









































































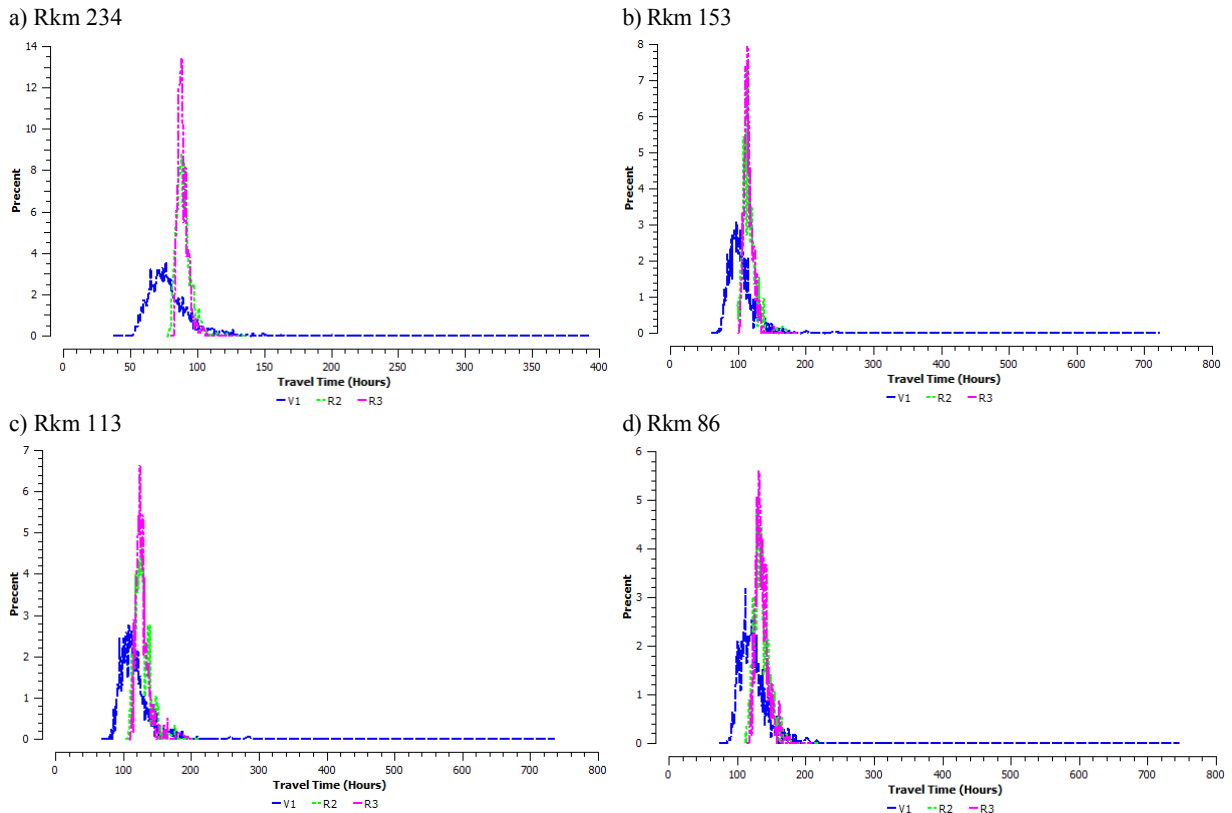






### 3.2.6 Downstream Mixing

To help induce downstream mixing of the release groups, the  $R_1$  release of subyearling Chinook salmon smolts was, on average, 60 h before the  $R_2$  release which, in turn, occurred 13 h before  $R_3$ . Plots of the arrival timing of the various release groups at downstream detection sites indicate reasonable mixing (Figure 3.6). The arrival modes for releases  $R_2$  and  $R_3$  were nearly synchronous. The modes for  $R_2$  and  $R_3$  were slightly later than the arrival mode for  $V_1$  but during the majority of the distribution of arrival times for  $V_1$  (Figure 3.6).



**Figure 3.6.** Frequency Distribution Plots of Downstream Arriving Timing (expressed as percentages) for Subyearling Chinook Salmon Releases  $V_1$ ,  $R_2$ , and  $R_3$  at Detection Arrays Located at (a) Rkm 234, (b), Rkm 153, (c) Rkm 113, and (d) Rkm 86. (See Figure 2.1). All times adjusted relative to the release time of  $R_1$ . The distributions averaged over all release groups.

## 3.3 Survival and Passage Estimates

This section contains estimates for dam passage survival, forebay-to-tailrace passage survival, forebay residence time, tailrace egress time, spill passage efficiency, and fish passage efficiency.

### 3.3.1 Dam Passage Survival

The estimates of dam passage survival were based on the virtual/paired-release design using capture history data (Appendix A, Tables A.1 and A.2) and the fitted tag-life curve (Figure 3.4). The estimator included tag-life-adjusted survival estimates for releases  $V_1$ ,  $R_2$ , and  $R_3$ . A total of six detection sites were

used in the analysis (Figure 2.1, Table 3.4), plus the pooling of detections at arrays rkm 49 – rkm 3, to assure all available information was used in the estimation process. A fully parameterized model with distinct survival and capture probabilities for each release group was used to assure robustness of the estimation procedure.

The estimate of dam passage survival was based on the survival of  $V_1$  to detection array  $D_1$  divided by an estimate of reach survival between the tailrace array (rkm 307) and  $D_1$ . Using the tag-life-adjusted survival estimates for subyearling Chinook salmon smolts (Table 3.4), dam passage survival at The Dalles Dam was calculated to be

$$\hat{S}_{\text{TDA}} = \frac{\hat{S}_1}{\left( \frac{\hat{S}_2}{\hat{S}_3} \right)} = \frac{0.9210}{\left( \frac{0.9707}{0.9912} \right)} = \frac{0.9210}{0.9793} = 0.9404$$

with an associated standard error of 0.0091.

Additional analyses indicated this estimate of survival was robust to the number of downstream detection arrays used and whether the downstream survival and detection probabilities were modeled to be homogeneous across reaches or not. The standard error is based on both the multinomial sampling error of the release-recapture process and the sampling error associated with the estimation of the probabilities of tag activation (Table 3.3).

The estimate of dam survival for subyearling Chinook salmon at The Dalles in 2010 achieves the BiOp requirement for  $\hat{S}_{\text{Dam}} \geq 0.93$  and the standard error requirement of  $\widehat{SE} \leq 0.015$ .

**Table 3.4.** Tag-Life-Adjusted Survival Estimates of Reach Survival and Detection Probabilities for Subyearling Chinook Salmon Smolts Used in Estimating Dam Passage Survival at The Dalles Dam in 2010. Parameter estimates based on fully parameterized release-recapture models for each group. Standard errors (SE) based on both the inverse hessian matrix and bootstrapping for key parameters (†) and only the inverse hessian matrix for associated parameters (\*).

**Survival Probabilities**

Release Group	Rkm 309 to 275		Rkm 275 to 234		Release to Rkm 234		Rkm 234 to 153		Rkm 153 to 113		Rkm 113 to 86.2	
	Estimate	SE†	Estimate	SE*	Estimate	SE†	Estimate	SE*	Estimate	SE*	Estimate	SE*
$V_1$	0.9210	0.005492	0.9794	0.003308	---	---	0.9332	0.005673	0.9814	0.003322	0.9875	0.002763
$R_2$	---	---	---	---	0.9707	0.006393	0.9556	0.007827	0.9904	0.004148	0.9746	0.006189
$R_3$	---	---	---	---	0.9912	0.004090	0.9591	0.007577	0.9839	0.004966	0.9930	0.003760

**Detection Probabilities**

Release Group	$D_1$		$D_2$		$D_3$		$D_4$		$D_5$		$\lambda$ Survival × Capture	
	Estimate	SE*	Estimate	SE*	Estimate	SE*	Estimate	SE*	Estimate	SE*	Estimate	SE*
$V_1$	0.9995	0.000460	0.9463	0.005006	0.8551	0.007936	0.9562	0.004647	0.9349	0.005677	0.9720	0.003875
$R_2$	---	---	0.9271	0.009549	0.8597	0.012820	0.9497	0.008178	0.9507	0.008251	0.9618	0.007343
$R_3$	---	---	0.9130	0.010228	0.8728	0.012190	0.9541	0.007697	0.9352	0.009238	0.9568	0.007720

\* Standard error is based on the inverse Hessian.

† Standard error is based on bootstrapping.

**3.3.2 Forebay-to-Tailrace Passage Survival**

The estimate of forebay-to-tailrace passage survival was calculated analogously to that of dam passage survival except the virtual –release group ( $V_1$ ) was composed of fish known to have arrived at the forebay (i.e., detection array rkm 311, Figure 2.1) rather than at the dam face. Although the capture history data for  $V_1$  changed (Appendix A, Table A.1), the same capture-history data were used for releases  $R_2$  and  $R_3$  (Appendix A, Table A.2). Using the same statistical model as was used in estimating dam passage survival, forebay-to-tailrace survival for yearling Chinook salmon was estimated to be

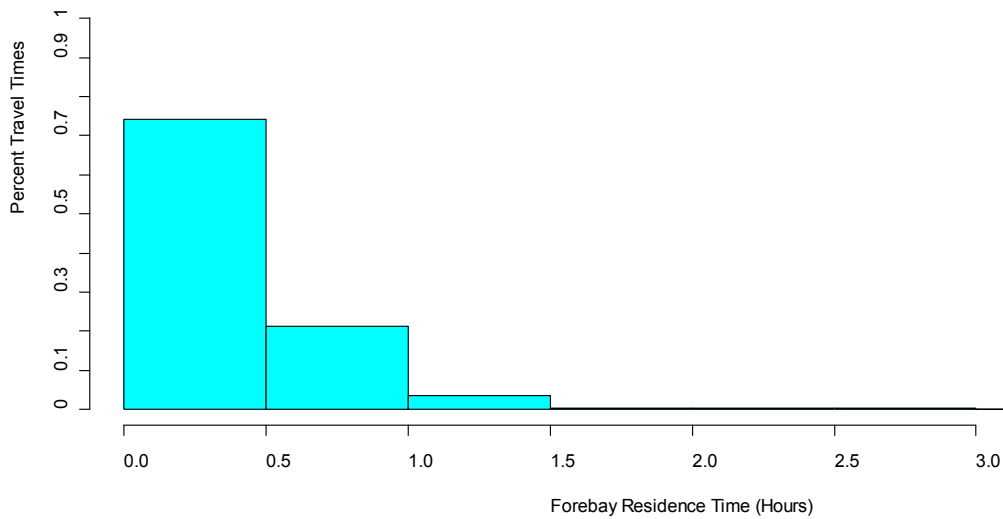
$$\hat{S}_{\text{Forebay-to-tailrace}} = 0.9356 (\widehat{SE} = 0.0092).$$

As might be expected, the forebay-to-tailrace survival estimate was slightly lower than the respective estimate of dam passage survival due to the additional travel distance above the dam. The Fish Accords do not have compliance standards for either the forebay-to-tailrace survival estimate or its standard error. Nevertheless, standard errors for the estimates of dam passage survival and forebay-to-tailrace should be similar because of the very similar sample sizes used in both calculations.

### 3.3.3 Forebay Residence Time

The forebay residence times were based on the times from the first detection within 100 m of the dam face to the last detection at the double array in front of The Dalles Dam. The timing of the first detection within 100 m of the dam was based on 3D tracking of the acoustic-tagged fish and interpretation of the time when the fish first crossed the 100-m distance threshold.

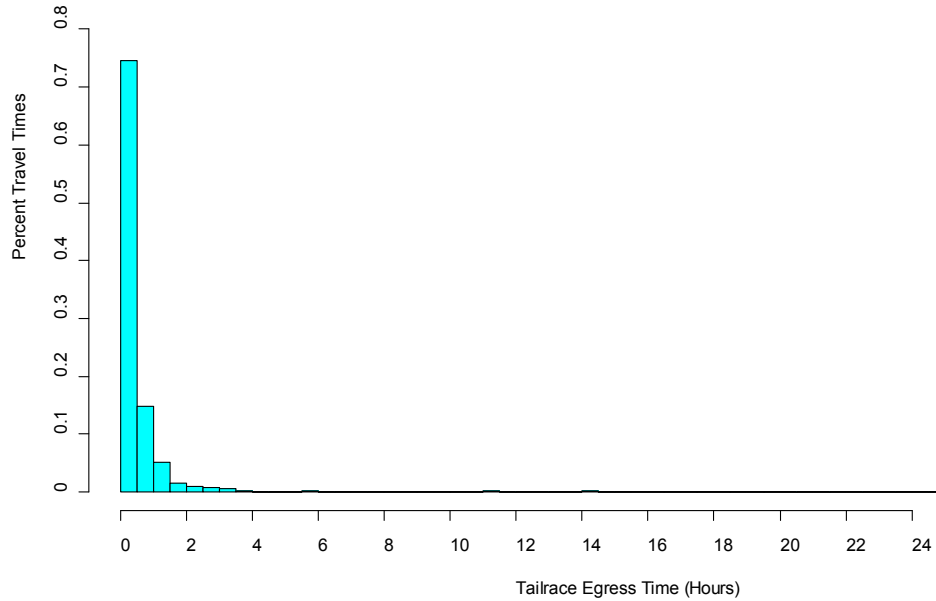
Distribution of forebay residence times ranged from 0.02 h to 169.2 h for subyearling Chinook salmon (Figure 3.7). Mean residence time for subyearling Chinook salmon smolts was estimated to be  $\bar{t} = 0.72$  h ( $\widehat{SE} = 0.28$ ,  $n = 1,584$ ). The median was 0.25 h.



**Figure 3.7.** Distribution of Forebay Residence Times for Subyearling Chinook Salmon Smolts at The Dalles Dam, 2010

### 3.3.4 Tailrace Egress Time

The tailrace egress time was calculated based on the time from the last detection of fish at the double array at the face of The Dalles Dam to the first detection at the BRZ tailrace array. The range of tailrace egress times for subyearling Chinook salmon was 0.098 h to 298.78 h (Figure 3.8). Mean tailrace egress time for subyearling Chinook salmon smolts was estimated to be  $\bar{t} = 1.42$  ( $\widehat{SE} = 0.28$ ,  $n = 2,054$ ). Like forebay residence time, the median was 0.25 h.



**Figure 3.8.** Distribution of Tailrace Egress Times for Subyearling Chinook Salmon Smolts at The Dalles Dam, 2010

### 3.3.5 Spill Passage Efficiency

Spill passage efficiency (SPE) is the fraction of the fish that passed through a hydropower project by the spillway. (In the Fish Accords, the definition of SPE also included sluice passage. This metric is presented below as Fish Passage Efficiency.) The double-detection array at the face of The Dalles Dam was used to identify and track fish as they entered the dam. Using the observed counts and assuming detection efficiency was 100%, the number of fish entering the spillway and powerhouse were used to estimate SPE using a binomial sampling model. For subyearling Chinook salmon smolts at The Dalles Dam in 2010, the proportion of fish that went through the spillway is estimated to be

$$\widehat{SPE} = 0.7122(\widehat{SE} = 0.0092, n = 2415).$$

### 3.3.6 Fish Passage Efficiency

Fish passage efficiency (FPE), called spill passage efficiency in the Fish Accords, is the fraction of the fish that passed through a hydropower project by the spillway and the sluiceway. As with spill passage efficiency, the double-detection array at the face of The Dalles Dam was used to identify and track fish as they entered the dam. Using the observed counts and assuming detection efficiency was 100%, the number of fish entering the spillway and powerhouse were used to estimate FPE using a binomial sampling model. For subyearling Chinook salmon smolts at The Dalles Dam in 2010, fish passage efficiency is estimated to be

$$\widehat{FPE} = 0.8298(\widehat{SE} = 0.0076, n = 2415).$$



## 4.0 Discussion

### 4.1 Historical Context

Historically, telemetry studies have been used to estimate survival rates for subyearling Chinook salmon passing The Dalles Dam. For radio-tag studies conducted during 2002, 2004, and 2005 (Counihan et al. 2006a, 2006b, 2006c), survival estimates were generated using the route-specific survival model for radio-tagged fish released by boat in the tailraces of John Day Dam (treatment) and The Dalles Dam (control). As summarized by Johnson et al. (2007:7.3), the mean dam survival rate for subyearling Chinook salmon over the three study-years was 0.883.

During the subyearling Chinook salmon migration in summer 2006, an acoustic-tag study was used to estimate passage survival at The Dalles Dam (Ploskey et al. 2007). The estimation process involved releases from the John Day and The Dalles Dam tailraces along with downstream detections at The Dalles Dam primary (rkm 275), The Dalles secondary (rkm 234), and Bonneville Dam primary (rkm 153) arrays. At The Dalles Dam, project passage survival was estimated to be 0.9404 ( $\widehat{SE} = 0.0091$ ) for subyearling Chinook salmon.

During 2008 and 2009, Weiland et al. (2009 and 2010, respectively) performed acoustic-tag studies at John Day Dam that included releases and downstream detection arrays allowing estimation of survival between forebay arrays at The Dalles and Bonneville dams. Specifically, tagged fish were released near Arlington, Oregon (rkm 390) and in the John Day Dam tailrace (rkm 343.4), and regrouped on The Dalles Dam forebay entrance array to create virtual releases for estimating single-release dam-passage survival rates for The Dalles Dam. Tag-life-corrected survival rates from 2 km upstream of The Dalles Dam to the Bonneville Dam forebay, estimated for subyearling Chinook salmon using a single-release model, were as follows ( $\pm 95\%$  CI):

Year	Subyearling Chinook Salmon
2008	0.931 $\pm$ 0.013
2009	0.789 $\pm$ 0.051

Thus, the 2010 dam passage survival of 0.9404 for subyearling Chinook salmon is higher than recent estimates of passage survival estimates from 2008 and 2009 for The Dalles Dam.

### 4.2 Statistical Performance

The BiOp requires estimates of dam passage survival with standard errors  $\leq 0.015$ . The numbers of tagged fish released (Table 2.1) and the detection probabilities at the downstream hydrophone arrays (Table 3.5) in summer 2010 were found to be adequate to achieve this precision requirement. The estimated standard error for subyearling Chinook salmon was  $<0.01$ . Therefore, the number of tagged fish released for the survival studies in future years should be comparable to those used in 2010 to help assure precision requirements will be achieved. Should levels of hydrophone deployment change, the number of fish tagged may need to be reassessed.

### 4.3 Model Assumptions

The summer subyearling Chinook salmon study at The Dalles Dam is the second full-scale application of the virtual/paired-release design of Skalski et al. (2010) in the FCRPS. The first study was the spring yearling Chinook salmon and steelhead study at the Dalles Dam (Pacific Northwest National Laboratory and University of Washington 2010). The virtual-paired release design worked as conceived. The virtual release group ( $V_1$ ) estimated smolt passage survival from the dam face to a downriver detection array at rkm 275. This array at rkm 275 was selected because it was sufficiently downriver to assure any fish that died during dam passage with a still active tag would not be detected on downstream arrays. A separate release of 21 dead fish with active tags at The Dalles Dam spillway in 2010 resulted in no downstream detections at rkm 275. To account for the extra mortality between the tailrace and the detection array at rkm 275, a paired release using groups  $R_2$  and  $R_3$  was used to estimate reach survival in the upper part of the Bonneville reservoir. The quotient of the survival estimates from the virtual release ( $V_1$ ) and paired release ( $R_2$  and  $R_3$ ) was the basis for the estimates of dam passage survival in this report.

Graphs of arrival timing (Figure 3.6) indicate the release timing of the different tag groups was appropriate for adequate downstream mixing of fish. Travel times were also sufficiently short relative to tag life to adequately adjust the release-recapture data for tag failure (Figure 3.5). In all cases, the probability that an acoustic tag was active at a downstream detection location was  $>0.999$  (Table 3.3). In other words, for this summer investigation, very little tag-life correction was needed to produce unbiased survival estimates.

The estimate of dam passage survival of  $\hat{S}_{TDA} = 0.9404$  ( $\widehat{SE} = 0.0091$ ) for subyearling Chinook salmon smolts was found to be robust to the number of downstream detection arrays used in the analysis and whether the release-recapture models were reparameterized for downstream homogeneity of survival and detection probabilities. Using as few as three downstream detection arrays (plus arrays rkm 3--153 pooled) produced the same survival results as those reported. Using even fewer downstream detection arrays still produced estimates of dam passage survival  $>0.93$ . We are therefore confident that the 2010 subyearling Chinook salmon survival study at The Dalles Dam met the BiOp survival standard.

## 5.0 References

- 3 Treaty Tribes-Action Agencies. 2008. Memorandum of Agreement Among the Umatilla, Warm Springs and Yakama Tribes, Bonneville Power Administration, U.S. Army Corps of Engineers, nd U.S. Bureau of Reclamation, Portland, Oregon, April 4, 2008. Available at <http://www.salmonrecovery.gov/ColumbiaBasinFishAccords.aspx>.
- Burnham, KP, DR Anderson, GC White, C Brownie, and KH Pollock. 1987. "Design and analysis methods for fish survival experiments based on release-recapture." *American Fisheries Society Monograph 5*. Bethesda, Maryland.
- Counihan, TD, G. Holmberg, CE Walker, and JM Hardiman. 2006a. *Survival estimates of migrant juvenile salmonids through The Dalles Dam using radiotelemetry, 2002*. Final report of research prepared for the U.S. Army Corps of Engineers, Portland, Oregon by the US Geological Survey, Cook, Washington.
- Counihan, TD, AL Puls, CE Walker, JM Hardiman, and GS Holmberg. 2006b. *Survival estimates of migrant juvenile salmonids through The Dalles Dam using radiotelemetry, 2004*. Final report of research prepared for the U.S. Army Corps of Engineers, Portland, Oregon by the US Geological Survey, Cook, Washington.
- Counihan, TD, AL Puls, CE Walker, JM Hardiman, and GS Holmberg. 2006c. *Survival estimates of migrant juvenile salmonids through The Dalles Dam using radiotelemetry, 2005*. Final report of research prepared for the U.S. Army Corps of Engineers, Portland, Oregon by the US Geological Survey, Cook, Washington.
- Johnson, GE, JW Beeman, IN Duran, and AL Puls. 2007. *Synthesis of juvenile salmonid passage studies at The Dalles Dam, Volume II, 2001-2005*. PNNL-16443, final report submitted to the U.S. Army Corps of Engineers, Portland District, Portland, Oregon, by Pacific Northwest National Laboratory, Richland, Washington.
- Li, T, and JJ Anderson. 2009. "The vitality model: A way to understand population survival and demographic heterogeneity." *Theoretical Population Biology* 76:118-131.
- Martinson, R, G Kovalchuk, and D Ballinger. 2006. *Monitoring of downstream salmon and steelhead at federal hydroelectric facilities. 2005-2006 Annual Report, Project No. 198712700, BPA Report DOE/BP-00022085-2, Portland, Oregon.*
- NOAA (National Atmospheric and Oceanic Administration) Fisheries. 2008. *Biological Opinion – Consultation on Remand for Operation of the Federal Columbia River Power System, 11 Bureau of Reclamation Projects in the Columbia Basin and ESA Section 10(a)(1)(A) Permit for Juvenile Fish Transportation Program*. National Marine Fisheries Service (NOAA Fisheries) – Northwest Region, Seattle, Washington. Available at <http://www.salmonrecovery.gov/>.
- Pacific Northwest National Laboratory and University of Washington. 2010. *Compliance monitoring of juvenile yearling Chinook salmon and steelhead survival and passage at The Dalles Dam, Spring 2010*. PNNL-19919, draft report submitted to the U.S. Army Corps of Engineers, Portland District, Portland, Oregon, by Pacific Northwest National Laboratory, Richland, Washington.

- Ploskey, GR, MA Weiland, JS Hughes, SR Zimmerman, RE Durham, ES Fischer, J Kim, RL Townsend, JR Skalski, and RL McComas. 2007. *Acoustic Telemetry Studies of Juvenile Chinook Salmon Survival at the Lower Columbia Projects in 2006*. PNNL-16560, final report prepared for U.S. Army Corps of Engineers District, Portland, Oregon, by Pacific Northwest National Laboratory, Richland, Washington.
- Seber, GAF. 1982. *The Estimation of Animal Abundance*. MacMillan, New York.
- Skalski, JR, RL Townsend, TW Steig, and S Hemstrom. 2010. "Comparison of two alternative approaches for estimating dam passage survival using acoustic-tagged sockeye salmon smolts." *North American Journal of Fisheries Management* 30:831-839.
- Townsend, RL, JR Skalski, P Dillingham, and TW Steig. 2006. "Correcting bias in survival estimation resulting from tag failure in acoustic and radiotelemetry studies." *Journal of Agricultural Biology and Environmental Statistics* 11(2):183-196.
- Weiland, MA, GR Ploskey, JS Hughes, Z Deng, T Fu, TJ Monter, GE Johnson, F Khan, MC Wilberding, AW Cushing, SA Zimmerman, DM Faber, RE Durham, RL Townsend, JR Skalski, J Kim, ES Fischer, and MM Meyer. 2009. *Acoustic Telemetry Evaluation of Juvenile Salmonid Passage and Survival at John Day Dam with Emphasis on the Prototype Surface Flow Outlet, 2008*. PNNL-18890, Pacific Northwest National Laboratory, Richland, WA.
- Weiland, MA and eighteen co-authors. 2010. *Acoustic telemetry evaluation of juvenile salmonid passage and survival proportions at John Day Dam, 2009*. PNNL-19422, draft final report submitted to the U.S. Army Corps of Engineers, Portland District, Portland, Oregon, by Pacific Northwest National Laboratory, Richland, Washington.

**Appendix A**  
**Capture History Data**



**Table A.1.** Capture Histories at Sites  $D_1 - D_6$  (Figure 2.1) for Release Group  $V_1$  for Subyearling Chinook Salmon Used in Estimating Dam Passage Survival and BRZ-to-BRZ Survival. A “1” Denotes Detection, “0” Denotes Nondetection, and “2” Denotes Detection and Censoring Due to Removal.

Capture History	$V_1$	
	Dam Passage Survival	BRZ-to-BRZ Survival
1 1 1 1 1 1:	1365	1361
0 1 1 1 1 1:	0	0
1 0 1 1 1 1:	86	86
0 0 1 1 1 1:	0	0
1 1 0 1 1 1:	226	226
0 1 0 1 1 1:	0	0
1 0 0 1 1 1:	10	10
0 0 0 1 1 1:	0	0
1 1 1 0 1 1:	66	66
0 1 1 0 1 1:	0	0
1 0 1 0 1 1:	2	2
0 0 1 0 1 1:	0	0
1 1 0 0 1 1:	11	11
0 1 0 0 1 1:	0	0
1 0 0 0 1 1:	0	0
0 0 0 0 1 1:	0	0
1 1 1 1 0 1:	83	83
0 1 1 1 0 1:	1	1
1 0 1 1 0 1:	4	4
0 0 1 1 0 1:	0	0
1 1 0 1 0 1:	30	30
0 1 0 1 0 1:	0	0
1 0 0 1 0 1:	0	0
0 0 0 1 0 1:	0	0
1 1 1 0 0 1:	5	5
0 1 1 0 0 1:	0	0
1 0 1 0 0 1:	0	0
0 0 1 0 0 1:	0	0
1 1 0 0 0 1:	0	0
0 1 0 0 0 1:	0	0
1 0 0 0 0 1:	0	0
0 0 0 0 0 1:	0	0
1 1 1 1 2 0:	0	0
0 1 1 1 2 0:	0	0
1 0 1 1 2 0:	0	0
0 0 1 1 2 0:	0	0
1 1 0 1 2 0:	0	0
0 1 0 1 2 0:	0	0
1 0 0 1 2 0:	0	0
0 0 0 1 2 0:	0	0
1 1 1 0 2 0:	0	0
0 1 1 0 2 0:	0	0
1 0 1 0 2 0:	0	0

Capture History	$V_1$	
	Dam Passage Survival	BRZ-to-BRZ Survival
001020:	0	0
110020:	0	0
010020:	0	0
100020:	0	0
000020:	0	0
111110:	41	41
011110:	0	0
101110:	3	3
001110:	0	0
110110:	6	6
010110:	0	0
100110:	0	0
000110:	0	0
111010:	1	1
011010:	0	0
101010:	0	0
001010:	0	0
110010:	0	0
010010:	0	0
100010:	0	0
000010:	0	0
111200:	0	0
011200:	0	0
101200:	0	0
001200:	0	0
110200:	0	0
010200:	0	0
100200:	0	0
000200:	0	0
111100:	22	22
011100:	0	0
101100:	3	3
001100:	0	0
110100:	2	2
010100:	0	0
100100:	0	0
000100:	0	0
112000:	0	0
012000:	0	0
102000:	0	0
002000:	0	0
111000:	32	31
011000:	0	0
101000:	1	1
001000:	0	0
120000:	31	31
020000:	0	0
110000:	141	141
010000:	0	0



Capture History	$V_1$	
	Dam Passage Survival	BRZ-to-BRZ Survival
2 0 0 0 0 0:	0	0
1 0 0 0 0 0:	54	54
0 0 0 0 0 0:	191	203
Total	2,417	2,424

**Table A.2.** Capture Histories at Sites  $D_1 - D_6$  (Figure 2.1) for Release Groups  $R_2$ , and  $R_3$  for Subyearling Chinook Salmon Used in Estimating Dam Passage Survival. A “1” Denotes Detection, “0” Denotes Nondetection, and “2” Denotes Detection and Censoring Due to Removal.

Capture History	Dam Passage Survival	
	$R_2$	$R_3$
1 1 1 1 1:	493	505
0 1 1 1 1:	38	47
1 0 1 1 1:	86	71
0 0 1 1 1:	6	9
1 1 0 1 1:	24	25
0 1 0 1 1:	4	2
1 0 0 1 1:	4	4
0 0 0 1 1:	0	1
1 1 1 0 1:	28	37
0 1 1 0 1:	0	2
1 0 1 0 1:	5	4
0 0 1 0 1:	0	2
1 1 0 0 1:	1	1
0 1 0 0 1:	0	0
1 0 0 0 1:	0	0
0 0 0 0 1:	0	0
1 1 1 2 0:	0	0
0 1 1 2 0:	0	0
1 0 1 2 0:	0	0
0 0 1 2 0:	0	0
1 1 0 2 0:	0	0
0 1 0 2 0:	0	0
1 0 0 2 0:	0	0
0 0 0 2 0:	0	0
1 1 1 1 0:	20	26
0 1 1 1 0:	2	1
1 0 1 1 0:	1	2
0 0 1 1 0:	0	0
1 1 0 1 0:	3	0
0 1 0 1 0:	0	0
1 0 0 1 0:	0	0
0 0 0 1 0:	0	1
1 1 2 0 0:	0	0

0 1 2 0 0:	0	0
1 0 2 0 0:	0	0
0 0 2 0 0:	0	0
1 1 1 0 0:	16	5
0 1 1 0 0:	2	1
1 0 1 0 0:	0	1
0 0 1 0 0:	1	0
1 2 0 0 0:	0	0
0 2 0 0 0:	0	0
1 1 0 0 0:	6	11
0 1 0 0 0:	1	0
2 0 0 0 0:	0	1
1 0 0 0 0:	33	31
0 0 0 0 0:	26	10
<hr/>		
Total	800	800
<hr/>		

## Distribution

**PDF**  
**Copies**

**External Distribution**

Brad Eppard  
USACE Portland District  
P.O. Box 2946  
Portland, OR 97204

Mike Langeslay  
USACE Portland District  
P.O. Box 2946  
Portland, OR 97204.

John Skalski  
University of Washington  
1325 4<sup>th</sup> Avenue  
Seattle, WA 98101

**PDF**  
**Copies**

**Local Distribution**

Pacific Northwest National Laboratory  
Tom Carlson                   BPO  
Gary Johnson                 BPO  
Gene Ploskey                 NBON  
Steve Schlahta               RCH  
Mark Weiland                 NBON







**US Army Corps  
of Engineers®**

Prepared for the U.S. Army Corps of Engineers, Portland District,  
under a Government Order with the U.S. Department of Energy  
Contract DE-AC05-76RL01830



**Pacific Northwest**  
NATIONAL LABORATORY

*Proudly Operated by **Battelle** Since 1965*

902 Battelle Boulevard  
P.O. Box 999  
Richland, WA 99352  
1-888-375-PNNL (7665)  
[www.pnl.gov](http://www.pnl.gov)



U.S. DEPARTMENT OF  
**ENERGY**