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Compliance Monitoring of Subyearling Chinook Salmon Survival and Passage at The Dalles Dam, Summer 2012

FINAL COMPLIANCE REPORT

JR Skalski
RL Townsend
AG Seaburg
GR Ploskey
MA Weiland
JS Hughes
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May 2013

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Pacific Northwest National Laboratory
Richland, Washington 99352

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Preface

This study was conducted 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 were Drs. Thomas J. Carlson and John R. Skalski, respectively. The USACE technical lead was Mr. Brad Eppard. Pacific Northwest National Laboratory subcontracted with the Pacific States Marine Fisheries Commission and Cascade Aquatics to help perform 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 as specified in the Columbia Basin Fish Accords. This compliance report for The Dalles Dam concerns the 2012 summer run of subyearling Chinook salmon.

Suggested citation for this report:

Skalski, JR, RL Townsend, AG Seaburg, GR Ploskey, MA Weiland, JS Hughes, CM Woodley, Z Deng, TJ Carlson, and GE Johnson. 2012. *Compliance Monitoring of Subyearling Chinook Salmon Survival and Passage at The Dalles Dam, Summer 2012.* PNNL-22195, 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 subyearling Chinook salmon at The Dalles Dam during summer 2012. Under the 2008 Federal Columbia River Power System Biological Opinion, dam passage survival is required to be greater than or equal to 0.93 and estimated with a standard error (SE) less than or equal to 0.015. The study also estimated survival from the forebay 2 km upstream of the dam and through the tailrace to 2 km downstream of the dam, forebay residence time, tailrace egress time, spill passage efficiency (SPE), and fish passage efficiency (FPE), as required by the 2008 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 acoustic-tagged subyearling Chinook salmon 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 7289 subyearling Chinook salmon was used in the virtual release. Sample sizes for the below-dam paired release were 788 (R_2) and 786 (R_3) for subyearling Chinook salmon. The Juvenile Salmon Acoustic Telemetry System (JSATS) tags (manufactured by Advanced Telemetry Systems, model number SS300, weighing 0.304 g in air) were surgically implanted in subyearling Chinook salmon.

The study results are summarized in the following tables.

Table ES.1. Estimates of dam passage survival[(a)] at The Dalles Dam during summer 2012. The standard error is in parentheses.

Period	Subyearling Chinook Salmon
17 June–20 July 2012	0.9469 (0.0059)

(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 during summer 2012. Standard errors are in parentheses.

Performance Metrics	Subyearling Chinook Salmon
Forebay-to-tailrace survival[(a)]	0.9462 (0.0059)
Forebay residence time (mean/median)	1.19 (0.01)/1.08 h
Tailrace egress time (mean/ median)	1.15 (0.14)/0.24 h
Spill passage efficiency[(b)]	0.7074 (0.0053)
Fish passage efficiency	0.7839 (0.0048)

(a) The forebay-to-tailrace survival estimate satisfies the "BRZ-to-BRZ" (boat-restricted zone) survival estimate in the Fish Accords.
(b) The definition in the Fish Accords includes passage at 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.

Year: 2012			
Study Site(s): The Dalles Dam			
Objective(s) of study: Estimate dam passage survival and other performance measures for subyearling Chinook salmon			
Hypothesis (if applicable): Not applicable; this is a compliance study			
Fish: Species-race: Subyearling Chinook salmon (CH0) Source: John Day Dam juvenile bypass system		Implant Procedure: Surgical: Yes Injected: No	
Size (median): CH0 Weight (g): 13.7 Length (mm): 112		Sample Size:[a] CH0 # release sites: 7 Total Release #: 8,863	
Tag: Type/model: Advanced Telemetry Systems (ATS); SS300 Weight: 0.304 g (air)	Analytical Model: Virtual/paired release	Characteristics of Estimate: Effects Reflected (direct, total, etc.): Direct Absolute or Relative: Absolute	

Environmental/Operating Conditions (daily from 17 June through 20 July 2012):

Statistic	Mean	Min	Max
River Discharge (kcfs):	335.2	279.6	414.5
Spill Discharge (kcfs):	136.2	111.2	196.2
Percent Spill (24 h/d):	40.4	35.4	49.7
Temperature (°C):	16.7	15.2	18.8
Total Dissolved Gas % (tailrace):	119.2	117.3	123.1

Treatment(s): None

Unique Study Characteristics: None

Survival and Passage Estimates (point estimate and SE):	CH0
Dam survival	0.9469 (0.0059)
Forebay-to-tailrace survival	0.9462 (0.0059)
Forebay residence time (mean/median)	1.19 (0.01)/1.08 h
Tailrace egress time (mean/median)	1.15 (0.14)/0.24 h
Spill passage efficiency	0.7074 (0.0053)
Fish passage efficiency	0.7839 (0.0048)

Compliance Results: Estimates of dam passage survival met compliance requirements for both point estimates and standard errors for subyearling Chinook salmon.

(a) Sample size includes all tagged fish, regardless of release location, contributing to the virtual-release group at The Dalles Dam face.

Acknowledgments

This study was the result of hard work by scientists from Cascade Aquatics, 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). Their teamwork and attention to detail were essential to the success of the study.

- Cascade Aquatics: B James, P James, E Anderson, C Green, E Green, J Herdman, K Martin, and H Watson
- PNNL: T Abel, C Brandt, A Bryson, E Choi, D Deng, G Dirkes, J Duncan, E Fischer, A Flory, T Fu, D Geist, M Greiner, K Hall, K Ham, R Herrington, J Horner, M Ingraham, R Karls, R Kaufman, F Khan, J Kim, B Lamarche, K Lavender, X Li, J Martinez, A Miracle, A Phillips, N Phillips, B Rayamajhi, G Roesijadi, D Saunders, S Southard, G Squeochs, A Thronas, N Trimble, J Varvinec, C Vernon, K Wagner, Y Yuan, and S Zimmerman
- PSMFC: R Martinson, G Kolvachuk, and D Ballenger, along with the helpful staff at John Day and Bonneville Dam Juvenile Smolt Facility. We also thank staff at PTAGIS for their continued assistance and N Tancreto for her help with the sort-by-code system at Bonneville Dam. In addition, we thank A Ajmani, M Bahnick, A Barnes, G Batten, C Beyer, R Blanchard, S Carpenter, A Collins, A Cook, J Cox, A Cushing, L Cushing, R Davis, T Elder, D Etherington, G George, D Grugett, B Harkleroad, M Hennen, T Levandowsky, S Marvin, T Mitchell, M Neumann, G Ottoway, K Paine, K Prather, J Robertson, T Royal, G Schilperoort, G Seybert, D Spiteri, P Tramel, D Trott, R Wall, and L Wood
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- 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
CH0	subyearling Chinook salmon
d	day(s)
FCRPS	Federal Columbia River Power System
FPC	Fish Passage Center
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	river kilometer(s)
ROR	run-of-river
RPA	Reasonable and Prudent Alternative
s	second(s)
SE	standard error
$\widehat{\mathrm{SE}}$	estimated standard error (from a sample)
SPE	spill passage efficiency
USACE	U.S. Army Corps of Engineers
UW	University of Washington
yr	year(s)

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1.0 Introduction

The compliance monitoring study reported herein was conducted by researchers at the Pacific Northwest National Laboratory (PNNL) and the University of Washington for the U.S. Army Corps of Engineers, Portland District (USACE) in 2012. 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; NMFS 2008), and provide additional performance measures at the dam for subyearling Chinook salmon as stipulated in the Columbia Basin Fish Accords (3 Treaty Tribes-Action Agencies 2008).

1.1 Background

The 2008 FCRPS BiOp 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):

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

The Memorandum of Agreement between the three lower river tribes and the Action Agencies (known informally as the Fish Accords), contains three additional requirements relevant to the 2012 survival studies (after Attachment A to the Fish Accords):

> <u>Dam Survival Performance Standard</u> – 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 . . . .
>
> <u>Spill Passage Efficiency and Delay Metrics</u> – Spill passage efficiency (SPE) and delay metrics under current spill conditions . . . are not expected to be degraded (“no backsliding”) with installation of new fish passage facilities at the dams . . . .
>
> <u>Future Research, Monitoring, and Evaluation</u> – The Action Agencies’ dam survival studies for purposes of determining juvenile dam passage performance will also collect information about SPE, 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 2012 summer acoustic-telemetry study of subyearling Chinook salmon at The Dalles Dam to assess the Action Agencies’ compliance with the performance requirements of the 2008 FCRPS BiOp and the Fish Accords.

1.2 Study Objectives

The purpose of the summer 2012 compliance monitoring at The Dalles Dam was to estimate performance measures for subyearling Chinook salmon as outlined in the FCRPS BiOp and Fish Accords. 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 ≥93% survival for summer stocks (i.e., subyearling Chinook salmon). Survival should be estimated with a standard error (SE) ≤1.5% (i.e., 95% confidence interval with half-width of ±3%; 3% = 1.96 SE ≈ 2 SE or 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 time from first detection on the forebay entrance array 2 km upstream of the dam to the time of last detection on the dam-face array.
- Tailrace egress time, defined as the average time fish take to travel from the dam to the downstream tailrace boundary, i.e., tailrace array 2 km downstream of the dam.
- Spill passage efficiency (SPE), defined as the fraction of fish going through the dam via the spillway.
- Fish passage efficiency (FPE), defined as the fraction of fish going through the dam via non-turbine routes.

Results are reported by performance measure. This report is designed to provide a succinct and timely summary of BiOp and Fish Accords performance measures.

1.3 Report Contents and Organization

The ensuing sections of this report contain the study methods, results, and related discussion. The appendices provide additional details about the tests of study assumptions (Appendix A) and present capture-history data used to estimate dam passage and forebay-to-tailrace survival rates (Appendix B).

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[1] Performance as defined in the 2008 FCRPS BiOp, Section 6.0.

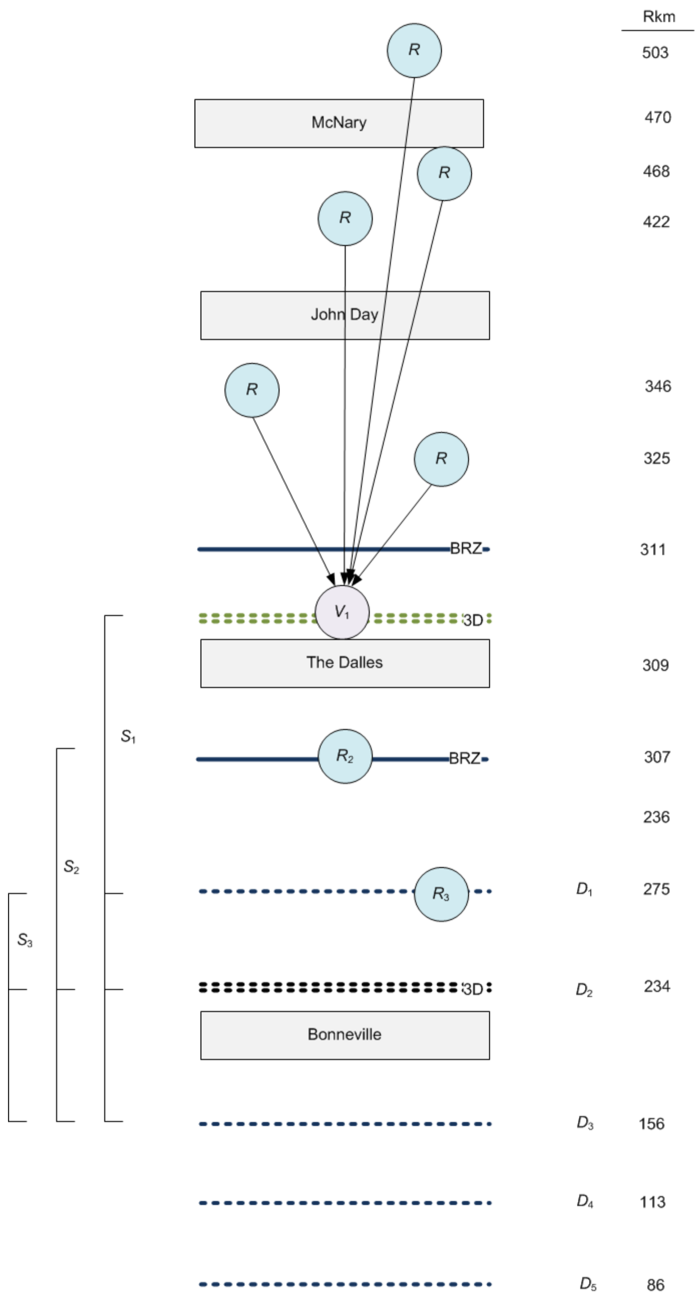
2.0 Methods

Study methods involved fish release and recapture; 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 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, 2010b, 2010c). 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 likely 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). 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 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. The sizes of the releases of the acoustic-tagged fish used in the dam passage survival estimate are summarized in Table 2.1.

The same release-recapture design was also used to estimate forebay-to-tailrace survival, except that the virtual-release group was constructed of fish known to have arrived at the forebay array (rkm 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. The passage-route data were used to calculate SPE and FPE at The Dalles Dam. The fish forming 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 503, 468, 422, 346, and 325. The below-dam release pair was composed of releases at R_2 and R_3 with detection arrays used in the survival analysis denoted by dashed lines. Only detection arrays at rkm 309, 275, 234, and 156 were used in estimating dam passage survival.

Table 2.1. Sample sizes of acoustic-tagged subyearlings regrouped to form V_1 or released in the tailrace or tailwater of The Dalles Dam in 2012.

Release Location	Subyearling Chinook Salmon
Virtual Release – The Dalles Dam (V_1)	7289
The Dalles Dam Tailrace (R_2)	788
Hood River, Oregon (R_3)	786

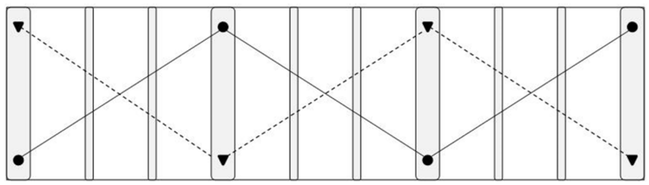


Figure 2.2. Front view schematic of hydrophone deployments at three turbines showing the double-detection arrays. The circles denote the hydrophones of Array 1 and the triangles denote the hydrophones of Array 2.

2.2 Handling, Tagging, and Release Procedures

Subyearling Chinook salmon were surgically implanted with both JSATS and passive integrated transponder (PIT) tags, transported to release locations, and released, as described in the following sections.

2.2.1 Acoustic Tags

The acoustic tags used in the summer 2012 study were manufactured by Advanced Telemetry Systems (ATS). Subyearling Chinook salmon were tagged with ATS model SS300 acoustic tags that were 10.7 mm long, 5.21 mm wide, 3.03 mm thick, and weighed 0.304 g in air. These tags had a nominal transmission rate of 1 pulse every 3 s and nominal tag life was expected to be about 25 d.

For the 2012 summer study, a single manufacturing lot of JSATS tags was used in tagging all the subyearling Chinook salmon. From this lot, 99 acoustic tags were systematically sampled over the course of the summer study for purposes of assessing tag life. 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 subyearling Chinook salmon used in the study were 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 and <300 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 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 dilution of the "maintenance" anesthesia was 40 mg/L. Using a micro-sharp, a 5- to 7-mm incision was made in the body cavity between the pelvic girdle and pectoral fin. A PIT tag was inserted followed by an acoustic tag. Both tags were inserted toward the anterior end of the fish. The incision was closed using a 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 12 to 36 h before being released into the river. The loading rate was five fish per bucket.

2.2.4 Release Procedure

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 below The Dalles Dam (R_2 and R_3) occurred for 33 consecutive days (from 18 June to 20 July 2012). Upstream releases began above McNary Dam on 13 June and the first subyearling Chinook was detected at The Dalles Dam on 17 June 2012. 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 acoustic-tagged fish to accommodate downstream mixing. Tailrace releases were timed to accommodate the approximately 10-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: 1100	Day 2: 0000
R_3 (rkm 275)	Day 1: 2100	Day 2: 1000

2.3 Acoustic Signal 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 s, 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 data set was combined PIT-tag detections for additional quality assurance/quality control analysis prior to survival analysis. Additional fields captured specialized information, where available. One such example was route of passage, which was assigned a value for events that immediately preceded 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 deviated from the expected upstream to downstream progression through arrays in the river. Except for possible detections on forebay entrance arrays after detection on a nearby dam-face array 1 to 3 km downstream, apparent upstream movements of tagged fish between arrays that were greater than 5 km apart or separated by one or more dams were very rare (<0.015% of all events) 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. (2009, 2011, 2013).

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 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). Tag-life-adjusted survival estimates were calculated using the methods of Townsend et al. (2006).

The joint likelihood used to model the three release groups was initially fully parameterized. Each of the three releases was allowed to have unique survival and detection parameters. If precision was adequate (i.e., $\widehat{\text{SE}} \leq 0.015$) with the fully parameterized model, no further modeling was performed. If initial precision was inadequate, then likelihood ratio tests were used to assess the homogeneity of parameters across release groups to identify the best parsimonious model to describe the capture-history data. This approach was used to help preserve both precision and robustness of the survival results. All calculations were performed using Program ATLAS (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 $(i = 1, \ldots, 3)$ (Figure 2.1). 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.

2.4.2 Tag-Life Analysis

For the 2012 summer study, tag failure times for the tags (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

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

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 the dam face (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:

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

where $S(t_1)$ is the average unconditional probability that the tag is active when detected at the first downriver detection array (rkm 275), and $S(t_0)$ is the average unconditional probability that the tag is active when detected at the virtual-release array (rkm 309).

2.4.3 Tests of Assumptions

Approaches to assumption testing are described below.

2.4.3.1 Burnham et al. (1987) Tests

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

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

where

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

and

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

The *F*-test was used in evaluating tagger effects.

2.4.3.4 Delayed Tag Effects

The fish forming the virtual-release group (i.e., V_1) came from multiple upstream release locations. If delayed effects of handling or tagging occurred, this could affect the performance of the virtual-release group. Consequently, downstream reach survivals and cumulative release survivals are compared among fish released at different upstream locations. The *F*-test (Equation (2.4)) evaluates whether reach survivals are homogeneous regardless of upstream release locations. If heterogeneity is detected, uppermost release groups might be eliminated from subsequent survival and related analyses.

2.4.3.5 Tag-Lot Effects

Because only one tag lot was used in the subyearling Chinook salmon survival analysis, examination of tag-lot effects was unnecessary.

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 that 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

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

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-detection 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-detection array on the upstream face 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 acoustic-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 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

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

Double-detection array probabilities were 100% for every route of passage through The Dalles Dam, so raw counts of fish by route did not have to be adjusted to estimate absolute numbers, and variances could be estimated from the first term in Equations (2.10) and (2.12), based on a binomial sampling model.

3.0 Results

The results cover five topics for subyearling Chinook salmon at The Dalles Dam during summer 2012: 1) fish collection, rejection, and tagging; 2) discharge and spill conditions; 3) run timing; 4) tests of assumptions; and 5) survival and passage estimates.

3.1 Fish Collection, Rejection, and Tagging

The total number of fish handled by PNNL in summer 2012 and the counts by handling category are listed in Table 3.1. Almost 16,000 subyearling Chinook salmon were handled; this total includes fish handled as part of survival studies for McNary, John Day, and Bonneville dams, as well as The Dalles Dam.

Table 3.1. Total number of subyearling Chinook salmon handled by PNNL during the summer 2012.

Handling Category	Number	Percentage
Retained for Tagging	15,328	96.8
Non-Candidate Based on Condition (rejected)	500	3.2
Total	**15,828**	

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 (CBSPSC 2011) and confirmed by the Anadromous Fish Evaluation Program Studies Review Work Group and the National Marine Fisheries Service in meetings during spring 2012 (B Eppard, personal communication, April 20, 2012). PNNL broadened the criteria to accept more fish. Fish were not accepted for tagging if they were moribund, or had obvious signs of progressed infections/diseases (e.g., fungus or furunculosis presence greater than 5% on one side of fish flank), open wounds that perforated the body cavity, skeletal deformities that would inhibit tag insertion or swimming ability, or descaling greater than 20% where there was no indication of scale growth or mucous coat present. 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. Number of observed malady types that warranted rejection of subyearling Chinook salmon handled by PNNL during the summer 2012.

Malady Type	Number of Maladies	Malady Percentage
Descaling >20%	139	24.7
Caudal Fin Missing	8	1.4
Skeletal Deformity	6	1.1
Damage/Injury	213	37.8
Diseases	197	35.0
Total	**563**[(a)]	

(a) Some fish had more than one malady; a total of 500 fish were rejected.

3.2 Discharge and Spill Conditions

The average daily total discharge at The Dalles Dam during the course of the study was 335.3 kcfs with a daily average percent spill of 40.4% (Figure 3.1). The spill level was near the 40% spill target for most of the summer investigation with an exception of 5–7 d during the first half of the study.

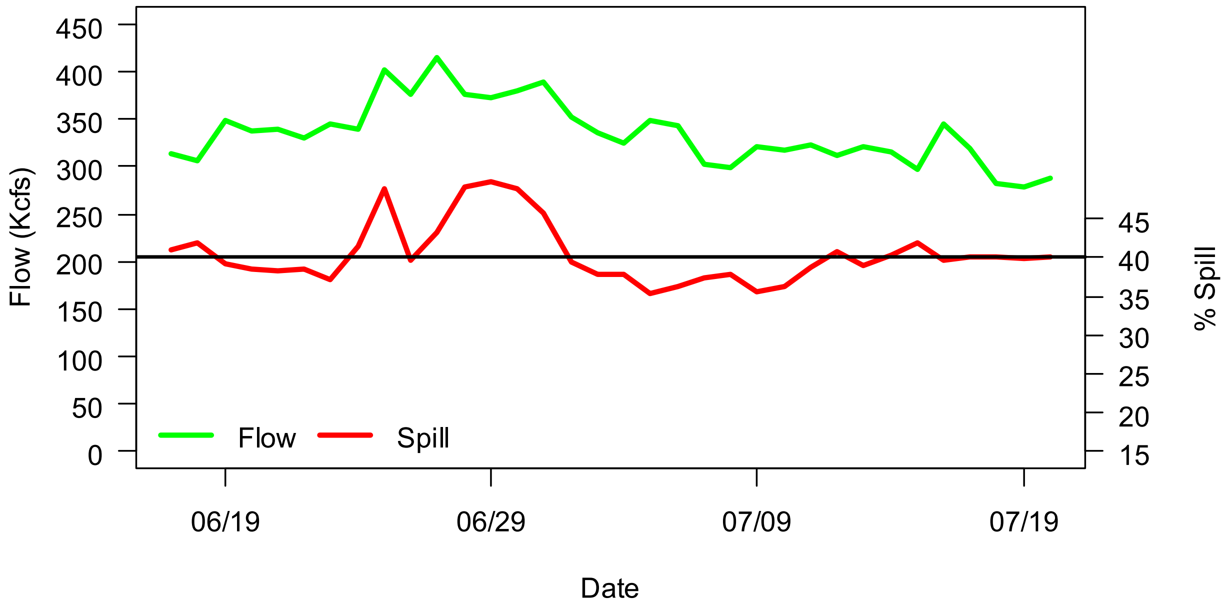


Figure 3.1. Daily average total discharge (kcfs) (green line) and percent spill (red line) at The Dalles Dam during the summer 2012 JSATS subyearling Chinook salmon study, 17 June to 20 July 2012.

3.3 Run Timing

The cumulative percentage of subyearling Chinook salmon estimated to have passed The Dalles Dam by date was calculated from smolt index data for John Day Dam obtained from the Fish Passage Center (Figure 3.2). Estimated travel time from John Day Dam to The Dalles Dam was 12 h. From 17 June, when tagged subyearling Chinook salmon first arrived at the dam, through the end of the study on 20 July 2012, 66.6% of the total subyearling Chinook salmon outmigration was estimated to have passed The Dalles Dam. By the end of the study on 20 July 2012, 69.3% of the total subyearling Chinook salmon run had passed the dam.

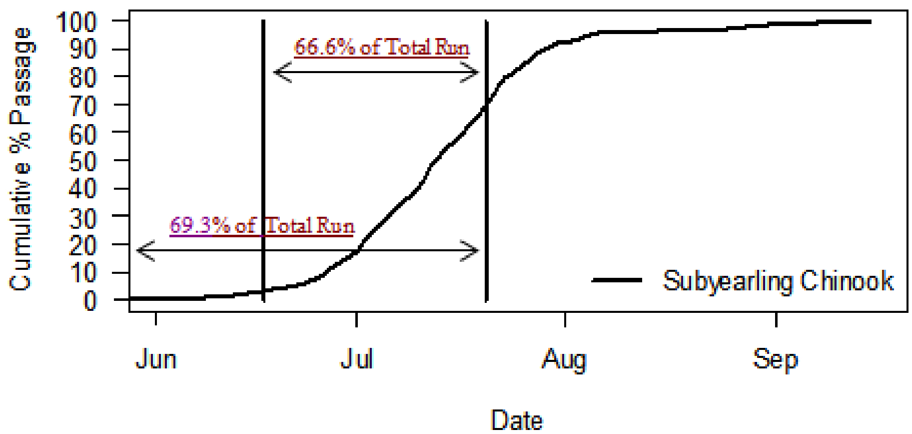


Figure 3.2. Plot of the cumulative percentage of subyearling Chinook salmon projected to have passed The Dalles Dam in 2012. Vertical lines mark the beginning and end of the summer survival study. Data are based on smolt monitoring data from John Day Dam and adjusted for 12-h travel time.

3.4 Assessment of Assumptions

The assessment of assumptions covers tagger effects, tag-lot effects, handling mortality and tag shedding, effects of tailrace and tailwater release locations, examination of time in-river, 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 the subyearling Chinook salmon associated with the JSATS survival studies at McNary, John Day, The Dalles, and Bonneville dams in summer 2012. Analyses showed tagger effort was homogeneously distributed across release locations. Within a replicate release, tagger effort was homogeneous within the project-specific releases (Appendix A). Examination of reach survivals and cumulative survivals from above McNary Dam to below Bonneville Dam found no consistent 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

A single tag lot was used in the summer 2012 JSATS survival study at The Dalles Dam. Therefore, there was no need for an assessment of tag-lot effects.

3.4.3 Handling Mortality and Tag Shedding

Fish were held for 12 to 36 h prior to release. The pre-release tagging mortality in summer 2012 was 0.18%. No tags were shed during the holding period.

3.4.4 Effects of Tailrace and Tailwater Release Locations

Survival rates for tagged subyearling Chinook salmon released at three or five adjacent locations across the tailrace and tailwater did not differ significantly based upon overlap of 95% confidence intervals (Figure 3.3). The uppermost plot in the figure shows survival rates for dam-passed fish regrouped on tailrace autonomous nodes to form three virtual releases across the tailrace. Regrouping dam-passed fish (V_1) on the tailrace array is problematic because it has the real potential to include some tagged fish that died during dam passage, which would violate survival model assumptions and underestimate survival in downstream reaches. Our intent was to provide some indication of the relative distribution of survival rates for fish regrouped at sites across the tailrace. An underlying assumption is that the probability of regrouping dead fish along with live fish is low and similar across the tailrace, but this assumption may not be valid.

We did not specify the number of fish regrouped on each autonomous node because that distribution can be highly biased by differences in tag detectability, which is inversely related to linear water velocity where each node was deployed. The distribution of numbers and the percentage of fish released at the five locations across the tailrace was not uniform (middle plot in Figure 3.3), because of an error in the first round of releases for the summer study. There were only supposed to have been four release locations in The Dalles Dam tailrace in 2012, and subyearlings released at Location R2_CR307_1 were supposed to have been released at R2_CR307_5. The distribution of releases across the tailwater release site near Hood River, Oregon) was uniform (bottom plot in Figure 3.3).

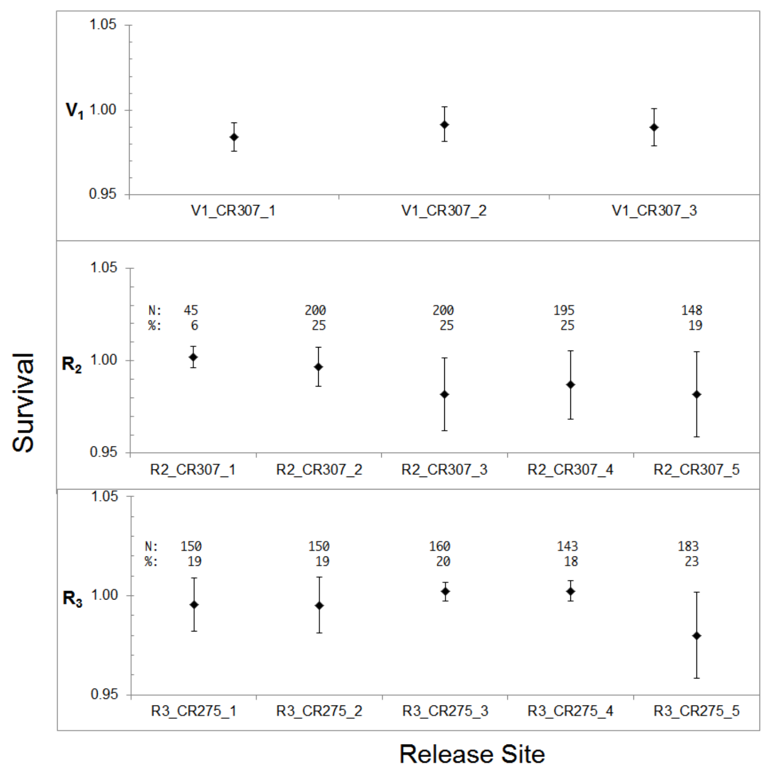


Figure 3.3. Distributions of tailrace detections of V_1 fish on autonomous nodes (top), numbers of fish released in the tailrace at five locations (middle), and survival rates by tailrace release location (bottom) to Bonneville Dam. Vertical bars are 95% confidence intervals on survival estimates.

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 Dalles Dam could result in biased survival estimates if fish from varying upriver release locations had different downriver survival rates. For this reason, reach survivals and cumulative survivals were compared across fish from different upriver release locations. There was evidence for subyearling Chinook salmon that the releases associated with the McNary investigation (i.e., releases at rkm 503, 468, and 422) had depressed survival by the time they reached Bonneville Dam (Appendix A). However, no such delayed effects were evident for subyearling Chinook salmon arriving at The Dalles Dam. Therefore, in constructing the virtual-release groups at the face of The Dalles 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 subyearling Chinook salmon (Figure 3.4). The length distributions for the three subyearling Chinook salmon releases (Figure 3.4) were quite similar. Mean length for the acoustic-tagged subyearling Chinook salmon was 112.7 mm. Mean length for subyearling Chinook salmon sampled by the Fish Passage Center at the John Day Dam smolt monitoring facility was 110.8 mm. Median fish size slowly decreased over the course of the study (Figure 3.5).

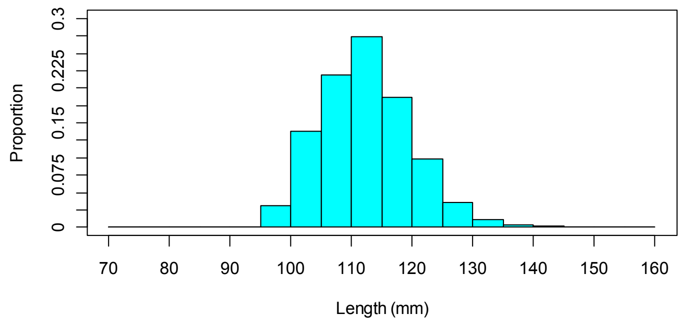
3.4.7 Tag-Life Corrections

For the summer study, 100 tags were systematically sampled to conduct a tag-life study. The vitality curve of Li and Anderson (2009) was fit to the tag-life study data (Figure 3.6). Average tag life was estimated to be 23.3 d.

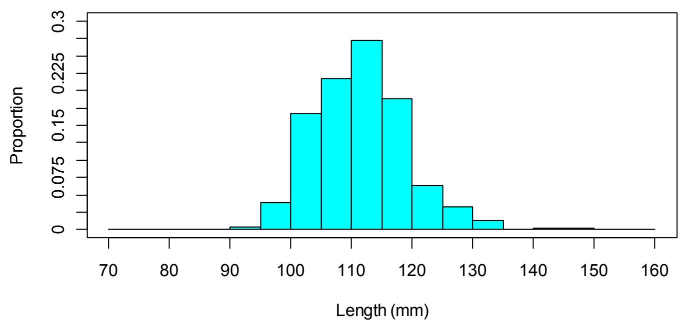
3.4.8 Arrival Distributions

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 subyearling Chinook salmon (Figure 3.7). 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) over the observed distribution of fish arrival times (i.e., time from tag activation to arrival). The probabilities of a JSATS tag being active at a downstream detection site were specific to release location. In all cases, the probability that a tag was active at a downstream detection site as far as rkm 156 for subyearling Chinook salmon was ≥0.9974 (Table 3.3).

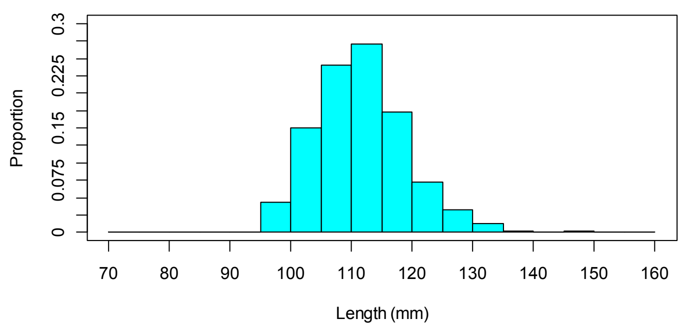
(a) The Dalles Dam (Release V_1)



(b) The Dalles Tailrace (Release R_2)



(c) The Dalles Tailwaters (Release R_3)



(d) ROR Subyearling Chinook at John Day Dam

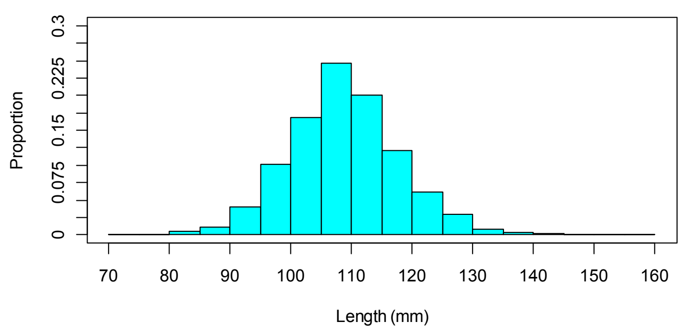


Figure 3.4. Relative frequency distributions for fish length (mm) of subyearling Chinook salmon used in a) release V_1, b) release R_2, c) release R_3, and d) ROR fish sampled at John Day Dam by the Fish Passage Center.

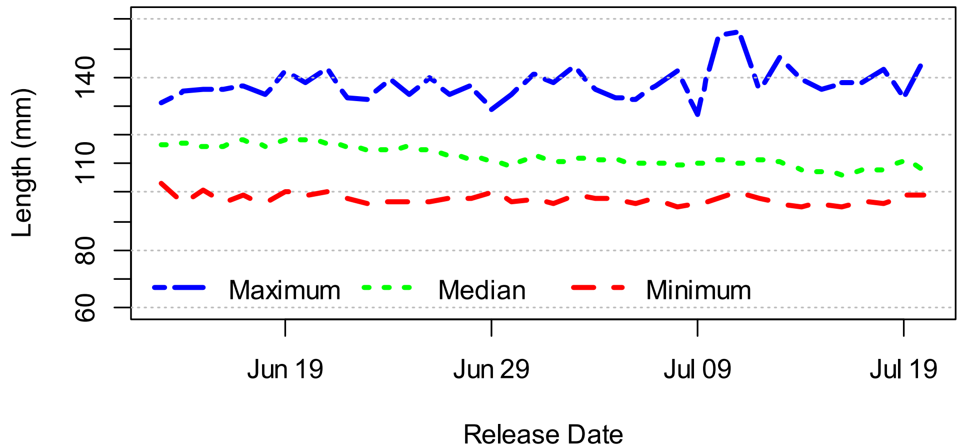


Figure 3.5. Ranges and median lengths of acoustic-tagged subyearling Chinook salmon used in the 2012 survival study. Releases were made daily from 13 June through 20 July at seven release locations: rkm 503, rkm 468, rkm 422, rkm 346, rkm 325, rkm 307, and rkm 275.

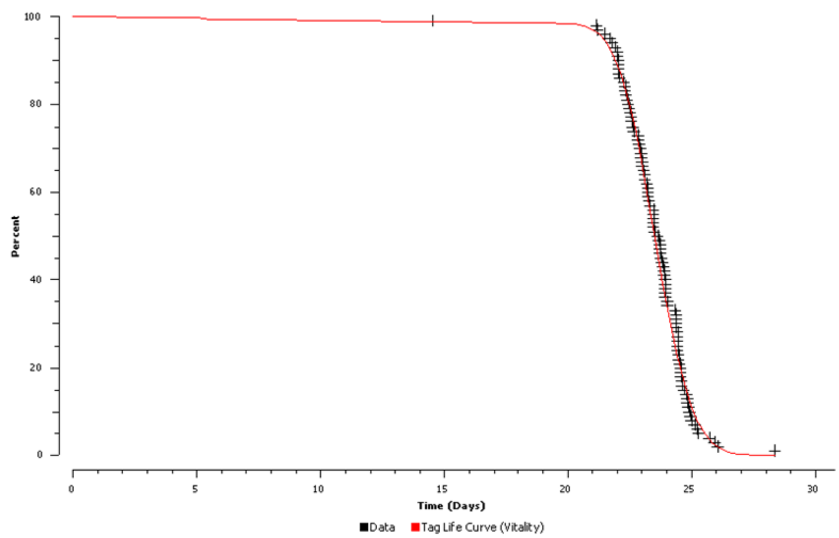


Figure 3.6. Observed time of tag failure and fitted survivorship curve using the vitality model of Li and Anderson (2009) for the 2012 summer tagging study.

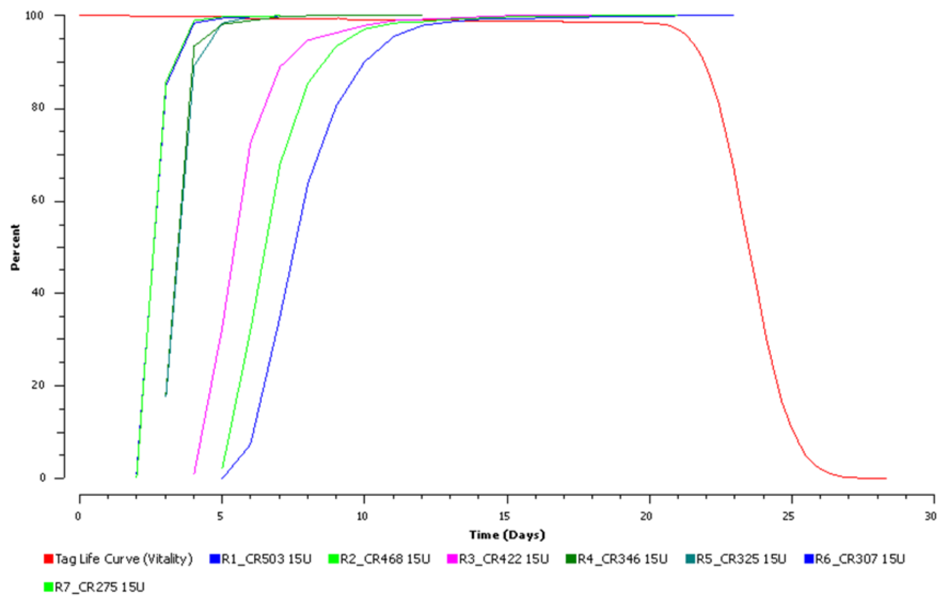


Figure 3.7. Plot of the fitted tag-life curve and the arrival-time distributions of subyearling Chinook salmon for releases V_1, R_2, and R_3 at the acoustic-detection array located at rkm 156 (Figure 2.1).

Table 3.3. Estimated probabilities (l) of an acoustic tag being active at a downstream detection site for subyearling Chinook salmon by tag release group. (Standard errors are in parentheses.)

Release Group	Detection Site			
	rkm 309	rkm 275	rkm 234	rkm 156
V_1 (rkm 501)	0.9950 (0.0068)	0.9997 (0.0005)	0.9992 (0.0010)	0.9983 (0.0019)
V_1 (rkm 468)	0.9958 (0.0058)	0.9997 (0.0005)	0.9992 (0.0010)	0.9986 (0.0019)
V_1 (rkm 422)	0.9966 (0.0047)	0.9997 (0.0005)	0.9993 (0.0011)	0.9986 (0.0019)
V_1 (rkm 346)	0.9983 (0.0024)	0.9996 (0.0005)	0.9992 (0.0011)	0.9986 (0.0020)
V_1 (rkm 325)	0.9983 (0.0024)	0.9997 (0.0005)	0.9992 (0.0011)	0.9986 (0.0020)
R_2 (rkm 307)	--	--	0.9981 (0.0027)	0.9974 (0.0036)
R_3 (rkm 275)	--	--	0.9981 (0.0027)	0.9974 (0.0036)

3.4.9 Downstream Mixing

The virtual release from the face of The Dalles Dam was continuously formed from the subyearling Chinook salmon arriving throughout the day and night. To help induce downstream mixing of the release groups, the R_2 release was approximately 10 h before the R_3. Plots of the arrival timing of the various release groups at downstream detection sites indicate reasonable mixing for subyearling Chinook salmon (Figure 3.8). The arrival modes for releases R_2 and R_3 were nearly synchronous.

a. rkm 234 b. rkm 156

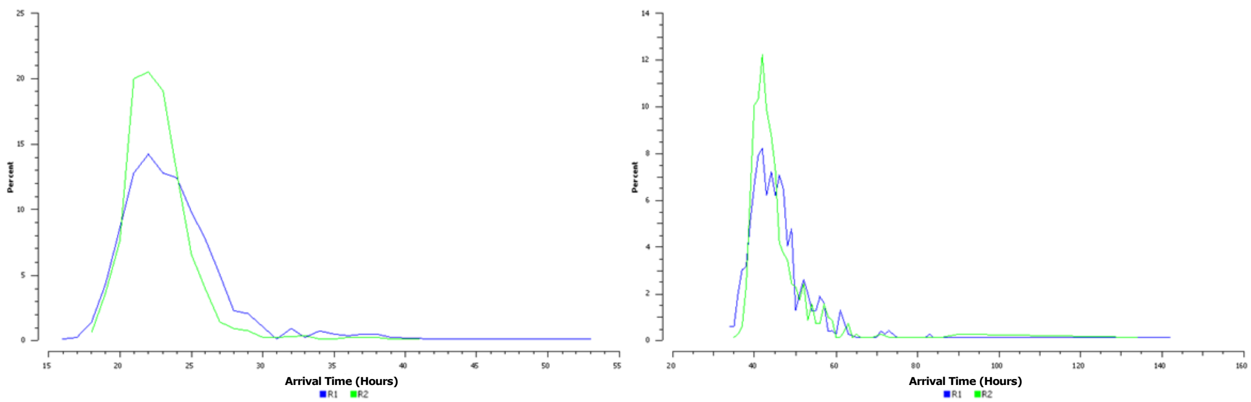


Figure 3.8. Frequency distribution plots of downstream arrival timing (expressed as percentages) for subyearling Chinook salmon releases R_2 and R_3 at detection arrays located at a) rkm 234, and b) rkm 156 (see Figure 2.1). All times adjusted relative to the release time of R_2.

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 estimate of dam passage survival was based on the virtual/paired-release design using capture-history data (Appendix B) and the fitted tag-life curve (Figure 3.6). The estimate was based on the tag-life-adjusted survival estimates for releases V_1, R_2, and R_3. The estimate of dam passage survival for subyearling Chinook salmon at The Dalles Dam was calculated as follows:

$$\hat{S}_{\text{Dam}} = \frac{0.9420}{\left(\frac{0.9886}{0.9937}\right)} = \frac{0.9420}{0.9949} = 0.9469$$ [1]

with an associated standard error of $\widehat{\text{SE}} = 0.0059$ (Table 3.4). No attempt was made to find a more parsimonious model because the full model had adequate precision. Also note the survival estimate from the virtual release (i.e., S_1), which includes dam passage and 36 km below the dam, also met the 2008 BiOp standard for summer run stocks.

[1] The estimate of 0.9469 was output from the analysis program; it is not 0.9468 because of rounding error in the later value.

Table 3.4. Tag-life-adjusted survival estimates of reach survival and detection probabilities for subyearling Chinook salmon smolts used in estimating dam passage survival at The Dalles Dam in the summer season in 2012. 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 (*).

	rkm 309 to 275		rkm 275 to 234		Release to rkm 234	
Release Group	$\hat{S}$	$\widehat{\text{SE}}$ †	$\hat{S}$	$\widehat{\text{SE}}$ *	$\hat{S}$	$\widehat{\text{SE}}$ †
V_1	0.9420	0.0028	0.9901	0.0013	---	---
R_2	---	---	---	---	0.9886	0.0048
R_3	---	---	---	---	0.9937	0.0041

Release Group	rkm 275		rkm 234	
	$\hat{p}$	$\widehat{\text{SE}}$ *	$\hat{p}$	$\widehat{\text{SE}}$ *
V_1	0.9999	0.0001	0.9966	0.0008
R_2	---	---	0.9942	0.0029
R_3	---	---	0.9928	0.0032

Release Group	rkm 234 to 156	
	$\hat{\lambda}$	$\widehat{\text{SE}}$ *
V_1	0.8589	0.0043
R_2	0.8919	0.0112
R_3	0.8932	0.0111

3.5.2 Forebay-to-Tailrace Passage Survival

The estimate of forebay-to-tailrace passage survival was calculated analogously to the estimate of dam passage survival except that the virtual-release group (V_1) was composed of fish known to have arrived at the forebay array (i.e., detection array rkm 311, Figure 2.1) rather than at the dam face. Although the capture-history data for V_1 changed (Appendix B), the same capture-history data were used for releases R_2 and R_3 (Appendix B). Using the same statistical model as was used in estimating dam passage survival, forebay-to-tailrace survival for subyearling Chinook salmon was calculated to be $\hat{S}_{\text{BRZ-BRZ}} = 0.9462$ ($\widehat{\text{SE}} = 0.0059$).

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

3.5.3 Forebay Residence Time

Forebay residence time was calculated based on the time from the first detection at the forebay BRZ array (rkm 311) to the last detection at the double-detection array in front of The Dalles Dam (rkm 309). For subyearling Chinook salmon, mean forebay residence time was $\bar{t}$ =1.19 h ($\widehat{SE}$ = 0.01), with a median value of 1.08 h (Table 3.5). The mode for forebay residence time was 1.5 hours (Figure 3.9).

Table 3.5. Estimated mean and median forebay residence times (h) and mean and median tailrace egress times for subyearling Chinook salmon at The Dalles Dam in 2012.

	Subyearling Chinook Salmon	
Performance Measure	Mean	Median
Forebay Residence Time	1.19 (0.01)	1.08
Tailrace Egress Time	1.15 (0.14)	0.24

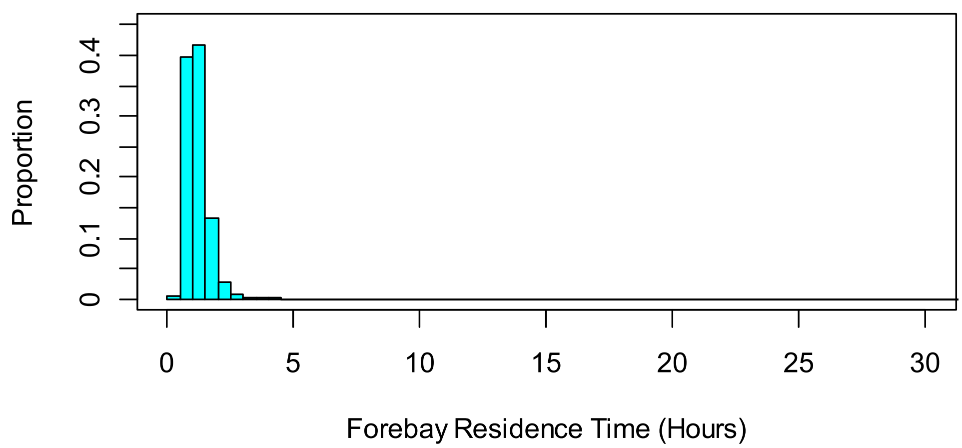


Figure 3.9. Distribution of forebay residence times for subyearling Chinook salmon at The Dalles Dam 2012.

3.5.4 Tailrace Egress Time

Tailrace egress time was calculated based on the time from the last detection of fish at the double-detection array at the face of The Dalles Dam (rkm 309) to the last detection at the BRZ tailrace array (rkm 307). For subyearling Chinook salmon, mean tailrace egress time was $\bar{t}$ = 1.15 h ($\widehat{SE}$ = 0.14) with a median value of 0.24 h (Table 3.5). The mode for subyearling Chinook salmon tailrace egress time was 0.5 h (Figure 3.10).

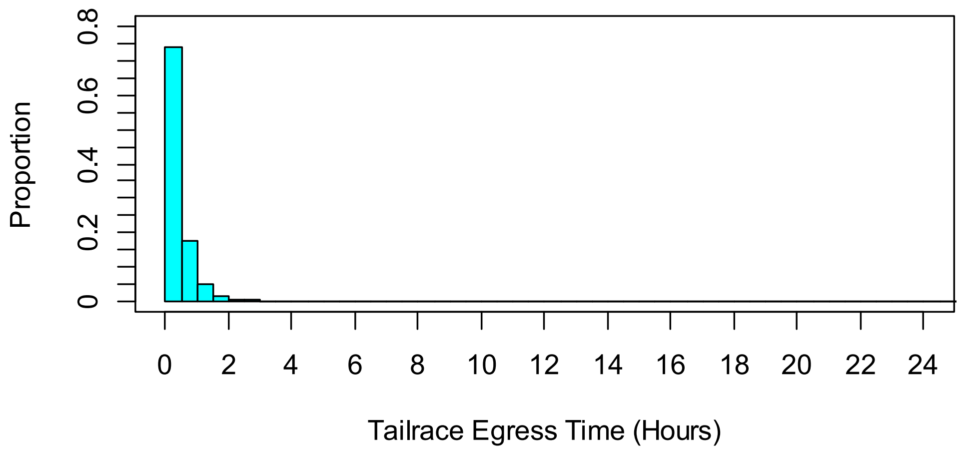


Figure 3.10. Distribution of tailrace egress times for subyearling Chinook salmon at The Dalles Dam, 2012.

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, which makes it equivalent to FPE estimated in the next section.) 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, sluiceway, and powerhouse were used to estimate SPE based on a multinomial sampling model. For subyearling Chinook salmon at The Dalles Dam in 2012, the proportion of fish that went through the spillway is estimated to be

$$\widehat{\text{SPE}} = 0.7074\left(\widehat{\text{SE}} = 0.0053\right).$$

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 sluiceway were used to estimate FPE based on a multinomial sampling model. For subyearling Chinook salmon at The Dalles Dam in 2012, FPE is estimated to be

$$\widehat{\text{FPE}} = 0.7839\left(\widehat{\text{SE}} = 0.0048\right).$$

4.0 Discussion

In this section, we discuss study conduct, study performance, and a cross-year summary for 2010–2012 compliance results.

4.1 Study Conduct

The many tests of assumptions (Appendix A) found the acoustic-tag study achieved good downstream mixing, with adequate tag life and with no evidence of adverse tagger effects. There was no evidence of delayed tagging/handling effects that would preclude the use of all upstream releases in forming the virtual-release group (i.e., V_1) at the face of The Dalles Dam.

In summer 2012, a single compliance study of subyearling Chinook salmon was performed. The estimated dam passage survival of $\hat{S}_{\text{Dam}} = 0.9469$ met the 2008 BiOp standard of $S_{\text{Dam}} \geq 0.93$ and with adequate precision of $\widehat{\text{SE}} = 0.0059$.

4.2 Study Performance – Spill Target

The spill target for the summer compliance test at The Dalles Dam was 40%. For the most part, spill percentages were within ±5% of 40%. There were a few days the spill percentage exceeded the range of 35–45% between 23 June and 1 July. Over the course of the study, average percent spill was 40.4% (Figure 3.1).

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 (Skalski et al. 2010a, 2012). Yearling Chinook salmon survival estimates in both years 2010 and 2011 were ≥0.96 with $\widehat{\text{SE}} \leq 0.015$ with a 2-yr average of $\hat{\hat{S}}_{\text{Dam}} =$ 0.9620. For juvenile steelhead, 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-yr average is $\hat{\hat{S}}_{\text{Dam}} =$ 0.9743 (Table 4.1). Both steelhead survival estimates had acceptable precision of $\widehat{\text{SE}} \leq 0.015$ (Table 4.1). For subyearling Chinook salmon, compliance tests were performed in 2010 (Skalski et al. 2010b) and 2012. Both of the subyearling Chinook salmon estimates of dam passage survival met the 2008 BiOp standard of $S_{\text{Dam}} \geq 0.93$ and with adequate precision ($\widehat{\text{SE}} \leq 0.015$). The 2-yr average for subyearling Chinook salmon was $\hat{\hat{S}}_{\text{Dam}} = 0.9436$.

In summary, five of the six compliance studies to date at The Dalles Dam met the 2008 BiOp standard for dam passage survival. The exception was the 2010 steelhead investigation (i.e., $\hat{S}_{\text{Dam}} = 0.9534 < 0.96$).

Table 4.1. Summary of estimates of dam passage survival at The Dalles Dam for yearling Chinook salmon, steelhead, and subyearling Chinook salmon in 2010–2012. Standard errors are 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
2012	N/A	N/A	0.9469 (0.0059)

5.0 References

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

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

CBSPSC (Columbia Basin Surgical Protocol Steering Committee). 2011. *Surgical Protocols for Implanting JSATS Transmitters into Juvenile Salmonids for Studies Conducted for the U.S. Army Corps of Engineers*. Version 1, U.S. Army Corps of Engineers, Portland District, Portland, Oregon.

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

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

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

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

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

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

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

Skalski JR, RL Townsend, A Seaburg, GE Johnson, GR Ploskey, and TJ Carlson. 2012. *Compliance Monitoring of Juvenile Yearling Chinook Salmon and Steelhead Survival and Passage at The Dalles Dam, Spring 2011*. PNNL-21124, Rev. 1, Pacific Northwest National Laboratory, Richland, Washington.

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

Weiland MA, GR Ploskey, JS Hughes, and fifteen co-authors. 2009. *Acoustic Telemetry Evaluation of Juvenile Salmonid Passage and Survival at John Day Dam with Emphasis on the Prototype Surface Flow Outlet, 2008*. PNNL-18890, final report submitted to the U.S. Army Corps of Engineers, Portland District, Portland, Oregon, by Pacific Northwest National Laboratory, Richland, Washington.

Weiland MA, GR Ploskey, JS Hughes, and sixteen coauthors. 2011. *Acoustic Telemetry Evaluation of Juvenile Salmonid Passage and Survival Proportions at John Day Dam, 2009*. PNNL-20766, final report submitted to the U.S. Army Corps of Engineers, Portland District, Portland, Oregon, by Pacific Northwest National Laboratory, Richland, Washington.

Weiland MA, CM Woodley, GR Ploskey, and twenty-three coauthors. 2013. *Acoustic Telemetry Evaluation of Juvenile Salmonid Passage and Survival at John Day Dam, 2010*. PNNL-22177, draft final report submitted to the U.S. Army Corps of Engineers, Portland District, Portland, Oregon, by Pacific Northwest National Laboratory, Richland, Washington.

Appendix A

Tests of Assumptions

Appendix A

Test of Assumptions

A.1 Tagger Effects

Tagger effects that go undetected could bias the survival studies results. For this reason, analyses are performed to assess whether tagger effort was balanced across release locations and whether fish tagged by different staff members have homogeneous downstream survival probabilities.

To minimize any tagger effects that go undetected, tagger effort should be balanced across release locations and within replicate releases. A total of eight taggers participated in the tagging of subyearling Chinook salmon. Tagger effort was found to be balanced across the nine release locations used in the Lower Columbia River JSATS survival study for summer 2012 (Table A.1). Tagger effort was also examined within the 32 replicate releases coordinated over the course of the summer study (Table A.2). To accommodate staff time off during the month-long study, tagger effort was conditionally balanced within the individual project releases (i.e., R_1–R_3, R_4–R_5, R_6–R_7, R_8–R_9) in all cases (Table A.2). The conditional balance contributed to the overall balance of the study over the summer season.

To test for tagger effects, reach survivals and cumulative survivals were calculated for fish tagged by different staff members at a release location (Table A.3). Of the 45 tests of homogeneous reach survivals, 5 were significant at $\alpha = 0.10$ (i.e., 11.11%). Of the 44 tests of homogeneous cumulative survival, 2 were significant at $\alpha = 0.10$ (i.e., 4.54%). One might expect 10% of the tests of homogeneity to be rejected by chance alone if homogeneity was true. Therefore, there was no evidence of tagger effects that would preclude using all fish from all taggers in the survival study.

Table A.1. Numbers of subyearling Chinook salmon tagged by each staff member by release location (R_1, R_2, …, R_9). Chi-square tests of homogeneity were not significant $\left(P\left(\chi^2_{56} \geq 4.8194\right) = 1\right)$.

Release location	Tagger							
	A	B	C	D	E	F	G	H
R1_CR503	358	309	327	304	255	287	287	397
R2_CR468	284	239	246	248	201	235	224	316
R3_CR422	289	239	255	241	192	236	218	314
R4_CR346	144	119	126	119	98	116	111	153
R5_CR325	144	119	123	122	93	111	114	157
R6_CR307	114	91	105	94	81	89	90	124
R7_CR275	109	88	103	101	78	90	90	127
R8_CR233	288	235	260	241	203	227	225	315
R9_CR156	285	229	263	242	199	233	232	312

Chi-square = 4.8194 df = 56 *P*-value = 1

Table A.2. Contingency tables with numbers of subyearling Chinook salmon tagged by each staff member per release location within a replicate release. A total of 32 replicate day or night releases were performed over the course of the summer 2012 study. Results of chi-square tests of homogeneity presented in the form of *P*-values.

a. Replicate 1

Release	A	B	C	D	E	F	G	H	*P*-value
R1_CR503	0	0	20	0	16	0	17	25	
R2_CR468	0	0	16	0	13	0	13	21	0.9992
R3_CR422	0	0	15	0	12	0	13	23	
R4_CR346	8	8	0	7	0	8	0	0	0.9876
R5_CR325	8	8	0	8	0	7	0	0	
R6_CR307	8	6	0	5	0	6	0	0	0.9841
R7_CR275	7	6	0	6	0	6	0	0	
R8_CR233	19	15	0	14	0	15	0	0	0.9824
R9_CR156	19	13	0	15	0	15	0	0	
Chi-square = 443.68				df = 56					<0.0001

b. Replicate 2

Release	A	B	C	D	E	F	G	H	*P*-value
R1_CR503	0	0	19	0	16	0	17	27	
R2_CR468	0	0	15	0	13	0	14	21	1
R3_CR422	0	0	16	0	12	0	14	21	
R4_CR346	10	9	0	7	0	9	0	0	0.9886
R5_CR325	10	8	0	8	0	9	0	0	
R6_CR307	8	6	0	5	0	6	0	0	0.9841
R7_CR275	7	6	0	6	0	6	0	0	
R8_CR233	0	0	16	0	12	0	14	21	0.9967
R9_CR156	0	0	17	0	12	0	14	20	
Chi-square = 452.75				df = 56					<0.0001

c. Replicate 3

Release	A	B	C	D	E	F	G	H	*P*-value
R1_CR503	23	19	0	17	0	19	0	0	
R2_CR468	17	15	0	15	0	16	0	0	0.9998
R3_CR422	18	15	0	15	0	15	0	0	
R4_CR346	11	8	0	8	0	8	0	0	0.9911
R5_CR325	10	8	0	9	0	8	0	0	
R6_CR307	0	0	6	0	5	0	5	9	0.9773
R7_CR275	0	0	6	0	4	0	6	9	
R8_CR233	0	0	16	0	13	0	14	19	0.9994
R9_CR156	0	0	16	0	13	0	14	20	
Chi-square = 451.42				df = 56					<0.0001

Table A.2. (contd)

d. Replicate 4

Release	A	B	C	D	E	F	G	H	*P*-value
R1_CR503	21	21	0	18	0	19	0	0	
R2_CR468	18	13	0	16	0	16	0	0	0.9884
R3_CR422	18	15	0	13	0	16	0	0	
R4_CR346	0	0	8	0	6	0	7	10	0.9929
R5_CR325	0	0	7	0	5	0	7	10	
R6_CR307	0	0	6	0	5	0	6	8	1
R7_CR275	0	0	6	0	5	0	6	8	
R8_CR233	0	0	15	0	12	0	14	22	0.8004
R9_CR156	0	0	16	0	13	0	17	17	
Chi-square = 444.32				df = 56					<0.0001

e. Replicate 5

Release	A	B	C	D	E	F	G	H	*P*-value
R1_CR503	22	20	0	19	0	18	0	0	
R2_CR468	18	15	0	15	0	15	0	0	1
R3_CR422	18	15	0	15	0	15	0	0	
R4_CR346	0	0	9	0	6	0	7	9	0.9904
R5_CR325	0	0	8	0	6	0	7	10	
R6_CR307	0	0	6	0	5	0	5	9	0.9853
R7_CR275	0	0	6	0	5	0	6	8	
R8_CR233	0	0	17	0	13	0	14	19	0.9701
R9_CR156	0	0	17	0	13	0	16	17	
Chi-square = 445.23				df = 56					<0.0001

f. Replicate 6

Release	A	B	C	D	E	F	G	H	*P*-value
R1_CR503	21	19	0	20	0	18	0	0	
R2_CR468	19	15	0	14	0	15	0	0	0.9990
R3_CR422	19	15	0	15	0	14	0	0	
R4_CR346	0	0	7	0	6	0	8	10	0.9901
R5_CR325	0	0	7	0	6	0	7	11	
R6_CR307	0	0	6	0	5	0	6	8	1
R7_CR275	0	0	6	0	5	0	6	8	
R8_CR233	18	15	0	15	0	15	0	0	0.9961
R9_CR156	17	16	0	15	0	15	0	0	
Chi-square = 443.39				df = 56					<0.0001

Table A.2. (contd)

g. Replicate 7

Release	A	B	C	D	E	F	G	H	*P*-value
R1_CR503	0	0	18	0	15	0	16	26	
R2_CR468	0	0	14	0	13	0	14	22	1
R3_CR422	0	0	14	0	13	0	14	22	
R4_CR346	0	0	8	0	6	0	7	10	0.9416
R5_CR325	0	0	8	0	5	0	9	9	
R6_CR307	7	6	0	6	0	6	0	0	1
R7_CR275	7	6	0	6	0	6	0	0	
R8_CR233	18	15	0	15	0	14	0	0	0.9932
R9_CR156	19	15	0	14	0	15	0	0	
Chi-square = 440.69				df = 56					<0.0001

h. Replicate 8

Release	A	B	C	D	E	F	G	H	*P*-value
R1_CR503	0	0	19	0	16	0	17	27	
R2_CR468	0	0	15	0	11	0	14	21	1
R3_CR422	0	0	15	0	12	0	14	22	
R4_CR346	9	7	0	8	0	7	0	0	1
R5_CR325	9	7	0	8	0	7	0	0	
R6_CR307	8	5	0	6	0	6	0	0	0.9841
R7_CR275	7	6	0	6	0	6	0	0	
R8_CR233	17	16	0	15	0	15	0	0	0.9701
R9_CR156	19	14	0	15	0	15	0	0	
Chi-square = 442.39				df = 56					<0.0001

i. Replicate 9

Release	A	B	C	D	E	F	G	H	P-value
R1_CR503	0	0	19	0	15	0	17	27	
R2_CR468	0	0	14	0	12	0	14	22	0.9890
R3_CR422	0	0	17	0	13	0	15	18	
R4_CR346	9	7	0	7	0	8	0	0	0.9876
R5_CR325	9	8	0	7	0	7	0	0	
R6_CR307	8	6	0	6	0	5	0	0	0.9290
R7_CR275	6	6	0	7	0	6	0	0	
R8_CR233	19	16	0	14	0	14	0	0	0.9882
R9_CR156	18	15	0	15	0	15	0	0	
Chi-square = 444.76				df = 56					<0.0001

Table A.2. (contd)

j. Replicate 10

Release	A	B	C	D	E	F	G	H	*P*-value
R1_CR503	0	0	19	0	16	0	18	26	
R2_CR468	0	0	16	0	12	0	12	21	0.9893
R3_CR422	0	0	16	0	13	0	16	18	
R4_CR346	10	7	0	7	0	7	0	0	0.9894
R5_CR325	9	8	0	7	0	7	0	0	
R6_CR307	7	6	0	7	0	5	0	0	0.9826
R7_CR275	7	6	0	6	0	6	0	0	
R8_CR233	0	0	16	0	13	0	15	18	0.9288
R9_CR156	0	0	17	0	11	0	14	21	
Chi-square = 443.9105				df = 56					<0.0001

k. Replicate 11

Release	A	B	C	D	E	F	G	H	*P*-value
R1_CR503	23	19	0	18	0	18	0	0	
R2_CR468	18	14	0	16	0	15	0	0	0.9980
R3_CR422	19	15	0	13	0	16	0	0	
R4_CR346	9	8	0	7	0	7	0	0	0.9886
R5_CR325	8	8	0	7	0	8	0	0	
R6_CR307	0	0	7	0	6	0	5	7	0.9552
R7_CR275	0	0	6	0	5	0	6	8	
R8_CR233	0	0	16	0	13	0	14	19	0.9936
R9_CR156	0	0	15	0	13	0	15	20	
Chi-square = 443.5449				df = 56					<0.0001

l. Replicate 12

Release	A	B	C	D	E	F	G	H	*P*-value
R1_CR503	23	19	0	19	0	17	0	0	
R2_CR468	19	13	0	15	0	15	0	0	0.9994
R3_CR422	18	14	0	15	0	15	0	0	
R4_CR346	0	0	8	0	6	0	7	10	0.9881
R5_CR325	0	0	8	0	7	0	7	9	
R6_CR307	0	0	7	0	5	0	5	8	1
R7_CR275	0	0	7	0	5	0	5	8	
R8_CR233	0	0	15	0	13	0	14	20	0.9548
R9_CR156	0	0	18	0	13	0	13	19	
Chi-square = 440.8645				df = 56					<0.0001

Table A.2. (contd)

m. Replicate 13

Release	A	B	C	D	E	F	G	H	*P*-value
R1_CR503	23	20	0	18	0	18	0	0	
R2_CR468	18	16	0	15	0	14	0	0	1
R3_CR422	18	16	0	14	0	15	0	0	
R4_CR346	0	0	8	0	6	0	7	10	1
R5_CR325	0	0	8	0	6	0	7	10	
R6_CR307	0	0	7	0	5	0	6	7	0.9841
R7_CR275	0	0	7	0	5	0	5	8	
R8_CR233	0	0	18	0	13	0	13	19	0.9967
R9_CR156	0	0	19	0	13	0	13	18	
Chi-square = 444.348				df = 56					<0.0001

n. Replicate 14

Release	A	B	C	D	E	F	G	H	*P*-value
R1_CR503	23	19	0	18	0	19	0	0	
R2_CR468	18	16	0	15	0	14	0	0	0.9992
R3_CR422	19	15	0	16	0	13	0	0	
R4_CR346	0	0	8	0	6	0	7	10	1
R5_CR325	0	0	8	0	6	0	7	10	
R6_CR307	0	0	8	0	5	0	4	8	0.9974
R7_CR275	0	0	7	0	5	0	4	8	
R8_CR233	18	15	0	15	0	15	0	0	0.9955
R9_CR156	18	14	0	15	0	16	0	0	
Chi-square = 446.1753				df = 56					<0.0001

o. Replicate 15

Release	A	B	C	D	E	F	G	H	*P*-value
R1_CR503	0	0	21	0	16	0	19	23	
R2_CR468	0	0	17	0	13	0	16	17	0.9967
R3_CR422	0	0	17	0	13	0	13	20	
R4_CR346	0	0	8	0	6	0	7	10	0.9853
R5_CR325	0	0	9	0	5	0	7	10	
R6_CR307	7	6	0	6	0	6	0	0	0.9826
R7_CR275	7	6	0	7	0	5	0	0	
R8_CR233	18	15	0	15	0	15	0	0	1
R9_CR156	18	15	0	15	0	15	0	0	
Chi-square = 445.4965				df = 56					<0.0001

Table A.2. (contd)

p. Replicate 16

Release	A	B	C	D	E	F	G	H	*P*-value
R1_CR503	0	0	21	0	16	0	19	23	
R2_CR468	0	0	16	0	13	0	15	19	0.9946
R3_CR422	0	0	16	0	11	0	14	22	
R4_CR346	9	7	0	8	0	7	0	0	0.9876
R5_CR325	9	8	0	7	0	7	0	0	
R6_CR307	7	6	0	6	0	6	0	0	0.9826
R7_CR275	7	5	0	7	0	6	0	0	
R8_CR233	19	14	0	16	0	14	0	0	0.9960
R9_CR156	18	15	0	16	0	14	0	0	
Chi-square = 445.4888				df = 56					<0.0001

q. Replicate 17

Release	A	B	C	D	E	F	G	H	*P*-value
R1_CR503	0	0	22	0	16	0	20	20	
R2_CR468	0	0	16	0	13	0	15	17	0.9852
R3_CR422	0	0	18	0	12	0	13	20	
R4_CR346	8	8	0	8	0	7	0	0	0.9876
R5_CR325	8	7	0	8	0	8	0	0	
R6_CR307	7	6	0	6	0	6	0	0	0.9826
R7_CR275	7	6	0	7	0	5	0	0	
R8_CR233	19	15	0	16	0	13	0	0	0.9772
R9_CR156	18	15	0	15	0	15	0	0	
Chi-square = 443.7151				df = 56					<0.0001

r. Replicate 18

Release	A	B	C	D	E	F	G	H	*P*-value
R1_CR503	0	0	20	0	16	0	19	24	
R2_CR468	0	0	15	0	13	0	14	21	0.9962
R3_CR422	0	0	18	0	13	0	13	19	
R4_CR346	9	7	0	8	0	7	0	0	0.9894
R5_CR325	10	7	0	7	0	7	0	0	
R6_CR307	7	6	0	6	0	6	0	0	0.9841
R7_CR275	8	5	0	6	0	6	0	0	
R8_CR233	0	0	16	0	12	0	15	19	0.9725
R9_CR156	0	0	17	0	13	0	13	20	
Chi-square = 444.3609				df = 56					<0.0001

Table A.2. (contd)

s. Replicate 19

Release	A	B	C	D	E	F	G	H	*P*-value
R1_CR503	22	19	0	19	0	19	0	0	0.9997
R2_CR468	16	16	0	16	0	14	0	0	
R3_CR422	18	15	0	15	0	15	0	0	
R4_CR346	9	8	0	7	0	7	0	0	0.9669
R5_CR325	10	7	0	8	0	6	0	0	
R6_CR307	0	0	7	0	5	0	6	7	0.9861
R7_CR275	0	0	6	0	5	0	6	8	
R8_CR233	0	0	16	0	13	0	13	21	0.9951
R9_CR156	0	0	17	0	12	0	13	21	
Chi-square = 444.6745				df = 56					<0.0001

t. Replicate 20

Release	A	B	C	D	E	F	G	H	*P*-value
R1_CR503	22	19	0	19	0	18	0	0	1
R2_CR468	18	16	0	15	0	14	0	0	
R3_CR422	18	15	0	15	0	15	0	0	
R4_CR346	0	0	8	0	6	0	7	10	1
R5_CR325	0	0	8	0	6	0	7	10	
R6_CR307	0	0	7	0	5	0	5	8	1
R7_CR275	0	0	7	0	5	0	5	8	
R8_CR233	0	0	16	0	13	0	14	20	0.9957
R9_CR156	0	0	16	0	12	0	14	21	
Chi-square = 442.6701				df = 56					<0.0001

u. Replicate 21

Release	A	B	C	D	E	F	G	H	*P*-value
R1_CR503	23	20	0	19	0	17	0	0	0.9993
R2_CR468	17	15	0	16	0	15	0	0	
R3_CR422	18	15	0	14	0	15	0	0	
R4_CR346	0	0	8	0	7	0	6	10	0.9887
R5_CR325	0	0	8	0	6	0	6	11	
R6_CR307	0	0	7	0	5	0	6	7	0.9861
R7_CR275	0	0	6	0	5	0	6	8	
R8_CR233	0	0	17	0	13	0	15	18	0.9814
R9_CR156	0	0	16	0	12	0	15	20	
Chi-square = 444.7641				df = 56					<0.0001

Table A.2. (contd)

v. Replicate 22

Release	A	B	C	D	E	F	G	H	*P*-value
R1_CR503	23	19	0	19	0	18	0	0	
R2_CR468	18	15	0	15	0	15	0	0	1
R3_CR422	18	15	0	16	0	14	0	0	
R4_CR346	0	0	8	0	7	0	7	9	0.9881
R5_CR325	0	0	8	0	6	0	7	10	
R6_CR307	0	0	7	0	5	0	7	6	0.9423
R7_CR275	0	0	7	0	5	0	5	7	
R8_CR233	18	14	0	17	0	14	0	0	0.9850
R9_CR156	18	15	0	15	0	14	0	0	
Chi-square = 444.6288				df = 56					<0.0001

w. Replicate 23

Release	A	B	C	D	E	F	G	H	*P*-value
R1_CR503	0	0	21	0	16	0	18	24	
R2_CR468	0	0	16	0	13	0	15	19	0.9996
R3_CR422	0	0	18	0	13	0	13	19	
R4_CR346	0	0	9	0	5	0	8	9	0.9853
R5_CR325	0	0	8	0	6	0	8	9	
R6_CR307	8	6	0	6	0	5	0	0	0.9861
R7_CR275	7	6	0	7	0	5	0	0	
R8_CR233	17	15	0	16	0	15	0	0	0.9959
R9_CR156	18	14	0	16	0	15	0	0	
Chi-square = 445.7262				df = 56					<0.0001

x. Replicate 24

Release	A	B	C	D	E	F	G	H	*P*-value
R1_CR503	0	0	21	0	16	0	18	24	
R2_CR468	0	0	17	0	13	0	13	20	0.9999
R3_CR422	0	0	17	0	13	0	13	20	
R4_CR346	9	7	0	8	0	7	0	0	1
R5_CR325	9	7	0	8	0	7	0	0	
R6_CR307	7	5	0	7	0	6	0	0	1
R7_CR275	7	5	0	7	0	6	0	0	
R8_CR233	18	15	0	16	0	14	0	0	0.9953
R9_CR156	18	14	0	16	0	15	0	0	
Chi-square = 443.9546				df = 56					<0.0001

Table A.2. (contd)

y. Replicate 25

Release	A	B	C	D	E	F	G	H	*P*-value
R1_CR503	0	0	22	0	16	0	17	23	
R2_CR468	0	0	17	0	13	0	13	19	0.9999
R3_CR422	0	0	17	0	13	0	15	18	
R4_CR346	8	7	0	9	0	7	0	0	0.9886
R5_CR325	8	8	0	8	0	7	0	0	
R6_CR307	7	6	0	6	0	6	0	0	0.9826
R7_CR275	7	5	0	7	0	6	0	0	
R8_CR233	17	16	0	15	0	15	0	0	0.9847
R9_CR156	18	14	0	15	0	15	0	0	
Chi-square = 441.9847				df = 56					<0.0001

z. Replicate 26

Release	A	B	C	D	E	F	G	H	*P*-value
R1_CR503	0	0	21	0	16	0	16	26	
R2_CR468	0	0	15	0	13	0	16	19	0.9846
R3_CR422	0	0	18	0	11	0	15	19	
R4_CR346	9	8	0	7	0	7	0	0	0.9669
R5_CR325	10	7	0	8	0	6	0	0	
R6_CR307	7	6	0	6	0	6	0	0	1
R7_CR275	7	6	0	6	0	6	0	0	
R8_CR233	0	0	19	0	13	0	12	19	0.8913
R9_CR156	0	0	16	0	12	0	15	19	
Chi-square = 446.1691				df = 56					<0.0001

aa. Replicate 27

Release	A	B	C	D	E	F	G	H	*P*-value
R1_CR503	23	19	0	20	0	17	0	0	
R2_CR468	16	16	0	17	0	14	0	0	0.9996
R3_CR422	17	15	0	17	0	14	0	0	
R4_CR346	10	7	0	7	0	7	0	0	0.9436
R5_CR325	10	7	0	8	0	5	0	0	
R6_CR307	0	0	6	0	5	0	5	9	0.9853
R7_CR275	0	0	6	0	5	0	6	8	
R8_CR233	0	0	16	0	12	0	13	22	0.9581
R9_CR156	0	0	15	0	13	0	15	20	
Chi-square = 445.4018				df = 56					<0.0001

Table A.2. (contd)

bb. Replicate 28

Release	A	B	C	D	E	F	G	H	*P*-value
R1_CR503	21	19	0	20	0	18	0	0	
R2_CR468	19	15	0	15	0	14	0	0	0.9998
R3_CR422	18	15	0	16	0	14	0	0	
R4_CR346	0	0	8	0	7	0	6	10	0.9847
R5_CR325	0	0	8	0	6	0	7	10	
R6_CR307	0	0	6	0	5	0	7	7	0.9861
R7_CR275	0	0	6	0	5	0	6	8	
R8_CR233	0	0	15	0	13	0	16	19	0.9819
R9_CR156	0	0	15	0	12	0	15	21	
Chi-square = 444.2154				df = 56					<0.0001

cc. Replicate 29

Release	A	B	C	D	E	F	G	H	*P*-value
R1_CR503	23	19	0	20	0	17	0	0	
R2_CR468	18	15	0	16	0	14	0	0	1
R3_CR422	18	15	0	15	0	15	0	0	
R4_CR346	0	0	7	0	7	0	7	10	0.9861
R5_CR325	0	0	8	0	6	0	7	10	
R6_CR307	0	0	6	0	5	0	6	8	0.9861
R7_CR275	0	0	7	0	5	0	6	7	
R8_CR233	0	0	16	0	12	0	15	20	0.9881
R9_CR156	0	0	16	0	12	0	16	18	
Chi-square = 443.5412				df = 56					<0.0001

dd. Replicate 30

Release	A	B	C	D	E	F	G	H	*P*-value
R1_CR503	22	19	0	21	0	17	0	0	
R2_CR468	17	14	0	17	0	15	0	0	0.9998
R3_CR422	17	14	0	17	0	15	0	0	
R4_CR346	0	0	8	0	6	0	7	9	0.9392
R5_CR325	0	0	6	0	6	0	8	10	
R6_CR307	0	0	6	0	5	0	6	8	0.9795
R7_CR275	0	0	7	0	4	0	6	8	
R8_CR233	19	14	0	16	0	14	0	0	0.9960
R9_CR156	18	15	0	16	0	14	0	0	
Chi-square = 444.5203				df = 56					<0.0001

Table A.2. (contd)

ee. Replicate 31

Release	A	B	C	D	E	F	G	H	P-value
R1_CR503	0	0	22	0	18	0	21	26	
R2_CR468	0	0	13	0	12	0	15	19	0.9994
R3_CR422	0	0	11	0	10	0	12	16	
R4_CR346	0	0	6	0	5	0	6	7	0.9974
R5_CR325	0	0	6	0	5	0	6	8	
R6_CR307	6	4	0	5	0	4	0	0	0.9773
R7_CR275	5	4	0	5	0	5	0	0	
R8_CR233	17	12	0	13	0	13	0	0	0.9754
R9_CR156	16	12	0	15	0	12	0	0	
Chi-square = 393.8158				df = 56					<0.0001

ff. Replicate 32

Release	A	B	C	D	E	F	G	H	*P*-value
R1_CR503	0	0	22	0	15	0	18	26	
R2_CR468	0	0	14	0	11	0	11	18	0.9986
R3_CR422	0	0	12	0	8	0	11	17	
R4_CR346	7	6	0	6	0	6	0	0	0.9951
R5_CR325	7	6	0	6	0	5	0	0	
R6_CR307	5	5	0	5	0	4	0	0	0.9773
R7_CR275	6	4	0	5	0	4	0	0	
R8_CR233	17	13	0	13	0	12	0	0	0.9773
R9_CR156	15	13	0	14	0	13	0	0	
Chi-square = 381.9773				df = 56					<0.0001

Table A.3. Estimates of reach and cumulative survival for subyearling Chinook salmon, along with *P*-values associated the *F*-tests of homogeneous survival across fish tagged by different staff members.

a. Release 1 (CR503) – Reach survival

	Release to CR470.0		CR470.0 to CR422.0		CR422.0 to CR349.0		CR349.0 to CR325.0		CR325.0 to CR309.0		CR309.0 to CR275.0		CR275.0 to CR234.0		CR234.0 to CR156.0		CR156.0 to CR113.0	
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE
A	0.9777	0.0078	0.9229	0.0143	0.9505	0.0121	0.9375	0.0139	0.9860	0.0070	0.9395	0.0142	0.9889	0.0065	0.9468	0.0147	0.9768	0.0106
B	0.9841	0.0072	0.9175	0.0158	0.9465	0.0135	0.9198	0.0168	0.9962	0.0041	0.9167	0.0178	1.0002	0.0002	0.9531	0.0150	0.9887	0.0083
C	0.9908	0.0053	0.8920	0.0172	0.9412	0.0138	0.9449	0.0138	0.9961	0.0039	0.9570	0.0127	0.9926	0.0058	0.9399	0.0158	0.9954	0.0054
D	0.9803	0.0080	0.9161	0.0161	0.9560	0.0124	0.9387	0.0148	0.9878	0.0070	0.9504	0.0140	0.9957	0.0043	0.9550	0.0139	1.0012	0.0007
E	0.9647	0.0116	0.9228	0.0170	0.9604	0.0130	0.9447	0.0155	0.9951	0.0049	0.9559	0.0144	0.9694	0.0124	0.9730	0.0122	0.9941	0.0063
F	0.9759	0.0091	0.9247	0.0158	0.9537	0.0131	0.9271	0.0165	0.9913	0.0061	0.9427	0.0154	0.9953	0.0047	0.9476	0.0155	0.9949	0.0056
G	0.9721	0.0097	0.9104	0.0171	0.9724	0.0103	0.9224	0.0171	0.9779	0.0098	0.9910	0.0064	0.9822	0.0091	0.9480	0.0155	0.9893	0.0077
H	0.9748	0.0079	0.9093	0.0146	0.9573	0.0108	0.9521	0.0117	1.0000	0.0000	0.9497	0.0123	0.9967	0.0033	0.9493	0.0132	0.9803	0.0090
P-value	0.5443		0.8721		0.7766		0.7610		0.2749		0.0246		0.0307		0.8701		0.2653	

b. Release 1 (CR503) – Cumulative survival

	Release to CR470.0		Release to CR422.0		Release to CR349.0		Release to CR325.0		Release to CR309.0		Release to CR275.0		Release to CR234.0		Release to CR156.0		Release to CR113.0	
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE
A	0.9777	0.0078	0.9022	0.0157	0.8575	0.0185	0.8039	0.0210	0.7927	0.0215	0.7447	0.0231	0.7364	0.0234	0.6973	0.0246	0.6811	0.0249
B	0.9841	0.0072	0.9029	0.0168	0.8547	0.0201	0.7861	0.0233	0.7832	0.0235	0.7179	0.0256	0.7181	0.0256	0.6844	0.0267	0.6766	0.0268
C	0.9908	0.0053	0.8838	0.0177	0.8318	0.0207	0.7859	0.0227	0.7829	0.0228	0.7492	0.0240	0.7437	0.0242	0.6990	0.0255	0.6958	0.0256
D	0.9803	0.0080	0.8980	0.0174	0.8586	0.0200	0.8059	0.0227	0.7961	0.0231	0.7566	0.0246	0.7533	0.0247	0.7194	0.0258	0.7202	0.0259
E	0.9647	0.0116	0.8902	0.0196	0.8549	0.0221	0.8076	0.0247	0.8037	0.0249	0.7682	0.0265	0.7447	0.0273	0.7246	0.0281	0.7204	0.0282
F	0.9759	0.0091	0.9024	0.0175	0.8606	0.0204	0.7979	0.0237	0.7909	0.0240	0.7456	0.0257	0.7422	0.0258	0.7033	0.0270	0.6997	0.0271
G	0.9721	0.0097	0.8850	0.0188	0.8606	0.0204	0.7939	0.0239	0.7763	0.0246	0.7693	0.0249	0.7556	0.0254	0.7163	0.0268	0.7087	0.0270
H	0.9748	0.0079	0.8864	0.0159	0.8485	0.0180	0.8079	0.0198	0.8079	0.0198	0.7672	0.0213	0.7647	0.0213	0.7259	0.0226	0.7116	0.0230
P-value	0.5443		0.9784		0.9788		0.9923		0.9813		0.8396		0.9452		0.9396		0.8998	

Table A.3. (contd)

c. Release 2 (CR468) – Reach survival

			Release to CR422.0		CR422.0 to CR349.0		CR349.0 to CR325.0		CR325.0 to CR309.0		CR309.0 to CR275.0		CR275.0 to CR234.0		CR234.0 to CR156.0		CR156.0 to CR113.0	
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE
A			0.9296	0.0152	0.9394	0.0147	0.9673	0.0114	0.9876	0.0073	0.9442	0.0150	0.9864	0.0078	0.9367	0.0166	0.9896	0.0076
B			0.9205	0.0175	0.9636	0.0126	0.9426	0.0161	0.9848	0.0087	0.9433	0.0166	0.9891	0.0077	0.9826	0.0112	0.9671	0.0145
C			0.9228	0.0170	0.9648	0.0122	0.9401	0.0161	0.9904	0.0069	0.9602	0.0138	0.9848	0.0089	0.9586	0.0146	0.9940	0.0062
D			0.9194	0.0173	0.9430	0.0154	0.9206	0.0185	0.9848	0.0087	0.9381	0.0173	0.9835	0.0094	0.9835	0.0114	0.9616	0.0161
E			0.9353	0.0173	0.9468	0.0164	0.9326	0.0188	0.9880	0.0085	0.9329	0.0195	0.9804	0.0112	0.9617	0.0161	0.9844	0.0110
F			0.9277	0.0169	0.9404	0.0160	0.9513	0.0150	0.9897	0.0073	0.9430	0.0167	0.9949	0.0055	0.9399	0.0179	0.9876	0.0090
G			0.9330	0.0167	0.9713	0.0116	0.9307	0.0179	1.0004	0.0004	0.9305	0.0186	0.9945	0.0057	0.9607	0.0152	0.9862	0.0097
H			0.9177	0.0155	0.9655	0.0107	0.9534	0.0126	0.9887	0.0065	0.9354	0.0152	0.9837	0.0081	0.9550	0.0134	0.9951	0.0048
P-value			0.9932		0.5042		0.5409		0.8623		0.9499		0.8961		0.2245		0.2164	

d. Release 2 (CR468) – Cumulative survival

			Release to CR422.0		Release to CR349.0		Release to CR325.0		Release to CR309.0		Release to CR275.0		Release to CR234.0		Release to CR156.0		Release to CR113.0	
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE
A			0.9296	0.0152	0.8732	0.0197	0.8447	0.0215	0.8342	0.0221	0.7877	0.0243	0.7770	0.0248	0.7278	0.0266	0.7202	0.0268
B			0.9205	0.0175	0.8870	0.0205	0.8361	0.0240	0.8234	0.0247	0.7767	0.0270	0.7682	0.0274	0.7548	0.0283	0.7300	0.0289
C			0.9228	0.0170	0.8902	0.0199	0.8369	0.0236	0.8289	0.0241	0.7959	0.0258	0.7838	0.0263	0.7513	0.0277	0.7468	0.0278
D			0.9194	0.0173	0.8669	0.0216	0.7981	0.0255	0.7859	0.0261	0.7373	0.0280	0.7251	0.0284	0.7132	0.0291	0.6858	0.0296
E			0.9353	0.0173	0.8856	0.0225	0.8259	0.0267	0.8159	0.0273	0.7612	0.0301	0.7463	0.0307	0.7177	0.0319	0.7065	0.0321
F			0.9277	0.0169	0.8723	0.0218	0.8298	0.0245	0.8213	0.0250	0.7745	0.0273	0.7705	0.0275	0.7242	0.0292	0.7152	0.0295
G			0.9330	0.0167	0.9063	0.0195	0.8434	0.0243	0.8438	0.0243	0.7851	0.0275	0.7808	0.0277	0.7501	0.0291	0.7398	0.0294
H			0.9177	0.0155	0.8861	0.0179	0.8448	0.0204	0.8353	0.0209	0.7813	0.0233	0.7686	0.0238	0.7340	0.0249	0.7305	0.0250
P-value			0.9932		0.9183		0.8893		0.8190		0.8566		0.8114		0.9441		0.8622	

Table A.3. (contd)

e. Release 3 (CR422) – Reach survival

					Release to CR349.0		CR349.0 to CR325.0		CR325.0 to CR309.0		CR309.0 to CR275.0		CR275.0 to CR234.0		CR234.0 to CR156.0		CR156.0 to CR113.0	
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE
A					0.9412	0.0138	0.9556	0.0125	0.9767	0.0094	0.9167	0.0174	0.9827	0.0086	0.9571	0.0137	0.9858	0.0086
B					0.9372	0.0157	0.9361	0.0165	0.9854	0.0084	0.9356	0.0173	0.9894	0.0074	0.9544	0.0158	0.9811	0.0112
C					0.9137	0.0176	0.9348	0.0163	0.9862	0.0080	0.9668	0.0123	0.9954	0.0049	0.9472	0.0159	0.9882	0.0083
D					0.9423	0.0151	0.9156	0.0185	1.0000	0.0000	0.8889	0.0218	0.9728	0.0120	0.9285	0.0194	0.9878	0.0093
E					0.9375	0.0175	0.9333	0.0186	1.0000	0.0000	0.9226	0.0206	0.9935	0.0064	0.9805	0.0111	1.0000	0.0000
F					0.9534	0.0137	0.9412	0.0158	1.0000	0.0000	0.9471	0.0155	0.9746	0.0112	0.9305	0.0189	0.9630	0.0149
G					0.9541	0.0142	0.9614	0.0134	0.9849	0.0086	0.9082	0.0206	0.9944	0.0056	0.9943	0.0057	1.0001	0.0001
H					0.9490	0.0124	0.9461	0.0131	0.9929	0.0050	0.9570	0.0121	0.9889	0.0065	0.9847	0.0076	1.0001	0.0001
P-value					0.6476		0.5717		0.2967		0.0291		0.3174		0.0040		0.0605	

f. Release 3 (CR422) – Cumulative survival

					Release to CR349.0		Release to CR325.0		Release to CR309.0		Release to CR275.0		Release to CR234.0		Release to CR156.0		Release to CR113.0	
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE
A					0.9412	0.0138	0.8993	0.0177	0.8784	0.0193	0.8052	0.0234	0.7913	0.0240	0.7573	0.0254	0.7465	0.0257
B					0.9372	0.0157	0.8773	0.0213	0.8645	0.0223	0.8089	0.0256	0.8003	0.0261	0.7638	0.0279	0.7494	0.0283
C					0.9137	0.0176	0.8541	0.0222	0.8424	0.0229	0.8144	0.0244	0.8107	0.0246	0.7679	0.0267	0.7588	0.0269
D					0.9423	0.0151	0.8627	0.0222	0.8627	0.0222	0.7669	0.0273	0.7460	0.0281	0.6927	0.0298	0.6842	0.0301
E					0.9375	0.0175	0.8750	0.0239	0.8750	0.0239	0.8073	0.0285	0.8021	0.0288	0.7865	0.0296	0.7865	0.0296
F					0.9534	0.0137	0.8973	0.0199	0.8973	0.0199	0.8499	0.0234	0.8283	0.0247	0.7707	0.0278	0.7422	0.0287
G					0.9541	0.0142	0.9173	0.0187	0.9034	0.0200	0.8205	0.0260	0.8159	0.0263	0.8112	0.0266	0.8113	0.0266
H					0.9490	0.0124	0.8979	0.0171	0.8915	0.0176	0.8532	0.0200	0.8437	0.0205	0.8308	0.0212	0.8309	0.0212
P-value					0.6476		0.3731		0.4859		0.3012		0.2486		0.0235		0.0064	

Table A.3. (contd)

g. Release 4 (CR346) – Reach survival

							Release to CR325.0		CR325.0 to CR309.0		CR309.0 to CR275.0		CR275.0 to CR234.0		CR234.0 to CR156.0		CR156.0 to CR113.0	
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE
A							1.0000	0.0000	1.0000	0.0000	0.9167	0.0230	0.9932	0.0076	0.9535	0.0185	1.0003	0.0003
B							1.0000	0.0000	0.9916	0.0084	0.9576	0.0185	0.9735	0.0151	0.9545	0.0199	1.0004	0.0004
C							1.0000	0.0000	0.9921	0.0079	0.9440	0.0206	0.9831	0.0119	0.9741	0.0147	1.0000	0.0000
D							1.0000	0.0000	1.0000	0.0000	0.8908	0.0286	1.0002	0.0002	0.9830	0.0135	0.9787	0.0149
E							1.0000	0.0000	0.9898	0.0102	0.9691	0.0176	0.9894	0.0106	0.9469	0.0234	0.9891	0.0121
F							1.0000	0.0000	1.0000	0.0000	0.9483	0.0206	1.0000	0.0000	0.9737	0.0156	0.9897	0.0103
G							1.0000	0.0000	1.0000	0.0000	0.9459	0.0215	0.9905	0.0095	0.9712	0.0164	1.0000	0.0000
H							0.9935	0.0065	0.9934	0.0066	0.9404	0.0193	0.9932	0.0070	0.9722	0.0141	0.9919	0.0080
P-value							0.9966		0.9572		0.2388		0.5865		0.8045		0.6814	

h. Release 4 (CR346) – Cumulative survival

							Release to CR325.0		Release to CR309.0		Release to CR275.0		Release to CR234.0		Release to CR156.0		Release to CR113.0	
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE
A							1.0000	0.0000	1.0000	0.0000	0.9167	0.0230	0.9104	0.0239	0.8681	0.0282	0.8683	0.0282
B							1.0000	0.0000	0.9916	0.0084	0.9496	0.0201	0.9244	0.0242	0.8824	0.0295	0.8827	0.0295
C							1.0000	0.0000	0.9921	0.0079	0.9365	0.0217	0.9206	0.0241	0.8968	0.0271	0.8968	0.0271
D							1.0000	0.0000	1.0000	0.0000	0.8908	0.0286	0.8909	0.0286	0.8758	0.0305	0.8571	0.0321
E							1.0000	0.0000	0.9898	0.0102	0.9592	0.0200	0.9490	0.0222	0.8986	0.0306	0.8888	0.0319
F							1.0000	0.0000	1.0000	0.0000	0.9483	0.0206	0.9483	0.0206	0.9233	0.0249	0.9138	0.0261
G							1.0000	0.0000	1.0000	0.0000	0.9459	0.0215	0.9369	0.0231	0.9099	0.0272	0.9099	0.0272
H							0.9935	0.0065	0.9869	0.0092	0.9281	0.0209	0.9218	0.0217	0.8961	0.0248	0.8889	0.0254
P-value							0.9966		0.9159		0.4336		0.6888		0.8919		0.8673	

Table A.3. (contd)

i. Release 5 (CR325) – Reach survival

																	Release to CR309.0		CR309.0 to CR275.0		CR275.0 to CR234.0		CR234.0 to CR156.0		CR156.0 to CR113.0	
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE
A																	0.9931	0.0069	0.9510	0.0180	1.0002	0.0002	0.9787	0.0127	0.9840	0.0112
B																	0.9832	0.0118	0.9402	0.0219	1.0015	0.0012	0.9252	0.0254	1.0000	0.0000
C																	1.0000	0.0000	0.9187	0.0246	1.0002	0.0003	0.9732	0.0153	1.0003	0.0003
D																	0.9918	0.0082	0.9752	0.0141	1.0000	0.0000	0.9658	0.0168	1.0003	0.0004
E																	0.9892	0.0107	0.9130	0.0294	0.9881	0.0118	0.9639	0.0205	1.0015	0.0012
F																	0.9910	0.0090	0.9545	0.0199	1.0000	0.0000	0.9631	0.0187	0.9891	0.0111
G																	1.0000	0.0000	0.9561	0.0192	1.0004	0.0004	0.9630	0.0182	1.0000	0.0000
H																	0.9809	0.0109	0.9610	0.0156	1.0002	0.0003	0.9667	0.0150	0.9936	0.0077
P-value																	0.8337		0.4055		0.5798		0.6072		0.5697	

j. Release 5 (CR325) – Cumulative survival

																	Release to CR309.0		Release to CR275.0		Release to CR234.0		Release to CR156.0		Release to CR113.0	
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE
A																	0.9931	0.0069	0.9444	0.0191	0.9446	0.0191	0.9245	0.0222	0.9097	0.0239
B																	0.9832	0.0118	0.9244	0.0242	0.9257	0.0243	0.8565	0.0322	0.8565	0.0322
C																	1.0000	0.0000	0.9187	0.0246	0.9189	0.0247	0.8943	0.0277	0.8945	0.0277
D																	0.9918	0.0082	0.9672	0.0161	0.9672	0.0161	0.9341	0.0225	0.9345	0.0225
E																	0.9892	0.0107	0.9032	0.0307	0.8925	0.0321	0.8602	0.0360	0.8615	0.0360
F																	0.9910	0.0090	0.9459	0.0215	0.9459	0.0215	0.9110	0.0272	0.9011	0.0284
G																	1.0000	0.0000	0.9561	0.0192	0.9565	0.0192	0.9211	0.0253	0.9211	0.0253
H																	0.9809	0.0109	0.9427	0.0186	0.9429	0.0186	0.9115	0.0228	0.9056	0.0235
P-value																	0.8337		0.5108		0.3564		0.3386		0.4658	

Table A.3. (contd)

k. Release 6 (CR 307) – Reach survival

											Release to CR275.0		CR275.0 to CR234.0		CR234.0 to CR156.0		CR156.0 to CR113.0	
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE
A											1.0000	0.0000	1.0000	0.0000	0.9474	0.0209	1.0000	0.0000
B											1.0000	0.0000	1.0000	0.0000	0.9780	0.0154	1.0000	0.0000
C											0.9905	0.0095	0.9905	0.0096	0.9916	0.0099	0.9895	0.0112
D											0.9894	0.0106	1.0002	0.0003	0.9795	0.0153	0.9879	0.0121
E											1.0000	0.0000	0.9753	0.0172	0.9873	0.0126	1.0000	0.0000
F											0.9775	0.0157	0.9774	0.0161	0.9654	0.0203	0.9867	0.0132
G											0.9889	0.0110	1.0000	0.0000	0.9775	0.0157	1.0000	0.0000
H											1.0000	0.0000	0.9923	0.0080	0.9590	0.0179	1.0005	0.0005
P-value											0.8550		0.6237		0.5666		0.9283	

l. Release 6 (CR307) – Cumulative survival

											Release to CR275.0		Release to CR234.0		Release to CR156.0		Release to CR113.0	
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE
A											1.0000	0.0000	1.0000	0.0000	0.9474	0.0209	0.9474	0.0209
B											1.0000	0.0000	1.0000	0.0000	0.9780	0.0154	0.9780	0.0154
C											0.9905	0.0095	0.9810	0.0133	0.9728	0.0163	0.9626	0.0187
D											0.9894	0.0106	0.9896	0.0106	0.9693	0.0182	0.9576	0.0208
E											1.0000	0.0000	0.9753	0.0172	0.9630	0.0210	0.9630	0.0210
F											0.9775	0.0157	0.9555	0.0220	0.9224	0.0286	0.9101	0.0303
G											0.9889	0.0110	0.9889	0.0110	0.9667	0.0189	0.9667	0.0189
H											1.0000	0.0000	0.9923	0.0080	0.9516	0.0193	0.9520	0.0193
P-value											0.8550		0.4015		0.5931		0.4837	

Table A.3. (contd)

m. Release 7 (CR275) – Reach survival

													Release to CR234.0		CR234.0 to CR156.0		CR156.0 to CR113.0	
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE
A													1.0000	0.0000	0.9729	0.0157	0.9901	0.0099
B													0.9886	0.0113	0.9770	0.0161	1.0006	0.0007
C													1.0001	0.0001	0.9911	0.0099	0.9792	0.0146
D													0.9607	0.0194	0.9700	0.0178	0.9881	0.0118
E													1.0000	0.0000	0.9872	0.0127	1.0000	0.0000
F													0.9891	0.0111	0.9773	0.0159	1.0001	0.0002
G													1.0000	0.0000	0.9667	0.0189	1.0000	0.0000
H													1.0010	0.0007	0.9597	0.0177	1.0000	0.0000
P-value													0.1548		0.8860		0.6569	

n. Release 7 (CR275) – Cumulative survival

													Release to CR234.0		Release to CR156.0		Release to CR113.0	
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE
A													1.0000	0.0000	0.9729	0.0157	0.9633	0.0180
B													0.9886	0.0113	0.9659	0.0193	0.9665	0.0194
C													1.0001	0.0001	0.9912	0.0098	0.9706	0.0167
D													0.9607	0.0194	0.9319	0.0253	0.9208	0.0269
E													1.0000	0.0000	0.9872	0.0127	0.9872	0.0127
F													0.9891	0.0111	0.9667	0.0189	0.9668	0.0189
G													1.0000	0.0000	0.9667	0.0189	0.9667	0.0189
H													1.0010	0.0007	0.9606	0.0173	0.9606	0.0173
P-value													0.1548		0.4022		0.4429	

Table A.3. (contd)

o. Release 8 (CR233) – Reach survival

															Release to CR156.0		CR156.0 to CR113.0	
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE
A															0.9938	0.0049	0.9889	0.0064
B															1.0004	0.0004	0.9954	0.0046
C															0.9885	0.0066	1.0000	0.0000
D															0.9967	0.0042	0.9867	0.0076
E															0.9901	0.0069	1.0002	0.0002
F															0.9912	0.0062	1.0001	0.0001
G															0.9959	0.0045	0.9952	0.0048
H															0.9908	0.0055	0.9966	0.0036
P-value															0.7721		0.3038	

p. Release 8 (CR233) – Cumulative survival

															Release to CR156.0		Release to CR113.0	
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE
A															0.9938	0.0049	0.9828	0.0077
B															1.0004	0.0004	0.9957	0.0042
C															0.9885	0.0066	0.9885	0.0066
D															0.9967	0.0042	0.9835	0.0082
E															0.9901	0.0069	0.9903	0.0069
F															0.9912	0.0062	0.9913	0.0062
G															0.9959	0.0045	0.9911	0.0063
H															0.9908	0.0055	0.9875	0.0063
P-value															0.7721		0.8956	

Table A.3. (contd)

q. Release 9 (CR156) – Reach survival

																	Release to CR113.0	
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE
A																	1.0000	0.0000
B																	1.0001	0.0001
C																	1.0003	0.0003
D																	1.0000	0.0000
E																	0.9900	0.0071
F																	0.9914	0.0060
G																	1.0000	0.0000
H																	1.0001	0.0001
P-value																	0.3604	

r. Release 9 (CR156) – Cumulative survival

																	Release to CR113.0	
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE
A																	1.0000	0.0000
B																	1.0001	0.0001
C																	1.0003	0.0003
D																	1.0000	0.0000
E																	0.9900	0.0071
F																	0.9914	0.0060
G																	1.0000	0.0000
H																	1.0001	0.0001
P-value																	0.3604	

A.2 Examination of Delayed Handling Effects

The purpose of these tests was to assess whether downstream reach survivals were affected by how far upstream subyearling Chinook salmon were released. Results of these tests were used to determine which upstream releases would contribute to the formation of the downstream virtual-release groups (i.e., V_1) at the faces of dams.

Downstream reach survivals began becoming significant between CR275 and CR234, and continued being significant further downriver (Table A.4). Comparison of cumulative reach survivals also began becoming significant after CR275 (Table A.5). The tests of homogeneous cumulative survival were repeated by sequentially omitting releases R_1, R_1–R_2, and R_1–R_3 (Table A.5). The sequential tests indicated the upper releases were contributing to the heterogeneity in survivals downriver. Therefore, in forming the release groups contributing to the V_1 releases for summer 2012, all available upstream releases were used at McNary, John Day, and The Dalles dams. However, R_1–R_3 above John Day Dam were omitted from the formation of the V_1 release at Bonneville Dam.

Table A.4. Comparison of reach survivals between tag releases from different upstream locations for subyearling Chinook salmon during the summer 2012 JSATS survival study in the Columbia River. Newly released and previously released fish were not compared within a reach (shaded).

	CR503		CR468		CR422		CR346		CR325		CR307		CR275		CR233		CR156		
Reach	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	P (F-test)
Release to CR470	0.9803	0.0030																	
CR470 to CR422	0.9147	0.0057	0.9274	0.0063															
CR422 to CR349	0.9556	0.0044	0.9558	0.0050	0.9443	0.0060													0.9760
CR349 to CR325	0.9367	0.0053	0.9437	0.0055	0.9408	0.0055	1.0005	0.0014											0.6578
CR325 to CR309	0.9918	0.0020	0.9894	0.0026	0.9905	0.0024	0.9962	0.0020	0.9925	0.0034									0.1576
CR309 to CR275	0.9500	0.0049	0.9414	0.0058	0.9318	0.0061	0.9382	0.0077	0.9480	0.0071	0.9952	0.0031							0.2535
CR275 to CR234	0.9911	0.0022	0.9875	0.0029	0.9868	0.0029	0.9908	0.0033	0.9996	0.0012	0.9929	0.0031	0.9944	0.0036					0.0121
CR234 to CR156	0.9518	0.0052	0.9593	0.0053	0.9606	0.0050	0.9670	0.0061	0.9639	0.0063	0.9725	0.0060	0.9753	0.0058	0.9992	0.0069			0.0606
CR156 to CR113	0.9900	0.0028	0.9842	0.0036	0.9889	0.0029	0.9942	0.0028	0.9958	0.0025	0.9962	0.0025	0.9947	0.0029	0.9962	0.0020	1.0037	0.0052	0.0155
CR113 to CR86 (λ)	0.9855	0.0030	0.9923	0.0024	0.9926	0.0023	0.9955	0.0024	0.9885	0.0037	0.9933	0.0031	0.9975	0.0019	0.9970	0.0014	0.9991	0.0009	0.0015

Table A.5. Comparison of cumulative survivals between tag releases from different upstream locations for subyearling Chinook salmon during the 2012 summer JSATS survival study in the Columbia River. *P*-values for tests of homogeneity computed using all release groups, omitting release R_1, omitting releases R_1 and R_2, or omitting releases R_1, R_2, and R_3.

	CR503 (R1)		CR468 (R2)		
Reach	Est	SE	Est	SE	*P*
CR422 to CR349	0.9556	0.0048	0.9558	0.0050	0.9770
CR422 to CR325	0.8952	0.0069	0.9019	0.0071	0.4986
CR422 to CR309	0.8878	0.0072	0.8924	0.0074	0.6559
CR422 to CR275	0.8434	0.0082	0.8401	0.0087	0.7825
CR422 to CR234	0.8359	0.0086	0.8296	0.0090	0.6128
CR422 to CR156	0.7956	0.0095	0.7958	0.0097	0.9882
CR422 to CR113	0.7877	0.0098	0.7833	0.0099	0.7521

	CR503 (R1)		CR468 (R2)		CR422 (R3)			
Reach	Est	SE	Est	SE	Est	SE	*P*	*P* -r1
CR349 to CR325	0.9367	0.0053	0.9437	0.0055	0.9413	0.0055	0.6515	0.7577
CR349 to CR309	0.9290	0.0056	0.9337	0.0060	0.9323	0.0060	0.8445	0.8690
CR349 to CR275	0.8826	0.0070	0.8789	0.0078	0.8687	0.0081	0.4123	0.3644
CR349 to CR234	0.8747	0.0073	0.8680	0.0082	0.8573	0.0086	0.3048	0.3679
CR349 to CR156	0.8326	0.0084	0.8327	0.0091	0.8234	0.0098	0.7096	0.4868
CR349 to CR113	0.8243	0.0086	0.8195	0.0093	0.8143	0.0102	0.7530	0.7064

	CR503 (R1)		CR468 (R2)		CR422 (R3)		CR346 (R4)				
Reach	Est	SE	Est	SE	Est	SE	Est	SE	*P*	*P* -r1	*P* -r1r2
CR325 to CR309	0.9918	0.0020	0.9894	0.0026	0.9905	0.0024	0.9962	0.0020	0.1576	0.0890	0.0681
CR325 to CR275	0.9422	0.0052	0.9314	0.0063	0.9230	0.0065	0.9346	0.0079	0.2191	0.4743	0.2568
CR325 to CR234	0.9338	0.0056	0.9197	0.0070	0.9108	0.0071	0.9259	0.0084	0.1304	0.3617	0.1698
CR325 to CR156	0.8888	0.0072	0.8823	0.0085	0.8749	0.0084	0.8954	0.0099	0.3672	0.2612	0.1144
CR325 to CR113	0.8799	0.0075	0.8684	0.0090	0.8652	0.0088	0.8902	0.0101	0.1761	0.1186	0.0620

	CR503 (R1)		CR468 (R2)		CR422 (R3)		CR346 (R4)		CR325 (R5)					
Reach	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	*P*	*P* -r1	*P* -r1r2	*P* -r1r2r3
CR309 to CR275	0.9500	0.0049	0.9414	0.0059	0.9318	0.0061	0.9382	0.0077	0.9480	0.0072	0.2597	0.3950	0.2602	0.3526
CR309 to CR234	0.9416	0.0054	0.9296	0.0065	0.9195	0.0066	0.9295	0.0083	0.9476	0.0074	0.0356	0.0493	0.0263	0.1036
CR309 to CR156	0.8962	0.0072	0.8917	0.0081	0.8832	0.0079	0.8989	0.0100	0.9133	0.0097	0.1633	0.1089	0.0706	0.3013
CR309 to CR113	0.8873	0.0076	0.8776	0.0085	0.8735	0.0082	0.8936	0.0103	0.9095	0.0102	0.0410	0.0258	0.0296	0.2727

Table A.5. (contd)

Reach	CR503 (R1)		CR468 (R2)		CR422 (R3)		CR346 (R4)		CR325 (R5)		CR307 (R6)					
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	*P*	*P* -r1	*P* -r1r2	*P* -r1r2r3
CR275 to CR234	0.9911	0.0023	0.9875	0.0030	0.9868	0.0029	0.9908	0.0033	0.9996	0.0012	0.9929	0.0031	0.0139	0.0091	0.0101	0.0557
CR275 to CR156	0.9434	0.0058	0.9474	0.0060	0.9479	0.0057	0.9581	0.0068	0.9635	0.0064	0.9656	0.0067	0.0490	0.1229	0.2070	0.7118
CR275 to CR113	0.9339	0.0063	0.9324	0.0067	0.9374	0.0062	0.9525	0.0072	0.9594	0.0068	0.9619	0.0070	0.0015	0.0045	0.0494	0.6166

Reach	CR503 (R1)		CR468 (R2)		CR422 (R3)		CR346 (R4)		CR325 (R5)		CR307 (R6)		CR275 (R7)					
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	*P*	*P* -r1	*P* -r1r2	*P* -r1r2r3
CR234 to CR156	0.9518	0.0052	0.9594	0.0053	0.9606	0.0050	0.9671	0.0061	0.9639	0.0063	0.9725	0.0061	0.9753	0.0058	0.0623	0.2921	0.3769	0.5409
CR234 to CR113	0.9423	0.0057	0.9442	0.0060	0.9499	0.0056	0.9614	0.0066	0.9597	0.0066	0.9689	0.0065	0.9700	0.0064	0.0029	0.0207	0.1625	0.5917

Reach	CR503 (R1)		CR468 (R2)		CR422 (R3)		CR346 (R4)		CR325 (R5)		CR307 (R6)		CR275 (R7)		CR233 (R8)					
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	*P*	*P* -r1	*P* -r1r2	*P* -r1r2r3
CR156 to CR113	0.9902	0.0028	0.9841	0.0035	0.9889	0.0030	0.9942	0.0028	0.9957	0.0025	0.9963	0.0026	0.9947	0.0029	0.9961	0.0020	0.0161	0.0116	0.3612	0.9736

Appendix B

Capture Histories Used in Estimating Dam Passage Survival

Appendix B

Capture Histories Used in Estimating Dam Passage Survival

B.1 Subyearling Chinook Salmon

Capture History	V1 (Season-Wide) Dam Passage Survival	V1 (Season-Wide) BRZ-to-BRZ Survival
111	5745	5748
011	1	1
101	20	20
001	0	0
120	75	75
020	0	0
110	949	950
010	0	0
200	0	1
100	74	74
000	425	431
Total	7289	7300

Capture History	Season-Wide Dam Passage Survival R2	Season-Wide Dam Passage Survival R3
11	689	690
01	4	5
20	0	1
10	84	83
00	11	7
Total	788	786

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