U.S. Army Corps of Engineers
Portland District

Survival Estimates of Migrant Juvenile Salmonids through Bonneville Dam using Radio-Telemetry

Annual Report of Research for 2001

Investigators: Timothy D. Counihan, Katherine J. Felton, Glen Holmberg, and James H. Petersen

United States Geological Survey
Biological Resources Division
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

Submitted: July 10, 2002
Contract No.: W66QKZ10109057

Table of Contents

Table of Contents ii

List of Figures iii

List of Tables v

Executive Summary ix

Introduction 1

Methods 4

Radio-telemetry detection arrays 4

Release locations 4

Collection, transport and tagging 4

Statistical methods 13

Results 17

Burnham Tests 17

Tests of the assumption of mixing of the treatment and control groups 18

Sequential evaluation of log-likelihood tests 30

Releases of dead radio-tagged fish 30

Survival Probability 33

Discussion 34

Acknowledgements 59

References 60

List of Figures

Figure 1. Schematic of estimable capture and survival probabilities (S = survival estimate, p = capture probability, and λ = S · p) from releases through Bonneville Dam and in the tailrace. Dams are represented by rectangles and ovals represent detection arrays. 5

Figure 2. Schematic of estimable capture and survival probabilities (S = survival estimate, p = capture probability, and λ = S · p) from releases through the juvenile bypass system at Bonneville Dam Powerhouse 2 and in the tailrace. Dams are represented by rectangles and ovals represent potential detection arrays. 6

Figure 3. The relation of the survival of yearling Chinook salmon released near Hood River, OR and known to have passed Bonneville Dam and total discharge..... 36

Figure 4. The relation of the survival of yearling Chinook salmon released near Hood River, OR and known to have passed Bonneville Dam and total turbine discharge. 37

Figure 5. The relation of the survival of yearling Chinook salmon released near Hood River, OR and known to have passed Bonneville Dam and total discharge through Bonneville Powerhouse 2. 38

Figure 6. Survival through all routes at Bonneville Dam during the 2001 migration season by release and the percent of discharge as spill during this period. 39

Figure 7. The relation of the survival of yearling Chinook salmon released through the Bonneville Dam powerhouse2 juvenile bypass system and total discharge. 41

Figure 8. The relation of the survival of yearling Chinook salmon released through the Bonneville Dam powerhouse2 juvenile bypass system and total turbine discharge. 42

Figure 9. The relation of the survival of yearling Chinook salmon released through the Bonneville Dam Powerhouse 2 juvenile bypass system and total discharge through Bonneville Dam Powerhouse 2..... 43

Figure 10. The relation of the survival of sub-yearling Chinook salmon released near Hood River, OR and known to have passed any route at Bonneville Dam and total river discharge. 47

Figure 11. The relation of the survival of sub-yearling Chinook salmon released near Hood River, OR and detected passing Bonneville Dam and total turbine discharge. 48

Figure 12. The relation of the survival of sub-yearling Chinook salmon released near Hood River, OR and detected passing Bonneville Dam and total discharge through Bonneville Dam Powerhouse 2..... 49

Figure 13. The relation of the survival of sub-yearling Chinook salmon released into the top of the Bonneville Dam Powerhouse 2 juvenile bypass system and total discharge. .. 51

Figure 14. The relation of the survival of sub-yearling Chinook salmon released into the top of the Bonneville Dam Powerhouse 2 juvenile bypass system and total turbine discharge. 52

Figure 15. The relation of the survival of sub-yearling Chinook salmon released into the top of the Bonneville Dam Powerhouse 2 juvenile bypass system and total discharge through Bonneville Dam Powerhouse 2. 53

List of Tables

Table 1. Release dates and times for paired releases of yearling Chinook salmon at Bonneville Dam, spring 2001. 7

Table 2. Release dates and times for paired releases of sub-yearling Chinook salmon at Bonneville Dam, summer 2001. 8

Table 4. The sample size (N), mean, standard deviation (SD), and range of fork lengths (mm) of yearling Chinook salmon released at Bonneville Dam, spring 2001..... 9

Table 5. The sample size (N), mean, standard deviation (SD), and range of weights (g) of yearling Chinook salmon released at Bonneville Dam, spring 2001..... 10

Table 6. The sample size (N), mean, standard deviation (SD), and range of fork lengths (mm) of sub-yearling Chinook salmon released at Bonneville Dam, summer 2001..... 11

Table 7. The sample size (N), mean, standard deviation (SD), and range of weights (g) of sub-yearling Chinook salmon released at Bonneville Dam, summer 2001..... 12

Table 8. Summary statistics for goodness-of-fit tests (tests 2 and 3, Burnham et al. 1987) for each of 15 paired releases of yearling Chinook, spring 2001. Treatment fish were released in the Bonneville reservoir at Hood River, OR and were detected at Bonneville Dam and control fish were released in the Bonneville Dam tailrace..... 19

Table 9. 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 2001. Treatment fish were released at the top of the juvenile bypass at Bonneville Dam Powerhouse 2 and control fish were released in the Bonneville Dam tailrace..... 20

Table 10. Summary statistics for goodness-of-fit tests (tests 2 and 3, Burnham et al. 1987) for each of 15 paired releases of yearling Chinook, spring 2001. Treatment fish were released in the Bonneville reservoir at Hood River, OR and passed through the turbines at Bonneville Dam and control fish were released in the Bonneville Dam tailrace..... 21

Table 11. Summary statistics for goodness-of-fit tests (tests 2 and 3, Burnham et al. 1987) for each of 15 paired releases of yearling Chinook, spring 2001. Treatment fish were released in the Bonneville reservoir at Hood River, OR and passed through non-turbine routes at Bonneville Dam and control fish were released in the Bonneville Dam tailrace..... 22

Table 12. Summary statistics for goodness-of-fit tests (tests 2 and 3, Burnham et al. 1987) for each of 12 paired releases of sub-yearling Chinook, summer 2001. Treatment fish were released in the Bonneville reservoir at Hood River, OR and were detected at Bonneville Dam and control fish were released in the Bonneville Dam tailrace. 23

Table 13. Summary statistics for goodness-of-fit tests (tests 2 and 3, Burnham et al. 1987) for each of 12 paired releases of sub-yearling Chinook, summer 2001. Treatment fish were released at the top of the juvenile bypass at Bonneville Dam Powerhouse 2 and control fish were released in the Bonneville Dam tailrace. 24

Table 14. The results of chi-square tests testing for similarities of arrival times between yearling Chinook salmon released near Hood River, OR that are know to have passed Bonneville Dam (treatment group) and in the tailrace of Bonneville Dam (control group) at radio-telemetry arrays at river kilometers 200, 194 and 181 below Bonneville Dam. . 25

Table 15. The results of chi-square tests testing for similarities of arrival times between yearling Chinook salmon released at the top of Powerhouse 2 juvenile bypass (treatment group) and in the tailrace of Bonneville Dam (control group) at radio-telemetry arrays at river kilometers 200, 194, and 181 below Bonneville Dam. 26

Table 16. The results of chi-square tests of yearling Chinook salmon released near Hood River, OR passing Bonneville Dam via Powerhouse 2 turbines, and detected at radio-telemetry arrays at river kilometers 200, 194, and 181 below Bonneville Dam. 27

Table 17. The results of chi-square tests of yearling Chinook salmon released near Hood River, OR passing Bonneville Dam via non-turbine routes and detected at radio-telemetry arrays at river kilometers 200, 194, and 181 below Bonneville Dam..... 28

Table 18. The results of chi-square tests of homogeneity testing for similarity in arrival times of paired releases of sub-yearling Chinook salmon released near Hood River, OR and known to have passed Bonneville Dam (treatment group) and in the tailrace of Bonneville Dam (control group) and detected at radio-telemetry arrays at river kilometers 200, 194, and 181..... 29

Table 19. The results of chi-square tests of homogeneity testing for similarity in arrival times of paired releases of sub-yearling Chinook salmon released at the top of the Bonneville Dam Powerhouse 2 juvenile bypass system (treatment group) and in the tailrace of Bonneville Dam (control group) and detected at radio-telemetry arrays at river kilometers 200, 194 and 181..... 29

Table 20. Frequency of models selected as a result of evaluating log-likelihood ratio tests that test for differences in survival and capture probabilities between control and treatment groups of paired releases of yearling Chinook salmon. Model designations indicate the parameters that control and treatment groups have in common. For instance, model designation lambda p2 s2 p1 indicates that all the survival and capture probabilities were found not to be significantly different between the control and release groups. Model designation CJS refers to Cormack-Jolly-Seber model estimates that assume all estimated parameters were different for the treatment and control groups. In all cases, use of the CJS models resulted from computational constraints (e.g., variance estimates incalculable) associated with the SURPH software program and do not indicate that all parameters were tested and found to be significantly different. 31

Table 21. Frequency of models selected as a result of evaluating log-likelihood ratio tests that test for differences in survival and capture probabilities between control and treatment groups of paired releases of yearling Chinook salmon known to have passed via turbine and non-turbine routes at Bonneville Dam. Model designations indicate the parameters that control and treatment groups have in common. For instance, model designation lambda p2 s2 p1 indicates that all the survival and capture probabilities were found not to be significantly different between the control and release groups. Model designation CJS refers to Cormack-Jolly-Seber model estimates that assume all estimated parameters were different for the treatment and control groups. In all cases, use of the CJS models resulted from computational constraints (e.g., variance estimates incalculable) associated with the SURPH software program and do not indicate that all parameters were tested and found to be significantly different. 31

Table 22. Frequency of models selected as a result of evaluating log-likelihood ratio tests that test for differences in survival and capture probabilities between control and treatment groups of paired releases of sub-yearling Chinook salmon. Model designations indicate the parameters that control and treatment groups have in common. For instance, model designation lambda p2 s2 p1 indicates that all the survival and capture probabilities were found not to be significantly different between the control and release groups. Model designation CJS refers to Cormack-Jolly-Seber model estimates that assume all parameters were different. In all cases, use of the CJS models resulted from computational constraints (e.g., variance estimates incalculable) associated with the SURPH software program and do not indicate that all parameters were tested and found to be significantly different. 32

Table 23. Survival probabilities and associated standard errors for yearling Chinook salmon passing via all routes at Bonneville Dam based on paired releases of yearling Chinook released near Hood River, OR and known to have passed Bonneville Dam and in the tailrace of Bonneville Dam downriver of the Powerhouse 2 juvenile bypass. 35

Table 24. Survival probabilities and associated standard errors for yearling Chinook salmon passing via the Powerhouse 2 (PH 2) juvenile bypass system based on paired releases of yearling Chinook released through the juvenile bypass at Powerhouse 2 and in the tailrace of Bonneville Dam downriver of the Powerhouse 2 juvenile bypass. 40

Table 25. Survival probabilities and associated standard errors for yearling Chinook salmon passing through turbines at Bonneville Dam under spill and no spill conditions. Survival is based on paired releases of yearling Chinook released near Hood River, OR and known to have passed Bonneville Dam via the turbines, and in the tailrace of Bonneville Dam downriver of the Powerhouse 2 juvenile bypass. 44

Table 26. Survival probabilities and associated standard errors for yearling Chinook salmon passing through non-turbine routes at Bonneville Dam under spill and no spill conditions. Survival is based on paired releases of yearling Chinook released near Hood River, OR and known to have passed Bonneville Dam via non-turbine routes, and in the tailrace of Bonneville Dam downriver of the Powerhouse 2 juvenile bypass. 45

Table 27. Survival probabilities and associated standard errors for sub-yearling Chinook salmon passing via all routes at Bonneville Dam based on paired releases of sub-yearling Chinook released near Hood River, OR and known to have passed Bonneville Dam and in the tailrace of Bonneville Dam downriver of the Powerhouse 2 juvenile bypass. 46

Table 28. Survival probabilities and associated standard errors for sub-yearling Chinook salmon passing via the Powerhouse 2 (PH 2) juvenile bypass system based on paired releases of sub-yearling Chinook released though the juvenile bypass at Powerhouse 2 and in the tailrace of Bonneville Dam downriver of the Powerhouse 2 juvenile bypass. 50

Table 29. Correlation matrix for total river discharge, total Powerhouse 2 (PH2) discharge, and total turbine discharge present during paired releases of sub-yearling Chinook released through the Powerhouse 2 juvenile bypass system during the summer migration 2001. 54

Table 30. The discharge and water temperature conditions of treatment (released near Hood River, OR and detected at Bonneville Dam) and control (released below the Powerhouse 2 juvenile bypass outfall) groups of sub-yearling Chinook salmon where significant differences in arrival times were indicated. 56

Executive Summary

During 2001, we estimated the survival of yearling and sub-yearling Chinook salmon at Bonneville Dam. The survival of paired releases of radio-tagged fish was evaluated using the paired release-recapture models of Burnham et al. (1987) that produce estimates that depict the survival of treatment (released above the project) groups in relation to control (released in the tailrace of the project) groups. The original objectives for the 2001 survival evaluation at Bonneville Dam were altered because of the low water conditions present during 2001. The scaled back objectives were to provide estimates of survival for fish passing via all routes at Bonneville Dam and to provide estimates of the survival of fish passing through the juvenile bypass system at Powerhouse 2.

The evaluation of the assumptions associated with the survival models used during these studies indicated that in general, the assumptions were satisfied. Similar to the survival evaluation during 1999 and 2000, the results of Burnham tests 2 and 3, that test the assumptions that upstream or downstream detections affect downstream survival and/or detection and whether upstream capture histories affect downstream survival and/or capture, were largely incalculable. We will continue to evaluate Burnham tests 2 and 3 in future years however; the utility of these tests to discern whether these assumptions have been met is confounded by the high capture probabilities now possible with the radio-telemetry detection arrays

Few differences in the arrival times of the treatment and control groups were detected. In those cases where we observed differences, we further examined the differences in river discharge and temperature conditions present during the passage of the treatment and control groups at the radio-telemetry arrays below Bonneville Dam and found that for most releases, the conditions were similar. The exception being a paired release group that passed Bonneville Dam on the Fourth of July. We hypothesize this result was due to atypical discharge conditions presumably due to decreased electricity demand on this holiday.

Releases of dead radio-tagged yearling and sub-yearling Chinook salmon at Bonneville Dam indicated that it was possible that dead fish may have been detected at the downriver radio-telemetry arrays. One dead radio-tagged yearling Chinook salmon was detected at all of the three radio-telemetry detection arrays below Bonneville Dam and one dead radio-tagged sub-yearling Chinook salmon was detected at the first radio-telemetry detection array below Bonneville Dam. False positive-detections from radio tags on dead fish may positively bias survival estimates (Skalski et al. 1998a). We reviewed and altered our operating procedures for performing this task during 2002; no dead radio-tagged fish were detected during 2002.

The survival of yearling Chinook salmon passing via all routes at Bonneville Dam was evaluated using paired releases made at Bonneville Dam (based on detections at Bonneville Dam of fish released near Hood River, OR) and in the tailrace of Bonneville

Dam. The survival probabilities ranged from 0.85 to 1.05. The average dam survival at Bonneville Dam for yearling Chinook salmon was estimated to be 0.937 (SE = 0.014). Dam survival during the day was estimated to be 0.923 (SE = 0.024) and night survival was estimated to be 0.949 (SE = 0.016). No significant differences were detected between day and night dam survival (one-tailed t-test, P = 0.19) but the power associated with this test was low ($1 - \beta = 0.22$). No significant relations were detected (linear regression, $P > 0.10$) between the dam survival of yearling Chinook salmon and total river discharge total turbine discharge, or total powerhouse discharge. Because of the low water year during 2001, appreciable spill at Bonneville Dam occurred during only the last 7 releases during the spring migration evaluation and allowed a comparison of the survival of yearling Chinook passing Bonneville Dam during periods of spill and no spill. Prior to the initiation of spill at Bonneville Dam, the survival of yearling Chinook passing through all routes at the project was 0.928 (n = 8, SE = 0.023) and after spill was initiated was 0.946 (n = 7, SE = 0.015). The survival for yearling Chinook salmon passing Bonneville Dam before and after spill was initiated was not statistically different (one tailed t-test, P = 0.27). However, the power associated with this test was low ($1 - \beta$ = 0.14).

Survival for yearling Chinook salmon released through the Powerhouse 2 juvenile bypass system (JBS) ranged from 0.78 to 1.1. The average survival probability through the JBS was estimated to be 0.962 (SE = 0.023). Survival through the juvenile bypass system during the day was estimated to be 0.953 (SE = 0.039) and night survival was estimated to be 0.971 (SE = 0.027). No significant differences were detected between day and night survival through the JBS (one tailed t-test, P = 0.35) with power ($1 - \beta = 0.10$). Similar to the results for dam survival, no significant relations were detected (linear regression, $P > 0.10$) between the juvenile bypass survival of yearling Chinook salmon and total river discharge, total turbine discharge, or total powerhouse discharge.

We separated the yearling Chinook paired releases groups (e.g., released near Hood River and detected at Bonneville Dam and in the tailrace of Bonneville Dam) into turbine passed and non-turbine passed fish. The survival of turbine passed fish ranged from 0.83 to 1.07. The average survival for turbine passed yearling Chinook was 0.929 (SE = 0.02). For non-turbine passed fish, survival probabilities ranged from 0.82 to 1.03. The average survival for non-turbine passed yearling Chinook was 0.937 (SE = 0.02). For turbine passed yearling Chinook, the average survival of fish passing during periods of spill was 0.900 (SE = 0.032) and during periods of no spill was 0.954 (SE = 0.024). The survival of turbine passed yearling Chinook passing during periods of spill and no spill were marginally significantly different (one-tailed t-test, P = 0.098) at an alpha level of 0.10. The average survival of non-turbine passed fish during periods of spill was 0.96 (SE = 0.018) and for periods of no spill was 0.91 (SE = 0.029). The difference between the average survival levels during periods of spill and no spill for non-turbine passed fish was found to be significantly different (one-tailed t-test, P = 0.086).

The dam survival of sub-yearling Chinook salmon passing via all routes at Bonneville Dam was based on the same release locations as those used for yearling Chinook salmon. The dam survival of sub-yearling Chinook salmon ranged from 0.73 to

1.08. The average dam survival probability was 0.902 (*SE* = 0.036). The average dam survival during day releases was estimated to be 0.895 (*SE* = 0.044) and during night releases was 0.910 (*SE* = 0.066). No significant differences between day and night dam survival were detected (one-tailed t-test, $P = 0.42$). No significant relations (linear regression, $P > 0.10$) between total river discharge, total turbine discharge, and total Powerhouse 2 discharge were detected.

Sub-yearling Chinook salmon were also released through the Powerhouse 2 juvenile bypass system (JBS) during 2001. Sub-yearling Chinook salmon JBS survival ranged from 0.62 to 1.28. The average JBS survival was estimated to be 0.90 (*SE* = 0.053). The average JBS survival for the day releases was estimated to be 0.870 (*SE* = 0.089) and for night releases was 0.946 (*SE* = 0.0374). The average survival estimates were not found to be significantly different between day and night releases (variance weighted one-tailed t-test, $P = 0.23$). Significant relations (linear regression, $P < 0.1$) between total river discharge, total turbine discharge, and total Powerhouse 2 discharge were detected.

Spill operations at Bonneville Dam were present during the last seven paired releases of yearling Chinook allowing post-hoc comparisons to be made between fish arriving during spill and no spill operations. No significant differences between the survival of fish passing via all routes at Bonneville Dam during spill and no spill operations were detected. However, when the paired releases were separated into turbine and non-turbine passed fish, there were significant differences in survival between fish passed during spill and no spill operations. The survival of yearling Chinook passing via the turbines was greater during periods of no spill versus spill operations while the opposite was true for non-turbine passed fish (e.g., survival was greater during periods of spill v. no spill operations). The opposite trends in survival between these two groups likely contributed to the insignificant difference in the survival of fish passing via all routes at Bonneville Dam during spill and no spill.

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. 1996, Smith et al. 1998, Hockersmith et al. 2000). 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.

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 and evaluated 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, NMFS 2001). During 2001, tests of the efficacy of different spill scenarios were slated to be conducted at Bonneville, John Day, and The Dalles Dams. However, due to the low water year experienced during 2001 most of the planned evaluations were not conducted because of the absence of spill at the projects originally targeted for evaluation. The motivation for conducting these evaluations was to identify which spill scenario will increase FPE 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. Also, to reduce predation associated with the old juvenile bypass outfall at Powerhouse 2, Bonneville Dam, a new Bonneville Dam juvenile bypass system and outfall became operational during 1999. Other actions designed to increase the survival of migrant salmonids as they migrate through projects in the lower Columbia River continue to be implemented. 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. 1996, Skalski et al. 1998, 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 relatively 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. 1997) and to monitor the behavior and passage routes of yearling and sub-yearling 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). 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. 1998), the high detection rates observed in radio-telemetry studies of migrant salmonids in the lower Columbia River suggest that the numbers of fish necessary to generate survival estimates with similar or greater precision could be reduced using radio-tagged fish. Recent technological advancements in radio telemetry equipment have also decreased the size, increased the life of transmitters, and eliminated many of the past problems associated with using this technique. Further, in areas where PIT-tag survival estimates continue to be calculated, the use of radio telemetry would provide a means of cross-validating these estimates using a different technique. 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 (Noah Adams, Eric Hockersmith, personal communication). 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 for yearling Chinook salmon.

In the National Marine Fisheries Service (NMFS) Federal Columbia River Power System (FCRPS) Biological Opinion (NMFS 2001), certain hydropower system actions have been proposed to improve the passage survival of in-river migrants through FCRPS dams and reservoirs. Included in these actions are enhanced spill and spillway improvements to facilitate higher spill levels without exceeding harmful TDG levels, improved flow management, physical improvements to both juvenile and adult fish passage facilities, and continuation of spill at collector projects to maximize survival rates of in-river migrants. The dam passage survival rate at Bonneville Dam is currently at an unacceptable level and thus, has been designated as a high priority for improvements (NMFS 2001). Specific dam operation measures for Bonneville Dam have

been described in the biological opinion including 24-hour spill with nighttime spill limited to the TDG cap and daytime spill limited to 75 kcfs for adult passage. Evaluations of survival during these different dam operations will therefore assist managers in determining the efficacy of the actions at improving the survival of in-river migrants. During 2001, we used radio-tagged yearling and sub-yearling Chinook salmon fish and radio detection arrays to generate survival estimates at Bonneville Dam, including dam survival and survival through the juvenile bypass system at Powerhouse 2. Estimates of spill survival were not generated because of the general lack of this dam operation condition at Bonneville Dam during 2001.

Methods

Radio-telemetry detection arrays

Radio-telemetry detection arrays were established at Bonneville Dam and also below Bonneville Dam at river kilometers 200, 194 and 181. Release and detection schemes used during 2001 are depicted in Figure 1 and Figure 2. The arrays at Bonneville dam spanned the breadth of the river channel and were set up so that passage through various routes of passage could be determined (Evans et al. 2001). Each array below Bonneville Dam was comprised of multiple antenna and receiver locations typically placed on channel markers so that fish passing through most of the river channel could be detected.

Release locations

Treatment groups were released mid-channel at river kilometer 276, near Hood River, OR and into the top of the Bonneville Dam Powerhouse 2 juvenile bypass system. The juvenile bypass releases were made at the north end of the Powerhouse 2 downstream salmonid migrant channel (DSM) where the dewatering unit is located, just upstream of the mouth of the Juvenile Bypass System conveyance pipe. Control fish were released mid-channel at river kilometer 232, near, but down river of, the outfall of the Bonneville Dam Powerhouse 2 Juvenile Bypass System conveyance pipe.

Collection, transport and tagging

Fish collection, transportation, tagging, holding, and release protocols are described in Evans et al. 2001. The yearling Chinook salmon releases at Bonneville Dam consisted of 15 releases in Bonneville Reservoir near Hood River, OR and 16 releases into the Powerhouse 2 juvenile bypass at Bonneville Dam that were grouped with 16 releases made in the Bonneville Dam tailrace to form the 15 Bonneville Dam and 16 juvenile bypass paired releases evaluated (see Table 1). The sub-yearling Chinook releases at Bonneville Dam consisted of 12 releases in the Bonneville Reservoir and 12 releases into the Powerhouse 2 juvenile bypass at Bonneville Dam that were grouped with 12 releases made in the Bonneville Dam tailrace to form the 12 paired releases evaluated (see Table 2). For the releases made near Hood River, OR fish were released and then interrogated at Bonneville Dam and based on these detections, we formulated release groups based on their presence or absence and also their route of passage at this project (see Figure 1). A total of 649 yearling Chinook salmon released in the Bonneville Reservoir at Hood River, 341 yearling Chinook salmon released into the Powerhouse 2 juvenile bypass at Bonneville Dam, and 336 yearling Chinook salmon released into the Bonneville Dam tailrace were included in these analyses (see Table 3 and Table 4). A total of 304 sub-yearling Chinook salmon released in the Bonneville Reservoir at Hood River, 292 sub-yearling Chinook salmon released into the Powerhouse 2 juvenile bypass at Bonneville Dam, and 291 sub-yearling Chinook salmon released into the Bonneville Dam tailrace were included in these analyses (see Table 5 and Table 6).

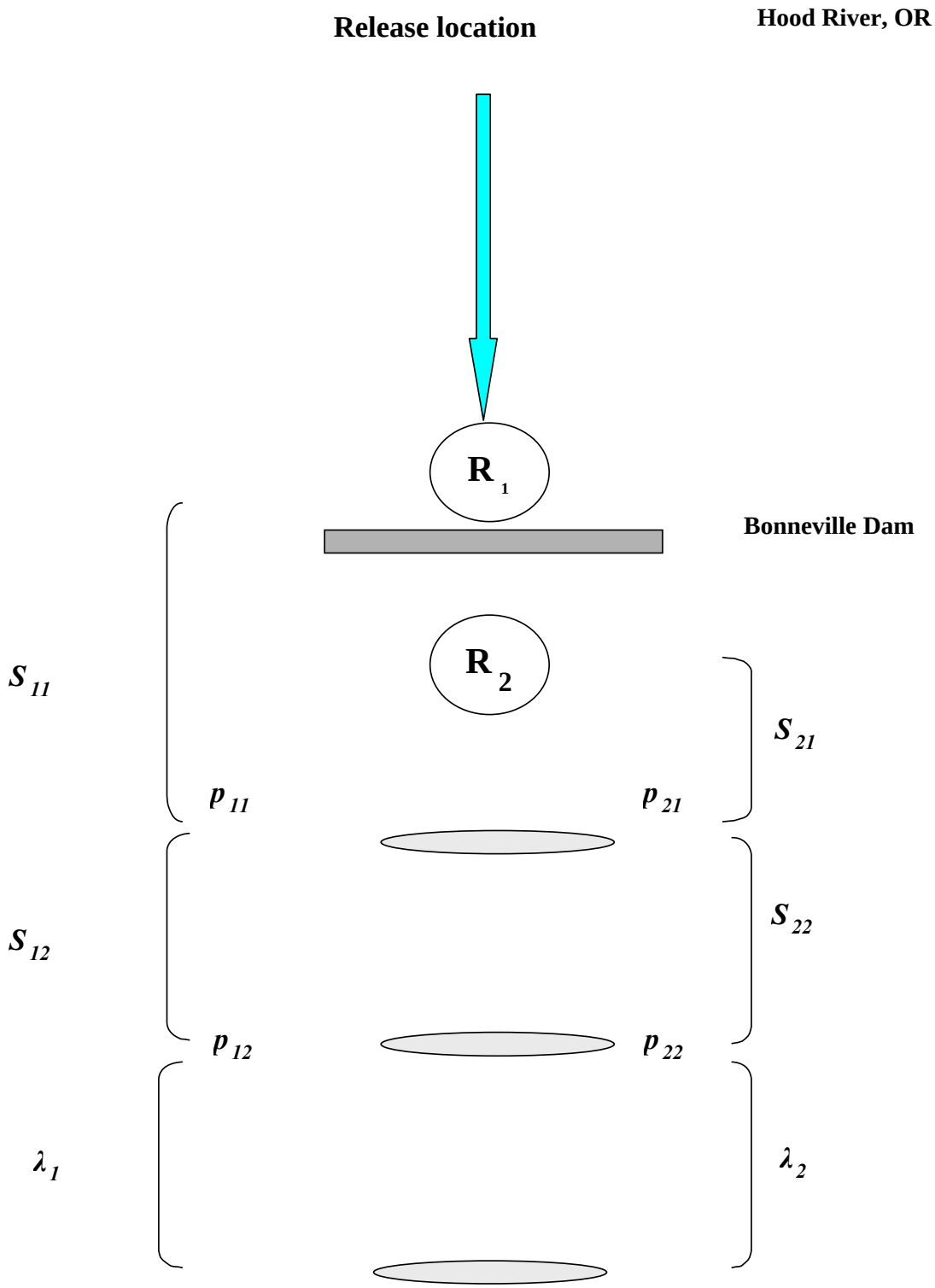

Figure 1. Schematic of estimable capture and survival probabilities (S = survival estimate, p = capture probability, and λ = S · p) from releases through Bonneville Dam and in the tailrace. Dams are represented by rectangles and ovals represent detection arrays.

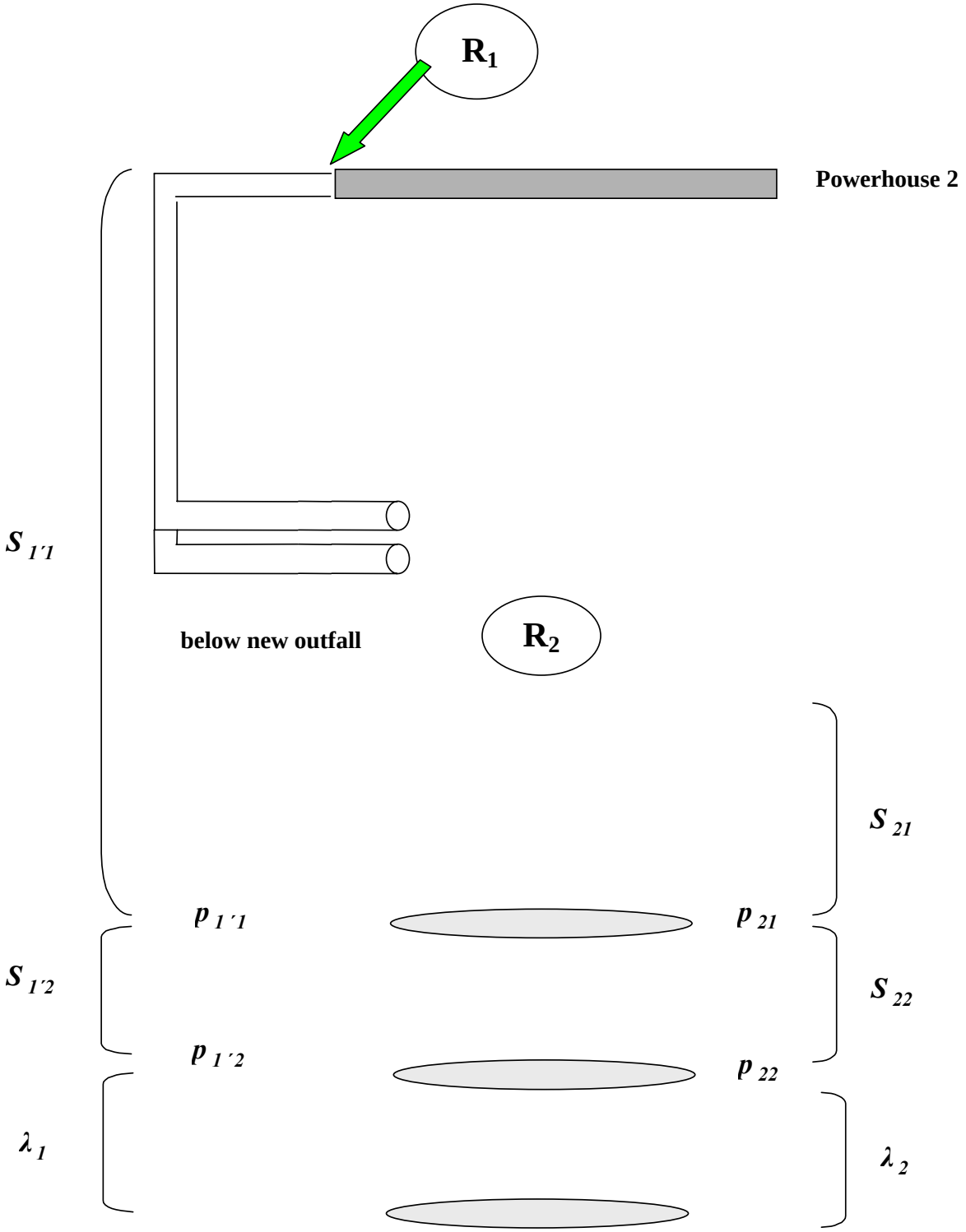

Figure 2. Schematic of estimable capture and survival probabilities (S = survival estimate, p = capture probability, and λ = S · p) from releases through the juvenile bypass system at Bonneville Dam Powerhouse 2 and in the tailrace. Dams are represented by rectangles and ovals represent potential detection arrays.

Table 1. Release dates and times for paired releases of yearling Chinook salmon at Bonneville Dam, spring 2001.

Paired Release	Bonneville Reservoir		Powerhouse 2 Juvenile Bypass		Bonneville Dam Tailrace	
	Date	Time	Date	Time	Date	Time
1	5/01/01	11:04	5/01/01	21:33	5/01/01	22:30
2	5/02/01	22:38	5/03/01	09:56	5/03/01	10:45
3	5/05/01	10:20	5/05/01	22:02	5/05/01	22:32
4	5/06/01	22:10	5/07/01	10:01	5/07/01	10:48
5	5/09/01	10:09	5/09/01	22:00	5/09/01	22:45
6	5/10/01	22:00	5/11/01	10:00	5/11/01	10:45
7	5/13/01	10:00	5/13/01	22:00	5/13/01	23:10
8	5/14/01	22:00	5/15/01	10:00	5/15/01	10:46
9	5/17/01	10:00	5/17/01	22:08	5/17/01	22:55
10	5/18/01	22:08	5/19/01	10:00	5/19/01	10:35
11	5/21/01	10:08	5/21/01	22:01	5/21/01	23:03
12	5/22/01	22:00	5/23/01	10:00	5/23/01	10:45
13	5/25/01	22:08	5/26/01	10:00	5/26/01	10:41
14	5/28/01	[a]	5/28/01	10:00	5/28/01	10:41
15	5/29/01	10:00	5/29/01	21:01	5/29/01	22:41
16	5/30/01	10:02	5/30/01	22:02	5/30/01	22:51

[a] –No release at this location on this date.

Table 2. Release dates and times for paired releases of sub-yearling Chinook salmon at Bonneville Dam, summer 2001.

Paired Release	Bonneville Reservoir		Powerhouse 2 Juvenile Bypass		Bonneville Dam Tailrace	
	Date	Time	Date	Time	Date	Time
1	7/01/01	10:00	7/01/01	22:00	7/01/01	23:30
2	7/02/01	22:00	7/03/01	09:45	7/03/01	10:30
3	7/04/01	10:00	7/04/01	21:30	7/04/01	22:45
4	7/05/01	22:00	7/06/01	10:00	7/06/01	10:30
5	7/07/01	10:30	7/07/01	22:00	7/07/01	22:45
6	7/08/01	22:05	7/09/01	09:55	7/09/01	11:15
7	7/10/01	10:05	7/10/01	22:05	7/10/01	22:45
8	7/11/01	21:30	7/12/01	09:00	7/12/01	10:00
9	7/12/01	21:08	7/13/01	08:55	7/13/01	09:41
10	7/13/01	21:15	7/14/01	09:00	7/14/01	10:15
11	7/14/01	21:15	7/15/01	09:15	7/15/01	10:15
12	7/19/01	10:15	7/19/01	21:00	7/19/01	22:15

Table 3. The sample size (N), mean, standard deviation (SD), and range of fork lengths (mm) of yearling Chinook salmon released at Bonneville Dam, spring 2001.

Paired	Boneville Reservoir				Powerhouse 2 Juvenile Bypass				Bonneville Tailrace			
Release	N	Mean	SD	Range	N	Mean	SD	Range	N	Mean	SD	Range
1	68	164	22	129-218	21	154	24	130-230	20	155	19	132-190
2	66	158	17	132-208	21	154	47	128-185	19	154	15	137-185
3	81	152	16	129-228	22	154	15	135-181	23	166	20	139-211
4	81	160	18	133-216	21	157	14	135-187	25	166	23	138-219
5	75	151	11	130-184	23	150	14	130-185	23	155	14	138-187
6	77	149	10	130-178	23	150	13	132-180	22	147	13	130-188
7	49	150	12	129-190	20	146	11	131-170	21	153	12	136-176
8	76	150	11	134-196	22	148	9	130-167	19	150	11	131-182
9	82	150	12	132-190	25	148	9	128-168	24	151	13	129-192
10	72	152	12	129-195	24	158	11	140-181	27	157	15	134-205
11	70	155	14	133-204	19	160	19	139-212	17	160	14	131-193
12	42	161	18	134-202	22	160	17	137-205	22	164	18	135-210
13	37	172	24	135-223	21	169	17	142-198	20	172	24	142-216
14	[a]	[a]	[a]	[a]	18	160	16	137-198	17	166	20	131-195
15	20	160	20	133-200	19	164	24	135-215	19	169	19	144-212
16	39	158	21	128-203	20	157	20	139-200	18	164	18	136-200
Overall	935	155	17	128-228	341	155	17	128-230	336	159	18	129-219

[a] –No release at this location on this date.

Table 4. The sample size (N), mean, standard deviation (SD), and range of weights (g) of yearling Chinook salmon released at Bonneville Dam, spring 2001.

Paired	Bonneville Reservoir				Powerhouse 2 Juvenile Bypass				Bonneville Tailrace			
Release	N	Mean	SD	Range	N	Mean	SD	Range	N	Mean	SD	Range
1	68	51.2	22.3	23.3-124.1	21	42.5	25.7	25.6-141.6	20	43.3	17.9	23.3 - 86.0
2	66	43.4	16.1	23.8-100.9	21	41.3	14.4	25.1 - 73.0	19	41.2	13.9	26.6 - 76.6
3	81	39.1	15.5	22.0-139.8	22	39.7	12.1	27.0 - 66.6	23	50.4	19.0	28.0 - 99.0
4	81	44.8	15.5	23.7-107.3	21	41.3	11.2	26.9 - 68.3	25	51.1	24.2	27.5-119.8
5	75	37.3	8.6	24.1 - 70.3	23	36.4	11.6	23.7 - 68.9	23	40.3	14.0	27.5 - 83.4
6	77	35.6	7.5	23.7 - 60.0	23	35.4	8.0	26.7 - 54.8	22	34.4	11.4	24.2 - 76.4
7	49	36.2	9.4	22.3 - 80.4	20	32.6	6.8	24.1 - 46.3	21	37.8	8.7	27.3 - 61.0
8	76	36.8	8.9	25.7 - 80.4	22	34.8	6.0	24.9 - 46.5	19	36.2	8.5	24.3 - 61.7
9	82	35.8	8.9	24.8 - 67.2	25	35.6	6.7	23.2 - 48.4	24	36.6	8.5	23.4 - 62.8
10	72	39.0	10.7	23.0 - 88.6	24	41.9	8.3	29.9 - 63.0	27	42.1	13.2	25.8 - 96.1
11	70	40.6	11.8	27.3 - 85.5	19	42.2	17.0	26.3 - 95.8	17	43.0	12.3	23.5 - 74.5
12	42	45.1	16.1	26.8 - 88.7	22	42.8	14.1	26.5 - 83.6	22	46.6	16.9	30.1-100.1
13	37	57.1	24.4	28.3-127.4	21	49.6	14.4	30.4 - 77.0	20	56.0	27.0	27.9-115.4
14	[a]	[a]	[a]	[a]	18	41.3	14.2	25.5 - 78.6	17	47.3	15.8	26.9 - 77.8
15	20	41.8	16.0	24.0 - 81.1	19	46.3	21.4	24.2 - 95.6	19	49.4	18.9	29.9 - 99.5
16	39	40.5	17.2	21.8 - 92.6	20	38.7	16.2	23.9 - 74.5	18	44.5	14.2	24.1 - 73.5
Overall	935	40.9	14.9	21.8-139.8	341	40.0	14.2	23.2-141.6	336	43.7	16.9	23.3-119.8

[a] –No release at this location on this date.

Table 5. The sample size (N), mean, standard deviation (SD), and range of fork lengths (mm) of sub-yearling Chinook salmon released at Bonneville Dam, summer 2001.

Paired	Bonneville Reservoir				Powerhouse 2 Juvenile Bypass				Bonneville Tailrace			
Release	N	Mean	SD	Range	N	Mean	SD	Range	N	Mean	SD	Range
1	50	121	5	115-140	21	120	4	115-128	18	122	6	115-138
2	50	123	10	113-162	14	126	9	115-146	18	120	4	115-131
3	52	122	7	115-145	24	121	7	115-136	25	123	8	115-148
4	51	120	5	115-141	32	121	9	115-156	19	121	10	115-151
5	49	119	8	115-159	25	121	8	115-151	25	118	5	115-131
6	57	122	7	115-142	25	120	6	115-136	36	121	5	115-132
7	52	121	5	115-136	26	121	5	115-135	25	122	7	115-141
8	50	121	6	115-139	25	120	6	115-134	25	123	7	115-144
9	53	124	6	115-143	25	126	5	119-140	25	125	7	116-141
10	50	124	6	116-145	21	126	9	118-161	25	123	4	116-133
11	56	124	5	117-141	28	122	6	115-145	23	121	3	117-128
12	55	123	5	115-142	26	121	4	116-132	27	123	6	115-143
Overall	625	122	7	113-162	292	122	7	115-161	291	122	6	115-151

Table 6. The sample size (N), mean, standard deviation (SD), and range of weights (g) of sub-yearling Chinook salmon released at Bonneville Dam, summer 2001.

Paired	Bonneville Reservoir				Powerhouse 2 Juvenile Bypass				Bonneville Tailrace			
Release	N	Mean	SD	Range	N	Mean	SD	Range	N	Mean	SD	Range
1	50	20.4	2.8	16.3-32.8	21	20.5	2.4	15.6-24.9	18	21.8	2.8	17.9-28.6
2	50	22.2	6.3	15.2-53.3	14	23.3	5.5	16.2-36.9	18	20.8	2.6	17.8-26.6
3	52	21.5	4.1	16.3-37.5	24	19.8	3.9	16.0-30.1	25	20.7	4.9	15.9-36.5
4	51	20.3	3.1	16.1-32.6	32	21.3	5.2	15.4-40.5	19	20.9	5.7	15.8-37.7
5	49	19.7	4.3	14.4-38.9	25	21.3	5.3	16.0-42.3	25	18.3	3.6	15.0-27.9
6	57	21.3	4.2	15.3-34.9	25	20.1	3.6	14.9-28.8	36	19.6	3.0	15.3-26.2
7	52	19.7	3.2	15.8-29.2	26	20.3	3.0	16.1-26.0	25	21.2	4.4	16.4-31.5
8	50	20.0	3.5	14.5-29.1	25	19.8	3.9	13.4-28.5	25	20.6	4.4	15.0-31.8
9	53	20.4	5.1	15.3-46.5	25	20.8	3.0	16.2-26.6	25	21.5	3.9	17.5-31.2
10	50	19.7	3.7	13.6-34.2	21	20.9	4.7	14.0-38.1	25	19.6	2.8	15.3-27.9
11	56	19.8	2.9	16.1-28.7	28	19.5	3.1	16.5-32.0	23	18.8	1.8	16.5-23.3
12	55	21.0	3.1	16.6-35.0	26	19.1	2.2	14.9-25.6	27	20.4	2.8	15.7-29.8
Overall	625	20.5	4.0	13.6-53.3	292	20.5	4.0	13.4-42.3	291	20.3	3.8	15.0-37.7

Statistical methods

We used the paired-release recapture models of Burnham et al. (1987) to estimate the survival of juvenile yearling and sub-yearling Chinook salmon through various routes at Bonneville Dam. 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 et al.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 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:

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

(1)

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

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

(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

$$\frac{S_{11}}{S_{21}} = \frac{S \cdot S_{21}}{S_{21}} = S.$$

(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) and evaluation at each project, 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 $\alpha_{EW} = 0.10$ using the 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. When the sequential procedures suggested that the treatment and control groups did not share all parameters in common we used Akaike's Information Criterion (AIC, Awake 1973) to select the most parsimonious model. The treatment and control groups were then assumed to not be mixed or mixed and that some other process had differentially affected the survival and/or capture probabilities for the groups given that they were traveling downriver at approximately the same time.

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

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

(4)

where k = number of replicate releases:

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

The weight W_i is calculated using the formula:

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

(5)

with variance

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

(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,

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

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*). Unfortunately, while the weighted average has been applied by others examining the survival of PIT-tagged salmonids in the Columbia River Basin, the use of this methodology for estimating mean survival using radio-tagged fish has resulted in certain estimates (e.g., those that have survival and capture probabilities near 1) having highly disproportionate weights that invariably results in estimates of survival that are very near 1 despite the fact that very few of the survival estimates reflect this value. While weighted averages are designed to weight the average by certain observations with given qualities or other derived variables or quantities and thus cannot be expected to represent the value that would exist given an un-weighted estimator, the use of a weighted estimator that always skews the evaluation to indicate that the survival of fish passing a given project is 1, when as researchers we know this to not be the case, is unacceptable. The high capture probabilities possible with current radio-telemetry systems and the nature of the way the SURPH software calculates the variance of the survival estimates of the individual releases (e.g., analogous to the binomial variance formula) have been identified as the cause of this result. Coordination between the USGS and the University of Washington, and subsequent efforts by University of Washington personnel have failed to resolve this matter. Consequently, we will evaluate the use of the weighted average, but will use the arithmetic mean to represent the survival of yearling Chinook salmon and steelhead trout at the various projects if it appears that the use of the weighted

estimator results in estimates that are disproportionately influenced by the methodology.

We evaluated t-tests (John Skalski, University of Washington, personal communication) to test for differences in the average survival of yearling and sub-yearling Chinook salmon passing through Bonneville Dam and also for fish released into the Powerhouse 2 juvenile bypass. Many of the comparisons made were post-hoc evaluations since we did not have prior knowledge of the dam operations that were ultimately used during 2001. We employed one-tailed t-tests to evaluate hypotheses designed to address the question of whether one survival estimate was larger (or smaller) than another. Directional hypotheses were generated based on expectations from previous research and/or the expectations and professional judgment of pertinent resource managers. All of the survival estimates compared were tested for equal variances using Bartlett's, the Brown-Forsythe, and Levene's tests for equal variance (SAS 1994). We also evaluated linear regressions to examine the relation of the survival estimates of our individual paired release groups at Bonneville Dam to various environmental and dam operation conditions present at these projects during 2001. All linear regressions were examined for outliers using regression diagnostics (e.g., studentized deleted residuals, Cook's distance, DFFITS, as per Neter et al. 1989). Outlying observations were eliminated where appropriate and the fit and significance of the resulting models were reexamined.

Results

Burnham Tests

The results of the Burnham Tests 2 and 3 testing assumptions A5 and A6 for releases of yearling Chinook near Hood River, OR and known to have passed Bonneville Dam and their corresponding tailrace releases were inconclusive. For Test 2, 10 of the 30 possible tests were incalculable due to the presence of all zeroes in either rows or columns in the chi-square contingency tables (Table 7). Of the tests that were calculated, goodness of fit was rejected for only 2 of the 30 tests ($P < 0.10$). For Test 3, similar results were obtained with 23 of the 30 tests incalculable and only one of the tests calculated for Test 3 suggesting lack of fit. For yearling Chinook salmon releases at the top of the juvenile bypass at Powerhouse 2 and their corresponding tailrace control group releases, 17 of 32 for Test 2 and 26 of 32 for Test 3 were incalculable; goodness of fit was not rejected for any of the tests (Table 8).

The altered dam operations during 2001 from those expected before the migration season (due to the low water year), allowed an unplanned grouping of the yearling Chinook release groups into paired release groups of turbine and non-turbine passed fish that passed during periods of spill and no spill. That is, spill operations were initiated approximately half way through our spring release season and although not planned, the change in operations allowed comparisons between these different

groups to be made. For turbine passed yearling Chinook, most tests for Test 2 were calculable (18 of 30 tests calculable); goodness of fit was rejected for only one apired release. For Test 3, the test were mostly incalculable (24 of 30 tests); goodness of fit was not rejected for any release (Table 9). For yearling Chinook passed via non-turbine routes at Bonneville Dam, the majority of tests for Test 2 were calculable (19 of 30; no tests suggested lack of fit. For Test 3 the majority of tests were not calculable (23 of 30); one test indicated that goodness of fit was rejected (Table 10).

For sub-yearling Chinook salmon released near Hood River, OR and known to have passed Bonneville Dam and corresponding tailrace control releases most tests for Test 2 were calculable (21 of 24). Only one test indicated that goodness of fit was rejected ($P < 0.10$; Table 3). However, most tests for Test 3 were incalculable for these releases (20 of 24) and only one significant difference was detected (Table 11). The results for Test 2 and 3 for sub-yearling Chinook salmon released through the Powerhouse 2 juvenile bypass were similar with 16 of the 24 tests for Test 2 calculable; goodness of fit rejected for one paired release; 19 of 24 tests for Test 3 incalculable; goodness of not rejected for any paired release (Table 12).

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

The chi-square tests for the paired releases of yearling Chinook salmon in the Bonneville Reservoir at Hood River and known to have passed Bonneville Dam and the control releases in the tailrace below the Powerhouse 2 juvenile bypass indicated only one significant difference in arrival times between the treatment and control release groups from the 45 tests evaluated (Table 13). For the paired releases of yearling Chinook released at the top of the Powerhouse 2 juvenile bypass and corresponding tailrace control releases, no significant differences were detected (Table 14). No significant differences in arrival times were observed for the paired release groups of turbine passed yearling Chinook salmon (Table 15) and only one significant result was observed for paired releases of fish passing via non-turbine routes (Table 16).

For the paired releases of sub-yearling Chinook salmon released near Hood River, OR and know to have passed Bonneville Dam (treatment group) and in the tailrace of Bonneville Dam (control group), the results of the chi-square tests of homogeneity indicated four significant differences in the arrival times of the treatment and control groups out of the 36 tests evaluated (Table 17). Of the 36 chi-square tests testing for differences in the arrival times of the sub-yearling Chinook salmon released at the top of Powerhouse 2 juvenile bypass system and in the tailrace of Bonneville Dams evaluated, no significant differences in arrival times were detected (Table 18).

Table 7. Summary statistics for goodness-of-fit tests (tests 2 and 3, Burnham et al. 1987) for each of 15 paired releases of yearling Chinook, spring 2001. Treatment fish were released in the Bonneville reservoir at Hood River, OR and were detected at Bonneville Dam and control fish were released in the Bonneville Dam tailrace.

			Test 2			Test 3	
Release	Population	Df	χ^2	P	df	χ^2	P
1	treatment	1	4.488	0.034		[a]	[a]
	Control	1	0.417	0.519		[a]	[a]
2	treatment	1	5.972	0.015		[a]	[a]
	Control		[a]	[a]		[a]	[a]
3	treatment	1	1.575	0.209		[a]	[a]
	Control	1	1.258	0.262		[a]	[a]
4	treatment	1	0.043	0.836		[a]	[a]
	Control		[a]	[a]		[a]	[a]
5	treatment		[a]	[a]		[a]	[a]
	Control	1	0.002	0.967	1	1.371	0.242
6	treatment	1	0.118	0.731		[a]	[a]
	Control	1	1.871	0.171	1	1.746	0.186
7	treatment		[a]	[a]		[a]	[a]
	Control		[a]	[a]		[a]	[a]
8	treatment	1	0.074	0.786		[a]	[a]
	Control		[a]	[a]		[a]	[a]
9	treatment	1	1.536	0.215	1	0.147	0.702
	Control	1	1.258	0.262		[a]	[a]
10	treatment	1	1.143	0.285	1	0.003	0.955
	Control	1	0.008	0.930	1	0.835	0.361
11	treatment	1	0.004	0.952		[a]	[a]
	Control	1	0.037	0.846		[a]	[a]
12	treatment	1	0.023	0.880		[a]	[a]
	Control	1	0.444	0.505	1	0.397	0.529
13	treatment		[a]	[a]		[a]	[a]
	Control		[a]	[a]		[a]	[a]
14	treatment	1	1.496	0.221		[a]	[a]
	Control		[a]	[a]		[a]	[a]
15	Treatment	1	0.622	0.430	1	5.740	0.017
	Control		[a]	[a]		[a]	[a]

[a] - Chi-square statistic was not calculable for these tests due to the presence of all zeroes in a row or column of the contingency table.

Table 8. 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 2001. Treatment fish were released at the top of the juvenile bypass at Bonneville Dam Powerhouse 2 and control fish were released in the Bonneville Dam tailrace.

		Test 2			Test 3		
Release	Population	df	χ^2	P	df	χ^2	P
1	Treatment	1	0.000	1.000	1	1.247	0.264
	Control	1	0.417	0.519		[a]	[a]
2	Treatment		[a]	[a]		[a]	[a]
	Control		[a]	[a]		[a]	[a]
3	Treatment	1	1.996	0.158		[a]	[a]
	Control	1	1.258	0.262		[a]	[a]
4	Treatment		[a]	[a]		[a]	[a]
	Control		[a]	[a]		[a]	[a]
5	Treatment		[a]	[a]		[a]	[a]
	Control	1	0.002	0.967	1	1.371	0.242
6	Treatment		[a]	[a]		[a]	[a]
	Control	1	1.871	0.171	1	1.746	0.186
7	Treatment	1	0.143	0.706	1	0.765	0.382
	Control		[a]	[a]		[a]	[a]
8	Treatment		[a]	[a]		[a]	[a]
	Control		[a]	[a]		[a]	[a]
9	Treatment	1	1.258	0.262		[a]	[a]
	Control	1	1.258	0.262		[a]	[a]
10	Treatment	1	0.497	0.481		[a]	[a]
	Control	1	0.008	0.930	1	0.835	0.361
11	Treatment	1	0.035	0.852		[a]	[a]
	Control	1	0.037	0.846		[a]	[a]
12	Treatment	1	0.273	0.601		[a]	[a]
	Control	1	0.444	0.505	1	0.397	0.529
13	Treatment		[a]	[a]		[a]	[a]
	Control		[a]	[a]		[a]	[a]
14	Treatment		[a]	[a]		[a]	[a]
	Control		[a]	[a]		[a]	[a]
15	Treatment		[a]	[a]		[a]	[a]
	Control		[a]	[a]		[a]	[a]
16	Treatment		[a]	[a]		[a]	[a]
	Control		[a]	[a]		[a]	[a]

[a] - Chi-square statistic was not calculable for these tests due to the presence of all zeroes in a row or column of the contingency table.

Table 9. Summary statistics for goodness-of-fit tests (tests 2 and 3, Burnham et al. 1987) for each of 15 paired releases of yearling Chinook, spring 2001. Treatment fish were released in the Bonneville reservoir at Hood River, OR and passed through the turbines at Bonneville Dam and control fish were released in the Bonneville Dam tailrace.

		Test 2			Test 3		
Release	Population	df	χ^2	P	df	χ^2	P
1	treatment		[a]	[a]		[a]	[a]
	control	1	0.417	0.519		[a]	[a]
2	treatment	1	3.976	0.046		[a]	[a]
	control		[a]	[a]		[a]	[a]
3	treatment	1	2.226	0.136		[a]	[a]
	control	1	1.258	0.262		[a]	[a]
4	treatment	1	0.143	0.706		[a]	[a]
	control		[a]	[a]		[a]	[a]
5	treatment		[a]	[a]		[a]	[a]
	control	1	0.002	0.967	1	1.371	0.242
6	treatment	1	0.001	0.980		a	a
	control	1	1.871	0.171	1	1.746	0.186
7	treatment		[a]	[a]		[a]	[a]
	control		[a]	[a]		[a]	[a]
8	treatment	1	0.142	0.706		[a]	[a]
	control		[a]	[a]		[a]	[a]
9	treatment	1	0.246	0.620	1	0.742	0.389
	control	1	1.258	0.262		[a]	[a]
10	treatment	1	1.276	0.259	1	0.045	0.832
	control	1	0.008	0.930	1	0.835	0.361
11	treatment	1	0.152	0.696		[a]	[a]
	control	1	0.037	0.846		[a]	[a]
12	treatment	1	2.226	0.136		[a]	[a]
	control	1	0.444	0.505	1	0.397	0.529
13	treatment		[a]	[a]		[a]	[a]
	control		[a]	[a]		[a]	[a]
14	treatment		[a]	[a]		[a]	[a]
	control		[a]	[a]		[a]	[a]
15	treatment		[a]	[a]		[a]	[a]
	control		[a]	[a]		[a]	[a]

[a] - Chi-square statistic was not calculable for these tests due to the presence of all zeroes in a row or column of the contingency table.

Table 10. Summary statistics for goodness-of-fit tests (tests 2 and 3, Burnham et al. 1987) for each of 15 paired releases of yearling Chinook, spring 2001. Treatment fish were released in the Bonneville reservoir at Hood River, OR and passed through non-turbine routes at Bonneville Dam and control fish were released in the Bonneville Dam tailrace.

		Test 2			Test 3		
Release	Population	df	χ^2	P	df	χ^2	P
1	treatment	1	2.226	0.136		[a]	[a]
	control	1	0.417	0.519		[a]	[a]
2	treatment	1	0.052	0.819		[a]	[a]
	control		[a]	[a]		[a]	[a]
3	treatment		[a]	[a]		[a]	[a]
	control	1	1.258	0.262		[a]	[a]
4	treatment	1	1.746	0.186		[a]	[a]
	control		[a]	[a]		[a]	[a]
5	treatment		[a]	[a]	1	1.371	0.242
	control	1	0.002	0.967		[a]	[a]
6	treatment	1	0.442	0.506		[a]	[a]
	control	1	1.871	0.171	1	1.746	0.186
7	treatment		[a]	[a]		[a]	[a]
	control		[a]	[a]		[a]	[a]
8	treatment	1	3.986	0.046		[a]	[a]
	control		a	A		[a]	[a]
9	treatment	1	2.415	0.120	1	1.264	0.261
	control	1	1.258	0.262		[a]	[a]
10	treatment	1	0.969	0.325	1	2.587	0.108
	control	1	0.008	0.930	1	0.835	0.361
11	treatment	1	0.021	0.884		[a]	[a]
	control	1	0.037	0.846		[a]	[a]
12	treatment	1	0	1.000		[a]	[a]
	control	1	0.444	0.505	1	0.397	0.529
13	treatment		[a]	[a]		[a]	[a]
	control		[a]	[a]		[a]	[a]
14	treatment		[a]	[a]		[a]	[a]
	control		[a]	[a]		[a]	[a]
15	treatment	1	1.010	0.315	1	3.734	0.053
	control		[a]	[a]		[a]	[a]

[a] - Chi-square statistic was not calculable for these tests due to the presence of all zeroes in a row or column of the contingency table.

Table 11. Summary statistics for goodness-of-fit tests (tests 2 and 3, Burnham et al. 1987) for each of 12 paired releases of sub-yearling Chinook, summer 2001. Treatment fish were released in the Bonneville reservoir at Hood River, OR and were detected at Bonneville Dam and control fish were released in the Bonneville Dam tailrace.

		Test 2			Test 3		
Release	Population	df	χ^2	P	df	χ^2	P
1	treatment	1	0.691	0.406		[a]	[a]
	control	1	0.217	0.641		[a]	[a]
2	treatment		[a]	[a]		[a]	[a]
	control	1	1.122	0.290		[a]	[a]
3	treatment	1	0.385	0.535		[a]	[a]
	control	1	0.174	0.676		[a]	[a]
4	treatment	1	0.152	0.697		[a]	[a]
	control	1	3.484	0.062		[a]	[a]
5	treatment	1	2.351	0.125		[a]	[a]
	control	1	0.348	0.555		[a]	[a]
6	treatment	1	1.423	0.233		[a]	[a]
	control	1	2.004	0.157		[a]	[a]
7	treatment	1	3.484	0.062	1	3.233	0.072
	control	1	0.069	0.793		[a]	[a]
8	treatment	1	0.137	0.711		[a]	[a]
	control	1	0.774	0.379	1	0.713	0.398
9	treatment	1	0.009	0.926		[a]	[a]
	control	1	4.153	0.042		[a]	[a]
10	treatment		[a]	[a]		[a]	[a]
	control		[a]	[a]		[a]	[a]
11	treatment	1	2.226	0.136	1	1.975	0.160
	control	1	0.036	0.849		[a]	[a]
12	treatment	1	0.035	0.852	1	0.000	1.000
	control	1	0.166	0.684		[a]	[a]

[a] - Chi-square statistic was not calculable for these tests due to the presence of all zeroes in a row or column of the contingency table.

Table 12. Summary statistics for goodness-of-fit tests (tests 2 and 3, Burnham et al. 1987) for each of 12 paired releases of sub-yearling Chinook, summer 2001. Treatment fish were released at the top of the juvenile bypass at Bonneville Dam Powerhouse 2 and control fish were released in the Bonneville Dam tailrace.

		Test 2			Test 3		
Release	Population	df	χ^2	P	df	χ^2	P
1	treatment		[a]	[a]		[a]	[a]
	control	1	0.217	0.641		[a]	[a]
2	treatment		[a]	[a]		[a]	[a]
	control	1	1.122	0.290		[a]	[a]
3	treatment		[a]	[a]		[a]	[a]
	control	1	0.174	0.676		[a]	[a]
4	treatment		[a]	[a]		[a]	[a]
	control	1	3.484	0.062		[a]	[a]
5	treatment		[a]	[a]		[a]	[a]
	control	1	0.348	0.555		[a]	[a]
6	treatment	1	0.383	0.536	1	1.247	0.264
	control	1	2.004	0.157		[a]	[a]
7	treatment	1	2.142	0.143		[a]	[a]
	control	1	0.069	0.793		[a]	[a]
8	treatment		[a]	[a]	1	0.592	0.442
	control	1	0.774	0.379	1	0.713	0.398
9	treatment	1	2.730	0.098	1	2.479	0.115
	control	1	4.153	0.042		[a]	[a]
10	treatment	1	4.363	0.037		[a]	[a]
	control		[a]	[a]		[a]	[a]
11	treatment		[a]	[a]		[a]	[a]
	control	1	0.036	0.849		[a]	[a]
12	treatment	1	1.371	0.242	1	1.122	0.290
	control	1	0.166	0.684		[a]	[a]

[a] - Chi-square statistic was not calculable for these tests due to the presence of all zeroes in a row or column of the contingency table.

Table 13. The results of chi-square tests testing for similarities of arrival times between yearling Chinook salmon released near Hood River, OR that are know to have passed Bonneville Dam (treatment group) and in the tailrace of Bonneville Dam (control group) at radio-telemetry arrays at river kilometers 200, 194 and 181 below Bonneville Dam.

Paired Release	Bonneville Dam to River Kilometer 200			Bonneville Dam to River Kilometer 194			Bonneville Dam to River Kilometer 181		
	DF	Chi-square	P	DF	Chi-square	P	DF	Chi-square	P
1	0	0	[a]	1	0.97	0.324	2	4.00	0.135
2	0	0	[a]	1	0.43	0.512	1	0.31	0.580
3	0	0	[a]	2	5.78	0.056	2	11.73	0.003
4	0	0	[a]	1	1.36	0.244	1	2.02	0.155
5	0	0	[a]	0	0	[a]	1	0.57	0.452
6	0	0	[a]	1	1.80	0.180	1	2.24	0.135
7	0	0	[a]	1	0.73	0.393	1	1.49	0.222
8	0	0	[a]	0	0	[a]	0	0	[a]
9	2	1.69	0.430	2	2.17	0.337	2	1.96	0.375
10	2	1.80	0.406	2	2.09	0.352	2	4.90	0.086
11	1	1.70	0.192	1	1.46	0.227	1	2.83	0.093
12	1	0.67	0.413	1	0.63	0.428	1	0.61	0.434
13	2	1.26	1.533	2	1.30	0.522	2	1.24	0.539
15	0	0	[a]	0	0	[a]	0	0	[a]
16	3	1.6	0.660	2	1.15	0.561	3	1.55	0.670

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

Table 14. The results of chi-square tests testing for similarities of arrival times between yearling Chinook salmon released at the top of Powerhouse 2 juvenile bypass (treatment group) and in the tailrace of Bonneville Dam (control group) at radio-telemetry arrays at river kilometers 200, 194, and 181 below Bonneville Dam.

Paired Release	Bonneville Dam to River kilometer 200			Bonneville Dam to River kilometer 194			Bonneville Dam to River kilometer 181		
	DF	Chi-square	P	DF	Chi-square	P	DF	Chi-square	P
1	1	1.03	0.310	1	1.09	0.296	3	5.18	0.159
2	1	0.31	0.579	1	0.12	0.720	2	2.32	0.314
3	2	2.20	0.333	1	2.10	0.147	2	2.29	0.317
4	1	1.28	0.258	1	0.57	0.450	1	0.57	0.450
5	0	0	[a]	0	0	[a]	0	0	[a]
6	1	0.84	0.360	1	0.85	0.358	1	0.85	0.358
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	1	1.45	0.229	1	1.37	0.243	1	1.40	0.237
11	0	0	[a]	0	0	[a]	1	0.92	0.339
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.

Table 15. The results of chi-square tests of yearling Chinook salmon released near Hood River, OR passing Bonneville Dam via Powerhouse 2 turbines, and detected at radio-telemetry arrays at river kilometers 200, 194, and 181 below Bonneville Dam.

	Bonneville Dam to River Kilometer 200			Bonneville Dam to River Kilometer 194			Bonneville Dam to River Kilometer 181		
Release	DF	Chi-square	P	DF	Chi-square	P	DF	Chi-square	P
1	0	0	[a]	1	2.08	0.149	2	3.12	0.210
2	0	0	[a]	1	0.06	0.811	1	0.03	0.854
3	0	0	[a]	2	4.49	0.106	2	9.48	0.009
4	0	0	[a]	1	1.42	0.233	1	1.35	0.246
5	0	0	[a]	0	0	[a]	1	0.93	0.335
6	0	0	[a]	1	1.89	0.169	1	2.49	0.114
7	0	0	[a]	0	0	[a]	0	0	[a]
8	0	0	[a]	0	0	[a]	0	0	[a]
9	1	0.63	0.428	1	0.67	0.413	1	0.60	0.439
10	1	1.45	0.229	2	2.51	0.284	2	5.70	0.058
11	1	1.04	0.309	1	0.79	0.375	1	1.03	0.310
12	0	0	[a]	0	0	[a]	0	0	[a]
13	1	2.07	0.150	1	2.07	0.150	1	1.97	0.161
14	0	0	[a]	0	0	[a]	0	0	[a]
15	0	0	[a]	0	0	[a]	0	0	[a]

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

Table 16. The results of chi-square tests of yearling Chinook salmon released near Hood River, OR passing Bonneville Dam via non-turbine routes and detected at radio-telemetry arrays at river kilometers 200, 194, and 181 below Bonneville Dam.

Release	Bonneville Dam to River Kilometer 200			Bonneville Dam to River Kilometer 194			Bonneville Dam to River Kilometer 181		
	DF	Chi-square	P	DF	Chi-square	P	DF	Chi-square	P
1	0	0	[a]	0	0	[a]	2	2.92	0.232
2	0	0	[a]	1	2.30	0.129	1	1.03	0.311
3	0	0	[a]	1	6.06	0.014	1	11.62	0.001
4	0	0	[a]	1	1.35	0.246	1	2.76	0.097
5	0	0	[a]	0	0	[a]	0	0	[a]
6	0	0	[a]	1	1.51	0.219	1	1.51	0.219
7	0	0	[a]	1	1.37	0.241	1	2.83	0.093
8	0	0	[a]	0	0	[a]	0	0	[a]
9	2	2.84	0.242	2	3.83	0.148	2	3.49	0.175
10	1	1.94	0.164	1	1.89	0.169	1	4.29	0.038
11	1	1.98	0.159	1	1.68	0.195	1	3.53	0.060
12	1	1.03	0.311	1	0.93	0.334	1	0.89	0.344
13	1	0.89	0.345	1	0.93	0.334	1	0.88	0.347
14	0	0	[a]	0	0	[a]	0	0	[a]
15	3	2.62	0.454	2	1.79	0.409	3	3.58	0.311

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

Table 17. The results of chi-square tests of homogeneity testing for similarity in arrival times of paired releases of sub-yearling Chinook salmon released near Hood River, OR and known to have passed Bonneville Dam (treatment group) and in the tailrace of Bonneville Dam (control group) and detected at radio-telemetry arrays at river kilometers 200, 194, and 181.

Paired Release	Bonneville Dam to River Kilometer 200			Bonneville Dam to River Kilometer 194			Bonneville Dam to River Kilometer 181		
	DF	Chi-square	P	DF	Chi-square	P	DF	Chi-square	P
1	0	0	[a]	0	0	[a]	1	1.04	0.308
2	0	0	[a]	1	13.84	<0.001	1	13.21	<0.001
3	0	0	[a]	0	0	[a]	1	2.47	0.116
4	0	0	[a]	1	0.12	0.727	1	0.42	0.519
5	0	0	[a]	1	2.01	0.157	1	7.59	0.006
6	0	0	[a]	0	0	[a]	0	0	[a]
7	0	0	[a]	0	0	[a]	1	1.44	0.230
8	0	0	[a]	0	0	[a]	1	1.07	0.300
9	0	0	[a]	1	0.74	0.391	2	2.84	0.241
10	0	0	[a]	0	0	[a]	1	3.47	0.063
11	0	0	[a]	0	0	[a]	0	0	[a]
12	0	0	[a]	1	4.97	0.026	1	9.11	0.003

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

Table 18. The results of chi-square tests of homogeneity testing for similarity in arrival times of paired releases of sub-yearling Chinook salmon released at the top of the Bonneville Dam Powerhouse 2 juvenile bypass system (treatment group) and in the tailrace of Bonneville Dam (control group) and detected at radio-telemetry arrays at river kilometers 200, 194 and 181.

Paired Release	Bonneville Dam to River Kilometer 200			Bonneville Dam to River Kilometer 194			Bonneville Dam to River Kilometer 181		
	DF	Chi-square	P	DF	Chi-square	P	DF	Chi-square	P
1	0	0	[a]	0	0	[a]	0	0	[a]
2	0	0	[a]	0	0	[a]	1	0.37	0.541
3	1	0.88	0.348	0	0	[a]	0	0	[a]
4	0	0	[a]	1	1.37	0.241	1	1.29	0.257
5	1	1.02	0.312	1	0.90	0.343	1	2.10	0.147
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]	1	0.64	0.425	1	1.06	0.303
10	1	1.31	0.253	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]

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

Sequential evaluation of log-likelihood tests

A sequential evaluation of log-likelihood tests testing for significant differences in the survival model parameters was also performed to further evaluate the assumption of mixing and evaluate assumption A9 (e.g., Releases R_1 and R_2 have the same survival probability in the lower river segment S_{21}). For the evaluation of the survival of yearling Chinook through Bonneville Dam the majority of releases showed significant differences ($P > 0.10$) in the survival and capture probabilities of the treatment and control groups (Table 19). However, the selection of Cormack-Jolly-Seber (CJS) models for 4 of 15 releases confounded the interpretation of the results of these tests. For the evaluation of the survival of yearling Chinook through the juvenile bypass system at Powerhouse 2, the evaluation of the log-likelihood tests indicated similar survival and capture probabilities for the majority of releases (Table 19). For the paired releases of turbine and non-turbine passed yearling Chinook similar results were obtained. For turbine passed yearling Chinook the results were not conclusive because the majority of the models selected were CJS (Table 20). For non-turbine passed yearling Chinook salmon all of the non-CJS models selected indicated no differences in the capture and survival probabilities in the reaches downriver of the first reach evaluated (Table 20).

For paired releases of sub-yearling Chinook salmon released as part of the evaluation of dam survival at Bonneville Dam the capture and survival probabilities (and joint survival and capture probabilities as represented by the lambda parameter) were found to be different between the treatment and control groups for approximately one-half of the releases (Table 21). Similar results were observed for the paired releases of sub-yearling Chinook salmon released as part of the evaluation of the survival through the Powerhouse 2 juvenile bypass system. Significant differences were found in the capture and survival probabilities between treatment and control groups in the river reaches evaluated below Bonneville Dam (Table 21).

Releases of dead radio-tagged fish

Dead radio-tagged yearling and sub-yearling Chinook salmon (30 of each species) were released in the tailrace release location below Bonneville dam to explore the likelihood of obtaining false-positive detections (e.g., detections of dead fish that would suggest they were alive) at arrays downstream of this project. One dead radio-tagged yearling Chinook salmon was detected at all of the three radio-telemetry detection arrays below Bonneville Dam and one dead radio-tagged sub-yearling Chinook salmon was detected at the first radio-telemetry detection array below Bonneville Dam suggesting that there was a possibility to have false-positive detections of yearling and sub-yearling Chinook at these arrays.

Table 19. Frequency of models selected as a result of evaluating log-likelihood ratio tests that test for differences in survival and capture probabilities between control and treatment groups of paired releases of yearling Chinook salmon. Model designations indicate the parameters that control and treatment groups have in common. For instance, model designation lambda p2 s2 p1 indicates that all the survival and capture probabilities were found not to be significantly different between the control and release groups. Model designation CJS refers to Cormack-Jolly-Seber model estimates that assume all estimated parameters were different for the treatment and control groups. In all cases, use of the CJS models resulted from computational constraints (e.g., variance estimates incalculable) associated with the SURPH software program and do not indicate that all parameters were tested and found to be significantly different.

	Yearling Chinook Salmon	
	Frequency	
Model	Dam Survival	Juvenile Bypass Survival
Lambda p2 S2 p1	6	12
Lambda p2 S2	0	2
Lambda s2	2	1
Lambda s2 p1	3	1
CJS	4	0

Table 20. Frequency of models selected as a result of evaluating log-likelihood ratio tests that test for differences in survival and capture probabilities between control and treatment groups of paired releases of yearling Chinook salmon known to have passed via turbine and non-turbine routes at Bonneville Dam. Model designations indicate the parameters that control and treatment groups have in common. For instance, model designation lambda p2 s2 p1 indicates that all the survival and capture probabilities were found not to be significantly different between the control and release groups. Model designation CJS refers to Cormack-Jolly-Seber model estimates that assume all estimated parameters were different for the treatment and control groups. In all cases, use of the CJS models resulted from computational constraints (e.g., variance estimates incalculable) associated with the SURPH software program and do not indicate that all parameters were tested and found to be significantly different.

	Yearling Chinook Salmon	
	Frequency	
Model	Turbine Survival	Non-turbine Survival
Lambda p2 S2 p1	4	8
Lambda p2 S2	2	0
Lambda s2	1	0
Lambda s2 p1	2	3
CJS	6	4

Table 21. Frequency of models selected as a result of evaluating log-likelihood ratio tests that test for differences in survival and capture probabilities between control and treatment groups of paired releases of sub-yearling Chinook salmon. Model designations indicate the parameters that control and treatment groups have in common. For instance, model designation lambda p2 s2 p1 indicates that all the survival and capture probabilities were found not to be significantly different between the control and release groups. Model designation CJS refers to Cormack-Jolly-Seber model estimates that assume all parameters were different. In all cases, use of the CJS models resulted from computational constraints (e.g., variance estimates incalculable) associated with the SURPH software program and do not indicate that all parameters were tested and found to be significantly different.

	Sub-Yearling Chinook Salmon	
	Frequency	
Model	Dam Survival	Juvenile Bypass Survival
Lambda p2 S2 p1	6	6
Lambda p2 S2	1	1
Lambda s2	1	1
Lambda s2 p1	2	0
p2 s2	1	1
Lambda p1 p2	0	1
p2s2p1	0	1
CJS	1	1

Survival Probability

The survival of yearling Chinook salmon passing via all routes at Bonneville Dam was evaluated using paired releases made at Bonneville Dam (based on detections of fish released near Hood River, OR at Bonneville Dam) and in the tailrace of Bonneville Dam. The survival probabilities ranged from 0.85 to 1.05 (Table 22). The average dam survival at Bonneville Dam for yearling Chinook salmon was estimated to be 0.937 (SE = 0.014). Dam survival during the day was estimated to be 0.923 (SE = 0.024) and night survival was estimated to be 0.949 (SE = 0.016). No significant differences were detected between day and night dam survival (one-tailed t-test, P = 0.19) but the power associated with this test was low ($1 - \beta = 0.22$). No significant relations were detected (linear regression, $P > 0.10$) between the dam survival of yearling Chinook salmon and total river discharge (Figure 2), total turbine discharge (Figure 3), or total Powerhouse 2 discharge (Figure 4). Because of the low water year during 2001, appreciable spill at Bonneville Dam occurred during only the last 7 releases during the spring migration evaluation (Figure 5) allowing a comparison of the survival of yearling Chinook passing Bonneville Dam during periods of spill and no spill. Prior to the initiation of spill at Bonneville Dam, the survival of yearling Chinook passing through all routes at the project was 0.928 (n = 8, SE = 0.023) and after spill was initiated was 0.946 (n = 7, SE = 0.015). The survival for yearling Chinook salmon passing Bonneville Dam before and after spill was initiated was not statistically different (one tailed t-test, P = 0.27). However, the power associated with this test was low ($1 - \beta = 0.14$).

For yearling Chinook salmon released at the top of the Powerhouse 2 juvenile bypass system (JBS) ranged from 0.78 to 1.1 (Table 23). The average survival through the JBS was estimated to be 0.962 (SE = 0.023). Survival through the juvenile bypass system during the day was estimated to be 0.953 (SE = 0.039) and night survival was estimated to be 0.971 (SE = 0.027). No significant differences were detected between day and night survival through the JBS (one tailed t-test, P = 0.35) with power ($1 - \beta$ = 0.10). Similar to the results for dam survival, no significant relations were detected (linear regression, $P > 0.10$) between the juvenile bypass survival of yearling Chinook salmon and total river discharge (Figure 6), total turbine discharge (Figure 7), or total powerhouse discharge (Figure 8).

As stated previously, we separated the yearling Chinook paired releases groups (e.g., released near Hood River and detected at Bonneville Dam and in the tailrace of Bonneville Dam) into turbine passed and non-turbine passed fish. The survival of turbine passed fish ranged from 0.83 to 1.07 (Table 24). The average survival for turbine passed yearling Chinook was 0.929 (SE = 0.02). For non-turbine passed fish the survival ranged from 0.82 to 1.03 (Table 25). The average survival for non-turbine passed yearling Chinook was 0.937 (SE = 0.02). For turbine passed yearling Chinook, the average survival of fish passing during periods of spill was 0.900 (SE = 0.032) and during periods of no spill was 0.954 (SE = 0.024). The survival of yearling Chinook turbine passed fish passing during periods of spill and no spill were marginally significantly different (one-tailed t-test, P = 0.098) at an alpha level of 0.10. The average survival of non-turbine passed fish during periods of spill was 0.96 (SE = 0.018) and for periods of no spill was

0.91 (*SE* = 0.029). The difference between the average survival levels during periods of spill and no spill was found to be significantly different (one-tailed t-test, *P* = 0.086).

The dam survival of sub-yearling Chinook salmon passing via all routes at Bonneville Dam was based on the same release locations as those used for yearling Chinook salmon. The dam survival of sub-yearling Chinook salmon ranged from 0.73 to 1.08 (Table 26). The estimated average dam survival was 0.902 (*SE* = 0.036). The average dam survival during day releases was estimated to be 0.895 (*SE* = 0.044) and during night releases was 0.910 (*SE* = 0.066). No significant differences between day and night dam survival were detected (one-tailed t-test, *P* = 0.42). No significant relations (linear regression, *P* > 0.10) between total river discharge (Figure 9), total turbine discharge (Figure 10), and total Powerhouse 2 discharge (Figure 11) were detected.

Sub-yearling Chinook salmon were also released at the top of the Powerhouse 2 juvenile bypass system (JBS) during 2001. Sub-yearling Chinook salmon JBS survival ranged from 0.62 to 1.28 (Table 27). The average JBS survival was estimated to be 0.90 (*SE* = 0.053). The average JBS survival for the day releases was estimated to be 0.870 (*SE* = 0.089) and for night releases was 0.946 (SE = 0.0374). The average survival estimates were not found to be significantly different between day and night releases (variance weighted one-tailed t-test, *P* = 0.23). Significant relations (linear regression, *P* < 0.10) between total river discharge (Figure 12), total turbine discharge (Figure 13), and total Powerhouse 2 discharge (Figure 14) were detected. Total river discharge, total turbine discharge, and total Powerhouse 2 discharge were all highly correlated (Table 28).

Discussion

Similar to our evaluations during 1999 and 2000, the majority of the Burnham Tests 2 and 3 were not accessible due to the presence of all zeroes in a row or column of the contingency tables for releases of yearling Chinook salmon at Bonneville Dam. The majority of tests were calculable for sub-yearling Chinook salmon; perhaps reflecting the lower capture probabilities and corresponding better representation of certain capture histories associated with the releases of these fish. 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 is limited by the high capture probabilities now possible with the radio-telemetry detection arrays. The results of these tests to date (e.g., during 1999, 2000, and 2001 studies) have been inconclusive. However, 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).

Table 22. Survival probabilities and associated standard errors for yearling Chinook salmon passing via all routes at Bonneville Dam based on paired releases of yearling Chinook released near Hood River, OR and known to have passed Bonneville Dam and in the tailrace of Bonneville Dam downriver of the Powerhouse 2 juvenile bypass.

Paired Release	Bonneville Dam Survival		
	Day/Night	Survival	Standard Error
1	Night	0.91	0.096
2	Day	0.91	0.103
3	Night	0.97	0.076
4	Day	0.91	0.078
5	Night	0.96	0.084
6	Day	1.05	0.077
7	Night	0.87	0.080
8	Day	0.85	0.086
9	Night	1.02	0.047
10	Day	0.90	0.068
11	Night	0.95	0.070
12	Day	0.90	0.082
13	Day	0.94	0.087
14	Night	0.94	0.097
15	Night	0.97	0.104

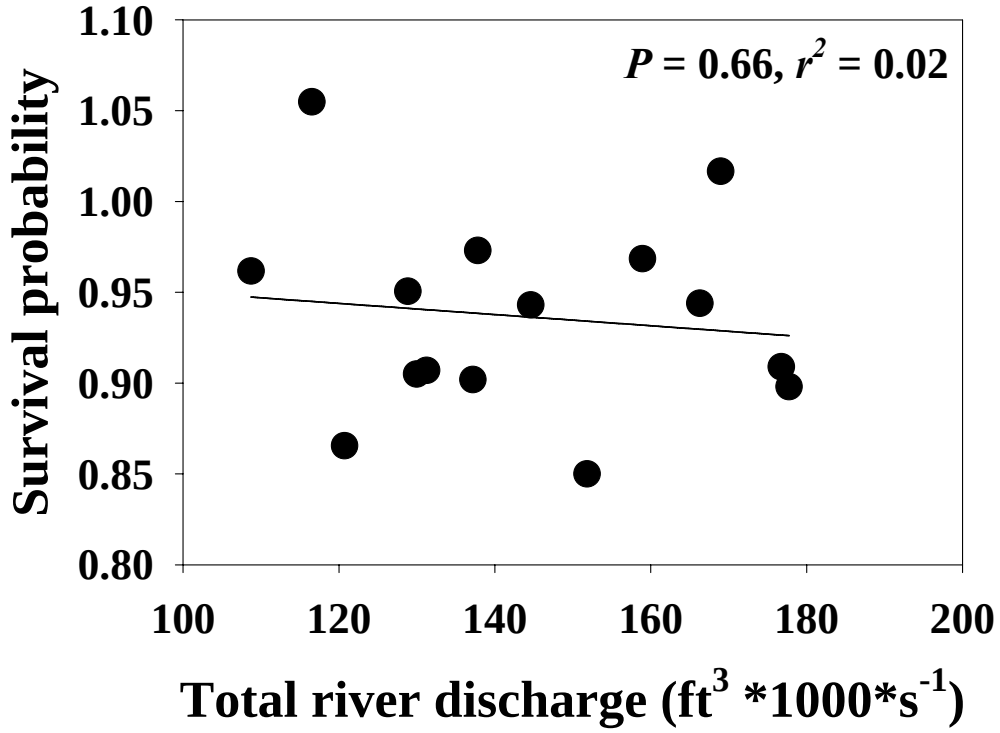

Figure 2. The relation of the survival of yearling Chinook salmon released near Hood River, OR and known to have passed Bonneville Dam and total discharge.

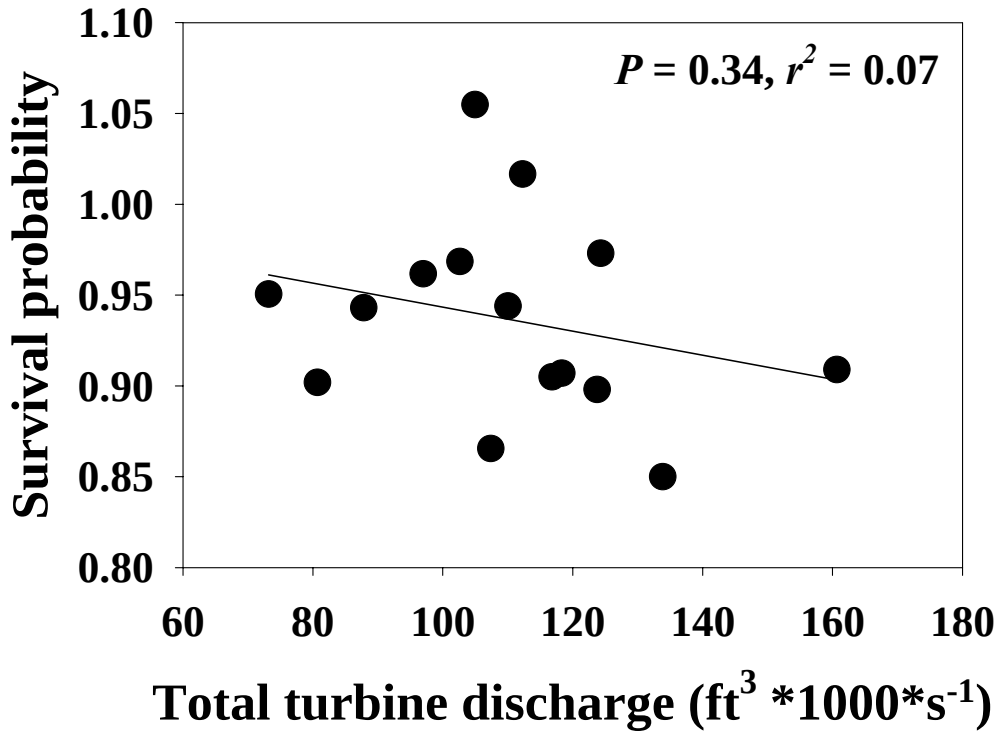

Figure 3. The relation of the survival of yearling Chinook salmon released near Hood River, OR and known to have passed Bonneville Dam and total turbine discharge.

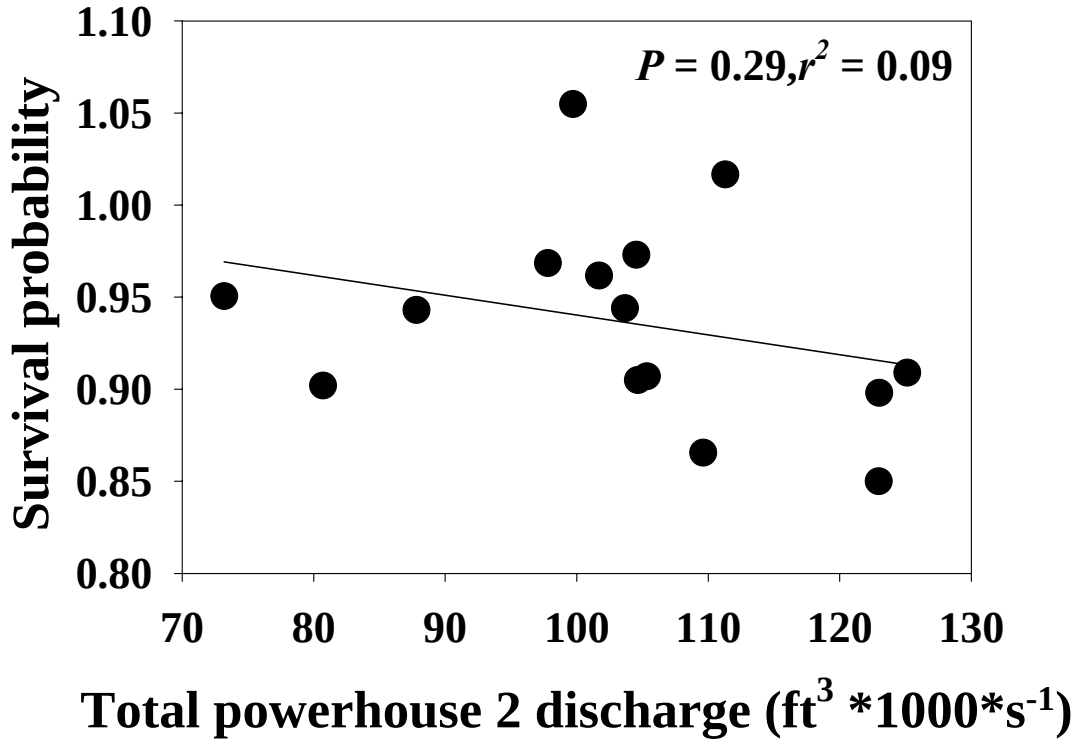

Figure 4. The relation of the survival of yearling Chinook salmon released near Hood River, OR and known to have passed Bonneville Dam and total discharge through Bonneville Powerhouse 2.

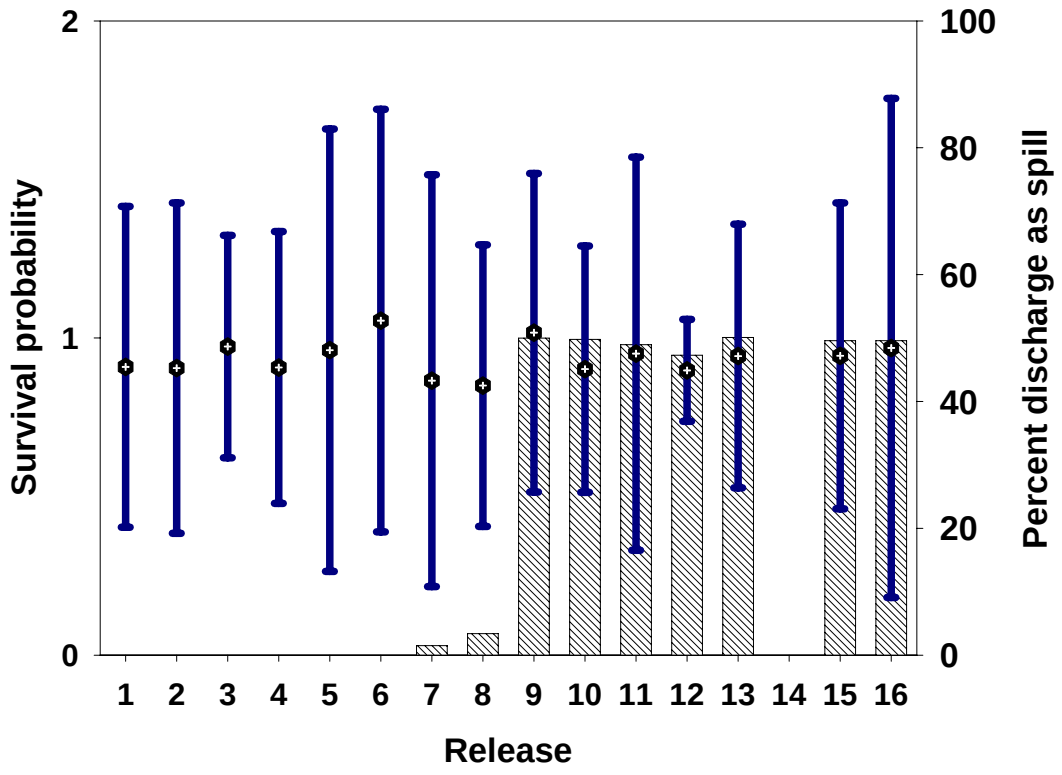

Figure 5. Survival through all routes at Bonneville Dam during the 2001 migration season by release and the percent of discharge as spill during this period.

Table 23. Survival probabilities and associated standard errors for yearling Chinook salmon passing via the Powerhouse 2 (PH 2) juvenile bypass system based on paired releases of yearling Chinook released through the juvenile bypass at Powerhouse 2 and in the tailrace of Bonneville Dam downriver of the Powerhouse 2 juvenile bypass.

Paired Release	Bonneville Dam PH 2 Juvenile Bypass Survival		
	Day/Night	Survival	Standard Error
1	Night	0.86	0.104
2	Day	1.00	0.116
3	Night	0.96	0.082
4	Day	1.00	0.104
5	Night	1.09	0.106
6	Day	1.10	0.109
7	Night	1.05	0.123
8	Day	1.00	0.035
9	Night	0.96	0.070
10	Day	0.79	0.086
11	Night	1.00	0.084
12	Day	1.00	0.076
13	Day	0.95	0.111
14	Day	0.78	0.115
15	Night	0.95	0.118
16	Night	0.90	0.125

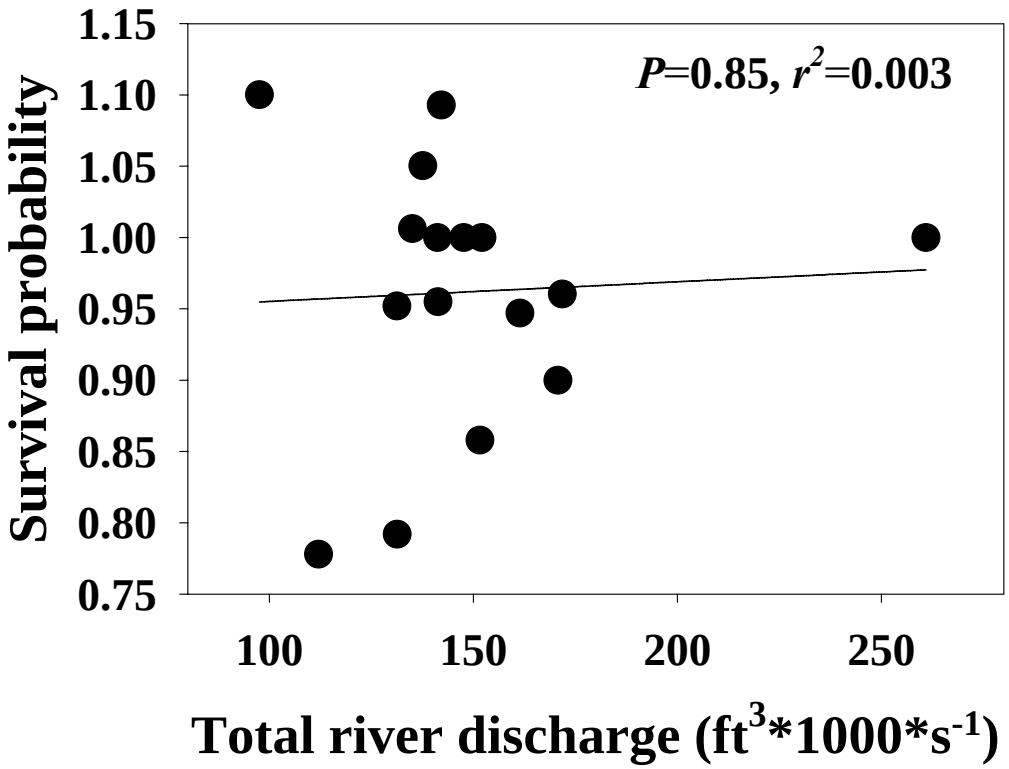

Figure 6. The relation of the survival of yearling Chinook salmon released through the Bonneville Dam powerhouse2 juvenile bypass system and total discharge.

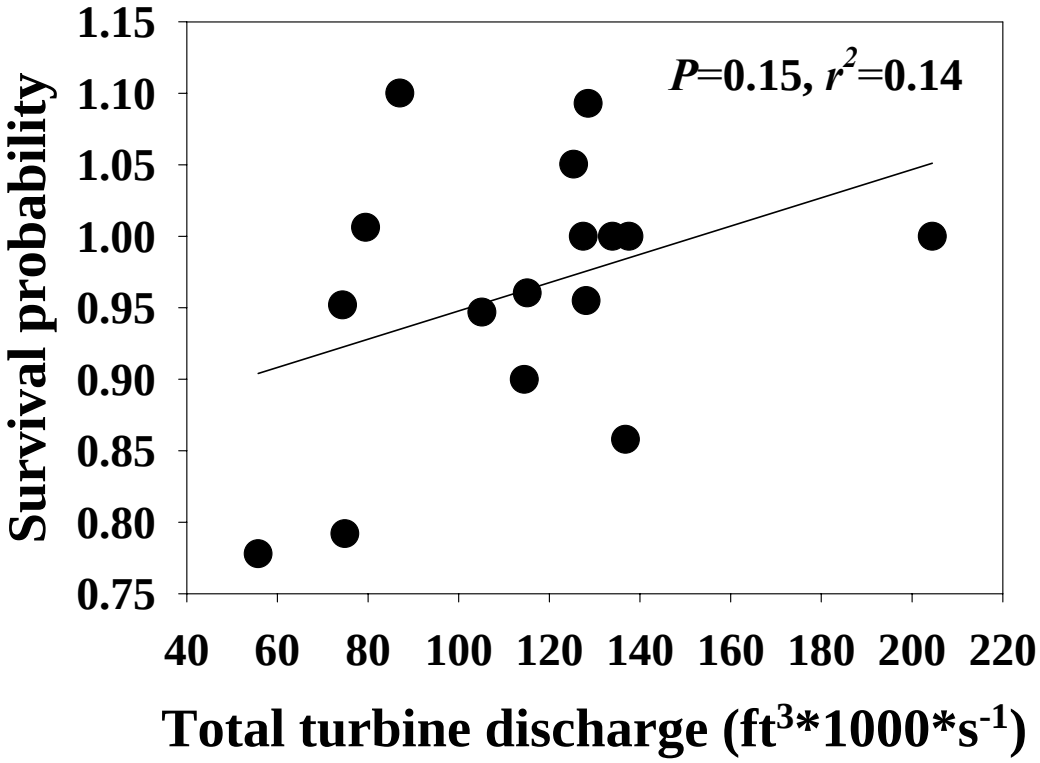

Figure 7. The relation of the survival of yearling Chinook salmon released through the Bonneville Dam powerhouse2 juvenile bypass system and total turbine discharge.

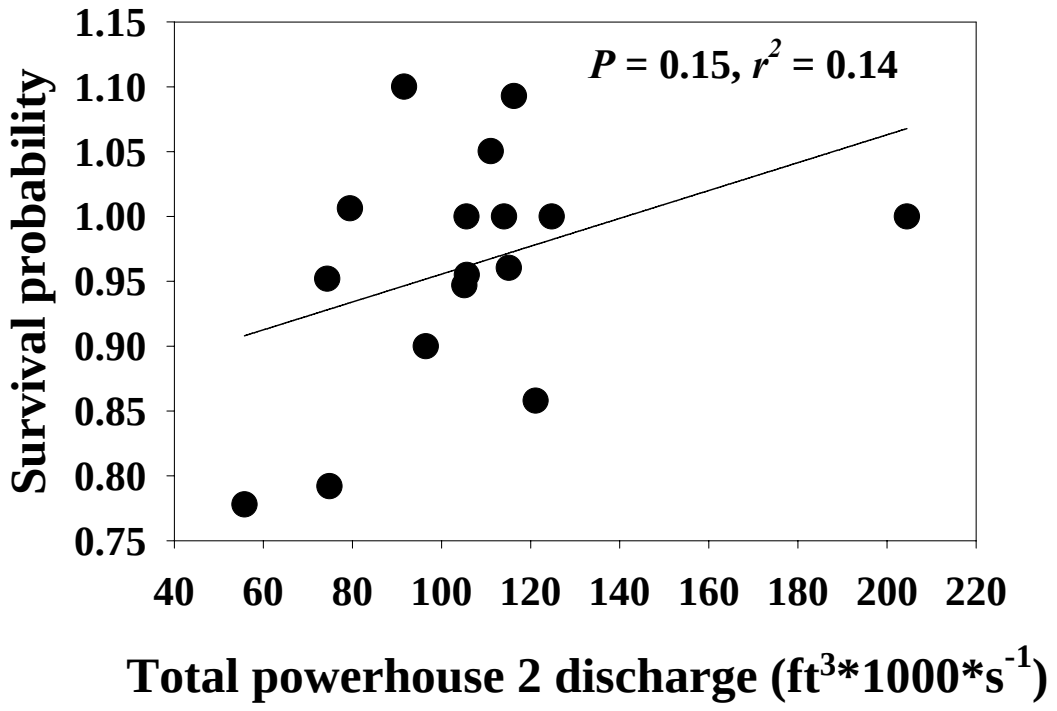

Figure 8. The relation of the survival of yearling Chinook salmon released through the Bonneville Dam Powerhouse 2 juvenile bypass system and total discharge through Bonneville Dam Powerhouse 2.

Table 24. Survival probabilities and associated standard errors for yearling Chinook salmon passing through turbines at Bonneville Dam under spill and no spill conditions. Survival is based on paired releases of yearling Chinook released near Hood River, OR and known to have passed Bonneville Dam via the turbines, and in the tailrace of Bonneville Dam downriver of the Powerhouse 2 juvenile bypass.

Paired Release	Bonneville Dam Turbine Survival		
	Percent Spill	Survival	Standard Error
1	0%	1.00	0.174
2	0%	0.88	0.114
3	0%	1.00	0.151
4	0%	0.95	0.081
5	0%	0.96	0.095
6	0%	1.07	0.078
7	1%	0.91	0.102
8	2%	0.86	0.093
9	30%	1.04	0.065
10	36%	0.84	0.090
11	39%	0.85	0.109
12	26%	0.85	0.119
13	35%	0.83	0.128
14	30%	1.00	0.175
15	31%	0.88	0.144

Table 25. Survival probabilities and associated standard errors for yearling Chinook salmon passing through non-turbine routes at Bonneville Dam under spill and no spill conditions. Survival is based on paired releases of yearling Chinook released near Hood River, OR and known to have passed Bonneville Dam via non-turbine routes, and in the tailrace of Bonneville Dam downriver of the Powerhouse 2 juvenile bypass.

Paired Release	Bonneville Dam Turbine Survival		
	Percent Spill	Survival	Standard Error
1	0%	0.85	0.122
2	0%	1.00	0.239
3	0%	0.96	0.080
4	0%	0.86	0.094
5	0%	0.96	0.110
6	0%	1.03	0.100
7	1%	0.83	0.107
8	2%	0.82	0.108
9	30%	0.99	0.056
10	36%	0.94	0.070
11	39%	0.99	0.074
12	26%	0.92	0.087
13	35%	1.00	0.110
14	30%	0.89	0.130
15	31%	1.02	0.109

Table 26. Survival probabilities and associated standard errors for sub-yearling Chinook salmon passing via all routes at Bonneville Dam based on paired releases of sub-yearling Chinook released near Hood River, OR and known to have passed Bonneville Dam and in the tailrace of Bonneville Dam downriver of the Powerhouse 2 juvenile bypass.

Paired Release	Bonneville Dam Survival		
	Day/Night	Survival	Standard Error
1	Night	0.90	0.092
2	Day	1.01	0.190
3	Night	1.08	0.133
4	Day	0.98	0.128
5	Night	0.81	0.117
6	Day	0.77	0.096
7	Night	0.73	0.130
8	Day	0.85	0.100
9	Day	0.78	0.098
10	Day	0.82	0.184
11	Day	1.05	0.219
12	Night	1.03	0.183

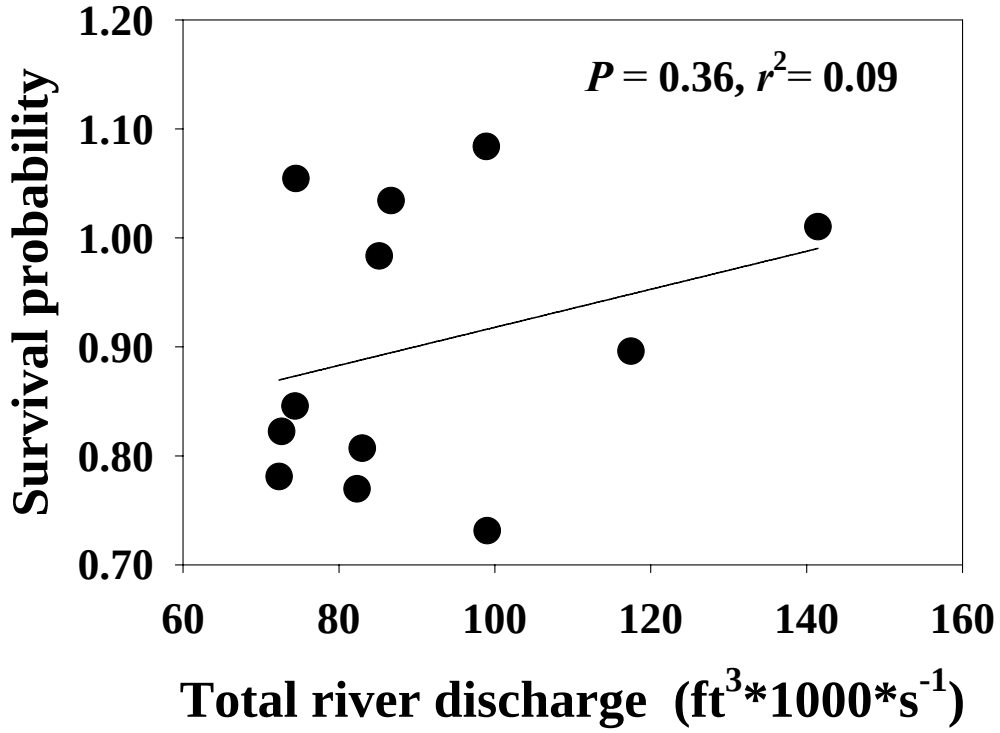

Figure 9. The relation of the survival of sub-yearling Chinook salmon released near Hood River, OR and known to have passed any route at Bonneville Dam and total river discharge.

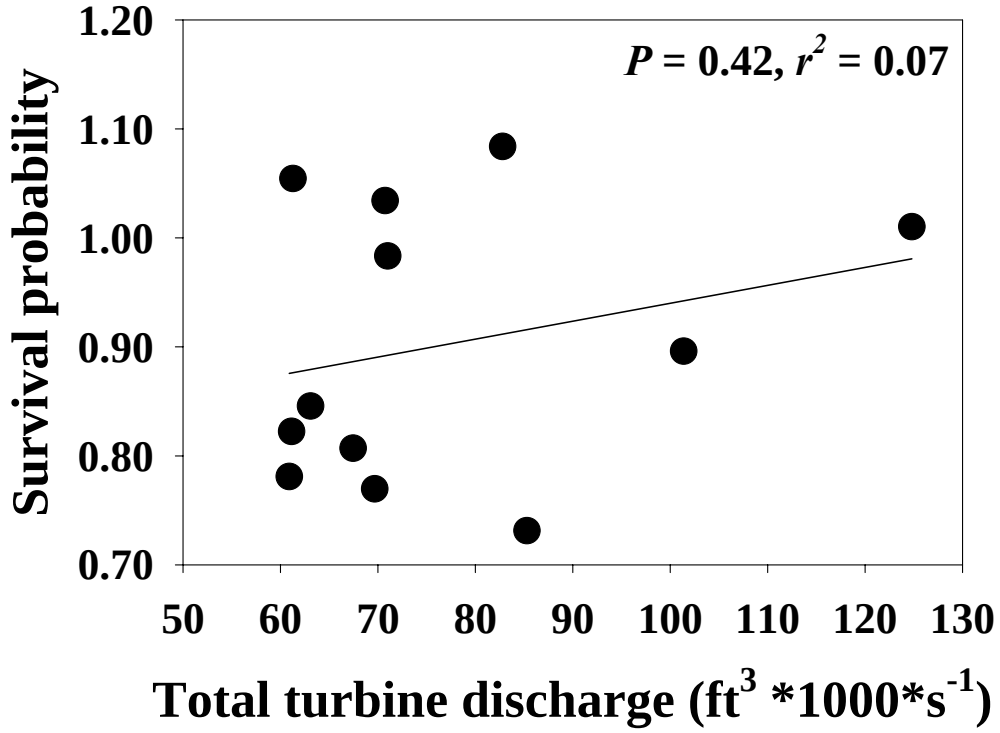

Figure 10. The relation of the survival of sub-yearling Chinook salmon released near Hood River, OR and detected passing Bonneville Dam and total turbine discharge.

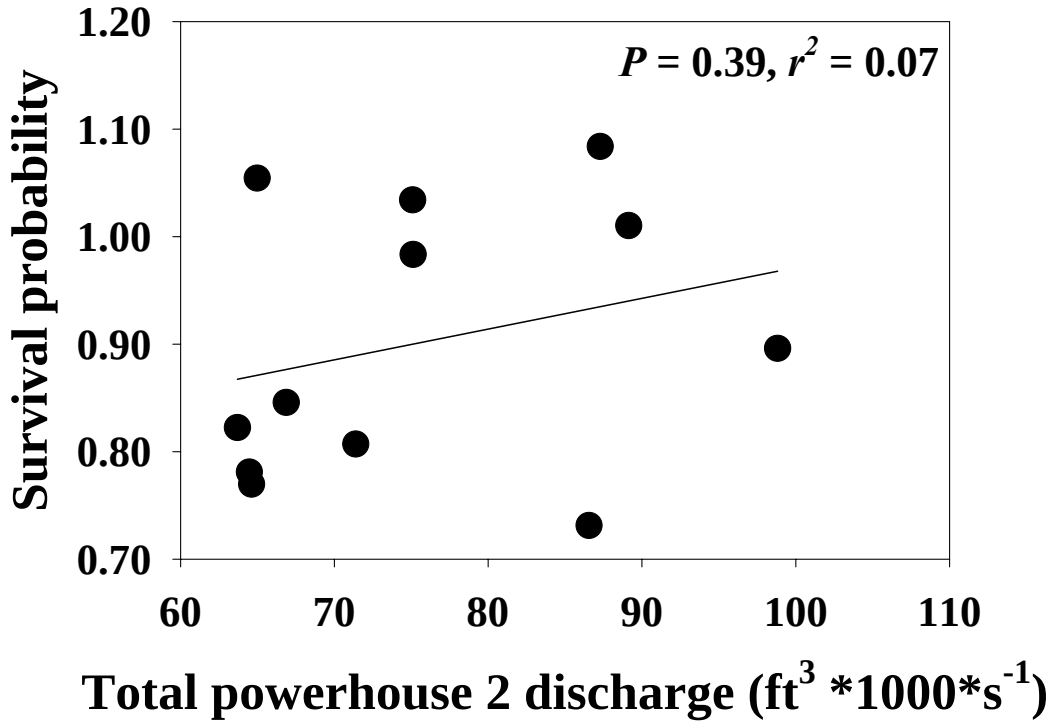

Figure 11. The relation of the survival of sub-yearling Chinook salmon released near Hood River, OR and detected passing Bonneville Dam and total discharge through Bonneville Dam Powerhouse 2.

Table 27. Survival probabilities and associated standard errors for sub-yearling Chinook salmon passing via the Powerhouse 2 (PH 2) juvenile bypass system based on paired releases of sub-yearling Chinook released though the juvenile bypass at Powerhouse 2 and in the tailrace of Bonneville Dam downriver of the Powerhouse 2 juvenile bypass.

Paired Release	Bonneville Dam PH 2 Juvenile Bypass Survival		
	Day/Night	Survival	Standard Error
1	Night	0.90	0.064
2	Day	1.28	0.214
3	Night	1.09	0.138
4	Day	0.86	0.129
5	Night	0.95	0.090
6	Day	0.77	0.114
7	Night	0.92	0.127
8	Day	0.91	0.097
9	Day	0.63	0.105
10	Day	1.02	0.170
11	Day	0.62	0.159
12	Night	0.88	0.174

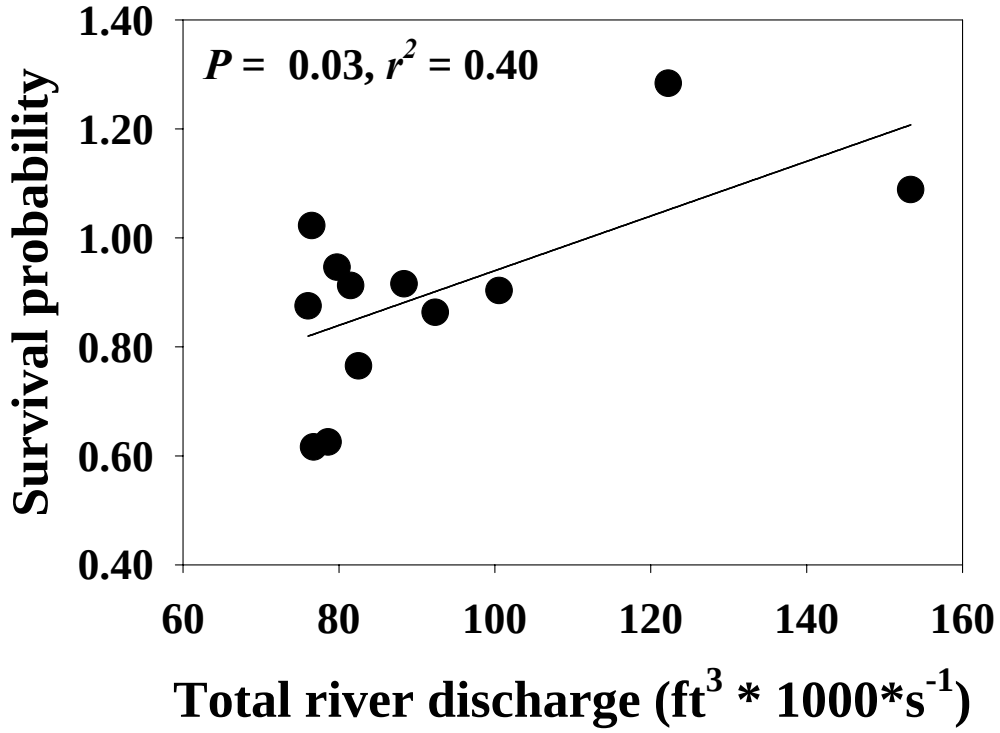

Figure 12. The relation of the survival of sub-yearling Chinook salmon released into the top of the Bonneville Dam Powerhouse 2 juvenile bypass system and total discharge.

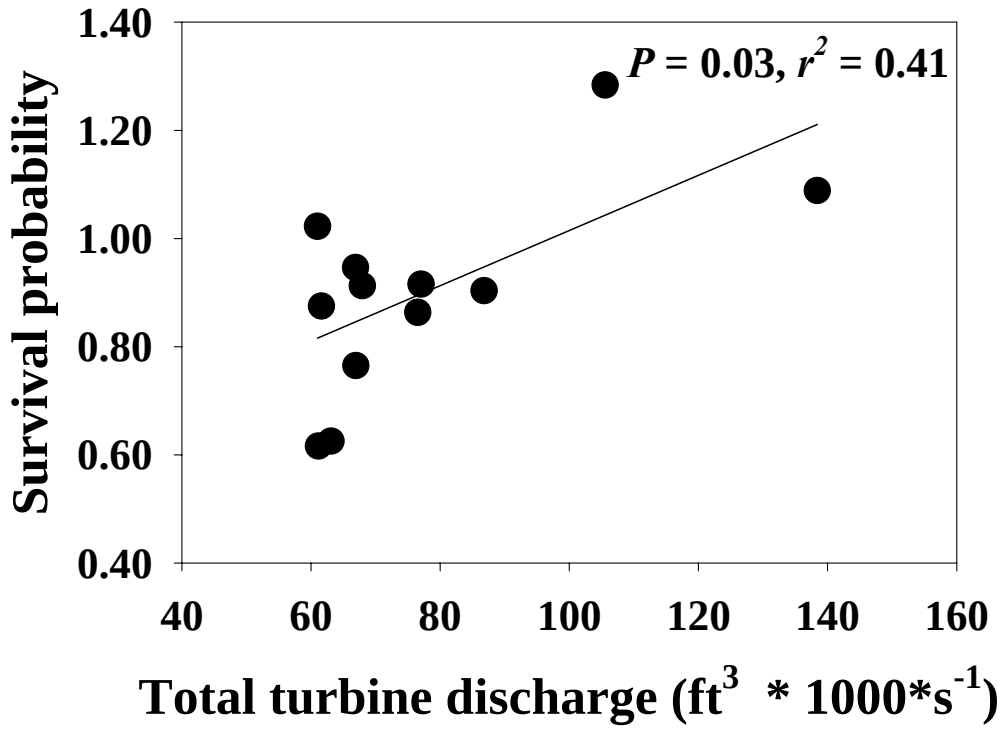

Figure 13. The relation of the survival of sub-yearling Chinook salmon released into the top of the Bonneville Dam Powerhouse 2 juvenile bypass system and total turbine discharge.

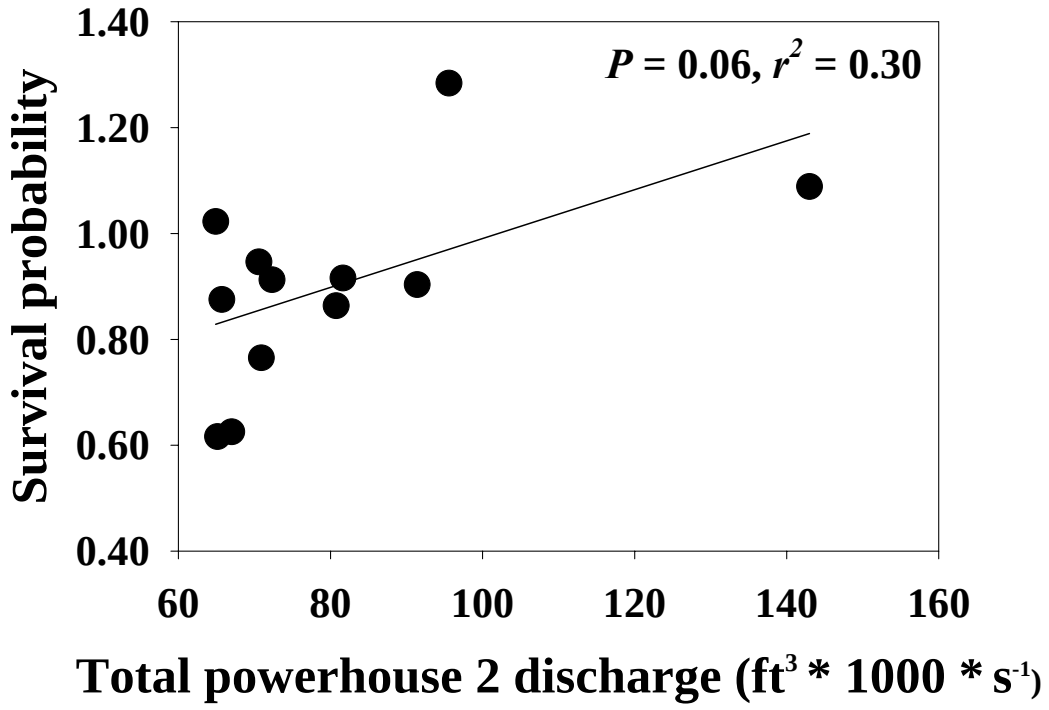

Figure 14. The relation of the survival of sub-yearling Chinook salmon released into the top of the Bonneville Dam Powerhouse 2 juvenile bypass system and total discharge through Bonneville Dam Powerhouse 2.

Table 28. Correlation matrix for total river discharge, total Powerhouse 2 (PH2) discharge, and total turbine discharge present during paired releases of sub-yearling Chinook released through the Powerhouse 2 juvenile bypass system during the summer migration 2001.

	Pearson's correlation coefficient (r)		
	Total River Discharge	Total Turbine Discharge	Total PH2 Discharge
Total river discharge	1.000	0.997	0.978
Total turbine discharge	0.997	1.000	0.985
Total PH2 discharge	0.978	0.985	1.000

Releases of yearling and sub-yearling Chinook salmon near Hood River, OR were conducted during 2001 to provide estimates of survival through Bonneville Dam. To generate survival estimates through Bonneville Dam corresponding releases of yearling Chinook were made in the tailrace of Bonneville Dam below the Powerhouse 2 juvenile bypass system outfall. Releases have to be timed so that fish released near Hood River, OR arrive at approximately the same time as the release of the control group in the tailrace area of Bonneville Dam. To accomplish this, we used travel time information from past studies conducted by the USGS to formulate the logistics associated with these releases. To a large extent, we were able to match the arrival and passage time of fish released near Hood River, OR at Bonneville Dam with the release times of fish below the Powerhouse 2 juvenile bypass system outfall and thus, have our treatment and control groups migrating downriver at approximately the same time. Only one test indicated significant differences in the arrival times of yearling Chinook salmon to Bonneville Dam.

However, four significant differences (out of 36 tests evaluated) in arrival times of treatment and control groups were detected for sub-yearling Chinook salmon released near Hood River, OR and interrogated at Bonneville Dam. The number of significant differences for this particular evaluation was greater at the array that was furthest downriver than the two arrays upriver of this location. This result suggests that the differences in arrival times between the treatment and control groups of sub-yearling Chinook became greater for those paired release groups as they traveled further downriver. In all cases the paired-releases of sub-yearling Chinook near Hood River, OR that were interrogated at Bonneville Dam arrived at the first telemetry array on the same day, suggesting that the treatment and control groups were mixed as they migrated through the first river reach (e.g., the reach that S_{11} and S_{21} were estimated; see Figure 1)

The results of the chi-square tests of homogeneity are intended to infer whether treatment and control groups are experiencing the same environmental conditions as they travel downriver (e.g., if the arrival times are significantly different then the treatment and control groups may have experienced different environmental conditions). To address whether this was the case, we evaluated the discharge and temperature conditions experienced by the two groups, where significant differences in arrival times were detected, given their arrival times at the downstream arrays. Differences in discharge and temperature conditions experienced by the treatment and control groups were present but minimal with the exception of the discharge conditions present for the paired release group 2 at the radio-telemetry array at rkm 194 (Table 30). The control group for this release passed this particular array on the evening of 3 July while the treatment group passed this array during the early morning of 4 July when the discharge through Bonneville Dam was reduced drastically, presumably to accommodate the reduced electricity demand on this holiday. For the remainder of the releases, discharge and temperature conditions were similar, suggesting that even though there were significant differences in arrival times between the treatment and

Table 29. The discharge and water temperature conditions of treatment (released near Hood River, OR and detected at Bonneville Dam) and control (released below the Powerhouse 2 juvenile bypass outfall) groups of sub-yearling Chinook salmon where significant differences in arrival times were indicated.

Release number (Array location in rkm)	Discharge ($ft^3 \cdot s^{-1} \cdot 1000$)		Water temperature (C)	
	Treatment	Control	Treatment	Control
2 (rkm 194)	103.63	145.34	18.99	18.79
2 (rkm 181)	102.56	121.59	19.1	18.81
5 (rkm 181)	83.72	82.83	19.18	19.45
12 (rkm 181)	100.35	92.48	19.33	19.23

control groups, the environmental conditions were similar. For the evaluations of the Powerhouse 2 juvenile bypass no significant differences were detected for yearling and sub-yearling Chinook. Thus, the assumption of mixing of the treatment and control groups was mostly satisfied during 2001 at Bonneville Dam.

A sequential evaluation of log-likelihood tests testing for significant difference in the survival model parameters was also performed to further evaluate the assumption of mixing. For yearling and sub-yearling Chinook salmon known to have passed Bonneville Dam, all but one of the models selected suggest that the survival of treatment and control groups were not significantly different in the river reaches evaluated below Bonneville Dam. However, there was some indication that the capture probabilities differed for the treatment and control groups. The selection of the Cormack-Jolly-Seber models further confounded the interpretation of these results. The mechanism for potential differences in the capture probabilities for the two groups remains unknown. However, difference in the water depths that the fish were migrating at and a variety of other factors could account for these differences.

Releases of dead radio-tagged yearling and sub-yearling Chinook salmon at Bonneville Dam indicated that it was possible that dead fish may have been detected at the downriver radio-telemetry arrays. One dead radio-tagged yearling Chinook salmon was detected at all of the three radio-telemetry detection arrays below Bonneville Dam and one dead radio-tagged sub-yearling Chinook salmon was detected at the first radio-telemetry detection array below Bonneville Dam. False positive-detections from radio tags on dead fish may positively bias survival estimates (Skalski et al. 1998a). We hypothesize that we are experiencing difficulties with the technique used to euthanize fish. We are continuing to refine the methods for this procedure to include pithing in addition to the MS 222 dose administered.

During 2002, we evaluated the application of our standard operating procedures for euthanizing fish and identified a potential error in the implementation of the procedures during 2001. Field staff at Bonneville Dam neglected to employ a screen that is designed to stop fish undergoing the procedure to go to the surface of the container and gulp air, a response of fish being anaesthetized with MS-222. During the spring of 2002 we conducted an informal experiment to address the adequacy of our procedures and found that some fish that were allowed to access the surface during the procedure became positively buoyant (USGS, unpublished data). Thus, the deviation from the established protocol may have increased the probability that the dead radio-tagged fish became positively buoyant, floated downriver, and were detected at the downstream radio telemetry arrays. Data collected at Bonneville Dam during 2002 indicates that no dead radio-tagged yearling Chinook salmon have been detected at any of the downstream arrays. Consequently, we have evidence suggesting a mechanism for the unusual finding of dead fish being detected at the

downstream arrays below Bonneville Dam (unusual because we have not documented the detection of dead fish at other projects, such as John Day and The Dalles dams) that is potentially an artifact of the procedures used during this part of the overall study and not indicative of normal field conditions.

Evaluations of the survival of yearling and sub-yearling Chinook salmon were made through Bonneville Dam's Powerhouse 2 juvenile bypass system and through all routes collectively at the project during 2001. No significant differences between the day and night survival of yearling and sub-yearling Chinook salmon were found. However the scaled back evaluations and the reduced number of releases because of logistical constraints caused by river conditions during 2001 (e.g., only 12 releases of sub-yearling Chinook were made during 2001 because of water temperature and fish collection constraints) resulted in tests with low statistical power. Evaluations of survival through Bonneville Dam were also conducted during 2000. The 2000 study was intended to help formulate and assess the adequacy of proposed logistics associated with using radio-telemetry to assess various measures of juvenile salmonid survival through this project. Dam operating conditions during 2001 differed from those during 2000 because of the low water year. For instance, the absence of spill for approximately one-half the period evaluated during the spring migration precludes meaningful comparisons of spill survival between years because only seven releases were conducted during the yearling Chinook evaluations and no releases of sub-yearling Chinook were made during spill operations during 2001.

Spill operations at Bonneville Dam were present during the last seven paired releases of yearling Chinook which allowed some post-hoc comparisons to be made between fish arriving during spill and no spill operations. No significant differences between the survival of fish passing via all routes during spill and no spill operations at Bonneville Dam were detected. However, when the paired releases were separated into turbine and non-turbine passed fish, significant differences in survival between fish passed during spill and no spill operations were detected. The survival of yearling Chinook passing via the turbines was greater during periods of no spill versus spill operations while the opposite was true for non-turbine passed fish (e.g., survival was greater during periods of spill v. no spill operations). The opposite trends in survival between these two groups likely contributed to the insignificant difference in the survival of fish passing via all routes at Bonneville Dam during spill and no spill.

Preliminary data suggests that discharge through Powerhouse 2 was greater during the periods of no spill than during spill operations, which would be expected. The altered immediate tailrace hydraulics caused by the higher discharge may have altered egress times or routes and also the distribution of predators in this area. However, these data also suggest that the specific operation of Powerhouse 2 (i.e., discharge through specific turbine units) did not differ drastically during spill and no spill operations.

Acknowledgements

We thank Blaine Ebberts, Mike Langeslay, and Rock Peters, and other personnel at the Army Corps of Engineers for their assistance in administering our contract and assisting with the logistics involved with coordinating this research at Bonneville Dam. We also thank the countless staff at the Columbia River Research Laboratory who participated in the planning and collection and processing of the data associated with these studies. We also acknowledge the assistance of the administrative staff at the Columbia River Research Laboratory for their support in managing the contract for this research.

References

Akaike, H. 1973. Information theory as an extension of the maximum likelihood prionciple. pp. 267-281 *in* B.N. Petrov, and F. Csaki (eds.) Second International Symposium on Information Theory. Akademiai Kiado, Budapest.

Bell, C.E., and B. Kynard. 1985. Mortality of adult American shad passing through a 17-MW Kaplan turbine at a low-head dam. North American Journal of Fisheries Management 5:33-38.

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.

Dawley, E.M., L.G. Gilbreath, E.P. Nunnallee, and B. P. Sandford. 1998. Relative 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.

Evans, S. D., J. M. Plumb, A. C. Bratz, K. S. Gates, N. S. Adams, and D. W. Rondorf. 2001. Passage behavior of radio-tagged juvenile salmonids at Dam associated with the surface bypass program, 2000. Report to the Army Corps of Engineers, United States Geological Survey, Cook, WA.

Giorgi, A.E., L. Stuehrenberg , and J.W. Wilson. 1985. Juvenile radio-tag study: Lower Granite Dam, 1985-86. Report prepared for the Bonneville Power Administration, U.S. Department of Energy, Portland, OR.

Hansel, C.H., R.S. Shively, J.E. Hensleigh, B.D. Liedtke, T. Hatton, R.E. Wardell, R.H. Wertheimer, and T.P. Poe. 1998. Movement, distribution, and behavior of radio-tagged sub-yearling Chinook salmon in the forebay of Bonneville Dam, 1998. Preliminary report to the U.S. Army Corps of Engineers, Portland, Oregon.

Hensleigh, J. E., R. S. Shively, H. C. Hansel, J. M. Hardiman, G. S. Holmberg, B. D. Liedtke, T. L. Martinelli, R. E. Wardell, R. H. Wertheimer, and T. P. Poe. 1999. Movement, distribution, and behavior of radio-tagged juvenile Chinook salmon and steelhead in John Day, The Dalles, and Bonneville Dam Forebays, 1997. Annual Report of Research to the U.S. Army Corps of Engineers, Portland District, Portland, Oregon, USA.

Holmberg, G.S., R.S. Shively, H.C. Hansel, T.L. Martinelli, M.B. Sheer, J.M. Hardiman, B.D. Liedtke, L.S. Blythe, and T.P. Poe. 1998. Movement, distribution, and behavior of radio-tagged juvenile Chinook salmon in John Day, The Dalles, and Bonneville Dam Forebays, 1996. Annual Report of Research to the U.S. Army Corps of Engineers, Portland District, Portland, Oregon, USA

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.

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.

Neter, J, W. Wasserman, and M. H. Kutner. 1989. Applied linear regression models. Richard D. Irwin, Inc. IL.

NMFS 2000 FCRPS Biological Opinion

Normandeau Associates, Inc., J.R. Skalski, and Parametrix, Inc. 1998. Feasibility of estimating smolt survival with radio telemetry through the Priest Rapids hydroelectric project, Columbia River, Washington. Report prepared for Grant County Public Utility District No. 2.

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.

SAS Institute. 1994. SAS\STAT Users Guide, Version 6, 4th Edition, Volume 2 SAS Institute, Cary, North Carolina.

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

Sheer, M.B., G.S. Holmberg, R.S. Shively, T.P. King, C.N. Frost, H.C. Hansel, T.M. Martinelli, and T.P. Poe. 1997. Movement, distribution, and passage behavior of radio-tagged juvenile Chinook salmon in John Day and The Dalles Dam forebays, 1995. Annual report of research, U.S. Army Corps of Engineers, Portland District, Portland, Oregon, USA.

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.

Skalski, J.R., R.L. Townsend, and A.E. Giorgi. 1998a. The design and analysis of salmonid tagging studies in the Columbia River Basin, Volume XI, Recommendations on the design and analysis of radiotelemetry studies of salmonid smolts to estimate survival and passage efficiencies. Report prepared for the U.S. Department of Energy, Bonneville Power Administration. Division of Fish and Wildlife, Contract DE-B179-90BP02341.

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

Smith, S. G., J.R. Skalski, 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.

Sokal, R.R., and Rohlf, F.J. 1995. Biometry, 3rd edition, Freeman, New York.

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.

Vendetti, D. A., D. W. Rondorf, and J. M. Kraut. 2000. Migratory behavior and forebay delay of radio-tagged juvenile fall Chinook salmon in a lower Snake

River impoundment. North American Journal of Fisheries Management. 20:41:52.

White, G.C. 1983. Numerical estimation of survival rates from band-recovery and biotelemetry data. Journal of Wildlife Management. 47:716-728.