PNNL-21124 Rev 1

US Army Corps of Engineers®

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

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

COMPLIANCE REPORT

JR Skalski
RL Townsend
AG Seaburg
GE Johnson
GR Ploskey
TJ Carlson

June 2012

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Pacific Northwest National Laboratory
Richland, Washington 99352

[1] University of Washington, Seattle, Washington.

Preface

This study was led by the Pacific Northwest National Laboratory and the University of Washington for the U.S. Army Corps of Engineers, Portland District (USACE). The Pacific Northwest National Laboratory and University of Washington project managers are Drs. Thomas J. Carlson and John R. Skalski, respectively. The USACE technical lead is Mr. Brad Eppard. Pacific Northwest National Laboratory subcontracted with the Pacific States Marine Fisheries Commission to help conduct the study. The study was designed to estimate dam passage survival at The Dalles Dam as stipulated by the 2008 Federal Columbia River Power System Biological Opinion and provide additional performance measures at that site as stipulated in the Columbia Basin Fish Accords.

This compliance report for The Dalles Dam focuses on 2011 spring run stocks—yearling Chinook salmon and steelhead. Subyearling Chinook salmon were not studied during 2011 because of high Columbia River discharge. Two additional reports for this study are scheduled to be delivered later in 2012: a supplemental report containing meta-data and the data used in the analyses, and a comprehensive technical report.

This report was originally submitted in February 2012. It was revised in May 2012 based on review comments from the Studies Review Work Group of the USCAE's Anadromous Fish Evaluation Program.

Suggested citation for this report:

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.

Executive Summary

The purpose of this compliance study was to estimate dam passage survival of yearling Chinook salmon and steelhead smolts at The Dalles Dam during spring 2011. Under the 2008 Federal Columbia River Power System Biological Opinion, dam passage survival is required to be greater than or equal to 0.96 and estimated with a standard error (SE) less than or equal to 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, as well as forebay residence time, tailrace egress time, and spill passage efficiency (defined below), as required in the Columbia Basin Fish Accords.

A virtual/paired-release design was used to estimate dam passage survival at The Dalles Dam. 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 pair of releases below The Dalles Dam. A total of 4,258 yearling Chinook salmon and 4,336 steelhead smolts were used in the virtual releases. Sample sizes for the below-dam paired releases were 799 (R_2) and 799 (R_3) for yearling Chinook salmon smolts and 800 (R_2) and 800 (R_3) for steelhead smolts. The Juvenile Salmon Acoustic Telemetry System tag (ATS-156dB), weighing 0.438 g in air, was used.

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., 29 April–17 May) when spill was about 40% and for the entire season, which includes higher spill levels from 18–30 May 2011. The study results are summarized in Tables ES.1, ES.2, and ES.3. Standard errors are in parentheses.

Table ES.1. Estimates of dam passage survival[(a)] at The Dalles Dam in 2011.

Spill Operations	Yearling Chinook Salmon	Steelhead
29 April–17 May 2011 (40% spill)	0.9721 (0.0104)	0.9924 (0.0115)
29 April–30 May 2011 (season-wide)	0.9600 (0.0072)	0.9952 (0.0083)

(a) Dam passage survival is defined as survival from the upstream dam face to a standardized tailrace reference point.

Table ES.2. Fish Accords performance measures at The Dalles Dam in 2011.

Performance Metrics	Yearling Chinook Salmon	Steelhead
Forebay-to-tailrace survival[(a)]		
• Early season (40% spill)	0.9712 (0.0104)	0.9921 (0.0115)
• Season-wide	0.9596 (0.0072)	0.9947 (0.0083)
Forebay residence time (mean)	1.31 h (0.14)	1.22 h (0.08)
Tailrace egress time (mean)	1.33 h (0.23)	1.97 h (0.25)
Spill passage efficiency[(b)]	0.658 (0.007)	0.754 (0.007)
Fish passage efficiency	0.831 (0.006)	0.891 (0.005)

(a) The forebay-to-tailrace survival estimate satisfies the “BRZ-to-BRZ” survival estimate in the Fish Accords.
(b) The definition in the Fish Accords includes passage the spillway and the ice and trash sluiceway at The Dalles Dam. However, the point estimate provided here includes only spillway passage, not sluiceway passage.

Table ES.3. Survival study summary.

<table>
<tr><td colspan="4">Year: 2011</td></tr>
<tr><td colspan="4">Study Site(s): The Dalles Dam</td></tr>
<tr><td colspan="4">Objective(s) of study: Estimate dam passage survival and other performance measures for yearling Chinook salmon and steelhead.</td></tr>
<tr><td colspan="4">Hypothesis (if applicable): Not applicable; this is a compliance study</td></tr>
<tr><td colspan="2">Fish:
Species-race: yearling Chinook salmon (CH1), steelhead (STH)
Source: John Day Dam fish collection facility</td><td colspan="2">Implant Procedure:
Surgical: Yes
Injected: No</td></tr>
<tr><td colspan="2">Size (median): CH1 STH
Weight: 32.19 g 73.16 g
Length: 148.3 mm 203.80 mm</td><td colspan="2">Sample Size: CH1 STH
release sites: 3 3
Total # released: 5856 5936</td></tr>
<tr><td>Tag:
Type/model: Advanced Telemetry Systems (ATS)-156dB
Weight (gm): 0.438 g (air)</td><td>Analytical Model:
Virtual/paired release</td><td colspan="2">Characteristics of Estimate: From arrival at dam face to tailrace
Effects Reflected (direct, total, etc.): Direct
Absolute or Relative: Absolute</td></tr>
<tr><td colspan="4">Environmental/Operating Conditions (daily from 29 April through 30 May 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 (deg C): mean 11.3, minimum 9.4, maximum 12.6
Total Dissolved Gas (tailrace): mean 359.4%, minimum 219.4%, maximum 497.3%
Treatment(s): None
Unique Study Characteristics: Involuntary spill conditions after 17 May 2011.</td></tr>
<tr><td colspan="2">Survival and Passage Estimates (value & SE):</td><td>CH1</td><td>STH</td></tr>
<tr><td colspan="2">Dam survival</td><td></td><td></td></tr>
<tr><td colspan="2">• 29 April–17 May 2011 (early season 40% spill)</td><td>0.9721 (0.0104)</td><td>0.9924 (0.0115)</td></tr>
<tr><td colspan="2">• 29 April–30 May 2011 (season-wide)</td><td>0.9600 (0.0072)</td><td>0.9952 (0.0083)</td></tr>
<tr><td colspan="2">Forebay-to-tailrace survival</td><td>0.9596 (0.0072)</td><td>0.9947 (0.0083)</td></tr>
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<tr><td colspan="2">Fish passage efficiency</td><td>0.831 (0.006)</td><td>0.891 (0.005)</td></tr>
<tr><td colspan="4">Compliance Results: Early season and season-wide estimates of dam passage survival for yearling Chinook and steelhead smolts met 2008 BiOp requirements $() \geq 0.96$. Standard errors were within acceptable range $() \leq 0.015$.</td></tr>
</table>

Acknowledgments

This study was the result of hard work by scientists from the Pacific Northwest National Laboratory (PNNL), Pacific States Marine Fisheries Commission (PSMFC), the U.S. Army Corps of Engineers, Portland District (USACE), and the University of Washington (UW) (listed below). Their teamwork and attention to detail were essential for the study to succeed in providing timely data to resource managers.

- PNNL: C Arimescu, T Able, G Batten, C Brandt, A Bryson, K Carter, E Choi, D Deng, K Deters, G Dirkes, J Duncan, D Faber, E Fischer, A Flory, T Fu, D Geist, K Hall, M Halvorsen, K Ham, K Hand, M Hennen, JL Hughes, JS Hughes, F Kahn, R Karls, J Kim, B LaMarche, K Larson, K Lavender, J Martinez, B Miller, A Miracle, A Phillips, G Ploskey, G Roesijadi, I Royer, D Saunders, J Smith, G Squeochs, S Southard, N Tavin, A Thronas, S Titzler, N Trimble, D Trott, K Wagner, C Woodley, J Varvinec, M Weiland S Zimmerman.
- PSMFC: G Kolvachuk and D Ballenger along with the helpful staff at John Day and Bonneville Dam Juvenile Smolt Facilities. In addition, B Babcock, R Blanchard, S Carpenter, A Collins, A Cushing, L Cushing, T Elder, D Etherington, M Gay, G George, A Halston, C Holzer, M Jenkins, K Knox, D Lock, R Martinson, D Marvin, T Monter, T Mitchell, M Neumann, T Royal, K Schaedel, N Tancreto, R Wall.
- USACE: B Eppard, M Langeslay, and electricians, mechanics, riggers, operators, and biologists at John Day (M Zyndol, T Hurd), The Dalles (B Cordie) and Bonneville dams (J Rerecich, B Hausmann, A Traylor).
- UW: J Lady and P Westhagen.

Acronyms and Abbreviations

°C	degree(s) Celsius
3D	three-dimensional
ATS	Advanced Telemetry Systems
BiOp	Biological Opinion
BRZ	boat-restricted zone
FCRPS	Federal Columbia River Power System
FPE	fish passage efficiency
g	gram(s)
h	hour(s)
JSATS	Juvenile Salmon Acoustic Telemetry System
kcfs	thousand cubic feet per second
km	kilometer(s)
L	liter(s)
m	meter(s)
mg	milligram(s)
mm	millimeter(s)
PIT	passive integrated transponder
PNNL	Pacific Northwest National Laboratory
PRI	pulse repetition interval
Rkm or rkm	river kilometer(s)
ROR	run-of-river
RPA	Reasonable and Prudent Alternative
s	second(s)
SE	standard error
SPE	spill passage efficiency
T2	Test 2
T3	Test 3
USACE	U.S. Army Corps of Engineers

Contents

Figures

Tables

1.0 Introduction

The compliance monitoring study reported here was led by researchers at Pacific Northwest National Laboratory (PNNL) and the University of Washington for the U.S. Army Corps of Engineers, Portland District (USACE). The purpose of the study was to estimate dam passage survival at The Dalles Dam as stipulated by the 2008 Federal Columbia River Power System (FCRPS) Biological Opinion (BiOp), and provide additional performance metrics at the dam as stipulated in the Columbia Basin Fish Accords for yearling Chinook salmon and steelhead (3 Treaty Tribes and Action Agencies 2008).

1.1 Background

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

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

The Columbia Basin Fish Accords were outlined in a Memorandum of Agreement between the three lower river tribes and the Action Agencies (3 Treaty Tribes and Action Agencies 2008). The Fish Accords contain three additional requirements relevant to the 2011 survival studies (after the Memorandum of Agreement 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. 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 SPE, 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 Configuration and Operations Plan updates, but not as principal or priority metrics over dam survival performance standards. Once a dam meets the survival performance standard, SPE and delay metrics may be monitored coincidentally with dam survival testing.

This report summarizes the results of the 2011 spring acoustic-telemetry study of yearling Chinook salmon and steelhead at The Dalles Dam to assess the Action Agencies' compliance with the performance criteria of the 2008 FCRPS BiOp and the Fish Accords.

1.2 Study Objectives

The purpose of spring 2011 compliance monitoring at The Dalles Dam was to estimate performance measures for yearling Chinook salmon and steelhead smolts as outlined in the FCRPS BiOp and Fish Accords. For each fish stock, the following metrics were estimated using the Juvenile Salmon Acoustic Telemetry System (JSATS) technology:

- Dam passage survival, defined as survival from the upstream face of the dam to a standardized reference point in the tailrace. Performance[1] should be ≥96% survival for spring stocks (i.e., yearling Chinook salmon and steelhead). Survival should be estimated with a standard error (SE) ≤1.5%.
- Forebay-to-tailrace survival, defined as 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, defined as the 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. (Recently, this has been amended to be the average time smolts take to travel from the forebay BRZ to passage at the dam.)
- Tailrace egress time, defined as the average time smolts take to travel from the dam to the downstream tailrace boundary, i.e., tailrace array 2 km downstream of the dam.
- SPE, defined as the fraction of fish going through the dam via the spillway.[2]
- Fish passage efficiency (FPE), defined as the fraction of fish going through the dam via the spillway and the sluiceway.[3]

Results are reported for the two fish stocks by performance measure. This report is designed to provide a succinct and timely summary of BiOp/Fish Accords performance measures. A comprehensive technical report scheduled for 2012 will provide detailed data on survival and fish passage for yearling and subyearling Chinook salmon and steelhead at The Dalles Dam in 2011. Similar studies for spring and summer 2010 were reported by Skalski et al. (2010a and b, respectively) and Johnson et al. (2011).

1.3 Report Contents and Organization

Study methods and results are described and discussed in the ensuing sections of this report. Appendix A contains additional details about the tests of study assumptions. Appendix B contains details about the capture history data used in estimating dam passage survival.

---

[1] Performance as defined in the 2008 FCRPS BiOp, Section 6.0.
[2] The definition of spill passage efficiency in the Fish Accords has traditionally been called fish passage efficiency.
[3] This was called spill passage efficiency in the Fish Accords. Efficiency metrics can differ among dams because available passage routes can differ.

2.0 Methods

Study methods involved the fish release and recapture design; the associated fish handling, tagging, and release procedures; acoustic signal processing; and analysis and statistical evaluation of passage and survival metrics.

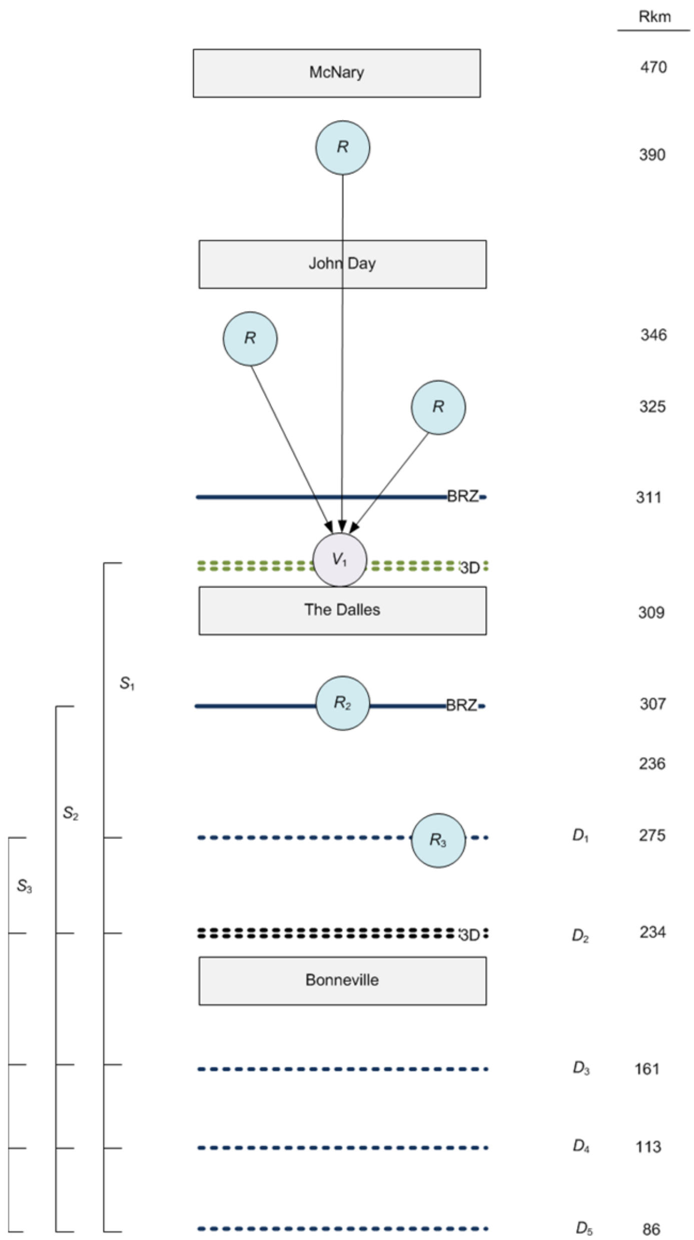
2.1 Release-Recapture Design

The release-recapture design used to estimate dam passage survival at The Dalles Dam consisted of a novel combination of a virtual release (V_1) of fish at the face of the dam and a pair of releases below the dam (Figure 2.1) (Skalski et al. 2010a, b, and c). Tagged fish were released above The Dalles Dam to supply a source of fish known to have arrived alive at the 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 next reservoir (i.e., to river kilometer [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 The Dalles Dam (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. The sizes of the releases of the acoustically tagged fish used in the dam passage survival estimates are summarized in Table 2.1.

Table 2.1. Sample sizes of acoustically tagged fish released in the yearling Chinook salmon and steelhead survival studies for The Dalles Dam in 2011.

Release Location	Yearling Chinook Salmon	Steelhead
Virtual Release (V_1)	4,258	4,336
The Dalles Dam Tailrace (R_2)	799	800
Hood River, Oregon (R_3)	799	800

The same release-recapture design was also used to estimate forebay-to-tailrace survival, except that the virtual-release group was constructed of fish known to have arrived at the forebay array (rkm 311). The same below-dam paired release was used to adjust for the extra release mortality below the dam as was used to estimate dam passage survival. The double-detection arrays at the face of the dam (Figure 2.2) were analyzed as two independent arrays to allow estimation of detection probabilities by route of passage and assign routes of passage. These passage-route data were used to calculate SPE and FPE at The Dalles Dam. The fish used in the virtual release at the face of the dam were also used to estimate tailrace egress time.



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

Figure 2.1. Schematic of the virtual/paired-release design used to estimate dam passage survival at The Dalles Dam. The virtual release (V_1) 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 used in the survival analysis denoted by dashed lines. Note that the arrays at rkm 311 and rkm 307 are not actually on the BRZ demarcations.

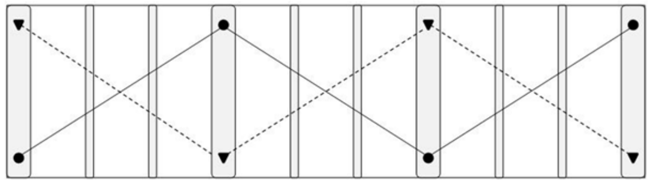


Figure 2.2. Front view schematic of hydrophone deployments at three turbines showing the double-detection arrays. The circles denote the hydrophones of Array 1 and the triangles denote the hydrophones of Array 2.

2.2 Handling, Tagging, and Release Procedures

Fish obtained from the John Day Dam juvenile bypass system were surgically implanted with JSATS tags, and then transported to three different release points, as described in the following sections.

2.2.1 Acoustic Tags

The acoustic tags used in the spring 2011 study were manufactured by Advanced Telemetry Systems (ATS). Each tag, model number ATS-156dB, measured 12.02 mm in length, 5.21 mm in width, 3.72 mm in thickness, and weighed 0.438 g in air. The tags had a nominal transmission rate of 1 pulse every 3 s. Nominal tag life was expected to be about 25 days.

For the 2011 spring study, five different manufacturing lots of JSATS tags were used in tagging the yearling Chinook salmon and steelhead smolts. Lot 1 was manufactured distinctly from lot 2, both of which were manufactured distinctly from lots 3–5. For each of these three major manufacturing lots of JSATS tags (i.e., 1, 2, 3–5), 50 to 59 acoustic tags were systematically sampled over the course of the yearling Chinook salmon and steelhead smolt tagging process. The tags were activated, held in river water, and monitored continuously until they failed. See Section 2.4.2 for statistical methods for the tag-life analysis.

2.2.2 Fish Source

The yearling Chinook salmon and steelhead used in the study were all obtained from the John Day Dam juvenile bypass system. The Pacific States Marine Fisheries Commission diverted fish from the juvenile bypass system into an examination trough, as described by Martinson et al. (2006). Fish ≥95 mm in length without malformations or excessive descaling (>20%) were selected for tagging.

2.2.3 Tagging Procedure

The fish to be tagged were anesthetized in an 18.9-L "knockdown" bucket with fresh river water and MS-222 (tricaine methanesulfonate; 80 mg/L). Anesthesia buckets were refreshed repeatedly to maintain the temperature within ±2°C of current river temperatures. Each fish was weighed and measured before tagging.

During surgery, each fish was placed ventral side up and a gravity-fed anesthesia supply line was placed into its mouth. The "maintenance" anesthesia was 40 mg/L. Using a surgical blade, a 6- to

8-mm incision was made in the body cavity between the pelvic girdle and pectoral fin. A passive integrated transponder (PIT) tag was inserted followed by an acoustic tag. Both tags were inserted toward the anterior end of the fish. The incision was closed using 5-0 Monocryl suture.

After closing the incision, the fish were placed in a dark 18.9-L transport bucket filled with aerated river water. Fish were held in these buckets for 18 to 24 h before being transported for release into the river. The loading rate was five fish per bucket.

2.2.4 Release Procedures

The fish tagged at John Day Dam were transported by truck to the release locations (Figure 2.1). Transportation routes were adjusted to provide equal travel times to each release location from John Day Dam. Upon arriving at a release site, fish buckets were transferred to a boat for transport to the in-river release location. There were five release locations at each release site across the river (Figure 2.1), and equal numbers of buckets of fish were released at each of the five locations.

Releases occurred for 32 consecutive days (from 29 April to 30 May 2011). Releases alternated between daytime and nighttime, every other day, over the course of the study. The timing of the releases at the release sites was staggered to help facilitate downstream mixing (Table 2.2).

Table 2.2. 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

2.3 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. 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.

The receptions of JSATS tag codes within raw data files from autonomous nodes were also processed to produce a data set of accepted tag-detection events, or events for short. A single file was processed at a time, and no information about receptions at other nodes was used. The Multipath and PRI filters described above were applied for each autonomous receiver, so each message was represented by no more than one reception. At least four messages passing the PRI filter were required for an acceptable tag-detection event.

The output of this process was a data set of events that summarized accepted tag detections for all times and locations where hydrophones or autonomous receivers 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 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. When messages are received at multiple hydrophones of a cabled array, the arrival timing of those messages 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 deviate 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 (3D) tracking of JSATS-tagged fish in the immediate forebay of The Dalles Dam was used to determine routes of passage to estimate SPE and FPE. Acoustic tracking is a common technique in bioacoustics based on time-of-arrival differences among different hydrophones. Usually, the process requires a three-hydrophone array for two-dimensional 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).

2.4 Statistical Methods

Statistical methods were used to estimate dam passage survival, analyze tag life, test assumptions, and estimate survival from the forebay to the tailrace, travel times, SPE, and FPE.

2.4.1 Estimation of Dam Passage Survival

Maximum likelihood estimation was used to estimate dam passage survival at The Dalles Dam 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

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

where $\hat{S}_i$ is the tag-life-corrected survival estimate for the ith 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 The Dalles Dam 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 (29 April–17 May 2011)
- Season-wide survival (29 April–30 May 2011).

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

2.4.2 Tag-Life Analysis

For the 2011 spring study, tag failure times for the three tag groups (see Section 2.2.1) were fit to the four-parameter vitality model of Li and Anderson (2009). The vitality model tends to fit acoustic-tag failure times well, because it allows for both early onset of random failure due to manufacturing as well as systematic battery failure later on. The survivorship function for the vitality model can be rewritten as

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

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

For the virtual-release group (V_1) based on fish known to have arrived at the dam and with active tags, the conditional probability of a tag being active, given the tag was active at the detection array at rkm 309, was used in the tag-life adjustment for that release group. The conditional probability of a tag being active at time t_1, given it was active at time t_0, was computed by the quotient:

$$P(t_1 | t_0) = \frac{S(t_1)}{S(t_0)}. \tag{2.3}$$

2.4.3 Tests of Assumptions

To test assumptions, the need to conduct Burnham et al. (1987) tests was considered, tests of mixing were conducted, and tagger effects were evaluated.

2.4.3.1 Burnham et al. (1987) Tests

Tests 2 and 3 (T2 and T3) of Burnham et al. (1987) have been used to assess whether upstream detection history has an effect on downstream survival. Such tests are most appropriate when fish are physically recaptured or segregated during capture as in the case with PIT-tagged fish going through the juvenile bypass system. 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.

2.4.3.2 Tests of Mixing

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

2.4.3.3 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. The single release-recapture model was used to estimate reach survivals for fish tagged by different individuals. The analysis evaluated whether any consistent pattern of reduced reach survivals existed for fish tagged by any of the tagging staff.

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

$$F_{k-1,\infty} = \frac{s_{\hat{S}}^2}{\left(\frac{\sum_{i=1}^{k} \text{Var}\left(\hat{S}_i \middle| S_i\right)}{k}\right)} \quad (2.4)$$

where

$$s_{\hat{S}}^2 = \frac{\sum_{i=1}^{k}\left(\hat{S}_i - \hat{\bar{S}}\right)^2}{k-1} \quad (2.5)$$

and

$$\hat{\bar{S}} = \frac{\sum_{i=1}^{k} \hat{S}_i}{k}. \quad (2.6)$$

The F-test was used in evaluating tagger effects.

2.4.4 Forebay-to-Tailrace Survival

The same virtual/paired-release methods used to estimate dam passage were also used to estimate forebay-to-tailrace survival. The only distinction was the virtual release group (V_1) was composed of fish known to have arrived alive at the forebay array (rkm 311) of The Dalles Dam instead of at the dam face (Figure 2.1).

2.4.5 Estimation of Travel Times

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

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

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

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

and where t_i was the travel time of the 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 The Dalles Dam 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 2 km above the dam to the last detection at the double array in front of The Dalles Dam.

2.4.6 Estimation of Spill Passage Efficiency

Spill passage efficiency was estimated by the fraction

$$\widehat{\text{SPE}} = \frac{\hat{N}_{SP}}{\hat{N}_{SP} + \hat{N}_{SL} + \hat{N}_T}, \tag{2.9}$$

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 1982:60) independently at each route. Calculating the variance in stages, the variance of $\widehat{\text{SPE}}$ was estimated as

$$\text{Var}\left(\widehat{\text{SPE}}\right) = \frac{\widehat{\text{SPE}}\left(1 - \widehat{\text{SPE}}\right)}{\sum_{i=1}^{3} \hat{N}_i} + \widehat{\text{SPE}}^2 \left(1 - \widehat{\text{SPE}}\right)^2 \cdot \left[\frac{\text{Var}\left(\hat{N}_T\right) + \text{Var}\left(\hat{N}_{SL}\right)}{\left(\hat{N}_T + \hat{N}_{SL}\right)^2} + \frac{\widehat{\text{Var}}\left(\hat{N}_{SP}\right)}{\hat{N}_{SP}^2}\right]. \tag{2.10}$$

2.4.7 Estimation of Fish Passage Efficiency

Fish passage efficiency[1] was estimated by the fraction

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

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

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

For timely production of this report, SPE and FPE estimates were based on the assumption of equal detection probabilities across the dam and a binomial sampling model.

[1] For The Dalles Dam, FPE was called spill passage efficiency in the Fish Accords.

3.0 Results

The results cover four topics: 1) fish collection, rejection, and tagging; 2) discharge and spill conditions; 3) tests of assumptions; and 4) survival and passage estimates.

3.1 Fish Collection, Rejection, and Tagging

The total number of fish handled by PNNL in spring 2011 and the counts and percentages of fish by handling category are listed in Table 3.1. Over 20,000 yearling Chinook salmon and juvenile steelhead were handled during the study.

Table 3.1. Total number of fish handled by PNNL during the spring of 2011 and counts of fish in several handling categories. CH1 = yearling Chinook salmon, and STH = juvenile steelhead.

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

(a) In 2011, PIT scanning occurred after fish condition assessment, so the listed non-candidate count is inflated by some PIT-tag–bearing fish that should have been rejected solely for having been tagged previously. The order of processing will be changed for 2012 to better estimate numbers of non-candidate fish.

Staff rejecting fish from tagging recorded the reasons by tallying the maladies observed (Table 3.2). Conditions were based on the general recommendations of the Columbia Basin Rejection Criteria (Columbia Basin Surgical Protocol Steering Committee 2011). PNNL broadened some criteria to accept more fish, including fish that on any one side had less than 5% fungus and open wounds, parasites that occurred on the head and flanks of the fish, operculum damage less than 75%, red fins, any abrasions, and scarring. If more than 5% of the sample the day before had a particular malady/infection, the following day fish with that malady were accepted after approval by the fish condition study manager.

Table 3.2. Total number of fish handled by PNNL during the spring of 2011 and counts of fish with common maladies. CH1 = yearling Chinook salmon, and STH = juvenile steelhead.

	CH1	% CH1	STH	% STH	**Total**
Moribund/Emaciated	10	0	8	0	**18**
Descaling > 20%	437	5	659	7	**1096**
Diseases	221	2	304	3	**525**
Damage/Injury	398	4	584	6	**982**
Skeletal Deformity	4	0	14	0	**18**
Non-Candidate	1070	11	1569	16	**2639**

3.2 Discharge and Spill Conditions

The average daily total discharge at the Dalles Dam during the first half of the study (29 April–17 May 2011) was 283 kcfs with an average percent spill of 39.7%. Over the entire course of the study, average daily total discharge was 359 kcfs with an average percent spill of 43.1% (Figure 3.1). By the end of the study, total discharge had increased to 497 kcfs and spill reached 50%.

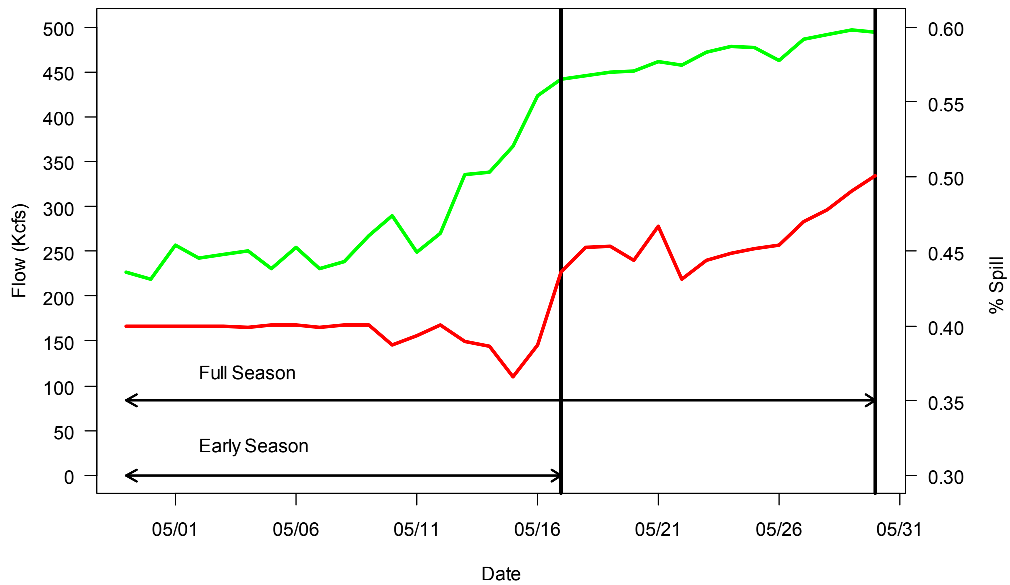


Figure 3.1. Daily average total discharge (kcfs) (green line) and percent spill (red line) at The Dalles Dam during the spring 2011 JSATS yearling Chinook salmon and steelhead study, 29 April to 30 May 2011.

3.3 Run Timing

The cumulative percent of yearling Chinook salmon and juvenile steelhead that had passed The Dalles Dam by date was calculated from smolt index data for John Day Dam obtained from the Fish Passage Center (Table 3.3). From April 29 through May 17, 2011, 46% of yearling Chinook salmon and 28% of juvenile steelhead had passed The Dalles Dam. By the end of the study on May 30, 2011, 87% of yearling Chinook salmon and 91% of juvenile steelhead had passed the dam.

Table 3.3. 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. CH1 = yearling Chinook salmon, and STH = juvenile steelhead.

		CH1			STH		
	Period	%First Date	%Last Date	%Total Run	%First Date	%Last Date	%Total Run
Early	4/29–5/17	7.70	53.57	45.88	18.09	46.01	27.92
Late	5/17–5/30	53.57	94.67	41.10	46.01	91.16	45.15
Season	4/29–5/30	7.70	94.67	86.98	18.09	91.16	73.07

3.4 Assessment of Assumptions

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

3.4.1 Examination of Tagger Effects

A total of eight different taggers assisted in tagging all of the yearling Chinook salmon and steelhead smolts associated with the JSATS survival studies at John Day, The Dalles, and Bonneville dams in spring 2011. Analyses found tagger effort was homogenously distributed either across all locations within a replicate release or within the project-specific releases within a replicate (Appendix A). Examination of reach survivals and cumulative survivals from above John Day Dam to below Bonneville Dam found no consistent or reproducible evidence that fish tagged by different staff members had different in-river survival rates (Appendix A). Therefore, fish tagged by all taggers were included in the estimation of survival and other performance measures.

3.4.2 Examination of Tag-Lot Effects

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

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

3.4.3 Handling Mortality and Tag Shedding

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

3.4.4 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 3.2). The percent of fish detected on four autonomous nodes in The Dalles Dam tailrace was weighted to try and equalize sampling effort and detectability among node locations. Sampling effort varied because some nodes stopped sampling prematurely because of damage or 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.

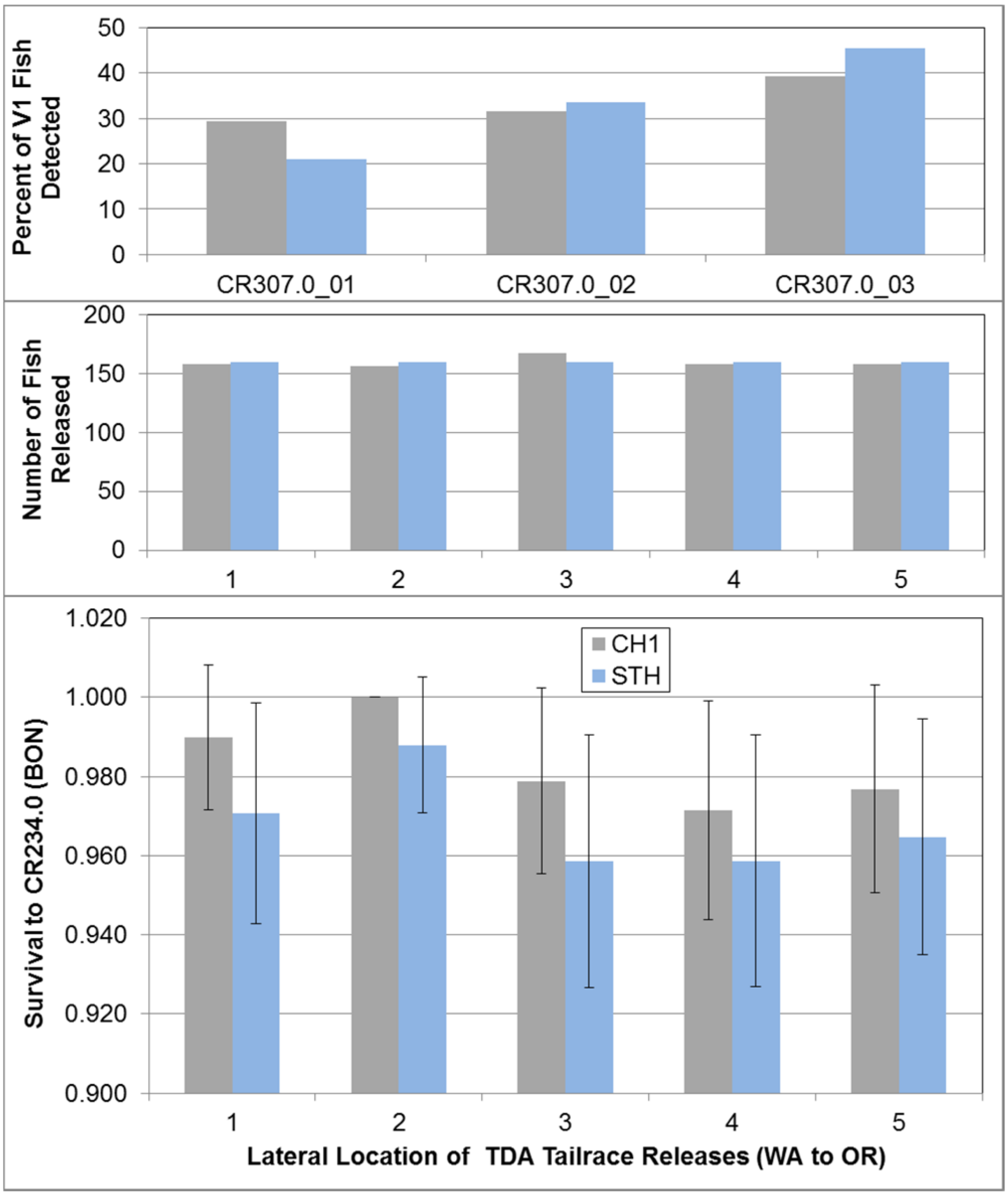


Figure 3.2. Distributions of tailrace detections of V_1 fish on autonomous nodes (top), numbers of fish released in the tailrace at five locations (middle), and survival rates by tailrace release location (bottom). Gray bars are for yearling Chinook salmon smolts; blue bars are for juvenile steelhead; vertical bars are 95% confidence intervals on survival estimates.

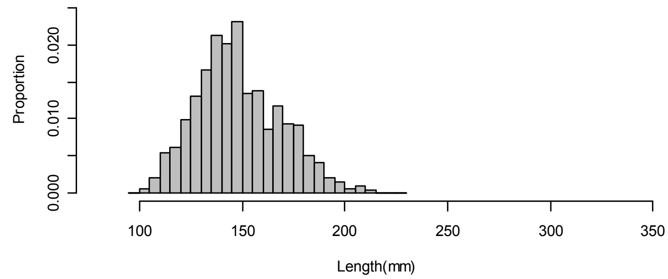
3.4.5 Examination of Time In-River on Survivals of Different Release Groups

The virtual release formed from the detections of upriver releases at the face of the dam could result in biased survival estimates if fish from varying upriver release locations had differential downriver survivals. For this reason, reach survivals and cumulative survivals were compared across fish from different upriver release locations. There were 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 (Appendix A). Therefore, in constructing the virtual releases at the face of the dam, fish from all available upriver release locations were used in subsequent survival and other parameter estimation.

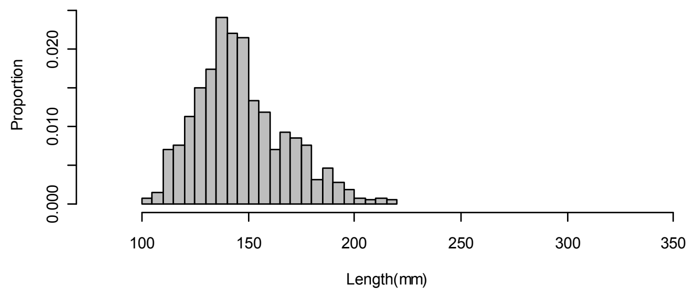
3.4.6 Fish Size Distribution

Comparison of JSATS-tagged fish with 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 3.3) and steelhead (Figure 3.4). The length distributions for the three yearling Chinook salmon releases (Figure 3.5) and the three steelhead releases (Figure 3.5) 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 3.5).

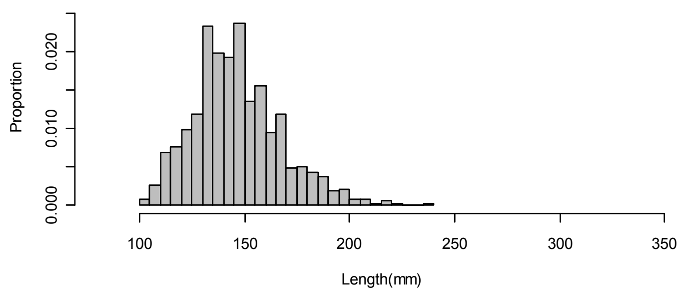
a. The Dalles Dam (Release V_1)



b. The Dalles Tailrace (Release R_2)



c. Bonneville Reservoir (Release R_3)



d. ROR Yearling Chinook at John Day Dam

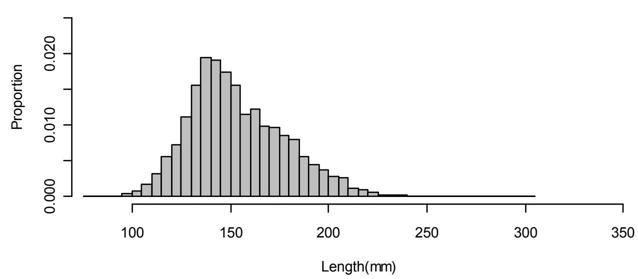
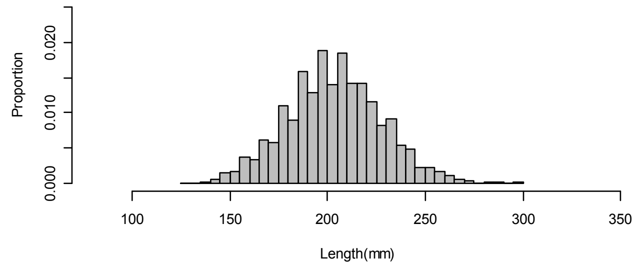
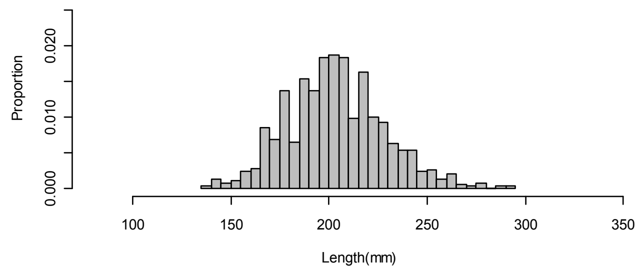


Figure 3.3. Relative frequency distributions for fish length (mm) of yearling Chinook salmon smolts used in a) release V_1, b) release R_2, c) release R_3, and d) ROR fish sampled at John Day Dam by the Fish Passage Center.

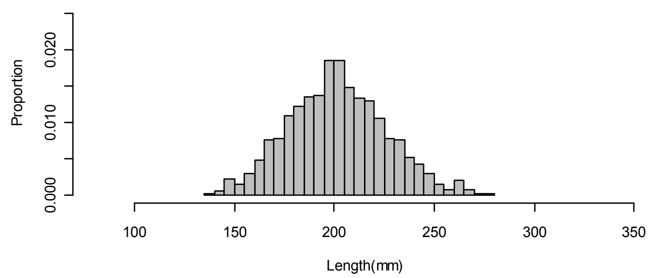
a. The Dalles Dam (Release V_1)



b. The Dalles Tailrace (Release R_2)



c. Bonneville Reservoir (Release R_3)



d. ROR Steelhead at John Day Dam

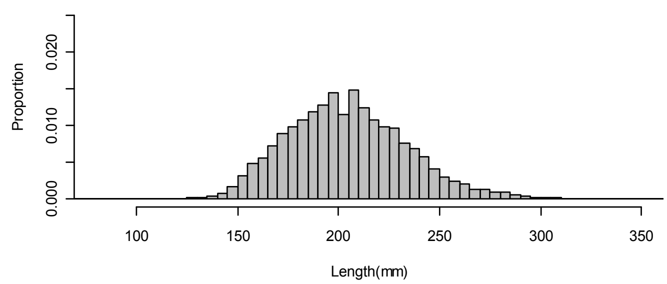
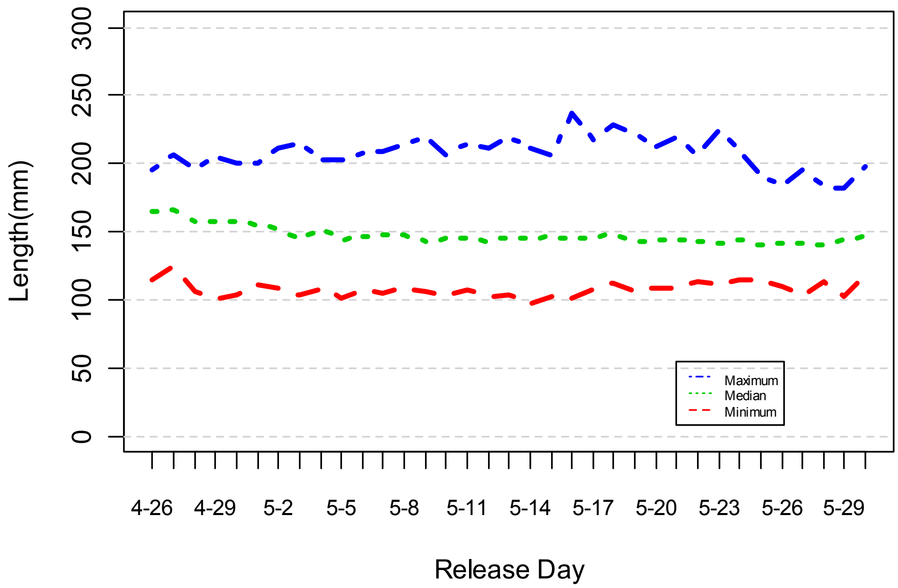


Figure 3.4. Relative frequency distributions for fish length (mm) of steelhead smolts used in a) release V_1, b) release R_2, c) release R_3, and d) ROR fish sampled at John Day Dam by the Fish Passage Center.

a. Yearling Chinook salmon smolts



b. Steelhead smolts

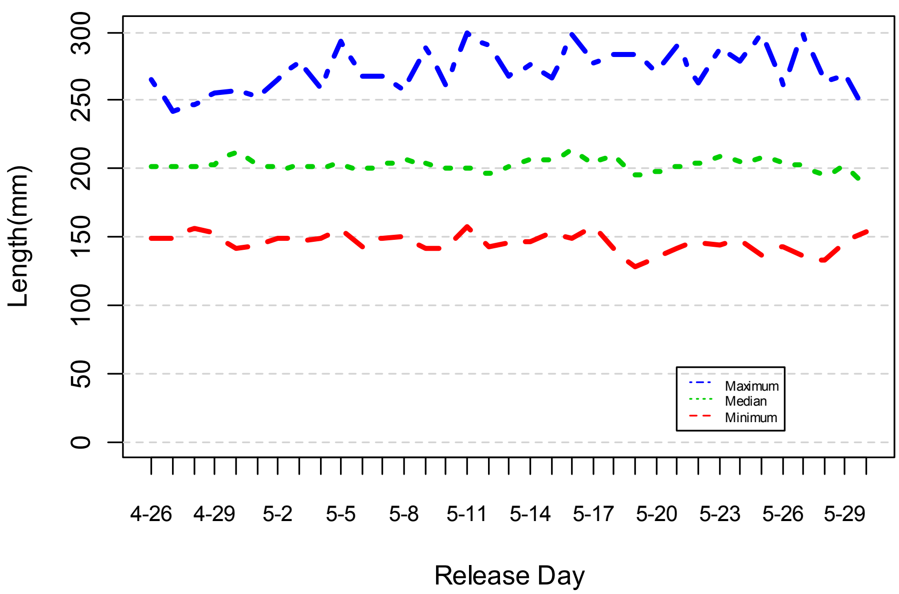


Figure 3.5. Ranges and median lengths of acoustically tagged a) yearling Chinook salmon and b) steelhead used in the 2011 survival studies. Releases were made daily from 29 April through 30 May at five release locations: rkm 390, rkm 346, rkm 325, rkm 307, and rkm 275.

3.4.7 Tag-Life Corrections

Vitality curves of Li and Anderson (2009) were fit independently to each of the lots 1, 2, and 3–5 (Figure 3.6). Mantel and Haenszel (1959) tests of homogeneous tag-life distributions found lot 1 was significantly different from lot 2 ($P = 0.0005$) and lots 3–5 ($P = 0.0023$), but lots 2 and lots 3–5 were not different ($P = 0.5698$) (Figure 3.7). Average tag lives were 31.74, 30.32, and 30.52 days for lots 1, 2, and 3–5, respectively.

3.4.8 Arrival Distributions

The estimated probability that an acoustic tag was active when fish arrived at a downstream detection array depends on the tag-life curve and the distribution of observed travel times for yearling Chinook salmon (Figure 3.8) and steelhead (Figure 3.9). Examination of the fish arrival distributions to 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 3.6, Figure 3.7) 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 3.4). 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 ≥ 0.9943 for steelhead smolts.

3.4.9 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 3.10) and steelhead (Figure 3.11) smolts. The arrival modes for releases R_2 and R_3 were nearly synchronous.

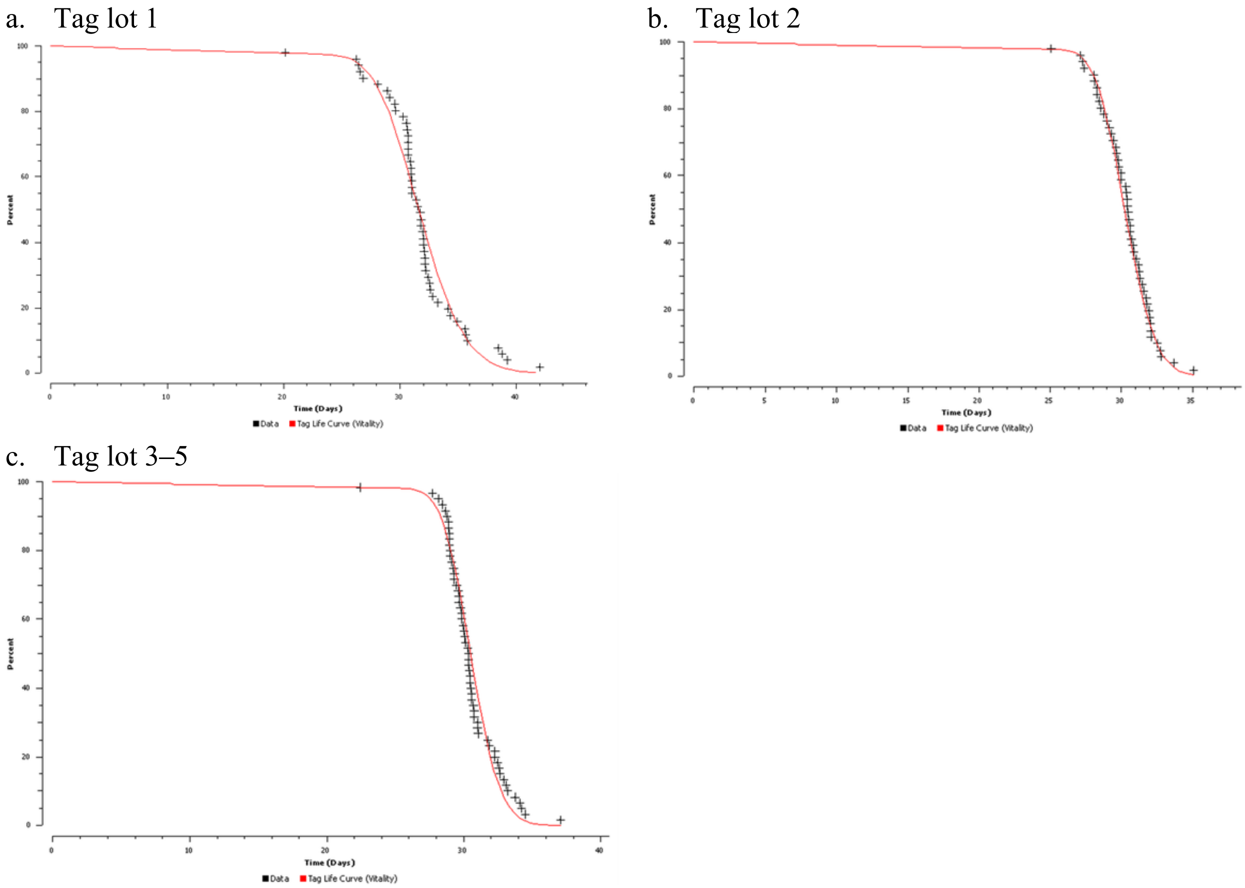


Figure 3.6. Observed time of tag failure and fitted survivorship curves using the vitality model of Li and Anderson (2009) for a) tag lot 1, b) tag lot 2, and c) tag lots 3–5.

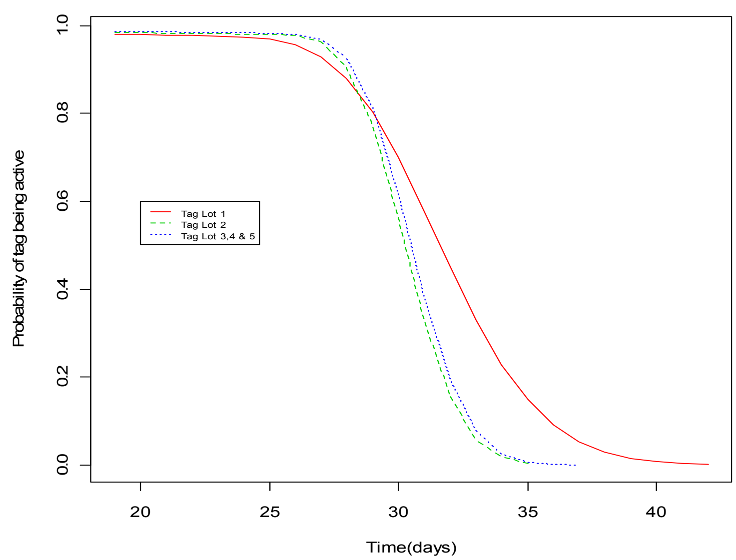
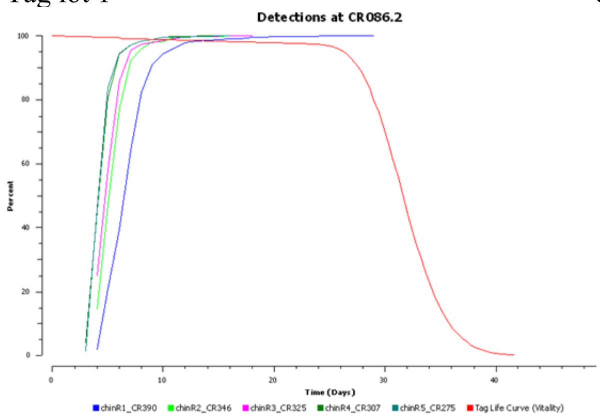


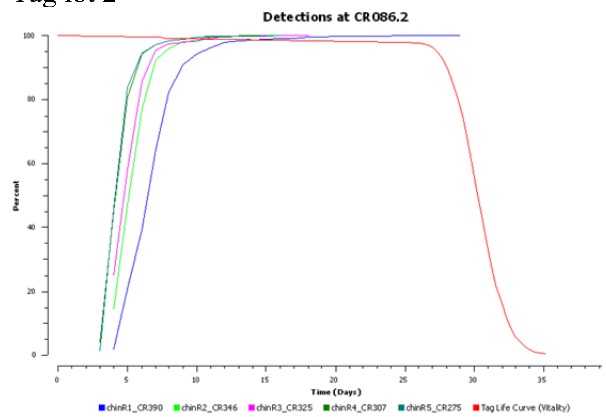
Figure 3.7. Comparison of fitted survivorship curves using the vitality model of Li and Anderson (2009) for JSATS tag lots 1, 2, and 3–5 used in the 2011 compliance studies.

Yearling Chinook salmon

a. Tag lot 1



b. Tag lot 2



c. Tag lots 3-5

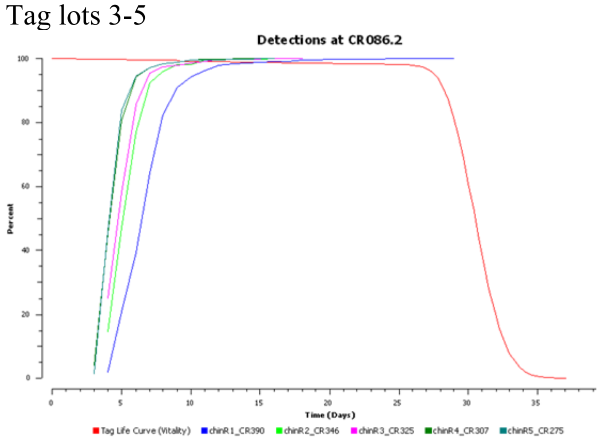
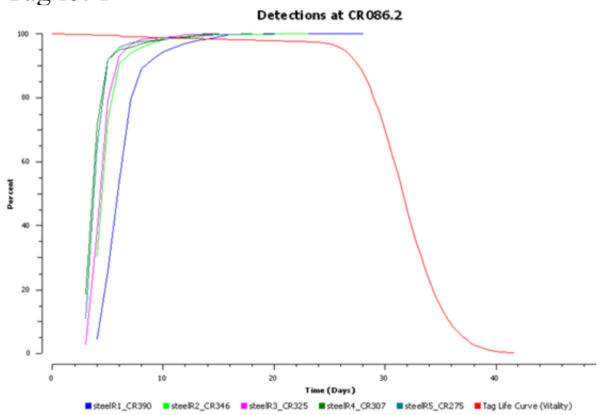


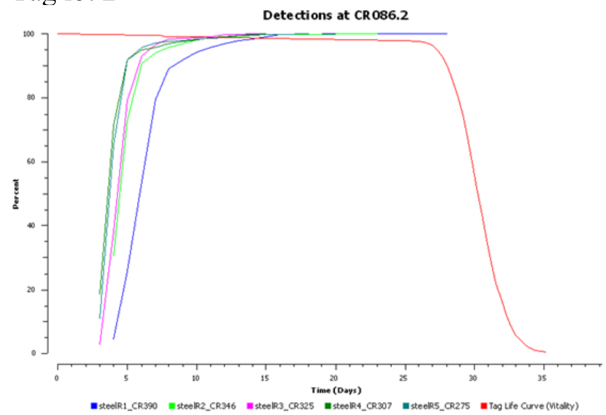
Figure 3.8. Plot of the fitted tag-life curves and the arrival-time distributions of yearling Chinook salmon smolts for releases V_1, R_2, and R_3 at the acoustic-detection array located at rkm 86 (Figure 2.1).

Steelhead

a. Tag lot 1



b. Tag lot 2



c. Tag lots 3-5

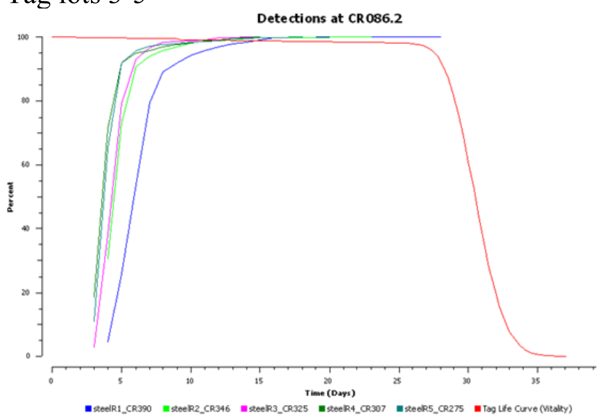


Figure 3.9. Plot of the fitted tag-life curves and the arrival-time distributions of steelhead smolts for releases V_1, R_2, and R_3 at the acoustic-detection array located at rkm 86 (Figure 2.1).

Table 3.4. 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

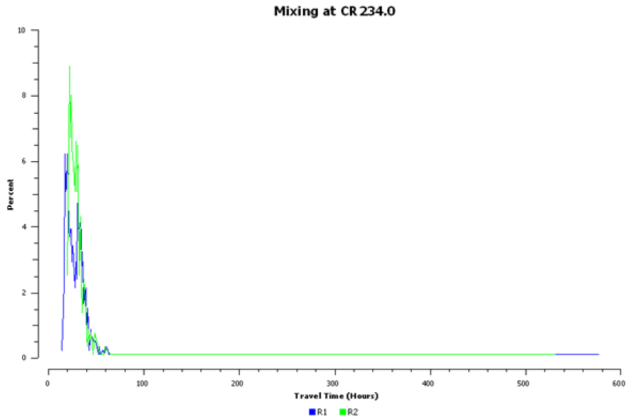
		Detection Site				
Release Group	Tag Lot	Rkm 275	Rkm 234	Rkm 161	Rkm 113	Rkm 86
V_1 (Rkm 390)	1	0.9993 (0.0007)	0.9985 (0.0015)	0.9970 (0.0022)	0.9963 (0.0027)	0.9959 (0.0030)
	2	0.9995 (0.0003)	0.9990 (0.0006)	0.9981 (0.0017)	0.9977 (0.0020)	0.9974 (0.0023)
	3–5	0.9997 (0.0008)	0.9992 (0.0020)	0.9988 (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 3.4. (contd)

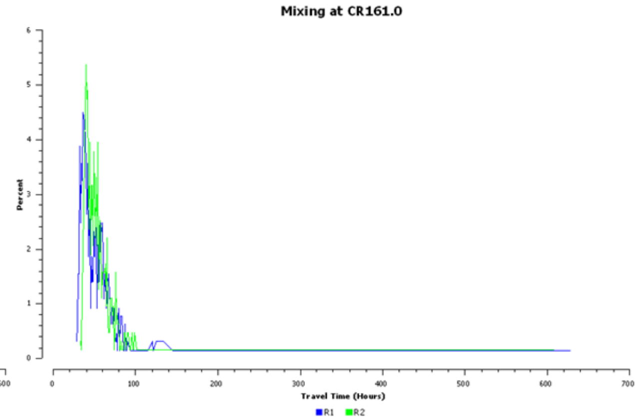
b. Steelhead

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)

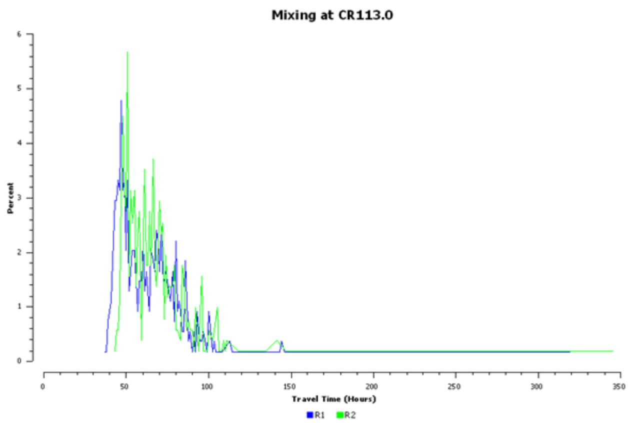
a. Rkm 234



b. Rkm 161



c. Rkm 113



d. Rkm 86

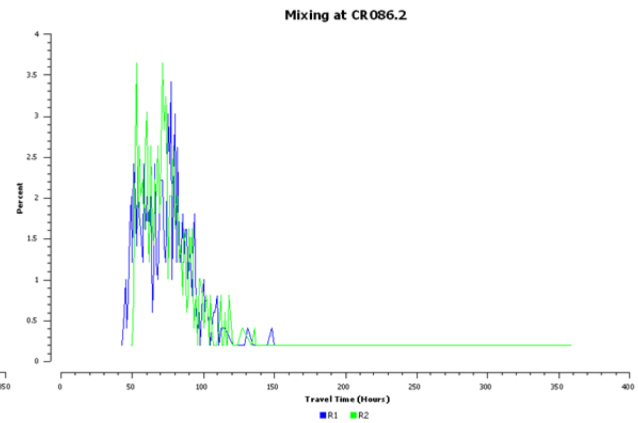
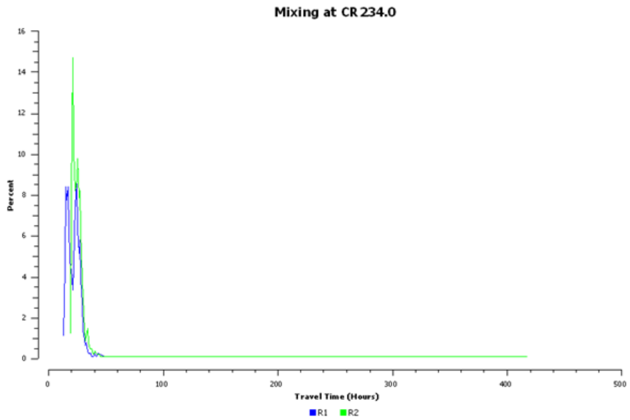
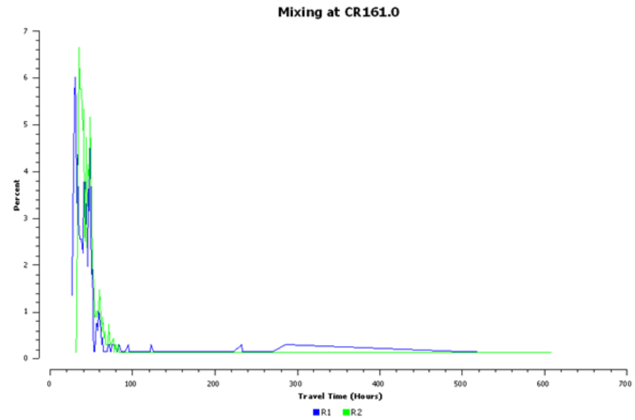


Figure 3.10. Frequency distribution plots of downstream arrival timing (expressed as percentages) for yearling Chinook salmon releases R_2 and R_3 at detection arrays located at a) rkm 234, b) rkm 161, c) rkm 113, and d) rkm 86 (see Figure 2.1). All times adjusted relative to the release time of R_2.

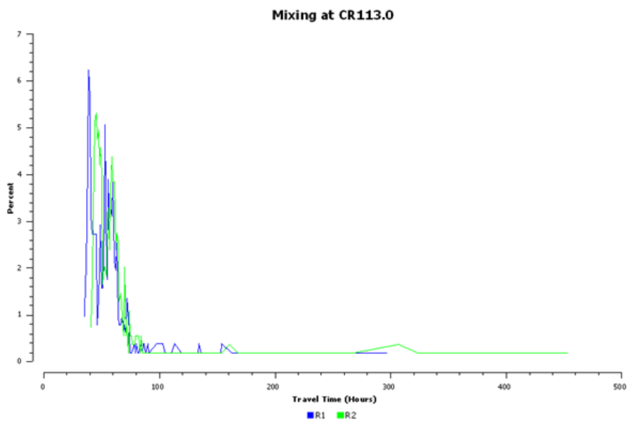
a. Rkm 234



b. Rkm 161



c. Rkm 113



d. Rkm 86

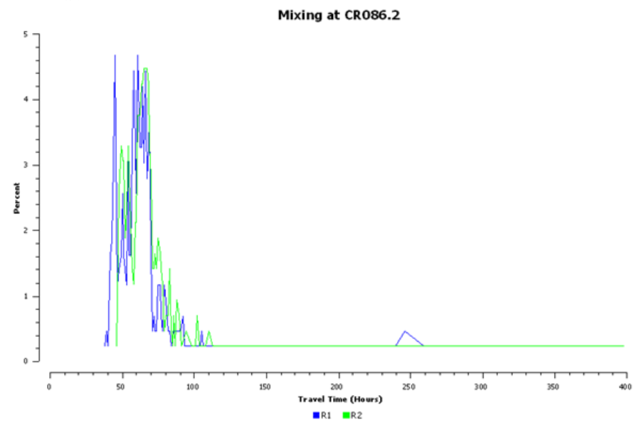


Figure 3.11. Frequency distribution plots of downstream arrival timing (expressed as percentages) for steelhead releases V_1, R_2, and R_3 at detection arrays located at a) rkm 234, b) rkm 161, c) rkm 113, and d) rkm 86 (see Figure 2.1). All times adjusted relative to the release time of R_2.

3.5 Survival and Passage Performance

This section contains estimates for dam passage survival, forebay-to-tailrace passage survival, forebay residence time, tailrace egress time, SPE, and FPE.

3.5.1 Dam Passage Survival

The estimates of dam passage survival were based on the virtual/paired-release design using capture history data (Appendix B) and the fitted tag-life curve (Figure 3.7). 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 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.

3.5.1.1 Yearling Chinook Salmon

The estimates of dam passage survival for yearling Chinook salmon smolts at The Dalles Dam were calculated for two periods of time. One period was from the beginning of the study on 29 April through 17 May 2011, while flows were moderate and spill was held constant at 40%. The second time frame was from the beginning to end of the study, 29 April to 30 May 2011, and includes the higher flows and spill levels in excess of 40% later in the season (Figure 3.1).

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

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

with an associated $\widehat{\text{SE}}$ of 0.0104 (Table 3.5). For the entire study period, dam passage survival for yearling Chinook salmon smolts was estimated to be

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

with an associated $\widehat{\text{SE}}$ of 0.0072 (Table 3.6). Both early season or season-wide estimate of dam passage survival exceeded the 2008 BiOp requirement for $\hat{S} \geq$ 0.9600 and both had $\widehat{\text{SE}} \leq 0.015$.

Table 3.5. 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 part (29 April–17 May) of the spring season in 2011. Parameter estimates based on fully parameterized release-recapture models for each group. SE based on both the inverse hessian matrix and bootstrapping for key parameters (†) and only the inverse hessian matrix for associated parameters (*).

Release Group	Rkm 309 to 275		Rkm 275 to 234		Release to Rkm 234		Rkm 234 to 153		Rkm 153 to 113	
	$\hat{S}$	$\widehat{SE}^{\dagger}$	$\hat{S}$	$\widehat{SE}^{*}$	$\hat{S}$	$\widehat{SE}^{\dagger}$	$\hat{S}$	$\widehat{SE}^{*}$	$\hat{S}$	$\widehat{SE}^{*}$
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

Release Group	Rkm 113 to 86.2		Rkm 275		Rkm 234		Rkm 161		Rkm 113	
	$\hat{\lambda}$	$\widehat{SE}^{*}$	$\hat{p}$	$\widehat{SE}^{*}$	$\hat{p}$	$\widehat{SE}^{*}$	$\hat{p}$	$\widehat{SE}^{*}$	$\hat{p}$	$\widehat{SE}^{*}$
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

Table 3.6. 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 for the season-wide spring study in 2011. Parameter estimates based on fully parameterized release-recapture models for each group. SE based on both the inverse hessian matrix and bootstrapping for key parameters (†) and only the inverse hessian matrix for associated parameters (*).

Release Group	Rkm 309 to 275		Rkm 275 to 234		Release to Rkm 234		Rkm 234 to 161		Rkm 161 to 113	
	$\hat{S}$	$\widehat{\text{SE}}^{\dagger}$	$\hat{S}$	$\widehat{\text{SE}}^{*}$	$\hat{S}$	$\widehat{\text{SE}}^{\dagger}$	$\hat{S}$	$\widehat{\text{SE}}^{*}$	$\hat{S}$	$\widehat{\text{SE}}^{*}$
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

Release Group	Rkm 113 to 86.2		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	0.7143	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

3.5.1.2 Steelhead

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

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

with an associated $\widehat{\text{SE}}$ of 0.0115 (Table 3.7). 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 The Dalles Dam was estimated to be

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

with an associated $\widehat{\text{SE}}$ of 0.0083 (Table 3.8). 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 and without sacrificing either attribute.

Table 3.7. 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 part (29 April–17 May) of the spring season in 2011. Parameter estimates based on fully parameterized release-recapture models for each group. SEs based on both the inverse hessian matrix and bootstrapping for key parameters (†) and only the inverse hessian matrix for associated parameters (*).

Release Group	Rkm 309 to 275		Rkm 275 to 234		Release to Rkm 234		Rkm 234 to 161		Rkm 161 to 113	
	$\hat{S}$	$\widehat{SE}^{\dagger}$	$\hat{S}$	$\widehat{SE}^{*}$	$\hat{S}$	$\widehat{SE}^{\dagger}$	$\hat{S}$	$\widehat{SE}^{*}$	$\hat{S}$	$\widehat{SE}^{*}$
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 86.2		Rkm 275		Rkm 234		Rkm 161		Rkm 113	
	$\hat{\lambda}$	$\widehat{SE}^{*}$	$\hat{p}$	$\widehat{SE}^{*}$	$\hat{p}$	$\widehat{SE}^{*}$	$\hat{p}$	$\widehat{SE}^{*}$	$\hat{p}$	$\widehat{SE}^{*}$
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 3.8. Tag-life-adjusted survival estimates of reach survival and detection probabilities for steelhead smolts used in estimating dam passage survival at The Dalles Dam for the season-wide spring study in 2011. Parameter estimates based on fully parameterized release-recapture models for each group. SE based on both the inverse hessian matrix and bootstrapping for key parameters (†) and only the inverse hessian matrix for associated parameters (*).

Release Group	Rkm 309 to 275		Rkm 275 to 234		Release to Rkm 234		Rkm 234 to 161		Rkm 161 to 113	
	$\hat{S}$	$\widehat{SE}^{\dagger}$	$\hat{S}$	$\widehat{SE}^{*}$	$\hat{S}$	$\widehat{SE}^{\dagger}$	$\hat{S}$	$\widehat{SE}^{*}$	$\hat{S}$	$\widehat{SE}^{*}$
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 86.2		CR275		CR234		CR161		CR113	
	$\hat{\lambda}$	$\widehat{SE}^{*}$	$\hat{p}$	$\widehat{SE}^{*}$	$\hat{p}$	$\widehat{SE}^{*}$	$\hat{p}$	$\widehat{SE}^{*}$	$\hat{p}$	$\widehat{SE}^{*}$
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

3.5.2 Forebay-to-Tailrace Passage Survival

The estimates of forebay-to-tailrace passage survival were calculated analogously to estimates of dam passage survival except that the virtual-release group (V_I) was composed of fish known to have arrived at the forebay (i.e., detection array rkm 311, Figure 2.1) rather than at the dam face. Although the capture history data for V_I changed (Appendix B, Table B.1), the same capture history data were used for releases R_2 and R_3 (Appendix B, Table B.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 (Table 3.9).

As might be expected, the forebay-to-tailrace survival estimates are slightly lower than the respective estimates of dam passage survival due to the additional travel distance above the dam. The Fish Accords do not have compliance standards for either the forebay-to-tailrace survival estimates or their standard errors. Nevertheless, 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.

Table 3.9. Estimates of forebay-to-tailrace survivals for yearling Chinook salmon and steelhead at The Dalles Dam for the early season and season-wide spring study in 2011.

Period	Yearling Chinook Salmon	Steelhead
Early Season (29 April–17 May)	0.9712 (0.0104)	0.9921 (0.0115)
Season-Wide (29 April–29 May)	0.9596 (0.0072)	0.9947 (0.0083)

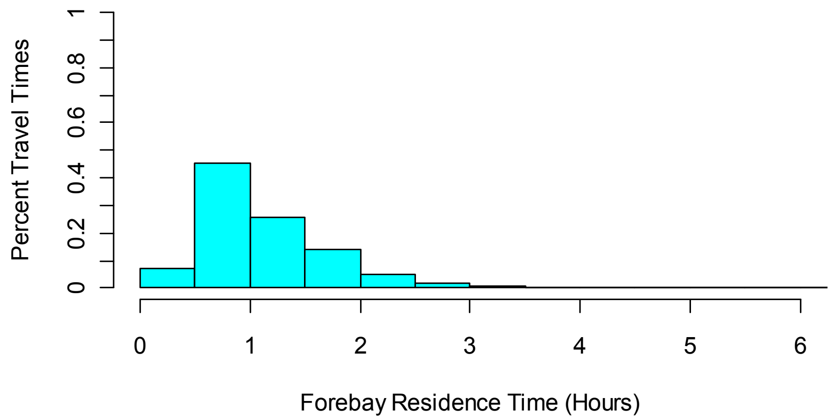
3.5.3 Forebay Residence Time

The forebay residence times were based on the times from the first detection at the forebay BRZ array at rkm 311 to the last detection at the double array in front of The Dalles Dam. For yearling Chinook salmon smolts, mean forebay residence time was $\bar{t}$ = 1.31 h ($\widehat{\text{SE}}$ = 0.15), with a median value of 0.97 h (Table 3.10). The majority of the fish reached the dam in less than 1 h (Figure 3.12). For steelhead smolts, mean forebay residence time was $\bar{t}$ = 1.22 h ($\widehat{\text{SE}}$ = 0.08), with a median value of 0.81 h (Table 3.10). The majority of steelhead reached the dam in less than 1 h (Figure 3.12).

Table 3.10. Estimated mean and median forebay residence times (h) and mean and median tailrace egress times for yearling Chinook salmon and steelhead smolts at The Dalles Dam in 2011.

	Yearling Chinook Salmon		Steelhead	
Performance Measure	Mean	Median	Mean	Median
Forebay Residence Time	1.31 (0.15)	0.97	1.22 (0.08)	0.81
Tailrace Egress Time	1.33 (0.23)	0.24	1.97 (0.25)	0.20

a. Yearling Chinook salmon



b. Steelhead

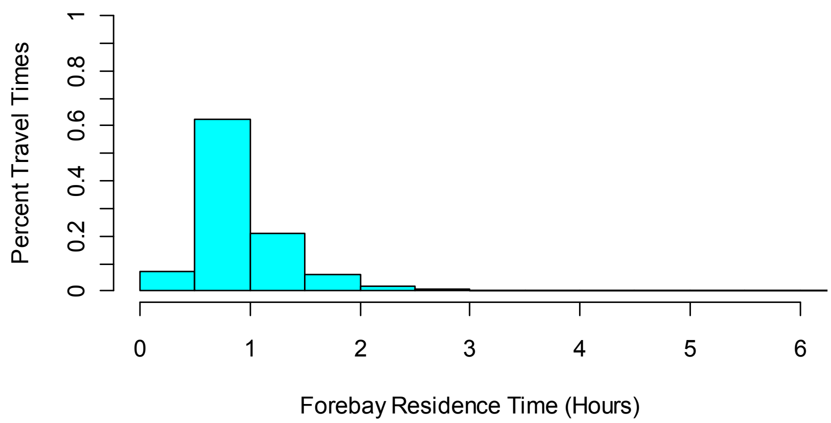
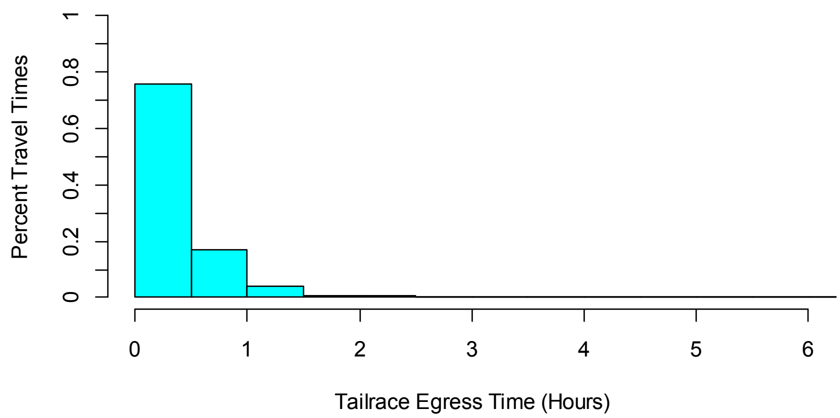


Figure 3.12. Distribution of forebay residence times for a) yearling Chinook salmon and b) steelhead smolts at The Dalles Dam 2011.

3.5.4 Tailrace Egress Time

The tailrace egress time was calculated based on the time from the last detection of fish at the double array at the face of The Dalles Dam to the last detection at the BRZ tailrace array. For yearling Chinook salmon smolts, mean tailrace egress time was $\bar{t}$ = 1.33 h ($\widehat{SE}$ = 0.23) with a median value of 0.24 h (Table 3.10). The majority of the yearling Chinook salmon passed through the dam and tailrace in less than 0.5 h (Figure 3.13). For steelhead smolts, mean tailrace egress time was $\bar{t}$ = 1.97 h ($\widehat{SE}$ = 0.25), with a median value of 0.20 h (Table 3.10). The majority of steelhead reached the dam in less than 0.5 h (Figure 3.13).

a. Yearling Chinook salmon



b. Steelhead

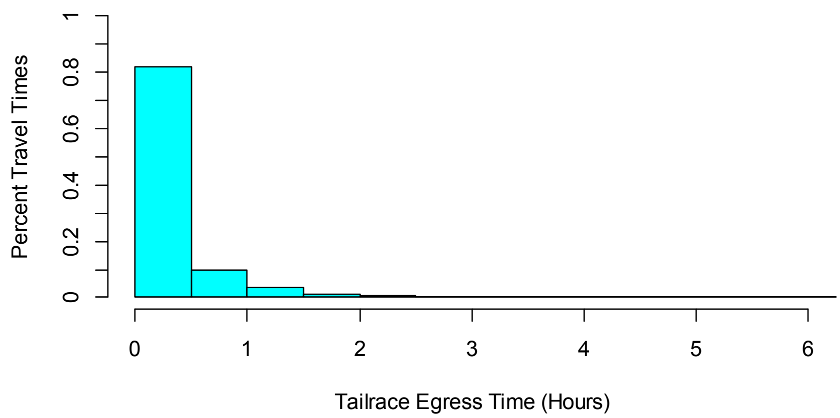


Figure 3.13. Distribution of tailrace egress times for a) yearling Chinook salmon and b) steelhead smolts at The Dalles Dam, 2011.

3.5.5 Spill Passage Efficiency

Spill passage efficiency is defined as the fraction of the fish that passed through a hydroproject by the spillway. (In the Fish Accords, the definition of SPE also included sluice passage. This metric is presented below as FPE.) The double-detection array at the face of The Dalles Dam was used to identify and track fish as they entered the dam. Using the observed counts and assuming a homogeneous detection process, the number of fish entering the spillway and powerhouse were used to estimate SPE based on a binomial sampling model. For yearling Chinook salmon smolts at The Dalles Dam in 2011, the proportion of fish that went through the spillway is estimated to be

$$\widehat{\text{SPE}}_{CH} = 0.658\left(\widehat{\text{SE}} = 0.007\right) \tag{3.5}$$

and for steelhead smolts

$$\widehat{\text{SPE}}_{ST} = 0.754\left(\widehat{\text{SE}} = 0.007\right). \tag{3.6}$$

3.5.6 Fish Passage Efficiency

Fish passage efficiency is the fraction of the fish that pass through a hydropower project by non-turbine routes (spillway and sluiceway at The Dalles Dam). As with SPE, the double-detection array at the face of The Dalles Dam was used to identify and track fish as they entered the dam. Using the observed counts and assuming a homogeneous detection process, the number of fish entering the spillway and powerhouse were used to estimate FPE using a binomial sampling model. For yearling Chinook salmon smolts at The Dalles Dam in 2011, FPE is estimated to be

$$\widehat{\text{FPE}}_{CH} = 0.831\left(\widehat{\text{SE}} = 0.006\right) \tag{3.7}$$

and for steelhead smolts

$$\widehat{\text{FPE}}_{ST} = 0.891\left(\widehat{\text{SE}} = 0.005\right). \tag{3.8}$$

4.0 Discussion

In this section, we discuss study conduct, study performance, and a cross-year summary for 2010 and 2011.

4.1 Study Conduct

Despite the high flows and elevated spill at The Dalles in 2011, the precision of the estimates of dam passage survival met the 2008 BiOp standard of SEs ≤ 0.015. This was true whether the analyses were performed for the early part of the study (i.e., 29 April–17 May 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 fourth and fifth arrays for added detections (Table 3.5 through Table 3.8). 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 SEs.

4.2 Study Performance

The 2011 spring compliance study at The Dalles Dam was interrupted by high flow conditions that resulted in spill levels in excess of 40% starting about 18 May 2011 (Figure 3.1). However, total discharge during the early part of the study from 29 April–17 May 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 $\hat{S} = 0.9600$ ($\widehat{\text{SE}} = 0.0072$) 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 estimate 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 The Dalles Dam does not appear to have been biased by the high flow and spill levels during the latter part of the investigation (18 through 30 May 2011). For yearling Chinook salmon, the season-wide estimate is lower than the early season value; the season-wide value should be able to 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. Monitoring of smolt size at time of tagging (Figure 3.5) also suggests there was no change in fish size during the course of the study that could have otherwise confounded results.

4.3 Cross-Year Summary

Formal compliance studies were conducted at The Dalles Dam with yearling Chinook salmon and steelhead during both spring 2010 and 2011. Yearling Chinook survival estimates in both years 2010 and 2011 were ≥ 0.96 with $\widehat{\text{SE}} \leq 0.015$ with a 2-year average of $\hat{\bar{S}} = 0.9620$. 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-year average is $\hat{\bar{S}} = 0.9743$ (Table 4.1). Both steelhead survival estimates had acceptable precision of $\widehat{\text{SE}} \leq 0.015$ (Table 4.1).

Table 4.1. 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	0.9600 (0.0072)	0.9952 (0.0083)	N/A
Two-Year Average	*0.9620*	*0.9743*	

5.0 References

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Appendix A

Tests of Assumptions

Appendix A

Test of Assumptions

A.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 A.1).

Tagger effects were also examined within each of the 32 replicate releases conducted over the course of the season (Table A.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 A.2). This conditional and unconditional balance within replicates is the reason for the overall balance observed in Table A.1. To minimize the number of contingency tables presented, results in Table A.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 A.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 A.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 A.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	
R2–CR346	0	15	19	18	0	0	24	0	0.9677
R3–CR325	0	9	14	10	0	0	17	0	
R4–CR307	0	11	12	10	0	0	17	0	0.9948
R5–CR275	0	12	12	10	0	0	16	0	
R6–CR233	10	0	0	0	11	10	0	19	0.8460
R7–CR161	11	0	0	0	13	7	0	17	
Chi-square = 496.3651			DF = 42			*P*-value < 0.0001			

d. Replicate 4

Release	A	B	C	D	E	F	G	H	*P*-value
R1–CR390	0	34	42	37	0	0	49	0	
R2–CR346	0	14	21	17	0	0	24	0	0.9977
R3–CR325	0	10	12	11	0	0	17	0	
R4–CR307	0	9	13	12	0	0	16	0	0.9318
R5–CR275	0	11	11	11	0	0	17	0	
R6–CR233	12	0	0	0	13	8	0	17	0.7459
R7–CR161	12	0	0	0	9	11	0	18	
Chi-square = 495.4415			DF = 42			*P*-value < 0.0001			

Table A.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 A.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 A.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	0.9873
R2–CR346	20	0	0	0	20	13	0	23	
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	0.9959
R2–CR346	17	0	0	0	17	15	0	26	
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 A.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 A.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 A.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 A.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 A.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 A.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 A.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 A.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 A.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 A.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 A.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	
	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$
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	
	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$
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 A.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 A.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 A.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 A.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*	

A.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 A.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 A.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 A.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 A.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	
	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$
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	
	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$
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 A.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	
	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$
Lot 1	0.9912	0.0062	0.9782	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	
	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$
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	
	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$
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 A.5. (contd)

7) Release 4 – Reach survival

	Release to CR275		CR275 to CR234		CR234 to CR161		CR161 to CR113	
	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$
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	
	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$
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	
	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$
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*	

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*	

Table A.5. (contd)

11) Release 6 – Reach survival

	Release to CR161		CR161 to CR113	
	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$
Lot 1	0.9802	0.0140	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	
	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$
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*	

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*	

Table A.5. (contd)

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	
	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$
Lot 1	0.9571	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	
	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$
Lot 1	0.9571	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*	

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*	

Table A.5. (contd)

17) Release 2 – Cumulative survival

	Release to CR325		Release to CR309		Release to CR275		Release to CR234		Release to CR161		Release to CR113	
	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$	$\hat{S}$	$\widehat{SE}$
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*	

19) Release 3 – Cumulative survival

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

20) Release 4 – Reach survival

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

Table A.5. (contd)

21) Release 4 – Cumulative survival

	Release to CR275		Release to CR234		Release to CR161		Release to CR113	
	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$
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*	

22) Release 5 – Reach survival

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

23) Release 5 – Cumulative survival

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

Table A.5. (contd)

24) Release 6 – Reach survival

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

25) Release 6 – Cumulative survival

	Release to CR161		Release to CR113	
	$\hat{S}$	$\widehat{\mathrm{SE}}$	$\hat{S}$	$\widehat{\mathrm{SE}}$
Lot 1	0.9802	0.0142	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	
	$\hat{S}$	$\widehat{\mathrm{SE}}$
Lot 1	0.9714	0.0240
Lot 2	0.9835	0.0160
Lot 3, 4, 5	0.9297	0.0282
P-value	*0.2303*	

A.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 were significant at $\alpha = 0.10$. In those 10 cases, the survival estimates typically differed by less than 0.01, and reach survival for the uppermost release group was often higher than that of the downriver release groups (Table A.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 α = 0.10 (Table A.7). In all cases, the upper 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 A.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

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

Table A.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 A.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

Table A.7. (contd)

Reach	CR390		CR346		CR325		CR307		CR275		P (F-test)
	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	
CR234 to CR161	0.9552	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

Reach	CR390		CR346		CR325		CR307		CR275		CR233		P (F-test)
	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	$\hat{S}$	$\widehat{\text{SE}}$	
CR161 to CR113	0.9508	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 A.7. (contd)

b. Steelhead

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

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

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

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

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

Appendix B

Capture Histories Used in Estimating Dam Passage Survival

Appendix B

Capture Histories Used in Estimating Dam Passage Survival

Table B.1. Capture histories at sites at rkm 275, 234, 161, 113, and 86 (Figure 2.1) 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)		V_1 (40% Spill)	
Capture History	Dam Passage Survival	BRZ-to-BRZ Survival	Dam Passage Survival	BRZ-to-BRZ Survival
1 1 1 1 1	1,683	1,690	1,435	1,440
0 1 1 1 1	57	58	5	5
1 0 1 1 1	0	0	0	0
0 0 1 1 1	0	0	0	0
1 1 0 1 1	224	227	140	140
0 1 0 1 1	15	15	0	0
1 0 0 1 1	0	0	0	0
0 0 0 1 1	0	0	0	0
1 1 1 0 1	498	499	392	392
0 1 1 0 1	30	30	3	3
1 0 1 0 1	0	0	0	0
0 0 1 0 1	0	0	0	0
1 1 0 0 1	89	90	61	62
0 1 0 0 1	12	12	2	2
1 0 0 0 1	0	0	0	0
0 0 0 0 1	0	0	0	0
1 1 1 1 0	530	539	217	219
0 1 1 1 0	101	101	6	6
1 0 1 1 0	0	0	0	0
0 0 1 1 0	0	0	0	0
1 1 0 1 0	131	132	58	59
0 1 0 1 0	30	30	3	3
1 0 0 1 0	0	0	0	0
0 0 0 1 0	0	0	0	0
1 1 1 0 0	275	278	97	97
0 1 1 0 0	69	69	6	6
1 0 1 0 0	0	0	0	0
0 0 1 0 0	0	0	0	0
1 2 0 0 0	61	61	58	58
0 2 0 0 0	0	0	0	0
1 1 0 0 0	223	227	131	131
0 1 0 0 0	26	27	3	3
1 0 0 0 0	23	23	17	17
0 0 0 0 0	179	182	114	117
Total	**4,256**	**4,290**	**2,748**	**2,760**

Table B.2. Capture histories at sites at rkm 234, 161, 113 and 86 (Figure 2.1) for release groups R_2, and R_3 for yearling Chinook salmon used in estimating dam passage survival. A "1" denotes detection, "0" denotes nondetection, and "2" denotes detection and censoring due to removal.

	Season-Wide Dam Passage Survival		40% Spill--Dam Passage Survival	
Capture History	R_2	R_3	R_2	R_3
1 1 1 1	334	312	283	251
0 1 1 1	0	0	0	0
1 0 1 1	45	40	29	22
0 0 1 1	0	0	0	0
1 1 0 1	104	124	78	83
0 1 0 1	0	0	0	0
1 0 0 1	12	14	4	5
0 0 0 1	0	0	0	0
1 1 1 0	128	115	42	40
0 1 1 0	0	0	0	0
1 0 1 0	34	40	10	15
0 0 1 0	0	0	0	0
1 1 0 0	77	79	16	16
0 1 0 0	0	0	0	0
2 0 0 0	1	4	1	4
1 0 0 0	49	57	21	26
0 0 0 0	15	14	15	8
Total	**799**	**799**	**499**	**470**

Table B.3. Capture histories at sites at rkm 275, 234, 161, 113, and 86 (Figure 2.1) 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)		V_1 (40% Spill)	
Capture History	Dam Passage Survival	BRZ-to-BRZ Survival	Dam Passage Survival	BRZ-to-BRZ Survival
1 1 1 1 1	1,545	1,547	1,367	1,368
0 1 1 1 1	81	82	4	4
1 0 1 1 1	0	0	0	0
0 0 1 1 1	0	0	0	0
1 1 0 1 1	88	89	52	52
0 1 0 1 1	12	12	1	1
1 0 0 1 1	0	0	0	0
0 0 0 1 1	0	0	0	0
1 1 1 0 1	502	504	407	407
0 1 1 0 1	51	51	6	6
1 0 1 0 1	0	0	0	0
0 0 1 0 1	0	0	0	0
1 1 0 0 1	37	37	24	24
0 1 0 0 1	11	11	1	1
1 0 0 0 1	0	0	0	0
0 0 0 0 1	0	0	0	0
1 1 1 1 0	768	772	385	386
0 1 1 1 0	177	177	11	12
1 0 1 1 0	0	0	0	0
0 0 1 1 0	0	0	0	0
1 1 0 1 0	101	102	33	33
0 1 0 1 0	31	31	1	1
1 0 0 1 0	0	0	0	0
0 0 0 1 0	0	0	0	0
1 1 1 0 0	349	354	133	135
0 1 1 0 0	104	104	5	5
1 0 1 0 0	0	0	0	0
0 0 1 0 0	0	0	0	0
1 2 0 0 0	34	34	31	31
0 2 0 0 0	0	0	0	0
1 1 0 0 0	223	226	121	122
0 1 0 0 0	44	45	4	4
1 0 0 0 0	60	60	53	53
0 0 0 0 0	113	116	80	81
Total	**4,331**	**4,354**	**2,719**	**2,726**

Table B.4. Capture histories at sites at rkm 234, 161, 113 and 86 (Figure 2.1) for release groups R_2, and R_3 for yearling Chinook salmon used in estimating dam passage survival. A "1" denotes detection, "0" denotes nondetection, and "2" denotes detection and censoring due to removal.

	Season-Wide Dam Passage Survival		40% Spill--Dam Passage Survival	
Capture History	R_2	R_3	R_2	R_3
1 1 1 1	302	312	253	270
0 1 1 1	0	0	0	0
1 0 1 1	18	20	10	9
0 0 1 1	0	0	0	0
1 1 0 1	102	86	80	57
0 1 0 1	0	0	0	0
1 0 0 1	6	6	4	1
0 0 0 1	0	0	0	0
1 1 2 0	0	0	0	0
0 1 2 0	0	0	0	0
1 0 2 0	0	0	0	0
0 0 2 0	0	0	0	0
1 1 1 0	163	186	68	73
0 1 1 0	0	0	0	0
1 0 1 0	30	28	7	3
0 0 1 0	0	0	0	0
1 2 0 0	0	0	0	0
0 2 0 0	0	0	0	0
1 1 0 0	96	92	29	28
0 1 0 0	0	0	0	0
2 0 0 0	0	0	0	0
1 0 0 0	56	58	29	25
0 0 0 0	27	12	20	9
Total	**800**	**800**	**500**	**475**

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