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Contract DE-AC05-76RL01830

Survival and Passage of Yearling Chinook Salmon and Steelhead at The Dalles Dam, Spring 2011

FINAL REPORT

Pacific Northwest National Laboratory
University of Washington

December 2012

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Final Report

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Preface

The study reported herein was conducted by the Pacific Northwest National Laboratory (PNNL) and the University of Washington (UW) for the U.S. Army Corps of Engineers, Portland District (USACE). The PNNL and UW project managers were Drs. Thomas J. Carlson and John R. Skalski, respectively. The USACE technical lead was Mr. Brad Eppard. The study was designed to estimate dam passage survival and other performance measures at The Dalles Dam as stipulated by the 2008 Federal Columbia River Power System Biological Opinion (BiOp) and the 2008 Columbia Basin Fish Accords.

The study is being documented in two types of reports: compliance and technical. A compliance report is delivered within 6 months of the completion of the field season and focuses on results of the performance metrics outlined in the 2008 BiOp and Fish Accords. A technical report is produced within the 18 months after field work, providing comprehensive documentation of a given study and results on route-specific survival estimates and fish passage distributions, which are not included in compliance reports. This technical report concerns the 2011 acoustic telemetry study at The Dalles Dam. The author order is based on the written contribution by the first six authors, followed by an alphabetical list of individuals who made significant contributions to overall conduct of the study from beginning to end.

Suggested citation:

Johnson G, J Kim, M Hennen, D Etherington, S Zimmerman, J Skalski, G Batten, T Carlson, S Carpenter, A Cushing, Z Deng, E Fisher, T Fu, M Greiner, J Hughes, F Khan, J Martinez, T Mitchell, G Ploskey, B Rayamajhi, I Royer, A Seaburg, R Townsend, M Weiland, and C Woodley. 2012. *Survival and Passage Yearling Chinook Salmon and Steelhead at The Dalles Dam, Spring 2011*. PNNL-21826, final report submitted to the U.S. Army Corps of Engineers, Portland District, Portland, Oregon, by Pacific Northwest National Laboratory, Richland, Washington.

Executive Summary

The acoustic telemetry study reported here was conducted by researchers at Pacific Northwest National Laboratory (PNNL) and the University of Washington (UW) for the U.S. Army Corps of Engineers, Portland District (USACE). The purpose of the study was to estimate dam passage survival and other performance measures for yearling Chinook salmon and steelhead at The Dalles Dam as stipulated by the 2008 Biological Opinion (BiOp) on operation of the Federal Columbia River Power System (FCRPS) and 2008 Columbia Basin Fish Accords. Under the 2008 FCRPS BiOp, dam passage survival should be ≥0.96 for yearling Chinook salmon and steelhead, estimated with a standard error (SE) ≤0.015. The study also estimated smolt passage survival from the forebay 2 km upstream of the dam to the tailrace 2 km below the dam,[1] among other metrics required in the Columbia Basin Fish Accords.

The objectives of the 2011 acoustic telemetry study of survival and passage at The Dalles Dam were to estimate the following performance measures, separately for yearling Chinook salmon (*Oncorhynchus tshawytscha*) and juvenile steelhead (*O. mykiss*):

1. Survivals: dam passage for the total project[2]; forebay-to-tailrace for the total project; dam passage by route (turbines, sluiceway, and spillway).
2. Travel Times: forebay residence; tailrace egress; project passage.
3. Passage Efficiencies: fish passage efficiency; spillway passage efficiency[3]; sluiceway passage efficiency relative to the total project; sluiceway passage efficiency relative to the powerhouse.
4. Distributions: forebay approach distribution; forebay vertical distribution; horizontal distribution of passage at the turbines, sluiceway, and spillway.

A virtual/paired-release design was used to estimate dam passage survival at The Dalles Dam during 2011. The approach included releases of acoustically tagged smolts above John Day Dam that contributed to the formation of a virtual release at the face of The Dalles Dam. A survival estimate from this release was adjusted by a paired release below the dam. A total of 5,854 yearling Chinook salmon and 5,931 steelhead were tagged and released in the study. The study methods are summarized in Table ES.1. Subyearling Chinook salmon were not studied because the extremely high flows during summer 2011 (158% of the 10-y average [2002-2011] for June 1 through August 31) were not typical river conditions.

The high flows during spring 2011 disrupted the 40% spill operations at The Dalles Dam. Therefore, dam passage survival was estimated for the early part of the study (i.e., April 29–May 17) when spill was about 40% and for the entire season, which includes higher spill levels during May 18–30, 2011. The study results are summarized in Tables ES.1, ES.2, ES.3, and ES.4. Standard errors are in parentheses.

[1] The forebay-to-tailrace survival estimate satisfies the “BRZ-to-BRZ” (boat-restricted zone) survival estimate called for in the Fish Accords.
[2] Dam passage survival is defined as survival from the upstream face of the dam to a standardized reference point in the tailrace.
[3] 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 Fish Accords, spill passage efficiency includes passage through the spillway and the ice and trash sluiceway at The Dalles Dam. Traditionally, this metric has been termed fish passage efficiency, which is also presented.

Table ES.1. Summary of Methods and Conditions at the Dalles Dam During 2011

Year: 2011					
Study Site(s): The Dalles Dam					
Objective(s) of study: Estimate dam passage survival and other performance measures for yearling Chinook salmon and steelhead.					
Hypothesis: Not applicable; this was a compliance study					
Fish Species-Race:			Implant Procedure:		
Yearling Chinook salmon (CH1), steelhead (STH)			Surgical: Yes		
Source: John Day Dam Smolt Monitoring Facility			Injected: No		
Size (median):	CH1	STH	Sample Size:	CH1	STH
Weight	32.19 g	73.16 g	# release sites:	3	3
Length	148.3 mm	203.8 mm	Total # released:	5,854	5,931
Tag:	Analytical Model:		Characteristics of Estimate:		
Type/model: Advanced Telemetry Systems ATS156-dB Weight (g): 0.438 g (air)	Virtual/paired release		From arrival at dam face to tailrace Effects Reflected (direct, total, etc.): Direct Absolute or Relative: Absolute		
Environmental/Operating Conditions (daily from April 29 through 30 May 30, 2011): Daily discharge (kcfs): mean 359, minimum 219, maximum 497 Spill: 24 h/d, 43.1% total discharge Sluice: 24 h/d, ~4.5 kcfs Temperature (°C): mean 11.3, minimum 9.4, maximum 12.6 Total Dissolved Gas (tailrace): mean 113%, minimum 107%, maximum 120% Treatment(s): None Unique Study Characteristics: Involuntary spill conditions after May 17, 2011.					

Table ES.2. Summary of Survival and Other Performance Metrics at the Dalles Dam During 2011. Standard errors are in parentheses.

Metric	CH1	STH
Dam passage survival		
• April 29–May 17, 2011 (early season 40% spill)	0.9721 (0.0104)	0.9924 (0.0115)
• April 29–May 30, 2011 (season-wide)	0.9600 (0.0074)	0.9952 (0.0083)
Forebay-to-tailrace survival	0.9596 (0.0072)	0.9947 (0.0083)
Forebay residence time (h) (median; mean)	0.97 (0.14); 1.31 (0.14)	0.81 (0.08); 1.22 (0.08)
Tailrace egress time (h) (median; mean)	0.24 (0.23); 1.33 (0.23)	0.20 (0.25); 1.97 (0.25)
Project passage time (h) (median; mean)	1.42 (0.22); 2.49 (0.22)	1.12 (0.25); 3.11 (0.25)
Spill passage efficiency	0.658 (0.007)	0.754 (0.007)
Fish passage efficiency	0.831 (0.006)	0.891 (0.005)
Compliance Results: Early season and season-wide estimates of dam passage survival for yearling Chinook and steelhead met 2008 BiOp requirements (≥ 0.96). Standard errors were within acceptable range (≤ 0.015).		

Table ES.3. Route-Specific Dam Passage Survival Estimates

	CH1			STH		
Route	Survival	SE	n	Survival	SE	n
Sluiceway	0.9914	0.0079	734	1.0097	0.0091	592
Spillway	0.9607	0.0077	2793	1.0038	0.0083	3243
Turbine	0.9297	0.0117	701	0.9189	0.0166	451

Table ES.4. Summary of Fish Distributions

Parameter	CH1	STH
Percentage of total that first approached at the powerhouse	72%	73%
Percentage of total first approached at the powerhouse but passed at the spillway	32%	44%
Depth of median vertical distribution (approx.)	~5 m	~4 m
Vertical distribution for day (D) versus night (N)	D shallower than N	D shallower than N
Percentage of total turbine passage at Fish Unit 1-MU 2	26%	24%
Percentage of total sluiceway passage at Sluice 1	97%	93%
Percentage of total spillway passage at Bay 8	22%	24%
Percentage of total spillway passage at Bays >8	14%	16%

Acknowledgments

We are grateful to dedicated scientists from PNNL, the 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.

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- USACE: B Eppard, M Langeslay, B. Cordie and electricians, mechanics, riggers, operators, and biologists at The Dalles Dam.

Acronyms and Abbreviations

°C	degree(s) Celsius
2D	two-dimensional
3D	three-dimensional (or dimensionally, dimensions)
ATS	Advanced Telemetry Systems
BiOp	Biological Opinion
BON	Bonneville Dam
BRZ	boat-restricted zone
CH1	yearling Chinook salmon
CF	compact flash
cfs	cubic foot(feet) per second
cm	centimeter(s)
COP	Configuration and Operations Plan
d	day(s)
DART	Data Access in Real Time
DSP	digital signal processing
FCRPS	Federal Columbia River Power System
FPE	fish passage efficiency
FGPA	field-programmable logic gate array
ft	foot(feet)
FU	Fish Unit
g	gram(s)
GPS	global positioning system
h	hour(s)
in.	inch(es)
JBS	juvenile bypass system
JDA	John Day Dam
JSATS	Juvenile Salmon Acoustic Telemetry System
kg	kilogram(s)
kHz	kilohertz
kcfs	thousand cubic feet per second
km	kilometer(s)
L	liter(s)
m	meter(s)
mg	milligram(s)
MLE	maximum-likelihood estimation
ml	milliliter(s)

mm	millimeter(s)
MOA	Memorandum of Agreement
MS-222	tricaine methanesulfonate
MSL	mean sea level
MW	megawatt(s)
NA	not applicable
NAD83	North American Datum of 1983
NAVD88	North American Vertical Datum of 1988
OR	Oregon
PIT	passive integrated transponder
PTAGIS	PIT Tag Information System
PNNL	Pacific Northwest National Laboratory
PRI	pulse repetition interval
psi	pound(s) per square inch
rkm	river kilometer(s)
RME	research, monitoring, and evaluation
ROR	run-of-river
RPA	Reasonable and Prudent Alternative
μs	microsecond(s)
s	second(s)
$\hat{S}$	survival estimate
SE	standard error
SMF	Smolt Monitoring Facility
SPE	spill passage efficiency
STH	juvenile steelhead
TDA	The Dalles Dam
USACE	U.S. Army Corps of Engineers
UW	University of Washington
WA	Washington
y	year(s)

Contents

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Tables

1.0 Introduction

The acoustic telemetry study reported here was conducted by researchers at Pacific Northwest National Laboratory (PNNL) and the University of Washington (UW) for the U.S. Army Corps of Engineers, Portland District (USACE). The purpose of the study was to estimate dam passage survival and other performance measures for yearling Chinook salmon (*Oncorhynchus tshawytscha*) and steelhead (*O. mykiss*) smolts during spring 2011 at The Dalles Dam (Figure 1.1), as 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).

Figure 1.1. Aerial Photograph of The Dalles Dam

1.1 Background

Since the 1970s, research has been conducted to support development of long-term operational and structural measures to protect juvenile salmonids at The Dalles Dam (TDA). Fish passage improvement strategies addressed the three primary passage routes at TDA—the spillway, sluiceway, and turbines—with the general intent being to increase spill and sluice passage and decrease turbine passage. Passage studies before and including 2005 were synthesized by Ploskey et al. (2001) and Johnson et al. (2007). In winter 2009/2010, the USACE constructed a wall in the spillway stilling basin that extended 830 ft downstream from the pier between Spill Bays 8 and 9 (Figure 1.2; see Section 1.4 for more information about the wall). The research and development effort to protect juvenile salmonids at TDA have culminated in the following operations and structures:

- sluiceway – maximum discharge (~4,500 cfs) distributed at six sluice entrances to provide a non-turbine passage route at the powerhouse;
- spillway – 40% spill out of total project discharge 24 h/d April into August at Bays 1–8 to provide a non-turbine passage route at the dam;
- spillway stilling basin – guidance wall to improve tailrace egress conditions.

With the above operations and structures established for juvenile salmonid protection, the USACE and resource agencies agreed to a formal evaluation of compliance relative to the 2008 FCRPS BiOp performance standards and Fish Accords at TDA during 2010 and 2011. For 2010 studies, special reports on BiOp compliance were prepared for spring 2010 (Skalski et al. 2010a) and summer 2010 (Skalski et al. 2010b). In addition, Johnson et al. (2011) provided a comprehensive technical report for the 2010 spring and summer survival studies. For 2011, Skalski et al. (2012) delivered a BiOp compliance report for the spring study.

Figure 1.2. The Dalles Dam Spillway Showing the Spill Wall at Bays 8/9

1.2 Performance Standards and Definitions

The FCRPS 2008 BiOp (NOAA Fisheries 2008) contains a Reasonable and Prudent Alternative (RPA) that includes actions calling for measurements of juvenile salmonid survival (RPA 52.1). This RPA action is being addressed as part of the federal research, monitoring, and evaluation (RME) effort for the FCRPS BiOp. Under RME Strategy 2 of the RPA, the FCRPS BiOp includes performance standards for juvenile salmonid survival in the FCRPS against which monitoring estimates must be compared by the Action Agencies.[1] The BiOp performance measures related to survival are defined in Table 1.1. The BiOp's performance standards for juvenile survival are as follows:

- <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 and steelhead and 93% average across all dams for Snake River subyearling Chinook….Survival should be estimated with a standard error (SE) ≤1.5%."

[1] The Bonneville Power Administration, U.S. Bureau of Reclamation, and U.S. Army Corps of Engineers are the Action Agencies.

The Fish Accords were outlined in a Memorandum of Agreement (MOA) between the three lower river tribes and the Action Agencies. The Fish Accords contain three additional requirements relevant to the 2011 survival studies, in accordance with MOA Attachment A:

- Dam Survival Performance Standard – "…meet the 96% dam passage survival standard for yearling Chinook and steelhead and the 93% standard for subyearling Chinook and achievement of the standard is based on 2 years of empirical survival data..."
- Spill Passage Efficiency and Delay Metrics – "Spill passage efficiency (SPE) and delay metrics under current spill conditions…are not expected to be degraded ("no backsliding") with installation of new fish passage facilities at the dams…"
- Future Research, Monitoring, and Evaluation – "The Action Agencies' dam survival studies for purposes of determining juvenile dam passage performance will also collect information about spill passage efficiency, BRZ-to-BRZ [boat-restricted zone] survival and delay, as well as other distribution and survival information. SPE and delay metrics will be considered in the performance check-ins or with COP [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."

Table 1.1. Definitions of Performance Measures

Measure	Definition
Dam passage survival	Survival from the upstream face of the dam to a standardized reference point in the tailrace.
Forebay-to-tailrace survival	Survival from a forebay array 2 km upstream of the dam to a tailrace array 2 km downstream. The forebay-to-tailrace survival estimate satisfies the "BRZ-to-BRZ" survival estimate called for in the Fish Accords.
Forebay residence time	Average time smolts take to travel from first detection on the array 2 km upstream of the dam to last detection on the dam-face array.
100-m forebay residence time	Average time smolts take to travel the last 100 m upstream of the dam before passing into the dam, i.e., from the 100-m mark to the dam face.
Tailrace egress time	Average time smolts take to travel from the dam to the downstream tailrace boundary, i.e., dam-face array to the tailrace array 2 km downstream of the dam.
Spill passage efficiency	Proportion of fish going through the dam via the spillway.[a]
Project passage time	Average time smolts take to travel from first detection on the array 2 km upstream of the dam to last detection on the array 2 km downstream of the dam
Fish passage efficiency	Proportion of fish going through the dam via the spillway and the sluiceway.[b]

(a) Spill passage efficiency in the Fish Accords has traditionally been called fish passage efficiency.
(b) Fish passage efficiency was called spill passage efficiency in the Fish Accords.

1.3 Objectives

The objectives for the 2011 acoustic telemetry study of survival and passage at TDA were to estimate the following performance measures separately for yearling Chinook salmon and steelhead from April 29 through May 30, 2011:

1. Survivals
   - Dam passage for the total project
   - Forebay-to-tailrace for the total project
   - Dam passage by route (turbines, sluiceway, and spillway)
2. Travel Times
   - Forebay residence
   - Tailrace egress
   - Project passage time
3. Passage Efficiencies
   - Fish passage efficiency
   - Spillway passage efficiency
   - Sluiceway passage efficiency relative to the total project
   - Sluiceway passage efficiency relative to the powerhouse
4. Distributions
   - Forebay approach distribution
   - Forebay vertical distribution
   - Horizontal distribution of passage at the turbines, sluiceway, and spillway.

1.4 Study Area Description

The Dalles Dam, located at river kilometer (rkm) 309, is the second closest dam to the Pacific Ocean in the FCRPS. The Dalles Dam includes a navigation lock, a spillway perpendicular to the main river channel, and a powerhouse parallel to the main river channel (Figure 1.1). The Dalles Dam is the only Portland District project that has the powerhouse running parallel instead of perpendicular to the main channel of the Columbia River. Full pool elevation is rated at 160 ft above mean sea level (MSL) and minimum operating pool elevation is 155 ft above MSL. The thalweg intersects the dam at the eastern end of the powerhouse and, although there are deep areas immediately in front of the powerhouse (Figure 1.3), much of the forebay is relatively shallow (<65 ft deep). There are deep canyons, shallow sills, and islands in the tailrace (Figure 1.3).

The powerhouse is 2,089 ft long and has a total generating capacity of 1,800 megawatts (MW) and total hydraulic capacity of 330 thousand cubic feet per second (kcfs). The powerhouse has 22 main units (MUs), numbered from the southwest (downstream) to the northeast (upstream) end. The powerhouse also has two small turbine units, called fish units (Fish Unit [FU] 1 and FU 2), whose discharge is used in the adult fish ladders. Each MU has three intakes, numbered again from southwest to northeast. Reference to a specific intake is expressed as the turbine unit and intake number; e.g., 2-1, 2-2, and 2-3 for the west, middle, and east intakes of MU 2, respectively. Main units usually are operated within 1% of peak efficiency to reduce unit cavitation and injury to juvenile fish. Flow through the MUs can range from about 9,000 to 14,000 cfs depending upon efficiency, head, desired power output, and other factors. Flow typically averages about 11,000 cfs per MU. The two FUs are located southwest of MU 1; the FUs have only two intakes each. Average discharge through the FUs is about 2,000 cfs. The turbine intake ceiling intersects the turbine intake trash racks of the MUs and FUs at elevation 141 ft. The face of the powerhouse is 11.3° off of vertical.

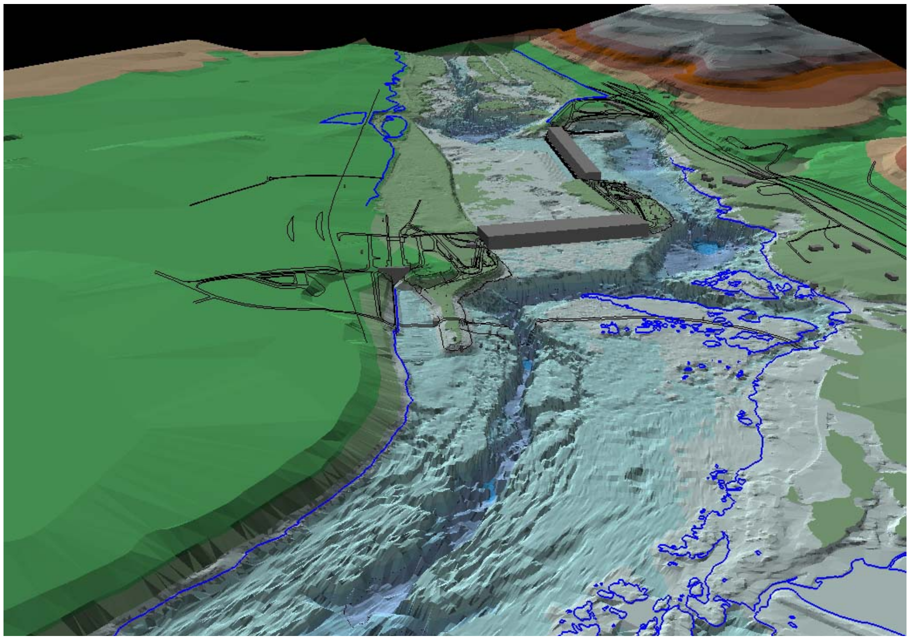


Figure 1.3. Perspective View of The Dalles Dam Showing Tailrace Bathymetry (provided by L. Ebner, USACE Hydraulics)

The ice and trash sluiceway is a channel that extends the entire length of the forebay side of the powerhouse. The sluiceway has three 20-ft-wide entrance gates positioned over each of the 22 turbine units. Water enters the sluiceway channel from the forebay when gates are moved off the sill at elevation 151 ft. A maximum of six sluice gates can be opened at any time before reaching the hydraulic capacity of the channel (~4,500 cfs). Flow into the sluiceway is dependent on forebay elevation and the number and location of open gates. For instance, given a forebay elevation equal to 158.4 ft (above MSL) and two sluice gate operating conditions (see above), flows over the individual weir gates range from 561 to 1,059 cfs, with the highest flows occurring at the west end nearest the sluiceway channel outlet. Overall, sluiceway discharge (~4,500 cfs) is a relatively small proportion of total project discharge (~2%). The ice and trash sluiceway has long been operated to pass juvenile salmonids at TDA. During 2001–2003, the three sluice gates above MU 1 were opened to release about 3,600 cfs during April–December. Since 2004, six gates are opened to maximize sluiceway discharge at about 4,500 cfs.

The 1,380-ft-long spillway comprises 23 bays with 50-ft-wide radial gates numbered sequentially from the Washington to the Oregon side. Individual spill-gate openings typically range from 0 to 14 ft and about 1,500 cfs of flow per foot of opening. The tailrace for the powerhouse is deep, but further downstream on the Oregon side it is shallow and has many islands and rock outcrops. The spillway was modified during winter 2003/2004 to include a spill wall 193 ft long that divides the stilling basin between Bays 6 and 7.

During winter 2009/2010, an additional larger spill wall was installed between Bays 8 and 9 (Figure 1.2 and Figure 1.4). This wall is 830 ft long, 10 ft wide, and 43 ft tall at the base of the spillway. It is anchored to the basalt rock substrate of the stilling basin. The purpose of the structure is to minimize predation on spillway-passed fish that occurs in the vicinity of the bridge and basin islands on the Oregon side of the river by guiding them directly to the thalweg downstream of the spillway.

Figure 1.4. Photographs of The Dalles Dam Stilling Basin and 2009/2010 Spill Wall (looking downstream)

1.5 Environmental Conditions

The environmental conditions section covers project discharge, spill, dissolved gas levels, and water temperature. Daily total project discharge during the study period (April 29 through May 30) averaged 359 kcfs and ranged between 219 and 497 kcfs (Figure 1.5), which was 40% higher than the 10-y average. Sluiceway discharge was relatively uniform, ~5.2 kcfs. Discharge and the spill percentage increased dramatically in mid-May (Figure 1.5). This necessitated analysis over two periods: early season (April 29 through May 17) and full season (April 29 through May 30) (Figure 1.5). During the full 2011 study period, the spill percentage out of total project discharge was 43.1%, but averaged over 50% from May 18 through May 30.

Normally spill for juvenile fish passage is confined to Bays 1−8, but in spring 2011 flows necessitated opening additional bays. Beginning late on May 16, Bays 9 and 12 were opened and on May 20 Bay 14 was opened; these bays remained open for the duration of the study. In addition, Bays 15, 17, 20, and 21 periodically spilled water with Bay 15 open for the greatest duration of time. Bays 10, 11, 13, 16, 18, 19, 22, and 23 were never opened during the study.

Operation of the 22 MUs was intermittent during the season except for MU 10, which was not used at all. All other turbine units were operating during a vast majority of the season; however, they were periodically shut down for hours or days at a time. Main turbine units 1, 9, 11, 12, and 18 were operating almost constantly during the season and were never shut down for more than a 24-h period. All functioning units were operating 24-h/d from May 20 through the end of the season. The two FUs were operated continuously throughout the study.

Total dissolved gas levels increased in mid-May from about 110% to around 120% in the latter part of the month (Figure 1.6a). Dissolved gas (measured as mm Hg) increased from about 830 mm Hg to around 900 mm Hg during the study (Figure 1.6b). Water temperature steadily increased from about 9 to about 12°C (Figure 1.6c).

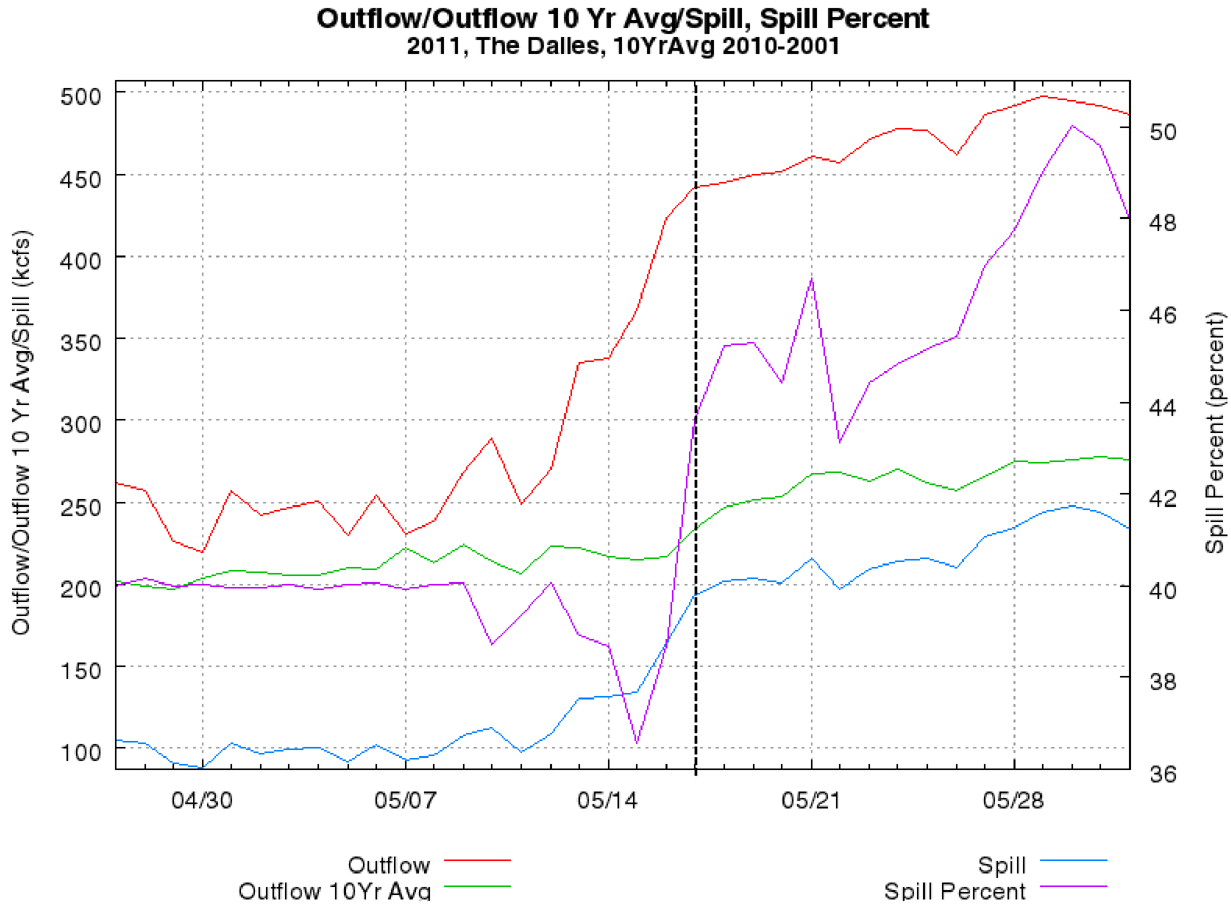


Figure 1.5. Outflow and Spill Discharge (kcfs) at The Dalles Dam During Spring 2011. The 10-y average is for the period 2001 through 2010. The vertical dashed line indicates the demarcation for the early season (April 29 through May 17), as opposed to the full season (April 29 through May 30). Data accessed from DART on September 18, 2012 (www.cbr.washington.edu/dart).

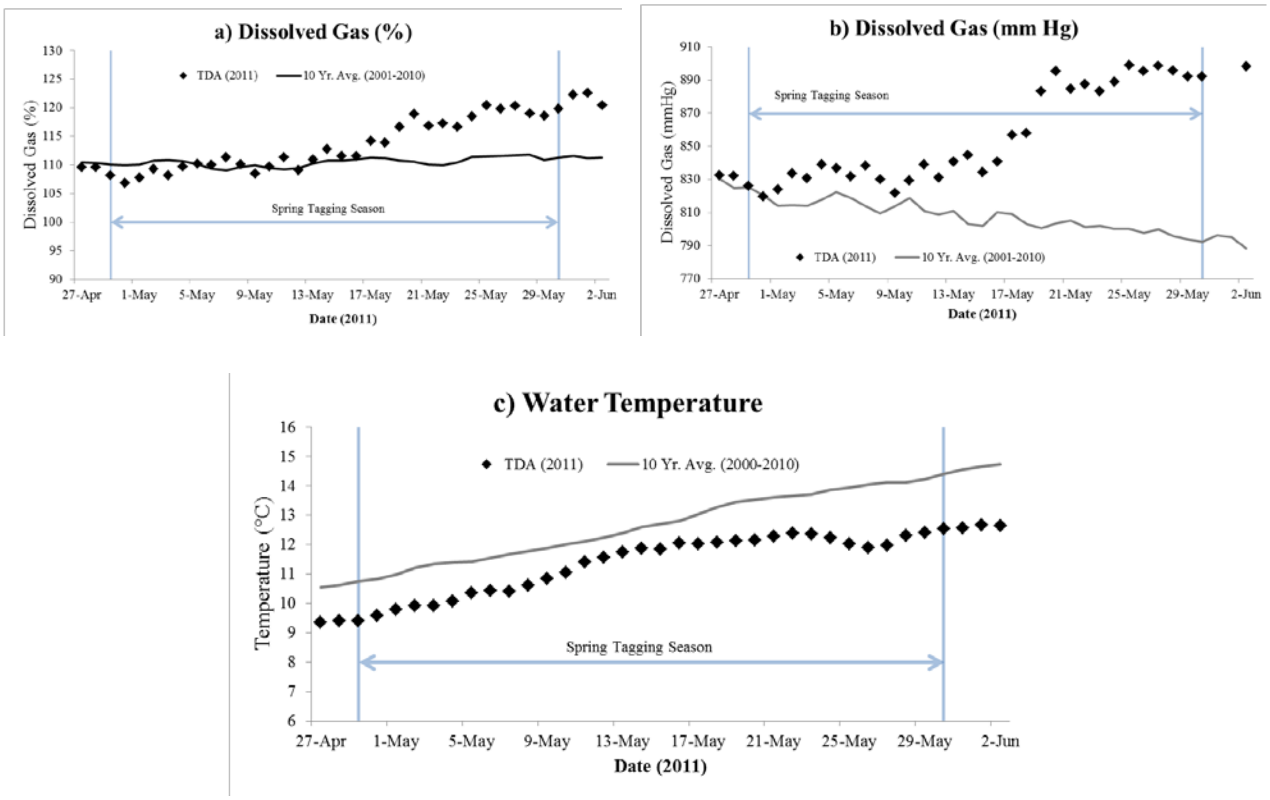


Figure 1.6. Water Quality Data from The Dalles Dam Water Quality Monitoring Station: a) Dissolved Gas (%), b) Dissolved Gas (mmHg), and c) Temperature (°C), Along with 10-y Averages.

1.6 Report Contents

This report contains six chapters and five appendices. The ensuing chapters present the methods (Chapter 2.0), followed by the study results for survival, travel time, passage efficiency, and distribution for yearling Chinook salmon (Chapter 3.0) and steelhead (Chapter 4.0). Discussion of study results (Chapter 5.0) and references (Chapter 6.0) close out the main body of the report (the latter lists references found in the appendices, too). The appendices provide Juvenile Salmon Acoustic Telemetry System performance data (Appendix A), tagging and release data (Appendix B), hydrophone deployment locations (Appendix C), capture histories (Appendix D), and an assessment of the assumptions for the survival estimates (Appendix E).

2.0 Methods

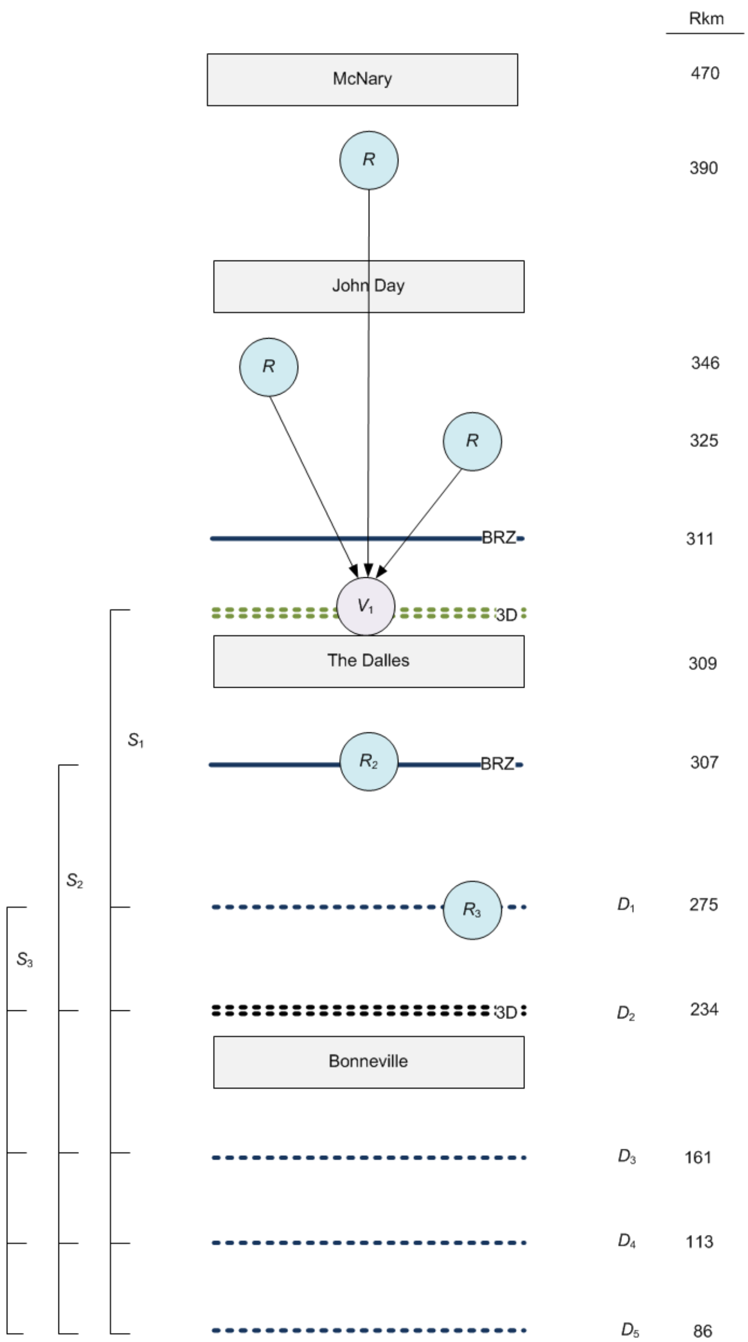
Study methods concern release-recapture design and hydrophone deployment; tag specifications and tag life; fish handling, tagging, and release procedures; detection of tagged fish; acoustic signal processing; and statistical methods. The primary research tool was the Juvenile Salmon Acoustic Telemetry System (JSATS; McMichael et al. 2010). In brief, an acoustic signal emitted by a transmitter implanted in a test fish is received at an underwater hydrophone and sent to a digital signal processor where the unique waveform is detected, then decoded, and the output is written to a storage device. Filtering involves identifying repeated identical tag codes that arrive at time intervals expected from a normally functioning acoustic tag like those implanted in fish. Performance data for the JSATS equipment are presented in Appendix A.

2.1 Release-Recapture Design and Sample Sizes

The release-recapture design used to estimate dam passage survival ($\hat{S}$) at TDA consisted of a combination of a virtual release (V_1) of fish detected on the dam-face, double-detection array (rkm 309) and a pair of releases (R_2 and R_3) below the dam (Figure 2.1) (Skalski et al. 2010a, b, and c). Tagged fish released at three locations upriver of TDA were combined to form a single virtual-release group of fish known to have arrived alive at the forebay face of the dam. 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 part of the way through the Bonneville Reservoir (i.e., to rkm 275) (Figure 2.1). The location for the detection array at rkm 275 was chosen so that there was 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, a paired release below TDA (i.e., R_2 and R_3) (Figure 2.1) was used to estimate survival in that segment of the reservoir below the dam. Dam passage survival was then estimated as the quotient of the survival estimates for the virtual release to that of the paired release (S_i). The overall sample sizes of each release of acoustically tagged fish used are summarized in Table 2.1.

Table 2.1. Sample Sizes of Acoustically Tagged Juvenile Chinook Salmon and Steelhead Used for Dam Passage Survival Estimates at The Dalles Dam in 2011

Release Location	Yearling Chinook Salmon	Steelhead
Virtual Release (V_1)	4,256	4,331
The Dalles Dam Tailrace (R_2)	799	800
Hood River, Oregon (R_3)	799	800
Total	5,854	5,931



$$\hat{S}_{\text{Dam}} = \frac{\hat{S}_1 \cdot \hat{S}_3}{\hat{S}_2} \qquad (2.1)$$

Figure 2.1. Schematic of the Virtual/Paired-Release Design Used to Estimate Dam Passage Survival at The Dalles Dam. The virtual-release (V_1) group (double dashed lines at rkm 309) was composed of fish that arrived at the dam face from release locations at rkm 390, rkm 346, and rkm 325. The below-dam release pair was composed of releases R_2 and R_3 with detection arrays (D_1-D_5) used in the survival analysis denoted by dashed lines. S_1 covers rkm 309-275; S_2 covers rkm 307-234; S_3 covers rkm 275-234. Note that the arrays at rkm 311 and rkm 307 are not actually on the BRZ demarcations.

The same release-recapture design was also used to estimate forebay-to-tailrace survival, except that the virtual-release group was constructed of fish detected on the forebay array (rkm 311), rather than the dam-face array (rkm 309). The same below-dam paired-release design was used to adjust for mortality in the reservoir below the dam as was used to estimate dam passage survival.

The double-detection arrays (Figure 2.2) mounted on the upstream face of TDA were used to construct the virtual-release group, identify passage routes, estimate travel times, and to track fish in three-dimensions (3D). The arrays were first analyzed independently to determine detection probabilities of each array separately, and then they were combined to form an overall detection probability. The passage-route data were used to calculate route-specific survival, spill passage efficiency (SPE; the fraction of total project passage passing through the spillway), and fish passage efficiency (FPE; the fraction of total project passage not passing through the turbines). In addition, the arrays were used to estimate forebay residence time and tailrace egress time. The 3D tracking information collected was used to determine forebay approach distributions, forebay vertical distributions, and horizontal passage distributions.

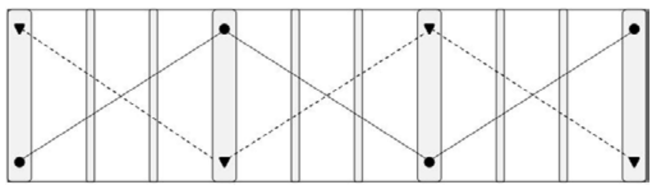


Figure 2.2. Front View Schematic of Hydrophone Deployments at Three Turbines Showing the Double-Detection Arrays. Circles denote the hydrophones of Array 1 and triangles denote the hydrophones of Array 2.

2.2 Tag Specifications and Tag Life

The JSATS acoustic tags used in the 2011 study (Figure 2.3) were manufactured by Advanced Telemetry Systems (ATS; model ATS156-dB). A JSATS tag consists of four main components: a silver-oxide button cell battery, a circuit board that controls the tagcode ID and pulse rate interval, a piezoceramic element that generates and sends the 416.7-kHz acoustic signal into the water, and an outer layer of epoxy covered with Parylene C, which is a biologically inert, waterproof coating. Each tag, model number ATS-156dB, measured 12.02 mm in length, 5.21 mm in width, 3.72 mm in thickness, and weighed 0.430 g in air. The tags had a nominal transmission rate of 1 pulse every 3 s. The nominal tag life at this pulse rate was expected to be about 25 d.

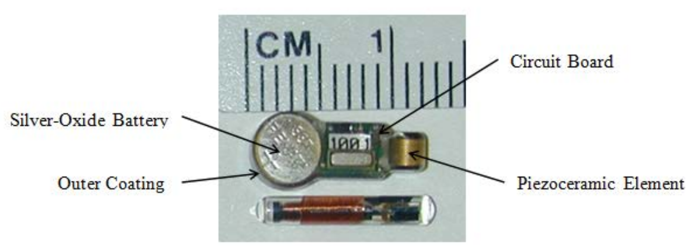


Figure 2.3. JSATS 0.43-g Acoustic Micro-Transmitter (Top) and Passive Integrated Transponder Tag (Bottom) that Were Surgically Implanted in Yearling Chinook Salmon and Steelhead Smolts in 2011

For an assessment of tag life, 159 acoustic tags were randomly sampled from the tags used in the spring season. The tags were activated, held in river water, and monitored continuously until they failed to produce any detectable transmissions. All acoustic tags were individually enclosed in water-filled plastic bags and suspended from a rotating foam ring, within a 2-m-diameter fiberglass tank. Two 90° × 180° hydrophones were positioned 90° apart in the bottom of the tank and angled upward at approximately 60° for optimum detection of acoustic transmissions from the test tag. Hydrophones were cabled to a quad-channel receiver that amplified all acoustic signals. All acoustic signals were then saved, decoded, and processed. Post-processing software calculated the number of hourly decodes for each acoustic tag, and therefore tag failure times could be determined within ±1 h. The tag failure times were fit to the four-parameter vitality model of Li and Anderson (2009). This 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 resulting probability density function describing the probability of tag survival as a function of time (*t*) can be rewritten as follows:

$$f(t) = 1 - \left(\Phi\left(\frac{1 - rt}{\sqrt{u^2 + s^2 t}} \right) - e^{\left(\frac{2u^2r^2}{s^4} + \frac{2r}{s^2} \right)} \Phi\left(\frac{2u^2 r + rt + 1}{\sqrt{u^2 + s^2 t}} \right) \right)^{e^{-kt}} \quad (2.2)$$

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 accidental or 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. Maximum-likelihood estimation (MLE) was used for estimating model parameters.

For the virtual-release (V_1) group composed of fish known to have arrived at the TDA dam-face detection array (CR309) with active tags, the conditional probability of tag activation was used in the tag-life adjustment for that release group (Townsend et al. 2006). The conditional probability of a tag being active (surviving) at a time t_1, given that it was active at the time of actual tag activation (t_0), was computed by the quotient

$$P\left(t_1 \middle| t_0\right) = \frac{S(t_1)}{S(t_0)}. \quad (2.3)$$

2.3 Handling, Tagging, and Release Procedures

Procedures for the handling, tagging, and releasing of 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 John Day Dam (JDA) juvenile bypass system (JBS) at the Smolt Monitoring Facility (SMF) were surgically implanted with JSATS tags, held for 18 to 30 h, and then transported to five different release locations on the Columbia River, as described in the following sections. A total of 5,854 yearling Chinook salmon and 5,931 steelhead were tagged and released for use in estimating survival and various passage metrics at TDA. Tagging and release data are presented in Appendix B.

2.3.1 Fish Source, Collection, and Selection Methods

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 acceptance 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, 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, the following day fish with that malady were accepted after approval by the fish condition study manager.

Over 20,000 yearling Chinook salmon and juvenile steelhead were handled during the study and we summarized the number and percent of fish collected for according to their fate (Table 2.2). Rejected and excluded fish were released to the river through the SMF holding system after recovering from the anesthesia. Accepted fish were counted and transferred into twelve 302.8-L pre-surgery holding tanks, where they were held for 18 to 30 h before surgery. The pre-surgery holding duration depended on the time of collection and the time of tagging on the next day. The majority of fish collected for the study were tagged and released alive. A small percentage of fish were tagged and released dead with active tags to test detection assumptions. In addition, fish were tagged for a concurrent study of fish condition. The extra fish collected but not used for tagging, due to daily tagging quotas being met, were released to the river through the JDA juvenile bypass outfall. We also summarized information for fish collected for tagging but rejected because of specific maladies (Table 2.3) or excluded for other reasons (Table 2.4).

Table 2.2. Summary of the Ultimate Fate of Yearling Chinook Salmon and Juvenile Steelhead Collected at John Day Dam and Used for the 2011 Dam Survival Studies

Fate	CH1		STH		Total	
	n	%	n	%	n	%
Rejected[a]	1,060	10.5	1,561	15.0	2,621	12.8
Excluded[b]	495	4.9	358	3.4	853	4.2
Tagged and released live	7,692	76.4	7,766	74.8	15,458	75.6
Tagged and released dead[c]	56	0.6	44	0.4	100	0.5
Tagged for fish condition study	180	1.8	179	1.7	359	1.8
Extra fish[d]	584	5.8	479	4.6	1,063	5.2
Total	10,067	100.0	10,387	100.0	20,454	100.0

(a) Due to maladies
(b) Moribund, holding mortality, previously tagged, did not meet length criteria, non-target species, mishandled
(c) Used specifically to meet detection assumptions
(d) Collected but not tagged due to daily tagging quota being met

Table 2.3. Summary of Fish Rejected from the 2011 Tagging Study Due to Failure to Meet Study Criteria Because of Specific Maladies

Malady Description	CH1		STH		Total	
	n	%	n	%	n	%
BKD[a]	28	2.6	4	0.3	32	1.2
Descaling (≥20%)	437	41.2	659	42.2	1,096	41.8
Exophthalmia	12	1.1	4	0.3	16	0.6
Fungus	101	9.5	200	12.8	301	11.5
Hemorrhaging	88	8.3	62	4.0	150	5.7
Lacerations/lesions	233	22.0	359	23.0	592	22.6
Opercular damage	77	7.3	163	10.4	240	9.2
Other	3	0.3	17	1.1	20	0.8
Parasites	77	7.3	79	5.1	156	6.0
Skeletal deformities	4	0.4	14	0.9	18	0.7
Total	1,060	100.0	1561	100.0	2,621	100.0

(a) BKD = bacterial kidney disease.

Table 2.4. Summary of Fish Excluded from Tagging Due to Failure to Meet Study Criteria in 2011

Reason for Exclusion	CH1		STH		Total	
	n	%	n	%	n	%
Moribund/Emaciated	10	2.0	8	2.2	18	2.1
Holding Mortality	14	2.8	3	0.8	17	2.0
Previously tagged	449	90.7	326	91.1	775	90.9
< 95 or > 260 mm	1	0.2	9	2.5	10	1.2
Wrong species	5	1.0	0	0.0	5	0.6
Mishandled	16	3.2	12	3.4	28	3.3
Total	495	100.0	358	100.0	853	100.0

2.3.2 Tagging Procedure

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. The majority of 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 2000-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 2.4), 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 equilibrium was regained.

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 un-intrusively 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.

Figure 2.4. Surgical Setup and Process

2.3.3 Recovery and Holding

After surgery, a maximum of five 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 2.5) and fish were held for 18 to 30 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 2.5. Post-Surgery Holding Tank with Recovery Buckets Containing Tagged Fish

2.3.4 Fish Transportation 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 with fresh river water prior to each release (Figure 2.6). 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 for delivering 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 water and oxygen levels were manually adjusted.

Figure 2.6. 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 2.5).

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 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 the 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 2.5. Relative Release Times for the Acoustically Tagged Fish to Accommodate Downstream Mixing. Releases were timed to accommodate the approximately 12-h travel time between R_2 and R_3.

	Relative Release Times	
Release Location	AM Start	PM Start
V_1 (rkm 309)	Continuous	Continuous
R_2 (rkm 307)	Day 1: 0300	Day 1: 1500
R_3 (rkm 275)	Day 1: 1500	Day 2: 0300

2.4 Detection of Tagged Fish

Two types of acoustic telemetry receiver arrays, cabled on the dams and autonomous at specific sites throughout the Columbia River, were deployed to detect fish surgically tagged with JSATS acoustic micro-transmitters as they passed downstream through the study reach between Roosevelt, Washington, at rkm 390 and Oak Point, Washington, at rkm 86 (Table 2.6). The Dalles Dam forebay detection array was used for creating a virtual fish release group, composed of tagged smolts arriving from upriver release locations at rkm 390, rkm 346, and rkm 325. This was the primary array used for estimating forebay residence time, project passage time, and the survival rate of fish passing from the forebay entrance through the tailrace. The dam-face array was used to regroup fish to form the virtual-release (V_1) group, assign specific passage routes, 3D track, calculate forebay residence and tailrace egress times, and act as the primary array for estimating the overall dam passage survival at TDA. The tailrace array was used for the tailrace egress time estimate, project passage time estimate, forebay-to-tailrace survival estimate, and was the location for the first paired fish release. The tailrace array was used for the tailrace egress time estimate and was the location for the first paired fish release. The array located near Hood River, Oregon, was used as the primary survival-detection array for all virtual releases of fish passing through TDA and was the location of the second paired fish release. The Bonneville Dam (BON) dam-face array was used as the secondary survival-detection array for estimating the survival of virtual fish releases at TDA, and as the primary survival-detection array for estimating survival of the tailrace and tailwater reference-release groups. The first BON tailwater array near Vancouver, Washington, was used as a tertiary survival-detection array for estimating the survival of virtual fish releases at TDA and as the secondary survival-detection array for estimating survival of the reference releases. The second BON tailwater array near Kalama, Washington, serves as the next higher order survival-detection array for both the virtual and reference releases of fish. The final downriver tailwater array near Oak Point, Washington, at rkm 86, can only be used for estimating the product of survival and detection probabilities (Lambda), for the last river reach between CR113 and CR086. This product was also used in the calculation of TDA dam passage survival rate. Deployment locations for both cabled and autonomous arrays are listed in Appendix C.

Table 2.6. Description, Location, Name, and Survival Model Function of Arrays Deployed in 2011. Array names were a concatenation of "CR" for Columbia River and the nearest whole river kilometer (rkm) to the array, as measured from the mouth of the Columbia River.

Array Description	Location	Array Name	Array Function
TDA Forebay	2.1 km upstream of TDA spillway	CR311	Virtual release array for forebay-to-tailrace survival estimates; forebay residence time; project passage time
TDA Dam Face	The Dalles Dam	CR309	Virtual release array for dam passage survival estimate assign route-specific passage; 3D tracking; forebay residence time; and tailrace egress time
TDA Tailrace	2 km downstream of TDA spillway	CR307	Paired fish release (reference) array; project passage time; tailrace egress time estimate; forebay-to-tailrace survival estimate
TDA Tailwater	Near Hood River, OR	CR275	Primary survival array for virtual releases of fish at TDA (forebay entrance or dam face); paired fish release location
BON Dam Face	Bonneville Dam	CR234	Secondary survival for TDA virtual releases; primary for TDA tailrace and tailwater reference fish releases
BON Tailwater 1	Near Vancouver, WA	CR161	Tertiary survival array for TDA virtual releases and secondary for TDA reference-release groups
BON Tailwater 2	Near Kalama, WA	CR113	Quaternary survival array for TDA virtual releases, and tertiary survival for TDA reference-release groups
BON Tailwater 3	Near Oak Point, WA	CR086	Estimate of the product of detection and survival probabilities (Lambda) for final river reach CR113 to CR086

2.4.1 Cabled Dam-Face Arrays

The cabled dam-face receiver was designed by PNNL for the USACE using an off-the-shelf user-built system (Weiland et al. 2011). Each cabled receiver consists of a computer, data-acquisition software, digital signal-processing cards with field-programmable gate array (DSP+FPGA), global positioning system (GPS) card, four-channel signal-conditioning receiver with gain control, hydrophones, and cables (Figure 2.7). The software that controls data acquisition and signal processing is the property of the USACE and is made available by the USACE as needed. All cabled receivers were tested for performance in an anechoic tank prior to deployment (Deng et al. 2010).

Two modular JSATS cabled arrays were deployed along the upstream face of TDA to detect JSATS-tagged smolts approaching the dam. A single dam-face cabled array consisted of 26 cabled receivers, each supporting up to 4 hydrophones. Hydrophones were deployed in a double-detection array pattern (Figure 2.2) where two cabled receivers alternate across four pier noses. In addition, to the purposes described in Section 2.2, the double-detection array pattern provides data redundancy and reduces data gaps.

A total of 52 hydrophones were deployed on powerhouse piers and associated receivers were housed in trailers on the forebay deck. Hydrophones were deployed on trolleys in pipes attached to the main piers at the powerhouse and spillway (Figure 2.8 and 2.9) in a known fixed geometry. Trolley pipes at the powerhouse were 4 in. in diameter, and made of powder-coated, schedule 40 steel that was slotted down one side for deployment of the trolley. A cone was attached to the top of the pipe to assist with trolley insertion (Figure 2.9). Pipes at the powerhouse were 80 ft long and extended from deck level at elevation 185 ft above MSL down to a mid-intake depth at elevation 105 above MSL. One hydrophone on each pier was deployed at a shallow elevation (147 ft above MSL) and another was deployed at a deep elevation (107 ft above MSL) to provide acceptable geometries for tracking an acoustically tagged fish in three dimensions and then assigning it a route of passage through the dam.

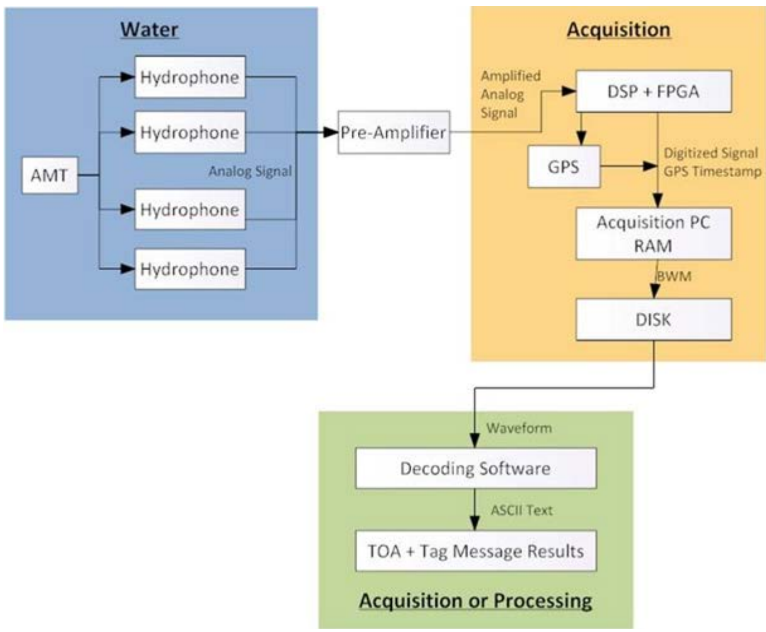


Figure 2.7. Schematic of Dam-Face Receiver System Showing the Main Components and Direction of Signal Acquisition and Processing. Abbreviations are as follows: AMT = acoustic micro-transmitter implanted in fish; DSP = digital signal processing card; FPGA = field programmable gate array; GPS = global positioning system; PC = personal computer; RAM = random access memory; BWM = binary waveform; TOA = time of arrival.

Figure 2.8. Location of Hydrophones on the Dam Face and in the Forebay of The Dalles Dam, 2010. The green and red symbols represent dam-face and clump mount hydrophones, respectively.

Figure 2.9. Trolley Pipe Mounted on a Main Pier of The Dalles Dam Powerhouse

At the spillway, 30 hydrophones were deployed in April and associated receivers were housed in the spillway galley. The hydrophones were mounted on trolleys that were deployed in 60-ft-long, 4-in.-diameter slotted pipes. At each spillway pier, one hydrophone was deployed at a shallow elevation (151 ft above MSL) and the other at a deep elevation (123 ft above MSL). Each steel trolley slid down inside the pipe and was guided by an extension arm that protruded from the slot. The arm positioned the anechoic baffled hydrophone perpendicular to the face of the dam (Figure 2.10).

Figure 2.10. Trolleys Used to Deploy Hydrophones at The Dalles Dam Powerhouse and Spillway, 2010. A 4-in.-diameter trolley with hydrophone for deploying in slotted pipes on powerhouse and spillway piers. 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 initial deployment plan for 2011 called for hydrophones deployed across only Bays 1–12 on the spillway. As runoff increased Columbia River flows to higher than expected an additional set of receivers were deployed to cover the south bays of the spillway, which were opened to pass the extra water. Eleven hydrophones on the spillway were lost in May and June between Bays 8 and 15 when high water velocities removed the trolley pipes from the pier noses. Due to continued high flows at the spillway these hydrophones were not replaced on the dam.

2.4.2 Autonomous Receiver 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 USACE to detect JSATS acoustic micro-transmitter tags in a riverine environment. Each node is an independent, self-contained data acquisition instrument, that may be anchored in the river where necessary, and it consists of a node top that houses the hydrophone, a pair of processing circuit boards, a compact flash card (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).

Autonomous nodes were deployed with the configuration shown in Figure 2.12. Nodes were attached to a 1.5-m section of rope with three 2.7-kg buoyancy floats, using a compression strap around the node's housing at its balance point. An acoustic release (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, depending 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 less than 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.

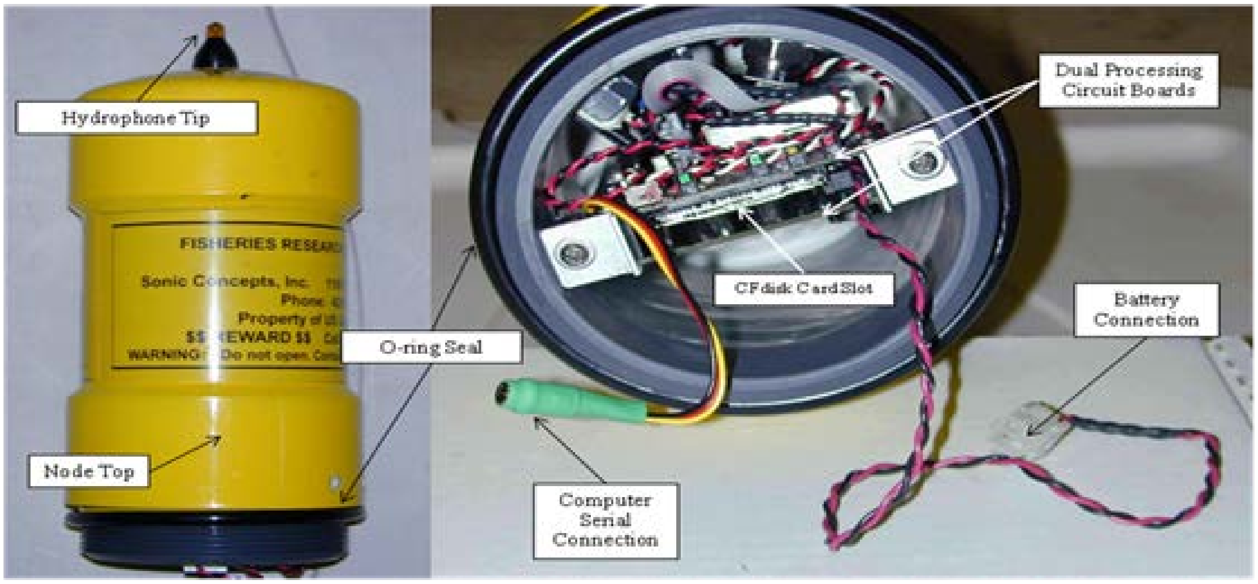


Figure 2.11. Outer (Left image) and Internal (Right) Views of an Autonomous Node Top

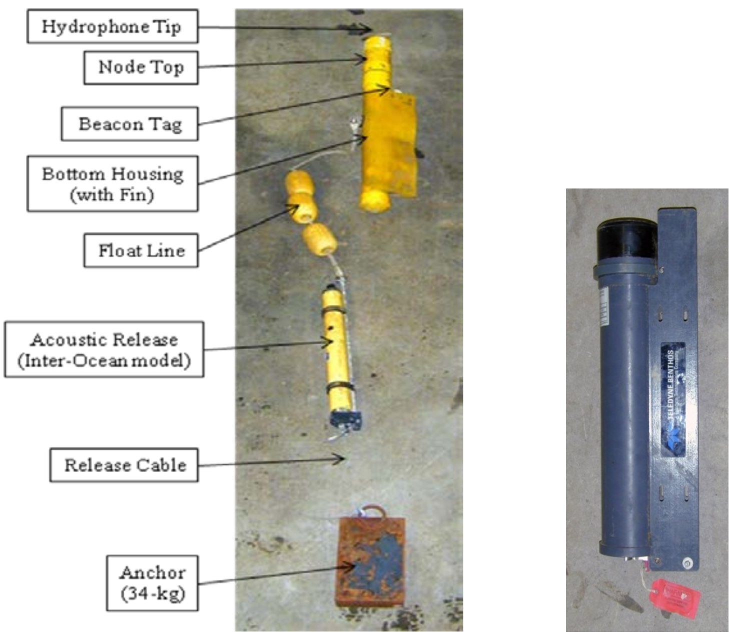


Figure 2.12. Autonomous Node Deployment Rigging (Left) and Teledyne Acoustic Release (Right)

Autonomous nodes were deployed in arrays located at specific sites for the lower Columbia River study (Figure 2.13). 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" and detects passing fish that had JSATS tags surgically implanted in their body cavities. Autonomous nodes in most of the arrays were deployed within 150 m of each adjacent node and less than about 75 m from shore.

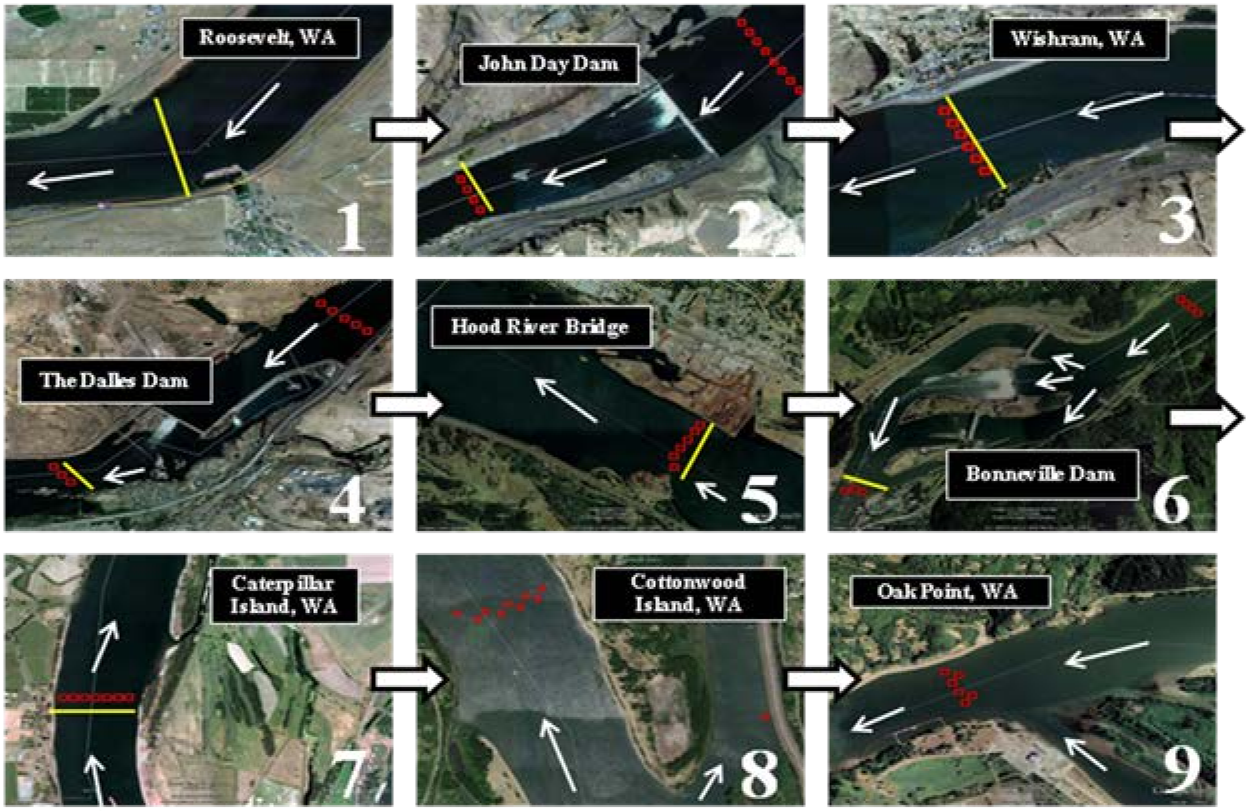


Image 1: fish release location R_1, near Roosevelt, Washington, at rkm 390; **Image 2:** John Day forebay array (right; CR351) and tailrace array (left; CR346) with associated fish release location R_2; **Image 3:** JDA tailwater array (CR325) with fish release location R_3, near Celilo, Oregon, and Wishram, WA; **Image 4:** The Dalles forebay array (right; CR311), tailrace array (left; CR307) and fish release location R_4; **Image 5:** TDA tailwater array (CR275) and fish release location R_5, near Hood River, OR, at rkm 275; **Image 6:** Bonneville forebay array (right; CR236), tailrace array (left; CR233) and fish release location R_6; **Image 7:** Bonneville tailwater array (CR161) and associated fish release location R_7, near Caterpillar Island and Vancouver, WA; **Image 8:** Bonneville tailwater array (CR113) near Cottonwood Island and KalamaWA; and **Image 9:** Bonneville tailwater array (CR086) near Oak Point, WA.

Figure 2.13. Location of the Seven Fish Release Transects (Yellow Lines in Images) and the Eleven Autonomous Node Arrays (Red Squares) Deployed to Detect Acoustically 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. In the text box below the figure, 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.

Eleven separate autonomous node arrays were deployed for the entire lower Columbia River study (Figure 2.13). Each array was named by concatenating CR (for Columbia River) with the nearest whole rkm 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 name CR351. A JDA tailrace egress array (CR346), which was also the second fish release site $R_{2,}$ 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 R_3 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 $R_{4,}$ was located about 2 km downstream of the TDA spillway. A sixth array (CR275) was located at the fifth release site $R_{5,}$ 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 $R_{6,}$ was located about 1 km downstream of the BON spillway. The next array (CR161) was the final release site R_7 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 upper end of Cottonwood Island. The last array (CR086) was located adjacent to Oak Point, Washington.

Autonomous nodes were recovered, serviced, and redeployed individually by boat, once every 2 weeks. Batteries only needed to be changed out once every 4 weeks. 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 surface, for retrieval onto 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 redeployment. Data files were also checked to verify that data was 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 assessed with the testing 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 USACE Portland District by University of Idaho.

2.5 Acoustic Signal Processing and Analysis

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.

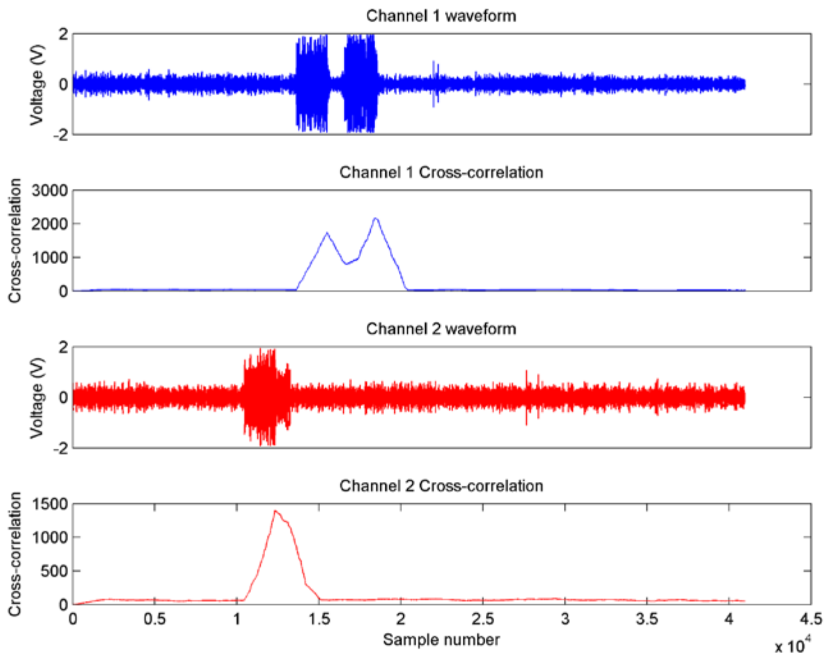


Figure 2.14. Example of Time-Domain Waveforms and Corresponding Cross-Correlations Acquired at the John Day Dam Spillway During a 2008 Study. The message portion was 1,860 samples (744 µs long). Note that multipath components were present in both channels. Decodes from the multipath components were filtered out in post-processing.

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 using standardized methods by two independent groups 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 repetition 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.

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 greater than 5 km apart or separated by one or more dams were very rare (<0.015%) and probably represented false positive detections on the upstream array. False positive detections usually will have close to the minimum number of messages and were deleted from the event data set before survival analysis.

Three-dimensional tracking of JSATS-tagged fish in the immediate forebay of TDA was used to determine routes of passage used to estimate passage efficiencies and horizontal distribution of passage, as well as forebay approach and forebay vertical distributions (Deng et al. 2011). Acoustic tracking is a common technique in bioacoustics based on time-of-arrival differences among different hydrophones. Usually, the process requires a three-hydrophone array for 2D tracking and a four-hydrophone array for 3D tracking. For this study, only 3D tracking was performed. The methods were similar to those described by Weiland et al. (2010) for JDA.

2.6 Statistical Methods

The statistical methods included tests of assumptions, estimation of dam passage survival, forebay-to-tailrace survival, travels times, passage efficiencies, and distributions. Capture histories and assessments of the survival model assumptions are contained in Appendices D and E, respectively.

2.6.1 Tests of Assumptions

2.6.1.1 Burnham et al. (1987) Tests

Tests 2 and 3 of Burnham et al. (1987) have been used in other studies 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 of 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.

2.6.1.2 Tagger Effects

Subtle differences in handling and tagging techniques can have an effect on the survival of acoustically tagged smolts used in the estimation of dam passage survival. For this reason, tagger effects were evaluated using the *F*-test (Appendix E.1). 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, where $\hat{S}_i$ is the tag-life-corrected survival estimate for the ith release group $(i = 1, \ldots, 3)$

$$F_{k-1,\infty} = \frac{s_{\hat{S}}^2}{\left(\dfrac{\sum_{i=1}^{k} \operatorname{Var}\left(\hat{S}_i \middle| S_i\right)}{k} \right)} \tag{2.5}$$

where

$$s_{\hat{S}}^2 = \frac{\sum_{i=1}^{k} \left(\hat{S}_i - \hat{\bar{S}}\right)^2}{k-1} \tag{2.6}$$

and

$$\hat{\bar{S}} = \frac{\sum_{i=1}^{k} \hat{S}_i}{k} . \tag{2.7}$$

2.6.1.3 Other Assumptions

Methods for tests of other assumptions in the survival model are presented concurrently with the results in Appendix E. These examinations included tag-lot effects, delayed handling effects, handling mortality and tag shedding, tailrace release location effects, time in-river, fish size distribution, tag-life corrections, arrival distributions, and downstream mixing.

2.6.2 Estimation of Dam Passage and Route-Specific Survivals

Maximum likelihood estimation was used to estimate dam passage survival at TDA 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.

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. 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. All calculations were performed using Program ATLAS (http://www.cbr.washington.edu/paramest/atlas/).

Dam passage survival was estimated by the function

$$\hat{S}_{\text{Dam}} = \frac{\hat{S}_1}{\left(\dfrac{\hat{S}_2}{\hat{S}_3}\right)} = \frac{\hat{S}_1 \cdot \hat{S}_3}{\hat{S}_2} \tag{2.8}$$

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.

During 2011, the compliance study at TDA was planned for a dam operation consisting of a 40% spill. High flow conditions in spring 2011, however, interrupted the prescribed spill level. 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:

- survival during 40% spill – early season (April 29–May 17, 2011)
- survival season-wide (April 29–May 30, 2011).

The estimates of dam passage survival were based on the virtual/paired-release design using capture-history data (Appendix D) and the fitted tag-life curve (Figure E.6). The estimate was based on the tag-life-adjusted survival estimates for releases V_1, R_2, and R_3. A total of five detection sites (D_1-D_5) were used in the analysis (Figure 2.1) to ensure all available information was used in the estimation process.

The number of arrays used in the survival analysis compensated for the lower detection probabilities in 2011 due to high river flows. Analogous estimates were produced for TDA route-specific survivals.

2.6.3 Estimation of Forebay-to-Tailrace Survival

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

2.6.4 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.,

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

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

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

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

The estimated tailrace egress time was based on the time from last detection of a fish at the double array at the dam face at TDA to the last detection at the tailrace array 2 km downstream of the dam. The estimated forebay residence times were based on the time from the first detection at the forebay BRZ array 2 km above the dam to the last detection at the double array in front of TDA. In summary, various travel times were estimated as follows:

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

2.6.5 Estimation of Passage Efficiencies

Spill passage efficiency was estimated by the fraction

$$\widehat{SPE} = \frac{\hat{N}_{SP}}{\hat{N}_{SP} + \hat{N}_{SL} + \hat{N}_{T}}, \tag{2.11}$$

where $\hat{N}_i$ is the estimated abundance of acoustically tagged fish through the *i*th route (*i* = spillway [SP], sluiceway, [SL], or turbines [T]). The double-detection array was used to estimate absolute abundance (*N*) through a route using the single mark-recapture model (Seber 1982) independently at each route. Calculating the variance in stages, the variance of $\widehat{\mathrm{SPE}}$ was estimated as

$$\mathrm{Var}\left(\widehat{\mathrm{SPE}}\right) = \frac{\widehat{\mathrm{SPE}}\left(1-\widehat{\mathrm{SPE}}\right)}{\sum_{i=1}^{3}\hat{N}_i} + \widehat{\mathrm{SPE}}^2\left(1-\widehat{\mathrm{SPE}}\right)^2 \cdot \left[\frac{\mathrm{Var}\left(\hat{N}_T\right)+\mathrm{Var}\left(\hat{N}_{SL}\right)}{\left(\hat{N}_T+\hat{N}_{SL}\right)^2} + \frac{\widehat{\mathrm{Var}}\left(\hat{N}_{SP}\right)}{\hat{N}_{SP}^2}\right]. \tag{2.12}$$

Fish passage efficiency[1] was estimated by the fraction

$$\widehat{\mathrm{FPE}} = \frac{\hat{N}_{SP} + \hat{N}_{SL}}{\hat{N}_{SP} + \hat{N}_{SL} + \hat{N}_{T}},$$

Calculating the variance in stages, the variance of $\widehat{\mathrm{FPE}}$ was estimated as

$$\mathrm{Var}\left(\widehat{\mathrm{FPE}}\right) = \frac{\widehat{\mathrm{FPE}}\left(1-\widehat{\mathrm{FPE}}\right)}{\sum_{i=1}^{3}\hat{N}_i} + \widehat{\mathrm{FPE}}^2\left(1-\widehat{\mathrm{FPE}}\right)^2 \cdot \left[\frac{\mathrm{Var}\left(\hat{N}_{SP}\right)+\mathrm{Var}\left(\hat{N}_{SL}\right)}{\left(\hat{N}_{SP}+\hat{N}_{SL}\right)^2} + \frac{\widehat{\mathrm{Var}}\left(\hat{N}_{T}\right)}{\hat{N}_{T}^2}\right]. \tag{2.13}$$

Spill passage efficiency and FPE estimates were based on the assumption of equal detection probabilities across the dam and a binomial sampling model.

2.6.6 Estimation of Distributions

The 3D tracks (Section 2.5) were used to determine forebay approach distributions, forebay vertical distributions, and horizontal passage distributions following the methods of Weiland et al. (2010). For the purpose of forebay approach distribution, the dam was partitioned into “arrival blocks” at a distance of 100 m from the dam—MU 22–MU 12; MU 11–FU 1; spillway south (Bays 10−23); spillway Bays 1–9; and spillway north (spillway wall north of May 1). The horizontal location (parallel to the face of the dam) where a tagged fish was first detected 100 m perpendicular from the dam was ascribed to an arrival block. Fish were tracked in 3D until they passed at a known portal in the dam, whence they were ascribed to a “passage block” analogous to the arrival block. The data were analyzed to determine the proportions of total tagged fish approaching the dam for a given arrival block by passage block. For vertical distribution, the average depth was determined for a given 3D tracked fish within distance bins centered

[1] Fish passage efficiency was called spill passage efficiency in the Fish Accords.

on 75 m, 50 m, 25 m, 10 m, and 5 m from the dam. The median depth for the population of tagged fish within a distance bin was determined and used to convey vertical distribution. Horizontal distributions were estimated by computing the proportions for each portal (turbine, sluice entrance, and spill bay) out of total passage at a given route (turbines, sluiceway, or spillway).

3.0 Results – Yearling Chinook Salmon

This section contains run timing data, estimates of survival rates, travel times, passage efficiencies, and distributions for yearling Chinook salmon at TDA during spring 2011. Performance of the JSATS equipment, tagging and release data, and capture-history data for acoustically tagged yearling Chinook salmon are presented in Appendices A, B, and D, respectively. The assessment of model assumptions showed that the assumptions were met, allowing estimation of survival rates for yearling Chinook salmon (Appendix E).

3.1 Run Timing

The cumulative percent of yearling Chinook salmon that had passed TDA by a specific date was calculated from smolt index data for JDA (40 km upstream; ~0.5 d travel time) obtained from the Fish Passage Center (Figure 3.1). From April 29 through May 17, 2011, 46% of yearling Chinook salmon had passed TDA. By the end of the study on May 30, 2011, 87% of yearling Chinook salmon had passed the dam.

Table 3.1. Cumulative Percentages of Juvenile Steelhead and Yearling Chinook Salmon that Had Passed The Dalles Dam in 2011. Data are based smolt monitoring data from John Day Dam and reflect a 12-h offset for travel time between John Day and The Dalles dams.

		%First Date	%Last Date	%Total Run
Early Season	4/29–5/17	7.70	53.57	45.88
Season-wide	4/29–5/30	7.70	94.67	86.98

3.2 Survival Estimates

The estimates of dam passage survival for yearling Chinook salmon smolts at TDA were calculated for two periods of time. One period was from the beginning of the study on April 29 through May 17, 2011, while flows were moderate and spill was held constant at 40%. The second time period was from the beginning to end of the study, April 29 through May 30, 2011, and includes the higher flows and spill levels in excess of 40% later in the season (Figure 1.5).

For the early part of the study, dam passage survival (CR309 to CR307) was estimated to be

$$\hat{S}_{\text{Dam}} = \frac{0.9591}{\left(\dfrac{0.9726}{0.9857}\right)} = \frac{0.9591}{0.9867} = 0.9721^{1} \qquad (3.1)$$

with an associated $\widehat{\text{SE}}$ of 0.0104 (Table 3.2). For the entire study period, dam passage survival for yearling Chinook salmon smolts was estimated to be

[1] The estimate of 0.9721 was output from the analysis program; it is not 0.9720 because of rounding error in the later value.

$$\hat{S}_{\text{Dam}} = \frac{0.9589}{\left(\frac{0.9839}{0.9851}\right)} = \frac{0.9589}{0.9988} = 0.9600^{1} \tag{3.2}$$

with an associated $\widehat{\text{SE}}$ of 0.0074[2] (Table 3.3). Both early season or season-wide estimate of dam passage survival exceeded the 2008 BiOp requirements for $\hat{S} \geq$ 0.9600 and $\widehat{\text{SE}} \leq$ 0.015.

Table 3.2. Tag-Life-Adjusted Survival Estimates of Reach Survival and Detection Probabilities for Yearling Chinook Salmon Smolts Used in Estimating Dam Passage Survival at The Dalles Dam in the Early Season (April 29–May 17) During 2011. Parameter estimates are based on fully parameterized release-recapture models for each group. The SE is based on both the inverse hessian matrix and bootstrapping for key parameters (†) and only the inverse hessian matrix for associated parameters (*). The $\hat{\lambda}$ is the joint probability of survival and detection in the last reach. The $\hat{p}$ is the probability of detection.

	Rkm 309 to 275		Rkm 275 to 234		Release to Rkm 234		Rkm 234 to 161		Rkm 161 to 113	
Release Group	$\hat{S}$	$\widehat{\text{SE}}^{\dagger}$	$\hat{S}$	$\widehat{\text{SE}}^{*}$	$\hat{S}$	$\widehat{\text{SE}}^{\dagger}$	$\hat{S}$	$\widehat{\text{SE}}^{*}$	$\hat{S}$	$\widehat{\text{SE}}^{*}$
V_1	0.9591	0.0038	0.9942	0.0016			0.9537	0.0045	0.9865	0.0054
R_2					0.9726	0.0077	0.9609	0.0094	0.9916	0.0110
R_3					0.9857	0.0060	0.9482	0.0109	1.0003	0.0127
	Rkm 113 to 86		Rkm 275		Rkm 234		Rkm 161		Rkm 113	
Release Group	$\hat{\lambda}$	$\widehat{\text{SE}}^{*}$	$\hat{p}$	$\widehat{\text{SE}}^{*}$	$\hat{p}$	$\widehat{\text{SE}}^{*}$	$\hat{p}$	$\widehat{\text{SE}}^{*}$	$\hat{p}$	$\widehat{\text{SE}}^{*}$
V_1	0.8478	0.0083	0.9893	0.0020	1.0	0.0	0.8863	0.0066	0.7753	0.0092
R_2	0.8573	0.0193			1.0	0.0	0.9306	0.0140	0.7919	0.0205
R_3	0.8325	0.0206			1.0	0.0	0.8990	0.0148	0.7562	0.0226

As might be expected, the forebay-to-tailrace survival estimates for yearling Chinook salmon are slightly lower than the respective estimates of dam passage survival due to the additional travel distance above the dam (Table 3.4). Standard errors for the estimates of dam passage survival and forebay-to-tailrace were similar because of the very similar sample sizes used in both sets of calculations.

[1] The estimate of 0.9600 was output from the analysis program; it is not 0.9601 because of rounding error in the later value.
[2] The standard error of 0.0074 was made by estimating the full variance, which made it 0.0002 higher than the standard error in the compliance report, which was based on the inverse Hessian only.

Table 3.3. Tag-Life-Adjusted Survival Estimates of Reach Survival and Detection Probabilities for Yearling Chinook Salmon Smolts Used in Estimating Dam Passage Survival at The Dalles Dam Season-Wide (April; 29−May 30) During 2011. Parameter estimation as described in Table 3.2.

	Rkm 309 to 275		Rkm 275 to 234		Release to Rkm 234		Rkm 234 to 161		Rkm 161 to 113	
Release Group	$\hat{S}$	$\widehat{\text{SE}}^{\dagger}$	$\hat{S}$	$\widehat{\text{SE}}^{*}$	$\hat{S}$	$\widehat{\text{SE}}^{\dagger}$	$\hat{S}$	$\widehat{\text{SE}}^{*}$	$\hat{S}$	$\widehat{\text{SE}}^{*}$
V_1	0.9589	0.0031	0.9945	0.0013			0.9531	0.0040	0.9604	0.0069
R_2					0.9839	0.0048	0.9541	0.0092	0.9467	0.0161
R_3					0.9851	0.0047	0.9451	0.0099	0.9571	0.0176
	Rkm 113 to 86		Rkm 275		Rkm 234		Rkm 161		Rkm 113	
Release Group	$\hat{\lambda}$	$\widehat{\text{SE}}^{*}$	$\hat{p}$	$\widehat{\text{SE}}^{*}$	$\hat{p}$	$\widehat{\text{SE}}^{*}$	$\hat{p}$	$\widehat{\text{SE}}^{*}$	$\hat{p}$	$\widehat{\text{SE}}^{*}$
V_1	0.7143	0.0086	0.9161	0.0044	1.0	0.0	0.8526	0.0061	0.7588	0.0084
R_2	0.7007	0.0197			1.0	0.0	0.8615	0.0135	0.7657	0.0190
R_3	0.6944	0.0205			1.0	0.0	0.8543	0.0139	0.7184	0.0203

Table 3.4. Estimates of Forebay-to-Tailrace Survival Estimates (CR311 to CR307) for Yearling Chinook Salmon at The Dalles Dam for the Early Season and Season-Wide Spring Study in 2011

Period	Survival
Early Season (April 29–May 17)	0.9712 (0.0104)
Season-Wide (April 29–May 30)	0.9596 (0.0072)

Route-specific, dam passage survival estimates (CR309 to CR234; TDA virtual release to BON) for yearling Chinook salmon were highest for the sluiceway (99.1%), followed by the spillway (96.1%) (Table 3.5). The lowest survival rates were through turbine routes (93.0%).

Table 3.5. Route-Specific, Season-Wide Dam Passage Survival Estimates for Yearling Chinook Salmon (CR309 to CR 234; TDA virtual release to BON)

Route	Survival	SE	n
Sluiceway	0.9914	0.0079	734
Spillway	0.9607	0.0077	2793
Turbine	0.9297	0.0117	701

3.3 Travel Times

For yearling Chinook salmon smolts, mean forebay residence time (CR 311 to CR 309) was 1.31 h ($\widehat{\text{SE}}$ = 0.14), with a median value of 0.97 h (Table 3.6). The majority of the fish reached the dam in less than 1.5 h (Figure 3.1a). Tailrace egress (CR309 to CR 311) averaged 1.33 h (Table 3.6). As in the forebay, most of the tagged fish exited the tailrace in less than 1 h (Figure 3.1). Mean total project passage time (CR 311 to CR 307) for yearling Chinook salmon was 2.49 h with a median of 1.42 h.

Table 3.6. Travel Times (h) for Yearling Chinook Salmon at The Dalles Dam in 2011. Standard errors are in parentheses.

Travel Time Metric	Segment	Mean	Median
Forebay Residence	CR311-309	1.31 (0.14)	0.97 (0.14)
Tailrace Egress	CR309-307	1.33 (0.23)	0.24 (0.23)
Project Passage	CR311-307	2.49 (0.22)	1.42 (0.22)

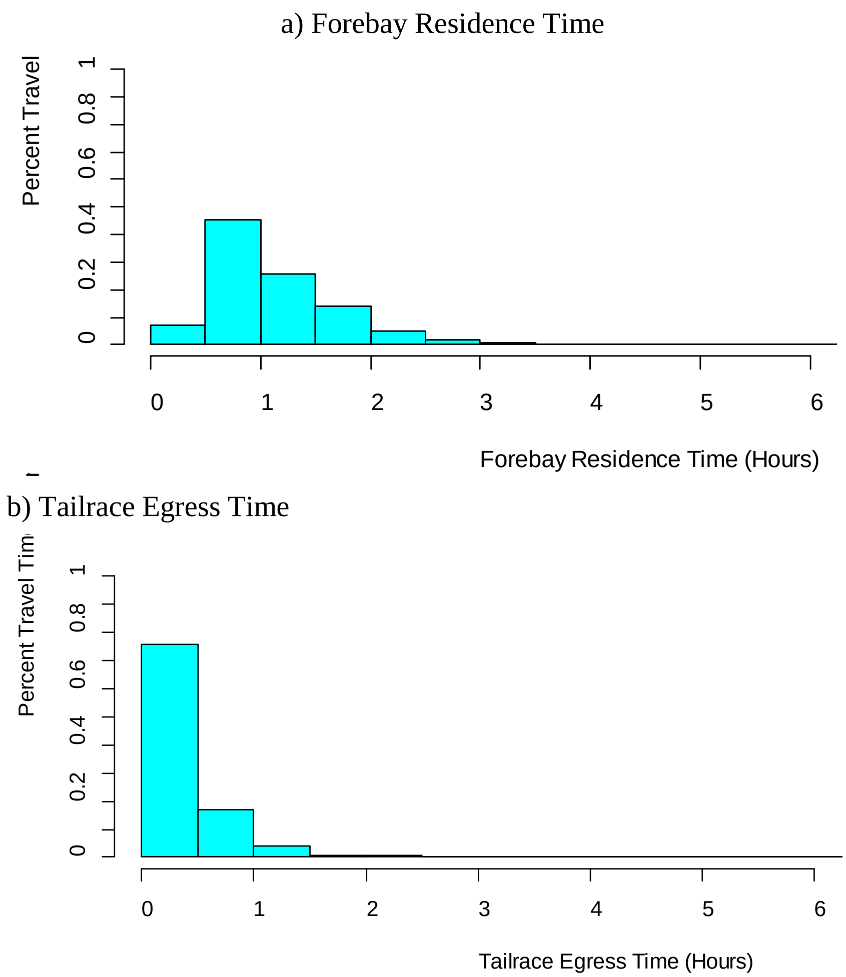


Figure 3.1. Distribution of Yearling Chinook Salmon a) Forebay Residence and b) Tailrace Egress Times at The Dalles Dam 2011

3.4 Passage Efficiencies

For the dam as a whole, 83% of the acoustically tagged yearling Chinook salmon passed via non-turbine routes (Table 3.7). For non-turbine passage out of total project passage, 66% occurred at the spillway and 17% at the sluiceway. Turbine passage was 17% of the total. For the powerhouse as a whole, 51% of the yearling Chinook passed via the sluiceway.

Fish passage efficiency was 17% higher during daytime than nighttime on an absolute basis (Table 3.7). Spillway passage efficiency was also higher (9%) during day than night. Sluiceway passage efficiency relative to the entire dam was 8% higher during day than night. Relative to the powerhouse, sluiceway passage efficiency was over twice as high during day than night.

Table 3.7. Passage Efficiencies for Yearling Chinook Salmon at The Dalles Dam During 2011. Sample sizes are slightly higher for passage efficiency estimates than route-specific survival estimates because of restrictions for tag-life corrections on fish used in survival estimates that do not apply to passage efficiencies.

Metric	Total	SE	n	Day	SE	n	Night	SE	n
Fish Passage Efficiency	0.831	0.006	4242	0.900	0.006	2478	0.734	0.011	1764
Spill Passage Efficiency	0.658	0.007	4242	0.691	0.009	2478	0.612	0.012	1764
Sluiceway Efficiency || Dam	0.173	0.006	4242	0.209	0.008	2478	0.122	0.008	1764
Sluiceway Efficiency || Powerhouse	0.506	0.013	1450	0.678	0.017	766	0.314	0.018	684

3.5 Distributions

This section covers forebay approach distribution, forebay vertical distribution, and horizontal distribution for yearling Chinook salmon during spring 2011 at TDA. Forebay approach distribution for yearling Chinook salmon, based on the time and location of first detection 100 m from the dam, was skewed toward the upstream half of the TDA powerhouse (MU 22 to MU 12), where 52% of the tagged yearling Chinook salmon first arrived (Figure 3.2a). Another 20% of the total arrived at the downstream portion of the powerhouse (MU 11 to FU 1). Twenty-eight percent of the yearling Chinook salmon approached the dam at the spillway after moving directly down the Washington side of the forebay. All tagged fish that approached the spillway directly passed there. Thirty-two percent of the total fish arriving at the dam approached within 100 m of the powerhouse before migrating over to the spillway and passing there. Arrival distributions for yearling Chinook salmon were similar between day and night (Figure 3.2b,c). During night, however, fish approaching the powerhouse were more likely to pass into the turbines or the sluiceway than move past the powerhouse to pass at the spillway, as observed during daytime.

Forebay vertical distribution, as indicated by the median depths of the 3D tracked last detection locations by distance (≤5 m, 10 m, 25 m, etc.) from the dam where fish passed, showed at least 50% of the tagged yearling Chinook salmon were in the surface 5 m of water in most locations (Figure 3.3). Vertical distribution was relatively constant as distance to the dam decreased for fish passing at the downstream half of the powerhouse, the southern spillway, and Bays 1–9. At the spillway north location, fish moved up in the water column to pass the dam. At the upstream half of the powerhouse (MU 12–22), fish sounded to pass the dam. Vertical distribution was generally shallower during day than night (Figure 3.3).

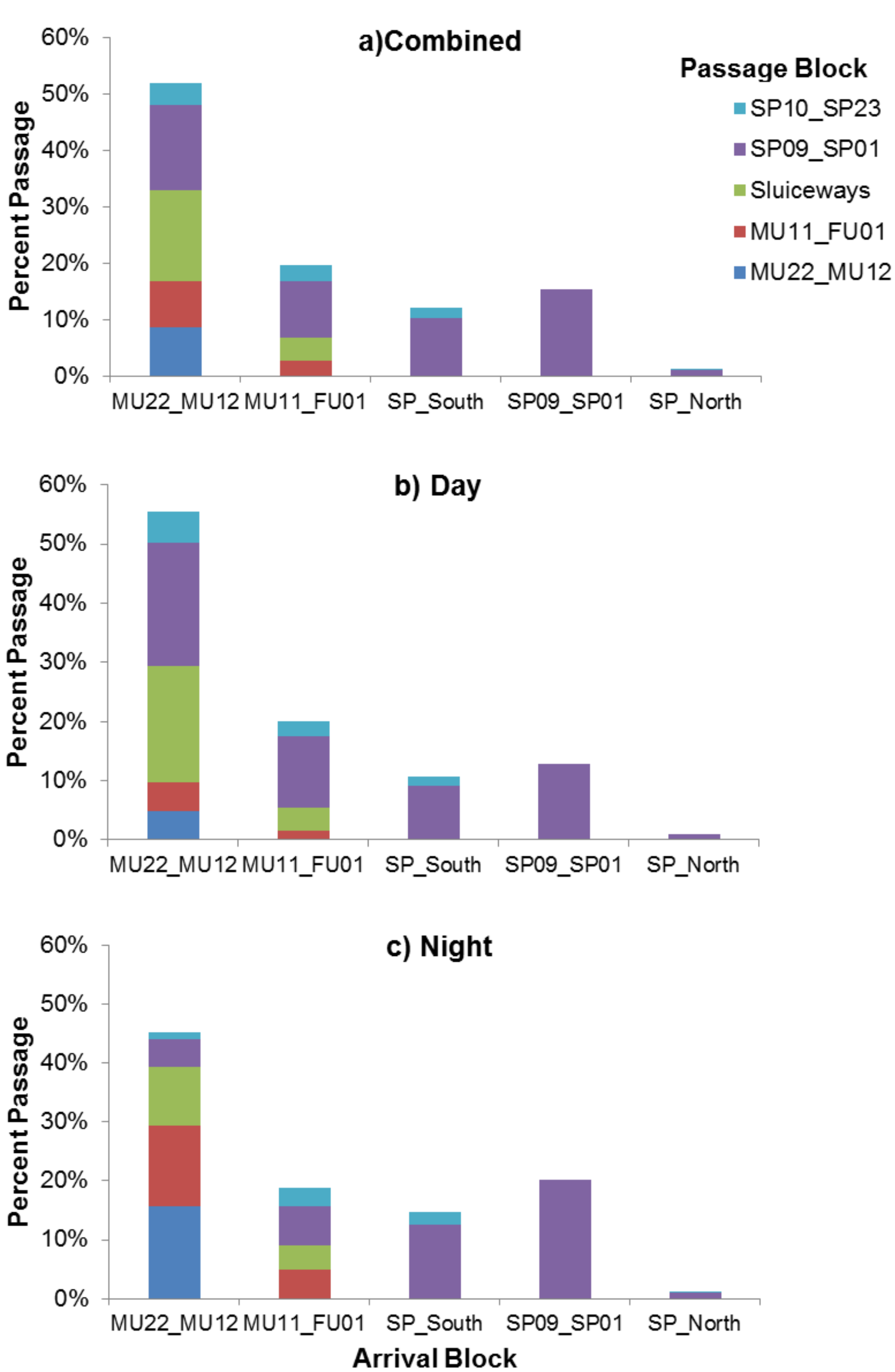


Figure 3.2. Yearling Chinook Salmon Approach and Passage Behavior Patterns at The Dalles Dam During 2011: a) Day/Night Combined; b) Day; and c) Night. The sum of the percent passages for the arrival blocks equals 100%. The sum of the percentages across all arrival blocks for a given passage block equals its passage efficiency (Table 3.7).

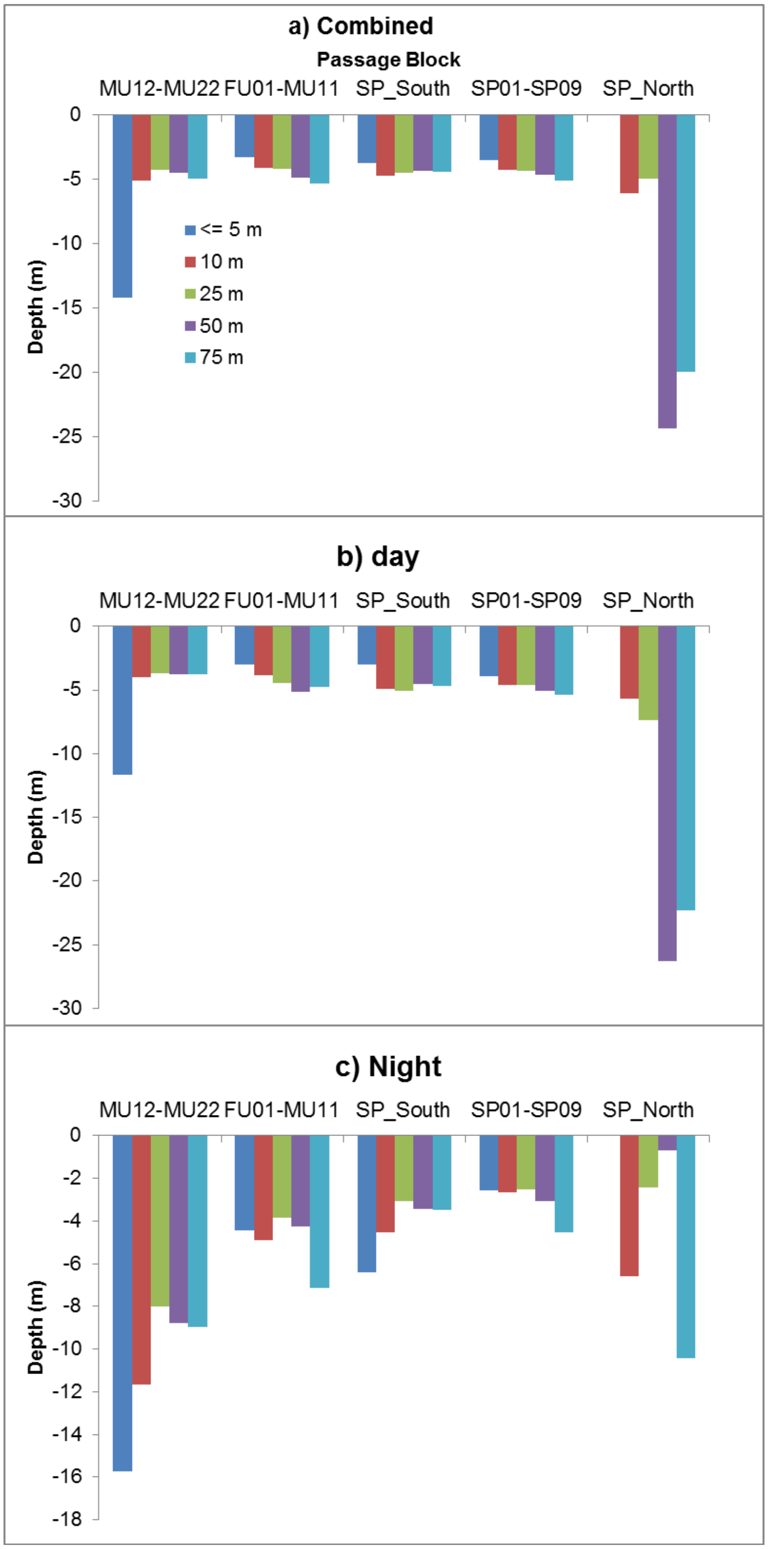


Figure 3.3. Forebay Vertical Distribution as Indicated by Median Depths of Last Detection by Distance (see legend) by Passage Block (location) from The Dalles Dam for Tagged Yearling Chinook Salmon During 2011. Depth is relative to the reference hydrophone. The reference hydrophone for powerhouse hydrophones was #51 P22_00S and for the spillway it was #86 S12_13S.

The horizontal distribution of turbine passage for yearling Chinook salmon was bi-modal with modes around MU 1 and MU 15 (Figure 3.4). At the sluiceway, 97% of total passage was at Sluice 1-1, 1-2, and 1-3, the sluiceway entrances above MU 1. Horizontal distribution of yearling Chinook salmon passage at the spillway was dominated by Bay 8, with 22% of total spillway passage. Normally voluntary spill for juvenile fish passage is confined to Bays 1−8 inside the spill wall, but in spring 2011 flows necessitated opening additional bays; 14% to of total spillway passage of yearling Chinook salmon occurred at Bays 9−17.

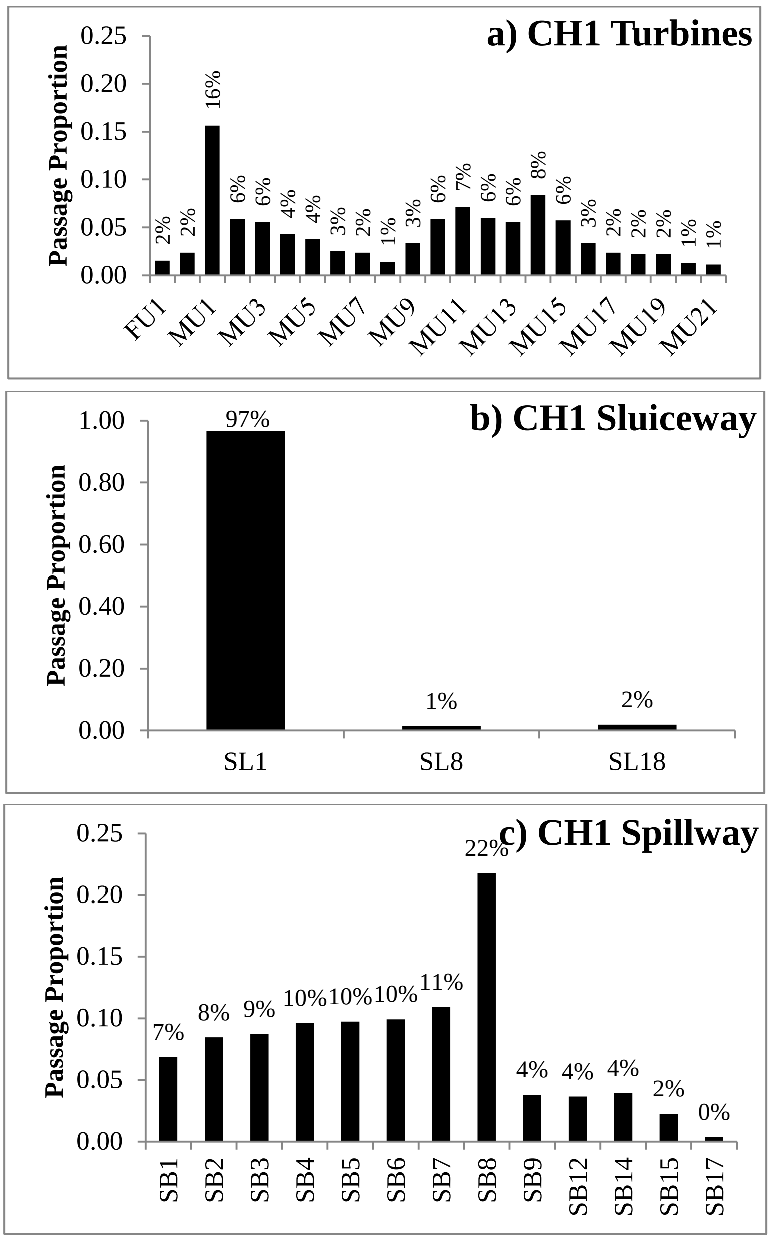


Figure 3.4. Horizontal Distribution of Passage for Yearling Chinook Salmon at the Turbines, Spillway, and Sluiceway

4.0 Results – Steelhead

This section contains run timing data, estimates of survival rates, travel times, passage efficiencies, and distributions for juvenile steelhead at TDA during spring 2011. Performance of the JSATS equipment, tagging and release data, and capture-history data for acoustically tagged juvenile steelhead are presented in Appendices A, B, and D, respectively. The assessment of model assumptions showed that the assumptions were met, allowing estimation of survival rates for juvenile steelhead (Appendix E).

4.1 Run Timing

The cumulative percent of juvenile steelhead that had passed TDA by a specific date was calculated from smolt index data for JDA (40 km upstream; ~0.5 d travel time) obtained from the Fish Passage Center (Table 4.1). From April 29 through May 17, 2011, 28% of juvenile steelhead had passed TDA. By the end of the study on May 30, 2011, 91% of juvenile steelhead had passed the dam.

Table 4.1. Cumulative Percentages of Juvenile Steelhead that Had Passed The Dalles Dam in 2011. Data are based smolt monitoring data from John Day Dam and reflect a 12-h offset for travel time between John Day and The Dalles dams.

		%First Date	%Last Date	%Total Run
Early Season	4/29–5/17	18.09	46.01	27.92
Season-wide	4/29–5/30	18.09	91.16	73.07

4.2 Survival Estimates

The estimate of dam passage survival (CR309 to CR307) for steelhead smolts at TDA during the early part of the study (i.e., April 29–May 17, 2011) was estimated to be

$$\hat{S}_{\text{Dam}} = \frac{0.9713}{\left(\frac{0.9626}{0.9834}\right)} = \frac{0.9713}{0.9788} = 0.9924^{1} \qquad (3.3)$$

with an associated $\widehat{\text{SE}}$ of 0.0115 (Table 4.2). Note the unadjusted survival estimate of the virtual-release group (V_1) from the dam face to rkm 275 of $\hat{S}_{V_1}$ = 0.9713 ($\widehat{\text{SE}}$ = 0.0032) also exceeded the 2008 BiOp requirements for dam passage survival.

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

$$\hat{S}_{\text{Dam}} = \frac{0.9764}{\left(\frac{0.9687}{0.9874}\right)} = \frac{0.9764}{0.9811} = 0.9952 \qquad (3.4)$$

[1] The estimate of 0.9924 was output from the analysis program; it is not 0.9923 because of rounding error in the later value.

with an associated $\widehat{\text{SE}}$ of 0.0083 (Table 4.3). Again, the unadjusted estimate of survival for the virtual release (V_1) of $\hat{S}_{V_1}$ = 0.9764 ($\widehat{\text{SE}}$ = 0.0024) exceeds BiOp standards.

In all of the above estimates of dam passage survival, the full models were used in providing parameter estimates. The philosophy was that as long as precision was adequate (i.e., $\widehat{\text{SE}} \leq$ 0.015), the full model that permits each release group (i.e., V_1, R_2, and R_3) to have unique survival and capture probabilities would also provide the most robust estimates of dam passage survival. In this way, both precision and robustness would be simultaneously achieved without sacrificing either attribute.

Table 4.2. Tag-Life-Adjusted Survival Estimates of Reach Survival and Detection Probabilities for Steelhead Smolts Used in Estimating Dam Passage Survival at The Dalles Dam in the Early Season (April 29–May 17) During 2011. Parameter estimates based on fully parameterized release-recapture models for each group. The SE is based on both the inverse hessian matrix and bootstrapping for key parameters (†) and only the inverse hessian matrix for associated parameters (*). The $\hat{\lambda}$ is the joint probability of survival and detection in the last reach. The $\hat{p}$ is the probability of detection.

Release Group	Rkm 309 to 275		Rkm 275 to 234		Release to Rkm 234		Rkm 234 to 161		Rkm 161 to 113	
	$\hat{S}$	$\widehat{\text{SE}}$ †	$\hat{S}$	$\widehat{\text{SE}}$ *	$\hat{S}$	$\widehat{\text{SE}}$ †	$\hat{S}$	$\widehat{\text{SE}}$ *	$\hat{S}$	$\widehat{\text{SE}}$ *
V_1	0.9713	0.0032	0.9801	0.0028			0.9547	0.0043	0.9951	0.0064
R_2					0.9626	0.0088	0.9437	0.0110	0.9858	0.0154
R_3					0.9834	0.0063	0.9495	0.0105	0.9706	0.0139
Release Group	**Rkm 113 to 86**		**Rkm 275**		**Rkm 234**		**Rkm 161**		**Rkm 113**	
	$\hat{\lambda}$	$\widehat{\text{SE}}$ *	$\hat{p}$	$\widehat{\text{SE}}$ *	$\hat{p}$	$\widehat{\text{SE}}$ *	$\hat{p}$	$\widehat{\text{SE}}$ *	$\hat{p}$	$\widehat{\text{SE}}$ *
V_1	0.7862	0.0098	0.9872	0.0022	1.0	0.0	0.9511	0.0045	0.7648	0.0098
R_2	0.7782	0.0226			1.0	0.0	0.9502	0.0106	0.7579	0.0230
R_3	0.7860	0.0218			1.0	0.0	0.9685	0.0086	0.8279	0.0206

Table 4.3. Tag-Life-Adjusted Survival Estimates of Reach Survival and Detection Probabilities for Steelhead Smolts Used in Estimating Dam Passage Survival at The Dalles Dam Season-Wide (April 29-May 30) During 2011. Parameter estimation as described in Table 4.2.

Release Group	Rkm 309 to 275		Rkm 275 to 234		Release to Rkm 234		Rkm 234 to 161		Rkm 161 to 113	
	$\hat{S}$	$\widehat{\text{SE}}$ †	$\hat{S}$	$\widehat{\text{SE}}$ *	$\hat{S}$	$\widehat{\text{SE}}$ †	$\hat{S}$	$\widehat{\text{SE}}$ *	$\hat{S}$	$\widehat{\text{SE}}$ *
V_1	0.9764	0.0024	0.9843	0.0021			0.9458	0.0039	0.9696	0.0080
R_2					0.9687	0.0064	0.9401	0.0097	0.9451	0.0189
R_3					0.9874	0.0043	0.9379	0.0096	0.9445	0.0178
Release Group	**Rkm 113 to 86**		**CR275**		**CR234**		**CR161**		**CR113**	
	$\hat{\lambda}$	$\widehat{\text{SE}}$ *	$\hat{p}$	$\widehat{\text{SE}}$ *	$\hat{p}$	$\widehat{\text{SE}}$ *	$\hat{p}$	$\widehat{\text{SE}}$ *	$\hat{p}$	$\widehat{\text{SE}}$ *
V_1	0.6159	0.0092	0.8771	0.0051	1.0	0.0	0.9177	0.0047	0.7417	0.0091
R_2	0.6239	0.0214			1.0	0.0	0.9130	0.0113	0.7477	0.0210
R_3	0.6081	0.0209			1.0	0.0	0.9154	0.0110	0.7830	0.0200

The forebay-to-tailrace survival estimates for steelhead are slightly lower than the respective estimates of dam passage survival due to the additional travel distance above the dam (Table 4.4). As with yearling Chinook salmon, standard errors for the estimates of dam passage survival and forebay-to-tailrace survival for steelhead were similar because of the very similar sample sizes used in both sets of calculations.

Table 4.4. Estimates of Forebay-to-Tailrace Survivals (CR311 to CR307) for Juvenile Steelhead at The Dalles Dam for the Early Season and Season-Wide Spring Study in 2011.

Period	Survival
Early Season (April 29–May 17)	0.9921 (0.0115)
Season-Wide (April 29–May 30)	0.9947 (0.0083)

Route-specific, dam passage survival estimates for steelhead were highest for the spillway and the sluiceway (100%) (Table 4.5). The lowest survivals were at the turbine route (91.9%).

Table 4.5. Route-Specific, Season-Wide Dam Passage Survival Estimates for Steelhead (CR309 to CR234; TDA virtual release to BON)

Route	Survival	SE	n
Sluiceway	1.0097	0.0091	592
Spillway	1.0038	0.0083	3243
Turbine	0.9189	0.0166	451

4.3 Travel Times

For steelhead smolts, mean forebay residence time was 1.22 h ($\widehat{SE}$ = 0.08), with a median value of 0.81 h Table 4.6). The majority of steelhead reached the dam in less than 1 h (Figure 4.1). Tailrace egress (CR309 to CR 307) averaged 1.97 h. As in the forebay, most of the tagged fish exited the tailrace in less than 1 h (Figure 4.1). Total project passage time (CR 311 to CR 307) for steelhead was 3.11 h with a median of 1.12 h.

Table 4.6. Travel Times (h) for Steelhead Smolts at The Dalles Dam in 2011. Standard errors are in parentheses.

Travel Time Metric	Segment	Mean	Median
Forebay Residence	CR311-309	1.22 (0.08)	0.81 (0.08)
Tailrace Egress	CR309-307	1.97 (0.25)	0.20 (0.25)
Project Passage	CR311-307	3.11 (0.25)	1.12 (0.25)

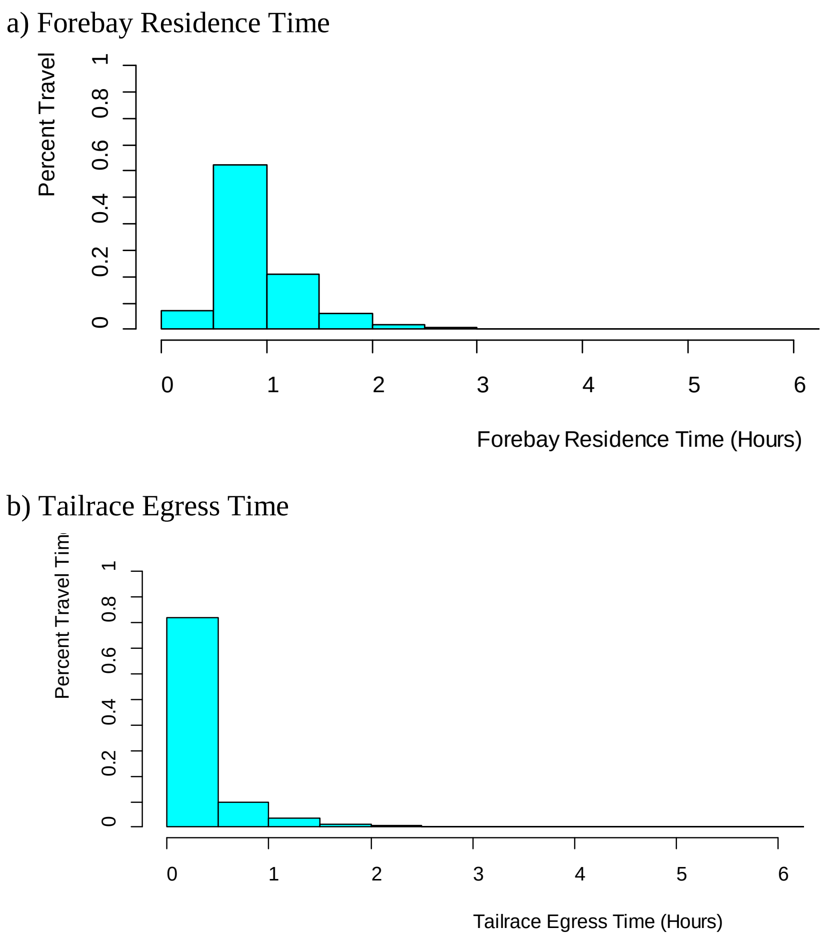


Figure 4.1. Distribution for Steelhead Smolts for a) Forebay Residence Times and b) Tailrace Egress Times at The Dalles Dam 2011

4.4 Passage Efficiencies

For the dam as a whole, 89% of the acoustically tagged steelhead passed via non-turbine routes (Table 4.7). Non-turbine passage out of total project passage was 75% at the spillway and 14% at the sluiceway. Turbine passage was 11% of the total. For the powerhouse as a whole, 56% of the steelhead passed via the sluiceway.

Fish passage efficiency was about 20% higher during daytime than nighttime on an absolute basis (Table 4.7). Spillway passage efficiency was also higher (19%) during day than night. In contrast, sluiceway passage efficiency relative to the entire dam was comparable between day and night; however, relative to the powerhouse, sluiceway efficiency was nearly twice as high during the day than night for juvenile steelhead.

Table 4.7. Passage Efficiencies for Steelhead at The Dalles Dam During 2011. Sample sizes are slightly higher for passage efficiency estimates than route-specific survival estimates because of restrictions for tag-life corrections on fish used in survival estimates that do not apply to passage efficiencies.

Metric	Total	SE	n	Day	SE	n	Night	SE	n
Fish Passage Efficiency	0.891	0.005	4302	0.952	0.004	2896	0.766	0.011	1406
Spill Passage Efficiency	0.754	0.007	4302	0.816	0.007	2896	0.625	0.013	1406
Sluiceway Efficiency ‖ Dam	0.138	0.005	4302	0.136	0.006	2896	0.141	0.009	1406
Sluiceway Efficiency ‖ Powerhouse	0.559	0.015	1059	0.741	0.019	532	0.376	0.021	527

4.5 Distributions

This section covers forebay approach distribution, forebay vertical distribution, and horizontal distribution for steelhead at TDA during spring 2011. As with yearling Chinook salmon, forebay approach distribution for steelhead was skewed to the upstream half of the TDA powerhouse (MU 22 to MU 12), where 56% of the tagged steelhead first arrived (Figure 4.2). Another 17% of the total arrived at the downstream portion of the powerhouse (MU 11—FU 1). Twenty-seven percent of the steelhead approached the dam at the spillway after moving directly down the Washington side of the forebay. Fish that approached the spillway always directly passed there. Forty-four percent of the total steelhead arriving at the dam approached within 100 m of the powerhouse before migrating over to the spillway and passing there. Arrival distributions for steelhead at MU 22–MU 12 showed a 5% absolute increase when comparing percentages of total arrivals within night (52%) and day periods (57%) (Figure 4.2). Fish approaching the powerhouse during night were more likely to pass into the turbines or the sluiceway than move past the powerhouse to pass at the spillway, as we observed during daytime.

Forebay vertical distribution, as indicated by the median depths of the 3D-tracked last detection locations by distance (≤5 m, 10 m, 25 m, etc.) from the dam where fish passed, showed at least 50% of the tagged steelhead were in the upper 4 m of the water column in most locations (Figure 4.3). The median depth was about 1 m shallower on approach to the spillway than on approach to the powerhouse. Vertical distribution was relatively constant as distance to the dam decreased for fish passing at Bays 1–9. The steelhead moved up in the water column as they approached and passed at the downstream portion of the powerhouse and northern spillway. At the spillway north location, fish moved up in the water column to pass the dam. At the upstream portion of the powerhouse (MU 12–22), fish sounded to pass the dam during night but not during day. Vertical distributions were 2 to 3 m shallower during day than night (Figure 4.3).

The horizontal distribution of turbine passage for steelhead was bi-modal with modes around MU 1 and MU 11-16 (Figure 3.4). At the sluiceway, 93% of total passage was at Sluice 1-1, 1-2, and 1-3, the sluiceway entrances above MU 1. Horizontal distribution of steelhead passage at the spillway was dominated by Bay 8, with 24% of total spillway passage. Normally voluntary spill for juvenile fish passage is confined to Bays 1−8 inside the spill wall, but in spring 2011 flows necessitated opening additional bays; 16% to of total spillway passage of steelhead occurred at Bays 9, 12, 14, 15, and 17. In addition, bays 20 and 21 were open for less than 16 h combined during the season and no fish passage was observed through these routes.

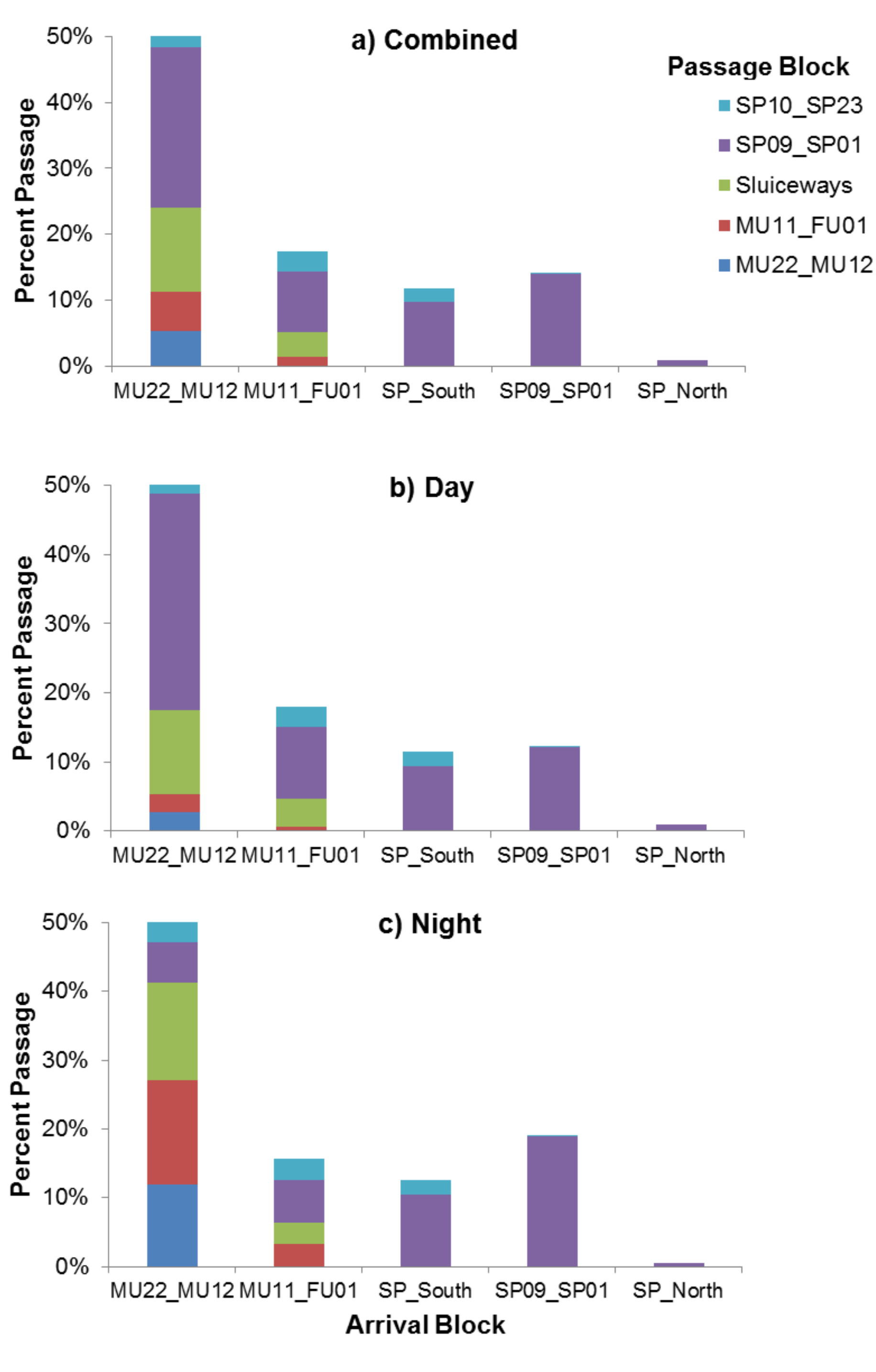


Figure 4.2. Steelhead Approach and Passage Behavior Patterns at The Dalles Dam During 2011: a) Day/Night Combined; b) Day; and c) Night. The sum of the percent passages for the arrival blocks equals 100%. The sum of the percentages across all arrival blocks for a given passage block equals its passage efficiency (Table 4.7).

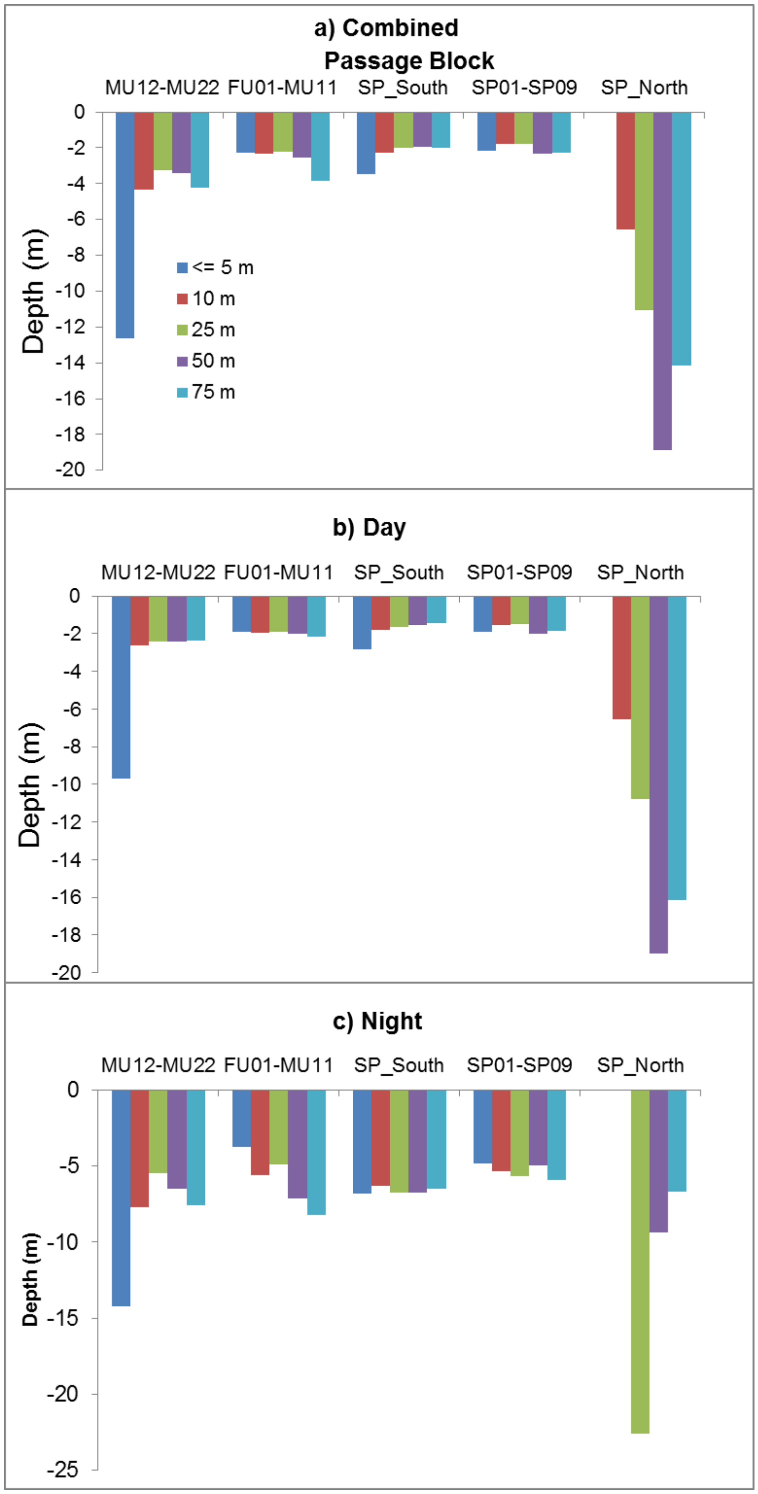


Figure 4.3. Forebay Vertical Distribution as Indicated by Median Depths of Last Detection by Distance (see legend) by Passage Block (location) from The Dalles Dam for Steelhead at The Dalles Dam During 2011: a) Day/Night Combined; b) Day; and c) Night. Depth is relative to the reference hydrophone. The reference hydrophone for powerhouse hydrophones was #51 P22_00S and for the spillway it was #86 S12_13S.

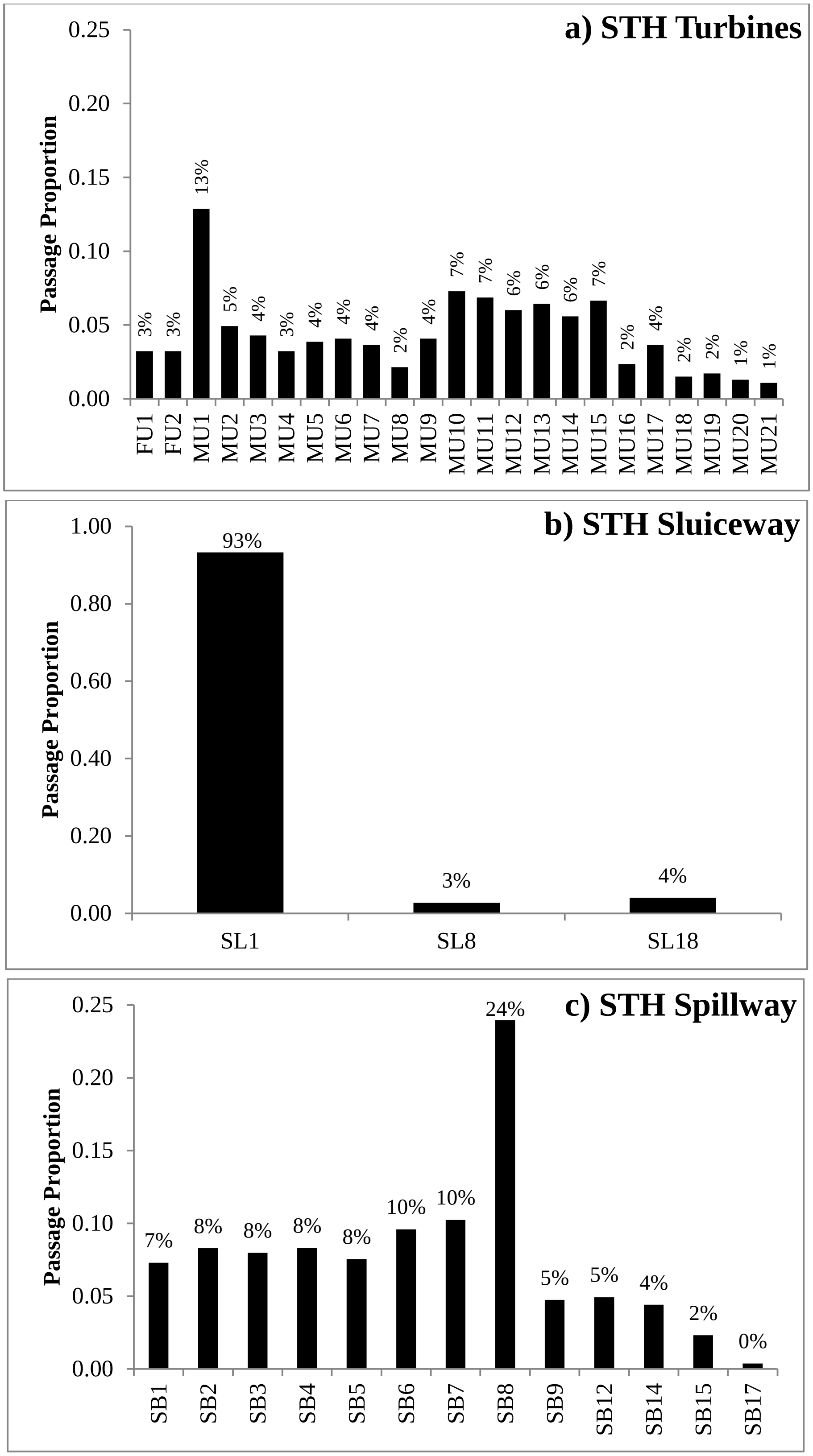


Figure 4.4. Horizontal Distribution of Passage for Steelhead at the a) Turbines, b) Spillway, and c) Sluiceway

5.0 Discussion

This section includes discussion of statistical performance and survival model assumptions, historical context, performance of the new spill wall, sluiceway passage and survival, and conclusions and recommendations.

5.1 Study Conduct

Despite the high flows and elevated spill at TDA in 2011, the precision of the estimates of dam passage survival met the 2008 BiOp standard of SEs $\leq$ 0.015. This was true whether the analyses were performed for the early part of the study (i.e., April 29–May 17 2011) or season-wide. The reason for this lies in the high detection probabilities at the first three downstream detection arrays (i.e., 0.85 $\leq p \leq$ 1.0) and the presence of the fourth and fifth arrays for added detections. The observed detection probabilities did not deviate appreciably from the anticipated rates of approximately 0.95. Therefore, the study was conducted properly as evidenced by high detection probabilities and low standard errors.

5.2 Study Performance

The 2011 spring compliance study at TDA was interrupted by high flow conditions that resulted in spill levels in excess of 40% starting about May 18, 2011 (Figure 1.5). However, the total discharge during the early part of the study from April 29 through May 17, 2011, was not particularly high, with an average total daily discharge of 283 kcfs and spill levels that averaged 39.7%. During the early part of the study, dam passage survival estimates for both yearling Chinook salmon and steelhead exceeded BiOp standards $\left(\hat{S} \geq 0.96\right)$ with values of 0.9721 ($\widehat{\text{SE}}$ = 0.0104) and 0.9924 ($\widehat{\text{SE}}$ = 0.0115), respectively. Dam passage survival for yearling Chinook salmon declined season-wide to a value of $\hat{S}$ = 0.9600 ($\widehat{\text{SE}}$ = 0.0074) despite higher discharge and spill percentage during the latter third of the study. Nevertheless, this estimate of dam passage survival for yearling Chinook salmon met BiOp requirements of $\hat{S} \geq$ 0.96. For steelhead smolts, the season-wide estimate of dam passage survival increased slightly over the early season estimate with a value of $\hat{S}$ = 0.9952 ($\widehat{\text{SE}}$ = 0.0083). Both early season estimates and season-wide estimates for steelhead smolts met BiOp requirements for survival and precision.

Overall, the 2011 spring compliance study for yearling Chinook salmon and steelhead at TDA does not appear to have been biased by the high flow and spill levels during the latter part of the investigation (May 18 through May 30, 2011). For yearling Chinook salmon, the season-wide estimate is lower than the early season value. Thus, the season-wide value could serve as a conservative estimate of dam passage survival. For steelhead smolts, there was little change between early season and season-wide estimates of dam passage survival. Both estimates greatly exceed BiOp requirements. Either value could be used with little change in inference.

5.3 Cross-Year Summary

Formal compliance studies were conducted at TDA with yearling Chinook salmon and steelhead during both spring 2010 and 2011. Yearling Chinook survival estimates in both years 2010 and 2011 were $\geq$ 0.96 with $\widehat{SE} \leq$ 0.015 with a 2-y average of $\hat{\bar{S}}$ = 0.9621. For steelhead smolts, the survival estimate in 2010 was below the BiOp standard with a value of 0.9534, while in 2011, the estimate of 0.9952 exceeded the standard. The 2-y average is $\hat{\bar{S}}$ = 0.9743 (Table 5.1). Both steelhead survival estimates had acceptable precision of $\widehat{SE} \leq$ 0.015 (Table 5.1).

Table 5.1. Summary of Estimates of Dam Passage Survival at The Dalles Dam for Yearling Chinook Salmon, Steelhead, and Subyearling Chinook Salmon Smolts in 2010 and 2011. Standard errors in parentheses.

Year	Yearling Chinook Salmon	Steelhead	Subyearling Chinook Salmon
2010	0.9641 (0.0096)	0.9534 (0.0097)	0.9404 (0.0091)
2011	0.9601 (0.0072)	0.9952 (0.0083)	NA
Two-Year Average	0.9621	0.9743	

6.0 References

3 Treaty Tribes-Action Agencies. 2008. *Memorandum of Agreement Among the Umatilla, Warm Springs and Yakama Tribes, Bonneville Power Administration, U.S. Army Corps of Engineers, and U.S. Bureau of Reclamation, Portland, Oregon, April 4, 2008*. Available at http://www.salmonrecovery.gov/ColumbiaBasinFishAccords.aspx.

Brown RS, SJ Cooke, GN Wagner, and MB Eppard (eds). 2010. *Methods for Surgical Implantation of Acoustic Transmitters in Juvenile Salmonids: A Review of Literature and Guidelines for Technique*. Prepared for the U.S. Army Corps of Engineers, Portland District, by Pacific Northwest National Laboratory, Richland, Washington.

Burnham, KP, DR Anderson, GC White, C Brownie, and KH Pollock. 1987. "Design and analysis methods for fish survival experiments based on release-recapture." *American Fisheries Society Monograph* 5.

CBSPSC (Columbia Basin Surgical Protocol Steering Committee). 2011. *Surgical Protocols for Implanting JSATS Transmitters into Juvenile Salmonids for Studies Conducted for the U.S. Army Corps of Engineers*. V1, 21 pp. U.S. Army Corps of Engineers, Portland District, Portland, Oregon.

Deng Z, MA Weiland, TJ Carlson, and MB Eppard. 2010. "Design and Instrumentation of a Measurement and Calibration System for an Acoustic Telemetry System." *Sensors* 10(4):3090-3099. doi:10.3390/s100403090

Deng ZD, MA Weiland, T Fu, TA Seim, BL Lamarche, EY Choi, TJ Carlson, and MB Eppard. 2011. "A Cabled Acoustic Telemetry System for Detecting and Tracking Juvenile Salmon: Part 2. Three-Dimensional Tracking and Passage Outcomes." *Sensors* 11(6):5661-5676. doi:10.3390/s110605661

Johnson, GE, JW Beeman, IN Duran, and AL Puls. 2007. *Synthesis of Juvenile Salmonid Passage Studies at The Dalles Dam, Volume II, 2001–2005*. PNNL-16443, final report submitted to the U.S. Army Corps of Engineers, Portland District, Portland, Oregon, by Pacific Northwest National Laboratory, Richland, Washington.

Johnson G, J Skalski, T Carlson, G Ploskey, M Weiland, D Deng, E Fischer, J Hughes, F Khan, J Kim, and R Townsend. 2011. *Survival and Passage Yearling and Subyearling Chinook Salmon and Steelhead at The Dalles Dam, 2010*. PNNL-20626, final report submitted to the U.S. Army Corps of Engineers, Portland District, Portland, Oregon, by Pacific Northwest National Laboratory, Richland, Washington and the University of Washington, Seattle, Washington.

Li T and JJ Anderson. 2009. "The vitality model: A way to understand population survival and demographic heterogeneity." *Theoretical Population Biology* 76:118–131.

Mantel N and W Haenszel. 1959. "Statistical Aspects of the Analysis of Data from Retrospective Studies of Disease." *Journal of the National Cancer Institute* 22:719–748.

Martinson R, G Kovalchuk, and D Ballinger. 2006. *Monitoring of Downstream Salmon and Steelhead at Federal Hydroelectric Facilities. 2005-2006 Annual Report*, Project No. 198712700, BPA Report DOE/BP-00022085-2, Portland, Oregon.

McMichael GA, MB Eppard, TJ Carlson, JA Carter, BD Ebberts, RS Brown, MA Weiland, GR Ploskey, RA Harnish, and Z Deng. 2010. "The Juvenile Salmon Acoustic Telemetry System: A New Tool." *Fisheries* 35(1):9–22.

NMFS (National Marine Fisheries Service). 2008. *Biological Opinion – Consultation on Remand for Operation of the Federal Columbia River Power System, 11 Bureau of Reclamation Projects in the Columbia Basin and ESA Section 10(a)(1)(A) Permit for Juvenile Fish Transportation Program.* National Marine Fisheries Service (NOAA Fisheries) – Northwest Region, Seattle, Washington. Available at: http://www.salmonrecovery.gov/.

Ploskey G, T Poe, A Giorgi, and G Johnson. 2001. *Synthesis of Radio Telemetry, Hydroacoustic, and Survival Studies of Juvenile Salmon at The Dalles Dam (1982-2000).* PNWD-3131, final report submitted to the U.S. Army Corps of Engineers, Portland District, Portland, Oregon, by Battelle–Pacific Northwest Division, Richland, Washington.

Ploskey GR, MA Weiland, JS Hughes, SA Zimmerman, RE Durham, ES Fischer, J Kim, RL Townsend, JR Skalski, and RL McComas. 2007. *Acoustic Telemetry Studies of Juvenile Chinook Salmon Survival at the Lower Columbia Projects in 2006*. PNNL-16560, draft technical report prepared for the U.S. Army Corps of Engineer District, Portland, Oregon, by Pacific Northwest National Laboratory, Richland, Washington.

Ploskey GR, MA Weiland, JS Hughes, SR Zimmerman, RE Durham, ES Fischer, J Kim, RL Townsend, JR Skalski, RA Buchanan, RL McComas. 2008. *Survival of Juvenile Chinook Salmon Passing the Bonneville Dam Spillway in 2007*. PNNL-18113, technical report prepared for the U.S. Army Corps of Engineer District, Portland, Oregon, by Pacific Northwest National Laboratory, Richland, Washington.

Seber GAF. 1982. *The Estimation of Animal Abundance*. MacMillan, New York.

Skalski JR, GE Johnson, and TJ Carlson. 2010a. *Compliance Monitoring of Juvenile Yearling Chinook Salmon and Steelhead Survival and Passage at The Dalles Dam, Spring 2010*. PNNL-19819, summary report submitted to the U.S. Army Corps of Engineers, Portland District, Portland, Oregon, by Pacific Northwest National Laboratory, Richland, Washington and the University of Washington, Seattle, Washington.

Skalski JR, GE Johnson, and TJ Carlson. 2010b. *Compliance Monitoring of Juvenile Yearling Chinook Salmon and Steelhead Survival and Passage at The Dalles Dam, Summer 2010*. PNNL-20042, summary report submitted to the U.S. Army Corps of Engineers, Portland District, Portland, Oregon, by Pacific Northwest National Laboratory, Richland, Washington and the University of Washington, Seattle, Washington.

Skalski JR, RL Townsend, TW Steig, and S Hemstrom. 2010c. "Comparison of two alternative approaches for estimating dam passage survival using acoustic-tagged sockeye salmon smolts." *North American Journal of Fisheries Management* 30:831-839.

Skalski, JR, RL Townsend, AG Seaburg, GE Johnson, and TJ Carlson. 2012. *Compliance Monitoring of Juvenile Yearling Chinook Salmon and Steelhead Survival and Passage at The Dalles Dam, Spring 2011*. PNNL-21124, compliance report submitted to the U.S. Army Corps of Engineers, Portland District, Portland, Oregon, by Pacific Northwest National Laboratory, Richland, Washington and the University of Washington, Seattle, Washington.

Townsend RL, JR Skalski, P Dillingham, and TW Steig. 2006. "Correcting bias in survival estimation resulting from tag failure in acoustic and radiotelemetry studies." *Journal of Agricultural Biology and Environmental Statistics* 11(2):183–196.

Weiland MA and eighteen co-authors. 2010. *Acoustic Telemetry Evaluation of Juvenile Salmonid Passage and Survival Proportions at John Day Dam, 2009*. PNNL-19422, draft final report submitted to the U.S. Army Corps of Engineers, Portland District, Portland, Oregon, by Pacific Northwest National Laboratory, Richland, Washington.

Weiland MA, ZD Deng, TA Seim, BL Lamarche, EY Choi, T Fu, TJ Carlson, AI Thronas, and MB Eppard. 2011. "A cabled acoustic telemetry system for detecting and tracking juvenile salmon: Part 1. Engineering design and instrumentation." *Sensors* 11(6):5645–5660. doi:10.3390/s110605645

Appendix A

JSATS Performance

Appendix A – JSATS Performance

This appendix contains data on the detection probabilities for the dam-face arrays and the autonomous arrays.

A.1 Detection Probabilities at Dam-Face Arrays

Detection probabilities for each dam-face array were greater than 99% and the combined detection probability for the double detection array used in the 2011 survival study was 100% for both tagged species (Table A.1).

Table A.1. Numbers of Tagged Fish Detected and Detection Probabilities for the TDA Dam-Face Arrays (N11 = detected on both arrays; N10 = detected on array 1 but not array 2; N01 = detected on array 2 but not array 1).

Species	TDA Double Detection Array	N11	N10	N01	Detection Probability at Array 1	Detection Probability at Array 2	Combined Detection Probability
CH1	4,253	4,245	5	3	0.9993	0.9988	1.0000
STH	4,314	4,305	5	4	0.9991	0.9988	1.0000

A.2 Detection Probabilities at Autonomous Nodes

Detection probabilities for the autonomous arrays were greater than 80% for yearling Chinook salmon, greater than 74% for steelhead, and greater than 85% for subyearling Chinook salmon (Table A.2).

Table A.2. Estimated Detection Probabilities, from Each Release Location, of the Node Arrays Used in Estimating Dam Passage Survival at TDA for Each Species. Standard errors for the estimates are in parentheses.

Release and Detection Arrays	Yearling Chinook	Steelhead
V_1 (rkm 309) to D_1 (rkm 275)	0.9161 (0.0044)	0.8771 (0.0051)
V_1 (rkm 309) to D_2 (rkm 234)	1.0000 (0.0000)	1.0000 (0.0000)
R_2 (rkm 307) to D_2 (rkm 234)	1.0000 (0.0000)	1.0000 (0.0000)
R_3 (rkm 275) to D_2 (rkm 234)	1.0000 (0.0000)	1.0000 (0.0000)
V_1 (rkm 309) to D_3 (rkm 161)	0.8526 (0.0061)	0.9177 (0.0047)
R_2 (rkm 307) to D_3 (rkm 161)	0.8615 (0.0135)	0.9130 (0.0113)
R_3 (rkm 275) to D_3 (rkm 161)	0.8543 (0.0139)	0.9154 (0.0110)
V_1 (rkm 309) to D_4 (rkm 113)	0.7588 (0.0084)	0.7417 (0.0091)
R_2 (rkm 307) to D_4 (rkm 113)	0.7657 (0.0190)	0.7477 (0.0210)
R_3 (rkm 275) to D_4 (rkm 113)	0.7184 (0.0203)	0.7830 (0.0200)

Appendix B

Tagging and Release Data

Appendix B – Tagging and Release Data

Tagging and release data are documented for yearling Chinook salmon and steelhead in Tables B.1 and B.2, respectively.

Table B.1. 2011 Yearling Chinook Salmon Tagged at John Day Dam and Released Live at Seven Sites and Dead at Four 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 B.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 B.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 B.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 B.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 B.2. 2011 Juvenile Steelhead Tagged at John Day Dam and Released Live at Seven Sites and Dead at 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

Table B.2. (contd)

Tag Date	Number Tagged	Release Date	Release Location	Number Released
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
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

Table B.2. (contd)

Tag Date	Number Tagged	Release Date	Release Location	Number Released
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
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

Table B.2. (contd)

Tag Date	Number Tagged	Release Date	Release Location	Number Released
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
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

Table B.2. (contd)

Tag Date	Number Tagged	Release Date	Release Location	Number Released
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
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 C

Deployment Locations for Dam-Face and Autonomous Node Hydrophones

Appendix C – Deployment Locations for Dam-Face and Autonomous Node Hydrophones

Deployment locations for hydrophones in dam-face arrays for the 2011 The Dalles Dam survival study are presented in Table C.1. Global positioning system locations for the nodes in the autonomous arrays are listed in Table C.2.

Table C.1. Hydrophone Locations in The Dalles Dam-Faced Array in 2010

Hydrophone Name	Latitude (NAD83)	Longitude (NAD83)	Elevation (NAVD88, ft)
TDA_S22_23D	45.6126721	-121.1313470	121.73
TDA_S22_23S	45.6126721	-121.1313470	146.15
TDA_S21_22D	45.6127685	-121.1315358	122.06
TDA_S21_22S	45.6127685	-121.1315358	145.06
TDA_S20_21D	45.6128656	-121.1317255	122.40
TDA_S20_21S	45.6128656	-121.1317255	145.73
TDA_S19_20D	45.6129626	-121.1319153	122.32
TDA_S19_20S	45.6129626	-121.1319153	145.49
TDA_S17_18D	45.6131565	-121.1322942	122.51
TDA_S17_18S	45.6131565	-121.1322942	143.93
TDA_S16_17D	45.6132548	-121.1324856	122.43
TDA_S16_17S	45.6132548	-121.1324856	144.08
TDA_S15_16D	45.6133508	-121.1326740	122.18
TDA_S15_16S	45.6133508	-121.1326740	143.66
TDA_S14_15D	45.6134463	-121.1328617	122.29
TDA_S14_15S	45.6134463	-121.1328617	144.00
TDA_S13_14D	45.6135439	-121.1330527	122.08
TDA_S13_14S	45.6135439	-121.1330527	143.89
TDA_S12_13D	45.6136409	-121.1332412	123.47
TDA_S12_13S	45.6136409	-121.1332412	151.06
TDA_S11_12D	45.6137372	-121.1334299	123.33
TDA_S11_12S	45.6137372	-121.1334299	151.00
TDA_S10_11D	45.6138335	-121.1336189	123.41
TDA_S10_11S	45.6138335	-121.1336189	151.08
TDA_S09_10S	45.6139316	-121.1338018	150.65
TDA_S09_10N	45.6139393	-121.1338174	150.70
TDA_S08_09D	45.6140275	-121.1339980	123.35
TDA_S08_09S	45.6140275	-121.1339980	151.10
TDA_S07_08D	45.6141251	-121.1341883	123.45
TDA_S07_08S	45.6141251	-121.1341883	151.20
TDA_S06_07D	45.6142215	-121.1343775	123.39
TDA_S06_07S	45.6142215	-121.1343775	151.06
TDA_S05_06D	45.6143184	-121.1345675	123.37

Table C.1. (contd)

Hydrophone Name	Latitude (NAD83)	Longitude (NAD83)	Elevation (NAVD88, ft)
TDA_S05_06S	45.6143184	-121.1345675	150.95
TDA_S04_05D	45.6144155	-121.1347571	123.48
TDA_S04_05S	45.6144155	-121.1347571	151.07
TDA_S03_04D	45.6145115	-121.1349452	123.31
TDA_S03_04S	45.6145115	-121.1349452	150.98
TDA_S02_03D	45.6146099	-121.1351377	123.24
TDA_S02_03S	45.6146099	-121.1351377	150.82
TDA_S01_02D	45.6147056	-121.1353252	123.25
TDA_S01_02S	45.6147056	-121.1353252	151.00
TDA_S00_01D	45.6147994	-121.1355107	123.55
TDA_S00_01S	45.6147994	-121.1355107	151.22
TDA_N04	45.6149133	-121.1357392	142.87
TDA_N03	45.6150256	-121.1359571	143.00
TDA_N02	45.6152700	-121.1363622	143.36
TDA_N01	45.6153492	-121.1365173	143.38
TDA_F00_01S	45.6158073	-121.1273525	146.93
TDA_F00_01D	45.6158228	-121.1273741	106.11
TDA_F01_02S	45.6158840	-121.1272402	146.89
TDA_F01_02D	45.6158995	-121.1272619	106.07
TDA_F02_P01S	45.6159637	-121.1271233	146.66
TDA_F02_P01D	45.6159793	-121.1271449	105.84
TDA_P01_02S	45.6161352	-121.1268723	147.73
TDA_P01_02D	45.6161508	-121.1268939	106.91
TDA_P02_03S	45.6162983	-121.1266337	147.80
TDA_P02_03D	45.6163139	-121.1266553	106.98
TDA_P03_04S	45.6164632	-121.1263926	147.95
TDA_P03_04D	45.6164788	-121.1264143	107.13
TDA_P04_05S	45.6166282	-121.1261515	147.82
TDA_P04_05D	45.6166437	-121.1261731	107.00
TDA_P05_06S	45.6167887	-121.1259159	147.78
TDA_P05_06D	45.6168043	-121.1259375	106.96
TDA_P06_07S	45.6169538	-121.1256758	147.88
TDA_P06_07D	45.6169694	-121.1256974	107.06
TDA_P07_08S	45.6171185	-121.1254349	147.80
TDA_P07_08D	45.6171341	-121.1254565	106.98
TDA_P08_SS1S	45.6172795	-121.1251883	148.27
TDA_P08_SS1D	45.6172894	-121.1252021	107.08
TDA_SS2_P09S	45.6174429	-121.1249488	147.98
TDA_SS2_P09D	45.6174527	-121.1249624	106.92
TDA_P09_10S	45.6176129	-121.1247124	147.57
TDA_P09_10D	45.6176285	-121.1247341	106.75
TDA_P10_11S	45.6177770	-121.1244719	148.22

Table C.1. (contd)

Hydrophone Name	Latitude (NAD83)	Longitude (NAD83)	Elevation (NAVD88, ft)
TDA_P10_11D	45.6177926	-121.1244936	107.40
TDA_P11_12S	45.6179410	-121.1242328	148.33
TDA_P11_12D	45.6179565	-121.1242544	107.51
TDA_P12_13S	45.6181069	-121.1239915	147.76
TDA_P12_13D	45.6181224	-121.1240132	106.94
TDA_P13_14S	45.6182718	-121.1237509	148.11
TDA_P13_14D	45.6182874	-121.1237726	107.29
TDA_P14_15S	45.6184358	-121.1235096	148.12
TDA_P14_15D	45.6184514	-121.1235312	107.30
TDA_P15_16S	45.6186007	-121.1232687	148.01
TDA_P15_16D	45.6186163	-121.1232904	107.19
TDA_P16_17S	45.6187658	-121.1230280	148.11
TDA_P16_17D	45.6187814	-121.1230497	107.29
TDA_P17_18S	45.6189303	-121.1227876	148.30
TDA_P17_18D	45.6189459	-121.1228092	107.48
TDA_P18_19S	45.6190950	-121.1225468	148.04
TDA_P18_19D	45.6191106	-121.1225685	107.22
TDA_P19_20S	45.6192590	-121.1223070	147.98
TDA_P19_20D	45.6192746	-121.1223286	107.16
TDA_P20_21S	45.6194241	-121.1220655	147.84
TDA_P20_21D	45.6194397	-121.1220872	107.02
TDA_P21_22S	45.6195887	-121.1218258	147.90
TDA_P21_22D	45.6196043	-121.1218474	107.08
TDA_P22_00S	45.6197495	-121.1215899	147.88
TDA_P22_00D	45.6197650	-121.1216116	107.06

Table C.2. Approximate Global Positioning System Coordinates of Autonomous Nodes Deployed in Arrays Just Above and Below The Dalles 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. (TDA Secondary Array is at BON Cabled Array – CR234.0).

Array_Node	Array Function	Latitude Degrees North	Longitude Degrees West	Approximate Depth (ft.)
CR311.0_01	TDA FB Entrance	45.6288000	-121.1157960	54.00
CR311.0_02		45.6278630	-121.1142710	65.67
CR311.0_03		45.6269450	-121.1126290	79.00
CR311.0_04		45.6261530	-121.1111270	97.50
CR311.0_05		45.6253450	-121.1096530	39.17
CR307.0_01	TDA Tailrace	45.6083160	-121.1510940	45.00
CR307.0_02		45.6072850	-121.1500350	49.33
CR307.0_03		45.6063758	-121.1488433	55.67
CR275.0_01	JDA Tertiary; TDA Primary	45.7091259	-121.4712970	22.50
CR275.0_02		45.7086224	-121.4717591	37.67
CR275.0_03		45.7078330	-121.4724400	63.92
CR275.0_04		45.7072915	-121.4729401	74.83
CR275.0_05		45.7066440	-121.4735049	112.00
CR275.0_06		45.7057667	-121.4734667	135.67
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

Table C.2. (contd)

Array_Node	Array Function	Latitude Degrees North	Longitude Degrees West	Approximate Depth (ft.)
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 D

Capture-History Data

Appendix D – Capture-History Data

Capture histories used in the TDA 2011 survival study are presented for yearling Chinook salmon (Tables D.1 through D.4) and steelhead (Tables D.5 through D.8).

Table D.1. Capture Histories at Sites at rkm 275, 234, 161, 113, and 86 for Release Group V_1 for Yearling Chinook Salmon Used in Estimating Dam Passage Survival and BRZ-to-BRZ Survival. A "1" denotes detection, "0" denotes nondetection, and "2" denotes detection and censoring due to removal.

	V_1 (Season-wide)	
Capture History	Dam Passage Survival	BRZ-to-BRZ Survival
1 1 1 1 1	1,683	1,690
0 1 1 1 1	57	58
1 0 1 1 1	0	0
0 0 1 1 1	0	0
1 1 0 1 1	224	227
0 1 0 1 1	15	15
1 0 0 1 1	0	0
0 0 0 1 1	0	0
1 1 1 0 1	498	499
0 1 1 0 1	30	30
1 0 1 0 1	0	0
0 0 1 0 1	0	0
1 1 0 0 1	89	90
0 1 0 0 1	12	12
1 0 0 0 1	0	0
0 0 0 0 1	0	0
1 1 1 1 0	530	539
0 1 1 1 0	101	101
1 0 1 1 0	0	0
0 0 1 1 0	0	0
1 1 0 1 0	131	132
0 1 0 1 0	30	30
1 0 0 1 0	0	0
0 0 0 1 0	0	0
1 1 1 0 0	275	278
0 1 1 0 0	69	69
1 0 1 0 0	0	0
0 0 1 0 0	0	0
1 2 0 0 0	61	61
0 2 0 0 0	0	0
1 1 0 0 0	223	227
0 1 0 0 0	26	27
1 0 0 0 0	23	23
0 0 0 0 0	179	182
Total	4,256	4,290

Table D.2. Capture Histories at Sites at rkm 234, 161, 113 and 86 for Release Groups R_2, and R_3 for Yearling Chinook Salmon 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	
Capture History	R_2	R_3
1 1 1 1	334	312
0 1 1 1	0	0
1 0 1 1	45	40
0 0 1 1	0	0
1 1 0 1	104	124
0 1 0 1	0	0
1 0 0 1	12	14
0 0 0 1	0	0
1 1 1 0	128	115
0 1 1 0	0	0
1 0 1 0	34	40
0 0 1 0	0	0
1 1 0 0	77	79
0 1 0 0	0	0
2 0 0 0	1	4
1 0 0 0	49	57
0 0 0 0	15	14
Total	799	799

Table D.3. Capture Histories at Sites at rkm 275, 234, 161, 113, and 86 for Release Group V_1 for Yearling Chinook Salmon Used in Estimating Dam Passage Survival Daytime and Nighttime Survival. A "1" denotes detection, "0" denotes nondetection, and "2" denotes detection and censoring due to removal.

	V_1 (Dam Passage Survival)	
Capture History	Daytime	Nighttime
1 1 1 1 1:	976	707
0 1 1 1 1:	40	17
1 0 1 1 1:	0	0
0 0 1 1 1:	0	0
1 1 0 1 1:	133	91
0 1 0 1 1:	4	11
1 0 0 1 1:	0	0
0 0 0 1 1:	0	0
1 1 1 0 1:	300	198
0 1 1 0 1:	18	12
1 0 1 0 1:	0	0
0 0 1 0 1:	0	0
1 1 0 0 1:	47	42
0 1 0 0 1:	8	4
1 0 0 0 1:	0	0
0 0 0 0 1:	0	0
1 1 1 1 0:	326	204
0 1 1 1 0:	64	37
1 0 1 1 0:	0	0
0 0 1 1 0:	0	0
1 1 0 1 0:	81	50
0 1 0 1 0:	16	14
1 0 0 1 0:	0	0
0 0 0 1 0:	0	0
1 1 1 0 0:	158	117
0 1 1 0 0:	37	32
1 0 1 0 0:	0	0
0 0 1 0 0:	0	0
1 2 0 0 0:	42	19
0 2 0 0 0:	0	0
1 1 0 0 0:	117	106
0 1 0 0 0:	15	11
1 0 0 0 0:	12	11
0 0 0 0 0:	84	95
Total	2478	1778

Table D.4. Yearling Chinook Salmon Used in Estimating Dam Passage Survival by Route Survival. A "1" denotes detection, "0" denotes nondetection, and "2" denotes detection and censoring due to removal.

	V_1 (Dam Passage by Route)			
Capture History	Powerhouse Passage Survival	Sluiceway Passage Survival	Spillway Passage Survival	Turbine Passage Survival
1 1 1 1 1	497	273	1183	215
0 1 1 1 1	30	17	27	13
1 0 1 1 1	0	0	0	0
0 0 1 1 1	0	0	0	0
1 1 0 1 1	79	47	145	32
0 1 0 1 1	4	0	11	4
1 0 0 1 1	0	0	0	0
0 0 0 1 1	0	0	0	0
1 1 1 0 1	164	87	331	75
0 1 1 0 1	15	6	15	9
1 0 1 0 1	0	0	0	0
0 0 1 0 1	0	0	0	0
1 1 0 0 1	31	14	58	17
0 1 0 0 1	6	4	6	2
1 0 0 0 1	0	0	0	0
0 0 0 0 1	0	0	0	0
1 1 1 1 0	192	102	336	90
0 1 1 1 0	38	18	63	20
1 0 1 1 0	0	0	0	0
0 0 1 1 0	0	0	0	0
1 1 0 1 0	41	16	90	25
0 1 0 1 0	14	7	16	7
1 0 0 1 0	0	0	0	0
0 0 0 1 0	0	0	0	0
1 1 1 0 0	121	57	152	63
0 1 1 0 0	27	14	41	13
1 0 1 0 0	0	0	0	0
0 0 1 0 0	0	0	0	0
1 2 0 0 0	13	6	48	7
0 2 0 0 0	0	0	0	0
1 1 0 0 0	99	51	124	48
0 1 0 0 0	8	3	18	5
1 0 0 0 0	9	4	14	5
0 0 0 0 0	62	8	115	51
Total	1450	734	2793	701

Table D.5. Capture Histories at Sites at rkm 275, 234, 161, 113, and 86 for Release Group V1 for Steelhead Salmon Used in Estimating Dam Passage Survival and BRZ-to-BRZ Survival. A "1" denotes detection, "0" denotes nondetection, and "2" denotes detection and censoring due to removal.

	V_1 (Season-wide)	
Capture History	Dam Passage Survival	BRZ-to-BRZ Survival
1 1 1 1 1	1,545	1,547
0 1 1 1 1	81	82
1 0 1 1 1	0	0
0 0 1 1 1	0	0
1 1 0 1 1	88	89
0 1 0 1 1	12	12
1 0 0 1 1	0	0
0 0 0 1 1	0	0
1 1 1 0 1	502	504
0 1 1 0 1	51	51
1 0 1 0 1	0	0
0 0 1 0 1	0	0
1 1 0 0 1	37	37
0 1 0 0 1	11	11
1 0 0 0 1	0	0
0 0 0 0 1	0	0
1 1 1 1 0	768	772
0 1 1 1 0	177	177
1 0 1 1 0	0	0
0 0 1 1 0	0	0
1 1 0 1 0	101	102
0 1 0 1 0	31	31
1 0 0 1 0	0	0
0 0 0 1 0	0	0
1 1 1 0 0	349	354
0 1 1 0 0	104	104
1 0 1 0 0	0	0
0 0 1 0 0	0	0
1 2 0 0 0	34	34
0 2 0 0 0	0	0
1 1 0 0 0	223	226
0 1 0 0 0	44	45
1 0 0 0 0	60	60
0 0 0 0 0	113	116
Total	4,331	4,354

Table D.6. Capture Histories at Sites at rkm 234, 161, 113 and 86 for Release Groups R2, and R3 for Steelhead Salmon Used in Estimating All Dam Passage Survival. A “1” denotes detection, “0” denotes nondetection, and “2” denotes detection and censoring due to removal.

	Season-wide Dam Passage Survival	
Capture History	R_2	R_3
1 1 1 1	302	312
0 1 1 1	0	0
1 0 1 1	18	20
0 0 1 1	0	0
1 1 0 1	102	86
0 1 0 1	0	0
1 0 0 1	6	6
0 0 0 1	0	0
1 1 2 0	0	0
0 1 2 0	0	0
1 0 2 0	0	0
0 0 2 0	0	0
1 1 1 0	163	186
0 1 1 0	0	0
1 0 1 0	30	28
0 0 1 0	0	0
1 2 0 0	0	0
0 2 0 0	0	0
1 1 0 0	96	92
0 1 0 0	0	0
2 0 0 0	0	0
1 0 0 0	56	58
0 0 0 0	27	12
Total	800	800

Table D.7. Capture Histories at Sites at rkm 275, 234, 161, 113, and 86 for Release Group V_1 for Steelhead Salmon Used in Estimating Dam Passage Survival Daytime and Nighttime Survival. A “1” denotes detection, “0” denotes nondetection, and “2” denotes detection and censoring due to removal.

	V_1 (Dam Passage Survival)	
Capture History	Daytime	Nighttime
1 1 1 1 1:	1072	473
0 1 1 1 1:	55	26
1 0 1 1 1:	0	0
0 0 1 1 1:	0	0
1 1 0 1 1:	55	33
0 1 0 1 1:	8	4
1 0 0 1 1:	0	0

Table D.7. (contd)

	V_1 (Dam Passage Survival)	
Capture History	Daytime	Nighttime
0 0 0 1 1:	0	0
1 1 1 0 1:	327	175
0 1 1 0 1:	35	16
1 0 1 0 1:	0	0
0 0 1 0 1:	0	0
1 1 0 0 1:	25	12
0 1 0 0 1:	2	9
1 0 0 0 1:	0	0
0 0 0 0 1:	0	0
1 1 1 2 0:	0	0
0 1 1 2 0:	0	0
1 0 1 2 0:	0	0
0 0 1 2 0:	0	0
1 1 0 2 0:	0	0
0 1 0 2 0:	0	0
1 0 0 2 0:	0	0
0 0 0 2 0:	0	0
1 1 1 1 0:	571	197
0 1 1 1 0:	131	46
1 0 1 1 0:	0	0
0 0 1 1 0:	0	0
1 1 0 1 0:	74	27
0 1 0 1 0:	16	15
1 0 0 1 0:	0	0
0 0 0 1 0:	0	0
1 1 2 0 0:	0	0
0 1 2 0 0:	0	0
1 0 2 0 0:	0	0
0 0 2 0 0:	0	0
1 1 1 0 0:	242	107
0 1 1 0 0:	62	42
1 0 1 0 0:	0	0
0 0 1 0 0:	0	0
1 2 0 0 0:	23	11
0 2 0 0 0:	0	0
1 1 0 0 0:	158	65
0 1 0 0 0:	23	21
2 0 0 0 0:	0	0
1 0 0 0 0:	42	18
0 0 0 0 0:	52	61
Total	2973	1358

Table D.8. Capture Histories at Sites at rkm 275, 234, 161, 113, and 86 for Release Group V_1 for Steelhead Salmon Used in Estimating Dam Passage Survival by Route Survival. A "1" denotes detection, "0" denotes nondetection, and "2" denotes detection and censoring due to removal.

	V_1 (Dam Passage by Route)			
Capture History	Powerhouse Passage Survival	Sluiceway Passage Survival	Spillway Passage Survival	Turbine Passage Survival
1 1 1 1 1	317	201	1218	110
0 1 1 1 1	18	8	60	10
1 0 1 1 1	0	0	0	0
0 0 1 1 1	0	0	0	0
1 1 0 1 1	22	14	66	8
0 1 0 1 1	2	2	10	0
1 0 0 1 1	0	0	0	0
0 0 0 1 1	0	0	0	0
1 1 1 0 1	134	78	365	54
0 1 1 0 1	13	9	38	4
1 0 1 0 1	0	0	0	0
0 0 1 0 1	0	0	0	0
1 1 0 0 1	13	8	24	4
0 1 0 0 1	4	3	7	1
1 0 0 0 1	0	0	0	0
0 0 0 0 1	0	0	0	0
1 1 1 1 0	184	104	579	78
0 1 1 1 0	52	30	124	22
1 0 1 1 0	0	0	0	0
0 0 1 1 0	0	0	0	0
1 1 0 1 0	18	8	83	9
0 1 0 1 0	7	5	23	2
1 0 0 1 0	0	0	0	0
0 0 0 1 0	0	0	0	0
1 1 1 0 0	100	54	247	46
0 1 1 0 0	25	13	78	12
1 0 1 0 0	0	0	0	0
0 0 1 0 0	0	0	0	0
1 2 0 0 0	4	4	30	0
0 2 0 0 0	0	0	0	0
1 1 0 0 0	58	33	163	25
0 1 0 0 0	13	3	31	10
1 0 0 0 0	19	8	41	9
0 0 0 0 0	56	7	56	47
Total	1059	592	3243	451

Appendix E

Assessment of Survival Model Assumptions

Appendix E – Assessment of Survival Model Assumptions

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

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 and steelhead. 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 yearling Chinook salmon $\left(P\left(\chi^2_{42} \geq 22.68\right) = 0.9935\right)$ or steelhead $\left(P\left(\chi^2_{42} \geq 10.62\right) = 1.00\right)$ (Table E.1).

Tagger effects were also examined within each of 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., R1–R3, R4–R5, and R6–R7 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 a release location (i.e., R1, …, R7) and species basis (Table E.3). Of the 56 tests of homogeneous reach survivals, 7 were found to be significant at α = 0.10 (i.e., 12.5%). It is expected 10% of the 56 tests (i.e., 5.6) would be significant at α = 0.10 when no effect exists. There was no consistent pattern, with two taggers responsible for two of seven significant results each, and three taggers 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 α = 0.10. Therefore, fish tagged by all taggers were considered acceptable for the survival analyses.

Table E.1. Numbers of Yearling Chinook Salmon and Steelhead Tagged by Each Staff Member by Release Locations (R1, R2, …, R7). Chi-square tests of homogeneity were not significant.

a. Yearling Chinook salmon and steelhead releases pooled

Release Location	Tagger							
	A	B	C	D	E	F	G	H
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. Yearling Chinook salmon

Release Location	Tagger							
	A	B	C	D	E	F	G	H
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. Steelhead

Release location	Tagger							
	A	B	C	D	E	F	G	H
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 Numbers 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.Replicate 1

Release	B	C	D	G
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	B	C	D	G
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	A	B	C	D	E	F	G	H	*P*-value
R1–CR390	0	39	44	34	0	0	49	0	0.9677
R2–CR346	0	15	19	18	0	0	24	0	
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	A	B	C	D	E	F	G	H	*P*-value
R1–CR390	0	34	42	37	0	0	49	0	0.9977
R2–CR346	0	14	21	17	0	0	24	0	
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	A	E	F	H
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	A	E	F	H
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	A	B	C	D	E	F	G	H	*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	A	B	C	D	E	F	G	H	*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	B	C	D	G
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	B	C	D	G
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	A	B	C	D	E	F	G	H	*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	A	B	C	D	E	F	G	H	*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	A	E	F	G	H
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	A	E	F	G	H
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	A	B	C	D	E	F	G	H	*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	A	B	C	D	E	F	G	H	*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	B	C	D	G
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	B	C	D	G
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	A	B	C	D	E	F	G	H	*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	A	B	C	D	E	F	G	H	*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	A	E	F	H
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	A	E	F	H
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	A	B	C	D	E	F	G	H	*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	A	B	C	D	E	F	G	H	*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	B	C	D	G
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	B	C	D	G
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	A	B	C	D	E	F	G	H	*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	A	B	C	D	E	F	G	H	*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	A	E	F	H
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	A	E	F	H
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	A	B	C	D	E	F	G	H	*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	A	B	C	D	E	F	G	H	*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) Yearling Chinook Salmon Smolts and b) Steelhead, Along with *P*-Values Associated with the *F*-Tests of Homogeneous Survival Across Fish Tagged by Different Staff Members

a. Yearling Chinook salmon smolts

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	
	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$
A	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
B	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
C	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
D	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
E	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
F	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
G	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
H	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	
	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$
A	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
B	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
C	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
D	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
E	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
F	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
G	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
H	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	
	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$
A	1.0005	0.0004	0.9853	0.0106	0.9474	0.0194	1.0000	0.0000	0.9568	0.0211	0.9785	0.0364
B	1.0000	0.0000	1.0000	0.0000	0.9616	0.0173	0.9908	0.0091	0.9540	0.0243	0.9583	0.0450
C	1.0001	0.0001	0.9931	0.0069	0.9046	0.0244	0.9919	0.0080	0.9154	0.0274	0.9372	0.0382
D	0.9932	0.0075	0.9690	0.0153	0.9459	0.0201	0.9911	0.0089	0.9676	0.0191	1.0046	0.0362
E	0.9879	0.0095	0.9783	0.0124	0.9731	0.0137	0.9919	0.0080	0.9643	0.0219	0.9551	0.0370
F	0.9827	0.0124	0.9908	0.0094	0.9725	0.0157	1.0000	0.0000	0.9351	0.0285	0.9268	0.0414
G	0.9746	0.0112	1.0002	0.0002	0.9690	0.0126	0.9942	0.0058	0.9585	0.0174	0.9448	0.0325
H	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	
	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$
A	1.0005	0.0004	0.9857	0.0103	0.9338	0.0213	0.9338	0.0213	0.8935	0.0284	0.8743	0.0403
B	1.0000	0.0000	1.0000	0.0000	0.9616	0.0173	0.9528	0.0188	0.9089	0.0293	0.8710	0.0457
C	1.0001	0.0001	0.9932	0.0068	0.8984	0.0250	0.8912	0.0257	0.8158	0.0339	0.7646	0.0420
D	0.9932	0.0075	0.9624	0.0165	0.9104	0.0249	0.9023	0.0258	0.8730	0.0303	0.8770	0.0419
E	0.9879	0.0095	0.9664	0.0148	0.9405	0.0196	0.9329	0.0205	0.8996	0.0284	0.8592	0.0384
F	0.9827	0.0124	0.9737	0.0151	0.9469	0.0211	0.9469	0.0211	0.8854	0.0334	0.8206	0.0439
G	0.9746	0.0112	0.9748	0.0112	0.9445	0.0164	0.9391	0.0170	0.9001	0.0231	0.8504	0.0345
H	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	
	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$
A	0.9803	0.0143	0.9375	0.0250	0.9882	0.0117	0.9612	0.0261	0.9579	0.0593
B	0.9886	0.0113	0.9791	0.0162	0.9744	0.0179	0.9209	0.0308	1.0148	0.0412
C	1.0000	0.0000	0.9592	0.0202	0.9888	0.0112	0.9506	0.0240	1.0080	0.0294
D	1.0000	0.0000	0.9413	0.0259	0.9865	0.0134	0.8863	0.0363	1.0341	0.0272
E	0.9899	0.0101	0.9796	0.0143	1.0000	0.0000	0.9901	0.0156	0.9946	0.0488
F	0.9738	0.0192	0.9565	0.0246	1.0000	0.0000	0.9418	0.0333	1.0445	0.0708
G	0.9763	0.0137	0.9597	0.0181	0.9904	0.0096	0.9298	0.0273	0.9241	0.0363
H	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	
	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$
A	0.9803	0.0143	0.9190	0.0277	0.9082	0.0292	0.8729	0.0367	0.8362	0.0593
B	0.9886	0.0113	0.9680	0.0195	0.9432	0.0247	0.8685	0.0369	0.8814	0.0505
C	1.0000	0.0000	0.9592	0.0202	0.9485	0.0225	0.9016	0.0312	0.9087	0.0397
D	1.0000	0.0000	0.9413	0.0259	0.9286	0.0281	0.8230	0.0419	0.8511	0.0483
E	0.9899	0.0101	0.9697	0.0172	0.9697	0.0172	0.9601	0.0228	0.9549	0.0494
F	0.9738	0.0192	0.9315	0.0296	0.9315	0.0296	0.8773	0.0417	0.9163	0.0720
G	0.9763	0.0137	0.9370	0.0219	0.9280	0.0231	0.8628	0.0332	0.7973	0.0406
H	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*	

7) Release 4 – Reach survival

	Release to CR275		CR275 to CR234		CR234 to CR161		CR161 to CR113	
	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$
A	1.0015	0.0016	0.9880	0.0120	0.9347	0.0336	0.8793	0.0537
B	0.9765	0.0164	1.0000	0.0000	0.9878	0.0181	0.9584	0.0470
C	1.0016	0.0013	0.9780	0.0154	0.9818	0.0193	0.9711	0.0369
D	0.9881	0.0118	1.0000	0.0000	0.9252	0.0312	0.9399	0.0418
E	1.0011	0.0011	0.9891	0.0108	0.9273	0.0324	0.8360	0.0514
F	0.9870	0.0129	1.0000	0.0000	0.9554	0.0263	1.0181	0.0456
G	0.9924	0.0081	0.9912	0.0087	0.9448	0.0233	0.9949	0.0436
H	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*	

Table E.3. (contd)

8) Release 4 – Cumulative survival

	Release to CR275		Release to CR234		Release to CR161		Release to CR113	
	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$
A	1.0015	0.0016	0.9895	0.0105	0.9249	0.0347	0.8133	0.0517
B	0.9765	0.0164	0.9765	0.0164	0.9645	0.0240	0.9244	0.0476
C	1.0016	0.0013	0.9796	0.0143	0.9617	0.0235	0.9340	0.0381
D	0.9881	0.0118	0.9881	0.0118	0.9142	0.0328	0.8593	0.0465
E	1.0011	0.0011	0.9902	0.0098	0.9182	0.0333	0.7676	0.0498
F	0.9870	0.0129	0.9870	0.0129	0.9430	0.0287	0.9600	0.0494
G	0.9924	0.0081	0.9837	0.0114	0.9294	0.0254	0.9247	0.0454
H	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*	

9) Release 5 – Reach survival

	Release to CR234		CR234 to CR161		CR161 to CR113	
	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$
A	0.9895	0.0105	0.9439	0.0356	0.8632	0.0641
B	0.9881	0.0118	0.9482	0.0268	0.9876	0.0405
C	0.9892	0.0107	0.9293	0.0283	1.0372	0.0474
D	0.9884	0.0116	0.9513	0.0263	0.9501	0.0414
E	0.9808	0.0135	0.9799	0.0211	0.9605	0.0530
F	0.9737	0.0184	0.9749	0.0246	0.9679	0.0542
G	0.9836	0.0115	0.9358	0.0250	0.9707	0.0456
H	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	
	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$
A	0.9895	0.0105	0.9340	0.0366	0.8062	0.0597
B	0.9881	0.0118	0.9369	0.0287	0.9253	0.0448
C	0.9892	0.0107	0.9193	0.0297	0.9535	0.0518
D	0.9884	0.0116	0.9403	0.0283	0.8933	0.0444
E	0.9808	0.0135	0.9610	0.0246	0.9231	0.0520
F	0.9737	0.0184	0.9493	0.0299	0.9188	0.0547
G	0.9836	0.0115	0.9205	0.0269	0.8935	0.0471
H	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	
	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$
A	0.9735	0.0224	0.9394	0.0400
B	1.0350	0.0142	0.9185	0.0467
C	0.9569	0.0232	0.9860	0.0300
D	0.9648	0.0237	0.9481	0.0440
E	0.9798	0.0177	0.9094	0.0373
F	0.9528	0.0264	1.0702	0.0530
G	0.9919	0.0152	0.9680	0.0400
H	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	
	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$
A	0.9735	0.0224	0.9145	0.0395
B	1.0350	0.0142	0.9507	0.0385
C	0.9569	0.0232	0.9436	0.0336
D	0.9648	0.0237	0.9147	0.0448
E	0.9798	0.0177	0.8911	0.0374
F	0.9528	0.0264	1.0196	0.0559
G	0.9919	0.0152	0.9601	0.0385
H	1.0044	0.0132	0.9603	0.0378
P-value	*0.0697*		*0.4992*	

13) Release 7 – Reach survival

	Release to CR113	
	$\hat{S}$	$\widehat{SE}$
A	0.9238	0.0481
B	0.9590	0.0466
C	0.9316	0.0382
D	0.9757	0.0473
E	0.9770	0.0328
F	0.9454	0.0397
G	0.9465	0.0321
H	0.9221	0.0366
P-value	*0.9611*	

Table E.3. (contd)

b. Steelhead salmon smolts

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	
	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$
A	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
B	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
C	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
D	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
E	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
F	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
G	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
H	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*	

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	
	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$
A	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
B	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
C	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
D	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
E	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
F	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
G	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
H	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*	

Table E.3. (contd)

16) Release 2 – Reach survival

	Release to CR325		CR325 to CR309		CR309 to CR275		CR275 to CR234		CR234 to CR161		CR161 to CR113	
	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$
A	1.0003	0.0003	0.9930	0.0072	0.9726	0.0140	0.9918	0.0082	0.9640	0.0180	0.9567	0.0359
B	1.0003	0.0003	0.9840	0.0112	0.9780	0.0138	0.9735	0.0151	0.9147	0.0270	0.9356	0.0464
C	0.9940	0.0064	0.9671	0.0145	0.9814	0.0116	0.9847	0.0107	0.9642	0.0170	1.0251	0.0483
D	0.9927	0.0077	0.9841	0.0111	0.9868	0.0112	0.9735	0.0151	0.9184	0.0283	0.8859	0.0446
E	1.0001	0.0001	0.9860	0.0098	0.9718	0.0139	1.0000	0.0000	0.9377	0.0227	0.9253	0.0386
F	0.9916	0.0087	0.9908	0.0091	0.9732	0.0153	1.0000	0.0000	0.9456	0.0245	0.9540	0.0556
G	0.9897	0.0074	0.9892	0.0076	0.9951	0.0054	0.9942	0.0058	0.9082	0.0220	0.9816	0.0336
H	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*	

17) Release 2 – Cumulative survival

	Release to CR325		Release to CR309		Release to CR275		Release to CR234		Release to CR161		Release to CR113	
	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$
A	1.0003	0.0003	0.9932	0.0070	0.9660	0.0154	0.9580	0.0168	0.9236	0.0236	0.8836	0.0386
B	1.0003	0.0003	0.9843	0.0110	0.9626	0.0173	0.9370	0.0216	0.8571	0.0321	0.8019	0.0487
C	0.9940	0.0064	0.9613	0.0155	0.9434	0.0188	0.9290	0.0206	0.8957	0.0254	0.9182	0.0496
D	0.9927	0.0077	0.9769	0.0132	0.9641	0.0170	0.9385	0.0211	0.8619	0.0329	0.7635	0.0455
E	1.0001	0.0001	0.9861	0.0098	0.9583	0.0167	0.9583	0.0167	0.8986	0.0268	0.8315	0.0409
F	0.9916	0.0087	0.9825	0.0123	0.9561	0.0192	0.9561	0.0192	0.9041	0.0296	0.8625	0.0559
G	0.9897	0.0074	0.9791	0.0104	0.9743	0.0116	0.9686	0.0126	0.8797	0.0242	0.8634	0.0371
H	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*	

Table E.3. (contd)

18) Release 3 – Reach survival

	Release to CR309		CR309 to CR275		CR275 to CR234		CR234 to CR161		CR161 to CR113	
	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$
A	0.9895	0.0105	0.9727	0.0186	0.9733	0.0186	0.9683	0.0232	1.0272	0.0569
B	1.0000	0.0000	0.9431	0.0256	0.9730	0.0189	0.9396	0.0280	1.0006	0.0656
C	1.0000	0.0000	0.9943	0.0104	0.9655	0.0196	0.9375	0.0273	1.0068	0.0559
D	0.9891	0.0108	0.9231	0.0279	1.0000	0.0000	0.9773	0.0215	0.9583	0.0563
E	1.0003	0.0004	0.9728	0.0181	0.9747	0.0177	0.8820	0.0361	1.0958	0.0930
F	0.9733	0.0186	0.9589	0.0232	1.0000	0.0000	0.9720	0.0258	0.9622	0.0677
G	0.9919	0.0081	0.9773	0.0141	0.9813	0.0131	0.9592	0.0211	0.9937	0.0471
H	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*	

19) Release 3 – Cumulative survival

	Release to CR309		Release to CR275		Release to CR234		Release to CR161		Release to CR113	
	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$
A	0.9895	0.0105	0.9625	0.0210	0.9368	0.0250	0.9072	0.0325	0.9319	0.0585
B	1.0000	0.0000	0.9431	0.0256	0.9176	0.0298	0.8622	0.0380	0.8627	0.0675
C	1.0000	0.0000	0.9943	0.0104	0.9600	0.0196	0.9000	0.0320	0.9062	0.0576
D	0.9891	0.0108	0.9130	0.0294	0.9130	0.0294	0.8923	0.0348	0.8551	0.0577
E	1.0003	0.0004	0.9731	0.0179	0.9485	0.0225	0.8365	0.0396	0.9167	0.0870
F	0.9733	0.0186	0.9333	0.0288	0.9333	0.0288	0.9072	0.0369	0.8729	0.0677
G	0.9919	0.0081	0.9693	0.0161	0.9512	0.0194	0.9124	0.0274	0.9067	0.0489
H	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*	

Table E.3. (contd)

20) Release 4 – Reach survival

	Release to CR275		CR275 to CR234		CR234 to CR161		CR161 to CR113	
	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$
A	0.9800	0.0140	1.0000	0.0000	0.9111	0.0317	0.8392	0.0507
B	0.9915	0.0111	0.9753	0.0172	0.8974	0.0347	0.9228	0.0503
C	1.0016	0.0013	0.9783	0.0152	0.9455	0.0250	0.9886	0.0495
D	0.9903	0.0121	0.9857	0.0142	0.9226	0.0315	0.9437	0.0558
E	0.9917	0.0104	0.9878	0.0121	0.9592	0.0236	0.9492	0.0574
F	1.0033	0.0034	0.9831	0.0168	0.9613	0.0288	0.9322	0.0600
G	0.9694	0.0157	0.9825	0.0123	0.9466	0.0237	0.9462	0.0459
H	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*	

21) Release 4 – Cumulative survival

	Release to CR275		Release to CR234		Release to CR161		Release to CR113	
	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$
A	0.9800	0.0140	0.9800	0.0140	0.8929	0.0336	0.7493	0.0510
B	0.9915	0.0111	0.9670	0.0187	0.8678	0.0375	0.8008	0.0534
C	1.0016	0.0013	0.9798	0.0141	0.9264	0.0279	0.9158	0.0518
D	0.9903	0.0121	0.9762	0.0166	0.9007	0.0344	0.8500	0.0580
E	0.9917	0.0104	0.9796	0.0143	0.9396	0.0269	0.8919	0.0574
F	1.0033	0.0034	0.9863	0.0136	0.9481	0.0313	0.8838	0.0597
G	0.9694	0.0157	0.9524	0.0190	0.9015	0.0289	0.8530	0.0472
H	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	
	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$
A	0.9895	0.0105	0.9602	0.0243	0.9177	0.0466
B	0.9659	0.0193	0.9664	0.0243	0.9081	0.0536
C	0.9804	0.0137	0.8727	0.0358	0.8720	0.0495
D	1.0000	0.0000	0.9673	0.0228	0.9061	0.0480
E	0.9897	0.0103	0.9436	0.0251	0.9521	0.0499
F	0.9868	0.0131	0.8860	0.0380	0.9851	0.0484
G	0.9917	0.0083	0.9342	0.0249	0.9445	0.0533
H	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	
	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$
A	0.9895	0.0105	0.9501	0.0261	0.8719	0.0472
B	0.9659	0.0193	0.9334	0.0300	0.8477	0.0541
C	0.9804	0.0137	0.8556	0.0371	0.7461	0.0509
D	1.0000	0.0000	0.9673	0.0228	0.8765	0.0481
E	0.9897	0.0103	0.9339	0.0267	0.8892	0.0517
F	0.9868	0.0131	0.8743	0.0392	0.8612	0.0557
G	0.9917	0.0083	0.9264	0.0259	0.8750	0.0534
H	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	
	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$
A	0.9728	0.0222	0.7971	0.0469
B	1.0103	0.0053	0.9490	0.0501
C	0.9562	0.0242	0.9724	0.0563
D	0.9438	0.0261	1.0223	0.0562
E	0.9529	0.0264	0.9205	0.0541
F	0.9518	0.0308	0.9206	0.0700
G	0.9458	0.0235	1.0321	0.0462
H	0.9668	0.0193	0.9900	0.0343
P-value	*0.5359*		*0.0487*	

25) Release 6 – Cumulative survival

	Release to CR161		Release to CR113	
	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$
A	0.9728	0.0222	0.7754	0.0460
B	1.0103	0.0053	0.9588	0.0482
C	0.9562	0.0242	0.9298	0.0565
D	0.9438	0.0261	0.9649	0.0574
E	0.9529	0.0264	0.8772	0.0536
F	0.9518	0.0308	0.8762	0.0683
G	0.9458	0.0235	0.9762	0.0472
H	0.9668	0.0193	0.9571	0.0348
P-value	*0.5359*		*0.1042*	

Table E.3. (contd)

26) Release 7 – Reach survival

	Release to CR113	
	$\hat{S}$	$\widehat{\text{SE}}$
A	0.8905	0.0440
B	0.9473	0.0501
C	0.9415	0.0479
D	0.9668	0.0443
E	0.9002	0.0464
F	0.9230	0.0578
G	0.9080	0.0468
H	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 yearling Chinook salmon and steelhead smolts. 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 survival rates. 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, 7 of the 9 significant results all occurred within the R_1 release of steelhead. Also in that case, tag lot 1 had the lowest survivals in 2 of the 7 instances, while tag lot 2 had the lowest survival in 5 instances.

We conclude that tag lots corrected for tag life have no significant effect on observed smolt 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) Yearling Chinook Salmon and b) Steelhead Smolts in the 2011 JSATS Survival Study. Chi-square tests of homogeneity performed for the overall table and pairwise comparisons of the below-dam release pairs.

a. Yearling Chinook salmon

	Tag lot			
Release location	1	2	3, 4, 5	*P*-value
R1–CR390	706	501	1303	
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. Steelhead

	Tag lot			
Release location	1	2	3, 4, 5	*P*-value
R1–CR390	698	498	1391	
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) Yearling Chinook Salmon and b) Steelhead Smolts, Along with *P*-Values Associated with the *F*-Tests of Homogeneous Survival Across Tag Lots

a. Yearling Chinook salmon smolts

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	
	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$
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	
z	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$
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	
zz	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$
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	
	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$
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	
	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$
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	
	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$
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	
	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$
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	
	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$
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	
	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$
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. Steelhead smolts

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	
	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$
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	
	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$
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	
	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$
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	
	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$
Lot 1	0.9933	0.0066	0.9800	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	
	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$
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	
	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$
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	
	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$
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	
	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$
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	
	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$
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 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 not significant.

One of the 10 reach comparisons was significant at $\alpha = 0.10$. In all 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 than a group released further downriver. These observations are not consistent with evidence of time-dependent tag effects.

Therefore, 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) Yearling Chinook Salmon and b) Steelhead 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. Yearling Chinook salmon

Reach	CR390		CR346		CR325		CR307		CR275		CR233		CR161		*P* (*F*-test)
	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	
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

Table E.6. (contd)

b. Steelhead

Reach	CR390		CR346		CR325		CR307		CR275		CR233		CR161		P (F-test)
	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	
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 Release Locations for Tagged a) Yearling Chinook Salmon and b) Steelhead During the 2011 JSATS Survival Study. *P*-values associated with *F*-tests of homogeneous survival.

a. Yearling Chinook salmon

	CR390		CR346		
Reach	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	*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	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	*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	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	*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

	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

Table E.7. (contd)

b. Steelhead

	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

	CR390		CR346		CR325		CR307		
Reach	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	*P* (*F*-test)
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

	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	0.9481	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

	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	0.9651	0.01067	0.9459	0.014803	0.9828	0.020228	0.9385	0.018589	0.94	0.017674	0.9403	0.017119	0.3321

E.4 Handling Mortality and Tag Shedding

Fish were held for 24 to 36 h prior to release. The pre-release tagging mortality in spring was 0.17%. No tags were shed during the 24-h holding period.

E.5 Examination of Tailrace Release Location Effects on Survival

We explored the distribution of weighted detections of V_1 fish 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 Bonneville Dam (Figure E.1). The percent of fish detected on four autonomous nodes in The Dalles Dam tailrace was weighted to try to equalize sampling effort and detectability among node locations. Sampling effort varied because some nodes stopped sampling prematurely because of damage or they were lost. Detectability varied because it is inversely related to water velocities, which were highest on the Washington side of the channel. On each node, the percent of all yearling Chinook detection events with only the minimum number of tag-code receptions (4) was used to index detectability loss, and it was 10% at CR307.0_01, 10% at CR307.0_02, and 5% at CR307.0_03. Percentages for juvenile steelhead were 10% at CR307.0_01, 10% at CR307.0_02, and 5% at CR307.0_03.

The uniform distribution of fish releases among five locations in the tailrace appeared to be reasonable given the observed weighted distribution of detections of V_1 fish. Fish that passed the dam were detected at only a slightly higher percentage detected on the Oregon side of the channel than they were on the Washington side. Survival rates by release location varied from 0.972 to 1.000 for yearling Chinook salmon smolts and from 0.959 to 0.988 for juvenile steelhead. Wide and overlapping 95% confidence intervals 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.

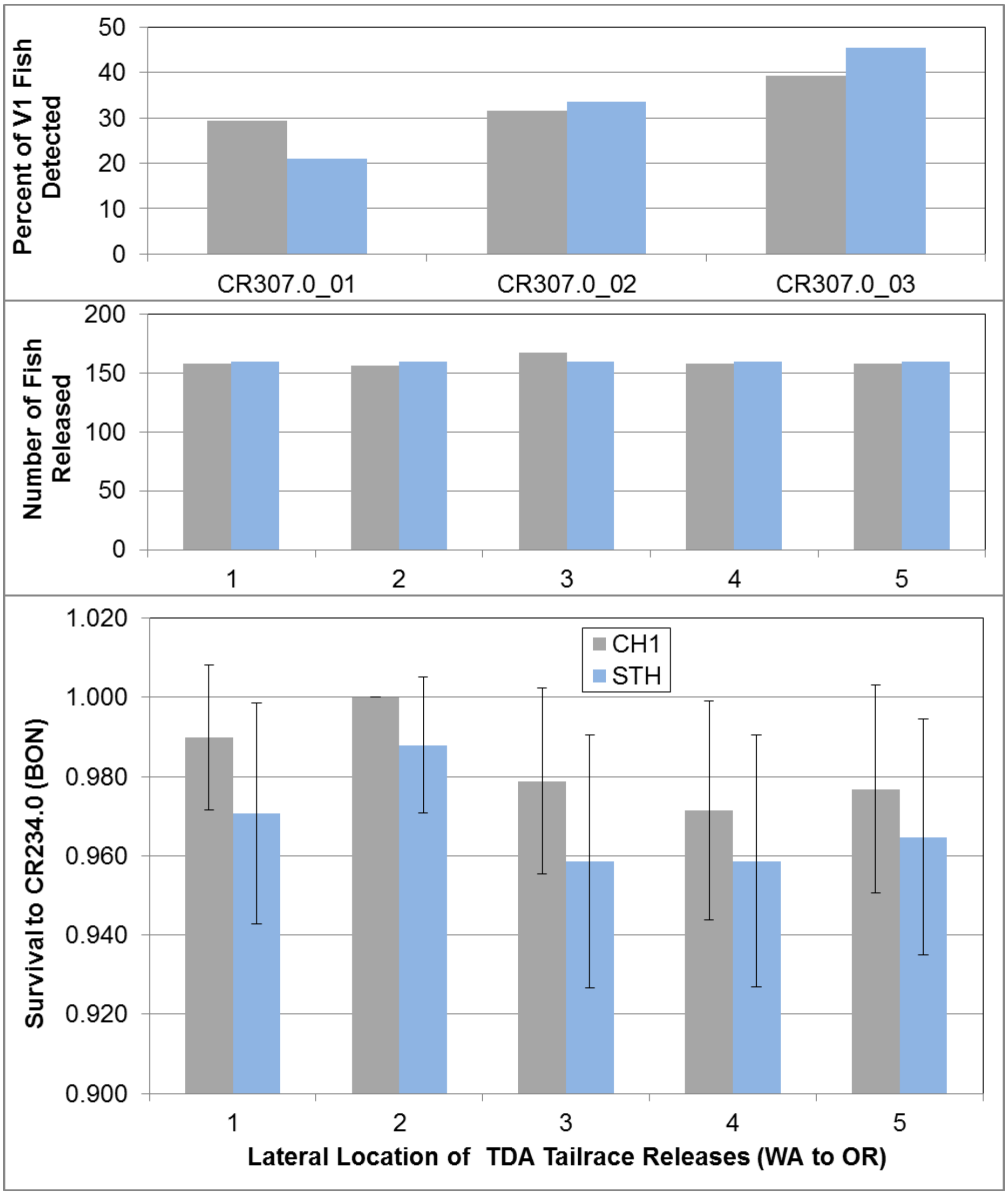


Figure E.1. Distributions of Tailrace Detections of V_1 Fish on Autonomous Nodes (top), Numbers of Fish Released in the Tailrace at Five Locations (middle), and Survival Rates by Tailrace Release Location (bottom). Gray bars are for yearling Chinook salmon smolts; blue bars are for juvenile steelhead; vertical bars are 95% confidence intervals on survival estimates.

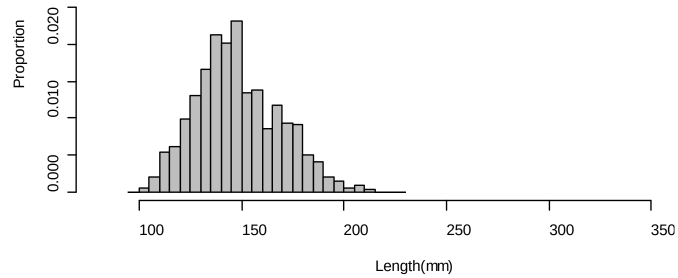
E.6 Examination of Time In-River on Survivals of Different Release Groups

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 different downriver survivals. 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 smolt survival for either yearling Chinook salmon or steelhead. 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.

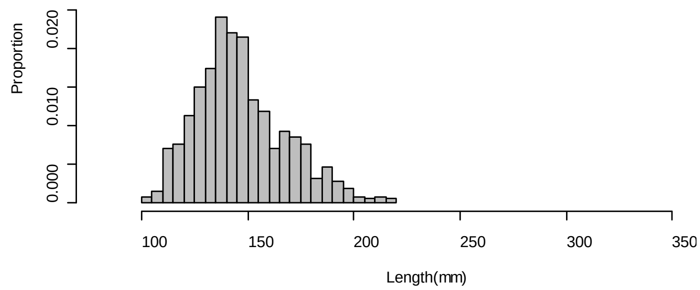
E.7 Fish Size Distribution

Comparison of JSATS-tagged fish with run-of-river (ROR) fish sampled at John Day Dam through the Smolt Monitoring Program shows that the length frequency distributions were generally well matched for yearling Chinook salmon (Figure E.2) and steelhead (Figure E.3). The length distributions for the three yearling Chinook salmon releases (Figure E.4) and the three steelhead releases (Figure E.4) were quite similar. Mean length for the acoustically tagged yearling Chinook salmon was 148.3 mm and for the steelhead it was 203.8 mm. Mean lengths for yearling Chinook salmon and steelhead sampled by the Fish Passage Center at the John Day Dam juvenile sampling facility were 151.4 mm and 199.1 mm, respectively. Fish size did not change over the course of the study (Figure E.4).

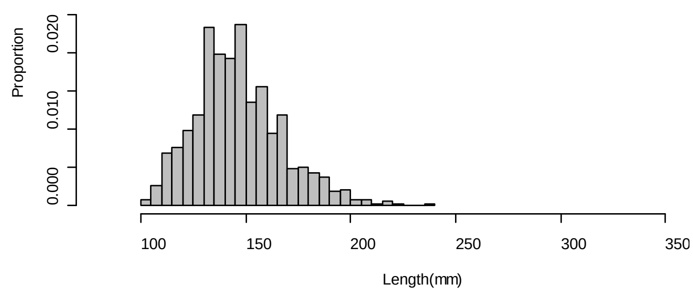
d. The Dalles Dam (Release V_1)



e. The Dalles Tailrace (Release R_2)



f. Bonneville Reservoir (Release R_3)



g. ROR Yearling Chinook at John Day Dam

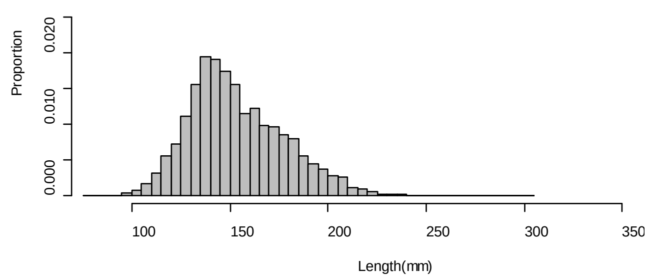
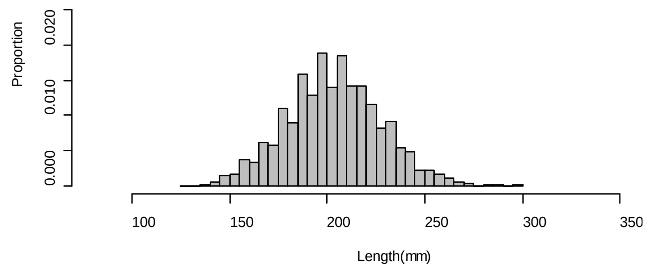
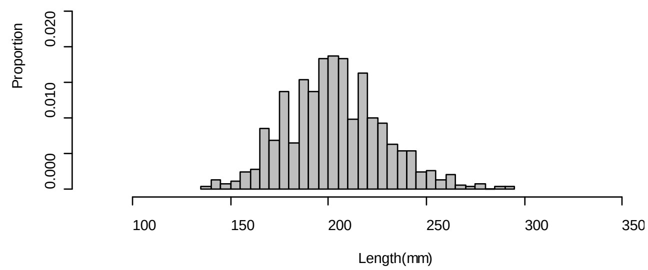


Figure E.2. Relative Frequency Distributions for Fish Length (mm) of Yearling Chinook Salmon Smolts Used in a) Release V_1, b) Release R_2, c) Release R_3, and d) ROR fish sampled at John Day Dam by the Fish Passage Center

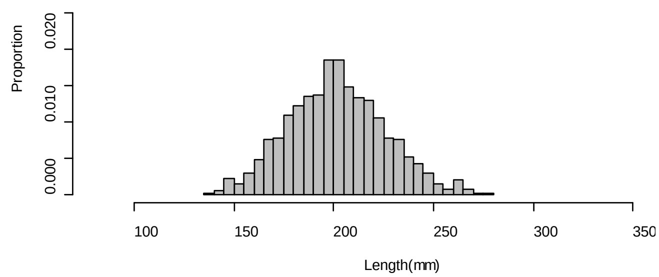
a. The Dalles Dam (Release V_1)



b. The Dalles Tailrace (Release R_2)



c. Bonneville Reservoir (Release R_3)



d. ROR Steelhead at John Day Dam

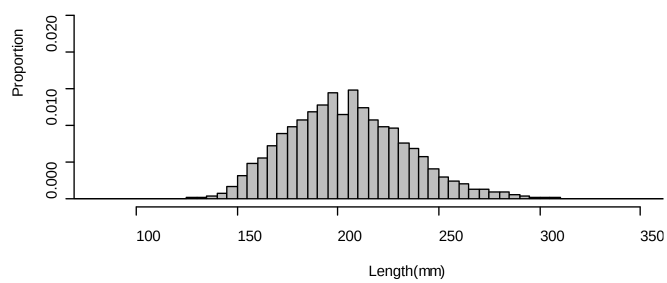
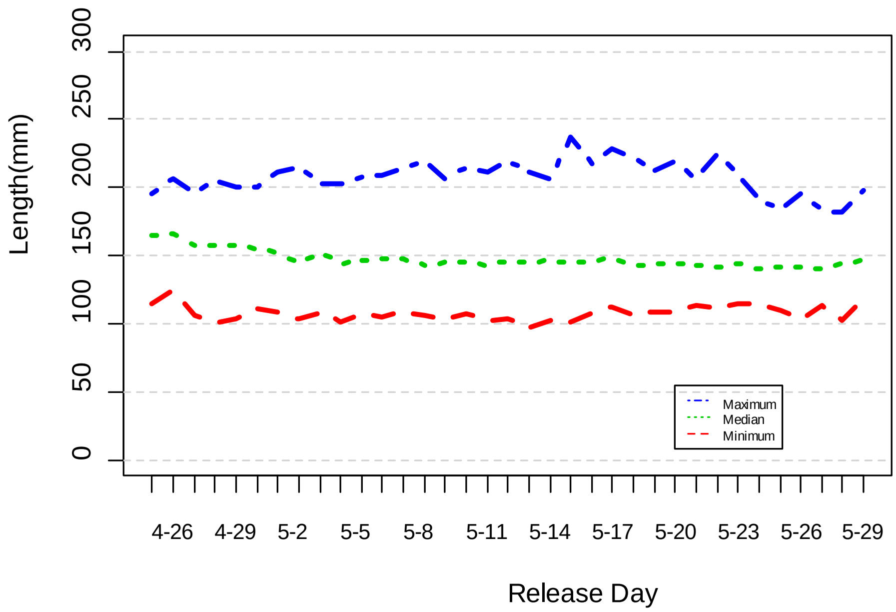


Figure E.3. Relative Frequency Distributions for Fish Length (mm) of Steelhead Smolts Used in a) Release V_1, b) Release R_2, c) Release R_3, and d) ROR Fish Sampled at John Day Dam by the Fish Passage Center

e. Yearling Chinook salmon smolts



f. Steelhead smolts

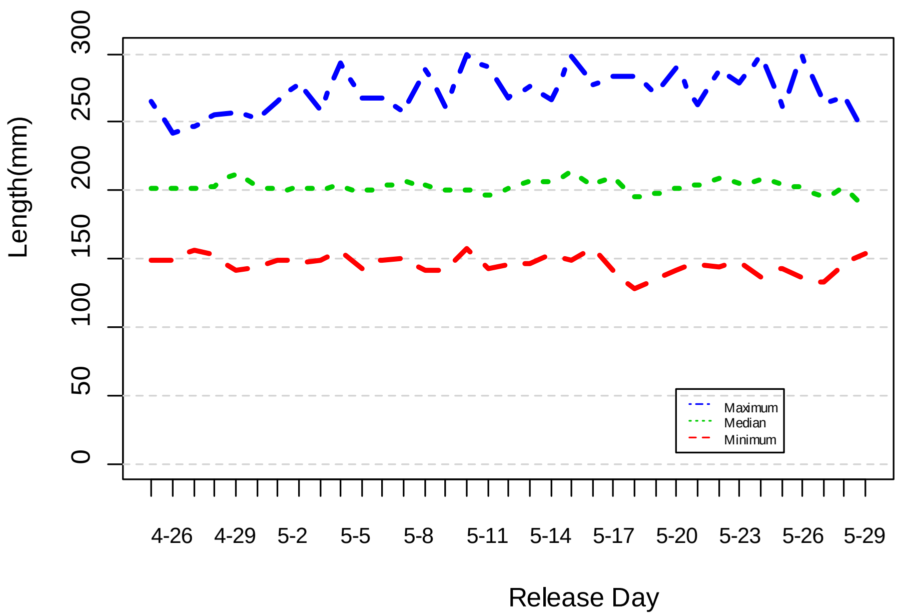


Figure E.4. Ranges and Median Lengths of Acoustically Tagged A) Yearling Chinook Salmon and B) Steelhead Used in the 2011 Survival Studies. Releases were made daily from April 29 through May 30 at five release locations: rkm 390, rkm 346, rkm 325, rkm 307, and rkm 275.

E.8 Tag-Life Corrections

Vitality curves of Li and Anderson (2009) were fit independently to each of the lots 1, 2, and 3–5 (Figure E.5). 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 E.6). Average tag lives were 31.74, 30.32, and 30.52 d for lots 1, 2, and 3–5, respectively.

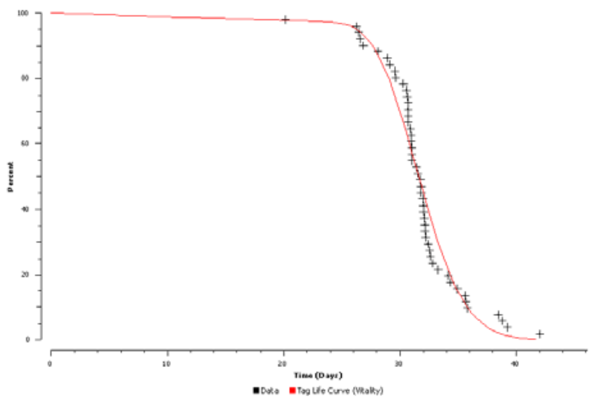
E.9 Arrival Distributions

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 for yearling Chinook salmon (Figure E.7) and steelhead (Figure E.8). Examination of the fish arrival distributions at the last detection array used in the survival analyses indicated all fish had passed through the study area before tag failure became an issue. These probabilities were calculated by integrating the tag survivorship curve (Figure E.7, Figure E.8) 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 probabilities of a JSATS tag being active at a downstream detection site were specific to release location, tag lot, and species (Table E.8.). In all cases, the probability that a tag was active at a downstream detection site as far as rkm 86 for yearling Chinook salmon smolts was ≥ 0.9937 and for steelhead smolts it was ≥ 0.9943.

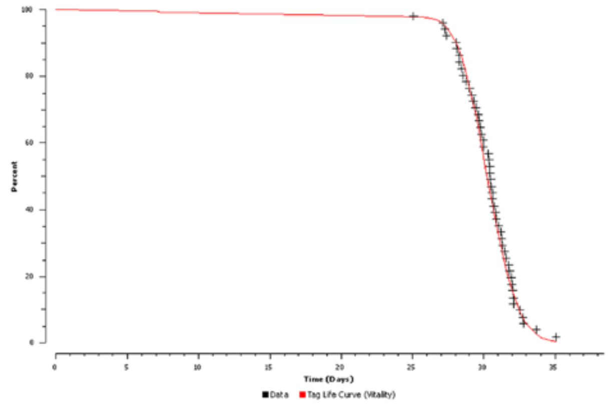
E.10 Downstream Mixing

The virtual release from the face of The Dalles Dam was continuously formed from the smolts arriving throughout the day and night. To help induce downstream mixing of the release groups, the R_2 release was 12 h before the R_3. The release schedule was used for both the yearling Chinook salmon and steelhead smolts. Plots of the arrival timing of the various release groups at downstream detection sites indicate reasonable mixing for both yearling Chinook salmon (Figure E.9) and steelhead (Figure E.10) smolts. The arrival modes for releases R_2 and R_3 were nearly synchronous.

a. Tag lot 1



b. Tag lot 2



c. Tag lot 3–5

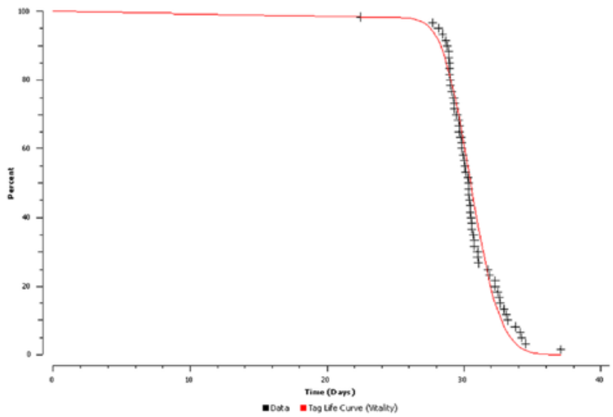


Figure E.5. Observed Time of Tag Failure and Fitted Survivorship Curves Using the Vitality Model of Li and Anderson (2009) for a) Tag Lot 1, b) Tag Lot 2, and c) Tag Lots 3–5

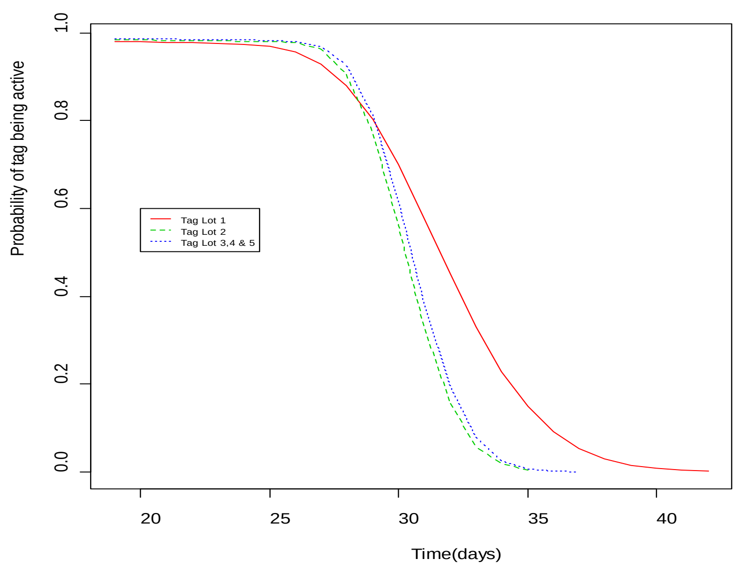
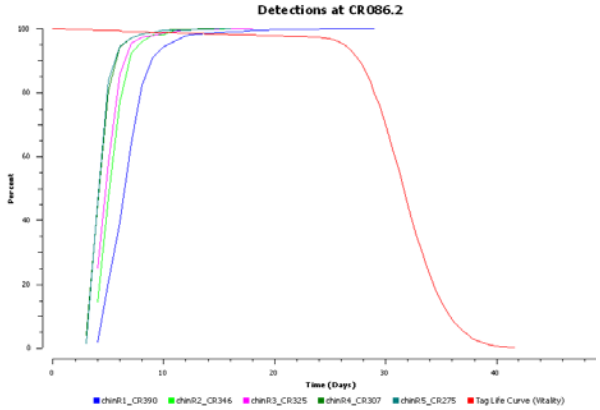


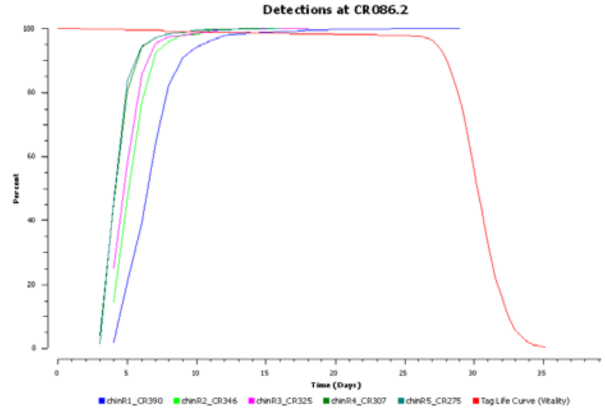
Figure E.6. Comparison of Fitted Survivorship Curves Using the Vitality Model of Li and Anderson (2009) for JSATS Tag Lots 1, 2, and 3–5 Used in the 2011 Compliance Studies

Yearling Chinook salmon

a. Tag lot 1



b. Tag lot 2



c. Tag lots 3-5

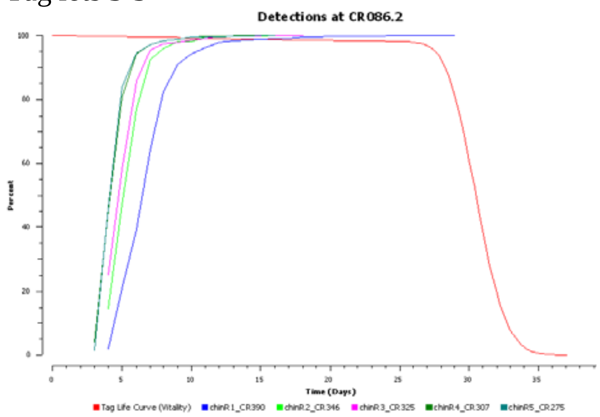
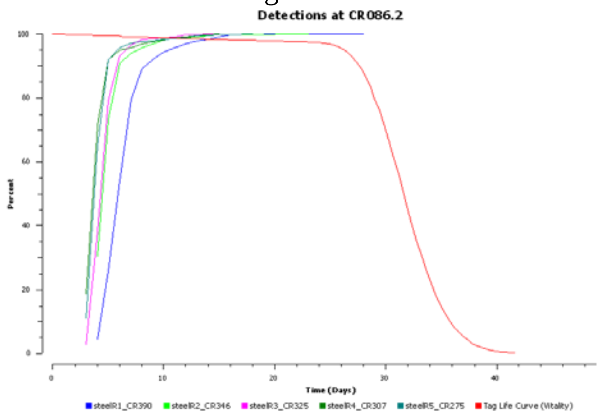


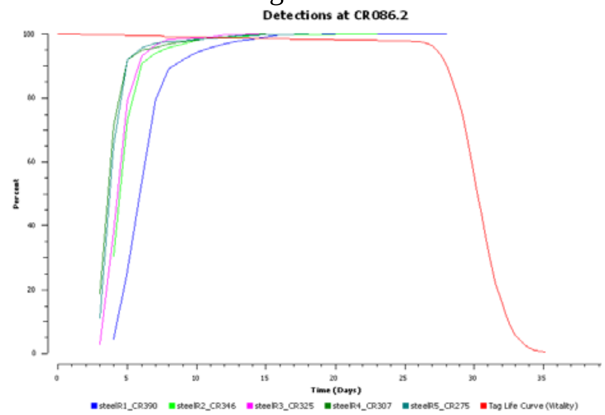
Figure E.7. Plot of the Fitted Tag-Life Curves and the Arrival-Time Distributions of Yearling Chinook Salmon Smolts for Releases V_1, R_2, and R_3 at the Acoustic-Detection Array Located at rkm 86 (Figure 2.1).

Steelhead

a. Tag lot 1



b. Tag lot 2



c. Tag lots 3-5

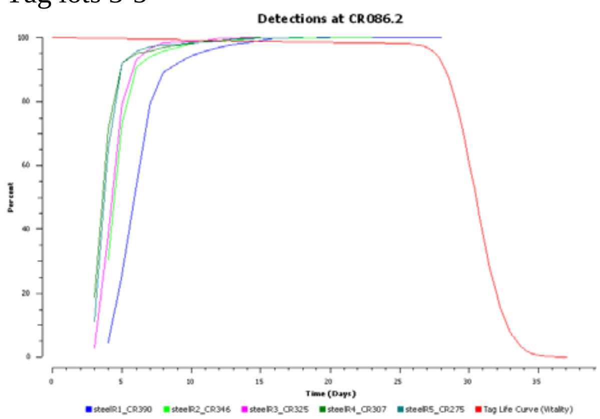


Figure E.8. Plot of the Fitted Tag-Life Curves and the Arrival-Time Distributions of Steelhead Smolts for Releases V_1, R_2, and R_3 at the Acoustic-Detection Array Located at rkm 86 (Figure 2.1)

Table E.8. Estimated Probabilities (*l*) of an Acoustic Tag Being Active at a Downstream Detection Site for a) Yearling Chinook Salmon Smolts and b) Steelhead Smolts by Tag Lot and Release Group. (Standard errors are in parentheses.)

a. Yearling Chinook Salmon

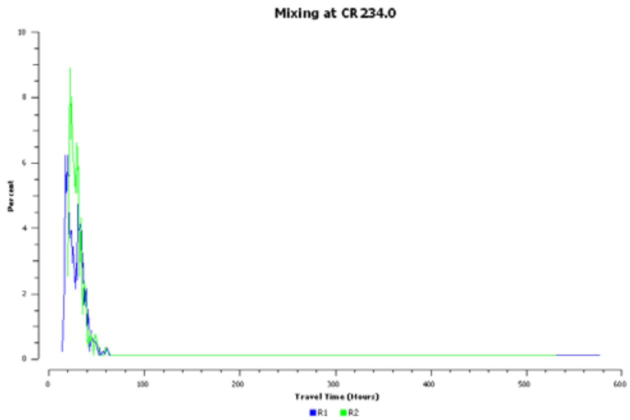
		Detection Site				
Release Group	Tag Lot	Rkm 275	Rkm 234	Rkm 161	Rkm 113	Rkm 86
V_1 (Rkm 390)	1	0.9993 (0.0007)	0.9985 (0.0015)	0.9970 (0.0022)	0.9963 (0.0027)	0.9959 (0.0030)
	2	0.9995 (0.0003)	0.9990 (0.0006)	0.9981 (0.0017)	0.9977 (0.0020)	0.9974 (0.0023)
	3–5	0.9997 (0.0008)	0.9992 (0.0020)	0.9988 (0.0039)	0.9985 (0.0050)	0.9984 (0.0055)
V_1 (Rkm 346)	1	0.9993 (0.0007)	0.9984 (0.0016)	0.9968 (0.0027)	0.9962 (0.0031)	0.9958 (0.0034)
	2	0.9994 (0.0004)	0.9988 (0.0007)	0.9979 (0.0019)	0.9973 (0.0023)	0.9972 (0.0025)
	3–5	0.9997 (0.0009)	0.9991 (0.0024)	0.9987 (0.0042)	0.9984 (0.0052)	0.9983 (0.0057)
V_1 (Rkm 325)	1	0.9992 (0.0009)	0.9983 (0.0018)	0.9969 (0.0025)	0.9963 (0.0030)	0.9959 (0.0033)
	2	0.9994 (0.0004)	0.9988 (0.0008)	0.9978 (0.0019)	0.9973 (0.0023)	0.9971 (0.0026)
	3–5	0.9996 (0.0010)	0.9991 (0.0022)	0.9987 (0.0042)	0.9984 (0.0051)	0.9982 (0.0060)
R_2 (Rkm 307)	1	--	0.9962 (0.0039)	0.9947 (0.0043)	0.9941 (0.0048)	0.9937 (0.0051)
	2	--	0.9971 (0.0018)	0.9961 (0.0033)	0.9957 (0.0038)	0.9954 (0.0040)
	3–5	--	0.9978 (0.0056)	0.9970 (0.0086)	0.9971 (0.0095)	0.9968 (0.0103)
R_3 (Rkm 275)	1	--	0.9965 (0.0036)	0.9948 (0.0042)	0.9940 (0.0049)	0.9938 (0.0050)
	2	--	0.9972 (0.0017)	0.9961 (0.0034)	0.9956 (0.0038)	0.9954 (0.0040)
	3–5	--	0.9977 (0.0058)	0.9970 (0.0093)	0.9969 (0.0101)	0.9967 (0.0106)

Table E.8. (contd)

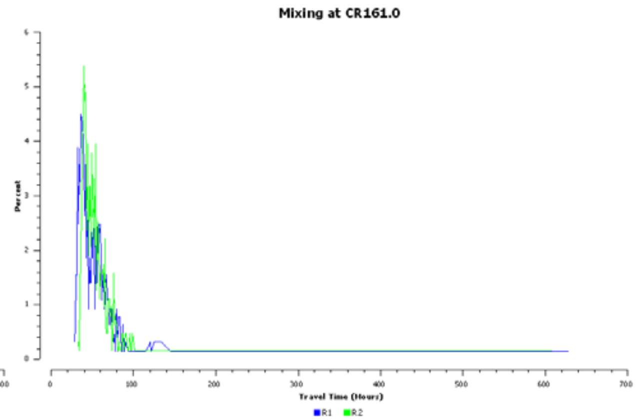
b. Steelhead

Release Group	Tag Lot	Detection Site				
		Rkm 275	Rkm 234	Rkm 161	Rkm 113	Rkm 86
V_1 (Rkm 390)	1	0.9994 (0.0005)	0.9988 (0.0011)	0.9975 (0.0029)	0.9971 (0.0035)	0.9965 (0.0038)
	2	0.9995 (0.0003)	0.9991 (0.0007)	0.9982 (0.0010)	0.9979 (0.0014)	0.9977 (0.0014)
	3–5	0.9992 (0.0010)	0.9988 (0.0021)	0.9982 (0.0038)	0.9986 (0.0047)	0.9985 (0.0053)
V_1 (Rkm 346)	1	0.9993 (0.0006)	0.9987 (0.0012)	0.9973 (0.0033)	0.9967 (0.0040)	0.9965 (0.0042)
	2	0.9994 (0.0004)	0.9990 (0.0008)	0.9981 (0.0010)	0.9978 (0.0014)	0.9975 (0.0015)
	3–5	0.9997 (0.0010)	0.9992 (0.0024)	0.9989 (0.0037)	0.9986 (0.0049)	0.9985 (0.0056)
V_1 (Rkm 325)	1	0.9993 (0.0006)	0.9987 (0.0012)	0.9973 (0.0032)	0.9968 (0.0039)	0.9966 (0.0041)
	2	0.9995 (0.0004)	0.9990 (0.0007)	0.9980 (0.0011)	0.9976 (0.0015)	0.9975 (0.0015)
	3–5	0.9997 (0.0010)	0.9993 (0.0022)	0.9988 (0.0040)	0.9986 (0.0049)	0.9984 (0.0058)
R_2 (Rkm 307)	1	--	0.9967 (0.0030)	0.9953 (0.0056)	0.9946 (0.0064)	0.9945 (0.0066)
	2	--	0.9975 (0.0019)	0.9965 (0.0019)	0.9960 (0.0025)	0.9958 (0.0024)
	3–5	--	0.9980 (0.0063)	0.9974 (0.0084)	0.9972 (0.0092)	0.9970 (0.0098)
R_3 (Rkm 275)	1	--	0.9967 (0.0030)	0.9952 (0.0058)	0.9945 (0.0065)	0.9943 (0.0067)
	2	--	0.9974 (0.0020)	0.9960 (0.0021)	0.9960 (0.0026)	0.9958 (0.0025)
	3–5	--	0.9978 (0.0068)	0.9973 (0.0087)	0.9970 (0.0096)	0.9969 (0.0101)

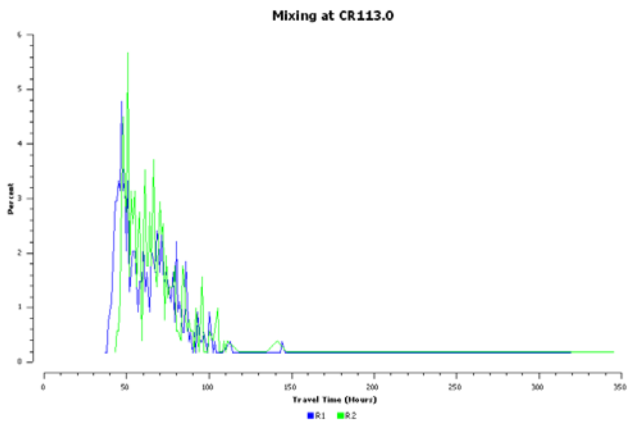
a. Rkm 234



b. Rkm 161



c. Rkm 113



d. Rkm 86

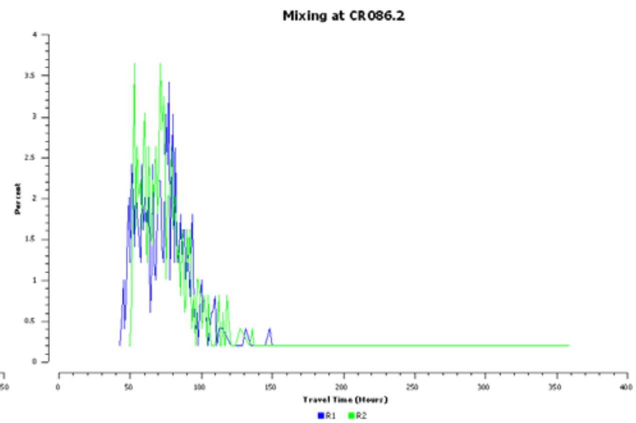
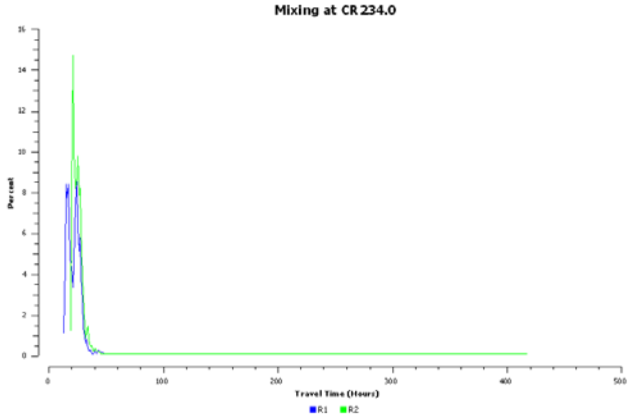
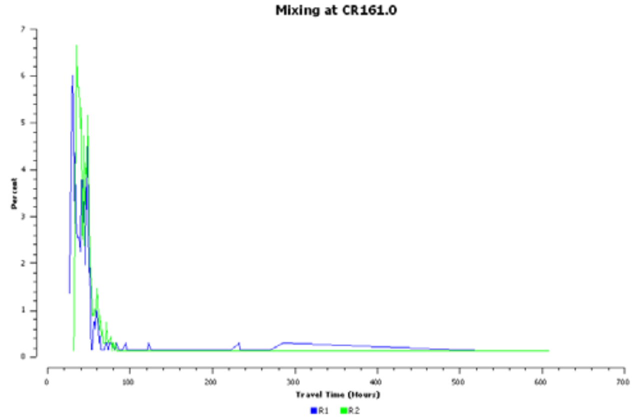


Figure E.9. Frequency Distribution Plots of Downstream Arrival Timing (expressed as percentages) for Yearling Chinook Salmon Releases R_2 and R_3 at Detection Arrays Located at a) rkm 234, b) rkm 161, c) rkm 113, and d) rkm 86 (see Figure 2.1). All times adjusted relative to the release time of R_2.

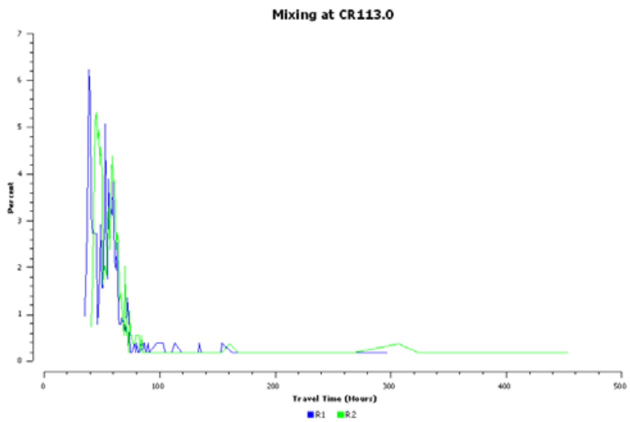
a. Rkm 234



b. Rkm 161



c. Rkm 113



d. Rkm 86

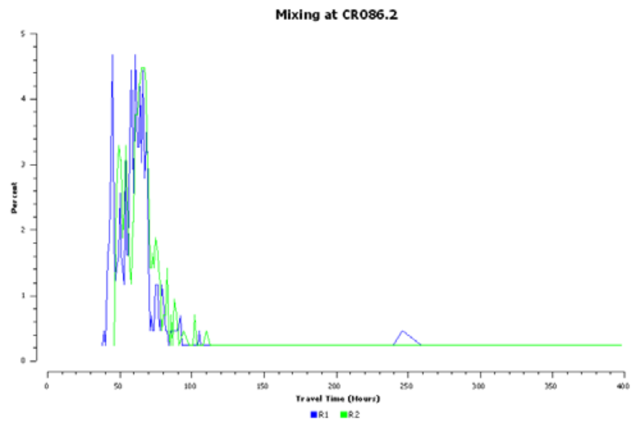


Figure E.10. Frequency Distribution Plots of Downstream Arrival Timing (expressed as percentages) for Steelhead Releases V_1, R_2, and R_3 at Detection Arrays Located at a) rkm 234, b) rkm 161, c) rkm 113, and d) rkm 86 (see Figure 2.1). All times adjusted relative to the release time of R_2.

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