PNNL-22125

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Contract DE-AC05-76RL01830

Compliance Monitoring of Yearling and Subyearling Chinook Salmon and Juvenile Steelhead Survival and Passage at McNary Dam, 2012

DRAFT COMPLIANCE REPORT

JR Skalski
RL Townsend
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CM Woodley
Z Deng
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January 2013

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Pacific Northwest National Laboratory
Richland, Washington 99352

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[1] University of Washington, Seattle, Washington.

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 (USACE). The PNNL and UW project managers were Drs. Thomas J. Carlson and John R. Skalski, respectively. The USACE technical lead was Mr. Brad Eppard. The study was designed to estimate dam passage survival at McNary Dam as stipulated by the 2008 Federal Columbia River Power System (FCRPS) Biological Opinion (BiOp) and provide additional performance measures as specified in the Columbia Basin Fish Accords.

This report summarizes the results of the compliance studies of yearling and subyearling Chinook salmon and steelhead at McNary Dam in 2012.

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Executive Summary

The purpose of this compliance study was to estimate dam passage survival of yearling and subyearling Chinook salmon and juvenile steelhead at McNary Dam during spring and summer 2012. Under the 2008 Federal Columbia River Power System (FCRPS) Biological Opinion (BiOp), dam passage survival should be greater than or equal to 0.96 for spring migrants and greater than or equal to 0.93 for summer, estimated with a standard error (SE) less than or equal to 0.015. The study also estimated juvenile salmonid passage survival from the forebay 2 km upstream of the dam and through the tailrace to 2 km downstream of the dam,[1] as well as the forebay residence time, tailrace egress time, spill passage efficiency (SPE), and fish passage efficiency (FPE), as required in the Columbia Basin Fish Accords (Fish Accords).

A virtual/paired-release design was used to estimate dam passage survival at McNary Dam. The approach included releases of acoustic-tagged juvenile salmonids above McNary Dam that contributed to the formation of a virtual release at the face of McNary Dam. A survival estimate from this release was adjusted by a paired release below McNary Dam. A total of 1360 yearling Chinook salmon, 1297 steelhead, and 2459 subyearling Chinook salmon were used in the virtual releases. Sample sizes for the below-dam paired releases were 1198 and 1200 for yearling Chinook salmon, 1199 and 1198 for juvenile steelhead, and 1993 and 1984 for subyearling Chinook salmon for the R_2 and R_3 released fish, respectively. The Juvenile Salmon Acoustic Telemetry System (JSATS) tags were manufactured by Advanced Telemetry Systems. Model SS300 tags, weighing 0.304 g in air, were surgically implanted in yearling and subyearling Chinook salmon, and Model SS130 tags, weighing 0.438 g in air, were surgically implanted in juvenile steelhead.

The 2012 Fish Passage Plan called for 40% spill in spring and 50% spill in summer, but those targets could not be maintained because of exceptionally high flow conditions. Dam passage survival was estimated seasonally regardless of spill conditions.

The study results are summarized in the following tables.

Table ES.1. Estimates of dam passage survival[(a)] at McNary Dam in 2012.

Spill Operations	Yearling Chinook Salmon	Steelhead	Subyearling Chinook Salmon
Season-wide spring	0.9616 (0.0140)	0.9908 (0.0183)	NA
Season-wide summer	NA	NA	0.9747 (0.0114)

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

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

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

Performance Measures	Yearling Chinook Salmon	Steelhead	Subyearling Chinook Salmon
Forebay-to-tailrace survival (season-wide)	0.9595 (0.0140)	0.9880 (0.0183)	0.9729 (0.0114)
Forebay residence time (mean/median)	3.01 (0.30)/1.76 h	2.67 (0.08)/1.78 h	2.86 (0.13)/1.77 h
Tailrace egress rate (mean/median)	2.87 (0.33)/0.41 h	1.85 (0.37)/0.34 h	3.01 (0.29)/0.38 h
Spill passage efficiency[(a)]	0.7246 (0.0121)	0.8315 (0.0104)	0.7832 (0.0083)
Fish passage efficiency	0.9676 (0.0048)	0.9768 (0.0042)	0.9089 (0.0058)

(a) The estimate of SPE includes the fraction of fish going through the temporary spill weir (TSW) and non-TSW spill bays.

Table ES.3. Survival study summary.

Year: 2012				
Study Site(s): McNary Dam				
Objective(s) of study: Estimate dam passage survival and other performance measures for yearling Chinook salmon, steelhead, and subyearling Chinook salmon.				
Hypothesis (if applicable): Not applicable; this is a compliance study.				
Fish: Species-race: yearling Chinook salmon (CH1), steelhead (STH), subyearling Chinook salmon (CH0) Source: John Day Dam Smolt Monitoring Facility		Implant Procedure: Surgical: Yes Injected: No		
Size (median): CH1 / STH / CH0 Weight (g): 28.2 / 75.6 / 14.4 Length (mm): 144 / 207 / 113		Sample Size: CH1 / STH / CH0 # Release Sites: 3 / 3 / 3 Total # Released: 3797 / 3797 / 6501		
Tag Type: Advanced Telemetry Systems (ATS)-156dB Model / Weight (air) CH1/CH0: SS300 / 0.304 g STH: SS130 / 0.438 g	Analytical Model: Virtual/paired-release model	Characteristics of Estimate: Effects Reflected (direct, total, etc.): Direct Absolute or Relative: Absolute		
Environmental/Operating Conditions (daily from 27 April 2012 through 30 May 2012): Discharge (kcfs): mean 354.1, minimum 295.0, maximum 398.8 Temperature (°C): mean 11.7, minimum 9.6, maximum 13.4 Total Dissolved Gas (tailrace): mean 119.5%, minimum 116.0%, maximum 122.3% Treatment(s): None Unique Study Characteristics: None				
Environmental/Operating Conditions (daily from 14 June 2012 through 16 July 2012): Discharge (kcfs): mean 355.6, minimum 308.3, maximum 414.4 Temperature (°C): mean 15.7, minimum 14.0, maximum 17.8 Total Dissolved Gas (tailrace): mean 121.8%, minimum 119.6%, maximum 126.0% Treatment(s): None Unique Study Characteristics: None				

Survival and Passage Estimates (value & SE):	CH1	STH	CH0
Dam survival			
• Spring, season-wide	0.9616 (0. 0140)	0.9908 (0.0183)	NA
• Summer, season-wide	NA	NA	0.9747 (0.0114)
Forebay-to-tailrace survival (season-wide)	0.9595 (0.0140)	0.9880 (0.0183)	0.9729 (0.0114)
Forebay residence time (median)	3.01 (0.30)/1.76 h	2.67 (0.08)/1.78 h	2.86 (0.13)/1.77 h
Tailrace egress rate (median)	2.87 (0.33)/0.41 h	1.85 (0.37)/0.34 h	3.01 (0.29)/0.38 h
Spill passage efficiency	0.7246 (0.0121)	0.8315 (0.0104)	0.7832 (0.0083)
Fish passage efficiency	0.9676 (0.0048)	0.9768 (0.0042)	0.9089 (0.0058)

Compliance Results: Estimates of dam passage survival met compliance requirements for CH1 and CH0 for both point estimates and standard errors. The point estimate for STH met compliance requirements and was significantly higher than benchmark at $P = 0.0462$.

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 (USACE), 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
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- UW: J Lady and P Westhagen

Acronyms and Abbreviations

°C	degree(s) Celsius
3D	three-dimensional
ATS	Advanced Telemetry Systems
BiOp	biological opinion
BRZ	boat-restricted zone
CH0	subyearling Chinook salmon
CH1	yearling Chinook salmon
FCRPS	Federal Columbia River Power System
FPC	Fish Passage Center
FPE	fish passage efficiency
g	gram(s)
h	hours(s)
JBS	juvenile bypass system
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
PSMFC	Pacific States Marine Fisheries Commission
rkm	river kilometer(s)
RME	research, monitoring, and evaluation
ROR	run-of-river
RPA	reasonable and prudent alternative
s	second(s)
SE	standard error
SPE	spill passage efficiency
STH	steelhead
USACE	U.S. Army Corps of Engineers
UW	University of Washington

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1.0 Introduction

The compliance monitoring studies reported herein were conducted by researchers at the Pacific Northwest National Laboratory (PNNL) and the University of Washington for the U.S. Army Corps of Engineers, Portland District (USACE) in spring and summer 2012. The purpose of these studies was to estimate dam passage survival at McNary Dam as stipulated by the 2008 Federal Columbia River Power System (FCRPS) Biological Opinion (BiOp; NMFS 2008) and provide additional performance measures at the dam as stipulated in the Columbia Basin Fish Accords for yearling and subyearling Chinook salmon and steelhead (3 Treaty Tribes-Action Agencies 2008).

1.1 Background

The FCRPS 2008 BiOp 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 estimates, as follows (after the RME Strategy 2 of the RPA):

> <u>Juvenile Dam Passage Performance Standards</u> – The Action Agencies juvenile performance standards are an average across Snake River and lower Columbia River dams of 96% average dam passage survival for spring Chinook 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):

> <u>Dam Survival Performance Standard</u> – Meet the 96% dam passage survival standard for yearling Chinook and steelhead and the 93% standard for subyearling Chinook. Achievement of the standard is based on 2 years of empirical survival data . . . .

> <u>Spill Passage Efficiency and Delay Metrics</u> − Spill passage efficiency (SPE) and delay metrics under current spill conditions . . . are not expected to be degraded ("no backsliding") with installation of new fish passage facilities at the dams . . . .

> <u>Future RME</u> − The Action Agencies' dam survival studies for purposes of determining juvenile dam passage performance will also collect information about SPE, BRZ-to-BRZ (boat-restricted zone) survival and delay, as well as other distribution and survival information. SPE and delay metrics will be considered in the performance check-ins or with Configuration and Operations Plan updates, but not as principal or priority metrics over dam survival performance standards. Once a dam meets the survival performance standard, SPE and delay metrics may be monitored coincidentally with dam survival testing.

This report summarizes the results of the 2012 acoustic telemetry studies of yearling and subyearling Chinook salmon and steelhead at McNary 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 2012 compliance monitoring at McNary Dam was to estimate performance measures for yearling and subyearling Chinook salmon and juvenile steelhead as outlined in the FCRPS BiOp and Fish Accords. For each fish stock, the following metrics were estimated using the Juvenile Salmon Acoustic Telemetry System (JSATS) technology:

- Dam passage survival, defined as survival from the upstream face of the dam to a standardized reference point in the tailrace. Performance[1] should be ≥96% survival for spring stocks (i.e., yearling Chinook salmon and steelhead) and ≥93% survival for summer stocks (i.e., subyearling Chinook salmon). Survival should be estimated with a standard error (SE) ≤1.5%.
- Forebay-to-tailrace survival, defined as survival from a forebay array 2 km upstream of the dam to a tailrace array 2 km downstream. The forebay-to-tailrace survival estimate satisfies the "BRZ-to-BRZ" survival estimated called for in the Fish Accords.
- Forebay residence time, defined as the time from first detection on the forebay entrance array, 2 km upstream of the dam, to the time of last detection on the dam-face array.
- Tailrace egress time, defined as the average travel time from last detection on the dam-face array to the last detection on the tailrace array 3 km downstream of the dam.
- Spill passage efficiency, defined as the fraction of fish going through the dam via the spillway.
- Fish passage efficiency (FPE), defined as the fraction of fish going through the dam via non-turbine routes.
- The high river flow conditions during 2012 prevented dam operators from meeting the specific spill targets for spring (40% spill) and summer seasons (50% spill), so survival results are season-wide regardless of prevailing spill levels during each season.

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

1.3 Report Contents and Organization

The ensuing sections of this report present the study methods, results, and related discussion. The final section of the report lists references cited in the main text. The appendixes contain supplemental information about the tests of assumptions and capture-history data used in estimating dam passage survival rates.

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

2.0 Methods

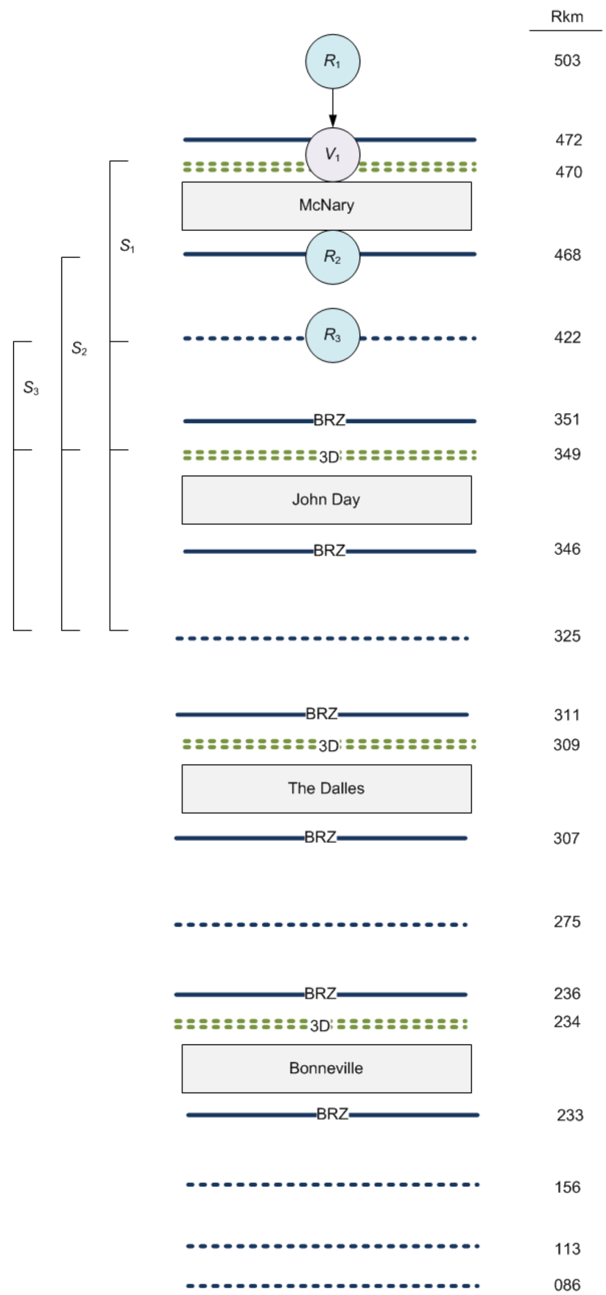
Study methods involved fish release and recapture; the associated fish handling, tagging, and release procedures; acoustic signal processing; and statistical and analytical approaches.

2.1 Release-Recapture Design

The release-recapture design used to estimate dam passage survival at McNary 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 were released above McNary Dam to supply a source of fish known to have arrived alive at the face of the dam. By releasing the fish far enough upstream, the fish should have arrived at the dam in a spatial pattern typical of run-of-river (ROR) fish. This virtual-release group was then used to estimate survival through the dam and part of the way through the next reservoir (i.e., river kilometer [rkm] 422) (Figure 2.1). To account and adjust for this extra reach mortality, a paired release below McNary Dam (i.e., R_2 and R_3) (Figure 2.1) was used to estimate survival in that segment of the reservoir below the dam. Dam passage survival was then estimated as the quotient of the survival estimates for the virtual release to that of the paired release. The sizes of the releases of the fish tagged with acoustic micro-transmitters 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 472). 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 the location of the last detection (i.e., the passage route). These passage-route data were used to calculate SPE and FPE at McNary Dam. The fish used in the virtual release at the face of the dam were also used to estimate tailrace egress time.

Two distinct manufacturing tag lots were used during the spring 2012 JSATS study, one for each fish stock, and another tag lot was used for the summer 2012 study. A total of 98 tags for yearling Chinook salmon, 100 for steelhead, and 99 tags for subyearling Chinook salmon were randomly sampled for the tag-life assessments. 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).



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

Figure 2.1. Schematic of the virtual/paired-release design used to estimate dam passage survival at McNary Dam. The virtual release (V_1) was composed of fish that arrived at the dam face from releases at rkm 503. 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-tagged fish releases used in the yearling and subyearling Chinook salmon and steelhead survival studies at McNary Dam in 2012.

Release Location	Yearling Chinook Salmon	Steelhead	Subyearling Chinook Salmon
Above McNary Dam (R_1)	1399	1400	2524
Virtual Release–McNary Dam (V_1)	1360	1297	2459
McNary Dam Tailrace (R_2)	1198	1199	1993
Crow Butte, WA (R_3)	1200	1198	1984

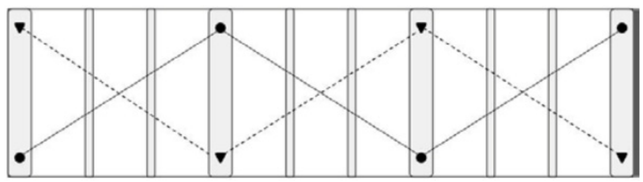


Figure 2.2. Front view schematic of hydrophone deployments at three turbines showing the double-detection arrays. The circles denote the hydrophones of Array 1 and the triangles denote the hydrophones of Array 2.

2.2 Handling, Tagging, and Release Procedures

Fish obtained from the John Day Dam juvenile bypass system (JBS) were surgically implanted with both JSATS and PIT tags and transported to three different release locations, as described in the following sections.

2.2.1 Acoustic Tags

The acoustic tags used in the 2012 studies were manufactured by Advanced Telemetry Systems (ATS). Yearling and subyearling Chinook salmon were tagged with ATS model SS300 acoustic tags that were 10.7 mm long, 5.21 mm wide, 3.03 mm thick, and weighed 0.304 g in air. These tags had a nominal transmission rate of 1 pulse every 3 s and nominal tag life was expected to be about 25 d. The ATS tag model SS130, used for juvenile steelhead; was 11.9 mm long, 5.1 mm wide, 3.7 mm thick, and weighed 0.438 g in air. This tag had a nominal transmission rate of 1 pulse every 3 s and nominal tag life was expected to be 33 d.

2.2.2 Fish Source

The yearling and subyearling Chinook salmon and steelhead used in the studies were all obtained from the John Day Dam JBS. The Pacific States Marine Fisheries Commission diverted fish from the JBS into an examination trough, as described by Martinson et al. (2006). Fish ≥95 and <300 mm in length without malformations or excessive descaling (>20%) were selected for tagging.

2.2.3 Tagging Procedure

The fish to be tagged were anesthetized in an 18.9-L "knockdown" bucket that contained fresh river water and MS-222 (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 passive integrated transponder (PIT) tag was inserted followed by an acoustic tag. Both tags were inserted toward the anterior end of the fish. The incision was closed using a 5-0 Monocryl suture.

After closing the incision, the fish were placed in a dark 18.9-L transport bucket filled with aerated river water. Fish were held in these buckets for 12 to 36 h before being 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 the release locations (Figure 2.1). Transportation routes were adjusted to provide equal travel times to each release location from John Day Dam. Upon arriving at a release site, fish buckets were transferred to a boat for transport to the in-river release location. There were five release locations at each release site across the river (Figure 2.1), and equal numbers of buckets of fish were released at each of the five locations.

Releases occurred for 34 consecutive days, 32 d per release site, in spring (from 27 April to 30 May 2012) and another 34 consecutive days in summer (from 13 June to 16 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 acoustic-tagged fish to accommodate downstream mixing. The virtual release occurred continuously from upstream release sites. Releases were timed to accommodate the approximately 24-h travel time between R_1 and R_2 and 32-h travel time between R_2 and R_3.

	Relative Release Times	
Release Location	Daytime Start	Nighttime Start
R_1 (rkm 503)	Day 2: 1000	Day 1: 2200
R_2 (rkm 468)	Day 3: 1000	Day 2: 2200
R_3 (rkm 422)	Day 4: 1800	Day 4: 0600

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 were received with an appropriate time interval between the leading edges of successive messages.

The receptions of JSATS tag codes within raw data files from autonomous nodes were also processed to produce a data set of accepted tag-detection events, or events for short. A single file was processed at a time, and no information about receptions at other nodes was used. The Multipath and PRI filters described above were used.

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 position relative to hydrophone locations.

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

Three-dimensional (3D) tracking of JSATS-tagged fish in the immediate forebay of McNary Dam was used to determine routes of passage to estimate SPE and FPE. Acoustic tracking is a common technique in bioacoustics based on time-of-arrival differences among different hydrophones. Usually, the process requires a three-hydrophone array for two-dimensional tracking and a four-hydrophone array for 3D tracking. For this study, only 3D tracking was performed. The methods were similar to those described by Weiland et al. (2009, 2011, 2013).

2.4 Statistical Methods

Statistical methods were used to test assumptions and estimate passage survival, tag life, forebay-to-tailrace survival, travel times, SPE, and FPE, as described below.

2.4.1 Estimation of Dam Passage Survival

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

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 (SE ≤ 0.015) with the fully parameterized model, no further modeling was performed. If initial precision was inadequate, then likelihood ratio tests were used to assess the homogeneity of parameters across release groups to identify the best parsimonious model to describe the capture-history data. This approach was used to help preserve both precision and robustness of the survival results. All calculations were performed using Program ATLAS (http://www.cbr.washington.edu/paramest/atlas/).

Dam passage survival was estimated by the function

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

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

2.4.2 Tag-Life Analysis

For each tag lot of JSATS tags, 98, 100, and 99 acoustic tags were systematically sampled over the course of the yearling Chinook salmon, juvenile steelhead, and subyearling Chinook salmon tagging studies, respectively. The tags were continuously monitored from activation to failure in ambient river water. For the yearling Chinook salmon and subyearling Chinook salmon tag-life studies, the failure times were fit to the four-parameter vitality model of Li and Anderson (2009). The vitality model tends to fit acoustic-tag failure times well because it allows for both early onset of random failure due to manufacturing as well as systematic battery failure later on.

The survivorship function for the vitality model can be rewritten as

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

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

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

For the steelhead tag-life study, the failure times were fit to the three-parameter Weibull distribution. The reason was there were no observed early tag failures prior to battery failure that would cause the shoulder of the tag-life curve to drop. The three-parameter Weibull distribution (Elandt-Johnson and Johnson 1980:62) with scale (λ), shape (β), and shift (γ) parameters has a probability density function of

$$f(t) = \frac{\beta}{\lambda} \left(\frac{t-\gamma}{\lambda} \right)^{\beta-1} e^{-\left(\frac{t-\gamma}{\lambda} \right)^{\beta}},$$

with survivorship function

$$S(t) = e^{-\left(\frac{t-\gamma}{\lambda} \right)^{\beta}},$$

cumulative density function

$$F(t) = 1 - e^{-\left(\frac{t-\gamma}{\lambda} \right)^{\beta}},$$

and hazard function

$$h(t) = \frac{\beta}{\lambda}\left(\frac{t-\gamma}{\lambda}\right)^{\beta-1}.$$

The three-parameter Weibull reduces to the two-parameter Weibull when $\gamma = 0$; it reduces to the exponential distribution when $\beta = 1$ and $\gamma = 0$.

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 470, 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 probablility that the tag is active when detected at the V_1 detection array (rkm 470), and $S(t_1)$ is the average unconditional probability that the tag is active when detected at the first downstram survival detection array (rkm 422).

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 JBS. However, acoustic-tag studies do not use physical recaptures to detect fish. Consequently, these tests have little or no relevance to acoustic-tag studies. Furthermore, the very high detection probabilities present in acoustic-tag studies frequently preclude calculation of these tests. For these reasons, these tests were not performed.

2.4.3.2 Tests of Mixing

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

2.4.3.3 Tagger Effects

Subtle differences in handling and tagging techniques can have an effect on the survival of juvenile salmonids 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

Delayed handling or tag effects were not a concern with fish tagged for the spring and summer studies at MCN as travel times from release through the study area were short.

2.4.3.5 Tag-Lot Effects

Because only one tag lot was used per survival analysis, examination of tag-lot effects was unnecessary.

2.4.4 Forebay-to-Tailrace Survival

The same virtual/paired-release methods used to estimate dam passage were also used to estimate forebay-to-tailrace survival. The only distinction was the virtual-release group (V_1) was composed of fish known to have arrived alive at the forebay array (rkm 472) of McNary Dam instead of at the dam face (Figure 2.1).

2.4.5 Estimation of Travel Times

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

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

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

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

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

The estimated tailrace egress time was based on the time from the last detection of a fish at the double array at the dam face at McNary Dam to the last detection at the tailrace array 2 km downstream of the dam (rkm 468). The estimated forebay residence times were based on the time from the first detection at the forebay BRZ array 2 km above the dam to the last detection at the double array on the upstream face of McNary Dam.

2.4.6 Estimation of Spill Passage Efficiency

Spill passage efficiency was estimated by the fraction

$$\widehat{\text{SPE}} = \frac{\hat{N}_{NTSW} + \hat{N}_{TSW}}{\hat{N}_{NTSW} + \hat{N}_{TSW} + \hat{N}_{TUR} + \hat{N}_{JBS}}, \tag{2.9}$$

where $\hat{N}_i$ is the estimated abundance of acoustic-tagged fish through the *i*th route (*i* = non-TSW [NTSW], temporary spill weir [TSW], turbines [TUR], and juvenile bypass system [JBS]). The double-detection array was used to estimate absolute abundance (*N*) through a route using the single mark-recapture model (Seber 1982:60) independently at each route. Calculating the variance in stages, the variance of $\widehat{\text{SPE}}$ was estimated as

$$\text{Var}\left(\widehat{\text{SPE}}\right) = \frac{\widehat{\text{SPE}}\left(1-\widehat{\text{SPE}}\right)}{\sum_{i=1}^{4}\hat{N}_i} + \widehat{\text{SPE}}^2\left(1-\widehat{\text{SPE}}\right)^2 \cdot \left[\frac{\text{Var}\left(\hat{N}_{NTSW}\right)+\text{Var}\left(\hat{N}_{TSW}\right)}{\left(\hat{N}_{NTSW}+\hat{N}_{TSW}\right)^2} + \frac{\widehat{\text{Var}}\left(\hat{N}_{TUR}\right)+\text{Var}\left(\hat{N}_{JBS}\right)}{\left(\hat{N}_{TUR}+\hat{N}_{JBS}\right)^2}\right]. \tag{2.10}$$

2.4.7 Estimation of Fish Passage Efficiency

Fish passage efficiency was estimated by the fraction

$$\widehat{\mathrm{FPE}} = \frac{\hat{N}_{NTSW} + \hat{N}_{TSW} + \hat{N}_{JBS}}{\hat{N}_{NTSW} + \hat{N}_{TSW} + \hat{N}_{JBS} + \hat{N}_{TUR}}, \tag{2.11}$$

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

$$\mathrm{Var}\left(\widehat{\mathrm{FPE}}\right) = \frac{\widehat{\mathrm{FPE}}\left(1-\widehat{\mathrm{FPE}}\right)}{\sum_{i=1}^{4}\hat{N}_i} + \widehat{\mathrm{FPE}}^2\left(1-\widehat{\mathrm{FPE}}\right)^2 \cdot \left[\frac{\mathrm{Var}\left(\hat{N}_{NTSW}\right) + \mathrm{Var}\left(\hat{N}_{TSW}\right) + \mathrm{Var}\left(\hat{N}_{JBS}\right)}{\left(\hat{N}_{NTSW} + \hat{N}_{TSW} + \hat{N}_{JBS}\right)^2} + \frac{\widehat{\mathrm{Var}}\left(\hat{N}_{TUR}\right)}{\hat{N}_{TUR}^2}\right]. \tag{2.12}$$

3.0 Results

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

3.1 Fish Collection, Rejection, and Tagging

The total number of fish handled by PNNL in spring and summer 2012 and the counts and percentages of fish by handling category are listed in Table 3.1. During the study, 29,645 yearling and subyearling Chinook salmon and juvenile steelhead were handled.

Table 3.1. Total number of fish handled by PNNL during the spring and summer of 2012 and counts of fish in several handling categories.

Handling Category	CH1	%CH1	STH	%STH	CH0	%CH0
Retained for Tagging	6555	96.3	6515	93.0	15,328	96.8
Non-Candidate based on Condition	253	3.7	494	7.0	500	3.2
Total Handled	**6808**		**7009**		**15,828**	

CH1 = yearling Chinook salmon, STH = juvenile steelhead, CH0 = subyearling Chinook salmon.

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 National Oceanic and Atmospheric Administration in meetings during spring 2012 (B Eppard, personal communication, April 20, 2012). PNNL broadened the criteria to accept more fish. Fish were not accepted for the project if they were moribund, or showed 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 was 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 yearling and subyearling Chinook salmon and juvenile steelhead handled by PNNL during spring and summer of 2012.

	CH1	% CH1	STH	% STH	CH0	% CH0	**Total**
Descaling >20%	65	25.7	139	28.1	139	27.8	**343**
Caudal Fin Missing	8	3.2	1	0.2	8	1.6	**17**
Diseases	107	42.3	274	55.5	197	39.4	**43**
Damage/Injury	88	34.8	141	28.5	213	42.6	**442**
Skeletal Deformity	16	6.3	21	4.3	6	1.2	**578**
Total Fish[(a)]	**253**		**494**		**500**		**1247**

(a) Each species averaged >1 malady per fish; 11.5% for CH1, 15.9% for STH, and 10.8% for CH0 of fish for each species had more than one malady.

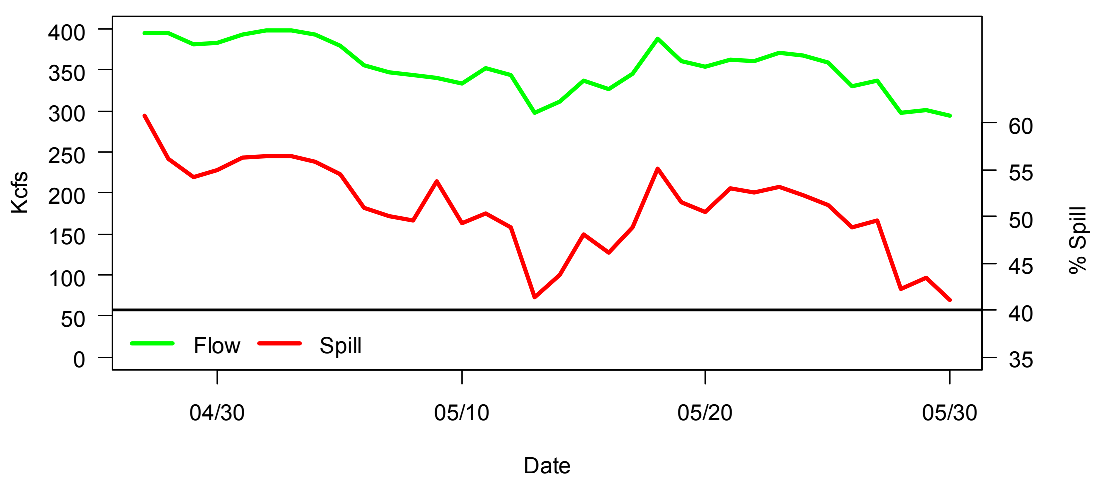
CH1 = yearling Chinook salmon, STH = juvenile steelhead, CH0 = subyearling Chinook salmon.

3.2 Discharge and Spill Conditions

From the onset of the spring study on 27 April 2012 through 30 May 2012, the percent spill at McNary Dam exceeded the 40% target. For the majority of the time, the percent spill also exceeded 40% ± 5% of the spill target (Figure 3.1a). For this reason, no attempt was made to identify and isolate the few days where spill was 35–45% and separately estimate dam passage survival for that period. Instead, dam passage survival was estimated season-wide during spring regardless of spill level.

During the summer survival study, spill levels exceeded the 50% target throughout the investigation. For most of the study period, spill levels also exceeded 50% ± 5%. For this reason, survival was estimated season-wide under prevailing conditions with no attempt to identify short periods of target conditions (Figure 3.1b).

a. Spring



b. Summer

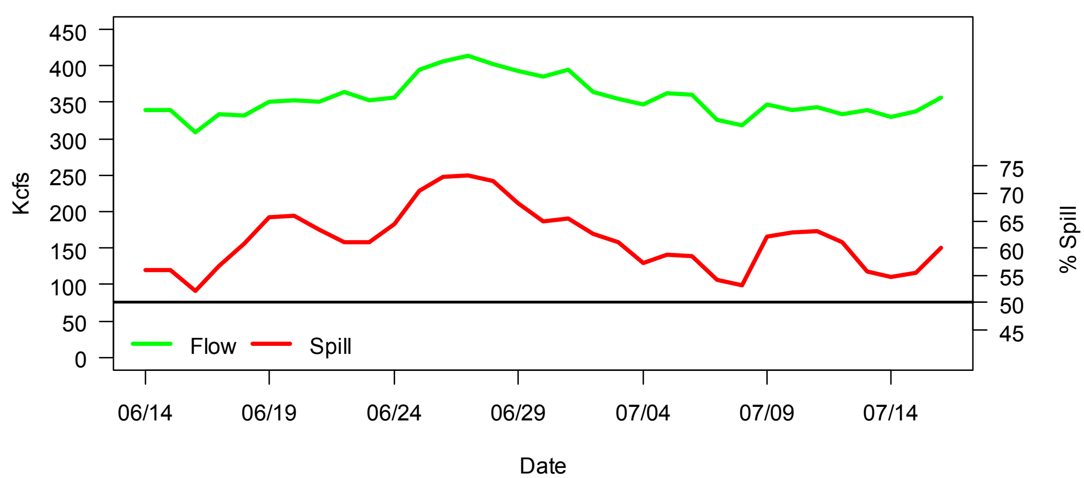
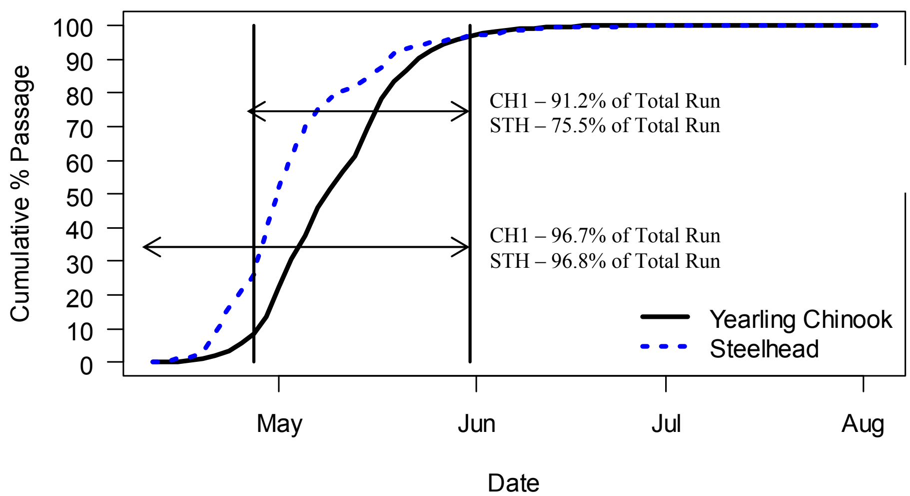


Figure 3.1. Daily average total discharge and percent spill at McNary Dam during the a) spring and b) summer JSATS survival studies in 2012.

3.3 Run Timing

The cumulative percentage of yearling Chinook salmon, juvenile steelhead, and subyearling Chinook salmon that had passed McNary Dam by date was calculated from smolt index data obtained from the Fish Passage Center (FPC; Figure 3.2). From 27 April, when the first fish in spring were released, through the end of the spring study on 30 May 2012, 91.2% of the yearling Chinook salmon and 75.5% of juvenile steelhead had passed McNary Dam. By the end of the study on 30 May 2012, 96.7% of yearling Chinook salmon run and 96.8% of juvenile steelhead run had passed McNary Dam. From 14 June, when the first fish in summer were released, through 16 July 2012, 48.7% of subyearling Chinook salmon had passed McNary Dam. By the end of the study on 16 July 2012, 53.9% of subyearling Chinook salmon run had passed McNary Dam.

a. Spring



b. Summer

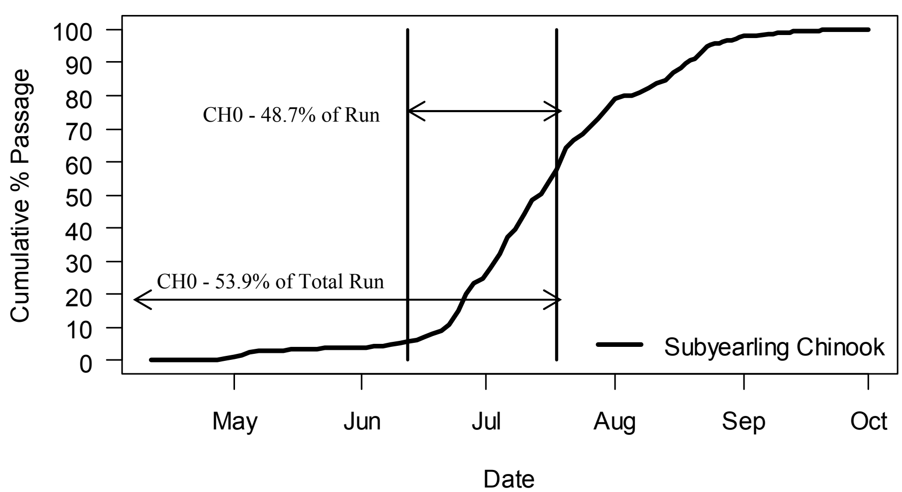


Figure 3.2. Plots of the cumulative percent of a) yearling Chinook salmon (CH1) and steelhead (STH) and b) subyearling Chinook salmon (CH0) that had passed McNary Dam in 2012 based on Fish Passage Center smolt indices. Vertical lines mark the beginning and end of the survival studies.

3.4 Assessment of Assumptions

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

3.4.1 Examination of Tagger Effects

A total of eight different taggers assisted in tagging all yearling and subyearling Chinook salmon and juvenile steelhead associated with the JSATS survival studies at McNary Dam in 2012. During the spring and summer studies, tagger effort was found to be homogeneously distributed 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

Because only one tag lot was used for each species in the spring study and one tag lot for the summer study in 2012, it was not possible to test for tag-lot effects.

3.4.3 Handling Mortality and Tag Shedding

Fish were held for 12 to 36 h prior to release. The post-tagging mortality in spring was 0.27% and 0.02% for yearling Chinook salmon and steelhead, respectively. One PIT tag was shed during the post-tagging holding period in spring. In summer, post-tagging mortality was 0.18% for subyearling Chinook salmon and no tags were shed.

3.4.4 Effects of Tailrace and Tailwater Release Locations on Survival

The survival rates for yearling Chinook salmon, steelhead, and subyearling Chinook salmon released at three or five adjacent sites across the tailrace and tailwater did not appear to differ significantly based upon overlap of 95% confidence intervals (Figure 3.3, Figure 3.4, and Figure 3.5, respectively). The topmost plot in each of the figures shows survival rates for dam-passed fish regrouped on tailrace autonomous nodes to form three virtual releases across the tailrace. We did not specify the number of fish regrouped on each autonomous node because that distribution can be highly biased by differences in tag detectability, which is inversely related to linear water velocity where each node was deployed. The distribution of numbers of fish released across the tailrace was uniform (see numbers and percentages in middle plots in Figure 3.3, Figure 3.4, and Figure 3.5). The distribution of numbers of fish released at four out of five sites (Sites 2–5) across the tailwater near Crow Butte State Park (CR422) also was uniform (see numbers and percentages in the bottom plots in Figure 3.3, Figure 3.4, and Figure 3.5). However, Tailwater Site 1 on the Washington side of the channel was the only site that could be safely accessed on occasions when wind and waves were high and dangerous, so it received 1.6–2.1 times more fish than the other sites across the transect.

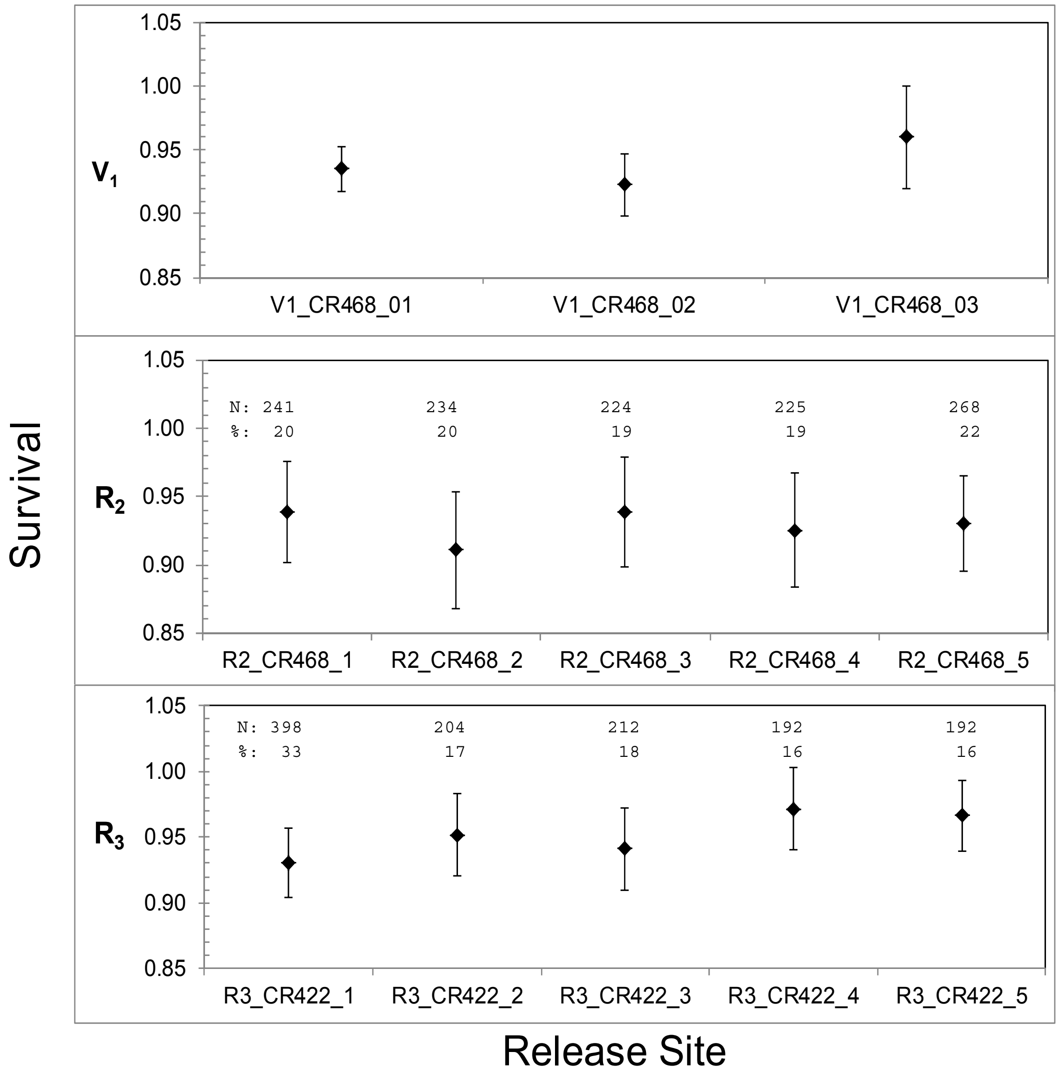


Figure 3.3. Single-release estimates of survival probabilities (Y axis) for yearling Chinook salmon released across the Columbia River downstream of McNary Dam at three or five locations from the Washington to the Oregon side of the channel (X axis). The top plot shows survival probabilities for the reach from the tailrace (CR468) to Crow Butte (CR422) for three virtual releases of fish formed by regrouping dam-passed fish (V_1) on the tailrace autonomous node that received the most receptions of each tag code. The middle plot shows reach survival probabilities of tailrace-released fish (R_2 at CR468) to John Day Dam (CR349), and the bottom plot shows reach survivals of tailwater-released fish (Crow Butte, Washington at CR422) to John Day Dam (CR349). Two lines of numbers above survival bars show the number of fish (N) and percent (%) of fish released at each site. Vertical error bars represent the extent of the 95% confidence intervals.

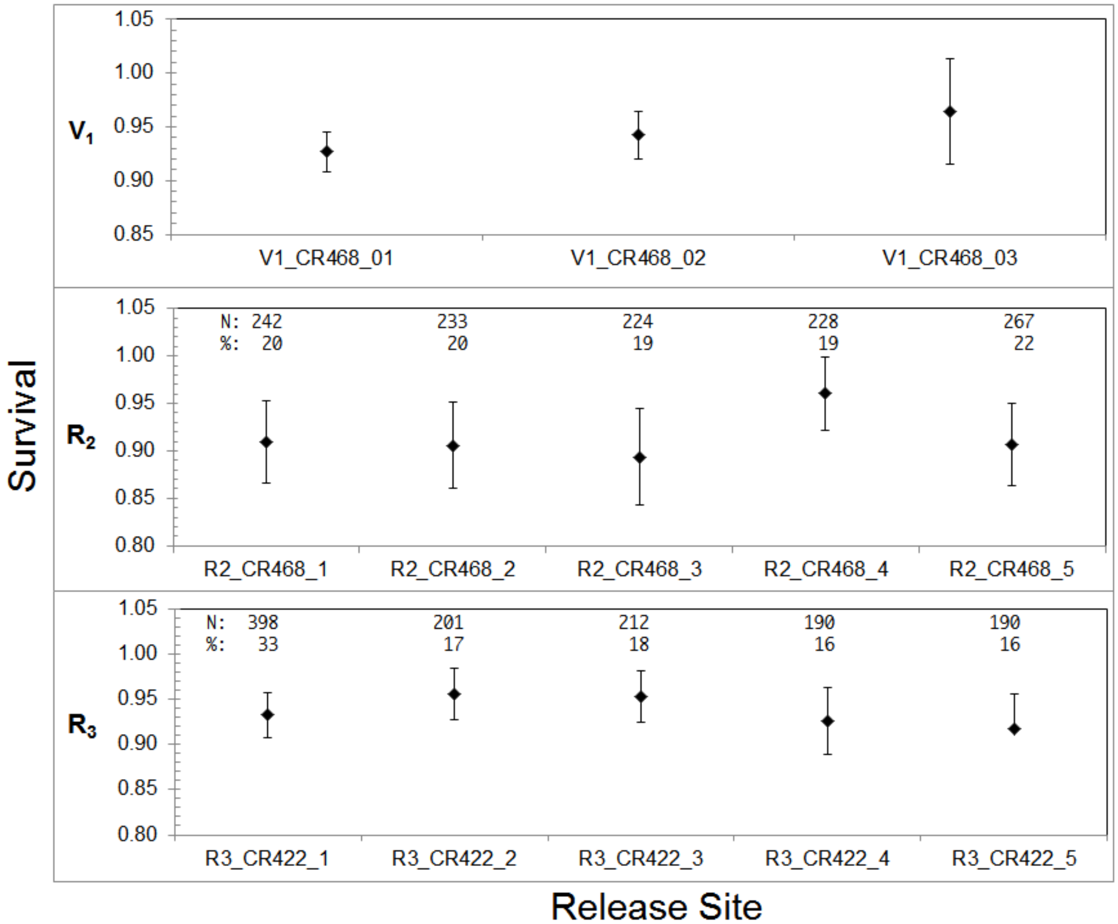


Figure 3.4. Single-release estimates of survival probabilities (Y axis) for juvenile steelhead released across the Columbia River downstream of McNary Dam at three or five locations from the Washington to the Oregon side of the channel (X axis). The top plot shows survival probabilities for the reach from CR468 to CR422 for three virtual releases of fish formed by regrouping dam-passed fish (V_1) on the tailrace autonomous node that received the most receptions of each tag code. The middle plot shows reach survival probabilities of tailrace-released fish (R_2 at CR468) to Crow Butte, Washington (CR422), and the bottom plot shows reach survivals of tailwater-released fish (Crow Butte, Washington at CR422) to John Day Dam (CR349). Two lines of numbers above survival bars show the number (N) and percent (%) of fish released at each site. Vertical error bars represent the extent of the 95% CI.

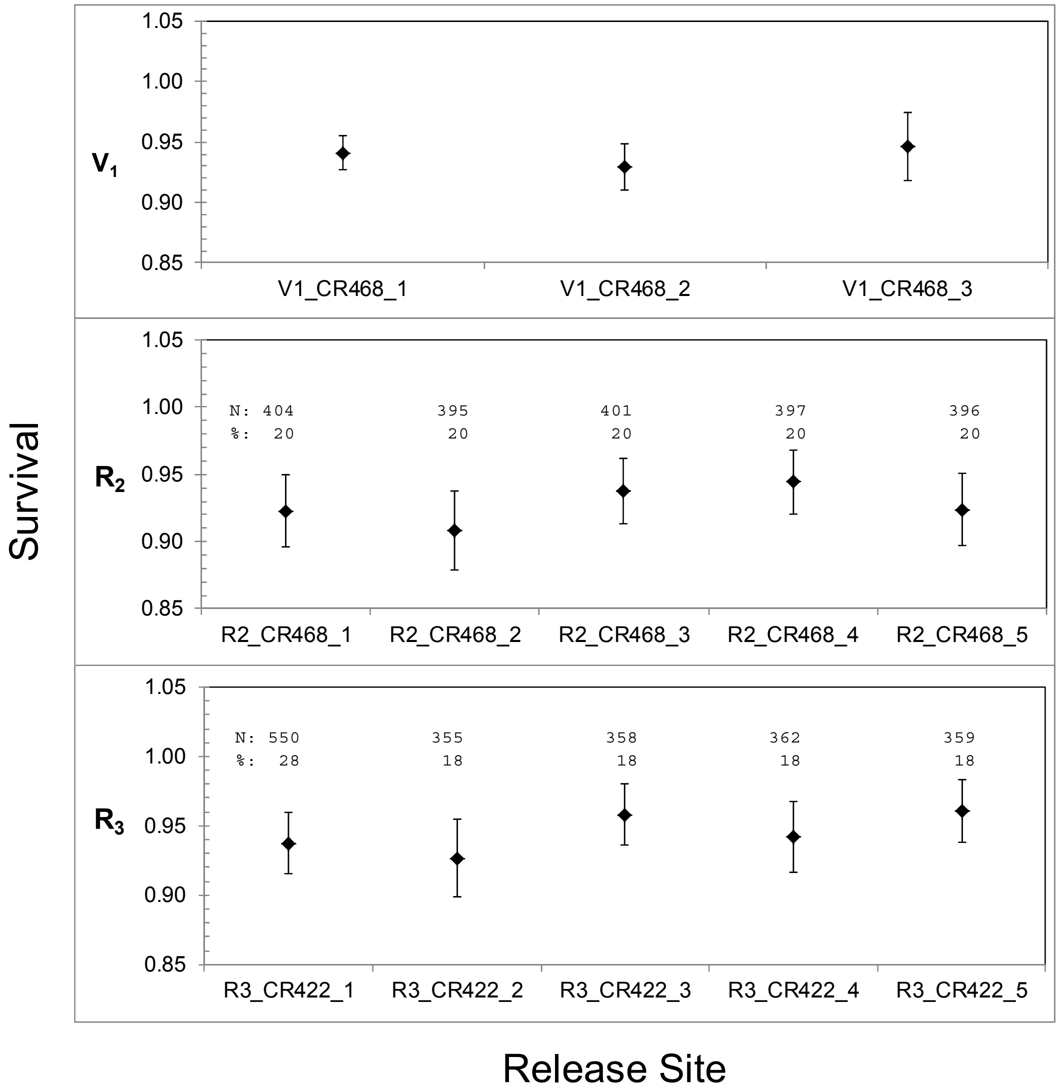


Figure 3.5. Single-release estimates of survival probabilities (Y axis) for subyearling Chinook salmon released across the Columbia River at three or five locations from the Washington to the Oregon side of the channel (X axis). The top plot shows survival probabilities for the reach from CR468 to CR422 for three virtual releases of fish formed by regrouping dam-passed fish on the tailrace autonomous node that received the most receptions of a tag code. The middle plot shows survival probabilities of tailrace-released fish from the tailrace (CR468) to near Crow Butte, Washington (CR422), and the bottom chart shows the survival rates for tailwater- released fish (CR422) to John Day Dam (CR349). Two lines of numbers above survival bars show the number (*N*) and percent (%) of fish released at each site. Vertical error bars represent the extent of the 95% CI.

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

Because the V_1 release group for the McNary survival studies was composed of fish from a single upstream release location, there was no need to evaluate whether time in-river had an effect on the survival of the fish forming that release group. Nevertheless, tests of homogeneity found no evidence of a relationship between time in-river and reach survivals for yearling Chinook salmon and steelhead (Appendix A).

For subyearling Chinook salmon, tests of homogeneity found evidence of delayed handling/tagging effects of the R_1–R_3 releases at and below Bonneville Dam (Appendix A). However, these findings had no effect on the survival analyses at McNary Dam.

3.4.6 Fish Size Distributions

Comparison of JSATS-tagged fish with ROR fish sampled at McNary Dam through the Smolt Monitoring Program shows that the length frequency distributions were generally well matched for yearling Chinook salmon (Figure 3.6), and steelhead (Figure 3.7). The size of subyearling Chinook salmon was somewhat larger than the fish sampled by the FPC (Figure 3.8). Mean lengths for the acoustic-tagged fish were 143.7 mm for yearling Chinook salmon, 206.7 mm for steelhead, and 112.9 mm for subyearling Chinook salmon. Mean lengths for yearling Chinook salmon, steelhead, and subyearling Chinook salmon sampled by the FPC at the McNary Dam juvenile sampling facility were 140.6 mm, 204.1 mm, and 104.9 mm, respectively. The length frequency distributions for the three yearling Chinook salmon releases (Figure 3.6), the three steelhead releases (Figure 3.7), and the three subyearling Chinook salmon releases (Figure 3.8) also were quite similar. Fish size did not change over the course of the spring study (Figure 3.9). During summer, the size of subyearling Chinook salmon declined slightly with time.

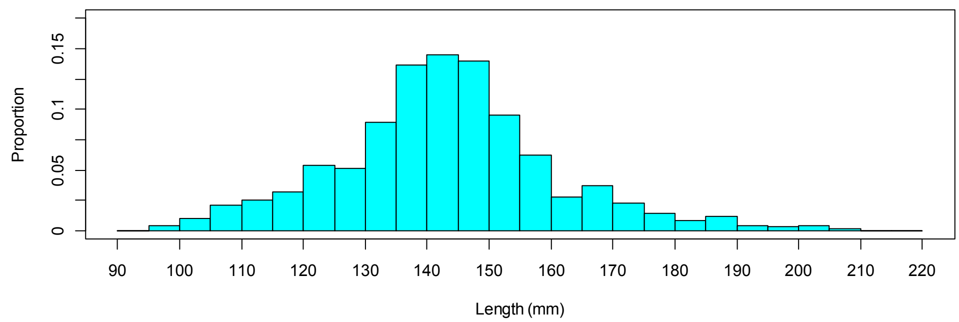
3.4.7 Tag-Life Corrections

During 2012, separate tag lots were used for each species in the spring and the summer study. From each of these tag lots, 98 to 100 tags were systematically sampled to conduct independent tag-life studies. A three-parameter Weibull curve was used to fit the tags used in the steelhead study, and the vitality curve of Li and Anderson (2009) was used to fit the yearling and subyearling Chinook salmon tag-life data (Figure 3.10). Average tag lives were 32.2 d, 23.0 d, and 23.3 d for the steelhead, yearling, and subyearling Chinook salmon tag lots, respectively.

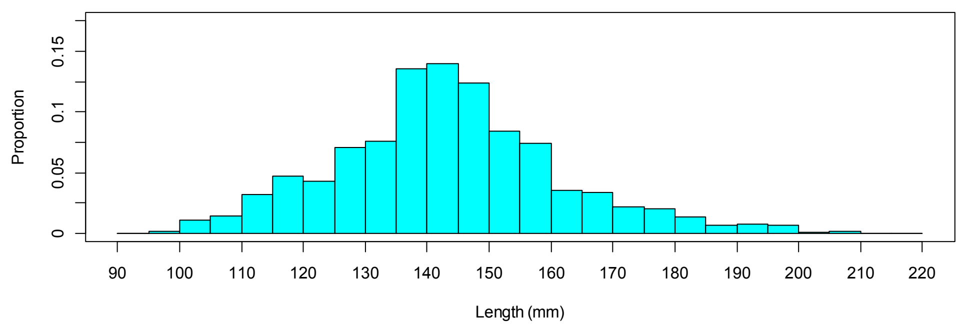
3.4.8 Arrival Distributions

The estimated probability that an acoustic tag was active when fish arrived at a downstream detection array depends on the tag-life curve and the distribution of observed travel times for yearling Chinook salmon, steelhead, and subyearling Chinook salmon (Figure 3.11). Examination of the fish arrival distributions to the last detection array used in the survival analyses indicated all fish had passed through the study area before tag failure became important. These probabilities were calculated by integrating the tag survivorship curve over the observed distribution of fish arrival times (i.e., time from tag activation to arrival; Figure 3.11). The probabilities of a JSATS tag being active at a downstream detection site were specific to release location, fish stock, and season (Table 3.3). In all cases, the probability a tag was active at a downstream detection site as far as rkm 325 was 99.25% for yearling Chinook salmon; 100% for juvenile steelhead; and 99.63% for subyearling Chinook salmon (Table 3.3).

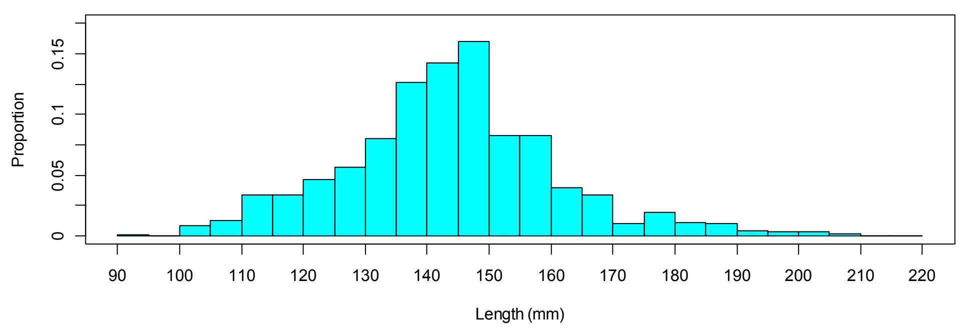
a. McNary Dam (Release V_1)



b. McNary Tailrace (Release R_2)



c. Mid-Reservoir (Release R_3)



d. ROR Yearling Chinook Salmon at John Day Dam

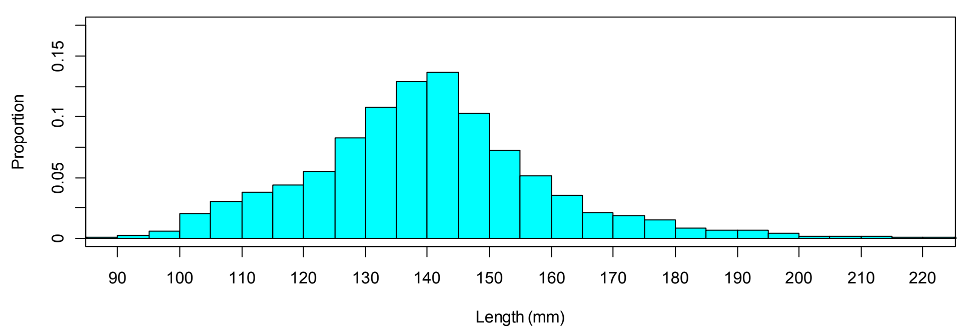
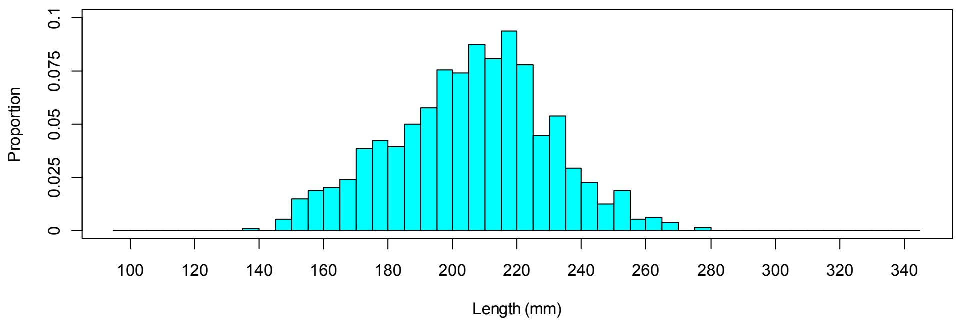
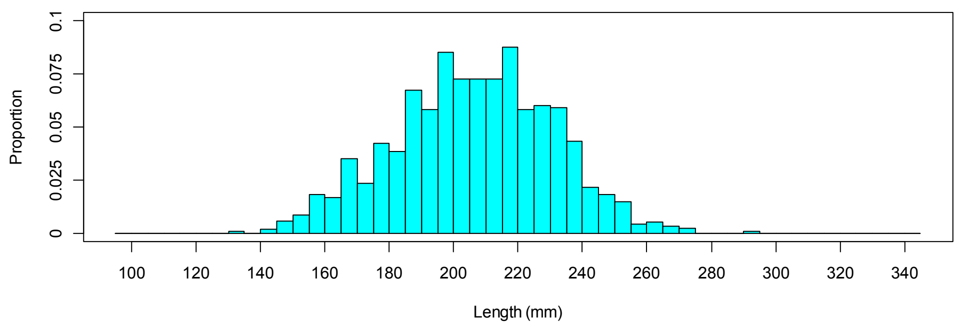


Figure 3.6. Relative frequency distributions for fish lengths (mm) of yearling Chinook salmon used in a) release V_1, b) release R_2, c) release R_3, and d) ROR fish sampled at John Day Dam by the Fish Passage Center in 2012.

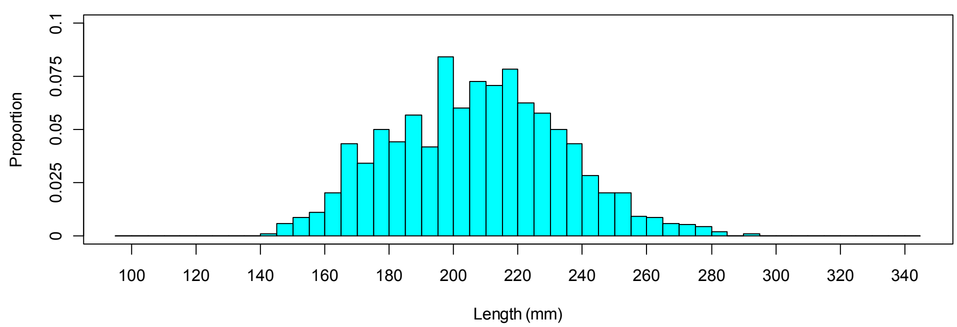
a. McNary Dam (Release V_1)



b. McNary Tailrace (Release R_2)



c. Mid-Reservoir (Release R_3)



d. ROR Steelhead at John Day Dam

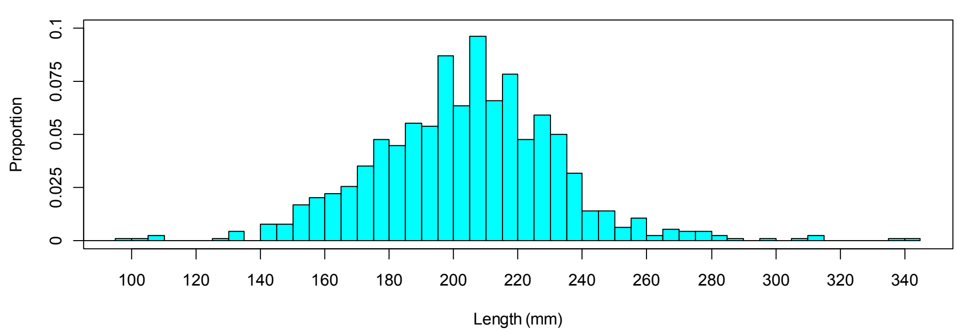
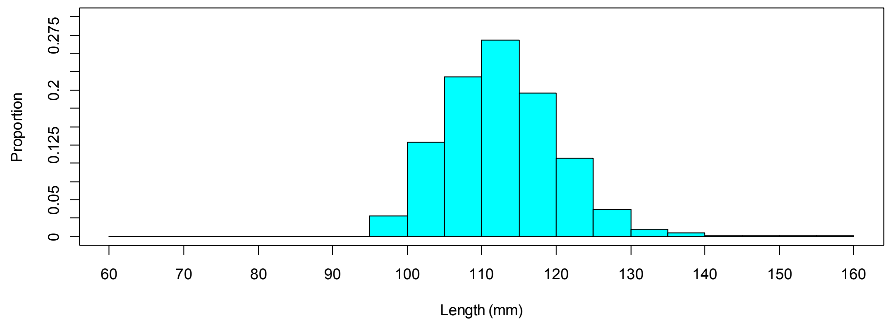
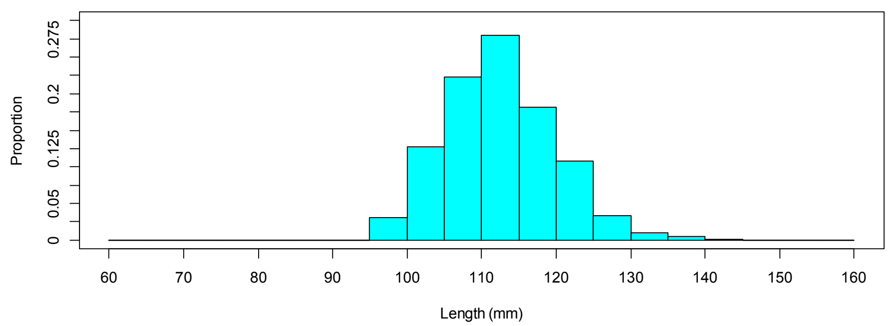


Figure 3.7. Relative frequency distributions for fish lengths (mm) of juvenile steelhead used in a) release V_1, b) release R_2, c) release R_3, and d) ROR fish sampled at John Day Dam by the Fish Passage Center in 2012.

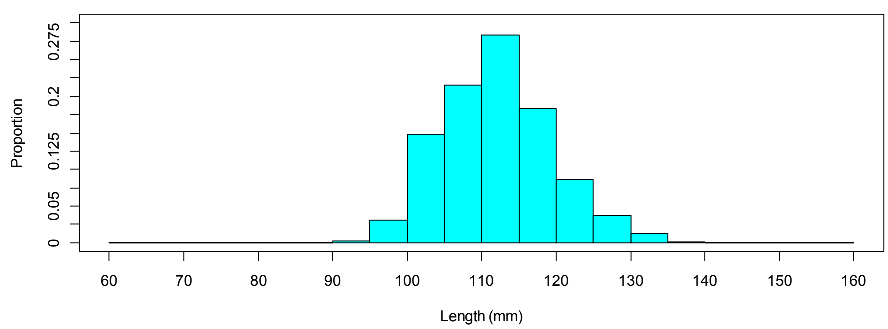
a. McNary Dam (Release V_1)



b. McNary Tailrace (Release R_2)



c. Mid-Reservoir (Release R_3)



d. ROR Subyearling Chinook Salmon at John Day Dam

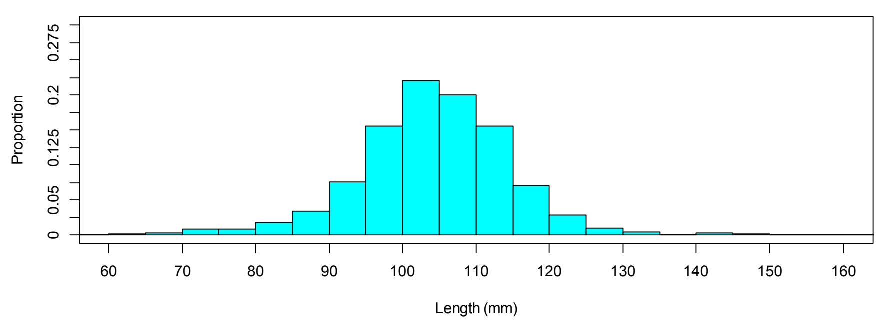
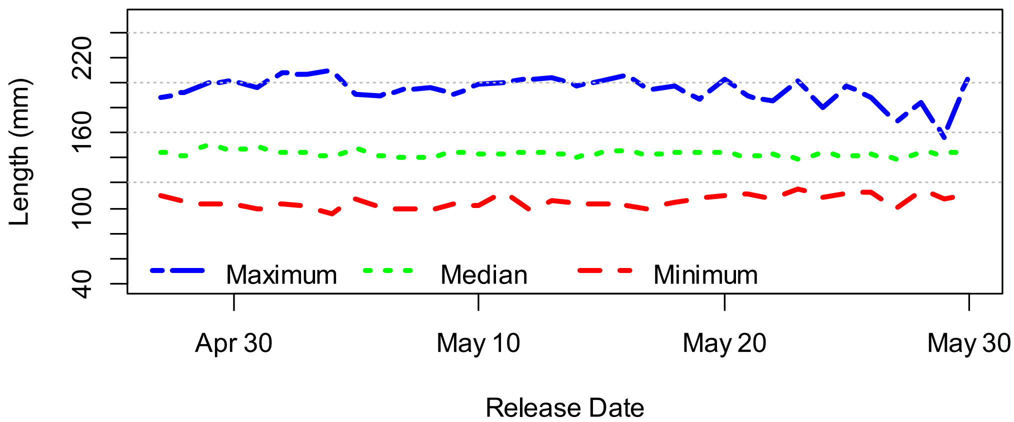
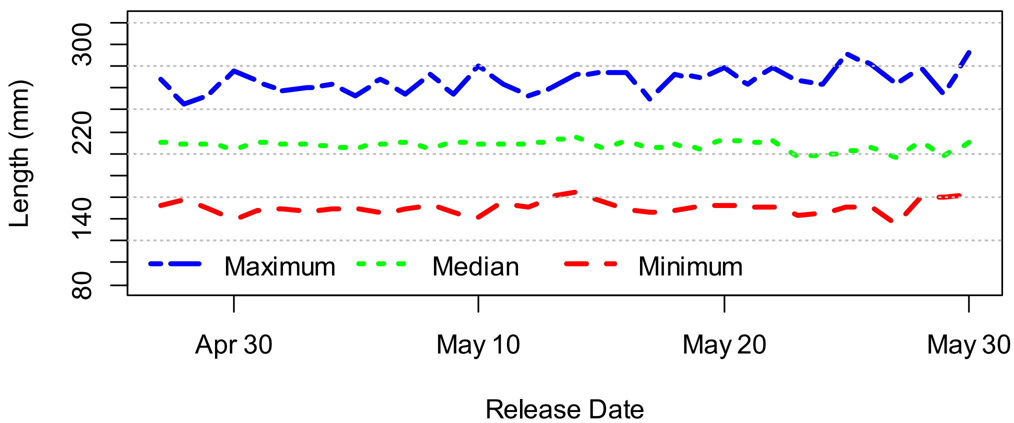


Figure 3.8. Relative frequency distributions for fish lengths (mm) of subyearling Chinook salmon used in a) release V_1, b) release R_2, c) release R_3, and d) ROR fish sampled during the study period at John Day Dam by the Fish Passage Center in 2012.

a. Yearling Chinook Salmon



b. Steelhead



c. Subyearling Chinook Salmon

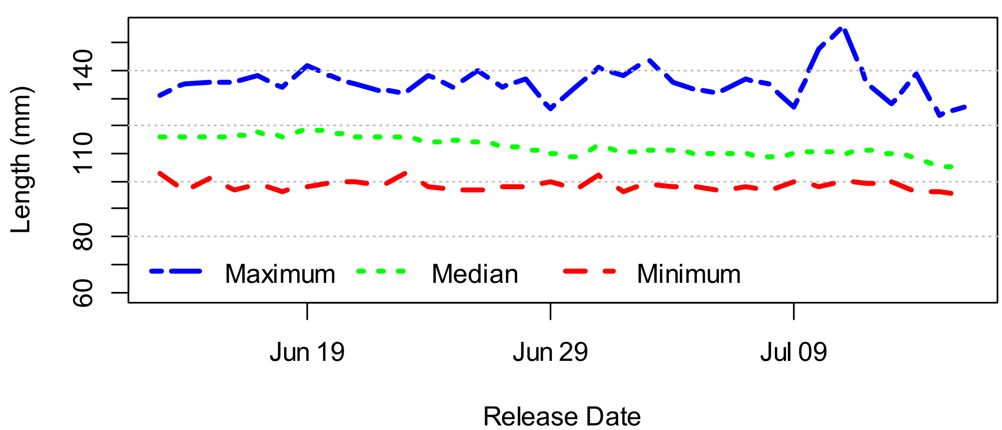
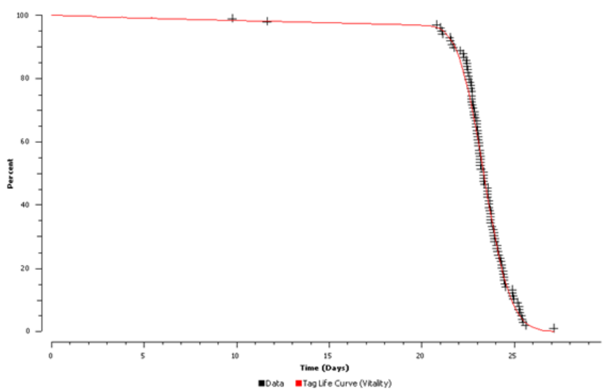
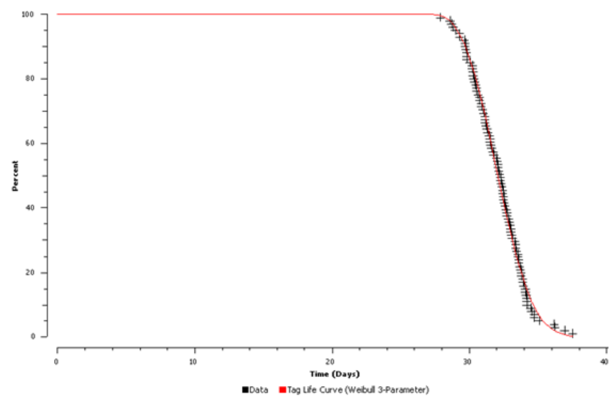


Figure 3.9. Range and median lengths of acoustic-tagged a) yearling Chinook salmon, b) steelhead, and c) subyearling Chinook salmon used in the 2012 survival studies.

a. Spring – Yearling Chinook Salmon



b. Spring – Steelhead



c. Summer – Subyearling Chinook Salmon

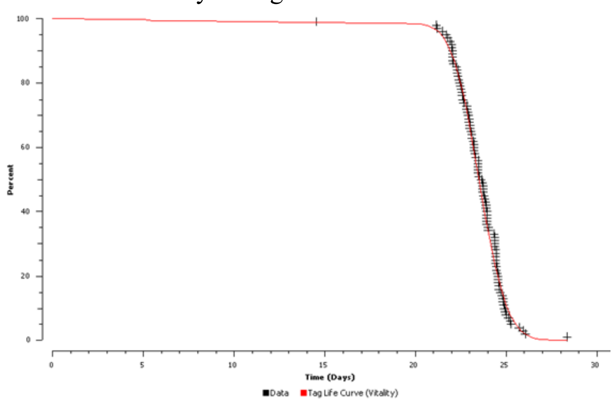
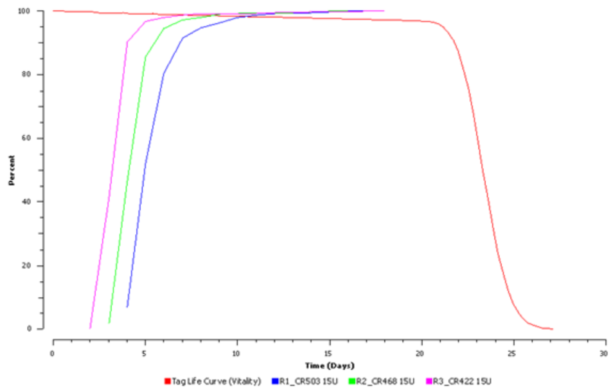
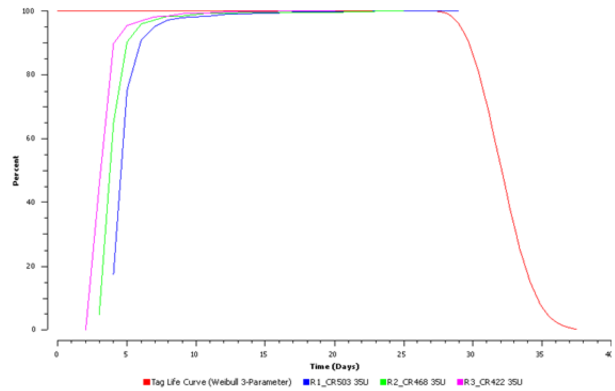


Figure 3.10. Observed time of tag failure and fitted survivorship curves using the vitality model of Li and Anderson (2009) for a) yearling Chinook salmon and c) subyearling Chinook salmon tag lots and a three-parameter Weibull model for b) steelhead.

a. Yearling Chinook Salmon



b. Steelhead



c. Subyearling Chinook Salmon

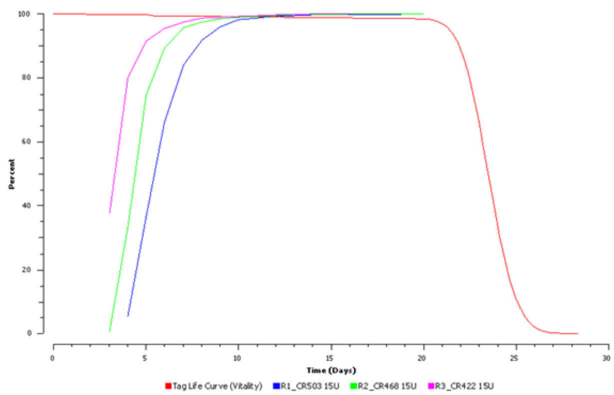


Figure 3.11. Plots of the fitted tag-life survivorship curve and the arrival-time distributions of a) yearling Chinook salmon, b) juvenile steelhead, and c) subyearling Chinook salmon for releases V_1, R_2, and R_3 at the acoustic-detection array located at rkm 325 (Figure 2.1).

3.4.9 Downstream Mixing

To help induce downstream mixing of the release groups, the R_1 release was 24 h before the R_2 release which, in turn, occurred 32 h before the R_3 release. The same release schedule was used for all three fish stocks. Plots of the arrival timing of the various release groups at downstream detection sites indicate reasonable mixing for yearling Chinook salmon (Figure 3.12), steelhead (Figure 3.13), and subyearling Chinook salmon (Figure 3.14). The arrival modes for V_1 and R_2 were synchronous and slightly earlier than the mode for R_3 for both yearling Chinook salmon and steelhead.

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

Release Group		Detection Site			
Stock	rkm	rkm 422	rkm 349	rkm 325	rkm 309
a. Yearling Chinook Salmon					
V_1[a]	472	0.9950 (0.0023)	0.9982 (0.0008)	0.9959 (0.0019)	0.9953 (0.0022)
R_2	468	--	--	0.9925 (0.0035)	0.9919 (0.0037)
R_3	422	--	--	0.9941 (0.0027)	0.9935 (0.0030)
b. Steelhead					
V_1[a]	472	1.0000 (<0.0001)	1.0000 (<0.0001)	1.0000 (<0.0001)	1.0000 (<0.0001)
R_2	468	--	1.0000 (<0.0001)	1.0000 (<0.0001)	1.0000 (<0.0001)
R_3	422	--	1.0000 (<0.0001)	1.0000 (<0.0001)	1.0000 (<0.0001)
c. Subyearling Chinook Salmon					
V_1[a]	472	0.9976 (0.0033)	0.9992 (0.0011)	0.9979 (0.0029)	0.9977 (0.0032)
R_2	468	--	--	0.9963 (0.0050)	0.9960 (0.0053)
R_3	422	--	--	0.9966 (0.0040)	0.9968 (0.0043)

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

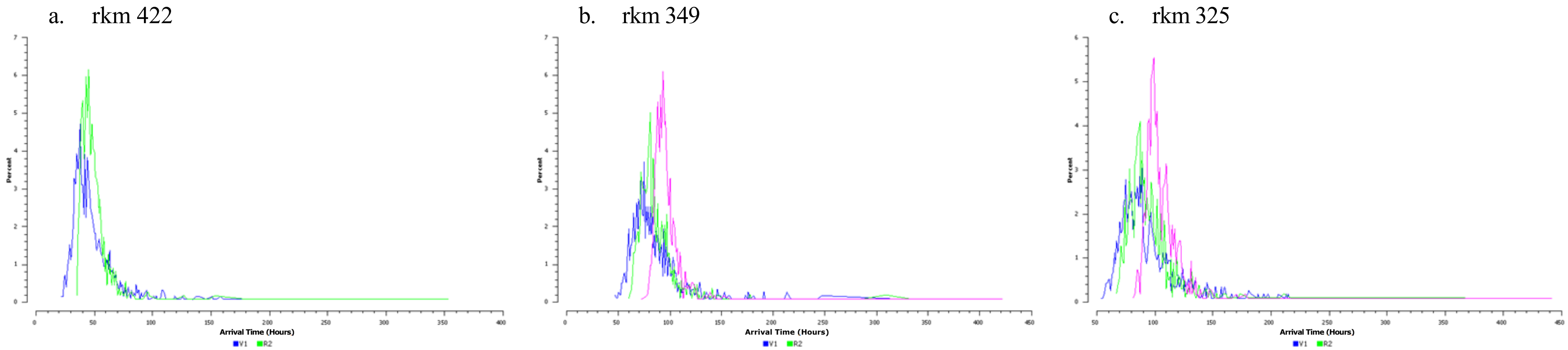


Figure 3.12. Frequency distribution plots of downstream arrival timing (expressed as percentages) for yearling Chinook salmon releases V_1, R_2, and R_3 at detection arrays located at a) rkm 422, b) rkm 349, and c) rkm 325 (see Figure 2.1). All times adjusted relative to the release time of V_1.

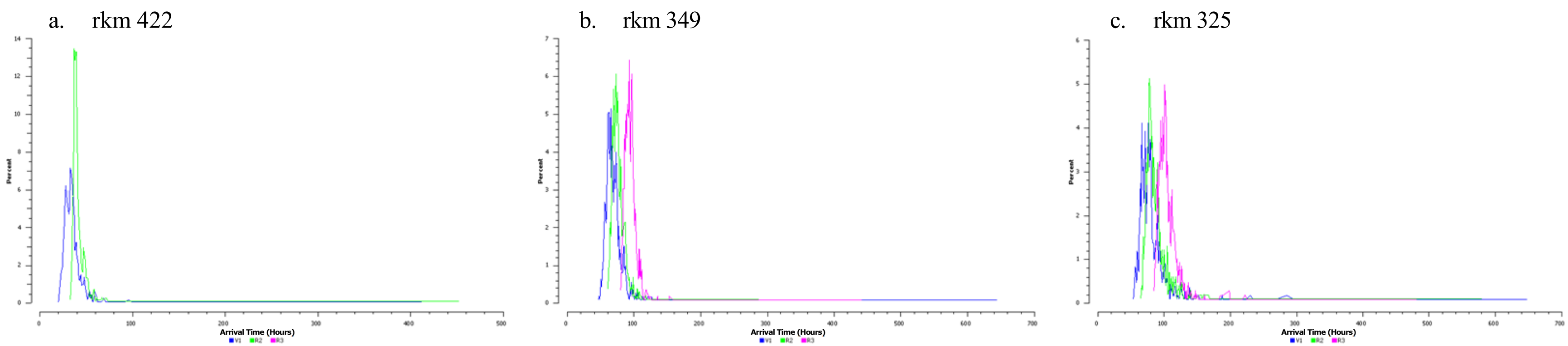


Figure 3.13. Frequency distribution plots of downstream arrival timing (expressed as percentages) for steelhead releases V_1, R_2, and R_3 at detection arrays located at a) rkm 422, b) rkm 349, and c) rkm 325 (see Figure 2.1). All times adjusted relative to the release time of V_1.

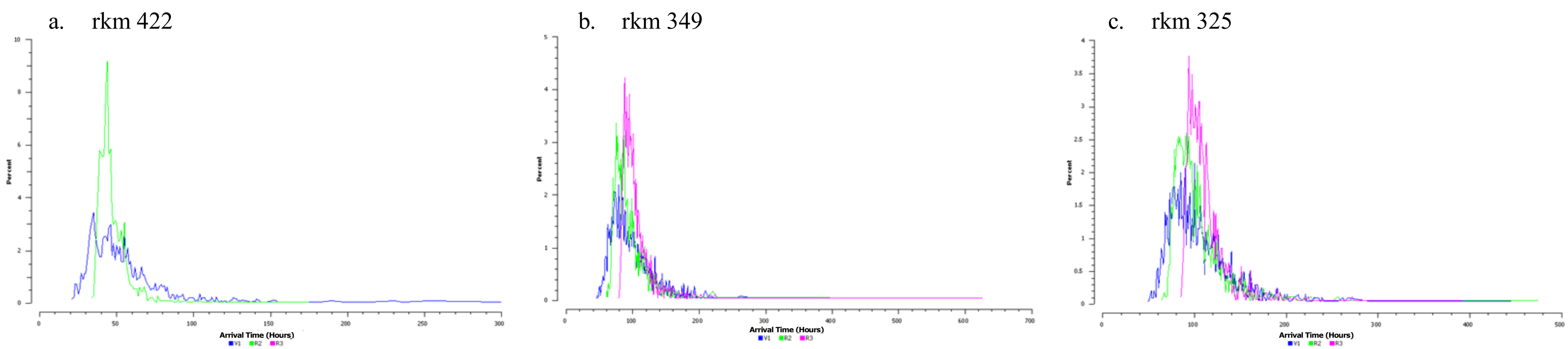


Figure 3.14. Frequency distribution plots of downstream arrival timing (expressed as percentages) for subyearling Chinook salmon releases V_1, R_2, and R_3 at detection arrays located at a) rkm 422, b) rkm 349, and c) rkm 325 (see Figure 2.1). All times adjusted relative to the release time of V_1.

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, and FPE.

3.5.1 Dam Passage Survival

The high river flows in 2012 interrupted the planned 40% spring spill and the 50% summer spill. No attempt was made to isolate the few days near target spill levels. Instead, season-wide survival estimates were calculated over the prevailing spill conditions.

3.5.1.1 Yearling Chinook Salmon

The estimate of season-wide dam passage survival for yearling Chinook salmon during spring 2012 was calculated to be

$$\hat{S}_{\text{Dam}} = \frac{0.9171}{\left(\frac{0.9050}{0.9489}\right)} = \frac{0.9171}{0.9537} = 0.9616$$

with a standard error of $\widehat{\text{SE}} = 0.0140$ (**Error! Reference source not found.**). This survival estimate exceeds the 2008 BiOp requirement of $\hat{S} \geq 0.96$ and meets the precision standard of $\widehat{\text{SE}} \leq 0.015$.

Table 3.4. Survival, detection, and λ parameters for final model used to estimate dam passage survival for yearling Chinook salmon during the season-wide spring study (27 April to 30 May 2012). Standard errors (SE) based on both the inverse Hessian matrix and bootstrapping for key parameters (†) and only the inverse Hessian matrix for associated parameters (*).

	CR470 to 422		CR422 to 349		Release to CR349	
Release	$\hat{S}$	$\widehat{\text{SE}}^{\dagger}$	$\hat{S}$	$\widehat{\text{SE}}^{*}$	$\hat{S}$	$\widehat{\text{SE}}^{\dagger}$
V_1	0.9171	0.0076	0.9501	0.0063	---	---
R_2	---	---	---	---	0.9050	0.0092
R_3	---	---	---	---	0.9489	0.0071

	CR422		CR349	
	$\hat{p}$	$\widehat{\text{SE}}^{*}$	$\hat{p}$	$\widehat{\text{SE}}^{*}$
V_1	1.0000	<0.0001	0.9991	0.0009
R_2	---	---	1.0000	<0.0001
R_3	---	---	1.0000	<0.0001

	CR349–325	
Release	$\hat{\lambda}$	$\widehat{\text{SE}}^{*}$
V_1	0.9709	0.0045
R_2	0.9559	0.0063
R_3	0.9581	0.0060

3.5.1.2 Steelhead

The estimate of season-wide dam passage survival for steelhead was calculated to be

$$\hat{S}_{\text{Dam}} = \frac{0.9136}{\left(\frac{0.8540}{0.9366}\right)} = \frac{0.9136}{0.9118} = 1.0019$$

with an estimated standard error of $\widehat{\text{SE}} = 0.0165$ (**Error! Reference source not found.**). This estimate of survival is slightly outside the admissible values for survival of $0 \le S \le 1$. The virtual releases for steelhead and yearling Chinook salmon yielded almost the same survival value to the below-dam detection array at rkm 422 (i.e., 0.9136 vs. 0.9171). The R_3 release for the two species also produced similar survival estimates of 0.9489 and 0.9366 for yearling Chinook salmon and steelhead, respectively. The difference in the estimates of dam passage survival for yearling Chinook salmon and steelhead lies in the estimates of S_2. The tagging studies for both species suggest considerable mortalities in the McNary tailwater (Figure 2.1), but the estimates of S_2 differ by five points (i.e., 0.9050 vs. 0.8540). This difference may be due, in part, to the lower-than-expected precision of the estimates of $\hat{S}_2$ with standard errors of ≈ 0.01.

Table 3.5. Survival, detection, and λ parameters for final model used to estimate dam passage survival for steelhead during the season-wide spring study (27 April to 30 May 2012). Standard errors (SE) based on both the inverse Hessian matrix and bootstrapping for key parameters (†) and only the inverse Hessian matrix for associated parameters (*).

	CR470 to 422		CR422 to 349		Release to CR349	
Release	$\hat{S}$	$\widehat{\text{SE}}^{\dagger}$	$\hat{S}$	$\widehat{\text{SE}}^{*}$	$\hat{S}$	$\widehat{\text{SE}}^{\dagger}$
V_1	0.9136	0.0078	0.9477	0.0065	---	---
R_2	---	---	---	---	0.8540	0.0102
R_3	---	---	---	---	0.9366	0.0070

	CR422		CR349	
Release	$\hat{p}$	$\widehat{\text{SE}}^{*}$	$\hat{p}$	$\widehat{\text{SE}}^{*}$
V_1	1.0000	<0.0001	0.9991	0.0009
R_2	---	---	1.0000	<0.0001
R_3	---	---	1.0000	<0.0001

	CR349–325	
Release	$\hat{\lambda}$	$\widehat{\text{SE}}^{*}$
V_1	0.9740	0.0048
R_2	0.9773	0.0047
R_3	0.9685	0.0052

Rather than using the detection arrays at rkm 349 and 325 in estimating dam passage survival (Figure 2.1), an alternative is to use the arrays at rkm 325 and 309. In this case,

$$\hat{S}_{\text{Dam}} = \frac{0.9136}{\left(\frac{0.8282}{0.8982}\right)} = \frac{0.9136}{0.9221} = 0.9908$$

with a standard error of $\widehat{\text{SE}} = 0.0183$ (**Error! Reference source not found.**). This estimate also meets the BiOp standard, but the standard error is too large (i.e., SE > 0.015). A more stringent precision requirement is for the estimate of dam passage survival to be significantly greater than the requirement of $S_{\text{Dam}} \geq 0.96$. The estimate of steelhead survival is significantly greater than 0.96 at a *P*-value of 0.0462.

Table 3.6. Survival, detection, and λ parameters for model using the next lower set of detection arrays to estimate dam passage survival for steelhead during the season-wide spring study (27 April to 30 May 2012). Standard errors (SE) based on both the inverse Hessian matrix and bootstrapping for key parameters (†) and only the inverse Hessian matrix for associated parameters (*).

	CR470 to 422		CR422 to 325		Release to CR349	
Release	$\hat{S}$	$\widehat{\text{SE}}^{\dagger}$	$\hat{S}$	$\widehat{\text{SE}}^{*}$	$\hat{S}$	$\widehat{\text{SE}}^{\dagger}$
V_1	0.9136	0.0078	0.9237	0.0077	---	---
R_2	---	---	---	---	0.8282	0.0109
R_3	---	---	---	---	0.8982	0.0087

	CR422		CR325	
Release	$\hat{p}$	$\widehat{\text{SE}}^{*}$	$\hat{p}$	$\widehat{\text{SE}}^{*}$
V_1	1.0000	<0.0001	0.9991	0.0009
R_2	---	---	0.9990	0.0010
R_3	---	---	1.0000	<0.0001

	CR325–309	
Release	$\hat{\lambda}$	$\widehat{\text{SE}}^{*}$
V_1	0.9945	0.0022
R_2	0.9940	0.0025
R_3	0.9926	0.0026

3.5.1.3 Subyearling Chinook Salmon

The estimate of season-wide dam passage survival for subyearling Chinook salmon during summer 2012 was calculated to be

$$\hat{S}_{\text{Dam}} = \frac{0.9149}{\left(\frac{0.8864}{0.9443}\right)} = \frac{0.9149}{0.9386} = 0.9747$$

with a standard error of $\widehat{\text{SE}} = 0.0114$ (**Error! Reference source not found.**). This estimate exceeds the 2008 BiOp requirements of $\hat{S} \geq 0.96$ and the precision standard of SE $\leq$ 0.015.

Table 3.7. Survival, detection, and λ parameters for final model used to estimate dam passage survival for subyearling Chinook salmon during the summer study. Standard errors (SE) based on both the inverse Hessian matrix and bootstrapping for key parameters (†) and only the inverse Hessian matrix for associated parameters (*).

	CR470 to 422		CR422 to 349		Release to CR349	
Release	$\hat{S}$	$\widehat{\text{SE}}^{\dagger}$	$\hat{S}$	$\widehat{\text{SE}}^{*}$	$\hat{S}$	$\widehat{\text{SE}}^{\dagger}$
V_1	0.9149	0.0057	0.9568	0.0044	---	---
R_2	---	---	---	---	0.8864	0.0086
R_3	---	---	---	---	0.9443	0.0066

	CR422		CR349	
Release	$\hat{p}$	$\widehat{\text{SE}}^{*}$	$\hat{p}$	$\widehat{\text{SE}}^{*}$
V_1	1.0000	< 0.0001	1.0000	< 0.0001
R_2	---	---	1.0000	< 0.0001
R_3	---	---	0.9994	0.0006

	CR349–325	
Release	$\hat{\lambda}$	$\widehat{\text{SE}}^{*}$
V_1	0.9371	0.0053
R_2	0.9431	0.0056
R_3	0.9408	0.0055

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 (i.e., detection array rkm 472, Figure 2.1) rather than at the dam face. These season-wide survival estimates were based on all release data across the season, regardless of spill conditions. Using the same statistical model as was used in estimating dam passage survival, forebay-to-tailrace survival for yearling Chinook salmon was

$$\hat{S}_{\text{forebay-to-tailrace}} = 0.9595(0.0140)$$

for steelhead,

$$\hat{S}_{\text{forebay-to-tailrace}} = 0.9880(0.0183)$$

and for subyearling Chinook salmon,

$$\hat{S}_{\text{forebay-to-tailrace}} = 0.9729(0.0114).$$

3.5.3 Forebay Residence Time

The forebay residence time was calculated from the first detection at the forebay BRZ array (rkm 351) to the last detection at the dam (rkm 349). For yearling Chinook salmon, the mean forebay residence time was estimated to be 3.01 h ($\widehat{\text{SE}}$ = 0.30), for steelhead it was estimated to be 2.67 h ($\widehat{\text{SE}}$ = 0.08), and for subyearling Chinook salmon it was estimated to be 2.86 h ($\widehat{\text{SE}}$ = 0.13) (Figure 3.15, Table 3.8). The distribution of forebay residence times indicates the mode for forebay residence times was 2 h for yearling Chinook salmon and steelhead and 1.5 h for subyearling Chinook salmon. Median residence times were 1.76 h, 1.78 h, and 1.77 h for yearling Chinook salmon, steelhead, and subyearling Chinook salmon, respectively (Table 3.8).

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 McNary Dam to the last detection at the BRZ tailrace array (Figure 3.16). Mean tailrace egress time for yearling Chinook salmon was estimated to be $\bar{t}$ = 2.87 h ($\widehat{\text{SE}}$ = 0.33). For juvenile steelhead, mean tailrace egress time was estimated to be $\bar{t}$ = 1.85 h ($\widehat{\text{SE}}$ = 0.37). Mean tailrace egress time for subyearling Chinook salmon was estimated to be $\bar{t}$ = 3.01 h ($\widehat{\text{SE}}$ = 0.29). Median egress times were 0.41, 0.34, and 0.38 h for yearling Chinook salmon, steelhead, and subyearling Chinook salmon, respectively (Table 3.8). For all three fish stocks, the mode for tailrace egress time was 0.5 h (Figure 3.16).

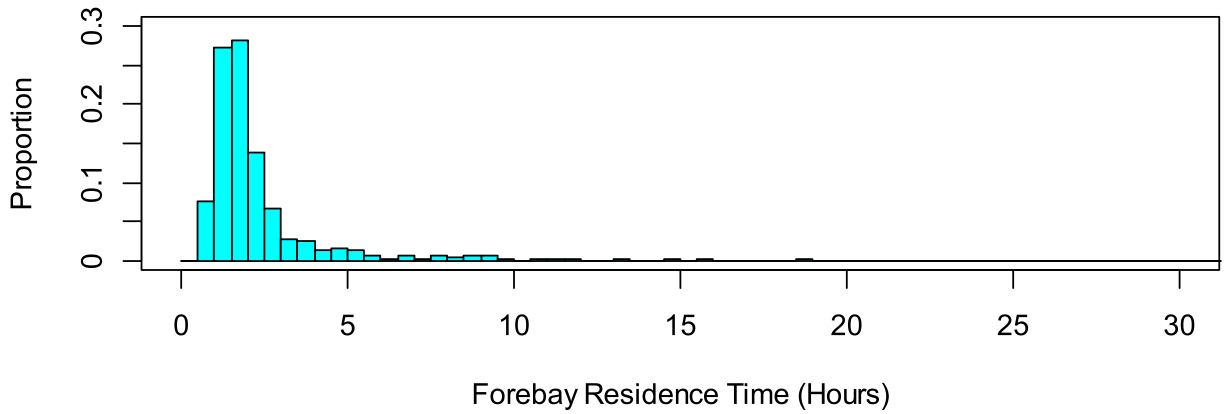
3.5.5 Spill Passage Efficiency

Spill passage efficiency is defined as the fraction of the fish that passed through a hydroproject by the spillway and temporary spill weirs. The double-detection array at the face of McNary Dam was used to identify and track fish as they entered the forebay. Using the observed counts because detection efficiency was constant (100%) across the dam, the numbers of fish entering the various routes at McNary Dam were used to estimate SPE based on a binomial sampling model. For yearling Chinook salmon, $\widehat{\text{SPE}}$ = 0.7246 (0.0121); for juvenile steelhead, $\widehat{\text{SPE}}$ = 0.8315 (0.0104); and for subyearling Chinook salmon, $\widehat{\text{SPE}}$ = 0.7832 (0.0083).

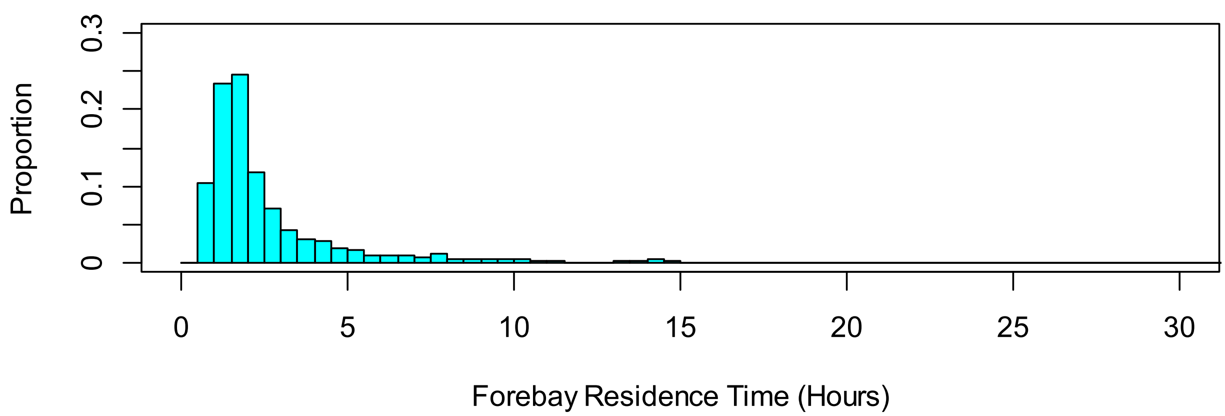
3.5.6 Fish Passage Efficiency

Fish passage efficiency, called SPE in the Fish Accords, is the fraction of the fish that passed through non-turbine routes at the dam. As with SPE, the double-detection array at the face of McNary Dam was used to identify and track fish as they entered the dam. Using the observed counts because detection efficiency was constant (100%) for all routes, the number of fish entering the various routes at McNary Dam were used to estimate FPE based on a binomial sampling model. For yearling Chinook salmon at McNary Dam in 2012, fish passage efficiency is estimated to be $\widehat{\text{FPE}}$ = 0.9676 (0.0048); for juvenile steelhead, $\widehat{\text{FPE}}$ = 0.9768 (0.0042); and for subyearling Chinook salmon, $\widehat{\text{FPE}}$ = 0.9089 (0.0058).

a. Yearling Chinook Salmon



b. Steelhead



c. Subyearling Chinook Salmon

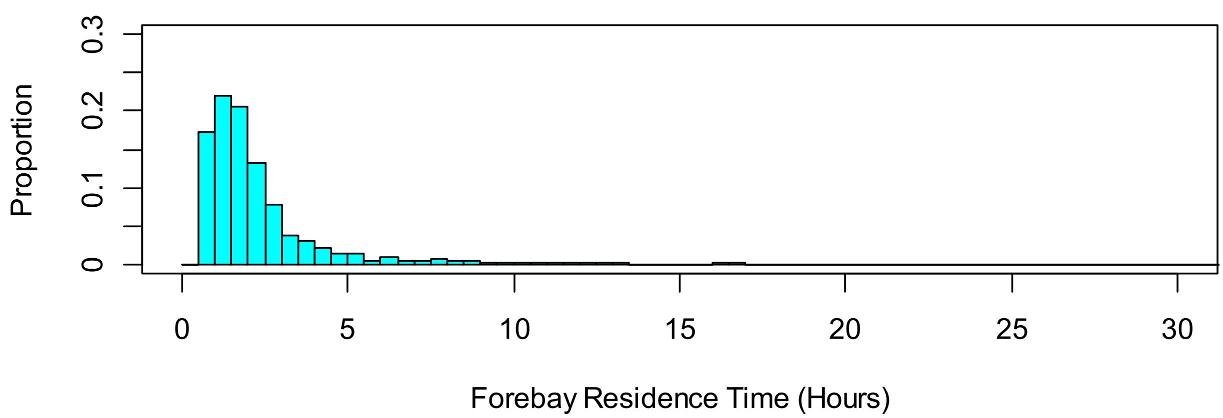
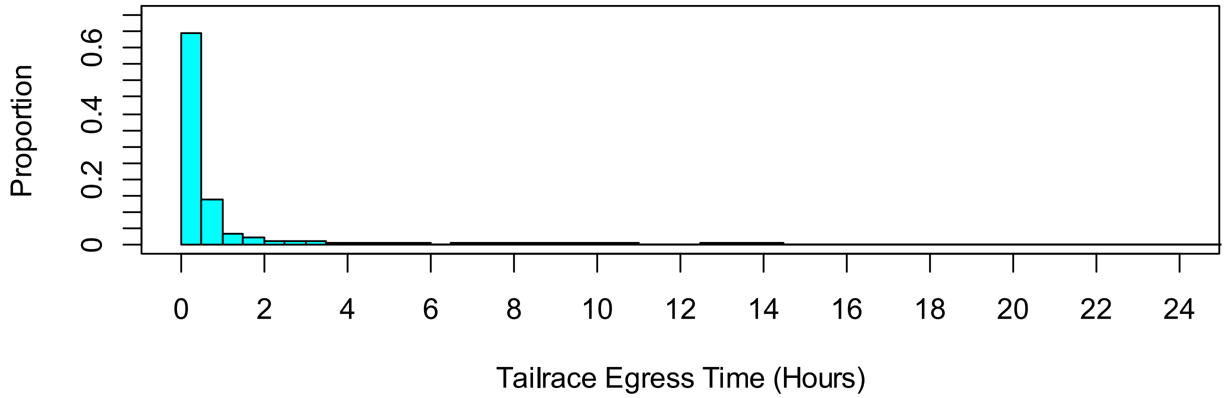


Figure 3.15. Distribution of forebay residence times for a) yearling Chinook salmon, b) steelhead, and c) subyearling Chinook salmon at McNary Dam, 2012.

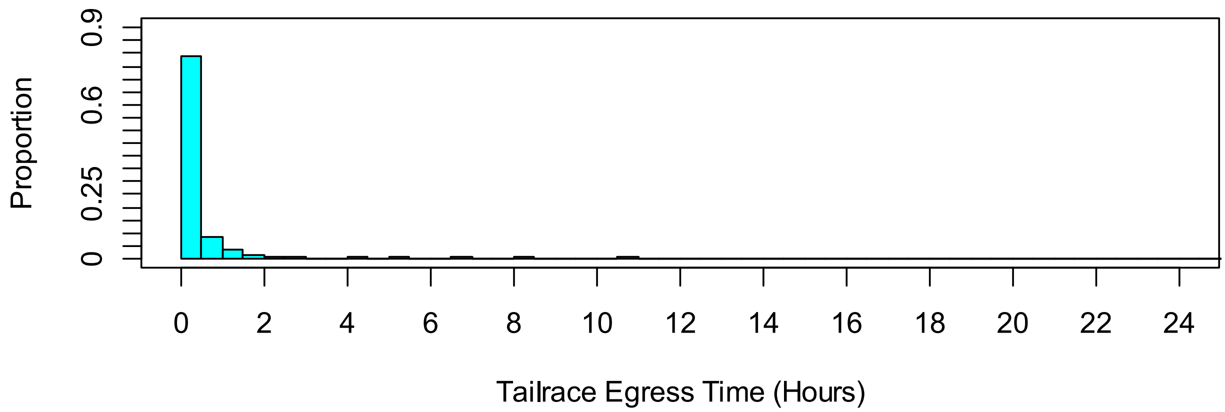
Table 3.8. Estimated mean and median forebay residence times (h) and mean and median tailrace egress times for yearling Chinook salmon, steelhead, and subyearling Chinook salmon at McNary Dam in 2012. (Standard errors in parentheses.)

Performance Measure	Yearling Chinook Salmon	Steelhead	Subyearling Chinook Salmon
Forebay Residence Time			
• Mean	3.01 (0.30)	2.67 (0.08)	2.86 (0.13)
• Median	1.76	1.78	1.77
Tailrace Egress Time			
• Mean	2.87 (0.33)	1.85 (0.37)	3.01 (0.29)
• Median	0.41	0.34	0.38

a. Yearling Chinook Salmon



b. Steelhead



c. Subyearling Chinook Salmon

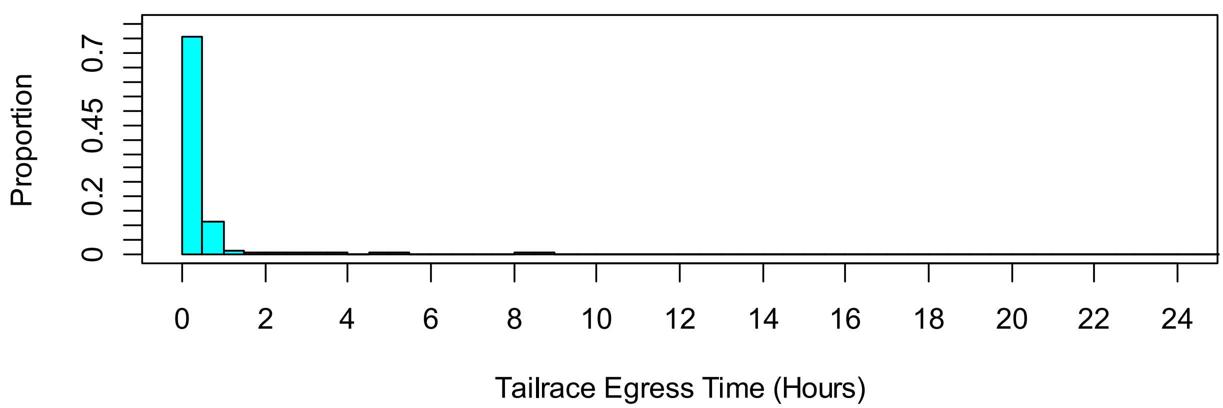


Figure 3.16. Distribution of tailrace egress times for a) yearling Chinook salmon, b) steelhead, and c) subyearling Chinook salmon at McNary Dam, 2012.

4.0 Discussion

The discussion describes the conduct of the 2012 study, study performance, and compares the 2012 compliance study estimates with previous studies at McNary 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 and no evidence of adverse tagger effects. Those results suggest the assumptions of the virtual/paired-release model were fulfilled, permitting valid estimation of dam passage survival and related parameters.

High flows during spring and summer 2012 resulted in mandatory spill levels above the planned 40% spill target in spring and 50% spill target in summer. Consequently, dam passage survivals were estimated under the prevailing spill conditions of 2012.

4.2 Study Performance

Estimates of dam passage survival for yearling Chinook salmon, steelhead, and subyearling Chinook salmon at McNary Dam in spring and summer 2012 met the 2008 BiOp standards for the point estimates (i.e., ≥0.96 for spring stocks; ≥0.93 for summer stocks), and precision (i.e., SE ≤ 0.015) was met for yearlings and subyearlings but not for steelhead. However, the estimate of dam passage survival for steelhead was significantly higher than the BiOp requirement of 0.96 at a *P*-value of 0.0462.

4.3 Comparison to Previous Studies at McNary Dam

Historically, both acoustic and radio telemetry studies have been used to estimate survival rates and passage efficiencies for yearling Chinook salmon, steelhead, and subyearling Chinook salmon passing McNary Dam. In the early 2000s, radio telemetry was the primary method for estimating survival rates throughout the lower Columbia River; in more recent years (2006–2009) acoustic telemetry has become the primary method for obtaining these estimates, and in 2012 the JSATS was first used at McNary Dam for obtaining these estimates.

For 2006–2009, Adams and Evans (2011) synthesized findings from multiple years of acoustic telemetry studies that estimated fish passage and survival rates at McNary Dam. Acoustic-tagged fish were released upstream of McNary Dam in the Mid-Columbia and used for estimating paired- and single-release dam passage survival rates.

For comparison, paired-release survival rates from 2006–2009 and 2012 are presented in Table 4.1. Survival rates for yearling Chinook salmon and steelhead in 2012—0.962 (0.014) and 0.991(0.018), respectively—were historically similar to paired-release survival rates. For subyearling Chinook salmon, paired-release survival rates for 2012 (0.975 [0.011]) were approximately 2% higher than the closest comparable year, 2008, in which survival was estimated to be 0.952 (0.013).

Table 4.1. Paired-release dam passage survival rates of yearling Chinook salmon, steelhead, and subyearling Chinook salmon at McNary Dam from 2006 to 2009 and 2012. Standard errors are in parentheses.

Year	Yearling Chinook Salmon	Steelhead	Subyearling Chinook Salmon
2006	0.959 (0.009)	N/A	0.948 (0.012)
2007	0.926 (0.013)	N/A	0.928 (0.018)
2008	0.954 (0.009)	0.991 (0.015)	0.952 (0.013)
2009	0.973 (0.009)	0.996 (0.012)	0.894 (0.013)
2012	0.962 (0.014)	0.991 (0.018)	0.975 (0.011)

Single-release survival rates from the same study years are presented in Table 4.2 for yearling Chinook salmon, steelhead, and subyearling Chinook salmon, along with estimates from the current study for comparison. The single-release dam passage survival rates for subyearling Chinook salmon in 2012 (0.915 [0.006]) was approximately 0.03–0.09 above the historic range (2006 to 2009). In contrast, yearling Chinook salmon and steelhead single-release survival estimates were at the lower end of the 2006–2009 historic range with 0.917 (0.008) and 0.914 (0.008) survival, respectively.

Table 4.2. Single-release dam passage survival rates of yearling Chinook salmon, steelhead, and subyearling Chinook salmon at McNary Dam from 2006 to 2009 and 2012. Standard errors are in parentheses.

Year	Yearling Chinook Salmon	Steelhead	Subyearling Chinook Salmon
2006	0.938 (0.007)	0.973 (0.010)	0.885 (0.009)
2007	0.921 (0.011)	0.897 (0.013)	0.863 (0.013)
2008	0.943 (0.007)	0.954 (0.011)	0.875 (0.009)
2009	0.946 (0.006)	0.943 (0.007)	0.823 (0.010)
2012	0.917 (0.008)	0.914 (0.008)	0.915 (0.006)

At McNary Dam, FPE has ranged widely since 2006. Table 4.3 summarizes FPE for yearling Chinook salmon, steelhead, and subyearling Chinook salmon from 2006–2009 and the current study year for comparison. In 2012, FPE was notably higher for all three salmonid species. For yearling and subyearling Chinook salmon, FPE was approximately 0.10 higher than noted historically, and for steelhead was approximately 0.05 higher than 2006–2009 estimates.

Spill passage efficiencies from 2006–2009 and the current study year are presented in Table 4.4. The SPE for all three salmonid stocks tagged and released for the 2012 JSATS study were markedly higher than historically noted from 2006–2009. For yearling Chinook salmon, SPE of 0.725 (0.012) was more than 0.05 higher than recorded previously. The same was true for steelhead with a 2012 SPE of 0.832 (0.010). The SPE for subyearling Chinook salmon was 0.783 (0.008) in 2012, and this was considerably higher than the closest comparable study year in 2008, when subyearling Chinook salmon were noted to have a SPE of 0.669.

Table 4.3. Estimates of fish passage efficiencies for yearling Chinook salmon, steelhead, and subyearling Chinook salmon at McNary Dam from 2006 to 2009 and 2012. Standard errors are in parentheses.

Year	Yearling Chinook Salmon	Steelhead	Subyearling Chinook Salmon
2006	0.875 (0.008)	0.898 (0.010)	0.735 (0.011)
2007	0.858 (0.008)	0.957 (0.006)	0.822 (0.009)
2008	0.869 (0.009)	0.917 (0.011)	0.810 (0.010)
2009	0.853 (0.010)	0.930 (0.008)	0.812 (0.010)
2012	0.968 (0.005)	0.977 (0.004)	0.909 (0.006)

Table 4.4. Estimates of spill passage efficiency for yearling Chinook salmon, steelhead, and subyearling Chinook salmon at McNary Dam from 2006 to 2009 and in 2012. Standard errors are in parentheses except for study years 2008 and 2009 because limited information was available.

Year	Yearling Chinook Salmon	Steelhead	Subyearling Chinook Salmon
2006	0.635 (0.012)	0.648 (0.016)	0.540 (0.012)
2007[(a)]	0.571 (0.009)[(a)]	0.785 (0.013)[(a)]	0.611 (0.010)[(a)]
2008	0.657 (0.012)	0.745 (0.014)	0.669
2009	0.538	0.688 (0.013)	0.645
2012	0.725 (0.012)	0.832 (0.010)	0.783 (0.008)

(a) From Adams and Counihan (2009).

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Appendix A

Tests of Assumptions

Appendix A

Test of Assumptions

A.1 Tagger Effects

A.1.1 Spring Study

Data from all five release locations in the two-dam study were examined for tagger effects. This was done to maximize the statistical power to detect tagger effects that might have influenced either or both of the McNary and John Day dam studies.

To minimize any tagger effects that might go undetected, tagger effort should be balanced across release locations and within replicates. A total of eight taggers participated in tagging the yearling Chinook salmon and steelhead during the spring study. Tagger effort was found to be balanced across the five release locations regardless of whether the data were pooled across species $\left(P\left(\chi^2_{28} \geq 7.8016\right) = 0.9999\right)$, or analyzed separately for yearling Chinook salmon $\left(P\left(\chi^2_{28} \geq 4.3024\right) \approx 1\right)$ or steelhead $\left(P\left(\chi^2_{28} \geq 5.1934\right) \approx 1\right)$ (Table A.1).

Tagger effort was examined within each of the 32 replicate releases conducted over the course of the spring study (Table A.2, Table A.3). Tagger effort was found to be balanced within replicates 1, 5, 9, 13, 17, 21, 25, and 29 $(P \approx 1)$. 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) (Table A.2, Table A.3) for the remainder of the replicate release groups. This conditional and unconditional balance within replicates is the reason for the overall balance observed in Table A.1.

To test for tagger effects, reach survivals and cumulative survivals were calculated for fish tagged by different staff members based on release location (i.e., R_1, …, R_5) and species (Table A.4). Of the 38 tests of homogeneous reach survivals, 6 were found to be significant at α = 0.10 (i.e., 15.8%). By chance alone, one might expect 10% of the 38 tests (i.e., 4) to be significant at α = 0.10 when no effect exists. Similarly, we found 11 of 38 tests of homogeneous cumulative survival to be significant at α = 0.10 (i.e., 28.9%). The percentages of rejections are higher than one might expect to see, but detailed examination of the data indicates no particular pattern in the results. No particular tagger had fish with consistently lower survival rates. All taggers had fish releases with the highest and lowest reach survival rates. For some unknown reason, there is more heterogeneity among the survival estimates across taggers than expected by binomial change alone, but no identifiable below-average taggers were observed. For this reason, all fish tagged by all taggers were included in the subsequent survival analyses.

Table A.1. Numbers of yearling Chinook salmon and steelhead tagged by each staff member by release location (i.e., R_1, R_2, ...). Chi-square tests of homogeneity were not significant for (a) yearling Chinook salmon or (b) steelhead.

a. Combined yearling Chinook salmon and steelhead

Release	A	B	C	D	E	F	G	H	*P*-value
R1_CR503	457	297	348	358	288	286	293	472	
R2_CR468	361	257	309	309	248	258	249	406	
R3_CR422	357	258	311	310	235	262	253	412	
R4_CR346	310	222	247	258	190	227	209	334	
R5_CR325	306	223	238	259	199	231	207	332	
Chi-square = 7.8016				df = 28					0.9999

b. Yearling Chinook salmon

Release	A	B	C	D	E	F	G	H	*P*-value
R1_CR503	225	152	172	179	141	145	145	240	
R2_CR468	182	129	155	155	122	127	121	207	
R3_CR422	180	131	157	154	116	131	126	205	
R4_CR346	153	112	124	129	94	113	102	170	
R5_CR325	146	115	115	131	101	115	102	170	
Chi-square = 4.3024				df = 28					1

c. Steelhead

Release	A	B	C	D	E	F	G	H	*P*-value
R1_CR503	232	145	176	179	147	141	148	232	
R2_CR468	179	128	154	154	126	131	128	199	
R3_CR422	177	127	154	156	119	131	127	207	
R4_CR346	157	110	123	129	96	114	107	164	
R5_CR325	160	108	123	128	98	116	105	162	
Chi-square = 5.1934				df = 28					1

Table A.2. Contingency tables with numbers of yearling 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 spring 2012 study. Results of chi-square tests of homogeneity presented in the form of *P*-values.

a. Replicate 1

Release	C	G	E	H	*P*-value
R1_CR503	10	9	9	16	0.9983
R2_CR468	10	7	8	12	
R3_CR422	10	8	7	12	
R4_CR346	9	6	6	11	0.9463
R5_CR325	7	7	6	12	
Chi-square = 0.9358		df = 12			1

b. Replicate 2

Release	C	G	E	H	A	B	D	F	*P*-value
R1_CR503	10	9	9	15	0	0	0	0	
R2_CR468	11	6	8	13	0	0	0	0	0.9864
R3_CR422	12	7	7	12	0	0	0	0	
R4_CR346	0	0	0	0	10	6	9	7	0.9416
R5_CR325	0	0	0	0	10	7	7	8	
Chi-square = 185.6299				df = 28					<0.0001

c. Replicate 3

Release	C	G	E	H	A	B	D	F	*P*-value
R1_CR503	11	10	10	12	0	0	0	0	
R2_CR468	10	7	8	13	0	0	0	0	0.9939
R3_CR422	10	7	8	13	0	0	0	0	
R4_CR346	0	0	0	0	10	6	9	7	0.9819
R5_CR325	0	0	0	0	9	7	8	7	
Chi-square = 83.6099				df = 28					<0.0001

d. Replicate 4

Release	C	G	E	H	A	B	D	F	*P*-value
R1_CR503	11	8	9	16	0	0	0	0	
R2_CR468	10	7	7	14	0	0	0	0	0.9983
R3_CR422	9	8	6	15	0	0	0	0	
R4_CR346	0	0	0	0	11	7	8	6	0.9827
R5_CR325	0	0	0	0	10	6	9	6	
Chi-square = 184.1847				df = 28					<0.0001

Table A.2. (contd)

e. Replicate 5

Release	A	B	D	F	*P*-value
R1_CR503	14	9	11	9	
R2_CR468	12	8	11	7	0.9999
R3_CR422	12	8	10	8	
R4_CR346	10	7	8	7	0.8918
R5_CR325	9	9	8	5	
Chi-square = 1.2926		df = 12			1

f. Replicate 6

Release	C	G	E	H	A	B	D	F	*P*-value
R1_CR503	0	0	0	0	15	9	13	7	
R2_CR468	0	0	0	0	13	8	10	7	0.9983
R3_CR422	0	0	0	0	12	8	10	8	
R4_CR346	8	6	7	10	0	0	0	0	0.9799
R5_CR325	8	7	6	11	0	0	0	0	
Chi-square = 184.2352				df = 28					<0.0001

g. Replicate 7

Release	C	G	E	H	A	B	D	F	*P*-value
R1_CR503	0	0	0	0	15	10	12	6	
R2_CR468	0	0	0	0	11	8	10	9	0.9103
R3_CR422	0	0	0	0	12	6	10	9	
R4_CR346	7	6	7	12	0	0	0	0	1
R5_CR325	7	6	7	12	0	0	0	0	
Chi-square = 185.2379				df = 28					<0.0001

h. Replicate 8

Release	C	G	E	H	A	B	D	F	P-value
R1_CR503	0	0	0	0	15	9	11	9	
R2_CR468	0	0	0	0	13	8	10	7	0.9999
R3_CR422	0	0	0	0	12	8	9	8	
R4_CR346	7	8	5	11	0	0	0	0	0.8848
R5_CR325	7	6	7	10	0	0	0	0	
Chi-square = 182.1678				df = 28					<0.0001

i. Replicate 9

Release	C	G	E	H	*P*-value
R1_CR503	11	9	8	16	
R2_CR468	10	8	7	13	1
R3_CR422	10	8	7	13	
R4_CR346	8	6	6	12	0.9667
R5_CR325	7	7	7	11	
Chi-square = 0.5237		df = 12			1

Table A.2. (contd)

j. Replicate 10

Release	C	G	E	H	A	B	D	F	*P*-value
R1_CR503	11	9	9	14	0	0	0	0	
R2_CR468	10	6	8	14	0	0	0	0	0.9986
R3_CR422	9	7	8	13	0	0	0	0	
R4_CR346	0	0	0	0	11	6	8	7	0.9532
R5_CR325	0	0	0	0	9	7	9	7	
Chi-square = 183.6209				df = 28					<0.0001

k. Replicate 11

Release	C	G	E	H	A	B	D	F	*P*-value
R1_CR503	10	8	10	16	0	0	0	0	
R2_CR468	11	9	6	12	0	0	0	0	0.9633
R3_CR422	9	7	8	14	0	0	0	0	
R4_CR346	0	0	0	0	9	7	9	7	0.9861
R5_CR325	0	0	0	0	9	6	9	8	
Chi-square = 186.6222				df = 28					<0.0001

l. Replicate 12

Release	C	G	E	H	A	B	D	F	*P*-value
R1_CR503	10	9	7	17	0	0	0	0	
R2_CR468	9	9	8	12	0	0	0	0	0.9903
R3_CR422	8	9	8	13	0	0	0	0	
R4_CR346	0	0	0	0	10	7	7	8	0.8837
R5_CR325	0	0	0	0	9	8	9	6	
Chi-square = 186.2008				df = 28					<0.0001

m. Replicate 13

Release	A	B	D	F	*P*-value
R1_CR503	15	9	10	9	
R2_CR468	13	7	10	8	0.9966
R3_CR422	11	8	11	8	
R4_CR346	9	8	8	7	0.9970
R5_CR325	9	8	7	7	
Chi-square = 1.5055		df = 12			0.9999

n. Replicate 14

Release	C	G	E	H	A	B	D	F	*P*-value
R1_CR503	0	0	0	0	14	9	11	9	
R2_CR468	0	0	0	0	12	8	10	8	1
R3_CR422	0	0	0	0	12	8	10	8	
R4_CR346	8	7	6	11	0	0	0	0	0.9861
R5_CR325	7	7	7	11	0	0	0	0	
Chi-square = 183.4326				df = 28					<0.0001

Table A.2. (contd)

o. Replicate 15

Release	C	G	E	H	A	B	D	F	*P*-value
R1_CR503	0	0	0	0	15	9	10	9	
R2_CR468	0	0	0	0	11	8	10	9	0.9918
R3_CR422	0	0	0	0	11	10	9	8	
R4_CR346	9	7	7	9	0	0	0	0	0.9532
R5_CR325	8	7	6	11	0	0	0	0	
Chi-square = 185.2049				df = 28					<0.0001

p. Replicate 16

Release	C	G	E	H	A	B	D	F	*P*-value
R1_CR503	0	0	0	0	16	9	11	8	
R2_CR468	0	0	0	0	10	9	10	8	0.9881
R3_CR422	0	0	0	0	12	9	9	8	
R4_CR346	8	6	6	12	0	0	0	0	0.9532
R5_CR325	8	7	7	10	0	0	0	0	
Chi-square = 185.3927				df = 28					<0.0001

q. Replicate 17

Release	C	G	E	H	*P*-value
R1_CR503	11	9	9	15	
R2_CR468	9	8	9	11	0.9957
R3_CR422	10	9	7	11	
R4_CR346	9	6	6	11	0.9872
R5_CR325	8	6	7	11	
Chi-square = 1.1469		df = 12			1

r. Replicate 18

Release	C	G	E	H	A	B	D	F	*P*-value
R1_CR503	11	10	7	15	0	0	0	0	
R2_CR468	10	8	8	12	0	0	0	0	0.9945
R3_CR422	11	8	8	11	0	0	0	0	
R4_CR346	0	0	0	0	10	7	8	7	0.9493
R5_CR325	0	0	0	0	8	8	8	8	
Chi-square = 185.0954				df = 28					<0.0001

s. Replicate 19

Release	C	G	E	H	A	B	D	F	*P*-value
R1_CR503	11	9	9	14	0	0	0	0	
R2_CR468	10	6	8	13	0	0	0	0	0.9985
R3_CR422	9	7	8	14	0	0	0	0	
R4_CR346	0	0	0	0	8	9	7	7	0.8110
R5_CR325	0	0	0	0	9	6	9	8	
Chi-square = 184.4256				df = 28					<0.0001

Table A.2. (contd)

t. Replicate 20

Release	C	G	E	H	A	B	D	F	*P*-value
R1_CR503	12	9	9	14	0	0	0	0	
R2_CR468	9	8	8	13	0	0	0	0	0.9998
R3_CR422	10	8	7	12	0	0	0	0	
R4_CR346	0	0	0	0	9	7	9	7	0.9437
R5_CR325	0	0	0	0	9	8	7	8	
Chi-square = 184.4286				df = 28					<0.0001

u. Replicate 21

Release	A	B	D	F	*P*-value
R1_CR503	14	9	11	9	
R2_CR468	12	8	9	9	0.9998
R3_CR422	12	9	9	8	
R4_CR346	10	7	7	7	0.9625
R5_CR325	9	7	9	7	
Chi-square = 0.5728		df = 12			1

v. Replicate 22

Release	C	G	E	H	A	B	D	F	*P*-value
R1_CR503	0	0	0	0	13	10	11	10	
R2_CR468	0	0	0	0	12	8	10	8	0.9994
R3_CR422	0	0	0	0	10	9	10	9	
R4_CR346	8	7	6	11	0	0	0	0	0.9847
R5_CR325	8	6	7	11	0	0	0	0	
Chi-square = 184.9371				df = 28					<0.0001

w. Replicate 23

Release	C	G	E	H	A	B	D	F	*P*-value
R1_CR503	0	0	0	0	14	8	11	11	
R2_CR468	0	0	0	0	11	8	10	9	0.9884
R3_CR422	0	0	0	0	11	9	11	7	
R4_CR346	7	7	7	11	0	0	0	0	0.9861
R5_CR325	8	7	6	11	0	0	0	0	
Chi-square = 185.8277				df = 28					<0.0001

x. Replicate 24

Release	C	G	E	H	A	B	D	F	*P*-value
R1_CR503	0	0	0	0	13	10	11	10	
R2_CR468	0	0	0	0	11	9	9	9	1
R3_CR422	0	0	0	0	11	9	10	8	
R4_CR346	8	7	6	11	0	0	0	0	0.9847
R5_CR325	8	6	7	11	0	0	0	0	
Chi-square = 184.6371				df = 28					<0.0001

Table A.2. (contd)

y. Replicate 25

Release	C	G	E	H	*P*-value
R1_CR503	11	10	10	13	
R2_CR468	9	8	7	14	0.9948
R3_CR422	10	8	7	13	
R4_CR346	8	7	6	11	1
R5_CR325	8	7	6	11	
Chi-square = 0.7352		df = 12			1

z. Replicate 26

Release	C	G	E	H	A	B	D	F	*P*-value
R1_CR503	11	9	9	15	0	0	0	0	
R2_CR468	8	8	8	14	0	0	0	0	0.9937
R3_CR422	10	9	6	13	0	0	0	0	
R4_CR346	0	0	0	0	8	7	8	7	0.9977
R5_CR325	0	0	0	0	9	7	8	7	
Chi-square = 182.2335				df = 28					<0.0001

aa. Replicate 27

Release	C	G	E	H	A	B	D	F	*P*-value
R1_CR503	11	9	9	15	0	0	0	0	
R2_CR468	9	8	7	14	0	0	0	0	0.9999
R3_CR422	10	8	7	13	0	0	0	0	
R4_CR346	0	0	0	0	9	6	8	8	0.9807
R5_CR325	0	0	0	0	10	7	8	7	
Chi-square = 183.7856				df = 28					<0.0001

bb. Replicate 28

Release	C	G	E	H	A	B	D	F	P-value
R1_CR503	10	9	8	17	0	0	0	0	
R2_CR468	10	8	7	13	0	0	0	0	0.9995
R3_CR422	10	8	7	13	0	0	0	0	
R4_CR346	0	0	0	0	10	8	8	6	0.9392
R5_CR325	0	0	0	0	9	7	8	8	
Chi-square = 185.6268				df = 28					<0.0001

cc. Replicate 29

Release	A	B	D	F	*P*-value
R1_CR503	13	10	11	10	
R2_CR468	11	9	10	7	0.9992
R3_CR422	11	8	10	9	
R4_CR346	9	7	8	8	1
R5_CR325	9	7	8	8	
Chi-square = 0.5707		df = 12			1

Table A.2. (contd)

dd. Replicate 30

Release	C	G	E	H	A	B	D	F	*P*-value
R1_CR503	0	0	0	0	13	10	12	9	
R2_CR468	0	0	0	0	11	8	10	9	0.9999
R3_CR422	0	0	0	0	11	8	10	9	
R4_CR346	9	7	4	12	0	0	0	0	0.7768
R5_CR325	6	6	6	13	0	0	0	0	
Chi-square = 186.4709				df = 28					<0.0001

ee. Replicate 31

Release	C	G	E	H	A	B	D	F	*P*-value
R1_CR503	0	0	0	0	14	11	12	10	
R2_CR468	0	0	0	0	9	8	8	7	0.9998
R3_CR422	0	0	0	0	10	7	8	8	
R4_CR346	6	4	5	8	0	0	0	0	0.9460
R5_CR325	5	5	4	9	0	0	0	0	
Chi-square = 159.5936				df = 28					<0.0001

ff. Replicate 32

Release	C	G	E	H	A	B	D	F	*P*-value
R1_CR503	0	0	0	0	12	11	11	10	
R2_CR468	0	0	0	0	10	7	8	6	0.9981
R3_CR422	0	0	0	0	10	7	8	8	
R4_CR346	5	5	4	7	0	0	0	0	0.9360
R5_CR325	5	5	5	5	0	0	0	0	
Chi-square = 151.1879				df = 28					<0.0001

Table A.3. Contingency tables with numbers of steelhead tagged by each staff member per release location within a replicate release. A total of 32 replicate day or nighttime releases were performed over the course of the spring 2012 study. Results of chi-square tests of homogeneity are presented in the form of *P*-values.

a. Replicate 1

Release	C	G	E	H	*P*-value
R1_CR503	11	8	10	15	
R2_CR468	10	7	8	12	0.9993
R3_CR422	10	8	7	13	
R4_CR346	8	6	7	11	1
R5_CR325	8	6	7	11	
Chi-square = 0.3823		df = 12			1

b. Replicate 2

Release	C	G	E	H	A	B	D	F	*P*-value
R1_CR503	10	8	10	16	0	0	0	0	
R2_CR468	9	7	8	14	0	0	0	0	1
R3_CR422	9	7	8	14	0	0	0	0	
R4_CR346	0	0	0	0	11	7	8	6	0.9872
R5_CR325	0	0	0	0	11	6	9	6	
Chi-square = 184.4663				df = 28					<0.0001

c. Replicate 3

Release	C	G	E	H	A	B	D	F	*P*-value
R1_CR503	12	9	11	12	0	0	0	0	
R2_CR468	9	8	7	14	0	0	0	0	0.9600
R3_CR422	9	8	7	14	0	0	0	0	
R4_CR346	0	0	0	0	11	7	8	6	0.9667
R5_CR325	0	0	0	0	12	6	7	7	
Chi-square = 187.048				df = 28					<0.0001

d. Replicate 4

Release	C	G	E	H	A	B	D	F	*P*-value
R1_CR503	11	9	10	14	0	0	0	0	
R2_CR468	9	8	8	13	0	0	0	0	1
R3_CR422	9	8	8	13	0	0	0	0	
R4_CR346	0	0	0	0	11	6	7	7	0.9970
R5_CR325	0	0	0	0	11	6	8	7	
Chi-square = 183.3133				df = 28					<0.0001

Table A.3. (contd)

e. Replicate 5

Release	A	B	D	F	*P*-value
R1_CR503	15	8	12	9	
R2_CR468	12	9	10	7	0.9985
R3_CR422	12	8	10	8	
R4_CR346	11	6	8	6	0.9768
R5_CR325	11	7	7	7	
Chi-square = 0.8446			df = 12		1

f. Replicate 6

Release	C	G	E	H	A	B	D	F	*P*-value
R1_CR503	0	0	0	0	15	8	11	9	
R2_CR468	0	0	0	0	13	8	9	8	0.9998
R3_CR422	0	0	0	0	13	7	10	7	
R4_CR346	9	6	6	11	0	0	0	0	0.9419
R5_CR325	8	6	8	10	0	0	0	0	
Chi-square = 183.4433				df = 28					<0.0001

g. Replicate 7

Release	C	G	E	H	A	B	D	F	*P*-value
R1_CR503	0	0	0	0	14	10	11	9	
R2_CR468	0	0	0	0	12	7	10	9	0.9980
R3_CR422	0	0	0	0	12	7	11	8	
R4_CR346	7	7	6	12	0	0	0	0	0.9906
R5_CR325	8	7	6	11	0	0	0	0	
Chi-square = 185.0656				df = 28					<0.0001

h. Replicate 8

Release	C	G	E	H	A	B	D	F	*P*-value
R1_CR503	0	0	0	0	14	9	12	9	
R2_CR468	0	0	0	0	12	7	11	8	0.9999
R3_CR422	0	0	0	0	13	7	10	8	
R4_CR346	8	7	6	11	0	0	0	0	0.9847
R5_CR325	8	6	7	11	0	0	0	0	
Chi-square = 184.6945				df = 28					<0.0001

Table A.3. (contd)

i. Replicate 9

Release	C	G	E	H	*P*-value
R1_CR503	11	9	9	15	
R2_CR468	9	9	8	12	0.9974
R3_CR422	10	7	7	14	
R4_CR346	7	7	6	11	0.9970
R5_CR325	8	7	6	11	
Chi-square = 0.6691		df = 12			1

j. Replicate 10

Release	C	G	E	H	A	B	D	F	*P*-value
R1_CR503	11	10	9	14	0	0	0	0	
R2_CR468	11	8	8	11	0	0	0	0	0.9986
R3_CR422	9	8	8	13	0	0	0	0	
R4_CR346	0	0	0	0	10	7	8	7	1
R5_CR325	0	0	0	0	10	7	8	7	
Chi-square = 184.6593				df = 28					<0.0001

k. Replicate 11

Release	C	G	E	H	A	B	D	F	*P*-value
R1_CR503	11	9	9	15	0	0	0	0	
R2_CR468	10	8	8	12	0	0	0	0	0.9974
R3_CR422	9	9	6	13	0	0	0	0	
R4_CR346	0	0	0	0	11	6	8	7	0.9516
R5_CR325	0	0	0	0	9	7	8	8	
Chi-square = 184.8016				df = 28					<0.0001

l. Replicate 12

Release	C	G	E	H	A	B	D	F	*P*-value
R1_CR503	10	10	9	14	0	0	0	0	
R2_CR468	10	7	8	13	0	0	0	0	0.9976
R3_CR422	9	7	8	14	0	0	0	0	
R4_CR346	0	0	0	0	11	6	8	7	0.9887
R5_CR325	0	0	0	0	10	7	8	7	
Chi-square = 184.1484				df = 28					<0.0001

Table A.3. (contd)

m. Replicate 13

Release	A	B	D	F	*P*-value
R1_CR503	15	10	10	9	0.9976
R2_CR468	12	8	10	8	
R3_CR422	11	8	11	8	
R4_CR346	9	7	9	7	0.9904
R5_CR325	10	7	8	7	
Chi-square = 0.7161			df = 12		1

n. Replicate 14

Release	C	G	E	H	A	B	D	F	*P*-value
R1_CR503	0	0	0	0	15	9	11	9	0.9999
R2_CR468	0	0	0	0	12	8	10	8	
R3_CR422	0	0	0	0	11	8	10	8	
R4_CR346	7	7	7	11	0	0	0	0	0.9861
R5_CR325	8	7	6	11	0	0	0	0	
Chi-square = 183.6893				df = 28					<0.0001

o. Replicate 15

Release	C	G	E	H	A	B	D	F	P-value
R1_CR503	0	0	0	0	15	9	12	8	0.9691
R2_CR468	0	0	0	0	11	8	10	9	
R3_CR422	0	0	0	0	11	10	8	9	
R4_CR346	7	8	7	9	0	0	0	0	0.9027
R5_CR325	9	6	7	10	0	0	0	0	
Chi-square = 186.7155				df = 28					<0.0001

p. Replicate 16

Release	C	G	E	H	A	B	D	F	*P*-value
R1_CR503	0	0	0	0	14	9	12	9	0.9361
R2_CR468	0	0	0	0	8	10	11	9	
R3_CR422	0	0	0	0	12	7	10	9	
R4_CR346	9	7	6	10	0	0	0	0	0.9886
R5_CR325	8	8	6	10	0	0	0	0	
Chi-square = 187.1404				df = 28					<0.0001

Table A.3. (contd)

q. Replicate 17

Release	C	G	E	H	*P*-value
R1_CR503	12	9	8	15	
R2_CR468	10	9	9	10	0.9882
R3_CR422	10	9	7	12	
R4_CR346	8	7	6	11	0.9911
R5_CR325	9	7	6	10	
Chi-square = 1.1282		df = 12			1

r. Replicate 18

Release	C	G	E	H	A	B	D	F	*P*-value
R1_CR503	11	9	10	14	0	0	0	0	
R2_CR468	10	7	8	13	0	0	0	0	0.9994
R3_CR422	10	8	7	13	0	0	0	0	
R4_CR346	0	0	0	0	9	7	8	8	0.9894
R5_CR325	0	0	0	0	10	7	8	7	
Chi-square = 184.8371				df = 28					<0.0001

s. Replicate 19

Release	C	G	E	H	A	B	D	F	*P*-value
R1_CR503	11	9	9	15	0	0	0	0	
R2_CR468	9	9	8	12	0	0	0	0	0.9998
R3_CR422	10	8	8	12	0	0	0	0	
R4_CR346	0	0	0	0	9	9	7	7	0.9465
R5_CR325	0	0	0	0	10	7	7	8	
Chi-square = 185.3981				df = 28					<0.0001

t. Replicate 20

Release	C	G	E	H	A	B	D	F	*P*-value
R1_CR503	11	10	9	14	0	0	0	0	
R2_CR468	9	8	7	14	0	0	0	0	0.9941
R3_CR422	11	9	7	11	0	0	0	0	
R4_CR346	0	0	0	0	8	7	9	8	0.9508
R5_CR325	0	0	0	0	10	7	8	7	
Chi-square = 186.0989				df = 28					<0.0001

Table A.3. (contd)

u. Replicate 21

Release	A	B	D	F	*P*-value
R1_CR503	16	9	11	8	
R2_CR468	11	8	10	8	0.9925
R3_CR422	11	8	10	9	
R4_CR346	10	7	8	7	1
R5_CR325	10	7	8	7	
Chi-square = 0.8351		df = 12			1

v. Replicate 22

Release	C	G	E	H	A	B	D	F	*P*-value
R1_CR503	0	0	0	0	15	10	10	9	
R2_CR468	0	0	0	0	11	8	10	9	0.9972
R3_CR422	0	0	0	0	11	8	10	9	
R4_CR346	9	7	6	10	0	0	0	0	0.9872
R5_CR325	8	7	7	10	0	0	0	0	
Chi-square = 185.2304				df = 28					<0.0001

w. Replicate 23

Release	C	G	E	H	A	B	D	F	*P*-value
R1_CR503	0	0	0	0	15	9	11	9	
R2_CR468	0	0	0	0	11	8	9	10	0.9804
R3_CR422	0	0	0	0	10	9	11	8	
R4_CR346	8	7	6	11	0	0	0	0	0.9901
R5_CR325	8	8	6	10	0	0	0	0	
Chi-square = 186.0532				df = 28					<0.0001

x. Replicate 24

Release	C	G	E	H	A	B	D	F	*P*-value
R1_CR503	0	0	0	0	15	9	11	9	
R2_CR468	0	0	0	0	11	9	10	8	0.9948
R3_CR422	0	0	0	0	10	9	10	9	
R4_CR346	8	7	7	10	0	0	0	0	0.9887
R5_CR325	8	7	6	11	0	0	0	0	
Chi-square = 185.4116				df = 28					<0.0001

Table A.3. (contd)

y. Replicate 25

Release	C	G	E	H	*P*-value
R1_CR503	12	10	8	14	
R2_CR468	10	8	8	12	0.9992
R3_CR422	10	7	8	13	
R4_CR346	8	7	6	11	0.9876
R5_CR325	7	8	6	11	
Chi-square = 0.8632		df = 12			1

z. Replicate 26

Release	C	G	E	H	A	B	D	F	*P*-value
R1_CR503	11	9	9	15	0	0	0	0	
R2_CR468	8	9	8	13	0	0	0	0	0.9987
R3_CR422	10	8	7	13	0	0	0	0	
R4_CR346	0	0	0	0	8	7	9	8	0.9488
R5_CR325	0	0	0	0	10	6	8	8	
Chi-square = 185.6711				df = 28					<0.0001

aa. Replicate 27

Release	C	G	E	H	A	B	D	F	*P*-value
R1_CR503	10	9	9	16	0	0	0	0	
R2_CR468	10	8	7	13	0	0	0	0	0.9994
R3_CR422	10	7	8	13	0	0	0	0	
R4_CR346	0	0	0	0	9	7	8	8	0.9886
R5_CR325	0	0	0	0	9	7	9	7	
Chi-square = 184.8612				df = 28					<0.0001

bb. Replicate 28

Release	C	G	E	H	A	B	D	F	*P*-value
R1_CR503	11	11	8	14	0	0	0	0	
R2_CR468	11	8	8	11	0	0	0	0	0.9973
R3_CR422	9	9	8	12	0	0	0	0	
R4_CR346	0	0	0	0	9	7	8	8	1
R5_CR325	0	0	0	0	9	7	8	8	
Chi-square = 184.8293				df = 28					<0.0001

Table A.3. (contd)

cc. Replicate 29

Release	A	B	D	F	*P*-value
R1_CR503	14	9	11	10	
R2_CR468	12	8	10	8	0.9998
R3_CR422	11	9	10	8	
R4_CR346	10	7	8	7	0.9508
R5_CR325	8	7	9	8	
Chi-square = 0.7372		df = 12			1

dd. Replicate 30

Release	C	G	E	H	A	B	D	F	*P*-value
R1_CR503	0	0	0	0	14	9	12	9	
R2_CR468	0	0	0	0	12	9	9	8	0.9984
R3_CR422	0	0	0	0	11	9	9	9	
R4_CR346	9	7	5	11	0	0	0	0	0.9853
R5_CR325	8	7	6	11	0	0	0	0	
Chi-square = 185.113				df = 28					<0.0001

ee. Replicate 31

Release	C	G	E	H	A	B	D	F	*P*-value
R1_CR503	0	0	0	0	13	9	10	8	
R2_CR468	0	0	0	0	10	6	8	7	0.9997
R3_CR422	0	0	0	0	9	7	8	7	
R4_CR346	6	5	5	7	0	0	0	0	0.9594
R5_CR325	4	5	4	7	0	0	0	0	
Chi-square = 146.3932				df = 28					<0.0001

ff. Replicate 32

Release	C	G	E	H	A	B	D	F	*P*-value
R1_CR503	0	0	0	0	13	9	12	8	
R2_CR468	0	0	0	0	9	7	7	7	0.9981
R3_CR422	0	0	0	0	9	6	8	7	
R4_CR346	5	5	4	7	0	0	0	0	0.9040
R5_CR325	6	3	4	7	0	0	0	0	
Chi-square = 145.6468				df = 28					<0.0001

Table A.4. Estimates of reach survival and cumulative survival for a) yearling Chinook salmon and b) steelhead, along with P-values associated with the F-tests of homogeneous survival across fish tagged by different staff members.

a. Yearling Chinook salmon

1) Release 1 (CR503) – Reach survival

	Release to CR422.0		CR422.0 to CR349.0		CR349.0 to CR325.0		CR325.0 to CR309.0		CR309.0 to CR234.0	
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE
A	0.9111	0.0190	0.9317	0.0176	0.9686	0.0126	0.9784	0.0107	0.9344	0.0185
B	0.8947	0.0249	0.9268	0.0224	0.9600	0.0175	1.0000	0.0000	0.9179	0.0251
C	0.9012	0.0228	0.9484	0.0178	0.9660	0.0150	0.9937	0.0071	0.9098	0.0247
D	0.8994	0.0225	0.9503	0.0171	0.9605	0.0158	1.0000	0.0000	0.9394	0.0199
E	0.8571	0.0296	0.9667	0.0164	0.9828	0.0121	0.9831	0.0123	0.9316	0.0247
F	0.8968	0.0253	0.9615	0.0170	0.9678	0.0159	0.9917	0.0083	0.9510	0.0199
G	0.9241	0.0220	0.9403	0.0205	0.9762	0.0136	0.9919	0.0081	0.9365	0.0225
H	0.9042	0.0190	0.9631	0.0128	0.9809	0.0095	0.9902	0.0069	0.9416	0.0166
P-value	0.6922		0.6846		0.9160		0.6937		0.9199	

2) Release 1 (CR503) – Cumulative survival

	Release to CR422.0		Release to CR349.0		Release to CR325.0		Release to CR309.0		Release to CR234.0	
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE
A	0.9111	0.0190	0.8489	0.0239	0.8222	0.0255	0.8044	0.0264	0.7517	0.0289
B	0.8947	0.0249	0.8292	0.0306	0.7961	0.0327	0.7961	0.0327	0.7307	0.0360
C	0.9012	0.0228	0.8547	0.0269	0.8256	0.0289	0.8204	0.0293	0.7464	0.0334
D	0.8994	0.0225	0.8547	0.0263	0.8210	0.0287	0.8210	0.0287	0.7712	0.0315
E	0.8571	0.0296	0.8286	0.0319	0.8143	0.0329	0.8006	0.0338	0.7458	0.0371
F	0.8968	0.0253	0.8623	0.0286	0.8345	0.0309	0.8276	0.0314	0.7871	0.0341
G	0.9241	0.0220	0.8690	0.0280	0.8483	0.0298	0.8414	0.0303	0.7880	0.0342
H	0.9042	0.0190	0.8708	0.0216	0.8542	0.0228	0.8458	0.0233	0.7964	0.0260
P-value	0.6922		0.9309		0.8989		0.9116		0.8012	

Table A.4. (contd)

3) 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 CR234.0	
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE
A	0.9066	0.0216	0.9879	0.0085	0.9691	0.0136	0.9809	0.0109	0.9420	0.0189
B	0.9147	0.0246	0.9407	0.0217	0.9369	0.0231	0.9904	0.0096	0.9728	0.0167
C	0.9161	0.0223	0.9718	0.0139	0.9639	0.0159	0.9848	0.0106	0.9425	0.0211
D	0.9484	0.0178	0.9456	0.0187	0.9565	0.0174	0.9924	0.0075	0.9084	0.0252
E	0.9262	0.0237	0.9912	0.0088	0.9821	0.0125	1.0000	0.0000	0.9733	0.0155
F	0.9055	0.0260	0.9478	0.0207	0.9266	0.0250	0.9901	0.0099	0.9504	0.0218
G	0.9587	0.0181	0.9914	0.0086	0.9826	0.0122	1.0000	0.0000	0.9395	0.0227
H	0.9227	0.0186	0.9895	0.0074	0.9365	0.0177	0.9892	0.0080	0.9257	0.0199
P-value	0.6034		0.0208		0.1745		0.8435		0.3297	

4) Release 2 (CR468) –Cumulative survival

	Release to CR422.0		Release to CR349.0		Release to CR325.0		Release to CR309.0		Release to CR234.0	
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE
A	0.9066	0.0216	0.8956	0.0227	0.8680	0.0251	0.8514	0.0264	0.8020	0.0296
B	0.9147	0.0246	0.8605	0.0305	0.8062	0.0348	0.7985	0.0353	0.7768	0.0369
C	0.9161	0.0223	0.8903	0.0251	0.8582	0.0280	0.8452	0.0291	0.7965	0.0327
D	0.9484	0.0178	0.8968	0.0244	0.8578	0.0281	0.8513	0.0286	0.7733	0.0337
E	0.9262	0.0237	0.9180	0.0248	0.9016	0.0270	0.9016	0.0270	0.8775	0.0298
F	0.9055	0.0260	0.8583	0.0309	0.7953	0.0358	0.7874	0.0363	0.7484	0.0385
G	0.9587	0.0181	0.9504	0.0197	0.9339	0.0226	0.9339	0.0226	0.8774	0.0300
H	0.9227	0.0186	0.9130	0.0196	0.8551	0.0245	0.8458	0.0251	0.7830	0.0287
P-value	0.6034		0.1751		0.0140		0.0077		0.0353	

Table A.4. (contd)

5) Release 3 (CR422) – Reach survival

	Release to CR349.0		CR349.0 to CR325.0		CR325.0 to CR309.0		CR309.0 to CR234.0	
	Est	SE	Est	SE	Est	SE	Est	SE
A	0.9389	0.0179	0.9527	0.0163	1.0000	0.0000	0.9516	0.0172
B	0.9389	0.0209	0.9098	0.0259	0.9910	0.0090	0.9455	0.0217
C	0.9745	0.0126	0.9542	0.0169	1.0000	0.0000	0.9272	0.0220
D	0.9482	0.0179	0.9723	0.0137	0.9929	0.0071	0.9357	0.0207
E	0.9397	0.0221	0.9817	0.0129	1.0006	0.0006	0.9443	0.0225
F	0.9313	0.0221	0.9672	0.0161	0.9746	0.0145	0.9056	0.0275
G	0.9524	0.0190	0.9667	0.0164	0.9569	0.0189	0.9662	0.0178
H	0.9317	0.0176	0.9581	0.0145	0.9891	0.0077	0.9415	0.0178
P-value	0.7931		0.1229		0.0752		0.6593	

6) Release 3 (CR422) – Cumulative survival

	Release to CR349.0		Release to CR325.0		Release to CR309.0		Release to CR234.0	
	Est	SE	Est	SE	Est	SE	Est	SE
A	0.9389	0.0179	0.8944	0.0229	0.8944	0.0229	0.8512	0.0267
B	0.9389	0.0209	0.8543	0.0309	0.8466	0.0316	0.8004	0.0350
C	0.9745	0.0126	0.9299	0.0204	0.9299	0.0204	0.8622	0.0278
D	0.9482	0.0179	0.9219	0.0217	0.9154	0.0225	0.8565	0.0283
E	0.9397	0.0221	0.9224	0.0248	0.9229	0.0249	0.8715	0.0312
F	0.9313	0.0221	0.9008	0.0261	0.8779	0.0286	0.7950	0.0354
G	0.9524	0.0190	0.9206	0.0241	0.8810	0.0289	0.8512	0.0320
H	0.9317	0.0176	0.8927	0.0216	0.8829	0.0225	0.8313	0.0264
P-value	0.7931		0.3975		0.3121		0.5294	

Table A.4. (contd)

7) Release 4 (CR346) – Reach survival

	Release to CR325.0		CR325.0 to CR309.0		CR309.0 to CR234.0	
	Est	SE	Est	SE	Est	SE
A	0.9935	0.0065	0.9737	0.0130	0.9126	0.0233
B	1.0002	0.0002	0.9820	0.0126	0.9560	0.0199
C	0.9919	0.0080	0.9919	0.0081	0.9705	0.0163
D	1.0000	0.0000	0.9767	0.0133	0.9534	0.0190
E	1.0000	0.0000	0.9574	0.0208	0.9558	0.0217
F	0.9912	0.0088	1.0000	0.0000	0.9291	0.0244
G	1.0000	0.0000	0.9902	0.0098	0.9406	0.0235
H	1.0000	0.0000	0.9941	0.0059	0.9529	0.0163
P-value	0.9217		0.3168		0.6115	

8) Release 4 (CR346) – Cumulative survival

	Release to CR325.0		Release to CR309.0		Release to CR234.0	
	Est	SE	Est	SE	Est	SE
A	0.9935	0.0065	0.9673	0.0144	0.8828	0.0261
B	1.0002	0.0002	0.9821	0.0125	0.9390	0.0229
C	0.9919	0.0080	0.9839	0.0113	0.9548	0.0194
D	1.0000	0.0000	0.9767	0.0133	0.9312	0.0225
E	1.0000	0.0000	0.9574	0.0208	0.9152	0.0288
F	0.9912	0.0088	0.9912	0.0088	0.9209	0.0255
G	1.0000	0.0000	0.9902	0.0098	0.9314	0.0250
H	1.0000	0.0000	0.9941	0.0059	0.9473	0.0172
P-value	0.9217		0.4389		0.5142	

Table A.4. (contd)

9) Release 5 (CR325) – Reach survival

	Release to CR309.0		CR309.0 to CR234.0	
	Est	SE	Est	SE
A	0.9932	0.0068	0.9385	0.0201
B	0.9826	0.0122	0.9217	0.0255
C	0.9913	0.0087	0.9744	0.0150
D	0.9771	0.0131	0.9551	0.0188
E	0.9802	0.0139	0.9192	0.0274
F	0.9826	0.0122	0.9207	0.0255
G	0.9804	0.0137	0.8909	0.0313
H	0.9941	0.0059	0.9121	0.0219
P-value	0.9313		0.2886	

10) Release 5 (CR325) – Cumulative survival

	Release to CR309.0		Release to CR234.0	
	Est	SE	Est	SE
A	0.9932	0.0068	0.9321	0.0209
B	0.9826	0.0122	0.9057	0.0275
C	0.9913	0.0087	0.9659	0.0171
D	0.9771	0.0131	0.9332	0.0222
E	0.9802	0.0139	0.9010	0.0297
F	0.9826	0.0122	0.9047	0.0274
G	0.9804	0.0137	0.8734	0.0331
H	0.9941	0.0059	0.9067	0.0224
P-value	0.9313		0.3072	

Table A.4. (contd)

b. Steelhead

1) Release 1 (CR503) – Reach survival

	Release to CR422.0		CR422.0 to CR349.0		CR349.0 to CR325.0		CR325.0 to CR309.0		CR309.0 to CR234.0	
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE
A	0.8796	0.0214	0.9310	0.0178	0.9474	0.0162	1.0000	0.0000	0.9722	0.0122
B	0.7986	0.0334	0.9652	0.0171	0.9369	0.0231	1.0000	0.0000	0.9245	0.0262
C	0.8239	0.0287	0.9448	0.0190	1.0000	0.0000	1.0000	0.0000	0.9726	0.0145
D	0.7933	0.0303	0.9577	0.0169	0.9779	0.0126	0.9925	0.0075	0.9404	0.0208
E	0.8844	0.0264	0.9692	0.0151	0.9920	0.0080	1.0005	0.0005	0.9709	0.0163
F	0.8298	0.0317	0.9231	0.0246	0.9811	0.0132	0.9904	0.0096	0.9417	0.0231
G	0.8851	0.0262	0.9389	0.0209	0.9752	0.0141	1.0000	0.0000	0.9792	0.0148
H	0.8966	0.0200	0.9618	0.0133	0.9746	0.0112	1.0006	0.0005	0.9482	0.0170
P-value	0.0229		0.5406		0.0428		0.8714		0.3292	

2) Release 1 (CR503) – Cumulative survival

	Release to CR422.0		Release to CR349.0		Release to CR325.0		Release to CR309.0		Release to CR234.0	
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE
A	0.8796	0.0214	0.8190	0.0253	0.7759	0.0274	0.7759	0.0274	0.7543	0.0283
B	0.7986	0.0334	0.7708	0.0350	0.7222	0.0373	0.7222	0.0373	0.6677	0.0394
C	0.8239	0.0287	0.7784	0.0313	0.7784	0.0313	0.7784	0.0313	0.7571	0.0325
D	0.7933	0.0303	0.7598	0.0319	0.7430	0.0327	0.7374	0.0329	0.6935	0.0345
E	0.8844	0.0264	0.8571	0.0289	0.8503	0.0294	0.8508	0.0295	0.8260	0.0317
F	0.8298	0.0317	0.7660	0.0357	0.7515	0.0364	0.7443	0.0368	0.7009	0.0387
G	0.8851	0.0262	0.8311	0.0308	0.8105	0.0323	0.8105	0.0323	0.7937	0.0338
H	0.8966	0.0200	0.8623	0.0226	0.8404	0.0241	0.8409	0.0241	0.7973	0.0269
P-value	0.0229		0.0661		0.0370		0.0256		0.0057	

Table A.4. (contd)

3) 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 CR234.0	
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE
A	0.9162	0.0207	0.9451	0.0178	0.9739	0.0129	0.9933	0.0067	0.9688	0.0150
B	0.8828	0.0284	0.9115	0.0267	0.9902	0.0098	1.0000	0.0000	0.9219	0.0269
C	0.9351	0.0199	0.9375	0.0202	0.9704	0.0146	1.0000	0.0000	0.9589	0.0185
D	0.9286	0.0208	0.9231	0.0223	0.9847	0.0107	1.0000	0.0000	0.9690	0.0153
E	0.8810	0.0289	0.9640	0.0177	0.9810	0.0133	0.9908	0.0097	0.9536	0.0218
F	0.9160	0.0242	0.9417	0.0214	0.9643	0.0175	1.0000	0.0000	0.9820	0.0130
G	0.9297	0.0226	0.9160	0.0254	1.0002	0.0002	0.9811	0.0132	0.9161	0.0274
H	0.9196	0.0193	0.9290	0.0190	0.9706	0.0130	0.9939	0.0060	0.9417	0.0188
P-value	0.5984		0.7263		0.4919		0.8238		0.2294	

4) Release 2 (CR468) – Cumulative survival

	Release to CR422.0		Release to CR349.0		Release to CR325.0		Release to CR309.0		Release to CR234.0	
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE
A	0.9162	0.0207	0.8659	0.0255	0.8433	0.0272	0.8376	0.0276	0.8115	0.0295
B	0.8828	0.0284	0.8047	0.0350	0.7968	0.0356	0.7968	0.0356	0.7345	0.0392
C	0.9351	0.0199	0.8766	0.0265	0.8506	0.0287	0.8506	0.0287	0.8156	0.0317
D	0.9286	0.0208	0.8571	0.0282	0.8441	0.0292	0.8441	0.0292	0.8179	0.0311
E	0.8810	0.0289	0.8492	0.0319	0.8330	0.0333	0.8254	0.0339	0.7871	0.0369
F	0.9160	0.0242	0.8626	0.0301	0.8318	0.0327	0.8318	0.0327	0.8169	0.0339
G	0.9297	0.0226	0.8516	0.0314	0.8517	0.0314	0.8356	0.0328	0.7655	0.0378
H	0.9196	0.0193	0.8543	0.0250	0.8291	0.0267	0.8241	0.0270	0.7761	0.0298
P-value	0.5984		0.8151		0.9408		0.9634		0.5815	

Table A.4. (contd)

5) Release 3 (CR422) – Reach survival

	Release to CR349.0		CR349.0 to CR325.0		CR325.0 to CR309.0		CR309.0 to CR234.0	
	Est	SE	Est	SE	Est	SE	Est	SE
A	0.9266	0.0196	0.9695	0.0134	0.9937	0.0063	0.9624	0.0152
B	0.9291	0.0228	0.9487	0.0204	1.0000	0.0000	0.9647	0.0177
C	0.9805	0.0111	0.9868	0.0093	0.9866	0.0094	0.9497	0.0189
D	0.9359	0.0196	0.9583	0.0167	0.9928	0.0072	0.9799	0.0126
E	0.9496	0.0201	0.9732	0.0153	0.9908	0.0091	0.9630	0.0182
F	0.9313	0.0221	0.9664	0.0165	1.0000	0.0000	0.9489	0.0208
G	0.9055	0.0260	0.9561	0.0192	1.0000	0.0000	0.9770	0.0159
H	0.9324	0.0175	0.9789	0.0104	0.9839	0.0092	0.9704	0.0133
P-value	0.3370		0.7138		0.7856		0.8674	

6) Release 3 (CR422) – Reach survival

	Release to CR349.0		Release to CR325.0		Release to CR309.0		Release to CR234.0	
	Est	SE	Est	SE	Est	SE	Est	SE
A	0.9266	0.0196	0.8983	0.0227	0.8927	0.0233	0.8591	0.0262
B	0.9291	0.0228	0.8815	0.0287	0.8815	0.0287	0.8504	0.0318
C	0.9805	0.0111	0.9675	0.0143	0.9545	0.0168	0.9065	0.0241
D	0.9359	0.0196	0.8969	0.0244	0.8904	0.0251	0.8725	0.0270
E	0.9496	0.0201	0.9241	0.0243	0.9157	0.0255	0.8818	0.0297
F	0.9313	0.0221	0.9000	0.0263	0.9000	0.0263	0.8540	0.0312
G	0.9055	0.0260	0.8658	0.0303	0.8658	0.0303	0.8459	0.0327
H	0.9324	0.0175	0.9127	0.0197	0.8980	0.0211	0.8715	0.0237
P-value	0.3370		0.1350		0.3479		0.8434	

Table A.4. (contd)

7) Release 4 (CR346) – Reach survival

	Release to CR325.0		CR325.0 to CR309.0		CR309.0 to CR234.0	
	Est	SE	Est	SE	Est	SE
A	0.9936	0.0063	0.9936	0.0064	0.9742	0.0127
B	1.0000	0.0000	1.0000	0.0000	0.9639	0.0179
C	0.9919	0.0081	1.0005	0.0005	0.9446	0.0213
D	0.9535	0.0185	0.9919	0.0081	0.9597	0.0180
E	1.0000	0.0000	1.0009	0.0008	0.9589	0.0209
F	0.9825	0.0123	0.9911	0.0089	0.9657	0.0178
G	0.9720	0.0160	1.0000	0.0000	0.9327	0.0246
H	0.9939	0.0061	0.9816	0.0105	0.9693	0.0138
P-value	0.0947		0.4834		0.8119	

8) Release 4 (CR346) – Cumulative survival

	Release to CR325.0		Release to CR309.0		Release to CR234.0	
	Est	SE	Est	SE	Est	SE
A	0.9936	0.0063	0.9873	0.0090	0.9618	0.0153
B	1.0000	0.0000	1.0000	0.0000	0.9639	0.0179
C	0.9919	0.0081	0.9924	0.0081	0.9374	0.0223
D	0.9535	0.0185	0.9457	0.0199	0.9076	0.0256
E	1.0000	0.0000	1.0009	0.0008	0.9598	0.0205
F	0.9825	0.0123	0.9737	0.0150	0.9402	0.0226
G	0.9720	0.0160	0.9720	0.0160	0.9065	0.0281
H	0.9939	0.0061	0.9756	0.0120	0.9456	0.0178
P-value	0.0947		0.0512		0.3512	

Table A.4. (contd)

9) Release 5 (CR325) – Reach survival

	Release to CR309.0		CR309.0 to CR234.0	
	Est	SE	Est	SE
A	0.9879	0.0088	0.9471	0.0188
B	1.0000	0.0000	0.9458	0.0221
C	0.9593	0.0178	0.9492	0.0202
D	0.9688	0.0154	0.9362	0.0221
E	1.0000	0.0000	0.9204	0.0278
F	0.9655	0.0169	0.9470	0.0213
G	0.9905	0.0095	0.9622	0.0189
H	0.9447	0.0180	0.9555	0.0171
P-value	0.0688		0.9297	

10) Release 5 (CR325) – Cumulative survival

	Release to CR309.0		Release to CR234.0	
	Est	SE	Est	SE
A	0.9879	0.0088	0.9357	0.0202
B	1.0000	0.0000	0.9458	0.0221
C	0.9594	0.0178	0.9106	0.0257
D	0.9688	0.0154	0.9070	0.0258
E	1.0000	0.0000	0.9204	0.0278
F	0.9655	0.0169	0.9143	0.0261
G	0.9905	0.0095	0.9530	0.0208
H	0.9447	0.0180	0.9027	0.0235
P-value	0.0688		0.7495	

A.1.2 Summer Study

Data from all nine release locations in the four-dam study were examined for tagger effects. This was again done to maximize the statistical power to detect tagger effects that might have influenced any of the lower Columbia River survival studies in summer 2012.

Tagger effort was balanced across the nine release locations and eight taggers (Table A.5) $\left(P\left(\chi^2_{56} \geq 4.8194\right) = 1\right)$. Tagger effort was also examined within each of the 32 replicate releases (Table A.6). Tagger effort was found to be balanced within the individual project releases (i.e., R_1–R_3, R_4–R_5, R_6–R_7, and R_8–R_9) within each of the replicate releases (Table A.7). These conditionally balanced designs within the individual replicates and the balance of taggers across projects resulted in the overall balanced design.

Tests of tagger effects were examined across the nine release locations based on both reach survivals and cumulative reach survivals (Table A.7). Five of the 45 tests of homogeneous reach survival across taggers were significant at α = 0.10 (i.e., 11.11%). Two of the 44 tests of homogeneous cumulative reach survival across taggers were significant at α = 0.10 (i.e., 4.55%). The rate of rejection in both cases is below that expected by chance alone, suggesting no evidence of tagger effects.

Based on the balanced release design (Table A.5 and Table A.6) and tests of homogeneity (Table A.7), all fish tagged by all staff members were used in the subsequent survival analyses for summer 2012.

Table A.5. Numbers of subyearling Chinook salmon tagged by each staff member by release location (i.e., R_1, R_2, . . .). Chi-square test of homogeneity was not significant $\left(P\left(\chi^2_{56} \geq 4.8194\right) = 1\right)$.

	Tagger							
Release location	E	C	H	G	B	D	F	A
R1_CR503	255	327	397	287	309	304	287	358
R2_CR468	201	246	316	224	239	248	235	284
R3_CR422	192	255	314	218	239	241	236	289
R4_CR346	98	126	153	111	119	119	116	144
R5_CR325	93	123	157	114	119	122	111	144
R6_CR307	81	105	124	90	91	94	89	114
R7_CR275	78	103	127	90	88	101	90	109
R8_CR233	203	260	315	225	235	241	227	288
R9_CR156	199	263	312	232	229	242	233	285
Chi-square = 4.8194				df = 56				P-value = 1

Table A.6. Contingency tables with numbers of subyearling Chinook salmon tagged by each staff member per release location within a replicate release. A total of 32 replicate day or night releases were performed over the course of the summer 2012 study. Results of chi-square tests of homogeneity presented in the form of *P*-values.

a. Replicate 1

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

b. Replicate 2

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

c. Replicate 3

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

Table A.6. (contd)

d. Replicate 4

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

e. Replicate 5

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

f. Replicate 6

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

Table A.6. (contd)

g. Replicate 7

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

h. Replicate 8

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

i. Replicate 9

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

Table A.6. (contd)

j. Replicate 10

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

k. Replicate 11

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

l. Replicate 12

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

Table A.6. (contd)

m. Replicate 13

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

n. Replicate 14

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

o. Replicate 15

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

Table A.6. (contd)

p. Replicate 16

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

q. Replicate 17

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

r. Replicate 18

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

Table A.6. (contd)

s. Replicate 19

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

t. Replicate 20

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

u. Replicate 21

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

Table A.6. (contd)

v. Replicate 22

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

w. Replicate 23

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

x. Replicate 24

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

Table A.6. (contd)

y. Replicate 25

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

z. Replicate 26

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

aa. Replicate 27

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

Table A.6. (contd)

bb. Replicate 28

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

cc. Replicate 29

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

dd. Replicate 30

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

Table A.6. (contd)

ee. Replicate 31

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

ff. Replicate 32

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

Table A.7. Estimates of reach and cumulative survival for subyearling Chinook salmon and associated *F*-test of homogeneous survival across fish tagged by different staff members.

a. Release 1 – 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 – 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.7. (contd)

c. Release 2 – 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 – 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.7. (contd)

e. Release 3 – 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 – 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.7. (contd)

g. Release 4 – 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 – 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.7. (contd)

i. Release 5 – 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 – 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.7. (contd)

k. Release 6 – 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 – 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.7. (contd)

m. Release 7 – 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 – 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.7. (contd)

o. Release 8 – 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 – 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.7. (contd)

q. Release 9 – 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 – 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

A.2.1 Spring Study

The purpose of these tests was to assess whether downstream reach survival rates were affected by how far upstream yearling and subyearling and juvenile steelhead were released. Results were used to determine which release groups were used in the construction of virtual-release groups at John Day Dam.

One of the 10 tests (i.e., 10%) of the reach survival comparisons was significant at α = 0.10 (Table A.8). In many instances, upriver releases of fish had equal or higher survival than fish released further downriver. Comparisons of cumulative survivals in reaches common to multiple release groups found 1 of 18 tests significant at α = 0.10 (i.e., 5.6%) (Table A.9). Once again, there was no relationship between time in-river and cumulative downriver survival.

Consequently, no evidence was found in the spring studies that would indicate delayed handling/tag effects. Therefore, fish from releases $R_1, \ldots, R_3$ were used in forming the virtual-release group at McNary Dam.

Table A.8. Comparison of reach survivals between tag releases from different upstream locations for a) yearling Chinook salmon and b) steelhead during the 2012 spring JSATS survival study in the Columbia River. Newly released and previously released fish were not compared within a reach (shaded).

a. Yearling Chinook salmon

Reach	CR503		CR468		CR422		CR346		CR325		*P* (*F*-test)
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	
Release to CR422	0.9060	0.0085	0.9288	0.0082							
CR422 to CR349	0.9506	0.0063	0.9743	0.0052	0.9498	0.0070					0.0037
CR349 to CR325	0.9712	0.0049	0.9568	0.0063	0.9582	0.0060	1.0004	0.0024			0.1500
CR325 to CR309	0.9911	0.0029	0.9908	0.0031	0.9894	0.0032	0.9844	0.0040	0.9896	0.0041	0.4547
CR309 to CR234	0.9357	0.0076	0.9434	0.0075	0.9414	0.0074	0.9474	0.0074	0.9313	0.0083	0.5960
CR234 to CR156 (λ)	0.9271	0.0083	0.9367	0.0080	0.9274	0.0084	0.9530	0.0071	0.9369	0.0082	0.1412

b. Steelhead

Reach	CR503		CR468		CR422		CR346		CR325		*P* (*F*-test)
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	
Release to CR422	0.8521	0.0095	0.9149	0.0081							
CR422 to CR349	0.9489	0.0064	0.9335	0.0075	0.9366	0.0070					0.1183
CR349 to CR325	0.9724	0.0049	0.9783	0.0046	0.9685	0.0052	0.9860	0.0037			0.3637
CR325 to CR309	0.9984	0.0013	0.9950	0.0022	0.9926	0.0026	0.9940	0.0025	0.9751	0.0049	0.2897
CR309 to CR234	0.9574	0.0063	0.9523	0.0069	0.9645	0.0058	0.9599	0.0064	0.9459	0.0074	0.3157
CR234 to CR156 (λ)	0.9054	0.0092	0.9107	0.0094	0.9124	0.0089	0.9300	0.0084	0.9237	0.0088	0.2778

Table A.9. Comparison of cumulative survivals between tag releases from different upstream locations for a) yearling Chinook salmon and b) steelhead during the 2012 spring JSATS survival study in the Columbia River.

a. Yearling Chinook salmon

	CR503		CR468		
Reach	Est	SE	Est	SE	*P* (*F*-test)
CR422 to CR349	0.9506	0.0063	0.9743	0.0051	0.0035
CR422 to CR325	0.9232	0.0078	0.9322	0.0078	0.4146
CR422 to CR309	0.9149	0.0082	0.9236	0.0083	0.4559
CR422 to CR234	0.8561	0.0104	0.8714	0.0105	0.3005

	CR503		CR468		CR422		
Reach	Est	SE	Est	SE	Est	SE	*P* (*F*-test)
CR349 to CR325	0.9712	0.0049	0.9568	0.0063	0.9581	0.0060	0.1482
CR349 to CR309	0.9625	0.0056	0.9480	0.0069	0.9480	0.0067	0.1831
CR349 to CR234	0.9005	0.0090	0.8943	0.0096	0.8925	0.0095	0.8182

	CR503		CR468		CR422		CR346		
Reach	Est	SE	Est	SE	Est	SE	Est	SE	*P* (*F*-test)
CR325 to CR309	0.9911	0.0029	0.9908	0.0031	0.9894	0.0032	0.9844	0.0040	0.4547
CR325 to CR234	0.9273	0.0080	0.9346	0.0079	0.9315	0.0079	0.9325	0.0082	0.9316

b. Steelhead

	CR503		CR468		
Reach	Est	SE	Est	SE	*P* (*F*-test)
CR422 to CR349	0.9489	0.0064	0.9335	0.0075	0.1183
CR422 to CR325	0.9235	0.0077	0.9132	0.0085	0.3692
CR422 to CR309	0.9220	0.0078	0.9087	0.0087	0.2550
CR422 to CR234	0.8827	0.0095	0.8654	0.0104	0.2194

	CR503		CR468		CR422		
Reach	Est	SE	Est	SE	Est	SE	*P* (*F*-test)
CR349 to CR325	0.9724	0.0049	0.9783	0.0046	0.9685	0.0052	0.3637
CR349 to CR309	0.9708	0.0050	0.9735	0.0051	0.9613	0.0058	0.2333
CR349 to CR234	0.9303	0.0078	0.9271	0.0083	0.9272	0.0079	0.9496

	CR503		CR468		CR422		CR346		
Reach	Est	SE	Est	SE	Est	SE	Est	SE	*P* (*F*-test)
CR325 to CR309	0.9983	0.0013	0.9950	0.0022	0.9926	0.0026	0.9940	0.0025	0.3065
CR325 to CR234	0.9567	0.0064	0.9475	0.0072	0.9574	0.0063	0.9541	0.0067	0.7108

A.2.2 Summer Study

Both the tests of homogeneous reach survival and cumulative survivals were significant in the last four or so reaches (Table A.10 and Table A.11). Further examination of the cumulative survivals indicated release groups R_1, R_2, and R_3 had depressed survival rates in and below reach CR325. *P*-values for tests of homogeneous cumulative survival became nonsignificant when these release groups were omitted from analyses below CR325 (Table A.11).

Releases R_1–R_3 were used in the analyses conducted at McNary, John Day, and The Dalles dams but not in the Bonneville Dam survival analysis or for the associated Fish Accords at that dam. No other release groups required omission in forming virtual-release groups (i.e., V_1) at the other three dams.

Table A.10. 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.11. 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 were 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.11. (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

Appendix B

Capture Histories Used in Estimating Dam Passage Survival

Appendix B

Capture Histories Used in Estimating Dam Passage Survival

B.1 Yearling Chinook Salmon

	V1 (Season-Wide)	
Capture History	Dam Passage Survival	BRZ-to-BRZ Survival
111	1143	1152
011	0	0
101	1	1
001	0	0
120	1	1
020	0	0
110	35	35
010	0	0
200	0	0
100	65	65
000	115	119
Total	1360	1373

	Season-Wide Dam Passage Survival	
Capture History	R2	R3
11	1026	1082
01	0	0
20	2	2
10	48	48
00	122	68
Total	1198	1200

B.2 Steelhead

	V1 (Season-Wide)	
Capture History	Dam Passage Survival	BRZ-to-BRZ Survival
111	1087	1090
011	0	0
101	1	1
001	0	0
120	6	6
020	0	0
110	29	29
010	0	0
200	0	0
100	62	62
000	112	116
Total	1297	1304

	Season-Wide Dam Passage Survival	
Capture History	R2	R3
11	992	1076
01	0	0
20	9	11
10	23	35
00	175	76
Total	1199	1198

B.3 Subyearling Chinook Salmon

Capture History	V1 (Season-Wide)	
	Dam Passage Survival	BRZ-to-BRZ Survival
111	2003	2005
011	0	0
101	0	1
001	0	0
120	10	10
020	0	0
110	135	135
010	0	0
200	0	0
100	100	100
000	211	216
Total	2459	2467

Capture History	Season-Wide Dam Passage Survival	
	R2	R3
11	1649	1740
01	0	1
20	11	17
10	100	109
00	233	117
Total	1993	1984

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