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Feasibility of Extracting Survival Information from Radio-Telemetry Studies at the John Day Dam, 1999.

Annual Report of Research

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Executive Summary

To examine the feasibility of extracting survival information from radio-telemetry studies of juvenile salmonids in the lower Columbia River, we evaluated the survival of yearling chinook salmon *Oncorhynchus tshawytscha* and steelhead trout *O. mykiss* released during fish passage efficiency (FPE) studies at John Day and The Dalles dams in 1999. Survival probabilities were estimated using the release/recapture models of Burnham et al. (1987). We determined that using radio-tagged yearling chinook salmon and steelhead trout to estimate survival probabilities is feasible and resulted in survival estimates with relatively high precision given the low numbers of fish tagged and released in the 1999 FPE study. However, alterations to the release scheme and various tagging protocols used during 1999 are necessary to ensure that the assumptions of the survival models are satisfied. Also, our results suggest an evaluation of the applicability of various assumption tests used in PIT-tag mark-recapture survival studies to radio-telemetry is necessary.

Tests of the survival model assumptions that upstream detections do not affect survival or capture probabilities (Burnham Tests 2 and 3) were largely incalculable due to the presence of all zeroes in either rows or columns of the chi-square contingency tables. We determined that the zeroes in the contingency tables were largely due to the absence of capture histories where fish were not detected at The Dalles Dam detection array and were subsequently detected at either the Bonneville Reservoir array or the Bonneville Dam array. While we will continue to evaluate Burnham tests 2 and 3 in future years, the utility of these procedures as tests of assumptions A5 and A6 seems affected by the high capture probabilities now possible with radio-telemetry detection arrays.

Arrival times of the Rock Creek released fish (treatment) and fish released at the John Day Dam juvenile bypass (control) were found to be significantly different ($P < 0.05$) at all detection arrays for the majority of the yearling chinook and steelhead trout releases. An analysis of the arrival times indicated that slight alterations to the release scheme used during 1999 would result in arrival time distributions that matched more closely.

Assumption A9, that states releases (R_1) and (R_2) have the same survival probability in the lower river segment (S_{21}), is satisfied if the paired releases mix as they migrate through the second river segment but can also be satisfied if the survival process is stable during passage by the two releases. Despite the differences in arrival times (lack of mixing) between the paired release groups, the results of the sequential model selection process indicated that the capture, survival and lambda probabilities for the river reaches below The Dalles Dam were not significantly different between the groups for the majority of the releases ($P > 0.10$).

Survival of yearling chinook passing via John Day Dam ranged from 0.81 to 1.35. The mean survival of yearling chinook salmon was estimated to be 0.99 (SE = 0.04). For steelhead trout passing via John Day Dam, survival ranged from 0.76 to 1.09. The mean survival of steelhead trout was estimated to be 0.93 (SE = 0.02). We will use the

estimates of survival and capture and lambda probabilities for future study design considerations but recommend that the absolute values be viewed in the context of the preliminary nature of the study and the fact that certain aspects of the study (e.g., no rotation of tagging personnel, etc.) confound the results. Further, as of the finalization of this report, the control release location used during 1999 (i.e., near the John Day Dam juvenile bypass outfall) has changed. In subsequent years (e.g., 2000, 2001, and 2002), the control group release location was moved further downstream and mid-channel of this location. Thus, the estimates provided in this report are not directly comparable to subsequent studies at John Day Dam.

Yearling chinook salmon tagged with Passive Integrated Transponder (PIT) tags were released concurrently with radio-tagged fish at the Rock Creek release site to provide comparisons of travel times between the two groups. Travel times for radio-tagged yearling chinook were significantly less than for PIT-tagged fish for the river reach from Rock Creek to John Day Dam ($P < 0.10$). Conversely, the travel times from John Day to Bonneville Dam were not significantly different ($P > 0.10$). The harmonic mean travel time from Rock Creek to John Day Dam for radio-tagged yearling chinook was 16.9 h (N =416, $Var(\bar{t}_H) = 0.084$) and 22.6 h (N = 68, $Var(\bar{t}_H) = 3.6$) for PIT-tagged fish. From Rock Creek to Bonneville Dam the harmonic mean travel time for radio-tagged yearling chinook was 67.7 h (N=285, $Var(\bar{t}_H) = 1.2$) versus 73.9 h (N=52, $Var(\bar{t}_H) = 14.7$) for the PIT-tagged fish. The differences between the harmonic means of the travel times of the two groups through both reaches were small (< 7 h).

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). 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 salmonid migrants.

The National Marine Fisheries Service and the Northwest Power Planning Council have established goals of 80% fish passage efficiency (FPE) for dams on the Columbia and Snake Rivers (Whitney et al. 1997). To help meet this goal, migrant salmonids are diverted from turbine passage by turbine bypass systems. However, the present turbine bypass systems do not divert sufficient numbers of fish to meet the 80% FPE goal. Thus, various levels and configurations of spill are used to help meet the established goal. 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).

During 1999, tests of the efficacy of different spill scenarios were conducted at both John Day and The Dalles Dams. The motivation for these evaluations was to identify which spill scenario will increase FPE and reduce predation of migrant juvenile salmonids. Scenarios include 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. Further, to reduce predation associated with the old juvenile bypass outfall at Powerhouse 2, Bonneville Dam, the new fish conveyance pipe and outfall became operational during 1999. Ultimately, these actions are designed to increase the survival of juvenile salmonids as they migrate through projects in the lower Columbia River. Thus, there is a need to estimate survival of migrant juvenile salmonids in the lower Columbia River to evaluate the utility of these management actions.

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. For instance, the development of the passive integrated transponder (PIT) tag, that allowed for the unique identification of fish (Prentice et al. 1990), offered many advantages over previous marking techniques (fin-clipping, freeze branding) used in survival studies. Consequently, PIT-tag recoveries 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 (Iwamato et al. 1994, Muir et al. 1995, Skalski et al. 1998b, Smith et al. 1998, Dawley et al. 1998).

However, the use of the PIT-tag technique relies on the availability of PIT-tag detectors at hydroelectric dams and these detectors are not present at all locations in the Columbia River Basin. The absence of PIT-tag detectors at certain projects (e.g., The Dalles Dam) and areas below Bonneville Dam has precluded survival estimation in some specific reaches of the Columbia River and fixed the spatial scale over which survival estimates can be made. Further, the relatively low detection probabilities associated with this technique requires that large numbers of fish be handled to obtain desired levels of precision in survival estimates (Skalski 1999b). Consequently, researchers have been motivated to examine the feasibility of using radio telemetry to generate survival estimates (Normandeau Associates, Inc. et al. 1998, Skalski 1999a).

Radio telemetry has been used extensively to evaluate the survival of fish and wildlife populations (White 1983, Bell and Kynard 1985, Giorgi et al. 1985, Pollock et al. 1996, Normandeau Associates, Inc. et al. 1998) and to monitor the behavior of yearling and subyearling chinook salmon *Oncorhynchus tshawytscha* and juvenile steelhead *O. mykiss* through hydroelectric projects in the Columbia River Basin (Sheer et al. 1997, Hansel et al. 1998, Holmberg et al. 1998, Hensleigh et al. 1999, Vendetti et al. 2000). Early in 1999, the U. S. Army Corps of Engineers, Portland District requested that the USGS examine the feasibility of extracting juvenile salmonid survival information from radio-tagged fish. Our objectives during 1999 were to 1) examine the feasibility of satisfying the assumptions of survival models with release and detection schemes used during 1999, 2) generate preliminary estimates on capture and survival probabilities for sample size estimation, and 3) provide insight into the logistics of conducting survival studies in the lower Columbia River using radio-tagged juvenile salmonids released as part of FPE studies at John Day and The Dalles dams.

Methods

Fish collection, transportation, tagging, holding, and release protocols are described in Hansel et. al (2000). Given the exploratory nature of this evaluation and the timing of the proposal of this topic, no attempt was made to alter the existing design of the fish passage efficiency studies at John Day and The Dalles dam to accommodate the assumptions of the survival estimation procedures used in this report. For example, tagging personnel were not rotated between the two release locations evaluated. Further, release timing was not specifically designed to promote mixing of paired releases.

Radio-telemetry detection arrays were set up at John Day, The Dalles, and Bonneville dams. An additional detection array was set up in Bonneville Reservoir near the town of Lyle, WA. Release and detection schemes used during 1999 are depicted in Figure 1. The arrays at each of the three dams spanned the breadth of the river channel and were set up so that passage through various routes of passage could be determined (Hansel et al. 2000). Conversely, the detection array in Bonneville Reservoir consisted of antennas placed only on the Washington shore. The Bonneville Reservoir array was included to examine the feasibility of using arrays set up in this fashion to facilitate survival estimation.

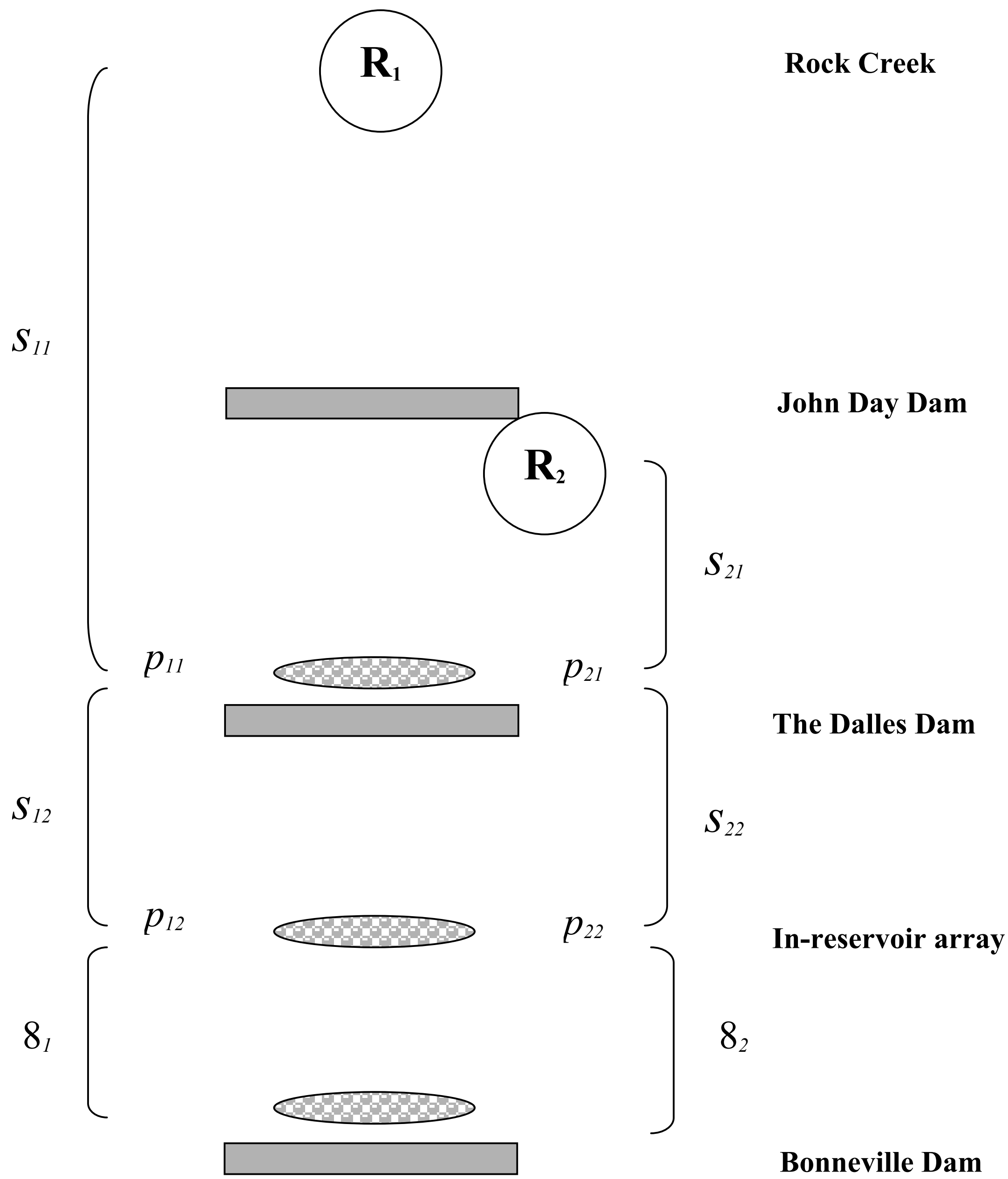

Figure 1. Schematic of estimable capture and survival probabilities (*S* = survival estimate, *p* = capture probability, and 8 = $S \cong p$) from releases at Rock Creek and near the John Day Dam outfall. Dams are represented by rectangles and ovals represent detection arrays.

The releases at Rock Creek consisted of 32 separate releases that were grouped with 16 releases near the outfall of the John Day Dam juvenile bypass to form the 16 paired releases evaluated (Table 1). A total of 412 yearling chinook salmon released at Rock Creek and 260 yearling chinook salmon released near the John Day Dam juvenile bypass outfall were included in these analyses (Tables 2 and 3). Similarly, 420 steelhead trout released at Rock Creek and 264 steelhead trout released near the John Day Dam juvenile bypass outfall were also evaluated (Tables 4 and 5). Paired release groups were formulated using fish released near Rock Creek, WA and subsequently detected passing John Day Dam. Thus, the numbers of fish used for the analyses presented in this report differ slightly from the numbers of fish used in the fish passage efficiency study (Hansel et. al. 2000). Also, due to technical problems at the radio-telemetry detection array in Bonneville Reservoir early in the migration season (Figure 1), the first two paired releases during 1999 were not used to estimate survival and test certain assumptions.

We used the paired-release recapture models of Burnham et al. (1987) to estimate the survival of juvenile yearling chinook salmon and steelhead trout through the lower Columbia River. There are assumptions associated with using the paired release-recapture (PR) model to estimate survival, some are biological and some pertain to the statistical models (Burnham et al. 1987, Skalski 1998b, 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

Table 1. Release dates and times for the paired releases of yearling chinook salmon and steelhead trout released near Rock Creek, WA and determined to have passed John Day Dam (treatment) and near the John Day Dam juvenile bypass outfall (control) during 1999.

	Rock Creek release A		Rock Creek release B		Juvenile Bypass outfall release	
Paired release	Release date	Release time	Release date	Release time	Release date	Release time
1	05/06	0000	05/07	1300	05/06	2100
2	05/07	2000	05/08	0900	05/08	0900
3	05/09	2000	05/10	0800	05/09	2100
4	05/10	2000	05/11	1100	05/11	0900
5	05/12	2000	05/13	0800	05/12	2100
6	05/13	2000	05/14	0800	05/14	0900
7	05/15	2000	05/16	0800	05/15	2100
8	05/16	2000	05/17	0800	05/17	0900
9	05/18	2000	05/19	0900	05/18	2100
10	05/19	2000	05/20	0800	05/20	0900
11	05/21	0800	05/21	2000	05/21	2100
12	05/22	2000	05/23	0800	05/23	0900
13	05/24	2000	05/25	0800	05/24	2100
14	05/25	2000	05/26	0800	05/26	0900
15	05/27	2000	05/28	0800	05/27	2100
16	05/28	2000	05/29	0800	05/29	0900

Table 2. The number released (N), mean, standard deviation (SD), and range of fork lengths (mm) of yearling chinook salmon released near Rock Creek, WA and determined to have passed John Day Dam (treatment) and near the John Day Dam juvenile bypass outfall (control) during 1999.

		Rock Creek release A				Rock Creek release B				Juvenile Bypass outfall release		
Paired release	N	Mean	SD	Range	N	Mean	SD	Range	N	Mean	SD	Range
1	13	167.5	33.3	125-222	15	152.3	22.1	123-195	19	159.8	25.6	133-220
2	14	167.6	25.8	139-213	15	174.2	28.9	142-222	18	185.8	37.1	129-230
3	15	155.9	21.2	131-191	12	165.9	21.0	146-208	20	176.9	24.8	135-227
4	13	186.5	30.6	142-228	20	184.9	21.6	141-220	19	183.1	14.1	153-210
5	20	167.0	32.8	126-233	10	178.7	30.5	136-223	19	160.3	25.9	129-211
6	10	171.4	40.6	129-246	20	166.5	22.2	140-235	18	170.7	21.6	135-205
7	19	177.7	25.9	142-215	10	165.7	23.3	141-216	19	171.3	21.1	146-218
8	10	158.6	48.2	133-214	21	170.0	18.5	135-230	18	179.1	17.5	160-223
9	19	173.4	20.4	135-216	10	151.8	8.1	145-167	19	169.5	21.4	136-221
10	10	161.0	16.7	135-180	20	163.4	20.2	137-201	19	159.5	18.5	127-197
11	7	157.9	17.6	137-189	9	156.9	17.1	135-190	18	165.9	18.5	135-201
12	19	155.9	31.2	148-197	21	160.7	15.4	132-194	18	162.9	23.5	136-219
13	21	159.9	17.7	135-193	10	162.9	13.1	134-176	16	158.8	13.0	138-179
14	10	180.1	23.5	151-220	24	162.7	20.2	134-210	17	155.8	21.9	129-226
15	21	161.1	22.9	134-211	12	166.7	22.8	135-220	20	156.8	18.9	131-194
16	12	163.0	21.3	135-198	7	156.1	17.4	140-181	20	154.4	20.1	132-230

Table 3. The sample size (N), mean, standard deviation (SD), and range of weights (g) of yearling chinook salmon released near Rock Creek, WA and determined to have passed John Day Dam (treatment) and near the John Day Dam juvenile bypass outfall (control) during 1999.

	Rock Creek release A				Rock Creek release B				Juvenile Bypass outfall release			
Paired release	N	Mean	SD	Range	N	Mean	SD	Range	N	Mean	SD	Range
1	14	54.1	35.2	19.9-116.8	15	40.3	18.3	18.5-78.4	18	42.6	25.0	21.1-112.7
2	15	48.9	23.3	25.2-105.2	15	-	-	-	18	77.9	39.0	19.7-137.6
3	14	41.3	17.4	23.6-72.3	12	46.3	16.7	31.0-77.6	18	56.8	25.6	23.0-123.8
4	13	69.0	37.3	27.5-131.1	19	69.4	25.3	27.1-112.7	20	59.5	17.1	29.5-91.5
5	14	53.9	36.8	21.2-146.5	11	60.8	31.0	25.6-113.8	15	42.2	22.3	19.4-98.8
6	13	60.3	50.5	20.4-167.6	19	49.3	27.4	26.8-150.6	14	50.1	17.8	22.5-83.3
7	13	59.6	25.8	26.3-100.1	9	46.6	20.2	25.8-87.1	24	51.4	22.4	28.0-104.7
8	12	56.6	19.4	32.6-98.6	12	50.2	19.7	22.5-125.4	22	56.6	20.0	39.4-110.3
9	16	52.2	19.5	21.9-103.5	12	33.6	7.3	21.0-45.4	19	48.9	22.1	21.4-114.0
10	10	41.0	12.8	21.7-54.7	21	43.3	16.2	25.6-74.8	19	39.2	14.7	21.1-71.4
11	9	40.6	15.1	23.2-66.1	10	38.1	15.1	23.5-70.8	19	43.4	14.3	22.4-75.8
12	20	40.6	14.9	23.1-76.5	18	40.3	12.4	20.3-69.3	19	42.5	21.0	21.0-103.1
13	21	39.7	14.2	22.3-71.2	14	40.0	9.1	21.2-49.6	17	37.3	9.3	25.1-53.4
14	13	56.4	22.8	31.2-97.1	26	42.0	18.0	22.3-92.9	19	36.3	19.9	20.1-105.3
15	24	40.0	16.5	21.7-74.5	12	44.3	24.2	22.2-108.8	20	35.7	13.0	21.0-62.0
16	12	41.2	15.7	23.2-65.4	21	35.2	12.2	24.8-54.3	19	35.3	16.9	20.7-71.3

Table 4. The sample size (N), mean, standard deviation (SD), and range of fork lengths (mm) of steelhead trout released near Rock Creek, WA and determined to have passed John Day Dam (treatment) and near the John Day Dam juvenile bypass outfall (control) during 1999.

	Rock Creek release A				Rock Creek release B				Juvenile Bypass outfall release			
Paired release	N	Mean	SD	Range	N	Mean	SD	Range	N	Mean	SD	Range
1	14	224.5	34.6	128-270	15	224.0	19.3	185-265	18	159.8	25.6	133-220
2	15	216.9	17.7	180-247	15	215.9	29.9	164-258	18	185.8	37.1	129-230
3	14	226.6	21.2	182-263	12	228.6	24.2	191-287	18	176.9	24.8	135-227
4	13	220.2	14.8	191-243	19	219.9	19.7	191-273	20	183.1	14.1	153-210
5	14	213.2	26.4	178-258	11	213.9	19.8	177-246	15	160.3	25.9	129-211
6	13	212.6	24.4	176-260	19	213.2	24.8	174-275	14	170.7	21.6	135-205
7	13	213.0	20.1	194-256	9	211.6	50.4	117-286	24	171.3	21.1	146-218
8	12	226.5	27.3	168-265	12	205.6	14.6	183-234	22	179.1	17.5	160-223
9	16	209.4	19.3	174-243	12	222.2	29.7	182-274	19	169.5	21.4	136-221
10	10	214.0	19.6	180-242	21	217.7	25.4	181-275	19	159.5	18.5	127-197
11	9	217.9	22.1	192-252	10	202.9	20.2	167-236	19	165.9	18.5	135-201
12	20	208.5	20.7	179-262	18	206.1	21.1	174-256	19	162.9	23.5	136-219
13	21	211.8	25.1	173-278	14	206.3	19.4	182-250	17	158.8	13.0	138-179
14	13	208.8	15.8	185-246	26	207.8	25.7	163-276	19	155.8	21.9	129-226
15	24	200.4	10.3	182-221	12	206.5	21.2	181-267	20	156.8	18.9	131-194
16	12	212.0	18.4	186-252	21	222.1	24.0	187-258	19	154.4	20.1	132-230

Table 5. The sample size (N), mean, standard deviation (SD), and range of weights (g) of steelhead trout released near Rock Creek, WA and determined to have passed John Day Dam (treatment) and near the John Day Dam juvenile bypass outfall (control) during 1999.

	Rock Creek release A				Rock Creek release B				Juvenile Bypass outfall release			
Paired release	N	Mean	SD	Range	N	Mean	SD	Range	N	Mean	SD	Range
1	14	110.0	34.3	68.0-177.8	15	97.8	26.6	56.0-169.6	18	159.8	25.6	133-220
2	15	95.7	28.9	67.7-138.0	15	-	-	-	18	185.8	37.1	129-230
3	14	99.4	27.3	48.8-149.8	12	109.6	43.3	64.4-227.5	18	176.9	24.8	135-227
4	13	93.4	16.7	64.3-119.3	19	94.1	26.0	56.5-170.4	20	183.1	14.1	153-210
5	14	86.1	34.2	47.6-150.5	11	83.1	21.1	44.0-111.5	15	160.3	25.9	129-211
6	13	82.8	30.5	44.5-153.8	19	85.4	34.7	28.8-186.4	14	170.7	21.6	135-205
7	13	86.6	26.7	59.7-138.5	9	95.8	56.6	45.8-198.1	24	171.3	21.1	146-218
8	12	107.2	31.3	69.2-163.2	12	71.5	22.3	45.8-134.4	22	179.1	17.5	160-223
9	16	78.6	22.9	46.4-131.1	12	98.2	39.7	55.9-179.4	19	169.5	21.4	136-221
10	10	79.0	20.1	52.5-120.7	21	90.2	35.0	47.0-176.7	19	159.5	18.5	127-197
11	9	87.6	28.7	57.7-131.1	10	67.4	19.7	35.6-103.8	19	165.9	18.5	135-201
12	20	77.6	25.9	41.7-155.6	18	72.4	25.2	43.5-138.2	19	162.9	23.5	136-219
13	21	82.0	30.9	44.6-161.2	14	74.4	23.5	52.0-132.0	17	158.8	13.0	138-179
14	13	76.9	20.3	48.2-127.3	26	77.3	36.4	35.8-197.5	19	155.8	21.9	129-226
15	24	66.6	9.8	49.0-88.2	12	73.0	25.8	47.6-148.7	20	156.8	18.9	131-194
16	12	81.6	27.2	53.7-147.0	21	93.2	31.0	57.5-145.6	19	154.4	20.1	132-230

assumptions named Test 2 that examine whether upstream 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.

Relative survival from Rock Creek to John Day Dam 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:

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

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 (i.e., The Dalles Dam, Bonneville Reservoir, and Bonneville Dam detection arrays). Because of the technical difficulties at the Bonneville reservoir detection array, the tests of arrival times were not conducted for the first two paired releases at this location. Tests were performed at $\forall = 0.10$. 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 $\forall_{EW} = 0.10$. The resulting significance level for the tests was 0.007.

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.

A weighted average of the survival estimates from the replicated releases can be calculated according to the formula:

$$\hat{\bar{S}} = \frac{\sum_{i=1}^{k} W_i \hat{S}_i}{\sum_{i=1}^{k} W_i} \qquad (4)$$

where k = number of replicate releases:

and where $\hat{S}_i$ = survival estimates from the ith release $(\mathrm{i} = 1, ..., k)$;

The weight W_{i} is calculated using the formula:

$$W_i = \frac{1}{\left(\frac{V\hat{a}r(\hat{S}_i)}{\hat{S}_i^2}\right)} = \frac{1}{CV(\hat{S}_i)^2} \tag{5}$$

with variance

$$Var\left(\hat{\bar{S}}\right) = \frac{\sum_{i=1}^{k} W_i\left(\hat{S}_i - \hat{\bar{S}}\right)^2}{(k-1)\sum_{i=1}^{k} W_i} \tag{6}$$

If the average is estimating a mean over some static process then weighting would be inversely proportional to the variance. However, in the release-recapture models,

$$Var(\hat{S}) \propto S^2$$

Therefore, the variance is correlated with the point estimates of survival. The weight (5) eliminates this correlation yet weights in proportion to the sampling precision (i.e., *CV*).

Yearling chinook salmon tagged with Passive Integrated Transponder (PIT) tags were released concurrently with radio-tagged fish at the Rock Creek release site to provide comparisons of travel times between the two groups. Travel times for radio-tagged fish were based on the first forebay detections by telemetry arrays at Bonneville and John Day dams. Travel times of PIT-tagged fish were from detections at the PIT-tag detectors at Bonneville and John Day dams as defined in Hansel et al. (2000). Mean travel time was summarized for the two tagging groups by computing the harmonic mean of the travel times (Skalski 1999a, 1999c) and its associated variance where:

$$\bar{t}_H = \frac{1}{\frac{1}{n}\sum_{i=1}^{n}\frac{1}{t_i}} = \frac{n}{\sum_{i=1}^{n}\frac{1}{t_i}}$$

where: t_i = travel time from Rock Creek to either the John Day Dam or to Bonneville Dam for the *i*th fish recovered (i = 1,….,n).

The variance for the harmonic mean was estimated by the approximate formula

$$V\hat{a}r(\bar{t}_H) = \frac{\left(\frac{s^2{}_{1/t}}{n}\right)}{\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{t_i}\right)^4}$$

and where

$$s_{1/t}^2 = \frac{\sum_{i=1}^{n}\left(\frac{1}{t_i} - \hat{\mu}_{1/t}\right)^2}{(n-1)},$$

$$\hat{\mu}_{1/t} = \frac{1}{n}\sum_{i=1}^{n}\frac{1}{t_i}$$

Similarity in travel times between PIT and radio-tagged fish were evaluated with a Z-statistic of the form

$$Z = \frac{\left|\bar{x}_{RAD} - \bar{x}_{PIT}\right|}{\sqrt{V\hat{a}r(\bar{x}_{RAD}) + V\hat{a}r(\bar{x}_{PIT})}}$$

to test the two-tailed hypothesis

$$H_o : \mu_{RAD} = \mu_{PIT}$$

$$H_A : \mu_{RAD} \neq \mu_{PIT}$$

with an ∀-level $P(Z > |Z_o|)$ with a type I error rate of ∀ = 0.10.

Results

The results of the Burnham Tests 2 and 3 testing assumptions A5 and A6 for the yearling chinook releases were inconclusive. For Test 2, 11 of the 32 possible tests were incalculable due to the presence of all zeroes in either rows or columns in the chi-square contingency tables (Table 6). Of the tests that were calculated, only 4 of the 21 tests were significant ($P < 0.10$). For Test 3, similar results were obtained with 12 of the 32 tests incalculable with only 4 of the 20 tests calculated for Test 3 indicating significant differences ($P < 0.10$). The sum of the chi-square values for Tests 2 and 3 that provide a measure of the overall fit of the data to the mark-recapture models were also largely incalculable (17 of 32) due to the absence of results from each of Test 2 and 3; four of the 15 tests calculated were significant ($P < 0.10$). All of the tests (Tests 2 and 3) calculated for the yearling chinook releases either had cells in the contingency tables that were < 1 or had more than 20% of the cells containing fewer than 5 observations.

For the steelhead trout releases, similar results were obtained for the Burnham Tests 2 and 3. Twenty, 25, and 27 of the tests were incalculable for Test 2, Test 3, and the combination of Tests 2 and 3, respectively (Table 7). For Test 2, 7 of the 12 tests calculated were significant ($P < 0.10$). Two of the 7 tests calculated for Test 3 indicated significant differences. For the sum of the chi-square values for Tests 2 and 3, 3 of the 5

Table 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 during 1999. Treatment fish were released near Rock Creek, WA and determined to have passed John Day Dam and control fish were released near the John Day Dam juvenile bypass outfall.

		Test 2			Test 3			Test2 +Test3		
Release	Population	df	χ^2	P	df	χ^2	P	df	χ^2	P
1	treatment	1	0.026	0.871		[a]	[a]		[a]	[a]
	control	1	0.603	0.438		[a]	[a]		[a]	[a]
2	treatment	1	0.243	0.622		[a]	[a]		[a]	[a]
	control		[a]	[a]		[a]	[a]		[a]	[a]
3	treatment	1	3.986	0.046	1	1.496	0.221	2	5.482	0.064
	control	1	3.233	0.072	1	0.522	0.470	2	3.755	0.150
4	treatment	1	5.629	0.018	1	0.276	0.599	2	5.905	0.052
	control	1	1.122	0.290	1	0.997	0.318	2	2.119	0.347
5	treatment	1	0.207	0.649	1	1.621	0.203	2	1.828	0.401
	control		[a]	[a]		[a]	[a]		[a]	[a]
6	treatment	1	1.996	0.158	1	4.237	0.040	2	6.233	0.044
	control	1	1.122	0.290	1	0.997	0.318	2	2.109	0.348
7	treatment	1	1.871	0.171	1	1.621	0.203	2	3.492	0.174
	control	1	0.765	0.382	1	1.371	0.242	2	2.137	0.344
8	treatment		[a]	[a]	1	4.237	0.040		[a]	[a]
	control		[a]	[a]		[a]	[a]		[a]	[a]
9	treatment	1	1.996	0.158	1	4.237	0.040	2	6.233	0.044
	control	1	0.219	0.640	1	0.000	1.000	2	0.219	0.896
10	treatment	1	2.121	0.145	1	1.871	0.171	2	3.992	0.132
	control		[a]	[a]	1	0.219	0.640		[a]	[a]
11	treatment	1	0.000	1.000		[a]	[a]		[a]	[a]
	control	1	1.875	0.171		[a]	[a]		[a]	[a]
12	treatment	1	0.070	0.791	1	4.248	0.039	2	4.318	0.115
	control		[a]	[a]		2.479	0.115		[a]	[a]
13	treatment	1	0.207	0.649	1	0.112	0.737	2	0.319	0.853
	control		[a]	[a]		[a]	[a]		[a]	[a]
14	treatment	1	1.342	0.247	1	0.131	0.717	2	1.473	0.853
	control	1	2.982	0.084		[a]	[a]		[a]	[a]
15	treatment		[a]	[a]	1	0.425	0.515		[a]	[a]
	control		[a]	[a]		[a]	[a]		[a]	[a]
16	treatment		[a]	[a]		[a]	[a]		[a]	[a]
	control		[a]	[a]	1	2.730	0.098		[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 7. Summary statistics for goodness-of-fit tests (tests 2 and 3, Burnham et al. 1987) for each of 16 paired releases of steelhead trout during 1999. Treatment fish were released near Rock Creek, WA and determined to have passed John Day Dam and control fish were released near the John Day Dam juvenile bypass outfall.

		Test 2			Test 3			Test2 +Test3		
Release	Population	df	χ^2	P	df	χ^2	P	df	χ^2	P
1	treatment	1	0.030	0.863		[a]	[a]		[a]	[a]
	control	1	1.975	0.160		[a]	[a]		[a]	[a]
2	treatment	1	[a]	[a]		[a]	[a]		[a]	[a]
	control	1	[a]	[a]		[a]	[a]		[a]	[a]
3	treatment	1	0.733	0.392	1	1.996	0.158	2	2.729	0.255
	control	1	[a]	[a]	1	2.982	0.084		[a]	[a]
4	treatment	1	[a]	[a]		[a]	[a]		[a]	[a]
	control		[a]	[a]		[a]	[a]		[a]	[a]
5	treatment		[a]	[a]		[a]	[a]		[a]	[a]
	control		[a]	[a]		[a]	[a]		[a]	[a]
6	treatment	1	2.121	0.145		[a]	[a]		[a]	[a]
	control		[a]	[a]		[a]	[a]		[a]	[a]
7	treatment	1	4.746	0.029		[a]	[a]		[a]	[a]
	control		[a]	[a]		[a]	[a]		[a]	[a]
8	treatment		[a]	[a]		[a]	[a]		[a]	[a]
	control		[a]	[a]	1	0.556	0.456		[a]	[a]
9	treatment		[a]	[a]		[a]	[a]		[a]	[a]
	control	1	8.163	0.004		[a]	[a]		[a]	[a]
10	treatment	1	5.490	0.019	1	2.246	0.134	2	7.736	0.021
	control		[a]	[a]		[a]	[a]		[a]	[a]
11	treatment	1	2.730	0.098	1	0.873	0.350	2	3.603	0.165
	control		[a]	[a]		[a]	[a]		[a]	[a]
12	treatment	1	2.871	0.090	1	2.746	0.097	2	5.617	0.060
	control		[a]	[a]		[a]	[a]		[a]	[a]
13	treatment	1	1.080	0.299		[a]	[a]		[a]	[a]
	control		[a]	[a]		[a]	[a]		[a]	[a]
14	treatment	1	6.992	0.008	1	0.799	0.377	2	7.791	0.020
	control		[a]	[a]		[a]	[a]		[a]	[a]
15	treatment		[a]	[a]		[a]	[a]		[a]	[a]
	control	1	2.982	0.084		[a]	[a]		[a]	[a]
16	treatment		[a]	[a]		[a]	[a]		[a]	[a]
	control		[a]	[a]		[a]	[a]		[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.

tests calculated were significant. All of the tests (Tests 2 and 3) calculated for the steelhead trout releases either had cells in the contingency tables that were < 1 or had more than 20% of the cells containing fewer than 5 observations.

The chi-square tests of homogeneity testing for the similarity in arrival times of paired releases of yearling chinook salmon and steelhead trout indicated that there were significant differences in arrival times between the two release groups. Ten of the 16 tests for yearling chinook salmon (Table 8) indicated significant differences in arrival times between the paired releases at The Dalles Dam ($P < 0.007$). All of the tests for steelhead trout arrival times at The Dalles Dam (Table 8) indicated significant differences in arrival times. Similar results were obtained for the arrival times of yearling chinook at the Bonneville Reservoir array (Table 9; 10 of 14 significant; $P < 0.007$) and steelhead trout (Table 9; 11 of 14 significant; $P < 0.007$). Arrival times at Bonneville Dam were also significantly different between the paired-release groups of yearling chinook salmon (Table 10; 10 of 16 significant; $P < 0.007$) and steelhead trout (Table 10; 14 of 16 significant; $P < 0.007$). To further examine the causes of the significant differences in arrival times, we pooled the arrival times for all yearling chinook (Figure 2) and steelhead trout (Figure 3) releases and examined them graphically. From these graphs we determined that fish released at the John Day Dam juvenile bypass releases generally arrived a day earlier than fish released at Rock Creek.

Despite the difference in arrival times of the release groups the sequential evaluation of the log-likelihood ratio tests indicated that the capture, survival and lambda probabilities were not significantly different between the treatment and control groups for the majority of the releases (Table 11). For yearling chinook and steelhead trout, only 2 of the 14 releases had capture probabilities that were significantly different ($P < 0.10$). The survival probabilities for the river reach from The Dalles Dam to the Bonneville Reservoir array near Lyle, WA were found to be significantly different ($P < 0.01$) for 2 and 3 of the 14 releases of yearling chinook salmon and steelhead trout, respectively. Lambda probabilities were significantly different ($P < 0.10$) in 2 of the 14 releases for both yearling chinook and steelhead.

We generated survival probabilities for yearling chinook salmon and steelhead trout (Table 12). Survival of yearling chinook passing via John Day Dam ranged from 0.81 to 1.35. The mean survival of yearling chinook salmon was estimated to be 0.99 (SE = 0.04). For steelhead trout passing via John Day Dam, survival ranged from 0.76 to 1.09. The mean survival of steelhead trout was estimated to be 0.93 (SE = 0.02). We will use the estimates of survival and capture and lambda probabilities for future study design considerations but recommend that the absolute values be viewed in the context of the preliminary nature of the study and the fact that certain aspects of the study (e.g., no rotation of tagging personnel, etc.) confound the results. Further, as of the finalization of this report, the control release location used during 1999 has been changed in subsequent years (e.g., 2000, 2001, and 2002) and thus the estimates provided in this report are not directly comparable to subsequent studies at John Day Dam.

Table 8. The results of chi-square tests of homogeneity testing for similarity in arrival times of paired releases of spring chinook salmon and steelhead trout at The Dalles Dam.

	Spring chinook			Steelhead trout		
Release	DF	Chi-square	P	DF	Chi-square	P
1	3	35.11	< 0.001	6	38.00	< 0.001
2	3	8.711	0.033	3	26.53	< 0.001
3	4	33.99	< 0.001	5	36.00	< 0.001
4	7	23.23	0.002	6	29.96	< 0.001
5	3	38.00	< 0.001	3	23.87	< 0.001
6	3	10.17	0.017	2	14.79	< 0.001
7	2	29.56	< 0.001	6	31.18	< 0.001
8	2	7.222	0.027	5	21.79	< 0.001
9	2	30.97	< 0.001	5	32.14	< 0.001
10	3	1.442	0.696	6	25.24	< 0.001
11	3	8.242	0.041	3	27.00	< 0.001
12	2	10.77	0.005	5	21.53	< 0.001
13	3	30.00	< 0.001	3	37.80	< 0.001
14	3	21.81	< 0.001	6	42.47	< 0.001
15	3	19.49	< 0.001	3	42.02	< 0.001
16	2	6.873	0.032	2	32.94	< 0.001

Table 9. The results of chi-square tests of homogeneity testing for similarity in arrival times of paired releases of spring chinook salmon and steelhead trout at the Bonneville Reservoir detection array.

	Spring chinook			Steelhead trout		
Release	DF	Chi-square	P	DF	Chi-square	P
3	5	27.23	< 0.001	5	27.19	< 0.001
4	8	28.49	< 0.001	5	30.20	< 0.001
5	4	13.28	0.001	3	18.90	< 0.001
6	3	12.93	0.005	3	17.79	< 0.001
7	3	26.47	< 0.001	7	22.67	0.002
8	2	9.700	0.008	5	26.50	< 0.001
9	2	24.10	< 0.001	6	20.49	0.002
10	2	11.38	0.003	5	28.28	< 0.001
11	3	9.100	0.028	4	13.31	0.010
12	3	20.86	< 0.001	5	30.37	< 0.001
13	2	21.60	< 0.001	3	18.14	< 0.001
14	3	9.70	0.021	6	8.490	0.204
15	4	30.06	< 0.001	3	40.00	< 0.001
16	2	3.340	0.188	3	9.092	0.028

Table 10. The results of chi-square tests of homogeneity testing for similarity in arrival times of paired releases of spring chinook salmon and steelhead trout at a Bonneville Dam.

	Spring chinook			Steelhead trout		
Release	DF	Chi-square	P	DF	Chi-square	P
1	4	25.76	< 0.001	6	19.32	0.003
2	2	2.529	0.282	5	15.24	0.009
3	5	20.76	< 0.001	6	26.09	< 0.001
4	5	27.12	< 0.001	7	27.01	< 0.001
5	4	16.73	0.002	3	19.22	< 0.001
6	5	10.80	0.056	5	8.944	0.111
7	5	27.76	< 0.001	7	20.32	0.005
8	2	7.375	0.025	6	22.67	< 0.001
9	3	20.42	< 0.001	7	22.11	0.002
10	3	5.900	0.117	6	22.17	0.001
11	5	11.25	0.047	3	17.75	< 0.001
12	3	13.07	0.004	4	18.55	< 0.001
13	2	19.43	< 0.001	3	30.66	< 0.001
14	3	17.16	< 0.001	6	39.92	< 0.001
15	3	13.28	0.004	4	24.55	< 0.001
16	2	5.744	0.057	3	25.00	< 0.001

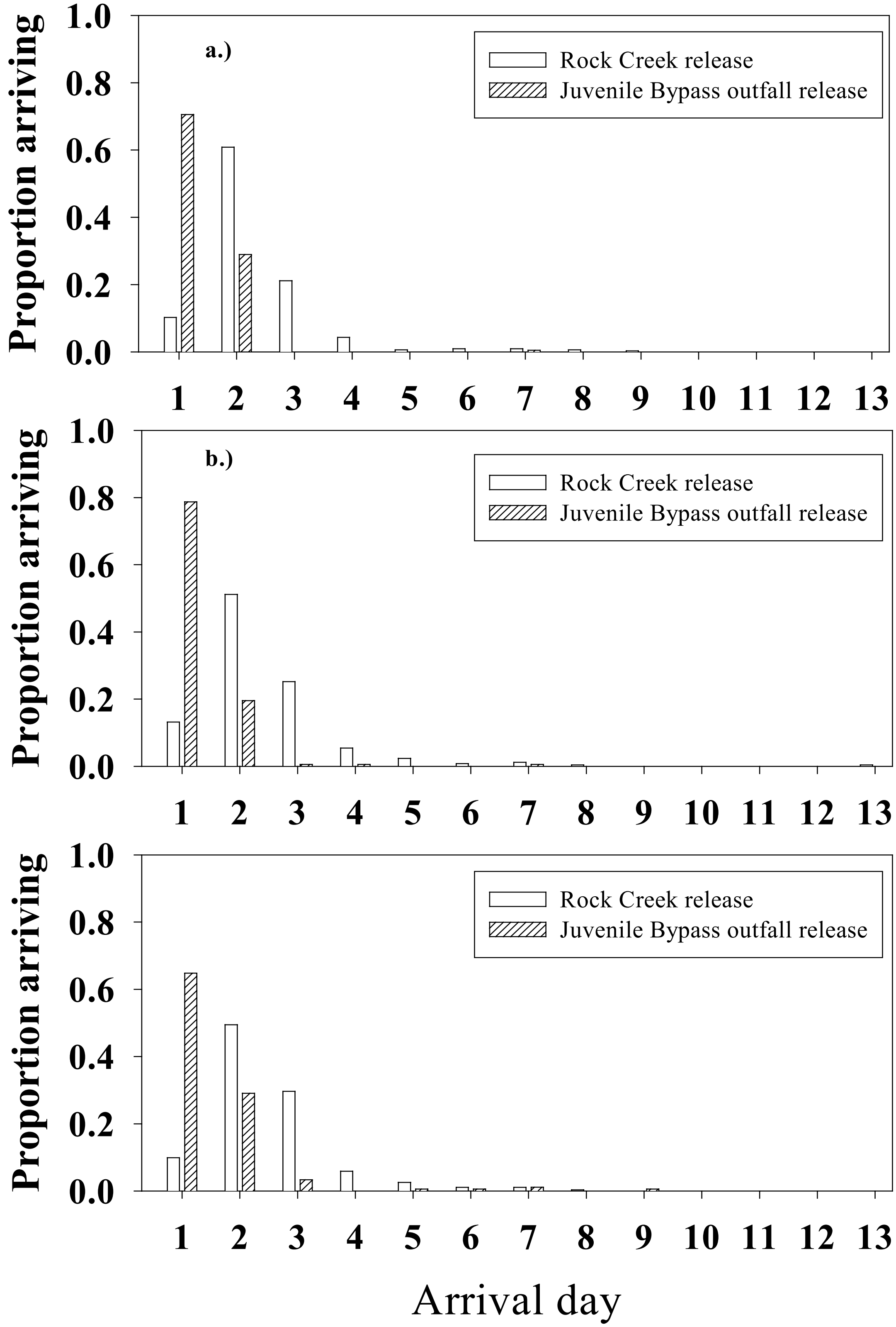

Figure 2. Proportion of spring chinook arriving at a.) The Dalles Dam b.) Bonneville Reservoir detection array c.) Bonneville Dam by arrival day. Arrival day represents the first day fish was contacted at the particular array (e.g., Arrival day = 1) and subsequent days after the first detection event.

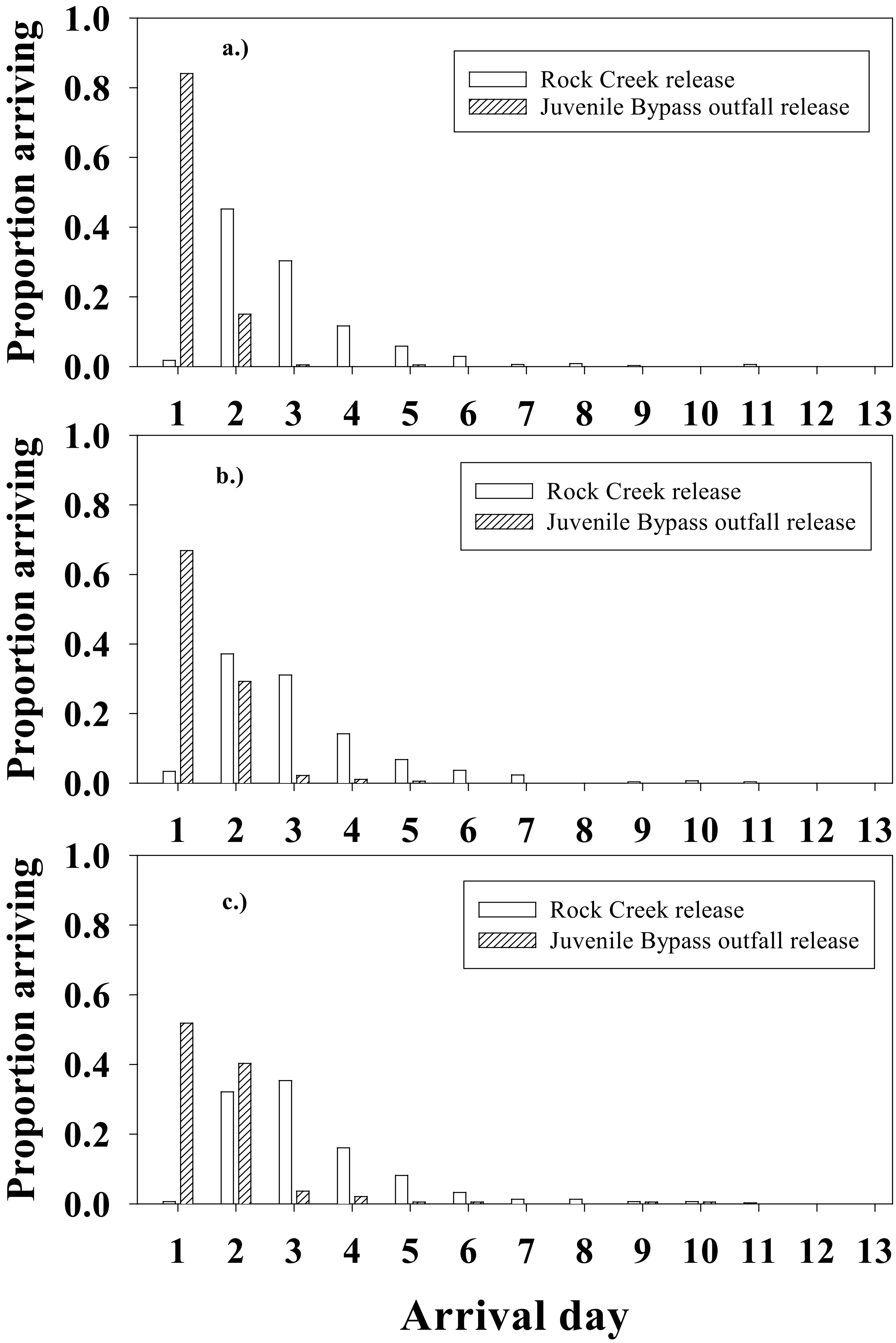

Figure 3. Proportion of steelhead trout arriving at a.) The Dalles Dam b.) Bonneville Reservoir detection array c.) Bonneville Dam by arrival day. Arrival day represents the first day fish was contacted at the particular array (e.g., Arrival day = 1) and subsequent days after the first detection event.

Table 11. Frequency of models selected as a result of evaluating log-liklihood ratio tests that test for differences in survival and capture probabilities between control and treatment groups. Model designations indicate the parameters that control and treatment groups have in common. For instance, model designation lambda indicates that only the product of the capture and survival probabilities in the final river reach were not found to be significantly different between the control and release groups.

	Frequency	
Model	Yearling chinook salmon	Steelhead trout
lambda	0	0
lambda p2	0	1
lambda p2 S2	0	0
lambda p2 S2 p1	8	8
lambda p2 p1	2	2
lambda s2 p1	1	0
lambda p2 S2	1	1
p2 s2 p1	2	2

Table 12. Survival probabilities and 95% confidence interval widths for individual paired releases of yearling chinook salmon and steelhead trout released near Rock Creek, WA and determined to have passed John Day Dam (treatment) and near the John Day Dam juvenile bypass outfall (control).

	Yearling chinook salmon		Steelhead trout	
Release	S	SE	S	SE
1	1.11	0.13	1.04	0.11
2	0.95	0.10	0.80	0.11
3	1.06	0.15	1.33	0.31
4	1.01	0.15	1.09	0.21
5	0.87	0.09	0.83	0.13
6	0.82	0.09	0.92	0.08
7	1.09	0.15	0.90	0.11
8	0.90	0.10	0.82	0.09
9	1.10	0.24	0.76	0.13
10	0.81	0.12	0.88	0.10
11	1.07	0.18	1.08	0.14
12	0.93	0.11	0.93	0.04
13	1.13	0.17	0.96	0.07
14	1.35	0.21	0.91	0.10

Travel times for radio-tagged yearling chinook were significantly less than for PIT-tagged fish for the river reach from Rock Creek to John Day Dam ($P < 0.10$). Conversely, the travel times from John Day to Bonneville Dam were not significantly different ($P > 0.10$). The harmonic mean travel time from Rock Creek to John Day Dam for radio-tagged yearling chinook was 16.9 h (N =416, $Var(\bar{t}_H) = 0.084$) and 22.6 h (N = 68, $Var(\bar{t}_H) = 3.6$) for PIT-tagged fish. From Rock Creek to Bonneville Dam the harmonic mean travel time for radio-tagged yearling chinook was 67.7 h (N=285, $Var(\bar{t}_H) = 1.2$) versus 73.9 h (N=52, $Var(\bar{t}_H) = 14.7$) for the PIT-tagged fish. The differences between the harmonic means of the travel times for the two groups were small (< 7 h) for both reaches.

Discussion

We determined that using radio-tagged yearling chinook and steelhead trout to estimate survival probabilities is feasible and resulted in survival estimates with high precision given the low numbers of fish tagged and released in the 1999 pilot study. 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). Similar to the advantages provided by PIT tags over other marking techniques (Sims and Ossiander 1981, Skalski et al. 1998b), the high detection rates observed in our FY 1999 radio-telemetry studies of migrant salmonids in the lower Columbia River suggest that survival estimates with similar precision to those from PIT tag studies can be generated using relatively small numbers of radio-tagged fish. However, alterations to the release scheme and various tagging protocols used during 1999 are necessary to further ensure that the assumptions of the survival models are satisfied to the greatest extent possible. Also, our results suggest that further evaluation of some of the assumption tests previously used in PIT-tag studies, that typically have lower capture probabilities, is necessary.

The results of the tests of assumptions A5 and A6 do not suggest that upstream detections affected downstream survival and/or detection. After evaluating the results of these tests, we discovered that the reason the tests were largely incalculable was due to the absence of certain capture histories within a particular release. Primarily, the lack of capture histories where fish were not detected at The Dalles Dam detection array but were subsequently detected at the Bonneville Reservoir detection array resulted in most of the incalculable tests. While we will continue to evaluate Burnham tests 2 and 3 in future years, the utility of these tests to discern whether assumptions A5 and A6 have been met appears to be constrained by the high capture probabilities now possible with the radio-telemetry detection arrays currently in use. Since we have constructed detection arrays that span the entire river channel, the possibility that this assumption could be violated if downstream detections were influenced by upstream passage routes is minimized (Skalski 1999a). Also, the lack of handling following initial release of radio-tagged fish also minimizes the risk that upstream detections affect survival (Skalski 1999a).

The release scenarios used during 1999 resulted in significantly different arrival times of treatment and control groups at detection arrays downstream of the release locations. Thus, alterations to the release strategies for future studies will be implemented based on these results. For instance, since we determined that the fish released at the John Day Dam juvenile bypass generally arrived a calendar day earlier than fish released at Rock Creek, releases in the John Day Dam tailrace will be made at a later time to promote mixing of the two groups. We examined the effect of hypothetically altering the release times of the juvenile bypass released fish by arbitrarily stipulating that the releases occurred a day later than they actually were. We determined that by making the tailrace releases a day later, the arrival distributions match more closely than for the original timing of the paired release groups. While the distributions matched more closely, the possibility that the null hypothesis (e.g., There is no statistical difference in arrival times at a particular detection array) may still be rejected due to the sensitivity of the assumption tests. The finding of significant differences does not necessarily indicate a violation of assumption A9 which stipulates that releases (R_1) and (R_2) have the same survival probability in the lower river segment (S_{21}).

Assumption A9 is satisfied if the paired releases mix as they migrate through the second river segment but can also be satisfied if the survival process is stable during passage by the two releases. Under similar flow and spill conditions, a stable survival process should be expected. The results of the sequential model selection process suggest that this may have been true for the majority of our releases despite the differences in arrival times. The results of the sequential model selection process suggest there is little evidence of a synergistic relationship between survival processes in the two river segments (i.e., fish released above the dam that survive the first river segment are no more or less susceptible to mortality in the second river segment than fish released below the dam; Assumption A8).

Further advancements in radio-telemetry technology will continue to improve the applicability of this technology for survival estimation purposes. The first assumption (A1) involves making inferences from the sample to the target population. For instance, if the size of the radio transmitter biases your fish sample to include only larger members of the population, then non-statistical inferences justifying the similarity between the target population and the sample are necessary. In past radio-telemetry studies, the size of the smallest radio transmitters available has resulted in this type of bias. However, recent advancements have led to the development of a coded radio transmitter that is much smaller than the transmitters previously available, which would allow us to include smaller fish in our sample and better represent the target population. The additional assumptions associated with modeling the survival probabilities were likely met through the procedures and protocols used during 1999.

Assumption A2 also regards making inferences to the target population. If tagging has a detrimental effect on survival, then survival estimates from the radio-tagged fish will be negatively biased (i.e., underestimated). However, when calculating relative survival estimates where the survival of treatment fish is expressed relative to the survival of control fish, any bias associated with tagging should cancel out, providing that the bias is the same for both the treatment and control groups. To limit the effects of tagging methods on fish, we have used the criteria established in Adams et al. (1998).

The development of the smaller tags mentioned in the discussion of assumption A1 (above) would further limit the impacts of tagging methods on sample fish.

Assumption A3 stipulates that mortality be negligible in the area near sampling stations so that mortality incorporated into the survival estimates occurs in the river reach in question and not during the sampling event. Our radio-tagged fish spend only a brief amount of time near the antenna array relative to that spent traveling between detection locations. The assumption of independence (A4) implies that the fate of any particular fish does not affect the fate of others. This assumption is common to all tagging studies and in a large system such as the Columbia River, there is no evidence to suggest that individual survival affects other individuals. Violations of A4 have little effect on the point estimate but may bias the variance estimate to be lower than it actually is.

Assumption A7 implies that fish do not lose their tags and thus, are misidentified as dead or not captured, and that dead fish are not incorrectly recorded as alive. Tag loss or radio failure would negatively bias survival estimates. Typically, the retention rate of radio tagging is high suggesting that the effects of tag loss on survival estimates would be minimal. For example, with the exception of one fish that became entangled in a tank structure, Adams et al. (1998) did not report any tag loss for chinook salmon with gastric and surgically implanted transmitters during a 21 d laboratory experiment. Dead fish drifting downstream could result in false-positive detections and upwardly bias survival estimates. However, a prudent selection of detection arrays that are sufficiently spaced would minimize this occurrence. Tagged salmonids eaten by piscivores could conceivably produce false positive detections if the predators move past a detection array. However, Northern pikeminnow (Ptychocheilus oregonensis), the most common predator in the lower Columbia River, tend to remain near dams if tagged there, while fish tagged in mid-reservoir areas occasionally moved considerable distances (Martinelli and Shively 1997). Northern pikeminnow and smallmouth bass (*Micropterus dolomieui*) free-flowing reaches of the Columbia and Snake rivers showed strong site fidelity, except during June when they often moved up small tributaries presumably for spawning (Petersen et al. 2000). During FY 2000, we will make releases of dead radio-tagged fish to evaluate the probability of false-positive detections given the current spacing of the radio-telemetry detection arrays and to determine what adjustments, if any, to the spacing are needed to satisfy this assumption.

Our results indicating that travel times for radio-tagged yearling chinook salmon were less than for PIT-tagged fish are consistent with the results of a recent study examining the differences between the two tagging methods. Hockersmith et al. (2000) in a comparative study of radio and PIT tagged fish released in the Snake River found that travel times of radio-tagged yearling chinook were slightly less than those of PIT-tagged fish. Similar to our findings, Hockersmith et al. (2000) also found statistically significant differences in travel times between the two groups in the reach from the release location to the first detection point and no significant differences in subsequent reaches. Differences in travel times between the two groups were slightly higher than we observed (approximately 14 h) but were small enough to be of questionable biological significance (Hockersmith et al. 2000). The differences we observed may have been caused by the differences in the detection methods for the two tagging groups. Radio-tagged fish are detected as they near the dam whereas PIT-tagged fish must travel through gatewells and bypass channels before they are detected. Thus, the PIT-tag delay could be the combination of 1) delay before gatewell entry, 2) delay in exiting the gatewell, 3) delay at the separator (John Beeman, personal communication). During 2000 we will conduct simultaneous releases with the National Marine Fisheries Service at The Dalles Dam to further examine the relation of survival estimates generated from release-recapture data obtained from fish tagged with PIT and radio-tags.

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