0.95; ± 0.033, 95% confidence interval) and spillbay 4 (0.98; ± 0.029, 95% confidence interval), suggesting that similar trends in the survival estimates were found for both the radio- and balloon tag studies (USGS This Report, Skalski et al., 2002). The estimated survival for the sub-yearling Chinook through spillbay 13 (0.97; ± 0.048, 95% confidence interval) was also lower than through spillbay 4 (1.00; ± 0.026, 95% confidence interval), however, both estimates were higher than for yearling Chinook salmon.

The lower survival estimates observed for yearling Chinook salmon and sub-yearling Chinook salmon released into spillbay13 could be a result of the turbulent environment immediately below the spillway at The Dalles Dam and a subsequent increase in the risk of injury and longer residence times in the stilling basin. The USGS used radio telemetry and drogues to investigate stilling basin residence time and lateral distribution at The Dalles Dam in 2001 and 2002 (Beeman et al. 2003 and 2004). The data from these studies suggest that fish passed via spillbay 13 exhibited a northward lateral movement across the stilling basin immediately below the spillway. Beeman et al. (2004) reported that 84% of the fish released from spillbay 13 moved north laterally, resulting in longer residence times in the stilling basin. Lateral movement from radio-tagged fish was also observed to a lesser extent from spillbays 4 and 9. Similarly, drogue releases by the USGS at The Dalles Dam exhibited a consistent northward lateral movement when released from the same spill bays as the radio-tagged Chinook salmon (Beeman et al. 2004). Further, in another concurrent study, Pacific Northwest National Laboratory (PNNL) used sensor fish (Normandeau Associates 2001) to evaluate stilling basin conditions encountered by fish passing through various spillbays. They observed that sensor fish passed through spillbays 9 and 11 were generally exposed to more severe hydraulic conditions including repeated soundings, and drastic, frequent velocity changes than those passed through spill bay 4 (Normandeau Associates 2001).

We also evaluated the survival of yearling and sub-yearling Chinook salmon through the turbines, spillway and ice and trash sluiceway at The Dalles Dam during 2002 using the Route Specific Survival Model. Previous evaluations of survival through these routes were conducted during 2000 and 2001. However, these evaluations were

conducted using releases of yearling and sub-yearling Chinook directly into these routes and the estimates were generated using the paired release recapture models of Burnham et al. (1988). During 2001, survival was estimated only through the ice and trash sluiceway. Survival estimates in 2002 suggest that survival was highest for yearling Chinook salmon passing via the ice and trash sluiceway, followed by the spillway and lastly through the turbines. Despite the different release and detection schemes and the different estimation procedure used during 2000 and 2002, similar trends in the survival estimates were observed (Figure 9).

During 2002, the ice and trash sluiceway survival estimates for yearling Chinook salmon were lower than for the previous two years, however, the 95% confidence intervals for the point estimates overlapped (Figure 9). During 2002, trends in the estimated survival for sub-yearling Chinook salmon passing through the ice and trash sluiceway, spillway, and turbines at The Dalles Dam were similar to those observed for yearling Chinook salmon. However, the trends in the point estimates, during 2002 were dissimilar (i.e., spillway survival was estimated to be lower than turbine survival) to those observed during 2000 (Figure 10). The low number of releases (n = 9: Counihan et al. 2002) made during 2000 resulted in point estimates with relatively large confidence intervals. Thus, there is a great deal of uncertainty regarding the interpretation of these results. The low number of releases made during 2000 were due to a reprioritization of research during this year and represent our efforts to address the reprioritization by allocating a fixed number tags to new tasks.

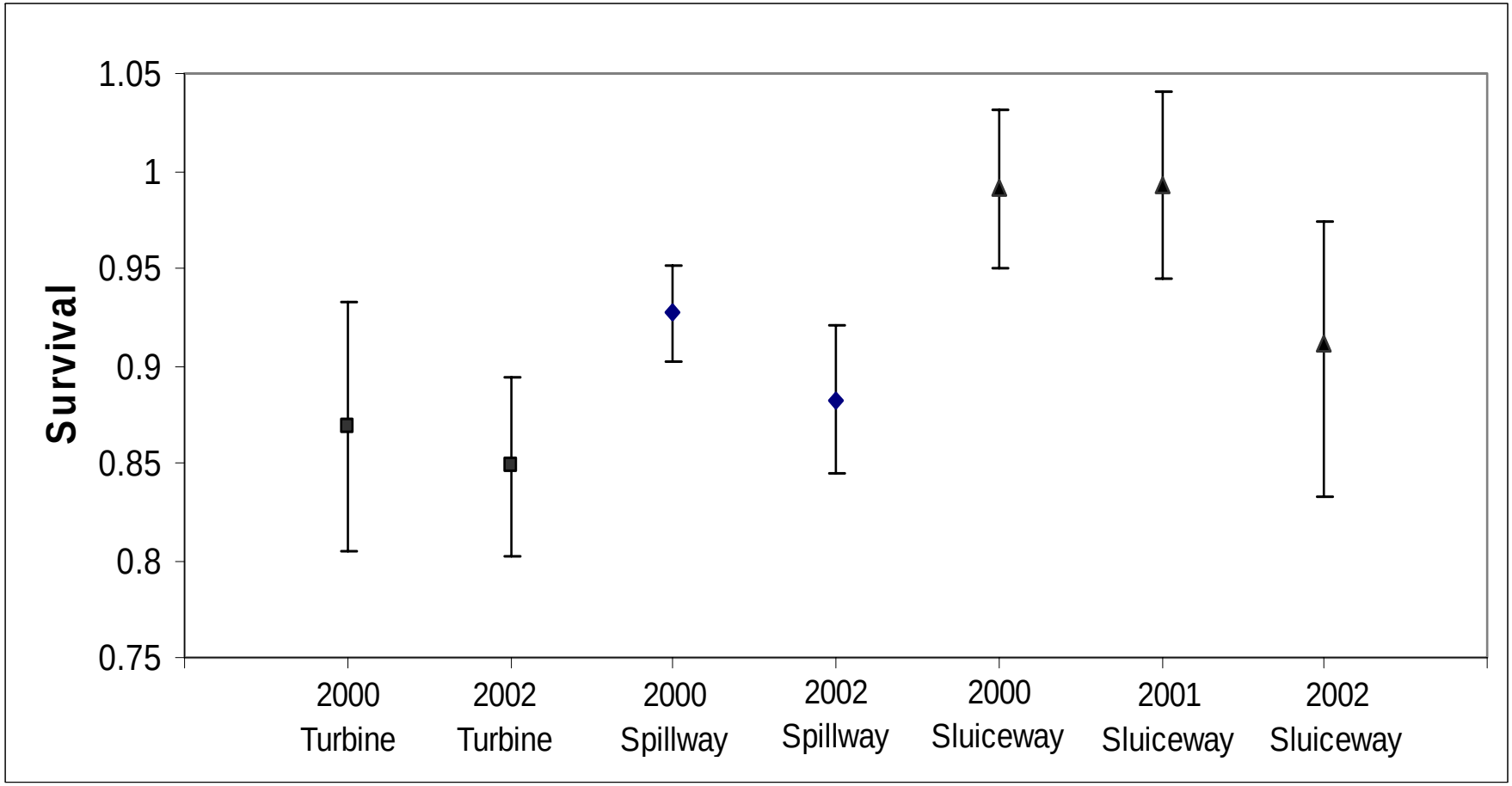

Figure 9. Yearling Chinook salmon survival estimates for The Dalles Dam through the turbines, spillway, and ice and trash sluiceway during 2000 to 2002. During 2000 and 2001, paired release-recapture models were used to estimate survival with fish released directly through the spillway, sluiceway, and turbine units. The error bars are 95% confidence intervals for 2000 and 2001. During 2002, maximum likelihood estimates of the route-specific passage and survival probabilities were calculated along with associated standard errors and profile likelihood 95% confidence intervals.

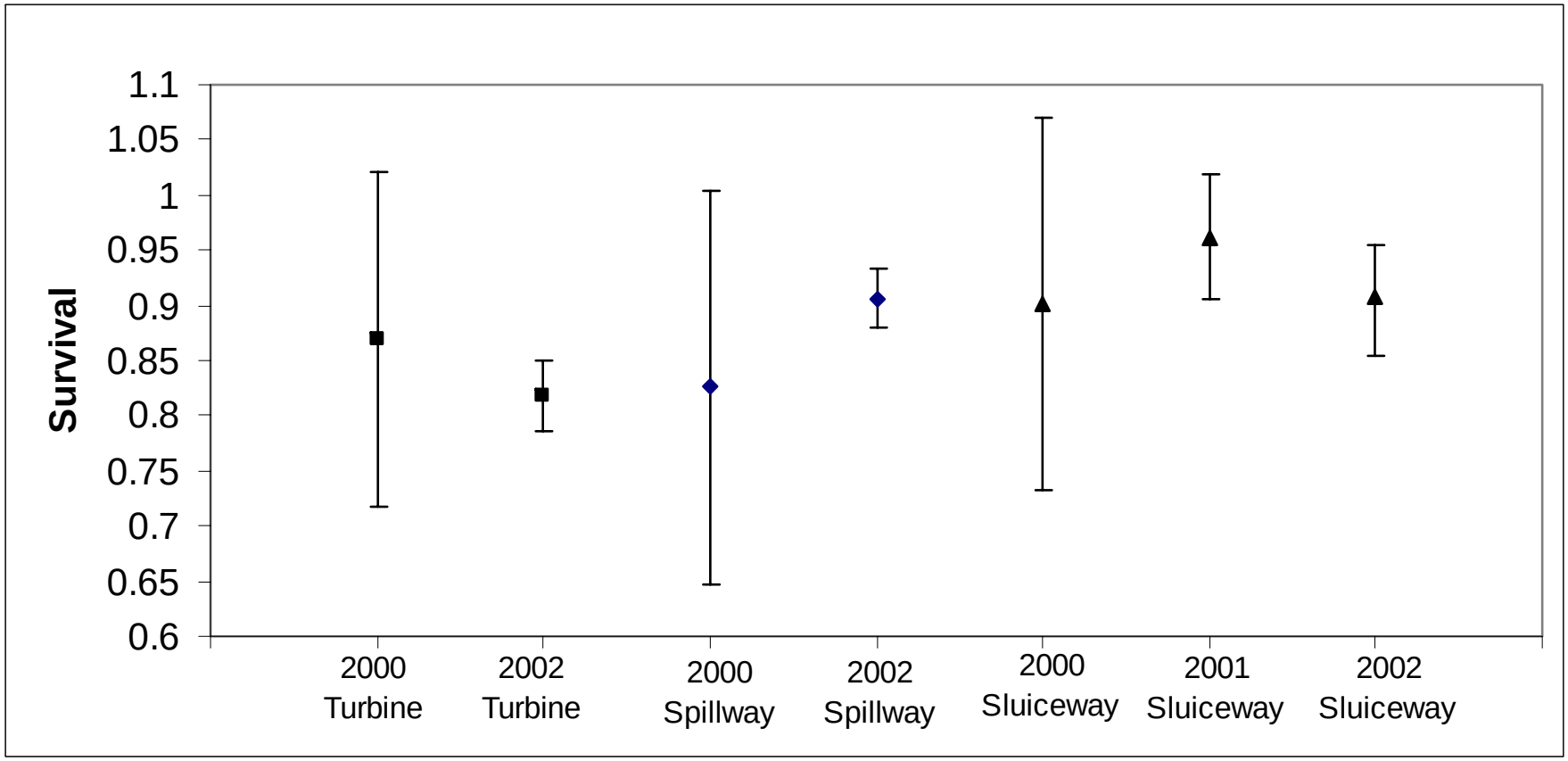

Figure 10. Sub-yearling Chinook salmon survival estimates for The Dalles Dam through the turbines, spillway, and ice and trash sluiceway during 2000 to 2002. During 2000 and 2001, paired release-recapture models were used to estimate survival with fish released directly through the spillway, sluiceway, and turbine units. The error bars are 95% confidence intervals for 2000 and 2001. During 2002, maximum likelihood estimates of the route-specific passage and survival probabilities were calculated along with associated standard errors and profile likelihood 95% confidence intervals.

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References

Beeman, J. W., H. H. Hansel, P. V. H. Haner, and J. Hardiman. 2001a. Estimates of fish and spill passage efficiency of radio-tagged juvenile steelhead and yearling Chinook salmon at John Day Dam, 2000. Prepared by U. S. Geological Survey, Cook, Washington for the U.S. Army Corps of Engineers, Portland, Oregon, contract W66QKZ00381910.

Beeman, J. W., H. H. Hansel, P. V. H. Haner, and J. Hardiman. 2001b. Estimates of fish-, spill- and sluiceway-passage efficiencies of radio-tagged juvenile steelhead and yearling Chinook salmon at The Dalles Dam, 2000. Prepared by U. S. Geological Survey, Cook, Washington for the U.S. Army Corps of Engineers, Portland, Oregon, contract W66QKZ00392015.

Beeman, J. W., S. Juhnke, K. Daniel, A. Daniel, and P. Haner. 2003. Estimate the stilling basin residence time, lateral distribution of passage, and relative survival of juvenile Chinook salmon passing through the spillway of The Dalles Dam, 2001: Annual report of research. Report of the U.S. Geological Survey for the U. S. Army Corps of Engineers, Portland, OR USA.

Beeman, J. W., S. Juhnke, H. Hansel, A. Daniel, L. Dingmon, and P. Haner. 2004. Estimate the stilling basin residence time and lateral distribution of juvenile Chinook salmon passing through the spillway of The Dalles Dam, 2002: Annual report of research. Report of the U.S. Geological Survey for the U. S. Army Corps of Engineers, Portland, OR USA, Contract W66QKZ20101602.

Bickford, S. A. and J. R. Skalski. 2000. Reanalysis and interpretation of 25 years of Snake-Columbia River juvenile salmonid survival studies. North American Journal of Fisheries Management 20:53-68.

Burnham, K.P., D.R Anderson, G.C. White, C. Brownie, and K.H. Pollock. 1987. Design and analysis methods for fish survival estimates based on release-recapture. American Fisheries Society Monograph No. 5.

Counihan, T. D., J. H. Petersen, N. S. Adams, R. S. Shively, and H. C. Hansel. 2001. Feasibility of Extracting Survival Information from Radio-Telemetry Studies at the John Day Dam. Annual report prepared by U. S. Geological Survey, Cook, Washington for the U.S. Army Corps of Engineers, Portland, Oregon.

Counihan, T. D., J. H. Petersen, and K. J. Felton. 2002. Survival Estimates of migrant Juvenile Salmonids in the Columbia River from John Day Dam through Bonneville Dam using Radio-Telemetry, 2000. Annual report prepared by U. S. Geological Survey, Cook, Washington for the U.S. Army Corps of Engineers, Portland, Oregon.

Dawley, E.M., L.G. Gilbreath, E.P. Nunnallee, and B. P. Sandford. 1998. Survival of juvenile salmon passing through the spillway of The Dalles Dam, 1997. Annual report prepared for the U.S. Army Corps of Engineers, Portland, OR. Contract MIPR E96970020.

Giorgi, A., M. Miller, and J. Stevenson. 2002. Mainstem passage strategies in the Columbia River System: transportation, spill and flow augmentation. Technical Report Northwest Power Planning Council, Portland, Oregon.

Hansel, C. H., J. W. Beeman, T. D. Counihan, J. M. Hardiman, B. D. Liedtke, M. S. Novick, and J. M. Plumb. 1999. Estimates of Fish-, Spill-, and Sluiceway-Passage Efficiencies of Radio-Tagged Juvenile Steelhead and Yearling Chinook Salmon at The Dalles Dam, 1999. Annual Report of Research to the U.S. Army Corps of Engineers, Portland District, Portland, Oregon, USA.

Hockersmith, E. E., W. D. Muir, S. G. Smith, B. P. Sandford, R. W. Perry, N. S. Adams, and D. W. Rondorf. 2003. Comparison of migration rate and survival between radio-tagged and PIT-tagged migrant yearling Chinook salmon in the Snake and Columbia Rivers. North American Journal of Fisheries Management 23:404-413.

Iwamato, R.N., Muir, W.D., Sandford, McIntyre, Frost, D.A., Williams, J.G., Smith, S.G., and J.R. Skalski. 1994. Survival estimates for the passage of juvenile Chinook salmon through Snake River Dams and reservoirs, 1993. Report prepared for the U.S. Department of Energy, Bonneville Power Administration. Division of Fish and Wildlife, Contract DE-A179-93BP10891, Project 93-29. 139 pp.

Lady, J.M., P. Westhagen, and J.R. Skalski. 2003. USER 2.0, User Specified Estimation Routine. U.S. Department of Energy, Bonneville Power Administration, Division of Fish and Wildlife, Portland, OR, Project No. 198910700

Leberton, J.D., K.P. Burnham, J. Clobert, and D. R. Anderson. 1992. Modeling survival and testing biological hypotheses: using marked animals: A unified approach. Ecological Monographs 62:67-118.

Muir, W.D., and eleven coauthors. 1995. Survival estimates or the passage of juvenile salmonids through Snake River Dams and reservoirs, 1994. Annual report prepared for the Bonneville Power Administration, Portland, OR and U.S. Army Corps of Engineers, Walla Walla, WA. Contract DE93-29A179-93B101891, Project 93-29. 187 p.
NMFS 2000 FCRPS Biological Opinion.

Normandeau Associates, J. R. Skalski, and Mid Columbia Consulting. 1996. Potential effects of modified spillbay configurations on fish condition and survival at The Dalles Dam, Columbia River. Prepared for the U. S. Army Corps of Engineers, Portland District, Portland, Oregon.

Normandeau Associates Inc. 2001. Feasibility of estimating direct mortality and injury on juvenile salmonids passing The Dalles Dam spillway during high discharge. Prepared for the U.S. Army Corps of Engineers Portland District, Portland, Oregon. Contact No. DACW68-96-D-0003.

NMFS 2000 FCRPS Biological Opinion

Ploskey, G., T. Poe, A. Giorgi, and G. Johnson. 2001 Draft. Synthesis of hydroacoustic, radio telemetry, and survival studies of juvenile salmon at The Dalles Dam (1982-2000). Technical Report, U.S. Army Corps of Engineers

Pollock, K.H., C.M. Bunck, S.R. Winterstein, and C.L. Chen. 1996. A capture-recapture survival model for radio-tagged animals. Journal of Applied Statistics.

Prentice, E. F., T. A. Flagg, and C. S. McCutcheon. 1990. Feasibility of using implantable passive integrated transponder (PIT) tags in salmonids. American Fisheries Society Symposium 7:317-322.

Raymond, H. L. 1979. Effects of dams and impoundments on migrations of juvenile Chinook salmon and steelhead from the Snake River, 1966-1975. Transactions of the American Fisheries Society 90:58-72.

Seber, G. A. F. 1982. The estimation of animal abundance and related parameters. Macmillan, New York.

Skalski, J. R. and Normandeau Associates Inc and Mid Columbia Consulting Inc. 2002. Estimated direct mortality and injury rates of juvenile salmonids in passage through The Dalles Dam spillway. Abstract presented in the Anadromous fish evaluation program 2002 Annual Review, U.S. Army Corps of Engineers, Portland, Oregon, Nov 18- 21, 2002.

Skalski, J. R., S.G. Smith, R.N. Iwamato, J.G. Williams, and A, Hoffman. 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.

Skalski, J. R., R. Townsend, J. Lady, A.E. Giorgi, J.R. Stevenson, and R.D. McDonald. 2002. Estimating route-specific passage and survival probabilities at a hydroelectric project from smolt radio-telemetry studies. Canadian Journal of Fisheries and Aquatic Sciences. 59:1385-1393.

Skalski, J.R. 1999a. Statistical methods to extract survival information from the John Day and The Dalles dams radiotag studies. Report to the Army Corps of Engineers.

Skalski, J.R. 1999b. Sample Size Calculations for conducting John Day Project smolt survival studies. Report to the Army Corps of Engineers.

Smith, S. G., J.R. Skalski, J.W. Schlechte, A. Hoffman, and V. Cassen. 1996. Introduction to SURPH.1 analysis of release-recapture data for survival studies. Report prepared for Bonneville Power Administration, Environment, Fish, and Wildlife, Portland, OR. DOE/BP-02341-3, October 1996.

Smith, S.G., W.D. Muir, E.E. Hockersmith, S. Achord, M.B. Eppard, T.E. Ruehle, and J.G. Williams. 1998. Survival estimates or the passage of juvenile salmonids through Snake River Dams and reservoirs, 1996. Annual report prepared for the Bonneville Power Administration, Portland, OR. Contract DE93-29A179-93B101891, Project 93-29. 197 p.

Stier, D.J. and B. Kynard. 1986. Use of radio telemetry to determine the mortality of Atlantic salmon smolts passed through a 17-MW Kaplan turbine at a low-head hydroelectric dam. Transactions of the American Fisheries Society. 115:771-775.

Appendix 1: Fork Lengths and Weights

Table A1.1. -The sample size (N), mean, standard deviation (SD), and range of fork lengths (mm) and weights (g) of yearling Chinook salmon released from John Day Dam tailrace and juvenile bypass system during spring 2002.

		Fork length (mm)			Weight (g)		
Release	N	Mean	SD	Range	Mean	SD	Range
1	18	148	10.8	130-165	31.2	6.4	20.4-41.2
2	40	154	10.4	133-182	36.4	8.1	22.0-61.3
3	37	150	12.6	132-180	34.0	8.9	20.9-56.8
4	38	151	14.5	123-190	35.1	10.6	23.3-69.7
5	39	148	12.6	119-176	32.5	8.3	15.7-54.3
6	19	146	7.1	132-160	29.9	4.4	23.2-38.5
7	39	144	9.3	125-167	30.4	5.8	20.4-44.2
8	40	150	9.5	132-178	34.4	7.4	22.2-56.5
9	40	153	12.7	133-191	34.5	9.6	21.9-70.0
10	39	148	14.4	125-185	31.6	9.3	18.6-59.0
11	37	148	11.9	128-199	31.4	9.3	20.5-78.3
12	20	145	12.0	124-178	30.2	8.7	18.0-53.9
13	39	143	13.8	121-183	29.8	9.5	17.3-60.1
14	38	146	17.1	120-204	29.7	12.7	16.8-77.8
15	20	138	13.1	126-189	25.7	8.9	18.1-60.6
16	40	146	12.2	127-179	31.3	8.1	20.3-55.6
17	40	141	9.9	119-170	29.5	6.1	16.1-48.9
18	40	140	11.0	122-178	28.3	7.2	20.0-58.1
19	34	148	17.3	122-201	32.6	12.6	17.3-76.9
20	38	144	12.5	123-177	28.9	8.6	18.1-51.9
21	39	140	12.2	124-184	28.9	8.2	18.4-57.8
22	19	144	15.9	126-184	29.3	11.0	18.7-67.6
23	37	154	20.4	131-203	36.2	16.9	19.2-78.8
24	38	148	14.5	125-189	32.8	10.2	17.5-63.5
25	20	140	12.3	127-177	25.3	9.4	18.5-55.9
26	40	151	20.1	124-189	34.9	15.2	19.1-69.9
27	38	149	16.4	123-186	32.8	11.4	17.0-61.5
28	34	140	14.2	120-170	28.2	8.4	16.1-49.0
29	30	151	15.5	124-182	34.7	9.9	21.9-57.4
30	33	153	20.0	120-195	36.1	14.6	17.4-69.1
31	36	146	16.8	122-195	30.9	11.6	19.7-70.2
32	18	147	12.7	130-183	28.0	8.0	21.0-54.3
33	39	152	15.1	125-181	34.4	10.7	19.5-59.7
34	38	156	18.2	127-191	36.0	12.9	18.7-61.5
35	20	152	11.7	134-179	34.4	10.1	23.7-60.6
36	39	165	24.0	126-215	46.2	19.8	21.6-107.3
37	36	150	16.6	130-195	36.5	11.7	22.7-68.7
38	40	151	18.9	126-194	32.1	13.4	19.1-71.8
39	37	147	15.5	132-190	32.2	10.4	23.4-60.7
Overall:	1326	148	15.6	119-215	32.6	11.2	15.7-107.3

Table A1.2. -The sample size (N), mean, standard deviation (SD), and range of fork lengths (mm) and weights (g) of sub-yearling Chinook salmon released from the John Day Dam at the tailrace and juvenile bypass system during summer 2002.

		Fork length (mm)			Weight (g)		
Release	N	Mean	SD	Range	Mean	SD	Range
1	112	116	5.0	110-132	16.7	2.5	13.6-25.7
2	108	114	4.5	108-132	15.6	4.1	12.6-50.8
3	107	116	3.7	110-126	15.7	1.5	13.1-20.5
4	109	115	3.8	110-139	16.4	2.0	14.0-27.9
5	59	117	4.7	111-132	16.0	2.2	13.3-22.9
6	108	115	3.6	110-131	15.5	1.8	13.1-24.0
7	45	113	2.9	110-123	15.1	1.3	13.1-18.7
8	109	115	3.5	110-132	16.5	1.8	13.6-26.9
9	48	115	3.4	110-125	15.8	1.6	13.0-20.2
10	111	115	5.1	110-137	15.6	2.4	12.7-29.0
11	46	113	3.3	110-123	16.4	1.7	14.0-21.1
12	120	114	3.4	110-130	16.2	1.7	13.2-24.5
13	51	114	2.9	110-123	15.2	1.2	13.5-19.0
14	98	113	2.6	110-124	15.2	1.3	13.0-20.6
15	53	113	2.6	110-121	15.6	1.4	13.3-19.3
16	97	113	4.6	109-135	16.3	2.6	13.3-28.0
17	48	113	2.5	110-120	14.9	1.3	13.0-18.7
18	99	114	3.8	110-131	15.3	1.9	13.0-23.2
19	44	114	6.1	110-138	16.3	3.2	14.0-29.5
20	74	114	4.1	110-127	16.5	2.3	13.2-23.7
21	32	113	3.5	107-121	14.9	1.6	13.0-19.9
22	81	114	3.9	110-130	15.7	2.1	13.0-22.6
23	38	113	2.8	110-120	15.6	1.3	13.4-18.1
24	102	117	8.5	108-145	17.5	4.3	13.1-35.0
25	41	116	6.9	110-143	16.4	3.5	13.0-29.8
26	115	116	6.3	110-142	16.6	3.1	13.1-31.2
27	35	117	7.4	110-137	17.3	3.4	13.8-27.5
28	83	116	6.8	109-142	16.9	4.5	13.0-46.7
29	31	117	8.9	110-145	17.3	4.1	13.1-30.6
30	112	116	7.0	110-142	17.2	3.5	13.0-31.1
31	34	117	7.1	110-140	17.1	3.4	14.2-29.0
32	92	117	7.7	109-140	18.1	3.7	13.4-28.8
33	40	117	7.5	110-147	16.9	3.7	13.4-32.0
34	81	119	8.8	110-142	18.1	4.3	13.4-30.1
35	44	118	7.6	110-137	18.2	3.5	14.4-27.3
36	81	119	7.0	110-141	18.8	3.6	14.1-29.4
37	42	117	4.8	111-133	17.2	2.7	13.8-25.7
38	82	115	5.1	110-131	16.8	2.7	13.8-26.2
39	39	116	6.1	110-135	16.8	3.2	12.8-29.8
40	79	117	7.9	110-140	18.8	4.4	13.3-34.8

Table A1.2 (Continued). -The sample size (N), mean, standard deviation (SD), and range of fork lengths (mm) and weights (g) of sub-yearling Chinook salmon released from the John Day Dam at the tailrace and juvenile bypass system during summer 2002.

		Fork length (mm)			Weight (g)		
Release	N	Mean	SD	Range	Mean	SD	Range
41	42	125	10.9	111-150	20.8	5.7	13.8-36.5
42	77	121	6.9	110-143	19.8	3.6	13.9-32.1
43	44	120	6.0	110-137	19.3	2.9	15.4-29.0
44	83	117	6.5	110-139	16.7	3.0	13.2-27.7
45	41	116	5.5	110-129	16.4	2.6	13.7-23.1
46	79	116	6.8	110-138	17.7	3.4	13.8-29.6
47	77	117	6.2	110-138	18.4	3.1	13.5-29.2
48	41	119	9.6	111-153	19.6	5.0	14.0-37.4
49	76	119	9.5	110-143	18.4	4.7	13.9-31.9
50	43	118	7.7	110-144	18.6	3.9	14.6-32.8
51	83	124	14.8	109-228	20.2	4.6	13.1-33.3
52	42	121	6.8	112-139	19.7	3.4	15.4-31.8
53	83	121	8.1	110-145	19.4	3.9	13.9-31.3
54	43	121	9.8	111-160	18.8	5.3	13.8-43.6
55	80	119	7.2	110-146	18.6	3.8	13.8-33.3
56	43	118	7.7	110-137	18.6	4.1	13.5-30.1
57	83	121	7.6	111-146	19.3	4.0	14.0-37.0
58	43	120	7.7	111-149	19.4	3.9	14.8-37.0
Overall:	4033	116	6.9	107-228	17.1	3.5	12.6-50.8

Table A1.3. -The sample size (N), mean, standard deviation (SD), and range of fork lengths (mm) of yearling Chinook salmon released at The Dalles Dam spillway during spring 2002. The Spillway Tailrace is approximately 56 m downstream of the spillway.

	Spillbay 4				Spillbay 9			
Release	N	Mean	SD	Range	N	Mean	SD	Range
1	20	153	10.1	138-170	20	154	11.1	138-189
2	20	147	9.2	126-162	20	150	16.4	120-187
3	20	147	15.6	114-176	19	149	11.8	132-170
4	20	148	14.1	128-174	20	147	12.1	126-172
5	19	147	13.7	125-171	20	149	10.5	128-169
6	20	139	8.0	124-152	20	143	13.3	128-173
7	20	151	17.4	130-200	20	148	17.1	130-190
8	20	150	21.6	120-200	20	151	18.1	127-190
9	18	141	10.2	122-167	18	139	9.8	116-159
10	18	152	18.7	123-190	20	147	14.1	128-180
11	20	155	20.2	125-185	19	150	17.9	128-199
12	20	144	14.4	120-179	20	147	18.7	122-188
13	20	148	19.7	125-190	19	151	15.8	124-183
14	20	151	14.7	137-189	19	161	9.2	144-176
15	19	158	14.0	136-182	20	166	19.2	139-194
16	19	153	20.1	132-213	20	150	13.4	132-183
Overall	313	149	16.0	114-213	314	150	15.6	116-199

Table A1.3 (continued).-The sample size (N), mean, standard deviation (SD), and range of fork lengths (mm) of yearling Chinook salmon released at The Dalles Dam spillway during spring 2002. The Spillway Tailrace is approximately 56 m downstream of the spillway.

	Spillbay 13				Spillway Tailrace			
Release	N	Mean	SD	Range	N	Mean	SD	Range
1	20	152	11.6	129-179	18	155	17.3	135-195
2	18	151	13.1	120-172	20	148	14.5	113-174
3	20	149	13.3	118-176	18	144	9.0	124-161
4	20	149	10.5	129-162	19	147	14.5	127-184
5	20	152	15.9	132-196	20	151	11.6	136-176
6	20	140	7.5	124-152	20	146	9.7	131-170
7	19	144	16.2	126-195	20	144	11.6	129-173
8	21	149	17.2	125-187	19	139	10.5	124-161
9	19	138	7.1	126-152	20	146	16.0	117-190
10	20	147	19.5	119-197	20	142	9.8	120-163
11	19	147	15.1	125-177	20	145	14.9	127-175
12	19	150	22.2	125-193	20	143	13.9	125-175
13	20	141	14.1	124-172	20	142	16.5	122-185
14	20	155	14.2	132-180	20	151	14.0	133-182
15	20	162	15.1	135-187	20	162	19.2	132-202
16	19	144	10.9	124-164	19	146	11.3	134-176
Overall	314	148	15.3	118-197	313	147	14.5	113-202

Table A1.4. -The sample size (N), mean, standard deviation (SD), and range of weights (g) of yearling Chinook salmon released at The Dalles Dam spillway during spring 2002. The Spillway Tailrace is approximately 56 m downstream of the spillway.

	Spillbay 4				Spillbay 9			
Release	N	Mean	SD	Range	N	Mean	SD	Range
1	20	33.7	6.7	25.3-47.2	20	35.1	9.8	23.8-68.8
2	20	29.3	4.8	19.1-37.5	20	32.9	11.8	15.3-63.2
3	20	31.7	10.9	14.1-56.6	19	31.9	8.2	21.8-50.0
4	20	31.1	9.0	19.1-49.5	20	29.8	7.0	17.4-42.7
5	19	30.0	8.5	18.7-46.7	20	31.8	7.2	18.4-47.0
6	20	24.2	4.1	18.2-33.3	20	27.3	9.5	17.1-51.3
7	20	34.5	14.4	20.4-81.6	20	32.3	14.0	20.6-69.9
8	20	33.6	16.7	16.2-82.3	20	33.4	13.4	17.9-66.5
9	18	26.3	5.5	18.4-40.2	18	25.1	5.3	16.0-38.5
10	18	32.5	12.7	14.2-62.3	20	29.0	9.3	17.1-54.0
11	20	35.6	14.5	17.9-57.7	19	31.7	12.3	19.4-69.5
12	20	29.2	9.4	15.4-54.5	20	31.7	13.2	17.8-64.4
13	20	30.4	12.9	17.8-59.5	19	31.8	10.9	18.4-59.1
14	20	31.6	10.8	22.6-59.0	19	37.6	7.0	26.1-49.3
15	19	36.9	10.4	23.0-54.2	20	43.9	16.1	23.1-70.2
16	19	34.8	17.2	22.0-95.9	20	31.1	8.7	20.8-56.4
Overall	313	31.6	11.5	14.1-95.9	314	32.3	11.2	15.3-70.2

Table A1.4 (Continued).-The sample size (N), mean, standard deviation (SD), and range of weights (g) of yearling Chinook salmon released at The Dalles Dam spillway during spring 2002. The Spillway Tailrace is approximately 56 m downstream of the spillway.

	Spillbay 13				Spillway Tailrace			
Release	N	Mean	SD	Range	N	Mean	SD	Range
1	20	32.9	8.7	20.9-56.6	18	37.7	15.9	21.9-75.0
2	18	32.6	7.9	15.4-48.0	20	31.2	9.6	13.4-52.9
3	20	32.0	8.7	16.7-52.0	18	28.3	5.3	15.8-38.2
4	20	30.6	6.3	18.3-39.6	19	29.9	9.9	18.5-56.5
5	19	34.6	12.2	20.0-73.5	20	33.1	8.4	24.3-52.9
6	20	24.4	4.3	16.2-33.2	20	28.6	7.3	18.7-50.8
7	19	29.7	13.4	18.0-77.4	20	28.5	7.2	19.5-47.5
8	21	32.5	12.8	17.6-64.8	19	25.3	6.2	17.9-39.0
9	19	23.0	4.0	17.2-30.6	20	28.0	10.0	15.2-60.2
10	20	31.0	14.8	16.1-77.9	20	26.8	6.0	18.4-42.4
11	19	29.9	9.6	19.9-53.3	20	28.9	9.9	18.7-50.9
12	19	33.2	14.8	18.3-62.6	20	27.6	8.1	18.1-48.0
13	20	26.0	8.8	17.6-48.6	20	30.6	14.3	18.7-76.4
14	20	34.3	10.0	19.3-52.5	20	30.4	9.9	18.7-56.8
15	20	39.6	10.9	25.0-61.7	20	40.8	14.9	22.7-79.8
16	19	26.6	6.1	16.8-40.0	19	28.4	6.7	22.5-47.7
Overall	313	30.8	10.7	15.4-77.9	313	30.2	10.4	13.4-79.8

Table A1.5. - The sample size (N), mean, standard deviation (SD), and range of fork lengths (mm) and weights (g) of yearling Chinook salmon at The Dalles Dam, Downstream Tailrace, 550 m downstream of the spillway during spring 2002.

		Fork length (mm)			Weight (g)		
Release	N	Mean	SD	Range	Mean	SD	Range
1	19	156	13.1	135-183	36.3	9.5	23.7-56.7
2	18	146	12.4	121-174	29.5	7.7	16.6-50.5
3	20	149	16.8	128-181	32.6	12.8	20.0-62.7
4	20	153	12.4	133-175	33.4	8.9	19.6-52.6
5	20	144	11.3	126-175	27.9	7.1	19.4-51.6
6	19	148	18.4	128-198	31.5	13.6	18.7-71.5
7	20	148	22.2	125-221	31.7	15.4	17.2-83.3
8	20	148	18.5	124-185	31.1	12.4	18.7-55.4
9	20	141	11.5	116-166	25.1	6.4	15.0-42.0
10	20	142	12.3	129-173	25.2	7.4	16.0-46.3
11	19	137	10.2	121-155	24.1	6.0	17.2-37.0
12	20	136	11.4	119-168	22.9	5.7	17.0-41.4
13	20	147	17.3	125-187	29.7	10.9	16.9-58.7
14	20	151	18.0	129-184	31.5	12.3	19.6-58.5
15	19	153	15.4	128-181	33.9	9.6	19.7-50.9
16	19	147	14.5	134-189	29.5	8.9	21.7-55.1
Overall	313	147	15.8	116-221	29.7	10.5	15.0-83.3

Table A1.6. -The sample size (N), mean, standard deviation (SD), and range of fork lengths (mm) of sub-yearling Chinook salmon released at The Dalles Dam spillway during summer 2002. The spillway tailrace is approximately 56 m downstream of the spillway.

	Spillbay 4				Spillbay 13				Spillway Tailrace			
Release	N	Mean	SD	Range	N	Mean	SD	Range	N	Mean	SD	Range
1	23	112	2.8	107-122	23	115	5.7	109-133	23	113	3.7	107-120
2	21	114	4.0	110-124	21	114	2.7	110-119	21	115	6.8	110-142
3	17	115	6.9	109-139	16	116	4.3	111-125	17	114	3.3	110-121
4	25	116	7.2	111-146	24	114	4.2	110-130	24	117	9.7	109-140
5	25	117	7.5	110-139	24	117	6.6	110-133	24	117	5.7	110-131
6	24	118	6.3	110-130	25	116	6.8	109-131	25	118	8.5	109-151
7	25	118	7.0	110-139	25	119	7.4	111-136	25	116	5.1	111-129
8	22	118	7.6	112-143	18	119	7.3	112-143	22	122	6.7	113-137
9	25	117	5.9	110-133	24	119	9.2	112-150	24	119	7.9	111-141
10	18	115	6.1	110-130	18	118	6.8	111-136	18	118	6.6	111-129
11	23	119	8.5	111-139	25	118	9.6	110-149	24	120	7.9	111-140
12	25	118	8.4	108-148	25	117	7.7	110-137	24	117	5.7	111-135
13	25	113	3.3	109-124	24	115	4.9	110-130	23	117	7.1	109-133
14	25	119	8.1	111-141	25	120	7.7	110-139	25	118	5.3	111-129
15	25	119	7.2	110-136	24	116	6.4	110-135	25	118	7.0	111-141
16	24	121	7.4	110-139	25	123	9.5	110-147	25	126	8.7	111-149
17	22	128	12.2	110-157	25	132	10.1	112-151	25	123	7.0	111-135
18	26	119	8.4	110-145	25	121	8.3	110-143	24	118	7.5	110-133
19	25	125	10.5	110-152	24	119	7.1	109-137	24	118	10.4	108-151
Overall	445	118	8.2	107-157	440	118	8.2	109-151	442	118	8.0	107-151

Table A1.7. -The sample size (N), mean, standard deviation (SD), and range of weights (g) of sub-yearling Chinook salmon released at The Dalles Dam spillway during summer 2002. The spillway tailrace is approximately 56 m downstream of the spillway.

Release	Spillbay 4				Spillbay 13*				Spillway Tailrace			
	N	Mean	SD	Range	N	Mean	SD	Range	N	Mean	SD	Range
1	23	14.3	1.3	13.1-18.0	23	15.4	2.7	12.4-22.8	23	14.4	1.5	13.0-18.6
2	21	14.9	2.2	13.1-21.9	21	15.0	1.2	13.5-18.6	21	15.2	3.6	13.2-29.9
3	17	15.8	3.1	13.2-26.4	16	16.1	2.1	13.1-20.6	17	15.4	1.8	13.6-19.7
4	25	16.4	4.0	13.0-32.6	24	14.8	1.8	13.0-21.0	24	16.3	4.6	13.0-28.4
5	25	16.6	3.5	13.1-26.7	24	16.6	3.3	13.0-25.9	24	16.4	2.8	13.8-23.4
6	24	16.7	2.9	13.1-21.6	25	16.3	3.4	13.1-25.2	25	17.2	4.4	13.1-34.4
7	25	17.0	3.1	13.3-26.8	25	17.4	3.7	13.3-24.7	25	16.6	2.5	13.1-22.8
8	22	17.5	4.2	13.8-32.5	18	18.2	4.0	14.3-30.2	22	19.0	3.7	13.9-28.3
9	25	16.8	3.1	13.2-25.9	24	17.5	4.8	13.1-34.3	24	18.3	4.3	14.0-31.6
10	18	16.0	2.8	13.4-22.8	18	16.9	2.8	13.8-23.2	18	16.8	3.1	13.8-23.8
11	23	18.2	4.3	13.7-28.0	25	17.3	4.6	13.9-31.3	24	18.3	4.1	13.5-30.7
12	25	17.0	4.0	13.1-31.0	25	16.8	3.8	13.6-27.7	24	16.7	2.6	13.6-24.8
13	25	14.7	1.5	13.1-19.4	24	15.6	2.3	13.2-21.9	23	16.6	3.2	13.0-24.9
14	25	18.0	3.8	14.0-27.1	25	17.9	3.5	13.8-28.1	25	17.3	2.8	13.7-24.5
15	25	17.8	3.1	13.4-24.7	24	16.7	3.3	13.5-25.0	25	17.7	4.2	13.2-33.5
16	24	19.6	4.1	13.5-27.8	25	19.1	4.6	12.8-32.9	25	20.9	4.2	14.5-33.6
17	22	22.2	6.9	13.5-42.4	25	24.2	5.3	14.0-34.3	25	19.2	3.4	13.4-25.9
18	26	17.8	4.0	13.9-29.8	25	18.4	4.1	13.8-29.4	24	17.3	4.0	13.6-26.8
19	25	20.5	6.1	13.4-40.8	24	17.5	3.1	13.2-24.7	24	17.7	5.3	13.0-36.1
Overall	445	17.3	4.2	13.0-42.4	440	17.3	4.1	12.4-34.3	442	17.3	4.0	13.0-36.1

Appendix 2: Burnham Tests 2 and 3

Table A2.1. -Summary statistics for goodness-of-fit tests (tests 2 and 3, Burnham et al. 1987) for each of 16 paired releases of yearling Chinook, spring 2002. Treatment fish were released in spillbay 4 at The Dalles Dam and control fish were released in the spillway tailrace at The Dalles Dam 56 m downstream of the spillway.

		Test 1			Test 2		
Release	Population	df	χ^2	P	df	χ^2	P
1	Treatment	1	0.360	0.549		[a]	[a]
	Control	1	0.175	0.676		[a]	[a]
2	Treatment	1	0.097	0.755	1	0.052	0.819
	Control	1	0.450	0.502		[a]	[a]
3	Treatment	1	2.116	0.146		[a]	[a]
	Control	1	0.345	0.557		[a]	[a]
4	Treatment	1	0.512	0.474	1	0.076	0.783
	Control	1	0.225	0.635		[a]	[a]
5	Treatment	1	1.776	0.183		[a]	[a]
	Control	1	1.270	0.260		[a]	[a]
6	Treatment	1	0.238	0.626	1	0.234	0.628
	Control	1	0.223	0.637	1	0.298	0.585
7	Treatment	1	0.011	0.918		[a]	[a]
	Control		[a]	[a]		[a]	[a]
8	Treatment	1	0.000	1.000		[a]	[a]
	Control	1	0.041	0.839		[a]	[a]
9	Treatment	1	0.192	0.661		[a]	[a]
	Control	1	0.013	0.908		[a]	[a]
10	Treatment	1	0.345	0.557		[a]	[a]
	Control	1	0.000	1.000		[a]	[a]
11	Treatment	1	0.703	0.402		[a]	[a]
	Control	1	0.109	0.742		[a]	[a]
12	Treatment		[a]	[a]		[a]	[a]
	Control	1	0.359	0.549		[a]	[a]
13	Treatment	1	0.345	0.557		[a]	[a]
	Control	1	0.026	0.871		[a]	[a]
14	Treatment		[a]	[a]		[a]	[a]
	Control	1	0.021	0.884		[a]	[a]
15	Treatment	1	1.347	0.246		[a]	[a]
	Control	1	0.281	0.596		[a]	[a]
16	Treatment		[a]	[a]		[a]	[a]
	Control	1	0.004	0.948		[a]	[a]

[a] - Chi-square statistic was not calculable for these tests due to the presence of only zeroes in rows or columns in the contingency tables.

Table A2.2. -Summary statistics for goodness-of-fit tests (tests 2 and 3, Burnham et al. 1987) for each of 16 paired releases of yearling Chinook, spring 2002. Treatment fish were released in spillbay 09 at The Dalles Dam and control fish were released in the spillway tailrace at The Dalles Dam approximately 56 m downstream of the spillway.

		Test 2			Test 3		
Release	Population	df	χ^2	P	df	χ^2	P
1	Treatment	1	0.267	0.606		[a]	[a]
	Control	1	0.175	0.676		[a]	[a]
2	Treatment	1	1.433	0.231		[a]	[a]
	Control	1	0.450	0.502		[a]	[a]
3	Treatment	1	1.915	0.166		[a]	[a]
	Control	1	0.345	0.557		[a]	[a]
4	Treatment	1	0.360	0.549		[a]	[a]
	Control	1	0.225	0.635		[a]	[a]
5	Treatment	1	0.222	0.638		[a]	[a]
	Control	1	1.270	0.260		[a]	[a]
6	Treatment	1	0.166	0.684		[a]	[a]
	Control	1	0.223	0.637	1	0.298	0.585
7	Treatment	1	1.695	0.193	1	0.442	0.506
	Control		[a]	[a]		[a]	[a]
8	Treatment	1	0.217	0.641		[a]	[a]
	Control	1	0.041	0.839		[a]	[a]
9	Treatment	1	0.000	1.000	1	0.381	0.537
	Control	1	0.013	0.908		[a]	[a]
10	Treatment	1	0.004	0.952		[a]	[a]
	Control	1	0.000	1.000		[a]	[a]
11	Treatment	1	1.377	0.240		[a]	[a]
	Control	1	0.109	0.742		[a]	[a]
12	Treatment	1	0.101	0.751		[a]	[a]
	Control	1	0.359	0.549		[a]	[a]
13	Treatment	1	0.004	0.952		[a]	[a]
	Control	1	0.026	0.871		[a]	[a]
14	Treatment	1	1.758	0.185		[a]	[a]
	Control	1	0.021	0.884		[a]	[a]
15	Treatment	1	0.098	0.755		[a]	[a]
	Control	1	0.281	0.596		[a]	[a]
16	Treatment	1	0.132	0.716		[a]	[a]
	Control	1	0.004	0.948		[a]	[a]

[a] - Chi-square statistic was not calculable for these tests due to the presence of only zeroes in rows or columns in the contingency tables.

Table A2.3. - Summary statistics for goodness-of-fit tests (tests 2 and 3, Burnham et al. 1987) for each of 16 paired releases of yearling Chinook, spring 2002. Treatment fish were released in spillbay 13 at The Dalles Dam and control fish were released in the spillway tailrace at The Dalles Dam approximately 56 m downstream of the spillway.

		Test 2			Test 3		
Release	Population	df	χ^2	P	df	χ^2	P
1	Treatment	1	0.731	0.393		[a]	[a]
	Control	1	0.175	0.676		[a]	[a]
2	Treatment		[a]	[a]		[a]	[a]
	Control	1	0.450	0.502		[a]	[a]
3	Treatment	1	0.265	0.607		[a]	[a]
	Control	1	0.345	0.557		[a]	[a]
4	Treatment	1	0.947	0.330	1	0.000	1.000
	Control	1	0.225	0.635		[a]	[a]
5	Treatment	1	0.791	0.374		[a]	[a]
	Control	1	1.270	0.260		[a]	[a]
6	Treatment	1	0.321	0.571	1	0.011	0.915
	Control	1	0.223	0.637	1	0.298	0.585
7	Treatment	1	0.272	0.602	1	0.997	0.318
	Control		[a]	[a]		[a]	[a]
8	Treatment	1	0.245	0.621		[a]	[a]
	Control	1	0.041	0.839		[a]	[a]
9	Treatment	1	0.013	0.910		[a]	[a]
	Control	1	0.013	0.908		[a]	[a]
10	Treatment	1	0.192	0.661		[a]	[a]
	Control	1	0.000	1.000		[a]	[a]
11	Treatment	1	0.147	0.702		[a]	[a]
	Control	1	0.109	0.742		[a]	[a]
12	Treatment	1	0.414	0.520		[a]	[a]
	Control	1	0.359	0.549		[a]	[a]
13	Treatment		[a]	[a]		[a]	[a]
	Control	1	0.026	0.871		[a]	[a]
14	Treatment	1	0.261	0.610		[a]	[a]
	Control	1	0.021	0.884		[a]	[a]
15	Treatment	1	0.114	0.736		[a]	[a]
	Control	1	0.281	0.596		[a]	[a]
16	Treatment	1	0.175	0.676		[a]	[a]
	Control	1	0.004	0.948		[a]	[a]

[a] - Chi-square statistic was not calculable for these tests due to the presence of only zeroes in rows or columns in the contingency tables.

Table A2.4. -Summary statistics for goodness-of-fit tests (tests 2 and 3, Burnham et al. 1987) for each of 16 paired releases of yearling Chinook, spring 2002. Treatment fish were released in the spillway tailrace approximately 56 m downstream of the spillway at The Dalles Dam and control fish were released at the tip of the navigational lock peninsula at The Dalles Dam.

		Test 2			Test 3		
Release	Population	df	χ^2	P	df	χ^2	P
1	Treatment	1	0.175	0.676		[a]	[a]
	Control	1	0.598	0.439		[a]	[a]
2	Treatment	1	0.450	0.502		[a]	[a]
	Control	1	0.011	0.916	1	0.960	0.327
3	Treatment	1	0.345	0.557		[a]	[a]
	Control	1	0.013	0.909	1	1.469	0.225
4	Treatment	1	0.225	0.635		[a]	[a]
	Control	1	0.013	0.909		[a]	[a]
5	Treatment	1	1.270	0.260		[a]	[a]
	Control	1	0.265	0.607		[a]	[a]
6	Treatment	1	0.223	0.637	1	0.298	0.585
	Control	1	0.281	0.596		[a]	[a]
7	Treatment		[a]	[a]		[a]	[a]
	Control	1	0.064	0.800		[a]	[a]
8	Treatment	1	0.041	0.839		[a]	[a]
	Control	1	0.268	0.604		[a]	[a]
9	Treatment	1	0.013	0.908		[a]	[a]
	Control	1	1.461	0.227		[a]	[a]
10	Treatment	1	0.000	1.000		[a]	[a]
	Control	1	0.010	0.921	1	1.723	0.189
11	Treatment	1	0.109	0.742		[a]	[a]
	Control	1	0.192	0.661		[a]	[a]
12	Treatment	1	0.359	0.549		[a]	[a]
	Control		[a]	[a]		[a]	[a]
13	Treatment	1	0.026	0.871		[a]	[a]
	Control	1	0.014	0.907		[a]	[a]
14	Treatment	1	0.101	0.751		[a]	[a]
	Control	1	1.621	0.203		[a]	[a]
15	Treatment	1	0.281	0.596		[a]	[a]
	Control	1	0.021	0.885		[a]	[a]
16	Treatment	1	0.004	0.948		[a]	[a]
	Control	1	1.746	0.186		[a]	[a]

[a] - Chi-square statistic was not calculable for these tests due to the presence of only zeroes in rows or columns in the contingency tables.

Table A2.5. -Summary statistics for goodness-of-fit tests (tests 2 and 3, Burnham et al. 1987) for each of 16 paired releases of yearling Chinook, spring 2002. Treatment fish were released in spillbay 4 at The Dalles Dam and control fish were released at the tip of the navigational lock peninsula at The Dalles Dam.

		Test 2			Test 3		
Release	Population	df	χ^2	P	df	χ^2	P
1	Treatment	1	0.360	0.549		[a]	[a]
	Control	1	0.598	0.439		[a]	[a]
2	Treatment	1	0.097	0.755	1	0.052	0.819
	Control	1	0.011	0.916	1	0.960	0.327
3	Treatment	1	2.116	0.146		[a]	[a]
	Control	1	0.013	0.909	1	1.469	0.225
4	Treatment	1	0.512	0.474	1	0.076	0.783
	Control	1	0.013	0.909		[a]	[a]
5	Treatment	1	1.776	0.183		[a]	[a]
	Control	1	0.265	0.607		[a]	[a]
6	Treatment	1	0.223	0.637	1	0.298	0.585
	Control	1	0.281	0.596		[a]	[a]
7	Treatment	1	0.011	0.918		[a]	[a]
	Control	1	0.064	0..800		[a]	[a]
8	Treatment	1	0.000	1.000		[a]	[a]
	Control	1	0.268	0.604		[a]	[a]
9	Treatment	1	0.192	0.661		[a]	[a]
	Control	1	1.461	0.227		[a]	[a]
10	Treatment	1	0.345	0.557		[a]	[a]
	Control	1	0.010	0.921	1	1.723	0.189
11	Treatment	1	0.703	0.402		[a]	[a]
	Control	1	0.192	0.661		[a]	[a]
12	Treatment		[a]	[a]		[a]	[a]
	Control		[a]	[a]		[a]	[a]
13	Treatment	1	0.345	0.557		[a]	[a]
	Control	1	0.014	0.907		[a]	[a]
14	Treatment		[a]	[a]		[a]	[a]
	Control	1	1.621	0.203		[a]	[a]
15	Treatment	1	1.347	0.246		[a]	[a]
	Control	1	0.281	0.596		[a]	[a]
16	Treatment		[a]	[a]		[a]	[a]
	Control		1.746	0.186		[a]	[a]

[a] - Chi-square statistic was not calculable for these tests due to the presence of only zeroes in rows or columns in the contingency tables.

Table A2.6. -Summary statistics for goodness-of-fit tests (tests 2 and 3, Burnham et al. 1987) for each of 16 paired releases of yearling Chinook, spring 2002. Treatment fish were released in spillbay 9 at The Dalles Dam and control fish were released at the tip of the navigational lock peninsula at The Dalles Dam.

		Test 2			Test 3		
Release	Population	df	χ^2	P	df	χ^2	P
1	Treatment	1	0.267	0.606		[a]	[a]
	Control	1	0.598	0.493		[a]	[a]
2	Treatment	1	1.433	0.231		[a]	[a]
	Control	1	0.011	0.916	1	0.960	0.327
3	Treatment	1	1.915	0.166		[a]	[a]
	Control	1	0.013	0.909	1	1.469	0.225
4	Treatment	1	0.360	0.549		[a]	[a]
	Control	1	0.013	0.909		[a]	[a]
5	Treatment	1	0.222	0.638		[a]	[a]
	Control	1	0.265	0.607		[a]	[a]
6	Treatment	1	0.166	0.684		[a]	[a]
	Control	1	0.281	0.596		[a]	[a]
7	Treatment	1	1.695	0.193	1	0.442	0.506
	Control	1	0.064	0.800		[a]	[a]
8	Treatment	1	0.217	0.641		[a]	[a]
	Control	1	0.268	0.604		[a]	[a]
9	Treatment	1	0.000	1.000	1	0.381	0.537
	Control	1	1.461	0.227		[a]	[a]
10	Treatment	1	0.004	0.952		[a]	[a]
	Control	1	0.010	0.921	1	1.723	0.189
11	Treatment	1	1.377	0.240		[a]	[a]
	Control	1	0.192	0.661		[a]	[a]
12	Treatment	1	0.101	0.751		[a]	[a]
	Control		[a]	[a]		[a]	[a]
13	Treatment	1	0.004	0.952		[a]	[a]
	Control	1	0.014	0.907		[a]	[a]
14	Treatment	1	1.758	0.185		[a]	[a]
	Control	1	1.621	0.203		[a]	[a]
15	Treatment	1	0.098	0.755		[a]	[a]
	Control	1	0.021	0.885		[a]	[a]
16	Treatment	1	0.132	0.716		[a]	[a]
	Control	1	1.746	0.186		[a]	[a]

[a] - Chi-square statistic was not calculable for these tests due to the presence of only zeroes in rows or columns in the contingency tables.

Table A2.7. -Summary statistics for goodness-of-fit tests (tests 2 and 3, Burnham et al. 1987) for each of 16 paired releases of yearling Chinook, spring 2002. Treatment fish were released in spillbay 13 at The Dalles Dam and control fish were released at the tip of the navigational lock peninsula at The Dalles Dam.

		Test 2			Test 3		
Release	Population	df	χ^2	P	df	χ^2	P
1	Treatment	1	0.731	0.393		[a]	[a]
	Control	1	0.598	0.439		[a]	[a]
2	Treatment		[a]	[a]		[a]	[a]
	Control	1	0.011	0.916	1	0.960	0.327
3	Treatment	1	0.265	0.607		[a]	[a]
	Control	1	0.013	0.909	1	1.469	0.225
4	Treatment	1	0.947	0.330	1	0.000	1.000
	Control	1	0.013	0.909		[a]	[a]
5	Treatment	1	0.791	0.374		[a]	[a]
	Control	1	0.265	0.607		[a]	[a]
6	Treatment	1	0.321	0.571	1	0.011	0.915
	Control	1	0.281	0.596		[a]	[a]
7	Treatment	1	0.272	0.602	1	0.997	0.318
	Control	1	0.064	0.800		[a]	[a]
8	Treatment	1	0.245	0.621		[a]	[a]
	Control	1	0.268	0.604		[a]	[a]
9	Treatment	1	0.013	0.910		[a]	[a]
	Control	1	1.461	0.227		[a]	[a]
10	Treatment	1	0.192	0.661		[a]	[a]
	Control		0.010	0.921	1	1.723	0.189
11	Treatment	1	0.147	0.702		[a]	[a]
	Control	1	0.192	0.661		[a]	[a]
12	Treatment	1	0.414	0.520		[a]	[a]
	Control		[a]	[a]		[a]	[a]
13	Treatment		[a]	[a]		[a]	[a]
	Control	1	0.014	0.907		[a]	[a]
14	Treatment	1	0.261	0.610		[a]	[a]
	Control	1	1.621	0.203		[a]	[a]
15	Treatment	1	0.114	0.736		[a]	[a]
	Control	1	0.021	0.885		[a]	[a]
16	Treatment	1	0.175	0.676		[a]	[a]
	Control	1	1.746	0.186		[a]	[a]

[a] - Chi-square statistic was not calculable for these tests due to the presence of only zeroes in rows or columns in the contingency tables.

Table A2.8. -Summary statistics for goodness-of-fit tests (tests 2 and 3, Burnham et al. 1987) for each of 20 paired releases of sub-yearling Chinook, fall 2002. Treatment fish were released in spillbay 4 at The Dalles Dam and control fish were released in The Dalles Dam tailrace approximately 56 m downstream of the spillway.

		Test 2			Test 3		
Release	Population	df	χ^2	P	df	χ^2	P
1	Treatment	1	0.310	0.578		[a]	[a]
	Control		[a]	[a]		[a]	[a]
2	Treatment		[a]	[a]		[a]	[a]
	Control	1	0.236	0.627		[a]	[a]
3	Treatment		[a]	[a]		[a]	[a]
	Control	1	0.005	0.945	1	1.469	0.225
4	Treatment		[a]	[a]		[a]	[a]
	Control	1	0.160	0.689		[a]	[a]
5	Treatment	1	0.000	1.000		[a]	[a]
	Control	1	0.032	0.859	1	1.469	0.225
6	Treatment	1	1.768	0.184		[a]	[a]
	Control	1	0.127	0.722	1	0.002	0.967
7	Treatment	1	2.537	0.111	1	0.997	0.318
	Control	1	0.260	0.610		[a]	[a]
8	Treatment	1	0.652	0.419		[a]	[a]
	Control		[a]	[a]		[a]	[a]
9	Treatment	1	0.184	0.668		[a]	[a]
	Control	1	0.485	0.486		[a]	[a]
10	Treatment	1	0.004	0.952		[a]	[a]
	Control		[a]	[a]		[a]	[a]
11	Treatment	1	0.125	0.724		[a]	[a]
	Control	1	1.679	0.195		[a]	[a]
12	Treatment	1	0.050	0.823		[a]	[a]
	Control	1	0.000	1.000		[a]	[a]
13	Treatment	1	0.003	0.958		[a]	[a]
	Control	1	0.001	0.976		[a]	[a]
14	Treatment	1	0.553	0.457		[a]	[a]
	Control	1	0.219	0.640	1	0.765	0.382
15	Treatment	1	0.152	0.697		[a]	[a]
	Control	1	0.038	0.846		[a]	[a]

[a] - Chi-square statistic was not calculable for these tests due to the presence of only zeroes in rows or columns in the contingency tables.

Table A2.8 (continued).-Summary statistics for goodness-of-fit tests (tests 2 and 3, Burnham et al. 1987) for each of 20 paired releases of sub-yearling Chinook, fall 2002. Treatment fish were released in spillbay 4 at The Dalles Dam and control fish were released in The Dalles Dam tailrace approximately 56 m downstream of the spillway.

		Test 2			Test 3		
Release	Population	df	χ^2	P	df	χ^2	P
16	Treatment		[a]	[a]		[a]	[a]
	Control	1	0.060	0.807	1	0.005	0.944
17	Treatment	1	0.625	0.429		[a]	[a]
	Control	1	0.197	0.657		[a]	[a]
18	Treatment	1	1.058	0.304		[a]	[a]
	Control	1	0.550	0.458	1	2.226	0.136
19	Treatment	1	6.455	0.011		[a]	[a]
	Control	1	0.160	0.689	1	3.233	0.072

[a] - Chi-square statistic was not calculable for these tests due to the presence of only zeroes in rows or columns in the contingency tables.

Table A2.9. -Summary statistics for goodness-of-fit tests (tests 2 and 3, Burnham et al. 1987) for each of 20 paired releases of sub-yearling Chinook, fall 2002. Treatment fish were released in spillbays 13 and 11 at The Dalles Dam and control fish were released in The Dalles Dam tailrace approximately 56 m downstream of the spillway.

		Test 2			Test 3		
Release	Population	df	χ^2	P	df	χ^2	P
1	Treatment	1	0.047	0.828		[a]	[a]
	Control		[a]	a		[a]	[a]
2	Treatment	1	0.356	0.551		[a]	[a]
	Control	1	0.236	0.627		[a]	[a]
3	Treatment	1	0.017	0.896		[a]	[a]
	Control	1	0.005	0.945	1	1.469	0.225
4	Treatment	1	0.130	0.718		[a]	[a]
	Control	1	0.160	0.689		[a]	[a]
5	Treatment	1	0.822	0.365	1	0.120	0.729
	Control	1	0.032	0.859	1	1.469	0.225
6	Treatment	1	0.064	0.800		[a]	[a]
	Control	1	0.127	0.722	1	0.002	0.967
7	Treatment	1	0.319	0.572	1	1.723	0.189
	Control	1	0.260	0.610		[a]	[a]
8	Treatment	1	1.565	0.211		[a]	[a]
	Control		[a]	[a]		[a]	[a]
9	Treatment	1	2.751	0.097		[a]	[a]
	Control	1	0.485	0.486		[a]	[a]
10	Treatment		[a]	[a]		[a]	[a]
	Control		[a]	[a]		[a]	[a]
11	Treatment	1	4.868	0.027		[a]	[a]
	Control	1	1.679	0.195		[a]	[a]
12	Treatment	1	0.518	0.472	1	0.261	0.610
	Control	1	0.000	1.000		[a]	[a]
13	Treatment	1	0.438	0.508	1	1.122	0.290
	Control	1	0.001	0.976		[a]	[a]
14	Treatment		[a]	[a]		[a]	[a]
	Control	1	0.219	0.640	1	0.765	0.382
15	Treatment	1	1.280	0.258		[a]	[a]
	Control	1	0.038	0.846		[a]	[a]
16	Treatment	1	6.987	0.008		[a]	[a]
	Control	1	0.060	0.807	1	0.005	0.944

[a] - Chi-square statistic was not calculable for these tests due to the presence of only zeroes in rows or columns in the contingency tables.

Table A2.9 (Continued).-Summary statistics for goodness-of-fit tests (tests 2 and 3, Burnham et al. 1987) for each of 20 paired releases of sub-yearling Chinook, fall 2002. Treatment fish were released in spillbays 13 and 11 at The Dalles Dam and control fish were released in The Dalles Dam tailrace approximately 56 m downstream of the spillway.

		Test 2			Test 3		
Release	Population	df	χ^2	P	df	χ^2	P
17	Treatment	1	0.021	0.883		[a]	[a]
	Control	1	0.197	0.657		[a]	[a]
18	Treatment		[a]	[a]		[a]	[a]
	Control	1	0.550	0.458	1	2.226	0.136
19	Treatment	1	0.986	0.321	1	0.272	0.602
	Control	1	0.160	0.689	1	3.233	0.072

[a] - Chi-square statistic was not calculable for these tests due to the presence of only zeroes in rows or columns in the contingency tables.

Appendix 3: Homogeneity of Arrival Times

Table A3.1. -Chi-square tests for homogeneity of arrival times of yearling Chinook salmon released from The Dalles Dam Spillbay 4 and The Dalles Dam spillway tailrace approximately 56 m downstream of the spillway, and detected at river kilometers 286, 273 and 235.

	River Kilometer 286			River Kilometer 273			River Kilometer 235		
Release	DF	Chi-square	P	DF	Chi-square	P	DF	Chi-square	P
1	1	0.89	0.343	2	1.33	0.513	2	1.08	0.580
2	0	0	[a]	0	0	[a]	1	0.85	0.353
3	1	0.01	0.909	1	0.67	0.411	2	4.28	0.117
4	1	1.17	0.278	0	0	[a]	1	0.91	0.338
5	0	0	[a]	0	0	[a]	1	0.87	0.349
6	0	0	[a]	0	0	[a]	0	0	[a]
7	0	0	[a]	0	0	[a]	0	0	[a]
8	0	0	[a]	0	0	[a]	0	0	[a]
9	0	0	[a]	0	0	[a]	0	0	[a]
10	0	0	[a]	0	0	[a]	0	0	[a]
11	0	0	[a]	0	0	[a]	0	0	[a]
12	0	0	[a]	0	0	[a]	0	0	[a]
13	0	0	[a]	0	0	[a]	1	0.92	0.336
14	0	0	[a]	0	0	[a]	0	0	[a]
15	0	0	[a]	0	0	[a]	1	1.08	0.297
16	0	0	[a]	0	0	[a]	0	0	[a]

[a] - All fish arrived on the same day at this detection array.

TableA3.2. -Chi-square tests for homogeneity of arrival times of yearling Chinook salmon released from The Dalles Dam spillbay 4 and The Dalles Dam tailrace approximately 550 m downstream of the spillway, and detected at river kilometers 286, 273 and 235.

	River Kilometer 286			River Kilometer 273			River Kilometer 235		
Release	DF	Chi-square	P	DF	Chi-square	P	DF	Chi-square	P
1	0	0	[a]	2	0.78	0.675	2	1.25	0.533
2	0	0	[a]	0	0	[a]	1	2.00	0.156
3	1	1.29	0.254	0	0	[a]	1	1.56	0.211
4	1	1.85	0.173	0	0	[a]	1	0.82	0.364
5	0	0	[a]	0	0	[a]	0	0	[a]
6	0	0	[a]	0	0	[a]	1	0.91	0.338
7	0	0	[a]	0	0	[a]	0	0	[a]
8	0	0	[a]	0	0	[a]	1	1.08	0.298
9	0	0	[a]	0	0	[a]	0	0	[a]
10	0	0	[a]	0	0	[a]	0	0	[a]
11	0	0	[a]	0	0	[a]	0	0	[a]
12	0	0	[a]	0	0	[a]	0	0	[a]
13	0	0	[a]	0	0	[a]	0	0	[a]
14	0	0	[a]	0	0	[a]	0	0	[a]
15	0	0	[a]	0	0	[a]	0	0	[a]
16	0	0	[a]	0	0	[a]	0	0	[a]

[a]- All fish arrived on the same day at this detection array.

TableA3.3. -Chi-square tests for homogeneity of arrival times of yearling Chinook salmon released from The Dalles Dam spillbay 9 and The Dalles Dam spillway tailrace approximately 56 m downstream of the spillway, and detected at river kilometers 286, 273 and 235.

	River Kilometer 286			River Kilometer 273			River Kilometer 235		
Release	DF	Chi-square	P	DF	Chi-square	P	DF	Chi-square	P
1	1	0.14	0.702	1	0.01	0.915	1	2.13	0.144
2	0	0	[a]	0	0	[a]	1	1.00	0.316
3	2	1.56	0.456	1	1.16	0.279	2	2.13	0.344
4	0	0	[a]	0	0	[a]	1	1.02	0.310
5	0	0	[a]	0	0	[a]	1	0.00	0.938
6	0	0	[a]	0	0	[a]	0	0	[a]
7	0	0	[a]	0	0	[a]	0	0	[a]
8	0	0	[a]	0	0	[a]	0	0	[a]
9	0	0	[a]	0	0	[a]	0	0	[a]
10	0	0	[a]	0	0	[a]	0	0	[a]
11	0	0	[a]	0	0	[a]	0	0	[a]
12	0	0	[a]	0	0	[a]	0	0	[a]
13	0	0	[a]	0	0	[a]	1	0.87	0.349
14	0	0	[a]	0	0	[a]	0	0	[a]
15	0	0	[a]	0	0	[a]	1	1.14	0.285
16	0	0	[a]	0	0	[a]	0	0	[a]

[a]- All fish arrived on the same day at this detection array.

TableA3.4. -Chi - square tests for homogeneity of arrival times of yearling Chinook salmon released from The Dalles Dam spillbay 9 and The Dalles Dam tailrace approximately 550 m downstream of the spillway and detected at river kilometers 286, 273 and 235.

Release	River Kilometer 286			River Kilometer 273			River Kilometer 235		
	DF	Chi-square	P	DF	Chi-square	P	DF	Chi-square	P
1	1	1.62	0.202	1	1.15	0.282	1	0.36	0.545
2	0	0	[a]	0	0	[a]	1	0.07	0.781
3	2	3.26	0.195	1	2.33	0.126	2	1.72	0.421
4	0	0	[a]	0	0	[a]	1	0.92	0.336
5	0	0	[a]	0	0	[a]	1	1.08	0.297
6	0	0	[a]	0	0	[a]	1	0.97	0.324
7	0	0	[a]	0	0	[a]	0	0	[a]
8	0	0	[a]	0	0	[a]	1	0.92	0.337
9	0	0	[a]	0	0	[a]	0	0	[a]
10	0	0	[a]	0	0	[a]	0	0	[a]
11	0	0	[a]	0	0	[a]	1	0.97	0.324
12	0	0	[a]	0	0	[a]	0	0	[a]
13	0	0	[a]	0	0	[a]	0	0	[a]
14	0	0	[a]	0	0	[a]	0	0	[a]
15	0	0	[a]	0	0	[a]	0	0	[a]
16	0	0	[a]	0	0	[a]	0	0	[a]

[a]- All fish arrived on the same day at this detection array.

TableA3.5. -Chi-square tests for homogeneity of arrival times of yearling Chinook salmon released from The Dalles Dam spillbay 13 and The Dalles Dam spillway tailrace approximately 56 m downstream of the spillway and detected at the radio telemetry detection arrays at river kilometers 286, 273 and 235.

Release	River Kilometer 286			River Kilometer 273			River Kilometer 235		
	DF	Chi-square	P	DF	Chi-square	P	DF	Chi-square	P
1	2	2.10	0.349	1	1.40	0.235	3	2.12	0.546
2	0	0	[a]	0	0	[a]	1	0.59	0.439
3	1	0.89	0.345	1	0.28	0.595	2	2.03	0.360
4	0	0	[a]	0	0	[a]	1	1.02	0.310
5	0	0	[a]	0	0	[a]	1	0.61	0.431
6	0	0	[a]	0	0	[a]	1	1.15	0.281
7	0	0	[a]	0	0	[a]	0	0	[a]
8	0	0	[a]	0	0	[a]	0	0	[a]
9	0	0	[a]	0	0	[a]	0	0	[a]
10	0	0	[a]	0	0	[a]	0	0	[a]
11	0	0	[a]	0	0	[a]	0	0	[a]
12	0	0	[a]	0	0	[a]	0	0	[a]
13	0	0	[a]	0	0	[a]	1	0.87	0.349
14	0	0	[a]	0	0	[a]	0	0	[a]
15	0	0	[a]	0	0	[a]	1	1.14	0.285
16	0	0	[a]	0	0	[a]	0	0	[a]

[a]-All fish arrived on the same day at this detection array.

TableA3.6. -Chi-square tests for homogeneity of arrival times of yearling Chinook salmon released from The Dalles Dam spillbay 13 and The Dalles Dam tailrace approximately 550 m downstream of the spillway and detected at the radio telemetry detection arrays at river kilometers 286, 273 and 235.

Release	River Kilometer 286			River Kilometer 273			River Kilometer 235		
	DF	Chi-square	P	DF	Chi-square	P	DF	Chi-square	P
1	1	1.32	0.249	0	0	[a]	3	2.50	0.475
2	0	0	[a]	0	0	[a]	1	0.00	0.944
3	0	0	[a]	1	1.92	0.165	1	0.05	0.823
4	0	0	[a]	0	0	[a]	1	0.92	0.336
5	0	0	[a]	0	0	[a]	0	0	[a]
6	0	0	[a]	0	0	[a]	1	0.00	0.931
7	0	0	[a]	0	0	[a]	0	0	[a]
8	0	0	[a]	0	0	[a]	1	0.92	0.337
9	0	0	[a]	0	0	[a]	0	0	[a]
10	0	0	[a]	0	0	[a]	0	0	[a]
11	0	0	[a]	0	0	[a]	1	1.03	0.310
12	0	0	[a]	0	0	[a]	0	0	[a]
13	0	0	[a]	0	0	[a]	0	0	[a]
14	0	0	[a]	0	0	[a]	0	0	[a]
15	0	0	[a]	0	0	[a]	0	0	[a]
16	0	0	[a]	0	0	[a]	0	0	[a]

[a]- All fish arrived on the same day at this detection array.

TableA3.7. -Chi-square tests for homogeneity of arrival times of sub-yearling Chinook salmon released from The Dalles Dam spillbay 4 and The Dalles Dam tailrace approximately 550 m downstream of the spillway and detected at the radio telemetry detection arrays at river kilometers 286, 273 and 235.

	River Kilometer 286			River Kilometer 273			River Kilometer 235		
Release	DF	Chi-square	P	DF	Chi-square	P	DF	Chi-square	P
1	0	0	[a]	1	0.67	0.412	1	1.12	0.289
2	0	0	[a]	0	0	[a]	0	0	[a]
3	0	0	[a]	0	0	[a]	0	0	[a]
4	0	0	[a]	1	0.55	0.455	1	.00	0.944
5	0	0	[a]	0	0	[a]	1	0.97	0.322
6	0	0	[a]	1	1.02	0.311	1	2.28	0.130
7	0	0	[a]	0	0	[a]	1	.00	0.951
8	0	0	[a]	0	0	[a]	0	0	[a]
9	0	0	[a]	0	0	[a]	0	0	[a]
10	0	0	[a]	0	0	[a]	1	0.91	0.339
11	0	0	[a]	0	0	[a]	0	0	[a]
12	0	0	[a]	1	0.72	0.395	1	0.98	0.322
13	0	0	[a]	1	0.87	0.350	0	0	[a]
14	0	0	[a]	0	0	[a]	0	0	[a]
15	1	1.08	0.298	1	0.44	0.505	1	1.02	0.312
16	0	0	[a]	0	0	[a]	0	0	[a]
17	0	0	[a]	0	0	[a]	0	0	[a]
18	0	0	[a]	0	0	[a]	1	2.00	0.157
19	1	1.13	0.287	0	0	[a]	0	0	[a]

[a]- All fish arrived on the same day at this detection array.

TableA3.8. -Chi-squaretests for homogeneity of arrival times of sub-yearling Chinook salmon released from The Dalles Dam spillbay 13 (with the exception of release 8 which occurred through Spillbay 11) and The Dalles Dam tailrace approximately 550 m downstream of the spillway and detected at the radio telemetry detection arrays at river kilometers 286, 273 and 235.

Release	River Kilometer 286			River Kilometer 273			River Kilometer 235		
	DF	Chi-square	P	DF	Chi-square	P	DF	Chi-square	P
1	0	0	[a]	0	0	[a]	2	2.00	0.367
2	0	0	[a]	0	0	[a]	0	0	[a]
3	0	0	[a]	0	0	[a]	0	0	[a]
4	0	0	[a]	1	0.22	0.636	1	0.00	0.973
5	1	1.30	0.253	1	1.48	0.223	1	0.84	0.357
6	0	0	[a]	1	0.68	0.407	1	0.02	0.884
7	0	0	[a]	0	0	[a]	1	0.85	0.354
8	0	0	[a]	1	0.38	0.532	0	0	[a]
9	0	0	[a]	0	0	[a]	1	1.02	0.311
10	0	0	[a]	0	0	[a]	1	0.85	0.353
11	0	0	[a]	0	0	[a]	1	1.02	0.312
12	0	0	[a]	1	0.92	0.336	1	1.11	0.290
13	0	0	[a]	2	2.02	0.363	0	0	[a]
14	0	0	[a]	0	0	[a]	0	0	[a]
15	0	0	[a]	1	0.96	0.324	1	1.02	0.312
16	0	0	[a]	0	0	[a]	0	0	[a]
17	0	0	[a]	0	0	[a]	0	0	[a]
18	0	0	[a]	0	0	[a]	1	1.02	0.311
19	0	0	[a]	0	0	[a]	0	0	[a]

[a]- All fish arrived on the same day at this detection array.

TableA3.9. -Chi-square tests for homogeneity of arrival times of sub-yearling Chinook salmon released from The Dalles Dam spillway tailrace approximately 56 m downstream of the spillway and The Dalles Dam tailrace approximately 550 m downstream of the spillway and detected at the radio telemetry detection arrays at river kilometers 286, 273 and 235.

Release	River Kilometer 286			River Kilometer 273			River Kilometer 235		
	DF	Chi-square	P	DF	Chi-square	P	DF	Chi-square	P
1	1	0.96	0.325	1	1.03	0.308	1	0.38	0.535
2	0	0	[a]	0	0	[a]	1	.007	0.931
3	1	1.10	0.292	1	0.67	0.411	2	2.01	0.365
4	0	0	[a]	0	0	[a]	1	.005	0.938
5	0	0	[a]	0	0	[a]	1	0.97	0.323
6	0	0	[a]	0	0	[a]	1	1.02	0.310
7	0	0	[a]	0	0	[a]	0	0	[a]
8	0	0	[a]	0	0	[a]	1	1.02	0.310
9	0	0	[a]	0	0	[a]	0	0	[a]
10	0	0	[a]	0	0	[a]	0	0	[a]
11	0	0	[a]	0	0	[a]	1	0.87	0.349
12	0	0	[a]	0	0	[a]	0	0	[a]
13	0	0	[a]	0	0	[a]	1	1.02	0.311
14	0	0	[a]	0	0	[a]	0	0	[a]
15	0	0	[a]	0	0	[a]	1	1.08	0.297
16	0	0	[a]	0	0	[a]	0	0	[a]

[a]- All fish arrived on the same day at this detection array.