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Survival and Passage of Juvenile Chinook Salmon and Steelhead Passing Through Bonneville Dam, 2010

Final Report

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September 2012



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Abstract

Pacific Northwest National Laboratory (PNNL) and subcontractors conducted an acoustic-telemetry study of juvenile salmonid fish passage and survival at Bonneville Dam in 2010. The study was conducted to assess the readiness of the monitoring system for official compliance studies under the 2008 Biological Opinion and Fish Accords and to assess performance measures including route-specific fish passage proportions, travel times, and survival based upon a single-release model. This also was the last year of evaluation of effects of a behavioral guidance structure installed in the Powerhouse 2 forebay. The study relied on releases of live Juvenile Salmon Acoustic Telemetry System tagged smolts in the Columbia River and used acoustic telemetry to evaluate the approach, passage, and survival of passing juvenile salmon. This study supports the U.S. Army Corps of Engineers continual effort to improve conditions for juvenile anadromous fish passing through Columbia River dams.

Preface

The U.S. Army Corps of Engineers (USACE) Portland District, contracted with the Pacific Northwest National Laboratory (PNNL), in Richland, Washington, to conduct an acoustic-telemetry survival study at the Bonneville Dam in 2010. The PNNL assembled a study team consisting of staff from PNNL, the Pacific States Marine Fisheries Commission (PSMFC), and the University of Washington. The Portland District provided all funding and oversight.

This final report presents behavioral and fish passage results for tagged yearling and subyearling Chinook salmon smolts and juvenile steelhead as part of a survival study conducted at Bonneville Dam during 2010.

This report was originally published in December 2011. It was revised in August 2012 to address review comments from the Studies Review Work Group of the USACE's Anadromous Fish Evaluation Program. One important change was to revise the fish collection section to clearly present numbers and percents of fish rejected, excluded, tagged and released alive or dead, and to list the sum of extra fish that were collected but not needed to fulfill the daily tagging quota. The fish passage efficiency statistics were added to Tables ES-2 and ES-3. A paragraph describing comparisons of spill treatment and day and night effects in summer and Table 6.8 were added to Section 6.6. We also added tables of subyearling Chinook survival results for combinations of day, night, and spill level to the appendices. We did not accept the recommendation of one reviewer to limit reporting to single-release survival estimates and to avoid using passage survival through the Bonneville Powerhouse 2 Corner Collector as a virtual reference release to make surrogate estimates of paired-release survival. All capture histories and single-release survival results were the primary focus of this report and were tabled in the Executive Summary and appendices. Estimation of surrogate paired-release survival estimates was a reasonable and informative exercise that was retained for readers that might be interested, but those estimates were not included in executive summary tables or appendices.

This report should be cited as follows:

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Executive Summary

Researchers at the Pacific Northwest National Laboratory collaborated with others at the Pacific States Marine Fisheries Commission, U.S. Army Corps of Engineers Portland District, and the University of Washington to conduct a 2010 study primarily to estimate survival rates of subyearling and yearling Chinook salmon smolts and juvenile steelhead passing through 1) the Bonneville Dam forebay, 2) the forebay, dam, and 81 km of tailwater, and 3) through the dam and its various routes and 81 km of tailwater. The study also estimated additional passage performance measures, most of which were stipulated in the Columbia Basin Fish Accords, evaluated affects of two spill treatments on passage and survival metrics, and evaluated the performance of the behavioral guidance structure (BGS) in the Powerhouse 2 (B2) forebay.

The 2010 study was not an official compliance test as described by the 2008 Federal Columbia River Power System Biological Opinion, because passage conditions for the dam had not been finalized. The Powerhouse 1 (B1) sluiceway was expanded for 2010 to roughly triple the amount of flow passing through surface-flow outlets from the B1 forebay, but flow was not accurately measured in 2010 and some of the floating sluiceway gates were sticking during the fish passage season. In addition, regional fishery managers wanted to add one more year of evaluation of a BGS installed in the B2 forebay. Managers also wanted to evaluate the effects of two spill treatments on fish-passage metrics and survival in summer 2010. One spill treatment consisted of a 24-h 95,000-cfs spill and the other consisted of 85,000-cfs day and 120,000-cfs night spill. Unit 11, which is adjacent to the Bonneville Powerhouse 2 Corner Collector (B2CC) and critical for proper functioning of that surface-flow outlet, was out of service throughout 2010. The Portland District also wanted researchers to evaluate the performance of two independent cabled arrays deployed on every dam face (B1, the spillway, and B2) to make certain that the arrays would be ready for an official compliance test in 2011.

Acoustically tagged subyearling and yearling Chinook salmon smolts and juvenile steelhead released in the Columbia River upstream of John Day Dam (near Arlington, Oregon), in The Dalles tailrace, and in the tailwater near Hood River, Oregon, that were detected either at the Bonneville Dam forebay entrance array or at the face of the dam were available to form virtual releases. Single-release passage-survival estimates were made for fish passing through two river reaches: 1) the dam and 81 km of tailwater and 2) the forebay, dam, and 81 km of tailwater. Releases of live acoustically tagged fish at three sites upstream of Bonneville Dam totaled 3880 yearling Chinook salmon and 3885 juvenile steelhead in spring and 4449 subyearling Chinook salmon in summer. These tagged fish were released to support passage survival studies at John Day Dam, The Dalles Dam, and Bonneville Dam in 2010. The Juvenile Salmon Acoustic Telemetry System tag model number ATS-156dB, weighing 0.438 g in air, was used in this investigation.

This report provides a comprehensive summary of 2010 results, including route-specific passage survival estimates. Dam-passage survival to the Bonneville tailrace could not be estimated in 2010 because there were no reference releases of fish in the Bonneville tailrace or tailwater. Forebay to tailrace survival could not be estimated for the same reason.

The study results are summarized in the following tables.

Table ES.1. Estimates of Single-Release, Tag-Life-Corrected Estimates of Dam-Passage Survival at Bonneville Dam in 2010

Duration	Passage Survival (dam and 81 km of tailwater)		
	Yearling Chinook Salmon	Steelhead	Subyearling Chinook Salmon
2010	0.952 (SE = 0.0040)	0.945 (SE = 0.0043)	0.958 (SE = 0.0055) ^(a)
During 24-h 95,000-cfs Spill (7/2 to 7/18) ^(b)			0.926 (SE = 0.0089)
During 85,000-cfs Day and 120,000-cfs Night Spill (7/2 to 7/18) ^(b)			0.903 (SE = 0.0111)

(a) The survival estimate for the entire summer study was based on virtual releases of fish regrouped from The Dalles tailrace and Hood River, Oregon, releases only because virtual release survival for fish released upstream of John Day and The Dalles dams near Roosevelt, Washington, was significantly lower than that of fish releases in the Bonneville pool.

(b) Survival estimates for the two spill treatments were based on virtual releases of fish regrouped from all upstream release sites to maximize power to detect differences. Pooled estimates were pooled over the period of time in which spill treatments were as prescribed.

Table ES.2. Fish Accords Performance Measures at Bonneville Dam in 2010

Performance Measures	Yearling Chinook Salmon	Steelhead	Subyearling Chinook Salmon ^(a)
Forebay Entrance Array to rkm 153 Survival	0.951 (SE = 0.0040)	0.944 (SE = 0.0043)	0.956 (SE = 0.0054)
Forebay Residence Time (h) (Median; Mean)	0.74; 1.27 (SE = 0.046)	1.69; 4.22 (SE = 0.112)	0.69; 1.14 (SE = 0.042)
100-m Forebay Residence Time (h) (Median; Mean)	0.18; 1.84 (SE = 0.267)	1.43; 6.06 (SE = 0.566)	0.13; 1.00 (SE = 0.164)
Tailrace Egress Time (h) (Median; Mean)	0.46; 0.94 (SE = 0.104)	0.41; 1.12 (SE = 0.135)	0.42; 1.45 (SE = 0.259)
Project Passage Time (h) (Median; Mean)	1.29; 2.21 (SE = 0.114)	2.40; 5.32 (SE = 0.177)	1.26; 2.58 (SE = 0.245)
Fish Passage Efficiency (FPE)	0.802 (SE = 0.007)	0.795 (SE = 0.007)	0.705 (SE = 0.0078)
Spill-Passage Efficiency (SPE) ^(b)	0.528 (SE = 0.009)	0.406 (SE = 0.009)	0.524 (SE = 0.009)
Spill + B2CC Passage Efficiency ^(c)	0.717 (SE = 0.008)	0.712 (SE = 0.008)	0.615 (SE = 0.008)

(a) Subyearling Chinook values are for the entire summer study period

(b) SPE is the number of fish passing the spillway divided by the number passing the entire dam.

(c) Spill + B2CC passage efficiency is a metric specified by the 2008 Fish Accords.

Table ES.3. Survival Study Summary

Year: 2010			
Study Site(s): Bonneville Dam			
Objective(s) of study: Estimate dam-passage survival for yearling Chinook salmon and steelhead and associated Fish Accords performance measures using a single-release survival model; evaluate whether the behavioral guidance structure (BGS) in the B2 forebay improved B2CC passage efficiency, and test two spill treatments to see which one improved subyearling Chinook salmon survival			
Hypothesis (Null = H0; Alternative = H1): H0: B2CC passage efficiency (2010 with B2 BGS) ≤ B2CC passage efficiency (2004 or 2005 without B2 BGS) H1: B2CC passage efficiency (2010 with B2 BGS) > B2CC passage efficiency (2004 or 2005 without B2 BGS) H0: Subyearling survival under 95 kcfs summer spill ≤ survival under 85 kcfs day/120 kcfs night spill H1: Subyearling survival under 95 kcfs summer spill > survival under 85 kcfs day/120 kcfs night spill			
Fish: Species race: Yearling Chinook salmon (CH1) Juvenile steelhead (STH) subyearling Chinook salmon (CH0)		Source: John Day Dam fish collection facility Implant Procedure: Surgical: Yes; Injected: No	
Size (median):	CH1	STH	CH0
Weight (g):	31.4	78.1	12.4
Length (mm):	152.0	214.0	110.0
	Sample Size:	CH1	STH
	# release sites:	3	3
	# releases	94	94
	Total # released:	3880	3885
		4449	
Tag:	Analytical Model:	Characteristics of Estimate:	
Type/model: Advanced Telemetry Systems (ATS)-156dB	Virtual single release	Effects Reflected (direct, total, etc.): Direct	
Weight (g): 0.438 g (air)		Absolute or Relative: Relative	
Environmental/Operating Conditions (daily from April 28 through July 18): Discharge (kcfs): mean 246.4, minimum 156.0, maximum 397.7 Temperature (°C – scroll case): mean 15.0, minimum 11.1, maximum 19.4 Total Dissolved Gas (tailrace): mean 111.5%, minimum 104.8%, maximum 117.4% Treatment(s): 95 kcfs spill and 85 kcfs spill during the day and 120 kcfs overnight from July 2–19, 2010 Unique Study Characteristics: Turbine Unit 11 was offline all year and turbine 13 operated very little in summer; first year B1 sluiceway was widened for increased discharge; the B2 BGS was installed in the B2 forebay; turbine intake extensions were installed at every other intake on north half of B2 (15A, 15C, 16B, 17A, 17C, 18B).			
Survival and Passage			
Estimates:	Yearling Chinook	Steelhead	Subyearling Chinook
Survival: Forebay entrance array (CR236) to CR153	0.951 (SE = 0.0040)	0.944 (SE = 0.0043)	0.956 (SE = 0.0054)
Survival: Dam face to the primary array (CR153)	0.952 (SE = 0.0040)	0.945 (SE = 0.0043)	0.958 (SE = 0.0055)
Forebay Residence Time (h) (median; mean)	0.74; 1.27 (SE = 0.046)	1.69; 4.22 (SE = 0.112)	0.69; 1.14 (SE = 0.042)
100-m Forebay Residence Time (h) (median; mean)	0.18; 1.84 (SE = 0.267)	1.43; 6.06 (SE = 0.566)	0.13; 1.00 (SE = 0.164)

Table ES.3. (contd)

Survival and Passage Estimates:	Yearling Chinook	Steelhead	Subyearling Chinook
Tailrace Egress Time (h) (median; mean)	0.46; 0.94 (SE = 0.104)	0.41; 1.12 (SE = 0.135)	0.42; 1.45 (SE = 0.259)
Project Passage Time (CR236 to CR233) (median; mean)	1.29; 2.21 (SE = 0.114)	2.40; 5.32 (SE = 0.177)	1.26; 2.58 (SE = 0.245)
Fish Passage Efficiency (FPE)	0.795 (SE = 0.007)	0.795 (SE=0.007)	0.795 (SE = 0.007)
Spill-Passage Efficiency	0.528 (SE = 0.009)	0.406 (SE = 0.009)	0.524 (SE = 0.009)
Spill + B2CC Passage Efficiency	0.717 (SE = 0.008)	0.712 (SE = 0.008)	0.615 (SE = 0.008)

Results: This was not an official compliance test requiring paired reference releases, but single-release estimates for yearling Chinook salmon still exceeded the 2008 Biological Opinion (BiOp) requirement of 0.96, and single-release estimates for steelhead were very close to the BiOp requirement and may have met the requirement had there been official reference releases to produce absolute survival estimates. Spill-passage efficiency was as high as or higher than previously reported for radio-telemetry and fixed aspect hydroacoustic studies. The B2 behavioral guidance structure installed in 2008, 2009, and 2010 increased the B2CC passage efficiency of yearling Chinook salmon by about 12.5% over 2004 and 2005 estimates, but benefits were not obvious for juvenile steelhead or subyearling Chinook salmon. A one-tailed paired t-test indicated that mean dam passage survival was significantly higher ($P = 0.047$) for subyearling Chinook salmon during the 95-kcfs spill treatment (0.926) than it was during the 85 kcfs day/120 kcfs night spill treatment (0.887). However, the calculated mean for the 85 kcfs day and 120 kcfs night treatment (0.887) was biased low by one point estimate on 7/15 (survival = 0.713; $n = 48$) relative to the pooled estimate for the season treatment (0.903). The $\frac{1}{2}$ 95% confidence intervals for the two pooled estimates of 0.926 (95-kcfs treatment) and 0.903 (85/120-kcfs treatment) overlapped, suggesting that those pooled estimates did not differ significantly between treatments.

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Advanced Telemetry Systems, Inc. (ATS) manufactured the acoustic tags. Autonomous and dam-mounted hydrophones were manufactured by Sonic Concepts, Seattle, Washington. Precision Acoustic Systems, also in Seattle, made the quad channel receivers and conducted node acceptance tests for PNNL. Cascade Aquatics, Inc. in Ellensburg, Washington, activated and delivered the acoustic tags. Schlosser Machine Shop fabricated anchors for autonomous nodes and frames for star clusters that were deployed in the spillway forebay.

Acronyms and Abbreviations

ATS	Advanced Telemetry Systems, Inc. [®]
B1	Bonneville Powerhouse 1
B2	Bonneville Powerhouse 2
B2CC	Bonneville Powerhouse 2 Corner Collector
B2 JBS	Bonneville Powerhouse 2 Juvenile Bypass System
BGS	behavior guidance structure
BiOp	Biological Opinion
BON	Bonneville Dam
BPA	Bonneville Power Administration
BRZ	boat restricted zone
°C	degree(s) Celsius or Centigrade
CF	CompactFlash (card)
cfs	cubic feet per second
CH0	subyearling Chinook salmon
CH1	yearling Chinook salmon
CI	confidence interval (95%)
CJS	Cormack-Jolly-Seber (model)
CL	confidence limit ($\pm \frac{1}{2}$ 95%)
cm	centimeter(s)
DART	Data Access in Real Time
FCRPS	Federal Columbia River Power System
ft	foot(feet)
g	gram(s)
gal	gallon(s)
g/L	gram(s) per liter
GPS	global positioning system
h	hour(s)
in.	inch(es)
JBS	Juvenile Bypass System
JMF	Juvenile Monitoring Facility below the Second Powerhouse (B2)
JSATS	Juvenile Salmon Acoustic Telemetry System
kcfs	thousands of cubic feet per second
kg	kilogram(s)
km	kilometer(s)
L	liter(s)
m	meter

MCN	McNary Dam
mg/L	milligram(s) per liter
mL	milliliter(s)
mm	millimeter(s)
MOA	Memorandum of Agreement
m/s	meter(s) per second
MS-222	tricaine methanesulfonate
MSL	mean sea level
NOAA	National Oceanic and Atmospheric Administration
PIT	passive integrated transponder
PNNL	Pacific Northwest National Laboratory
PSMFC	Pacific States Marine Fisheries Commission
PTAGIS	Passive Integrated Transponder (PIT) Tag Information System
PVC	polyvinyl chloride
rkm	river kilometer
RME	research, monitoring, and evaluation
ROR	run-of-river
RPA	Reasonable and Prudent Alternative
μs	microsecond(s)
s	second(s)
SAS	Statistical Analysis System
SE	standard error
SPE	spill-passage efficiency
STH	juvenile steelhead
USACE	U.S. Army Corps of Engineers
UW	University of Washington

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1.0 Introduction

In a continual effort to improve conditions for juvenile anadromous fish passing through Columbia River dams, the U.S. Army Corps of Engineers (USACE) Portland District has funded numerous evaluations of fish passage and survival. In 2010, researchers at the Pacific Northwest National Laboratory (PNNL) in collaboration with the Pacific States Marine Fisheries Commission (PSMFC), USACE, Portland District, and the University of Washington (UW), conducted this juvenile fish passage and survival study.

1.1 Study Goals

The primary goal of this study was to estimate the survival of yearling and subyearling Chinook salmon and juvenile steelhead passing through the dam by various routes and 81 km of tailwater using a single-release survival model. This effort provided the opportunity to evaluate the adequacy of the proposed monitoring system for conducting official compliance studies in future years. Additional passage performance measures stipulated by the Columbia Basin Fish Accords also were estimated, as were single-release estimates of route-specific survival rates. Performance measures included spill passage efficiency, forebay residence time, tailrace egress time, and project passage time. A behavioral guidance structure (BGS) was still installed in the Bonneville Powerhouse 2 (B2) forebay, and its effect on performance measures was evaluated as well in both seasons. A goal specific to the summer study was to evaluate effects of two spillway discharge treatments on survival rates and passage performance measures.

The 2010 study was not an official compliance test as described by the 2008 Federal Columbia River Power System (FCRPS) Biological Opinion (BiOp; NOAA 2008), because passage conditions for the dam had not been finalized. The Bonneville Powerhouse 1 (B1) sluiceway was expanded for 2010 to roughly triple the amount of flow passing through surface-flow outlets from the B1 forebay, but flow was not accurately measured in 2010 and some of the floating sluiceway gates were sticking during the fish passage season. Both of these conditions should be remedied for 2011. In addition, regional fishery managers wanted to add one more year of B2 behavioral guidance structure (BGS) evaluation and for summer 2010 wanted to evaluate effects of two spill treatments on fish-passage metrics and survival. Unit 11, which is adjacent to the Bonneville Powerhouse 2 Corner Collector (B2CC) and critical for proper functioning of that surface-flow outlet, was out of service throughout 2010. The USACE also wanted researchers to evaluate the performance of two independent cabled arrays deployed on every dam face (B1, the spillway, and B2) for detecting and tracking fish to make certain that the arrays would be ready for an official compliance test in 2011.

1.2 Background

The consequence of our inability to manage and predict salmon populations is both ecologically and socially costly and has been thoroughly demonstrated over the past 20–30 years. Three factors help to explain the difficulty of understanding salmon passage and behavior. First, salmonids are exposed to a multi-dimensional complex of environmental conditions, which is difficult to replicate experimentally or to mathematically model (Underwood et al. 2000; Kerr 1990). Next, salmonids move across a heterogeneous environment, both natural and manmade, which requires addressing the questions of

individual fitness, loss and gain, movements and behavior (Beitinger and Fitzpatrick 1979; Kramer et al. 1997; Hochachaka 1990). Lastly, biologists struggle to link individual fitness response to population level responses (Kerr 1990) resulting in a disjuncture between local and regional efforts and results. This specifically applies to the FCRPS. While outmigrating juvenile salmonids maneuver through the complicated FCRPS, their stress load and injuries, whether additive or synergistic, alter their fitness and subsequently their performance.¹ While this knowledge seems common, no one to date has attempted to fully capture outmigrating juvenile salmonids' fitness data and apply them to population level fitness.

Over the past 25 years, much work has been done to increase passage survival rates for juvenile salmonids at the three lower main-stem dams. Progress at dams has entailed structural and operational improvements designed to benefit juvenile salmonid passage while minimizing impacts on power production as much as possible. For example, there has been extensive work on in-turbine screen systems and juvenile bypass system (JBS) facilities at McNary Dam (MCN), John Day Dam (JDA), and Bonneville Dam (BON). Also, numerous spill-level evaluations have been conducted at all three dams. At Bonneville Dam in 2009 a surface-flow outlet was refurbished at B2, a BGS was deployed in the B2 forebay, spillway flow deflectors were modified and have been studied, and the B1 sluiceway was reconfigured. Given these major improvements, the 2008 BiOp called for performance standards and required the USACE to collect data on juvenile salmonid survival rates to compare to the BiOp standards starting in 2010.

While prescribed comparisons of dam survival with standards in the BiOp are very important, there are also ongoing needs to evaluate route-specific passage proportions and survivals, forebay resident times, tailrace egress times, and to occasionally test structures or operations to identify new ways of improving dam survival. Without route-specific information, it is difficult or impossible to determine why a dam failed to meet a standard or to identify ways to fix problems. Baseline biological data on fish distributions were summarized by Giorgi and Stevenson (1995) for JDA, The Dalles Dam (TDA), and BON; by Anglea et al. (2001) for JDA; by Johnson et al. (2007) and Ploskey et al. (2001) for TDA, and by Ploskey et al. (2007a) for BON. During the early 2000s, fish-passage proportions were most often estimated using fixed-aspect hydroacoustic or radio-telemetry methods, and survival estimates with active tags were based on detections of radio-tagged fish above and below the dams.

Before 2006, acoustic telemetry had only been used twice at Portland District projects, once at BON (Faber et al. 2001) and once at TDA (Cash et al. 2005). These studies focused on fish approach and passage. The Juvenile Salmon Acoustic Telemetry System (JSATS) was designed to meet the needs of passage and survival studies for juvenile salmonids in the Columbia River basin, and it avoids many of the limitations of other telemetry systems. In 2006, non-route-specific survival studies were conducted at JDA, TDA, and BON to assess the feasibility of using the JSATS for estimating dam-passage survival (Ploskey et al. 2007b). In 2007, a JSATS acoustic-telemetry survival study was conducted at the BON spillway (Ploskey et al. 2008), and in 2008, a JSATS route-specific survival study was conducted at JDA (Weiland et al. 2009), the BON spillway (Ploskey et al. 2009), and B2 (Faber et al. 2010). In 2009, JSATS route-specific studies were conducted at JDA (Weiland et al. 2011a) and B2 (Faber et al. 2011). The technology and tools for using JSATS are maturing thanks to significant advances with each year of

¹ Performance designates a volume of capacities where the volume is determined by the environmental conditions and interactions among the systems which contribute to those capabilities (Bennett 1989). Performance specifically refers to the application of various levels of biological organization from simple physiological functions to more complex organismal responses.

study. The dam-face arrays deployed at JDA in 2008 detected over 99% of the tagged juvenile salmonids approaching the dam, and most approaching fish were successfully tracked. Over 98% were assigned a route of passage with high confidence. In 2009, the double array at JDA had a detection efficiency of 96.4% for yearling Chinook salmon smolts, 95.6% for steelhead, and 97.9% for subyearling Chinook salmon smolts. High detection efficiencies also were observed in survival studies conducted in 2010 and spring 2011.

In 2009, PNNL conducted an acoustic-telemetry study at BON (Faber et al 2011). The study evaluated the effects of the BGS located in the forebay of the B2 and estimated passage and survival of yearling Chinook salmon (CH1), subyearling Chinook salmon (CH0), and juvenile steelhead (STH) passing downstream through this powerhouse, the dam as a whole, and through B1 and the spillway combined. The BGS was deployed to increase the survival of fish passing through B2 by increasing the percentage of outmigrating smolts entering the B2CC—a surface-flow outlet known to be a relatively benign route for downstream passage at this dam. The BGS benefitted the collection efficiency and effectiveness for CH1 passing through the B2CC, but did not change STH or CH0 collection efficiency compared to prior study years. The B2CC passage efficiency for STH is very high with or without the BGS. Survival estimates for all smolts passing downstream through B2 were very high using triple-, paired-, and single-release Cormack-Jolly-Seber (Cormack 1965; Jolly 1965; Seber 1965) modeling methods and would meet current BiOp standards. Turbine unit 11 provides flow into the south of the B2 where the B2CC is located; thus, the fact that this unit was off during summer may have reduced B2CC efficiency for CH0. To satisfactorily test the effect the BGS has on improving the B2CC efficiency for CH0, turbine 11 should be operational throughout the testing period.

The 2008 BiOp on operation of the FCRPS contains a Reasonable and Prudent Alternative (RPA) that includes actions calling for measurements of juvenile salmonid survival (RPAs 52.1 and 58.1). These RPAs are being addressed as part of the federal research, monitoring, and evaluation (RME) effort for the FCRPS BiOp. Most importantly, the FCRPS BiOp includes performance standards for juvenile salmonid survival in the FCRPS against which the Action Agencies (Bonneville Power Administration, Bureau of Reclamation, and USACE) must compare compliance testing performance estimates, as follows (after the RME Strategy 2 of the RPA):

Juvenile Dam Passage Performance Standards – The Action Agencies’ juvenile performance standards are an average across Snake River and lower Columbia River dams of 96% average dam passage survival for spring Chinook salmon and steelhead and 93% average across all dams for Snake River subyearling Chinook. Dam passage survival is defined as survival from the upstream face of the dam to a standardized reference point in the tailrace.

The 2008 *Columbia Basin Fish Accords Memorandum of Agreement [MOA] between the Three Treaty Tribes and FCRPS Action Agencies (3 Treaty Tribes and Action Agencies 2008)*, known informally as the Fish Accords,¹ contains three additional requirements relevant to the 2010 survival studies (after the MOA Attachment A):

Dam Survival Performance Standard – Meet the 96% dam passage survival standard for yearling Chinook salmon and steelhead and the 93% standard for subyearling Chinook. Achievement of the standard is based on 2 years of empirical survival data...

¹ Available at http://www.salmonrecovery.gov/Files/BiologicalOpinions/MOA_ROD.pdf.

Spill-Passage Efficiency and Delay Metrics – Spill-passage efficiency (SPE) and delay metrics under current spill conditions . . . are not expected to be degraded (“no backsliding”) with installation of new fish-passage facilities at the dams....

Future Research, Monitoring and Evaluation – The Action Agencies’ dam survival studies for purposes of determining juvenile dam passage performance will also collect information about SPE, survival and delay between boat-restricted zones (BRZs), and other distribution and survival information. SPE and delay metrics will be considered in the performance check-ins or with Configuration and Operations Plan updates, but not as principal or priority metrics over dam survival performance standards. Once a dam meets the survival performance standard, SPE and delay metrics may be monitored coincidentally with dam survival testing.

This report summarizes the results of the 2010 spring acoustic-telemetry study of CH1 and STH at BON. This study is a precursor to a full-scale compliance study to be performed in 2011. Only single-release survival estimates were calculated for BON because there were no paired reference releases of fish downstream of BON in 2010. Therefore, BiOp performance standards were not explicitly tested. Surviving acoustically tagged juvenile STH and CH1 smolts released in the Columbia River upstream of JDA (near Arlington, Oregon), in TDA tailrace, and in the tailwater near Hood River, Oregon, were available to form virtual releases either at the BON forebay entrance array or at the face of the dam. Single-release passage survival estimates were made for fish passing through two river reaches: 1) the dam and 81 km of tailwater and 2) the forebay, dam, and 81 km of tailwater. A total of 3880 CH1 smolts and 3885 juvenile STH were tagged and released to support survival studies at JDA, TDA, and BON in spring 2010. The JSATS tag model number ATS-156dB, weighing 0.438 g in air, was used in this investigation.

1.3 Study Overview

The purpose of spring 2010 monitoring at BON was to estimate single-release survival rates for CH1 and STH smolts, evaluate B2 BGS performance, and evaluate fish-passage metrics specified by the 2008 Fish Accords by taking advantage of fish released for the BiOp performance testing at TDA. For each fish stock, the following metrics were estimated using the JSATS technology:

- In this report, dam-passage survival is defined as survival from the upstream face of the dam to the first survival array located 81 km downstream of BON. The survival estimate includes the mortality of fish in this 81-km river reach in addition to mortalities associated with dam passage. A single-release point estimate >96% also would exceed the BiOp standard for a paired-release estimate, because the single-release estimate is more conservative than the paired-release estimate.
- In this report, we present two estimates of fish-passage efficiency (FPE): 1) SPE, which is defined as the number of fish passing through the spillway divided by the number passing the dam, and 2) spill + B2CC passage efficiency, as specified in the 2008 Fish Accords.
- Forebay residence time, defined by the median, mean, and standard error of the mean times that smolts take to travel the last 100-m upstream of the dam before passing into the dam (i.e., from the 100-m mark to the dam face).
- Tailrace egress time, defined as the median, mean, and standard error of the mean times that smolts take to travel through the dam to the downstream tailrace boundary.

- Project passage time, defined as the median, mean, and standard error of the mean times that smolts take to travel from the forebay entrance array through the dam to the tailrace egress array.
- Survival from the forebay entrance array to the primary array 81 km downstream of the dam was estimated instead of forebay-to-tailrace survival, which was specified as BRZ-to-BRZ survival in the Fish Accords. Forebay-to-tailrace survival estimates require tailrace and tailwater reference releases that were not part of the 2010 study. We did provide a single-release estimate of survival from the forebay entrance array to the dam face.

The purpose of 2010 monitoring at BON was to estimate performance measures outlined in the 2008 FCRPS BiOp and the Fish Accords for CH1 and juvenile STH in spring and for subyearling Chinooks salmon in summer using a single-release passage and survival model, evaluate B2 BGS performance, and evaluate the effects of two spill treatments in summer.

The study methods and results described in the ensuing sections of this report are reported by run of fish and performance measure.

1.4 Study Area

The BON project area and modeled river discharge relative to historical estimates are described below.

1.4.1 Bonneville Lock and Dam

Bonneville Lock and Dam consists of several dam structures that together span the Columbia River between Oregon and Washington at rkm 235.1, about 65 km east of Portland, Oregon. From the Oregon shore north toward Washington, the current project is composed of a navigation lock, the 10-turbine-unit B1, Bradford Island, an 18-gate spillway, Cascades Island, and the 8-turbine-unit B (Figure 1.1).

Primary fish passage routes include the spillway and two powerhouses; however, within each powerhouse, passage can be through surface-flow outlets, turbines, or the JBS. Smolts enter the JBS after encountering screens in the upper part of the turbine intakes. Screens divert fish to gatewell slots where they pass through orifices opening into a bypass channel, which carries them to an outfall downstream of the dam. The JBS at B1 was removed in 2004 because other routes were safer for fish. In 2003, the ice-trash sluiceway channel at B2 was modified and lengthened so that water was discharged downstream from the tip of Cascades Island in 2004 and thereafter. The modified B2 sluiceway has since been referred to as the B2CC. All modifications were specifically designed to maximize non-turbine passage and survival of juvenile salmonids. In 2008 and 2009, a BGS was installed in the B2 forebay to guide fish toward the B2CC (Figure 1.2), and this device was still installed for testing in 2010.

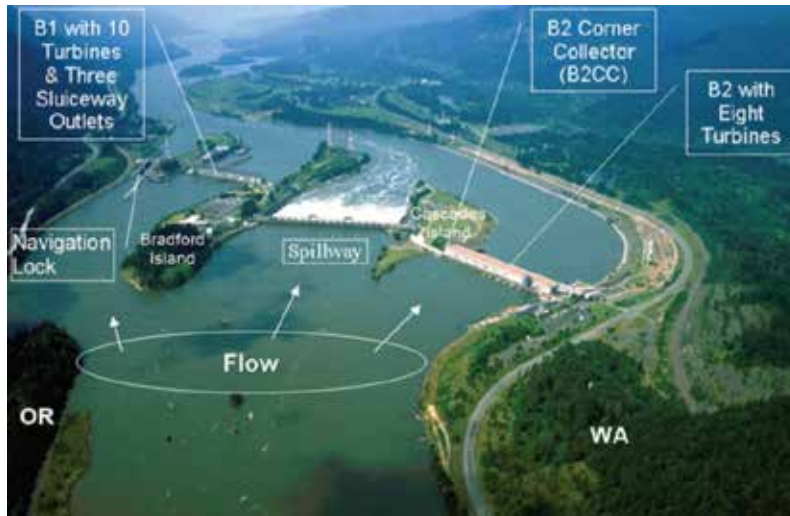


Figure 1.1. Plan View of the Bonneville Dam Project. The B1 sluiceway outlets and the B2 Corner Collector are surface overflow passage routes.



Figure 1.2. The Behavioral Guidance Structure with One Section Shown out of the Water (top); and as Deployed in the Forebay of the Bonneville Dam Second Powerhouse (B2; bottom)

Fish with implanted passive integrated transponder (PIT) and acoustic tags were released at three locations upstream of BON and were detected on arrays of underwater hydrophones deployed at six river cross sections from rkm 236 to 86 (Figure 1.3). An array is a group of underwater receivers (nodes) deployed across an entire cross section of the river to listen for acoustic tags. Receivers located on the dam were cabled together and time synchronized by a global positioning system (GPS) clock, and receivers away from the dam were battery power devices called autonomous nodes. The distance between the uppermost release site near Roosevelt, Washington, and the last survival array at Oak Point, Washington, was 304 rkm. Excluding distances traveled by fish released at sites upstream of BON, the study area covered about 150 km of the lower Columbia River from BON to Oak Point, Washington, at rkm 86 (Figure 1.3). Cabled underwater hydrophones were deployed at two depths (shallow and deep) on every major pier at B1, B2, and the spillway to detect the passage of tagged fish and to assign passage routes based on a combination of three-dimensional (3D) tracking, two-dimensional (2D) tracking, and the location of last detection. Detection data from the primary array at CR153 and two downstream arrays deployed by a post-FCRPS (Estuary) survival study were used to enumerate capture histories and estimate the survival of smolts passing through BON.

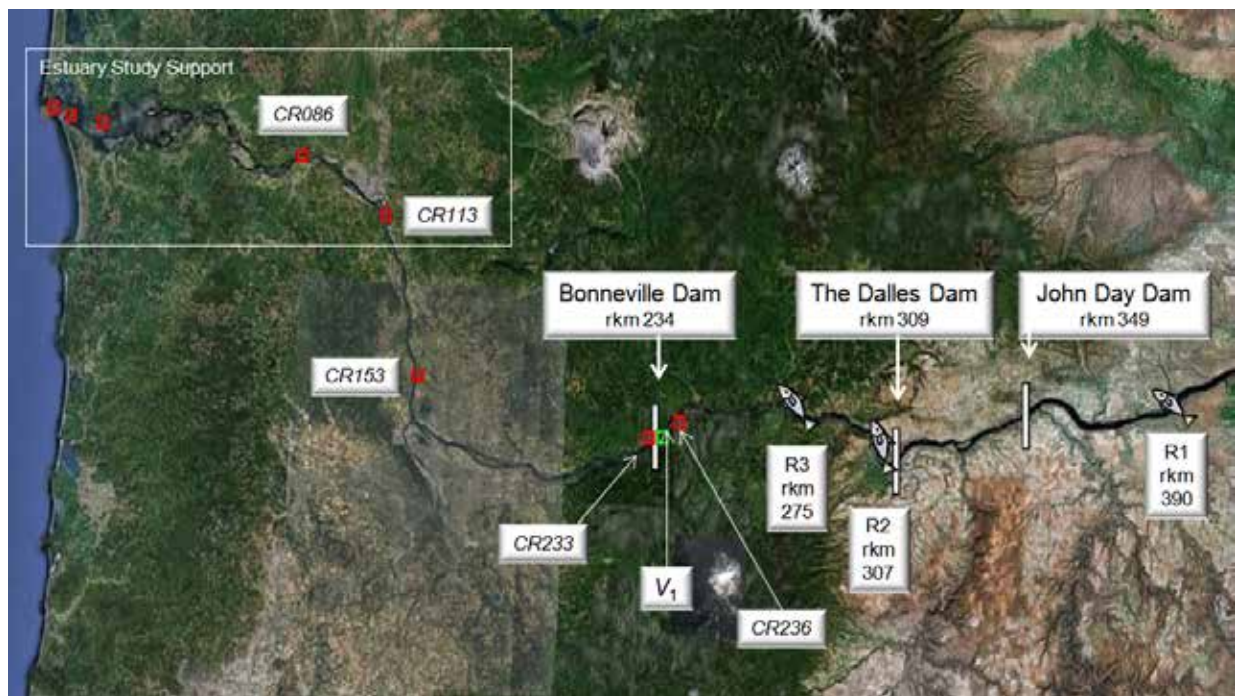


Figure 1.3. Bonneville Dam Study Area. Fish were released at three sites (R1, R2, and R3) upstream of Bonneville Dam and those detected at the face of BON were grouped to form a virtual release (V_1). Arrays of acoustic receivers were deployed in the BON forebay, tailrace, and at least six survival detection sites downstream, although only detections on arrays CR153, CR113, and CR086 were used to estimate survival in this report. (The background image was derived from Google Maps.)

1.4.2 Modeled River Discharge Relative to Historical Estimates

Modeled river discharge for water year 2009–2010 was between the 5th and 95th percentile of modeled discharge between 1929 and 1999 (Figure 1.4).

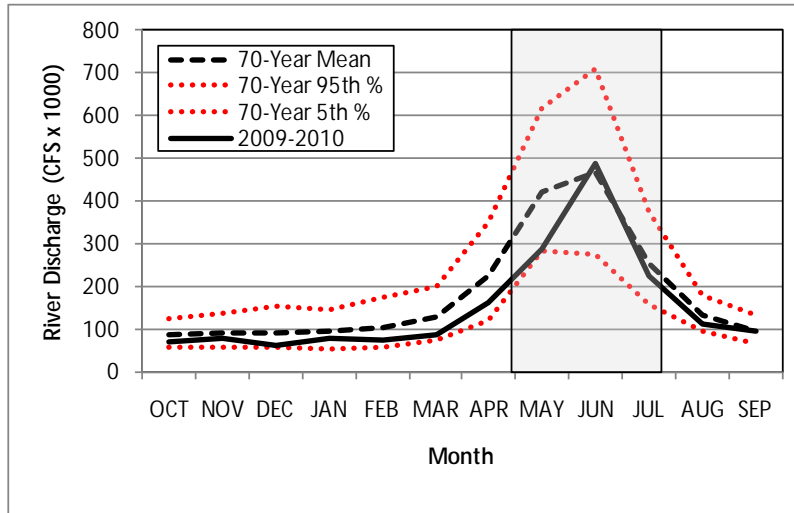


Figure 1.4. Plot of Modeled Columbia River Discharge in the 2009–2010 Water Year and Modeled 70-Year (1929–1999) Discharge. The mean and 5th and 95th percentiles are presented. Historical modeled estimates are from 2000 Level Modified Flow Report, and modeled estimates water year 2009-2010 were from River Forecast Center Runoff Model.

1.5 Definitions

For this report, we define virtual single-release survival, travel time, and passage efficiency metrics (Table 1.1). The survival metrics differ from those in the virtual paired-reference release design of Skalski (2009).

Table 1.1. Definitions of Performance Measures in This Study

Measure	Definition
Dam-passage survival	Survival from the upstream face of the dam to the primary survival detection array located 81 km downstream from the dam.
Forebay to primary array survival	Survival from a forebay array 2 km upstream of the dam to the primary survival detection array located 81 km downstream from the dam.
Paired-release survival	Virtual single-release survival estimates for the dam and non-B2CC routes were divided by the virtual single-release estimate for fish passing through the B2CC to provide a surrogate paired-release estimate of survival. The B2CC typically has a virtual single-release survival rates that are as high as or higher than those of tailrace reference releases of fish, which were not part of this study. Therefore, paired-release estimates reported here should be conservative relative paired-release estimates based on actual tailrace reference releases of fish.
Forebay residence time	Median and average times required for smolts to travel from the time of first detection on the forebay entrance array until the time of last detection on the dam-face array
100-m forebay residence time	Median and average times required for smolts to travel the last 100 m of forebay until they pass through the dam
Tailrace egress time	Median and average time required for smolts to pass through the tailrace after they pass through the dam, i.e., from time of last detection on the dam-face array until the time of last detection on the tailrace egress array

Table 1.1. (contd)

Measure	Definition
Spill-passage efficiency	Proportion of fish passing through the dam via the spillway, ^(a) and the proportion of fish passing through the spillway and B2CC ^(b)
Project-passage time	Median and average time smolts take to travel from first detection on the array 2 km upstream of the dam until the last detection on the tailrace exit array 2-km downstream of the dam
Fish-passage efficiency	Proportion of fish passing through the dam via the spillway, sluiceway, and JBS. ^(c)

(a) The historical definition.
(b) 2008 Fish Accord definition of spill-passage efficiency.
(c) By non-turbine routes.

1.6 Report Contents and Organization

The ensuing chapters of this report present the study methods (Chapter 2.0), followed by results for survival, travel time, passage efficiency, and passage distribution information for CH1 (Chapter 3.0), STH (Chapter 4.0), and CH0 (Chapter 5.0). Discussion (Chapter 6.0) and references (Chapter 7.0) close out the main body of the report. In the appendices, we provide the fish tagging and release data (Appendix A), hydrophone locations (Appendix B), capture histories (Appendix C), detection and survival estimates (Appendix D), and an assessment of the assumptions for the survival estimates (Appendix E).

2.0 Methods

Study methods cover environmental conditions, the release-recapture design and hydrophone deployment; tag life; fish handling, tagging, and release procedures; acoustic signal processing; and statistical methods. The primary research tool was the JSATS (McMichael et al. 2010).

2.1 Environmental Collections

Water discharge data by spill bay and turbine unit and elevation data for the forebay and tailrace are acquired by the USACE in 5-minute increments by the automated data-acquisition system at BON. Operators at the dam provided the data weekly. The 5-minute discharge data for the entire dam and spillway were averaged by day and plotted together with daily averages for the previous 10-year period to provide some historical perspective for 2010 observations. Average water discharge and forebay water temperature data from 1999 through 2009 were downloaded from the UW Data Access in Real Time website (DART; <http://www.cbr.washington.edu/dart>).

Spill treatments in summer were broken into eight consecutive 2-day blocks. Each block consisted of 1 day of randomly selected spill treatment followed by another day with the alternative treatment. Spill treatments consisted of either 24 h of 95-kcfs spill or 85-kcfs day and 120-kcfs night spill. Treatments began after river discharge lowered to levels deemed manageable by the dam operators.

2.2 Release-Recapture Design and Sample Sizes

The release-recapture design used to estimate dam-passage survival at BON consisted of a combination of a virtual release (V_1) of fish at the forebay entrance array or at the face of the dam and the detection of the same fish below the dam (Figure 2.1). Releases of tagged fish near Roosevelt, Washington, TDA tailrace, and Hood River, Oregon, supplied a source of fish known to have arrived alive at the forebay entrance array or at the face of BON. By releasing the fish far enough upstream, they should have arrived at the dam in a spatial pattern typical of run-of-river (ROR) fish. This virtual-release group was then used to estimate survival of fish passing through the forebay, dam, and to 81 km downstream of the dam or the dam and 81 km of tailwater (Figure 2.1). We were unable to account and adjust for this extra mortality in the tailwater because there were no paired releases of fish below BON. The sizes of the releases of the acoustic- and PIT-tagged fish used in the dam-passage survival estimates are summarized in Table 2.1.

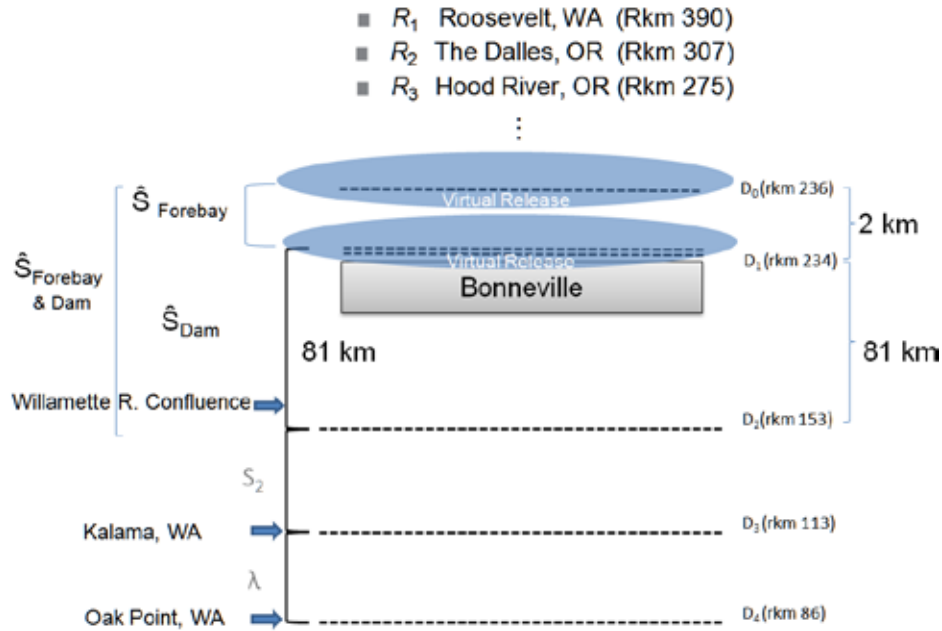


Figure 2.1. Schematic of the 2010 Study Design. The diagram shows the three releases of fish that could be regrouped to form virtual releases at the forebay entrance array (D_0) or dam-face array (D_1) and subsequent detections or non-detections on three downstream arrays (D_2 , D_3 , and D_4) that were used to create capture histories for estimating single-release survival rates down to the primary array (D_2).

Table 2.1. Sample Sizes of Acoustic-Tag Releases Used in the 2010 Survival Study at Bonneville Dam

Release Location	Yearling Chinook	Juvenile Steelhead	Subyearling Chinook Salmon		
			Pooled Treatments	85-kcfs Day/ 120-kcfs Night Spill	24-h, 95-kcfs Spill
Above John Day near Arlington, Oregon (R_1)	2287	2288	2849		
The Dalles Dam Tailrace (R_2)	796	799	800		
Bonneville Reservoir (R_3)	797	798	800		
Total Tagged and Released (R_1 , R_2 , and R_3)	3880	3885	4449		
Virtual Release Numbers (V_1)					
Dam and 81 km of tailwater passage	3358	3373	1443 ^(a)	725 ^(b)	896 ^(b)

(a) Based on TDA tailrace and Hood River releases only.

(b) Based on all upstream releases (Roosevelt, TDA tailrace, and Hood River) during respective spill treatments.

2.2.1 Federal and State Permitting

Records were kept on all smolts handled and collected (both target and non-target species) for permit accounting. Collections were conducted in conjunction with routine sampling at the Smolt Monitoring Facility (SMF) at JDA to minimize handling impacts. Surgical candidates collected from routine SMF target sample sizes were accounted for under permits issued to the SMF. Additional fish needed to meet research needs (beyond SMF goals) were accounted for under separate federal and state permits. A

federal scientific take permit was authorized for this study by the National Oceanic and Atmospheric Administration (NOAA) Fisheries Hydropower Division's FCRPS Branch and administered by NOAA (permit number 13-09PNNL40). The Oregon Department of Fish and Wildlife authorized take for this study under permit number P14273. The federal and Oregon permits were both authorized under the 2004 FCRPS BiOp. All requirements and guidelines of both permits were met and reports of collection and release were reported to both agencies.

2.2.2 Acoustic and PIT Tags

The acoustic tags used in the 2010 study (Figure 2.2) were manufactured by Advanced Telemetry Systems, Inc.[®] (ATS). Each tag, model number ATS-156dB, measured 12.02 mm in length, 5.21 mm in width, 3.72 mm in thickness, and weighed 0.430 g in air (0.29 g in water). The tags had a nominal transmission rate of 1 pulse every 3 seconds. Nominal tag life was expected to be about 25 days. Each tag was acoustically activated by Cascade Aquatics, Inc., using a Pinger dish designed by ATS to activate or deactivate tags. Each pulse from an activated JSATS tag contains a complex phase-encoded signal that uniquely identifies the transmitting tag without varying pulse duration.

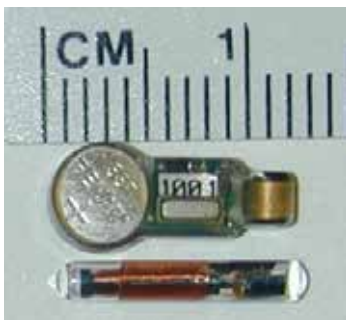


Figure 2.2. JSATS 0.43-g Acoustic Micro-Transmitter and PIT Tag Surgically Implanted in Yearling and Subyearling Chinook Salmon and Steelhead Smolts in 2010

2.3 The Collection and Tagging Site

Fish obtained from the JDA JBS were surgically implanted with JSATS tags, and then transported to three different release points, as described in the following sections. The SMF is situated on the south side of JDA at the downriver edge of the JBS where bypassed juvenile salmonids and other fishes are routed through a series of flumes and dewatering structures. Smolts can be diverted into the SMF as part of a sample of the JBS population for routine smolt monitoring (Martinson et al. 2006) or directed into the tailrace through an outfall pipe located downstream of the facility. Routinely sampled smolts also were rerouted to the tailrace outfall after they were examined unless they were selected for tagging as part of this study of survival rates.

2.4 Fish Collection, Tagging, and Holding

The collection, tagging, holding, and release of fish during this study are described in the following sections.

2.4.1 Collection

Juvenile salmonids were diverted from the JBS and then routed into a 1795-gal holding tank in the SMF. About 150–200 smolts and other fishes were crowded with a panel net into a 20- by 24-in. pre-anesthetic chamber. The water level in the chamber was lowered to about 8 in. (48 L) at which point fish were anesthetized with 60 mL of a stock tricaine methanesulfonate (MS-222) solution prepared at a concentration of 50 g/L. Once they were anesthetized, fish were routed into the examination trough. Technicians added MS-222 as needed to maintain sedation, and 5 to 10 mL of PolyAqua™ was added to reduce fish stress. Water temperatures were monitored in the main holding tank and in the examination trough, and water in the trough was refreshed before temperatures there increased more than 2°C above those observed in the main holding tank.

Once fish were in the examination trough, smolts targeted for surgical procedures were evaluated in accordance with the following criteria:

- Qualifying (Acceptable) Conditions
 - size ≥ 95 mm
 - visible elastomer tag(s) present or absent
 - adipose-fin clipped or unclipped
 - presence of trematodes, copepods, leeches
 - short operculum
 - healed (moderate) injuries (e.g., bird strikes)
 - $\leq 3\%$ fungal patch
 - minor fin blood
 - partial descaling (3–19%)
 - STH with eroded pectoral or ventral fins (likely hatchery STH).
- Disqualifying Conditions
 - $\geq 20\%$ descaling
 - body punctures (showing blood, e.g., predator marks, bird strikes, head wounds, nose/snout injuries)
 - obvious signs of bacterial kidney disease
 - eye hemorrhage or pop eye
 - $> 3\%$ coverage with fungus
 - deformed or emaciated
 - holdovers (fish not “spring” CH1 or “summer” CH0)
 - PIT- or radio-tagged or other post-surgical fishes
 - notable operculum damage (except short operculum)
 - presence of columnaris, furuncles
 - injured caudal peduncles
 - injured caudal fins

- fin hemorrhage.

We summarized the number and percent of fish collected for tagging according to their fate (Table 2.2). Excluded fish were released to the river through the SMF holding system after a 30-minute recovery period. Accepted fish were counted and moved in approximately equal proportions to six 80-gal pre-surgery holding tanks, where they were held for 18 to 30 hours before surgery. The pre-surgery holding duration depended on the time of collection and the time of tagging on the next day. Fish that were rejected during the tagging process were placed in a recovery tank to allow anesthesia to wear off and then were released back to the river through the bypass system. Most fish were tagged and released alive. We also tallied the number and percent of fish rejected from tagging because of maladies (Table 2.3) and excluded for other reasons (Table 2.5).

Table 2.2. Summary of the Number and Percent of Fish that Were Rejected, Excluded, Tagged and Released Alive, Tagged and Released Dead, or Exceeded the Daily Tagging Quota in 2010

Fate Statistics	CH1		STH		CH0		Total	
	n	%	n	%	n	%	n	%
Rejected ^a	297	6.5	427	8.9	430	7.6	1154	7.7
Excluded ^b	209	4.5	309	6.4	330	5.8	848	5.6
Tagged and Released Live	3880	84.3	3885	80.9	4449	78.8	12214	81.2
Tagged and Released Dead ^c	33	0.7	37	0.8	67	1.2	137	0.9
Extra Fish ^d	182	4.0	147	3.1	369	6.5	698	4.6
Collected	4601	100.0	4805	100.0	5645	100.0	15051	100.0

(a) Because of maladies.

(b) Too short, too long, previously tagged, dead, wrong species, dropped, or jumped.

(c) Beyond overnight mortalities, others were sacrificed.

(d) Collected but not evaluated before the tagging quota was met.

Table 2.3. Number and Percent Rejected Because of Maladies

Malady Description	CH1		STH		CH0		Total	
	n	%	n	%	n	%	n	%
BKD	2	0.7	0	0.0	2	0.5	4	0.3
Descaling ($\geq 20\%$)	148	49.8	212	49.6	226	52.6	586	50.8
Emaciated	1	0.3	0	0.0	1	0.2	2	0.2
Exophthalmia	16	5.4	5	1.2	5	1.2	26	2.3
Fin Rot	5	1.7	1	0.2	5	1.2	11	1.0
Fungus	49	16.5	60	14.1	9	2.1	118	10.2
Hemorrhaging	9	3.0	2	0.5	5	1.2	16	1.4
Lacerations	25	8.4	50	11.7	69	16.0	144	12.5
Lesions	12	4.0	22	5.2	26	6.0	60	5.2
Operculum Damage	13	4.4	41	9.6	33	7.7	87	7.5
Other	8	2.7	23	5.4	4	0.9	35	3.0
Parasites	0	0.0	4	0.9	34	7.9	38	3.3
Skeletal Deformities	9	3.0	7	1.6	11	2.6	27	2.3
Total	297	100.0	427	100.0	430	100.0	1154	100.0

Table 2.4. Number and Percent Excluded from Tagging for Other Reasons

Reason for Exclusion	CH1		STH		CHO		Total	
	n	%	n	%	n	%	n	%
Moribund	0	0.0	0	0.0	2	0.6	2	0.2
Previously tagged	168	80.4	156	50.5	120	36.4	444	52.4
< 95 or > 260 mm	1	0.5	150	48.5	202	61.2	353	41.6
Wrong species	40	19.1	3	1.0	5	1.5	48	5.7
Dropped/Jumped	0	0.0	0	0.0	1	0.3	1	0.1
Total	209	100.0	309	100.0	330	100.0	848	100.0

2.4.2 Tagging

The number of personnel on hand was the biggest contributor to ensuring that all tagged fish were handled as efficiently and un-intrusively as possible to minimize handling times. A team of eight or nine people conducted the tagging process. One individual was responsible for anesthetizing fish and delivering them to be weighed and measured; two people were responsible for weighing, measuring, and recording data; one person was responsible for taking lateral photographs with a high-resolution digital camera; three people performed surgeries to implant tags in the fish; and one or two people were responsible for moving tagged fish into the post-surgery tanks.

The team followed the latest guidelines for surgical implantation of acoustic transmitters in juvenile salmonids (USACE 2011). Procedure development is an ongoing process initiated by the USACE for contractors conducting survival studies. Numerous steps were taken to minimize the handling impacts of collection and surgical procedures. Most smolts used for tagging were part of the routine collection for SMF monitoring and additional fish did not have to be collected to meet the tagging quota on most days.

Fish were netted in small groups from the 80-gal holding tanks and placed in a 5-gal “knockdown” bucket with water and 20 mL of a 40-g/L stock solution of MS-222. Once a fish lost equilibrium, it was transferred to a processing table in a small container of river water. Species type, whether the adipose fin was intact or clipped, and fork length (± 1 mm) were recorded on a GTCO CalComp Drawing Board VI digitizer board. Fish were weighed (± 0.01 g) on an Ohaus Navigator scale and returned to the small transfer container along with an assigned PIT tag and an activated acoustic tag. Length, weight, species type, tag codes, and fin clip were all added automatically into the tagging database by PIT Tag Information System (PTAGIS) P3 software to minimize human error. The transfer container, fish, and tags were assigned a recovery bucket number and passed to the photo table. Photographs were taken of both sides of the fish while in the transfer container and then given to a surgeon for tag implantation.

An established protocol was used in the tagging process to help minimize the handling impact on tagged fish. All surgical instruments were sterilized daily in an autoclave and each surgeon used four complete sets of instruments during each day’s tagging. When a set was not being used, it was placed in a 70% ethanol solution for approximately 10 minutes. The instruments were then transferred to a distilled water bath for 10 minutes, to remove residual ethanol and any remaining particles, before being used again. To reduce the disruption of the mucus membrane at the incision, Poly-Aqua was used to help replace the membrane that was removed from the fish’s epidermal layers. Anesthesia buckets were kept

within $\pm 1^{\circ}\text{C}$ of river temperature. Anesthesia solutions were either replaced or cooled with ice when temperatures exceeded protocols.

During surgery (Figure 2.3), the fish to be tagged were anesthetized in an 18.9-L (5-gal) “knockdown” bucket with fresh river water and MS-222 (tricaine methanesulfonate; 80 mg/L). Anesthesia buckets were refreshed repeatedly to maintain the temperature within $\pm 2^{\circ}\text{C}$ of current river temperatures. Each fish was weighed and measured before tagging. Then, each fish was placed ventral side up and a gravity-fed anesthesia supply line was placed into its mouth. The dilution of the “maintenance” anesthesia was 40 mg/L. Using a #15 surgical blade or a Micro-Sharp stab scalpel with a 5-mm blade (depending on the surgeon’s preference), a 6- to 8-mm incision was made ventrally in the body cavity, 3 mm from and parallel to the mid-ventral line and equidistant from the pelvic girdle and pectoral fin. A PIT tag was inserted followed by an acoustic tag. Both tags were inserted toward the anterior end of the fish. Two interrupted sutures of 5-0 monofilament with an RB-1 needle were used to close the incision. After closing the incision, the fish were placed in a 5-gal aerated recovery bucket and closely monitored until fish had reestablished equilibrium. Each bucket held one to five fish depending on the size of the fish and the number to be released at each site. Water in the transport buckets also was within $\pm 1^{\circ}\text{C}$ of river water temperature. Each transport bucket had many 3/8-inch-diameter holes drilled through the upper one third of its height and around its circumference to allow water to flow through each bucket when it was submerged in a large post-surgery holding tank that had fresh river water flowing through it (Figure 2.4). The large holding tanks were insulated to keep the water temperature within acceptable limits. Fish were held in these tanks for 18 to 30 hours before being transported for release into the river.



Figure 2.3. Surgical Implantation of Tags



Figure 2.4. Post-Surgery Holding Tank with Recovery Buckets

2.5 Transport and Release

Tagged fish were transported from JDA by truck to the three release locations: Roosevelt, Washington, upstream of JDA near rkm 390; TDA tailrace near rkm 307; Hood River near rkm 275. To transport tagged fish, two $\frac{3}{4}$ -ton trucks were outfitted with two 180-gal Bonar insulated totes. The totes could hold ten 5-gal fish buckets. The totes had snug-fitting lids and extra space to accommodate the addition of ice on hot days. A network of valves and plastic tubing was attached to an oxygen tank for delivering oxygen to the totes from a 2200-psi oxygen tank during transport. The Bonar totes were filled with fresh river water before fish buckets were removed from the post-surgery holding tanks and placed in the totes. Air lines were then placed into the totes. A YSI meter was used to measure the dissolved oxygen and the temperature of water in the totes before, during, and after transport to make sure that these properties stayed within acceptable limits. Transportation routes were adjusted to provide equal travel times to each release location from JDA.

Upon arriving at a release site, fish buckets were transferred to a boat for transport to the in-river release location. There were five release locations at each release cross section. Equal numbers of buckets of fish were released at each of the five locations for a given cross-section. During spring, releases occurred for 37 consecutive days (from April 28 to June 1, 2010). During summer, releases occurred for 35 consecutive days (from June 13 to July 17, 2010). Releases alternated between daytime and nighttime, every other day, over the course of the study. The timing of the releases at the three locations was staggered to help facilitate downstream mixing (Table 2.3).

Just before fish were released in the river, fish buckets were opened to check for dead fish. Every dead fish was returned to the tagging facility and scanned with a BioMark portable transceiver PIT-tag scanner to identify the implanted PIT-tag code. The associated acoustic-tag code was identified later from tagging data which recorded all pairs of PIT and acoustic tags implanted in fish the previous day. Dead tagged fish were released once a week to determine if they were detected on downstream survival-detection arrays. Post-tagging, pre-release mortalities were low for each run of fish studied in 2010 (YC = 0.1%; STH = 0.05%; SYC = 0.22%).

Table 2.5. Relative Release Times for the Acoustic-Tagged Fish to Accommodate Downstream Mixing. Releases were timed to accommodate the approximately 60-h travel time between R_1 and R_2 and the 13-h travel time between R_2 and R_3 .

Release Location	Relative Release Times	
	Daytime Start	Nighttime Start
R_1 (rkm 390)	Day 1: 0900 h	Day 2: 2000 h
R_2 (rkm 307)	Day 3: 2000 h	Day 5: 0900 h
R_3 (rkm 275)	Day 4: 0900 h	Day 5: 2200 h

2.6 Detection of Tagged Fish

Two types of JSATS arrays—cabled and autonomous—were deployed to detect fish implanted with JSATS acoustic transmitters and released at Roosevelt, Washington, as they passed downstream through the study reach between the BON forebay array, at rkm 236, and Oak Point, Washington, at rkm 86 (Table 2.1). An array is defined as a group of nodes deployed within 1 km of a specific river cross section to detect acoustically tagged fish. Nodes were deployed at distances ≤ 150 m from each other and ≤ 90 m from the shore. However, additional nodes sometimes had to be deployed in entrances to or exits from side channels formed by islands downstream of BON.

2.6.1 Cabled Dam-Face Arrays

The cabled dam-face receiver was designed by PNNL for the USACE Portland District using an off-the-shelf user-build system (Weiland et al. 2011b). Each cabled receiver consists of a computer, data-acquisition software, digital signal-processing cards with field-programmable logic gate array (DSP+FPGA), GPS card, a four-channel signal-conditioning receiver with gain control, hydrophones, and cables (Figure 2.5). The software that controls data acquisition and signal processing is the property of the USACE and is made available by the USACE as needed.

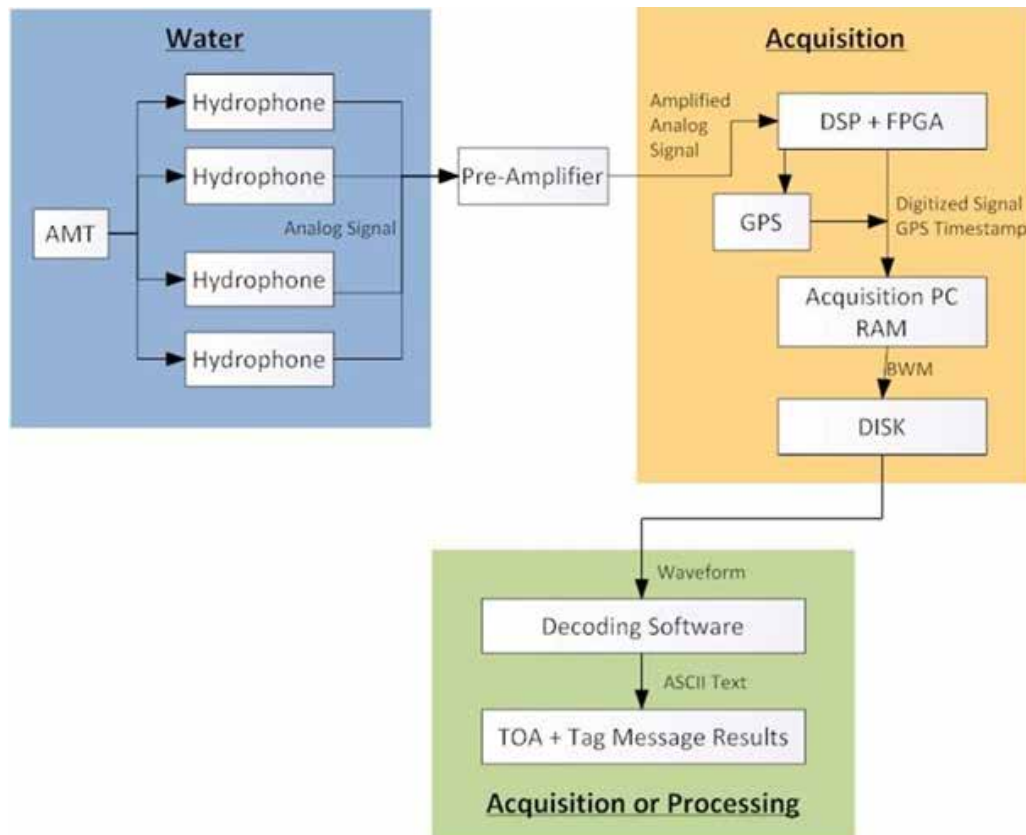


Figure 2.5. Schematic of Dam-Face Receiver System Showing the Main Components and Direction of Signal Acquisition and Processing. Abbreviations are as follows: AMT = acoustic micro-transmitter implanted in fish; DSP = digital signal processing card; FPGA = field programmable logic gate array; GPS = global positioning system; PC = personal computer; RAM = random access memory; BWM = binary waveform; TOA = time of arrival.

A modular JSATS cabled array was deployed along the upstream face of BON to detect JSATS-tagged smolts approaching the dam. Two hydrophones were deployed at different depths on each main pier and eight hydrophones were attached to clump mounts that were lowered to the bottom of the forebay about 33 m upstream of the dam face (Figure 2.7). Clump-mounted hydrophones were deployed to provide additional detections off of the plane of the dam face to increase the resolution of 3D tracking (Deng et al. 2011a).

The dam-face cabled array consisted of 84 cabled hydrophones mounted on piers or walls adjacent to piers and distributed among 22 four-channel receivers. Hydrophones were deployed on trolleys in pipes attached to the main piers at the powerhouse and spillway and on some adjacent concrete walls (Figure 2.6) in a known fixed geometry. The GPS coordinates and elevations of dam-face mounted cabled hydrophones are listed in Appendix B. Trolley pipes at the powerhouse were 4 in. in diameter, and made of powder-coated schedule 40 steel pipe that were slotted down one side for deployment of the trolley. Pipes at the powerhouses were 80 ft long and extended from deck level at elevation 90 ft above mean sea level (MSL) down to a mid-intake depth at elevation ranging from 12 to 15 ft above MSL (Figure 2.7). A cone was attached to the top of the pipe to assist with trolley insertion. At the powerhouses (B1 and B2), hydrophones were deployed at two elevations, one shallow (between about 63 and 70 ft above MSL) and the other deep (between about 12 and 15 ft above MSL). The precise

elevation of each hydrophone was calculated by measuring cable and trolley lengths between shallow and deep hydrophones and the length of cable to the top of the pipe and the slope of the pier on which the slotted pipe was mounted. Reference beacons (Figure 2.8) transmitting at 156 dB \parallel 1 μ Pa at 1 m were attached to four or five hydrophone trolleys at each dam structure so that transmitted signals could be detected by every hydrophone on each dam face. Detection of beacon signals provided feedback on hydrophone performance throughout the season.

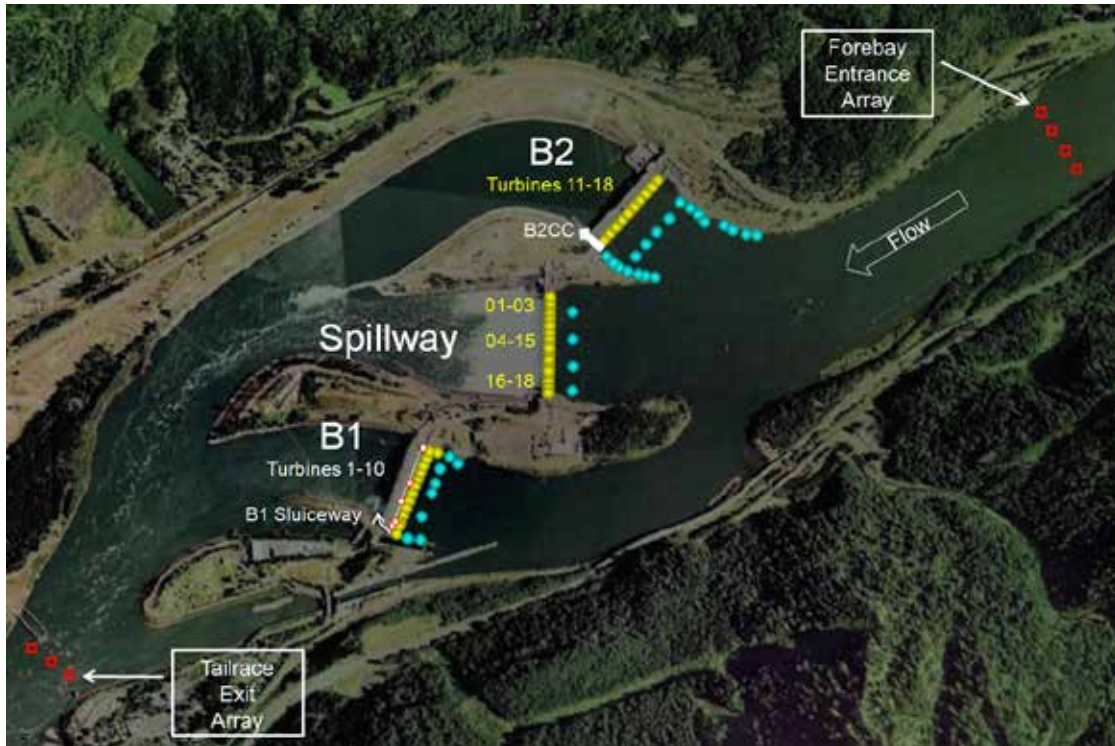


Figure 2.6. Location of Hydrophones on the Dam Face (yellow dots) and in the Immediate B1, B2, and Spillway Forebays (blue dots) of Bonneville Dam in 2010. Red squares indicate positions of autonomous node deployments in the forebay entrance array and tailrace exit array. The direction of surface-flow outlet flow is indicated by white arrows at each powerhouse.

Ten clump mounts were also deployed in the forebays about 75–100 m upstream of dam faces and away from shore. There were four at B2, four at the spillway, and two at B1. At B1, two hydrophones also were deployed on either side of the pier extending upstream from between turbines 6 and 7. Each clump mount and B1 pier mount had a single hydrophone that was used to verify positioning of pier nose deployed hydrophones. There also were 15 near-shore hydrophones deployed on buoys in the B2 forebay.



Figure 2.7. Four-Inch-Diameter Trolley Pipe Mounted on Piers at B2 (upper inset view of pipe top). Similar 4-in.-diameter pipes were installed at B1.

At the spillway, hydrophones were mounted on trolleys that were deployed in 8-in.-diameter vertical slotted pipes that extended from about 4 ft above maximum pool to the elevation of the ogee (Figure 2.8). At each spillway pier, one hydrophone was deployed at a shallow elevation (65.87–68.05 ft above MSL) and the other at a deep elevation (38.12–40.39 ft above MSL). The exact elevation of each hydrophone to the nearest 0.01 ft was determined by measuring cable and trolley lengths between hydrophones and the length of cable suspending the trolleys below the top of each pipe.



Figure 2.8. Trolleys Used to Deploy Hydrophones at B1 and B2 (left) and the Spillway (right). The photos show 4-in.- (left) and 8-in.- (right) diameter trolleys for slotted pipes. Each trolley had a steel arm to support a hydrophone that was surrounded by a plastic cone lined with anechoic material to prevent sound reception from a downstream direction. The white polyvinyl chloride object immediately to the right of the hydrophone baffle in the left picture is a reference beacon that was attached to four or five trolleys at each dam structure (B1, spillway, and B2).

The 3D double-detection array at the face of BON used to compose the virtual-release group was also used to identify the passage routes of fish through the dam. These passage-route data were used to calculate SPE and spill + B2CC passage efficiency. The 3D tracking data were further used to estimate forebay residence time within the 100-m zone nearest the dam. The fish used in the virtual release at the face of the dam were used to estimate tailrace egress time.

In addition to the detection arrays identified in Figure 2.9, hydrophone arrays were deployed below BON at rkm 49, 37, 22, 8, and 3. These arrays served as potential additional downstream detection arrays to improve precision in the survival analysis for BON.

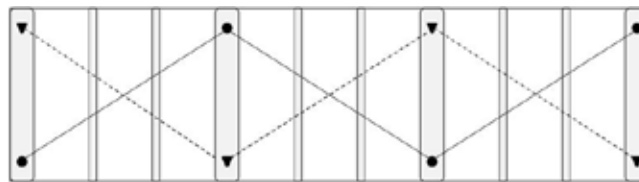


Figure 2.9. Front View Schematic of Hydrophone Deployments at Three Turbines Showing the Double-Detection Arrays. The circles denote the hydrophones of Array 1 and the triangles denote the hydrophones of Array 2.

2.6.2 Autonomous Node Arrays

The Sonic Concepts autonomous acoustic-telemetry receiver (node) used in this study consisted of two coupled parts. The top was made from Schedule 40 10.16-cm-diameter polyvinyl chloride (PVC) pipe that was capped at the top and had a fitting with male threading at the bottom (see Figure 2.10). The cap was modified for watertight seating of a hydrophone, and the body below the cap housed the analog and digital boards for processing detected tag signals. A lubricated 10.16-cm-diameter rubber O-ring was

fitted over the lower threaded end so that it would form a watertight seal when the node top was screwed together with the bottom. The node bottom was made from approximately 1 m of 10.16-cm-diameter PVC pipe and the upper end had a fitting with female threads for coupling it to the node top. The lower end of the node bottom was capped and a stainless-steel harness was located just below the upper fitting so the node could be attached to an anchor system, which is described later. An acoustic beacon that transmitted a signal four times louder than acoustic tags once every 15 seconds was attached to the outside of the battery housing just below the threaded end of the housing. This beacon was used to determine the location of a node if it didn't surface after it was acoustically released from an anchor. Beacons also could be used to determine when an adjacent node disappeared.



Figure 2.10. Side (left) and Bottom (right) View of a Node Top

Before deployment, 28-day lithium-ion batteries were gently lowered into the node bottom and secured in place with a battery-retention device. Wires from the batteries were attached to connectors from the analog board in the node top. One end of a serial cable was connected to a plug from the board set in the node top and the other end was plugged into a laptop computer so that staff could communicate with the node, set its date and time, and verify detection of a beacon tag. Next, a 1-gigabyte SanDisk Extreme III CompactFlash (CF) card was mounted in a slot on the board set, and the node top and bottom were screwed together until beveled edges of each piece compressed the O-ring to form a watertight seal. Just before putting the node into the water, we verified that a light-emitting diode on the node top housing was flashing, which indicated that the node was functioning properly and data would be written to the CF card. In the water, air space within the sealed node provided positive buoyancy, while the batteries in the node bottom provided ballast to help keep the node upright.

The length of autonomous node rigging varied with water depth at deployment sites. As shown in Figure 2.11, a 1.5-m section of line with three 2.72-kg buoyancy floats was attached to a strap half way between the node tip and node bottom. An InterOcean Systems Model 11 acoustic release was attached to the other end of the 1.5-m line. The length of the 0.48-cm-diameter wire rope anchor line deployed varied with water depth, from 0.3 to 2 m long. One end of the anchor line was swagged to a 76.2-mm ring that fit into the mechanical latch end of the acoustic release and the other end was shackled to a 34-kg anchor. In water <5.5 m deep, we bound the node, float line, and acoustic release together with 1-m-long zip-ties and used a short (0.3-m) anchor line to keep the entire package under 1.5 m long.

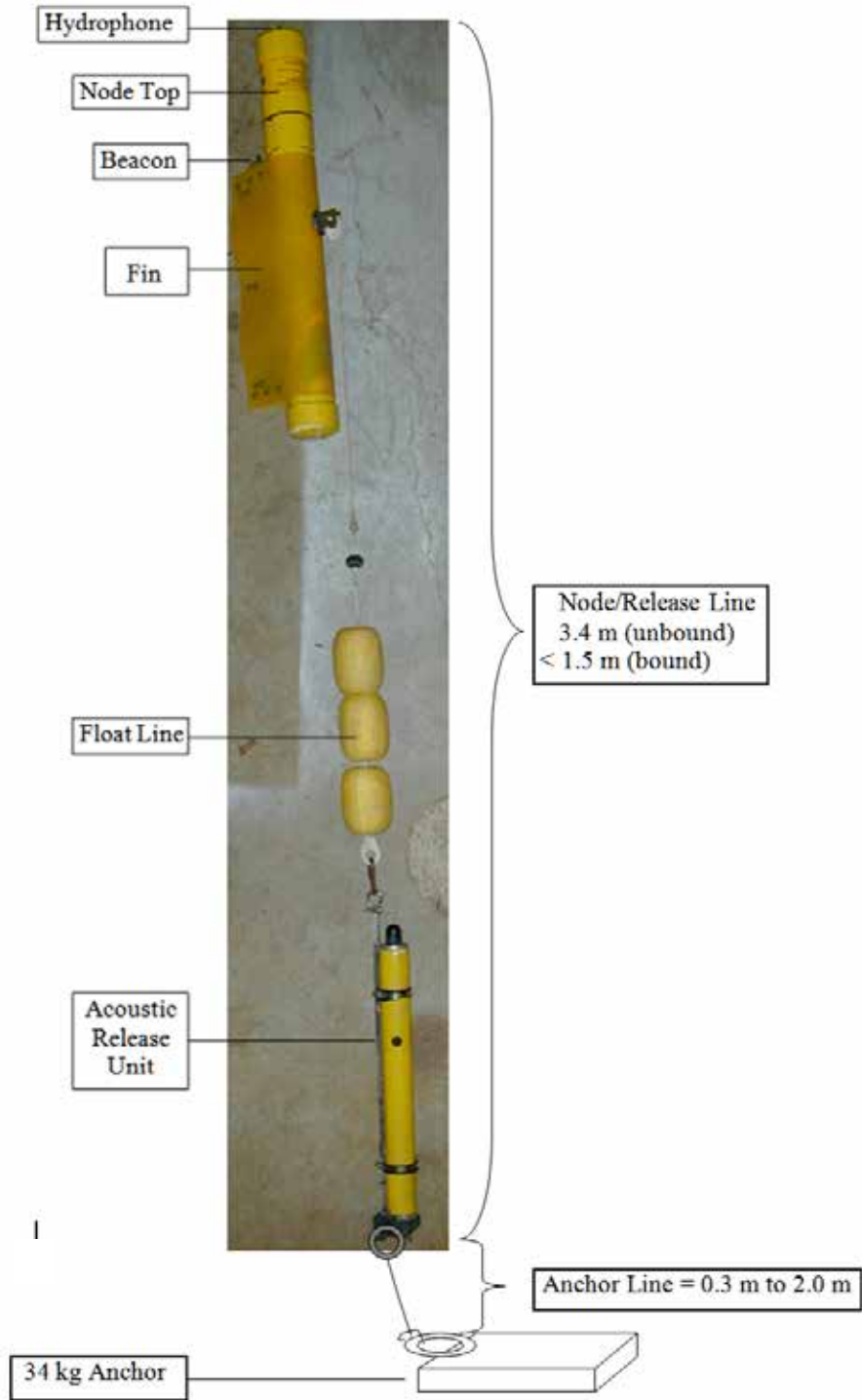


Figure 2.11. Autonomous Node Rigging

Autonomous nodes were deployed in arrays across river cross sections to detect tagged fish migrating downstream through the study area. Autonomous node arrays for calculating project passage travel times in the BON forebay and tailrace near rkm 236.0 and 233.0, respectively (Figure 2.6; Figure 2.12a), and three arrays used for survival detection and calculations were deployed at rkm 153, 113, and 86.2

(Figure 2.12 panels b, c, and d). The GPS coordinates and depths of autonomous node deployments are listed in Appendix B.

(a) BON Forebay (upper right) & Tailrace (lower left) Arrays



(b) Primary Survival Detection Array



(c) Secondary Survival Detection Array



(d) Tertiary Survival Detection Array



Figure 2.12. Locations of Autonomous Nodes in Study Arrays. Arrays were located in the BON forebay (CR236) and tailrace (CR233) (Panel a), the primary array near Knapp, Washington, about 10 km downstream of the Columbia and Willamette River confluence (CR153; Panel b), the secondary array near Kalama, Washington (CR113; Panel c), and tertiary array near Oak Point, Washington (CR086; Panel d).

2.6.3 Node Retrieval, Servicing, and Redeployment

Autonomous nodes were first deployed in late April, retrieved every 2 weeks to download data, and redeployed. Batteries were replaced every 28 days. The last recovery data in 2010 was on August 9. The post-FCRPS study deployed and serviced the Kalama and Oak Point arrays monthly. These post-FCRPS arrays were used as secondary and tertiary survival arrays, respectively. The first step in servicing a node was to trigger its acoustic release by entering a release-specific code into a transceiver to transmit an acoustic signal to the release mechanism to free the acoustic release and node from the anchor. After the node, floats, and acoustic release surfaced, they were retrieved by boat (Figure 2.13). The next step was to dry the node with a towel, open it, eject the CF card, and download data from the card to a laptop computer. The data file was checked to verify that the node collected data throughout its deployment, records were continuous, and records included time stamps and tag detections. The CF card was replaced

every time nodes were retrieved. When data were corrupt, the node top was replaced with a new one and the faulty top was sent to Sonic Concepts in Seattle for repair. The most common problem was damage to the hydrophone tip.



Figure 2.13. Autonomous Node Retrieval

2.7 Project Discharge and Water Temperature

Project discharge data by spill bay and turbine unit and forebay and tailwater elevations were acquired in 5-minute increments by the automated data-acquisition systems at BON and provided by the Portland District. Average discharge and forebay water temperature data from 1999 through 2008 were downloaded from the DART (Data Access in Real Time) website (<http://www.cbr.washington.edu/dart>) and plotted. Five-minute discharges for the entire project and spillway were averaged by day and plotted along with 10-year averages.

2.8 Acoustic Signal Processing

Processing of acoustic signals involved the use of binary waveform data files, filtering of decoded data, and tracking of fish movements.

2.8.1 Binary Waveform Data Files

Data collected by the JSATS cabled hydrophones were encoded candidate messages saved in binary time-domain waveform files. Figure 2.13 shows the waveforms of an actual example acquired at the JDA spillway on June 18, 2008. The waveform files were then processed by a decoding utility (Waveform Utilities developed by the USACE and PNNL) that identifies valid tag signals and computes the tag code and time of arrival using Binary Phase Shift keying. Binary Phase Shift keying is a digital-modulation technique that transmits messages by altering the phase of the carrier wave. Several filtering algorithms were then applied to the raw results from the decoding utilities to exclude spurious data and false positives.

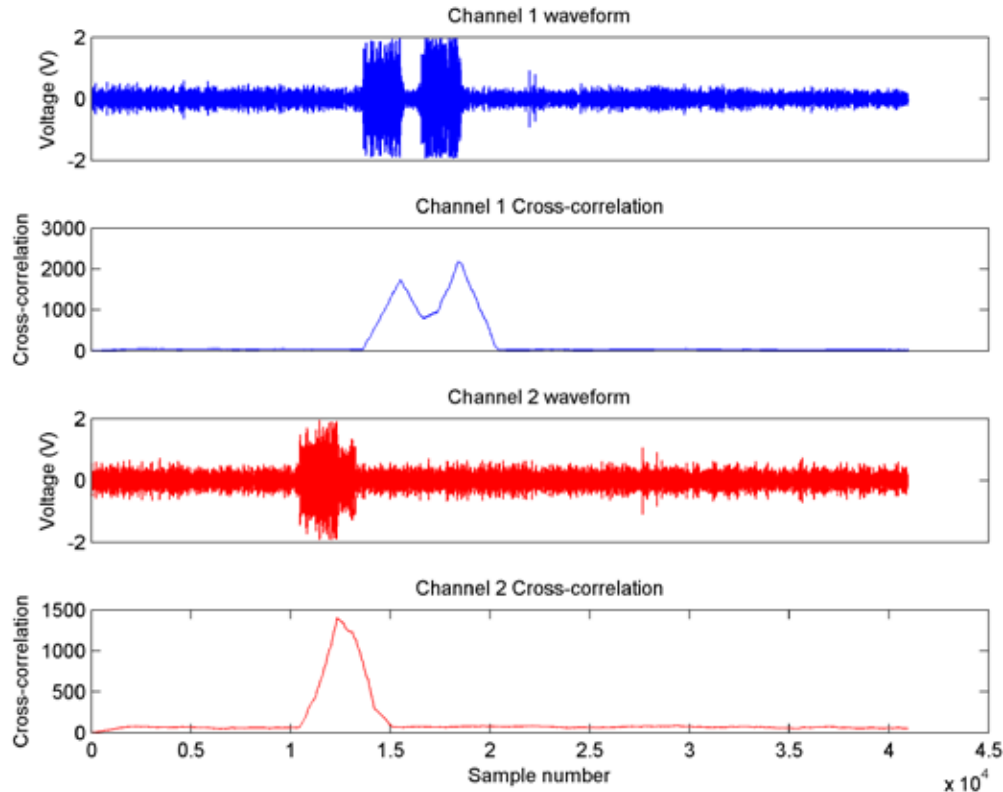


Figure 2.14. Example of Time-Domain Waveforms and Corresponding Cross-Correlations Acquired at the John Day Dam Spillway. The message portion was 1860 samples (744 μ s long). Note that multipath components were present in both channels. Decodes from the multipath components were filtered out in post-processing.

Transmissions of JSATS tag codes received on cabled and autonomous hydrophones were recorded in raw data files. These files were downloaded periodically and transported to PNNL offices in North Bonneville and Richland, Washington, for processing.

2.8.2 Filtering Decoded Data

Receptions of tag codes within raw data files were processed to produce a data set of accepted tag-detection events. For cabled arrays, detections from all hydrophones at a dam were combined for processing. The following three filters were used for data from cabled arrays:

- **Multipath filter:** For data from each individual cabled hydrophone, all tag-code receptions that occur within 0.156 seconds after an initial identical tag code reception were deleted under the assumption that closely lagging signals are multipath. Initial code receptions were retained. The delay of 0.156 seconds was the maximum acceptance window width for evaluating a pulse repetition interval (PRI) and was computed as $2(\text{PRI_Window} + 12 \times \text{PRI_Increment})$. Both PRI_Window and PRI_Increment were set at 0.006, which was chosen to be slightly larger than the potential rounding error in estimating PRI to two decimal places.
- **Multi-detection filter:** Receptions were retained only if the same tag code was received at another hydrophone in the same array within 0.3 seconds because receptions on separate hydrophones within 0.3 seconds (about 450 m of range) were likely from a single tag transmission.

- PRI filter: Only those series of receptions of a tag code (or “messages”) that were consistent with the pattern of transmissions from a properly functioning JSATS acoustic tag were retained. Filtering rules were evaluated for each tag code individually, and it was assumed that only a single tag would be transmitting that code at any given time. For the cabled system, the PRI filter operated on a message, which included all receptions of the same transmission on multiple hydrophones within 0.3 seconds. Message time was defined as the earliest reception time across all hydrophones for that message. Detection required that at least six messages were received with an appropriate time interval between the leading edges of successive messages.

Like the cabled-array data, receptions of JSATS tag codes within raw autonomous node data files are processed to produce a data set of accepted tag detection events. A single file is processed at a time, and no information on receptions at other nodes is used. The following two filters are used during processing of autonomous node data:

- Multipath filter: Same as for the cabled-array data.
- PRI filter: Retain only those series of receptions of a tag code (or “hits”) that were consistent with the pattern of transmissions from a properly functioning JSATS acoustic tag. Each tag code was processed individually, and it was assumed that only a single tag will be transmitting that code at any given time.

The output of the filtering processes for both cabled and autonomous hydrophones was a data set of events that summarized accepted tag detections for all times and locations where hydrophones were operating. Each unique event record included a basic set of fields that indicated the unique identification number of the fish, the first and last detection time for the event, the location of detection, and how many messages were detected within the event. This list was combined with accepted tag detections from the autonomous arrays and PIT-tag detections for additional quality assurance/quality control analysis prior to survival analysis. Additional fields captured specialized information, where available. One such example was route of passage, which was assigned a value for those events that immediately preceded passage at a dam based on spatial tracking of tagged fish movements to a location of last detection. Multiple receptions of messages within an event can be used to triangulate successive tag positions relative to hydrophone locations.

One of the most important quality control steps was to examine the chronology of detections of every tagged fish on all arrays above and below the dam-face array to identify any detection sequences that deviated from the expected upstream to downstream progression through arrays in the river. Except for possible detections on forebay entrance arrays after detection on a nearby dam-face array 1 to 3 km downstream, apparent upstream movements of tagged fish between arrays that were greater than 5 km apart or separated by one or more dams were very rare (<0.015%) and probably represented false positive detections on the upstream array. False positive detections usually will have close to the minimum number of messages and were deleted from the event data set before survival analysis.

2.8.3 Tracking Fish Movements

Tagged fish in the immediate forebay of BON were tracked in three dimensions to determine routes of passage into the B1 surface-flow outlets and B2CC passage efficiency, and some combination of 3D, 2D, and last detection was used to assign other routes of passage through the dam. Acoustic tracking is a

common technique in bioacoustics based on time-of-arrival differences among different hydrophones. Usually, the process requires a three-hydrophone array for 2D tracking and a four-hydrophone array for 3D tracking. Our methods for 3D tracking are described in detail by Deng et al. (2011a).

2.9 Statistical Methods

The statistical methods include tests of assumptions and estimation of dam-passage survival, forebay- and dam-passage survival, travel times, passage efficiencies, and distributions.

2.9.1 Tests of Assumptions

There were several assumptions of the survival model that could be readily tested. The following table describes survival model assumptions and subsequent sections describe testing conducted in 2010.

As explained in the *Statistical Design for the Lower Columbia River Acoustic-Tag Investigations of Dam Passage Survival and Associated Metrics* by Skalski (2009), the assumptions of the virtual single-release model and tests of the assumptions are as follows:

Assumption	Test
A1. Individuals marked for the study are a representative sample from the population of inference.	Compare run timing distributions for the test fish versus the smolt monitoring data by species. Compare fish size and other fitness measures between tagged fish and run-at-large.
A2. All sampling events are “instantaneous.” That is, sampling occurs over a negligible distance relative to the length of the intervals between sampling events.	No test; the time a tagged fish spends at a sampling array is relatively brief compared to the time of travel between arrays.
A3. The fate of each tagged individual is independent of the fate of all others.	No test; commonly accepted as true in tagging studies.
A4. All tagged individuals alive at a sampling location have the same probability of surviving until the end of that event.	Tests 2 and 3 of Burnham et al. (1987) can be used to assess whether upstream detection has an effect on downstream survival.
A5. All tagged individuals alive at a sampling location have the same probability of being detected on that event.	No test; this assumption is satisfied by placing hydrophone arrays across the breadth of the river so that all fish, regardless of location, have the same probability of detection. Lab-derived tag-life and tag-expulsion data will be used to assess this assumption.
A6. All tags are correctly identified and the status of smolt (i.e., alive or dead) is correctly assessed.	Releases of dead tagged fish at the dams will be used to confirm the absence of false positive detections due to fish dying during dam passage but being detected downriver. Further, if dead fish are detected at the first detection array downstream of the dam, deployment of multiple additional arrays will allow flexibility to select arrays farther downstream to ensure this assumption is not violated. In addition, because tag loss or failure would violate the assumption, we will perform laboratory tag-life assessments. Release teams checked every bucket carefully for dropped acoustic and PIT tags before releasing fish.

Assumption	Test
A7. Survival in the lower river segment of the first reach is conditionally independent of survival in the upper river segment.	Comparison of the survival estimates through the two downstream reaches formed by the three below-dam hydrophone arrays for the three release groups can therefore be used to help assess the validity of this assumption. Laboratory tagging effects research using run-of-river untagged, PIT-only, and AT+PIT groups collected at the time of tagging and through the sort-by-code systems will be used to assess this assumption. Survival by release location and river reach will be assessed to test for tagging effects.
A8. The virtual release group is constructed of tagged fish known to have passed through the dam.	A double-detection array in the forebay increases detection probabilities close to 1.0 and will be used to test for homogeneous detection rates.
A9. All fish arriving at the dam have an equal probability of inclusion in the virtual release group, independent of passage route through the dam.	This assumption is met by having very high detection probabilities on dam-face arrays. Thus, we will estimate array detection probabilities.

2.9.1.1 Probability of Detection

Detection probabilities are an integral part of the survival estimation. For any particular passage route the following variables are defined based on detection on two independent hydrophone arrays at the dam face:

- n_{10} = number of tagged smolts detected by the first array but not the second
- n_{01} = number of tagged smolts detected at the second array but not the first
- n_{11} = number of tagged smolts detected at both the first and second arrays.

From these counts of smolts with various route-specific detection histories, absolute passage abundance (\hat{N}) of tagged smolts can be estimated as

$$\hat{N} = \frac{(n_{10} + n_{11} + 1)(n_{01} + n_{11} + 1)}{(n_{11} + 1)} - 1 \quad (2.1)$$

or

$$\hat{N} = \frac{(n_1 + 1)(n_2 + 1)}{(n_{11} + 1)} - 1 \quad (2.2)$$

where $n_1 = n_{10} + n_{11}$ and $n_2 = n_{01} + n_{11}$ with associated variance estimate (Seber 1982)

$$\text{Var}(\hat{N}) = \frac{(n_1 + 1)(n_2 + 1)(n_1 - n_{11})(n_2 - n_{11})}{(n_{11} + 1)^2(n_{11} + 2)} \quad (2.3)$$

The estimated probability of detection (p_1) in the first array is calculated as

$$\hat{p}_1 = \frac{n_{11}}{n_2} \quad (2.4)$$

and the probability of detection (p_2) in the second array as

$$\hat{p}_2 = \frac{n_{11}}{n_1} \quad (2.5)$$

The overall probability of a smolt being detected in the double-array system is given by

$$\hat{P} = 1 - (1 - \hat{p}_1)(1 - \hat{p}_2) = \frac{n_{11}(n_1 + n_2 + n_{11})}{n_1 n_2} \quad (2.6)$$

We estimated passage abundance and the proportion of fish passing through every route through the dam (i.e., B1 sluiceway, B1 turbines, spillway, B2CC, B2 JBS, B2 turbines) as well as for composite routes such as B1 (B1 sluiceway and B1 turbines) or B2 (B2CC, B2 JBS, and B2 turbines). For example, the proportion of the acoustic-tagged smolts passing through the B2CC (\hat{P}_{B2CC}) was estimated as follows:

$$\hat{P}_{B2CC} = \frac{\hat{N}_{B2CC}}{\hat{N}_{B1_sluiceway} + \hat{N}_{B1_turbines} + \hat{N}_{Spill} + N_{B2CC} + \hat{N}_{B2_JBS} + N_{B2_turbines}}, \quad (2.7)$$

where N_i is the absolute passage through the i th route, as described above.

2.9.1.2 Burnham et al. 1987 Tests

Tests 2 and 3 of Burnham et al. (1987) have been used to assess whether upstream detection history has an effect on downstream survival. Such tests are most appropriate when fish are physically recaptured or segregated during capture as in the case with PIT-tagged fish going through the JBS. However, acoustic-tag studies do not use physical recaptures to detect fish. Consequently, there is little or no relevance of these tests in acoustic-tag studies. Furthermore, the very high detection probabilities present in acoustic-tag studies frequently preclude calculation of these tests. For these reasons, these tests were not performed.

2.9.1.3 Tests of Mixing

Evaluation of homogeneous arrival of release groups at downriver detection sites was based on graphs of arrival distributions. The graphs were used to identify any systematic and meaningful departures from mixing. Ideally, the arrival distributions should overlap one another with similarly timed modes.

2.9.1.4 Tagger Effects

Subtle differences in handling and tagging techniques can have an effect on the survival of acoustic-tagged smolts used in the estimation of dam-passage survival. For this reason, tagger effects on juvenile STH and CH1 smolts were evaluated as part of the compliance study at TDA (Skalski et al. 2010a, b). In that analysis, the single release-recapture model was used to estimate reach survivals for fish tagged by different individuals. The analysis evaluated whether any consistent pattern of reduced reach survivals existed for fish tagged by any of the tagging staff.

For k independent reach survival estimates, a test of equal survival was performed using the F -test

$$F_{k-1, \infty} = \frac{s_{\hat{S}}^2}{\frac{\sum_{i=1}^k \text{Var}(\hat{S}_i | S_i)}{k}} \quad (2.8)$$

where $s_{\hat{S}}^2 = \frac{\sum_{i=1}^k (\hat{S}_i - \bar{\hat{S}})^2}{k-1}$ and $\bar{\hat{S}} = \frac{\sum_{i=1}^k \hat{S}_i}{k}$.

The F -test was used in evaluating tagger effects.

2.9.2 Tag-Life Study

All tags for the spring season were delivered prior to April 23, 2010, and tags from all manufacturing dates were randomly mixed prior to the use of any tags. After mixing, 49 tags were randomly selected for a spring tag-life assessment. Similarly, all tags for summer deployments were delivered prior to the tagging of any fish during the summer tagging season and following mixing, 50 tags were removed randomly for a summer tag-life assessment. As described by Skalski (2009), "...tag loss and tag failure would also violate Assumption A6" (see Assumption Testing above). The possibility of acoustic-tag failure depends on travel time relative to battery life. A tag-life curve was constructed for the spring tags and the summer tags. Tag-life curves and the cumulative percent of tags passing survival-detection arrays downstream of each dam were plotted together as a function of time since tag activation. We made tag-life corrections to survival estimates, as described in the next section based upon the method described by Townsend et al. (2006).

2.9.3 Estimation of Survival Rates

The design for estimating survival for fish passing through 2-km of forebay, the dam, and 81-km of tailwater or through just the dam and 81 km of tailwater was illustrated in Figure 2.1. Fish detections assigned to the virtual release at the dam face along subsequent capture histories on three survival detection arrays downstream of the dam were further divided by route of passage assignments or summer spill treatment to estimate route- or treatment-specific survival rates.

2.9.3.1 Processing Software and Approach

The 2010 study was a virtual single-release study design in which fish from multiple upstream releases that were detected either by the forebay entrance array or by the dam-face array were entered into a virtual release group specific to one of those arrays. We used TagPro software to select fish releases and detection sites from the 2010 database. TagPro software is an acoustic-tag data preprocessor for survival estimation software programs including Active Tag Life Adjusted Survival (ATLAS) and Survival Under Proportional Hazards SURPH (<http://www.cbr.washington.edu/analysis.html>). TagPro data files were loaded into ATLAS Version 1.2.1 (6/1/2011) to create virtual single-release capture history files. The three downstream survival detection arrays produced $2^3 = 8$ possible capture histories for each release group (111, 011, 101, 001, 110, 010, 100, and 000), where a 1 indicates detection, and a zero indicates no detection on each of three successive survival-detection arrays. For example, “111” indicates detection on all three arrays, whereas “010” indicates detection on the second array but not on the first or third arrays. The ATLAS User Manual (see Section 3.3, pages 34–40 in Lady et al. 2010) describes in detail analyses for several study designs including the virtual single-release design used in this study. Tags detected on the dam-face array and then detected or not detected on the three downstream survival detection arrays were in a single TagPro file used to estimate dam-passage survival for a specific run of fish studied. Those files were divided into smaller files according to route-of-passage criteria (B1 turbines, B1 surface-flow outlets, spillway, B2CC, B2 turbines, or B2 JBS) using the Statistical Analysis System (SAS) and resulting route-specific detection histories were analyzed separately in ATLAS using the virtual single-release option to obtain route-specific survival estimates for each run of fish. Similarly, we used SAS to divide large dam-passage TagPro detection files into smaller files according to the spill treatment in effect at the time that each tagged CHO passed the dam in summer to provide estimates for each spill treatment. We also divided the summer dam-passage data by spill block and treatment.

2.9.3.2 Tag-Life Corrections to Survival Rates

A virtual release group is composed of fish known to have arrived alive at an acoustic array. These fish may be composed of individuals from multiple release groups upstream. As such, they may have had different times inriver and require different tag-life corrections. Assuming all fish in a virtual release have the same downstream survival and detection processes, their subsequent capture histories may be modeled by a joint likelihood (see pages 71 and 72 in Lady et al. 2010). The tag-life corrections for the virtual release site are the unconditional tag survival probabilities from the actual release site to the virtual release site. Corrections for downstream survival detection arrays are conditional tag survival probabilities, given that the tags were alive at the virtual release site. Tag-life corrections for each release of fish detected at a virtual release site are used to calculate subsequent tag-life corrections at downstream arrays but are not used to directly adjust survival rates.

2.9.4 Estimation of Travel Times

Travel times associated with forebay residence and tailrace egress were estimated using medians and arithmetic averages, i.e.,

$$\bar{t} = \frac{\sum_{i=1}^n t_i}{n}, \quad (2.9)$$

with the variance of \bar{t} estimated by

$$\text{Var}(\bar{t}) = \frac{\sum_{i=1}^n (t_i - \bar{t})^2}{n(n-1)}, \quad (2.10)$$

and where t_i was the travel time of the i^{th} fish ($i=1, \dots, n$).

Various travel time metrics for individual fish passing the dam were determined as follows:

- Forebay residence time was calculated by subtracting the time of last detection on the dam-face array from the time of first detection on the forebay entrance array.
- 100-m forebay residence time was calculated by subtracting the time of last detection at the dam face from the time of first detection 100 m upstream of the dam face.
- Tailrace egress time was calculated by subtracting the time of last detection at the dam-face array from the time of last detection at the tailrace exit array downstream of the dam.
- Project passage time was calculated by subtracting the time of first detection on the forebay entrance array from the time of last detection on the tailrace egress array.

2.9.5 Estimation of Passage Efficiencies

Spill-passage efficiency was estimated by the fraction

$$\text{SPE} = \frac{\hat{N}_{\text{spillway}}}{\hat{N}_{\text{B1_sluice}} + \hat{N}_{\text{B1_turbines}} + \hat{N}_{\text{Spill}} + \hat{N}_{\text{B2CC}} + \hat{N}_{\text{B2_JBS}} + \hat{N}_{\text{B2_turbines}}}, \quad (2.11)$$

where \hat{N}_i is the absolute passage through the i^{th} route through the dam.

The double-detection array was used to estimate absolute abundance (N) through a route using the single mark-recapture model (Seber 1982) independently at each route.

Calculating the variance in stages, the variance of SPE was estimated as

$$\text{Var}(\text{SPE}) = \frac{\text{SPE}(1-\text{SPE})}{\sum_{i=1}^3 \hat{N}_i} + \text{SPE}^2(1-\text{SPE})^2 \times \frac{\hat{e} \text{Var}(\hat{N}_{\text{B1}}) + \text{Var}(\hat{N}_{\text{B2}})}{\hat{e} (\hat{N}_{\text{B1}} + \hat{N}_{\text{B2}})^2} + \frac{\text{Var}(\hat{N}_{\text{spillway}})}{\hat{N}_{\text{spillway}}^2} \frac{\hat{u}}{\hat{u}} \quad (2.12)$$

where \hat{N}_{B1} is the absolute number passing through B1 (B1 sluiceway + B2 turbine), and \hat{N}_{B2} is the absolute number passing through B2 (B2CC + B2 JBS + B2 turbines).

Spillway + B2CC passage efficiency, as required by the 2008 Fish Accords, was calculated as

$$\text{SPE}_2 = \frac{\hat{N}_{\text{spillway}} + \hat{N}_{\text{B2CC}}}{\hat{N}_{\text{B1_sluice}} + \hat{N}_{\text{B1_turbines}} + \hat{N}_{\text{Spillway}} + \hat{N}_{\text{B2CC}} + \hat{N}_{\text{B2_JBS}} + \hat{N}_{\text{B2_turbines}}}, \quad (2.13)$$

where \hat{N}_i is the absolute passage through the i th route through the dam. The variance of spillway + B2CC passage efficiency was calculated using the delta method (Seber 1982:7–9):

$$\text{Var}(\text{SPE}_2) = \frac{\text{SPE}_2(1-\text{SPE}_2)}{\sum_{i=1}^4 \hat{N}_i} + \text{SPE}_2^2(1-\text{SPE}_2)^2 \times \frac{\text{Var}(\hat{N}_{B1}) + \text{Var}(\hat{N}_{B2_JBS}) + \text{Var}(\hat{N}_{B2_turbines})}{(\hat{N}_{B1} + \hat{N}_{B2_JBS} + \hat{N}_{B2_turbines})^2} + \frac{\text{Var}(\hat{N}_{\text{spillway+B2CC}})}{\hat{N}_{\text{spillway+B2CC}}^2} \quad (2.14)$$

where $\hat{N} = \hat{N}_{\text{spillway+B2CC}} + \hat{N}_{B1} + \hat{N}_{B2_JBS} + \hat{N}_{B2_turbines}$

Fish-passage efficiency was estimated by the fraction

$$\text{FPE} = \frac{\hat{N}_{\text{Spillway}} + \hat{N}_{B1_sluice} + \hat{N}_{B2CC} + \hat{N}_{B2_JBS}}{\hat{N}}, \quad (2.15)$$

where \hat{N} is the sum of absolute passage through all routes at the dam. Calculating the variance in stages, the variance of FPE was estimated as

$$\text{Var}(\text{FPE}) = \frac{\text{FPE}(1-\text{FPE})}{\sum_{i=1}^5 \hat{N}_i} + \text{FPE}^2(1-\text{FPE})^2 \cdot \quad (2.16)$$

$$\frac{\text{Var}(\hat{N}_{\text{Spill}}) + \text{Var}(\hat{N}_{B1_sluice}) + \text{Var}(\hat{N}_{B2CC}) + \text{Var}(\hat{N}_{B2_JBS})}{(\hat{N}_{\text{Spill}} + \hat{N}_{B1_sluice} + \hat{N}_{B2CC} + \hat{N}_{B2_JBS})^2} + \frac{\text{Var}(\hat{N}_T)}{\hat{N}_T^2}, \quad (2.17)$$

where \hat{N}_T is the absolute number of fish passing through B1 and B2 turbines and other terms were defined previously.

2.9.6 Estimation of Distributions

The two- and three-dimensional tracks (Section 2.8.3) were used to determine forebay approach distributions and horizontal distributions of passage through the dam. Bonneville Dam provides a unique setting to study fish behavior and passage because it has two islands that separate the spillway from two powerhouses. For every fish detected more than once by the dam-face array, we examined the location of first and last detections at dam structures and used those records to evaluate behavior in the forebay upstream of the dam. Horizontal distributions of passage through the dam were evaluated among the three dam structures (B1, spillway, and B2) and among major passage routes through the dam. Vertical distributions were not evaluated except to differentiate between sluiceway- and turbine-passed fish at B1 and B2.

3.0 Results – Environmental Conditions

Environmental conditions include river discharge, water temperature, and forebay elevation.

3.1 River Discharge

Total water discharge at BON in 2010 fluctuated between 150 and 275 kcfs during the spring tagging period (Figure 3.1). These levels were consistently below the previous 10-year average. Starting in June, discharge increased to levels well above the 10-year average, peaking at 398 kcfs on June 12. After this peak, total outflow began a general decline, reaching 156 kcfs at the end of the summer tagging period on July 14. By the end of this period total outflow fluctuated near the 10-year average.

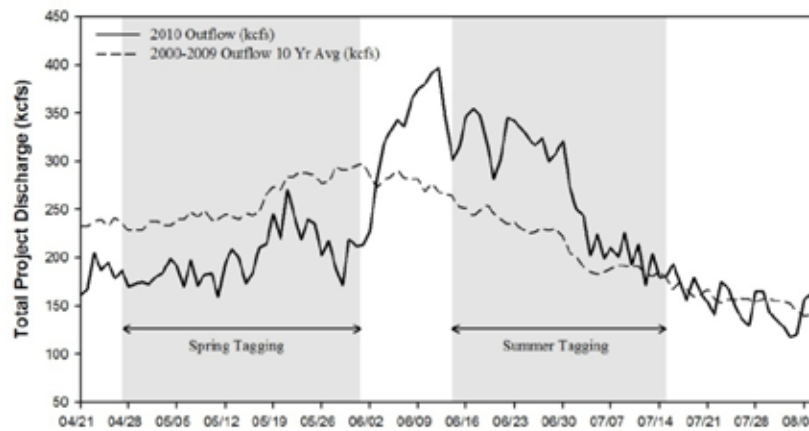


Figure 3.1. Average Daily Water Discharge (kcfs) from Bonneville Dam During the 2010 Study and for the Preceding 10-Year (2000–2009) Period

Daily spill discharge was within 25 kcfs of the average for the previous 10 years until June 6 and higher than the average after June 6 (Figure 3.2).

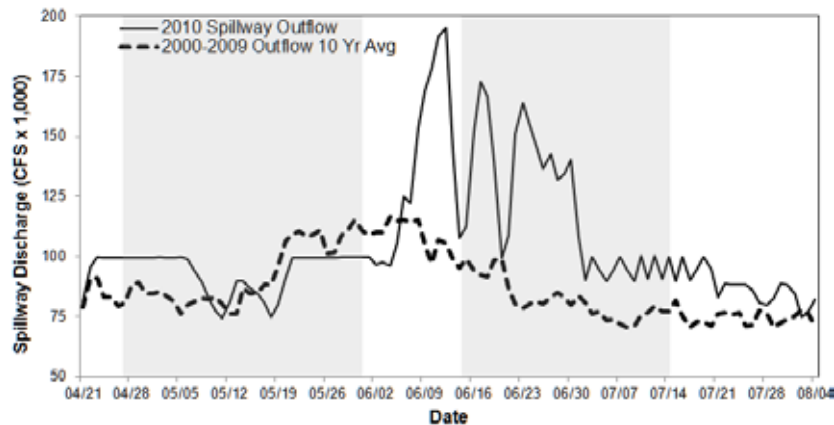


Figure 3.2. Daily Outflow and Spill Discharge of Water from Bonneville Dam for the Period from April 26 Through June 13, 2010 (labeled outflow and spill) and 10-Year Averages from 2000 Through 2009

3.2 Water Temperature

The daily average water temperature for 2010 started at 11.3°C on April 28, very close to the previous 10-year average of 10.7°C (Figure 3.3). Temperatures steadily increased throughout the study, but by the end of the spring tagging season 2010 temperatures were ~1.0–1.5°C below the 10-year average. This trend continued through the end of July.

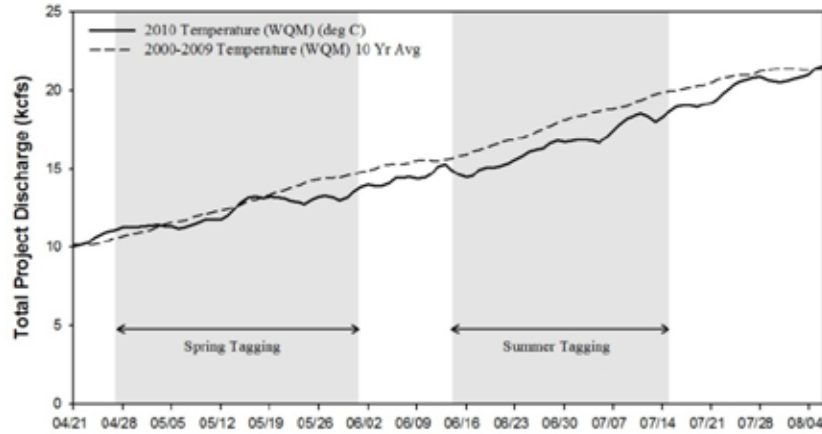


Figure 3.3. Bonneville Dam Average Daily Forebay Water Temperatures (°C) During the 2010 Study and for the Preceding 10-Year Period

3.3 Forebay Elevation

In 2010, forebay elevation ranged from 73.14 to 77.77 ft and averaged 75.34 ft above MSL. The median elevation was identical to the mean (Figure 3.4).

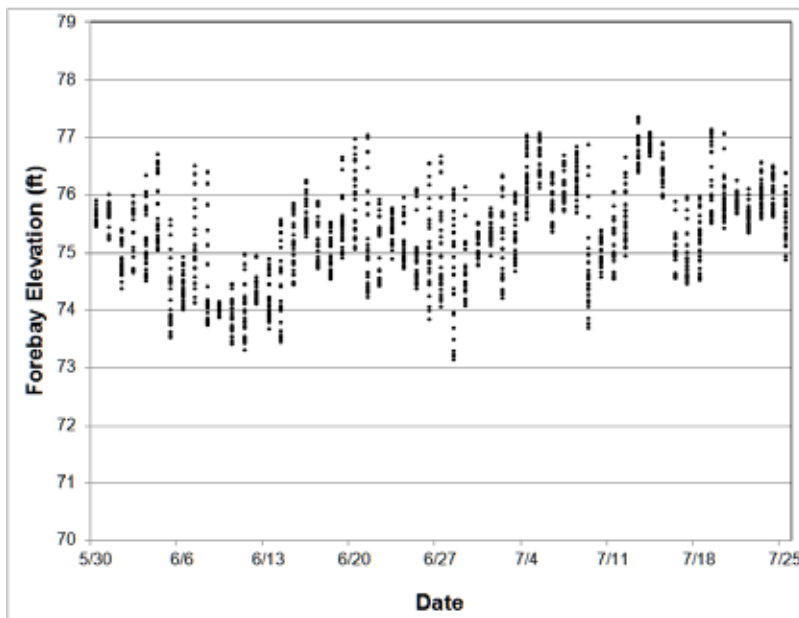


Figure 3.4. Bonneville Dam Hourly Estimates of Forebay Elevation. Elevation is in feet above MSL.

3.4 Summer Spill Treatments

Spill treatments occurred from July 2–18, when river discharge had lowered to levels deemed manageable by the dam operators (Figure 3.5). There were eight consecutive treatments in total; each treatment was composed of a 2-day block. On the first day of each block, a randomly selected spill treatment was executed, followed by a second day with the alternative treatment. Spill treatments consisted of either 24 h of 95-kcfs spill or a cycle of 85-kcfs day and 120-kcfs night spill.

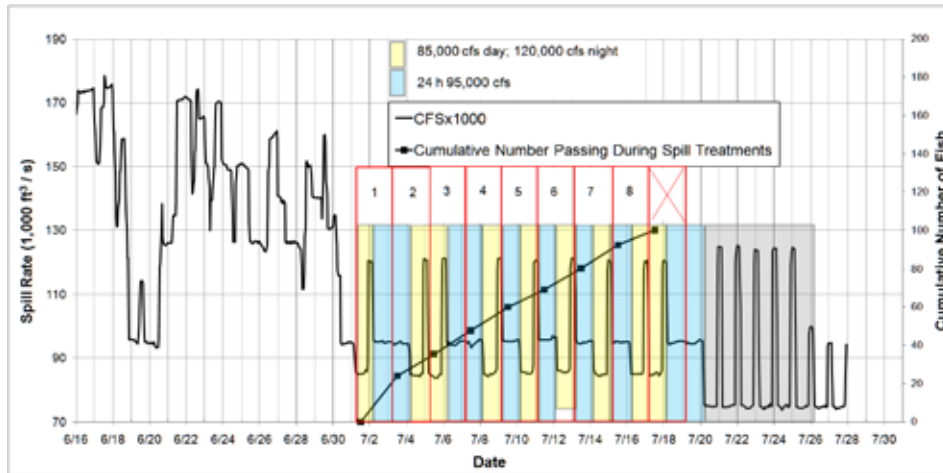


Figure 3.5. Plot of Spill Discharge Rate During Summer 2010 Showing Eight Successfully Realized Spill Treatment Blocks. Each block consisted of one randomly selected 1-day treatment followed by the alternative treatment.

4.0 Results – Yearling Chinook Salmon

This section contains estimates of survival rates, travel times, passage efficiencies and distributions for CH1 at BON during spring 2010. Appendices to this report include related tagging and release data (Appendix A), hydrophone location data (Appendix B), capture history data (Appendix C), detection and survival probabilities (Appendix D), and an assessment of model assumptions (Appendix E).

The single-release design worked as conceived for CH1. Performance of the JSATS technology was good. The combined detection probability of the two independent dam-face arrays, based on a Lincoln Peterson index, exceeded 99% for every route, and detection probabilities of autonomous arrays were >0.80 for dam and forebay+dam-passage survival estimates (Appendix D.1 and D.2). Detection probabilities on survival detection arrays for dam+ 81 km of tailwater passage and forebay+dam+81 km of tailwater-passage survival estimates also exceeded 80%. The survival model assumptions were met. The distribution of fish lengths for CH1 selected for tagging was very similar to the distribution for the same run in SMF samples at JDA (Figure E.1). Post-tagging mortality was only 0.1%, and no acoustic tags were shed between the time of tagging and the time of release. Travel times were sufficiently short relative to tag life to adequately adjust the release-recapture data for tag failure (Figure E.4). For dam-passage survival estimates, the probability that an acoustic tag was active at a downstream detection location was >0.99 (Table E.1; Figure E.5). Implementation produced near-perfect balance for the CH1 (Table E.4). Auxiliary analyses found no tagger effects (Table E.7) that might confound estimation of dam-passage survival. A separate release of 30 dead fish with active tags into the B2CC in spring 2010 resulted in no downstream detections at rkm 153, 113, or 86. Downstream mixing of virtual release fish with reference release fish was not an issue because there were no reference releases of fish in the BON tailrace in 2010.

4.1 Survival Estimates

The single-release estimate of tag-life-adjusted dam passage for CH1 V_1 traveling from the BON dam-face array CR234 to detection array CR153 was calculated to be

$$\hat{S}_{\text{BON \& Tailwater}} = \hat{S}_1 = 0.952 \quad (4.1)$$

with an associated standard error of 0.0040. The standard error was 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. The single-release estimate of dam-passage survival for CH1 at BON in 2010 did not exceed the BiOp requirements of $\hat{S}_{\text{Dam}} \geq 0.960$ but the SE was ≤ 0.015 .

We also calculated a paired-release estimate of dam-passage survival by dividing the single-release estimate (above) by an estimate of B2CC-passage survival (0.9909; SE = 0.0046) and that quotient met the BiOp standard:

$$\frac{\hat{S}_1}{\hat{S}_{\text{B2CC}}} = \frac{0.9519}{0.9909} = 0.9610; \quad \text{Paired SE} = 0.0060. \quad (4.2)$$

An estimate of forebay-to-tailrace-passage survival could not be calculated because there were no tailrace reference releases in 2010, so we made a single-release estimate of passage survival for yearlings passing through 2 km of forebay, the dam, and 81 km of tailwater:

$$\hat{S}_{\text{forebay, dam, tailwater}} = 0.951 (\text{SE} = 0.0040). \quad (4.3)$$

This estimate was 0.001 lower than the single-release estimate for passage through the dam and 81 km of tailwater, and presumably this difference represents mortality attributable to passage through 2 km of forebay.

Route-specific, single-release dam-passage survival estimates for CH1 were highest for the B2CC (99.0%), B1 turbines (98.7%), B2 JBS (98.1), B1 sluiceway (98.0%), B2 turbines (95.7%), and the spillway (93.5%; Table 4.1).

Table 4.1. Route-Specific Dam-Passage Survival Estimates for Yearling Chinook Salmon

Metric	Route	Estimate	SE	n
Dam-Passage Survival	B2CC	0.991	0.0046	634
	B1 turbines	0.987	0.0148	129
	B2 JBS	0.981	0.0104	218
	B1 sluiceway	0.980	0.0238	64
	B2 turbines	0.957	0.0093	533
	Spillway	0.935	0.0061	1766

4.2 Travel Times

Median travel times for CH1 from the first detection on the forebay entrance array 2 km upstream of the dam until the last detection on the dam-face array was about 0.74 h and from the last dam-face detection until the last tailrace array detection was about 0.46 h (Table 4.2). The mean travel time was higher for forebay residence (1.27 h) than it was for tailrace egress (0.94 h). Mean and median travel times for project passage based on first detections on the forebay entrance array located 2 km upstream of the dam and last detections on the tailrace egress array were 2.21 h and 1.29 h, respectively. There were no significant differences in travel time metrics between day and night time periods for CH1.

Table 4.2. Travel Times (h) for Yearling Chinook Salmon

Metric	n	Median	Mean	SE
Forebay Residence (CR236 to CR234)	3346	0.743	1.268	0.0456
100-m Forebay Residence	415	0.178	1.844	0.2675
Tailrace Egress (CR234 to CR233)	3246	0.455	0.943	0.1042
Project Passage (CR236 to CR233)	3259	1.290	2.213	0.1142

4.3 Passage Efficiencies

Dam FPE was 11% higher during daytime than it was at night on an absolute basis, and 95% confidence intervals on those estimates did not overlap (Table 4.3). In examining FPE components, we observed that SPE was only 3.1% higher during day than it was at night, but B2CC passage efficiency relative to the dam was a full 8% higher during the day than it was at night. Relative to B2, B2CC efficiency was 21.6% higher during the day than it was at night. B2 FGE also was higher during the day than it was at night by 17.1%. Other day-night differences did not appear to differ significantly based on overlapping 95% confidence intervals.

Table 4.3. Passage Efficiencies for Yearling Chinook Salmon

Metric	Period	Estimate	SE	n
FPE	Overall	0.802	0.0069	3345
	Day	0.842	0.0079	2156
	Night	0.729	0.0129	1189
SPE	Overall	0.528	0.0086	3345
	Day	0.539	0.0107	2156
	Night	0.509	0.0145	1189
SPE+B2CC	Overall	0.717	0.0078	3345
	Day	0.756	0.0092	2156
	Night	0.647	0.0139	1189
B1 Sluiceway B1 = B1 FPE	Overall	0.330	0.0338	194
	Day	0.292	0.0415	120
	Night	0.392	0.0567	74
B1 Sluiceway Dam	Overall	0.019	0.0024	3345
	Day	0.016	0.0027	2156
	Night	0.024	0.0045	1189
B2CC B2	Overall	0.458	0.0134	1385
	Day	0.539	0.0169	875
	Night	0.322	0.0207	510
B2CC Dam	Overall	0.190	0.0068	3345
	Day	0.218	0.0089	2156
	Night	0.138	0.0100	1189
B2 FGE	Overall	0.290	0.0166	751
	Day	0.368	0.0240	405
	Night	0.199	0.0215	346
B2 JBS Passage Efficiency Dam	Overall	0.065	0.0043	3345
	Day	0.069	0.0055	2156
	Night	0.058	0.0068	1189

4.4 Passage Distributions

The distributions of all detection events on the four forebay entrance array nodes were uniform, with only a slightly lower percent detected on the Washington shore node (17.5%) than on the other three nodes toward the south, which accounted for 28, 27, and 28% of events, respectively. The distribution of passage at the three dam structures more closely followed the distribution of flow among the three structures than the distribution of detection events on the forebay array. The distribution of flow and fish passage through the dam was as follows: B1 passed 6% of yearlings in 13% of project flow; the spillway

passed 52% of yearlings in 45% of river flow; B2 passed 42% of yearlings in 42% of flow. Over 99% of yearling Chinook passed through the Bonneville project at the dam structure where they were first detected, and this was true during high spill (spill $\geq 35\%$ = 99.8%) and low spill level (<35% = 99.2%).

A plot of the distribution of passage among individual routes through the dam clearly shows that more CH1 passed through the spillway and B2 than through B1 (Figure 4.1). The plot also shows that surface-flow outlets passed a high percentage of fish at each powerhouse. Percent passage was slightly higher through end spill bays than through middle spill bays. Percent passage through the JBS was higher than the percent passing any individual turbine, and over half (52%) of B2 turbine-passed yearlings went through three out of seven operational turbines at the south end of B2. If turbine 11 had not been out of service, the passage through southern B2 turbines likely would have been even higher.

4.5 Effect of the B2 Behavioral Guidance System

The mean B2CC passage efficiency for CH1 was 32.4% for the pre-BGS years and 44.9% for the post-BGS years—an increase of 12.5% (Table 4.4). A formal t-test only had 50.2% power to detect a significant difference, but a one-way hypothesis test that the post-BGS percentage was higher than the pre-BGS percentage was significant ($P = 0.0277$) at a 5% level. The percent of turbine-passed yearlings decreased from an average of 44% in 2004–2005 studies to an average of 32.6% in 2008–2010 studies, a decrease of 11.4% (Table 4.4). This difference was not significant above the level of chance ($\alpha = 0.05$) in a one-tailed t-test ($P = 0.0618$), but power to detect differences was low.

Table 4.4. Passage Percentage for Tagged Yearling Chinook Salmon Migrating Downstream Through B2CC and B2 Turbine Routes. Data from 2004 and 2005 are from U.S. Geological Survey radio-telemetry studies (Counihan et al. 2006a and b, respectively), and data from 2008, 2009, and 2010 are from the PNNL acoustic-telemetry studies (Faber et al. 2010, 2011; this study, respectively).

Year	B2CC	Turbine	BGS
2004	35.5	43.5	none
2005	29.3	44.0	none
2008	49.0	33.0	installed
2009	40.0	40.0	installed
2010	45.8	25.2	Installed

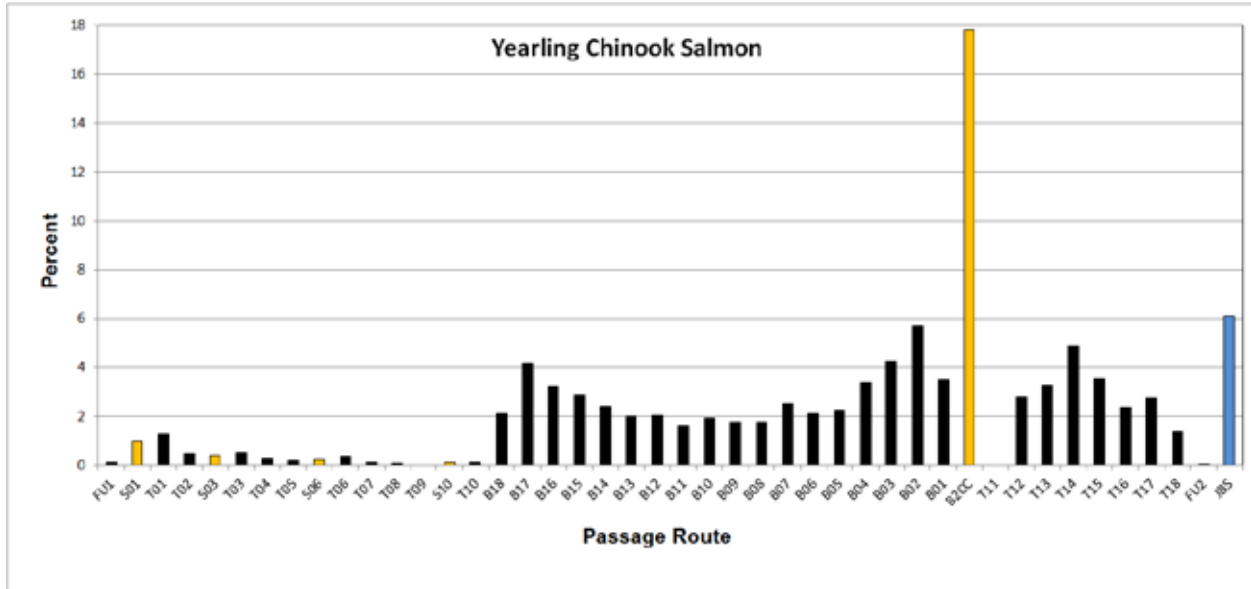


Figure 4.1. Horizontal Distribution of Yearling Chinook Salmon Passage in Spring 2010. Percent passage through surface-flow outlets (S01, S03, S06, S10, and the B2CC) are shown as gold bars, and B1 outlets are displayed to the left of the adjacent turbine with the same number, although they are actually physically located above the adjacent turbines. Abbreviations are as follows FU = fish units; S01, S03, S06, S10 = B1 sluiceway outlets; T1–T10 = B1 turbines; B01–B18 = spill bays; B2CC = B2 Corner Collector; T11–T18 = B2 turbines; JBS = B2 juvenile bypass system.

5.0 Results – Juvenile Steelhead

This section contains estimates of survival rates, travel times, passage efficiencies and distributions for juvenile STH at BON during spring 2010. Appendices to this report include related tagging and release data (Appendix A), hydrophone location data (Appendix B), capture history data (Appendix C), detection and survival probabilities (Appendix D), and an assessment of model assumptions (Appendix E).

The single-release design worked as conceived for juvenile STH. Performance of the JSATS technology was good. The combined detection probability of the two independent dam-face arrays, based on a Lincoln Peterson index, exceeded 99% for every route, and detection probabilities of autonomous arrays were >0.75 for dam+81 km of tailwater and forebay+dam+81 km of tailwater-passage survival estimates (Appendix D.9 and D.10). The survival model assumptions were met. The distribution of juvenile STH lengths selected for tagging was very similar to the distribution for the same run in SMF samples at JDA (Figure E.1). Post-tagging mortality was only 0.05%, and no acoustic tags were shed between the time of tagging and the time of release. Travel times were sufficiently short relative to tag life to adequately adjust the release-recapture data for tag failure (Figure E.6). For dam-passage survival estimates, the probability that an acoustic tag was active at a downstream detection location was >0.99 (Table E.2). Study implementation produced near-perfect balance for the juvenile STH (Table E.5). Auxiliary analyses found no tagger effects (Table E.8) that might confound estimation of dam-passage survival. A separate release of 30 dead fish with active tags into the B2CC in spring 2010 resulted in no downstream detections at rkm 153, 113, or 86. Downstream mixing of virtual release fish with reference release fish was not an issue because there were no reference releases of fish in the BON tailrace in 2010.

5.1 Survival Estimates

The single-release estimate of tag-life-adjusted dam passage for juvenile STH V_1 traveling from the BON dam-face array CR234 to detection array CR153 was calculated to be

$$\hat{S}_{\text{BON \& Tailwater}} = \hat{S}_1 = 0.945 \quad (5.1)$$

with an associated standard error of 0.0043. The standard error was 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. The single-release estimate of dam-passage survival for juvenile STH at BON in 2010 did not exceed the BiOp requirements of $\hat{S}_{\text{Dam}} \geq 0.960$ but the $\hat{S}E$ was ≤ 0.015 .

A paired-release estimate of dam-passage survival also was calculated by dividing the single-release estimate (above) by an estimate of B2CC-passage survival (0.975; $\hat{S}E = 0.0046$) and that quotient met the BiOp standard:

$$\frac{\hat{S}_1}{\hat{S}_{\text{B2CC}}} = \frac{0.945}{0.975} = 0.969; \quad \text{Paired } \hat{S}E = 0.0070. \quad (5.2)$$

An estimate of forebay-to-tailrace-passage survival could not be calculated because there were no tailrace reference releases in 2010, so a single-release estimate for juvenile STH passing through 2 km of forebay, the dam, and 81 km of tailwater was calculated:

$$\hat{S}_{\text{forebay, dam, tailwater}} = 0.944 (\text{SE} = 0.0043). \quad (5.3)$$

This estimate was 0.001 lower than the single-release estimate for passage through the dam and 81 km of tailwater, and presumably this difference represents mortality attributable to passage through 2 km of forebay.

Route-specific, single-release dam-passage survival estimates for juvenile STH were highest for the B2 JBS (97.8%), B2CC (97.5%), B1 sluiceway (96.3%), spillway (93.9%), B2 turbines (91.1%), and B1 turbines (90.0%) (Table 5.1).

Table 5.1. Route-Specific Dam-Passage Survival Estimates for Juvenile Steelhead

Metric	Route	Estimate	SE	n
Dam-Passage Survival	B2 JBS	0.978	0.0112	199
	B2CC	0.975	0.0054	1030
	B1 sluiceway	0.963	0.0260	80
	Spillway	0.939	0.0069	1364
	B2 turbines	0.911	0.0125	574
	B1 turbines	0.900	0.0284	116

5.2 Travel Times

Median travel times for juvenile STH from the first detection on the forebay entrance array 2 km upstream of the dam until the last detection on the dam-face array was about 1.69 h and from the last dam-face detection until the last tailrace detection was about 0.41 h (Table 5.2). The mean travel time for forebay residence (4.22 h) was 3.8 h longer for than for tailrace egress (0.42 h). Median and mean travel times for project passage based on first detections on the forebay entrance array and last detections on the tailrace egress array were about 2.40 h and 5.32 h, respectively. Median forebay residence time was significantly longer during the day (2.32 h) than it was at night (median = 1.19 h), as was median project passage time (day 2.99 h; night = 1.9 h). Median estimates of 100-m forebay residence time and tailrace egress time did not differ between day and night time periods.

Table 5.2. Travel Times (h) for Juvenile Steelhead

Metric	n	Median	Mean	SE
Forebay Residence (CR236 to CR234)	3358	1.687	4.219	0.1120
100-m Forebay Residence	435	1.426	6.060	0.5664
Tailrace Egress (CR234 to CR233)	3269	0.414	1.121	0.1351
Project Passage (CR236 to CR233)	3271	2.397	5.316	0.1765

5.3 Passage Efficiencies

Dam FPE was 10.8% higher during daytime than it was at night on an absolute basis and 95% confidence intervals on those estimates did not overlap (Table 5.3). In examining FPE components, SPE was observed to be 21.5% higher at night than it was during the day, so it could not help to explain why FPE was higher during the day than at night. The B2CC passage efficiency relative to the dam for juvenile STH was 31.1% higher during the day than it was at night. Relative to B2, B2CC passage efficiency for juvenile STH was 33.1% higher during the day (72%) than it was at night (38.9%), and overall the B2CC passed 57.1% of juvenile STH that entered the B2 forebay. B2 FGE also was 9.8% higher during the day than it was at night. Other day-night differences did not differ significantly based on overlap of 95% confidence intervals.

Table 5.3. Passage Efficiencies for Juvenile Steelhead

Metric	Period	Estimate	SE	n
FPE	Overall	0.795	0.0070	3363
	Day	0.855	0.0090	1493
	Night	0.747	0.0101	1870
SPE	Overall	0.406	0.0085	3363
	Day	0.287	0.0120	1493
	Night	0.501	0.0116	1870
SPE+B2CC	Overall	0.712	0.0078	3363
	Day	0.766	0.0110	1493
	Night	0.669	0.0109	1870
B1 Sluiceway B1 = B1 FPE	Overall	0.408	0.0351	196
	Day	0.611	0.0570	72
	Night	0.290	0.0408	124
B1 Sluiceway Dam	Overall	0.024	0.0026	3363
	Day	0.029	0.0040	1493
	Night	0.019	0.0032	1870
B2CC B2	Overall	0.571	0.0117	1803
	Day	0.720	0.0140	993
	Night	0.389	0.0171	810
B2CC Dam	Overall	0.306	0.0079	3363
	Day	0.479	0.0130	1493
	Night	0.168	0.0087	1870
B2 FGE	Overall	0.257	0.0157	773
	Day	0.320	0.0280	278
	Night	0.222	0.0187	495
B2 JBS Passage Efficiency Dam	Overall	0.059	0.0041	3363
	Day	0.060	0.006	1493
	Night	0.059	0.0054	1870

5.4 Passage Distributions

The distributions of all detection events on the four forebay entrance array nodes were uniform, with only a slightly lower percent detected on the Washington shore node (16.9%) than on the other three nodes toward the south, which accounted for 28, 27, and 28% of STH detection events, respectively. The distribution of passage at the three dam structures more closely followed the distribution of flow among the three structures than the distribution of detection events on the forebay array. The distribution of flow and fish passage through the dam was as follows: B1 passed 6% of STH in 13% of project flow; the spillway passed 40% of STH in 45% of river flow; B2 passed 54% of STH in 42% of flow. Only 88% of juvenile STH passed through the Bonneville project at the dam structure where they were first detected, and this was true during high spill (spill $\geq 35\%$ = 88.5%) and low spill levels (<35% = 87.6%). Of the 352 STH that passed at an alternate structure than where first detected, 88.9% entered but subsequently rejected the spillway. Out of the 1,638 STH that first approached the spillway, 313 (19.1%) subsequently passed at one of the powerhouses. About 91% of milling STH (n = 286) that first approached the spillway passed at B2. In contrast, only 2.2% (n = 39) of STH that approached either B1 (n = 202) or B2 (n = 1569) passed at another dam structure.

A plot of the distribution of passage among individual routes through the dam clearly shows that more juvenile STH passed through the spillway and B2 than through B1 (Figure 5.1) and that surface-flow outlets passed a high percentage of fish at each powerhouse. Percent passage was slightly higher through end spill bays 2–3 and 16–18 than through most other bays in the middle of the spillway. Percent passage through the JBS was higher than the percent passing all but one turbine, and 61.5% of B2 turbine-passed STH went through three out of seven operational turbines at the south end of B2 even though turbine 11 was out of service all spring.

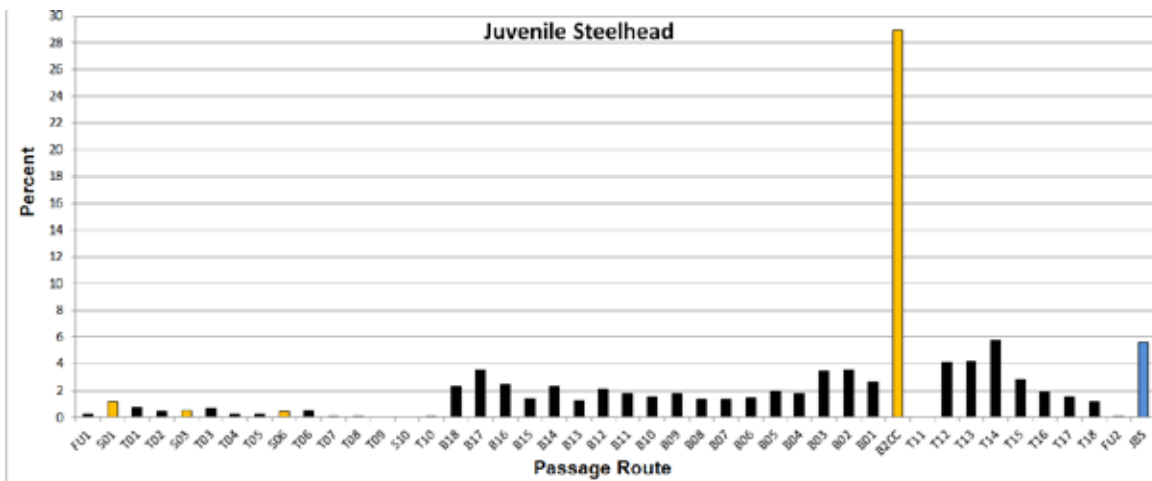


Figure 5.1. Horizontal Distribution of Juvenile Steelhead Passage in Spring 2010. Percent passage through surface-flow outlets (S01, S03, S06, S10, and the B2CC) are shown as gold bars, and B1 outlets are displayed to the left of the adjacent turbine with the same number, although they are actually physically located above the adjacent turbines. Abbreviations are as follows FU = fish units; S01, S03, S06, S10 = B1 sluiceway outlets; T1–T10 = B1 turbines; B01–B18 = spill bays; B2CC = B2 Corner Collector; T11–T18 = B2 turbines; JBS = B2 juvenile bypass system.

5.5 Effect of the B2 Behavioral Guidance System

There was insufficient power to reliably detect significant differences with available sample sizes, but the mean B2CC passage efficiency for juvenile steelhead was 67.1% for the pre BGS years and 58.1% for the post BGS years, a decrease of 9.1% (Table 5.4). The percent of turbine-passed juvenile STH increased 5.5% from an average of 14.6% in 2004–2005 studies to an average of 20.1% in 2008–2010 studies (Table 5.4).

Table 5.4. Passage Percentage for Tagged Juvenile Steelhead Migrating Downstream Through B2CC and B2 Turbine Routes. Data from 2004 and 2005 are from USGS radio-telemetry studies (Counihan et al. 2006a and b, respectively), and data from 2008, 2009, and 2010 are from the PNNL acoustic-telemetry studies (Faber et al. 2010, 2011; and this study, respectively).

Year	B2CC	Turbine	BGS
2004	73.0	16.7	none
2005	67.1	12.4	none
2008	75.0	16.0	installed
2009	59.0	27.0	installed
2010	57.1	17.2	installed

6.0 Results – Subyearling Chinook Salmon

This section contains estimates of survival rates, travel times, passage efficiencies, and passage distributions for CH0 at BON during summer 2010. Appendices to this report include related tagging and release data (Appendix A), hydrophone location data (Appendix B), capture history data (Appendix C), detection and survival probabilities (Appendix D), and an assessment of model assumptions (Appendix E).

The single-release design worked as conceived for CH0. Performance of the JSATS technology was good. The combined detection probability of the two independent dam-face arrays, based on a Lincoln Peterson index, exceeded 99% for every route, and detection probabilities of autonomous arrays were >0.85 for dam+81 km of tailwater and forebay+dam+81 km of tailwater-passage survival estimates, (Appendix D, Tables D.17 and D.18). The survival model assumptions were met. The distribution of CH0 salmon lengths selected for tagging was shifted slightly (about 7 mm) to the right of the distribution for fish in SMF samples because no fish <95 mm were tagged (Figure E.2). The median length of tagged subyearlings was 6.5 mm longer than that of untagged fish passing through the JDA SMF. The length distributions for the CH0 among releases were quite similar, and the median length of tagged fish across the course of the study remained stable (Skalski et al. 2010b). Tagging mortality was only 0.22%, and no acoustic tags were shed between the time of tagging and the time of release. Travel times were sufficiently short relative to tag life to adequately adjust the release-recapture data for tag failure (Figure E.7). For dam-passage survival estimates, the probability that an acoustic tag was active at a downstream detection location was >0.99 (Table E.3). Study implementation produced near-perfect balance for the CH0 (Table E.6). Auxiliary analyses found no tagger effects (Table E.9) that might confound estimation of dam-passage survival. A separate release of 67 dead fish with active tags into the B2CC in summer 2010 resulted in no downstream detections at rkm 153, 113, or 86. Downstream mixing of virtual release fish with reference release fish was not an issue because there were no reference releases of fish in the BON tailrace in 2010.

6.1 Survival Estimates

The single-release estimate of tag-life-adjusted dam passage for CH0 V_1 traveling from the BON dam-face array CR234 to detection array CR153 was calculated to be

$$\hat{S}_{\text{BON \& Tailwater}} = \hat{S}_1 = 0.958 \quad (6.1)$$

with an associated standard error of 0.0055. The standard error was 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. The single-release estimate of dam-passage survival for CH0 at BON in 2010 was based only on a virtual release of tagged fish released in the TDA tailrace and near Hood River, Oregon ($n = 1443$). This point estimate exceeded the 2008 BiOp standard of 0.930, and the standard error was less than the BiOP requirement ($\hat{S}E \leq 0.015$). Fish released near Roosevelt, Oregon, were not included in the virtual release because BON virtual release survival of those fish (0.933; $\hat{S}E = 0.0058$; $n = 2033$) was significantly lower than that of those released downstream of TDA and Hood River, based on non-overlap of 95% confidence intervals (Figure 6.1). Nevertheless, the virtual release

survival of Roosevelt-released subyearlings also met the 2008 BiOp standard (point estimate ≥ 0.930 and $\hat{SE} \leq 0.015$). The 95% confidence intervals on day and night virtual release estimates of survival overlapped, and this suggests that day-night differences in virtual single-release survival were not significant.

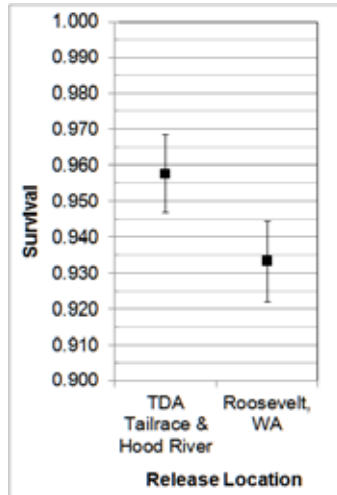


Figure 6.1. Plot of Virtual Single-Release Survival Estimates and 95% Confidence Intervals for Subyearlings Released in The Dalles Tailrace and Near Hood River, Oregon Compared to an Estimate for Fish Released Near Roosevelt, Washington

We calculated a paired-release estimate of dam-passage survival by dividing the single-release estimate (above) by an estimate of B2CC-passage survival and that quotient met the BiOp standard, as did its standard error:

$$\frac{\hat{S}_1}{\hat{S}_{B2CC}} = \frac{0.958}{0.970} = 0.9870; \quad \text{Paired release } \hat{SE} = 0.0117. \quad (6.2)$$

An estimate of forebay-to-tailrace passage survival could not be calculated because there were no tailrace reference releases in 2010, so we calculated a single-release estimate of passage survival for subyearlings passing 2 km of forebay, the dam, and 81 km of tailwater:

$$\hat{S}_{\text{forebay, dam, tailwater}} = 0.956 (\hat{SE} = 0.0054). \quad (6.3)$$

This estimate was 0.0021 lower than the single-release estimate for passage through the dam and 81 km of tailwater, and presumably this difference represents mortality attributable to passage through 2 km of forebay. The virtual single-release estimate for subyearlings passing through 2 km of forebay, the dam, and 81 km of tailwater also was based on fish released in The Dalles tailrace and near Hood River, Oregon (n = 1571).

Table 6.1 shows route-specific, virtual single-release estimates of dam-passage survival for subyearlings ranked from highest to lowest. Even the lowest route-specific single-release estimate at the spillway met the 2008 BiOp requirement.

Table 6.1. Route-Specific Dam-Passage Survival Estimates for Subyearling Chinook Salmon

Metric	Route	Estimate	SE	n
Dam-Passage Survival	B2 JBS	0.976	0.0154	113
	B2CC	0.970	0.0101	311
	B1 turbines	0.967	0.0081	568
	B1 sluiceway	0.943	0.0173	196
	B2 turbines	0.936	0.0117	437
	Spillway	0.930	0.0062	1787

6.2 Travel Times

Statistical estimates of travel times were based on fish in all releases upstream of BON (Table 6.2), because we did not see obvious travel-time differences for subyearlings in the Roosevelt release and those released downstream of TDA. The median forebay residence time for subyearlings was only 6.7% slower than estimates for CH1, but 41% slower than estimates for STH. Trends were similar for median project passage times. The median egress time was faster than the forebay residence time, but this was true for all three runs of fish.

Table 6.2. Travel Times (h) for Subyearling Chinook Salmon

Metric	n	Median	Mean	SE
Forebay Residence (CR236 to CR234)	3444	0.6933	1.1444	0.0421
100-m Forebay Residence	761	0.1331	1.0004	0.1640
Tailrace Egress (CR234 to CR233)	2993	0.4192	1.4454	0.2587
Project Passage (CR236 to CR233)	3233	1.2597	2.5804	0.2447

6.3 Passage Efficiencies

Statistical estimates of passage efficiencies were based on fish in all releases upstream of BON (Table 6.3), because we did not observe obvious differences for subyearlings in the Roosevelt release and those released downstream of TDA. Day and night differences had the potential to be confounded by spill treatments, so we estimated passage metrics by day or night and spill treatment. Significant differences are based on the non-overlap of 95% confidence intervals.

Under the 24-h, 95-kcfs spill treatment, FPE was 21.4% higher during daytime than it was at night on an absolute basis, and 95% confidence intervals on those estimates did not overlap (Table 6.3). Similarly, estimates of SPE, spill + B2CC passage efficiency, B2CC passage efficiency relative to B2 and the dam, and B1 sluiceway efficiency relative to the dam all were higher during the day than they were at night under 24-h, 95 kcfs spill, based on non-overlap of 95% confidence intervals.

Table 6.3. Passage Efficiencies for Subyearling Chinook Salmon

Metric	Period	Estimate	SE	n
FPE	Overall	0.705	0.0078	3412
	95 kcfs day	0.816	0.0158	604
	95 kcfs night	0.602	0.0296	274
	85 kcfs day	0.747	0.0187	541
	120 kcfs night	0.746	0.0331	173
Spill-Passage Efficiency	Overall	0.524	0.0086	3412
	95 kcfs day	0.632	0.0196	604
	95 kcfs night	0.423	0.0298	274
	85 kcfs day	0.514	0.0215	541
	120 kcfs night	0.595	0.0373	173
Spill+B2CC Passage Efficiency	Overall	0.615	0.0083	3412
	95 kcfs day	0.780	0.0169	604
	95 kcfs night	0.471	0.0302	274
	85 kcfs day	0.669	0.0202	541
	120 kcfs night	0.642	0.0365	173
B1 Sluiceway B1 = B1 FPE	Overall	0.257	0.0158	764
	95 kcfs day	0.258	0.0786	31
	95 kcfs night	0.453	0.0684	53
	85 kcfs day	0.247	0.0468	85
	120 kcfs night	0.421	0.1133	19
B1 Sluiceway Dam	Overall	0.057	0.0040	3412
	95 kcfs day	0.013	0.0047	604
	95 kcfs night	0.088	0.0171	274
	85 kcfs day	0.039	0.0083	541
	120 kcfs night	0.046	0.0160	173
B2CC B2	Overall	0.361	0.0164	861
	95 kcfs day	0.466	0.0361	191
	95 kcfs night	0.124	0.0321	105
	85 kcfs day	0.472	0.0374	178
	120 kcfs night	0.157	0.0509	51
B2CC Dam	Overall	0.091	0.0049	3412
	95 kcfs day	0.147	0.0144	604
	95 kcfs night	0.047	0.0128	274
	85 kcfs day	0.155	0.0156	541
	120 kcfs night	0.046	0.0160	173
B2 FGE	Overall	0.205	0.0172	550
	95 kcfs day	0.137	0.0341	102
	95 kcfs night	0.130	0.0351	92
	85 kcfs day	0.223	0.0430	94
	120 kcfs night	0.233	0.0644	43
B2 JBS Dam	Overall	0.033	0.0031	3412
	95 kcfs day	0.023	0.0061	604
	95 kcfs night	0.044	0.0124	274
	85 kcfs day	0.039	0.0083	541
	120 kcfs night	0.058	0.0177	173

During the daytime, 95-kcfs spill treatment produced higher FPE, SPE, spill + B2CC passage efficiency, and B1 sluiceway efficiency relative to the dam than did the 85- kcfs spill treatment (Table 6.3). During the nighttime, the 120-kcfs spill treatment provided for higher FPE, SPE, and spill + B2CC passage efficiency than did the 95-kcfs spill treatment. However, the 95- kcfs day treatment provided higher FPE, spill+B2CC passage efficiency, and B2CC passage efficiency (relative to B2 or the entire dam) than did the 120-kcfs night treatment. The 85- kcfs day treatment also provided for higher B2CC passage efficiency for subyearlings (relative to B2 or the dam) than did the 120- kcfs night treatment. The 85- kcfs day treatment provided for higher FPE, spill+B2CC passage efficiency, and B2CC passage efficiency (re: B2 and the dam) than did the 95- kcfs night treatment. There were no apparent differences in B2 JBS efficiency relative to the dam among spill treatment and day/night conditions (Table 6.3).

6.4 Passage Distributions

The distributions of all detection events on the four forebay entrance array nodes were relatively uniform. From the Oregon shore north toward Washington, the percent of all subyearling detections on the four nodes were 23%, 22%, 34%, and 21%. The distribution of passage at the three dam structures more closely followed the distribution of flow among the three structures than the distribution of detection events on the forebay array. The distribution of flow and fish passage through the dam was as follows: B1 passed 22% of subyearlings in 16% of project flow; the spillway passed 51% of subyearlings in 50% of river flow; B2 passed 27% of subyearlings in 34% of flow. Over 99% of subyearlings passed through the Bonneville project at the dam structure where they were first detected, and this was true during high spill (spill \geq 35% = 99.8%) and lower spill (<35% = 100%) levels.

A plot of the distribution of passage among individual routes through the dam clearly shows that more CH0 passed through the spillway and B2 than through B1 (Figure 6.2). This pattern is consistent with observations for CH0 and CH1. The plot also shows that surface-flow outlets passed a high percentage of fish at each powerhouse. Percent passage was slightly higher through end spill bays 2–3 and 16–17 than through most other bays. Percent passage through the JBS was similar to the percent passing through turbine 14, although it was higher than the percent passing other individual turbines. Turbine 11 was out of service all summer and turbine 13 only ran a couple of days during the summer study.

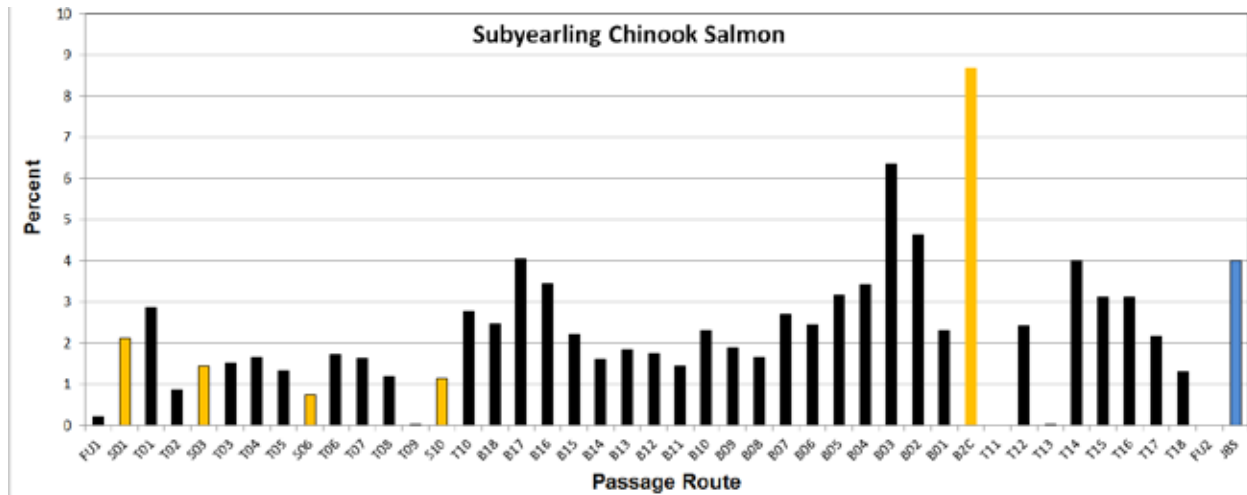


Figure 6.2. Horizontal Distribution of Subyearling Chinook Salmon Passage in Spring 2010. Percent passage through surface-flow outlets (S01, S03, S06, S10, and the B2CC) are shown as gold bars, and B1 outlets are displayed to the left of the adjacent turbine with the same number, although they are actually physically located above the adjacent turbines. Abbreviations are as follows FU = fish units; S01, S03, S06, S10 = B1 sluiceway outlets; T1–T10 = B1 turbines; B01–B18 = spill bays; B2CC = B2 Corner Collector; T11–T18 = B2 turbines; JBS = B2 juvenile bypass system.

6.5 Effect of the B2 Behavioral Guidance System

There was insufficient statistical power to reliably detect significant differences given available sample sizes, but the mean B2CC passage efficiency for subyearlings was similar for the pre- and post-BGS periods (Pre BGS averaged 44.9% and Post BGS averaged 42.7%; Table 6.4). The mean percent of turbine-passed subyearlings also was very similar for the two treatment periods (pre BGS averaged 41.2% and post BGS averaged 40.8%; Table 6.4).

Table 6.4. Passage Percentage for Tagged Subyearling Chinook Salmon Migrating Downstream Through B2CC and B2 Turbine Routes. Data from 2004 and 2005 are from USGS radio-telemetry studies (Counihan et al. 2006a and b, respectively), and data from 2008, 2009, and 2010 are from the PNNL acoustic-telemetry studies (Faber et al. 2010, 2011; and this study, respectively).

Year	B2CC	Turbine	BGS
2004	43.4	43.3	none
2005	46.4	39.0	none
2008	40.0	43.0	installed
2009	52.0	36.0	installed
2010	36.1	43.4	Installed

6.6 Effects of Spill Treatments on Performance Metrics

We used virtual releases of all fish released upstream of BON (Roosevelt, The Dalles tailrace, and Hood River) to evaluate the effects of the two spill treatments on dam-passage survival in summer 2010.

Survival estimates by treatment date are listed in Table 6.5. A plot of these data shows a typical summer decline in survival after July 10 for both treatments, but pairs of treatments consistently had overlapping 95% confidence intervals (Figure 6.3). A paired, two-tailed t-test based on the point estimates of survival rates in Table 6.5 detected no significant difference between the treatments, but the statistical power of this test was very low (0.284). A one-tailed t-test on the same data was significant ($P = 0.0484$; $\alpha = 0.05$; Table 6.6), indicating that the 24-h, 95-kcfs spill treatment provided higher survival for subyearlings than the 85-kcfs day and 120-kcfs night treatment.

Table 6.5. Virtual Single-Release Dam-Passage Survival Estimates and 95% Confidence Intervals (CIs) by Spill Treatment in Summer 2010

Date	24-h, 95-kcfs Spill			Date	Day 85- and Night 120-kcfs Spill		
	Survival	1/2 95% CI	n		Survival	1/2 95% CI	n
7/3	0.945	0.0652	51	7/2	0.952	0.0337	161
7/4	0.962	0.0307	154	7/5	0.973	0.0386	71
7/7	0.966	0.0462	59	7/6	0.929	0.0450	127
7/8	0.955	0.0335	152	7/9	0.960	0.0457	73
7/10	0.947	0.0368	147	7/11	0.853	0.0842	68
7/12	0.914	0.0548	109	7/13	0.842	0.0791	82
7/14	0.851	0.0640	120	7/15	0.713	0.1297	48
7/16&19	0.866	0.0657	104	7/17&18	0.875	0.0662	194
Mean	0.923		845	Mean	0.887		824

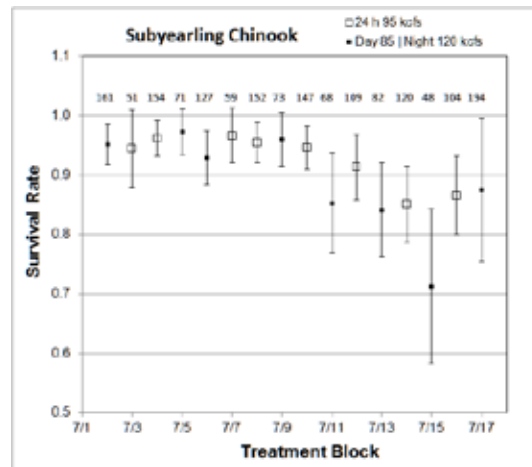


Figure 6.3. Plot of Subyearling Chinook Salmon Survival Rates by Spill Treatment Date. Estimates for the last two spill treatments ($n = 104$ and $n = 194$) were based on pooling fish by treatment from blocks 8 and 9.

Table 6.6. Statistical Tests on Subyearling Chinook Salmon Survival by Spill Treatment. The table includes one- and two-tailed t-test results for data in Table 6.5. Those data passed a normality test and a test on variance equality.

Statistics	24-h 95-kcfs Spill	Day 85- and Night 120-kcfs Spill
Mean	0.9256	0.8870
Variance	0.0020	0.0075
Observations	8	8
Pearson Correlation	0.8062	
Hypothesized Mean Difference	0	
df	7	
t Stat	1.9161	
P(T≤t) one-tail	0.0484	
t Critical one-tail	1.8946	
P(T≤t) two-tail	0.0969	
t Critical two-tail	2.3646	

None of the other survival estimates (forebay virtual, spillway virtual, or Roosevelt releases) differed significantly between the two 24-h spill treatments tested in summer 2010 based upon overlap of 95% confidence intervals (Table 6.7).

Table 6.7. Passage Survival and 95% Confidence Interval Estimates for Two River Reaches During Two Spill Treatments

Survival Metric	24-h 95-kcfs Spill			85-kcfs Day/120-kcfs Night Spill		
	Point Estimate	Lower 95% CI	Upper 95% CI	Point Estimate	Lower 95% CI	Upper 95% CI
<i>Virtual releases formed from fish from all upstream releases</i>						
Forebay Entrance to CR153	0.9261	0.9087	0.9435	0.9030	0.8813	0.9247
Spillway to CR153	0.9241	0.9004	0.9478	0.8774	0.8443	0.9105
<i>Virtual releases formed from fish from Roosevelt, Washington, only (CR390)</i>						
Dam to CR153	0.8956	0.8675	0.9237	0.8766	0.8430	0.9102

We observed no significant differences in travel time and passage efficiency metrics between the two spill treatments, as prescribed in the study design, based on overlap of 95% confidence intervals (Table 6.8). We did find differences in some passage efficiency metrics among combinations of spill and day/night conditions (see Section 6.3 above), but significant differences were not observed for survival rates or travel times.

At the request of the Studies Review Work Group, we also compared survival and passage metrics among spill treatments during day and night periods. The only significant differences based on non-overlap of 95% confidence intervals were SPE and spill + B2CC passage efficiency (Table 6.9). Estimates of SPE were higher during the 95-kcfs day treatment than during the 95-kcfs night treatment or during the 85-kcfs day treatment. SPE also was higher during the 120-kcfs night treatment than during the 95-kcfs night treatment. For spill + B2CC passage efficiency, the 95-kcfs day treatment was higher than the 95-kcfs night, 85-kcfs day, and 120-kcfs night treatments. The 95-kcfs night spill treatment

provided lower spill + B2CC passage efficiency than the 85-kcfs day treatment and the 120-kcfs night treatment, but that efficiency was similar for the 85-kcfs day treatment and the 120-kcfs night treatment.

Table 6.8. Comparison of Subyearling Chinook Salmon Travel Time and Passage Metrics Under the Two Summer Spill Treatments. Differences indicated in the last column were not considered to be different if there was overlap in ½ 95% confidence intervals ($1.96 \times \text{SE}$) for the two estimates.

Metric	95 kcfs Spill 7/2-7/18			85D/120N kcfs Spill 7/2-7/18			Different?
	SE	n		SE	n		
Median Forebay Residence Time (CR236 to CR234)	0.795	0.0617	884	0.943	0.1671	720	No
Median 100-m Forebay Residence Time (100 m to CR234)	0.271	0.2671	120	0.471	0.9137	124	No
Median Egress Time (dam to end of tailrace; CR234 to CR233)	0.483	0.0890	851	0.482	0.0643	678	No
Median Project Passage Time (CR236 to CR233)	1.371	0.1101	861	1.533	0.1888	684	No
FPE Dam	0.749	0.0146	878	0.747	0.0163	714	No
Spill Passage Efficiency Dam	0.567	0.0167	878	0.534	0.0187	714	No
Spill + B2CC Passage Efficiency Dam	0.683	0.0157	878	0.662	0.0177	714	No
B1 Sluiceway Passage Efficiency B1	0.381	0.0530	84	0.279	0.0440	104	No
B2CC Passage Efficiency B2	0.345	0.0276	296	0.402	0.0324	229	No
B2 JBS Passage Efficiency B2	0.088	0.0165	296	0.135	0.0226	229	No
B2 FGE (B2 Screen Efficiency) (B2 turbine + B2 JBS)	0.134	0.0245	194	0.226	0.0357	137	No
B2 FPE B2	0.432	0.0288	296	0.537	0.0330	229	No
B1 Sluiceway Passage Efficiency Dam	0.036	0.0063	878	0.041	0.0074	714	No
B2CC Passage Efficiency Dam	0.116	0.0108	878	0.129	0.0125	714	No
B2 JBS Passage Efficiency Dam	0.030	0.0057	878	0.043	0.0076	714	No

Table 6.9. Survival Study Summary Statistics by Spill Treatment During Day and Night Periods

Spill Treatment (7/2 to 7/18)	Survival Dam Passage + 81 km of Tailwater	Survival Spillway Passage + 81 km of Tailwater	Median Forebay Residence Time	Median 100 m Forebay Residence Time	Median Egress Time	Median Project Passage Time	Spill Passage Efficiency Dam	Spill + B2CC Passage Efficiency Dam
95-kcfs Day Spill	0.9241	0.9217	0.7674	0.4758	0.4775	1.3200	0.6262	0.7721
SE	0.0109	0.0140	0.0825	0.5173	0.0775	0.1166	0.0196	0.0170
n	621	382	614	58	590	595	610	610
95-kcfs Night Spill	0.9306	0.9323	0.8960	0.1672	0.5314	1.4732	0.4173	0.4640
SE	0.0154	0.0236	0.0732	0.1441	0.2757	0.2843	0.0296	0.0299
n	285	116	280	63	265	270	278	278
85-kcfs Day Spill	0.9077	0.8893	0.9949	0.6661	0.5047	1.6035	0.5092	0.6630
SE	0.0125	0.0189	0.2120	1.2116	0.1193	0.2553	0.0214	0.0202
n	553	278	552	93	519	520	546	546
120-kcfs Night Spill	0.8884	0.8454	0.7839	0.1851	0.4008	1.3338	0.5954	0.6416
SE	0.0237	0.0357	0.1623	0.3174	0.0790	0.1949	0.0373	0.0365
n	178	103	173	32	161	166	173	173

Table 6.9. (contd)

Spill Treatment (7/2 to 7/18)	Survival Dam Passage + 81 km of Tailwater	Survival Spillway Passage + 81 km of Tailwater	Median Forebay Residence Time	Median 100 m Forebay Residence Time	Median Egress Time	Median Project Passage Time	Spill Passage Efficiency Dam	Spill + B2CC Passage Efficiency Dam
Difference in 95-kcfs Day & 95 kcfs Night?	No	No	No	No	No	No	Yes	Yes
Difference in 95-kcfs Day & 85 kcfs Day?	No	No	No	No	No	No	Yes	Yes
Difference in 95-kcfs Day and 120-kcfs Night?	No	No	No	No	No	No	No	Yes
Difference in 95-kcfs Night and 85-kcfs Day?	No	No	No	No	No	No	No	Yes
Difference in 95-kcfs Night & 120-kcfs Night?	No	No	No	No	No	No	Yes	Yes
Difference in 85-kcfs Day & 120-kcfs Night?	No	No	No	No	No	No	No	No

7.0 Discussion

This section includes discussion of the statistical performance and survival model assumptions, historical context for 2010 estimates, day and night effects on passage metrics, effects of spillway discharge treatments in summer, and the performance of the B2 behavioral guidance structure in 2010.

7.1 Statistical Performance and Survival Model Assumptions

The survival study at BON in 2010 was not an official BiOp test because there were no tailrace and tailwater reference releases of fish as called for in the design by Skalski et al. (2010). Among other objectives, the 2010 study at BON was intended to verify that the proposed acoustic-tag monitoring system at the dam and downstream arrays would be adequate for an official BiOp study in 2011. For each run of fish in the 2010 study, we calculated a virtual paired-release survival estimate based on the ratio of virtual single-release survival rates of fish passing the dam and fish passing through the B2CC. This is not exactly the same as the virtual/paired-release design, but it did provide estimates of precision that were higher than estimates from the single-release model and similar in magnitude to those expected from the virtual/paired-release design.

The 2008 BiOp requires estimates of dam-passage survival with standard errors ≤ 0.015 . The numbers of tagged fish released (Table 2.1; Appendix A) and the detection probabilities at the downstream autonomous node arrays (Appendix D, Sections D.1.1, D.2.1, D.3.1) in 2010 were sufficient to meet this precision requirement. Even when we calculated standard errors for paired-release dam-passage survival estimates using B2CC-passed fish as a virtual reference release, standard errors were ≤ 0.007 for CH1 and STH and < 0.012 for CH0. Therefore, the number of tagged fish released for the survival studies in future years should be comparable to those used in 2010 to help ensure precision requirements will be achieved. If autonomous node densities in downstream survival detection arrays are changed or river discharge increases substantially, the number of fish tagged may need to be reassessed.

Testing of survival model assumptions (Appendix E) indicated that there were no serious violations that would invalidate the 2010 results. Length frequency distributions of tagged fish and the untagged fish passing through the JDA SMF were very similar for CH1 and juvenile STH. The 95-mm length limit imposed by acoustic-tag weight and acceptable tag burdens for small fish resulted in a slightly high grading of fish lengths for CH0, as indicated by a 6.5-mm difference in median lengths of tagged and untagged fish. Post-tagging and pre-release mortality was low (CH1: 0.1%, STH: 0.05%; CH0: 0.22%), and no acoustic tags were shed. In 2010, the study team released 97 dead fish with active acoustic tags into the B2CC, and none of these fish were detected on survival detection arrays located 81, 121, and 148 km downstream from the dam. Tag life was more than adequate for the survival study, and the probability of a tag being active when fish passed the downstream survival detection arrays exceeded 99%. There were no observed tagger effects in 2010. Downstream mixing was not an assumption for the virtual single-release survival model. It also was not an issue for paired-release estimates based on the survival of fish passing through the dam and the B2CC, because fish in both of these virtual releases passed the dam during all hours of the day and B2CC-passed fish were a subset of dam-passed fish.

7.2 Historical Context

The following sections compare historical estimates of survival rates, travel time, and passage efficiency with estimates in this report.

7.2.1 Survival Estimates

We provide context for 2010 dam-passage survival estimates by tabling them with estimates from previous studies. Before 2008, there was no BGS installed in the B2 forebay like there was from 2008 through 2010. The USGS conducted paired-release survival studies at B2 using radio telemetry in 2002, 2004, and 2005, which included dam passage of fish passing through the JBS, B2CC, and turbines (Counihan et al. 2003; Counihan et al. 2006a, b).

We visually looked for obvious non-overlap of ½ 95% confidence intervals to judge whether CH1 survival estimates in Table 7.1 differed among years. For this exercise, estimates >1 were set to 1.0 so that obvious positive bias in point estimates would be eliminated. By these criteria, there were no significant differences in dam-passage survival among years. Survival rates of B1-passed yearlings were lower in 2002 and 2004 than they were in 2010, but estimates for 2002, 2004, and 2005 did not differ. Spillway survival rates appeared to be higher in 2002 than they were in 2004 and 2005, and the point estimate in 2010 was 3.4% lower than the 2002 estimate, although confidence intervals for 2002 and 2010 overlapped slightly. Survival of B2-, B2CC-, B2 JBS-, and B2 turbine-passed yearlings did not differ among years. Survival of B2CC passed fish was very high in all years and the multi-year average would rank it as the best route of passage through the dam for yearlings. Survival estimates for yearlings passing through B2 turbines was surprisingly high (grand mean = 0.967). A ranking of general routes and subroutes from highest to lowest according to the grand average survival rate (Table 7.1) was as follows: B2CC, JBS, B2, turbines, B1, and the spillway.

We visually looked for obvious non-overlapping of ½ 95% confidence intervals to judge whether juvenile STH survival estimates in Table 7.2 differed among years. For this exercise, estimates >1 were set to 1.0 so that obvious positive bias in point estimates would be eliminated. Using these criteria, none of the passage survival rates in Table 7.2 differed significantly, except for the 2005 and 2008 turbine-passage estimates. We ranked routes from best to worst for STH according to the grand mean survival rate as follows: B2CC, JBS, B2, spillway or B1 (tied), and turbines.

For CH0, we again looked for obvious non-overlapping of ½ 95% confidence intervals to judge whether survival estimates in Table 7.3 differed among years. For this exercise, estimates >1 were again set to 1.0 so that obvious positive bias in point estimates would be eliminated. Using these criteria, dam-passage survival was higher in 2008 and 2010 than it was in 2004 and 2005, and the 2005 estimate was higher than the 2004 estimate. The confidence interval in 2009 was wide and overlapped intervals for all other dam-passage survival estimates. The B1-passage survival was higher in 2010 than it was in 2004, but the estimates in 2005 and 2010 were similar. The 2010 spill-passage survival rate was higher than rates in 2004 and 2005. Estimates of B2-, B2CC-, and JBS-passage survival did not differ among study years. Turbine-passage survival was higher in 2008, 2009, and 2010 than it was in 2004 and 2005. We ranked routes from best to worst for subyearlings according to the grand mean survival rate as follows: B2CC, JBS, B2, B1, turbines, and the spillway.

Table 7.1. Survival of Yearling Chinook Salmon that Passed Through Various Routes at Bonneville Dam in Some Years from 2002 Through 2010. Numbers in parentheses are ½ 95% confidence limits. Unless otherwise indicated, estimates were derived from paired-release CJS recapture models that used control releases of fish in the tailrace of BON. Data from 2002 to 2005 were reported from radio-telemetry studies conducted by the USGS, and 2008 and 2009 data are from acoustic-telemetry studies conducted by PNNL.

Year	B1	Spillway	B2	B2CC	JBS	Turbines	Dam
2002	0.902 (0.063)	0.977 (0.023)	0.993 (0.028)				0.977 (0.038)
2004	0.913 (0.041)	0.910 (0.021)	0.979 (0.029) ^(a)	1.016 (0.017)	0.970 (0.024)	0.951 (0.021)	0.951 (0.015)
2005	0.950 (0.031)	0.913 (0.035)	0.998 (0.015) ^(a)	1.021 (0.012)	1.008 (0.016)	0.966 (0.017)	0.966 (0.013)
2008			1.005 (0.030)	1.021 (0.034)	1.017 (0.045)	0.979 (0.037)	0.969 (0.025)
2009	0.952 (0.014) ^(b,c)		0.986 (0.008) ^(c)	0.996 (0.004) ^(d)	0.988 (0.013) ^(c)	0.970 (0.020) ^(c)	0.962 (0.011) ^(c)
2010	0.994 (0.026) ^(c)	0.943 (0.015) ^(c)	0.985 (0.013) ^(c)	0.991 (0.009) ^(d)	0.990 (0.023) ^(c)	0.971 (0.018) ^(c)	0.961 (0.012) ^(c)
Grand Average	0.940	0.936	0.991	1.009	0.9946	0.967	0.970

(a) Calculated as an average of rates for B2 routes.

(b) B1 and spillway combined estimate.

(c) Relative release estimate, using fish passing through the B2CC as the paired control fish.

(d) Single-release estimate.

Table 7.2. Survival of Juvenile Steelhead that Passed Through Various Routes at Bonneville Dam in Some Years from 2004 Through 2010. Numbers in parentheses are ½ 95% confidence limits. Unless otherwise indicated, estimates were derived from paired-release CJS recapture models that used control releases of fish in the tailrace of BON. Data from 2002 to 2005 were reported from radio-telemetry studies conducted by the USGS, and 2008 and 2009 data are from acoustic-telemetry studies conducted by PNNL.

Year	B1	Spillway	B2	B2CC	JBS	Turbines	Dam
2004	0.965 (0.034)	0.979 (0.023)	0.956 (0.042) ^(a)	1.030 (0.017)	0.951 (0.024)	0.889 (0.038)	0.991 (0.016)
2005	0.933 (0.030)	0.955 (0.021)	0.944 (0.027) ^(a)	1.009 (0.012)	0.956 (0.016)	0.868 (0.035)	0.963 (0.013)
2008			0.982 (0.019)	0.984 (0.027)	0.984 (0.045)	0.982 (0.024)	0.972 (0.010)
2009	0.961 (0.021) ^(b,c)		0.979 (0.026) ^(c)	0.993 (0.020) ^(d)	0.964 (0.013) ^(c)	0.946 (0.054) ^(c)	0.970 (0.013) ^(c)
2010	0.950 (0.042)	0.963 (0.017)	0.979 (0.015)	0.975 (0.011)	1.003 (0.025)	0.933 (0.025)	0.969 (0.014)
Grand Average	0.952	0.952	0.968	0.998	0.972	0.924	0.973

(a) Calculated as an average of rates for B2 routes.

(b) B1 and spillway combined estimate.

(c) Relative release estimate, using fish passing through the B2CC as the paired control fish.

(d) Single-release estimate.

Table 7.3. Survival of Subyearling Chinook Salmon that Passed Through Various Routes at Bonneville Dam in Some Years from 2004 Through 2010. Numbers in parentheses are ½ 95% confidence limits. Unless otherwise indicated, estimates were derived from paired-release CJS recapture models that used control releases of fish in the tailrace of BON. Data from 2002 to 2005 were reported from radio-telemetry studies conducted by the USGS, and 2008 and 2009 data are from acoustic-telemetry studies conducted by PNNL.

Year	B1	Spillway	B2	B2CC	JBS	Turbines	Dam
2004	0.831 (0.110)	0.876 (0.025)	0.904 (0.060) ^(a)	0.980 (0.023)	0.926 (0.048)	0.825 (0.037)	0.891 (0.020)
2005	0.976 (0.072)	0.911 (0.018)	0.964 (0.026) ^(a)	1.013 (0.015)	0.984 (0.028)	0.895 (0.028)	0.938 (0.014)
2008			0.981 (0.016)	0.996 (0.016)	0.991 (0.024)	0.954 (0.020)	0.970 (0.014)
2009	0.930 (0.062) ^(b,c)		0.991 (0.063) ^(c)	0.942 (0.054) ^(d)	0.933 (0.087) ^(c)	0.998 (0.079) ^(c)	0.959 (0.063) ^(c)
2010	0.990 (0.025)	0.959 (0.023)	0.983 (0.025)	0.970 (0.020)	1.006 (0.037)	0.965 (0.031)	0.987 (0.023)
Grand Average	0.929	0.915	0.965	0.978	0.968	0.927	0.949

(a) Calculated as an average of rates for B2 routes.

(b) B1 and spillway combined estimate.

(c) Relative release estimate, using fish passing through the B2CC as the paired control fish.

(d) Single-release estimate.

The ranking of routes in 2010 varied among the runs of fish studied, but it is important to note that the spillway ranked as the worst route for passing CH1 and CH0 smolts (see Table 7.1 and Table 7.3). For juvenile STH, the spillway ranked fourth after the B2 JBS, B2CC, and B1 sluiceway, but the spill-passage survival rate of 0.939 for STH was only slightly better than rates observed for CH1 (0.935) and CH0 (0.930) passing the spillway. The turbines at B1 and B2 clearly were the worst routes for passing STH, probably because injury associated with blade strike is directly correlated with fish length (Ploskey and Carlson 2004; Deng et al. 2007, 2011b). The median length of tagged juvenile STH (214 mm) was considerably longer than that of CH1 (152 mm) and CH0 (110 mm) smolts.

Survival of fish passing through the B1 sluiceway was high in spring (CH1 = 0.980; STH = 0.963), but in summer, B1 sluiceway-passage survival of subyearlings was only 0.943, 2.4% lower than the rate for subyearlings passing through B1 turbines. The reason for lower B1 sluiceway survival in summer might be related to debris loading on the B1 sluiceway route because the hydrograph clearly peaked in summer (Figure 3.1). The shallow openings in the B1 surface-flow outlets are more prone to clogging than the B2CC outlet, which provided high survival in both seasons.

7.2.2 Travel Time Estimates

Forebay residence times were longer for STH than for Chinook salmon smolts, and this was not a surprise given the extensive searching behavior exhibited by STH in the B2 forebay. A full 12% of STH passed the project at a dam structure other than the one at which they were first detected. Out of the 1,638 STH that first approached the spillway, 313 (19.1%) subsequently passed at one of the powerhouses. In contrast, only 2.2% (n = 39) of STH that approached either B1 (n = 202) or B2 (n =

1569) passed at another dam structure. The median 100-m forebay residence time also was very short for Chinook salmon smolts (0.133-0.178 h) compared with that of STH(1.426 h).

The 100-m forebay residence time can be a misleading metric because the number of fish that can be tracked from 100 m upstream from the dam to the dam face is higher for quiet forebay areas such as B1 than it is in noisy areas such as the spillway. Historically, forebay residence times were calculated for each dam structure at Bonneville as the time from first detection by radio telemetry (presumably about 100 m from antennas) until the time of passage through the dam. Historical average estimates summarized by Ploskey et al. (2007a) for juvenile STH were 5.4 h for B1, 0.3 for the spillway and 3.0 h for B2. The average of those mean estimates for juvenile steelhead was 2.9 h, and this was 48% of the mean estimate of 6.1 h in this study. About 40% of the STH in the 2010 sample were detected in the B1 forebay, which was acoustically very quiet relative to the spillway and somewhat quieter than the B2 forebay. The high proportion of STH from B1 likely biased the 2010 average 100-m residence time estimate high because flow through B1 was less than flow through the spillway or B2. The median travel time for STH in 2010 was 1.43 h and this was slightly lower than the historical average residence time for STH passing B2 and the spillway (1.65 h). Estimates of forebay residence summarized by Ploskey et al. (2007a) for CH1 were 2.2 h for B1, 0.2 for the spillway, and 0.5 for B2. The average of those mean estimates (0.97 h) was about 52% of the 2010 estimate for yearlings (1.87 h), which likely was biased high by having 43% of the sample from the B1 forebay, where the range of acoustic detection was high but forebay flow through the B1 powerhouse was low. The median forebay residence time for yearlings was just 0.17 h in 2010, and this was lower than the average historical estimate for yearlings passing B2 and the spillway. For CH0 smolts, average estimates of forebay residence times summarized by Ploskey et al. (2007a), were 4.4 h at B1, 0.4 h at the spillway, and 0.2 h at B2. The average of the historical means for the three locations (1.67 h) was reasonably close to the mean estimate for the dam in summer 2010 (1.57 h). The median 100-m forebay residence time for subyearlings was just 0.133 h. We prefer the use of median forebay residence times instead of means because they are less susceptible to bias by fish readily detected in quiet areas with low flow to carry fish to passage through the dam. Unfortunately, we could not find median estimates of forebay residence times to compare with 2010 estimates.

Holmberg et al. (2001) estimated median tailrace egress times for STH and CH1 and CH0. The estimated median egress times from the forebay to the B2 outfall vicinity for juvenile STH that passed B1 was 0.41 h and for STH passing the spillway it was 0.43 h, and those historical egress times were reasonably close to our median estimate of 0.414 h for STH in 2010. Their estimate of median egress times from the forebay to the B2 outfall vicinity for CH1 that passed B1 was 0.49 h and for yearlings passing the spillway it was 0.41 h. Those historical estimates were reasonably close to our median estimate of 0.455 h for yearlings in spring 2010. Their estimated median egress times from the forebay to the B2 outfall vicinity for subyearling Chinook that passed B1 was 0.40 h and for those subyearlings passing the spillway it was 0.41 h. Those historical egress times were close to our median estimate of 0.42 h for subyearlings in summer 2010.

Historical estimates of project passage time were not directly available from previous studies so we had no historical estimates to compare with 2010 estimates.

7.2.3 Passage-Efficiency Estimates

Passage-efficiency metrics for each run of fish studied in 2010 were compared to available historical estimates as summarized by Ploskey et al. (2007a; Table 7.4). Most metrics were within the range of historical estimates, and those that were not within that range usually were off by only a few percentage points. For example, FPE estimates for STH and CH0 were within range, but FPE for CH1 was about 4.4% higher than the historical range. Other 2010 estimates that were slightly outside of their historical range were as follows: B1 sluiceway efficiency relative to B1 for subyearlings (-3.3% below historical minimum), B2CC efficiency relative to B2 (STH = -1.9%; subyearlings = -0.3%), and B2 FGE (STH = -8.3%, CH1 = -4%, and subyearlings = -1.5%).

Table 7.4. Comparison of Passage-Efficiency Metric Estimates in 2010 Relative to Available Historical Ranges for Non-Drought Years

Metric (Percent)	STH ^(a)	Historical Range ^(b)	CH1 ^(a)	Historical Range ^(b)	CH0 ^(a)	Historical Range ^(b)
Fish-Passage Efficiency (FPE) Dam	79.5	78–86	80.2	71–76	70.5	68–90
Spill-Passage Efficiency (SPE) Dam	40.6	26–55	52.8	33–57	52.4	35–65
Spill + B2CC Passage Efficiency Dam	71.2		71.7		61.5	
B1 Sluiceway Passage Efficiency B1 (B1 FPE)	40.8	29–65	33.0	29–53	25.7	29–59
B2CC Passage Efficiency B2	57.10	59–75	45.8	29–49	36.1 ^(c)	37–40
B2 Fish-Guidance Efficiency JBS+Turbine	25.7	34–59	29	33–46	20.5	22–47
B1 Sluiceway Passage Efficiency Dam	2.4		1.9		5.7	
B2CC Passage Efficiency Dam	30.6		19.0		9.1	
B2 JBS Passage Efficiency Dam	5.9		6.5		3.3	

(a) STH = juvenile steelhead; CH1 = yearling Chinook salmon; CH0 = subyearling Chinook salmon.

(b) Non-drought years except for B2 FGE.

(c) Unit 11 out of service all year and Unit 13 operated only a few hours.

There was no backsliding on SPE in 2010. Historical estimates of SPE for non-drought spring periods ranged from 0.26 to 0.55 for juvenile STH and from 0.33 to 0.57 for CH1 (summarized by Ploskey et al. 2007a). The spring 2010 estimate of SPE was 0.406 for STH and 0.528 for CH1, and both of these estimates fall within the respective historical ranges for non-drought years. Historical estimates of subyearling SPE for non-drought summers ranged from 0.35 to 0.65 (summarized by Ploskey et al. 2007a). The 2010 estimate of SPE for subyearlings (0.524) is near the middle of the historical range for subyearlings in non-drought years.

7.3 Day and Night Effects on Passage Metrics

We found significant differences in some passage metrics related to day and night passage in spring or to combinations of day and night and spill condition in summer that could have important management implications. For CH1 smolts (Table 4.3), we observed that FPE, spill + B2CC passage efficiency, and B2CC passage efficiency relative to B2 or the entire dam, and B2 JBS efficiency were all higher during the day than they were at night. The biggest difference was for in CH1 B2 FPE, which was 25.1% higher during the day (70.7%) than it was at night (45.7%). The CH1 B2CC-passage efficiency was 21.6% higher during the day than it was at night. For juvenile STH (Table 5.3), several metrics were higher

during the day than they were at night, including B2CC passage efficiency relative to B2 (+33.1%) or relative to the dam (+31%), B1 sluiceway passage efficiency relative to B1 (+32.1%), B2 FPE (+28.5%), FPE (+10.8%), and spillway+B2CC passage efficiency (+9.7%). It is interesting to note that daytime periods had 9.7% higher spillway+B2CC passage efficiency than nighttime periods in spite of the fact that spillway passage efficiency was 21.4% lower during the day than it was at night. For CH0 under the 95-kcfs spill treatment, daytime estimates were higher than nighttime estimates of FPE (+21.4%), SPE (+20.9%), spill + B2CC passage efficiency (30.9%), B2CC passage efficiency relative to B2 and the dam (+34.2%), and B2CC passage efficiency relative to the dam (+10%). The passage efficiency of the B1 sluiceway relative to the entire dam was the only metric that actually was lower during the day than at night, and that was an artifact of most B1 turbines being shut down at night to accommodate 120-kcfs spill treatments. The B1 sluiceway becomes the only option when B1 turbine operations are severely curtailed.

Fixed-aspect hydroacoustic and especially acoustic camera sampling of smolts passing into the B2CC and B1 sluiceway previously revealed that more smolts actively enter these surface-flow outlets during the day than enter at night (Ploskey et al. 2005, 2006). Sampling with a dual frequency identification sonar at the B1 sluiceway outlet above turbine 3 in 2005 clearly indicated that most smolts hold position upstream of the sluiceway outlet at night, where they are routinely attacked by piscivores. During the daytime, smolts were recorded actively passing into the sluiceway in schools and piscivore attacks were less common during the day than they were at night.

7.4 Effect of Spillway Discharge Treatments in Summer

We could not detect a significant difference between the two prescribed spill treatments tested in 2010 by comparing pooled survival estimates and associated 95% confidence intervals or by comparing similar measures for other fish passage metrics. The seasonal decline in subyearling survival was common to both spill treatments, and pairs of treatments in statistical blocks consistently had overlapping 95% confidence intervals (see Figure 6.2).

The summer treatment study called for 16 blocks of paired spill treatments, with a randomized order of treatments within blocks. Unfortunately, river discharge overwhelmed dam operators' ability to provide prescribed spill treatments during the first half of the summer study between June 16 and July 1 (see Figure 3.3), and nine out of 16 pairs of 1-day treatments were realized, but the 24-h, 95-kcfs treatment in the ninth block only had six fish in it, so we pooled fish from the same treatments in blocks 8 and 9. Formal statistical tests lacked power to detect significant differences in survival, although a one-tailed t-test on data in Table 6.5 was significant ($P = 0.0484$; $\alpha = 0.05$; Table 6.3). This result suggested that the 24-h, 95-kcfs spill treatment provided higher mean survival for subyearlings than did the 85-kcfs day and 120-kcfs night treatment. However, the calculated mean for the 85-kcfs day and 120-kcfs night treatment (0.887) was biased low by one point estimate on July 15 (survival = 0.713; $n = 48$) relative to the seasonal pooled estimate for the same treatment (0.903), and this bias suggest that this test result is not reliable. The July 15 sample size for 48 fish was the smallest for any block and treatment.

7.5 Performance of the B2 Behavior Guidance Structure

If successful, the behavioral guidance structure in the B2 forebay should have substantially increased yearling B2CC passage efficiency and reduced the percentage passing through turbines in 2008, 2009,

and 2010 over passage rates observed in 2004 and 2005 before the BGS was installed. Any increase in B2 JBS passage proportions would be a bonus.

The B2 BGS showed some benefit for CH1 by increasing B2CC passage efficiency by about 12.5%, but a similar benefit was not obvious for juvenile STH and CH0. The survival of B2- and B2CC-passed fish of the three runs studied did not differ between pre- and post-BGS years. Having turbine 11, which is adjacent to the B2CC, out of service in spring and summer reduced the strength of lateral surface flows toward the south along the face of the powerhouse toward the B2CC and may have adversely affected B2CC passage efficiency in 2010. In summer, turbine 13 ran only a few hours, and the combined loss of turbines 11 and 13 resulted in an atypical horizontal passage distribution that was much higher through the north turbine than through the south turbines. When all B2 turbines are running, fish passage typically is higher through turbines 11–14 than through turbines 15–18 (Ploskey et al. 2007a), and that skew is believed to be responsible for good B2CC passage performance.

8.0 Conclusions and Recommendations

The JSATS deployed at BON performed well and appears to be ready for an official BiOp test in 2011. The B2 BGS showed some benefit for CH1 by increasing B2CC passage efficiency by about 12.5%, but such benefit was not obvious for juvenile STH and CH0. We could not detect a significant difference between the two spill treatments tested in 2010 by comparing pooled survival estimates or fish-passage metrics and their associated 95% confidence intervals for CH0. Point estimates of survival for pairs of treatment days within blocks consistently had overlapping $\frac{1}{2}$ 95% confidence intervals. Formal statistical tests on eight pairs of survival rates lacked power to detect significant differences, but the 24-h, 95-kcfs point estimate was 2% higher than the point estimate under the 85-kcfs day and 120-kcfs night spill treatment.

Recommendations derived from the 2010 BON study are as follows:

1. Proceed with an official BiOp and Fish Accord compliance test in 2011. The JSATS acoustics monitoring system appears to be ready barring unforeseen circumstances.
2. Based on preliminary results of the 2010 study, we recommend that the Portland District remove the BGS from the B2 forebay before the 2011 study. We also recommended that the Portland District try to have turbines 11–14 in operation for any future compliance tests, because those units seem to be important for setting up forebay circulation that enhances B2CC passage efficiency.
3. We believe that the USACE should deploy focused stadium lighting at strategic locations within about 100 m of surface-flow outlets at B1 and B2. This could start with a temporary test deployment to determine whether the light deployment could successfully change the nighttime holding behavior of smolts upstream of surface-flow outlets, so that smolts would readily enter surface-flow outlets from the forebays like they do during the daytime. Many fish-passage metrics and especially those related to surface-flow outlets were significantly higher during the day than they were at night (see Section 7.3). In addition, previous acoustic camera studies at BON surface-flow outlets indicate clear differences in smolt behavior and the frequency of piscivore predator attacks during day and night periods (also in Section 7.3). If test light deployments are successful in changing smolt passage behavior at night, permanent light deployments should be designed and installed.
4. Debris clogging surface-flow outlets in the B1 forebay should be cleared as soon as possible, particularly in summer when river discharge typically peaks each year. Survival of fish passing through the B1 sluiceway was high in spring (CH1 = 0.980; STH = 0.963), but in summer, B1 sluiceway-passage survival of subyearlings was only 0.943, 2.4% lower than the rate for subyearlings passing through B1 turbines. The shallow openings in the B1 surface-flow outlets are more prone to clogging in summer than is the B2CC outlet, which provides for relatively high passage survival in spring and summer.
5. We recommend operating the project to avoid any further increase in the number or percent of fish passing through the spillway, until the underlying cause for its poor fish-passage survival performance is understood. We observed that point estimates of spill-passage survival were lower than point estimates for any other route used by CH1 and CH0. For STH smolts, the point estimate (0.935) was only higher than survival estimates for fish passing through B1 and B2 turbines (0.911 and 0.900, respectively). For STH smolts, spill-passage survival (0.939) was lower than passage survival for the B2 JBS (0.978), B2CC (0.975), and the B1 sluiceway (0.963). The 85-kcfs day and 120-kcfs night spill treatment in summer produced a point estimate of virtual release survival that was

2.3% lower than the point estimate for the 24-h, 95-kcfs spill treatment. Given the apparent risk to subyearlings passing the spillway under the 85-kcfs day and 120- kcfs night treatment, we cannot in good conscience recommend further use of the latter treatment until the reason for poor spill-passage survival is understood.

6. The analysis of STH behavior in the forebay areas prior to passage (see Section 4.5 on passage distributions and discussion of travel time estimates in Section 7.2.2) made it clear that a lot of juvenile STH are rejecting the spillway as a passage route and passing through B1 or B2. If spill-passage survival could be improved, we would readily recommend installing two or three top spill weirs to reduce the spillway rejection rate for STH. However, STH that rejected the spillway in favor of B2 passage experienced 97.6% survival as opposed to 93.7% survival for STH passing through the spillway.

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Appendix A
Fish-Tagging Tables

Appendix A - Fish-Tagging Tables

Table A.1. 2010 Yearling Chinook Salmon Tagged at John Day Dam and Released Live at Three Sites

Tag Date	Release Date	Number Tagged	Release Location	Number Released	Mortalities
4/27/2010	4/28/2010	72	Roosevelt	72	
4/28/2010	4/29/2010	72	Roosevelt	72	
4/29/2010	4/30/2010	97	Roosevelt	72	
			TDA tailrace	25	
4/30/2010	5/1/2010	97	Roosevelt	72	
			Hood River	25	
5/1/2010	5/2/2010	147	Roosevelt	72	
			TDA tailrace ^(a)	50	
			Hood River	25	
5/2/2010	5/3/2010	96	Roosevelt	72	
			Hood River	24	
5/3/2010	5/4/2010	147	Roosevelt	72	
			TDA tailrace ^(a)	49	1
			Hood River	25	
5/4/2010	5/5/2010	103	Roosevelt	72	5 ^(b)
			Hood River	26	
5/5/2010	5/6/2010	147	Roosevelt	71	1
			TDA tailrace ^(a)	50	
			Hood River	25	
5/6/2010	5/7/2010	97	Roosevelt	72	
			Hood River	25	
5/7/2010	5/8/2010	147	Roosevelt	71	1
			TDA tailrace ^(a)	49	1
			Hood River	25	
5/8/2010	5/9/2010	97	Roosevelt	72	
			Hood River	25	
5/9/2010	5/10/2010	148	Roosevelt	72	1 ^(b)
			TDA tailrace ^(a)	50	
			Hood River	25	
5/10/2010	5/11/2010	23			23 ^(b)
5/11/2010	5/12/2010	147	Roosevelt	72	
			TDA tailrace ^(a)	50	
			Hood River	25	
5/12/2010	5/13/2010	194	Roosevelt	144	
			Hood River	50	
5/13/2010	5/14/2010	146	Roosevelt	72	
			TDA tailrace ^(a)	50	
			Hood River	24	

Table A.1. (contd)

Tag Date	Release Date	Number Tagged	Release Location	Number Released	Mortalities
5/14/2010	5/15/2010	97	Roosevelt	72	
			Hood River	25	
5/15/2010	5/16/2010	147	Roosevelt	72	
			TDA tailrace ^(a)	50	
			Hood River	25	
5/16/2010	5/17/2010	97	Roosevelt	72	
			Hood River	25	
5/17/2010	5/18/2010	146	Roosevelt	72	
			TDA tailrace ^(a)	49	
			Hood River	25	
5/18/2010	5/19/2010	96	Roosevelt	71	
			Hood River	25	
5/19/2010	5/20/2010	147	Roosevelt	72	
			TDA tailrace ^(a)	50	
			Hood River	25	
5/20/2010	5/21/2010	97	Roosevelt	72	
			Hood River	25	
5/21/2010	5/22/2010	147	Roosevelt	72	
			TDA tailrace ^(a)	50	
			Hood River	25	
5/22/2010	5/23/2010	97	Roosevelt	72	
			Hood River	25	
5/23/2010	5/24/2010	147	Roosevelt	72	
			TDA tailrace ^(a)	50	
			Hood River	25	
5/24/2010	5/25/2010	97	Roosevelt	72	
			Hood River	25	
5/25/2010	5/26/2010	146	Roosevelt	71	
			TDA tailrace ^(a)	50	
			Hood River	25	
5/26/2010	5/27/2010	97	Roosevelt	72	
			Hood River	25	
5/27/2010	5/28/2010	147	Roosevelt	73	
			TDA tailrace ^(a)	50	
			Hood River	24	
5/28/2010	5/29/2010	83	Roosevelt	58	
			Hood River	25	
5/29/2010	5/30/2010	75	TDA tailrace ^(a)	50	
			Hood River	25	
5/30/2010	5/31/2010	25	Hood River	25	
5/31/2010	6/1/2010	48	TDA tailrace	24	
			Hood River	24	

(a) Two releases (0800–0900 hours and 1900–2000 hours).

(b) Sacrificed to reach dead tagged fish quota for spring.

Table A.2. 2010 Juvenile Steelhead Tagged at John Day Dam and Released Live at Three Sites

Tag Date	Release Date	Number Tagged	Release Location	Number Released	Mortalities
4/27/2010	4/28/2010	72	Roosevelt	71	1
4/28/2010	4/29/2010	72	Roosevelt	72	
4/29/2010	4/30/2010	97	Roosevelt	72	
			TDA tailrace	25	
4/30/2010	5/1/2010	97	Roosevelt	72	
			Hood River	25	
5/1/2010	5/2/2010	147	Roosevelt	72	
			TDA tailrace ^(a)	50	
			Hood River	25	
5/2/2010	5/3/2010	96	Roosevelt	72	
			Hood River	24	
5/3/2010	5/4/2010	150	Roosevelt	75	
			TDA tailrace ^(a)	49	1
			Hood River	25	
5/4/2010	5/5/2010	105	Roosevelt	71	
			Hood River	26	
					8 ^(b)
5/5/2010	5/6/2010	147	Roosevelt	72	
			TDA tailrace ^(a)	50	
			Hood River	25	
5/6/2010	5/7/2010	97	Roosevelt	72	
			Hood River	25	
5/7/2010	5/8/2010	147	Roosevelt	72	
			TDA tailrace ^(a)	50	
			Hood River	25	
5/8/2010	5/9/2010	97	Roosevelt	72	
			Hood River	25	
5/9/2010	5/10/2010	147	Roosevelt	72	
			TDA tailrace ^(a)	50	
			Hood River	25	
5/10/2010	5/11/2010	27			27 ^(b)
5/11/2010	5/12/2010	147	Roosevelt	72	
			TDA tailrace ^(a)	50	
			Hood River	25	
5/12/2010	5/13/2010	192	Roosevelt	142	
			Hood River	50	
5/13/2010	5/14/2010	146	Roosevelt	72	
			TDA tailrace ^(a)	50	
			Hood River	24	
5/14/2010	5/15/2010	97	Roosevelt	72	
			Hood River	25	
5/15/2010	5/16/2010	146	Roosevelt	71	
			TDA tailrace ^(a)	50	
			Hood River	25	
5/16/2010	5/17/2010	97	Roosevelt	72	
			Hood River	25	

Table A.2. (contd)

Tag Date	Release Date	Number Tagged	Release Location	Number Released	Mortalities
5/17/2010	5/18/2010	147	Roosevelt	72	
			TDA tailrace ^(a)	50	
			Hood River	25	
5/18/2010	5/19/2010	97	Roosevelt	72	
			Hood River	25	
5/19/2010	5/20/2010	147	Roosevelt	72	
			TDA tailrace ^(a)	50	
			Hood River	25	
5/20/2010	5/21/2010	97	Roosevelt	72	
			Hood River	25	
5/21/2010	5/22/2010	147	Roosevelt	72	
			TDA tailrace ^(a)	50	
			Hood River	25	
5/22/2010	5/23/2010	97	Roosevelt	72	
			Hood River	25	
5/23/2010	5/24/2010	147	Roosevelt	72	
			TDA tailrace ^(a)	50	
			Hood River	25	
5/24/2010	5/25/2010	97	Roosevelt	72	
			Hood River	25	
5/25/2010	5/26/2010	147	Roosevelt	72	
			TDA tailrace ^(a)	50	
			Hood River	25	
5/26/2010	5/27/2010	97	Roosevelt	72	
			Hood River	25	
5/27/2010	5/28/2010	147	Roosevelt	72	
			TDA tailrace ^(a)	50	
			Hood River	25	
5/28/2010	5/29/2010	83	Roosevelt	58	
			Hood River	25	
5/29/2010	5/30/2010	75	TDA tailrace ^(a)	50	
			Hood River	25	
5/30/2010	5/31/2010	25	Hood River	25	
5/31/2010	6/1/2010	49	TDA tailrace	25	
			Hood River	24	

(a) Two releases (0800–0900 hours and 1900–2000 hours).

(b) Sacrificed to reach a dead tagged fish quota for spring.

Table A.3. 2010 Summer Subyearling Chinook Salmon Smolts Tagged at John Day Dam and Released Live at Three Sites

Tag Date	Release Date	Number Tagged	Release Location	Number Released	Mortalities
6/12/2010	6/13/2010	89	Roosevelt	89	
6/13/2010	6/14/2010	88	Roosevelt	88	
6/14/2010	6/15/2010	114	Roosevelt	89	
			TDA tailrace	25	
6/15/2010	6/16/2010	114	Roosevelt	89	
			Hood River	25	
6/16/2010	6/17/2010	165	Roosevelt	89	
			TDA tailrace ^(a)	50	
			Hood River	25	1
6/17/2010	6/18/2010	114	Roosevelt	89	
			Hood River	24	1
6/18/2010	6/19/2010	177	Roosevelt	88	1
			TDA tailrace ^(a)	50	
			Hood River	25	13 ^(b)
6/19/2010	6/20/2010	114	Roosevelt	89	
			Hood River	25	
6/20/2010	6/21/2010	164	Roosevelt	89	
			TDA tailrace ^(a)	50	
			Hood River	25	
6/21/2010	6/22/2010	113	Roosevelt	89	
			Hood River	24	
6/22/2010	6/23/2010	164	Roosevelt	89	
			TDA tailrace ^(a)	50	
			Hood River	25	
6/23/2010	6/24/2010	115	Roosevelt	89	
			Hood River	26	
6/24/2010	6/25/2010	135	Roosevelt	75	
			TDA tailrace ^(a)	40	
			Hood River	20	
6/25/2010	6/26/2010	128	Roosevelt	89	
			Hood River	25	
					14 ^(b)
6/26/2010	6/27/2010	162	Roosevelt	89	
			TDA tailrace ^(a)	50	
			Hood River	23	
6/27/2010	6/28/2010	116	Roosevelt	90	
			Hood River	25	1
6/28/2010	6/29/2010	165	Roosevelt	90	
			TDA tailrace ^(a)	49	1
			Hood River	24	1
6/29/2010	6/30/2010	114	Roosevelt	89	
			Hood River	25	

Table A.3. (contd)

Tag Date	Release Date	Number Tagged	Release Location	Number Released	Mortalities
6/30/2010	7/1/2010	193	Roosevelt	103	
			TDA tailrace ^(a)	60	
			Hood River	30	
7/1/2010	7/2/2010	113	Roosevelt	89	1
			Hood River	23	
7/2/2010	7/3/2010	164	Roosevelt	89	
			TDA tailrace ^(a)	50	
			Hood River	25	
7/3/2010	7/4/2010	114	Roosevelt	89	
			Hood River	25	
7/4/2010	7/5/2010	164	Roosevelt	89	
			TDA tailrace ^(a)	50	
			Hood River	25	
7/5/2010	7/6/2010	125	Roosevelt	88	1
			Hood River	25	11 ^(b)
7/6/2010	7/7/2010	164	Roosevelt	89	
			TDA tailrace ^(a)	50	
			Hood River	25	
7/7/2010	7/8/2010	114	Roosevelt	89	
			Hood River	25	
7/8/2010	7/9/2010	163	Roosevelt	88	1
			TDA tailrace ^(a)	49	
			Hood River	25	
7/9/2010	7/10/2010	129	Roosevelt	89	15 ^(b)
			Hood River	25	
7/10/2010	7/11/2010	163	Roosevelt	89	1
			TDA tailrace ^(a)	50	
			Hood River	23	
7/11/2010	7/12/2010	115	Roosevelt	90	1
			Hood River	24	
7/12/2010	7/13/2010	166	Roosevelt	90	1
			TDA tailrace ^(a)	50	
			Hood River	25	
7/13/2010	7/14/2010	115	Roosevelt	90	
			Hood River	25	
7/14/2010	7/15/2010	82	TDA tailrace ^(a)	52	
			Hood River	30	
7/15/2010	7/16/2010	31	Hood River	29	2 ^(b)
7/16/2010	7/17/2010	50	TDA tailrace ^(a)	25	
			Hood River	25	

(a) Two releases (0800–0900 hours and 1900–2000 hours).

(b) Sacrificed to reach a dead tagged fish quota for summer.

Appendix B

Hydrophone and Autonomous Node Deployment Tables

Appendix B - Hydrophone and Autonomous Node Deployment Tables

Table B.1. Hydrophone Locations in the Bonneville Dam-Face Array in 2010

Hydrophone Name	Latitude (NAD83)	Longitude (NAD83)	Elevation (NAVD88, ft)
BS_00_D	45.6457754	-121.9406238	43.25
BS_00_S	45.6457754	-121.9406238	70.08
BS_01_D	45.6456319	-121.9406189	43.26
BS_01_S	45.6456319	-121.9406189	70.09
BS_02_D	45.6454679	-121.9406235	42.38
BS_02_S	45.6454679	-121.9406235	70.25
BS_03_D	45.6453039	-121.9406281	42.72
BS_03_S	45.6453039	-121.9406281	70.64
BS_04_D	45.6451386	-121.9406335	42.88
BS_04_S	45.6451386	-121.9406335	70.59
BS_05_D	45.6449734	-121.9406385	42.55
BS_05_S	45.6449734	-121.9406385	70.67
BS_06_D	45.6448104	-121.9406426	42.42
BS_06_S	45.6448104	-121.9406426	70.34
BS_07_D	45.6446455	-121.9406479	42.47
BS_07_S	45.6446455	-121.9406479	70.39
BS_08_D	45.6444806	-121.9406530	43.73
BS_08_S	45.6444806	-121.9406530	71.27
BS_09_D	45.6443162	-121.9406579	43.72
BS_09_S	45.6443162	-121.9406579	71.38
BS_10_D	45.6441527	-121.9406624	43.31
BS_10_S	45.6441527	-121.9406624	70.60
BS_11_D	45.6439873	-121.9406677	43.19
BS_11_S	45.6439873	-121.9406677	70.86
BS_12_D	45.6438228	-121.9406723	42.63
BS_12_S	45.6438228	-121.9406723	70.38
BS_13_D	45.6436600	-121.9406773	43.22
BS_13_S	45.6436600	-121.9406773	70.93
BS_14_D	45.6434942	-121.9406824	43.12
BS_14_S	45.6434942	-121.9406824	70.78
BS_15_D	45.6433303	-121.9406880	43.26
BS_15_S	45.6433303	-121.9406880	70.80
BS_16_D	45.6431654	-121.9406920	42.37
BS_16_S	45.6431654	-121.9406920	69.79

Table B.1. (contd)

Hydrophone Name	Latitude (NAD83)	Longitude (NAD83)	Elevation (NAVD88, ft)
BS_17_D	45.6429996	-121.9406974	41.45
BS_17_S	45.6429996	-121.9406974	69.20
BS_18_D	45.6428602	-121.9407015	42.98
BS_18_S	45.6428602	-121.9407015	70.85
BPH1NWW	45.6403227	-121.9457555	72.14
BPH1SWW	45.6403065	-121.9457652	67.53
BSS_F1S	45.6390935	-121.9468644	67.59
B01_F1D	45.6391509	-121.9467887	16.09
B01_F1S	45.6391630	-121.9468228	66.45
B01_02D	45.6393625	-121.9466646	16.08
B01_02S	45.6393721	-121.9467003	66.44
B02_03D	45.6395733	-121.9465415	16.14
B02_03S	45.6395811	-121.9465780	66.50
B03_04D	45.6397863	-121.9464179	15.97
B03_04S	45.6397915	-121.9464554	66.33
B04_05D	45.6399809	-121.9463025	15.99
B04_05S	45.6399945	-121.9463354	66.35
B05_06D	45.6401955	-121.9461767	15.88
B05_06S	45.6402045	-121.9462127	66.24
B06_7ND	45.6404088	-121.9460488	23.57
B06_7NS	45.6404088	-121.9460488	66.45
B06_7SD	45.6403921	-121.9460630	18.04
B06_7SS	45.6403921	-121.9460630	60.97
B07_08D	45.6406087	-121.9459354	15.76
B07_08S	45.6406199	-121.9459701	66.12
B08_09D	45.6408202	-121.9458109	15.71
B08_09S	45.6408290	-121.9458470	66.07
B09_10D	45.6410285	-121.9456890	15.84
B09_10S	45.6410370	-121.9457253	66.20
B1N_10D	45.6412207	-121.9455825	15.83
B1N_10S	45.6412207	-121.9455825	66.19
BNORWAL	45.6412335	-121.9450736	74.09
B1S_SW1	45.6386370	-121.9461653	66.90
BCC_11S	45.6472569	-121.9383610	71.52
BCC_11D	45.6472491	-121.9383485	58.94
B11_12D	45.6474348	-121.9380910	16.01
B11_12S	45.6474492	-121.9381139	69.81
B12_13S	45.6476410	-121.9378682	69.58
B12_13D	45.6476267	-121.9378454	17.58
B13_14D	45.6478239	-121.9375939	17.95
B13_14S	45.6478382	-121.9376167	69.95
B14_15S	45.6480298	-121.9373713	69.69

Table B.1. (contd)

Hydrophone Name	Latitude (NAD83)	Longitude (NAD83)	Elevation (NAVD88, ft)
B14_15D	45.6480155	-121.9373484	17.69
B15_16D	45.6482032	-121.9371106	17.89
B15_16S	45.6482176	-121.9371335	69.89
B16_17S	45.6484092	-121.9368895	69.56
B16_17D	45.6483949	-121.9368667	17.56
B17_18D	45.6485863	-121.9366197	17.76
B17_18S	45.6486007	-121.9366425	69.76
B18_19S	45.6487928	-121.9363969	69.81
B18_19D	45.6487785	-121.9363741	17.81
B19_NOS	45.6489836	-121.9361548	71.57
B15A_T1	45.6479821	-121.9372776	72.97
B15C_T2	45.6480989	-121.9371235	72.99
B17A_T3	45.6483647	-121.9367849	72.84
B18B_T4	45.6486162	-121.9364637	73.37
BGS_C01	45.6468219	-121.9383161	75.74
BGS_C02	45.6466241	-121.9380157	75.42
BGS_C03	45.6464991	-121.9378074	75.70
BGS_C04	45.6463806	-121.9374317	75.61
BGS_C05	45.6462957	-121.9369925	75.74
BGS_C06	45.6462442	-121.9366974	75.68
BGS_C07	45.6462059	-121.9363118	75.72
BGS_W01	45.6483706	-121.9352006	75.73
BGS_W02	45.6481994	-121.9348416	75.59
BGS_W03	45.6480165	-121.9345007	75.72
BGS_W04	45.6478505	-121.9338666	75.57
BGS_W06	45.6477023	-121.9334464	75.56
BGS_W07	45.6475595	-121.9330686	75.63
BGS_W08	45.6474384	-121.9325314	75.58

Table B.2. Approximate Global Positioning System Coordinates of Autonomous Nodes Deployed in Arrays Just Above and Below Bonneville Dam in 2010. Array_Node is a concatenation of an array name and an autonomous node number. The array name is a concatenation of “CR” for Columbia River, with a three-digit number corresponding to river kilometer upstream of the mouth of the Columbia River. Nodes within an array are numbered from the Washington to the Oregon shore.

Array_Node	Array Function	Latitude Degrees North	Longitude Degrees West
CR236.0_01	BON Forebay	45.6509740	-121.9203458
CR236.0_02		45.6504350	-121.9198846
CR236.0_03		45.6498599	-121.9193208
CR236.0_04		45.6493209	-121.9188596
CR233.0_01	BON Egress	45.6350168	-121.9624832
CR233.0_02		45.6350270	-121.9613769
CR233.0_03		45.6346313	-121.9606050
CR153.0_01	BON Primary	45.7449562	-122.7858224
CR153.0_02		45.7445609	-122.7660408
CR153.0_03		45.7465749	-122.7629473
CR153.0_04		45.7452083	-122.7637150
CR153.0_05		45.7441297	-122.7652561
CR113.0_01	BON Secondary	46.0633259	-122.8693984
CR113.0_02		46.0707306	-122.8868271
CR113.0_03		46.0699943	-122.8872084
CR113.0_04		46.0693229	-122.8888071
CR113.0_05		46.0694009	-122.8900944
CR113.0_06		46.0711953	-122.8919111
CR113.0_07		46.0687756	-122.8902994
CR113.0_08		46.0691116	-122.8916534
CR113.0_09		46.0684816	-122.8922447
CR113.0_10		46.0689276	-122.8939764
CR086.2_01	BON Tertiary	46.1860936	-123.1806843
CR086.2_02		46.1859806	-123.1792560
CR086.2_03		46.1849006	-123.1805780
CR086.2_04		46.1841513	-123.1789230
CR086.2_05		46.1840586	-123.1778617
CR086.2_06		46.1834166	-123.1784803

Appendix C
Capture Histories

Appendix C - Capture Histories

This appendix contains detailed capture histories for each of the three runs of fish studied at Bonneville Dam in 2010. In capture history tables, the headings of columns 2 through 9 have three digits and each digit represents a detection (1) or non-detection (0) at three successive survival arrays (CR153, CR113, and CR086).

C.1 Capture Histories of Yearling Chinook Salmon in Spring

C.1.1 Bonneville Dam Passage

Table C.1. Bonneville Dam Passage Capture History for Yearling Chinook Salmon

	1 1 1	0 1 1	1 0 1	0 0 1	1 1 0	0 1 0	1 0 0	0 0 0
Number of Fish	2278	525	141	44	121	48	27	174

C.1.2 Forebay and Dam Passage

Table C.2. Forebay Virtual Release Capture History for Yearling Chinook Salmon

	1 1 1	0 1 1	1 0 1	0 0 1	1 1 0	0 1 0	1 0 0	0 0 0
Number of Fish	2287	527	142	44	121	48	27	177

C.1.3 B1 Sluiceway Passage

Table C.3. B1 Sluiceway Virtual Release Capture History for Yearling Chinook Salmon

	1 1 1	0 1 1	1 0 1	0 0 1	1 1 0	0 1 0	1 0 0	0 0 0
Number of Fish	34	20	4	1	1	1	1	2

C.1.4 B1 Turbine Passage

Table C.4. B1 Turbine Virtual Release Capture History for Yearling Chinook Salmon

	1 1 1	0 1 1	1 0 1	0 0 1	1 1 0	0 1 0	1 0 0	0 0 0
Number of Fish	68	40	8	2	5	1	2	3

C.1.5 Spillway Passage

Table C.5. Bonneville Spillway Virtual Release Capture History for Yearling Chinook Salmon

	1 1 1	0 1 1	1 0 1	0 0 1	1 1 0	0 1 0	1 0 0	0 0 0
Number of Fish	1175	260	80	23	63	32	12	121

C.1.6 B2CC Passage

Table C.6. B2CC Passage Capture History for Yearling Chinook Salmon

	1 1 1	0 1 1	1 0 1	0 0 1	1 1 0	0 1 0	1 0 0	0 0 0
Number of Fish	488	78	15	9	23	7	6	8

C.1.7 B2 JBS Passage

Table C.7. B2 JBS Passage Capture History for Yearling Chinook Salmon

	1 1 1	0 1 1	1 0 1	0 0 1	1 1 0	0 1 0	1 0 0	0 0 0
Number of Fish	152	36	9	4	6	3	2	5

C.1.8 B2 Turbine Passage

Table C.8. B2 Turbine Passage Capture History for Yearling Chinook Salmon

	1 1 1	0 1 1	1 0 1	0 0 1	1 1 0	0 1 0	1 0 0	0 0 0
Number of Fish	356	91	25	5	23	4	4	25

C.2 Capture Histories of Juvenile Steelhead Salmon in Spring

C.2.1 Bonneville Dam Passage

Table C.9. Bonneville Dam Passage Capture History for Juvenile Steelhead

	1 1 1	0 1 1	1 0 1	0 0 1	1 1 0	0 1 0	1 0 0	0 0 0
Number of Fish	2089	642	140	72	148	41	36	205

C.2.2 Forebay and Dam Passage

Table C.10. Forebay Virtual Release Capture History for Juvenile Steelhead

	1 1 1	0 1 1	1 0 1	0 0 1	1 1 0	0 1 0	1 0 0	0 0 0
Number of Fish	2088	642	141	73	149	41	36	206

C.2.3 B1 Sluiceway Passage

Table C.11. B1 Sluiceway Virtual Release Capture History for Juvenile Steelhead

	1 1 1	0 1 1	1 0 1	0 0 1	1 1 0	0 1 0	1 0 0	0 0 0
Number of Fish	44	19	4	3	4	0	2	4

C.2.4 B1 Turbine Passage

Table C.12. B1 Turbine Virtual Release Capture History for Juvenile Steelhead

	1 1 1	0 1 1	1 0 1	0 0 1	1 1 0	0 1 0	1 0 0	0 0 0
Number of Fish	57	33	4	6	3	1	0	12

C.2.5 Spillway Passage

Table C.13. Bonneville Spillway Virtual Release Capture History for Juvenile Steelhead

	1 1 1	0 1 1	1 0 1	0 0 1	1 1 0	0 1 0	1 0 0	0 0 0
Number of Fish	828	262	69	18	64	15	17	91

C.2.6 B2CC Passage

Table C.14. B2CC Passage Capture History for Juvenile Steelhead

	1 1 1	0 1 1	1 0 1	0 0 1	1 1 0	0 1 0	1 0 0	0 0 0
Number of Fish	681	194	38	21	42	16	8	30

C.2.7 B2 JBS Passage

Table C.15. B2 JBS Passage Capture History for Juvenile Steelhead

	1 1 1	0 1 1	1 0 1	0 0 1	1 1 0	0 1 0	1 0 0	0 0 0
Number of Fish	134	31	10	8	9	2	0	5

C.2.8 B2 Turbine Passage

Table C.16. B2 Turbine Passage Capture History for Juvenile Steelhead

	1 1 1	0 1 1	1 0 1	0 0 1	1 1 0	0 1 0	1 0 0	0 0 0
Number of Fish	343	103	15	16	26	7	9	55

C.3 Capture Histories of Subyearling Chinook Salmon in Summer

C.3.1 Bonneville Dam Passage

Table C.17. Bonneville Dam Passage Capture History for Subyearling Chinook Salmon

	1 1 1	0 1 1	1 0 1	0 0 1	1 1 0	0 1 0	1 0 0	0 0 0
Number of Fish ^(a)	1044	160	52	8	0	0	86	10

(a) After BON dam-face virtual release of subyearlings from TDA tailrace and Hood River releases only.

C.3.2 Bonneville Dam Passage (24-h, 95-kcfs Spill Treatment)

Table C.18. Bonneville Dam Passage Capture History for Subyearling Chinook Salmon During the 24-h, 95-kcfs Spill Treatment (Figure 3.5)

	1 1 1	0 1 1	1 0 1	0 0 1	1 1 0	0 1 0	1 0 0	0 0 0
Number of Fish ^(a)	700	49	28	1	0	0	22	1

(a) After BON dam-face virtual release of subyearlings from all upstream releases (Roosevelt, TDA tailrace, and Hood River).

C.3.3 Bonneville Dam Passage Under the 85 kcfs Day & 120 kcfs Night Spill Treatment (V1 from All Upstream Releases)

Table C.19. Bonneville Dam Passage Capture History for Subyearling Chinook Salmon During the 85- kcfs Day and 120-kcfs Night Spill Treatment (Figure 3.5)

	1 1 1	0 1 1	1 0 1	0 0 1	1 1 0	0 1 0	1 0 0	0 0 0
Number of Fish ^(a)	572	27	19	1	0	0	19	2

(a) After BON dam-face virtual release of subyearlings from all upstream releases (Roosevelt, TDA tailrace, and Hood River).

C.3.4 Dam Passage During Day 95-kcfs Spill

Table C.20. Dam Passage Virtual Release Capture History for Subyearling Chinook Salmon Passing During Day 95-kcfs Spill

	1 1 1	0 1 1	1 0 1	0 0 1	1 1 0	0 1 0	1 0 0	0 0 0
Number of Fish	479	37	15	1	17	0	18	48

C.3.5 Dam Passage During Night 95-kcfs Spill

Table C.21. Dam Passage Virtual Release Capture History for Subyearling Chinook Salmon Passing During Night 95-kcfs Spill

	1 1 1	0 1 1	1 0 1	0 0 1	1 1 0	0 1 0	1 0 0	0 0 0
Number of Fish	221	12	13	0	5	1	9	20

C.3.6 Dam Passage During the Day 85-kcfs Spill

Table C.22. Dam Passage Virtual Release Capture History for Subyearling Chinook Salmon Passing During Day 85-kcfs Spill

	1 1 1	0 1 1	1 0 1	0 0 1	1 1 0	0 1 0	1 0 0	0 0 0
Number of Fish	429	19	18	0	17	1	12	51

C.3.7 Dam Passage During the Night During 120-kcfs Spill

Table C.23. Dam Passage Virtual Release Capture History for Subyearling Chinook Salmon Passing During Night 85-kcfs Spill

	1 1 1	0 1 1	1 0 1	0 0 1	1 1 0	0 1 0	1 0 0	0 0 0
Number of Fish	143	8	1	1	2	1	2	20

C.3.8 Forebay and Dam Passage (V1 from TDA Tailrace and Hood River Releases

Table C.24. Forebay Virtual Release Capture History for Subyearling Chinook Salmon

	1 1 1	0 1 1	1 0 1	0 0 1	1 1 0	0 1 0	1 0 0	0 0 0
Number of Fish ^(a)	1132	175	58	10	90	13	20	73

(a) After BON forebay virtual release of subyearlings from TDA tailrace and Hood River releases only.

C.3.9 B1 Sluiceway Passage

Table C.25. B1 Sluiceway Virtual Release Capture History for Subyearling Chinook Salmon

	1 1 1	0 1 1	1 0 1	0 0 1	1 1 0	0 1 0	1 0 0	0 0 0
Number of Fish	128	25	11	0	14	2	4	12

C.3.10 B1 Turbine Passage

Table C.26. B1 Turbine Virtual Release Capture History for Subyearling Chinook Salmon

	1 1 1	0 1 1	1 0 1	0 0 1	1 1 0	0 1 0	1 0 0	0 0 0
Number of Fish	378	89	12	5	39	15	9	21

C.3.11 Spillway Passage

Table C.27. Bonneville Spillway Virtual Release Capture History for Subyearling Chinook Salmon

	1 1 1	0 1 1	1 0 1	0 0 1	1 1 0	0 1 0	1 0 0	0 0 0
Number of Fish	1238	188	66	11	109	16	30	129

C.3.12 Spillway Passage During 24-h 95-kcfs Spill Treatment

Table C.28. Bonneville Spillway Virtual Release Capture History for Subyearling Chinook Salmon Passing During the 24-h 95-kcfs Spill Treatment

	1 1 1	0 1 1	1 0 1	0 0 1	1 1 0	0 1 0	1 0 0	0 0 0
Number of Fish	387	27	15	1	11	1	17	39

C.3.13 Spillway Passage During the 85-kcfs Day /120-kcfs Night Spill Treatment

Table C.29. Bonneville Spillway Virtual Release Capture History for Subyearling Chinook Salmon Passing During the 85-kcfs Day/120 kcfs Night Spill Treatment

	1 1 1	0 1 1	1 0 1	0 0 1	1 1 0	0 1 0	1 0 0	0 0 0
Number of Fish	287	18	9	0	14	1	5	47

C.3.14 Spillway Passage During the Day 95-kcfs Spill

Table C.30. Bonneville Spillway Virtual Release Capture History for Subyearling Chinook Salmon Passing during Day 95-kcfs Spill

	1 1 1	0 1 1	1 0 1	0 0 1	1 1 0	0 1 0	1 0 0	0 0 0
Number of Fish	295	23	10	1	8	0	14	31

C.3.15 Spillway Passage During Night 95-kcfs Spill

Table C.31. Bonneville Spillway Virtual Release Capture History for Subyearling Chinook Salmon Passing During Night 95-kcfs Spill

	1 1 1	0 1 1	1 0 1	0 0 1	1 1 0	0 1 0	1 0 0	0 0 0
Number of Fish	92	4	5	0	3	1	3	8

C.3.16 Spillway Passage During Day 85-kcfs Spill

Table C.32. Bonneville Spillway Virtual Release Capture History for Subyearling Chinook Salmon Passing During Day 85-kcfs Spill

	1 1 1	0 1 1	1 0 1	0 0 1	1 1 0	0 1 0	1 0 0	0 0 0
Number of Fish	209	12	9	0	12	1	4	31

C.3.17 Spillway Passage During Night 120-kcfs Spill

Table C.33. Bonneville Spillway Virtual Release Capture History for Subyearling Chinook Salmon Passing During Night 120-kcfs Spill

	1 1 1	0 1 1	1 0 1	0 0 1	1 1 0	0 1 0	1 0 0	0 0 0
Number of Fish	78	6	0	0	2	0	1	16

C.3.18 B2CC Passage

Table C.34. B2CC Passage Capture History for Subyearling Chinook Salmon

	1 1 1	0 1 1	1 0 1	0 0 1	1 1 0	0 1 0	1 0 0	0 0 0
Number of Fish	249	24	11	1	4	5	7	10

C.3.19 B2 JBS Passage

Table C.35. B2 JBS Passage Capture History for Subyearling Chinook Salmon

	1 1 1	0 1 1	1 0 1	0 0 1	1 1 0	0 1 0	1 0 0	0 0 0
Number of Fish	76	11	8	1	9	2	2	3

C.3.20 B2 Turbine Passage

Table C.36. B2 Turbine Passage Capture History for Subyearling Chinook Salmon

	1 1 1	0 1 1	1 0 1	0 0 1	1 1 0	0 1 0	1 0 0	0 0 0
Number of Fish	332	49	10	1	14	2	1	28

Appendix D

Detection and Survival Probabilities

Appendix D - Detection and Survival Probabilities

D.1 Detection and Survival of Yearling Chinook Salmon

D.1.1 Bonneville Dam Passage

Table D.1. Bonneville Dam Passage Detection and Survival Rates for Yearling Chinook Salmon

Survival Detail:

	CR234.0 to CR153.0		CR153.0 to CR113.0	
	Estimate	s.e.†	Estimate	s.e.*
Yearling Chinook - All Upstream Releases	0.9519	0.003968	0.9938	0.002057

Capture Detail:

	CR153.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	s.e.*	Estimate	s.e.*	Estimate	s.e.*
Yearling Chinook - All Upstream Releases	0.8046	0.007057	0.9381	0.004409	0.9437	0.004250

* Standard error is based on the inverse Hessian.

† Standard error is based on bootstrapping.

D.1.2 Forebay and Dam Passage

Table D.2. Forebay Virtual Release Detection and Survival Rates for Yearling Chinook Salmon

Survival Detail:

	CR236.0 to CR153.0		CR153.0 to CR113.0	
	Estimate	s.e.†	Estimate	s.e.*
Yearling Chinook - All Upstream Releases	0.9513	0.004014	0.9939	0.002049

Capture Detail:

	CR153.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	s.e.*	Estimate	s.e.*	Estimate	s.e.*
Yearling Chinook - All Upstream Releases	0.8047	0.007043	0.9380	0.004403	0.9439	0.004235

* Standard error is based on the inverse Hessian.

† Standard error is based on bootstrapping.

D.1.3 B1 Sluiceway Passage

Table D.3. B1 Sluiceway Virtual Release Detection and Survival Rates for Yearling Chinook Salmon

Survival Detail:

	CR234.0 to CR153.0		CR153.0 to CR113.0	
	Estimate	s.e.†	Estimate	s.e.*

Yearling Chinook - All Upstream Releases	0.9795	0.023829	0.9788	0.024905
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Capture Detail:

	CR153.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	s.e.*	Estimate	s.e.*	Estimate	s.e.*
Yearling Chinook - All Upstream Releases	0.6393	0.061482	0.9153	0.036258	0.9648	0.024812

* Standard error is based on the inverse Hessian.

† Standard error is based on bootstrapping.

D.1.4 B1 Turbine Passage

Table D.4. B1 Turbine Virtual Release Detection and Survival Rates for Yearling Chinook Salmon

Survival Detail:

	CR234.0 to CR153.0		CR153.0 to CR113.0	
	Estimate	s.e.†	Estimate	s.e.*
Yearling Chinook - All Upstream Releases	0.9871	0.014753	0.9810	0.017072

Capture Detail:

	CR153.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	s.e.*	Estimate	s.e.*	Estimate	s.e.*
Yearling Chinook - All Upstream Releases	0.6532	0.042741	0.9153	0.025638	0.9479	0.020926

* Standard error is based on the inverse Hessian.

† Standard error is based on bootstrapping.

D.1.5 Spillway Passage

Table D.5. Bonneville Spillway Virtual Release Detection and Survival Rates for Yearling Chinook Salmon

Survival Detail:

	CR234.0 to CR153.0		CR153.0 to CR113.0	
	Estimate	s.e.†	Estimate	s.e.*
Yearling Chinook - All Upstream Releases	0.9349	0.006142	0.9960	0.002672

Capture Detail:

	CR153.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	s.e.*	Estimate	s.e.*	Estimate	s.e.*
Yearling Chinook - All Upstream Releases	0.8071	0.009764	0.9330	0.006374	0.9385	0.006173

* Standard error is based on the inverse Hessian.

† Standard error is based on bootstrapping.

D.1.6 B2CC Passage

Table D.6. B2CC Passage Detection and Survival Rates for Yearling Chinook Salmon

Survival Detail:

	CR234.0 to CR153.0		CR153.0 to CR113.0	
	Estimate	s.e.†	Estimate	s.e.*
Yearling Chinook - All Upstream Releases	0.9909	0.004625	0.9916	0.004625

Capture Detail:

	CR153.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	s.e.*	Estimate	s.e.*	Estimate	s.e.*
Yearling Chinook - All Upstream Releases	0.8484	0.014404	0.9593	0.008133	0.9502	0.008961

* Standard error is based on the inverse Hessian.

† Standard error is based on bootstrapping.

D.1.7 B2 JBS Passage

Table D.7. B2 JBS Passage Detection and Survival Rates for Yearling Chinook Salmon

Survival Detail:

	CR234.0 to CR153.0		CR153.0 to CR113.0	
	Estimate	s.e.†	Estimate	s.e.*
Yearling Chinook - All Upstream Releases	0.9814	0.010443	0.9920	0.008447

Capture Detail:

	CR153.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	s.e.*	Estimate	s.e.*	Estimate	s.e.*
Yearling Chinook - All Upstream Releases	0.7952	0.027846	0.9353	0.017348	0.9549	0.014885

* Standard error is based on the inverse Hessian.

† Standard error is based on bootstrapping.

D.1.8 B2 Turbine Passage

Table D.8. B2 Turbine Passage Detection and Survival Rates for Yearling Chinook Salmon

Survival Detail:

	CR234.0 to CR153.0		CR153.0 to CR113.0	
	Estimate	s.e.†	Estimate	s.e.*
Yearling Chinook - All Upstream Releases	0.9568	0.009312	0.9946	0.004990

Capture Detail:

	CR153.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	s.e.*	Estimate	s.e.*	Estimate	s.e.*
Yearling Chinook - All Upstream Releases	0.8016	0.017764	0.9371	0.011116	0.9436	0.010652

* Standard error is based on the inverse Hessian.

† Standard error is based on bootstrapping.

D.2 Detection and Survival of Juvenile Steelhead

D.2.1 Bonneville Dam Passage

Table D.9. Bonneville Dam Passage Detection and Survival Rates for Juvenile Steelhead

Survival Detail:

	CR234.0 to CR153.0		CR153.0 to CR113.0	
	Estimate	s.e.†	Estimate	s.e.*
Steelhead - All Upstream Releases	0.9445	0.004329	0.9906	0.002524

Capture Detail:

	CR153.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	s.e.*	Estimate	s.e.*	Estimate	s.e.*
Steelhead - All Upstream Releases	0.7589	0.007643	0.9280	0.004766	0.9358	0.004556

* Standard error is based on the inverse Hessian.

† Standard error is based on bootstrapping.

D.2.2 Forebay and Dam Passage

Table D.10. Forebay Virtual Release Detection and Survival Rates for Juvenile Steelhead

Survival Detail:

	CR236.0 to CR153.0		CR153.0 to CR113.0	
	Estimate	s.e.†	Estimate	s.e.*
Steelhead - All Upstream Releases	0.9442	0.004326	0.9906	0.002525

Capture Detail:

	CR153.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	s.e.*	Estimate	s.e.*	Estimate	s.e.*
Steelhead - All Upstream Releases	0.7588	0.007642	0.9273	0.004785	0.9354	0.004567

* Standard error is based on the inverse Hessian.

† Standard error is based on bootstrapping.

D.2.3 B1 Sluiceway Passage

Table D.11. B1 Sluiceway Virtual Release Detection and Survival Rates for Juvenile Steelhead

Survival Detail:

	CR234.0 to CR153.0		CR153.0 to CR113.0	
	Estimate	s.e.†	Estimate	s.e.*
Steelhead - All Upstream Releases	0.9629	0.025966	0.9695	0.026130

Capture Detail:

	CR153.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	s.e.*	Estimate	s.e.*	Estimate	s.e.*
Steelhead - All Upstream Releases	0.7027	0.053133	0.9000	0.035857	0.9407	0.028960

* Standard error is based on the inverse Hessian.

† Standard error is based on bootstrapping.

D.2.4 B1 Turbine Passage

Table D.12. B1 Turbine Virtual Release Detection and Survival Rates for Juvenile Steelhead

Survival Detail:

	CR234.0 to CR153.0		CR153.0 to CR113.0	
	Estimate	s.e.†	Estimate	s.e.*
Steelhead - All Upstream Releases	0.9001	0.028439	1.0000	0.000000

Capture Detail:

	CR153.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	s.e.*	Estimate	s.e.*	Estimate	s.e.*
Steelhead - All Upstream Releases	0.6142	0.047761	0.9025	0.029280	0.9605	0.019550

* Standard error is based on the inverse Hessian.

† Standard error is based on bootstrapping.

D.2.5 Spillway Passage

Table D.13. Bonneville Spillway Virtual Release Detection and Survival Rates for Juvenile Steelhead

Survival Detail:

	CR234.0 to CR153.0		CR153.0 to CR113.0	
	Estimate	s.e.†	Estimate	s.e.*
Steelhead - All Upstream Releases	0.9389	0.006932	0.9884	0.004274

Capture Detail:

	CR153.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	s.e.*	Estimate	s.e.*	Estimate	s.e.*
Steelhead - All Upstream Releases	0.7651	0.011962	0.9261	0.007626	0.9329	0.007346

* Standard error is based on the inverse Hessian.

† Standard error is based on bootstrapping.

D.2.6 B2CC Passage

Table D.14. B2CC Passage Detection and Survival Rates for Juvenile Steelhead

Survival Detail:

	CR234.0 to CR153.0		CR153.0 to CR113.0	
	Estimate	s.e.†	Estimate	s.e.*
Steelhead - All Upstream Releases	0.9751	0.005422	0.9943	0.003747

Capture Detail:

	CR153.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	s.e.*	Estimate	s.e.*	Estimate	s.e.*
Steelhead - All Upstream Releases	0.7671	0.013419	0.9368	0.007960	0.9383	0.007909

* Standard error is based on the inverse Hessian.

† Standard error is based on bootstrapping.

D.2.7 B2 JBS Passage

Table D.15. B2 JBS Passage Detection and Survival Rates for Juvenile Steelhead

Survival Detail:

	CR234.0 to CR153.0		CR153.0 to CR113.0	
	Estimate	s.e.†	Estimate	s.e.*
Steelhead - All Upstream Releases	0.9784	0.011221	1.0000	0.000000

Capture Detail:

	CR153.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	s.e.*	Estimate	s.e.*	Estimate	s.e.*
Steelhead - All Upstream Releases	0.7876	0.029420	0.9062	0.021043	0.9427	0.016914

* Standard error is based on the inverse Hessian.

† Standard error is based on bootstrapping.

D.2.8 B2 Turbine Passage

Table D.16. B2 Turbine Passage Detection and Survival Rates for Juvenile Steelhead

Survival Detail:

	CR234.0 to CR153.0		CR153.0 to CR113.0	
	Estimate	s.e.†	Estimate	s.e.*
Steelhead - All Upstream Releases	0.9111	0.012548	0.9824	0.007666

Capture Detail:

	CR153.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	s.e.*	Estimate	s.e.*	Estimate	s.e.*
Steelhead - All Upstream Releases	0.7529	0.019098	0.9350	0.011287	0.9316	0.011578

* Standard error is based on the inverse Hessian.

† Standard error is based on bootstrapping.

D.3 Detection and Survival of Subyearling Chinook Salmon

D.3.1 Bonneville Dam Passage (V1 from TDA Tailrace and Hood River Releases)

Table D.17. Bonneville Dam Passage Detection and Survival Rates for Subyearling Chinook Salmon

Survival Detail:

	CR234.0 to CR153.0		CR153.0 to CR113.0	
	Estimate	s.e.†	Estimate	s.e.*
Summer - TDA tailrace and Hood River	0.9576	0.005475	0.9876	0.003658

Capture Detail:

	CR153.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	s.e.*	Estimate	s.e.*	Estimate	s.e.*
Summer - TDA tailrace and Hood River	0.8691	0.009146	0.9525	0.005981	0.9262	0.007253

* Standard error is based on the inverse Hessian.

† Standard error is based on bootstrapping.

D.3.2 Bonneville Dam Passage Under the 24-h, 95-kcfs Spill Treatment (V1 from All Upstream Releases)

Table D.18. Bonneville Dam Passage Detection and Survival Rates for Subyearling Chinook Salmon During the 24-h, 95-kcfs Spill Treatment

Survival Detail:

	CR234.0 to CR153.0		CR153.0 to CR113.0	
	Estimate	s.e.†	Estimate	s.e.*
Summer - All Upstream Releases	0.9262	0.008931	0.9663	0.006584

Capture Detail:

	CR153.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	s.e.*	Estimate	s.e.*	Estimate	s.e.*
Summer - All Upstream Releases	0.9363	0.008627	0.9627	0.006792	0.9702	0.006119

* Standard error is based on the inverse Hessian.

† Standard error is based on bootstrapping.

D.3.3 Bonneville Dam Passage Under the 85 kcfs Day and 120 kcfs Night Spill Treatment (V1 from All Upstream Releases)

Table D.19. Bonneville Dam Passage Detection and Survival Rates for Subyearling Chinook Salmon During the 85 kcfs Day and 120 kcfs Night Spill Treatment

Survival Detail:

	CR234.0 to CR153.0		CR153.0 to CR113.0	
	Estimate	s.e.†	Estimate	s.e.*
Summer - All Upstream Releases	0.9030	0.011085	0.9786	0.005945

Capture Detail:

	CR153.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	s.e.*	Estimate	s.e.*	Estimate	s.e.*
Summer - All Upstream Releases	0.9531	0.008355	0.9677	0.007107	0.9661	0.007265

* Standard error is based on the inverse Hessian.

† Standard error is based on bootstrapping.

D.3.4 Dam Passage During Day 95-kcfs Spill

Table D.20. Bonneville Dam Passage Detection and Survival Rates for Subyearling Chinook Salmon During Day 95-kcfs Spill

Survival Detail:

	CR234.0 to CR153.0		CR153.0 to CR113.0	
	Estimate	s.e.†	Estimate	s.e.*
Summer - All Release Upstrea	0.9217	0.014076	0.9580	0.011210

Capture Detail:

	CR153.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	s.e.*	Estimate	s.e.*	Estimate	s.e.*
Summer - All Release Upstrea	0.9288	0.014010	0.9666	0.009911	0.9755	0.008569

Notes:

* Standard error is based on the inverse Hessian.

† Standard error is based on bootstrapping.

D.3.5 Dam Passage During Night 95-kcfs Spill

Table D.21. Bonneville Dam Passage Detection and Survival Rates for Subyearling Chinook Salmon During Night 95-kcfs Spill

Survival Detail:

	CR234.0 to CR153.0	CR153.0 to CR113.0

	Estimate	s.e.†	Estimate	s.e.*
Summer - All Release Upstream	0.9306	0.015419	0.9650	0.011908

Capture Detail:

	CR153.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	s.e.*	Estimate	s.e.*	Estimate	s.e.*
Summer - All Release Upstream	0.9484	0.013934	0.9472	0.014264	0.9749	0.010119

Notes:

* Standard error is based on the inverse Hessian.

† Standard error is based on bootstrapping.

D.3.6 Dam Passage During the Day 85-kcfs Spill

Table D.22. Bonneville Dam Passage Detection and Survival Rates for Subyearling Chinook Salmon During Day 85-kcfs Spill

Survival Detail:

	CR234.0 to CR153.0		CR153.0 to CR113.0	
	Estimate	s.e.†	Estimate	s.e.*
Summer - All Release Upstream	0.8893	0.018919	0.9850	0.008543

Capture Detail:

	CR153.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	s.e.*	Estimate	s.e.*	Estimate	s.e.*
Summer - All Release Upstream	0.9465	0.014435	0.9609	0.012786	0.9444	0.014974

Notes:

* Standard error is based on the inverse Hessian.

† Standard error is based on bootstrapping.

D.3.7 Dam Passage During the Night during 120-kcfs Spill

Table D.23. Bonneville Dam Passage Detection and Survival Rates for Subyearling Chinook Salmon During Night 120-kcfs Spill

Survival Detail:

	CR234.0 to CR153.0		CR153.0 to CR113.0	
	Estimate	s.e.†	Estimate	s.e.*
Summer - All Release Upstream	0.8454	0.035749	0.9877	0.012269

Capture Detail:

	CR153.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	s.e.*	Estimate	s.e.*	Estimate	s.e.*
Summer - All Release Upstream	0.9302	0.027471	1.0000	0.000000	0.9767	0.016252

Notes:

* Standard error is based on the inverse Hessian.

† Standard error is based on bootstrapping.

D.3.8 Forebay and Dam Passage (V1 from TDA Tailrace and Hood River Releases)

Table D.24. Forebay Virtual Release Detection and Survival Rates for Subyearling Chinook Salmon

Survival Detail:

	CR236.0 to CR153.0		CR153.0 to CR113.0	
	Estimate	s.e.†	Estimate	s.e.*
Summer - TDA TR and Hood River	0.9555	0.005379	0.9882	0.003471

Capture Detail:

	CR153.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	s.e.*	Estimate	s.e.*	Estimate	s.e.*
Summer - TDA TR and Hood River	0.8660	0.008860	0.9505	0.005847	0.9270	0.006930

Notes:

* Standard error is based on the inverse Hessian.

† Standard error is based on bootstrapping.

D.3.9 B1 Sluiceway Passage

Table D.25. B1 Sluiceway Virtual Release Detection and Survival Rates for Subyearling Chinook Salmon

Survival Detail:

	CR234.0 to CR153.0		CR153.0 to CR113.0	
	Estimate	s.e.†	Estimate	s.e.*
Summer - All Upstream Releases	0.9424	0.017319	0.9808	0.012890

Capture Detail:

	CR153.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	s.e.*	Estimate	s.e.*	Estimate	s.e.*
Summer - All Upstream Releases	0.8500	0.026615	0.9329	0.019533	0.9053	0.022520

* Standard error is based on the inverse Hessian.

† Standard error is based on bootstrapping.

D.3.10 B1 Turbine Passage

Table D.26. B1 Turbine Virtual Release Detection and Survival Rates for Subyearling Chinook Salmon

Survival Detail:

	CR234.0 to CR153.0		CR153.0 to CR113.0	
	Estimate	s.e.†	Estimate	s.e.*
Summer - All Upstream Releases	0.9671	0.008108	0.9831	0.006876

Capture Detail:

	CR153.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	s.e.*	Estimate	s.e.*	Estimate	s.e.*
Summer - All Upstream Releases	0.7974	0.017329	0.9649	0.008368	0.8964	0.013355

* Standard error is based on the inverse Hessian.

† Standard error is based on bootstrapping.

D.3.11 Spillway Passage

Table D.27. Bonneville Spillway Virtual Release Detection and Survival Rates for Subyearling Chinook Salmon

Survival Detail:

	CR234.0 to CR153.0		CR153.0 to CR113.0	
	Estimate	s.e.†	Estimate	s.e.*
Summer - All Upstream Releases	0.9304	0.006196	0.9833	0.003817

Capture Detail:

	CR153.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	s.e.*	Estimate	s.e.*	Estimate	s.e.*
Summer - All Upstream Releases	0.8679	0.008391	0.9488	0.005687	0.9194	0.006912

* Standard error is based on the inverse Hessian.

† Standard error is based on bootstrapping.

D.3.12 Spillway Passage During the 24-h, 95-kcfs Spill Treatment

Table D.28. Bonneville Spillway Virtual Release Detection and Survival Rates for Subyearling Chinook Salmon During the 24-h, 95-kcfs Spill Treatment

Survival Detail:

	CR234.0 to CR153.0		CR153.0 to CR113.0	
	Estimate	s.e.†	Estimate	s.e.*
Summer - All Release Upstream	0.9241	0.012114	0.9615	0.009415

Capture Detail:

	CR153.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	s.e.*	Estimate	s.e.*	Estimate	s.e.*
Summer - All Upstream Releases	0.9344	0.011777	0.9628	0.009128	0.9718	0.008016

Notes:

* Standard error is based on the inverse Hessian.

† Standard error is based on bootstrapping.

D.3.13 Spillway Passage During the 85-kcfs Day/120-kcfs Night Spill Treatment

Table D.29. Bonneville Spillway Virtual Release Detection and Survival Rates for Subyearling Chinook Salmon During the 85-kcfs Day/120-kcfs Night Spill Treatment

Survival Detail:

	CR234.0 to CR153.0	CR153.0 to CR113.0

	Estimate	s.e.†	Estimate	s.e.*
Summer - All Upstream Releases	0.8774	0.016885	0.9855	0.007074

Capture Detail:

	CR153.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	s.e.*	Estimate	s.e.*	Estimate	s.e.*
Summer - All Upstream Releases	0.9422	0.012861	0.9713	0.009416	0.9531	0.011816

Notes:

* Standard error is based on the inverse Hessian.

† Standard error is based on bootstrapping.

D.3.14 Spillway Passage During Day 95-kcfs Spill

Table D.30. Bonneville Spillway Virtual Release Detection and Survival Rates for Subyearling Chinook Salmon During Day 95-kcfs Spill

Survival Detail:

	CR234.0 to CR153.0		CR153.0 to CR113.0	
	Estimate	s.e.†	Estimate	s.e.*
Summer - All Upstream Releases	0.9217	0.014076	0.9580	0.011210

Capture Detail:

	CR153.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	s.e.*	Estimate	s.e.*	Estimate	s.e.*
Summer - All Upstream Releases	0.9288	0.014010	0.9666	0.009911	0.9755	0.008569

Notes:

* Standard error is based on the inverse Hessian.

† Standard error is based on bootstrapping.

D.3.15 Spillway Passage During Night 95-kcfs Spill

Table D.31. Bonneville Spillway Virtual Release Detection and Survival Rates for Subyearling Chinook Salmon Passing During Night 95-kcfs Spill

Survival Detail:

	CR234.0 to CR153.0		CR153.0 to CR113.0	
	Estimate	s.e.†	Estimate	s.e.*
Summer - All Upstream Releases	0.9323	0.023606	0.9728	0.016653

Capture Detail:

	CR153.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	s.e.*	Estimate	s.e.*	Estimate	s.e.*
Summer - All Upstream Releases	0.9524	0.020783	0.9505	0.021584	0.9600	0.019596

Notes:

* Standard error is based on the inverse Hessian.

† Standard error is based on bootstrapping.

D.3.16 Spillway Passage During the Day 85-kcfs Spill

Table D.32. Bonneville Spillway Virtual Release Detection and Survival Rates for Subyearling Chinook Salmon Passing the spillway During Day 85-kcfs Spill

Survival Detail:

	CR234.0 to CR153.0		CR153.0 to CR113.0	
	Estimate	s.e.†	Estimate	s.e.*
Summer - All Upstream Releases	0.8893	0.018919	0.9850	0.008543

Capture Detail:

	CR153.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	s.e.*	Estimate	s.e.*	Estimate	s.e.*
Summer - All Upstream Releases	0.9465	0.014435	0.9609	0.012786	0.9444	0.014974

Notes:

* Standard error is based on the inverse Hessian.

† Standard error is based on bootstrapping.

D.3.17 Spillway Passage During Night 120-kcfs Spill

Table D.33. Bonneville Spillway Virtual Release Detection and Survival Rates for Subyearling Chinook Salmon Passing the spillway During Night 120-kcfs Spill

Survival Detail:

	CR234.0 to CR153.0		CR153.0 to CR113.0	
	Estimate	s.e.†	Estimate	s.e.*
Summer - All Upstream Releases	0.8454	0.035749	0.9877	0.012269

Capture Detail:

	CR153.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	s.e.*	Estimate	s.e.*	Estimate	s.e.*
Summer - All Upstream Releases	0.9302	0.027471	1.0000	0.000000	0.9767	0.016252

Notes:

* Standard error is based on the inverse Hessian.

† Standard error is based on bootstrapping.

D.3.18 B2CC Passage

Table D.34. B2CC Passage Detection and Survival Rates for Subyearling Chinook Salmon

Survival Detail:

	CR234.0 to CR153.0		CR153.0 to CR113.0	
	Estimate	s.e.†	Estimate	s.e.*
Summer - All Upstream Releases	0.9704	0.010104	0.9755	0.009666

Capture Detail:

	CR153.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	s.e.*	Estimate	s.e.*	Estimate	s.e.*
Summer - All Upstream Releases	0.8980	0.017654	0.9579	0.011896	0.9681	0.010467

* Standard error is based on the inverse Hessian.

† Standard error is based on bootstrapping.

D.3.19 B2 JBS Passage

Table D.35. B2 JBS Passage Detection and Survival Rates for Subyearling Chinook Salmon

Survival Detail:

	CR234.0 to CR153.0		CR153.0 to CR113.0	
	Estimate	s.e.†	Estimate	s.e.*
Summer - All Upstream Releases	0.9759	0.015447	0.9894	0.015611

Capture Detail:

	CR153.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	s.e.*	Estimate	s.e.*	Estimate	s.e.*
Summer - All Upstream Releases	0.8692	0.032601	0.9063	0.029749	0.8878	0.031887

* Standard error is based on the inverse Hessian.

† Standard error is based on bootstrapping.

D.3.20 B2 Turbine Passage

Table D.36. B2 Turbine Passage Detection and Survival Rates for Subyearling Chinook Salmon

Survival Detail:

	CR234.0 to CR153.0		CR153.0 to CR113.0	
	Estimate	s.e.†	Estimate	s.e.*
Summer - All Upstream Releases	0.9363	0.011736	0.9983	0.002835

Capture Detail:

	CR153.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	s.e.*	Estimate	s.e.*	Estimate	s.e.*
Summer - All Upstream Releases	0.8725	0.016510	0.9719	0.008341	0.9597	0.009870

* Standard error is based on the inverse Hessian.

† Standard error is based on bootstrapping.

Appendix E

Assessment of Survival Model Assumptions

Appendix E - Assessment of Survival Model Assumptions

The assessment of assumptions covers fish size distribution, handling mortality and tag shedding, tag-life corrections, arrival distributions, and tagger effects. Downstream mixing was not an issue with the Bonneville Dam (BON) study in 2010 because there were no downstream releases of fish. Our use of B2CC-passage survival estimates as a reference release was assured to have downstream mixing because dam-passed and B2CC-passed fish arrived at all hours of the day from the two most upstream release locations.

E.1 Fish Size Distribution

Comparison of acoustic-tagged fish with run-of-river (ROR) fish sampled at John Day Dam (JDA) through the Smolt Monitoring Program shows that the length frequency distributions were generally well matched for yearling Chinook salmon (CH1) and juvenile steelhead (STH) (Figure E.1). For STH, the upper size limit for the tagged fish was 260 mm, and none of the very large fish (>260 mm) were tagged. Median length for acoustic-tagged CH1 was 153 mm. For STH smolts, the median length of the tagged fish was 214 mm. The median length of tagged CH1 and STH remained stable throughout the study (Skalski et al. 2010a).

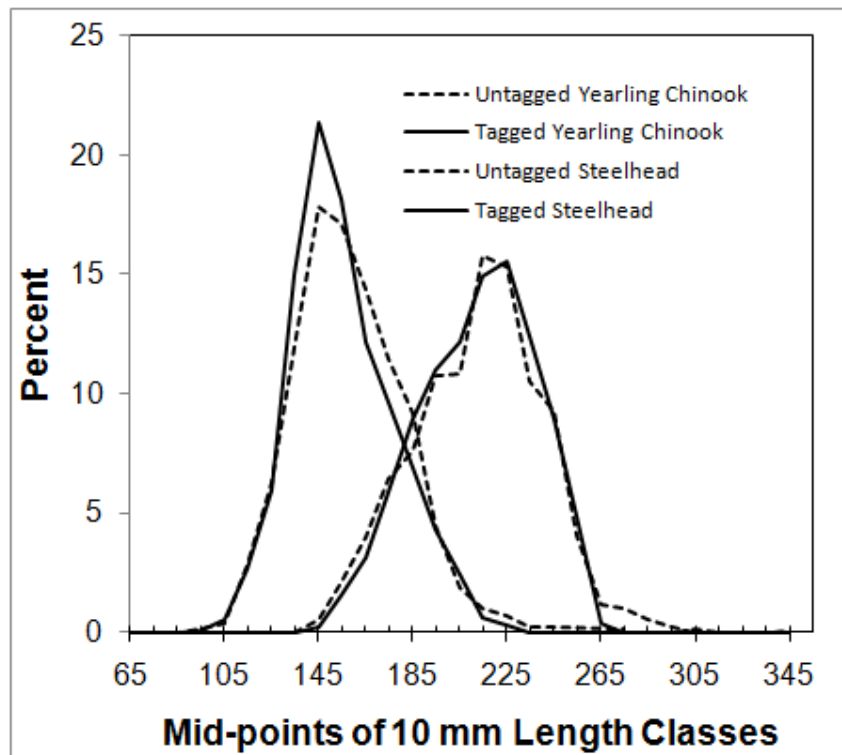


Figure E.1. Comparison of Length Frequency Distributions of Tagged and Untagged Fish Passing the John Day Dam Smolt Monitoring Facility

Comparison of acoustic-tagged fish with ROR fish sampled at JDA through the Smolt Monitoring Program shows that the length frequency distributions were generally well-matched for subyearling Chinook salmon (CH0) (Figure E.2). The tagged fish had less representation in the 95- to 100-mm and

105- to 110-mm categories than the ROR fish because no fish <95 mm were tagged. The length distributions for the three CH0 releases were quite similar, and the median length of tagged fish across the course of the study remained stable (Skalski et al. 2010b).

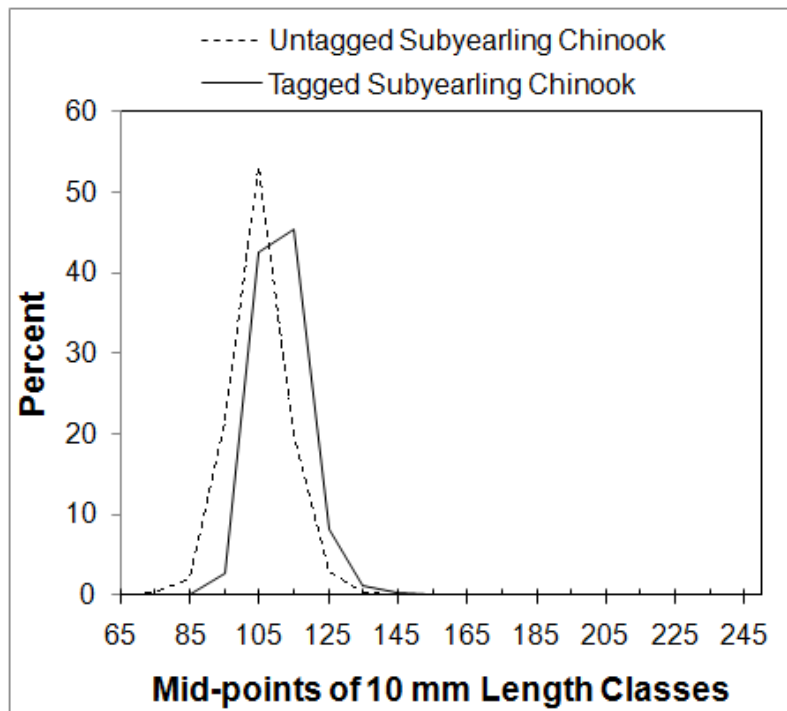


Figure E.2. Relative Length Frequency Distributions of Tagged and Untagged Subyearling Chinook in John Day Smolt Monitoring Facility Samples in Summer 2010

E.2 Handling Mortality and Tag Shedding

Fish were held for 24 h prior to release. The 24-h tagging mortality was 0.10% for CH1, 0.05% for juvenile STH, and 0.22% for CH0. No tags were shed during the 24-h holding period in either season.

E.3 Tag-Life Corrections

For the spring 2010 study, mean tag life ($n = 49$) was 32.73 days. The earliest tag failure was at 7.8 days and the longest at 39.6 days (Figure E.3). The failure-time data for the acoustic tags was fit to a four-parameter vitality model of Li and Anderson (2009). The maximum likelihood estimates for the four model parameters were $\hat{r} = 0.02963$, $\hat{s} = -5.59145 \times 10^{-9}$, $\hat{k} = 0.00173$, and $\hat{u} = 0.05730$. This tag-life survivorship model was subsequently used to estimate the probabilities of tag failure and provide tag-life-adjusted estimates of smolt survival.

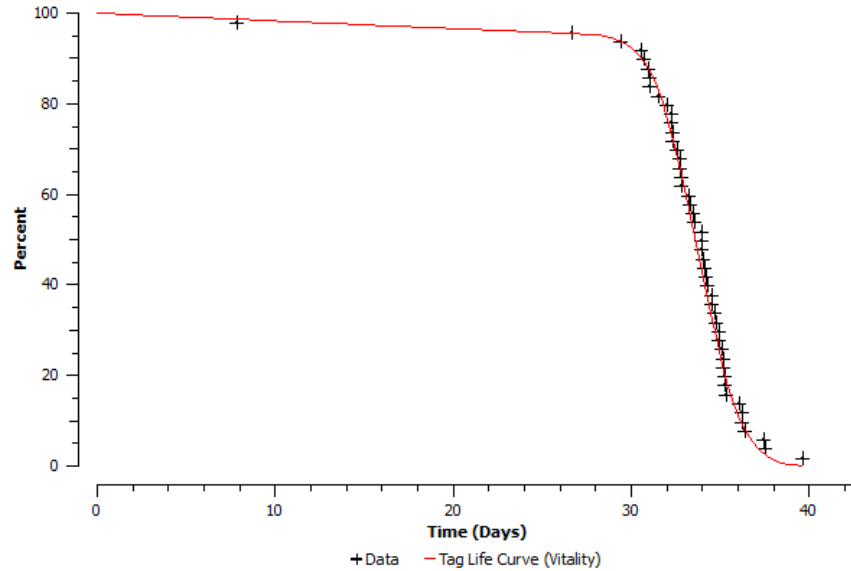


Figure E.3. Individual Failure Times for the $n = 49$ Acoustic Tags Used in the Tag-Life Study, Along with the Fitted Four-Parameter Vitality Model of Li and Anderson (2009) for Spring 2010

For the summer study, mean tag life ($n = 50$) was 35.54 days. The earliest tag failure was at 31.27 days and the longest at 40.13 days (Figure E.4). The failure-time data for the acoustic tags was fit to a four-parameter vitality model of Li and Anderson (2009). The maximum likelihood estimates for the four model parameters were $\hat{r} = 0.028261$, $\hat{s} = -2.91111 \times 10^{-9}$, $\hat{k} = 0$, and $\hat{u} = 0.058789$ (Figure C.6). This tag-life survivorship model was subsequently used to estimate the probabilities of tag failure and provide tag-life-adjusted estimates of smolt survival.

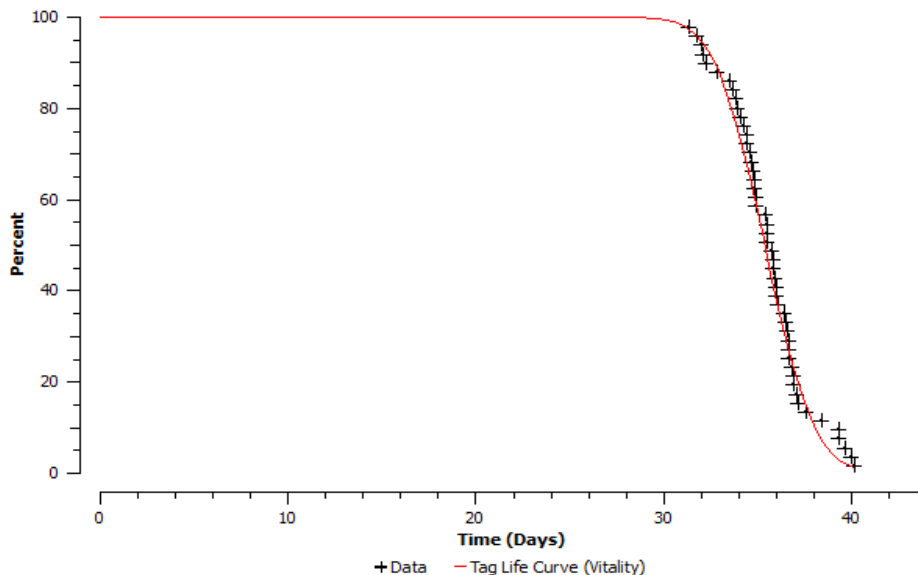


Figure E.4. Individual Failure Times for the $n = 49$ Acoustic Tags Used in the Tag-Life Study, Along with the Fitted Four-Parameter Vitality Model of Li and Anderson (2009) for Summer 2010

E.4 Arrival Distributions at Downstream Arrays

The estimated probability an acoustic tag was active when fish arrived at a downstream detection array depends on the tag-life curve and the distribution of observed travel times. These probabilities were calculated by integrating the tag survivorship curves (Figures E.3 and E.4) over the observed distribution of fish arrival times (i.e., time from tag activation to arrival) for the three tagged fish stocks separately. The estimated probabilities of tag activation for the various release groups at the different detection arrays always exceeded 0.98. The tag-life-adjusted survival estimates were based on the estimated probabilities of tag activation reported in Table E.1, E.2, and E.3 for the respective runs of fish studied.

The last distinct detection array used in the survival analysis was rkm 86.2 (Figure 2.12). Plots of the arrival distributions of the three release groups (i.e., V_1 , R_2 , and R_3) to that array indicate the CH1 (Figure E.5), STH (E.6), and CH0 (Figure E.7) should have arrived well before tag failure became problematic. Tag-life adjustments to survival estimates would be incomplete if fish have arrival times beyond the range of observed tag lives.

Table E.1. Estimated Probabilities (L) of an Acoustic Tag Being Active When a Yearling Chinook Salmon Arrived at a Detection Array Used in Estimating Dam-Passage Survival at Bonneville Dam in 2010. For the V_1 release, the L values are the conditional probability a tag is active, given it was active at the time the group was formed at the detection array at rkm 234. (Standard errors are in parentheses.)

Release			Detection Sites			
Group	Site	Bin	D0: CR234.0	D1: CR153.0	D2: CR113.0	D3: CR086.2
V1	Yearling Chinook - All Upstr	1	0.9878 (0.006508)	0.9981 (0.001025)	0.9972 (0.001486)	0.9967 (0.001800)

Table E.2. Estimated Probabilities (L) of an Acoustic Tag Being Active When a Steelhead Arrived at a Detection Array Used in Estimating Dam-Passage Survival at Bonneville Dam in 2010. For the V_1 release, the L values are the conditional probability a tag is active, given it was active at the time the group was formed at the detection array at rkm 234. (Standard errors are in parentheses.)

Release			Detection Sites			
Group	Site	Bin	D0: CR234.0	D1: CR153.0	D2: CR113.0	D3: CR086.2
V1	Steelhead - All Upstream Sit	1	0.9872 (0.007080)	0.9981 (0.001089)	0.9972 (0.001577)	0.9967 (0.001861)

Table E.3. Estimated Probabilities (L) of an Acoustic Tag Being Active When a Subyearling Chinook Salmon Arrived at a Detection Array Used in Estimating Dam-Passage Survival at Bonneville Dam in 2010. For the V_1 release, the L values are the conditional probability a tag is active, given it was active at the time the group was formed at the detection array at rkm 234. (Standard errors are in parentheses.)

Release			Detection Sites			
Group	Site	Bin	D0: CR234.0	D1: CR153.0	D2: CR113.0	D3: CR086.2
V1	Summer - All Release Upstrea	1	1.0000 (0.002390)	1.0000 (0.000690)	1.0000 (0.000993)	1.0000 (0.001207)

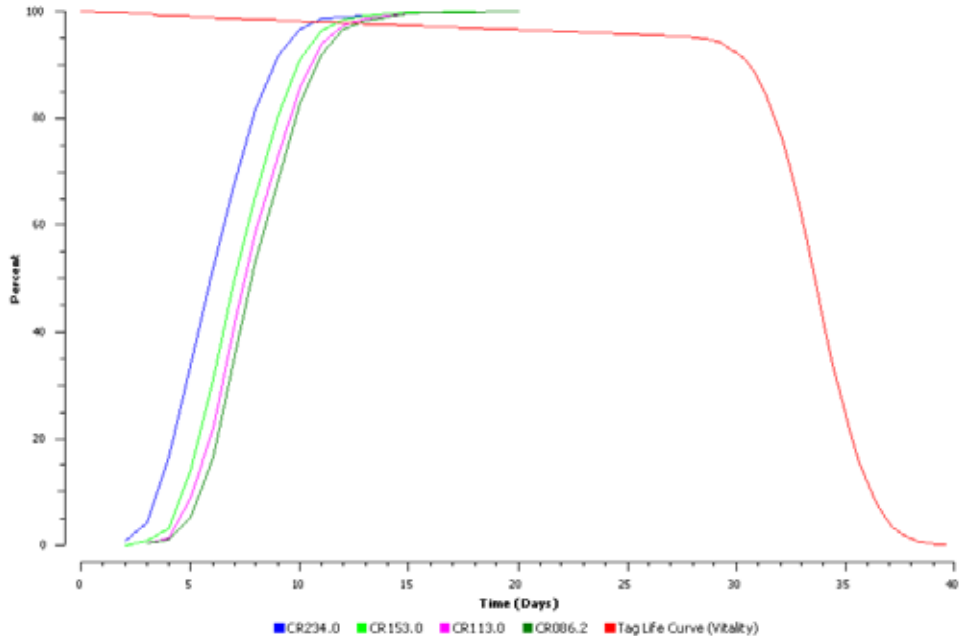


Figure E.5. Fish Passage Plots (expressed as percentages) of Downstream Arrival Timing for All Yearling Chinook Salmon Release V_1 at Detection Arrays Located at Rkm 234, Rkm 153, Rkm 113, and Rkm 86.2 Versus Tag-Life Curve. All times adjusted relative to the release time of V_1 . The distributions averaged over all release groups.

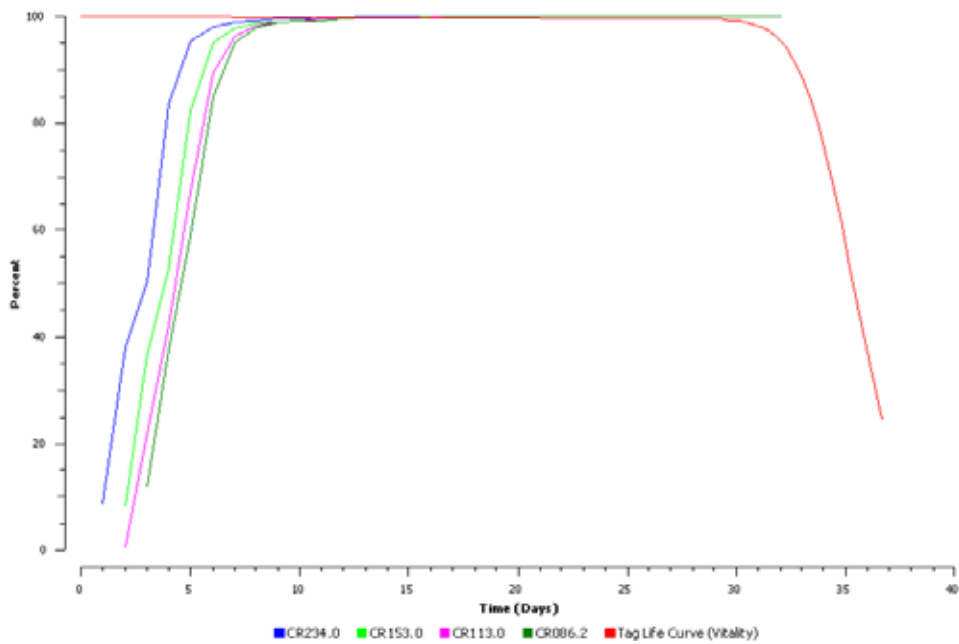


Figure E.6. Fish Passage Plots (expressed as percentages) of Downstream Arriving Timing for All Steelhead Release, V_1 at Detection Arrays Located at Rkm 234, Rkm 153, Rkm 113, and Rkm 86.2 Versus Tag-Life Curve. All times adjusted relative to the release time of V_1 . The distributions averaged over all release groups.

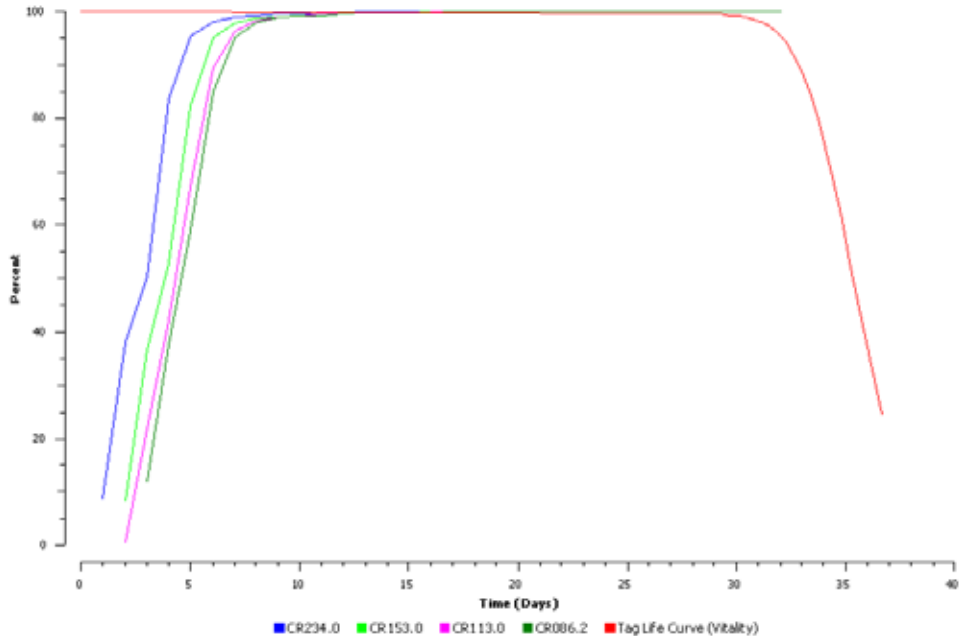


Figure E.7. Fish Passage Plots (expressed as percentages) of Downstream Arriving Timing for All Subyearling Chinook Salmon Release V_1 at Detection Arrays Located at Rkm 234, Rkm 153, Rkm 113, and Rkm 86.2 Versus Tag-Life Curve. All times adjusted relative to the release time of V_1 . The distributions averaged over all release groups.

E.5 Tagger Effects

Having various fish handlers tag the same proportions of fish for release at each of the release sites helped minimize but did not necessarily eliminate handling effects in the survival study. The study was therefore designed to balance tagger effort across locations. Implementation produced near-perfect balance for the CH1 (Table E.3), STH (Table E.4), and CH0 (Table E.5) releases.

To further assess whether tagger effects may have occurred, reach survivals for the fish tagged by the different staff were calculated using the Cormack-Jolly-Seber single release-recapture model. For both CH1 (Table E.6) and STH (Table E.7), reach survivals were found to be homogeneous ($P > 0.05$) across all reaches examined. For this reason, all fish, regardless of fish tagger, were included in the survival analyses for CH1 and STH.

For CH0, significant ($P < 0.05$) heterogeneity was detected (Table E.8). However, further examination indicated that seasonal trends in survival were confounding attempts to assess the presence of tagger effects using the F -tests because the effect of the various taggers was not evenly distributed across the course of the study. Fish tagged by tagger G had lower survivals because that staff member only tagged fish towards the end of the season. Fish tagged by tagger B had very good survival because that staff member only tagged fish at the beginning of the study. The remaining taggers had fish with intermediate survivals because they tagged fish more or less across the breadth of the season. The fish tagged by different staff during the same time were examined; survivals were homogeneous with no obvious evidence of any tagger effect. Therefore, fish tagged by all taggers were included in the analysis for this report.

Table E.4. Number of Yearling Chinook Salmon Tagged at Each Release Site by Tagger. Tagger effort was homogeneous ($P(\chi^2_{10} \geq 1.0336) = 0.9998$)

Release Location	Tagger						Total
	#1	#2	#3	#4	#5	#6	
R_1	441	356	311	350	372	457	2287
R_2	149	123	110	129	124	161	796
R_3	152	126	109	117	130	163	797
Total Tags	742	605	530	596	626	781	3880

Table E.5. Number of Steelhead Tagged at Each Release Site by Tagger. Tagger effort was homogeneous ($P(\chi^2_{10} \geq 0.5851) = 1.0000$)

Release Location	Tagger						Total
	#1	#2	#3	#4	#5	#6	
R_1	430	359	331	354	365	449	2288
R_2	155	124	114	126	125	155	799
R_3	157	121	112	126	126	156	798
Total Tags	742	604	557	606	616	760	3885

Table E.6. Number of Subyearling Chinook Salmon Tagged at Each Release Site by Tagger. Tagger effort was homogeneous ($P(\chi^2_{12} \geq 8.6496) = 0.7325$).

Release Location	Tagger							Total
	A	B	C	D	E	F	G	
R_1	436	489	463	454	171	369	467	2,849
R_2	132	135	116	123	40	108	146	800
R_3	131	133	128	119	35	115	139	800
Total Tags	699	757	707	696	246	592	752	4,449

Table E.7. Cormack-Jolly-Seber Estimates of Reach Survivals by Release Site and Tagger for Yearling Chinook Salmon Smolts. Standard errors in parentheses. *F*-tests below each release and reach test for homogeneity of survival across taggers. No tests were significant ($\alpha < 0.05$).

		Cormack-Jolly-Seber Survival					
Release Site	Tagger	Release to Rkm 309	Rkm 309 to 275	Rkm 275 to 234	Rkm 234 to 153	Rkm 153 to 113	Rkm 113 to 86
Roosevelt Chinook	#1	0.8912 (0.0148)	0.9364 (0.0123)	0.9790 (0.0076)	0.9165 (0.0147)	0.9975 (0.0034)	1.0000 (<0.0001)
	#2	0.8934 (0.0164)	0.9527 (0.0119)	0.9910 (0.0057)	0.9512 (0.0134)	0.9790 (0.0102)	1.0000 (<0.0001)
	#3	0.8489 (0.0203)	0.9318 (0.0155)	0.9797 (0.0090)	0.9554 (0.0135)	0.9953 (0.0054)	1.0000 (<0.0001)
	#4	0.8943 (0.0164)	0.9457 (0.0128)	0.9767 (0.0088)	0.9383 (0.0148)	0.9789 (0.0102)	0.9917 (0.0141)
	#5	0.9140 (0.0145)	0.9382 (0.0131)	0.9906 (0.0053)	0.9215 (0.0152)	0.9985 (0.0048)	0.9899 (0.0131)
	#6	0.9059 (0.0137)	0.9348 (0.0121)	0.9798 (0.0072)	0.9282 (0.0136)	0.9880 (0.0070)	1.0000 (0.0165)
	<i>F</i> -test	1.9448	0.3597	0.7243	1.2466	1.5091	0.2137
	<i>P</i> -value	0.0828	0.8763	0.6051	0.2840	0.1832	0.9569
		Release to Rkm 275	Rkm 275 to 234	Rkm 234 to 153	Rkm 153 to 113	Rkm 113 to 86	
The Dalles Dam Chinook	#1		0.9731 (0.0132)	0.9798 (0.0118)	0.9295 (0.0216)	1.0000 (0.0073)	1.0000 (<0.0001)
	#2		0.9756 (0.0139)	0.9750 (0.0142)	0.9403 (0.0219)	1.0000 (<0.0001)	1.0000 (0.0260)
	#3		0.9909 (0.0089)	0.9821 (0.0128)	0.9534 (0.0206)	1.0000 (<0.0001)	0.9986 (0.0403)
	#4		0.9690 (0.0152)	0.9760 (0.0137)	0.9275 (0.0237)	0.9916 (0.0101)	0.9933 (0.0230)
	#5		0.9919 (0.0079)	0.9756 (0.0139)	0.9419 (0.0214)	1.0000 (0.0145)	0.9795 (0.0180)
	#6		0.9813 (0.0106)	0.9943 (0.0062)	0.9568 (0.0168)	0.9925 (0.0086)	1.0000 (<0.0001)
	<i>F</i> -test		0.6328	0.3480	0.3221	0.2312	0.1259
	<i>P</i> -value		0.6747	0.8838	0.9000	0.9490	0.9866
		Release to Rkm 234	Rkm 234 to 153	Rkm 153 to 113	Rkm 113 to 86		
Hood River Chinook	#1		0.9737 (0.0130)	0.9599 (0.0162)	1.0000 (0.0083)	1.0000 (<0.0001)	
	#2		0.9921 (0.0078)	0.9710 (0.0159)	0.9821 (0.0138)	1.0000 (<0.0001)	
	#3		0.9816 (0.0128)	0.9445 (0.0223)	1.0000 (<0.0001)	1.0000 (<0.0001)	
	#4		0.9829 (0.0119)	0.9485 (0.0207)	1.0000 (<0.0001)	0.9841 (0.0356)	
	#5		0.9923 (0.0076)	0.9473 (0.0200)	0.9928 (0.0098)	1.0000 (0.0305)	
	#6		0.9945 (0.0060)	0.9510 (0.0172)	1.0000 (<0.0001)	0.9440 (0.0242)	
	<i>F</i> -test		0.1386	0.2795	0.9024	0.6280	
	<i>P</i> -value		0.9834	0.9246	0.4783	0.6784	

Table E.8. Cormack-Jolly-Seber Estimates of Reach Survivals by Release Site and Tagger for Steelhead Smolts. Standard errors in parentheses. *F*-tests below each release and reach test for homogeneity of survival across taggers. No tests were significant ($\alpha < 0.05$).

		Cormack-Jolly-Seber Survivals					
Release Site	Tagger	Release to Rkm 309	Rkm 309 to 275	Rkm 275 to 234	Rkm 234 to 153	Rkm 153 to 113	Rkm 113 to 86
Roosevelt Steelhead	#1	0.8930 (0.0149)	0.9505 (0.0111)	0.9699 (0.0089)	0.9107 (0.0153)	0.9978 (0.0041)	1.0000 (<0.0001)
	#2	0.8831 (0.0170)	0.9621 (0.0107)	0.9671 (0.0102)	0.9131 (0.0166)	1.0000 (0.0083)	0.9869 (0.0225)
	#3	0.9063 (0.0160)	0.9600 (0.0113)	0.9831 (0.0077)	0.8978 (0.0186)	0.9824 (0.0102)	1.0000 (<0.0001)
	#4	0.8729 (0.0177)	0.9320 (0.0143)	0.9725 (0.0097)	0.9479 (0.0149)	0.9683 (0.0134)	0.9934 (0.0254)
	#5	0.9151 (0.0146)	0.9372 (0.0133)	0.9776 (0.0084)	0.9069 (0.0172)	0.9805 (0.0105)	0.9737 (0.0208)
	#6	0.9065 (0.0137)	0.9656 (0.0090)	0.9804 (0.0072)	0.9118 (0.0149)	0.9892 (0.0076)	0.9895 (0.0239)
	<i>F</i> -test	1.0452	1.4044	0.5128	1.1099	1.5660	0.2701
	<i>P</i> -value	0.3890	0.2192	0.7668	0.3525	0.1659	0.9297
			Release to Rkm 275	Rkm 275 to 234	Rkm 234 to 153	Rkm 153 to 113	Rkm 113 to 86
The Dalles dam Steelhead	#1		0.9806 (0.0110)	0.9803 (0.0113)	0.9333 (0.0205)	1.0000 (<0.0001)	0.9967 (0.0345)
	#2		0.9758 (0.0138)	0.9752 (0.0141)	0.9527 (0.0205)	0.9805 (0.0151)	0.9944 (0.0206)
	#3		0.9912 (0.0087)	0.9734 (0.0151)	0.9478 (0.0218)	0.9902 (0.0120)	1.0000 (<0.0001)
	#4		0.9920 (0.0078)	0.9840 (0.0112)	0.9843 (0.0114)	1.0000 (0.0075)	1.0000 (<0.0001)
	#5		0.9920 (0.0078)	0.9919 (0.0079)	0.9504 (0.0215)	0.9673 (0.0189)	0.9905 (0.0096)
	#6		0.9742 (0.0127)	1.0000 (<0.0001)	0.9781 (0.0135)	0.9855 (0.0129)	0.9594 (0.0224)
	<i>F</i> -test		0.6342	0.8435	1.0881	0.9839	0.6524
	<i>P</i> -value		0.6736	0.5185	0.3646	0.4258	0.6597
				Release to Rkm 234	Rkm 234 to 153	Rkm 153 to 113	Rkm 113 to 86
Hood River Steelhead	#1			0.9745 (0.0126)	0.9416 (0.0190)	1.0000 (<0.0001)	1.0000 (<0.0001)
	#2			0.9669 (0.0162)	0.9600 (0.0190)	0.9891 (0.0117)	1.0000 (<0.0001)
	#3			0.9732 (0.0152)	0.9565 (0.0202)	0.9900 (0.0120)	1.0000 (<0.0001)
	#4			0.9687 (0.0156)	0.9429 (0.0212)	1.0000 (<0.0001)	0.9875 (0.0238)
	#5			0.9920 (0.0078)	0.9785 (0.0140)	0.9945 (0.0110)	1.0000 (<0.0001)
	#6			0.9430 (0.0187)	0.9151 (0.0239)	0.9846 (0.0138)	0.9620 (0.0314)
	<i>F</i> -test			1.1524	1.1703	0.3951	0.9084
	<i>P</i> -value			0.3303	0.3211	0.8525	0.4743

Table E.9. Cormack-Jolly-Seber Estimates of Reach Survivals by Release Site and Tagger for Subyearling Chinook Salmon. *F*-tests below each release and reach test for homogeneity of survival across taggers. No tests were significant ($\alpha < 0.05$).

Release Site		Cormack-Jolly-Seber Survival											
		Release to Rkm 309		Rkm 309 to 275		Rkm 275 to 234		Rkm 234 to 153		Rkm 153 to 113		Rkm 113 to 86	
		Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
R_1	A	0.8395 (5)	0.0177	0.9141 (4)	0.0147	0.9671 (5)	0.0104	0.9426 (4)	0.0138	0.9810 (4)	0.0086	0.9912 (4)	0.0061
	B	0.8938 (2)	0.0141	0.9394 (3)	0.0115	1.0000 (2)	0.0044	0.9592 (2)	0.0102	0.9909 (2)	0.0052	0.9980 (3)	0.0023
	C	0.8522 (4)	0.0165	0.9465 (2)	0.0114	1.0000 (2)	0.0000	0.9195 (5)	0.0142	0.9965 (1)	0.0034	0.9989 (2)	0.0045
	D	0.8027 (6)	0.0187	0.9033 (5)	0.0155	0.9520 (6)	0.0124	0.9126 (6)	0.0168	0.9732 (5)	0.0106	0.9746 (6)	0.0101
	E	0.9357 (1)	0.0188	0.9562 (1)	0.0162	1.0000 (2)	0.0000	0.9782 (1)	0.0133	0.9822 (3)	0.0125	1.0000 (1)	0.0096
	F	0.8910 (3)	0.0163	0.9016 (6)	0.0165	0.9879 (4)	0.0068	0.9500 (3)	0.0135	0.9722 (6)	0.0107	0.9787 (5)	0.0094
	G	0.7795 (7)	0.0194	0.8908 (7)	0.0165	0.9515 (7)	0.0138	0.8806 (7)	0.0198	0.9692 (7)	0.0111	0.9648 (7)	0.0117
All Taggers	<i>F</i> -test	9.8531		2.9625		6.8130		4.9085		1.1627		2.8155	
	<i>P</i> -value	<0.0001		0.0068		<0.0001		<0.0001		0.3229		0.0097	
Tagger G Omitted	<i>F</i> -test	7.5949		2.6425		7.6624		3.1904		1.1168		2.1171	
	<i>P</i> -value	<0.0001		0.0215		<0.0001		0.0070		0.3487		0.0603	
Release Site		Cormack-Jolly-Seber Survival											
		Release 309 to 275		Rkm 275 to 234		Rkm 234 to 153		Rkm 153 to 113		Rkm 113 to 86			
		Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE		
R_2	A	0.9924 (3)	0.0074	0.9807 (5)	0.0132	0.9511 (5)	0.0201	0.9925 (4.5)	0.0098	0.9761 (4)	0.0155		
	B	0.9704 (7)	0.0146	0.9874 (2)	0.0108	0.9619 (4)	0.0183	0.9814 (6)	0.0136	0.9842 (3)	0.0121		
	C	0.9914 (5)	0.0085	0.9806 (6)	0.0153	0.9421 (6)	0.0239	0.9925 (4.5)	0.0118	0.9511 (7)	0.0226		
	D	0.9918 (4)	0.0080	0.9867 (3)	0.0116	0.9637 (3)	0.0178	1.0000 (2)	0.0175	0.9671 (5)	0.0170		
	E	1.0000 (1.5)	0.0071	1.0000 (1)	0.0071	0.9750 (2)	0.0247	1.0000 (2)	0.0084	1.0000 (1.5)	0.0072		
	F	1.0000 (1.5)	0.0000	0.9819 (4)	0.0129	0.9902 (1)	0.0097	1.0000 (2)	0.0000	1.0000 (1.5)	0.0000		
	G	0.9795 (6)	0.0117	0.9785 (7)	0.0142	0.9226 (7)	0.0237	0.9777 (7)	0.0137	0.9592 (6)	0.0181		
All Taggers	<i>F</i> -test	1.3856		0.3499		1.1805		0.6034		1.6362			
	<i>P</i> -value	0.2159		0.9103		0.3130		0.7279		0.1326			
Tagger G Omitted	<i>F</i> -test	1.5552		0.3728		0.7505		0.4070		1.7774			
	<i>P</i> -value	0.1691		0.8676		0.5856		0.8443		0.1138			

E.6 References

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