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Contract DE-AC05-76RL01830

Survival and Passage of Juvenile Chinook Salmon and Steelhead Passing Through Bonneville Dam, 2011

FINAL REPORT

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June 2013

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Pacific Northwest National Laboratory
Richland, Washington 99352

[1] Pacific State Marine Fisheries Commission, Portland, Oregon.
[2] Columbia Basin Research, University of Washington, Seattle, Washington.

Abstract

Pacific Northwest National Laboratory (PNNL) and subcontractors conducted an acoustic-telemetry study of juvenile salmonid fish passage and survival at Bonneville Dam in 2011. 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 virtual/paired-release model. 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 using a virtual-release, paired-reference release survival model. 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 (CENWP) contracted with the Pacific Northwest National Laboratory (PNNL), in Richland, Washington, to conduct an acoustic-telemetry survival study at the Bonneville Dam in 2011. 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 report presents detailed results of the fish passage and survival of tagged yearling Chinook salmon smolts and juvenile steelhead passing Bonneville Dam during spring 2011.

This report should be cited as follows:

Ploskey GR, GW Batten III, AW Cushing J Kim, GE Johnson, JR Skalski, RL Townsend, AG Seaburg, TJ Carlson, SM Carpenter, Z Deng, DJ Etherington, ES Fischer, T Fu, MJ Greiner, MJ Hennen, JS Hughes, JJ Martinez, TD Mitchell, B Rayamajhi, MA Weiland, CM Woodley, and SA Zimmerman. 2013. *Survival and Passage of Juvenile Chinook Salmon and Steelhead Passing Through Bonneville Dam, 2010*. PNNL-22178, Final Report, Pacific Northwest National Laboratory, Richland, Washington.

Executive Summary

Researchers at Pacific Northwest National Laboratory collaborated with others from the Pacific States Marine Fisheries Commission, U.S. Army Corps of Engineers Portland District, and the University of Washington to conduct a 2011 study primarily to estimate dam passage survival for yearling Chinook salmon and juvenile steelhead. The study estimated additional passage performance measures, many stipulated in the 2008 Columbia Basin Fish Accords (forebay-to-tailrace survival, fish passage efficiency (FPE), spill passage efficiency (SPE), spill+Bonneville Powerhouse 2 Corner Collector (B2CC) passage efficiency, forebay residence time, and tailrace egress time) and route-specific passage proportions and survival rates. A summer study for subyearling Chinook salmon was cancelled because of very high river discharge.

The 2011 study was an official compliance test as described by the 2008 Federal Columbia River Power System Biological Opinion. 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 or 2011. The behavioral guidance device in the B2 forebay, which had been tested for 3 years, was removed for 2011 because measured benefits in improving B2 FPE and survival were minimal. Unit 11, which is adjacent to the B2CC was out of service throughout 2011, as it was in 2010.

Subyearling and yearling Chinook salmon smolts and juvenile steelhead tagged with acoustic micro-transmitters (acoustic-tagged) and released in the Columbia River upstream of John Day Dam (near Arlington, Oregon), in The Dalles Dam 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. Virtual/paired-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 tagged fish at three sites upstream of Bonneville Dam totaled 7,692 yearling Chinook salmon and 7,766 juvenile steelhead. These tagged fish were released to support passage survival studies at John Day Dam, The Dalles Dam, and Bonneville Dam in 2011. 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 2011 results, including route-specific passage survival estimates.

The study results are summarized in the following tables.

Table ES.1. Estimates of virtual/paired-release, tag-life-corrected estimates of dam passage survival at Bonneville Dam in 2011. Standard errors are presented in parentheses.

Period of Performance	Yearling Chinook Salmon	Steelhead
Early season (April 30–May 13)	0.9569 (0.0042)[(b)]	0.9755 (0.0180)
Season-wide (April 30–May 31)	0.9597 (0.0176)	0.9647 (0.0212)

(a) Dam passage survival is defined as survival from the upstream face of the dam to a standardized reference point in the tailrace.
(b) Used V_1 in a single-release model.

Table ES.2. Fish Accords performance measures at Bonneville Dam in 2011. Standard errors are presented in parentheses.

Performance Measures	Yearling Chinook Salmon	Juvenile Steelhead
Forebay-to-tailrace survival[a]		
Early season (April 30–May 13)	0.9579 (0.0042)	0.9752 (0.0180)
Season-wide (April 30–May 31)	0.9528 (0.0175)	0.9589 (0.0211)
Median and Mean Forebay residence time, h	0.55; 5.34 (0.46)	0.85; 7.00 (0.43)
Median and Mean Tailrace egress time, h	0.38; 1.89 (0.19)	0.39; 3.77 (0.32)
Spill passage efficiency [b]	0.5810 (0.0066)	0.5600 (0.0066)
Spill+B2CC passage efficiency	0.6100 (0.0065)	0.6530 (0.0063)
Fish passage efficiency	0.7170 (0.0060)	0.7490 (0.0057)

(a) The forebay-to-tailrace survival estimate satisfies the "BRZ-to-BRZ" (boat-restricted zone) survival estimate called for in the Fish Accords.

(b) Spill passage efficiency presented here is the proportion of fish passing the dam at the spillway out of total project passage. However, by definition in the 2008 Fish Accords, spill passage efficiency includes passage through the spillway and B2CC at Bonneville Dam, so this combined metric also is presented in the next row.

Table ES.3. Survival study summary.

<table>
<tr><td colspan="4">Year: 2011</td></tr>
<tr><td colspan="4">Study Site(s): Bonneville Dam</td></tr>
<tr><td colspan="4">Objective(s) of study: Estimate dam passage survival for yearling Chinook salmon and steelhead and associated Fish Accords performance measures using a virtual-paired-reference release survival model.</td></tr>
<tr><td colspan="4">Hypotheses: None</td></tr>
<tr><td colspan="2">Fish: Species race:
Yearling Chinook salmon (CH1)
Juvenile steelhead (STH)</td><td colspan="2">Implant Procedure:
Surgical: Yes
Injected: No</td></tr>
<tr><td colspan="2">Source: John Day Dam fish collection facility
Implant Procedure: Surgical: Yes; Injected: No</td><td colspan="2"></td></tr>
<tr><td colspan="2">Size (median): CH1 STH
Weight (g): 32.39 72.42
Length (mm): 148.5 203.2</td><td colspan="2">Sample Size: CH1 STH
release sites: 3 3
releases 32 32
Total # released: 7,692 7,766</td></tr>
<tr><td>Tag:
Type/model: Advanced Telemetry Systems (ATS)-
Weight (g): 0.438 (air)</td><td>Analytical Model:
Virtual/paired-reference release</td><td colspan="2">Characteristics of Estimate:
Effects Reflected (direct, total, etc.): Direct
Absolute or Relative: Relative</td></tr>
<tr><td colspan="4">Environmental/Operating Conditions (daily from 30 April through 31 May 2011):
Discharge (kcfs): mean 380.9, minimum 231.6, maximum 506.5
Temperature (°C – scroll case): mean 11.4, minimum 9.5, maximum 12.8
Total Dissolved Gas (tailrace): mean 116.1%, minimum 110.2%, maximum 122.5%
Treatment(s): None
Unique Study Characteristics: The river was above flood stage after 13 May 2011. Turbine 11 was out of service all spring; second year that B1 sluiceway was automated; the B2 behavior guidance structure was removed from the B2 forebay after being tested in 2008, 2009, and 2010.</td></tr>
<tr><td colspan="2">Survival and Passage Estimates (value and SE):</td><td>Yearling Chinook</td><td>Steelhead</td></tr>
<tr><td colspan="2">Dam survival</td><td></td><td></td></tr>
<tr><td colspan="2">• Early season</td><td>0.9569 (0.0042)</td><td>0.9755 (0.0180)</td></tr>
<tr><td colspan="2">• Entire season</td><td>0.9597 (0.0176)</td><td>0.9647 (0.0212)</td></tr>
<tr><td colspan="2">Forebay-to-tailrace survival</td><td></td><td></td></tr>
<tr><td colspan="2">• Early season</td><td>0.9579 (0.0042)</td><td>0.9752 (0.0180)</td></tr>
<tr><td colspan="2">• Entire season</td><td>0.9528 (0.0175)</td><td>0.9589 (0.0211)</td></tr>
<tr><td colspan="2">Forebay residence time</td><td>5.34 h (0.46)</td><td>7.00 h (0.43)</td></tr>
<tr><td colspan="2">Tailrace egress rate</td><td>1.89 h (0.19)</td><td>3.77 h (0.32)</td></tr>
<tr><td colspan="2">Spill passage efficiency</td><td>0.5810 (0.0066)</td><td>0.5600 (0.0066)</td></tr>
<tr><td colspan="2">Spill+B2CC passage efficiency</td><td>0.6100 (0.0065)</td><td>0.6530 (0.0063)</td></tr>
<tr><td colspan="2">Fish passage efficiency</td><td>0.7170 (0.0060)</td><td>0.7490 (0.0057)</td></tr>
<tr><td colspan="4">Compliance Results: The steelhead estimate of dam passage survival met the survival requirement (i.e., >0.96), but the standard error exceeded the Biological Opinion (BiOp) requirement. The yearling Chinook salmon estimate did not meet the BiOp requirement.</td></tr>
</table>

Table ES.4. Summary of route-specific passage survival rates and proportions.

Metric	Yearling Chinook Salmon			Juvenile Steelhead		
	Estimate	SE	n	Estimate	SE	n
B2CC passage survival	0.9928	0.0226	165	0.9877	0.0268	542
B2 JBS passage survival	0.9819	0.0243	181	0.9377	0.0413	66
Surface-flow outlet passage survival	0.9741	0.0223	531	0.9712	0.0263	1,002
B1 sluiceway passage survival	0.9685	0.0239	366	0.9534	0.0277	460
B1 turbine passage survival	0.9677	0.0214	1,166	0.9362	0.0258	1,301
Turbine (B1 and B2) passage survival	0.9617	0.0211	1,616	0.9340	0.0256	1,463
Spillway passage survival	0.9567	0.0207	3,122	0.9646	0.0257	3,064
B2 turbine passage survival	0.9469	0.0231	450	0.9185	0.0334	162
Fish passage efficiency (FPE) || dam	0.717	0.0060	5,711	0.749	0.0057	5,833
SPE+B2CC efficiency || dam	0.610	0.0065	5,711	0.653	0.0063	5,833
Spill passage efficiency (SPE) || dam	0.581	0.0066	5,711	0.560	0.0066	5,833
B1 sluiceway efficiency || dam	0.064	0.0032	5,711	0.079	0.0035	5,833
B1 turbine passage efficiency || dam	0.204	0.0054	5,711	0.223	0.0055	5,833
B2CC efficiency || dam	0.029	0.0022	5,711	0.093	0.0038	5,833
B2 JBS passage efficiency || dam	0.043	0.0027	5,711	0.017	0.0017	5,833
B2 turbine passage efficiency || dam	0.079	0.0036	5,711	0.028	0.0022	5,833
B1 sluiceway efficiency || B1=B1 FPE	0.239	0.0109	1,532	0.261	0.0105	1,761
B2 FPE || B2	0.478	0.0170	862	0.799	0.0141	804
B2CC efficiency || B2	0.191	0.0134	862	0.674	0.0165	804
B2 JBS passage efficiency || B2	0.287	0.0154	862	0.124	0.0116	804
B2 FGE (screen efficiency)	0.354	0.0181	697	0.382	0.0300	262

JBS = juvenile bypass system.

The results section of this report includes tables comparing metric estimates among time periods including early, late, and the full spring study period and between day and nighttime periods (Table ES.5).

Table ES.5. Metric comparisons among time periods by report table.

Metric Compared Among Time Periods	Table
CH1 dam passage survival	Table 4.1
CH1 forebay to tailrace survival	Table 4.2
CH1 travel time estimates	Table 4.4 and Table 4.5
CH1 passage efficiencies	Table 4.7 and Table 4.8
STH dam passage survival	Table 5.1
STH forebay to tailrace survival	Table 5.2
STH travel time estimates	Table 5.4 and Table 5.5
STH passage efficiencies	Table 5.7 and Table 5.8

Acknowledgments

We are grateful to dedicated scientists from the PNNL, Pacific States Marine Fisheries Commission (PSMFC), and the USACE. Their teamwork and attention to detail, schedule, and budget were essential for the study to succeed in providing timely results to decision-makers.

- **PNNL**: T Able, C Brandt, A Bryson, K Carter, E Choi, K Deters, G Dirkes, J Duncan, A Flory, D Geist, K Hall, M Halvorsen, K Ham, K Hand, JL Hughes, R Karls, B LaMarche, K Larson, K Lavender, B Miller, A Miracle, A Phillips, H Ren, G Roesijadi, D Saunders, J Smith, G Squeochs, S Southard, N Tavin, A Thronas, S Titzler, N Trimble, D Trott, K Wagner, J Varvinec, and Y Yuan.
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Acronyms and Abbreviations

ATS	Advanced Telemetry Systems, Inc.®
B1	Bonneville Powerhouse 1
B2	Bonneville Powerhouse 2
B2CC	Bonneville Powerhouse 2 Corner Collector
B2FGE	Bonneville Powerhouse 2 fish guidance efficiency
B2 JBS	Bonneville Powerhouse 2 Juvenile Bypass System
BGS	behavior guidance structure
BiOp	Biological Opinion
BON	Bonneville Dam
BRZ	boat-restricted zone
°C	degree(s) Celsius or Centigrade
CENWP	Corps of Engineers Northwest, Portland District
CF	CompactFlash (card)
CH0	subyearling Chinook salmon
CH1	yearling Chinook salmon
CI	confidence interval (95%)
CJS	Cormack-Jolly-Seber (model)
cm	centimeter(s)
2D	two-dimensional
3D	three-dimensional
DART	Data Access in Real Time
dB	decibel(s)
DSP+FPGA	digital signal-processing field-programmable logic gate array
FCRPS	Federal Columbia River Power System
Fish Accords	Columbia Basin Fish Accords
ft	foot(feet)
g	gram(s)
g/L	gram(s) per liter
GPS	global positioning system
h	hour(s)
in.	inch(es)
JBS	Juvenile Bypass System
JDA	John Day Dam
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(s)
MCN	McNary Dam
mg/L	milligram(s) per liter
min	minute(s)
mL	milliliter(s)
mm	millimeter(s)
MOA	Memorandum of Agreement
MS-222	tricaine methanesulfonate
MSL	mean sea level
NOAA	National Oceanic and Atmospheric Administration
μPa	micropascal(s)
PIT	passive integrated transponder
PNNL	Pacific Northwest National Laboratory
psi	pound(s) per square inch
PSMFC	Pacific States Marine Fisheries Commission
PTAGIS	Passive Integrated Transponder (PIT) Tag Information System
rkm	river kilometer
RME	research, monitoring, and evaluation
ROR	run-of-river
RPA	Reasonable and Prudent Alternative
μs	microsecond(s)
s	second(s)
SE	standard error
SMF	Smolt Monitoring Facility
SPE	spill passage efficiency
STH	juvenile steelhead
USACE	U.S. Army Corps of Engineers
UW	University of Washington
WA	Washington
wk	week(s)
yr	year(s)

Contents

Figures

Tables

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 (CENWP) has funded numerous evaluations of fish passage and survival. In spring 2011, researchers at the Pacific Northwest National Laboratory (PNNL) in collaboration with the Pacific States Marine Fisheries Commission (PSMFC), CENWP, and the University of Washington (UW), conducted a juvenile fish passage and survival study at Bonneville Dam (BON; Figure 1.1). The goal of the study was to determine compliance for yearling Chinook salmon and steelhead for various performance measures stipulated by the 2008 Federal Columbia River Power System (FCRPS) Biological Opinion (BiOp; NOAA Fisheries 2008), and Columbia Basin Fish Accords (Fish Accords; 3 Treaty Tribes and Action Agencies 2008). Skalski et al. (2012) reported BON 2011 compliance results. Building on the compliance report, this document now provides a comprehensive technical report of the results of the BON 2011 study.

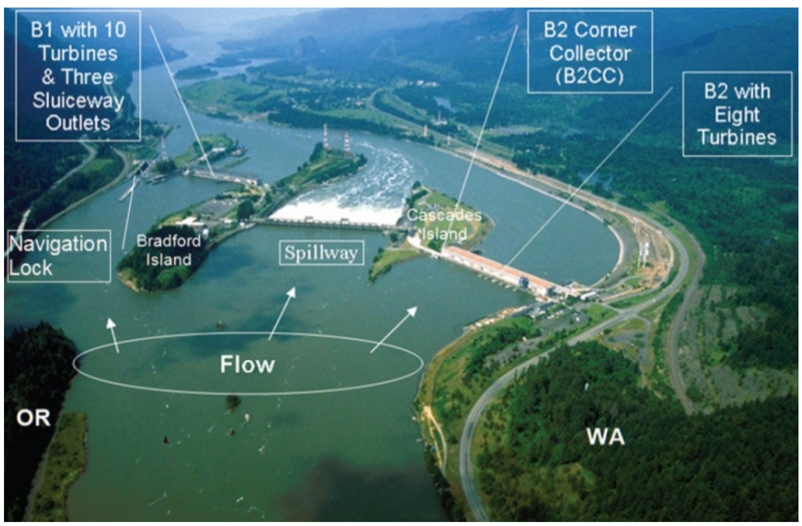


Figure 1.1. Plan view of the Bonneville Dam project. The Bonneville Powerhouse 1 (B1) sluiceway outlets and the Bonneville Powerhouse 2 Corner Collector (B2CC) are surface overflow passage routes.

1.1 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 to 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 model mathematically (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), which results 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 loads and injuries, whether additive or synergistic, alter their fitness and subsequently their performance. 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, extensive work has been done on in-turbine screen systems and juvenile bypass system (JBS) facilities at McNary Dam (MCN), John Day Dam (JDA), and BON. Also, numerous spill-level evaluations have been conducted at all three dams. At BON in 2009 a surface-flow outlet was refurbished at the Bonneville Powerhouse 2 (B2), a behavioral guidance structure (BGS) was deployed in the B2 forebay,[1] spillway flow deflectors were modified and have been studied, and the Bonneville Powerhouse 1 (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 for comparison with the BiOp standards (detailed below in Section 1.2, Performance Standards). At Bonneville Dam, the first compliance study was conducted in spring 2011.

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 CENWP 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, JSATS route-specific survival studies were 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 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.

[1] The BGS was removed after the 2010 test.

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 Bonneville Powerhouse 2 Corner Converter (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 (CJS; Cormack 1965; Jolly 1965; Seber 1965) modeling methods and would meet current BiOp standards. Turbine unit 11 provides flow into the south of B2 where the B2CC is located; thus, the fact that this unit was off during summer may have reduced B2CC efficiency for CH0.

In 2010, PNNL studied smolt survival and passage at BON using acoustic telemetry (Ploskey et al. 2012a, b). This study was not an official compliance test requiring paired reference releases, but single-release estimates for CH1 still exceeded the BiOp requirement of 0.96, and single-release estimates for STH 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 BGS tested in 2008, 2009, and 2010 increased the B2CC passage efficiency of CH1 by about 12.5% over 2004 and 2005 estimates, but benefits were not obvious for juvenile STH or CH0. A one-tailed paired t-test indicated that mean dam passage survival was significantly higher (P = 0.047) for CH0 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 July 15 (survival = 0.713; n = 48) relative to the pooled estimate for the season treatment (0.903). The 95% confidence intervals (CIs) 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.

1.2 Performance Standards and Definitions

The 2008 BiOp on operation of the FCRPS contains a Reasonable and Prudent Alternative (RPA) that includes actions calling for measurement 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):

> <u>Juvenile Dam Passage Performance Standards</u> – 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 2011 survival studies (after the MOA Attachment A):

> <u>Dam Survival Performance Standard</u> – 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....
>
> <u>Spill Passage Efficiency and Delay Metrics</u> – 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....
>
> <u>Future Research, Monitoring and Evaluation</u> − 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 spring 2011 acoustic-telemetry study of CH1 and STH at BON. This study is the first full-scale compliance study for BON. For this report, we report survival, travel time, and passage efficiency metrics (defined in Table 1.1).

1.3 Study Objectives

The study objectives were to estimate the following metrics for CH1 and STH separately. Where applicable, performance standards from the BiOp and Fish Accords are reiterated for emphasis.

1. Survival rates
   a. Dam passage survival − Performance[2] should be ≥96% survival for spring stocks (i.e., CH0 and STH). Survival should be estimated with a standard error (SE) ≤1.5%.
   b. Forebay-to-tailrace survival − The forebay-to-tailrace survival estimate satisfies the "BRZ-to-BRZ" survival estimate called for in the Fish Accords.
2. Travel times[3]
   a. Forebay residence time
   b. Tailrace egress time
   c. Project passage time

[1] Available at http://www.salmonrecovery.gov/Files/BiologicalOpinions/MOA_ROD.pdf.
[2] Performance as defined in the 2008 FCRPS BiOp, Section 6.0.
[3] For the tagged CH1 and STH detected, we estimated the mean, standard error, and median travel times for forebay residence, egress, and project passage.

3. Passage efficiencies

    a. Spill passage efficiency, defined as the fraction of fish going through the dam via the spillway.

    b. Spill+B2CC passage efficiency ($\widehat{SPE}_2$), defined as the fraction of fish passing through the dam via the spillway and B2CC (as defined by the 2008 Fish Accords).

    c. Fish passage efficiency, defined as the fraction of fish going through the dam via non-turbine routes.

4. Passage distributions

    a. Forebay approach

    b. Forebay vertical

    c. Horizontal.

Table 1.1. Definitions of performance measures. Columbia River kilometers are in parentheses; BON is at CR234.

Measure	Definition
Dam passage survival	Survival from the upstream face of the dam to a standardized reference point in the tailrace (CR234–CR233).
Forebay to tailrace survival	Survival from a forebay array 2 km upstream of the dam to a tailrace array 1 km downstream (CR236–CR233). The forebay-to-tailrace survival estimate satisfies the “BRZ-to-BRZ” survival estimate called for in the Fish Accords.
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 (CR236–CR234).
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 (CR234–CR233).
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 1-km downstream of the dam (CR236–CR233).
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]
Fish passage efficiency	Proportion of fish passing through the dam via the spillway, B1 sluiceway, B2CC, and B2 JBS.[c]

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

1.4 Study Area

Bonneville Lock and Dam consist 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 B2 (Figure 1.1).

Primary fish passage routes include the spillway and two powerhouses, but 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.

1.5 Report Contents and Organization

The ensuing chapters of this report present the study methods (Chapter 2.0), followed by results for environmental conditions (Chapter 3.0). Next are results for survival, travel time, passage efficiency, and passage distribution information for CH1 (Chapter 4.0) and STH (Chapter 5.0). Discussion (Chapter 6.0), conclusions and recommendations (Chapter 7.0), and references (Chapter 8.0) 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 used 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).

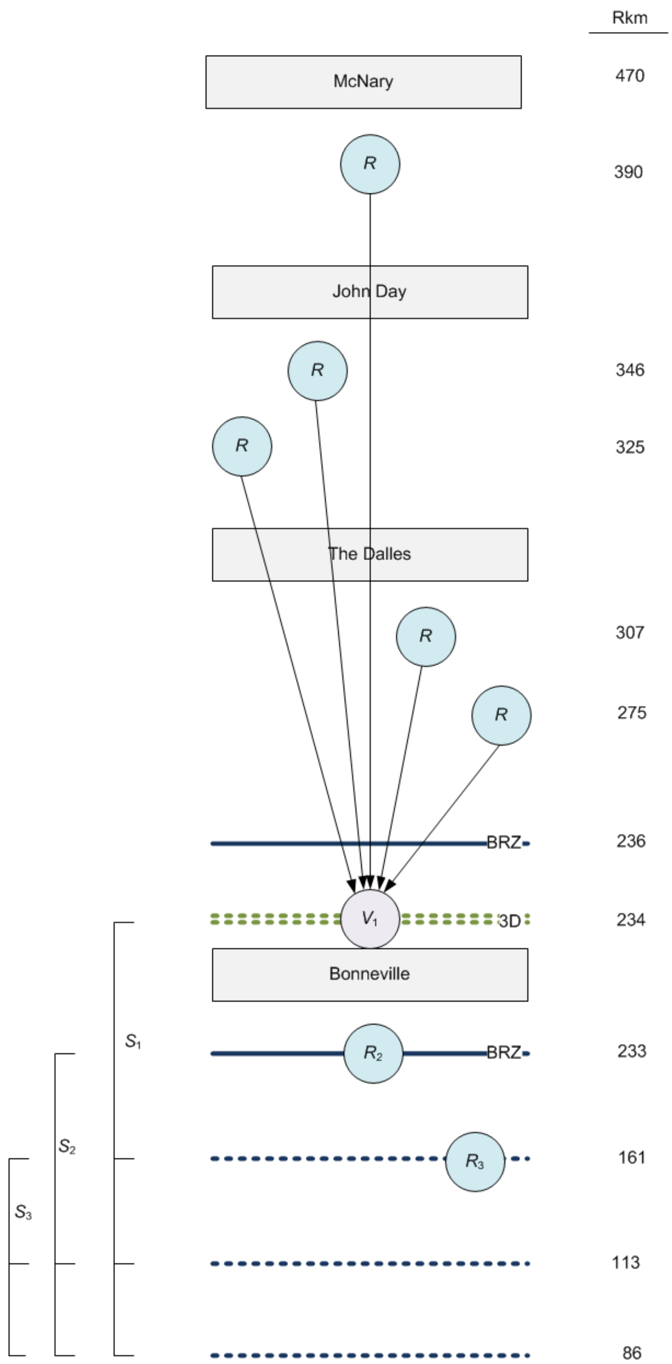
2.1 Environmental Collections

Water discharge data by spill bay and turbine unit and elevation data for the forebay and tailrace are acquired by the USACE in 5-min increments by the automated data-acquisition system at BON. Operators at the dam provided the data weekly. The 5-min discharge data for the entire dam and spillway were averaged by day and plotted together with daily averages for the previous 10-yr 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).

2.2 Release-Recapture Design and Sample Sizes

The release-recapture design used to estimate dam passage survival at BON consisted of a novel combination of a virtual release (V_1) of fish at the face of the dam and a paired release below the dam (Figure 2.1) (Skalski et al. 2009). Tagged fish released at five sites upstream of BON were used to supply a source of fish known to have arrived alive at the face of the dam. Upstream release sites were near Roosevelt, Washington (rkm 390), which is 41 km upstream of JDA; the JDA tailrace (rkm 346); Celilo, Oregon (rkm 325); TDA tailrace (rkm 307); and Hood River, Oregon (rkm 275). 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 through the dam and some distance beyond (i.e., rkm 161) (Figure 2.1). The location for the detection array at rkm 161 was chosen so that there was little or no chance of detecting fish that died during dam passage and floated downriver with still-active tags. To account and adjust for this extra reach mortality, we estimated survival in the river segment below BON by making paired releases in the tailrace at R_2 and in the tailwater near Knapp, Washington at R_3 (Figure 2.1). Dam passage survival was then estimated as the quotient of the survival estimates for the virtual release to that of the paired release. The sizes of the releases of the acoustic-tagged fish used in the dam passage survival estimates are summarized in Table 2.1.

The same release-recapture design was also used to estimate forebay-to-tailrace survival, except that the virtual-release group was constructed of fish known to have arrived at the forebay array (rkm 236). The same below-dam paired release was used to adjust for the extra release mortality below the dam as was used to estimate dam passage survival. Dam-face double-detection arrays were analyzed as two independent arrays to allow estimation of detection probabilities by route of passage and assign routes of passage. These passage-route data were used to calculate SPE, spill+B2CC passage efficiency, and FPE at BON. Detections on the forebay entrance array and dam-face array were used to estimate forebay residence time. The fish used in the virtual release at the face of the dam were also used to estimate tailrace egress time.



$$\hat{S}_{\text{Dam}} = \frac{\hat{S}_1 \cdot \hat{S}_3}{\hat{S}_2}$$

Figure 2.1. Schematic of the virtual/paired-release design used to estimate dam passage survival at Bonneville Dam during spring 2011. The virtual release (V_1) was composed of fish that arrived at the dam face from the release locations at rkm 390, 346, 325, 307, and 275. The below-dam release pair was composed of releases R_2 and R_3 with detection arrays used in the survival analysis denoted by dashed lines.

Table 2.1. Sample sizes of tagged fish released for the 2011 survival study at Bonneville Dam.

Release Location	Yearling Chinook Salmon	Steelhead
Upriver Releases (R_1)	6,100	6,180
Virtual Release (V_1)[(a)]	5,542	5,663
Bonneville Tailrace (R_2)	798	792
Bonneville Reservoir (R_3)	794	794

(a) These numbers include fish from R_1 that survival to be regrouped at Bonneville Dam.

2.3 Tags and Tag Life

The acoustic tags used in the 2011 study (Figure 2.2) were manufactured by Advanced Telemetry Systems, Inc.® (ATS). Each tag, model number ATS-156dB, measured 12.02 mm long, 5.21 mm wide, 3.72 mm thick, and weighed 0.430 g in air (0.29 g in water). The tags had a nominal transmission rate of 1 pulse every 3 s. Nominal tag life was expected to be about 25 d. 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.

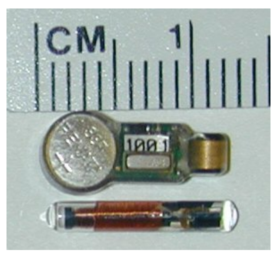


Figure 2.2. JSATS 0.43-g acoustic micro-transmitter and passive integrated transponder tag surgically implanted in yearling and subyearling Chinook salmon and juvenile steelhead in 2010.

Three distinct manufacturing lots of tags were used during the spring 2011 JSATS study, (i.e., 1, 2, and 3–5). From each of these tag lots, approximately 50 tags (i.e., 50, 50, and 59, respectively) were randomly sampled to be used in tag-life assessments. The tags were activated, held in river water, and monitored continuously until they failed. 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. The information from the tag-life study was used to adjust the perceived survival estimates from the CJS release-recapture model according to the methods of Townsend et al. (2006).

2.4 Fish Collection, Tagging, and Holding

Procedures for handling, tagging, and releasing fish to be used in this study followed USACE protocols set forth by the Columbia Basin Surgical Protocol Steering Committee (CBSPSC 2011). Fish obtained from the JDA JBS were surgically implanted with JSATS tags, held for 12 to 36 h, and then transported to five different release locations on the Columbia River, as described in the following sections.

2.4.1 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 18-11-PNNL40). The Oregon Department of Fish and Wildlife authorized take for this study under permit number 16251c. All requirements and guidelines of both permits were met, and reports of collection and release were reported to both agencies. We also applied for and received a Washington State Scientific Collection Permit (# 11-174).

2.4.2 Collection

The SMF is situated on the Oregon shore at the downriver edge of the JBS where juvenile salmonids and other fishes diverted from turbine intakes are routed through a series of gates, chutes, flumes, and dewatering structures. Smolts in the JBS can be diverted into the SMF as part of routine smolt monitoring or directed into the tailrace through an outfall pipe located downstream of the facility. Pacific States Marine Fisheries Commission employees systematically diverted fish from the JBS into holding tanks and then to an examination trough in the SMF, as described by Martinson et al. (2006). Smolts sampled in the SMF were examined, enumerated, and either selected for tagging as part of this study or released into the tailrace outfall.

Juvenile salmonids were diverted from the bypass system and routed into a 6,795-L holding tank in the SMF. About 150 to 200 smolts and other fishes were crowded with a panel net into a 51.2- by 6.14-cm pre-anesthetic chamber. Water levels in the chamber were lowered to about 20.5 cm 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 anesthetized, fish were routed into the examination trough for identification and enumeration. Technicians added MS-222 as needed to maintain sedation and 5 to 10 mL of PolyAqua™ to limit handling damage and reduce fish stress. Water temperatures were monitored in the main holding tank and examination trough to ensure temperatures in the trough were maintained within 2°C of the main holding tank.

Once fish were in the examination trough, Chinook salmon and steelhead smolts selected for surgical procedures were evaluated in accordance with accepted criteria based on the general recommendations of the Columbia Basin Rejection Criteria (CBSPSC 2011). PNNL broadened some criteria to accept more fish, including fish that on any one side had less than 5% fungus and open wounds, parasites that occurred on the head and flanks of the fish, operculum damage less than 75%, red fins, any abrasions, and scarring. If more than 5% of the sample the day before had a particular malady/infection, the following day fish with that malady were accepted after approval by the fish condition study manager. The total number of fish handled by PNNL in spring 2011 and the counts and percentages of fish by handling category are listed in Table 2.2. Over 20,000 CH1 and STH were handled during the study. Staff rejecting fish from tagging recorded the reasons by tallying the maladies observed (Table 2.3).

Table 2.2. Total number of fish handled by PNNL during the spring of 2011 and counts of fish in several handling categories. These data include fish tagged for releases as part of studies at John Day and Bonneville dams.

Handling Category	CH1	%CH1	STH	%STH	**Total**
Tagged at JDA	7,929	79	8,003	77	**15,932**
Extras (released)	584	6	479	5	**1,063**
Drop/Jump (released)	16	0	12	0	**28**
Previously Tagged (released)	449	4	326	3	**775**
<95 or >300 mm Fork Length (released)	1	0	9	0	**10**
Pre-Tagging Mortalities (released)	14	0	3	0	**17**
Non-Candidate Based on Condition[(a)]	1,070	11	1,569	16	**2,639**
Total Handled	**10,063**		**10,401**		**20,464**

In 2011, passive integrated transponder (PIT) scanning occurred after fish condition assessment, so the listed non-candidate count is inflated by some PIT-tag–bearing fish that should have been rejected solely for having been tagged previously. The order of processing will be changed for 2012 to better estimate numbers of non-candidate fish.
CH1 = yearling Chinook salmon, and STH = juvenile steelhead.

Table 2.3. Total number of fish handled by PNNL during the spring of 2011 and counts of fish with common maladies. These data include fish tagged for releases as part of studies at John Day and Bonneville dams.

Handling Category	CH1	% CH1	STH	% STH	**Total**
Moribund/Emaciated	10	0	8	0	**18**
Descaling >20%	437	5	659	7	**1,096**
Diseases	221	2	304	3	**525**
Damage/Injury	398	4	584	6	**982**
Skeletal Deformity	4	0	14	0	**18**
Non-Candidate	1,070	11	1,569	16	**2,639**

CH1 = yearling Chinook salmon, and STH = juvenile steelhead.

2.4.3 Tagging

The surgical team followed the latest guidelines for surgical implantation of acoustic transmitters in juvenile salmonids (Brown et al. 2010; CBSPC 2011). Numerous steps were taken to minimize the handling impacts of collection and surgical procedures on study fish. Most of the smolts used for tagging were part of the routine fish collection of the smolt monitoring program, 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 302.8-L holding tanks and placed in a 24.6-L bucket containing an 80-mg/L concentration of MS-222 anesthetic and river water. Once a fish lost equilibrium, it was transferred to a data collection/processing table in a small container of river water and anesthetic. Each fish was assigned a species type, surgeon, release location, adipose fin intact or clipped, fork length (±1 mm), and fish condition comments (e.g., <20% descaling) on a GTCO CalComp DrawingBoard® VI™ digitizer board. Fish were then weighed (±0.1 g) on a 2,000-g Ohaus® Scout *Pro* scale and returned to the small transfer container along with their assigned passive integrated transponder (PIT) and acoustic tag. Length, weight, species type, tag codes, fin clips, condition comments, surgeons, and release locations were all added automatically to the tagging database by PIT Tag Information System (PTAGIS) P3 software to minimize human error. The transfer container, fish, and tags were then passed to the photo table where photographs of each side of the fish were taken for documentation. Finally, fish were transferred to their assigned surgeon for tag implantation.

An established protocol was used to help minimize negative impacts that surgical procedures and handling might cause. Each surgeon systematically rotated between six 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 min. The instruments were then transferred to a distilled water bath for 10 min to remove residual ethanol and any remaining particles before being used again. After completion of daily tagging operations, all surgical instruments were sterilized in an autoclave. PolyAqua® was used to protect damaged areas of the fish's mucus membrane, reduce the possibility of infection, and aid in healing. Water in anesthesia and recovery buckets was refreshed repeatedly to maintain temperatures within ±1°C of river water temperatures, and sodium bicarbonate was added to anesthesia buckets to act as a pH buffer.

During surgery (Figure 2.3), each fish was placed ventral side up and a gravity-fed "maintenance" anesthesia (40 mg/L) and a fresh river water supply line was placed into its mouth. Using a surgical or stab blade, a 5- to 7-mm incision was made along the linea alba 3 to 5 mm anterior of the pelvic girdle. A PIT tag was inserted followed by an acoustic tag with the acoustic element pointing posterior. Both tags were inserted at an angle toward the anterior end of the fish to minimize internal damage. The incision was closed with two interrupted stitches using Ethicon 5-0 Monocryl sutures and a taper point needle. After closing the incision, the fish were placed in a dark 24.6-L transport bucket filled with aerated river water and monitored until they regained equilibrium.

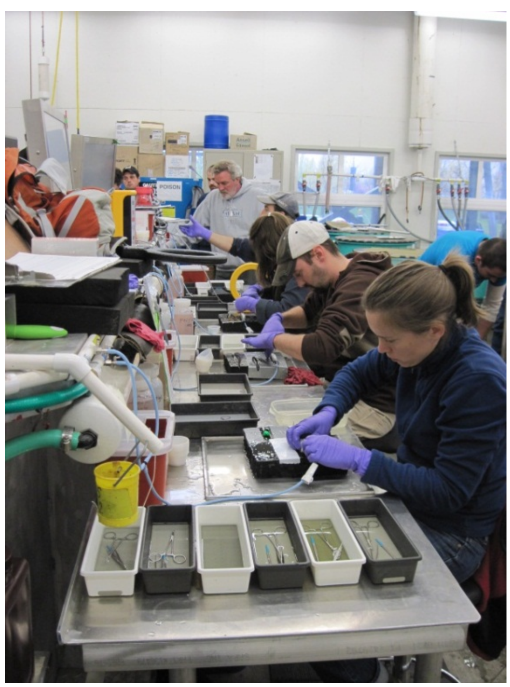


Figure 2.3. Surgical stations and surgeons implanting tags.

The tagging process required a team of 11 or more people to conduct daily operations and everyone strived to ensure that all collected and tagged fish were handled as efficiently and unintrusively as possible. Individuals were assigned to specific tasks within the tagging process, which included one individual responsible for anesthetizing fish, one for delivering fish to and from the various stations, two people for assigning tagging information and recording data, one person for taking photographs with a high-resolution digital camera, four people to perform surgeries to implant tags in the fish, one person to attend to the post-surgical transport buckets making sure only the correct fish made it into each bucket, and one or two people responsible for moving tagged fish in transport buckets to post-surgery holding tanks.

2.4.4 Recovery and Holding

After surgery, a maximum of 5 tagged fish were placed in 24.6-L aerated transport buckets and closely monitored until fish had reestablished equilibrium. Each bucket held one to five fish depending on the number to be released at each release site. The buckets were then transferred to an outdoor post-surgery holding tank continuously supplied with fresh river water (Figure 2.4) and fish were held for 12 to 36 h prior to being released at specific locations and times. Dissolved oxygen and water temperature were closely monitored in the insulated holding tanks to ensure they were within acceptable limits.

Figure 2.4. Post-surgery holding tank with recovery buckets containing tagged fish.

2.5 Transport and Release

Buckets with tagged fish were transported from JDA by truck to five release locations on the Columbia River (Figure 2.1). Transportation routes were adjusted to provide equal travel times to each release location from JDA. To transport tagged fish, ¾-ton trucks were outfitted with two 681-L insulated Bonar totes filled half to three-quarters full of fresh river water prior to each release (Figure 2.5). Fish buckets were removed from the post-surgery holding tanks and placed in the totes, which could hold up to nine fish buckets. A network of valves and plastic tubing was attached to an oxygen tank to deliver oxygen to the totes from a 2,200-psi oxygen tank during transport. A YSI meter was used to monitor the dissolved oxygen and temperature of the river water in the totes before and during transport to ensure they were within acceptable limits. If water parameters were outside acceptable limits, river-water ice was added to cool the water and oxygen levels were manually adjusted.

Figure 2.5. Fish release transport trucks and totes.

Upon arriving at a release site, fish buckets were transferred to a boat for transport to the five in-river release locations at each release cross section. Generally, equal numbers of fish were released at each of the five locations for a given cross section. During spring, releases occurred day and night for 36 consecutive days (April 26 to May 31, 2011) and the timing of the releases at the five locations was staggered to help facilitate downstream mixing (Table 2.4).

Just before fish were released in the river, fish buckets were opened to check for dead or moribund fish. If dead fish were observed, they were removed 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 that recorded all pairs of PIT tags and acoustic tags implanted in fish the previous day. These dead fish along with other intentionally sacrificed tagged fish were released in the tailrace of each dam throughout the study period to determine whether they were detected on downstream survival-detection arrays. Post-tagging, pre-release mortalities were low for each run of fish studied in 2011 (CH1 = 0.31%; STH = 0.08%).

Table 2.4. Relative release times for the acoustic-tagged fish to accommodate downstream mixing.

Release Location	Relative Release Times	
V_1 (rkm 234)	Continuous	Continuous
R_2 (rkm 233)	Day 1: 0800	Day 1: 2000
R_3 (rkm 161)	Day 2: 0500	Day 2: 1700

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 (Figure 2.1). An array is defined as a group of nodes deployed within 1 km of a specific river cross section to detect acoustic-tagged fish. Array descriptions, locations, names, and functions are described in Table 2.5. 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.

Table 2.5. Description, location, name, and survival model function of arrays deployed for the 2011 Bonneville Dam study. Array names were a concatenation of "CR" for Columbia River and the nearest whole river kilometer to the array, as measured from the mouth of the Columbia River.

Array Description	Location	Array Name	Array Function
BON Forebay	2 km upstream of BON	CR236	Regroup fish for a virtual release to estimate forebay to tailrace survival; the first detection on the forebay entrance array is used with the last detection on the dam-face array to estimate median and mean forebay residence times.
BON Dam Face	Bonneville Dam	CR234	Regroup fish to form virtual releases of fish to estimate dam passage survival and route-specific passage survival rates. Provides the last detection time on the dam-face array for estimating forebay residence time and tailrace egress time.
BON Tailrace	1 km downstream of the spillway	CR233	Samples of last detection times on this array are used to estimate median and mean tailrace egress times for fish known to have passed the dam.
BON Tailwater 1	Near Vancouver, WA	CR161	Primary survival detection array for virtual releases of fish at BON (forebay entrance or dam face); first of a pair of reference-release groups.
BON Tailwater 2	Near Kalama, WA	CR113	Secondary survival array for BON virtual releases and tailrace reference releases; primary survival detection for second reference release downstream of BON.
BON Tailwater 3	Near Oak Point, WA	CR086	Estimate of the product of detection and survival probabilities (Lambda) for the final river reach CR113 to CR086.

2.6.1 Cabled Dam-Face Arrays

The cabled dam-face receiver was designed by PNNL for the CENWP 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), global positional system (GPS) card, a four-channel signal-conditioning receiver with gain control, hydrophones, and cables (Figure 2.6). The software that controls data acquisition and signal processing is the property of the USACE and is made available by the USACE as needed.

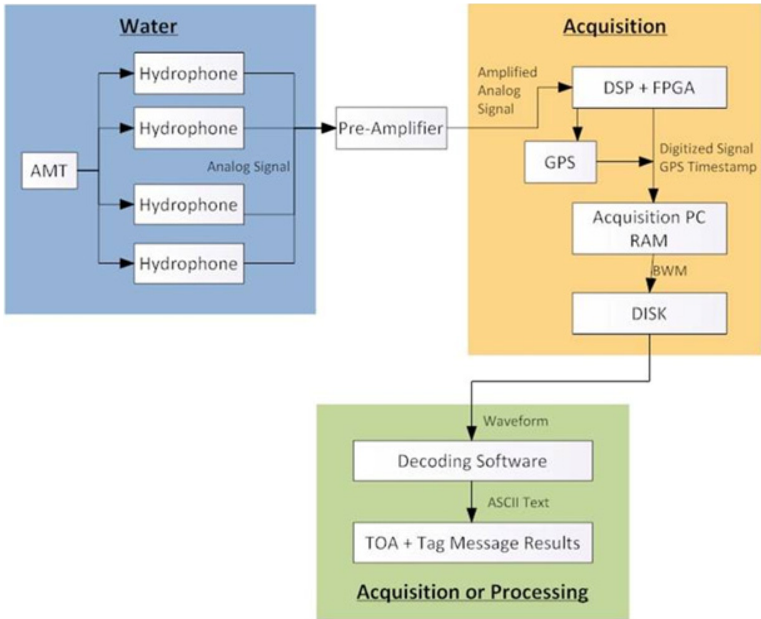


Figure 2.6. Schematic of dam-face receiver system showing the main components and direction of signal acquisition and processing. Abbreviations are as follows: AMT = acoustic micro-transmitter implanted in fish; DSP = digital signal processing card; FPGA = field programmable logic gate array; GPS = global 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 shallow and deep on each main pier (Figure 2.7). 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.

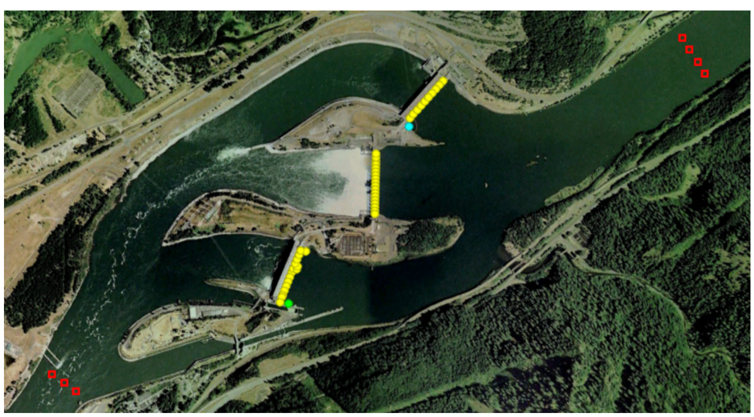


Figure 2.7. Location of hydrophones on the upstream faces of three dam structures at the Bonneville project in 2011. Red squares indicate positions of autonomous node deployments in the forebay entrance array and tailrace exit array.

At the powerhouses and spillway, hydrophones were mounted on 4- or 8-in.-diameter trolleys (Figure 2.8). Trolleys were deployed in slotted pipes attached to the main piers at the powerhouse and spillway and on some adjacent concrete walls (e.g., B2 pipes in Figure 2.9) in a known fixed geometry. 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. The GPS coordinates and elevations of dam-face-mounted cabled hydrophones are listed in Appendix B.

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).

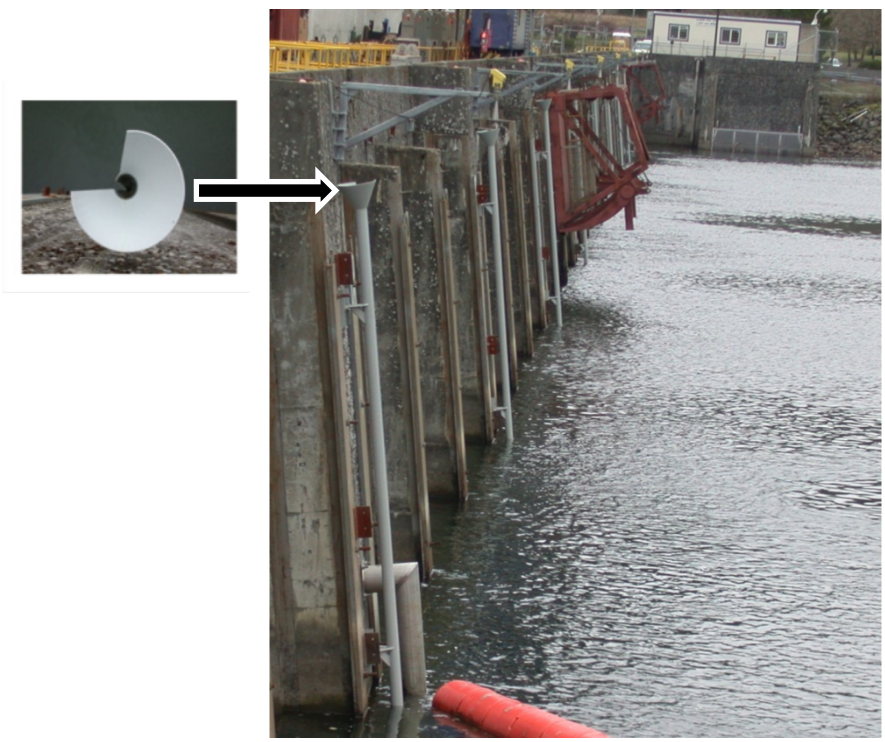


Figure 2.9. Four-inch-diameter trolley pipes mounted on piers at B2 (upper inset view of pipe top). Similar 4-in.-diameter pipes were installed at B1.

Trolley pipes at the powerhouse were 4 in. in diameter and made of powder-coated schedule 40 steel pipe that was slotted down one side for deployment of the trolley. Pipes at the powerhouses were 80 ft long and extended from deck level at an elevation of 90 ft above mean sea level (MSL) down to a mid-intake depth at an elevation ranging from 12 to 15 ft above MSL. 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). Reference beacons (as described in Figure 2.8) transmitting at 156 dB || 1 μPa 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.

The 8-in.-diameter slotted pipes at the spillway extended from about 4 ft above maximum pool to the elevation of the ogee. At each spillway pier, one hydrophone trolley was deployed at a shallow elevation (65.87–68.05 ft above MSL) and the other was deployed at a deep elevation (38.12–40.39 ft above MSL).

The three-dimensional (3D) cabled detection array on the upstream face of BON was used to track fish to a route of passage and the 3D array could be processed as two independent arrays each consisting of alternating shallow and deep hydrophones on adjacent piers (Figure 2.10) to allow for estimation of the combined array detection efficiency for each route. Passage-route data were used to calculate FPE, SPE, and spill+B2CC passage efficiency. The last detection time of fish on the dam-face arrays was used with first detection times on the forebay entrance array to estimate forebay residence time and with the last detection time on the tailrace array to estimate tailrace egress time. Fish detected on the dam-face array were regrouped to form a virtual release of fish known to have reached BON from upstream release sites.

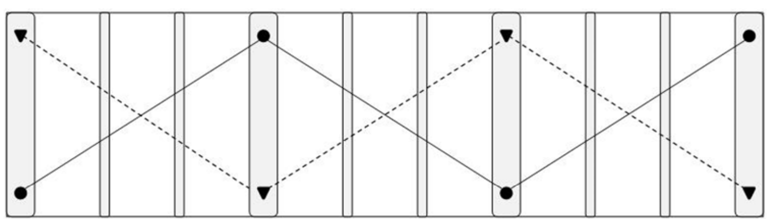


Figure 2.10. Front view schematic of hydrophone deployments at three turbines showing the double-detection arrays. The circles denote the hydrophones of Array 1 and the triangles denote the hydrophones of Array 2.

2.6.2 Autonomous Node Arrays

The autonomous acoustic-telemetry receiver, hereafter referred to as an autonomous node or simply node, was designed and developed by Sonic Concepts and PNNL for the CENWP to detect JSATS acoustic tags in a riverine environment. Each node is an independent, self-contained data-acquisition instrument, that may be anchored in the river where necessary; each consists of a node top that houses the hydrophone, a pair of processing circuit boards, a Compact Flash (CF) card for data storage, and a battery and serial cable connectors (Figure 2.11). The node top threads into another sealed section of polyvinyl chloride pipe that houses an internal battery pack and traps air to provide buoyancy. The outside of the bottom housing supports an external beacon tag and stabilizing fin to help keep the detecting hydrophone tip upright in the water column. A computer installed with custom software may be directly connected to a node for configuring and assessing its operation, in addition to viewing data collection in real time. All autonomous node tops were tested for acceptable detection performance in a specialized anechoic testing tank prior to deployment (Deng et al. 2010).

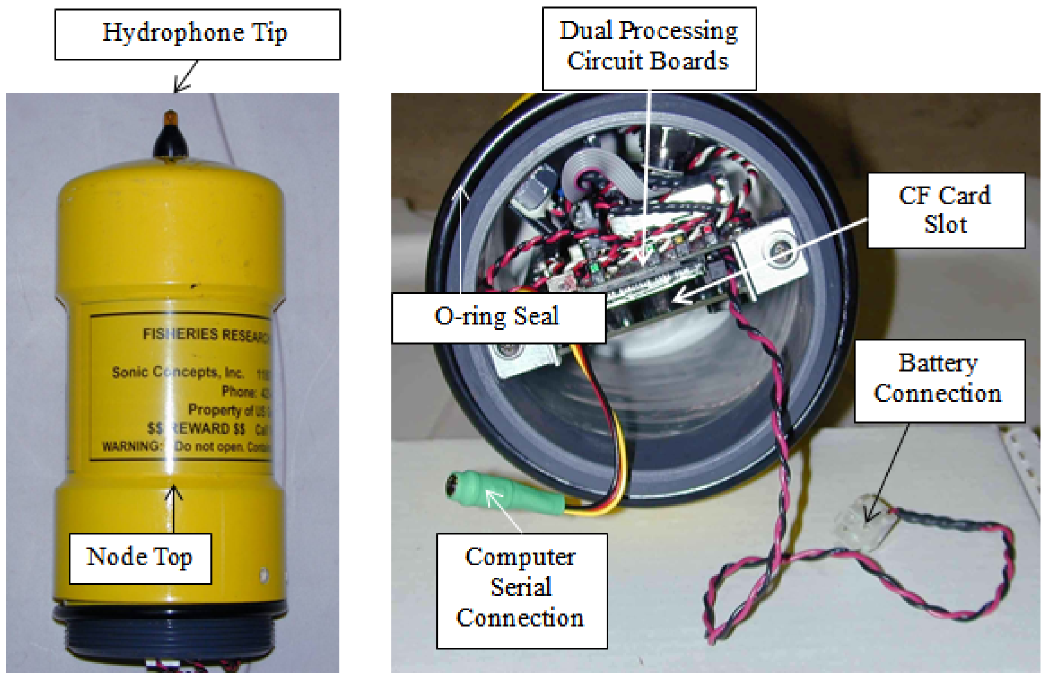


Figure 2.11. Outer (left image) and internal (right) views of an autonomous node top.

Autonomous nodes were deployed in arrays located at specific sites for the lower Columbia River study. An autonomous node array is defined as a line of autonomous nodes deployed on the riverbed, across the entire width of a river cross section, perpendicular to the river flow. Each array acts as a "passage gate" that detects the JSATS tags surgically implanted in the body cavities of passing fish. Autonomous nodes in most of the arrays were deployed within 150 m of each adjacent node and less than about 75 m from shore.

Eleven separate autonomous node arrays were deployed for the entire lower Columbia River study (Figure 2.12). Each array was named by concatenating CR (for Columbia River) with the nearest whole river kilometer upstream from the mouth of the river. For example, the first and farthest upriver node array was in the JDA forebay near rkm 351 and was named CR351. A JDA tailrace egress array (CR346), which was also the second fish release site was located at rkm 346 about 3 km downstream of the downstream deck of the JDA powerhouse. A third array (CR325) was located at the third release site at rkm 325, between Celilo Village, Oregon, and Wishram, Washington. The Dalles Dam forebay entrance array (CR311) was located about 2 km upstream of the TDA spillway face. A TDA tailrace egress array (CR307), which was also the fourth release site was located about 2 km downstream of the TDA spillway. A sixth array (CR275) was located at the fifth release site at rkm 275, about 2.1 km upriver of the Hood River Bridge. The BON forebay entrance array (CR236) was located at rkm 236, about 2 km upstream of the BON spillway face. A BON tailrace egress array (CR233) and the sixth release site was located about 1 km downstream of the BON spillway. The next array (CR161) was the final release site and was located near Vancouver, Washington, about 0.75 km upstream from the tip of

Caterpillar Island. The tenth array (CR113) was 7.5 km downriver of Kalama, Washington, adjacent to the upper end of Cottonwood Island. The last array (CR086) was located adjacent to Oak Point, Washington.

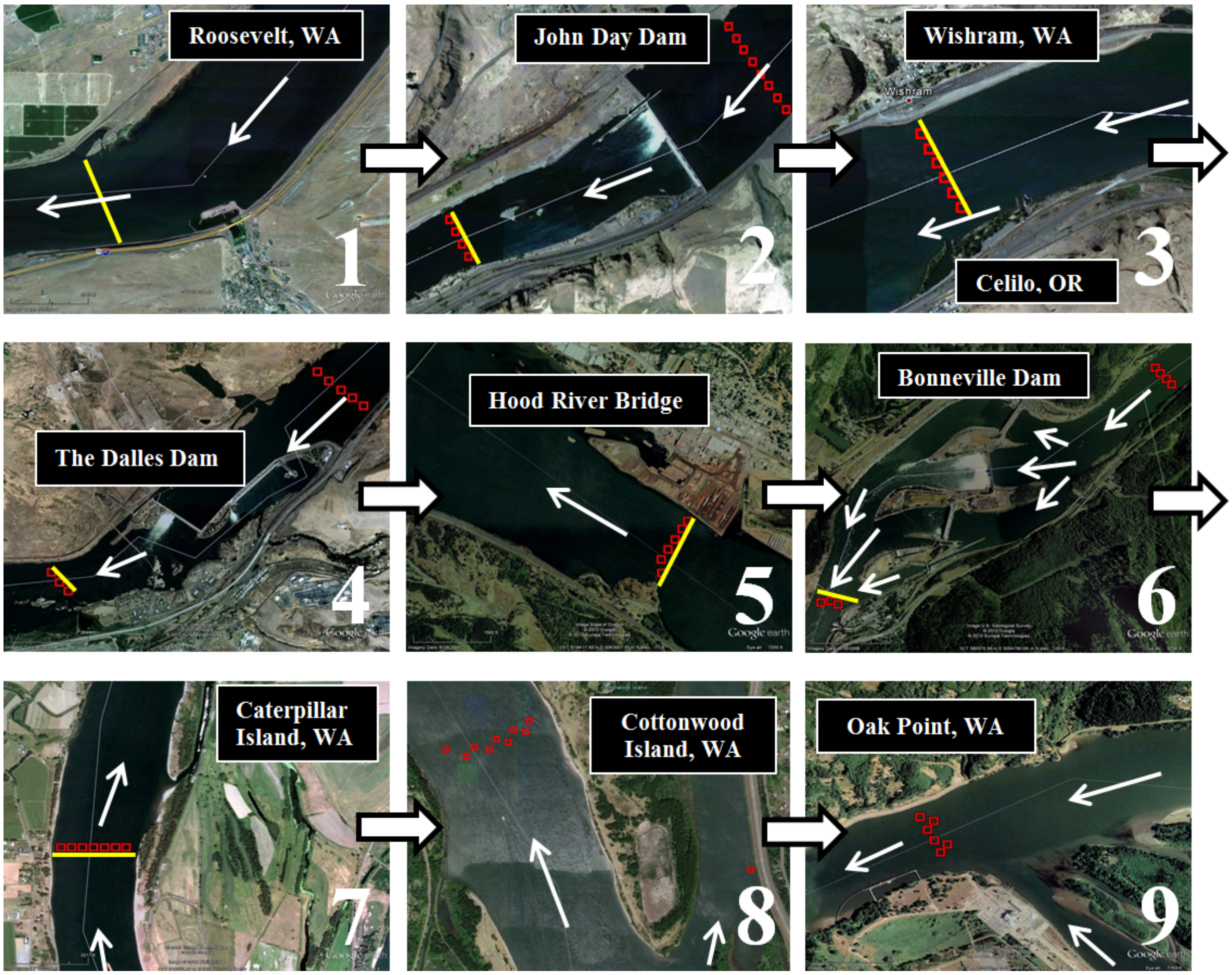


Image 1: Fish release location near Roosevelt, Washington, at rkm 390. **Image 2**: JDA forebay array (right; CR351) and tailrace array (left; CR346) with associated fish release location. **Image 3**: JDA tailwater array (CR325) with fish release location, near Celilo, Oregon, and Wishram, Washington. **Image 4**: TDA forebay array (right; CR311), tailrace array (left; CR307) and fish release location. **Image 5**: TDA tailwater array (CR275) and fish release location near Hood River, Oregon, at rkm 275. **Image 6**: BON forebay array (right; CR236), tailrace array (left; CR233) and fish release location. **Image 7**: BON tailwater array (CR161) and associated fish release location near Caterpillar Island and Vancouver, Washington. **Image 8**: BON tailwater array (CR113) near Cottonwood Island and Kalama, Washington. **Image 9**: BON tailwater array (CR086) near Oak Point, Washington. Array names are presented in parentheses, and the three-digit number at the end of each name is the river kilometer distance upstream from the mouth of the Columbia River.

Figure 2.12. Location of the seven fish release transects (yellow lines in images) and the eleven autonomous node arrays (red squares) deployed to detect acoustic-tagged fish migrating downstream. Black bordered arrows, between Google Earth images, indicate the order of images from upstream to downstream, and the direction of water flow within each image is indicated by white arrows.

Autonomous nodes were deployed with the configuration shown in Figure 2.13. Nodes were attached to a 1.5-m section of rope with three 2.7-kg buoyancy floats, at a compression strap around the node's housing at its balance point. An acoustic release device (Inter-Ocean Model 111 or Teledyne Benthos Model 875-T) was attached to the lower end of the 1.5-m line. Lengths of wire rope measuring 0.3, 1.0, or 2.0 m, dependent on water depth, connect the mechanism of the acoustic release to a 34-kg steel anchor. The shorter 0.3-m lengths of wire rope were used in water less than about 7.0 m deep; the 1.0-m lengths were used in water under 20.0 m deep; and 2.0-m lengths were used in deeper locations and in the three farthest downriver arrays, where constantly shifting, sandy substrates had the potential to both foul the release mechanism or bury the entire release.

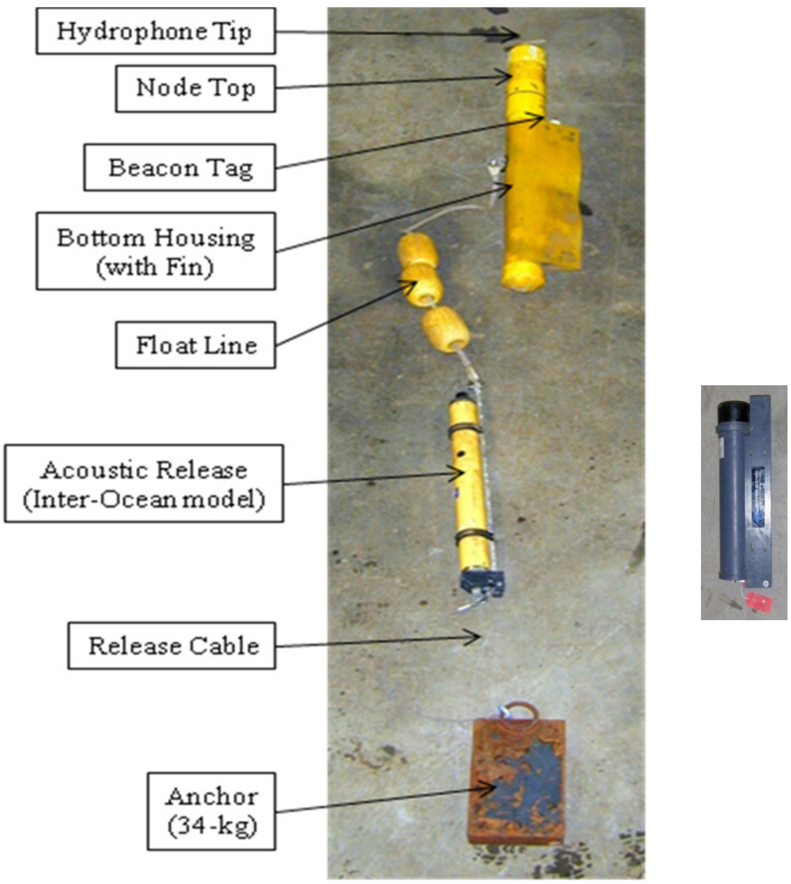


Figure 2.13. Autonomous node deployment rigging (left) and teledyne acoustic release (right).

Autonomous nodes were recovered, serviced, and redeployed individually by boat, once every 2 wk. Batteries only needed to be changed out once every 4 wk. Node recovery began with communicating with the attached acoustic release, by sending a release-specific acoustic code into the river through a transducer connected to a mobile command module. Upon successful receipt of this coded signal, the release’s latch mechanism is triggered to open, freeing the node and acoustic release device to rise to the water’s surface for retrieval into the boat. Each node servicing included recording a node’s internal clock time drift for the deployment period, downloading collected data, syncing the node clock back to the correct satellite time, and confirming each node’s proper functionality before redeploying it. Data files were also checked to verify that data were collected during the entire deployment, records were continuous, and records included time stamps and beacon tag detections. If any operational issues or data corruption were noticed, the node top was replaced, and the suspect node top was tested in a laboratory tank, before it was sent back to Sonic Concepts for repair. The most common problems experienced during the field study included damage to the relatively delicate hydrophone tip, poor communication with the Teledyne acoustic releases in high water flow tailraces, and acoustic releases getting buried by sand waves at arrays downstream of BON.

For the 2011 survival studies, all autonomous node arrays were deployed and collecting data by April 25, and they were serviced through the end of June, to ensure data acquisition for the entire period that implanted acoustic tags would still be transmitting. Node arrays were also deployed for additional data collection from July through the end of October, in support of the 2011 lamprey survival study conducted for the CENWP by University of Idaho.

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-min increments by the automated data-acquisition systems at BON and provided by the CENWP. 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-yr averages.

2.8 Acoustic Signal Processing

Data collected by the JSATS cabled hydrophones were encoded candidate messages saved in binary time-domain waveform files. Figure 2.14 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 (JSATS Decoder 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 (Weiland et al. 2011). Several filtering algorithms were then applied to the raw results from the decoding utilities to exclude spurious data and false positives.

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's North Bonneville offices for processing. Tag-detection data from JSATS autonomous nodes were processed by two independent groups using standardized methods as a quality-control measure as in previous studies (Ploskey et al. 2007, 2008). 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 s 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 s was the maximum acceptance window width for evaluating a pulse rate interval (PRI) and was computed as 2(PRI_Window+12×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 s because receptions on separate hydrophones within 0.3 s (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 s. 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.

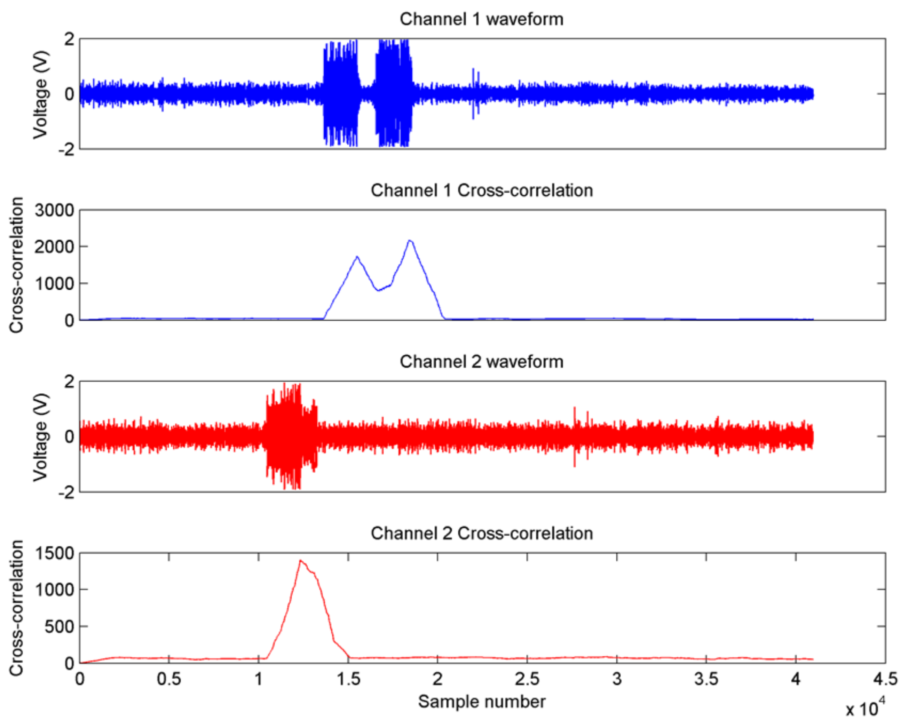


Figure 2.14. Example of time-domain waveforms and corresponding cross-correlations acquired at the John Day Dam spillway during a 2008 study. The message portion was 1,860 samples (744 µs long). Note that multipath components were present in both channels. Decodes from the multipath components were filtered out in post-processing.

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**. 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 were retained. Each tag

code was processed individually, and it was assumed that only a single tag would be transmitting that code at any given time. At least four messages passing the PRI filter were required for an acceptable tag-detection event.

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 during 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 capture specialized information, where available. One such example was route of passage, which was assigned a value for those events that immediately precede 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 position 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 more 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.

Three-dimensional tracking of JSATS-tagged fish in the immediate forebay of TDA was used to determine routes of passage, to estimate passage efficiencies and horizontal distribution of passage, as well as forebay approach and forebay vertical distributions (Deng et al. 2011a). 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 two-dimensional (2D) tracking and a four-hydrophone array for 3D tracking. For this study, only 3D tracking was performed.

2.9 Statistical Methods

Statistical methods were used to test assumptions and estimate passage survival, tag life, forebay-to-tailrace survival, travel times, SPE, spill+B2CC passage efficiency, and FPE.

2.9.1 Tests of Assumptions

Approaches to assumption testing are described below.

2.9.1.1 Burnham et al. (1987) Tests

Tests 2 and 3 (T2 and T3) 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.

2.9.1.2 Tests of Mixing

Evaluation of the 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.

2.9.1.3 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 were evaluated. 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

$$F_{k-1,\infty} = \frac{s_{\hat{S}}^2}{\left(\dfrac{\sum_{i=1}^{k} \widehat{\mathrm{Var}}\left(\hat{S}_i \middle| S_i\right)}{k} \right)} \tag{2.1}$$

where

$$s_{\hat{S}}^2 = \frac{\sum_{i=1}^{k} \left(\hat{S}_i - \hat{\bar{S}}\right)^2}{k-1} \tag{2.2}$$

and

$$\hat{\bar{S}} = \frac{\sum_{i=1}^{k} \hat{S}_i}{k} \tag{2.3}$$

The F-test was used in evaluating tagger effects as well as tag-lot effects.

2.9.2 Tag-Life Analysis

For each of the three major manufacturing lots of JSATS tags (i.e., 1, 2, 3–5), 50–59 acoustic tags were systematically sampled over the course of the yearling Chinook salmon and steelhead smolt tagging process. The tags were continuously monitored from activation to failure in ambient river water. For each tag lot, the failure times were fit to the four-parameter vitality model of Li and Anderson (2009). The vitality model tends to fit acoustic-tag failure times well, because it allows for both early onset of random failure due to manufacturing as well as systematic battery failure later on.

The survivorship function for the vitality model can be rewritten as

$$S(t)=1-\left(\Phi\left(\frac{1-rt}{\sqrt{u^2+s^2t}}\right)-e^{\left(\frac{2u^2r^2}{s^4}+\frac{2r}{s^2}\right)}\Phi\left(\frac{2u^2r+rt+1}{\sqrt{u^2+s^2t}}\right)\right)^{e^{-kt}} \tag{2.4}$$

where Φ = cumulative normal distribution
r = average wear rate of components
s = standard deviation in wear rate
k = rate of accidental failure
u = standard deviation in quality of original components.

The random failure component, in addition to battery discharge, gives the vitality model additional latitude to fit tag-life data not found in other failure-time distributions such as the Weibull or Gompertz. Parameter estimation was based on maximum likelihood estimation.

For the virtual-release group (V_1) based on fish known to have arrived at the dam and with active tags, the conditional probability of tag activation, given the tag was active at the detection array at rkm 349, was used in the tag-life adjustment for that release group. The conditional probability of tag activation at time t_1, given it was active at time t_0, was computed by the following quotient:

$$P\left(t_1 \middle| t_0\right)=\frac{S(t_1)}{S(t_0)}. \tag{2.5}$$

2.9.3 Estimation of Passage Survival

Maximum likelihood estimation was used to estimate dam passage survival at BON based on the virtual/paired-release design. The capture histories from all the replicate releases, both daytime and nighttime, were pooled to produce the estimate of dam passage survival. A joint likelihood model was constructed of a product multinomial with separate multinomial distributions describing the capture histories of the separate release groups (i.e., V_1, R_2, and R_3) and differentiated by tag lot. The major manufacturing lots (i.e., 1, 2, 3–5) had separately estimated tag-life corrections, but we assumed that all fish from a release location had common reach survival parameters.

The joint likelihood used to model the three release groups was initially fully parameterized. Each of the three releases was allowed to have unique survival and detection parameters. If precision was adequate (i.e., SE ≤0.015) with the fully parameterized model, no further modeling was performed. If initial precision was inadequate, then likelihood ratio tests were used to assess the homogeneity of parameters across release groups to identify the best parsimonious model to describe the capture-history data. This approach was used to help preserve both precision and robustness of the survival results. All calculations were performed using Program ATLAS (Active Tag-Life Adjusted Survival; Lady et al. 2010, http://www.cbr.washington.edu/paramest/atlas/).

Dam passage survival was estimated by the function

$$\hat{S}_{\text{Dam}} = \frac{\hat{S}_1}{\left(\dfrac{\hat{S}_2}{\hat{S}_3}\right)} = \frac{\hat{S}_1 \cdot \hat{S}_3}{\hat{S}_2} \tag{2.6}$$

where $\hat{S}_i$ is the tag-life-corrected survival estimate for the *i*th release group $(i = 1,\ldots,3)$. The variance of $\hat{S}_{\text{Dam}}$ was estimated in a two-step process that incorporated both the uncertainty in the tag-life corrections and the release-recapture processes.

In 2011, the compliance test at BON was disrupted by high flow conditions in late spring. Consequently, a post facto approach to examining dam passage survival during spring 2011 was necessary. Two alternative estimates of dam passage survival were computed as follows:

1. Survival during early period (April 30–May 13, 2011)
2. Survival during entire season, including high flows (April 30–May 31, 2011).

In estimating dam passage survival during a particular segment of the study, all fish in releases R_2 and R_3 (see Figure 2.1) during the period were used in the analyses.

Route-specific survivals were estimated analogously to dam passage survival (Equation 2.6), except that the virtual release (V_1) was formed by regrouping fish known to have passed through a specific route.

2.9.4 Estimation of Forebay-to-Tailrace Survival

The same virtual/paired-release methods used to estimate dam passage were also used to estimate forebay-to-tailrace survival (Figure 2.1). The only distinction was the virtual-release group (V_1) was composed of fish known to have arrived alive at the forebay array (rkm 236) of BON instead of at the dam face.

2.9.5 Estimation of Travel Times

Travel times associated with forebay residence time and tailrace egress were estimated using arithmetic averages as specified in the Fish Accords, i.e.,

$$\bar{t} = \frac{\sum_{i=1}^{n} t_i}{n}, \tag{2.7}$$

with the variance of $\bar{t}$ estimated by

$$\widehat{\text{Var}}(\bar{t}) = \frac{\sum_{i=1}^{n} (t_i - \bar{t})^2}{n(n-1)}, \tag{2.8}$$

and where t_i was the travel time of the ith fish $(i=1,\ldots,n)$. Median travel times were also computed and reported.

Tailrace egress time was calculated by subtracting the time of last detection of a fish on the dam-face array (rkm 234) from its time of last detection on the tailrace array (rkm 233). Forebay residence time was calculated by subtracting the time of first detection of a fish on the forebay entrance array (rkm 236) from the time of last detection on the dam-face array (rkm 234). For forebay residence time and tailrace egress time, we estimated the mean, standard error, and median travel times.

2.9.6 Estimation of Spill Passage Efficiency

Spill passage efficiency was estimated by the fraction

$$\widehat{\mathrm{SPE}} = \frac{\hat{N}_{SP}}{\hat{N}_{B1SL} + \hat{N}_{B1T} + \hat{N}_{SP} + \hat{N}_{B2CC} + \hat{N}_{B2T} + \hat{N}_{B2JBS}}, \tag{2.9}$$

where $\hat{N}_i$ is the estimated abundance of acoustic-tagged fish through the ith route (i = B1 sluiceway [B1SL], B1 turbines [B1T], spillway [SP], B2CC, B2 JBS, and B2 turbines [B2T]). The double-detection array was used to estimate absolute abundance (N) through every route using the single mark-recapture model (Seber 1982:60) independently at each route. Calculating the variance in stages, the variance of $\widehat{\mathrm{SPE}}$ was estimated as

$$\mathrm{Var}\left(\widehat{\mathrm{SPE}}\right) = \frac{\mathrm{SPE}(1-\mathrm{SPE})}{\sum_{i=1}^{6} N_i} + \mathrm{SPE}^2(1-\mathrm{SPE})^2 \cdot \left[\frac{\mathrm{Var}\left(\hat{N}_{SP}\right)}{\left(\hat{N}_{SP}\right)^2} + \frac{\mathrm{Var}\left(\hat{N}_{B1SL}\right) + \mathrm{Var}\left(\hat{N}_{B1T}\right) + \mathrm{Var}\left(\hat{N}_{B2CC}\right) + \mathrm{Var}\left(\hat{N}_{B2T}\right) + \mathrm{Var}\left(\hat{N}_{B2JBS}\right)}{\left(\hat{N}_{B1SL} + \hat{N}_{B1T} + \hat{N}_{B2CC} + \hat{N}_{B2T} + \hat{N}_{B2JBS}\right)^2} \right]. \tag{2.10}$$

2.9.7 Estimation of Spill+B2CC Passage Efficiency

Spill+B2CC passage efficiency was estimated by the fraction

$$\widehat{\mathrm{SPE}_2} = \frac{\hat{N}_{SP} + \hat{N}_{B2CC}}{\hat{N}_{B1SL} + \hat{N}_{B1T} + \hat{N}_{SP} + \hat{N}_{B2CC} + \hat{N}_{B2T} + \hat{N}_{B2JBS}}. \tag{2.11}$$

The double-detection array was used to estimate absolute abundance (N) through a route using the single mark-recapture model (Seber 1982:60) independently at each route. Calculating the variance in stages, the variance of $\widehat{\mathrm{SPE}}_2$ was estimated as

$$\mathrm{Var}\left(\mathrm{SPE}_2\right)=\frac{\mathrm{SPE}_2\left(1-\mathrm{SPE}_2\right)}{\sum_{i=1}^{6}\hat{N}_i}+\mathrm{SPE}_2^2\left(1-\mathrm{SPE}_2\right)^2\cdot$$

$$\cdot\left[\frac{\mathrm{Var}\left(\hat{N}_{SP}\right)+\mathrm{Var}\left(\hat{N}_{B2CC}\right)}{\left(N_{SP}+N_{B2CC}\right)^2}+\frac{\mathrm{Var}\left(\hat{N}_{B1SL}\right)+\mathrm{Var}\left(\hat{N}_{B1T}\right)+\mathrm{Var}\left(\hat{N}_{B2T}\right)+\mathrm{Var}\left(\hat{N}_{B2JBS}\right)}{\left(N_{B1SL}+N_{B1T}+N_{B2T}+N_{B2JBS}\right)^2}\right]. \tag{2.12}$$

2.9.8 Estimation of Fish Passage Efficiency

Fish passage efficiency was estimated by the fraction

$$\widehat{\mathrm{FPE}}=\frac{\hat{N}_{B1SL}+\hat{N}_{SP}+\hat{N}_{B2CC}+\hat{N}_{B2JBS}}{\hat{N}_{B1SL}+\hat{N}_{B1T}+\hat{N}_{SP}+\hat{N}_{B2CC}+\hat{N}_{B2T}+\hat{N}_{B2JBS}}. \tag{2.13}$$

The double-detection array was used to estimate absolute abundance (N) through a route using the single mark-recapture model (Seber 1982:60) independently at each route. Calculating the variance in stages, the variance of $\widehat{\mathrm{FPE}}$ was estimated as

$$\mathrm{Var}\left(\widehat{\mathrm{FPE}}\right)=\frac{\mathrm{FPE}\left(1-\mathrm{FPE}\right)}{\sum_{i=1}^{6}N_i}+\mathrm{FPE}^2\left(1-\mathrm{FPE}\right)^2$$

$$\cdot\left[\frac{\mathrm{Var}\left(\hat{N}_{B1SL}\right)+\mathrm{Var}\left(\hat{N}_{SP}\right)+\mathrm{Var}\left(\hat{N}_{B2CC}\right)+\mathrm{Var}\left(\hat{N}_{B2JBS}\right)}{\left(\hat{N}_{B1SL}+\hat{N}_{SP}+\hat{N}_{B2CC}+\hat{N}_{B2JBS}\right)^2}+\frac{\mathrm{Var}\left(\hat{N}_{B1T}\right)+\mathrm{Var}\left(\hat{N}_{B2T}\right)}{\left(\hat{N}_{B1T}+\hat{N}_{B2T}\right)^2}\right]. \tag{2.14}$$

Point estimates and standard errors for SPE, spill+B2CC efficiency, and FPE in this report differ slightly from estimates and errors reported in the BON 2011 BiOp compliance report (Skalski et al. 2012), because estimates in this report were based on the absolute numbers of fish passing through each route. Absolute numbers were calculated from raw numbers of fish and the combined detection efficiency of the two independent arrays of hydrophones sampling each route. In contrast, passage efficiencies and associated variances in the BON compliance report for spring 2011 (Skalski et al. 2012) were calculated from raw counts of fish passing each route, assuming that every route had 100% detection efficiency, to expedite the BiOp reporting process. Those calculations only require the raw counts by route and the first term of the variance formulas described above. The second term in the variance formulas listed above calculates additional variance related to adjustments for array detection efficiency. The only route with less than 100% detection efficiency in 2011 was the spillway (95.57% for CH1 and 95.20% for STH).

2.9.9 B1 Sluiceway Passage Efficiency

The B1 sluiceway passage efficiency relative to the entire dam was estimated by the fraction

$$\widehat{\text{B1SL}} = \frac{\hat{N}_{B1SL}}{\hat{N}_{B1SL} + \hat{N}_{B1T} + \hat{N}_{SP} + \hat{N}_{B2CC} + \hat{N}_{B2T} + \hat{N}_{B2JBS}}, \tag{2.15}$$

The double-detection array was used to estimate absolute abundance (N) through a route using the single mark-recapture model (Seber 1982:60) independently at each route. Calculating the variance in stages, the variance of $\widehat{\text{B1SL}}$ was estimated as

$$\text{Var}\left(\widehat{\text{B1SL}}\right) = \frac{\text{B1SL}(1-\text{B1SL})}{\sum_{i=1}^{6} N_i} + \text{B1SL}^2(1-\text{B1SL})^2 \cdot \left[\frac{\text{Var}\left(\hat{N}_{B1SL}\right)}{\left(\hat{N}_{B1SL}\right)^2} + \frac{\text{Var}\left(\hat{N}_{B1T}\right) + \text{Var}\left(\hat{N}_{SP}\right) + \text{Var}\left(\hat{N}_{B2CC}\right) + \text{Var}\left(\hat{N}_{B2T}\right) + \text{Var}\left(\hat{N}_{B2JBS}\right)}{\left(\hat{N}_{B1T} + \hat{N}_{SP} + \hat{N}_{B2CC} + \hat{N}_{B2T} + \hat{N}_{B2JBS}\right)^2}\right]. \tag{2.16}$$

2.9.10 B2CC Passage Efficiency

The B2CC passage efficiency relative to the entire dam was estimated by the fraction

$$\widehat{\text{B2CC}} = \frac{\hat{N}_{B2CC}}{\hat{N}_{B1SL} + \hat{N}_{B1T} + \hat{N}_{SP} + \hat{N}_{B2CC} + \hat{N}_{B2T} + \hat{N}_{B2JBS}}, \tag{2.17}$$

The double-detection array was used to estimate absolute abundance (N) through a route using the single mark-recapture model (Seber 1982:60) independently at each route. Calculating the variance in stages, the variance of B2CC passage efficiency was estimated as

$$\text{Var}\left(\widehat{\text{B2CC}}\right) = \frac{\text{B2CC}(1-\text{B2CC})}{\sum_{i=1}^{6} N_i} + \text{B2CC}^2(1-\text{B2CC})^2 \cdot \left[\frac{\text{Var}\left(\hat{N}_{B2CC}\right)}{\left(\hat{N}_{B2CC}\right)^2} + \frac{\text{Var}\left(\hat{N}_{B1SL}\right) + \text{Var}\left(\hat{N}_{B1T}\right) + \text{Var}\left(\hat{N}_{SP}\right) + \text{Var}\left(\hat{N}_{B2T}\right) + \text{Var}\left(\hat{N}_{B2JBS}\right)}{\left(N_{B1SL} + N_{B1T} + N_{SP} + N_{B2T} + N_{B2JBS}\right)^2}\right]. \tag{2.18}$$

2.9.11 B2 JBS Passage Efficiency

The B2 JBS passage efficiency relative to the entire dam was estimated by the fraction

$$\widehat{\text{B2JBS}} = \frac{\hat{N}_{\text{B2JBS}}}{\hat{N}_{B1SL} + \hat{N}_{B1T} + \hat{N}_{SP} + \hat{N}_{B2CC} + \hat{N}_{B2T} + \hat{N}_{B2JBS}}, \tag{2.19}$$

The double-detection array was used to estimate absolute abundance (N) through a route using the single mark-recapture model (Seber 1982:60) independently at each route. Calculating the variance in stages, the variance of B2CC passage efficiency was estimated as

$$\mathrm{Var}\left(\widehat{\mathrm{B2JBS}}\right)=\frac{\widehat{\mathrm{B2JBS}}\left(1-\widehat{\mathrm{B2JBS}}\right)}{\sum_{i=1}^{6}N_i}+\widehat{\mathrm{B2JBS}}^2\left(1-\widehat{\mathrm{B2JBS}}\right)^2$$

$$\cdot\left[\frac{\mathrm{Var}\left(\hat{N}_{\mathrm{B2JBS}}\right)}{\left(\hat{N}_{\mathrm{B2JBS}}\right)^2}+\frac{\mathrm{Var}\left(\hat{N}_{B1SL}\right)+\mathrm{Var}\left(\hat{N}_{B1T}\right)+\mathrm{Var}\left(\hat{N}_{SP}\right)+\mathrm{Var}\left(\hat{N}_{B2CC}\right)+\mathrm{Var}\left(\hat{N}_{B2T}\right)}{\left(\hat{N}_{B1SL}+\hat{N}_{B1T}+\hat{N}_{SP}+\hat{N}_{B2CC}+\hat{N}_{B2T}\right)^2}\right]. \quad (2.20)$$

2.9.12 Turbine Passage Efficiencies

Although not routinely used, we calculated B1 turbine passage efficiency and its associated variance relative to the entire dam and B2 turbine passage efficiency and its variance relative to the entire dam using pairs of equations like those used for other routes (e.g., see Equations 2.19 and 2.20 above).

2.9.13 Passage Efficiencies Relative to a Local Dam

The B1 sluiceway passage efficiency relative to B1 was estimated by the fraction

$$\widehat{\mathrm{B1SL}}_{\mathrm{B1}}=\frac{\hat{N}_{B1SL}}{\hat{N}_{B1SL}+\hat{N}_{B1T}}, \quad (2.21)$$

The double-detection array was used to estimate absolute abundance (N) through a route using the single mark-recapture model (Seber 1982:60) independently at each route. Calculating the variance in stages, the variance of $\widehat{\mathrm{B1SL}}_{\mathrm{B1}}$ was estimated as

$$\mathrm{Var}\left(\widehat{\mathrm{B1SL}}_{\mathrm{B1}}\right)=\frac{\widehat{\mathrm{B1SL}}_{\mathrm{B1}}\left(1-\widehat{\mathrm{B1SL}}_{\mathrm{B1}}\right)}{\sum_{i=1}^{2}N_i}+\widehat{\mathrm{B1SL}}_{\mathrm{B1}}^2\left(1-\widehat{\mathrm{B1SL}}_{\mathrm{B1}}\right)^2$$

$$\cdot\left[\frac{\mathrm{Var}\left(\hat{N}_{B1SL}\right)}{\left(\hat{N}_{B1SL}\right)^2}+\frac{\mathrm{Var}\left(\hat{N}_{B1T}\right)}{\left(\hat{N}_{B2T}\right)^2}\right]. \quad (2.22)$$

The B2CC passage efficiency relative to B2 was estimated by the fraction

$$\widehat{\mathrm{B2CC}}_{\mathrm{B2}}=\frac{\hat{N}_{B2CC}}{\hat{N}_{B2CC}+\hat{N}_{B2T}+\hat{N}_{B2JBS}}, \quad (2.23)$$

The double-detection array was used to estimate absolute abundance (*N*) through a route using the single mark-recapture model (Seber 1982:60) independently at each route. Calculating the variance in stages, the variance of $\widehat{\mathrm{B2CC}_{\mathrm{B2}}}$ was estimated as

$$\mathrm{Var}\left(\widehat{\mathrm{B2CC}_{\mathrm{B2}}}\right)=\frac{\widehat{\mathrm{B2CC}_{\mathrm{B2}}}\left(1-\widehat{\mathrm{B2CC}_{\mathrm{B2}}}\right)}{\sum_{i=1}^{3}N_i}+\widehat{\mathrm{B2CC}_{\mathrm{B2}}}^{2}\left(1-\widehat{\mathrm{B2CC}_{\mathrm{B2}}}\right)^{2}$$
$$\cdot\left[\frac{\mathrm{Var}\left(\hat{N}_{B2CC}\right)}{\left(\hat{N}_{B2CC}\right)^{2}}+\frac{\mathrm{Var}\left(\hat{N}_{B2T}\right)+\mathrm{Var}\left(\hat{N}_{B2JBS}\right)}{\left(\hat{N}_{B2T}+\hat{N}_{B2JBS}\right)^{2}}\right]. \tag{2.24}$$

The B2 JBS passage efficiency relative to B2 was estimated by the fraction

$$\widehat{\mathrm{B2JBS}_{\mathrm{B2}}}=\frac{\hat{N}_{B2JBS}}{\hat{N}_{B2CC}+\hat{N}_{B2T}+\hat{N}_{B2JBS}}, \tag{2.25}$$

The double-detection array was used to estimate absolute abundance (*N*) through a route using the single mark-recapture model (Seber 1982:60) independently at each route. Calculating the variance in stages, the variance of $\widehat{\mathrm{B2CC}_{\mathrm{B2}}}$ was estimated as

$$\mathrm{Var}\left(\widehat{\mathrm{B2JBS}_{\mathrm{B2}}}\right)=\frac{\widehat{\mathrm{B2JBS}_{\mathrm{B2}}}\left(1-\widehat{\mathrm{B2JBS}_{\mathrm{B2}}}\right)}{\sum_{i=1}^{3}N_i}+\widehat{\mathrm{B2JBS}_{\mathrm{B2}}}^{2}\left(1-\widehat{\mathrm{B2JBS}_{\mathrm{B2}}}\right)^{2}$$
$$\cdot\left[\frac{\mathrm{Var}\left(\hat{N}_{B2JBS}\right)}{\left(\hat{N}_{B2JBS}\right)^{2}}+\frac{\mathrm{Var}\left(\hat{N}_{B2CC}\right)+\mathrm{Var}\left(\hat{N}_{B2T}\right)}{\left(\hat{N}_{B2CC}+\hat{N}_{B2T}\right)^{2}}\right]. \tag{2.26}$$

The B2 fish guidance efficiency (B2FGE) was estimated by the fraction

$$\widehat{\mathrm{B2FGE}}=\frac{\hat{N}_{B2JBS}}{\hat{N}_{B2T}+\hat{N}_{B2JBS}}, \tag{2.27}$$

The double-detection array was used to estimate absolute abundance (*N*) through a route using the single mark-recapture model (Seber 1982:60) independently at each route. Calculating the variance in stages, the variance of $\widehat{\mathrm{B2FGE}}$ was estimated as

$$\mathrm{Var}\left(\widehat{\mathrm{B2FGE}}\right)=\frac{\widehat{\mathrm{B2FGE}}\left(1-\widehat{\mathrm{B2FGE}}\right)}{\sum_{i=1}^{2}N_i}+\widehat{\mathrm{B2FGE}}^{2}\left(1-\widehat{\mathrm{B2FGE}}\right)^{2}$$
$$\cdot\left[\frac{\mathrm{Var}\left(\hat{N}_{B2JBS}\right)}{\left(\hat{N}_{B2JBS}\right)^{2}}+\frac{\mathrm{Var}\left(\hat{N}_{B2T}\right)}{\left(\hat{N}_{B2T}\right)^{2}}\right]. \tag{2.28}$$

2.9.14 Estimation of Passage Distributions

The 2D and 3D tracks (end of Section 2.8) were used to determine forebay approach distributions and horizontal distributions of passage through the dam. Bonneville Dam provides a unique setting in which 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. Median depths of fish approaching B1, the spillway, and B2 were plotted for the entire spring season and for daytime and nighttime periods in spring. Depths of individual fish approaching B1 turbines with open sluiceway outlets above them were carefully tracked, and fish above an elevation located 65 ft above MSL were assigned to the sluiceway whereas deeper fish were assigned to turbine passage.

3.0 Results – Environmental Conditions

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

3.1 River Discharge

The daily total discharge at BON during the first part of the JSATS survival study (April 30–May 13, 2011) ranged from 231 to 333 kcfs and averaged 272.3 kcfs. During the latter part (May 14–31, 2011) discharge was between 358 and 506 kcfs, averaging 465 kcfs. Total water discharge at BON in 2011 fluctuated between 231 and 506 kcfs and averaged 381 kcfs during the entire tagging period (Figure 3.1). These levels were consistently above the previous 10-yr average. Starting May 13, discharge increased sharply to levels approaching 500 kcfs and remained for the last week of the tagging period, peaking at 506 kcfs on May 30.

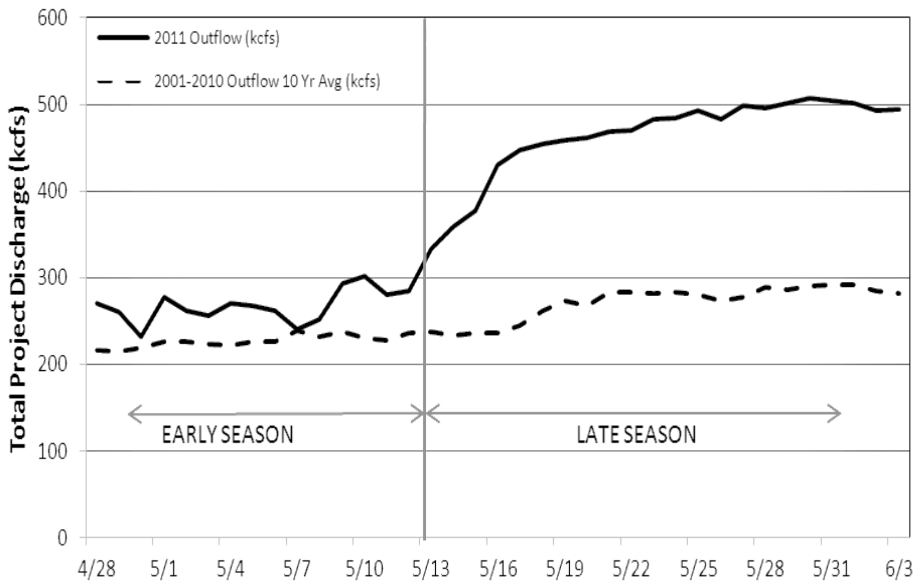


Figure 3.1. Average daily water discharge (kcfs) from Bonneville Dam during the 2011 study and for the preceding 10-yr (2001–2010) period.

Daily spill discharge was within 25 kcfs of the average for the previous 10 yr during the early season of the study until May 13, and averaged 153 kcfs above normal between May 14 and 31 (Figure 3.2).

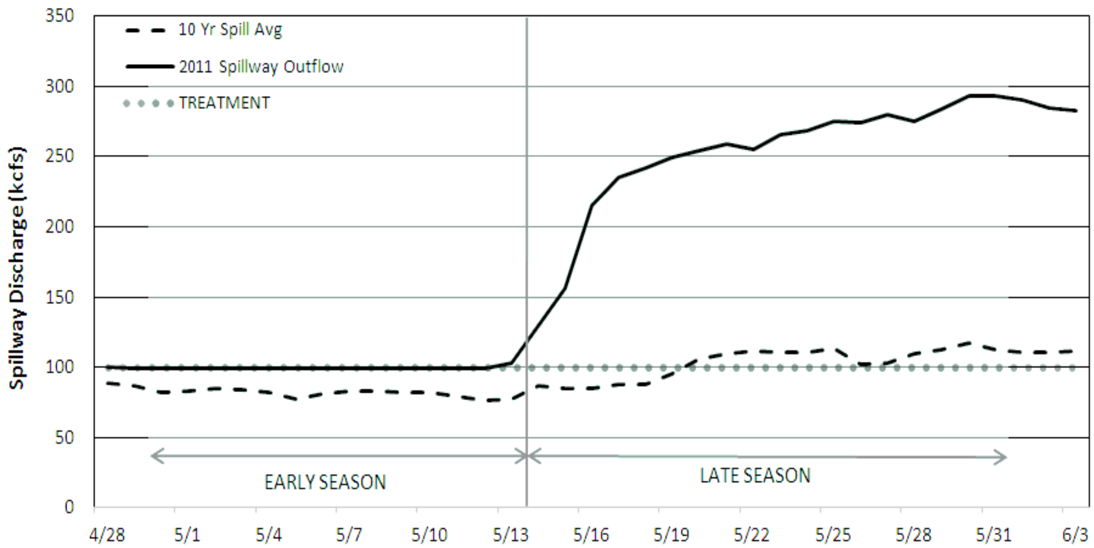


Figure 3.2. Daily spill discharge of water from Bonneville Dam for the period from April 30 through May 31, 2011 (labeled outflow and spill) and 10-yr averages from 2001 through 2010.

3.2 Water Temperature

The daily average water temperature for 2011 started at 9.5°C on April 30, below the previous 10-yr average of 10.9°C (Figure 3.3). Temperatures steadily increased throughout the study, but by the end of the spring tagging season 2011 temperatures were ~2.0°C below the 10-yr average. This trend continued through the end of May.

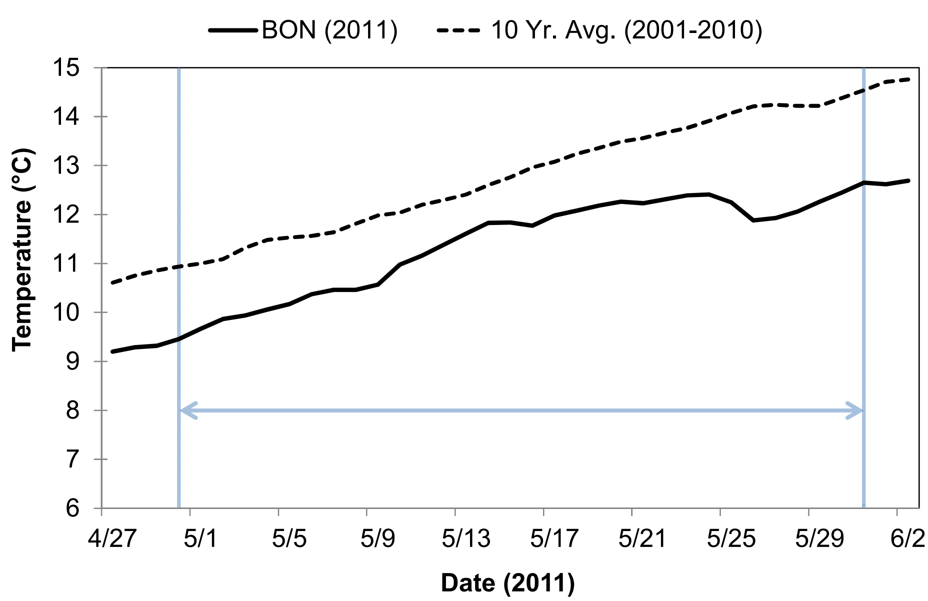


Figure 3.3. Bonneville Dam average daily forebay water temperatures (°C) during the 2011 study and for the preceding 10-yr period.

3.3 Forebay Elevation

In 2011, forebay elevation ranged from 71.60 to 75.33 ft and averaged 73.36 ft above MSL. The median elevation was 73.29 (Figure 3.4).

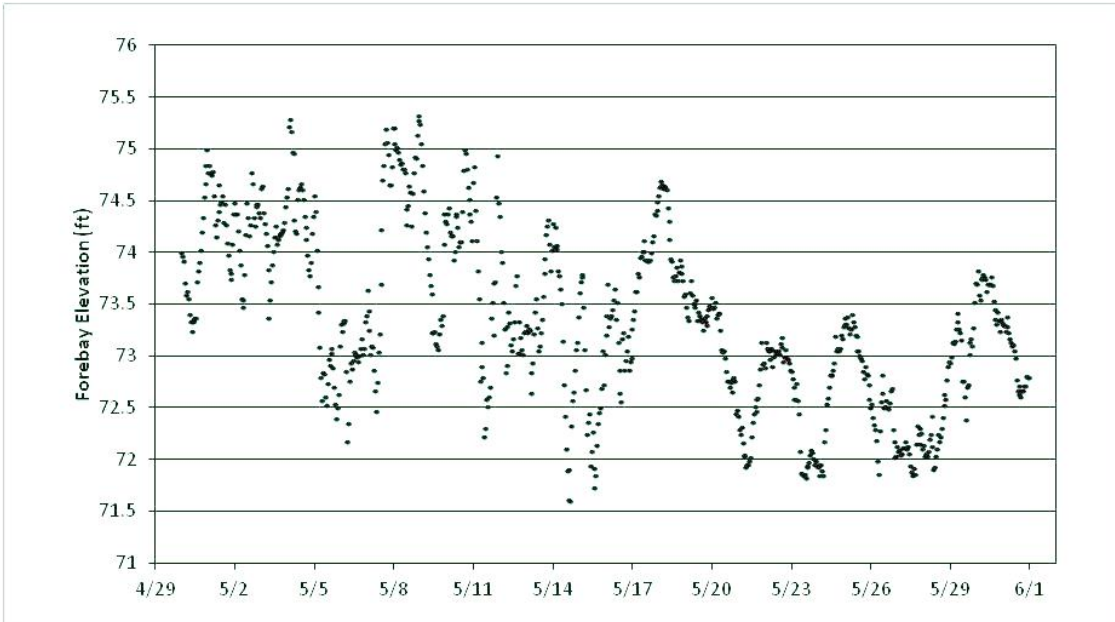


Figure 3.4. Bonneville Dam hourly estimates of forebay elevation. Elevation is in feet above MSL.

3.4 Run Timing

The cumulative percent of CH1 and STH that had passed BON by date was calculated from smolt index data obtained from the Fish Passage Center at BON (Figure 3.5). From April 27 through May 13, 2011, when operators were able to hold spill to 100 kcfs, 68.4% of CH1 and 52.2% of STH had passed BON. By the end of the study on May 31, 2011, 98.6% of CH1 and 91.4% of STH had passed BON.

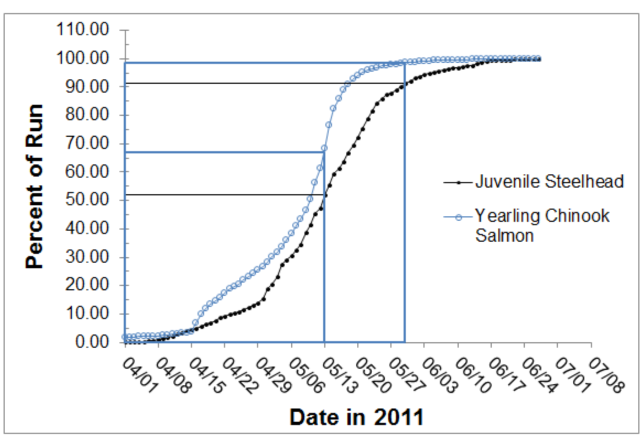


Figure 3.5. Plots of the cumulative percent of juvenile steelhead and yearling Chinook salmon that had passed Bonneville Dam in 2011.

3.5 Assessment of Assumptions

The assessment of assumptions covers tagger effects, tag-lot effects, delayed handling effects, fish size distributions, tag-life corrections, arrival distributions, and downstream mixing.

3.5.1 Examination of Tagger Effects

A total of eight different taggers assisted in tagging all CH1 and STH associated with the JSATS survival studies at JDA, TDA, and BON in spring 2011. Analyses found tagger effort was homogeneously distributed either across all locations within a replicate release or within the project-specific releases within a replicate (Appendix A). Examination of reach survivals and cumulative survivals from above JDA to below BON found no consistent or reproducible evidence that fish tagged by different staff members had different in-river survival rates (Appendix A). Therefore, fish tagged by all taggers were included in the estimation of survival and other performance measures.

3.5.2 Examination of Tag-Lot Effects

Three major tag lots (i.e., 1, 2, and 3–5) were used in the tagging of the CH1 and STH during the 2011 JSATS investigations. Overall, tag lots were not homogeneously distributed across all release locations (Appendix A). However, they were homogeneously distributed within each of the below-dam paired releases (i.e., R_2–R_3, R_4–R_5, and R_6–R_7) used in the virtual/paired-release design (Appendix A).

After correcting for differences in tag life, there was no consistent or reproducible evidence to indicate differences in survival for fish tagged by the different tag lots. Therefore, fish tagged from all tag lots were used in the estimation of survival and other performance measures.

3.5.3 Handling Mortality and Tag Shedding

Fish were held for 24 to 36 h prior to release. The pre-release tagging mortality in spring was 0.31% for CH1 and 0.08% for STH. No tags were shed during the 24-h holding period.

3.5.4 Examination of Tailrace Release Location Effects on Survival

We explored the distribution of weighted detections of dam-passed fish (V_1 in Figure 2.1) on tailrace autonomous nodes relative to the distribution of reference releases among five locations in the tailrace, and examined the effect of tailrace release location on single-release survival rates to an array near Vancouver, Washington, at rkm 161 (Figure 3.6). The percent of fish detected on three autonomous nodes in the Bonneville tailrace was weighted to equalize sampling effort among node locations. Sampling effort varied because some nodes stopped sampling prematurely because of damage or they were lost. Detectability, as indicated by the percent of detections that only had the minimum number of hits, did not vary among the tailrace locations.

The uniform distribution of fish releases among five locations in the tailrace appeared to be reasonable given the observed distribution of detections of dam-passed fish (V_1 in Figure 2.1) weighted only for sampling effort (Figure 3.6). Fish that passed the dam were detected at only a slightly higher percentage on the middle node than on nodes on either side of the channel. Survival rates to Vancouver varied from 0.982 to 0.992 for CH1 and from 0.945 to 0.991 for STH. Wide and overlapping 95% CIs suggest that point estimates of survival rates did not differ significantly among release locations. Low precision is expected given sample sizes of about 150 fish per location over the study season.

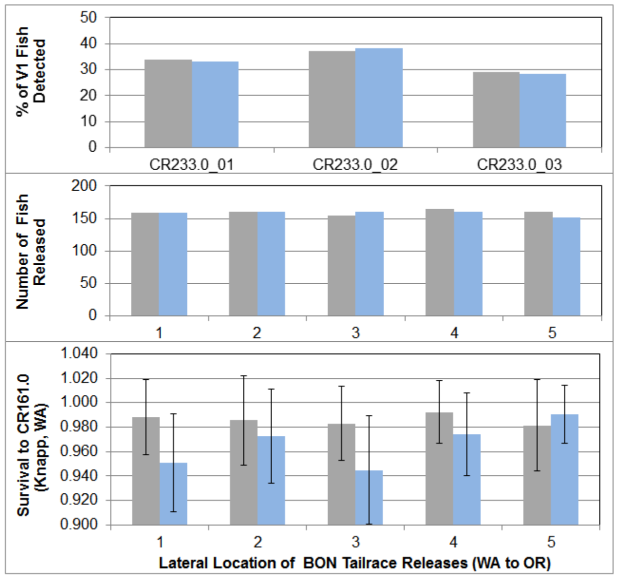


Figure 3.6. Distributions of tailrace detections of V_1 fish (see Figure 2.1) on autonomous nodes (top), numbers of fish released in the tailrace at five locations (middle), and survival rates by tailrace release location (bottom). Gray bars are for CH1; blue bars are for STH; vertical bars are 95% CIs on survival estimates.

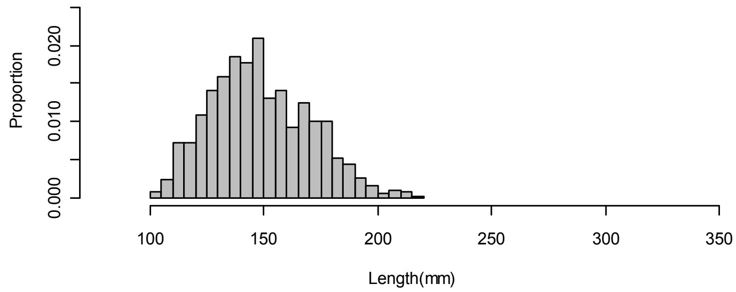
3.5.5 Examination of Time In-River on Survivals of Different Release Groups

The virtual release formed from the detections of upriver releases at the face of the dam could result in biased survival estimates if fish from varying upriver release locations had differential downriver survival rates. For this reason, reach survivals and cumulative survivals were compared across fish from different upriver release locations. There was no consistent or reproducible evidence to suggest that the amount of time (i.e., distance) in river had a subsequent effect on downriver survival for either CH1 or STH (Appendix A). Therefore, in constructing the virtual releases at the face of the dam, fish from all available upriver release locations were used in subsequent survival and other parameter estimation.

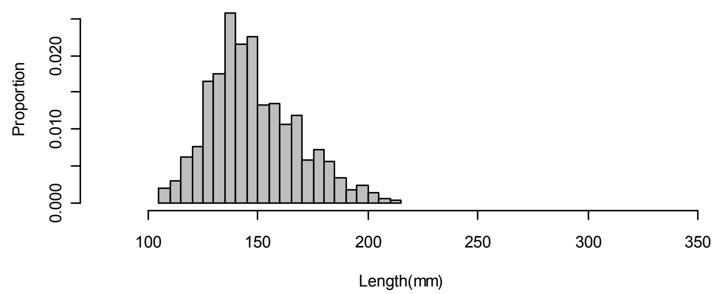
3.5.6 Fish Size Distribution

Comparison of JSATS-tagged fish with ROR fish sampled at JDA through the Smolt Monitoring Program shows that the length frequency distributions were generally well matched for CH1 (Figure 3.7) and STH (Figure 3.8). The length distributions for the three CH1 releases (Figure 3.7) and the three STH releases (Figure 3.8) were quite similar. Mean lengths for the acoustic-tagged CH1 and STH were 148.5 mm and 203.2 mm, respectively. Mean lengths for CH1 and STH sampled by the Fish Passage Center at the BON juvenile monitoring facility (JMF) were 145.4 mm and 207.2 mm, respectively. Fish size did not change over the course of the study (Figure 3.9).

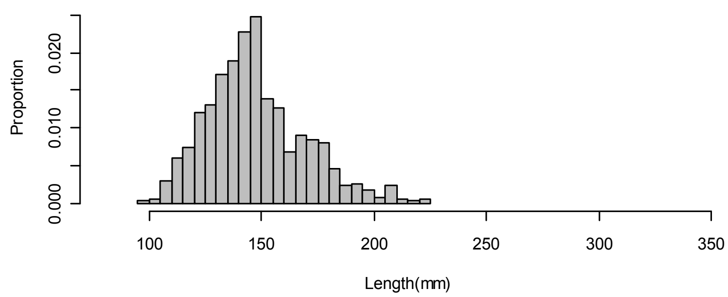
(a) Bonneville Dam (Release V_1)



(b) Bonneville Tailrace (Release R_2)



(c) Mid-Reservoir (Release R_3)



(d) ROR Yearling Chinook at John Day Dam

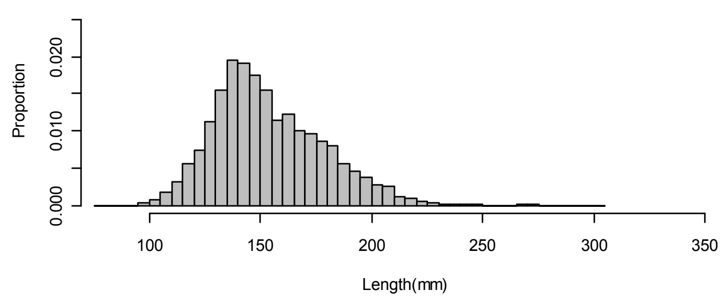
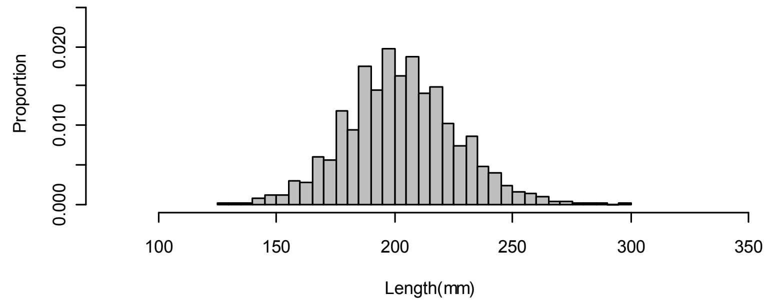
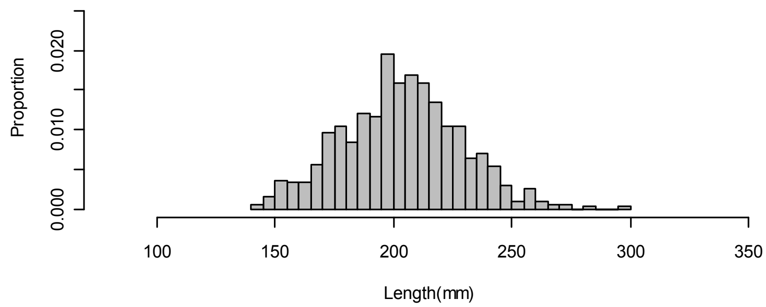


Figure 3.7. Relative frequency distributions for fish lengths (mm) of CH1 used in a) release V_1, b) release R_2, c) release R_3, and d) ROR fish sampled at John Day Dam by the Fish Passage Center.

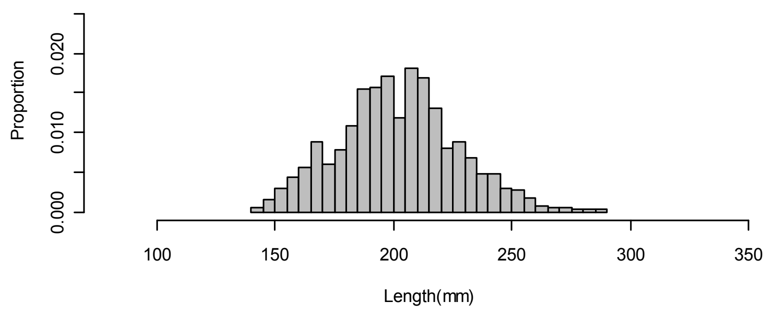
(a) Bonneville Dam (Release V_1)



(b) Bonneville Tailrace (Release R_2)



(c) Mid-Reservoir (Release R_3)



(d) ROR Steelhead at John Day Dam

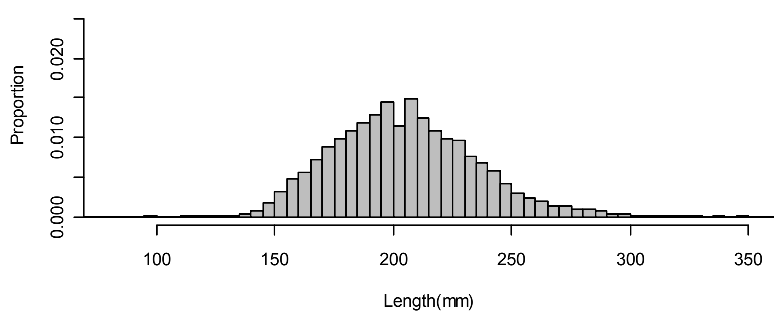
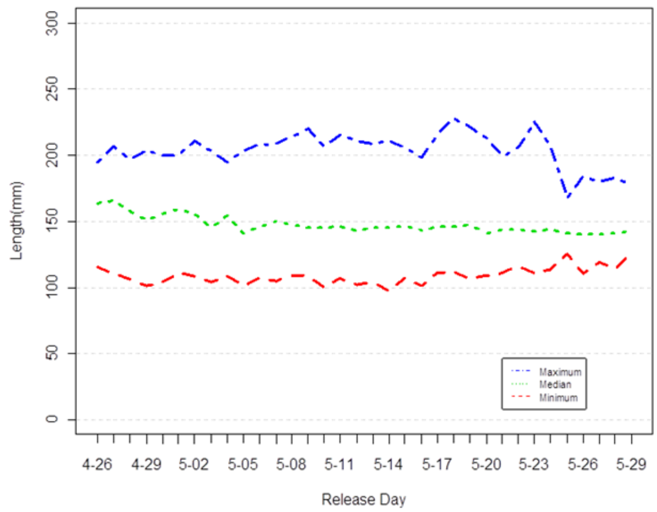


Figure 3.8. Relative frequency distributions for fish lengths (mm) of STH used in a) release V_1, b) release R_2, c) release R_3, and d) ROR fish sampled at John Day Dam by the Fish Passage Center.

(a) Yearling Chinook salmon



(b) Juvenile Steelhead

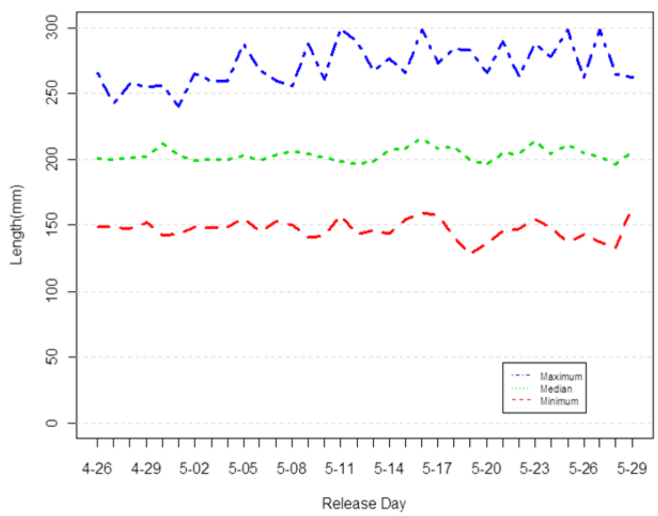
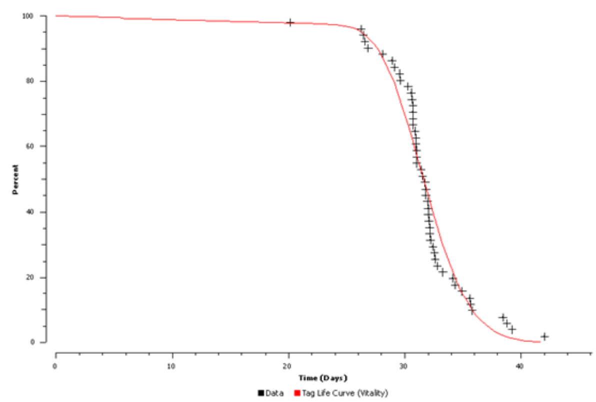


Figure 3.9. Range and median lengths of acoustic-tagged CH1 and STH used in the 2011 survival studies. Releases were made daily from April 30 through May 31 at seven release locations: rkm 390, rkm 346, rkm 325, rkm 307, rkm 275, rkm 233, and rkm 161.

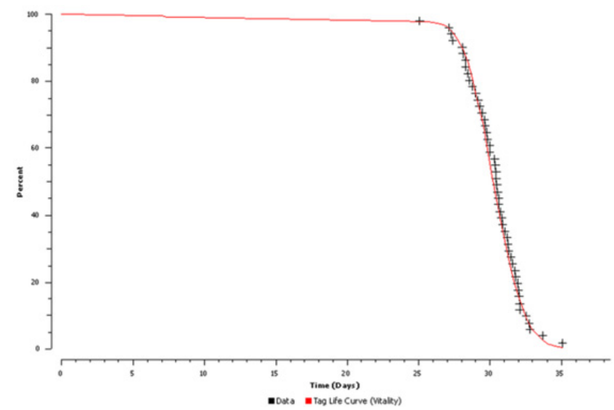
3.5.7 Tag-Life Corrections

During the 2011 spring study, five different manufacturing lots of JSATS tags were used in tagging the CH1 and STH. Lot 1 was manufactured distinctly from lot 2, which was manufactured distinctly from lots 3–5. From each of these three groups of tag lots, 50–59 tags were systematically sampled to conduct independent tag-life studies. Vitality curves of Li and Anderson (2009) were fit independently to each of the lots 1, 2, and 3–5 (Figure 3.10). Mantel and Haenszel (1959) tests of homogeneous tag-life distributions found lot 1 was significantly different from lot 2 ($P = 0.0005$) and lots 3–5 ($P = 0.0023$), but lots 2 and lots 3–5 were not different ($P = 0.5698$) (Figure 3.10, Figure 3.11). Average tag lives were 31.74, 30.32, and 30.52 days for lots 1, 2, and 3–5, respectively.

a. Tag lot 1



b. Tag lot 2



c. Tag lot 3–5

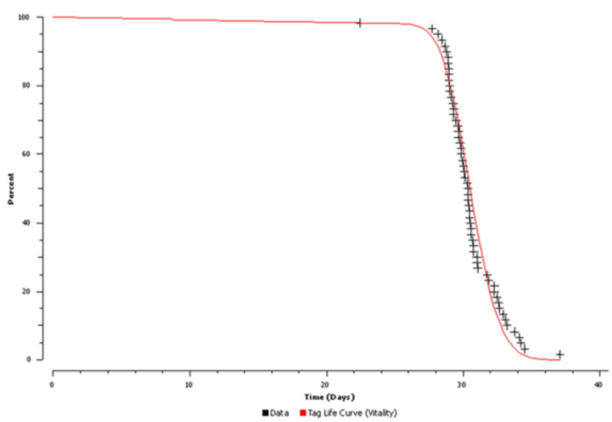


Figure 3.10. Observed time of tag failure and fitted survivorship curves using the vitality model of Li and Anderson (2009) for a) tag lot 1, b) tag lot 2, and c) tag lots 3–5.

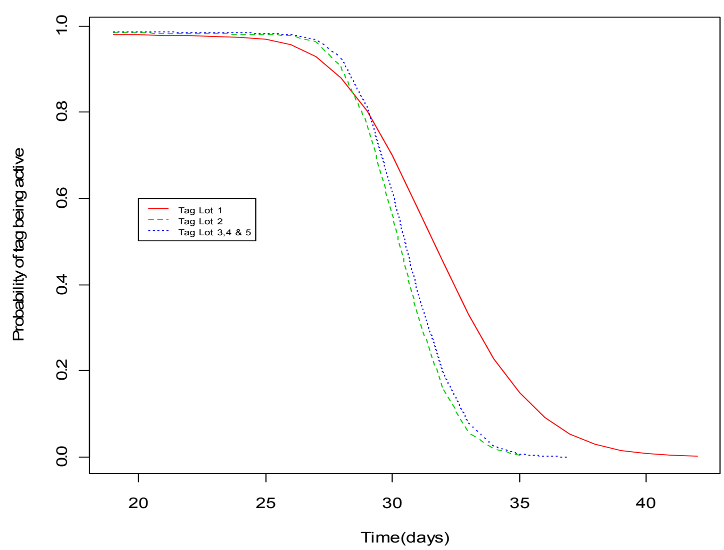
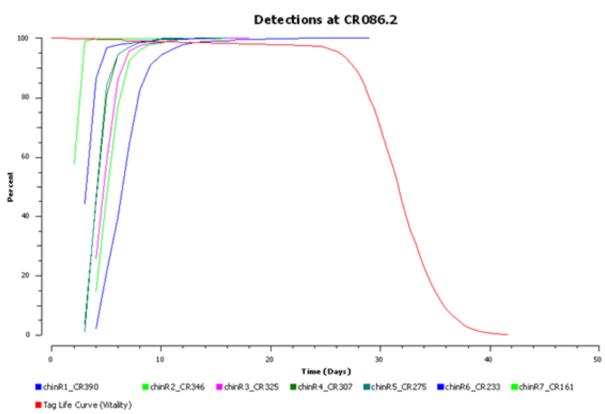


Figure 3.11. Comparison of fitted survivorship curves using the vitality model of Li and Anderson (2009) for JSATS tag lots 1, 2, and 3–5 used in the 2011 compliance studies.

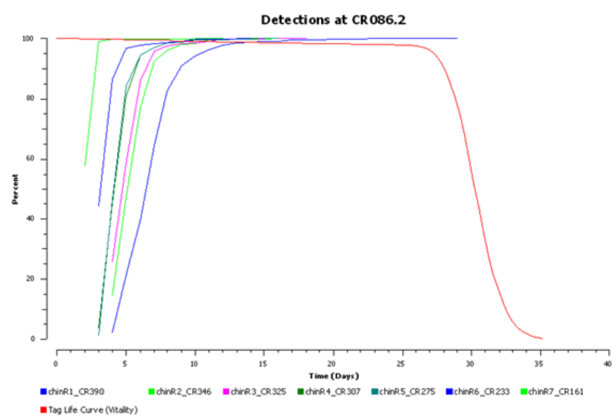
3.5.8 Arrival Distributions

The estimated probability that 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 (Figure 3.12 and Figure 3.13). Examination of the fish arrival distributions to the last detection array used in the survival analyses indicated all fish that arrived had passed through the study area before tag failure became important. The probabilities that acoustic tags were active downstream were calculated by integrating the tag survivorship curve (Figure 3.12 and Figure 3.13) over the observed distribution of fish arrival times (i.e., time from tag activation to arrival). The three separate tag-life survivorship models for tag lots 1, 2, and 3–5 were used to estimate the probabilities of tag failure and provide tag-life-adjusted estimates of smolt survival. The probability of a JSATS tag being active at a downstream detection site was specific to release location, tag lot, and species (Table 3.1). In all cases, the probability a tag was active at a downstream detection site as far as rkm 86 for CH1 was ≥ 0.9947 and ≥ 0.9952 for STH.

Tag lot 1



Tag lot 2



Tag lots 3–5

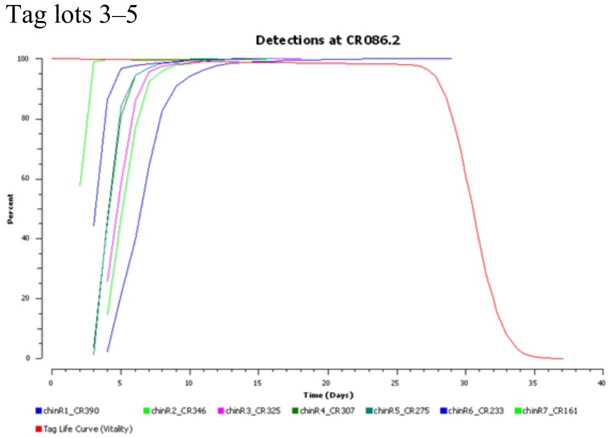


Figure 3.12. Plots of the fitted tag-life survivorship curves for tag lots 1, 2, 3–5 and the arrival-time distributions of CH1 from CR390, CR346, CR325, CR307, CR275, CR233, and CR161 at the acoustic-detection array located at rkm 86 (Figure 2.1).

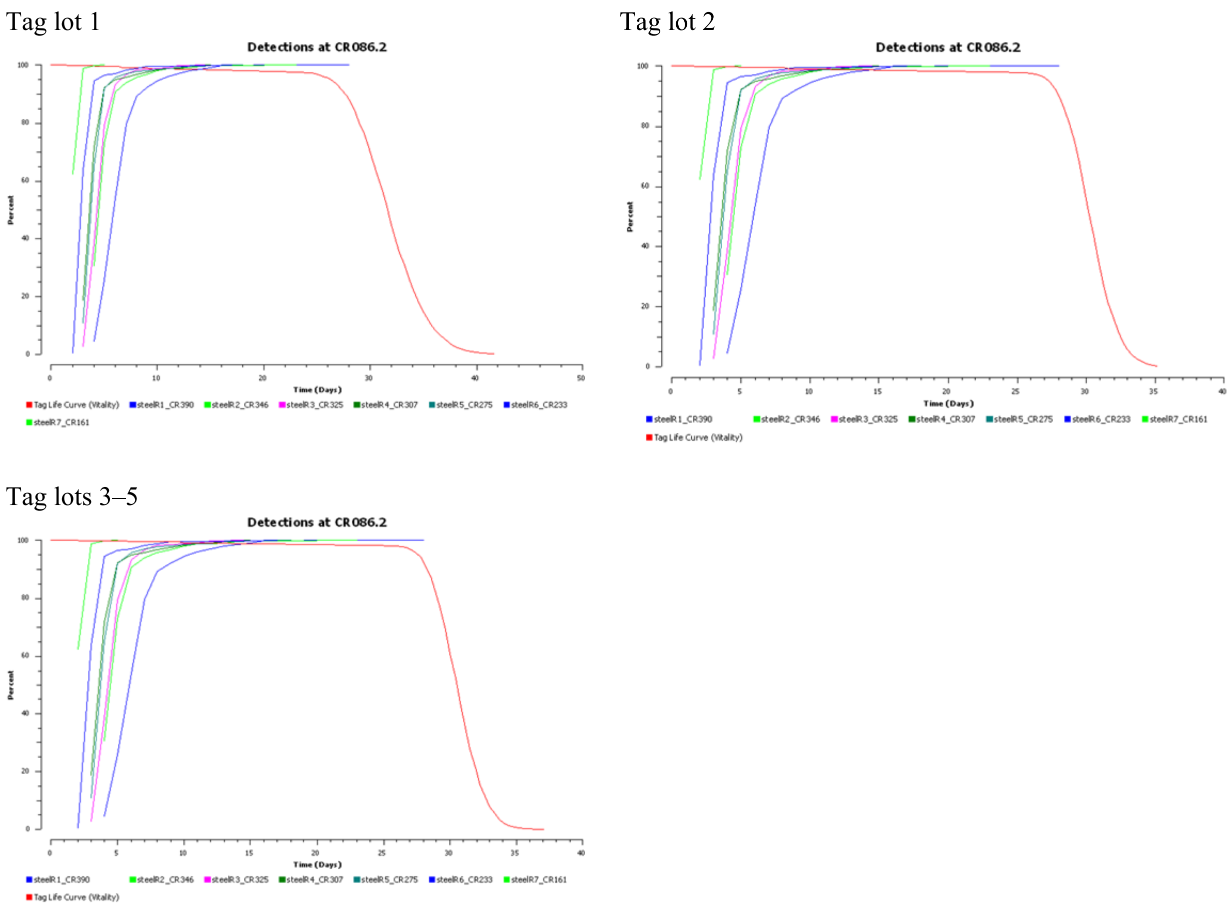


Figure 3.13. Plots of the fitted tag-life survivorship curves for tag lots 1, 2, 3–5 and the arrival-time distributions of STH for releases from CR390, CR346, CR325, CR307, CR275, CR233, and CR161 at the acoustic-detection array located at rkm 86 (Figure 2.1).

3.5.9 Downstream Mixing

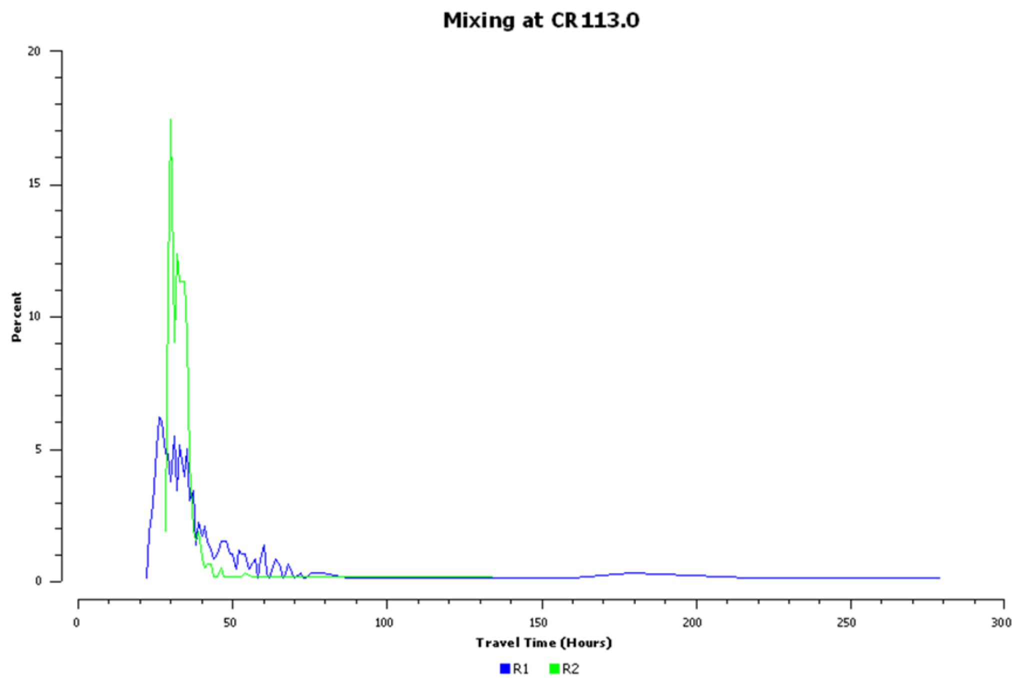
The virtual release from the face of BON was continuously formed from the smolts arriving throughout day and night. To help induce downstream mixing of the release groups, the R_2 release was 21 h before the R_3 release, based on travel times through that reach in an average year. This release schedule was used for both the CH1 and STH. Plots of the arrival timing of the various release groups at downstream detection sites indicate reasonable mixing for both CH1 (Figure 3.14) and STH (Figure 3.15). The survival modes for releases R_2 and R_3 were nearly synchronous. The virtual release (V_1) from the face of BON was continuous and, for this reason, its arrival distribution was not plotted in association with those of R_2 and R_3.

Table 3.1. Estimated probabilities (L) of an acoustic tag being active at a downstream detection site for a) CH1 and b) STH by tag lot and release group. Standard errors are in parentheses.

a. CH1				
		Detection Site		
Release Group	Tag Lot	rkm 161	rkm 113	rkm 86
V_1 (rkm 390)[(a)]	1	0.9985 (0.0011)	0.9977 (0.0016)	0.9974 (0.0019)
	2	0.9991 (0.0007)	0.9987 (0.0010)	0.9985 (0.0012)
	3–5	0.9995 (0.0016)	0.9992 (0.0025)	0.9990 (0.0031)
V_1 (rkm 346)[(a)]	1	0.9983 (0.0014)	0.9978 (0.0018)	0.9974 (0.0021)
	2	0.9991 (0.0008)	0.9985 (0.0012)	0.9984 (0.0013)
	3–5	0.9995 (0.0016)	0.9992 (0.0025)	0.9990 (0.0032)
V_1 (rkm 325)[(a)]	1	0.9986 (0.0011)	0.9980 (0.0016)	0.9977 (0.0019)
	2	0.9990 (0.0008)	0.9986 (0.0011)	0.9983 (0.0013)
	3–5	0.9995 (0.0015)	0.9992 (0.0024)	0.9990 (0.0032)
V_1 (rkm 307)[(a)]	1	0.9985 (0.0012)	0.9979 (0.0018)	0.9975 (0.0021)
	2	0.9990 (0.0008)	0.9985 (0.0012)	0.9983 (0.0014)
	3–5	0.9991 (0.0017)	0.9992 (0.0025)	0.9990 (0.0033)
V_1 (rkm 275)[(a)]	1	0.9983 (0.0014)	0.9975 (0.0020)	0.9973 (0.0022)
	2	0.9989 (0.0009)	0.9984 (0.0013)	0.9982 (0.0014)
	3–5	0.9992 (0.0020)	0.9991 (0.0029)	0.9989 (0.0035)
R_2 (rkm 233)	1	--	0.9950 (0.0041)	0.9947 (0.0043)
	2	--	0.9966 (0.0027)	0.9963 (0.0029)
	3–5	--	0.9976 (0.0067)	0.9973 (0.0075)
R_3 (rkm 161)	1	--	0.9972 (0.0024)	0.9967 (0.0027)
	2	--	0.9977 (0.0018)	0.9974 (0.0020)
	3–5	--	0.9982 (0.0048)	0.9981 (0.0053)
b. STH				
V_1 (rkm 390)[(a)]	1	0.9987 (0.0011)	0.9983 (0.0016)	0.9978 (0.0019)
	2	0.9991 (0.0008)	0.9987 (0.0011)	0.9985 (0.0013)
	3–5	0.9994 (0.0017)	0.9992 (0.0025)	0.9991 (0.0030)
V_1 (rkm 346)[(a)]	1	0.9985 (0.0014)	0.9979 (0.0019)	0.9978 (0.0021)
	2	0.9992 (0.0008)	0.9987 (0.0011)	0.9985 (0.0013)
	3–5	0.9995 (0.0016)	0.9992 (0.0026)	0.9990 (0.0031)
V_1 (rkm 325)[(a)]	1	0.9986 (0.0013)	0.9981 (0.0018)	0.9979 (0.0020)
	2	0.9989 (0.0010)	0.9985 (0.0013)	0.9985 (0.0014)
	3–5	0.9994 (0.0017)	0.9992 (0.0025)	0.9990 (0.0032)
V_1 (rkm 307)[(a)]	1	0.9985 (0.0014)	0.9978 (0.0020)	0.9977 (0.0021)
	2	0.9990 (0.0009)	0.9985 (0.0013)	0.9984 (0.0014)
	3–5	0.9993 (0.0020)	0.9991 (0.0028)	0.9990 (0.0033)
V_1 (rkm 275)[(a)]	1	0.9984 (0.0015)	0.9978 (0.0021)	0.9976 (0.0022)
	2	0.9986 (0.0011)	0.9985 (0.0013)	0.9983 (0.0015)
	3–5	0.9994 (0.0018)	0.9991 (0.0028)	0.9990 (0.0033)
R_2 (rkm 233)	1	--	0.9957 (0.0040)	0.9952 (0.0044)
	2	--	0.9968 (0.0028)	0.9966 (0.0030)
	3–5	--	0.9976 (0.0070)	0.9974 (0.0076)
R_3 (rkm 161)	1	--	0.9972 (0.0026)	0.9969 (0.0029)
	2	--	0.9977 (0.0020)	0.9976 (0.0022)
	3–5	--	0.9982 (0.0053)	0.9981 (0.0056)

(a) Conditional probabilities of a tag being active, given they were active when a fish first arrived at the dam face.

(a) rkm 113



(b) rkm 86

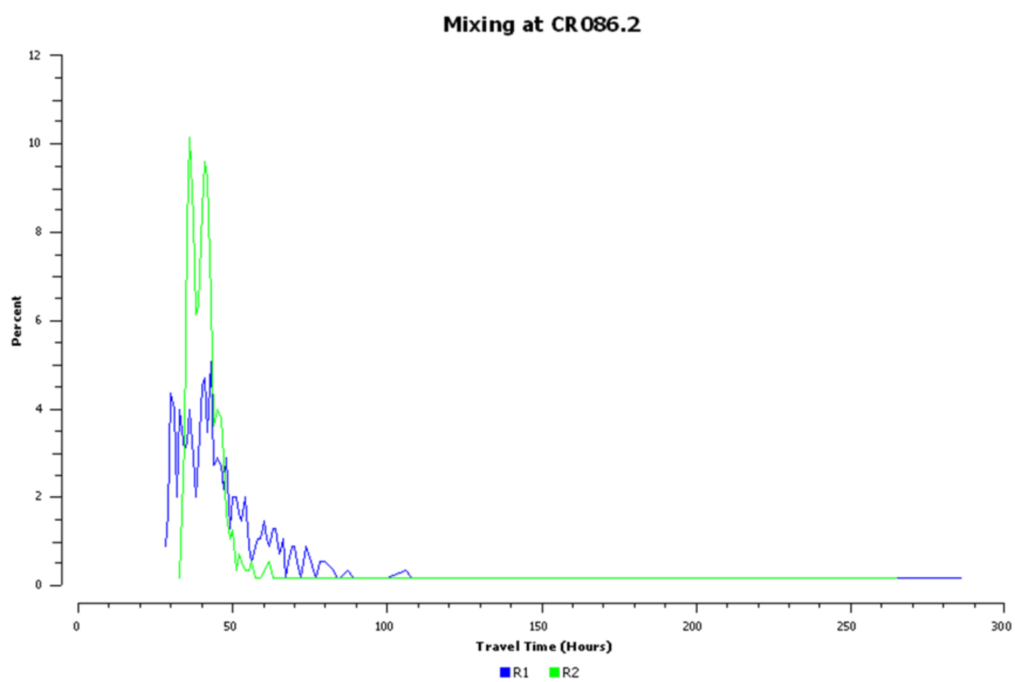
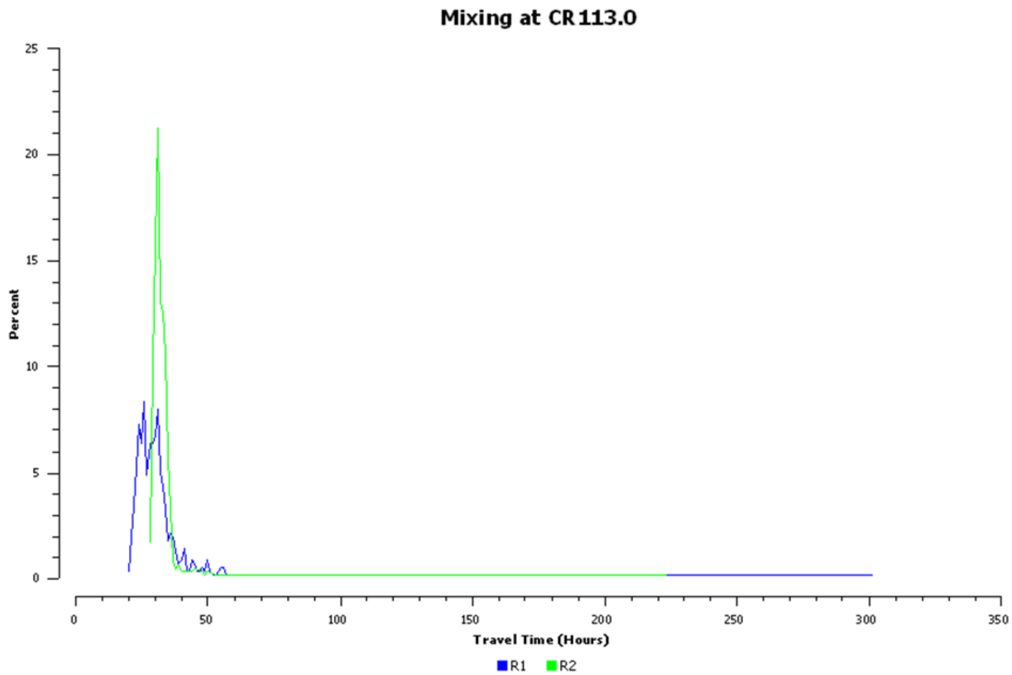


Figure 3.14. Frequency distribution plots of downstream arrival timing (expressed as percentages) for yearling Chinook salmon releases R_2 and R_3 at detection arrays located at a) rkm 113 and b) rkm 86 (see Figure 2.1).

(a) rkm 113



(b) rkm 86

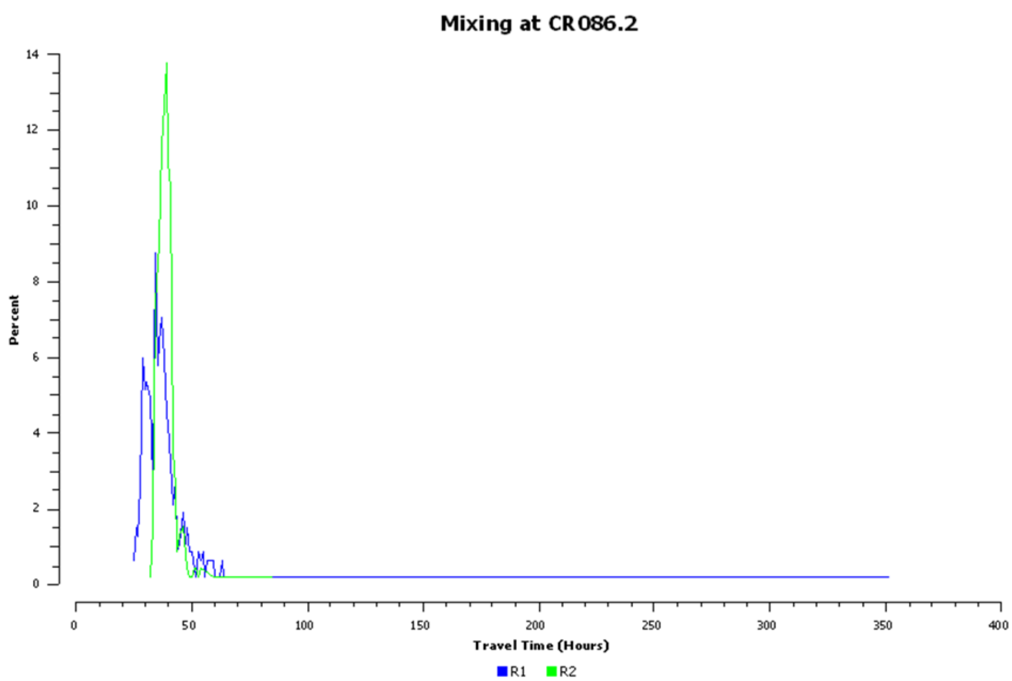


Figure 3.15. Frequency distribution plots of downstream arrival timing (expressed as percentages) for steelhead releases R_2 and R_3 at detection arrays located at a) rkm 113 and b) rkm 86 (see Figure 2.1).

4.0 Results – Yearling Chinook Salmon

This section provides information about array performance, survival rates, travel times, passage efficiencies, and distributions for CH1 at BON during spring 2011. 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).

4.1 Detection Array Performance

The performance of the two independent arrays of hydrophones sampling the forebay was acceptable throughout the study. The combined detection probability of the two independent dam-face arrays, based on a Lincoln Peterson index, was 0.9879 for the entire dam and 1.000 for every route, except the spillway, where it was 0.9557.

The tag-detection performance of arrays of autonomous nodes also was good during the early season before the river entered flood stage (see river discharge in Figure 3.1). During the early season, detection probabilities were high enough (Appendix D, Section D.1.1) to provide an acceptable standard error (0.0131) for dam passage survival. High river discharge after May 13 severely reduced autonomous array detection probabilities, and the standard error for the season-wide survival estimate (Appendix D, Section D.1.3; 0.0172) exceeded the BiOp standard of 0.015.

4.2 Dam Passage Survival Estimates

The estimates of dam passage survival for CH1 at BON were calculated for three periods of time. One period was from the beginning of the study on April 27 through May 13, 2011, while flows were moderate and spill was held at 100 kcfs. The second time period was from May 14 through the end of the study on May 31, 2011 and includes only the higher flow and spill levels later in the season, and the third period encompassed the entire study period (Figure 3.1).

For the early part of the study, dam passage survival was estimated to be

$$\hat{S}_{\text{Dam}} = 0.9569 \tag{3.1}$$

with a standard error of $\widehat{\text{SE}} = 0.0042$. This estimate was not corrected for survival between release locations for R_2 and R_3, because the paired-release estimated survival in that extra reach was estimated to be

$$\frac{0.9942}{0.9857} = 1.0086 \quad . \tag{3.2}$$

Therefore, the more reasonable approach was to assume the extra-reach survival between rkm 233 and 161 to be 1.0 and estimate dam passage survival using the virtual release (V_1) to rkm 161 (Appendix D, Section D.1.1).

For the late study period, dam passage survival for CH1 is estimated to be

$$\hat{S}_{\text{Dam}} = \frac{0.9807}{\left(\frac{0.9418}{0.9625}\right)} = \frac{0.9807}{0.9785} = 1.0023$$

with a standard error of $\widehat{\text{SE}} = 0.0447$. Survival was higher when river flow was higher, but high flow during the late season depressed autonomous node detection rates and greatly increased the standard error. Details of the estimates are presented in Appendix D, Section D.1.2. There was overlapping of ½ 95% CIs for the early and late season estimates despite a 0.0454 difference between the point estimates.

For the entire study period, dam passage survival for CH1 is estimated to be

$$\hat{S}_{\text{Dam}} = \frac{0.9584}{\left(\frac{0.9531}{0.9544}\right)} = \frac{0.9584}{0.9986} = 0.9597 \tag{3.3}$$

with a standard error of $\widehat{\text{SE}} = 0.0176$. Likelihood ratio tests indicated the detection probability at CR113 and the $\lambda(=S \cdot p)$ parameters in the last reach were homogeneous between the three release groups, allowing estimation using a reduced model $P\left(\chi_4^2 \geq 2.9220\right) = 0.5710)$. Because the full model did not achieve the prescribed level of precision in the 2008 BiOp, model evaluation was used to find a more parsimonious model that validly equated downstream parameter values between release groups and improved precision. This more parsimonious model also failed to achieve adequate precision as specified in the 2008 BiOp. Details are presented in Appendix D, Section D.1.3.

4.2.1 Day and Night Estimates for Three Study Periods

Four distinct virtual releases of fish were formed based upon the time of passage through the dam (early season day or night and late season day or night). The resulting capture histories for the dam and three downstream survival-detection arrays were analyzed to estimate survival for each virtual release (Table 4.1). Night and day were defined by passage time relative to the time of civil sunrise and sunset for BON. The survival differences between fish passing through BON during the night or day during the entire, early, and late seasons were not significant given the overlap of 95% CIs (1.96 × SE).

Table 4.1. Dam passage survival estimates for yearling Chinook salmon.

Metric	Period	Estimate	SE	n
Dam Passage Entire Season	Day	0.9586	0.0206	3,323
	Night	0.9649	0.0210	2,219
Dam Passage Early Season[a]	Day	0.9545	0.0056	1,497
	Night	0.9599	0.0064	995
Dam Passage Late Season	Day	0.9973	0.0447	1,876
	Night	1.0110	0.0458	1,165

(a) Because the R_2/R_3 ratio is greater than 1.0, it is recommended the "V_1" survival estimate be used as the best estimate of dam-passage survival.

4.2.2 Forebay-to-Tailrace Passage Survival

The estimates of forebay-to-tailrace passage survival (BRZ-to-BRZ) were calculated analogously to estimates of dam passage survival except the virtual-release group (V_1) was composed of fish known to have arrived at the forebay array (i.e., detection array rkm 236, Figure 2.1) rather than at the dam face. The analyses used the same statistical models used in estimating dam passage survival. Only entire season and early season survivals were calculated. The full-season estimates for CH1 were made from a reduced model because likelihood ratio tests indicated the detection probability at CR113 and the $\lambda(=S \cdot p)$ parameters in the last reach were homogeneous between the three release groups. The full model was used for the early season estimate for CH1 and STH.

The estimates of forebay-to-tailrace survival (Table 4.2) were very close to the estimates of dam passage survival, and were not significantly different. The difference in early to late season dam passage survival was significant.

Table 4.2. Summary of the estimates of forebay-to-tailrace survival at Bonneville Dam in 2011 for CH1 and STH for early season (April 30–May 13, 2011), and the entire study (April 30–May 31, 2011). Standard errors are in parentheses.

Period	Forebay-to-Tailrace	N
Early Season (April 30–May 13)	0.9579 (0.0042)	2,492
Season-Wide (April 30–May 31)	0.9528 (0.0175)	5,529

4.2.3 Route-Specific Passage Survival

Route-specific, single-release dam passage survival estimates for CH1 were highest for the B2CC (99.3%), B2 JBS (98.2%), surface-flow outlets combined (97.4%), and the B1 sluiceway (98.0%). The lowest survival rates (<0.96) were for fish passing through B2 turbines and the spillway (Table 4.3).

Table 4.3. Entire season route-specific dam-passage survival estimates for yearling Chinook salmon.

Metric	Estimate	SE	n
B2CC	0.9928	0.0226	165
B2 JBS	0.9819	0.0243	181
Surface-Flow Outlet	0.9741	0.0223	531
B1 Sluiceway	0.9685	0.0239	366
B1 Turbines	0.9677	0.0214	1,166
Turbine (B1 and B2)	0.9617	0.0211	1,616
Spillway	0.9567	0.0207	3,122
B2 Turbines	0.9469	0.0231	450

4.3 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 were short, ranging from 0.45 h during the high flow late season to 0.65 during the early season that had normal flows (Table 4.4). Over the entire season, forebay residence time was 0.55 h (SE = 0.46). Median egress times from the last dam-face detection until the last tailrace-array detection also were short, ranging from 0.34 h during the high flow late season to 0.42 h during the early season that had normal flows (Table 4.4). Mean travel times also are presented in Table 4.4, but those estimates are overly influenced by a few fish that traveled much slower than most.

Table 4.4. Travel times (h) for yearling Chinook salmon.

Passage Time Metrics and Statistics	All Season			Early Season			Late Season		
	Hours	SE	n	Hours	SE	n	Hours	SE	n
Median Forebay Residence	0.55	0.46	5,595	0.65	0.16	2,552	0.45	0.82	3,043
Median Tailrace Egress	0.38	0.19	3,847	0.42	0.28	2,248	0.34	0.25	1,599
Mean Forebay Residence	5.34	0.46	5,595	2.18	0.16	2,552	8.00	0.82	3,043
Mean Tailrace Egress	1.89	0.19	3,847	2.19	0.28	2,248	1.47	0.25	1,599

Travel times statistics also were estimated for day and night periods of fish passage, based on the time of passage relative to the time of civil sunrise and sunset, but none of the differences in median travel times between daytime and nighttime estimates were significant based on the overlapping of standard errors (Table 4.5). Mean estimates of forebay residence time and tailace egress time were lower at night than they were during the day, but only the tailrace egress estimates appeared to differ significantly based on nonoverlapping of 95% CIs.

Table 4.5. Forebay residence and tailrace egress times (h) for yearling Chinook salmon passing during daytime and nighttime.

Metric	Day			Night			
	Estimate	SE	n	Estimate	SE	n	Sig?
Forebay Residence Times (CR236 to							
Median	0.57	0.64	3,362	0.54	0.61	2,233	No
Mean	5.96	0.64	3,362	4.42	0.61	2,233	No
Tailrace Egress Times (CR234 to CR233)							
Median	0.38	0.32	2,215	0.39	0.15	1,632	No
Mean	2.55	0.32	2,215	1.01	0.15	1,632	Yes

4.4 Passage Efficiencies

Project passage metrics were estimated for the entire season (Table 4.6) and were compared for day and night periods (Table 4.7), and for early and late seasons (Table 4.8). Relative to the entire dam, FPE, B2CC efficiency, and B2 JBS efficiency were higher during the day than they were at night, whereas B2 turbine efficiency was higher at night than during the day. Relative to B2 only, B2 FPE, B2CC efficiency, B2 JBS efficiency, and B2 FGE were higher during the day than they were at night.

Relative to the entire dam, FPE, SPE+B2CC, and SPE were all significantly higher during the late season than they were during the early season, whereas B2CC efficiency, B2 JBS efficiency, and B2 turbine efficiency were significantly higher during the early season compared with the late season. High flows in the late season resulted in a larger percentage of fish passing through the spillway (68.2%) compared with the early season (47.9%) and higher efficiencies of FPE for the late season, but significantly lowered efficiencies for the B2CC, B2 JBS, and B2 turbines. We observed no significant differences between early and late season for B1.

Table 4.6. Passage efficiencies for all yearling Chinook salmon passing Bonneville Dam in 2011.

Metric	Estimate	SE	n
Fish Passage Efficiency (FPE) || Dam	0.717	0.0060	5,711
SPE+B2CC Efficiency || Dam	0.610	0.0065	5,711
Spill Passage Efficiency (SPE) || Dam	0.581	0.0066	5,711
B1 Sluiceway Efficiency || Dam	0.064	0.0032	5,711
B1 Turbine Passage Efficiency || Dam	0.204	0.0054	5,711
B2CC Efficiency || Dam	0.029	0.0022	5,711
B2 JBS Passage Efficiency || Dam	0.043	0.0027	5,711
B2 Turbine Passage Efficiency || Dam	0.079	0.0036	5,711
B1 Sluiceway Efficiency || B1=B1 FPE	0.239	0.0109	1,532
B2 FPE	0.478	0.0170	862
B2CC Efficiency || B2	0.191	0.0134	862
B2 JBS Passage Efficiency || B2	0.287	0.0154	862
B2 FGE (Screen Efficiency)	0.354	0.0181	697

Table 4.7. Day and night passage efficiencies for yearling Chinook salmon.

	Day			Night			
Metric	Estimate	SE	n	Estimate	SE	n	Different?
Fish Passage Efficiency (FPE) || Dam	0.731	0.0076	3,451	0.696	0.0098	2,269	Yes
SPE+B2CC Efficiency || Dam	0.615	0.0084	3,451	0.603	0.0104	2,269	No
Spill Passage Efficiency (SPE) || Dam	0.581	0.0085	3,451	0.582	0.0105	2,269	No
B1 Sluiceway Efficiency || Dam	0.062	0.0041	3,451	0.067	0.0052	2,269	No
B1 Turbine Passage Efficiency || Dam	0.214	0.0070	3,451	0.188	0.0082	2,269	No
B2CC Efficiency || Dam	0.034	0.0031	3,451	0.021	0.0030	2,269	Yes
B2 JBS Passage Efficiency || Dam	0.054	0.0039	3,451	0.026	0.0034	2,269	Yes
B2 Turbine Passage Efficiency || Dam	0.054	0.0039	3,451	0.116	0.0067	2,269	Yes
B1 Sluiceway Efficiency || B1 (B1 FPE)	0.225	0.0135	955	0.262	0.0183	577	No
B2 FPE || B2	0.619	0.0219	491	0.291	0.0236	371	Yes
B2CC Efficiency || B2	0.238	0.0192	491	0.129	0.0174	371	Yes
B2 JBS Efficiency || B2	0.381	0.0219	491	0.162	0.0191	371	Yes
B2 FGE (Screen Efficiency)	0.500	0.0259	374	0.186	0.0216	323	Yes

Table 4.8. Early and late season passage efficiencies for yearling Chinook salmon.

Metric	Early (<5/13) Estimate	SE	n	Late (≥5/13) Estimate	SE	n	Different?
Fish Passage Efficiency (FPE) || Dam	0.662	0.0094	2,547	0.775	0.0075	3,351	Yes
SPE+B2CC Efficiency || Dam	0.529	0.0099	2,547	0.693	0.0084	3,351	Yes
Spill Passage Efficiency (SPE) || Dam	0.479	0.0099	2,547	0.682	0.0085	3,351	Yes
B1 Sluiceway Efficiency || Dam	0.055	0.0045	2,547	0.068	0.0044	3,351	No
B1 Turbine Efficiency || Dam	0.210	0.0081	2,547	0.188	0.0069	3,351	No
B2CC Efficiency || Dam	0.050	0.0043	2,547	0.011	0.0018	3,351	Yes
B2 JBS Passage Efficiency || Dam	0.078	0.0053	2,547	0.014	0.0021	3,351	Yes
B2 Turbine Efficiency || Dam	0.128	0.0066	2,547	0.037	0.0033	3,351	Yes
B1 Sluiceway Efficiency || B1=B1 FPE	0.206	0.0156	675	0.265	0.0151	857	No
B2 FPE || B2	0.501	0.0196	653	0.407	0.0340	209	No
B2CC Efficiency || B2	0.196	0.0180	653	0.177	0.0264	209	No
B2 JBS Efficiency || B2	0.305	0.0180	653	0.230	0.0291	209	No
B2 FGE (Screen Efficiency)	0.501	0.0196	525	0.279	0.0342	172	Yes

4.5 Passage Distributions

The distributions of all detection events on the four forebay entrance array nodes helped to explain why the spillway and B1 passed more fish than B2 in spring 2012 (Figure 4.1). About 65.7% of autonomous node tag detections occurred on the node closest to the Oregon shore; 30.9% occurred on two mid-channel nodes; and just 3.4% occurred near the Washington shore. The distribution of passage at the three major dam structures was correlated with flow among the structures ($r^2 = 0.80$), but B1 passed 28% of the CH1 in just 20% of the flow compared to B2 passing just 15% of fish in 28% of flow. When spill was ≥35%, 59% of yearlings passed at the spillway compared to 41% that passed through B1 and B2. When spill was <35%, only 37% of fish passed through the spillway compared to the 63% of yearlings that passed through B1 and B2. When spill levels were increased, the percent of fish passing via the spillway also increased and there was a noticeable reduction in percentages passing through B1 and B2.

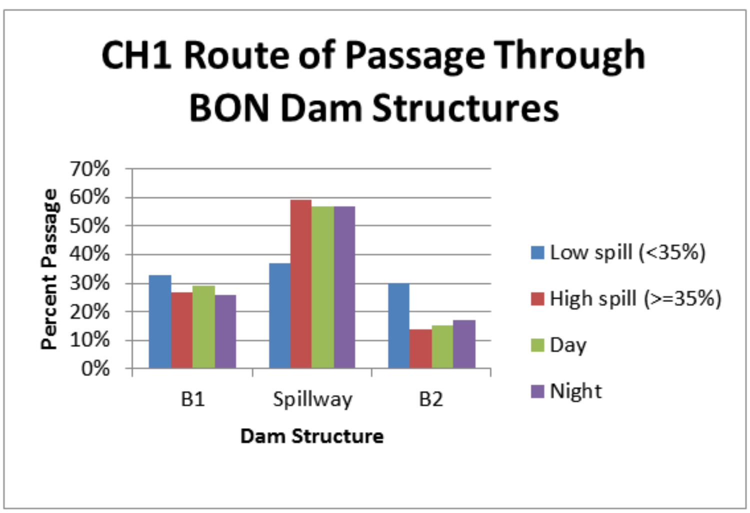


Figure 4.1. Distribution of passage of yearling Chinook salmon among three dam structures during high spill, low spill, day, and night.

More than 99% of CH1 passed through the Bonneville project at the dam structure where they were first detected, and this was true during high spill (spill ≥35% = 99.96%) and low spill levels (<35% = 100%), and during the day and night periods. Only two fish approached B1 and later passed through the spillway and did so during the day when spill was ≥35%.

4.5.1 Horizontal Passage Distributions

A plot of the distribution of CH1 passage among individual routes through the dam clearly shows that more CH1 passed through the spillway, particularly through end bays, than through B1 or B2 (Figure 4.2). The top four individual routes for passing CH1 included spill bays 3 and 17, B1 turbine 10, and the B2 JBS. Individual routes that passed >3% of CH1 (30% of all individual routes) included seven spill bays (1, 2, 3, 4, 5, 17, and 18), three B1 turbines, the B1 sluiceway outlet (S10), and the B2 JBS and B2CC. Figure 4.3 shows that the B1 sluiceway and B2CC together passed about 10% of the CH1 known to have passed the entire dam. Estimates of surface-flow outlet efficiency relative to the adjacent powerhouse were low compared with historical averages. Relative to B2, the B2CC passed only 19.1% of CH1, and relative to B1, the B1 sluiceway passed 23.9% of CH1, and these estimates are both below the lower end of the historical range (29%). During the early spring season, when river discharge was close to average, CH1 passage through the B1 sluiceway, B1 turbines, B2 JBS, and B2 turbines was higher than it was during the late spring season (Figure 4.4). When river discharge was high during the late spring season, passage proportions were much higher through the spillway and the B2CC than they were during the early spring season when river discharge was average (Figure 4.4). We only observed obvious day-and-night differences in passage proportions through three composite routes: the B2CC and B2 JBS had higher passage proportions during the day than at night, and B2 turbines passed proportionally more CH1 at night than during the day (Figure 4.5).

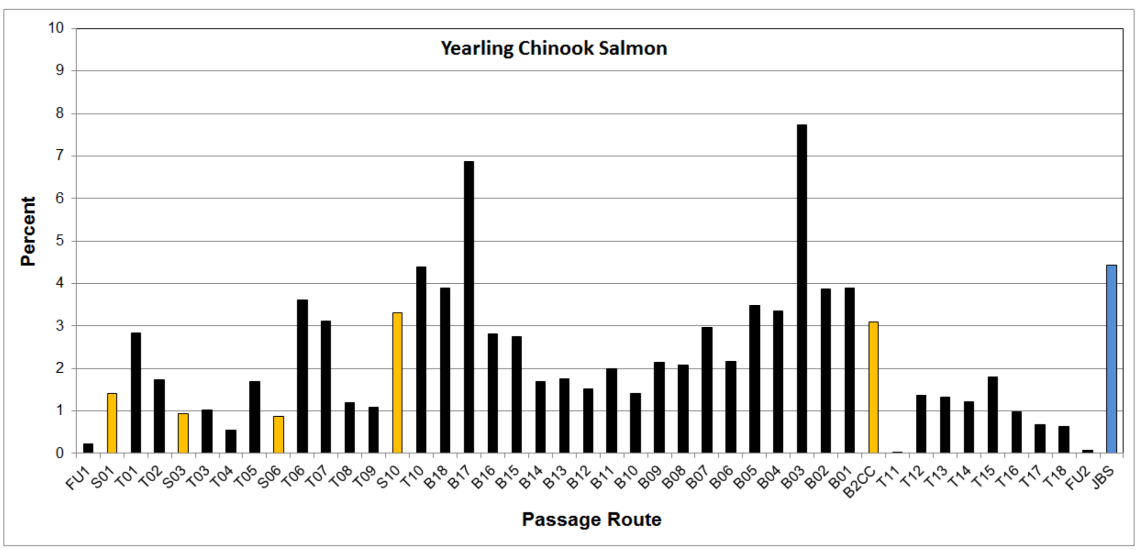


Figure 4.2. Horizontal distribution of yearling Chinook salmon passage in spring 2010. Percent passage through surface-flow outlets (S01, S03, S06, S10, and the B2CC) are shown as gold bars, and B1 outlets are displayed to the left of the adjacent turbine with the same number, although they are actually 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.

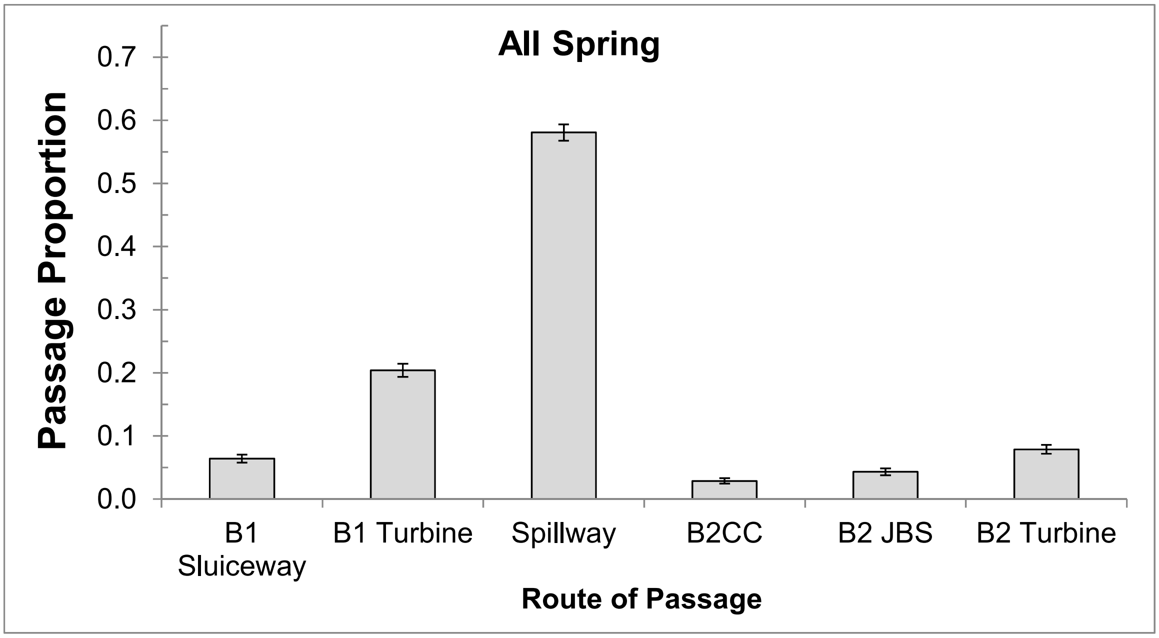


Figure 4.3. Passage route proportions for yearling Chinook salmon during spring (April 30–May 31) 2011.

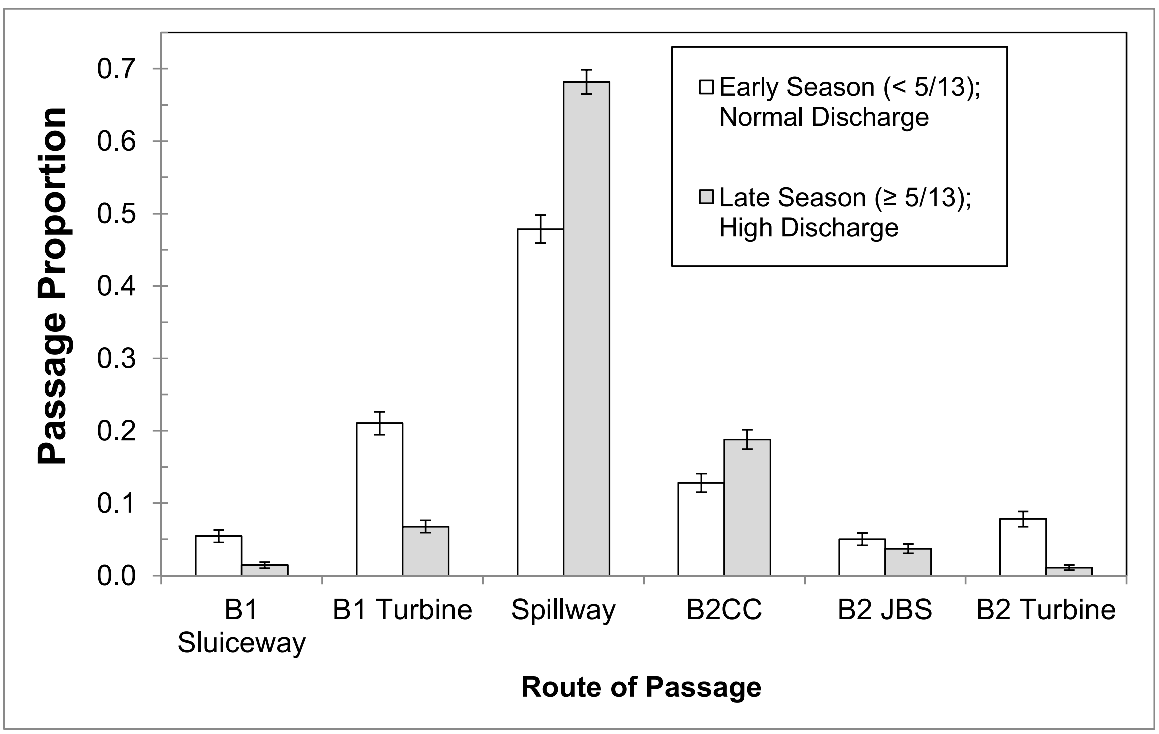


Figure 4.4. Passage route proportions for yearling Chinook salmon passing through Bonneville Dam during early and late seasons.

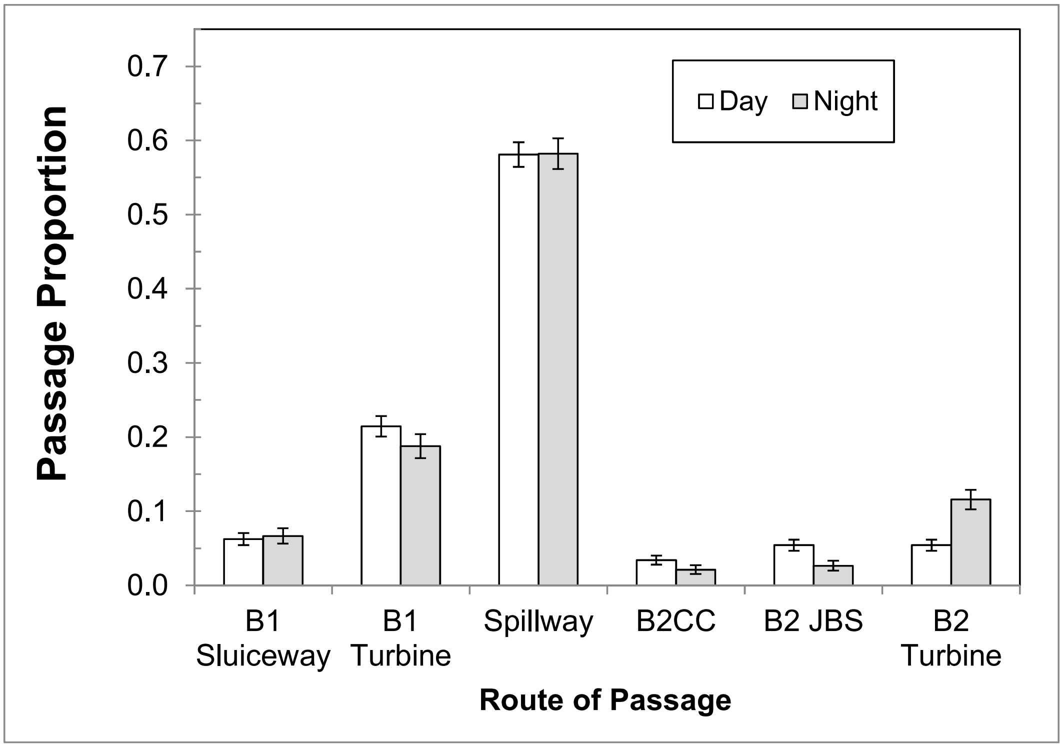


Figure 4.5. Passage route proportions for yearling Chinook salmon passing through Bonneville Dam during daytime and nighttime periods in spring.

The efficiency of the B2CC relative to B2 in 2011 was the lowest observed to date (Table 4.9). It was 10.2 to 16.4% lower than estimates for 2004 and 2005 before the B2 BGS was installed, and it was 20.9 to 29.9% lower than estimates in 2008, 2009, and 2010 when the BGS was installed (Table 4.9). The JBS at B2 passed 28.7% of fish passing via B2, making it more efficient than the B2CC for CH1. The FPE of B2 was 47.8%.

Table 4.9. 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; and Ploskey et al. 2012a, b, 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
2011	19.1	52.2	none

4.5.2 Forebay Vertical Distribution

Yearling Chinook salmon were vertically distributed within 10 m of the surface from 25 m to less than 5 m from the dam face at all three dam structures (Figure 4.6). At B1, CH1 were within 4 to 5 m of the water's surface throughout their approach from 25 m upstream to the dam face.

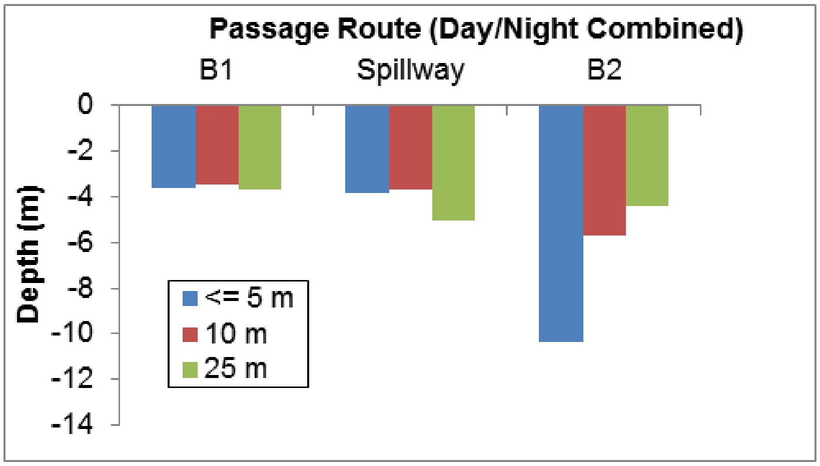


Figure 4.6. Season-wide (April 30–May 31) median vertical approach and passage distribution of yearling Chinook salmon by route through Bonneville Dam.

Differences in daytime and nighttime estimates of median depth were <2.5 m for fish within 25 m of B1 piers, 10 m of spillway piers, and 5 m of B2 piers (Figure 4.7). However, median depths of CH1 that were 10 to 25 m upstream of B2 piers or 25 m upstream of spillway piers were more than 4 m greater at night than they were during the day.

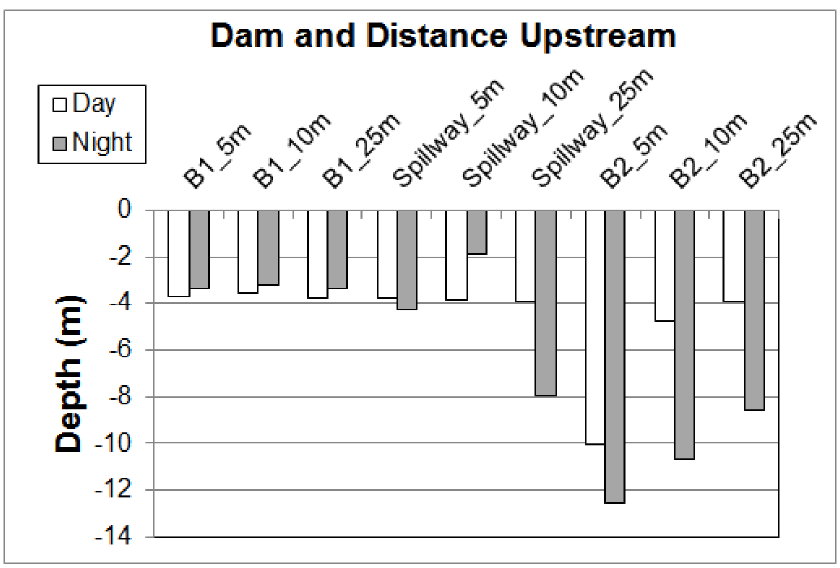


Figure 4.7. Season-wide (April 30–May 31) day median vertical approach and passage distribution of yearling Chinook salmon by route through Bonneville Dam.

5.0 Results – Juvenile Steelhead

This section provides information about detection-array performance, survival rates, travel times, passage efficiencies, and distributions for STH at BON during spring 2011. 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).

5.1 Detection-Array Performance

The performance of the two independent arrays of hydrophones sampling the forebay was acceptable throughout the study for STH. The combined detection probability of the two independent dam-face arrays, based on a Lincoln Peterson index, was 0.988 for the entire dam and 1.000 for every route, except the spillway, where it was 0.9520.

The tag-detection performance of arrays of autonomous nodes was higher during the early season than it was during the late season when the river entered flood stage (see river discharge in Figure 3.1). During the early season, detection probabilities averaged 0.98 at CR161, 0.81 at CR113, and 0.86 (Lambda) at CR086 (Appendix D, Section D.2.2), but they were still not high enough to provide to provide an acceptable standard error (0.0180 > 0.015) for dam passage survival. High river discharge after May 13 severely reduced autonomous array detection probabilities to an average of 0.86 at CR161, 0.66 at CR113, and 0.38 (Lambda) at CR086, which drove up the standard error on survival to over 0.05. The standard error for the season-wide survival estimate (Appendix D, Section D.2.1; 0.0212) also exceeded the BiOp standard of 0.015.

5.2 Dam Passage Survival Estimates

The estimates of dam passage survival for STH at BON were calculated for two periods of time. One period was from the beginning of the study on April 27 through May 13, 2011, while flows were moderate and spill was held at 100 kcfs. The second time period was from the beginning to the end of the study on May 31, 2011, and it includes the higher flow and spill levels later in the season (Figure 3.1).

For the initial period of the study before high flow levels began (i.e., April 30–May 13, 2011), the dam passage survival for steelhead was estimated to be

$$\hat{S}_{\text{Dam}} = \frac{0.9527}{\left(\frac{0.9634}{0.9865}\right)} = \frac{0.9527}{0.9766} = 0.9755 \tag{5.1}$$

with an associated standard error of $\widehat{\text{SE}} = 0.0180$. A likelihood ratio test found that the downstream detection and survival for the three release groups could not be equated $\left(P\left(\chi_4^2 \geq 9.0592\right) = 0.0600\right)$ and, as such, a full model was used in parameter estimation (Appendix D, Section D.2.2).

For the entire spring study, dam passage survival for steelhead was estimated to be

$$\hat{S}_{\text{Dam}} = \frac{0.9491}{\left(\frac{0.9247}{0.9398}\right)} = \frac{0.9491}{0.9839} = 0.9647 \tag{5.2}$$

with an estimated standard error of $\widehat{\text{SE}} = 0.0212$ (Appendix D, Section D.2.1). A likelihood ratio found the downstream detection and $\lambda(=S \cdot p)$ parameters were not significantly different between the three release groups $\left(P\left(\chi_4^2 \geq 5.1830\right) = 0.2690\right)$ and, as such, the estimate of dam passage survival was based on a reduced model. Despite the reduced model, precision was not adequate to meet the BiOp standard (i.e., $\widehat{\text{SE}} < 0.015$). Details are presented in Appendix D, Section D.2.1.

5.2.1 Day and Night Estimates for Three Study Periods

Four distinct virtual releases of fish were formed based upon the time of passage through the dam (early season day or night and late season day or night), and resulting capture histories for the dam and three downstream survival-detection arrays were analyzed to estimate survival for each virtual release (Table 5.1). Night and day were defined by passage time relative to the time of civil sunrise and sunset for BON. All point estimates of survival had overlapping 95% CIs (1.96 × SE). The survival differences between fish passing through BON during the night or day during the early and entire seasons likely were not significant given substantial overlapping of 95% CIs.

Table 5.1. Dam passage survival estimates for juvenile steelhead.

Metric	Period	Estimate	SE	n
Dam Passage Entire Season	Day	0.9598	0.0255	3,729
	Night	0.9532	0.0257	1,934
Dam Passage Early Season	Day	0.9762	0.0183	1,776
	Night	0.9744	0.0193	738
Dam Passage Late Season	Day[(a)]	0.9658	0.0069	1,938
	Night[(a)]	0.9490	0.0086	1,193

(a) Because the R_2/R_3 ratio is greater than 1.0, it is recommended that the "V_1" value be used instead of "Dam Survival."

5.2.2 Forebay-to-Tailrace Passage Survival

The estimates of forebay-to-tailrace passage survival were calculated analogously to estimates of dam passage survival except the virtual-release (V_1) group was composed of fish known to have arrived at the forebay array (i.e., detection array rkm 236, Figure 2.1) rather than at the dam face. The analyses used the same statistical models used in estimating dam passage survival. The full-season estimates for STH were made from a reduced model because likelihood ratio tests indicated the detection probability at CR113 and the $\lambda(=S \cdot p)$ parameters in the last reach were homogeneous between the three release groups. The full model was used for the early season estimate for STH.

The estimates of forebay-to-tailrace survival (Table 5.2) were very close to the estimates of dam passage survival; the greatest difference was 0.0069 across all comparisons. Standard errors were also comparable because sample sizes were nearly the same.

Table 5.2. Summary of the estimates of forebay-to-tailrace survival at Bonneville Dam in 2011 for STH for early season (April 30–May 13, 2011) and the entire study (April 30–May 31, 2011). Standard errors are in parentheses.

Period	Steelhead
Early Season (April 30–May 13)	0.9752 (0.0180)
Season-Wide (April 30–May 31)	0.9589 (0.0211)

5.2.3 Route-Specific Passage Survival

Route-specific, single-release dam passage survival estimates for STH were highest for the B2CC (98.8%), surface-flow outlets combined (97.1%), spillway (96.5%), and the B1 sluiceway (95.3%). The lowest survival rates were for fish passing through the turbines. Interestingly, the survival estimate for B2 JBS was not much better than the B1 turbines, but significantly better than B2 turbines (Table 5.3).

Table 5.3. Route-specific dam passage survival estimates for juvenile steelhead.

Metric	Estimate	SE	n
B2CC	0.9877	0.0268	542
B2 JBS	0.9377	0.0413	66
Surface-Flow Outlet	0.9712	0.0263	1,002
B1 Sluiceway	0.9534	0.0277	460
B1 Turbines	0.9362	0.0258	1,301
Turbine (B1 and B2)	0.9340	0.0256	1,463
Spillway	0.9646	0.0257	3,064
B2 Turbines	0.9185	0.0334	162

5.3 Travel Times

Median travel times for 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 were short, ranging from 0.51 h during the high-flow late season to 1.67 h during the normal-flow early season (Table 5.4). Over the entire season, forebay residence time was 0.85 h (SE = 0.43). Median egress times from the last dam-face detection until the last tailrace-array detection also were short, ranging from 0.35 h during the high-flow late season to 0.41 h during the normal-flow early season (Table 5.4). Mean travel times also are presented in Table 5.4, but those estimates are overly influenced by a few fish that traveled much slower than most.

Table 5.4. Travel times (h) for juvenile steelhead.

Passage Time Metrics and Statistics	All Season			Early Season			Late Season		
	Hours	SE	n	Hours	SE	n	Hours	SE	n
Median Forebay Residence	0.85	0.43	5,696	1.67	0.55	2,544	0.51	0.63	3,152
Median Tailrace Egress	0.39	0.32	3,789	0.41	0.40	2,297	0.35	0.52	1,492
Mean Forebay Residence	7.00	0.43	5,696	7.52	0.55	2,544	6.58	0.63	3,152
Mean Tailrace Egress	3.77	0.32	3,789	3.30	0.40	2,297	4.49	0.52	1,492

Travel times statistics also were estimated for day and night periods of fish passage (Table 5.5, based on the time of passage relative to the time of civil sunrise and sunset; none of the differences in median travel times between daytime and nighttime estimates were significant based on the overlapping of standard errors. Mean estimates of forebay residence time and tailrace egress time were lower at night than they were during the day, but only the tailrace egress estimates appeared to differ significantly based on nonoverlapping 95% CIs.

Table 5.5. Forebay residence and tailrace egress times (h) for juvenile steelhead passing during daytime and nighttime.

Passage Time Metrics and Statistics	Day			Night		
	Hours	SE	n	Hours	SE	n
Median Forebay Residence	0.98	0.64	3,201	0.71	0.52	2,495
Median Tailrace Egress	0.36	0.24	1,960	0.42	0.60	1,829
Mean Forebay Residence	7.44	0.64	3,201	6.43	0.52	2,495
Mean Tailrace Egress	2.27	0.24	1,960	5.37	0.60	1,829

5.4 Passage Efficiencies

Project passage metrics were estimated for the entire season (Table 5.6) and were compared for day/night (Table 5.7) and early/late season (Table 5.8) flow rate differences. The FPE, SPE+B2CC, SPE, B2CC relative to both the dam and B2, B1 sluiceway relative to B1 (B1 FPE), B2 FPE, and B2 FGE were all significantly higher during the day than at night, while both B1 and B2 turbine efficiencies were significantly higher during the night than during the day.

Fish passage efficiency, SPE+B2CC, and SPE were all significantly higher during the late season than they were during the early season, while B1 sluiceway, B1 and B2 turbines, B2CC relative to both the dam and B2, B2 JBS, and B2 FPE were significantly higher during the early season compared with the late season. High flows in the late season resulted in a larger percentage of fish passing through the spillway (68.9%) compared with the early season (41.2%), leading to higher associated metrics: FPE, SPE, and SPE+B2CC, but significantly lower passage efficiencies through the powerhouses.

Table 5.6. Passage efficiencies for all juvenile steelhead passing Bonneville Dam in 2011.

Metric	Estimate	SE	n
Fish Passage Efficiency (FPE) || Dam	0.749	0.0057	5,833
SPE+B2CC Efficiency || Dam	0.653	0.0063	5,833
Spill Passage Efficiency (SPE) || Dam	0.560	0.0066	5,833
B1 Sluiceway Efficiency || Dam	0.079	0.0035	5,833
B1 Turbine Efficiency || Dam	0.223	0.0055	5,833
B2CC Efficiency || Dam	0.093	0.0038	5,833
B2 JBS Passage Efficiency || Dam	0.017	0.0017	5,833
B2 Turbine Efficiency || Dam	0.028	0.0022	5,833
B1 Sluiceway Efficiency || B1=B1 FPE	0.261	0.0105	1,761
B2 FPE	0.799	0.0141	804
B2CC Efficiency || B2	0.674	0.0165	804
B2 JBS Passage Efficiency || B2	0.124	0.0116	804
B2 FGE (Screen Efficiency)	0.382	0.0300	262

Table 5.7. Day and night passage efficiencies for juvenile steelhead passing Bonneville Dam in 2011.

	Day			Night			
Metric	Estimate	SE	n	Estimate	SE	n	Different?
Fish Passage Efficiency (FPE) || Dam	0.835	0.0064	3,408	0.648	0.0095	2,562	Yes
SPE+B2CC Efficiency || Dam	0.736	0.0076	3,408	0.561	0.0099	2,269	Yes
Spill Passage Efficiency (SPE) || Dam	0.603	0.0085	3,408	0.527	0.0100	2,562	Yes
B1 Sluiceway Efficiency || Dam	0.080	0.0047	3,408	0.073	0.0051	2,562	No
B1 Turbine Efficiency || Dam	0.145	0.0061	3,408	0.315	0.0092	2,562	Yes
B2CC Efficiency || Dam	0.133	0.0058	3,408	0.035	0.0036	2,562	Yes
B2 JBS Passage Efficiency || Dam	0.019	0.0023	3,408	0.014	0.0023	2,562	No
B2 Turbine Efficiency || Dam	0.019	0.0024	3,408	0.037	0.0038	2,562	Yes
B1 Sluiceway Efficiency || B1=B1 FPE	0.356	0.0173	769	0.188	0.0124	992	Yes
B2 FPE || B2	0.887	0.0131	583	0.566	0.0333	221	Yes
B2CC Efficiency || B2	0.777	0.0172	583	0.403	0.0330	221	Yes
B2 JBS Efficiency || B2	0.110	0.0129	583	0.163	0.0248	221	No
B2 FGE (Screen efficiency)	0.492	0.0438	130	0.273	0.0388	132	Yes

Table 5.8. Early and late season passage efficiencies for juvenile steelhead passing Bonneville Dam in 2011.

	Early (<5/13)			Late (≥5/13)			
Metric	Estimate	SE	n	Estimate	SE	n	Different?
Fish Passage Efficiency (FPE) || Dam	0.701	0.0091	2,541	0.797	0.0070	3,451	Yes
SPE+B2CC Efficiency || Dam	0.583	0.0098	2,541	0.721	0.0080	3,451	Yes
Spill Passage Efficiency (SPE) || Dam	0.412	0.0098	2,541	0.689	0.0083	3,451	Yes
B1 Sluiceway Efficiency || Dam	0.089	0.0056	2,541	0.068	0.0043	3,451	Yes
B1 Turbine Efficiency || Dam	0.259	0.0087	2,541	0.186	0.0067	3,451	Yes
B2CC Efficiency || Dam	0.170	0.0075	2,541	0.032	0.0030	3,451	Yes
B2 JBS Passage Efficiency || Dam	0.029	0.0033	2,541	0.008	0.0015	3,451	Yes
B2 Turbine Efficiency || Dam	0.041	0.0039	2,541	0.017	0.0022	3,451	Yes
B1 Sluiceway Efficiency || B1=B1 FPE	0.255	0.0147	883	0.268	0.0149	878	No
B2 FPE || B2	0.831	0.0152	610	0.696	0.0330	194	Yes
B2CC Efficiency || B2	0.710	0.0184	610	0.562	0.0356	194	Yes
B2 JBS Efficiency || B2	0.121	0.0132	610	0.134	0.0245	194	No
B2 FGE (Screen Efficiency)	0.418	0.0371	177	0.306	0.0500	85	No

5.5 Passage Distributions

The distributions of all detection events on the four forebay entrance array nodes helped to explain why the spillway and B1 passed more fish than B2 in spring 2011, as shown in Figure 5.1. About 67.6% of autonomous node tag detections occurred on the node closest to the Oregon shore; 30.4% occurred on two mid-channel nodes, and just 2.0% occurred near the Washington shore. The distribution of passage at the three major dam structures was correlated with flow among the structures ($r^2 = 0.80$), but B1 passed 31% of the STH in just 20% of the flow compared to B2 passing just 14% of fish in 28% of flow. When spill was ≥35%, 57% of juveniles passed at the spillway compared to 43% that passed through B1 and B2. When spill was <35%, only 31% of fish passed through the spillway compared to the 69% of juveniles that passed through B1 and B2.

Almost 2.8% of the STH did not pass through the Bonneville project at the dam structure where they were first detected, and of these over 85% rejected the spillway and re-routed through either B1 or B2. This milling behavior was much more pronounced during low spill (9.8% re-routed) than it was during high spill (2.0%), and higher during day (3.3%) than at the night (1.6%).

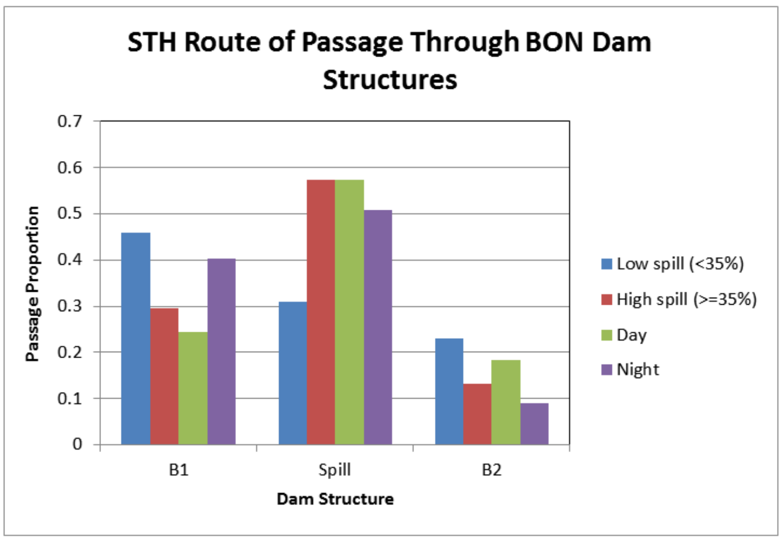


Figure 5.1. Distribution of passage of STH through Bonneville Dam structures during low spill, high spill, day, and night.

5.5.1 Horizontal Passage Distributions

A plot of the distribution of passage among individual routes through the dam clearly shows that more STH passed through the spillway (56%) than through B1 or B2 routes (Figure 5.2). The top four individual routes of passage included the B2CC and spill bays 17, 18, and 3. Individual routes that passed >3% of STH (25.6% of all individual routes) included the B2CC, five spill bays (from highest to lowest: 17, 18, 3, 16, and 5), B1 turbine 10, B1 sluiceway outlet 10, and B1 turbines 6 and 7. Figure 5.3 shows that the B1 sluiceway and B2CC together passed about 8% of the STH known to have passed the entire dam. Relative to B2, the B2CC passed 67.4% of STH, which was within to the historical range of 59 to 75%. Relative to B1, the B1 sluiceway passed 26.1% of STH, and this was slightly below the historical range of 29 to 65%. Higher levels of spill during the late season increased the percent of fish passing via the spillway by reducing the percentages passing via the B1 sluiceway, B1 turbines, the B2CC, and the B2 turbines (Figure 5.4). Spillway and B2CC passage was higher during the day than it was at night, and turbine passage through B1 or B2 was higher at night than it was during the day (Figure 5.5).

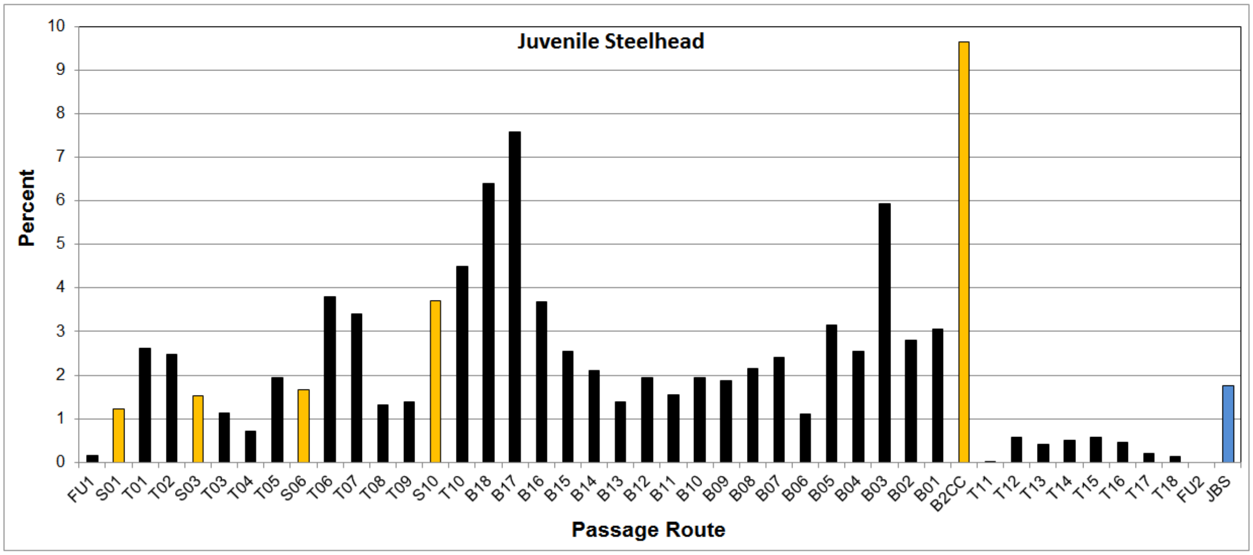


Figure 5.2. Horizontal distribution of juvenile steelhead passage in spring 2011. Percent passage through surface-flow outlets (S01, S03, S06, S10, and the B2CC) are shown as gold bars, and B1 outlets are displayed to the left of the adjacent turbine with the same number, although they are actually physically 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 JBS.

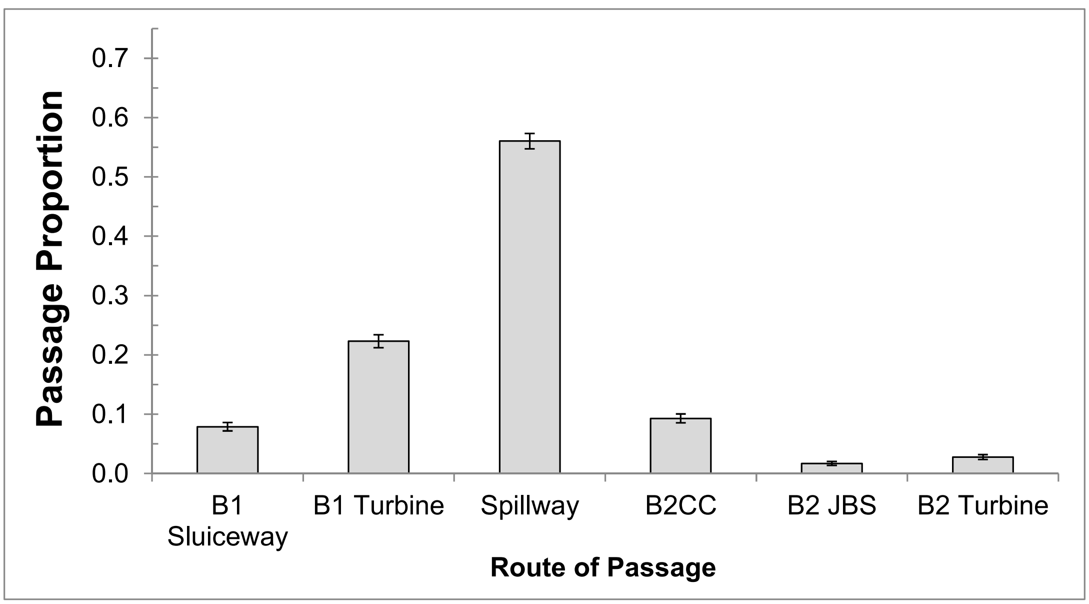


Figure 5.3. Passage route proportions for steelhead during spring (April 30–May 31) 2011.

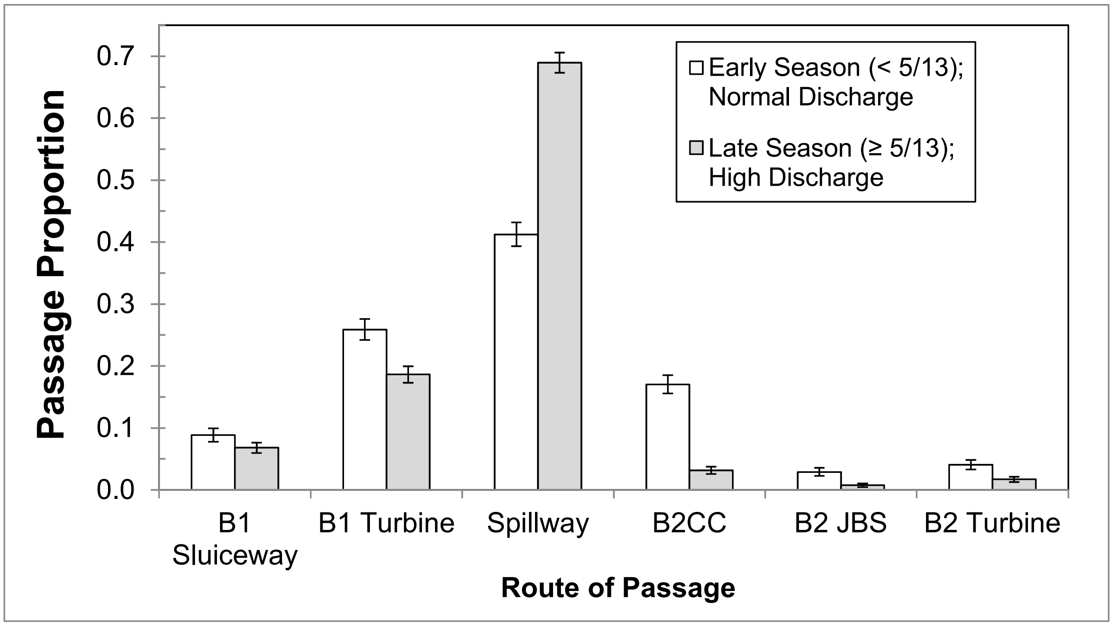


Figure 5.4. Passage route proportions for steelhead passing through Bonneville Dam during early and late seasons.

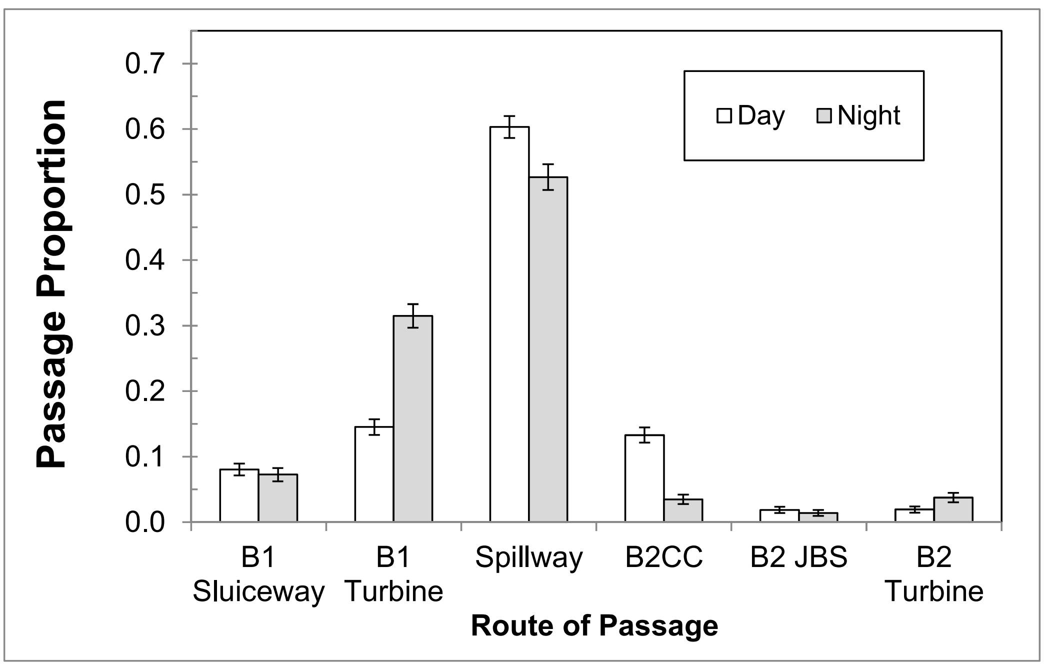


Figure 5.5. Passage route proportions for steelhead passing through Bonneville Dam during day and night periods in spring 2011.

The efficiency of the B2CC relative to B2 in 2011 was comparable to estimates for 2004 and 2005 before the B2 BGS was installed (Table 5.9). Efficiency also was higher in 2011 than it was in 2009 and 2010 when the BGS was installed (Table 5.9). The JBS at B2 passed 12.44% of STH passing via B2, and the FPE of B2 was 79.9%.

Table 5.9. Passage percentage for tagged juvenile steelhead migrating downstream through B2. 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; 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
2011	67.41	20.2	none

5.5.2 Forebay Vertical Distribution

The STH were vertically distributed within 4 m of the surface from 25 m to less than 5 m out from the dam face (Figure 5.6). Approach depths were shallower during the day (Figure 5.7) than they were at night (Figure 5.8). The depth profiles at B1 for day and night looked similar; the final passage depths at 5 m out from the dam face were 2.62 and 4.48 m, respectively. A similar trend was observed for B2 (STH were deeper at night than during the day), but at night there was a clear 5.3-m increase in median detection depth as fish approached from 10 m upstream of the dam face to within 5 m that was not observed during the day. The spillway showed similar profiles with a 5-m passage depth of 1.70 and 4.74 m for day and night, respectively.

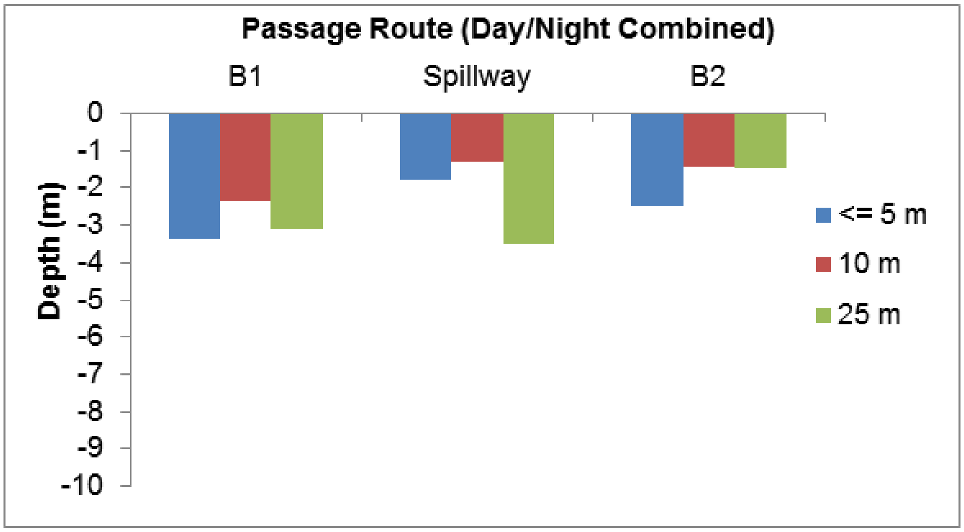


Figure 5.6. Season-wide (April 30–May 31) median vertical approach and passage distribution of STH by route through Bonneville Dam.

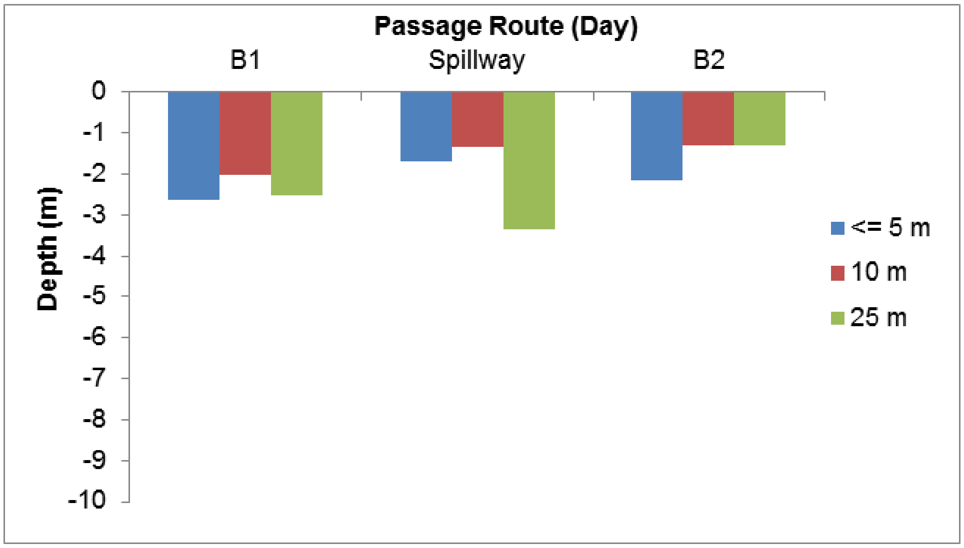


Figure 5.7. Season-wide (April 30–May 31) day median vertical approach and passage distribution of STH by route through Bonneville Dam.

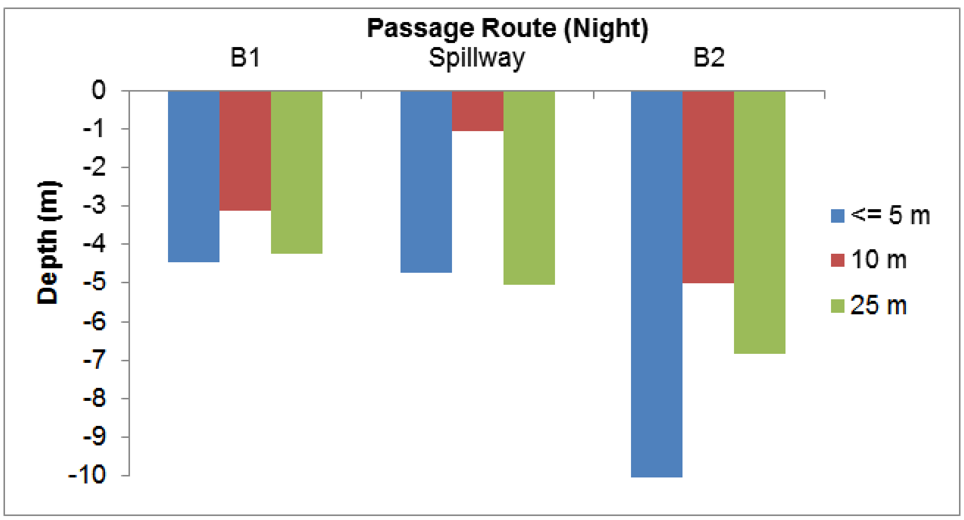


Figure 5.8. Season-wide (April 30–May 31) night median vertical approach and passage distribution of STH by route through Bonneville Dam.

6.0 Discussion

This section includes discussion of the statistical performance and survival model assumptions, historical context for 2011 estimates, day and night effects on passage metrics, and the effects of spillway discharge on early and late parts of the spring season.

6.1 Statistical Performance and Survival Model Assumptions

The large spring runoffs in 2011 resulted in higher flow volumes and more spill at BON than initially planned. The conditions affected the 2011 JSATS compliance studies at BON in three ways. Most notably, the summer CH0 compliance study was cancelled. Secondly, the planned 100-kcfs spill level was interrupted beginning on May 13, 2011 with spill levels exceeding 200 kcfs by the end of the spring investigations (Figure 3.1). Thirdly, detection probabilities at the below-BON hydrophone arrays were much lower than anticipated. Detection probabilities at CR161 ranged from 0.85 to 0.95, while prior experience resulted in detection probabilities greater than 0.95. At CR113, observed detection probabilities ranged from 0.75 to 0.82 rather than the 0.90 that was anticipated. These lower detection probabilities resulted in lower precision for the estimates of dam passage survival than required by the 2008 BiOp. The estimated standard errors from the virtual/paired-release design ranged from 0.0176 to 0.0212 instead of being ≤0.0150.

Testing of survival model assumptions (Appendix E) indicated that there were no serious violations that would invalidate the 2011 results. Length frequency distributions of tagged fish and the untagged fish passing through the JDA SMF were very similar for CH1 and juvenile STH. Post-tagging and pre-release mortality was low (CH1: 0.31%, STH: 0.08), and no acoustic tags were shed. In 2011, the study team released 50 dead fish with active acoustic tags into the B2CC (n=6) and the spillway (n=44), and none of these fish were detected on survival-detection arrays located 73, 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 2011. Plots of the arrival timing of the various release groups at downstream detection sites indicate reasonable mixing for both CH1 (Figure 3.14) and STH (Figure 3.15).

6.2 Historical Context

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

6.2.1 Survival Estimates

We provide context for 2011 dam passage survival estimates by tabling them with estimates from previous studies. Before 2008, there was no BGS in the B2 forebay like there was from 2008 through 2010. The U.S. Geological Survey (USGS) conducted paired-release survival studies at B2 using radio telemetry in 2002, 2004, and 2005, and those studies included passage survival estimates for fish passing through the JBS, B2CC, and turbines (Counihan et al. 2003, 2006a, 2006b).

We looked for obvious nonoverlapping 95% CIs to judge whether CH1 survival estimates in Table 6.1 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 the survival rates of B2-, B2CC-, B2 JBS-, turbine-, or dam-passed CH1 among years. However, survival rates of B1-passed yearlings were significantly lower in 2002, 2004, and 2009 than they were in 2010, but estimates for 2002, 2004, 2005, 2009, and 2011 did not differ. Spillway survival rates were significantly lower in 2004 and 2005 than they were in 2002, and they were lower in 2004 than they were in 2009. Spillway estimates for 2009, 2010, and 2012 did not differ significantly from estimates for 2002 or 2005. 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 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 6.1) was as follows: B2CC, B2 JBS, B2, turbines, B1, and then the spillway.

Table 6.1. Survival of yearling Chinook salmon that passed through various routes at Bonneville Dam in some years from 2002 through 2011. 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, 2009, 2010, and 2011 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]
2011	0.968 (0.021)	0.957 (0.041)	0.964 (0.022)	0.994 (0.041)	0.982 (0.048)	0.962 (0.041)	0.960 (0.034)
Average	0.947	0.942	0.987	1.007	0.993	0.967	0.964

(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.

We visually looked for obvious nonoverlapping 95% CIs to judge whether juvenile STH survival estimates in Table 6.2 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 estimates for STH passing through B1, the spillway, or B2, differed significantly among years, and the only one pair of years of dam passage survival estimates differed (2004 was higher than the estimate in 2011).

However, B2CC passage survival was higher in 2005 than it was in 2010, although the gap between the 95% confidence intervals was only 0.002. The survival rate of STH passing through the B2 JBS appeared to be higher in 2010 (1) than it was in 2005 (0.956) or in 2011 (0.940). The survival rates for turbine passed STH did not differ significantly in 2008, 2009, 2010, or 2011, but the 2008, 2010, and 2011 estimates, which ranged from 0.933 to 0.982, were higher than the 2005 estimate of 0.868. We ranked routes from best to worst for STH according to the grand mean survival rate as follows: B2CC, B2, B2 JBS, spillway, B1, and turbines.

Table 6.2. Survival of STH that passed through various routes at Bonneville Dam in some years from 2004 through 2011. 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, 2009, 2010, and 2011 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)[c]	0.961 (0.017)[c]	0.979 (0.015)[c]	0.975 (0.011)[d]	1.003 (0.025)[c]	0.933 (0.025)[c]	0.969 (0.014)[c]
2011	0.941 (0.026)	0.965 (0.050)	0.969 (0.027)	0.994 (0.065)	0.940 (0.033)	0.934 (0.026)	0.965 (0.006)
Average	0.950	0.963	0.968	0.998	0.966	0.925	0.972

(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 2011 varied among the runs of fish studied, but it is important to note that the spillway ranked as the worst route for passing CH1, as it did in 2010 (see Table 6.1). For STH in 2011 (Table 6.2), the spillway ranked third after the B2CC and B2, but the spill passage survival rate of 0.965 for STH was only slightly better than rates observed for CH1 (0.957). 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 STH was 203.2 mm compared with a median length of 148.5 mm for CH1.

In spring 2011, survival rates of fish passing through the B1 sluiceway (CH1 = 0.969; STH = 0.954) were lower by 2.5% and 4%, repectively, than rates for fish passing through the B2CC (0.994 for both runs). The reason for lower B1 sluiceway survival might be related to debris loading at shallow B1 sluiceway entrances. The shallow openings in the B1 surface-flow outlets are more prone to clogging than the B2CC outlet.

6.2.2 Travel Time Estimates

Median forebay residence times were longer for STH (0.85 h) than for CH1 (0.55 h), and this was not a surprise given the extensive searching behavior exhibited by STH in forebay areas. While median forebay residence times for CH1 were similar in 2011 (0.55 h) and 2010 (0.74 h), the median time for STH was 53% shorter in 2011 (0.85 h) than it was in 2010 (1.69 h). Shorter residence times in 2011 likely resulted from much higher river discharge in spring 2011 than occurred in spring 2010. In 2010, when river discharge was average, 10.3% of STH approaching one of three dam structures eventually passed at a different structure, whereas this percentage dropped to just 2.9% in 2011 when river discharge was above average during the late season. Out of the 3,234 STH that first approached the spillway in 2011, 163 (5.0%) subsequently passed at one of the powerhouses, but in 2010 when river discharge was average, 18% of STH approaching the spillway finally passed the dam at B1 or B2.

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. We tried estimating 100-m forebay residence times in 2010, but the estimates were biased by significant differences in the range of tag detection at the three dam structures, so we abandoned that metric. For example, tagged fish approaching B1 could be detected at ranges >200 m, whereas detections in the noisy spillway forebay usually were less than 100 m. Historical average estimates summarized by Ploskey et al. (2007a) for STH were 5.4 h for B1, 0.3 h for the spillway and 3.0 h for B2. The average of those mean estimates for STH was 2.9 h, and this was 41% of the mean estimate of 7.0 h in this study. About 31% of the STH in the 2011 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 2011 average estimate high because flow through B1 was less than flow through the spillway or B2. Estimates of forebay residence summarized by Ploskey et al. (2007a) for CH1 were 2.2 h for B1, 0.2 h for the spillway, and 0.5 for B2. The average of those mean estimates (0.97 h) was about 18% of the 2011 estimate for yearlings (5.34 h), which likely was biased high by having 28% 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 0.55 h in 2011, and this was lower than the average historical estimate for yearlings passing B2 and the spillway. When reporting forebay residence times, we prefer the use of medians rather than means because medians are less susceptible to bias by fish readily detected in quiet areas with low flow. Unfortunately, we could not find historical median estimates of forebay residence times to compare with 2010 and 2011 estimates.

Holmberg et al. (2001) estimated median tailrace egress times for STH and CH1. The estimated median egress times from the forebay to the B2 outfall vicinity for 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 0.39 h for STH in 2011. 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 was 0.41 h. Those historical estimates were reasonably close to our median estimate of 0.39 h for yearlings in spring 2011.

6.2.3 Passage-Efficiency Estimates

Passage-efficiency metrics for each run of fish studied in 2011 were compared to available historical estimates as summarized by Ploskey et al. (2007a; Table 6.3). Metrics were either within or lower than the range of historical estimates. For example, the FPE estimate for CH1 was within the historical range, but the STH estimate was 3.1% lower than the bottom of the historical range. For STH, B2CC passage efficiency with respect to B2 was within the historical range, but for CH1 it was 9.9% below the minimum of the historical range. The fraction of flow passing through the B2CC was lower in 2011 than in previous years because of much higher river discharge in 2011 than in previous years. The B1 sluiceway efficiency relative to B1 was 2.9% lower than historical minimum for STH and 5.1% below the minimum for CH1.

Table 6.3. Comparison of passage-efficiency metric estimates in 2011 relative to available historical ranges for non-drought years.

Metric (Percent)	STH[a]	Historical Range[b]	CH1[a]	Historical Range[b]
Fish-Passage Efficiency (FPE) || Dam	74.9	78–86	71.7	71–76
Spill-Passage Efficiency (SPE) || Dam	56.0	26–55	58.1	33–57
Spill+B2CC Passage Efficiency || Dam	65.3		61.0	
B1 Sluiceway Passage Efficiency || B1	26.1	29–65	23.9	29–53
B2CC Passage Efficiency || B2	67.4	59–75	19.1	29–49
B2 FGE	38.2	34–59	35.4	33–51
B1 Sluiceway Passage Efficiency || Dam	7.9		6.4	
B2CC Passage Efficiency || Dam	9.3		2.9	
B2 JBS Passage Efficiency || Dam	12.4		4.3	

(a) STH = juvenile steelhead; CH1 = yearling Chinook salmon.
(b) Non-drought years except for B2 FGE.
(c) Unit 11 was out of service all year and unit 13 was operated only a few hours.

The 2011 estimates of SPE were within the historical range and indicate no backsliding from historical estimates as long as spillway discharge has been used to facilitate passage of juvenile salmonids through non-turbine routes. Historical estimates of SPE for non-drought spring periods ranged from 26% to 55% for STH and from 33% to 57% for CH1 (summarized by Ploskey et al. 2007a). The spring 2011 estimate of SPE was 54.4% for STH and 56.6% for CH1.

6.2.4 Day and Night Effects on Passage Metrics

We found significant differences in some passage metrics related to daytime and nighttime passage that could have important management implications. Findings described in this and the previous paragraph strongly support the hypothesis that juvenile fish passage through non-turbine routes could be increased by lighting surface-flow outlets from the forebay at night. We recommend testing this hypothesis using temporary lighting with on and off treatments or simply installing cost-efficient lighting within 75 m of all surface-flow outlets. These could be high-intensity mercury vapor lights on lamp posts to brightly illuminate outlets or a bright as a bank of baseball stadium lights to change night to day in these areas. The effort might be justified for enhancing juvenile fish passage and public safety. For CH1 (Table 4.7), we observed that FPE, B2CC passage efficiency relative to B2 or the entire dam, B2 JBS efficiency relative B2 or the entire dam, B2 FGE (Powerhouse Screen Efficiency), B2 FPE, and B1 JBS efficiency were all higher during the day than they were at night. The biggest difference was in CH1 B2 FPE, which was 32.8% higher during the day (61.9%) than it was at night (29.1%). The CH1 B2CC passage efficiency relative to B2 was 10.9% higher during the day than it was at night. For STH (Table 5.7), most metrics were higher during the day than they were at night: B2CC passage efficiency relative to B2 (37.4%), B2 FPE (32.1%), B2 FGE (22.0%), FPE (18.8%), spill+B2CC passage efficiency (17.5%), B1 sluiceway passage efficiency relative to B1 (16.9%), B2CC passage efficiency relative to the dam (9.8%), and spillway passage efficiency (7.7%). 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.

6.3 Early and Late Effects on Passage Metrics

Increases in SPE between the early and late spring seasons increased FPE but at the expense of passage proportions through other non-turbine routes, including the B2CC and B2 JBS for both species and the B1 sluiceway relative to the entire dam for STH.

We found significant differences in some passage metrics between early and late season. For CH1 (Table 4.8), the FPE relative to the dam, spill+B2CC passage efficiency, and SPE were lower during the early season than during the late season when river discharge increased significantly. In contrast and relative to the entire dam, B2CC efficiency, B2 JBS efficiency, and B2 turbine passage efficiency were all higher during the early season than they were during the late season. The largest increase from the early to the late season was observed in spill passage efficiency (16.3%), and the largest decrease between early and late season was B2 JBS efficiency relative to the dam (6.2%).

For STH (Table 5.8), FPE, spill+B2CC passage efficiency, and SPE were lower during the early season than during the late season when river discharge was significantly higher, while B2CC efficiency relative to B2 and the dam, B2 FPE, and B2 JBS efficiency relative to the dam were higher during the early season than during the late season. The largest differences from the early season to the late season were SPE (+24.1%) and B2CC efficiency relative to B2 (-14.8%). The efficiency of B2 to pass STH during the high flows of late season decreased, but was offset by an increase in SPE leading to an increase in FPE relative to the dam.

7.0 Conclusions and Recommendations

The JSATS deployed at BON performed about as expected for normal flow during the early season, but because of the higher than normal flows in late spring 2011, detection at downstream survival arrays was depressed and resulted in standard errors in excess of the 2008 BiOp standard of 0.015.

Recommendations derived from the 2011 BON study are as follows:

1. Proceed with an official BiOp and Fish Accord compliance test in 2012. To bring future standard errors below 0.015 we make three recommendations: 1) add two autonomous nodes to every downstream array to increase node densities by 33.3% at Knapp, 20% at Kalama, and 33.3% at Oak Point; 2) double sample sizes for reference releases in the tailrace and tailwater from 800 to 1,600 for each species; and 3) reduce the PRI from 3 s to 2 s for tags implanted in fish for reference releases below BON. We also recommend that the CENWP 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.
2. We recommend that the USACE deploy one bank of stadium lights above surface-flow outlets at B1, the B2CC, and turbines 11, 12, and 13 at 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 6.2.4). In addition, previous acoustic camera studies at BON surface-flow outlets indicated clear differences in smolt behavior and the frequency of piscivore predator attacks during day and night periods. If test light deployments are successful in changing smolt passage behavior at night, permanent light deployments should be designed and installed.
3. Debris clogging surface-flow outlets in the B1 forebay should be cleared as soon as possible, particularly in summer (or in a high-flow spring) when river discharge typically peaks. Survival of fish passing through the B1 sluiceway was relatively high in spring (CH1 = 0.969; STH = 0.953), but was not significantly different from survival passing through the B1 turbines. The shallow openings in the B1 surface-flow outlets are more prone to clogging in high flows than is the B2CC outlet, which provides for relatively high passage survival in spring and summer.
4. We recommend operating the project to avoid further increases in the number or percent of CH1 passing through the spillway until the underlying cause for its poor fish passage survival rate is understood. We observed that point estimates of spill passage survival were lower than point estimates for any other route used by CH1 (0.957) except for B2 turbines (0.947). For STH, the spillway point estimate (0.965) was higher than survival estimates for fish passing through B1 and B2 turbines (0.936 and 0.919, respectively), B2 JBS (0.938), and the B1 sluiceway (0.953), but in 2010 spillway survival rates for STH were lower (93.7%) relative to the B2CC (97.6%). Very high spill levels appear to take fish from other benign routes such as the B2CC, B1 sluiceway, and B2 JBS, and those routes had better survival rates for CH1 than did the spillway. For STH, spill passage survival (0.965) also was lower than passage survival for the B2CC (0.988). If reduced survival rates for spillway-passed fish were somehow related to concrete apron erosion and rock deposition in the spillway stilling basin, concrete repair efforts the winter of 2012–2013 should improve spillway passage survival. If estimated spillway survival estimates are significantly higher in 2014, it might be

time to consider test installations of top-spill weirs to reduce STH rejection of the spillway in average water years (see Section 4.5 on passage distributions and discussion of travel time estimates in Section 7.2.2).

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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 or dead at three sites.

Tag Date	Number Tagged	Release Date	Release Location	Number Released
2011-04-25	80	2011-04-26	Roosevelt	80
2011-04-26	81	2011-04-27	Roosevelt	81
2011-04-27	185	2011-04-28	Celilo	25
			JDA_tailrace	75
			Roosevelt	84
		2011-04-29	JDA_SPILL[a]	1
2011-04-28	208	2011-04-29	Celilo	25
			Hood River	25
			JDA_SPILL[a]	2
			Roosevelt	81
			TDA tailrace	50
		2011-04-30	Hood River	25
2011-04-29	233	2011-04-30	BON tailrace	50
			Celilo	25
			JDA_tailrace	76
			Roosevelt	81
		2011-05-01	TDA_SPILL[a]	1
2011-04-30	255	2011-05-01	Celilo	25
			Hood River	25
			Knapp	48
			Roosevelt	82
			TDA tailrace	50
		2011-05-02	Hood River	25
2011-05-01	232	2011-05-02	BON tailrace	50
			Celilo	25
			JDA_tailrace	75
			Roosevelt	82
2011-05-02	255	2011-05-03	Celilo	25
			Hood River	25
			Knapp	48
			Roosevelt	82
			TDA tailrace	50
		2011-05-04	Hood River	25

Table A.1. (contd)

Tag Date	Number Tagged	Release Date	Release Location	Number Released
2011-05-03	243	2011-05-03	JDA_SPILL[a]	5[b]
			TDA_SPILL[a]	5[b]
		2011-05-04	BON tailrace	50
			Celilo	25
			JDA_tailrace	74
			Roosevelt	82
		2011-05-10	JDA_SPILL[a]	2
2011-05-04	254	2011-05-05	Celilo	25
			Hood River	25
			Knapp	46
			Roosevelt	82
			TDA tailrace	49
		2011-05-06	Hood River	25
		2011-05-10	JDA_SPILL[a]	2
2011-05-05	233	2011-05-06	BON tailrace	50
			Celilo	25
			JDA_tailrace	76
			Roosevelt	82
2011-05-06	257	2011-05-07	Celilo	25
			Hood River	25
			Knapp	50
			Roosevelt	82
			TDA tailrace	50
		2011-05-08	Hood River	22
		2011-05-10	BON_B2CC[a]	3
2011-05-07	233	2011-05-08	BON tailrace	50
			Celilo	25
			JDA_tailrace	76
			Roosevelt	82
2011-05-08	257	2011-05-09	Celilo	25
			Hood River	25
			Knapp	50
			Roosevelt	82
			TDA tailrace	50
		2011-05-10	BON_B2CC[a]	1
			Hood River	24
2011-05-09	233	2011-05-10	BON tailrace	50
			Celilo	25
			JDA_tailrace	76
			Roosevelt	82

Table A.1. (contd)

Tag Date	Number Tagged	Release Date	Release Location	Number Released
2011-05-10	257	2011-05-11	Celilo	25
			Hood River	25
			Knapp	49
			Roosevelt	81
			TDA tailrace	50
		2011-05-12	Hood River	25
		2011-05-15	JDA_SPILL[a]	1
			TDA_SPILL[a]	1
2011-05-11	233	2011-05-12	BON tailrace	50
			Celilo	25
			JDA_tailrace	76
			Roosevelt	82
2011-05-12	255	2011-05-13	Celilo	25
			Hood River	25
			Knapp	49
			Roosevelt	81
			TDA tailrace	50
		2011-05-14	Hood River	25
2011-05-13	233	2011-05-14	BON tailrace	50
			Celilo	25
			JDA_tailrace	76
			Roosevelt	82
2011-05-14	255	2011-05-15	Celilo	24
			Hood River	25
			JDA_SPILL[a]	1
			Knapp	48
			Roosevelt	82
			TDA tailrace	50
			TDA_SPILL[a]	1
		2011-05-16	Hood River	24
2011-05-15	233	2011-05-15	JDA_SPILL[a]	1
		2011-05-16	BON tailrace	50
			Celilo	25
			JDA_tailrace	75
			Roosevelt	82
2011-05-16	256	2011-05-17	Celilo	25
			Hood River	25
			Knapp	49
			Roosevelt	82
			TDA tailrace	50
		2011-05-18	Hood River	25

Table A.1. (contd)

Tag Date	Number Tagged	Release Date	Release Location	Number Released
2011-05-17	243	2011-05-17	BON_SPILL[(a)]	10[(b)]
		2011-05-18	BON tailrace	50
			Celilo	25
			JDA_tailrace	76
			Roosevelt	82
2011-05-18	256	2011-05-19	Celilo	25
			Hood River	25
			Knapp	49
			Roosevelt	82
			TDA tailrace	50
		2011-05-20	Hood River	25
2011-05-19	233	2011-05-20	BON tailrace	50
			Celilo	25
			JDA_tailrace	76
			Roosevelt	81
		2011-05-22	TDA_SPILL[(a)]	1
2011-05-20	255	2011-05-21	Celilo	25
			Hood River	25
			Knapp	48
			Roosevelt	82
			TDA tailrace	50
		2011-05-22	Hood River	25
2011-05-21	233	2011-05-22	BON tailrace	49
			Celilo	25
			JDA_tailrace	75
			Roosevelt	82
		2011-05-24	BON_SPILL[(a)]	2
2011-05-22	257	2011-05-23	Celilo	25
			Hood River	25
			Knapp	50
			Roosevelt	82
			TDA tailrace	50
		2011-05-24	Hood River	25
2011-05-23	233	2011-05-24	BON tailrace	49
			BON_SPILL[(a)]	1
			Celilo	25
			JDA_tailrace	75
			Roosevelt	82
		2011-05-29	BON_SPILL[(a)]	1

Table A.1. (contd)

Tag Date	Number Tagged	Release Date	Release Location	Number Released
2011-05-24	140	2011-05-25	Celilo	20
			Hood River	20
			Knapp	40
			TDA tailrace	40
		2011-05-26	Hood River	20
2011-05-25	221	2011-05-26	BON tailrace	50
			Celilo	25
			JDA_tailrace	76
			Roosevelt	68
		2011-05-29	BON_SPILL[a]	2
2011-05-26	245	2011-05-27	Celilo	25
			Hood River	24
			Knapp	50
			Roosevelt	70
			TDA tailrace	50
		2011-05-28	Hood River	25
		2011-05-29	BON_SPILL[a]	1
2011-05-27	135	2011-05-28	BON tailrace	50
			Celilo	25
			JDA_tailrace	60
2011-05-28	205	2011-05-29	Celilo	30
			Hood River	30
			Knapp	50
			TDA tailrace	60
		2011-05-30	Hood River	35
2011-05-29	50	2011-05-30	BON tailrace	50
2011-05-30	81	2011-05-30	BON_SPILL[a]	7[b]
			TDA_SPILL[a]	4[b]
		2011-05-31	Knapp	70

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

Table A.2. 2011 juvenile steelhead tagged at John Day Dam and released live/dead at seven/four sites.

Tag Date	Number Tagged	Release Date	Release Location	Number Released
2011-04-25	80	2011-04-26	Roosevelt	80
2011-04-26	82	2011-04-27	Roosevelt	82
2011-04-27	183	2011-04-28	Celilo	25
			JDA_tailrace	76
			Roosevelt	82
2011-04-28	207	2011-04-29	Celilo	25
			Hood River	25
			JDA_SPILL[a]	1
			Roosevelt	81
			TDA tailrace	50
		2011-04-30	Hood River	25
2011-04-29	233	2011-04-30	BON tailrace	49
			Celilo	25
			JDA_tailrace	76
			Roosevelt	82
		2011-05-01	TDA_SPILL[a]	1
2011-04-30	257	2011-05-01	Celilo	25
			Hood River	25
			Knapp	50
			Roosevelt	82
			TDA tailrace	50
		2011-05-02	Hood River	25
2011-05-01	233	2011-05-02	BON tailrace	50
			Celilo	25
			JDA_tailrace	76
			Roosevelt	82
2011-05-02	257	2011-05-03	Celilo	25
			Hood River	25
			Knapp	50
			Roosevelt	82
			TDA tailrace	50
		2011-05-04	Hood River	25
2011-05-03	243	2011-05-03	BON_SPILL[a]	10[b]
		2011-05-04	BON tailrace	50
			Celilo	25
			JDA_tailrace	76
			Roosevelt	82
2011-05-04	257	2011-05-05	Celilo	22
			Hood River	25
			Knapp	50
			Roosevelt	82
			TDA tailrace	50
		2011-05-06	Hood River	25
		2011-05-10	TDA_SPILL[a]	3

Table A.2. (contd)

Tag Date	Number Tagged	Release Date	Release Location	Number Released
2011-05-05	232	2011-05-06	BON tailrace	49
			Celilo	25
			JDA_tailrace	76
			Roosevelt	82
2011-05-06	257	2011-05-07	Celilo	25
			Hood River	25
			Knapp	50
			Roosevelt	82
			TDA tailrace	50
		2011-05-08	Hood River	25
2011-05-07	230	2011-05-08	BON tailrace	47
			Celilo	25
			JDA_tailrace	76
			Roosevelt	80
		2011-05-10	BON_B2CC[a]	1
			TDA_SPILL[a]	1
2011-05-08	257	2011-05-09	Celilo	25
			Hood River	25
			Knapp	50
			Roosevelt	82
			TDA tailrace	50
		2011-05-10	Hood River	25
2011-05-09	230	2011-05-10	BON tailrace	48
			BON_B2CC[a]	1
			Celilo	25
			JDA_tailrace	74
			Roosevelt	82
2011-05-10	257	2011-05-11	Celilo	25
			Hood River	25
			Knapp	50
			Roosevelt	82
			TDA tailrace	50
		2011-05-12	Hood River	25
2011-05-11	230	2011-05-12	BON tailrace	50
			Celilo	25
			JDA_tailrace	75
			Roosevelt	80
2011-05-12	257	2011-05-13	Celilo	25
			Hood River	25
			Knapp	50
			Roosevelt	82
			TDA tailrace	50
		2011-05-14	Hood River	25

Table A.2. (contd)

Tag Date	Number Tagged	Release Date	Release Location	Number Released
2011-05-13	226	2011-05-14	BON tailrace	47
			Celilo	25
			JDA_tailrace	72
			Roosevelt	82
2011-05-14	257	2011-05-15	Celilo	25
			Hood River	25
			Knapp	50
			Roosevelt	82
			TDA tailrace	50
		2011-05-16	Hood River	25
2011-05-15	232	2011-05-16	BON tailrace	49
			Celilo	25
			JDA_tailrace	76
			Roosevelt	82
2011-05-16	256	2011-05-17	Celilo	25
			Hood River	25
			Knapp	49
			Roosevelt	77
			TDA tailrace	50
		2011-05-18	Hood River	25
		2011-05-22	JDA_SPILL[a]	2
			TDA_SPILL[a]	3
2011-05-17	243	2011-05-17	JDA_SPILL[a]	5[b]
			TDA_SPILL[a]	5[b]
		2011-05-18	BON tailrace	50
			Celilo	25
			JDA_tailrace	76
			Roosevelt	82
2011-05-18	257	2011-05-19	Celilo	25
			Hood River	25
			Knapp	50
			Roosevelt	82
			TDA tailrace	50
		2011-05-20	Hood River	25
2011-05-19	232	2011-05-20	BON tailrace	50
			Celilo	25
			JDA_tailrace	75
			Roosevelt	81
		2011-05-22	JDA_SPILL[a]	1

Table A.2. (contd)

Tag Date	Number Tagged	Release Date	Release Location	Number Released
2011-05-20	257	2011-05-21	Celilo	25
			Hood River	25
			Knapp	50
			Roosevelt	82
			TDA tailrace	50
		2011-05-22	Hood River	25
2011-05-21	232	2011-05-22	BON tailrace	50
			Celilo	25
			JDA_tailrace	75
			Roosevelt	82
2011-05-22	257	2011-05-23	Celilo	25
			Hood River	25
			Knapp	50
			Roosevelt	82
			TDA tailrace	50
		2011-05-24	Hood River	25
2011-05-23	233	2011-05-24	BON tailrace	50
			Celilo	25
			JDA_tailrace	76
			Roosevelt	82
2011-05-24	252	2011-05-25	Celilo	25
			Hood River	25
			Knapp	45
			Roosevelt	82
			TDA tailrace	50
		2011-05-26	Hood River	25
2011-05-25	220	2011-05-26	BON tailrace	49
			Celilo	25
			JDA_tailrace	76
			Roosevelt	70
2011-05-26	245	2011-05-27	Celilo	25
			Hood River	25
			Knapp	50
			Roosevelt	70
			TDA tailrace	50
		2011-05-28	Hood River	25
2011-05-27	139	2011-05-28	BON tailrace	49
			Celilo	25
			JDA_tailrace	65
2011-05-28	175	2011-05-29	Celilo	25
			Hood River	25
			Knapp	50
			TDA tailrace	50
		2011-05-30	Hood River	25

Table A.2. (contd)

Tag Date	Number Tagged	Release Date	Release Location	Number Released
2011-05-29	55	2011-05-30	BON tailrace	55
2011-05-30	60	2011-05-30	BON_SPILL[a]	10[b]
		2011-05-31	Knapp	50

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

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 2011.

Hydrophone Name	Latitude (NAD83)	Longitude (NAD83)	Elevation (NAVD88, ft)
BON_BSOUWAL	45.6386370	-121.9461653	63.57
BON_BSS_F1S	45.6390935	-121.9468644	64.26
BON_B01_F1D	45.6391509	-121.9467887	12.76
BON_B01_F1S	45.6391630	-121.9468228	63.12
BON_B01_02D	45.6393625	-121.9466646	12.75
BON_B01_02S	45.6393721	-121.9467003	63.11
BON_B02_03D	45.6395733	-121.9465415	12.81
BON_B02_03S	45.6395811	-121.9465780	63.17
BON_B03_04D	45.6397863	-121.9464179	12.64
BON_B03_04S	45.6397916	-121.9464554	63.00
BON_B04_05D	45.6399809	-121.9463025	12.66
BON_B04_05S	45.6399945	-121.9463354	63.02
BON_B05_06D	45.6401955	-121.9461767	12.55
BON_B05_06S	45.6402045	-121.9462127	62.91
BON_B06_07SD	45.6403728	-121.9460149	39.50
BON_B06_07SS	45.6403728	-121.9460149	62.01
BON_B06_07ND	45.6403950	-121.9460006	39.82
BON_B06_07NS	45.6403950	-121.9460006	62.32
BON_B07_08D	45.6406087	-121.9459354	12.43
BON_B07_08S	45.6406199	-121.9459701	62.79
BON_B08_09D	45.6408202	-121.9458109	12.38
BON_B08_09S	45.6408290	-121.9458470	62.74
BON_B09_10D	45.6410285	-121.9456890	12.51
BON_B09_10S	45.6410370	-121.9457253	62.87
BON_B1N_10D	45.6412173	-121.9455332	42.64
BON_B1N_10S	45.6412173	-121.9455332	65.31
BON_B1S_NW1	45.6412335	-121.9450736	70.76
BON_BS18D	45.6428602	-121.9407015	39.65
BON_BS18S	45.6428602	-121.9407015	67.52
BON_BS17_18D	45.6429996	-121.9406974	38.12
BON_BS17_18S	45.6429996	-121.9406974	65.87
BON_BS16_17D	45.6431654	-121.9406920	39.04
BON_BS16_17S	45.6431654	-121.9406920	66.46
BON_BS15_16D	45.6433303	-121.9406880	39.93
BON_BS15_16S	45.6433303	-121.9406880	67.47
BON_BS14_15D	45.6434942	-121.9406824	39.79
BON_BS14_15S	45.6434942	-121.9406824	67.45

Table B.1. (contd)

Hydrophone Name	Latitude (NAD83)	Longitude (NAD83)	Elevation (NAVD88, ft)
BON_BS13_14D	45.6436600	-121.9406773	39.89
BON_BS13_14S	45.6436600	-121.9406773	67.60
BON_BS12_13D	45.6438228	-121.9406723	39.30
BON_BS12_13S	45.6438228	-121.9406723	67.05
BON_BS11_12D	45.6439873	-121.9406677	39.86
BON_BS11_12S	45.6439873	-121.9406677	67.53
BON_BS10_11D	45.6441527	-121.9406624	39.98
BON_BS10_11S	45.6441527	-121.9406624	67.27
BON_BS09_10D	45.6443162	-121.9406579	40.39
BON_BS09_10S	45.6443162	-121.9406579	68.05
BON_BS08_09D	45.6444806	-121.9406530	40.40
BON_BS08_09S	45.6444806	-121.9406530	67.94
BON_BS07_08D	45.6446455	-121.9406479	39.14
BON_BS07_08S	45.6446455	-121.9406479	67.06
BON_BS06_07D	45.6448104	-121.9406426	39.09
BON_BS06_07S	45.6448104	-121.9406426	67.01
BON_BS05_06D	45.6449734	-121.9406385	39.22
BON_BS05_06S	45.6449734	-121.9406385	67.34
BON_BS04_05D	45.6451386	-121.9406335	39.55
BON_BS04_05S	45.6451386	-121.9406335	67.26
BON_BS03_04D	45.6453039	-121.9406281	39.39
BON_BS03_04S	45.6453039	-121.9406281	67.31
BON_BS02_03D	45.6454679	-121.9406235	39.05
BON_BS02_03S	45.6454679	-121.9406235	66.92
BON_BS01_02D	45.6456320	-121.9406189	39.93
BON_BS01_02S	45.6456320	-121.9406189	66.76
BON_BS01D	45.6457754	-121.9406238	39.92
BON_BS01S	45.6457754	-121.9406238	66.75
BON_B2CC	45.6471297	-121.9384317	67.85
BON_BCC_11D	45.6472482	-121.9383498	55.61
BON_BCC_11S	45.6472565	-121.9383615	68.19
BON_B11_12D	45.6474381	-121.9380962	25.48
BON_B11_12S	45.6474493	-121.9381136	66.48
BON_B12_13D	45.6476300	-121.9378506	25.25
BON_B12_13S	45.6476408	-121.9378685	66.25
BON_B13_14D	45.6478271	-121.9375990	25.62
BON_B13_14S	45.6478379	-121.9376170	66.62
BON_B14_15D	45.6480187	-121.9373536	25.36
BON_B14_15S	45.6480323	-121.9373691	66.36
BON_B15_16D	45.6482065	-121.9371158	25.56
BON_B15_16S	45.6482153	-121.9371326	66.56
BON_B16_17D	45.6483981	-121.9368719	25.23
BON_B16_17S	45.6484092	-121.9368895	66.23
BON_B17_18D	45.6485896	-121.9366249	25.43

Table B.1. (contd)

Hydrophone Name	Latitude (NAD83)	Longitude (NAD83)	Elevation (NAVD88, ft)
BON_B17_18S	45.6486004	-121.9366429	66.43
BON_B18_19D	45.6487817	-121.9363793	25.48
BON_B18_19S	45.6487929	-121.9363969	66.48
BON_B19_NOS	45.6489836	-121.9361548	68.52
BON_BS15_16S	45.6433303	-121.9406880	67.47
BON_BS14_15D	45.6434942	-121.9406824	39.79
BON_BS14_15S	45.6434942	-121.9406824	67.45
BON_BS13_14D	45.6436600	-121.9406773	39.89
BON_BS13_14S	45.6436600	-121.9406773	67.60
BON_BS12_13D	45.6438228	-121.9406723	39.30
BON_BS12_13S	45.6438228	-121.9406723	67.05
BON_BS11_12D	45.6439873	-121.9406677	39.86
BON_BS11_12S	45.6439873	-121.9406677	67.53
BON_BS10_11D	45.6441527	-121.9406624	39.98
BON_BS10_11S	45.6441527	-121.9406624	67.27
BON_BS09_10D	45.6443162	-121.9406579	40.39
BON_BS09_10S	45.6443162	-121.9406579	68.05
BON_BS08_09D	45.6444806	-121.9406530	40.40
BON_BS08_09S	45.6444806	-121.9406530	67.94
BON_BS07_08D	45.6446455	-121.9406479	39.14
BON_BS07_08S	45.6446455	-121.9406479	67.06
BON_BS06_07D	45.6448104	-121.9406426	39.09
BON_BS06_07S	45.6448104	-121.9406426	67.01

Table B.2. Approximate global positioning system coordinates of autonomous nodes deployed in arrays just above and below Bonneville Dam in 2011. 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	Approximate Depth (ft.)
CR236.0_01	BON FB Entrance	45.6509740	-121.9203482	57.10
CR236.0_02		45.6504683	-121.9198470	73.67
CR236.0_03		45.6498739	-121.9193021	64.42
CR236.0_04		45.6493513	-121.9187782	69.80
CR233.0_01	BON Egress	45.6341819	-121.9622137	47.25
CR233.0_02		45.6350270	-121.9613769	45.00
CR233.0_03		45.6346314	-121.9606050	55.00
CR161.0_01	BON Primary; TDA Tertiary	45.6973678	-122.7668926	43.17
CR161.0_02		45.6990221	-122.7675621	48.20
CR161.0_03		45.6935628	-122.7705201	47.80
CR161.0_04		45.6971690	-122.7704219	53.83
CR161.0_05		45.6935429	-122.7730925	61.00
CR161.0_06		45.6971691	-122.7733903	63.50
CR161.0_07		45.6881037	-122.7769715	66.67
CR113.0_01	BON Secondary	46.0609000	-122.8680000	32.00
CR113.0_02		46.0708498	-122.8867690	55.75
CR113.0_03		46.0722902	-122.8878710	51.50
CR113.0_04		46.0700258	-122.8872546	56.50
CR113.0_05		46.0696271	-122.8898707	50.25
CR113.0_06		46.0711950	-122.8918170	49.00
CR113.0_07		46.0689128	-122.8903057	47.00
CR113.0_08		46.0690583	-122.8915857	36.38
CR113.0_09		46.0684814	-122.8922708	37.75
CR113.0_10		46.0689134	-122.8940163	33.38
CR086.2_01	BON Tertiary	46.1861079	-123.1803823	72.00
CR086.2_02		46.1858202	-123.1791326	75.75
CR086.2_03		46.1851714	-123.1797049	70.25
CR086.2_04		46.1843789	-123.1790797	61.25
CR086.2_05		46.1840911	-123.1778821	51.00
CR086.2_06		46.1834783	-123.1785065	59.00

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 2011.

C.1 Capture Histories of Yearling Chinook Salmon in Spring

Table C.1. Capture histories at sites at rkm 161, 113, and 86 for release group V_1 for yearling Chinook salmon (CH1) used in estimating dam passage survival. A "1" denotes detection, "0" denotes nondetection, and "2" denotes detection and censoring due to removal.

	V_1 (Dam Passage Survival Season-Wide)				
Capture History	R1_CR390 11U	R2_CR346 11U	R3_CR325 11U	R4_CR307 11U	R5_CR275 11U
1 1 1:	949	469	329	334	312
0 1 1:	126	78	35	45	40
1 0 1:	289	151	89	104	124
0 0 1:	56	25	21	12	14
1 2 0:	0	0	0	0	0
0 2 0:	0	0	0	0	0
1 1 0:	345	160	132	128	115
0 1 0:	83	47	32	34	40
2 0 0:	0	0	0	0	0
1 0 0:	193	99	55	77	79
0 0 0:	123	60	44	43	51
Total	**2,164**	**1,089**	**737**	**777**	**775**

Table C.2. Capture histories at sites at rkm 161, 113, and 86 for release group V_1 for CH1 used in estimating BRZ-to-BRZ survival. A "1" denotes detection, "0" denotes nondetection, and "2" denotes detection and censoring due to removal.

	V_1 (BRZ-to-BRZ Passage Survival Season-Wide)				
Capture History	R1_CR390 11U	R2_CR346 11U	R3_CR325 11U	R4_CR307 11U	R5_CR275 11U
1 1 1:	946	468	329	331	308
0 1 1:	126	77	35	45	40
1 0 1:	289	151	88	103	120
0 0 1:	56	25	21	12	13
1 2 0:	0	0	0	0	0
0 2 0:	0	0	0	0	0
1 1 0:	341	158	129	126	110
0 1 0:	82	46	32	34	37
2 0 0:	0	0	0	0	0
1 0 0:	190	99	55	76	74
0 0 0:	132	73	47	49	56
Total	**2,162**	**1,097**	**736**	**776**	**758**

Table C.3. Capture histories at sites at rkm 113 and 86 for release groups R_2 and R_3 for CH1 used in estimating all dam passage survival. A "1" denotes detection, "0" denotes nondetection, and "2" denotes detection and censoring due to removal.

	Dam Passage Survival (Season-Wide)	
Capture History	R_2	R_3
1 1:	424	421
0 1:	127	131
2 0:	0	0
1 0:	155	152
0 0:	92	90
Total	**798**	**794**

Table C.4. Capture histories at sites at rkm 161, 113, and 86 for release group V_1 for CH1 used in estimating day-time dam passage survival. A "1" denotes detection, "0" denotes nondetection, and "2" denotes detection and censoring due to removal.

	V_1 (Dam Passage Survival – Daytime)				
Capture History	R1_CR390 11U	R2_CR346 11U	R3_CR325 11U	R4_CR307 11U	R5_CR275 11U
1 1 1:	613	276	195	207	186
0 1 1:	79	49	23	27	20
1 0 1:	173	89	59	65	70
0 0 1:	29	18	12	6	7
1 2 0:	0	0	0	0	0
0 2 0:	0	0	0	0	0
1 1 0:	213	100	91	82	60
0 1 0:	45	21	21	17	22
2 0 0:	0	0	0	0	0
1 0 0:	109	55	39	51	49
0 0 0:	70	42	36	26	26
Total	**1,331**	**650**	**476**	**481**	**440**

Table C.5. Capture histories at sites at rkm 161, 113, and 86 for release group V_1 for CH1 used in estimating night-time dam passage survival. A "1" denotes detection, "0" denotes nondetection, and "2" denotes detection and censoring due to removal.

	V_1 (Dam Passage Survival – Nighttime)				
Capture History	R1_CR390 11U	R2_CR346 11U	R3_CR325 11U	R4_CR307 11U	R5_CR275 11U
1 1 1:	336	193	134	127	126
0 1 1:	47	29	12	18	20
1 0 1:	116	62	30	39	54
0 0 1:	27	7	9	6	7
1 2 0:	0	0	0	0	0
0 2 0:	0	0	0	0	0
1 1 0:	132	60	41	46	55
0 1 0:	38	26	11	17	18
2 0 0:	0	0	0	0	0
1 0 0:	84	44	16	26	30
0 0 0:	53	18	8	17	25
Total	**833**	**439**	**261**	**296**	**335**

Table C.6. Capture histories at sites at rkm 161, 113, and 86 for release group V_1 for CH1 used in estimating dam passage survival by route. A "1" denotes detection, "0" denotes nondetection, and "2" denotes detection and censoring due to removal.

Capture History	V_1 (Dam Passage by Route) B1 Sluice	B1 Turbine	Spillway	B2 JBS	B2 Turbine	B2CC	All Turbine	All SFO
1 1 1:	143	498	1,278	113	246	94	744	237
0 1 1:	25	66	189	16	18	7	84	32
1 0 1:	49	191	398	21	58	33	249	82
0 0 1:	8	25	78	3	8	2	33	10
1 2 0:	0	0	0	0	0	0	0	0
0 2 0:	0	0	0	0	0	0	0	0
1 1 0:	74	187	508	13	52	22	239	96
0 1 0:	9	46	144	3	21	2	67	11
2 0 0:	0	0	0	0	0	0	0	0
1 0 0:	39	96	321	7	19	3	115	42
0 0 0:	19	57	206	5	28	2	85	21
Total	**366**	**1,166**	**3,122**	**181**	**450**	**165**	**1,616**	**531**

Table C.7. Capture histories at sites at rkm 161, 113, and 86 for release group V_1 for CH1 used in estimating early spring dam passage survival. A "1" denotes detection, "0" denotes nondetection, and "2" denotes detection and censoring due to removal.

Capture History	V_1 (Dam Passage Survival – Early Spring) R1_CR390 11U	R2_CR346 11U	R3_CR325 11U	R4_CR307 11U	R5_CR275 11U
1 1 1:	682	321	228	235	223
0 1 1:	29	24	8	12	10
1 0 1:	158	83	46	54	58
0 0 1:	7	1	4	2	2
1 2 0:	0	0	0	0	0
0 2 0:	0	0	0	0	0
1 1 0:	55	22	17	17	21
0 1 0:	6	1	2	0	2
2 0 0:	0	0	0	0	0
1 0 0:	20	7	7	3	7
0 0 0:	46	21	15	15	15
Total	**1,003**	**480**	**327**	**338**	**338**

Table C.8. Capture histories at sites at rkm 161, 113, and 86 for release group V_1 for CH1 used in estimating early spring BRZ-to-BRZ survival. A "1" denotes detection, "0" denotes nondetection, and "2" denotes detection and censoring due to removal.

Capture History	V_1 (BRZ-to-BRZ Passage Survival – Early Spring)				
	R1_CR390 11U	R2_CR346 11U	R3_CR325 11U	R4_CR307 11U	R5_CR275 11U
1 1 1:	684	321	228	235	223
0 1 1:	30	24	8	12	10
1 0 1:	160	84	46	54	58
0 0 1:	7	1	4	2	2
1 2 0:	0	0	0	0	0
0 2 0:	0	0	0	0	0
1 1 0:	57	22	17	17	21
0 1 0:	6	1	2	0	2
2 0 0:	0	0	0	0	0
1 0 0:	20	7	7	3	7
0 0 0:	46	21	13	15	15
Total	**1,010**	**481**	**325**	**338**	**338**

Table C.9. Capture histories at sites at rkm 113 and 86 for release groups R_2 and R_3 for CH1 used in estimating early spring all dam passage survival. A "1" denotes detection, "0" denotes nondetection, and "2" denotes detection and censoring due to removal.

	Dam Passage Survival (Early Spring)	
Capture History	R_2	R_3
1 1:	264	259
0 1:	61	59
2 0:	0	0
1 0:	17	12
0 0:	8	10
Total	**350**	**340**

Table C.10. Capture histories at sites at rkm 161, 113, and 86 for release group V_1 (R_1 to R_5 pooled) for CH1 used in estimating early spring dam passage survival daytime and nighttime. A "1" denotes detection, "0" denotes nondetection, and "2" denotes detection and censoring due to removal.

	V_1 (Dam Passage Survival – Early Spring)	
Capture History	Daytime	Nighttime
1 1 1:	1,006	684
0 1 1:	44	39
1 0 1:	248	153
0 0 1:	7	9
1 2 0:	0	0
0 2 0:	0	0
1 1 0:	87	46
0 1 0:	7	5
2 0 0:	0	0
1 0 0:	27	17
0 0 0:	71	42
Total	**1,497**	**995**

Table C.11. Capture histories at sites at rkm 161, 113, and 86 for release group V_1 for CH1 used in estimating late spring dam passage survival. A "1" denotes detection, "0" denotes nondetection, and "2" denotes detection and censoring due to removal.

Capture History	V_1 (Dam Passage Survival – Late Spring)				
	R1_CR390 11U	R2_CR346 11U	R3_CR325 11U	R4_CR307 11U	R5_CR275 11U
1 1 1:	264	146	101	99	89
0 1 1:	97	54	27	33	30
1 0 1:	128	65	43	50	66
0 0 1:	49	24	17	10	12
1 2 0:	0	0	0	0	0
0 2 0:	0	0	0	0	0
1 1 0:	289	137	115	111	94
0 1 0:	77	45	30	34	38
2 0 0:	0	0	0	0	0
1 0 0:	173	92	48	74	72
0 0 0:	77	38	29	28	36
Total	**1,154**	**601**	**410**	**439**	**437**

Table C.12. Capture histories at sites at rkm 161, 113, and 86 for release group V_1 for CH1 used in estimating late spring dam passage survival – daytime. A "1" denotes detection, "0" denotes nondetection, and "2" denotes detection and censoring due to removal.

Capture History	V_1 (Dam Passage Survival – Daytime Late Spring)				
	R1_CR390 11U	R2_CR346 11U	R3_CR325 11U	R4_CR307 11U	R5_CR275 11U
1 1 1:	178	106	63	70	53
0 1 1:	62	37	16	23	16
1 0 1:	70	36	31	32	36
0 0 1:	27	17	10	6	5
1 2 0:	0	0	0	0	0
0 2 0:	0	0	0	0	0
1 1 0:	173	88	82	70	45
0 1 0:	42	21	19	17	20
2 0 0:	0	0	0	0	0
1 0 0:	96	52	36	49	43
0 0 0:	41	25	26	19	18
Total	**689**	**382**	**283**	**286**	**236**

Table C.13. Capture histories at sites at rkm 161, 113, and 86 for release group V_1 for CH1 used in estimating late spring dam passage survival – nighttime. A "1" denotes detection, "0" denotes nondetection, and "2" denotes detection and censoring due to removal.

Capture History	V_1 (Dam Passage Survival – Nighttime Late Spring)				
	R1_CR390 11U	R2_CR346 11U	R3_CR325 11U	R4_CR307 11U	R5_CR275 11U
1 1 1:	86	40	38	29	36
0 1 1:	35	17	11	10	14
1 0 1:	58	29	12	18	30
0 0 1:	22	7	7	4	7
1 2 0:	0	0	0	0	0
0 2 0:	0	0	0	0	0
1 1 0:	116	49	33	41	49
0 1 0:	35	24	11	17	18
2 0 0:	0	0	0	0	0
1 0 0:	77	40	12	25	29
0 0 0:	36	13	3	9	18
Total	**465**	**219**	**127**	**153**	**201**

Table C.14. Capture histories at sites at rkm 113 and 86 for release groups R_2 and R_3 for CH1 used in estimating late spring all dam passage survival. A "1" denotes detection, "0" denotes nondetection, and "2" denotes detection and censoring due to removal.

	Dam Passage Survival (Late Spring)	
Capture History	R_2	R_3
1 1:	160	162
0 1:	66	72
2 0:	0	0
1 0:	138	140
0 0:	84	80
Total	**448**	**454**

C.2 Capture Histories of Juvenile Steelhead Salmon in Spring

Table C.15. Capture histories at sites at rkm 161, 113, and 86 for release group V_1 for juvenile steelhead (STH) salmon used in estimating dam passage survival. A "1" denotes detection, "0" denotes nondetection, and "2" denotes detection and censoring due to removal.

	V_1 (Dam Passage Survival Season-Wide)				
Capture History	R1_CR390 35U	R2_CR346 35U	R3_CR325 35U	R4_CR307 35U	R5_CR275 35U
1 1 1:	899	457	273	301	312
0 1 1:	59	24	18	18	20
1 0 1:	306	150	98	102	86
0 0 1:	23	14	11	6	6
1 2 0:	0	0	0	0	0
0 2 0:	0	0	0	0	0
1 1 0:	518	238	189	163	186
0 1 0:	69	31	33	30	28
2 0 0:	0	0	0	0	0
1 0 0:	246	132	79	96	91
0 0 0:	131	73	43	51	53
Total	**2,251**	**1,119**	**744**	**767**	**782**

Table C.16. Capture histories at sites at rkm 161, 113, and 86 for release group V_1 for STH used in estimating BRZ-to-BRZ survival. A "1" denotes detection, "0" denotes nondetection, and "2" denotes detection and censoring due to removal.

	V_1 (BRZ-to-BRZ Passage Survival Season-Wide)				
Capture History	R1_CR390 35U	R2_CR346 35U	R3_CR325 35U	R4_CR307 35U	R5_CR275 35U
1 1 1:	899	457	273	300	312
0 1 1:	58	24	18	18	20
1 0 1:	305	149	98	102	84
0 0 1:	22	14	11	6	6
1 2 0:	0	0	0	0	0
0 2 0:	0	0	0	0	0
1 1 0:	511	235	187	162	185
0 1 0:	66	31	32	30	26
2 0 0:	0	0	0	0	0
1 0 0:	245	131	78	96	89
0 0 0:	141	82	46	56	57
Total	**2,247**	**1,123**	**743**	**770**	**779**

Table C.17. Capture histories at sites at rkm 113 and 86 for release groups R_2 and R_3 for STH used in estimating all dam passage survival. A "1" denotes detection, "0" denotes nondetection, and "2" denotes detection and censoring due to removal.

Capture History	Dam Passage Survival (Season-Wide)	
	R_2	R_3
1 1:	353	360
0 1:	114	97
2 0:	0	0
1 0:	195	218
0 0:	130	119
Total	**792**	**794**

Table C.18. Capture histories at sites at rkm 161, 113, and 86 for release group V_1 for STH used in estimating day-time dam passage survival. A "1" denotes detection, "0" denotes nondetection, and "2" denotes detection and censoring due to removal.

Capture History	V_1 (Dam Passage Survival – Daytime)				
	R1_CR390 35U	R2_CR346 35U	R3_CR325 35U	R4_CR307 35U	R5_CR275 35U
1 1 1:	615	301	201	193	233
0 1 1:	34	16	12	14	11
1 0 1:	198	87	65	67	58
0 0 1:	17	11	7	4	2
1 2 0:	0	0	0	0	0
0 2 0:	0	0	0	0	0
1 1 0:	310	138	124	119	110
0 1 0:	35	19	29	27	11
2 0 0:	0	0	0	0	0
1 0 0:	171	80	56	79	52
0 0 0:	74	44	29	39	37
Total	**1,454**	**696**	**523**	**542**	**514**

Table C.19. Capture histories at sites at rkm 161, 113, and 86 for release group V_1 for STH used in estimating night-time dam passage survival. A "1" denotes detection, "0" denotes nondetection, and "2" denotes detection and censoring due to removal.

Capture History	V_1 (Dam Passage Survival-Nighttime)				
	R1_CR390 35U	R2_CR346 35U	R3_CR325 35U	R4_CR307 35U	R5_CR275 35U
1 1 1:	284	156	72	108	79
0 1 1:	25	8	6	4	9
1 0 1:	108	63	33	35	28
0 0 1:	6	3	4	2	4
1 2 0:	0	0	0	0	0
0 2 0:	0	0	0	0	0
1 1 0:	208	100	65	44	76
0 1 0:	34	12	4	3	17
2 0 0:	0	0	0	0	0
1 0 0:	75	52	23	17	39
0 0 0:	57	29	14	12	16
Total	**797**	**423**	**221**	**225**	**268**

Table C.20. Capture histories at sites at rkm 161, 113, and 86 for release group V_1 for STH used in estimating dam passage survival by route. A "1" denotes detection, "0" denotes nondetection, and "2" denotes detection and censoring due to removal.

Capture History	V_1 (Dam Passage by Route)							
	B1 Sluice	B1 Turbine	Spillway	B2 JBS	B2 Turbine	B2CC	All Turbine	All SFO
1 1 1:	178	551	1,062	30	81	331	632	509
0 1 1:	14	25	78	4	2	12	27	26
1 0 1:	70	152	390	12	25	85	177	155
0 0 1:	6	10	36	0	1	6	11	12
1 2 0:	0	0	0	0	0	0	0	0
0 2 0:	0	0	0	0	0	0	0	0
1 1 0:	103	256	808	10	25	65	281	168
0 1 0:	12	45	120	3	1	4	46	16
2 0 0:	0	0	0	0	0	0	0	0
1 0 0:	47	154	393	2	12	26	166	73
0 0 0:	30	108	177	5	15	13	123	43
Total	**460**	**1,301**	**3,064**	**66**	**162**	**542**	**1,463**	**1,002**

Table C.21. Capture histories at sites at rkm 161, 113, and 86 for release group V_1 for STH used in estimating early spring dam passage survival. A "1" denotes detection, "0" denotes nondetection, and "2" denotes detection and censoring due to removal.

Capture History	V_1 (Dam Passage Survival – Early Spring)				
	R1_CR390 35U	R2_CR346 35U	R3_CR325 35U	R4_CR307 35U	R5_CR275 35U
1 1 1:	625	331	195	220	232
0 1 1:	10	9	5	3	4
1 0 1:	152	83	50	60	40
0 0 1:	3	3	1	3	1
1 2 0:	0	0	0	0	0
0 2 0:	0	0	0	0	0
1 1 0:	107	59	41	36	38
0 1 0:	6	2	1	1	0
2 0 0:	0	0	0	0	0
1 0 0:	26	13	9	8	10
0 0 0:	44	28	15	18	18
Total	**973**	**528**	**317**	**349**	**343**

Table C.22. Capture histories at sites at rkm 161, 113, and 86 for release group V_1 for STH used in estimating early spring BRZ-to-BRZ survival. A "1" denotes detection, "0" denotes nondetection, and "2" denotes detection and censoring due to removal.

Capture History	V1 (BRZ-to-BRZ Passage Survival – Early Spring)				
	R1_CR390 35U	R2_CR346 35U	R3_CR325 35U	R4_CR307 35U	R5_CR275 35U
1 1 1:	626	331	195	223	232
0 1 1:	10	9	5	3	4
1 0 1:	151	83	50	60	40
0 0 1:	3	3	1	3	1
1 2 0:	0	0	0	0	0
0 2 0:	0	0	0	0	0
1 1 0:	107	59	41	37	38
0 1 0:	5	2	1	1	0
2 0 0:	0	0	0	0	0
1 0 0:	26	13	9	8	10
0 0 0:	45	28	15	18	18
Total	**973**	**528**	**317**	**353**	**343**

Table C.23. Capture histories at sites at rkm 113 and 86 for release groups R_2 and R_3 for STH used in estimating early spring all dam passage survival. A "1" denotes detection, "0" denotes nondetection, and "2" denotes detection and censoring due to removal.

Capture History	Dam Passage Survival (Early Spring)	
	R_2	R_3
1 1:	246	248
0 1:	53	56
2 0:	0	0
1 0:	25	33
0 0:	19	13
Total	**343**	**350**

Table C.24. Capture histories at sites at rkm 161, 113, and 86 for release group V_1 (R_1 to R_5 pooled) for STH used in estimating early spring dam passage survival daytime and nighttime. A "1" denotes detection, "0" denotes nondetection, and "2" denotes detection and censoring due to removal.

Capture History	V_1 (Dam Passage Survival – Early Spring)	
	Daytime	Nighttime
1 1 1:	1,162	442
0 1 1:	22	9
1 0 1:	251	134
0 0 1:	8	3
1 2 0:	0	0
0 2 0:	0	0
1 1 0:	194	90
0 1 0:	7	3
2 0 0:	0	0
1 0 0:	46	20
0 0 0:	86	37
Total	**1,776**	**738**

Table C.25. Capture histories at sites at rkm 161, 113, and 86 for release group V_1 for STH used in estimating late spring dam passage survival. A "1" denotes detection, "0" denotes nondetection, and "2" denotes detection and censoring due to removal.

Capture History	V_1 (Dam Passage Survival – Late Spring)				
	R1_CR390 35U	R2_CR346 35U	R3_CR325 35U	R4_CR307 35U	R5_CR275 35U
1 1 1:	274	124	77	81	80
0 1 1:	48	15	13	15	16
1 0 1:	150	65	47	42	46
0 0 1:	20	11	10	3	5
1 2 0:	0	0	0	0	0
0 2 0:	0	0	0	0	0
1 1 0:	411	179	145	127	148
0 1 0:	63	29	31	29	28
2 0 0:	0	0	0	0	0
1 0 0:	217	117	70	88	81
0 0 0:	86	44	28	33	35
Total	**1,269**	**584**	**421**	**418**	**439**

Table C.26. Capture histories at sites at rkm 161, 113, and 86 for release group V_1 for STH used in estimating late spring dam passage survival – daytime. A "1" denotes detection, "0" denotes nondetection, and "2" denotes detection and censoring due to removal.

Capture History	V_1 (Dam Passage Survival – Daytime Late Spring)				
	R1_CR390 35U	R2_CR346 35U	R3_CR325 35U	R4_CR307 35U	R5_CR275 35U
1 1 1:	150	71	54	62	42
0 1 1:	26	10	8	13	7
1 0 1:	93	36	30	34	26
0 0 1:	14	9	7	2	1
1 2 0:	0	0	0	0	0
0 2 0:	0	0	0	0	0
1 1 0:	232	94	97	103	81
0 1 0:	32	17	27	26	11
2 0 0:	0	0	0	0	0
1 0 0:	148	70	50	75	45
0 0 0:	44	24	18	28	21
Total	**739**	**331**	**291**	**343**	**234**

Table C.27. Capture histories at sites at rkm 161, 113, and 86 for release group V_1 for STH used in estimating late spring dam passage survival – nighttime. A "1" denotes detection, "0" denotes nondetection, and "2" denotes detection and censoring due to removal.

Capture History	V_1 (Dam Passage Survival – Nighttime Late Spring)				
	R1_CR390 35U	R2_CR346 35U	R3_CR325 35U	R4_CR307 35U	R5_CR275 35U
1 1 1:	124	53	23	19	38
0 1 1:	22	5	5	2	9
1 0 1:	57	29	17	8	20
0 0 1:	6	2	3	1	4
1 2 0:	0	0	0	0	0
0 2 0:	0	0	0	0	0
1 1 0:	179	85	48	24	67
0 1 0:	31	12	4	3	17
2 0 0:	0	0	0	0	0
1 0 0:	69	47	20	13	36
0 0 0:	42	20	10	5	14
Total	**530**	**253**	**130**	**75**	**205**

Table C.28. Capture histories at sites at rkm 113 and 86 for release groups R_2 and R_3 for STH used in estimating late spring all dam passage survival. A "1" denotes detection, "0" denotes nondetection, and "2" denotes detection and censoring due to removal.

	Dam Passage Survival (Late Spring)	
Capture History	R_2	R_3
1 1:	107	112
0 1:	61	41
2 0:	0	0
1 0:	170	185
0 0:	111	106
Total	**449**	**444**

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 Survival – Early Season

Table D.1. Bonneville early season dam passage detection and survival rates for yearling Chinook salmon (CH1).

Dam Survival:

	Estimate	s.e.†
Dam Survival:	0.9569[(a)]	0.004210
(a) V_1 survival was used to estimate dam-passage survival because R_2 survival was > R_3 survival.		

Survival Summary:

	Estimate	s.e.†
V1	0.9569	0.004210
R2	0.9923	0.008786
R3	0.9808	0.009664

Survival Detail for Fitted Model:

	CR234.0 to CR161.0		CR161.0 to CR113.0		Release to CR113.0	
	Estimate	**s.e.†**	**Estimate**	**s.e.***	**Estimate**	**s.e.†**
R1_CR390 11U	0.9569	0.004210	0.9951	0.003250	---	---
R2_CR346 11U	0.9569	0.004210	0.9951	0.003250	---	---
R3_CR325 11U	0.9569	0.004210	0.9951	0.003250	---	---
R4_CR307 11U	0.9569	0.004210	0.9951	0.003250	---	---
R5_CR275 11U	0.9569	0.004210	0.9951	0.003250	---	---
R6_CR233 11U	---	---	---	---	0.9923	0.008786
R7_CR161 11U	---	---	---	---	0.9808	0.009664

Capture Detail for Fitted Model:

	CR161.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	**s.e.***	**Estimate**	**s.e.***	**Estimate**	**s.e.***
R1_CR390 11U	0.9528	0.004394	0.8102	0.008385	0.9256	0.006008
R2_CR346 11U	0.9528	0.004394	0.8102	0.008385	0.9256	0.006008
R3_CR325 11U	0.9528	0.004394	0.8102	0.008385	0.9256	0.006008
R4_CR307 11U	0.9528	0.004394	0.8102	0.008385	0.9256	0.006008
R5_CR275 11U	0.9528	0.004394	0.8102	0.008385	0.9256	0.006008
R6_CR233 11U	---	---	0.8123	0.021659	0.9398	0.014226
R7_CR161 11U	---	---	0.8145	0.021799	0.9560	0.012500

Notes:

** Standard error is based on only the inverse Hessian.*
† Standard error is based on bootstrapping.
‡ Because the R2/R3 ratio is greater than 1.0, it is recommended that the "V1" value be used instead of "Dam Survival"

D.1.2 Bonneville Dam Passage Survival – Late Season

Table D.2. Bonneville late season dam passage detection and survival rates for CH1.

Dam Survival:

	Estimate	s.e.†
Dam Survival:	1.0023	0.044733

Survival Summary:

	Estimate	s.e.†
V1	0.9807	0.006039
R2	0.9418	0.030699
R3	0.9625	0.030610

Survival Detail for Fitted Model:

	CR234.0 to CR161.0		CR161.0 to CR113.0		Release to CR113.0	
	Estimate	**s.e.†**	**Estimate**	**s.e.***	**Estimate**	**s.e.†**
R1_CR390 11U	0.9807	0.006039	0.9574	0.014235	---	---
R2_CR346 11U	0.9807	0.006039	0.9574	0.014235	---	---
R3_CR325 11U	0.9807	0.006039	0.9574	0.014235	---	---
R4_CR307 11U	0.9807	0.006039	0.9574	0.014235	---	---
R5_CR275 11U	0.9807	0.006039	0.9574	0.014235	---	---
R6_CR233 11U	---	---	---	---	0.9418	0.030699
R7_CR161 11U	---	---	---	---	0.9625	0.030610

Capture Detail for Fitted Model:

	CR161.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	**s.e.***	**Estimate**	**s.e.***	**Estimate**	**s.e.***
R1_CR390 11U	0.7569	0.008803	0.6695	0.012554	0.4922	0.011441
R2_CR346 11U	0.7569	0.008803	0.6695	0.012554	0.4922	0.011441
R3_CR325 11U	0.7569	0.008803	0.6695	0.012554	0.4922	0.011441
R4_CR307 11U	0.7569	0.008803	0.6695	0.012554	0.4922	0.011441
R5_CR275 11U	0.7569	0.008803	0.6695	0.012554	0.4922	0.011441
R6_CR233 11U	---	---	0.7080	0.030246	0.5370	0.028891
R7_CR161 11U	---	---	0.6923	0.030172	0.5365	0.028699

Notes:

* *Standard error is based on only the inverse Hessian.*
† *Standard error is based on bootstrapping*

D.1.3 Bonneville Dam Passage Survival – Entire Study

Table D.3. Bonneville Dam passage detection and survival rates for CH1 over the entire season.

Dam Survival:

	Estimate	s.e.†
Dam Survival:	0.9597	0.017606

Survival Summary:

	Estimate	s.e.†
V1	0.9584	0.003404
R2	0.9531	0.013229
R3	0.9544	0.012774

Survival Detail for Fitted Model:

	CR234.0 to CR161.0		CR161.0 to CR113.0		Release to CR113.0	
	Estimate	s.e.†	Estimate	s.e.*	Estimate	s.e.†
R1_CR390 11U	0.9584	0.003404	0.9555	0.005708	---	---
R2_CR346 11U	0.9584	0.003404	0.9555	0.005708	---	---
R3_CR325 11U	0.9584	0.003404	0.9555	0.005708	---	---
R4_CR307 11U	0.9584	0.003404	0.9555	0.005708	---	---
R5_CR275 11U	0.9584	0.003404	0.9555	0.005708	---	---
R6_CR233 11U	---	---	---	---	0.9531	0.013229
R7_CR161 11U	---	---	---	---	0.9544	0.012774

Capture Detail for Fitted Model:

	CR161.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	s.e.*	Estimate	s.e.*	Estimate	s.e.*
R1_CR390 11U	0.8542	0.005139	0.7571	0.006252	0.7147	0.006398
R2_CR346 11U	0.8542	0.005139	0.7571	0.006252	0.7147	0.006398
R3_CR325 11U	0.8542	0.005139	0.7571	0.006252	0.7147	0.006398
R4_CR307 11U	0.8542	0.005139	0.7571	0.006252	0.7147	0.006398
R5_CR275 11U	0.8542	0.005139	0.7571	0.006252	0.7147	0.006398
R6_CR233 11U	---	---	0.7571	0.006252	0.7147	0.006398
R7_CR161 11U	---	---	0.7571	0.006252	0.7147	0.006398

Notes:

* *Standard error is based on only the inverse Hessian.*
† *Standard error is based on bootstrapping.*

D.1.4 Forebay and Dam Passage

Table D.4. Forebay virtual release detection and survival rates for CH1.

Dam Survival:

	Estimate	s.e.†
Dam Survival:	0.9528	0.017520

Survival Summary:

	Estimate	s.e.†
V1	0.9515	0.003668
R2	0.9524	0.013889
R3	0.9537	0.013089

Survival Detail for Fitted Model:

	CR236.0 to CR161.0		CR161.0 to CR113.0		Release to CR113.0	
	Estimate	s.e.†	Estimate	s.e.*	Estimate	s.e.†
R1_CR390 11U	0.9515	0.003668	0.9558	0.005701	---	---
R2_CR346 11U	0.9515	0.003668	0.9558	0.005701	---	---
R3_CR325 11U	0.9515	0.003668	0.9558	0.005701	---	---
R4_CR307 11U	0.9515	0.003668	0.9558	0.005701	---	---
R5_CR275 11U	0.9515	0.003668	0.9558	0.005701	---	---
R6_CR233 11U	---	---	---	---	0.9524	0.013889
R7_CR161 11U	---	---	---	---	0.9537	0.013089

Capture Detail for Fitted Model:

	CR161.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	s.e.*	Estimate	s.e.*	Estimate	s.e.*
R1_CR390 11U	0.8544	0.005157	0.7576	0.006260	0.7170	0.006403
R2_CR346 11U	0.8544	0.005157	0.7576	0.006260	0.7170	0.006403
R3_CR325 11U	0.8544	0.005157	0.7576	0.006260	0.7170	0.006403
R4_CR307 11U	0.8544	0.005157	0.7576	0.006260	0.7170	0.006403
R5_CR275 11U	0.8544	0.005157	0.7576	0.006260	0.7170	0.006403
R6_CR233 11U	---	---	0.7576	0.006260	0.7170	0.006403
R7_CR161 11U	---	---	0.7576	0.006260	0.7170	0.006403

Notes:

* *Standard error is based on only the inverse Hessian.*
† *Standard error is based on bootstrapping.*

D.1.5 Forebay and Dam Passage – Early Spring

Table D.5. Forebay – early season virtual release detection and survival rates for CH1.

Dam Survival:

	Estimate	s.e.†
Dam Survival:	0.9579[a]	0.004197
(a) V_1 survival was used to estimate dam-passage survival because R_2 survival was > R_3 survival.		

Survival Summary:

	Estimate	s.e.†
V1	0.9579	0.004197
R2	0.9923	0.008784
R3	0.9808	0.009640

Survival Detail for Fitted Model:

	CR236.0 to CR161.0		CR161.0 to CR113.0		Release to CR113.0	
	Estimate	s.e.†	Estimate	s.e.*	Estimate	s.e.†
R1_CR390 11U	0.9579	0.004197	0.9954	0.003249	---	---
R2_CR346 11U	0.9579	0.004197	0.9954	0.003249	---	---
R3_CR325 11U	0.9579	0.004197	0.9954	0.003249	---	---
R4_CR307 11U	0.9579	0.004197	0.9954	0.003249	---	---
R5_CR275 11U	0.9579	0.004197	0.9954	0.003249	---	---
R6_CR233 11U	---	---	---	---	0.9923	0.008784
R7_CR161 11U	---	---	---	---	0.9808	0.009640

Capture Detail for Fitted Model:

	CR161.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	s.e.*	Estimate	s.e.*	Estimate	s.e.*
R1_CR390 11U	0.9525	0.004398	0.8094	0.008388	0.9247	0.006032
R2_CR346 11U	0.9525	0.004398	0.8094	0.008388	0.9247	0.006032
R3_CR325 11U	0.9525	0.004398	0.8094	0.008388	0.9247	0.006032
R4_CR307 11U	0.9525	0.004398	0.8094	0.008388	0.9247	0.006032
R5_CR275 11U	0.9525	0.004398	0.8094	0.008388	0.9247	0.006032
R6_CR233 11U	---	---	0.8123	0.021659	0.9398	0.014226
R7_CR161 11U	---	---	0.8145	0.021799	0.9560	0.012500

Notes:

** Standard error is based on only the inverse Hessian.*
† Standard error is based on bootstrapping.
‡ Because the R2/R3 ratio is greater than 1.0, it is recommended that the "V1" value be used instead of "Dam Survival"

D.1.6 Bonneville Dam Passage – Late Spring – High Spill

Table D.6. Forebay – late season virtual release detection and survival rates for CH1.

Dam Survival:

	Estimate	s.e.†
Dam Survival:	1.0023	0.044733

Survival Summary:

	Estimate	s.e.†
V1	0.9807	0.006039
R2	0.9418	0.030699
R3	0.9625	0.030610

Survival Detail for Fitted Model:

	CR234.0 to CR161.0		CR161.0 to CR113.0		Release to CR113.0	
	Estimate	**s.e.†**	**Estimate**	**s.e.***	**Estimate**	**s.e.†**
R1_CR390 11U	0.9807	0.006039	0.9574	0.014235	---	---
R2_CR346 11U	0.9807	0.006039	0.9574	0.014235	---	---
R3_CR325 11U	0.9807	0.006039	0.9574	0.014235	---	---
R4_CR307 11U	0.9807	0.006039	0.9574	0.014235	---	---
R5_CR275 11U	0.9807	0.006039	0.9574	0.014235	---	---
R6_CR233 11U	---	---	---	---	0.9418	0.030699
R7_CR161 11U	---	---	---	---	0.9625	0.030610

Capture Detail for Fitted Model:

	CR161.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	**s.e.***	**Estimate**	**s.e.***	**Estimate**	**s.e.***
R1_CR390 11U	0.7569	0.008803	0.6695	0.012554	0.4922	0.011441
R2_CR346 11U	0.7569	0.008803	0.6695	0.012554	0.4922	0.011441
R3_CR325 11U	0.7569	0.008803	0.6695	0.012554	0.4922	0.011441
R4_CR307 11U	0.7569	0.008803	0.6695	0.012554	0.4922	0.011441
R5_CR275 11U	0.7569	0.008803	0.6695	0.012554	0.4922	0.011441
R6_CR233 11U	---	---	0.7080	0.030246	0.5370	0.028891
R7_CR161 11U	---	---	0.6923	0.030172	0.5365	0.028699

Notes:

* *Standard error is based on only the inverse Hessian.*
† *Standard error is based on bootstrapping.*

D.1.7 Bonneville Dam Passage – Daytime

Table D.7. Bonneville daytime dam passage detection and survival rates for CH1.

Dam Survival:

	Estimate	s.e.†
Dam Survival:	0.9586	0.020639

Survival Summary:

	Estimate	s.e.†
V1	0.9560	0.004568
R2	0.9453	0.016952
R3	0.9479	0.015554

Survival Detail for Fitted Model:

	CR234.0 to CR161.0		CR161.0 to CR113.0		Release to CR113.0	
	Estimate	**s.e.†**	**Estimate**	**s.e.***	**Estimate**	**s.e.†**
R1_CR390 11U	0.9560	0.004568	0.9569	0.007476	---	---
R2_CR346 11U	0.9560	0.004568	0.9569	0.007476	---	---
R3_CR325 11U	0.9560	0.004568	0.9569	0.007476	---	---
R4_CR307 11U	0.9560	0.004568	0.9569	0.007476	---	---
R5_CR275 11U	0.9560	0.004568	0.9569	0.007476	---	---
R6_CR233 11U	---	---	---	---	0.9453	0.016952
R7_CR161 11U	---	---	---	---	0.9479	0.015554

Capture Detail for Fitted Model:

	CR161.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	**s.e.***	**Estimate**	**s.e.***	**Estimate**	**s.e.***
R1_CR390 11U	0.8622	0.006428	0.7603	0.009095	0.7138	0.009332
R2_CR346 11U	0.8622	0.006428	0.7603	0.009095	0.7138	0.009332
R3_CR325 11U	0.8622	0.006428	0.7603	0.009095	0.7138	0.009332
R4_CR307 11U	0.8622	0.006428	0.7603	0.009095	0.7138	0.009332
R5_CR275 11U	0.8622	0.006428	0.7603	0.009095	0.7138	0.009332
R6_CR233 11U	---	---	0.7695	0.017941	0.7325	0.018405
R7_CR161 11U	---	---	0.7627	0.018108	0.7349	0.018446

Notes:

* *Standard error is based on only the inverse Hessian.*
† *Standard error is based on bootstrapping.*

D.1.8 Bonneville Dam Passage – Nighttime

Table D.8. Bonneville nighttime dam passage detection and survival rates for CH1.

Dam Survival:

	Estimate	s.e.†
Dam Survival:	0.9649	0.020992

Survival Summary:

	Estimate	s.e.†
V1	0.9622	0.005403
R2	0.9453	0.015491
R3	0.9479	0.014786

Survival Detail for Fitted Model:

	CR234.0 to CR161.0		CR161.0 to CR113.0		Release to CR113.0	
	Estimate	**s.e.†**	**Estimate**	**s.e.***	**Estimate**	**s.e.†**
R1_CR390 11U	0.9622	0.005403	0.9592	0.009850	---	---
R2_CR346 11U	0.9622	0.005403	0.9592	0.009850	---	---
R3_CR325 11U	0.9622	0.005403	0.9592	0.009850	---	---
R4_CR307 11U	0.9622	0.005403	0.9592	0.009850	---	---
R5_CR275 11U	0.9622	0.005403	0.9592	0.009850	---	---
R6_CR233 11U	---	---	---	---	0.9453	0.015491
R7_CR161 11U	---	---	---	---	0.9479	0.014786

Capture Detail for Fitted Model:

	CR161.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	**s.e.***	**Estimate**	**s.e.***	**Estimate**	**s.e.***
R1_CR390 11U	0.8416	0.008506	0.7448	0.011656	0.7013	0.011876
R2_CR346 11U	0.8416	0.008506	0.7448	0.011656	0.7013	0.011876
R3_CR325 11U	0.8416	0.008506	0.7448	0.011656	0.7013	0.011876
R4_CR307 11U	0.8416	0.008506	0.7448	0.011656	0.7013	0.011876
R5_CR275 11U	0.8416	0.008506	0.7448	0.011656	0.7013	0.011876
R6_CR233 11U	---	---	0.7695	0.017941	0.7325	0.018405
R7_CR161 11U	---	---	0.7627	0.018108	0.7349	0.018446

Notes:

* *Standard error is based on only the inverse Hessian.*
† *Standard error is based on bootstrapping.*

D.1.9 Bonneville Dam Passage – Daytime – Early Spring

Table D.9. Bonneville early season daytime dam passage detection and survival rates for CH1 (R_1 to R_5 pooled to V_1).

Dam Survival:

	Estimate	s.e.†
Dam Survival:	0.9545[(a)]	0.005550
(a) V_1 survival was used to estimate dam-passage survival because R_2 survival was > R_3 survival.		

Survival Summary:

	Estimate	s.e.†
V1	0.9545	0.005550
R2	0.9923	0.008810
R3	0.9808	0.009729

Survival Detail for Fitted Model:

	CR234.0 to CR161.0		CR161.0 to CR113.0		Release to CR113.0	
	Estimate	s.e.†	Estimate	s.e.*	Estimate	s.e.†
V1_CR234 11U	0.9545	0.005550	0.9967	0.004291	---	---
R6_CR233 11U	---	---	---	---	0.9923	0.008810
R7_CR161 11U	---	---	---	---	0.9808	0.009729

Capture Detail for Fitted Model:

	CR161.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	s.e.*	Estimate	s.e.*	Estimate	s.e.*
V1_CR234 11U	0.9585	0.005330	0.8046	0.010976	0.9180	0.008121
R6_CR233 11U	---	---	0.8123	0.021659	0.9398	0.014226
R7_CR161 11U	---	---	0.8145	0.021799	0.9560	0.012500

Notes:

** Standard error is based on only the inverse Hessian.*
† Standard error is based on bootstrapping.
‡ Because the R2/R3 ratio is greater than 1.0, it is recommended that the "V1" value be used instead of "Dam Survival"

D.1.10 Bonneville Dam Passage – Daytime – Late Spring

Table D.10. Bonneville late season daytime dam passage detection and survival rates for CH1.

Dam Survival:

	Estimate	s.e.†
Dam Survival:	0.9973	0.044721

Survival Summary:

	Estimate	s.e.†
V1	0.9758	0.007494
R2	0.9418	0.031379
R3	0.9625	0.031004

Survival Detail for Fitted Model:

	CR234.0 to CR161.0		CR161.0 to CR113.0		Release to CR113.0	
	Estimate	**s.e.†**	**Estimate**	**s.e.***	**Estimate**	**s.e.†**
R1_CR390 11U	0.9758	0.007494	0.9407	0.016477	---	---
R2_CR346 11U	0.9758	0.007494	0.9407	0.016477	---	---
R3_CR325 11U	0.9758	0.007494	0.9407	0.016477	---	---
R4_CR307 11U	0.9758	0.007494	0.9407	0.016477	---	---
R5_CR275 11U	0.9758	0.007494	0.9407	0.016477	---	---
R6_CR233 11U	---	---	---	---	0.9418	0.031379
R7_CR161 11U	---	---	---	---	0.9625	0.031004

Capture Detail for Fitted Model:

	CR161.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	**s.e.***	**Estimate**	**s.e.***	**Estimate**	**s.e.***
R1_CR390 11U	0.7702	0.010969	0.6980	0.015356	0.5196	0.014419
R2_CR346 11U	0.7702	0.010969	0.6980	0.015356	0.5196	0.014419
R3_CR325 11U	0.7702	0.010969	0.6980	0.015356	0.5196	0.014419
R4_CR307 11U	0.7702	0.010969	0.6980	0.015356	0.5196	0.014419
R5_CR275 11U	0.7702	0.010969	0.6980	0.015356	0.5196	0.014419
R6_CR233 11U	---	---	0.7080	0.030246	0.5370	0.028891
R7_CR161 11U	---	---	0.6923	0.030172	0.5365	0.028699

Notes:

* *Standard error is based on only the inverse Hessian.*
† *Standard error is based on bootstrapping.*

D.1.11 Bonneville Dam Passage – Nighttime – Early Spring

Table D.11. Bonneville early season nighttime dam passage detection and survival rates for CH1 (R_1 to R_5 pooled to V_1).

Dam Survival:

	Estimate	s.e.†
Dam Survival:	0.9599[(a)]	0.006424
(a) V_1 survival was used to estimate dam-passage survival because R_2 survival was > R_3 survival.		

Survival Summary:

	Estimate	s.e.†
V1	0.9599	0.006424
R2	0.9923	0.008779
R3	0.9808	0.009700

Survival Detail for Fitted Model:

	CR234.0 to CR161.0		CR161.0 to CR113.0		Release to CR113.0	
	Estimate	**s.e.†**	**Estimate**	**s.e.***	**Estimate**	**s.e.†**
V1_CR234 11U	0.9599	0.006424	0.9937	0.004987	---	---
R6_CR233 11U	---	---	---	---	0.9923	0.008779
R7_CR161 11U	---	---	---	---	0.9808	0.009700

Capture Detail for Fitted Model:

	CR161.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	**s.e.***	**Estimate**	**s.e.***	**Estimate**	**s.e.***
V1_CR234 11U	0.9434	0.007554	0.8169	0.012999	0.9344	0.008920
R6_CR233 11U	---	---	0.8123	0.021659	0.9398	0.014226
R7_CR161 11U	---	---	0.8145	0.021799	0.9560	0.012500

Notes:

* *Standard error is based on only the inverse Hessian.*
† *Standard error is based on bootstrapping.*
‡ *Because the R2/R3 ratio is greater than 1.0, it is recommended that the "V1" value be used instead of "Dam Survival"*

D.1.12 Bonneville Dam Passage – Nighttime – Late Spring

Table D.12. Bonneville late season nighttime dam passage detection and survival rates for CH1.

Dam Survival:

	Estimate	s.e.†
Dam Survival:	1.0110	0.045816

Survival Summary:

	Estimate	s.e.†
V1	0.9893	0.009752
R2	0.9418	0.030022
R3	0.9625	0.030218

Survival Detail for Fitted Model:

	CR234.0 to CR161.0		CR161.0 to CR113.0		Release to CR113.0	
	Estimate	**s.e.†**	**Estimate**	**s.e.***	**Estimate**	**s.e.†**
R1_CR390 11U	0.9893	0.009752	0.9937	0.027378	---	---
R2_CR346 11U	0.9893	0.009752	0.9937	0.027378	---	---
R3_CR325 11U	0.9893	0.009752	0.9937	0.027378	---	---
R4_CR307 11U	0.9893	0.009752	0.9937	0.027378	---	---
R5_CR275 11U	0.9893	0.009752	0.9937	0.027378	---	---
R6_CR233 11U	---	---	---	---	0.9418	0.030022
R7_CR161 11U	---	---	---	---	0.9625	0.030218

Capture Detail for Fitted Model:

	CR161.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	**s.e.***	**Estimate**	**s.e.***	**Estimate**	**s.e.***
R1_CR390 11U	0.7353	0.014681	0.6196	0.021498	0.4458	0.018670
R2_CR346 11U	0.7353	0.014681	0.6196	0.021498	0.4458	0.018670
R3_CR325 11U	0.7353	0.014681	0.6196	0.021498	0.4458	0.018670
R4_CR307 11U	0.7353	0.014681	0.6196	0.021498	0.4458	0.018670
R5_CR275 11U	0.7353	0.014681	0.6196	0.021498	0.4458	0.018670
R6_CR233 11U	---	---	0.7080	0.030246	0.5370	0.028891
R7_CR161 11U	---	---	0.6923	0.030172	0.5365	0.028699

Notes:

* *Standard error is based on only the inverse Hessian.*
† *Standard error is based on bootstrapping.*

D.1.13 B1 Sluiceway Passage

Table D.13. Bonneville Dam B1 sluiceway passage detection and survival rates for CH1 (R_1 to R_5 pooled to V_1).

Dam Survival:

	Estimate	s.e.†
Dam Survival:	0.9685	0.023866

Survival Summary:

	Estimate	s.e.†
V1	0.9658	0.012500
R2	0.9453	0.015032
R3	0.9479	0.014569

Survival Detail for Fitted Model:

	CR234.0 to CR161.0		CR161.0 to CR113.0		Release to CR113.0	
	Estimate	s.e.†	Estimate	s.e.*	Estimate	s.e.†
R1-R5 11U	0.9658	0.012500	0.9522	0.025324	---	---
R6_CR233 11U	---	---	---	---	0.9453	0.015032
R7_CR161 11U	---	---	---	---	0.9479	0.014569

Capture Detail for Fitted Model:

	CR161.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	s.e.*	Estimate	s.e.*	Estimate	s.e.*
R1-R5 11U	0.8636	0.019555	0.7467	0.028995	0.6694	0.029699
R6_CR233 11U	---	---	0.7695	0.017941	0.7325	0.018405
R7_CR161 11U	---	---	0.7627	0.018108	0.7349	0.018446

Notes:

* *Standard error is based on only the inverse Hessian.*
† *Standard error is based on bootstrapping.*

D.1.14 B1 Turbine Passage

Table D.14. Bonneville Dam B1 turbine passage detection and survival rates for CH1 (R_1 to R_5 pooled to V_1).

Dam Survival:

	Estimate	s.e.†
Dam Survival:	0.9677	0.021418

Survival Summary:

	Estimate	s.e.†
V1	0.9651	0.006957
R2	0.9453	0.016437
R3	0.9479	0.015254

Survival Detail for Fitted Model:

	CR234.0 to CR161.0		CR161.0 to CR113.0		Release to CR113.0	
	Estimate	**s.e.†**	**Estimate**	**s.e.***	**Estimate**	**s.e.†**
R1-R5 11U	0.9651	0.006957	0.9806	0.013023	---	---
R6_CR233 11U	---	---	---	---	0.9453	0.016437
R7_CR161 11U	---	---	---	---	0.9479	0.015254

Capture Detail for Fitted Model:

	CR161.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	**s.e.***	**Estimate**	**s.e.***	**Estimate**	**s.e.***
R1-R5 11U	0.8648	0.010745	0.7231	0.016022	0.7077	0.016113
R6_CR233 11U	---	---	0.7695	0.017941	0.7325	0.018405
R7_CR161 11U	---	---	0.7627	0.018108	0.7349	0.018446

Notes:

* *Standard error is based on only the inverse Hessian.*
† *Standard error is based on bootstrapping.*

D.1.15 Spillway Passage

Table D.15. Bonneville Dam spillway passage detection and survival rates for CH1 (R_1 to R_5 pooled to V_1).

Dam Survival:

	Estimate	s.e.†
Dam Survival:	0.9567	0.020715

Survival Summary:

	Estimate	s.e.†
V1	0.9540	0.005007
R2	0.9453	0.017156
R3	0.9479	0.015656

Survival Detail for Fitted Model:

	CR234.0 to CR161.0		CR161.0 to CR113.0		Release to CR113.0	
	Estimate	**s.e.†**	**Estimate**	**s.e.***	**Estimate**	**s.e.†**
R1-R5 11U	0.9540	0.005007	0.9432	0.008490	---	---
R6_CR233 11U	---	---	---	---	0.9453	0.017156
R7_CR161 11U	---	---	---	---	0.9479	0.015656

Capture Detail for Fitted Model:

	CR161.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	**s.e.***	**Estimate**	**s.e.***	**Estimate**	**s.e.***
R1-R5 11U	0.8416	0.007167	0.7550	0.009757	0.6924	0.010028
R6_CR233 11U	---	---	0.7695	0.017941	0.7325	0.018405
R7_CR161 11U	---	---	0.7627	0.018108	0.7349	0.018446

Notes:

* *Standard error is based on only the inverse Hessian.*
† *Standard error is based on bootstrapping.*

D.1.16 B2 JBS Passage

Table D.16. Bonneville Dam B2 JBS passage detection and survival rates for CH1 (R_1 to R_5 pooled to V_1).

Dam Survival:

	Estimate	s.e.†
Dam Survival:	0.9819	0.024348

Survival Summary:

	Estimate	s.e.†
V1	0.9792	0.012902
R2	0.9453	0.015703
R3	0.9479	0.014907

Survival Detail for Fitted Model:

	CR234.0 to CR161.0		CR161.0 to CR113.0		Release to CR113.0	
	Estimate	s.e.†	Estimate	s.e.*	Estimate	s.e.†
R1-R5 11U	0.9792	0.012902	0.9719	0.017946	---	---
R6_CR233 11U	---	---	---	---	0.9453	0.015703
R7_CR161 11U	---	---	---	---	0.9479	0.014907

Capture Detail for Fitted Model:

	CR161.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	s.e.*	Estimate	s.e.*	Estimate	s.e.*
R1-R5 11U	0.8698	0.025882	0.8431	0.029401	0.8899	0.026026
R6_CR233 11U	---	---	0.7695	0.017941	0.7325	0.018405
R7_CR161 11U	---	---	0.7627	0.018108	0.7349	0.018446

Notes:

* *Standard error is based on only the inverse Hessian.*
† *Standard error is based on bootstrapping.*

D.1.17 B2 Turbine Passage

Table D.17. Bonneville Dam B2 turbine passage detection and survival rates for CH1 (R_1 to R_5 pooled to V_1).

Dam Survival:

	Estimate	s.e.†
Dam Survival:	0.9469	0.023054

Survival Summary:

	Estimate	s.e.†
V1	0.9443	0.011585
R2	0.9453	0.014101
R3	0.9479	0.014116

Survival Detail for Fitted Model:

	CR234.0 to CR161.0		CR161.0 to CR113.0		Release to CR113.0	
	Estimate	**s.e.†**	**Estimate**	**s.e.***	**Estimate**	**s.e.†**
R1-R5 11U	0.9443	0.011585	0.9927	0.014001	---	---
R6_CR233 11U	---	---	---	---	0.9453	0.014101
R7_CR161 11U	---	---	---	---	0.9479	0.014116

Capture Detail for Fitted Model:

	CR161.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	**s.e.***	**Estimate**	**s.e.***	**Estimate**	**s.e.***
R1-R5 11U	0.8834	0.015990	0.8000	0.022019	0.7835	0.022444
R6_CR233 11U	---	---	0.7695	0.017941	0.7325	0.018405
R7_CR161 11U	---	---	0.7627	0.018108	0.7349	0.018446

Notes:

* *Standard error is based on only the inverse Hessian.*
† *Standard error is based on bootstrapping.*

D.1.18 B2CC Passage

Table D.18. Bonneville Dam B2 corner collector passage detection and survival rates for CH1 (R_1 to R_5 pooled to V_1).

Dam Survival:

	Estimate	s.e.†
Dam Survival:	0.9928	0.022600

Survival Summary:

	Estimate	s.e.†
V1	0.9901	0.008594
R2	0.9453	0.014959
R3	0.9479	0.014535

Survival Detail for Fitted Model:

	CR234.0 to CR161.0		CR161.0 to CR113.0		Release to CR113.0	
	Estimate	s.e.†	Estimate	s.e.*	Estimate	s.e.†
R1-R5 11U	0.9901	0.008594	1.0317	0.018250	---	---
R6_CR233 11U	---	---	---	---	0.9453	0.014959
R7_CR161 11U	---	---	---	---	0.9479	0.014535

Capture Detail for Fitted Model:

	CR161.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	s.e.*	Estimate	s.e.*	Estimate	s.e.*
R1-R5 11U	0.9313	0.020003	0.7426	0.037488	0.8082	0.035238
R6_CR233 11U	---	---	0.7695	0.017941	0.7325	0.018405
R7_CR161 11U	---	---	0.7627	0.018108	0.7349	0.018446

Notes:

** Standard error is based on only the inverse Hessian.*
† Standard error is based on bootstrapping.

D.1.19 All BON Turbine Passage

Table D.19. Bonneville Dam all turbine passage detection and survival rates for CH1 (R_1 to R_5 pooled to V_1).

Dam Survival:

	Estimate	s.e.†
Dam Survival:	0.9617	0.021073

Survival Summary:

	Estimate	s.e.†
V1	0.9591	0.005949
R2	0.9453	0.015950
R3	0.9479	0.015021

Survival Detail for Fitted Model:

	CR234.0 to CR161.0		CR161.0 to CR113.0		Release to CR113.0	
	Estimate	**s.e.†**	**Estimate**	**s.e.***	**Estimate**	**s.e.†**
R1-R5 11U	0.9591	0.005949	0.9820	0.009999	---	---
R6_CR233 11U	---	---	---	---	0.9453	0.015950
R7_CR161 11U	---	---	---	---	0.9479	0.015021

Capture Detail for Fitted Model:

	CR161.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	**s.e.***	**Estimate**	**s.e.***	**Estimate**	**s.e.***
R1-R5 11U	0.8700	0.008936	0.7459	0.013066	0.7303	0.013183
R6_CR233 11U	---	---	0.7695	0.017941	0.7325	0.018405
R7_CR161 11U	---	---	0.7627	0.018108	0.7349	0.018446

Notes:

** Standard error is based on only the inverse Hessian.*
† Standard error is based on bootstrapping.

D.1.20 All SFO Passage

Table D.20. Bonneville Dam all surface overflow passage detection and survival rates for CH1 (R_1 to R_5 pooled to V_1).

Dam Survival:

	Estimate	s.e.†
Dam Survival:	0.9741	0.022312

Survival Summary:

	Estimate	s.e.†
V1	0.9714	0.008998
R2	0.9453	0.016033
R3	0.9479	0.015069

Survival Detail for Fitted Model:

	CR234.0 to CR161.0		CR161.0 to CR113.0		Release to CR113.0	
	Estimate	**s.e.†**	**Estimate**	**s.e.***	**Estimate**	**s.e.†**
R1-R5 11U	0.9714	0.008998	0.9794	0.017956	---	---
R6_CR233 11U	---	---	---	---	0.9453	0.016033
R7_CR161 11U	---	---	---	---	0.9479	0.015069

Capture Detail for Fitted Model:

	CR161.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	**s.e.***	**Estimate**	**s.e.***	**Estimate**	**s.e.***
R1-R5 11U	0.8867	0.014649	0.7452	0.022936	0.7155	0.023273
R6_CR233 11U	---	---	0.7695	0.017941	0.7325	0.018405
R7_CR161 11U	---	---	0.7627	0.018108	0.7349	0.018446

Notes:

** Standard error is based on only 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.21. Bonneville Dam passage detection and survival rates for juvenile steelhead (STH).

Dam Survival:

	Estimate	s.e.†
Dam Survival:	0.9647	0.0212

Survival Summary:

	Estimate	s.e.†
V1	0.9491	0.0034
R2	0.9247	0.0156
R3	0.9398	0.0148

Survival Detail for Fitted Model:

	CR234.0 to CR161.0		CR161.0 to CR113.0		Release to CR113.0	
	Estimate	s.e.†	Estimate	s.e.*	Estimate	s.e.†
R1_CR390 35U	0.9491	0.0034	0.9594	0.0065	---	---
R2_CR346 35U	0.9491	0.0034	0.9594	0.0065	---	---
R3_CR325 35U	0.9491	0.0034	0.9594	0.0065	---	---
R4_CR307 35U	0.9491	0.0034	0.9594	0.0065	---	---
R5_CR275 35U	0.9491	0.0034	0.9594	0.0065	---	---
R6_CR233 35U	---	---	---	---	0.9247	0.0156
R7_CR161 35U	---	---	---	---	0.9398	0.0148

Capture Detail for Fitted Model:

	CR161.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	s.e.*	Estimate	s.e.*	Estimate	s.e.*
R1_CR390 35U	0.9164	0.0041	0.7533	0.0067	0.6199	0.0069
R2_CR346 35U	0.9164	0.0041	0.7533	0.0067	0.6199	0.0069
R3_CR325 35U	0.9164	0.0041	0.7533	0.0067	0.6199	0.0069
R4_CR307 35U	0.9164	0.0041	0.7533	0.0067	0.6199	0.0069
R5_CR275 35U	0.9164	0.0041	0.7533	0.0067	0.6199	0.0069
R6_CR233 35U	---	---	0.7533	0.0067	0.6199	0.0069
R7_CR161 35U	---	---	0.7533	0.0067	0.6199	0.0069

Notes:

* *Standard error is based on only the inverse Hessian.*
† *Standard error is based on bootstrapping.*

D.2.2 Bonneville Dam Passage – Early Season

Table D.22. Bonneville early season dam passage detection and survival rates for STH.

Dam Survival:

	Estimate	s.e.†
Dam Survival:	0.9755	0.018010

Survival Summary:

	Estimate	s.e.†
V1	0.9527	0.004357
R2	0.9634	0.013326
R3	0.9865	0.011449

Survival Detail for Fitted Model:

	CR234.0 to CR161.0		CR161.0 to CR113.0		Release to CR113.0	
	Estimate	**s.e.†**	**Estimate**	**s.e.***	**Estimate**	**s.e.†**
R1_CR390 35U	0.9527	0.004357	1.0017	0.004226	---	---
R2_CR346 35U	0.9527	0.004357	1.0017	0.004226	---	---
R3_CR325 35U	0.9527	0.004357	1.0017	0.004226	---	---
R4_CR307 35U	0.9527	0.004357	1.0017	0.004226	---	---
R5_CR275 35U	0.9527	0.004357	1.0017	0.004226	---	---
R6_CR233 35U	---	---	---	---	0.9634	0.013326
R7_CR161 35U	---	---	---	---	0.9865	0.011449

Capture Detail for Fitted Model:

	CR161.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	**s.e.***	**Estimate**	**s.e.***	**Estimate**	**s.e.***
R1_CR390 35U	0.9776	0.003072	0.8049	0.008795	0.8490	0.008166
R2_CR346 35U	0.9776	0.003072	0.8049	0.008795	0.8490	0.008166
R3_CR325 35U	0.9776	0.003072	0.8049	0.008795	0.8490	0.008166
R4_CR307 35U	0.9776	0.003072	0.8049	0.008795	0.8490	0.008166
R5_CR275 35U	0.9776	0.003072	0.8049	0.008795	0.8490	0.008166
R6_CR233 35U	---	---	0.8227	0.022085	0.9080	0.017583
R7_CR161 35U	---	---	0.8158	0.022233	0.8828	0.019210

Notes:

* *Standard error is based on only the inverse Hessian.*
† *Standard error is based on bootstrapping.*

D.2.3 Forebay and Dam Passage

Table D.23. Forebay virtual release detection and survival rates for STH.

Dam Survival:

	Estimate	s.e.†
Dam Survival:	0.9589	0.021085

Survival Summary:

	Estimate	s.e.†
V1	0.9434	0.003800
R2	0.9238	0.017174
R3	0.9389	0.015709

Survival Detail for Fitted Model:

	CR236.0 to CR161.0		CR161.0 to CR113.0		Release to CR113.0	
	Estimate	**s.e.†**	**Estimate**	**s.e.***	**Estimate**	**s.e.†**
R1_CR390 35U	0.9434	0.003800	0.9589	0.006442	---	---
R2_CR346 35U	0.9434	0.003800	0.9589	0.006442	---	---
R3_CR325 35U	0.9434	0.003800	0.9589	0.006442	---	---
R4_CR307 35U	0.9434	0.003800	0.9589	0.006442	---	---
R5_CR275 35U	0.9434	0.003800	0.9589	0.006442	---	---
R6_CR233 35U	---	---	---	---	0.9238	0.017174
R7_CR161 35U	---	---	---	---	0.9389	0.015709

Capture Detail for Fitted Model:

	CR161.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	**s.e.***	**Estimate**	**s.e.***	**Estimate**	**s.e.***
R1_CR390 35U	0.9177	0.004034	0.7541	0.006725	0.6222	0.006879
R2_CR346 35U	0.9177	0.004034	0.7541	0.006725	0.6222	0.006879
R3_CR325 35U	0.9177	0.004034	0.7541	0.006725	0.6222	0.006879
R4_CR307 35U	0.9177	0.004034	0.7541	0.006725	0.6222	0.006879
R5_CR275 35U	0.9177	0.004034	0.7541	0.006725	0.6222	0.006879
R6_CR233 35U	---	---	0.7541	0.006725	0.6222	0.006879
R7_CR161 35U	---	---	0.7541	0.006725	0.6222	0.006879

Notes:

* *Standard error is based on only the inverse Hessian.*
† *Standard error is based on bootstrapping.*

D.2.4 Forebay and Dam Passage – Early Spring

Table D.24. Forebay – early season virtual release detection and survival rates for STH.

Dam Survival:

	Estimate	s.e.†
Dam Survival:	0.9752	0.018007

Survival Summary:

	Estimate	s.e.†
V1	0.9524	0.004357
R2	0.9634	0.013343
R3	0.9865	0.011445

Survival Detail for Fitted Model:

	CR236.0 to CR161.0		CR161.0 to CR113.0		Release to CR113.0	
	Estimate	**s.e.†**	**Estimate**	**s.e.***	**Estimate**	**s.e.†**
R1_CR390 35U	0.9524	0.004357	1.0016	0.004213	---	---
R2_CR346 35U	0.9524	0.004357	1.0016	0.004213	---	---
R3_CR325 35U	0.9524	0.004357	1.0016	0.004213	---	---
R4_CR307 35U	0.9524	0.004357	1.0016	0.004213	---	---
R5_CR275 35U	0.9524	0.004357	1.0016	0.004213	---	---
R6_CR233 35U	---	---	---	---	0.9634	0.013343
R7_CR161 35U	---	---	---	---	0.9865	0.011445

Capture Detail for Fitted Model:

	CR161.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	**s.e.***	**Estimate**	**s.e.***	**Estimate**	**s.e.***
R1_CR390 35U	0.9781	0.003039	0.8057	0.008775	0.8493	0.008151
R2_CR346 35U	0.9781	0.003039	0.8057	0.008775	0.8493	0.008151
R3_CR325 35U	0.9781	0.003039	0.8057	0.008775	0.8493	0.008151
R4_CR307 35U	0.9781	0.003039	0.8057	0.008775	0.8493	0.008151
R5_CR275 35U	0.9781	0.003039	0.8057	0.008775	0.8493	0.008151
R6_CR233 35U	---	---	0.8227	0.022085	0.9080	0.017583
R7_CR161 35U	---	---	0.8158	0.022233	0.8828	0.019210

Notes:

* *Standard error is based on only the inverse Hessian.*
† *Standard error is based on bootstrapping.*

D.2.5 Bonneville Dam Passage – Late Spring – High Spill

Table D.25. Bonneville late season dam passage detection and survival rates for STH.

Dam Survival:

	Estimate	s.e.†
Dam Survival:	‡0.9044	0.056360

Survival Summary:

	Estimate	s.e.†
V1	0.9592	0.005303
R2	0.9709	0.045286
R3	0.9154	0.037912

Survival Detail for Fitted Model:

	CR234.0 to CR161.0		CR161.0 to CR113.0		Release to CR113.0	
	Estimate	**s.e.†**	**Estimate**	**s.e.***	**Estimate**	**s.e.†**
R1_CR390 35U	0.9592	0.005303	0.9901	0.017405	---	---
R2_CR346 35U	0.9592	0.005303	0.9901	0.017405	---	---
R3_CR325 35U	0.9592	0.005303	0.9901	0.017405	---	---
R4_CR307 35U	0.9592	0.005303	0.9901	0.017405	---	---
R5_CR275 35U	0.9592	0.005303	0.9901	0.017405	---	---
R6_CR233 35U	---	---	---	---	0.9709	0.045286
R7_CR161 35U	---	---	---	---	0.9154	0.037912

Capture Detail for Fitted Model:

	CR161.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	**s.e.***	**Estimate**	**s.e.***	**Estimate**	**s.e.***
R1_CR390 35U	0.8559	0.007272	0.6506	0.014108	0.3844	0.011066
R2_CR346 35U	0.8559	0.007272	0.6506	0.014108	0.3844	0.011066
R3_CR325 35U	0.8559	0.007272	0.6506	0.014108	0.3844	0.011066
R4_CR307 35U	0.8559	0.007272	0.6506	0.014108	0.3844	0.011066
R5_CR275 35U	0.8559	0.007272	0.6506	0.014108	0.3844	0.011066
R6_CR233 35U	---	---	0.6369	0.037102	0.3863	0.029259
R7_CR161 35U	---	---	0.7320	0.035807	0.3771	0.028126

Notes:

* *Standard error is based on only the inverse Hessian.*
† *Standard error is based on bootstrapping.*

‡ *Because the R2/R3 ratio is greater than 1.0, it is recommended that the "V1" value be used instead of "Dam Survival"*

D.2.6 Bonneville Dam Passage – Daytime

Table D.26. Bonneville daytime dam passage detection and survival rates for STH.

Dam Survival:

	Estimate	s.e.†
Dam Survival:	0.9598	0.025509

Survival Summary:

	Estimate	s.e.†
V1	0.9514	0.004041
R2	0.9176	0.017627
R3	0.9258	0.016802

Survival Detail for Fitted Model:

	CR234.0 to CR161.0		CR161.0 to CR113.0		Release to CR113.0	
	Estimate	**s.e.†**	**Estimate**	**s.e.***	**Estimate**	**s.e.†**
R1_CR390 35U	0.9514	0.004041	0.9481	0.008083	---	---
R2_CR346 35U	0.9514	0.004041	0.9481	0.008083	---	---
R3_CR325 35U	0.9514	0.004041	0.9481	0.008083	---	---
R4_CR307 35U	0.9514	0.004041	0.9481	0.008083	---	---
R5_CR275 35U	0.9514	0.004041	0.9481	0.008083	---	---
R6_CR233 35U	---	---	---	---	0.9176	0.017627
R7_CR161 35U	---	---	---	---	0.9258	0.016802

Capture Detail for Fitted Model:

	CR161.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	**s.e.***	**Estimate**	**s.e.***	**Estimate**	**s.e.***
R1_CR390 35U	0.9188	0.004930	0.7596	0.009225	0.6388	0.009511
R2_CR346 35U	0.9188	0.004930	0.7596	0.009225	0.6388	0.009511
R3_CR325 35U	0.9188	0.004930	0.7596	0.009225	0.6388	0.009511
R4_CR307 35U	0.9188	0.004930	0.7596	0.009225	0.6388	0.009511
R5_CR275 35U	0.9188	0.004930	0.7596	0.009225	0.6388	0.009511
R6_CR233 35U	---	---	0.7559	0.019878	0.6443	0.020456
R7_CR161 35U	---	---	0.7877	0.019128	0.6229	0.020163

Notes:

** Standard error is based on only the inverse Hessian.*
† Standard error is based on bootstrapping.

D.2.7 Bonneville Dam Passage - Nighttime

Table D.27. Bonneville nighttime dam passage detection and survival rates for STH.

Dam Survival:

	Estimate	s.e.†
Dam Survival:	0.9532	0.025694

Survival Summary:

	Estimate	s.e.†
V1	0.9448	0.005996
R2	0.9176	0.019004
R3	0.9258	0.017605

Survival Detail for Fitted Model:

	CR234.0 to CR161.0		CR161.0 to CR113.0		Release to CR113.0	
	Estimate	**s.e.†**	**Estimate**	**s.e.***	**Estimate**	**s.e.†**
R1_CR390 35U	0.9448	0.005996	0.9940	0.012895	---	---
R2_CR346 35U	0.9448	0.005996	0.9940	0.012895	---	---
R3_CR325 35U	0.9448	0.005996	0.9940	0.012895	---	---
R4_CR307 35U	0.9448	0.005996	0.9940	0.012895	---	---
R5_CR275 35U	0.9448	0.005996	0.9940	0.012895	---	---
R6_CR233 35U	---	---	---	---	0.9176	0.019004
R7_CR161 35U	---	---	---	---	0.9258	0.017605

Capture Detail for Fitted Model:

	CR161.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	**s.e.***	**Estimate**	**s.e.***	**Estimate**	**s.e.***
R1_CR390 35U	0.9119	0.007087	0.7242	0.013878	0.5716	0.013653
R2_CR346 35U	0.9119	0.007087	0.7242	0.013878	0.5716	0.013653
R3_CR325 35U	0.9119	0.007087	0.7242	0.013878	0.5716	0.013653
R4_CR307 35U	0.9119	0.007087	0.7242	0.013878	0.5716	0.013653
R5_CR275 35U	0.9119	0.007087	0.7242	0.013878	0.5716	0.013653
R6_CR233 35U	---	---	0.7559	0.019878	0.6443	0.020456
R7_CR161 35U	---	---	0.7877	0.019128	0.6229	0.020163

Notes:

* *Standard error is based on only the inverse Hessian.*
† *Standard error is based on bootstrapping.*

D.2.8 Bonneville Dam Passage – Daytime – Early Spring

Table D.28. Bonneville early season daytime dam passage detection and survival rates for STH (R_1 to R_5 pooled to V_1).

Dam Survival:

	Estimate	s.e.†
Dam Survival:	0.9762	0.018256

Survival Summary:

	Estimate	s.e.†
V1	0.9533	0.005143
R2	0.9634	0.013420
R3	0.9865	0.011456

Survival Detail for Fitted Model:

	CR234.0 to CR161.0		CR161.0 to CR113.0		Release to CR113.0	
	Estimate	**s.e.†**	**Estimate**	**s.e.***	**Estimate**	**s.e.†**
V1_CR234 35U	0.9533	0.005143	0.9986	0.004838	---	---
R6_CR233 35U	---	---	---	---	0.9634	0.013420
R7_CR161 35U	---	---	---	---	0.9865	0.011456

Capture Detail for Fitted Model:

	CR161.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	**s.e.***	**Estimate**	**s.e.***	**Estimate**	**s.e.***
V1_CR234 35U	0.9775	0.003658	0.8205	0.010102	0.8550	0.009466
R6_CR233 35U	---	---	0.8227	0.022085	0.9080	0.017583
R7_CR161 35U	---	---	0.8158	0.022233	0.8828	0.019210

Notes:

* *Standard error is based on only the inverse Hessian.*
† *Standard error is based on bootstrapping.*

D.2.9 Bonneville Dam Passage – Daytime – Late Spring

Table D.29. Bonneville late season daytime dam passage detection and survival rates for STH.

Dam Survival:

	Estimate	s.e.†
Dam Survival:	0.9658	0.00688
(a) V_1 survival was used to estimate dam-passage survival because R_2 survival was > R_3 survival.		

Survival Summary:

	Estimate	s.e.†
V1	0.9658	0.006880
R2	0.9709	0.045631
R3	0.9154	0.038120

Survival Detail for Fitted Model:

	CR234.0 to CR161.0		CR161.0 to CR113.0		Release to CR113.0	
	Estimate	s.e.†	Estimate	s.e.*	Estimate	s.e.†
R1_CR390 35U	0.9658	0.006880	0.9756	0.022885	---	---
R2_CR346 35U	0.9658	0.006880	0.9756	0.022885	---	---
R3_CR325 35U	0.9658	0.006880	0.9756	0.022885	---	---
R4_CR307 35U	0.9658	0.006880	0.9756	0.022885	---	---
R5_CR275 35U	0.9658	0.006880	0.9756	0.022885	---	---
R6_CR233 35U	---	---	---	---	0.9709	0.045631
R7_CR161 35U	---	---	---	---	0.9154	0.038120

Capture Detail for Fitted Model:

	CR161.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	s.e.*	Estimate	s.e.*	Estimate	s.e.*
R1_CR390 35U	0.8516	0.009451	0.6374	0.018236	0.3810	0.014242
R2_CR346 35U	0.8516	0.009451	0.6374	0.018236	0.3810	0.014242
R3_CR325 35U	0.8516	0.009451	0.6374	0.018236	0.3810	0.014242
R4_CR307 35U	0.8516	0.009451	0.6374	0.018236	0.3810	0.014242
R5_CR275 35U	0.8516	0.009451	0.6374	0.018236	0.3810	0.014242
R6_CR233 35U	---	---	0.6369	0.037102	0.3863	0.029259
R7_CR161 35U	---	---	0.7320	0.035807	0.3771	0.028126

Notes:

** Standard error is based on only the inverse Hessian.*
† Standard error is based on bootstrapping.
‡ Because the R2/R3 ratio is greater than 1.0, it is recommended that the "V1" value be used instead of "Dam Survival"

D.2.10 Bonneville Dam Passage – Nighttime – Early Spring

Table D.30. Bonneville early season nighttime dam passage detection and survival rates for STH (R_1 to R_5 pooled to V_1).

Dam Survival:

	Estimate	s.e.†
Dam Survival:	0.9744	0.019292

Survival Summary:

	Estimate	s.e.†
V1	0.9516	0.008061
R2	0.9634	0.013341
R3	0.9865	0.011440

Survival Detail for Fitted Model:

	CR234.0 to CR161.0		CR161.0 to CR113.0		Release to CR113.0	
	Estimate	**s.e.†**	**Estimate**	**s.e.***	**Estimate**	**s.e.†**
V1_CR234 35U	0.9516	0.008061	1.0000	0.000000	---	---
R6_CR233 35U	---	---	---	---	0.9634	0.013341
R7_CR161 35U	---	---	---	---	0.9865	0.011440

Capture Detail for Fitted Model:

	CR161.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	**s.e.***	**Estimate**	**s.e.***	**Estimate**	**s.e.***
V1_CR234 35U	0.9778	0.005665	0.7757	0.015784	0.8386	0.013944
R6_CR233 35U	---	---	0.8227	0.022085	0.9080	0.017583
R7_CR161 35U	---	---	0.8158	0.022233	0.8828	0.019210

Notes:

** Standard error is based on only the inverse Hessian.*
† Standard error is based on bootstrapping.

D.2.11 Bonneville Dam Passage – Nighttime – Late Spring

Table D.31. Bonneville late season nighttime dam passage detection and survival rates for STH.

Dam Survival:

	Estimate	s.e.†
Dam Survival:	0.9490	0.008626
(a) V_1 survival was used to estimate dam-passage survival because R_2 survival was > R_3 survival.		

Survival Summary:

	Estimate	s.e.†
V1	0.9490	0.008626
R2	0.9709	0.046009
R3	0.9154	0.038357

Survival Detail for Fitted Model:

	CR234.0 to CR161.0		CR161.0 to CR113.0		Release to CR113.0	
	Estimate	**s.e.†**	**Estimate**	**s.e.***	**Estimate**	**s.e.†**
R1_CR390 35U	0.9490	0.008626	1.0143	0.026639	---	---
R2_CR346 35U	0.9490	0.008626	1.0143	0.026639	---	---
R3_CR325 35U	0.9490	0.008626	1.0143	0.026639	---	---
R4_CR307 35U	0.9490	0.008626	1.0143	0.026639	---	---
R5_CR275 35U	0.9490	0.008626	1.0143	0.026639	---	---
R6_CR233 35U	---	---	---	---	0.9709	0.046009
R7_CR161 35U	---	---	---	---	0.9154	0.038357

Capture Detail for Fitted Model:

	CR161.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	**s.e.***	**Estimate**	**s.e.***	**Estimate**	**s.e.***
R1_CR390 35U	0.8626	0.011369	0.6711	0.022221	0.3896	0.017575
R2_CR346 35U	0.8626	0.011369	0.6711	0.022221	0.3896	0.017575
R3_CR325 35U	0.8626	0.011369	0.6711	0.022221	0.3896	0.017575
R4_CR307 35U	0.8626	0.011369	0.6711	0.022221	0.3896	0.017575
R5_CR275 35U	0.8626	0.011369	0.6711	0.022221	0.3896	0.017575
R6_CR233 35U	---	---	0.6369	0.037102	0.3863	0.029259
R7_CR161 35U	---	---	0.7320	0.035807	0.3771	0.028126

Notes:

** Standard error is based on only the inverse Hessian.*
† Standard error is based on bootstrapping.
‡ Because the R2/R3 ratio is greater than 1.0, it is recommended that the "V1" value be used instead of "Dam Survival"

D.2.12 B1 Sluiceway Passage

Table D.32. Bonneville Dam B1 sluiceway passage detection and survival rates for STH (R_1 to R_5 pooled to V_1).

Dam Survival:

	Estimate	s.e.†
Dam Survival:	0.9534	0.027727

Survival Summary:

	Estimate	s.e.†
V1	0.9450	0.011938
R2	0.9176	0.018159
R3	0.9258	0.017118

Survival Detail for Fitted Model:

	CR234.0 to CR161.0		CR161.0 to CR113.0		Release to CR113.0	
	Estimate	s.e.†	Estimate	s.e.*	Estimate	s.e.†
R1-R5 35U	0.9450	0.011938	0.9871	0.024427	---	---
R6_CR233 35U	---	---	---	---	0.9176	0.018159
R7_CR161 35U	---	---	---	---	0.9258	0.017118

Capture Detail for Fitted Model:

	CR161.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	s.e.*	Estimate	s.e.*	Estimate	s.e.*
R1-R5 35U	0.9164	0.014139	0.7164	0.027533	0.6254	0.027626
R6_CR233 35U	---	---	0.7559	0.019878	0.6443	0.020456
R7_CR161 35U	---	---	0.7877	0.019128	0.6229	0.020163

Notes:

* *Standard error is based on only the inverse Hessian.*
† *Standard error is based on bootstrapping.*

D.2.13 B1 Turbine Passage

Table D.33. Bonneville Dam B1 turbine passage detection and survival rates for STH (R_1 to R_5 pooled to V_1).

Dam Survival:

	Estimate	s.e.†
Dam Survival:	0.9362	0.025819

Survival Summary:

	Estimate	s.e.†
V1	0.9280	0.007913
R2	0.9177	0.017757
R3	0.9258	0.016873

Survival Detail for Fitted Model:

	CR234.0 to CR161.0		CR161.0 to CR113.0		Release to CR113.0	
	Estimate	s.e.†	Estimate	s.e.*	Estimate	s.e.†
R1-R5 35U	0.9280	0.007913	0.9321	0.013266	---	---
R6_CR233 35U	---	---	---	---	0.9177	0.017757
R7_CR161 35U	---	---	---	---	0.9258	0.016873

Capture Detail for Fitted Model:

	CR161.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	s.e.*	Estimate	s.e.*	Estimate	s.e.*
R1-R5 35U	0.9230	0.008271	0.7805	0.015236	0.6568	0.016033
R6_CR233 35U	---	---	0.7559	0.019878	0.6443	0.020456
R7_CR161 35U	---	---	0.7877	0.019128	0.6229	0.020163

Notes:

* *Standard error is based on only the inverse Hessian.*
† *Standard error is based on bootstrapping.*

D.2.14 Spillway Passage

Table D.34. Bonneville Dam spillway passage detection and survival rates for STH (R_1 to R_5 pooled to V_1).

Dam Survival:

	Estimate	s.e.†
Dam Survival:	0.9646	0.025697

Survival Summary:

	Estimate	s.e.†
V1	0.9561	0.004482
R2	0.9176	0.018174
R3	0.9258	0.017112

Survival Detail for Fitted Model:

	CR234.0 to CR161.0		CR161.0 to CR113.0		Release to CR113.0	
	Estimate	**s.e.†**	**Estimate**	**s.e.***	**Estimate**	**s.e.†**
R1-R5 35U	0.9561	0.004482	0.9706	0.010794	---	---
R6_CR233 35U	---	---	---	---	0.9176	0.018174
R7_CR161 35U	---	---	---	---	0.9258	0.017112

Capture Detail for Fitted Model:

	CR161.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	**s.e.***	**Estimate**	**s.e.***	**Estimate**	**s.e.***
R1-R5 35U	0.9062	0.005839	0.7280	0.011245	0.5514	0.010939
R6_CR233 35U	---	---	0.7559	0.019878	0.6443	0.020456
R7_CR161 35U	---	---	0.7877	0.019128	0.6229	0.020163

Notes:

* *Standard error is based on only the inverse Hessian.*
† Standard error is based on bootstrapping.

D.2.15 B2 JBS Passage

Table D.35. Bonneville Dam B2 JBS passage detection and survival rates for STH (R_1 to R_5 pooled to V_1).

Dam Survival:

	Estimate	s.e.†
Dam Survival:	0.9377	0.041337

Survival Summary:

	Estimate	s.e.†
V1	0.9294	0.032938
R2	0.9176	0.018425
R3	0.9258	0.017261

Survival Detail for Fitted Model:

	CR234.0 to CR161.0		CR161.0 to CR113.0		Release to CR113.0	
	Estimate	s.e.†	Estimate	s.e.*	Estimate	s.e.†
R1-R5 35U	0.9294	0.032938	1.0382	0.041682	---	---
R6_CR233 35U	---	---	---	---	0.9176	0.018425
R7_CR161 35U	---	---	---	---	0.9258	0.017261

Capture Detail for Fitted Model:

	CR161.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	s.e.*	Estimate	s.e.*	Estimate	s.e.*
R1-R5 35U	0.8813	0.042107	0.7391	0.064746	0.7234	0.065251
R6_CR233 35U	---	---	0.7559	0.019878	0.6443	0.020456
R7_CR161 35U	---	---	0.7877	0.019128	0.6229	0.020163

Notes:

* *Standard error is based on only the inverse Hessian.*
† *Standard error is based on bootstrapping.*

D.2.16 B2 Turbine Passage

Table D.36. Bonneville Dam B2 turbine passage detection and survival rates for STH (R_1 to R_5 pooled to V_1).

Dam Survival:

	Estimate	s.e.†
Dam Survival:	0.9185	0.033375

Survival Summary:

	Estimate	s.e.†
V1	0.9104	0.022903
R2	0.9176	0.017511
R3	0.9258	0.016732

Survival Detail for Fitted Model:

	CR234.0 to CR161.0		CR161.0 to CR113.0		Release to CR113.0	
	Estimate	**s.e.†**	**Estimate**	**s.e.***	**Estimate**	**s.e.†**
R1-R5 35U	0.9104	0.022903	0.9717	0.029225	---	---
R6_CR233 35U	---	---	---	---	0.9176	0.017511
R7_CR161 35U	---	---	---	---	0.9258	0.016732

Capture Detail for Fitted Model:

	CR161.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	**s.e.***	**Estimate**	**s.e.***	**Estimate**	**s.e.***
R1-R5 35U	0.9704	0.014595	0.7615	0.040821	0.7616	0.040828
R6_CR233 35U	---	---	0.7559	0.019878	0.6443	0.020456
R7_CR161 35U	---	---	0.7877	0.019128	0.6229	0.020163

Notes:

* *Standard error is based on only the inverse Hessian.*
† *Standard error is based on bootstrapping.*

D.2.17 B2CC Passage

Table D.37. Bonneville Dam B2 corner collector passage detection and survival rates for STH (R_1 to R_5 pooled to V_1).

Dam Survival:

	Estimate	s.e.†
Dam Survival:	0.9877	0.026762

Survival Summary:

	Estimate	s.e.†
V1	0.9790	0.006631
R2	0.9176	0.017511
R3	0.9258	0.016732

Survival Detail for Fitted Model:

	CR234.0 to CR161.0		CR161.0 to CR113.0		Release to CR113.0	
	Estimate	**s.e.†**	**Estimate**	**s.e.***	**Estimate**	**s.e.†**
R1-R5 35U	0.9790	0.006631	0.9836	0.011604	---	---
R6_CR233 35U	---	---	---	---	0.9176	0.017511
R7_CR161 35U	---	---	---	---	0.9258	0.016732

Capture Detail for Fitted Model:

	CR161.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	**s.e.***	**Estimate**	**s.e.***	**Estimate**	**s.e.***
R1-R5 35U	0.9563	0.009119	0.7903	0.019540	0.8327	0.018400
R6_CR233 35U	---	---	0.7559	0.019878	0.6443	0.020456
R7_CR161 35U	---	---	0.7877	0.019128	0.6229	0.020163

Notes:

* *Standard error is based on only the inverse Hessian.*
† *Standard error is based on bootstrapping.*

D.2.18 All BON Turbine Passage

Table D.38. Bonneville Dam all turbine passage detection and survival rates for STH (R_1 to R_5 pooled to V_1).

Dam Survival:

	Estimate	s.e.†
Dam Survival:	0.9340	0.025633

Survival Summary:

	Estimate	s.e.†
V1	0.9258	0.007550
R2	0.9176	0.018108
R3	0.9258	0.017071

Survival Detail for Fitted Model:

	CR234.0 to CR161.0		CR161.0 to CR113.0		Release to CR113.0	
	Estimate	s.e.†	Estimate	s.e.*	Estimate	s.e.†
R1-R5 35U	0.9258	0.007550	0.9370	0.012227	---	---
R6_CR233 35U	---	---	---	---	0.9176	0.018108
R7_CR161 35U	---	---	---	---	0.9258	0.017071

Capture Detail for Fitted Model:

	CR161.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	s.e.*	Estimate	s.e.*	Estimate	s.e.*
R1-R5 35U	0.9284	0.007523	0.7780	0.014279	0.6684	0.014994
R6_CR233 35U	---	---	0.7559	0.019878	0.6443	0.020456
R7_CR161 35U	---	---	0.7877	0.019128	0.6229	0.020163

Notes:

* *Standard error is based on only the inverse Hessian.*
† *Standard error is based on bootstrapping.*

D.2.19 All SFO Passage

Table D.39. Bonneville Dam all surface overflow passage detection and survival rates for STH (R_1 to R_5 pooled to V_1).

Dam Survival:

	Estimate	s.e.†
Dam Survival:	0.9712	0.026312

Survival Summary:

	Estimate	s.e.†
V1	0.9626	0.006573
R2	0.9176	0.018003
R3	0.9258	0.017006

Survival Detail for Fitted Model:

	CR234.0 to CR161.0		CR161.0 to CR113.0		Release to CR113.0	
	Estimate	**s.e.†**	**Estimate**	**s.e.***	**Estimate**	**s.e.†**
R1-R5 35U	0.9626	0.006573	0.9793	0.011671	---	---
R6_CR233 35U	---	---	---	---	0.9176	0.018003
R7_CR161 35U	---	---	---	---	0.9258	0.017006

Capture Detail for Fitted Model:

	CR161.0		CR113.0		CR086.2 Survival*Capture	
	Estimate	**s.e.***	**Estimate**	**s.e.***	**Estimate**	**s.e.***
R1-R5 35U	0.9391	0.008037	0.7621	0.016070	0.7442	0.016276
R6_CR233 35U	---	---	0.7559	0.019878	0.6443	0.020456
R7_CR161 35U	---	---	0.7877	0.019128	0.6229	0.020163

Notes:

* *Standard error is based on only the inverse Hessian.*
† *Standard error is based on bootstrapping.*

Appendix E

Assessment of Survival Model Assumptions

Appendix E

Tests of Assumptions

E.1 Tagger Effects

All of the data from the seven releases associated with the three-dam study were examined for tagger effects. This was done because of the interrelationship between the multiple releases and estimation of dam passage survival at a specific location and to increase the statistical power to detect effects.

To minimize any tagger effects that might go undetected, tagger effort should be balanced across release locations and within replicates. A total of eight taggers participated in the tagging of yearling Chinook salmon (CH1) and juvenile steelhead (STH). Tagger effort was found to be balanced across the seven release locations regardless whether the data were pooled across species $\left(P\left(\chi^2_{42} \geq 27.70\right) = 0.9562\right)$ or analyzed separately by CH1 $\left(P\left(\chi^2_{42} \geq 22.68\right) = 0.9935\right)$ or STH $\left(P\left(\chi^2_{42} \geq 10.62\right) = 1.00\right)$ (Table E.1).

Tagger effort was also examined within each the 32 replicate releases conducted over the course of the season (Table E.2). Tagger effort was found to be balanced within replicates 1, 2, 5, 6, 9, 10, 13, 14, 17, 18, 21, 22, 25, 26, 29, and 30 ($P \geq 0.9982$). To accommodate staff time off during the month-long study, tagger effort was conditionally balanced within the individual project releases (i.e., R_1–R_3, R_4–R_5, and R_6–R_7) for the remaining replicates ($P \geq 0.7459$) (Table E.2). This conditional and unconditional balance within replicates is the reason for the overall balance observed in Table E.1. To minimize the number of contingency tables presented, results in Table E.2 are pooled across species.

To test for tagger effects, reach survivals and cumulative survivals were calculated for fish tagged by different staff members on the basis of release location (i.e., R1, …, R7) and species (Table E.3). Of the 56 tests of homogeneous reach survivals, 7 were found to be significant at $\alpha = 0.10$ (i.e., 12.5%). By chance alone, we might expect 10% of 56 tests (i.e., 5.6) to be significant at $\alpha = 0.10$ when no effect exists. There was no consistent pattern; two taggers were responsible for two of seven significant results each, and three taggers were responsible for one significant result each. Similarly, only 2 of 54 (3.7%) tests of the homogeneous cumulative survivals were found to be significant at $\alpha = 0.10$. Therefore, fish tagged by all taggers were considered acceptable for the survival analyses.

Table E.1. Numbers of CH1 and STH tagged by each staff member by release locations (R1, R2, …, R7). Chi-square tests of homogeneity were not significant.

a. CH1 and STH releases pooled

Release Location	Tagger							
	Amanda	Kate	Kathleen	Kyle	MaryBeth	Rhonda	Shon	Tyrell
R1–CR390	581	576	668	569	528	456	899	820
R2–CR346	279	254	302	263	293	227	388	383
R3–CR325	193	173	197	176	196	148	248	265
R4–CR307	195	176	197	168	200	150	249	264
R5–CR275	190	172	195	176	201	152	242	271
R6–CR233	189	179	190	179	196	150	246	261
R7–CR161	192	178	196	179	191	141	246	265

$P\left(\chi^2_{42} \geq 27.70\right) = 0.9562$

b. CH1

Release Location	Tagger							
	Amanda	Kate	Kathleen	Kyle	MaryBeth	Rhonda	Shon	Tyrell
R1–CR390	280	292	335	284	252	216	447	404
R2–CR346	136	127	147	133	149	113	197	191
R3–CR325	98	88	97	84	99	73	125	135
R4–CR307	95	85	98	84	102	77	123	135
R5–CR275	95	84	93	86	104	76	122	139
R6–CR233	94	90	97	*86*	101	75	125	130
R7–CR161	93	91	102	90	97	67	122	132

$P\left(\chi^2_{42} \geq 22.68\right) = 0.9935$

c. STH

Release Location	Tagger							
	Amanda	Kate	Kathleen	Kyle	MaryBeth	Rhonda	Shon	Tyrell
R1–CR390	301	284	333	285	276	240	452	416
R2–CR346	143	127	155	130	144	114	191	192
R3–CR325	95	85	100	92	97	75	123	130
R4–CR307	100	91	99	84	98	73	126	129
R5–CR275	95	88	102	90	97	76	120	132
R6–CR233	95	89	93	93	95	75	121	131
R7–CR161	99	87	94	89	94	74	124	133

$P\left(\chi^2_{42} \geq 10.62\right) \doteq 1.00$

Table E.2. Contingency tables with number of fish tagged by each staff member per release location within a replicate release. A total of 32 replicate day or nighttime releases were performed over the course of the 2011 investigations. Results of the chi-square tests of homogeneity are presented for each table.

a. Replicate 1

Release	Kate	Kathleen	Kyle	Shon
R1–CR390	35	40	31	54
R2–CR346	14	21	16	25
R3–CR325	10	14	10	16
R4–CR307	10	14	11	15
R5–CR275	11	12	13	14
R6–CR233	10	12	12	16
R7–CR161	9	12	11	18

Chi-square = 2.7577 DF = 18 *P*-value = 1

b. Replicate 2

Release	Kate	Kathleen	Kyle	Shon
R1–CR390	36	44	32	51
R2–CR346	17	20	14	24
R3–CR325	12	12	10	16
R4–CR307	12	12	11	15
R5–CR275	10	14	11	15
R6–CR233	11	12	11	15
R7–CR161	10	12	11	15

Chi-square = 1.2674 DF = 18 *P*-value = 1

c. Replicate 3

Release	Amanda	Kate	Kathleen	Kyle	MaryBeth	Rhonda	Shon	Tyrell	*P*-value
R1–CR390	0	39	44	34	0	0	49	0	
R2–CR346	0	15	19	18	0	0	24	0	0.9677
R3–CR325	0	9	14	10	0	0	17	0	
R4–CR307	0	11	12	10	0	0	17	0	0.9948
R5–CR275	0	12	12	10	0	0	16	0	
R6–CR233	10	0	0	0	11	10	0	19	0.8460
R7–CR161	11	0	0	0	13	7	0	17	

Chi-square = 496.3651 DF = 42 *P*-value < 0.0001

d. Replicate 4

Release	Amanda	Kate	Kathleen	Kyle	MaryBeth	Rhonda	Shon	Tyrell	*P*-value
R1–CR390	0	34	42	37	0	0	49	0	
R2–CR346	0	14	21	17	0	0	24	0	0.9977
R3–CR325	0	10	12	11	0	0	17	0	
R4–CR307	0	9	13	12	0	0	16	0	0.9318
R5–CR275	0	11	11	11	0	0	17	0	
R6–CR233	12	0	0	0	13	8	0	17	0.7459
R7–CR161	12	0	0	0	9	11	0	18	

Chi-square = 495.4415 DF = 42 *P*-value < 0.0001

Table E.2. (contd)

e. Replicate 5

Release	Amanda	MaryBeth	Rhonda	Tyrell
R1–CR390	37	31	24	71
R2–CR346	16	18	15	26
R3–CR325	11	11	10	18
R4–CR307	10	11	9	20
R5–CR275	11	11	9	19
R6–CR233	12	12	9	17
R7–CR161	13	11	9	16
Chi-square = 4.8581		DF = 18		*P*-value=0.9991

f. Replicate 6

Release	Amanda	MaryBeth	Rhonda	Tyrell
R1–CR390	37	40	29	58
R2–CR346	17	17	14	28
R3–CR325	11	10	10	19
R4–CR307	12	11	9	18
R5–CR275	11	10	10	19
R6–CR233	11	13	9	17
R7–CR161	12	10	9	16
Chi-square = 1.5118		DF = 18		*P*-value = 1

g. Replicate 7

Release	Amanda	Kate	Kathleen	Kyle	MaryBeth	Rhonda	Shon	Tyrell	*P*-value
R1–CR390	36	0	0	0	37	29	0	62	
R2–CR346	19	0	0	0	18	12	0	27	0.9966
R3–CR325	12	0	0	0	12	9	0	17	
R4–CR307	12	0	0	0	12	10	0	15	0.9449
R5–CR275	12	0	0	0	13	8	0	17	
R6–CR233	0	11	12	10	0	0	17	0	0.9176
R7–CR161	0	10	15	10	0	0	15	0	
Chi-square = 493.4409				DF = 42				*P*-value < 0.0001	

h. Replicate 8

Release	Amanda	Kate	Kathleen	Kyle	MaryBeth	Rhonda	Shon	Tyrell	*P*-value
R1–CR390	36	0	0	0	37	30	0	61	
R2–CR346	15	0	0	0	17	14	0	28	0.9970
R3–CR325	12	0	0	0	11	8	0	16	
R4–CR307	13	0	0	0	12	10	0	15	0.9747
R5–CR275	12	0	0	0	12	9	0	17	
R6–CR233	0	10	13	11	0	0	15	0	0.9910
R7–CR161	0	10	14	10	0	0	16	0	
Chi-square = 486.5198				DF = 42				*P*-value < 0.0001	

Table E.2. (contd)

i. Replicate 9

Release	Kate	Kathleen	Kyle	Shon
R1–CR390	35	43	38	48
R2–CR346	16	20	16	24
R3–CR325	10	13	11	16
R4–CR307	11	14	9	16
R5–CR275	11	13	10	16
R6–CR233	10	11	11	15
R7–CR161	11	12	11	16
Chi-square = 1.2239		DF = 18		*P*-value = 1

j. Replicate 10

Release	Kate	Kathleen	Kyle	Shon
R1–CR390	33	43	36	52
R2–CR346	14	21	16	25
R3–CR325	11	14	10	15
R4–CR307	10	14	10	16
R5–CR275	8	13	11	15
R6–CR233	10	13	12	15
R7–CR161	10	14	11	15
Chi-square = 1.0171		DF = 18		*P*-value = 1

k. Replicate 11

Release	Amanda	Kate	Kathleen	Kyle	MaryBeth	Rhonda	Shon	Tyrell	*P*-value
R1–CR390	0	34	43	36	0	0	51	0	
R2–CR346	0	16	21	15	0	0	24	0	0.9939
R3–CR325	0	12	11	11	0	0	16	0	
R4–CR307	0	11	14	10	0	0	15	0	0.9832
R5–CR275	0	10	15	11	0	0	14	0	
R6–CR233	12	0	0	0	12	10	0	15	0.9900
R7–CR161	13	0	0	0	12	9	0	16	
Chi-square = 491.1992				DF = 42			*P*-value < 0.0001		

l. Replicate 12

Release	Amanda	Kate	Kathleen	Kyle	MaryBeth	Rhonda	Shon	Tyrell	*P*-value
R1–CR390	0	34	46	36	0	0	48	0	
R2–CR346	0	15	21	17	0	0	23	0	0.9999
R3–CR325	0	11	13	11	0	0	15	0	
R4–CR307	0	13	14	10	0	0	13	0	0.8539
R5–CR275	0	12	11	13	0	0	13	0	
R6–CR233	13	0	0	0	11	9	0	16	0.9295
R7–CR161	12	0	0	0	12	7	0	18	
Chi-square = 491.908					DF = 42			*P*-value < 0.0001	

Table E.2. (contd)

m. Replicate 13

Release	Amanda	MaryBeth	Rhonda	Shon	Tyrell
R1–CR390	34	0	27	50	51
R2–CR346	19	17	16	0	24
R3–CR325	12	11	10	0	17
R4–CR307	12	12	9	0	17
R5–CR275	12	12	9	0	17
R6–CR233	13	13	7	0	17
R7–CR161	12	11	8	0	18
Chi-square = 140.8547		DF = 24		*P*-value < 0.0001	

n. Replicate 14

Release	Amanda	MaryBeth	Rhonda	Shon	Tyrell
R1–CR390	35	0	31	48	50
R2–CR346	18	19	14	0	23
R3–CR325	13	12	9	0	16
R4–CR307	13	13	10	0	14
R5–CR275	12	12	9	0	17
R6–CR233	12	11	10	0	17
R7–CR161	14	13	7	0	16
Chi-square = 137.8706		DF = 24		*P*-value < 0.0001	

o. Replicate 15

Release	Amanda	Kate	Kathleen	Kyle	MaryBeth	Rhonda	Shon	Tyrell	*P*-value
R1–CR390	41	0	0	0	39	32	0	52	
R2–CR346	20	0	0	0	20	13	0	23	0.9873
R3–CR325	13	0	0	0	11	8	0	18	
R4–CR307	13	0	0	0	12	8	0	17	0.9345
R5–CR275	14	0	0	0	11	10	0	15	
R6–CR233	0	13	11	10	0	0	16	0	0.9161
R7–CR161	0	10	12	11	0	0	17	0	
Chi-square = 494.3843				DF = 42					<0.0001

p. Replicate 16

Release	Amanda	Kate	Kathleen	Kyle	MaryBeth	Rhonda	Shon	Tyrell	*P*-value
R1–CR390	40	0	0	0	39	32	0	52	
R2–CR346	17	0	0	0	17	15	0	26	0.9959
R3–CR325	13	0	0	0	12	8	0	17	
R4–CR307	12	0	0	0	12	9	0	17	0.9933
R5–CR275	12	0	0	0	12	8	0	18	
R6–CR233	0	11	11	10	0	0	15	0	0.9883
R7–CR161	0	12	10	11	0	0	15	0	
Chi-square = 484.8889				DF = 42					<0.0001

Table E.2. (contd)

q. Replicate 17

Release	Kate	Kathleen	Kyle	Shon
R1–CR390	32	42	33	55
R2–CR346	15	17	18	23
R3–CR325	12	10	12	16
R4–CR307	11	11	11	17
R5–CR275	12	9	12	17
R6–CR233	11	12	10	16
R7–CR161	12	10	11	15
Chi-square = 3.1892		DF = 18		*P*-value = 1

r. Replicate 18

Release	Kate	Kathleen	Kyle	Shon
R1–CR390	36	42	35	50
R2–CR346	17	16	16	26
R3–CR325	11	11	12	15
R4–CR307	12	11	9	18
R5–CR275	11	11	11	16
R6–CR233	12	11	13	14
R7–CR161	12	12	12	14
Chi-square = 2.7843		DF = 18		*P*-value = 1

s. Replicate 19

Release	Amanda	Kate	Kathleen	Kyle	MaryBeth	Rhonda	Shon	Tyrell	*P*-value
R1–CR390	0	41	36	38	0	0	49	0	
R2–CR346	0	17	18	16	0	0	25	0	0.9882
R3–CR325	0	11	12	13	0	0	14	0	
R4–CR307	0	11	11	12	0	0	16	0	0.9352
R5–CR275	0	13	12	10	0	0	15	0	
R6–CR233	14	0	0	0	12	8	0	16	0.9704
R7–CR161	12	0	0	0	12	9	0	17	
Chi-square = 492.9525			DF = 42						<0.0001

t. Replicate 20

Release	Amanda	Kate	Kathleen	Kyle	MaryBeth	Rhonda	Shon	Tyrell	*P*-value
R1–CR390	0	39	37	36	0	0	52	0	
R2–CR346	0	18	16	17	0	0	24	0	0.9996
R3–CR325	0	11	12	12	0	0	15	0	
R4–CR307	0	12	12	12	0	0	14	0	0.9836
R5–CR275	0	11	13	11	0	0	15	0	
R6–CR233	12	0	0	0	12	10	0	16	0.9705
R7–CR161	12	0	0	0	12	8	0	17	
Chi-square = 490.2024			DF = 42						<0.0001

Table E.2. (contd)

u. Replicate 21

Release	Amanda	MaryBeth	Rhonda	Tyrell
R1–CR390	41	41	29	53
R2–CR346	20	18	14	24
R3–CR325	12	13	9	16
R4–CR307	13	14	8	15
R5–CR275	11	15	8	16
R6–CR233	11	14	10	15
R7–CR161	11	12	8	17
Chi-square = 1.8491		DF = 18		*P*-value = 1

v. Replicate 22

Release	Amanda	MaryBeth	Rhonda	Tyrell
R1–CR390	39	40	32	48
R2–CR346	20	18	15	23
R3–CR325	10	15	10	15
R4–CR307	12	14	9	15
R5–CR275	12	14	8	16
R6–CR233	10	13	10	17
R7–CR161	12	11	10	17
Chi-square = 2.6222		DF = 18		*P*-value = 1

w. Replicate 23

Release	Amanda	Kate	Kathleen	Kyle	MaryBeth	Rhonda	Shon	Tyrell	*P*-value
R1–CR390	41	0	0	0	41	30	0	52	
R2–CR346	18	0	0	0	20	15	0	23	0.9994
R3–CR325	12	0	0	0	14	9	0	15	
R4–CR307	13	0	0	0	12	10	0	15	0.9949
R5–CR275	12	0	0	0	12	10	0	16	
R6–CR233	0	10	11	12	0	0	16	0	0.9904
R7–CR161	0	11	11	11	0	0	17	0	
Chi-square = 490.2628				DF = 42					<0.0001

x. Replicate 24

Release	Amanda	Kate	Kathleen	Kyle	MaryBeth	Rhonda	Shon	Tyrell	*P*-value
R1–CR390	40	0	0	0	45	27	0	52	
R2–CR346	16	0	0	0	22	14	0	23	0.9923
R3–CR325	12	0	0	0	12	9	0	17	
R4–CR307	12	0	0	0	13	8	0	17	0.9590
R5–CR275	11	0	0	0	12	10	0	17	
R6–CR233	0	12	13	11	0	0	14	0	0.9836
R7–CR161	0	11	12	12	0	0	15	0	
Chi-square = 491.5424				DF = 42					<0.0001

Table E.2. (contd)

y. Replicate 25

Release	Kate	Kathleen	Kyle	Shon
R1–CR390	39	47	36	40
R2–CR346	16	16	16	26
R3–CR325	10	13	11	16
R4–CR307	12	11	10	17
R5–CR275	10	12	11	17
R6–CR233	12	12	11	15
R7–CR161	11	11	11	12
Chi-square = 5.3708		DF = 18		*P*-value = 0.9982

z. Replicate 26

Release	Kate	Kathleen	Kyle	Shon
R1–CR390	36	38	37	53
R2–CR346	16	20	16	24
R3–CR325	11	13	11	15
R4–CR307	10	13	11	16
R5–CR275	11	13	11	15
R6–CR233	11	11	11	16
R7–CR161	10	10	8	12
Chi-square = 1.0206		DF = 18		*P*-value = 1

aa. Replicate 27

Release	Amanda	Kate	Kathleen	Kyle	MaryBeth	Rhonda	Shon	Tyrell	*P*-value
R1–CR390	0	35	40	35	0	0	54	0	
R2–CR346	0	18	17	17	0	0	23	0	0.9981
R3–CR325	0	12	12	11	0	0	15	0	
R4–CR307	0	10	10	11	0	0	14	0	0.9924
R5–CR275	0	10	11	10	0	0	14	0	
R6–CR233	12	0	0	0	13	11	0	14	0.9939
R7–CR161	12	0	0	0	13	10	0	15	
Chi-square = 480.2391				DF = 42					<0.0001

bb. Replicate 28

Release	Amanda	Kate	Kathleen	Kyle	MaryBeth	Rhonda	Shon	Tyrell	*P*-value
R1–CR390	0	38	41	39	0	0	46	0	
R2–CR346	0	16	18	18	0	0	24	0	0.9984
R3–CR325	0	10	11	10	0	0	14	0	
R4–CR307	0	11	11	9	0	0	14	0	0.9284
R5–CR275	0	9	13	10	0	0	13	0	
R6–CR233	12	0	0	0	12	9	0	16	0.8987
R7–CR161	10	0	0	0	15	10	0	15	
Chi-square = 478.3536				DF = 42					<0.0001

Table E.2. (contd)

cc. Replicate 29

Release	Amanda	MaryBeth	Rhonda	Tyrell
R1–CR390	37	43	34	50
R2–CR346	18	18	16	24
R3–CR325	13	14	8	15
R4–CR307	12	13	9	16
R5–CR275	12	12	10	15
R6–CR233	11	12	10	16
R7–CR161	12	12	10	16
Chi-square = 1.2964		DF = 18		*P*-value = 1

dd. Replicate 30

Release	Amanda	MaryBeth	Rhonda	Tyrell
R1–CR390	21	21	16	24
R2–CR346	17	21	16	22
R3–CR325	12	13	10	15
R4–CR307	12	12	10	16
R5–CR275	11	14	10	15
R6–CR233	12	12	10	16
R7–CR161	12	13	9	16
Chi-square = 0.9309		DF = 18		*P*-value = 1

ee. Replicate 31

Release	Amanda	Kate	Kathleen	Kyle	MaryBeth	Rhonda	Shon	Tyrell	*P*-value
R1–CR390	33	0	0	0	35	26	0	44	
R2–CR346	14	0	0	0	16	11	0	19	1.0000
R3–CR325	12	0	0	0	12	10	0	16	
R4–CR307	12	0	0	0	13	11	0	19	0.9684
R5–CR275	12	0	0	0	15	11	0	17	
R6–CR233	0	13	13	13	0	0	16	0	0.9986
R7–CR161	0	14	15	14	0	0	17	0	
Chi-square = 473.8784			DF = 42						<0.0001

ff. Replicate 32

Release	Amanda	Kate	Kathleen	Kyle	MaryBeth	Rhonda	Shon	Tyrell	*P*-value
R1–CR390	33	0	0	0	39	28	0	40	
R2–CR346	15	0	0	0	17	13	0	20	0.9976
R3–CR325	13	0	0	0	13	11	0	18	
R4–CR307	12	0	0	0	14	11	0	18	0.9925
R5–CR275	13	0	0	0	14	13	0	20	
R6–CR233	0	12	12	11	0	0	15	0	0.9958
R7–CR161	0	15	14	14	0	0	17	0	
Chi-square = 486.7447			DF = 42						<0.0001

Table E.3. Estimates of reach survival and cumulative survival for a) CH1 and b) STH, along with *P*-values associated with the *F*-tests of homogeneous survival across fish tagged by different staff members.

a. CH1

1) Release 1 – Reach survival

	Release to CR349		CR349 to CR325		CR325 to CR309		CR309 to CR275		CR275 to CR234		CR234 to CR161		CR161 to CR113	
	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$
Amanda	0.9823	0.0079	0.9636	0.0113	0.9968	0.0039	0.9579	0.0125	0.9958	0.0042	0.9908	0.0132	0.9345	0.0297
Kate	0.9795	0.0083	0.9613	0.0115	0.9965	0.0037	0.9561	0.0125	0.9958	0.0042	0.9874	0.0123	0.9435	0.0255
Kathleen	0.9731	0.0088	0.9601	0.0109	0.9935	0.0046	0.9493	0.0126	0.9888	0.0064	0.9399	0.0162	0.9447	0.0278
Kyle	0.9824	0.0078	0.9501	0.0131	0.9731	0.0101	0.9688	0.0109	1.0000	0.0000	0.9502	0.0154	0.9874	0.0248
MaryBeth	0.9643	0.0117	0.9628	0.0122	1.0011	0.0006	0.9650	0.0123	0.9951	0.0049	0.9379	0.0194	0.9355	0.0343
Rhonda	0.9815	0.0092	0.9573	0.0140	0.9955	0.0051	0.9604	0.0141	0.9886	0.0080	0.9497	0.0209	0.9252	0.0373
Shon	0.9799	0.0066	0.9703	0.0081	0.9881	0.0053	0.9811	0.0067	0.9949	0.0036	0.9441	0.0127	0.9993	0.0187
Tyrell	0.9802	0.0069	0.9622	0.0096	0.9951	0.0038	0.9602	0.0101	0.9970	0.0030	0.9455	0.0139	0.9529	0.0228
P-value	*0.8084*		*0.9719*		*0.0087*		*0.6973*		*0.7485*		*0.0858*		*0.5196*	

2) Release 1 – Cumulative survival

	Release to CR349		Release to CR325		Release to CR309		Release to CR275		Release to CR234		Release to CR161		Release to CR113	
	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$
Amanda	0.9823	0.0079	0.9465	0.0135	0.9435	0.0139	0.9038	0.0176	0.9000	0.0179	0.8917	0.0213	0.8332	0.0301
Kate	0.9795	0.0083	0.9416	0.0138	0.9382	0.0141	0.8970	0.0179	0.8932	0.0181	0.8820	0.0210	0.8321	0.0275
Kathleen	0.9731	0.0088	0.9343	0.0136	0.9282	0.0141	0.8812	0.0178	0.8713	0.0183	0.8190	0.0223	0.7737	0.0296
Kyle	0.9824	0.0078	0.9334	0.0149	0.9083	0.0172	0.8799	0.0193	0.8799	0.0193	0.8361	0.0228	0.8255	0.0296
MaryBeth	0.9643	0.0117	0.9284	0.0163	0.9294	0.0163	0.8969	0.0192	0.8926	0.0195	0.8371	0.0252	0.7831	0.0351
Rhonda	0.9815	0.0092	0.9395	0.0163	0.9353	0.0169	0.8983	0.0208	0.8880	0.0215	0.8433	0.0276	0.7802	0.0374
Shon	0.9799	0.0066	0.9508	0.0102	0.9395	0.0113	0.9218	0.0127	0.9171	0.0131	0.8658	0.0170	0.8652	0.0223
Tyrell	0.9802	0.0069	0.9431	0.0115	0.9385	0.0120	0.9012	0.0149	0.8985	0.0150	0.8496	0.0189	0.8096	0.0251
P-value	*0.8084*		*0.9613*		*0.7767*		*0.7912*		*0.7700*		*0.2749*		*0.3320*	

Table E.3. (contd)

3) Release 2 – Reach survival

	Release to CR325		CR325 to CR309		CR309 to CR275		CR275 to CR234		CR234 to CR161		CR161 to CR113	
	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$
Amanda	1.0005	0.0004	0.9853	0.0106	0.9474	0.0194	1.0000	0.0000	0.9568	0.0211	0.9785	0.0364
Kate	1.0000	0.0000	1.0000	0.0000	0.9616	0.0173	0.9908	0.0091	0.9540	0.0243	0.9583	0.0450
Kathleen	1.0001	0.0001	0.9931	0.0069	0.9046	0.0244	0.9919	0.0080	0.9154	0.0274	0.9372	0.0382
Kyle	0.9932	0.0075	0.9690	0.0153	0.9459	0.0201	0.9911	0.0089	0.9676	0.0191	1.0046	0.0362
MaryBeth	0.9879	0.0095	0.9783	0.0124	0.9731	0.0137	0.9919	0.0080	0.9643	0.0219	0.9551	0.0370
Rhonda	0.9827	0.0124	0.9908	0.0094	0.9725	0.0157	1.0000	0.0000	0.9351	0.0285	0.9268	0.0414
Shon	0.9746	0.0112	1.0002	0.0002	0.9690	0.0126	0.9942	0.0058	0.9585	0.0174	0.9448	0.0325
Tyrell	0.9898	0.0074	0.9895	0.0076	0.9523	0.0158	0.9937	0.0063	0.9546	0.0219	0.9101	0.0350
P-value	*0.2701*		*0.3361*		*0.1281*		*0.9480*		*0.7861*		*0.7442*	

4) Release 2 – Cumulative survival

	Release to CR325		Release to CR309		Release to CR275		Release to CR234		Release to CR161		Release to CR113	
	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$
Amanda	1.0005	0.0004	0.9857	0.0103	0.9338	0.0213	0.9338	0.0213	0.8935	0.0284	0.8743	0.0403
Kate	1.0000	0.0000	1.0000	0.0000	0.9616	0.0173	0.9528	0.0188	0.9089	0.0293	0.8710	0.0457
Kathleen	1.0001	0.0001	0.9932	0.0068	0.8984	0.0250	0.8912	0.0257	0.8158	0.0339	0.7646	0.0420
Kyle	0.9932	0.0075	0.9624	0.0165	0.9104	0.0249	0.9023	0.0258	0.8730	0.0303	0.8770	0.0419
MaryBeth	0.9879	0.0095	0.9664	0.0148	0.9405	0.0196	0.9329	0.0205	0.8996	0.0284	0.8592	0.0384
Rhonda	0.9827	0.0124	0.9737	0.0151	0.9469	0.0211	0.9469	0.0211	0.8854	0.0334	0.8206	0.0439
Shon	0.9746	0.0112	0.9748	0.0112	0.9445	0.0164	0.9391	0.0170	0.9001	0.0231	0.8504	0.0345
Tyrell	0.9898	0.0074	0.9793	0.0104	0.9326	0.0182	0.9267	0.0189	0.8846	0.0271	0.8050	0.0352
P-value	*0.2701*		*0.3867*		*0.4513*		*0.4331*		*0.4395*		*0.4395*	

Table E.3. (contd)

5) Release 3 – Reach survival

	Release to CR309		CR309 to CR275		CR275 to CR234		CR234 to CR161		CR161 to CR113	
	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$
Amanda	0.9803	0.0143	0.9375	0.0250	0.9882	0.0117	0.9612	0.0261	0.9579	0.0593
Kate	0.9886	0.0113	0.9791	0.0162	0.9744	0.0179	0.9209	0.0308	1.0148	0.0412
Kathleen	1.0000	0.0000	0.9592	0.0202	0.9888	0.0112	0.9506	0.0240	1.0080	0.0294
Kyle	1.0000	0.0000	0.9413	0.0259	0.9865	0.0134	0.8863	0.0363	1.0341	0.0272
MaryBeth	0.9899	0.0101	0.9796	0.0143	1.0000	0.0000	0.9901	0.0156	0.9946	0.0488
Rhonda	0.9738	0.0192	0.9565	0.0246	1.0000	0.0000	0.9418	0.0333	1.0445	0.0708
Shon	0.9763	0.0137	0.9597	0.0181	0.9904	0.0096	0.9298	0.0273	0.9241	0.0363
Tyrell	0.9798	0.0128	0.9147	0.0246	1.0000	0.0000	0.9734	0.0219	0.9332	0.0431
P-value	*0.7449*		*0.4098*		*0.7639*		*0.2063*		*0.4650*	

6) Release 3 – Cumulative survival

	Release to CR309		Release to CR275		Release to CR234		Release to CR161		Release to CR113	
	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$
Amanda	0.9803	0.0143	0.9190	0.0277	0.9082	0.0292	0.8729	0.0367	0.8362	0.0593
Kate	0.9886	0.0113	0.9680	0.0195	0.9432	0.0247	0.8685	0.0369	0.8814	0.0505
Kathleen	1.0000	0.0000	0.9592	0.0202	0.9485	0.0225	0.9016	0.0312	0.9087	0.0397
Kyle	1.0000	0.0000	0.9413	0.0259	0.9286	0.0281	0.8230	0.0419	0.8511	0.0483
MaryBeth	0.9899	0.0101	0.9697	0.0172	0.9697	0.0172	0.9601	0.0228	0.9549	0.0494
Rhonda	0.9738	0.0192	0.9315	0.0296	0.9315	0.0296	0.8773	0.0417	0.9163	0.0720
Shon	0.9763	0.0137	0.9370	0.0219	0.9280	0.0231	0.8628	0.0332	0.7973	0.0406
Tyrell	0.9798	0.0128	0.8963	0.0262	0.8963	0.0262	0.8725	0.0322	0.8142	0.0441
P-value	*0.7449*		*0.3474*		*0.5715*		*0.2765*		*0.3432*	

Table E.3. (contd)

7) Release 4 – Reach survival

	Release to CR275		CR275 to CR234		CR234 to CR161		CR161 to CR113	
	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$
Amanda	1.0015	0.0016	0.9880	0.0120	0.9347	0.0336	0.8793	0.0537
Kate	0.9765	0.0164	1.0000	0.0000	0.9878	0.0181	0.9584	0.0470
Kathleen	1.0016	0.0013	0.9780	0.0154	0.9818	0.0193	0.9711	0.0369
Kyle	0.9881	0.0118	1.0000	0.0000	0.9252	0.0312	0.9399	0.0418
MaryBeth	1.0011	0.0011	0.9891	0.0108	0.9273	0.0324	0.8360	0.0514
Rhonda	0.9870	0.0129	1.0000	0.0000	0.9554	0.0263	1.0181	0.0456
Shon	0.9924	0.0081	0.9912	0.0087	0.9448	0.0233	0.9949	0.0436
Tyrell	0.9711	0.0146	0.9917	0.0083	0.9704	0.0197	0.9724	0.0419
P-value	*0.2677*		*0.7656*		*0.5274*		*0.0888*	

8) Release 4 – Cumulative survival

	Release to CR275		Release to CR234		Release to CR161		Release to CR113	
	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$
Amanda	1.0015	0.0016	0.9895	0.0105	0.9249	0.0347	0.8133	0.0517
Kate	0.9765	0.0164	0.9765	0.0164	0.9645	0.0240	0.9244	0.0476
Kathleen	1.0016	0.0013	0.9796	0.0143	0.9617	0.0235	0.9340	0.0381
Kyle	0.9881	0.0118	0.9881	0.0118	0.9142	0.0328	0.8593	0.0465
MaryBeth	1.0011	0.0011	0.9902	0.0098	0.9182	0.0333	0.7676	0.0498
Rhonda	0.9870	0.0129	0.9870	0.0129	0.9430	0.0287	0.9600	0.0494
Shon	0.9924	0.0081	0.9837	0.0114	0.9294	0.0254	0.9247	0.0454
Tyrell	0.9711	0.0146	0.9630	0.0163	0.9344	0.0247	0.9086	0.0426
P-value	*0.2677*		*0.8464*		*0.8839*		*0.0441*	

Table E.3. (contd)

9) Release 5 – Reach survival

	Release to CR234		CR234 to CR161		CR161 to CR113	
	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$
Amanda	0.9895	0.0105	0.9439	0.0356	0.8632	0.0641
Kate	0.9881	0.0118	0.9482	0.0268	0.9876	0.0405
Kathleen	0.9892	0.0107	0.9293	0.0283	1.0372	0.0474
Kyle	0.9884	0.0116	0.9513	0.0263	0.9501	0.0414
MaryBeth	0.9808	0.0135	0.9799	0.0211	0.9605	0.0530
Rhonda	0.9737	0.0184	0.9749	0.0246	0.9679	0.0542
Shon	0.9836	0.0115	0.9358	0.0250	0.9707	0.0456
Tyrell	0.9712	0.0142	0.9235	0.0307	0.9268	0.0492
P-value	*0.9496*		*0.8070*		*0.4299*	

10) Release 5 – Cumulative survival

	Release to CR234		Release to CR161		Release to CR113	
	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$
Amanda	0.9895	0.0105	0.9340	0.0366	0.8062	0.0597
Kate	0.9881	0.0118	0.9369	0.0287	0.9253	0.0448
Kathleen	0.9892	0.0107	0.9193	0.0297	0.9535	0.0518
Kyle	0.9884	0.0116	0.9403	0.0283	0.8933	0.0444
MaryBeth	0.9808	0.0135	0.9610	0.0246	0.9231	0.0520
Rhonda	0.9737	0.0184	0.9493	0.0299	0.9188	0.0547
Shon	0.9836	0.0115	0.9205	0.0269	0.8935	0.0471
Tyrell	0.9712	0.0142	0.8969	0.0326	0.8313	0.0468
P-value	*0.9496*		*0.8755*		*0.4359*	

Table E.3. (contd)

11) Release 6 – Reach survival

	Release to CR161		CR161 to CR113	
	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$
Amanda	0.9735	0.0224	0.9394	0.0400
Kate	1.0350	0.0142	0.9185	0.0467
Kathleen	0.9569	0.0232	0.9860	0.0300
Kyle	0.9648	0.0237	0.9481	0.0440
MaryBeth	0.9798	0.0177	0.9094	0.0373
Rhonda	0.9528	0.0264	1.0702	0.0530
Shon	0.9919	0.0152	0.9680	0.0400
Tyrell	1.0044	0.0132	0.9561	0.0404
P-value	*0.0697*		*0.1837*	

12) Release 6 – Cumulative survival

	Release to CR161		Release to CR113	
	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$
Amanda	0.9735	0.0224	0.9145	0.0395
Kate	1.0350	0.0142	0.9507	0.0385
Kathleen	0.9569	0.0232	0.9436	0.0336
Kyle	0.9648	0.0237	0.9147	0.0448
MaryBeth	0.9798	0.0177	0.8911	0.0374
Rhonda	0.9528	0.0264	1.0196	0.0559
Shon	0.9919	0.0152	0.9601	0.0385
Tyrell	1.0044	0.0132	0.9603	0.0378
P-value	*0.0697*		*0.4992*	

Table E.3. (contd)

13) Release 7 – Reach survival

	Release to CR113	
	$\hat{S}$	$\widehat{\mathrm{SE}}$
Amanda	0.9238	0.0481
Kate	0.9590	0.0466
Kathleen	0.9316	0.0382
Kyle	0.9757	0.0473
MaryBeth	0.9770	0.0328
Rhonda	0.9454	0.0397
Shon	0.9465	0.0321
Tyrell	0.9221	0.0366
P-value	*0.9611*	

b. STH

14) Release 1 – Reach survival

	Release to CR349		CR349 to CR325		CR325 to CR309		CR309 to CR275		CR275 to CR234		CR234 to CR161		CR161 to CR113	
	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$
Amanda	0.9601	0.0113	0.9860	0.0070	0.9934	0.0051	0.9768	0.0098	0.9826	0.0086	0.9573	0.0150	0.8991	0.0293
Kate	0.9508	0.0128	0.9814	0.0083	0.9962	0.0039	0.9849	0.0086	0.9651	0.0121	0.9382	0.0159	1.0187	0.0308
Kathleen	0.9369	0.0133	0.9873	0.0064	0.9901	0.0057	0.9683	0.0102	0.9887	0.0065	0.9645	0.0129	1.0048	0.0323
Kyle	0.9686	0.0104	0.9601	0.0118	0.9886	0.0065	0.9781	0.0093	0.9872	0.0073	0.9612	0.0140	0.9568	0.0304
MaryBeth	0.9783	0.0088	0.9634	0.0115	0.9882	0.0069	0.9829	0.0088	0.9817	0.0091	0.9491	0.0178	0.9302	0.0380
Rhonda	0.9584	0.0129	0.9739	0.0106	0.9955	0.0046	0.9972	0.0047	0.9892	0.0076	0.9270	0.0190	0.9763	0.0341
Shon	0.9515	0.0101	0.9696	0.0083	0.9952	0.0034	0.9819	0.0068	0.9840	0.0065	0.9368	0.0129	1.0022	0.0231
Tyrell	0.9736	0.0079	0.9778	0.0073	0.9954	0.0036	0.9688	0.0092	0.9818	0.0074	0.9495	0.0131	0.9490	0.0285
P-value	*0.1645*		*0.2884*		*0.8869*		*0.3137*		*0.5454*		*0.6392*		*0.0930*	

Table E.3. (contd)

15) Release 1 – Cumulative survival

	Release to CR349		Release to CR325		Release to CR309		Release to CR275		Release to CR234		Release to CR161		Release to CR113	
	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$
Amanda	0.9601	0.0113	0.9467	0.0130	0.9405	0.0138	0.9186	0.0161	0.9027	0.0172	0.8641	0.0213	0.7769	0.0302
Kate	0.9508	0.0128	0.9331	0.0148	0.9296	0.0152	0.9155	0.0170	0.8836	0.0191	0.8289	0.0227	0.8444	0.0341
Kathleen	0.9369	0.0133	0.9251	0.0144	0.9159	0.0152	0.8869	0.0175	0.8769	0.0180	0.8458	0.0207	0.8499	0.0333
Kyle	0.9686	0.0104	0.9299	0.0151	0.9193	0.0161	0.8992	0.0179	0.8877	0.0187	0.8533	0.0218	0.8164	0.0323
MaryBeth	0.9783	0.0088	0.9424	0.0141	0.9313	0.0152	0.9153	0.0170	0.8986	0.0182	0.8528	0.0235	0.7933	0.0369
Rhonda	0.9584	0.0129	0.9334	0.0161	0.9292	0.0166	0.9266	0.0171	0.9167	0.0178	0.8497	0.0240	0.8296	0.0362
Shon	0.9515	0.0101	0.9225	0.0126	0.9181	0.0129	0.9015	0.0141	0.8870	0.0149	0.8310	0.0181	0.8328	0.0259
Tyrell	0.9736	0.0079	0.9519	0.0105	0.9476	0.0110	0.9180	0.0137	0.9013	0.0146	0.8557	0.0183	0.8121	0.0289
P-value	*0.1645*		*0.7891*		*0.7715*		*0.7262*		*0.8003*		*0.9448*		*0.7588*	

16) Release 2 – Reach survival

	Release to CR325		CR325 to CR309		CR309 to CR275		CR275 to CR234		CR234 to CR161		CR161 to CR113	
	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$
Amanda	1.0003	0.0003	0.9930	0.0072	0.9726	0.0140	0.9918	0.0082	0.9640	0.0180	0.9567	0.0359
Kate	1.0003	0.0003	0.9840	0.0112	0.9780	0.0138	0.9735	0.0151	0.9147	0.0270	0.9356	0.0464
Kathleen	0.9940	0.0064	0.9671	0.0145	0.9814	0.0116	0.9847	0.0107	0.9642	0.0170	1.0251	0.0483
Kyle	0.9927	0.0077	0.9841	0.0111	0.9868	0.0112	0.9735	0.0151	0.9184	0.0283	0.8859	0.0446
MaryBeth	1.0001	0.0001	0.9860	0.0098	0.9718	0.0139	1.0000	0.0000	0.9377	0.0227	0.9253	0.0386
Rhonda	0.9916	0.0087	0.9908	0.0091	0.9732	0.0153	1.0000	0.0000	0.9456	0.0245	0.9540	0.0556
Shon	0.9897	0.0074	0.9892	0.0076	0.9951	0.0054	0.9942	0.0058	0.9082	0.0220	0.9816	0.0336
Tyrell	0.9952	0.0052	0.9839	0.0092	0.9532	0.0156	0.9933	0.0066	0.9433	0.0206	0.9399	0.0453
P-value	*0.7902*		*0.7547*		*0.4981*		*0.4474*		*0.5105*		*0.5348*	

Table E.3. (contd)

17) Release 2 – Cumulative survival

	Release to CR325		Release to CR309		Release to CR275		Release to CR234		Release to CR161		Release to CR113	
	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$
Amanda	1.0003	0.0003	0.9932	0.0070	0.9660	0.0154	0.9580	0.0168	0.9236	0.0236	0.8836	0.0386
Kate	1.0003	0.0003	0.9843	0.0110	0.9626	0.0173	0.9370	0.0216	0.8571	0.0321	0.8019	0.0487
Kathleen	0.9940	0.0064	0.9613	0.0155	0.9434	0.0188	0.9290	0.0206	0.8957	0.0254	0.9182	0.0496
Kyle	0.9927	0.0077	0.9769	0.0132	0.9641	0.0170	0.9385	0.0211	0.8619	0.0329	0.7635	0.0455
MaryBeth	1.0001	0.0001	0.9861	0.0098	0.9583	0.0167	0.9583	0.0167	0.8986	0.0268	0.8315	0.0409
Rhonda	0.9916	0.0087	0.9825	0.0123	0.9561	0.0192	0.9561	0.0192	0.9041	0.0296	0.8625	0.0559
Shon	0.9897	0.0074	0.9791	0.0104	0.9743	0.0116	0.9686	0.0126	0.8797	0.0242	0.8634	0.0371
Tyrell	0.9952	0.0052	0.9792	0.0103	0.9333	0.0182	0.9271	0.0188	0.8745	0.0260	0.8220	0.0445
P-value	*0.7902*		*0.7126*		*0.7533*		*0.6753*		*0.7042*		*0.3265*	

18) Release 3 – Reach survival

	Release to CR309		CR309 to CR275		CR275 to CR234		CR234 to CR161		CR161 to CR113	
	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$
Amanda	0.9895	0.0105	0.9727	0.0186	0.9733	0.0186	0.9683	0.0232	1.0272	0.0569
Kate	1.0000	0.0000	0.9431	0.0256	0.9730	0.0189	0.9396	0.0280	1.0006	0.0656
Kathleen	1.0000	0.0000	0.9943	0.0104	0.9655	0.0196	0.9375	0.0273	1.0068	0.0559
Kyle	0.9891	0.0108	0.9231	0.0279	1.0000	0.0000	0.9773	0.0215	0.9583	0.0563
MaryBeth	1.0003	0.0004	0.9728	0.0181	0.9747	0.0177	0.8820	0.0361	1.0958	0.0930
Rhonda	0.9733	0.0186	0.9589	0.0232	1.0000	0.0000	0.9720	0.0258	0.9622	0.0677
Shon	0.9919	0.0081	0.9773	0.0141	0.9813	0.0131	0.9592	0.0211	0.9937	0.0471
Tyrell	0.9846	0.0108	0.9720	0.0156	0.9806	0.0136	0.9542	0.0219	0.9348	0.0474
P-value	*0.6295*		*0.2810*		*0.7382*		*0.2099*		*0.7317*	

Table E.3. (contd)

19) Release 3 – Cumulative survival

	Release to CR309		Release to CR275		Release to CR234		Release to CR161		Release to CR113	
	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$
Amanda	0.9895	0.0105	0.9625	0.0210	0.9368	0.0250	0.9072	0.0325	0.9319	0.0585
Kate	1.0000	0.0000	0.9431	0.0256	0.9176	0.0298	0.8622	0.0380	0.8627	0.0675
Kathleen	1.0000	0.0000	0.9943	0.0104	0.9600	0.0196	0.9000	0.0320	0.9062	0.0576
Kyle	0.9891	0.0108	0.9130	0.0294	0.9130	0.0294	0.8923	0.0348	0.8551	0.0577
MaryBeth	1.0003	0.0004	0.9731	0.0179	0.9485	0.0225	0.8365	0.0396	0.9167	0.0870
Rhonda	0.9733	0.0186	0.9333	0.0288	0.9333	0.0288	0.9072	0.0369	0.8729	0.0677
Shon	0.9919	0.0081	0.9693	0.0161	0.9512	0.0194	0.9124	0.0274	0.9067	0.0489
Tyrell	0.9846	0.0108	0.9570	0.0186	0.9385	0.0211	0.8954	0.0288	0.8370	0.0484
P-value	*0.6295*		*0.2229*		*0.8869*		*0.7561*		*0.9586*	

20) Release 4 – Reach survival

	Release to CR275		CR275 to CR234		CR234 to CR161		CR161 to CR113	
	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$
Amanda	0.9800	0.0140	1.0000	0.0000	0.9111	0.0317	0.8392	0.0507
Kate	0.9915	0.0111	0.9753	0.0172	0.8974	0.0347	0.9228	0.0503
Kathleen	1.0016	0.0013	0.9783	0.0152	0.9455	0.0250	0.9886	0.0495
Kyle	0.9903	0.0121	0.9857	0.0142	0.9226	0.0315	0.9437	0.0558
MaryBeth	0.9917	0.0104	0.9878	0.0121	0.9592	0.0236	0.9492	0.0574
Rhonda	1.0033	0.0034	0.9831	0.0168	0.9613	0.0288	0.9322	0.0600
Shon	0.9694	0.0157	0.9825	0.0123	0.9466	0.0237	0.9462	0.0459
Tyrell	0.9678	0.0175	0.9612	0.0190	0.9630	0.0209	0.9974	0.0569
P-value	*0.2631*		*0.7965*		*0.5862*		*0.5751*	

Table E.3. (contd)

21) Release 4 – Cumulative survival

	Release to CR275		Release to CR234		Release to CR161		Release to CR113	
	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$
Amanda	0.9800	0.0140	0.9800	0.0140	0.8929	0.0336	0.7493	0.0510
Kate	0.9915	0.0111	0.9670	0.0187	0.8678	0.0375	0.8008	0.0534
Kathleen	1.0016	0.0013	0.9798	0.0141	0.9264	0.0279	0.9158	0.0518
Kyle	0.9903	0.0121	0.9762	0.0166	0.9007	0.0344	0.8500	0.0580
MaryBeth	0.9917	0.0104	0.9796	0.0143	0.9396	0.0269	0.8919	0.0574
Rhonda	1.0033	0.0034	0.9863	0.0136	0.9481	0.0313	0.8838	0.0597
Shon	0.9694	0.0157	0.9524	0.0190	0.9015	0.0289	0.8530	0.0472
Tyrell	0.9678	0.0175	0.9302	0.0224	0.8958	0.0290	0.8935	0.0565
P-value	*0.2631*		*0.2717*		*0.6473*		*0.4050*	

22) Release 5 – Reach survival

	Release to CR234		CR234 to CR161		CR161 to CR113	
	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$
Amanda	0.9895	0.0105	0.9602	0.0243	0.9177	0.0466
Kate	0.9659	0.0193	0.9664	0.0243	0.9081	0.0536
Kathleen	0.9804	0.0137	0.8727	0.0358	0.8720	0.0495
Kyle	1.0000	0.0000	0.9673	0.0228	0.9061	0.0480
MaryBeth	0.9897	0.0103	0.9436	0.0251	0.9521	0.0499
Rhonda	0.9868	0.0131	0.8860	0.0380	0.9851	0.0484
Shon	0.9917	0.0083	0.9342	0.0249	0.9445	0.0533
Tyrell	0.9773	0.0130	0.9559	0.0206	1.0495	0.0510
P-value	*0.6971*		*0.0880*		*0.2866*	

Table E.3. (contd)

23) Release 5 – Cumulative survival

	Release to CR234		Release to CR161		Release to CR113	
	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$
Amanda	0.9895	0.0105	0.9501	0.0261	0.8719	0.0472
Kate	0.9659	0.0193	0.9334	0.0300	0.8477	0.0541
Kathleen	0.9804	0.0137	0.8556	0.0371	0.7461	0.0509
Kyle	1.0000	0.0000	0.9673	0.0228	0.8765	0.0481
MaryBeth	0.9897	0.0103	0.9339	0.0267	0.8892	0.0517
Rhonda	0.9868	0.0131	0.8743	0.0392	0.8612	0.0557
Shon	0.9917	0.0083	0.9264	0.0259	0.8750	0.0534
Tyrell	0.9773	0.0130	0.9342	0.0237	0.9804	0.0518
P-value	*0.6971*		*0.1194*		*0.1531*	

24) Release 6 – Reach survival

	Release to CR161		CR161 to CR113	
	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$
Amanda	0.9728	0.0222	0.7971	0.0469
Kate	1.0103	0.0053	0.9490	0.0501
Kathleen	0.9562	0.0242	0.9724	0.0563
Kyle	0.9438	0.0261	1.0223	0.0562
MaryBeth	0.9529	0.0264	0.9205	0.0541
Rhonda	0.9518	0.0308	0.9206	0.0700
Shon	0.9458	0.0235	1.0321	0.0462
Tyrell	0.9668	0.0193	0.9900	0.0343
P-value	*0.5359*		*0.0487*	

Table E.3. (contd)

25) Release 6 – Cumulative survival

	Release to CR161		Release to CR113	
	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$
Amanda	0.9728	0.0222	0.7754	0.0460
Kate	1.0103	0.0053	0.9588	0.0482
Kathleen	0.9562	0.0242	0.9298	0.0565
Kyle	0.9438	0.0261	0.9649	0.0574
MaryBeth	0.9529	0.0264	0.8772	0.0536
Rhonda	0.9518	0.0308	0.8762	0.0683
Shon	0.9458	0.0235	0.9762	0.0472
Tyrell	0.9668	0.0193	0.9571	0.0348
P-value	*0.5359*		*0.1042*	

26) Release 7 – Reach survival

	Release to CR113	
	$\hat{S}$	$\widehat{\mathrm{SE}}$
Amanda	0.8905	0.0440
Kate	0.9473	0.0501
Kathleen	0.9415	0.0479
Kyle	0.9668	0.0443
MaryBeth	0.9002	0.0464
Rhonda	0.9230	0.0578
Shon	0.9080	0.0468
Tyrell	0.8905	0.0440
P-value	*0.9540*	

E.2 Examination of Tag-Lot Effects

Three different tag lots were used in the tagging of the CH1 and STH. Overall, the tag lots were not evenly distributed among the seven release locations (Table E.4). However, closer examination found the below-dam release pairs (i.e., R_2–R_3, R_4–R_5, and R_6–R_7) to be homogeneous with regard to tag-lot allocation ($P \geq 0.9415$). This pairwise homogeneity is particularly important in the virtual/paired-release design where the downstream pair is used to estimate the extra-reach mortality needed to adjust the survival estimate from the virtual forebay release.

Tests of homogeneous reach survivals across tag lots by release locations were performed (Table E.5). These tests looked for any tag-lot effects not accounted for by the tag-lot-specific tag-life corrections. Of the 56 tests of homogeneous reach survivals across tag lots, 11 were significant at $P \leq 0.10$ (i.e., 19%). However, there was no particular pattern to the lot-specific reach survivals. Tag lot 1 had the lowest survival in 3 of the 11 significant tests, lot 2 had the lower survival in 3 tests, and lots 3–5 had the lowest survival in 5 tests.

In the 54 tests of homogeneous cumulative survival, 9 were significant at $P \leq 0.10$ (i.e., 16.7%). However, the tests of cumulative survival are not independent within an analysis of a release group. For example, seven of the nine significant results all occurred within the R_1 release of STH. Also in that case, tag lot 1 had the lowest survivals in two of the seven instances, while tag lot 2 had the lowest survival in five instances.

We conclude that tag lots corrected for tag life have no significant effect on observed survivals. Therefore, fish tagged from all tag lots should be used in the analyses.

Table E.4. Numbers of tags used per tag lot at each release location for a) CH1 and b) STH in the 2011 Juvenile Salmon Acoustic Telemetry System (JSATS) survival study. Chi-square tests of homogeneity performed for the overall table and pairwise comparisons of the below-dam release pairs.

a. CH1

	Tag lot			
Release Location	1	2	3, 4, 5	*P*-value
R1–CR390	706	501	1,303	
R2–CR346	226	302	665	0.9801
R3–CR325	150	200	449	
R4–CR307	150	149	500	0.9805
R5–CR275	150	146	503	
R6–CR233	100	150	548	0.9323
R7–CR161	96	146	552	
Chi-square = 211.77		DF = 12		<0.0001

b. STH

	Tag lot			
Release Location	1	2	3, 4, 5	*P*-value
R1–CR390	698	498	1,391	
R2–CR346	228	302	666	0.9415
R3–CR325	150	197	450	
R4–CR307	150	150	500	1.0000
R5–CR275	150	150	500	
R6–CR233	99	146	547	0.9681
R7–CR161	100	150	544	
Chi-square = 178.67		DF = 12		<0.0001

Table E.5. Estimates of reach survival and cumulative survival for a) CH1 and b) STH, along with *P*-values associated with the *F*-tests of homogeneous survival across tag lots.

a. CH1

1) Release 1 – Reach survival

	Release to CR349		CR349 to CR325		CR325 to CR309		CR309 to CR275		CR275 to CR234		CR234 to CR161		CR161 to CR113	
	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$
Lot 1	0.9802	0.0052	0.9578	0.0077	0.9924	0.0034	0.9664	0.0071	0.9937	0.0032	0.9587	0.0081	1.0025	0.0041
Lot 2	0.9801	0.0063	0.9528	0.0096	0.9914	0.0043	0.9501	0.0101	0.9954	0.0032	0.9570	0.0107	0.9839	0.0124
Lot 3, 4, 5	0.9762	0.0042	0.9672	0.0050	0.9922	0.0027	0.9665	0.0053	0.9951	0.0022	0.9719	0.0095	0.9512	0.0226
P-value	*0.8312*		*0.4029*		*0.9774*		*0.2268*		*0.9067*		*0.4775*		*0.0520*	

2) Release 1 – Cumulative survival

	Release to CR349		Release to CR325		Release to CR309		Release to CR275		Release to CR234		Release to CR161		Release to CR113	
	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$
Lot 1	0.9802	0.0052	0.9389	0.0090	0.9317	0.0095	0.9004	0.0113	0.8947	0.0116	0.8577	0.0133	0.8598	0.0138
Lot 2	0.9801	0.0063	0.9338	0.0111	0.9258	0.0117	0.8796	0.0146	0.8756	0.0148	0.8380	0.0170	0.8245	0.0191
Lot 3, 4, 5	0.9762	0.0042	0.9442	0.0064	0.9368	0.0068	0.9054	0.0081	0.9009	0.0083	0.8756	0.0117	0.8329	0.0205
P-value	*0.8312*		*0.7192*		*0.7177*		*0.2511*		*0.2898*		*0.1713*		*0.3508*	

3) Release 2 – Reach survival

			CR349 to CR325		CR325 to CR309		CR309 to CR275		CR275 to CR234		CR234 to CR161		CR161 to CR113	
			$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$
Lot 1			0.9912	0.0062	0.9869	0.0077	0.9409	0.0159	0.9952	0.0048	0.9662	0.0127	0.9762	0.0127
Lot 2			0.9868	0.0066	0.9799	0.0081	0.9623	0.0111	0.9893	0.0061	0.9498	0.0132	1.0133	0.0066
Lot 3, 4, 5			0.9913	0.0037	0.9939	0.0032	0.9531	0.0084	0.9961	0.0027	0.9688	0.0139	0.9316	0.0296
P-value			*0.8128*		*0.3376*		*0.4611*		*0.5483*		*0.5465*		*0.0096*	

Table E.5. (contd)

4) Release 2 – Cumulative survival

	Release to CR325		Release to CR309		Release to CR275		Release to CR234		Release to CR161		Release to CR113	
	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$
Lot 1	0.9912	0.0062	0.9782	0.0098	0.9204	0.0180	0.9159	0.0185	0.8849	0.0213	0.8639	0.0236
Lot 2	0.9868	0.0066	0.9669	0.0103	0.9305	0.0146	0.9205	0.0156	0.8743	0.0191	0.8860	0.0201
Lot 3, 4, 5	0.9913	0.0037	0.9852	0.0047	0.9390	0.0093	0.9353	0.0095	0.9061	0.0159	0.8441	0.0269
P-value	*0.8128*		*0.3195*		*0.6600*		*0.6329*		*0.4803*		*0.4571*	

5) Release 3 – Reach survival

	Release to CR309		CR309 to CR275		CR275 to CR234		CR234 to CR161		CR161 to CR113	
	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$
Lot 1	0.9800	0.0114	0.9728	0.0134	0.9790	0.0120	0.9787	0.0122	0.9948	0.0112
Lot 2	0.9950	0.0050	0.9448	0.0162	0.9946	0.0054	0.9380	0.0180	0.9852	0.0149
Lot 3, 4, 5	0.9831	0.0063	0.9478	0.0108	0.9943	0.0040	0.9511	0.0152	1.0146	0.0379
P-value	*0.3806*		*0.2811*		*0.2815*		*0.1597*		*0.6857*	

6) Release 3 – Cumulative survival

	Release to CR309		Release to CR275		Release to CR234		Release to CR161		Release to CR113	
	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$
Lot 1	0.9800	0.0114	0.9533	0.0172	0.9333	0.0204	0.9134	0.0230	0.9086	0.0250
Lot 2	0.9950	0.0050	0.9401	0.0168	0.9350	0.0174	0.8771	0.0235	0.8641	0.0261
Lot 3, 4, 5	0.9831	0.0063	0.9318	0.0120	0.9265	0.0123	0.8812	0.0183	0.8941	0.0354
P-value	*0.3806*		*0.6137*		*0.9326*		*0.4326*		*0.5469*	

Table E.5. (contd)

7) Release 4 – Reach survival

	Release to CR275		CR275 to CR234		CR234 to CR161		CR161 to CR113	
	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$
Lot 1	0.9867	0.0094	0.9932	0.0067	0.9663	0.0150	0.9913	0.0106
Lot 2	0.9799	0.0115	0.9795	0.0117	0.9648	0.0155	1.0147	0.0060
Lot 3, 4, 5	0.9926	0.0040	0.9954	0.0033	0.9655	0.0146	0.9260	0.0318
P-value	*0.5987*		*0.3169*		*0.9975*		*0.0043*	

8) Release 4 – Cumulative survival

	Release to CR275		Release to CR234		Release to CR161		Release to CR113	
	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$
Lot 1	0.9867	0.0094	0.9800	0.0114	0.9470	0.0184	0.9388	0.0207
Lot 2	0.9799	0.0115	0.9597	0.0161	0.9259	0.0215	0.9396	0.0225
Lot 3, 4, 5	0.9926	0.0040	0.9880	0.0049	0.9539	0.0152	0.8833	0.0296
P-value	*0.5987*		*0.2137*		*0.5377*		*0.1777*	

9) Release 5 – Reach survival

	Release to CR234		CR234 to CR161		CR161 to CR113	
	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$
Lot 1	0.9733	0.0132	0.9381	0.0200	0.9890	0.0165
Lot 2	1.0000	0.0000	0.9656	0.0153	0.9896	0.0136
Lot 3, 4, 5	0.9801	0.0062	0.9592	0.0154	0.9686	0.0362
P-value	*0.1775*		*0.4899*		*0.7849*	

Table E.5. (contd)

10) Release 5 – Cumulative survival

	Release to CR234		Release to CR161		Release to CR113	
	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$
Lot 1	0.9733	0.0132	0.9131	0.0231	0.9031	0.0273
Lot 2	1.0000	0.0000	0.9656	0.0153	0.9556	0.0199
Lot 3, 4, 5	0.9801	0.0062	0.9401	0.0162	0.9106	0.0335
P-value	*0.1775*		*0.1338*		*0.3440*	

11) Release 6 – Reach survival

	Release to CR161		CR161 to CR113	
	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$
Lot 1	0.9802	0.0140	0.9897	0.0155
Lot 2	0.9934	0.0066	1.0023	0.0079
Lot 3, 4, 5	0.9951	0.0104	0.9472	0.0243
P-value	*0.5635*		*0.0608*	

12) Release 6 – Cumulative survival

	Release to CR161		Release to CR113	
	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$
Lot 1	0.9802	0.0140	0.9701	0.0204
Lot 2	0.9934	0.0066	0.9956	0.0103
Lot 3, 4, 5	0.9951	0.0104	0.9425	0.0225
P-value	*0.5635*		*0.1277*	

Table E.5. (contd)

13) Release 7 – Reach survival

	Release to CR113	
	$\hat{S}$	$\widehat{\text{SE}}$
Lot 1	0.9874	0.0156
Lot 2	0.9790	0.0139
Lot 3, 4, 5	0.9552	0.0229
P-value	*0.4180*	

b. STH

14) Release 1 – Reach survival

	Release to CR349		CR349 to CR325		CR325 to CR309		CR309 to CR275		CR275 to CR234		CR234 to CR161		CR161 to CR113	
	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$
Lot 1	0.9571	0.0077	0.9623	0.0074	0.9907	0.0038	0.9637	0.0074	0.9771	0.0061	0.9691	0.0072	1.0002	0.0083
Lot 2	0.9318	0.0113	0.9761	0.0071	0.9957	0.0031	0.9756	0.0073	0.9725	0.0078	0.9427	0.0117	0.9965	0.0137
Lot 3, 4, 5	0.9705	0.0045	0.9809	0.0038	0.9932	0.0023	0.9858	0.0036	0.9902	0.0031	0.9492	0.0083	0.9969	0.0258
P-value	*0.0037*		*0.0960*		*0.5329*		*0.0489*		*0.0945*		*0.1095*		*0.9867*	

15) Release 1 – Cumulative survival

	Release to CR349		Release to CR325		Release to CR309		Release to CR275		Release to CR234		Release to CR161		Release to CR113	
	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$
Lot 1	0.9571	0.0077	0.9211	0.0102	0.9125	0.0107	0.8793	0.0123	0.8592	0.0132	0.8326	0.0142	0.8328	0.0158
Lot 2	0.9318	0.0113	0.9096	0.0129	0.9057	0.0131	0.8835	0.0144	0.8593	0.0156	0.8101	0.0178	0.8072	0.0207
Lot 3, 4, 5	0.9705	0.0045	0.9520	0.0057	0.9455	0.0061	0.9321	0.0069	0.9229	0.0072	0.8760	0.0102	0.8734	0.0237
P-value	*0.0037*		*0.0085*		*0.0150*		*0.0017*		*0.0002*		*0.0045*		*0.0674*	

Table E.5. (contd)

16) Release 2 – Reach survival

	CR349 to CR325		CR325 to CR309		CR309 to CR275		CR275 to CR234		CR234 to CR161		CR161 to CR113	
	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$
Lot 1	1.0000	0.0000	0.9868	0.0075	0.9733	0.0107	0.9909	0.0064	0.9449	0.0155	1.0030	0.0135
Lot 2	0.9834	0.0073	0.9899	0.0058	0.9864	0.0068	0.9897	0.0059	0.9416	0.0140	0.9960	0.0136
Lot 3, 4, 5	0.9992	0.0015	0.9813	0.0054	0.9735	0.0067	0.9879	0.0049	0.9425	0.0124	0.9594	0.0360
P-value	*0.0775*		*0.6208*		*0.4398*		*0.9344*		*0.9853*		*0.3713*	

17) Release 2 – Cumulative survival

	Release to CR325		Release to CR309		Release to CR275		Release to CR234		Release to CR161		Release to CR113	
	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$
Lot 1	1.0000	0.0000	0.9868	0.0075	0.9605	0.0129	0.9518	0.0142	0.8993	0.0200	0.9021	0.0234
Lot 2	0.9834	0.0073	0.9735	0.0092	0.9603	0.0112	0.9503	0.0125	0.8949	0.0177	0.8913	0.0213
Lot 3, 4, 5	0.9992	0.0015	0.9805	0.0054	0.9545	0.0084	0.9429	0.0090	0.8887	0.0145	0.8526	0.0332
P-value	*0.0775*		*0.4602*		*0.9084*		*0.8561*		*0.9118*		*0.3803*	

18) Release 3 – Reach survival

	Release to CR309		CR309 to CR275		CR275 to CR234		CR234 to CR161		CR161 to CR113	
	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$
Lot 1	0.9933	0.0066	0.9866	0.0094	0.9796	0.0117	0.9376	0.0202	1.0246	0.0164
Lot 2	0.9898	0.0071	0.9282	0.0185	0.9669	0.0133	0.9675	0.0138	0.9913	0.0193
Lot 3, 4, 5	0.9912	0.0044	0.9737	0.0081	0.9878	0.0061	0.9577	0.0144	1.0688	0.0563
P-value	*0.9221*		*0.0034*		*0.3863*		*0.4209*		*0.3039*	

Table E.5. (contd)

19) Release 3 – Cumulative survival

	Release to CR309		Release to CR275		Release to CR234		Release to CR161		Release to CR113	
	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$
Lot 1	0.9933	0.0066	0.9800	0.0114	0.9600	0.0160	0.9001	0.0245	0.9222	0.0291
Lot 2	0.9898	0.0071	0.9188	0.0195	0.8883	0.0224	0.8595	0.0249	0.8520	0.0295
Lot 3, 4, 5	0.9912	0.0044	0.9651	0.0091	0.9533	0.0099	0.9130	0.0167	0.9758	0.0522
P-value	*0.9221*		*0.0058*		*0.0042*		*0.2107*		*0.0739*	

20) Release 4 – Reach survival

	Release to CR275		CR275 to CR234		CR234 to CR161		CR161 to CR113	
	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$
Lot 1	0.9933	0.0066	0.9463	0.0185	0.9362	0.0206	1.0211	0.0192
Lot 2	0.9800	0.0114	0.9932	0.0068	0.9522	0.0177	0.9952	0.0142
Lot 3, 4, 5	0.9821	0.0064	0.9897	0.0051	0.9501	0.0141	0.9230	0.0360
P-value	*0.4905*		*0.0070*		*0.7848*		*0.0157*	

21) Release 4 – Cumulative survival

	Release to CR275		Release to CR234		Release to CR161		Release to CR113	
	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$
Lot 1	0.9933	0.0066	0.9400	0.0194	0.8800	0.0265	0.8986	0.0319
Lot 2	0.9800	0.0114	0.9733	0.0132	0.9268	0.0213	0.9224	0.0249
Lot 3, 4, 5	0.9821	0.0064	0.9720	0.0074	0.9235	0.0154	0.8524	0.0338
P-value	*0.4905*		*0.1706*		*0.2305*		*0.2554*	

Table E.5. (contd)

22) Release 5 – Reach survival

	Release to CR234		CR234 to CR161		CR161 to CR113	
	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$
Lot 1	0.9867	0.0094	0.9259	0.0216	1.0030	0.0124
Lot 2	0.9867	0.0094	0.9601	0.0162	0.9755	0.0187
Lot 3, 4, 5	0.9840	0.0056	0.9436	0.0137	0.9586	0.0378
P-value	*0.9654*		*0.3840*		*0.4582*	

23) Release 5 – Cumulative survival

	Release to CR234		Release to CR161		Release to CR113	
	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$
Lot 1	0.9867	0.0094	0.9135	0.0230	0.9163	0.0256
Lot 2	0.9867	0.0094	0.9473	0.0184	0.9241	0.0250
Lot 3, 4, 5	0.9840	0.0056	0.9285	0.0145	0.8901	0.0358
P-value	*0.9654*		*0.4494*		*0.6900*	

24) Release 6 – Reach survival

	Release to CR161		CR161 to CR113	
	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$
Lot 1	0.9802	0.0142	0.9934	0.0163
Lot 2	0.9659	0.0151	0.9911	0.0136
Lot 3, 4, 5	0.9705	0.0117	0.9449	0.0301
P-value	*0.7527*		*0.1916*	

Table E.5. (contd)

25) Release 6 – Cumulative survival

	Release to CR161		Release to CR113	
	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$
Lot 1	0.9802	0.0142	0.9738	0.0211
Lot 2	0.9659	0.0151	0.9573	0.0198
Lot 3, 4, 5	0.9705	0.0117	0.9170	0.0288
P-value	*0.7527*		*0.2147*	

26) Release 7 – Reach survival

	Release to CR113	
	$\hat{S}$	$\widehat{\text{SE}}$
Lot 1	0.9714	0.0240
Lot 2	0.9835	0.0160
Lot 3, 4, 5	0.9297	0.0282
P-value	*0.2303*	

E.3 Examination of Delayed Handling Effects

The purpose of the tests of delayed handling effects was to assess whether downstream reach survivals were affected by how far upstream smolts were released. The results of these tests were used to determine which release groups were included in the constructs of a downstream virtual-release group. Data were pooled across taggers and tag lots in performing these analyses because previous tests of tag-lot and tagger effects were nonsignificant.

One of the 10 reach comparisons were significant at $\alpha = 0.10$. In those 10 cases, the survival estimates typically differed by less than 0.01, and reach survival for the uppermost release group was often higher than that of the downriver release groups (Table E.6). Comparison of cumulative survivals in reaches common to multiple release groups found 4 of 30 (i.e., 13.3%) tests to be significant at $\alpha = 0.10$ (Table E.7). In all cases, the uppermost release group (R_1) had higher survival rates than a group released further downriver. These observations are not consistent with evidence of time-dependent tag effects.

In conclusion, no evidence was found that a delayed handling/tag effect may affect the survival studies. For this reason, all available upriver releases were used in the construction of virtual-release groups at the face of John Day, The Dalles, and Bonneville dams.

Table E.6. Comparison of reach survivals between tag releases from different upstream locations for a) CH1 and b) STH during the 2011 JSATS survival study. Shaded reach survivals were not included in the *F*-tests of homogeneous survival because they represent new releases. Newly released fish and previously released fish were not compared within a reach.

a. CH1

	CR390		CR346		CR325		CR307		CR275		CR233		CR161		
Reach	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	*P* (*F*-test)
Release to CR349	0.9810	0.0029													
CR349 to CR325	0.9620	0.0039	0.9923	0.0029											
CR325 to CR309	0.9924	0.0019	0.9892	0.0031	0.9874	0.0043									0.3788
CR309 to CR275	0.9636	0.0039	0.9538	0.0062	0.9525	0.0077	0.9915	0.0038							0.3760
CR275 to CR234	0.9954	0.0016	0.9947	0.0024	0.9919	0.0036	0.9924	0.0034	0.9851	0.0047					0.7845
CR234 to CR161	0.9551	0.0054	0.9518	0.0080	0.9464	0.0095	0.9541	0.0092	0.9451	0.0099	0.9863	0.0067			0.8916
CR161 to CR113	0.9577	0.0094	0.9515	0.0133	0.9799	0.0155	0.9467	0.0161	0.9571	0.0176	0.9586	0.0144	0.9479	0.0141	0.6943

b. STH

	CR390		CR346		CR325		CR307		CR275		CR233		CR161		
Reach	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	*P* (*F*-test)
Release to CR349	0.9623	0.0039													
CR349 to CR325	0.9757	0.0032	0.9975	0.0020											
CR325 to CR309	0.9932	0.0017	0.9847	0.0036	0.9932	0.0033									0.0328
CR309 to CR275	0.9795	0.0031	0.9769	0.0046	0.9663	0.0068	0.9867	0.0047							0.1489
CR275 to CR234	0.9831	0.0029	0.9895	0.0033	0.9807	0.0054	0.9816	0.0052	0.9874	0.0043					0.4732
CR234 to CR161	0.9480	0.0052	0.9367	0.0080	0.9495	0.0092	0.9401	0.0097	0.9379	0.0096	0.9659	0.0082			0.7484
CR161 to CR113	0.9691	0.0107	0.9528	0.0151	0.9938	0.0208	0.9451	0.0189	0.9445	0.0178	0.9501	0.0175	0.9258	0.0167	0.2810

Table E.7. Comparison of cumulative survivals between different upstream tag-release locations for a) CH1 and b) STH during the 2011 JSATS survival study. *P*-values associated with *F*-tests of homogeneous survival.

a. CH1

	CR390		CR346		
Reach	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	*P* (*F*-test)
CR325 to CR309	0.9924	0.001879	0.9955	0.0035	0.4352
CR325 to CR275	0.9565	0.004293	0.9542	0.010577	0.8403
CR325 to CR234	0.9524	0.004486	0.9515	0.010804	0.9387
CR325 to CR161	0.9097	0.006679	0.9178	0.020062	0.7017
CR325 to CR113	0.873	0.009901	0.8403	0.035585	0.3760

	CR390		CR346		CR325		
Reach	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	*P* (*F*-test)
CR309 to CR275	0.9636	0.003938	0.9538	0.00623	0.9525	0.007725	0.3794
CR309 to CR234	0.9591	0.00417	0.9487	0.006539	0.9447	0.00827	0.2754
CR309 to CR161	0.9173	0.006508	0.9035	0.009765	0.8932	0.01192	0.2085
CR309 to CR113	0.8778	0.009878	0.8603	0.013978	0.8763	0.017157	0.6184

	CR390		CR346		CR325		CR307		
Reach	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	*P* (*F*-test)
CR275 to CR234	0.9953	0.00159	0.9947	0.002434	0.9919	0.003578	0.9924	0.003353	0.7922
CR275 to CR161	0.9484	0.005704	0.9459	0.008373	0.9400	0.010208	0.9453	0.009765	0.9199
CR275 to CR113	0.9175	0.009446	0.908	0.013089	0.9168	0.016292	0.9057	0.016121	0.9067

Table E.7. (contd)

	CR390		CR346		CR325		CR307		CR275		
Reach	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	*P* (*F*-test)
CR234 to CR161	0.9552	0.005388	0.9519	0.007953	0.9465	0.009451	0.9542	0.009151	0.9452	0.009856	0.8898
CR234 to CR113	0.9148	0.009493	0.9057	0.013356	0.9275	0.016155	0.9033	0.016241	0.9047	0.017662	0.7595

	CR390		CR346		CR325		CR307		CR275		CR233		
Reach	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	*P* (*F*-test)
CR161 to CR113	0.9508	0.009279	0.9467	0.01329	0.9683	0.014953	0.9425	0.016114	0.9475	0.017317	0.951	0.014248	0.8584

b. STH

	CR390		CR346		
Reach	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	*P* (*F*-test)
CR325 to CR309	0.9932	0.001732	0.9847	0.003614	0.0339
CR325 to CR275	0.9732	0.003501	0.9623	0.00573	0.1045
CR325 to CR234	0.9566	0.004246	0.9521	0.006327	0.5548
CR325 to CR161	0.9075	0.006436	0.8938	0.009622	0.2366
CR325 to CR113	0.8798	0.011103	0.8527	0.015729	0.1593

	CR390		CR346		CR325		
Reach	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	*P* (*F*-test)
CR309 to CR275	0.9795	0.003114	0.9770	0.004568	0.9663	0.006767	0.1449
CR309 to CR234	0.9628	0.003942	0.9667	0.005313	0.9476	0.007999	0.0587
CR309 to CR161	0.9137	0.006254	0.9055	0.009175	0.8998	0.011579	0.5660
CR309 to CR113	0.8869	0.011095	0.8628	0.015653	0.8932	0.021076	0.3864

Table E.7. (contd)

Reach	CR390		CR346		CR325		CR307		P (F-test)
	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	
CR275 to CR234	0.9832	0.002878	0.9895	0.003287	0.9807	0.005444	0.9816	0.005216	0.4769
CR275 to CR161	0.9346	0.005959	0.9251	0.008922	0.9334	0.010451	0.9199	0.011227	0.6431
CR275 to CR113	0.9049	0.010877	0.8887	0.015463	0.9408	0.020741	0.8824	0.019403	0.0699

Reach	CR390		CR346		CR325		CR307		CR275		P (F-test)
	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	
CR234 to CR161	0.9481	0.005237	0.9368	0.007967	0.9496	0.00921	0.9402	0.009665	0.938	0.009601	0.7478
CR234 to CR113	0.9192	0.010907	0.8925	0.015407	0.9437	0.020814	0.8886	0.019067	0.8859	0.018182	0.0788

Reach	CR390		CR346		CR325		CR307		CR275		CR233		P (F-test)
	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	
CR161 to CR113	0.9651	0.01067	0.9459	0.014803	0.9828	0.020228	0.9385	0.018589	0.94	0.017674	0.9403	0.017119	0.3321

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