PNNL-22188

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Contract DE-AC05-76RL01830

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

FINAL COMPLIANCE REPORT

JR Skalski
RL Townsend
AG Seaburg
GR Ploskey
MA Weiland
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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 (PNNL) and the University of Washington (UW) for the U.S. Army Corps of Engineers, Portland District (CENWP). The PNNL and UW project managers were Drs. Thomas J. Carlson and John R. Skalski, respectively. The CENWP technical lead was Mr. Brad Eppard. Pacific Northwest National Laboratory subcontracted with the Pacific States Marine Fisheries Commission to help conduct the study. The study was designed to estimate dam passage survival at Bonneville Dam as stipulated by the 2008 Federal Columbia River Power System Biological Opinion and provide additional performance measures as specified in the 2008 Columbia Basin Fish Accords (Fish Accords).

This compliance report for Bonneville Dam focuses on the 2012 summer run of subyearling Chinook salmon.

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Executive Summary

The purpose of this compliance study was to estimate dam passage survival of subyearling Chinook salmon at Bonneville Dam during summer 2012. Under the 2008 Federal Columbia River Power System Biological Opinion (BiOp), dam passage survival should be greater than or equal to 0.93 for summer migrants and estimated with a standard error (SE) less than or equal to 0.015. The study also estimated smolt passage survival from the forebay 2 km upstream of the dam to the tailrace 1 km below the dam, as well as forebay residence time, tailrace egress, and spill passage efficiency, as required in the 2008 Columbia Basin Fish Accords.

A virtual/paired-release design was used to estimate dam passage survival at Bonneville Dam. The approach included releases of acoustic-tagged smolts above Bonneville Dam that contributed to the formation of a virtual release at the face of the dam. A survival estimate from this release was adjusted by a paired release below Bonneville Dam. A total of 14,033 subyearling Chinook salmon were tagged and released during the summer study. However, 6501 of the subyearlings released at three transects (rkm 503, 468, and 422) upstream of John Day Dam (rkm 349) had to be excluded from survival analyses because they showed evidence of delayed tag effects at or downstream of Bonneville Dam. Hence, only 3367 tagged subyearlings released between rkm 346 and 275 and known to have arrived at the face of Bonneville Dam (rkm 234) were regrouped to form a virtual release to estimate dam-passage survival. Downstream reference releases included 1994 fish at rkm 233 and 1995 subyearlings at rkm 156. The Juvenile Salmon Acoustic Telemetry System (JSATS) acoustic micro-transmitters (tags) were manufactured by Advanced Telemetry Systems. Model number SS300 tags, 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 Bonneville Dam in summer 2012.

Period of Performance	Subyearling Chinook Salmon
Season-wide (19 June–22 July)	0.9739 (0.0069)[b]

(a) Dam passage survival is defined as survival from the upstream face of the dam to a standardized reference point in the tailrace.
(b) Dam survival was based on V_1 and R_2 releases only, as >100% survival was estimated from R_3.

Table ES.2. Fish Accords performance measures at Bonneville Dam in 2012. Standard errors are in parentheses.

Performance Measures	Subyearling Chinook Salmon
Forebay-to-tailrace survival[(a)]	0.9735 (0.0053) [(b)]
Forebay residence time (mean/median)	1.13 (0.04)/0.48 h
Tailrace egress rate (mean/median)	1.31 (0.18)/0.36 h
Spill passage efficiency (SPE)[(c)]	0.5320 (0.0086)
Spill+B2CC passage efficiency (SPE_2)[(d)]	0.5706 (0.0085)
Fish passage efficiency	0.6985 (0.0079)

(a) The forebay-to-tailrace survival estimate satisfies the "BRZ-to-BRZ" survival estimate called for in the Fish Accords.
(b) Dam survival was based on V_1 and R_2 releases only, as >100% survival was estimated from R_3.
(c) Spill passage efficiency (SPE) presented here is the proportion of fish passing the dam at the spillway out of total project passage.
(d) Spill+Bonneville Powerhouse 2 Corner Collector (B2CC) passage efficiency (spill+B2CC efficiency = SPE_2) includes proportions of fish passing the dam at the spillway and the B2CC out of total project passage.

Table ES.3. Survival study summary.

Year: 2012			
Study Site(s): Bonneville 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 smolt monitoring facility		Implant Procedure: Surgical: Yes Injected: No	
Size (median): CH0 Weight (g): 13.4 Length (mm): 111		Sample Size: CH0 # release sites: 6 Total # used to estimate dam-passage survival 7356	
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 19 June through 22 July 2012):

Statistic	Mean	Min	Max
River Discharge (kcfs):	353.0	292.1	421.0
Spill Discharge (kcfs):	149.2	98.3	215.7
Percent Spill (24 h/day):	41.9	31.6	51.9
Temperature (°C):	17.0	15.2	18.9
Total Dissolved Gas % (tailrace):	116.0	112.1	121.4

Spill Treatments: 6/16-7/20: 85 kcfs day/120 kcfs night vs. 95 kcfs day and night (precluded by high river flow)
7/21-8/31: 75 kcfs day/gas cap at night (precluded by high river flow)

Unique Study Characteristics: None

Survival and Passage Estimates (value & SE):	CH0
Dam survival	
• Season-wide	0.9739 (0.0069[a]
Forebay-to-tailrace survival	0.9735 (0.0053)[a]
Forebay residence time	1.13 (0.04)/0.48 h
Tailrace egress rate	1.31 (0.18)/0.36 h
Spill passage efficiency	0.5320 (0.0086)
Fish passage efficiency	0.6985 (0.0079)

Compliance Results: Estimates of dam passage survival met compliance requirements for CH0 for both point estimates and standard errors.

(a) Dam survival was based on V_1 and R_2 releases only, as >100% survival was estimated from R_3.

Acknowledgments

This study was the result of hard work by dedicated scientists from Cascade Aquatics, Pacific Northwest National Laboratory (PNNL), Pacific States Marine Fisheries Commission (PSMFC), the U.S. Army Corps of Engineers, Portland District (CENWP), and the University of Washington (UW). Their teamwork and attention to detail, schedule, and budget were essential for the study to succeed in providing high-quality, timely results to decision-makers.

- 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, G Johnson, 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
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- UW: J Lady and P Westhagen.

Acronyms and Abbreviations

°C	degree(s) Celsius
3D	three-dimensional
ATS	Advanced Telemetry Systems
B1	Bonneville Powerhouse 1
B2	Bonneville Powerhouse 2
B2CC	Bonneville Powerhouse 2 Corner Collector
BiOp	Biological Opinion
BRZ	boat-restricted zone
CENWP	U.S. Army Corps of Engineers, Portland District
CH0	subyearling Chinook salmon
FCRPS	Federal Columbia River Power System
FPE	fish passage efficiency
g	gram(s)
h	hour(s)
JSATS	Juvenile Salmon Acoustic Telemetry System
kcfs	thousand cubic feet per second
km	kilometer(s)
L	liter(s)
m	meter(s)
mg	milligram(s)
mm	millimeter(s)
PIT	passive integrated transponder
PNNL	Pacific Northwest National Laboratory
PRI	pulse repetition interval
rkm	river kilometer(s)
RME	research, monitoring, and evaluation
ROR	run-of-river
RPA	Reasonable and Prudent Alternative
s	second(s)
SE	standard error
$\widehat{SE}$	estimated standard error (from a sample)
SPE	spill passage efficiency
SPE_2	spill+B2CC passage efficiency
UW	University of Washington
USACE	U.S. Army Corps of Engineers

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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 (CENWP) in 2012. The purpose of the study was to estimate dam passage survival at Bonneville Dam as stipulated by the 2008 Federal Columbia River Power System (FCRPS) Biological Opinion (BiOp; NMFS 2008) and to provide additional performance measures at the dam as stipulated in the Columbia Basin Fish Accords for subyearling Chinook salmon (3 Treaty Tribes-Action Agencies 2008).

1.1 Background

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

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

The 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 Memorandum of Agreement):

> Dam Survival Performance Standard – Meet the 96% dam passage survival standard for yearling Chinook salmon and steelhead and the 93% standard for subyearling Chinook. Achievement of the standard is based on 2 years of empirical survival data….
>
> Spill Passage Efficiency and Delay Metrics − Spill passage efficiency (SPE) and delay metrics under current spill conditions… are not expected to be degraded ("no backsliding") with installation of new fish passage facilities at the dams….
>
> Future Research, Monitoring and Evaluation − The Action Agencies' dam survival studies for purposes of determining juvenile dam passage performance will also collect information about SPE, survival and delay between boat-restricted zones (BRZs), and other distribution and survival information. SPE and delay metrics will be considered in the performance check-ins or with Configuration and Operations Plan updates, but not as principal or priority metrics over dam survival performance standards. Once a dam meets the survival performance standard, SPE and delay metrics may be monitored coincidentally with dam survival testing.

This report summarizes the results of the 2012 summer acoustic-telemetry study of subyearling Chinook salmon at Bonneville Dam to assess the Action Agencies' compliance with the performance criteria of the BiOp and Fish Accords.

1.2 Study Objectives

The purpose of the summer 2012 compliance monitoring at Bonneville 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 is 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 is defined as survival from a forebay array 2 km upstream of the dam to a tailrace array 1 km downstream of the dam. The forebay-to-tailrace survival estimate satisfies the "BRZ-to-BRZ" survival estimated called for in the Fish Accords.
- Forebay residence time is calculated by subtracting the time of first detection on the forebay entrance array (river kilometer [rkm] 236) from the time of last detection on the dam-face array (rkm 234). For the population of tagged smolts passing the forebay, we estimated the mean, standard error, and median forebay residence time.
- Tailrace egress time is calculated by subtracting the time of last detection on the dam-face array (rkm 234) from the time of last detection on the tailrace array (rkm 233). For the population of tagged smolts passing through the tailrace, we estimated the mean, standard error, and median egress time.
- Spill passage efficiency (SPE) is defined as the fraction of fish going through the dam via the spillway.
- Spill+B2CC passage efficiency is defined as the fraction of fish passing through the dam via the spillway and B2CC, as defined by the 2008 Fish Accords.
- Fish passage efficiency (FPE) is defined as the fraction of fish going through the dam via non-turbine routes.

The intent of the summer 2012 study was to assess compliance with dam passage survival under two alternative spill regimes. Performed in 2-d blocks, the alternative spill conditions were 85 kcfs day/120 kcfs night versus 95 kcfs all day. The high flows in 2012 disrupted the spill trials. Consequently, a post-facto approach to examining dam passage survival in summer 2012 was necessary. Dam passage survival was estimated season-wide under prevailing spill and flow levels.

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

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

1.3 Report Contents and Organization

Study methods and results are described and discussed in the ensuing sections of this report. The appendices contain additional details about the tests of study assumptions and capture-history data used in estimating dam passage survival rates.

2.0 Methods

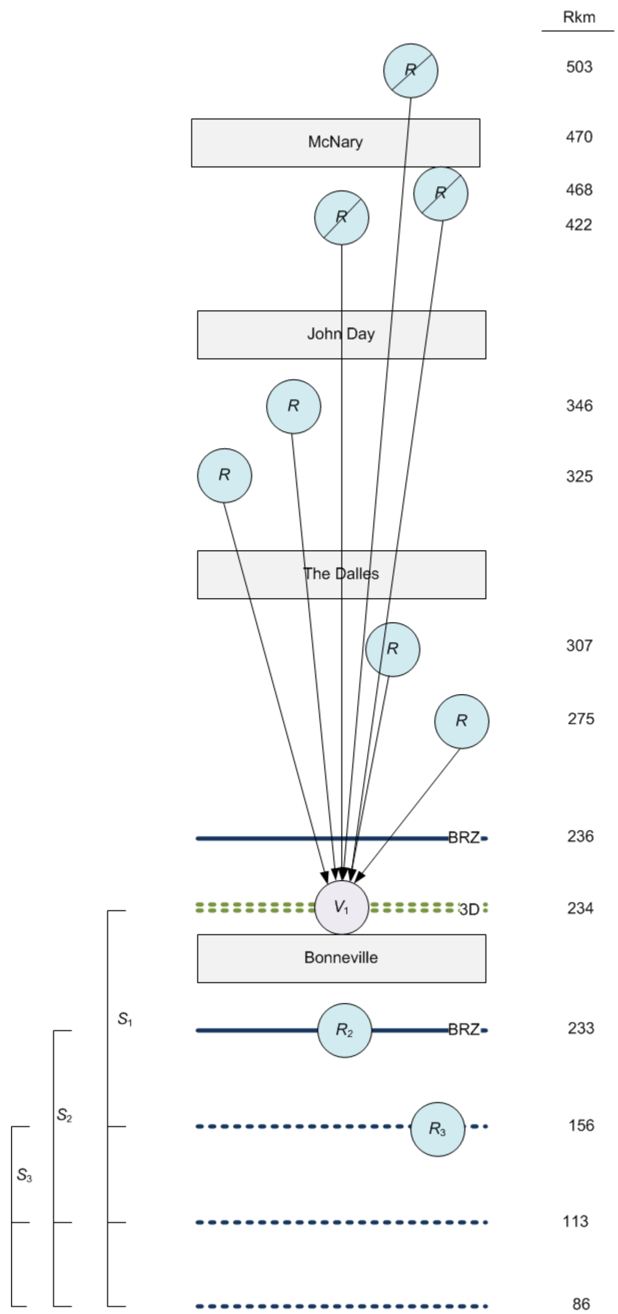
Study methods involved fish release and recapture; the associated fish-handling, tagging, and release procedures; acoustic signal processing; and statistical and analytical evaluation of passage and survival metrics.

2.1 Release-Recapture Design

The release-recapture design used to estimate dam passage survival at Bonneville Dam consisted of a novel combination of a virtual release (V_1) of fish at the face of the dam and a paired release below the dam (Figure 2.1) (Skalski et al. 2010a, 2010b). Tagged fish released at seven sites upstream of Bonneville Dam were used as potential sources of fish known to have arrived alive at the face of the dam. Upstream release sites were near Port Kelly (rkm 503); the McNary tailrace (rkm 468); Crow Butte (rkm 422); the John Day Dam tailrace (rkm 346); Celilo, Oregon (rkm 325); The Dalles Dam tailrace (rkm 307); and Hood River, Oregon (rkm 275). By releasing the fish far enough upstream, they should have arrived at the dam in a spatial pattern typical of run-of-river (ROR) fish. An analysis of delayed tag effects found releases from rkm 503, 468, and 422 started to show signs of delayed tag effects at or downstream of Bonneville Dam. Hence, only fish from release locations between rkm 346 and 275 were used in subsequent analyses. This virtual-release group was then used to estimate survival through the dam and some distance beyond (i.e., rkm 156) (Figure 2.1). To account and adjust for this extra reach mortality, we made paired releases below Bonneville Dam in the tailrace at R_2 and in the tailwater near Knapp, Washington at R_3 (Figure 2.1), to estimate survival in that river segment 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 downstream release, except when the survival of R3 fish was ≥1. The location for the detection array at rkm 156 was chosen so that there was little or no chance of detecting fish that died during dam passage and floated downriver with still-active tags. The sizes of the releases of the acoustic-tagged fish used in the dam passage survival estimates are summarized in Table 2.1.

The same release-recapture design was also used to estimate forebay-to-tailrace survival, except that the virtual-release group was constructed of fish known to have arrived at the forebay array (rkm 236). The same below-dam paired release was used to adjust for the extra release mortality below the dam as was used to estimate dam passage survival. The double-detection arrays at the face of the dam (Figure 2.2) were analyzed as two independent arrays to allow estimation of detection probabilities by route of passage and assign routes of passage. These passage-route data were used to calculate SPE, spill+B2CC passage efficiency, and FPE at Bonneville Dam. Detections on the forebay entrance array and dam-face array were used to estimate forebay residence time. The fish used in the virtual release at the face of the dam were also used to estimate tailrace egress time.

Two tag lots were used during the summer 2012 JSATS study. All upstream releases came from a single tag lot. Below-dam releases used JSATS tags with a faster pulse rate to enhance downstream detection probabilities. Random samples of approximately 100 tags each were used in separate tag-life studies. The tags were activated, held in river water, and monitored continuously until they failed. The information from the tag-life study was used to adjust the perceived survival estimates from the Cormack-Jolly-Seber release-recapture model according to the methods of Townsend et al. (2006).



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

Figure 2.1. Schematic of the virtual/paired-release design used to estimate dam passage survival at Bonneville Dam. The virtual release (V_1) was composed of fish that arrived at the dam face from the release locations at rkm 346, 325, 307, and 275. Analysis found fish from release locations 503, 468, and 422 exhibited signs of delayed tag effects. Fish from these locations were therefore excluded from the survival analyses. The below-dam release pair was composed of releases R_2 and R_3 with detection arrays used in the survival analysis denoted by dashed lines.

Table 2.1. Sample sizes of acoustic-tag releases used to estimate dam-passage survival for subyearling Chinook salmon at Bonneville Dam in 2012.

Release Location	Subyearling Chinook Salmon
Virtual Release (V_1)	3367[(a)]
Bonneville Tailrace (R_2)	1994
Bonneville Reservoir (R_3)	1995

(a) Fish released from sites at or downstream of CR346 and known to have arrived at the dam face. Release sites above CR346 were deemed too far to be included in the Bonneville study by assumption tests (Appendix A).

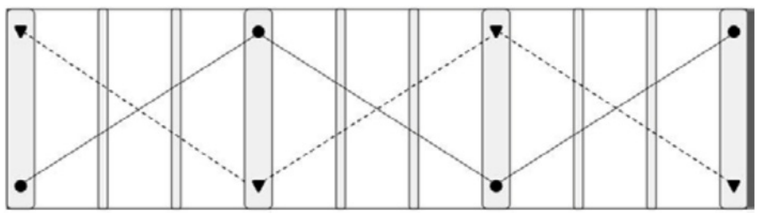


Figure 2.2. Front view schematic of hydrophone deployments at three turbines showing the double-detection arrays. Circles denote four hydrophones contributing to Array 1 and triangles denote four hydrophones contributing to Array 2. The alternating shallow and deep hydrophone deployment pattern on successive piers was used at all turbines and spill bays at the dam.

2.2 Handling, Tagging, and Release Procedures

Fish obtained from the John Day Dam juvenile bypass system were surgically implanted with both JSATS and passive integrated transponder (PIT) tags and transported to nine different release locations (Figure 2.1), 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 implanted 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.

For the summer study, one tag lot was used for releases upstream of Bonneville Dam (i.e., V_1) and another for releases below the dam (i.e., R_2 and R_3). From each tag lot, 98–99 tags were systematically sampled for tag-life studies. The tags were activated, held in river water, and monitored continuously until they failed. Fish released upstream of Bonneville Dam had tags with a nominal transmission rate of 1 pulse every 3 s and a nominal tag life of about 23 d. To increase detection probabilities below the dam for the R_2 and R_3 releases, those fish were implanted with tags with 2-s pulse repetition intervals, which reduced the nominal tag life to about 15 d.

2.2.2 Fish Source

The subyearling Chinook salmon used in the study were all obtained from the John Day Dam juvenile bypass system. The Pacific States Marine Fisheries Commission diverted fish from the juvenile bypass system into an examination trough, as described by Martinson et al. (2006). Fish ≥95 mm and <300 mm long 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 to 100 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 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 transported for release into the river. The loading rate was five fish per bucket.

2.2.4 Release Procedures

All fish were tagged at John Day Dam and transported by truck to release locations (Figure 2.1). Transportation routes for reference release pairs below study dams were standardized to provide equal transport times. In practice, transport times were similar for the seven upstream release sites and longer (2.5 h) but identical for the two reference releases downstream of Bonneville Dam. Upon arriving at each release site (Table 2.1), fish buckets were transferred to a boat for transport to five release locations spanning the width of the river, and equal numbers of buckets of fish were released at each of the five locations.

Releases occurred for 33 consecutive days (from 20 June to 22 July 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 the acoustic-tagged fish to accommodate downstream mixing.

Release Location	Relative Release Times	
V_1 (rkm 234)	Continuous	Continuous
R_2 (rkm 233)	Day 1: 0400	Day 2: 1600
R_3 (rkm 161)	Day 1: 2300	Day 3: 1100

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:

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

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

Three-dimensional (3D) tracking of JSATS-tagged fish in the immediate forebay of Bonneville 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, and 2013).

2.4 Statistical Methods

Statistical methods were used to test assumptions and estimate dam passage survival, forebay-to-tailrace survival, travel times, SPE, and FPE.

2.4.1 Estimation of Passage Survival

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

The joint likelihood used to model the three release groups was initially fully parameterized. Each of the three releases was allowed to have unique survival and detection parameters. If precision was adequate (i.e., $\widehat{\text{SE}} \leq 0.015$) 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

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

where $\hat{S}_i$ is the tag-life-corrected survival estimate for the *i*th 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 each of the two major manufacturing lots of JSATS tags (i.e., upstream vs. downstream), 98−99 acoustic tags were systematically sampled over the course of the subyearling Chinook salmon tagging process. The tags were continuously monitored from activation to failure in ambient river water. For each tag lot, the failure times were fit to the four-parameter vitality model of Li and Anderson (2009). The vitality model tends to fit acoustic-tag failure times well, it allows for both early onset of random failure due to manufacturing as well as systematic battery failure later on.

The survivorship function for the vitality model can be rewritten as

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

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

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

For the virtual-release group (V_1) based on fish known to have arrived at the dam and with active tags, the conditional probability of tag activation, given the tag was active at the detection array at rkm 234, was used in the tag-life adjustment for that release group. The conditional probability of tag activation at time t_1, given it was active at time t_0, was computed by the quotient

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

where $S(t_0)$ is the average unconditional probability that the tag is active when detected at the V_1 detection array (rkm 234) , and $S(t_1)$ is the average unconditional probability that the tag is active when detected at the first downstream survival detection array (rkm 156).

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

2.4.3.3 Tagger Effects

Subtle differences in handling and tagging techniques can have an effect on the survival of acoustically tagged smolts used in the estimation of dam passage survival. For this reason, tagger effects were evaluated. The single release-recapture model was used to estimate reach survivals for fish tagged by different individuals. The analysis evaluated whether any consistent pattern of reduced reach survivals existed for fish tagged by any of the tagging staff.

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

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

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

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

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 (2.4) evaluates whether reach survivals are homogeneous regardless of upstream release locations. If heterogeneity is detected, the uppermost release groups might be eliminated from subsequent survival and related analyses.

2.4.3.5 Tag-Lot Effects

Reach survivals of fish bearing 3-s tags and 2-s tags were compared in the reach below Bonneville Dam.

2.4.4 Estimation of Forebay-to-Tailrace Survival

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

2.4.5 Estimation of Travel Times

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

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

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

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

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

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

2.4.6 Estimation of Spill Passage Efficiency

Spill passage efficiency was estimated by the fraction

$$\widehat{\text{SPE}} = \frac{\hat{N}_{SP}}{\hat{N}_{SP} + \hat{N}_{B1SL} + + \hat{N}_{B1T} + \hat{N}_{2JBS} + \hat{N}_{B2CC} + \hat{N}_{B2T}}, \tag{2.9}$$

where $\hat{N}_i$ is the estimated abundance of acoustic-tagged fish through the *i*th route (i = spillway [SP], Bonneville Powerhouse 1 sluiceway [B1SL], Powerhouse 1 turbines [B1T], Bonneville Power house 2 juvenile bypass system [B2JBS], Powerhouse 2 Corner Collector [B2CC], and Powerhouse 2 turbines [B2T]). 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

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

2.4.7 Estimation of Spill+B2CC Passage Efficiency

Spill+B2CC passage efficiency was estimated by the fraction

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

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

$$\text{Var}\left(\text{SPE}_2\right) = \frac{\text{SPE}_2(1-\text{SPE}_2)}{\sum_{i=1}^{6} \hat{N}_i} + \text{SPE}_2^2(1-\text{SPE}_2)^2 \cdot \left[\frac{\text{Var}\left(\hat{N}_{SP}\right) + \text{Var}\left(\hat{N}_{B2CC}\right)}{\left(N_{SP} + N_{B2CC}\right)^2} + \frac{\text{Var}\left(\hat{N}_{B1SL}\right) + \text{Var}\left(\hat{N}_{B1T}\right) + \text{Var}\left(\hat{N}_{B2JBS}\right) + \text{Var}\left(\hat{N}_{B2T}\right)}{\left(N_{B1SL} + N_{B1T} + N_{B2JBS} + N_{B2T}\right)^2}\right]. \tag{2.12}$$

2.4.8 Estimation of Fish Passage Efficiency

Fish passage efficiency was estimated by the fraction

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

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

$$\text{Var}\left(\widehat{\text{FPE}}\right) = \frac{\text{FPE}\left(1-\text{FPE}\right)}{\sum_{i=1}^{6} N_i} + \text{FPE}^2\left(1-\text{FPE}\right)^2 \cdot \left[\frac{\text{Var}\left(\hat{N}_{SP}\right) + \text{Var}\left(\hat{N}_{B2CC}\right) + \text{Var}\left(\hat{N}_{B1SL}\right) + \text{Var}\left(\hat{N}_{B2JBS}\right)}{\left(N_{SP} + N_{B2CC} + N_{B1SL} + N_{B2JBS}\right)^2} + \frac{\text{Var}\left(\hat{N}_{B1T}\right) + \text{Var}\left(\hat{N}_{B2T}\right)}{\left(N_{B1T} + N_{B2T}\right)^2}\right]. \tag{2.14}$$

Double array detection probabilities ranged from 0.9978 at the spillway to 100% for all other passage routes through Bonneville Dam, so raw counts of fish by route did not have to be adjusted to estimate absolute numbers, and variances could be estimated from first term in Equations (2.10) and (2.12), based on a binomial sampling model.

3.0 Results

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

3.1 Fish Collection, Rejection, and Tagging

The total number of fish handled by PNNL in summer 2012 and the counts by handling category are listed in Table 3.1. Almost 16,000 subyearling Chinook salmon were handled during the study.

Table 3.1. Total number of subyearling Chinook salmon handled by PNNL during the summer of 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 Studies Review Work Group and the National Atmospheric and Oceanic Administration in meetings during spring 2012 (Eppard, personal communication, 20 April 2012). PNNL broadened the criteria to accept more fish. Fish were not accepted for the project 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, and descaling greater than 20% where there is no indication of scale growth or slime 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 of 2012.

	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 Fish[(a)]	**563**	

(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 Bonneville Dam during the JSATS survival study (19 June–22 July 2012) was 353.2 kcfs with an average percent spill of 41.9% (Figure 3.1). Average spill during the summer study was 149.2 kcfs, and very high river discharge prevented operators from delivering planned spill treatments consisting of 24 h of 95 kcfs spill alternated with 24 h of 85 kcfs day and 120 kcfs night spill.

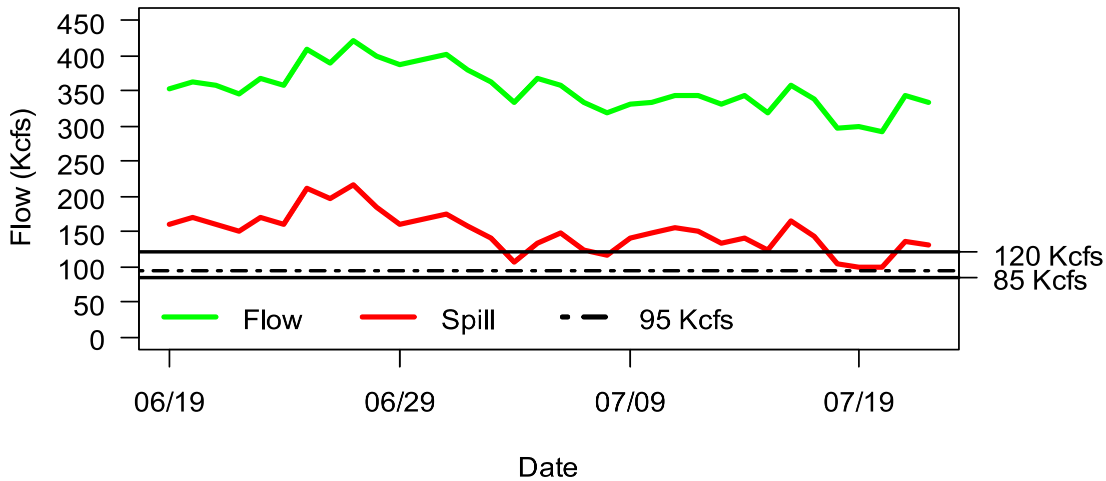


Figure 3.1. Daily average total discharge (kcfs) and spill (kcfs) at Bonneville Dam during the 2012 JSATS study for subyearling Chinook salmon from 19 June to 22 July 2012. Horizontal black lines identify upper and lower limits of spill for a planned 85 kcfs day/120 kcfs night spill treatment, and the dashed line indicates at 95 kcfs spill level for the alternate 2-d treatment.

3.3 Run Timing

Of the subyearling Chinook passing through Bonneville Dam from 15 June through 31 October 2012, the cumulative percentage of subyearling Chinook salmon that had passed during the tagging study was calculated from smolt index data obtained from the Fish Passage Center (Figure 3.2). From 19 June, when the first tagged subyearlings arrived at the dam, through the end of the study on 22 July 2012, 80.5% of subyearling Chinook salmon had passed Bonneville Dam. By the end of the study on 22 July, 82.5% of the total subyearling Chinook salmon run had passed Bonneville Dam.

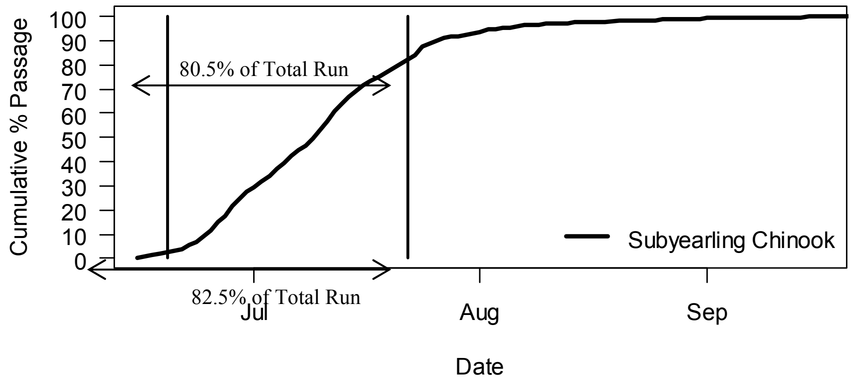


Figure 3.2. Plots of the cumulative percentage of subyearling Chinook salmon that passed Bonneville Dam in 2012. Vertical lines indicate the start and end of the summer survival study. Values were calculated from Bonneville Dam smolt monitoring data.

3.4 Assessment of Assumptions

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

3.4.1 Examination of Tagger Effects

A total of eight different taggers assisted in tagging the subyearling Chinook salmon associated with the JSATS survival studies at Bonneville Dam in summer 2012. Analyses found tagger effort was homogeneously distributed either across all locations within a replicate release or within the project-specific releases within a replicate (Appendix A). Examination of reach survivals and cumulative survivals from above McNary Dam to below Bonneville Dam found no consistent or reproducible evidence that fish tagged by different staff members had different in-river survival rates (Appendix A). Therefore, fish tagged by all taggers were included in the estimation of survival and other performance measures.

3.4.2 Examination of Tag-Lot Effects

A single tag lot was used for all the upstream releases contributing to the V_1 release. A separate tag lot with a different pulse rate was used for the R_2 and R_3 releases. Tag life was expected to be different between these two tag lots because of the different pulse rates, and separate adjustments to survival probabilities were performed. The purpose of the faster pulse rate for the downstream releases was to increase detection probabilities, thereby improving the precision of the estimate of dam passage survival at Bonneville Dam. No difference in reach survival could be detected between these two tag lots (Appendix A, $P = 0.9736$).

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 was 0.18% for subyearling Chinook salmon. No tags were shed during the holding period in summer.

3.4.4 Examination of Tailrace and Tailwater Release Locations on Survival

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 the 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.

The distribution of numbers and the percent of fish released at the five locations across the tailrace was uniform (middle plot in Figure 3.3), as was the distribution of releases across the tailwater release site near Knapp, Washington (bottom plot in Figure 3.3). 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.

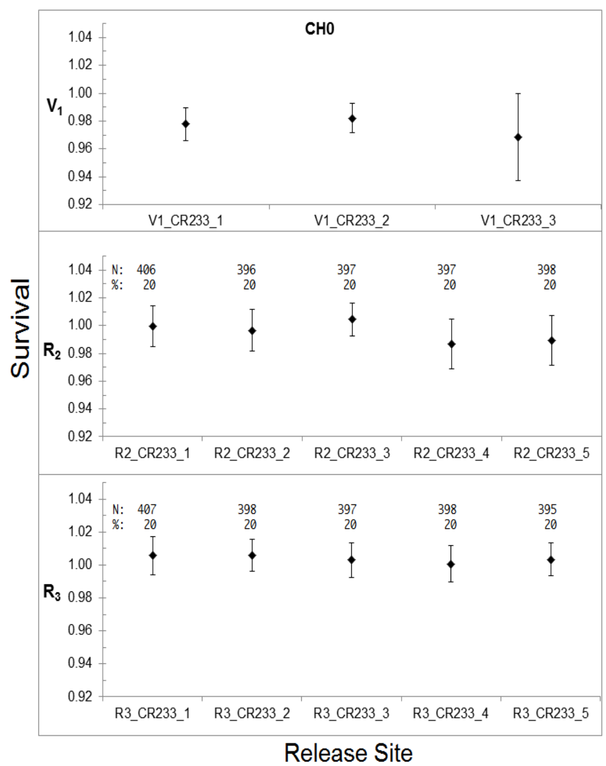


Figure 3.3. Single-release survivals for subyearling Chinook salmon released at three or five locations across the Columbia River at the tailrace and tailwater sites. The top plot shows survivals for the reach from CR233 to CR156 for three virtual releases of fish formed by regrouping dam-passed fish on the tailrace autonomous node that received the most receptions of each tag code. The middle and bottom plots show survivals for R_2 fish released in the Bonneville tailrace and R_3 fish released in the tailwater near Knapp, Washington. Vertical error bars represent the extent of the 95% confidence interval.

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

The virtual release formed from the detections of upriver releases at the face of the dam could result in biased survival estimates if fish from different upriver release locations had differential downriver survival rates. For this reason, reach survivals and cumulative survivals were compared across fish from the seven different upriver release locations. Analyses found that the R_1–R_3 releases associated with the McNary Dam survival study exhibited decreased survival compared to the R_4–R_7 releases at or below Bonneville Dam (Appendix A, Table A.5). For this reason, fish from releases R_1–R_3 were excluded in the formation of the virtual-release group (V_1) at Bonneville Dam.

3.4.6 Fish Size Distribution

Comparison of fish tagged at John Day Dam with ROR fish sampled at Bonneville Dam through the Smolt Monitoring Program shows that the length frequency distributions were not well matched for subyearling Chinook salmon (Figure 3.4). The reason was the limitation of tagging only fish ≥95 mm while the ROR fish included smaller individuals. 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 111.8 mm. Mean length for subyearling Chinook salmon sampled by the Fish Passage Center (19 June–22 July 2012) at the Bonneville Dam juvenile sampling facility was 106.9 mm. Fish size declined slightly over the course of the study (Figure 3.5).

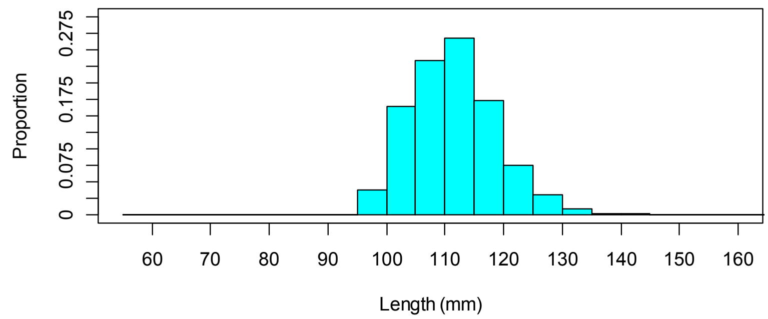
3.4.7 Tag-Life Corrections

During the 2012 summer study, two different lots of JSATS tags with different pulse rates were used in tagging the subyearling Chinook salmon. Vitality curves of Li and Anderson (2009) were fit to these two tag lots (Figure 3.6). Average tag lives were 23.3 and 15.0 d for the upstream and downstream releases, respectively.

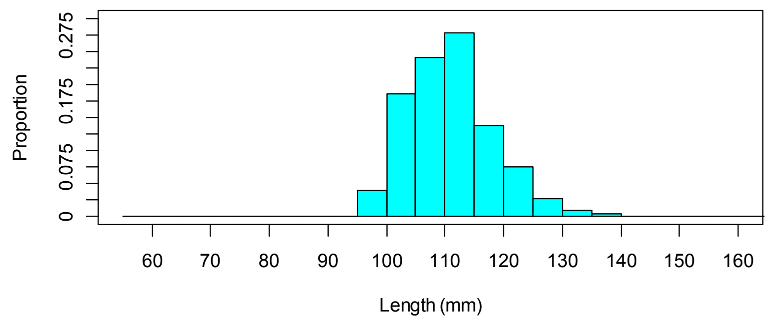
3.4.8 Arrival Distributions

The estimated probability an acoustic tag was active when fish arrived at a downstream detection array depends on the tag-life curve and the distribution of observed travel times (Figure 3.7). Examination of the fish arrival distributions to the last detection array used in the survival analyses indicated all fish that arrived had passed through the study area before tag failure became important. The probabilities that acoustic tags were active downstream were calculated by integrating the tag survivorship curve (Figure 3.7) over the observed distribution of fish arrival times (i.e., time from tag activation to arrival). The two separate tag-life survivorship models for tags used in V_1 vs. R_2 and R_3 releases were used to estimate the probabilities of tag failure and provide tag-life-adjusted estimates of smolt survival. The probabilities of a JSATS tag being active at a downstream detection site were specific to release location and tag lot (Table 3.3). In all cases, the probability a tag was active at a downstream detection site as far as rkm 86 for subyearling Chinook salmon was ≥ 0.9926.

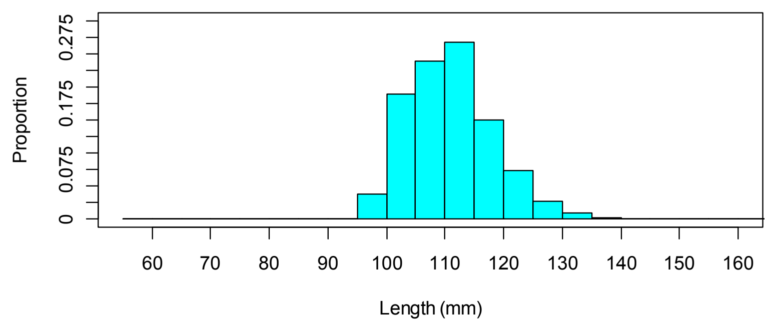
(a) Bonneville Dam (Release V_1)



(b) Bonneville Tailrace (Release R_2)



(c) Mid-Reservoir (Release R_3)



(d) ROR Subyearling Chinook at Bonneville Dam

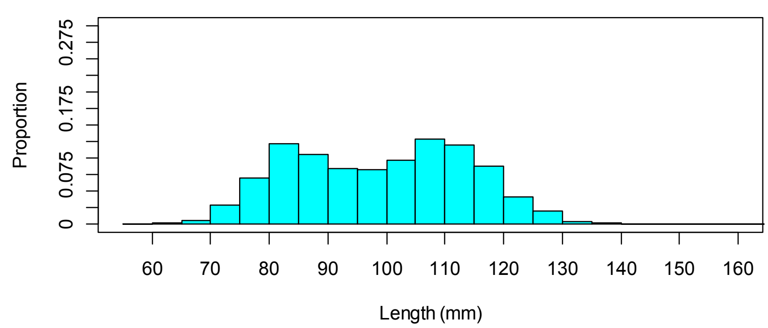


Figure 3.4. Relative frequency distributions for fish lengths (mm) of subyearling Chinook salmon used in a) Release V_1, b) Release R_2, c) Release R_3, and d) ROR fish sampled at Bonneville Dam by the Fish Passage Center (19 June–22 July 2012).

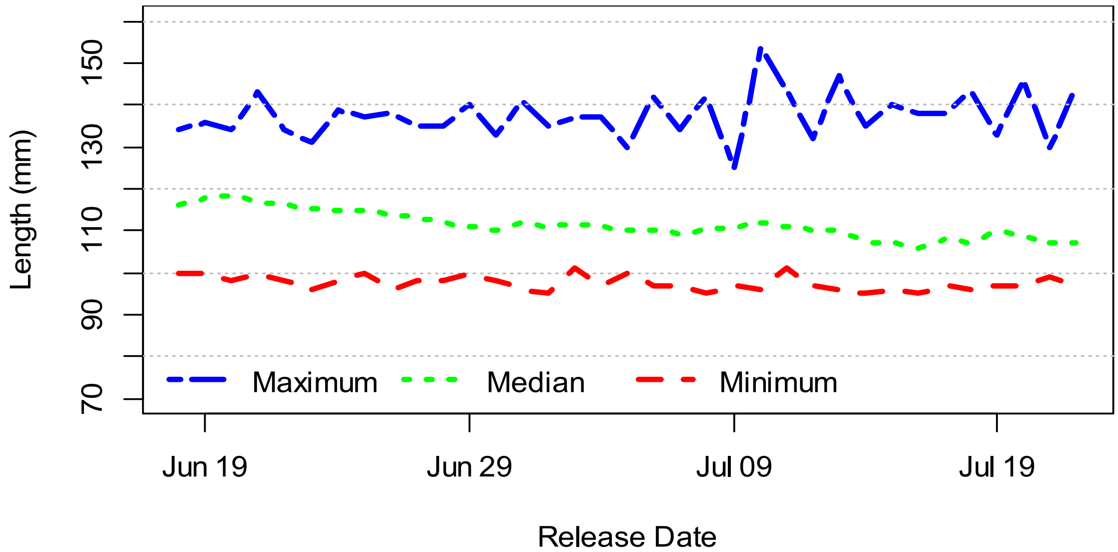
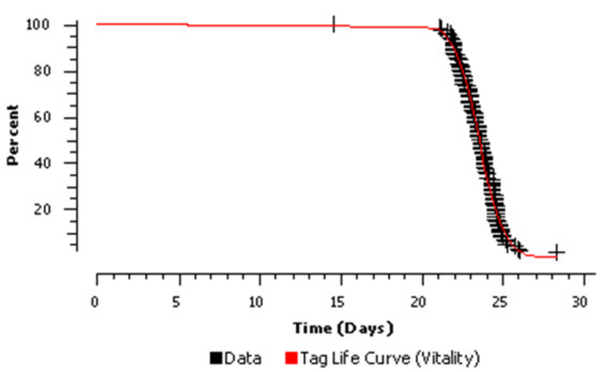


Figure 3.5. Range and median length of acoustic-tagged subyearling Chinook salmon used in the 2012 survival studies. Releases were made daily from 20 June through 22 July at six release locations: rkm 346, rkm 325, rkm 307, rkm 275, rkm 233, and rkm 161.

a. V_1 release



b. R_2 and R_3 releases

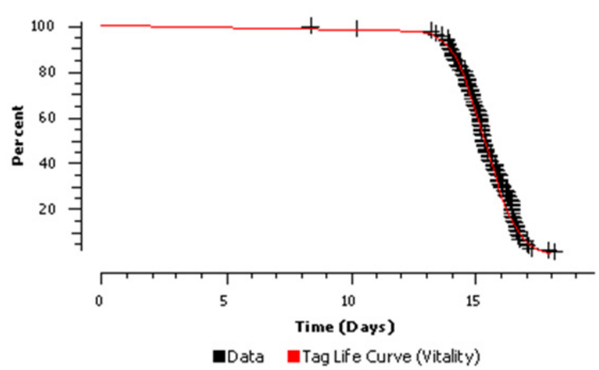


Figure 3.6. Observed time of tag failure and fitted survivorship curves using the vitality model of Li and Anderson (2009) for a) V_1 release and b) R_2 and R_3 releases used in the Bonneville Dam study.

a. V_1 release

b. R_2 and R_3 releases

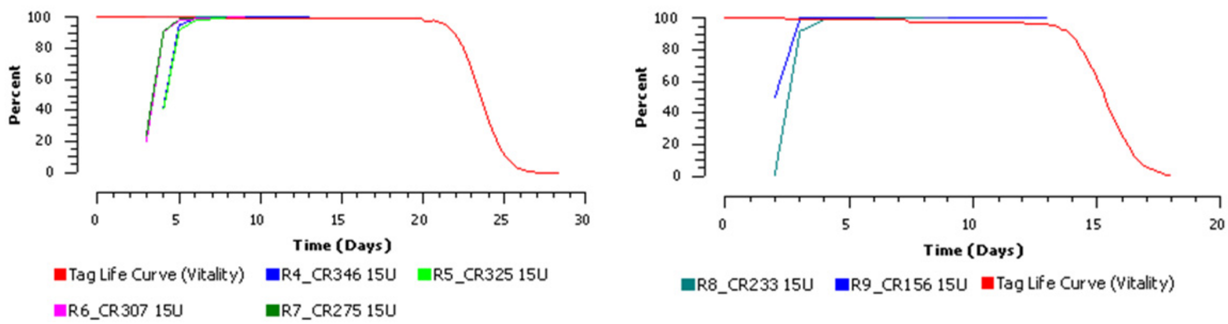


Figure 3.7. Plots of the fitted tag-life survivorship curves for tags used in a) V_1 and b) R_2 and R_3 releases and the arrival-time distributions of subyearling Chinook salmon from CR346, CR325, CR307, CR275, CR233, and CR156 at the acoustic-detection array located at rkm 86 (Figure 2.1).

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

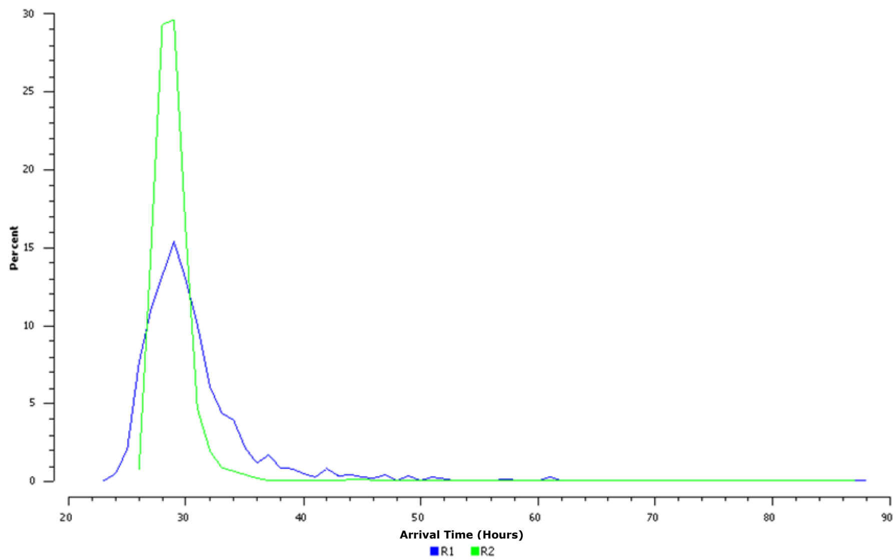
	Detection Site		
Release Group	rkm 156	rkm 113	rkm 86
V_1 (rkm 346)[(a)]	0.9994 (0.0009)	0.9991 (0.0013)	0.9988 (0.0015)
V_1 (rkm 325)[(a)]	0.9993 (0.0009)	0.9990 (0.0013)	0.9988 (0.0016)
V_1 (rkm 307)[(a)]	0.9993 (0.0009)	0.9990 (0.0013)	0.9988 (0.0016)
V_1 (rkm 275)[(a)]	0.9993 (0.0009)	0.9990 (0.0013)	0.9988 (0.0016)
R_2 (rkm 233)	--	0.9932 (0.0060)	0.9926 (0.0066)
R_3 (rkm 156)	--	0.9944 (0.0050)	0.9937 (0.0055)

(a) Releases used in the formation of the virtual release (V_1).

3.4.9 Downstream Mixing

The virtual-release from the face of Bonneville Dam was continuously formed from the smolts arriving throughout day and night. To help induce downstream mixing of the release groups, the R_2 release was 19 h before the R_3 release, based on travel times through that reach in an average year. 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. The virtual release (V_1) from the face of Bonneville Dam was continuous and, for this reason, its arrival distribution was not plotted in association with those of R_2 and R_3.

(a) rkm 113



(b) rkm 86

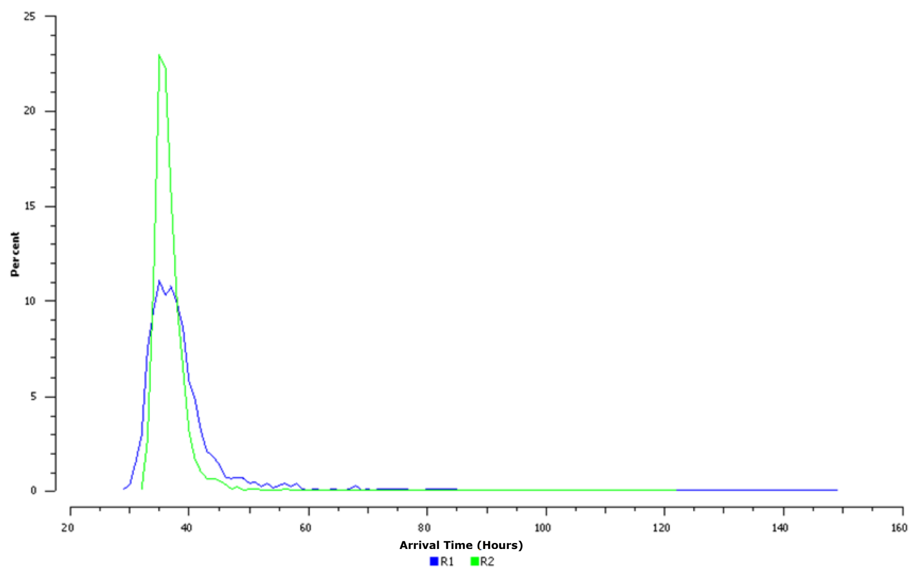


Figure 3.8. Frequency distribution plots of downstream arrival timing (expressed as percentages) for subyearling Chinook salmon releases R_2 and R_3 at detection arrays located at a) rkm 113 and b) rkm 86 (see Figure 2.1).

3.5 Survival and Passage Performance

Survival and passage performance metrics include dam passage survival, forebay-to-tailrace passage survival, forebay residence time, tailrace-to-egress time, SPE, spill+B2CC passage efficiency, and FPE.

3.5.1 Dam Passage Survival

The season-wide estimate of dam passage survival for subyearling Chinook salmon at Bonneville Dam was calculated as follows

$$\hat{S}_{\text{Dam}} = \frac{0.9693}{\left(\frac{0.9953}{1.0037}\right)} \stackrel{\text{set}}{=} \frac{0.9693}{0.9953} = 0.9739$$

with an associated standard error of $\widehat{\text{SE}} = 0.0069$ (Table 3.4). This estimate is based on setting $\hat{S}_3 = 1.0$, its maximum, which is equivalent to treating the V_1 and R_2 releases as a paired-release design. Also, note, the virtual release estimate of 0.9693 (0.0031), which estimates survival from the face of the dam to 78 km below Bonneville Dam, also meets the 2008 BiOp standard of ≥0.93.

3.5.2 Forebay-to-Tailrace Passage Survival

The estimates of forebay-to-tailrace passage survival were calculated analogously to that of dam passage survival except the virtual-release group (V_1) was composed of fish known to have arrived at the forebay array (i.e., detection array rkm 236, Figure 2.1) rather than at the dam face. The analyses used the same statistical model and approach used in estimating dam passage survival.

The estimate of forebay-to-tailrace survival of $\hat{S} = 0.9735$ ($\widehat{\text{SE}} = 0.0053$) was only slightly smaller than the estimate of dam passage survival. Standard errors were also comparable because sample sizes were nearly the same.

3.5.3 Forebay Residence Time

The forebay residence times were based on the times from the first detection at the forebay (BRZ) array to the last detection at the double array in front of Bonneville Dam. The forebay array was located 2 km upstream of the dam.

The majority of the subyearling Chinook salmon had a forebay residence time of ≤0.5 h with a mode of 0.5 h (Figure 3.9). Median residence time was 0.48 h for subyearling Chinook salmon (Table 3.5). Mean forebay residence time for subyearling Chinook salmon was estimated to be 1.13 h ($\widehat{\text{SE}} = 0.04$).

Table 3.4. Survival, detection, and λ parameters for final model used to estimate dam passage survival for subyearling Chinook salmon for summer 2012. Standard errors are in parentheses.

	$\hat{S}$			$\hat{\lambda}$
Release	Release CR234–156	CR156–113	Release–CR113	CR113–CR86
V_1	0.9693 (0.0031)	0.9951 (0.0013)	---	0.9938 (0.0014)
R_2	---	---	0.9953 (0.0063)	0.9970 (0.0014)
R_3	---	---	1.0037 (0.0050)	0.9991 (0.0009)

	$\hat{p}$	
Release	CR156	CR113
V_1	0.9106 (0.0050)	0.9656 (0.0032)
R_2	---	0.9689 (0.0039)
R_3	---	0.9698 (0.0038)

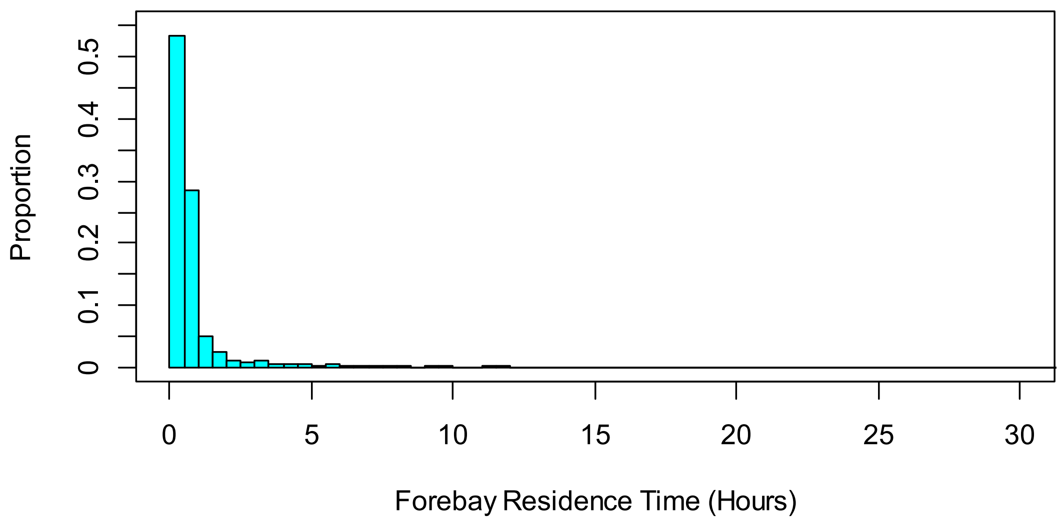


Figure 3.9. Distribution of forebay residence time for subyearling Chinook salmon at Bonneville Dam, 2012.

Table 3.5. Forebay residence (h) and tailrace egress times (h) for subyearling Chinook salmon at Bonneville Dam in 2012. Standard errors are in parentheses.

	Subyearling Chinook Salmon	
Performance Measure	Mean	Median
Forebay Residence Time	1.13 (0.04)	0.48
Tailrace Egress Time	1.31 (0.18)	0.36

3.5.4 Tailrace Egress Time

The tailrace egress time was calculated based on the time from the last detection of fish at the double array at the face of Bonneville Dam to the last detection at the BRZ tailrace array. The tailrace array was located 1 km below the dam. The majority of subyearling Chinook salmon had a tailrace regress time of ≤0.5 h (Figure 3.10). Mean tailrace egress time for subyearling Chinook salmon was estimated to be 1.31 h ($\widehat{\text{SE}}$ = 0.18). Median egress time was 0.36 h for subyearling Chinook salmon (Table 3.5).

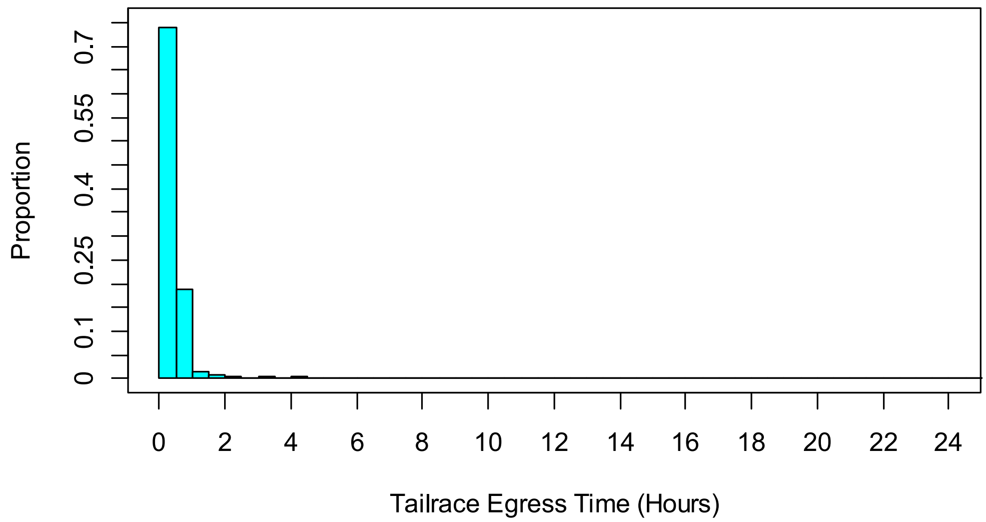


Figure 3.10. Distribution of tailrace egress times for subyearling Chinook salmon at Bonneville Dam, 2012.

3.5.5 Spill Passage Efficiency

Spill passage efficiency is defined as the fraction of the fish that passed through a hydropower project by the spillway. The double-detection array at the face of Bonneville Dam was used to identify and track fish as they entered the forebay. Using the observed counts and assuming a common detection probability at all routes, SPE was calculated using a binomial sampling model. For subyearling Chinook smolts, SPE = 0.5320 ($\widehat{\text{SE}}$ = 0.0086).

3.5.6 Spill+B2CC Passage Efficiency

The 2008 Fish Accords required an estimate of spill+B2CC passage efficiency, which the Fish Accords referred to as SPE. We calculated this metric by dividing the numbers of fish tracked passing the spillway and B2CC by the total number passing the dam, assuming a common detection probability at all routes and a multinomial sampling model. For subyearling Chinook salmon, the estimate of this proportion was 0.5706 ($\widehat{\text{SE}}$ = 0.0085).

3.5.7 Fish Passage Efficiency

Fish passage efficiency is the fraction of the fish that passed through a hydropower project by non-turbine routes (the spillway, the B1 sluiceway, the B2CC, and the B2JBS). As with SPE, the double-detection array at the face of Bonneville Dam was used to identify and track fish as they entered the dam. Using the observed counts and assuming a common detection probability at all passage routes, FPE was calculated using a multinomial sampling model. For subyearling Chinook salmon at Bonneville Dam in 2012, FPE is estimated to be FPE = 0.6985 ($\widehat{SE}$ = 0.0079).

4.0 Discussion

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

4.1 Study Conduct

The many tests of assumptions (Appendix A) found the acoustic-tag study achieved good downstream mixing with adequate tag life. Analysis of delayed handling/tag effects found releases R_1–R_3 associated with the McNary Dam survival study had depressed survivals at or below Bonneville Dam. Therefore, these release groups could not be used to contribute fish to the formation of the virtual release at Bonneville Dam. Nevertheless, the virtual-release group had a sample size of $V_1 = 3367$, which was more than adequate for the purposes of estimating dam passage survival at Bonneville Dam.

In summer 2012, a single compliance study of subyearling Chinook salmon was performed. The estimate of dam passage survival of $\hat{S}_{\text{Dam}} = 0.9739$ ($\widehat{\text{SE}} = 0.0069$) met the 2008 BiOp standard of $S_{\text{Dam}} \geq 0.93$ with adequate precision (SE $\leq$ 0.015).

4.2 Study Performance

The two spill treatments could not be formed during the summer compliance study because of high river flow. Average spill during the course of the study was 149.2 kcfs. Average percent spill was 41.9%. Therefore, season-wide survival at Bonneville Dam was calculated under prevailing flow and spill conditions.

4.3 Cross-Year Summary

In 2010, no formal compliance studies were performed at Bonneville Dam, but available equipment was used to estimate survival from the face of the dam to a hydrophone array 81 km below the dam (rkm 153) using a single release-recapture model (Ploskey et al. 2012). In essence, it was the virtual release V_1 by itself without correction for any extra-mortality between the tailrace and the downstream detection array (Table 4.1). Hence, the single-release estimates using just the virtual releases at the dam face should be conservative.

Formal compliance studies were performed at Bonneville Dam in 2011 (Skalski et al. 2012) and 2012. To date, the two estimates of dam passage survival for subyearling Chinook salmon met the 2008 BiOp standards. For the two spring stocks, compliance studies have yet to satisfy both the point estimate and precision criteria. In 2011, studies were hampered by low precision because high flow levels decreased detection probabilities. In 2010, the conservative single-release survival estimates from the virtual releases to 81 km below the dam were too low to meet the 2008 BiOp standards for spring stocks, however, both the 2008 BiOp point estimate and precision requirement were met for subyearling Chinook salmon.

Table 4.1. Summary of 2010, 2011, and 2012 estimates of dam passage survival using best available information from either a conservative single-release model or the virtual/paired-release model by fish stock at Bonneville Dam.

Year	Yearling Chinook Salmon	Steelhead	Subyearling Chinook Salmon
2010	0.952 (0.0040)[(a)]	0.945 (0.0043)[(a)]	0.958 (0.0055)[(a)]
2011	0.9597 (0.0176)	0.9647 (0.0212)	N/A
2012	N/A	N/A	0.9739 (0.0069)

(a) Single-release model using the V_1 release to estimate survival from the dam face to 81 km below the dam.

5.0 References

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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 survivals.

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 Juvenile Salmon Acoustic Telemetry System (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 α = 0.10 (i.e., 11.11%). Of the 44 tests of homogeneous cumulative survival, 2 were significant at α = 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 are 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
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
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 smolts 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 to be significant further downriver (Table A.4). Comparison of cumulative reach survivals also began to be 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). These sequential tests indicated these 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 releases 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) Est	CR503 (R1) SE	CR468 (R2) Est	CR468 (R2) SE	CR422 (R3) Est	CR422 (R3) SE	CR346 (R4) Est	CR346 (R4) SE	CR325 (R5) Est	CR325 (R5) SE	CR307 (R6) Est	CR307 (R6) 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) Est	CR503 (R1) SE	CR468 (R2) Est	CR468 (R2) SE	CR422 (R3) Est	CR422 (R3) SE	CR346 (R4) Est	CR346 (R4) SE	CR325 (R5) Est	CR325 (R5) SE	CR307 (R6) Est	CR307 (R6) SE	CR275 (R7) Est	CR275 (R7) 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) Est	CR503 (R1) SE	CR468 (R2) Est	CR468 (R2) SE	CR422 (R3) Est	CR422 (R3) SE	CR346 (R4) Est	CR346 (R4) SE	CR325 (R5) Est	CR325 (R5) SE	CR307 (R6) Est	CR307 (R6) SE	CR275 (R7) Est	CR275 (R7) SE	CR233 (R8) Est	CR233 (R8) 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

A.3 Tag-Lot Effects

During the summer 2012 study, JSATS tagged fish released upstream of Bonneville Dam had a pulse rate once every 3 s, while tag releases downstream of the dam had a pulse rate of once every 2 s. The more frequent pulse rate for downstream releases was used to increase the detection probability of these fish in the survival studies. Any tag-lot differences are therefore confounded by release locations.

Nevertheless, a comparison of reach survivals below Bonneville Dam for fish tagged with the two different pulse rates was performed. No significant difference was detected for releases R_4–R_7 vs. R_8 (Table A.6, $P = 0.9736$).

Table A.6. Comparison of reach survival (i.e., CR156–CR113) for fish tagged with tag lot 1 (CR346 through CR275) and tag lot 2 for the subyearling Chinook salmon study at Bonneville Dam in 2012.

	Lot 1								Lot 2		
	CR346 (R4)		CR325 (R5)		CR307 (R6)		CR275 (R7)		CR233 (R8)		
Reach	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	*P*-value
CR156 t0 CR113	0.9942	0.0028	0.9957	0.0025	0.9963	0.0026	0.9947	0.0029	0.9961	0.0020	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	BRZ-to-BRZ Survival
111	2834	2848
011	279	281
101	103	104
001	8	8
120	0	0
020	0	0
110	17	18
010	3	3
200	0	0
100	16	16
000	107	109
Total	3367	3387

Capture History	Season-Wide Dam Passage Survival R2	R3
11	1903	1928
01	61	60
20	0	0
10	7	3
00	23	4
Total	1994	1995

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