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BiOp Performance Testing: Passage and Survival of Yearling and Subyearling Chinook Salmon and Juvenile Steelhead at Little Goose Dam, 2012

FINAL BiOp Performance Testing Report

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RL Townsend
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May 2013

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Preface

This study was conducted by the Pacific Northwest National Laboratory (PNNL) and the University of Washington (UW) for the U.S. Army Corps of Engineers, Walla Walla District (USACE). The PNNL and UW project managers were Geoffrey A. McMichael and John R. Skalski, respectively. The USACE technical lead was Tim Wik. The study was designed to estimate dam passage survival at Little Goose Dam as stipulated by the 2008 Federal Columbia River Power System Biological Opinion, and provide additional performance measures at that site as stipulated in the Columbia Basin Fish Accords.

This report summarizes the performance and survival studies performed at Little Goose Dam during spring and summer 2012.

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Executive Summary

The purpose of this passage and survival study was to estimate fish performance metrics associated with passage through Little Goose Dam for emigrating yearling and subyearling Chinook salmon and steelhead smolts in 2012. The metrics estimated during this study included dam passage survival, forebay-to-tailrace survival, forebay residence time, tailrace egress time, and spill passage efficiency (SPE). Under the 2008 Federal Columbia River Power System (FCRPS) Biological Opinion (BiOp), dam passage survival is required to be greater than or equal to 0.96 for spring migrants, and greater than or equal to 0.93 for summer migrants, and estimated with a standard error (SE) less than or equal to 0.015. The study also estimated smolt passage survival from the forebay (0.9 km upstream of the dam) to the tailrace (1.5 km below the dam), also known as "BRZ-to-BRZ survival".[1] Forebay residence time, tailrace egress time, and SPE were also estimated, as required in the Columbia Basin Fish Accords (Fish Accords).

A virtual-paired-release design was used to estimate dam passage survival at Little Goose Dam. The approach included releases of acoustic-tagged smolts above Little Goose Dam that contributed to the formation of a virtual release at the face of Little Goose Dam. A survival estimate from the virtual release was adjusted by a paired release below Little Goose Dam. A total of 1,761 yearling Chinook salmon, 1,742 steelhead, and 2,684 subyearling Chinook salmon were used in the virtual releases. Sample sizes for the below-dam paired releases were 1,198 and 1,200 yearling Chinook salmon, 1,201 and 1,202 steelhead, and 2,095 and 2,096 subyearling Chinook salmon. The Juvenile Salmon Acoustic Telemetry System (JSATS) tag model number SS300 with a single 348 battery, weighing 0.346 g in air, was used in this investigation.

All Little Goose Dam passage and survival metrics measured in 2012 for yearling and subyearling Chinook salmon and juvenile steelhead are presented in Tables ES.1 and ES.2. Table ES.3 provides a summary of the passage and survival study at Little Goose Dam in 2012.

Table ES.1. Estimates of dam passage survival[(a)] at Little Goose Dam in 2012. Parentheses denote standard error.

Spill Operations	Yearling Chinook Salmon	Steelhead	Subyearling Chinook Salmon
Season-wide spring	0.9822 (0.0076)	0.9948 (0.0081)	NA
≤9 May 2012	0.9748 (0.0126)	0.9967 (0.0142)	NA
≥10 May 2012	0.9867 (0.0096)	0.9932 (0.0097)	NA
Season-wide summer	NA	NA	0.9508 (0.0097)

(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 is analogous the "BRZ-to-BRZ" (boat-restricted zone) survival estimate referred to in the Fish Accords.

Table ES.2. Fish Accords performance measures at Little Goose Dam in 2012. Parentheses denote standard error.

Performance Measures	Yearling Chinook Salmon	Steelhead	Subyearling Chinook Salmon
Forebay residence time (mean/median)	6.34 h (0.22)/2.58 h	5.84 h (0.23)/2.67 h	7.86 h (0.56)/2.80 h
Spill passage efficiency (SPE)[a]	0.6528 (0.0113)	0.5609 (0.0119)	0.7249 (0.0086)

(a) The SPE includes the spillway and adjustable spillway weir passage.

Table ES.3. Little Goose Dam 2012 survival study summary.

Year: 2012

Study Site(s): Little Goose 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 performance standard study.

Fish:
- Species-race: yearling Chinook salmon (CH1), steelhead (STH), subyearling Chinook salmon (CH0)
- Source: Lower Monumental Dam juvenile fish collection facility

Implant Procedure:
- Surgical: Yes
- Injected: No

Size (median):	CH1	STH	CH0
Weight:	24.8	85.9	13.6
Length:	136	214	109

Sample Size:	CH1	STH	CH0
# release sites[a]:	3	3	3
Total # released:	4,198	4,202	7,189

Tags:
Type/model: Advanced Telemetry Systems (ATS) − SS300 and Biomark HPT12 PIT tag
Weight (g): SS300 = 0.346 g (air), HPT12 = 0.100 g (air)

Analytical Model:
Virtual-paired-release model

Characteristics of Estimate:
Effects Reflected (direct, total, etc.): Direct
Absolute or Relative: Absolute

Spring Environmental/Operating Conditions (daily from 29 April 2012 through 27 May 2012):
Discharge (kcfs): mean 106.7, minimum 77.1, maximum 144.5
Temperature (°C): mean 11.1, minimum 8.9, maximum 12.6
Total Dissolved Gas (tailrace): mean 111.3%, minimum 105.1%, maximum 120.7%
Spill: mean 31.8%, minimum 26.4%, maximum 43.3% (target spill 30%)
Unique Study Characteristics: None

Summer Environmental/Operating Conditions (daily from 5 June 2012 through 6 July 2012):
Discharge (kcfs): mean 80.9, minimum 49.1, maximum 123.7
Temperature (°C): mean 14.6, minimum 11.7, maximum 17.8
Total Dissolved Gas (tailrace): mean 114.4%, minimum 111.4%, maximum 120.2%
Spill: mean 38.5%, minimum 29.8%, maximum 61.0% (target spill 30%)
Unique Study Characteristics: None

Survival and Passage Estimates (value & SE):	CH1	STH	CH0
• ≤9 May 2012	0.9748 (0.0126)	0.9967 (0.0142)	NA
• ≥10 May 2012	0.9867 (0.0096)	0.9932 (0.0097)	NA
• Season-wide spring	0.9822 (0.0076)	0.9948 (0.0081)	NA
• Season-wide summer	NA	NA	0.9508 (0.0097)
Forebay-to-tailrace survival (season-wide)	0.9813 (0.0076)	0.9943 (0.0081)	0.9454 (0.0098)
Forebay residence time (mean/median)	6.34 h (0.22)/2.58 h	5.84 h (0.23)/2.67 h	7.86 h (0.56)/2.80 h
Tailrace egress time (mean/median) [b]	1.35 h (0.06)/0.58 h	1.12 h (0.10)/0.68 h	1.41 h (0.05)/0.78 h
Spill passage efficiency (SPE)	0.6528 (0.0113)	0.5609 (0.0119)	0.7249 (0.0086)
Fish passage efficiency (FPE)	0.9625 (0.0045)	0.9800 (0.0033)	0.9507 (0.0042)

(a) Includes all locations that contributed fish to the survival estimate.
(b) Based upon PIT-tag detections for bypassed fish, acoustic-tag detections for removals.

Acknowledgments

This study was the result of hard work by dedicated scientists from the Pacific Northwest National Laboratory (PNNL), Pacific States Marine Fisheries Commission (PSMFC), the U.S. Army Corps of Engineers, Walla Walla 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.

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Acronyms and Abbreviations

°C	degree(s) Celsius
3D	three-dimensional
ATS	Advanced Telemetry Systems
BFL	Bio-Acoustics & Flow Laboratory
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
kHz	kilohertz
km	kilometer(s)
L	liter(s)
LGS	Little Goose Dam
LMN	Lower Monumental Dam
m	meter(s)
mg	milligram(s)
mm	millimeter(s)
NA	not applicable
NOAA	National Oceanic and Atmospheric Administration
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

SMP	Smolt Monitoring Program
SPE	spill passage efficiency
STH	steelhead
USACE	U.S. Army Corps of Engineers
UW	University of Washington
VPR	virtual-paired-release

Contents

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Tables

1.0 Introduction

The passage and survival study reported here was conducted by researchers at Pacific Northwest National Laboratory (PNNL) and the University of Washington for the U.S. Army Corps of Engineers, Walla Walla District (USACE) during the spring and summer of 2012. The purpose of the study was to estimate dam passage survival at Little Goose Dam as stipulated by the 2008 Federal Columbia River Power System (FCRPS) Biological Opinion (BiOp; NOAA Fisheries 2008)) and provide additional performance measures at the dam as stipulated in the Columbia Basin Fish Accords (Fish Accords) for yearling Chinook salmon and steelhead (Three Treaty Tribes-Action Agencies 2008 [Memorandum of Agreement]).

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 (i.e., 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; 3 Treaty Tribes-Action Agencies 2008), 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. The 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 spring and summer acoustic-telemetry studies of yearling Chinook salmon, steelhead, and subyearling Chinook salmon at Little Goose Dam to assess the Action Agencies' compliance with the performance criteria of the BiOp and Fish Accords.

1.2 Study Objectives

The purpose of spring and summer 2012 performance and survival monitoring at Little Goose Dam was to estimate performance measures for yearling Chinook salmon, steelhead, and subyearling Chinook salmon smolts as outlined in the FCRPS BiOp and Fish Accords. For each fish stock, the following metrics were estimated using the Juvenile Salmon Acoustic Telemetry System (JSATS; McMichael et al. 2010) technology:

- Dam passage survival is defined as survival from the upstream face of the dam to a standardized reference point in the tailrace. Dam passage survival[1] should be ≥96% for spring stocks (i.e., yearling Chinook salmon and steelhead) and ≥93% for the summer stock (i.e., subyearling Chinook salmon). For all stocks, survival should be estimated with a standard error (SE) ≤1.5%. Note that a standard error of 1.5% is equivalent to the half-width of a 95% confidence interval of ±3% (i.e., ≈1.96 × 1.5%).
- Forebay-to-tailrace survival is defined as survival from the forebay array (located 0.9 km upstream of the dam) to the tailrace array (located 1.5 km downstream of the dam). The forebay-to-tailrace survival estimate satisfies the "BRZ-to-BRZ" survival estimated called for in the Fish Accords.
- Forebay residence time is defined as the average time smolts take to travel from the forebay BRZ (located 0.9 km upstream of the dam) to the entrance into the dam.
- Tailrace egress time is defined as the average time smolts take to travel from the dam to the tailrace array (located 1.5 km downstream of the dam).
- Spill Passage Efficiency (SPE) is defined as the fraction of fish going through the dam via the spillway, including the spillway weir.
- Fish passage efficiency (FPE) is defined as the fraction of fish going through the dam via non-turbine routes, including the spillway, the spillway weir, and the juvenile bypass system (JBS).

The Fish Accord metrics relevant for Little Goose Dam are shown in Table 1.1.

Table 1.1. Fish Accords passage metrics for Little Goose Dam spill passage efficiency and forebay delay (from Table 1 of Attachment A in the Fish Accords).

	Most Recent SPE	Date of SPE Data Source	Most Recent Median Forebay Delay
Yearling Chinook	57–82	2006–2007	4.4–6.5 h
Steelhead	36–51	2006–2007	5.5–36.3 h
Subyearling Chinook	58–84	2006–2007	6.8–16.3 h

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

The intent of the spring and summer 2012 studies was, in part, to evaluate performance under operational conditions called for in the Fish Operations Plans (U.S. Army Corps of Engineers 2012). The high flow conditions during 2012 necessitated operations that sometimes exceeded the spill proportion specified in the Fish Operations Plans. For this reason, survival results are presented both season-wide and independently for early and late spring.

1.3 Report Contents and Organization

This report is designed to provide a succinct and timely summary of BiOp/Fish Accords performance measures. Study results are reported for the three fish stocks by performance measure. The ensuing sections present study methods, results, and associated discussion. Appendices contain tables of acoustic receiver locations (Appendix A), supplementary information about tests of assumptions (Appendix B), capture histories used in estimating dam passage survival (Appendix C), bias corrections for detections of dead tagged fish (Appendix D), and comparisons of estimated survival from passive integrated transponder (PIT) and acoustic tags as well as comparisons between tailrace release groups (Appendix E).

2.0 Methods

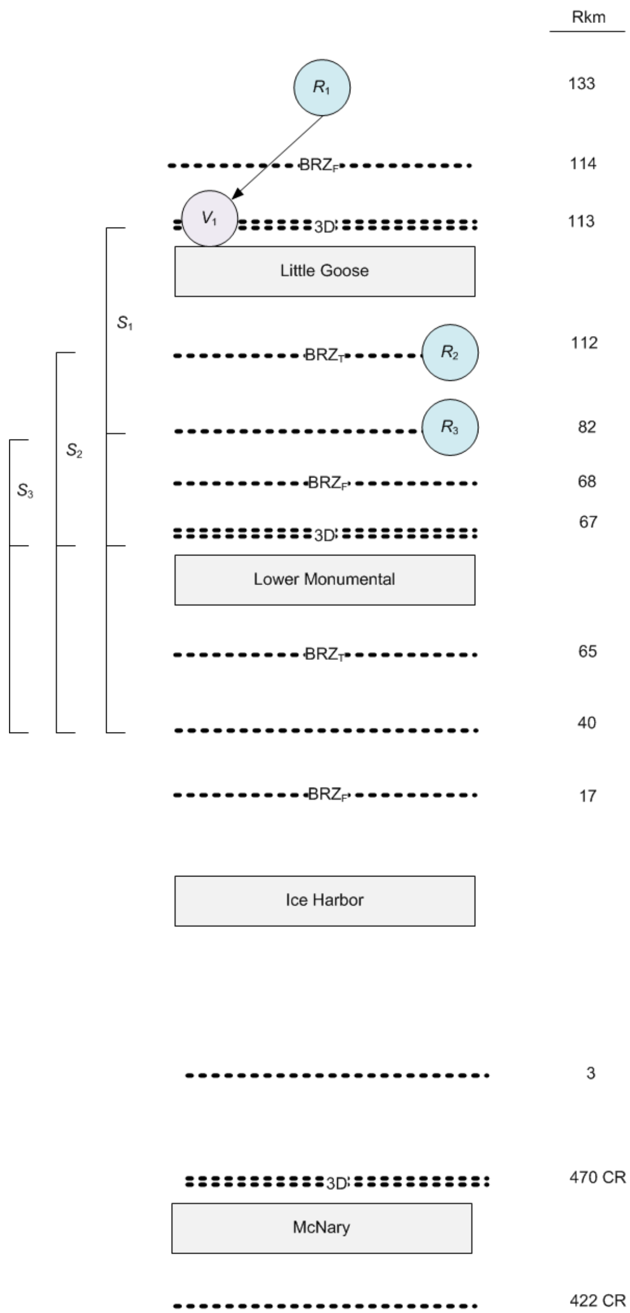
Study methods involved fish release and recapture; the associated fish handling, tagging, and release procedures; acoustic signal processing; and statistical and analytical approaches.

2.1 Release-Recapture Design

The release-recapture design used to estimate dam passage survival at Little Goose Dam consisted of a 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 20 km upstream from Little Goose Dam to supply a source of fish known to have arrived alive at the face of the dam. By releasing the fish far enough upstream, they should have arrived at the dam in a spatial pattern typical of run-of-river (ROR) fish. The virtual-release group, formed immediately on the upstream side of the dam by using detections on the acoustic receivers, was then used to estimate survival through the dam and part of the way through the next reservoir (i.e., river kilometer [rkm] 82) (Figure 2.1). To account and adjust for mortality downstream of the tailrace boundary, a paired release below Little Goose Dam (i.e., R_2 and R_3) (Figure 2.1) was used to estimate survival in that segment of the reservoir below the tailrace boundary. 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 acoustic-tagged fish used in the dam passage survival estimates are summarized in Table 2.1.

The same release-recapture design was also used to estimate forebay-to-tailrace survival, except that the virtual-release group was composed of fish known to have arrived at the forebay array (rkm 113). 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 assigned the passage route using three-dimensional (3D) tracks and the location of the last detections. These passage-route data were used to calculate SPE and FPE at Little Goose Dam. The fish included in the virtual release at the face of the dam were used to estimate tailrace egress time.

One manufacturing lot of tags was used during the spring 2012 JSATS study. Another tag lot was used during the summer investigation. From each of these tag lots, 75 tags were randomly sampled to be used in tag-life assessments. These tags were activated, held in water, and monitored continuously until they failed. The information from the tag-life study was used to adjust the survival estimates from the Cormack-Jolly-Seber release-recapture model using the methods of Townsend et al. (2006).



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

Figure 2.1. Schematic of the virtual-paired-release design used to estimate dam passage survival at Little Goose Dam. The virtual release (V_1) was composed of fish that arrived at the dam face from the release at rkm 133. The below-dam release pair was composed of releases R_2 and R_3 with detection arrays denoted by dashed lines. Arrays used in the analyses are denoted by brackets.

Table 2.1. Locations and sample sizes of acoustic-tagged fish releases used in the yearling Chinook salmon, steelhead, and subyearling Chinook salmon survival studies at Little Goose Dam in 2012.

Release Location	rkm	Yearling Chinook Salmon	Steelhead	Subyearling Chinook Salmon
Above Little Goose (R_1)	133	1,800	1,799	2,998
Virtual Release (V_1)	113	1,761	1,742	2,684
Little Goose Dam Tailrace (R_2)	112	1,198	1,201	2,095
Mid-Reservoir (R_3)	82	1,200	1,202	2,096

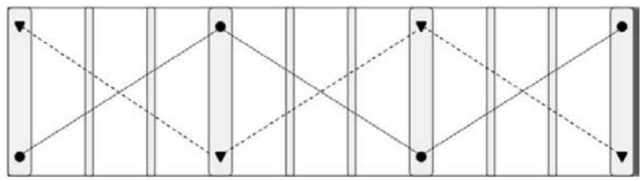


Figure 2.2. Front view schematic of hydrophone deployments at three turbines showing the double-detection arrays. The circles denote the hydrophones of Array 1 and the triangles denote the hydrophones of Array 2.

2.2 Handling, Tagging, and Release Procedures

Fish obtained from the Lower Monumental Dam JBS were surgically implanted with JSATS tags, and then transported to the three different release points (Figure 2.1), as described in the following sections.

2.2.1 Acoustic Tags

The acoustic tags used in the spring 2012 study were manufactured by Advanced Telemetry Systems (ATS). Each tag, model number SS300, measured 10.79 mm in length, 5.26 mm in width, 3.65 mm in thickness, and weighed 0.346 g in air. The tags had a nominal transmission rate of 1 pulse every 3 s in spring (yearling Chinook salmon and steelhead) and every 4.2 s in summer (subyearling Chinook salmon). Nominal tag life was expected to be about 30 d in spring and 40 d in summer.

2.2.2 Fish Source

The yearling Chinook salmon, steelhead, and subyearling Chinook salmon used in the study were obtained from the Lower Monumental Dam JBS. USACE staff diverted fish from the JBS into an examination trough; Smolt Monitoring Program (SMP) staff then examined these fish as described by Lind and Price (2009). After SMP examination, yearling Chinook salmon, steelhead and subyearling Chinook salmon ≥95 mm in fork length were transferred to PNNL sampling tanks for further examination. Individual fish were accepted for the current study based on a number of predetermined acceptance/exclusion criteria outlined (below) by the Columbia Basin Surgical Protocol Steering Committee (USACE 2011) for BiOp testing.

Fish was accepted if it:	Was a yearling spring Chinook salmon or steelhead collected in the spring, or a subyearling fall Chinook salmon collected in the summer
	Was between 95- and 300-mm fork length
	Had an intact or clipped adipose fin
	Was tagged or not tagged with coded wire or elastomer tag

Fish was excluded if it:

Was a non-target species

Showed signs of prior surgery (e.g., radio tags, sutures, or PIT-tag scars)

Indicated a positive reading when put through a PIT-tag reader

Was moribund or emaciated

Had malformations such as spinal deformities

Exhibited descaling greater than 20% on any side of the body

Had physical injuries severe enough to impede performance, such as:

- Opercular damage (missing or folded over greater than 75%)
- Exophthalmia (pop eye)
- Eye hemorrhages (greater than 10% of the eye); fish with cataracts were not rejected
- Head or body injuries (e.g., emboli, hemorrhages, lacerations)
- Fins torn away from body and/or Stage 5 erosion

Showed evidence of disease or infections, symptoms included:

- Fungal infections on the body surface
- Gill necrosis
- Open lesions on the body or fins
- Swollen body
- Ulcers
- Copepod parasites on the eyes or gills (greater than 25% coverage).

Fish selected for the current study were held for 18 to 30 h in holding tanks prior to surgery. Non-sorted or excluded fish were returned to the river below the dam, diverted to a recovery tank on non-transport days, or routed directly onto a barge on transport days.

2.2.3 Tagging Procedure

The fish to be tagged were anesthetized in a 10-L “knockdown” solution of river water and buffered MS-222 (tricaine methanesulfonate; 80–100 mg/L). In this “knockdown” solution, fish reached stage 4 anesthesia within 2 to 3 min (Summerfelt and Smith 1990). Anesthesia containers were refreshed repeatedly to maintain the temperature within ±2°C of current river temperatures. Sedated fish were weighed, measured, assessed for noteworthy abnormalities (e.g., minor descaling, fin erosion, predation marks, etc.), assigned tag codes, and assigned to a surgeon before tagging.

During surgery each fish was placed ventral side up in a v-shaped groove in a foam pad. A “maintenance” dose of anesthesia (40 mg/L) was supplied throughout the surgery from a gravity-fed line inserted in the fish’s mouth. A scalpel blade was used to make a 5- to 7-mm incision on the linea alba (ventral mid-line), ending 3 to 5 mm anterior of the pelvic girdle. A PIT tag was inserted into the coelom followed by the acoustic transmitter (battery end inserted toward the head of the fish). Both tags were inserted slightly anterior and parallel to the incision. The incision was closed using 5-0 absorbable monofilament with two simple, interrupted sutures tied with reinforced square knots (Deters et al. 2012). Knots were made with one wrap on each of four throws.

After closing the incision, the fish were placed in a partially perforated dark-colored 22.7-L transport bucket filled with aerated river water. Fish were held in these partially perforated buckets within a trough of flow-through river water for 11 to 30 h before being transported for release into the river. The loading rate was typically five fish per bucket.

2.2.4 Release Procedures

All fish were tagged at Lower Monumental Dam and transported in insulated totes by truck to the release locations (Figure 2.1). Supplemental oxygen was provided when required during transit to maintain approximately 8 to 10 mg/L dissolved oxygen. Ice made from river water was also used when necessary to maintain transport water temperatures within ~2°C of ambient river water. Transportation routes were adjusted to provide equal travel times to the locations of the paired releases downstream from Little Goose Dam. Upon arriving at a release site, fish buckets were transferred to a boat for transport to the in-river release location. Air was bubbled into release buckets during boat transport. There were five release locations at each release site across the river (Figure 2.1), and equal numbers of fish were released at each of the five locations.

Releases at R_1 occurred for 28 consecutive days (from 24 April to 25 May 2012) for the spring study. Releases occurred for 32 consecutive days (from 4 June to 5 July 2012) for the summer study. Releases alternated between daytime and nighttime, every other day, over the course of the study. The timing of the releases at R_1 and R_3 were staggered to help facilitate downstream mixing (Table 2.2).

Table 2.2. Relative release times for the acoustic-tagged fish to accommodate downstream mixing. Releases were timed to accommodate the travel time between R_1 and R_2 and between R_2 and R_3.

		Relative Release Times	
Study	Release Location	Daytime Start	Nighttime Start
Spring	R_1 (rkm 133)	Day 1: 1600	Day 1: 0800
	R_2 (rkm 112)	Day 2: 1200	Day 3: 0400
	R_3 (rkm 82)	Day 3: 0800	Day 3: 0200
Summer	R_1 (rkm 133)	Day 1: 1900	Day 1: 0700
	R_2 (rkm 112)	Day 2: 1200	Day 2: 2400
	R_3 (rkm 82)	Day 3: 0800	Day 2: 1900

2.3 Acoustic Signal Detection and Processing

Prior to deployment, all hydrophones and receivers were evaluated in an acoustic tank lined with anechoic materials at the PNNL Bio-Acoustics & Flow Laboratory (BFL) (Deng et al. 2010). The BFL is accredited by the American Association for Laboratory Accreditation to ISO/IEC 17025:2005, which is the international standard for calibration and testing laboratories. The accreditation scope (Certificate Number 3267.01) includes hydrophone sensitivity measurements and power level measurements of sound sources for frequencies from 50 kHz to 500 kHz for both military equipment and commercial components. The deployment locations of the receivers are provided in Appendix A.

Transmissions of JSATS tag codes received on cabled and autonomous receivers were recorded in data files on media that were downloaded weekly (cabled) or bi-weekly (autonomous). These files were transported to PNNL's Richland offices for processing. Receptions of tag codes within data files were processed to produce a data set of accepted tag-detection events. For cabled arrays, tag code receptions from all hydrophones at a dam were combined for processing. Autonomous node receptions were processed by node, without information on receptions at other nodes within the array. The following three filters were used:

- Multipath filter: For data from each individual autonomous receiver, all tag-code receptions that occurred 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. For cabled data, tag-code receptions occurring within 0.3 s were deleted. This larger window for multipath in cabled data is consistent with previous studies at dams in the lower Columbia River.
- Multi-detection filter (cabled data only): 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 "hits") that are consistent with the pattern of transmissions from a properly functioning JSATS acoustic tag were retained. Filtering rules are evaluated for each tag code individually, and it is assumed that only a single tag will be transmitting that code at any given time. For a cabled system, the PRI filter operates on a message that includes all receptions of the same transmission on multiple hydrophones within 0.3 s. Each autonomous receiver is processed independently, so each hit represents a message. Message time is defined as the earliest reception time across all hydrophones for that message. Detection requires that at least four (autonomous) or six messages (cabled) are received with an appropriate time interval between the leading edges of successive messages.
- Mimic filter: Detection events were checked to see if they occurred simultaneously with receptions of three to four codes that have been identified to have similar characteristics. Rarely, tags emitting these codes have been found to generate what are referred to as "mimic" receptions of the code of interest. Events were deleted if there was evidence that this was occurring.

The output of this process was a data set of events that included accepted tag detections for all times and locations where receivers were operating. Each unique event record included a basic set of fields that indicated the unique identification number of the fish, the first and last detection time for the event, the location of detection, and how many messages were detected within the event. This list was combined with PIT-tag detections for additional quality assurance/quality control analysis prior to survival analysis. Additional fields captured specialized information, where available. One such example was route of passage, which was assigned a value for those events that immediately preceded 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.

An additional quality control step was to examine the chronology of detections of every tagged fish as they were detected passing through the river on multiple arrays. Upstream movement past a dam or out-of-sequence detections were used to identify anomalous detection events. These anomalous detection events were sometimes a small number of receptions due to noise, but could also be a large number of detections of a tag that had been dropped near a receiver array after fish or bird predation. If the apparent behavior was impossible for a live fish, the anomalous detection was excluded from the detection history used for survival analysis.

Three-dimensional tracking of JSATS-tagged fish in the immediate forebay of Little Goose Dam was used to determine routes of passage to estimate SPE. 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 Deng et al. (2011) and Weiland et al. (2011). For example, route of passage was assigned a value for the events that immediately precede passage at a dam based on spatial tracking of tagged fish movements to a location of last detection.

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

Dam passage survival was estimated by the function

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

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

In 2012, passage and survival tests at Little Goose Dam were planned for dam operation conditions at 30% spill. High flow conditions in 2012 interrupted the intended spill levels. Consequently, a *post-facto* approach to examining dam passage survival in 2012 was necessary. Four alternative estimates of dam passage survival were computed as follows:

- Spring: ≤9 May 2012
- Spring: ≥10 May 2012
- Season-wide spring
- Season-wide summer.

The spring season was divided because before 10 May spill levels were generally in excess of 30%, and after 10 May, spill levels were closer to the 30% target level.

2.4.2 Tag-Life Analysis

A random sample of 75 JSATS tags was selected from each tag lot (spring or summer). The reception of messages from those individual tags was continuously monitored from activation to failure in water. For each tag lot, the failure times were fit to the four-parameter vitality model of Li and Anderson (2009). The vitality model tends to fit acoustic-tag failure times well, 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

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

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

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

For the virtual-release group (V_1) based on fish known to have arrived at the dam and with active tags, the conditional probability of a tag being active, given the tag was active at the detection array at rkm 113, 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

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

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

2.4.3.2 Tests of Mixing

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

2.4.3.3 Tagger Effects

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

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

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

where

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

and

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

This F-test was used in evaluating tagger effects.

2.4.3.4 Tag Lot Effects

Because only one tag lot was used for survival analyses within a season, examination of tag-lot effects was unnecessary.

2.4.4 Forebay-to-Tailrace Survival

The same virtual-paired-release methods used to estimate dam passage were also used to estimate forebay-to-tailrace survival. The only distinction was that the virtual-release group (V_1) was composed of fish known to have arrived alive at the forebay array (rkm 114) of Little Goose 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

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

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

Tailrace egress was calculated two different ways corresponding to current and historical methods of calculations. The first method estimated tailrace egress time was based on the time from last detection of a fish at the double array at the dam face at Little Goose Dam to the last detection at the tailrace array 1.5 km downstream of the dam (rkm 112). The second method, which has been used in the past, uses the time of the last detection in the fish bypass system rather than at the dam face for the fish that went through the bypass system. The estimated forebay residence times were based on the time from the first detection at the forebay BRZ array 0.9 km above the dam to the last detection at the double array in front of Little Goose Dam.

2.4.6 Estimation of Spill Passage Efficiency

SPE was estimated by the fraction

$$\widehat{\mathrm{SPE}} = \frac{\hat{N}_{SP} + \hat{N}_{ASW}}{\hat{N}_{SP} + \hat{N}_{ASW} + \hat{N}_{TUR} + \hat{N}_{JBS}}, \tag{2.9}$$

where $\hat{N}_i$ is the estimated abundance of acoustic-tagged fish through the *i*th route (i = spill [SP], adjustable spill weir [ASW], 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 $\widehat{\mathrm{SPE}}$ was estimated as

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

2.4.7 Estimation of Fish Passage Efficiency

FPE was estimated by the fraction

$$\widehat{\text{FPE}} = \frac{\hat{N}_{SP} + \hat{N}_{ASW} + \hat{N}_{JBS}}{\hat{N}_{SP} + \hat{N}_{ASW} + \hat{N}_{JBS} + \hat{N}_{TUR}}, \tag{2.11}$$

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

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

To expedite this report, it was assumed all routes had equal probability of detection and calculations of $\widehat{\text{SPE}}$ and $\widehat{\text{FPE}}$ were based on a binomial sampling model.

3.0 Results

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

3.1 Fish Collection, Acceptance, and Tagging

Over 29,000 yearling and subyearling Chinook salmon and juvenile steelhead were handled as part of the BiOp passage and survival studies at Little Goose Dam (LGS) and Lower Monumental Dam (LMN) in 2012 (Table 3.1). Fish for studies at both dams were collected at the same time and were not differentiated until the time of tagging; thus the number of fish handled, not available for tagging, and excluded from the study because of their physical condition are combined in Table 3.1.

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. Fish were released as part of BiOp passage and survival studies at LGS and LMN. A higher number of fish than required were available for tagging to ensure sample size targets were met each day. Fish that were not used for tagging were released alive into the tailrace of LMN through the JBS outfall pipe each day.

Handling Category	CH1	STH	CH0	**Total**
Total handled	7,921	7,989	13,563	**29,473**
Previously tagged	207	246	503	**956**
Did not meet size (<95 or >300 mm FL)	36	0	534	**570**
Not available for tagging	243	246	1,037	**1,526**
% Not available for tagging	3.1%	3.1%	7.6%	**5.2%**
Met all acceptance criteria	7,678	7,743	12,526	**27,947**
Excluded for condition	331	510	293	**1,134**
% Excluded	4.3%	6.6%	2.3%	**4.1%**
Number tagged for live release	6,220	6,235	11,026	**23,481**
Post-tagging mortality	21	17	41	**79**
% Mortality	0.3%	0.3%	0.4%	**0.3%**

CH1 = yearling Chinook salmon; STH = juvenile steelhead; CH0 = subyearling Chinook salmon; FL = fork length.

All fish used in this study were evaluated based on a set of pre-determined criteria outlined by the USACE Surgical Protocols Committee. Overall, 4.1% of the fish that met all of the acceptance criteria for these studies were excluded based on physical condition (Table 3.2). The primary reason for exclusion of yearling Chinook salmon, steelhead, and subyearling Chinook salmon was descaling over 20% of one side of the body.

Table 3.2. Total number of fish and reasons for exclusion for tagging by PNNL during spring and summer of 2012. Percentages are based on the total number of fish that met all acceptance criteria.

Reason for Exclusion	CH1	% CH1	STH	% STH	CH0	%CH0	**Total**
Moribund/emaciated	10	0.1	4	0.1	2	0	**16**
Skeletal deformities	6	0.1	9	0.1	0	0	**15**
>20% descaling	267	3.5	286	3.7	221	1.8	**774**
Physical injuries	30	0.4	103	1.3	57	0.5	**190**
Disease and infection	18	0.2	108	1.4	13	0.1	**139**
Total	**331**	**4.3**	**510**	**6.6**	**293**	**2.3**	**1,134**

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

A total of 15,591 fish were released at R_1, R_2, and R_3 as part of the BiOp passage and survival study at Little Goose Dam (Table 3.3). In addition, 58 dead fish (n = 14 CH1, n = 12 STH, and, n = 32 CH0) were released from the spillway weir at Little Goose Dam to evaluate the assumptions of the virtual-paired-release survival estimate.

Table 3.3. Total number of fish released at R_1, R_2, and R_3 locations by PNNL during the spring and summer of 2012.

	Species			
Release Location	CH1	STH	CH0	**Total**
R_1	1,800	1,799	2,998	**6,597**
R_2	1,198	1,201	2,095	**4,494**
R_3	1,200	1,204	2,096	**4,500**
Dead fish releases	14	12	32	**58**
Total	**4,212**	**4,216**	**7,221**	**15,649**

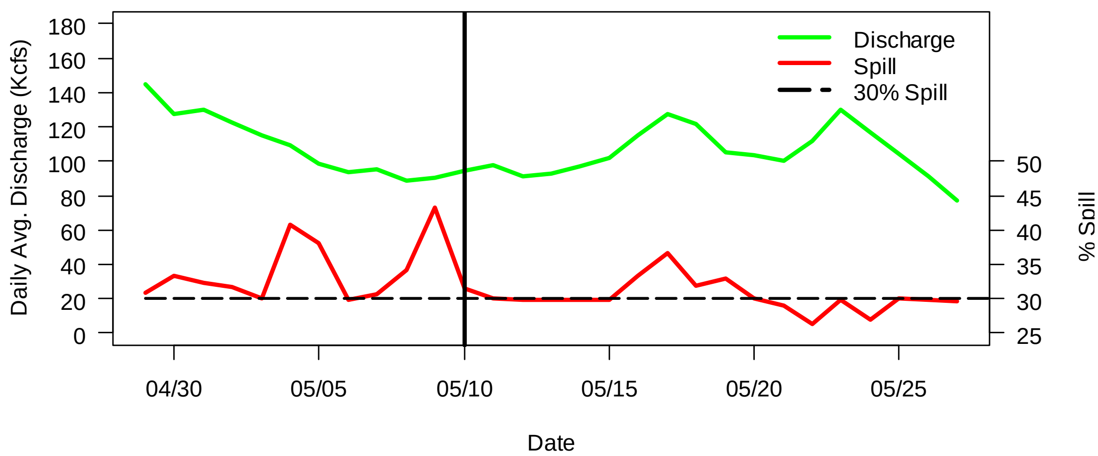
CH1 = yearling Chinook salmon; STH = juvenile steelhead; CH0 = subyearling Chinook salmon.

3.2 Discharge and Spill Conditions

The spill operations at Little Goose Dam were targeted at 30% for both spring and summer studies. High discharge in 2012 resulted in mandatory spill at levels higher than the target in spring (Figure 3.1a). Prior to 10 May, spill percentage typically exceeded 30%, while on and after 10 May, spill levels more closely approximated 30%. For this reason, spring survival was estimated season-wide as well as before and after 10 May 2012. Little Goose Dam project discharge averaged 106.7 kcfs (range 77–145 kcfs) during the spring study period. This was within the middle 90th percentile of the previous 70-year average spring flow record (5th to 95th percentile) in the Snake River, which was 54.9 to 154.9 kcfs.

During the summer study, spill was typically above 30% (Figure 3.1b). No attempt was made to extract data for the few days when spill was near 30%. Only a season-wide estimate of survival was calculated for summer 2012. Little Goose Dam project discharge averaged 80.9 kcfs (range 49–124 kcfs) during the summer study period. This was within the middle 90th percentile of the previous 70-year record (5th to 95th percentile) in the Snake River, which was 30.9 to 128.5 kcfs during the study period.

a. Spring



b. Summer

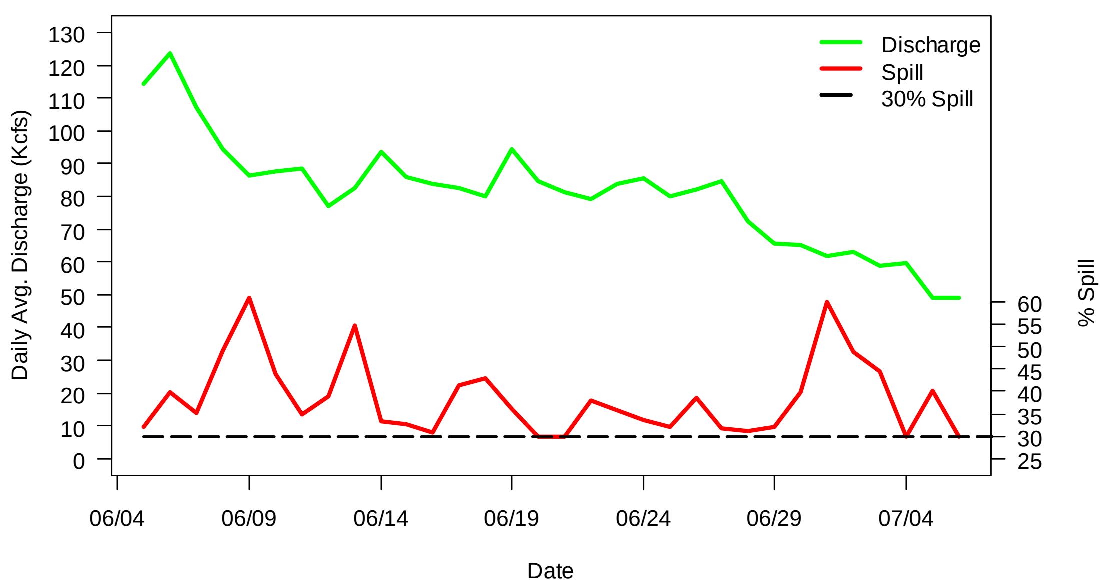
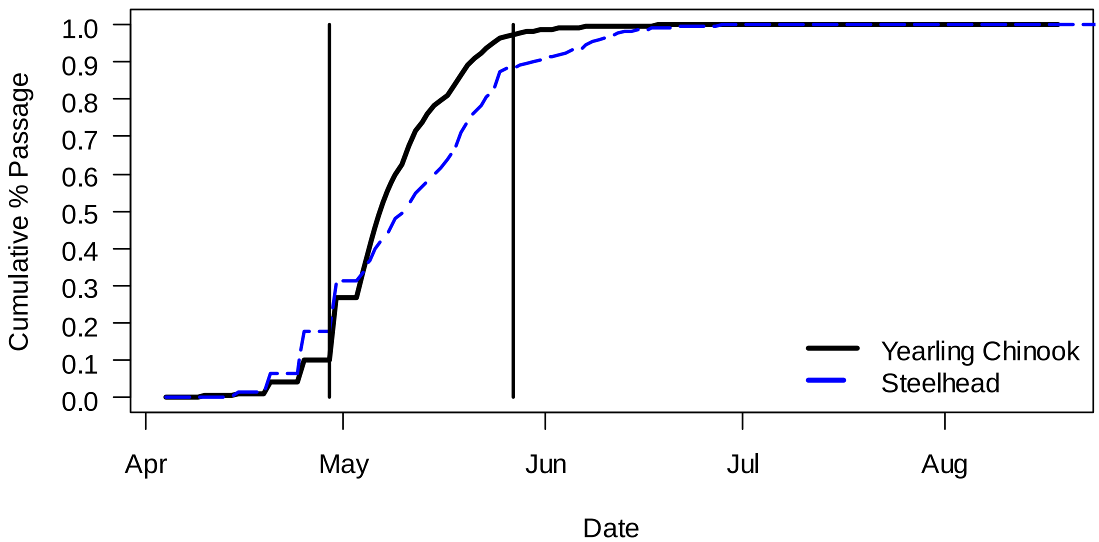


Figure 3.1. Daily average total discharge (kcfs) (green line) and percent spill (red line) at Little Goose Dam during the a) spring yearling Chinook salmon and steelhead study, 29 April to 27 May 2012, and b) summer subyearling Chinook salmon study, 5 June to 6 July 2012. The black dashed line represents 30% spill.

3.3 Run Timing

The cumulative percent of yearling Chinook salmon and juvenile steelhead that had passed Little Goose Dam by date was calculated from smolt index data obtained from the Fish Passage Center (FPC; Figure 3.2). From 29 April to 27 May 2012, 87.3% of the yearling Chinook salmon and 70.7% of the steelhead smolts passed through Little Goose Dam based on the FPC index counts. From 5 June to 6 July 2012, 79.1% of the subyearling Chinook salmon passed through Little Goose Dam based on the FPC index counts.

a. Spring



b. Summer

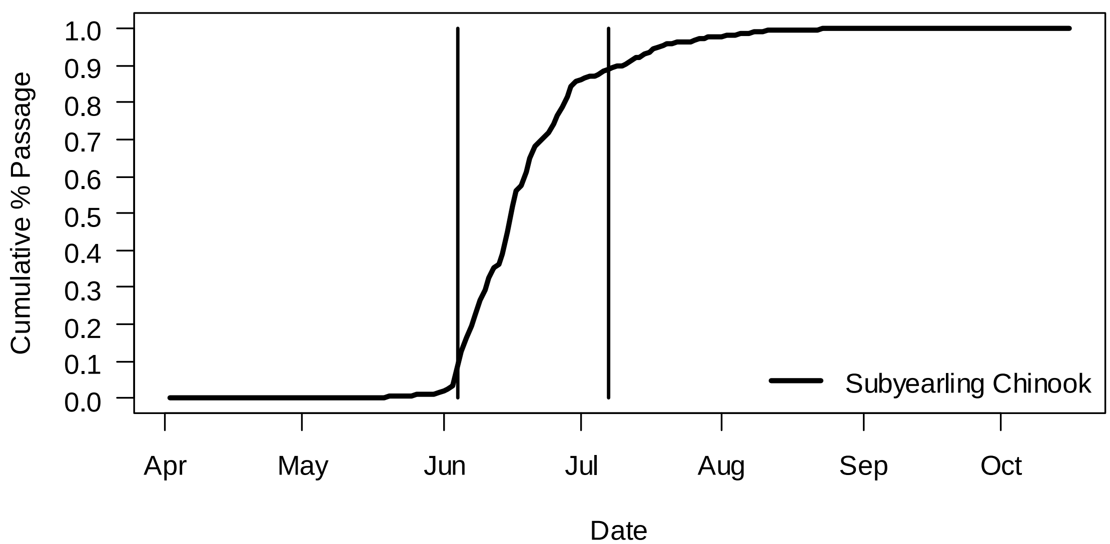


Figure 3.2. Plots of the cumulative percent of a) juvenile steelhead and yearling Chinook salmon and b) subyearling Chinook salmon that passed Little Goose Dam in 2012. Vertical lines indicate start and stop times of the survival studies.

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

Eight different taggers assisted in tagging all of the yearling and subyearling Chinook salmon and steelhead smolts associated with the JSATS survival studies at Little Goose Dam in 2012. Analyses found tagger effort was homogenously distributed either across all locations within a replicate release or within the project-specific releases within a replicate (Appendix B). Examination of reach survivals and cumulative survivals from above Little Goose Dam to below Ice Harbor Dam found no consistent or reproducible evidence that fish tagged by different staff members had different in-river survival rates (Appendix B). Therefore, fish tagged by all taggers were included in the estimation of survival and other performance measures during both spring and summer studies.

3.4.2 Examination of Tag-Lot Effects

Because only one tag lot was used in the spring study and only one tag lot was used in the summer study, no examination of tag-lot effects was performed.

3.4.3 Handling Mortality and Tag Shedding

Fish were held for 12 to 36 h between tagging and release. The mortality rate during the post-surgery holding period was 0.3% (n = 21 of 6,220) for yearling Chinook salmon and 0.3% (n = 17 of 6,235) for steelhead. The post-surgery mortality rate was 0.4% (n = 41 of 11,026) for subyearling Chinook salmon. No tags were shed during the holding period.

3.4.4 Effect of Tailrace Release Positions on Survival

The survival rates for yearling Chinook salmon, steelhead, and subyearling Chinook salmon released at five adjacent locations across the Little Goose Dam tailrace did not appear to differ significantly among release positions across the channel (Figure 3.3 and Figure 3.4).

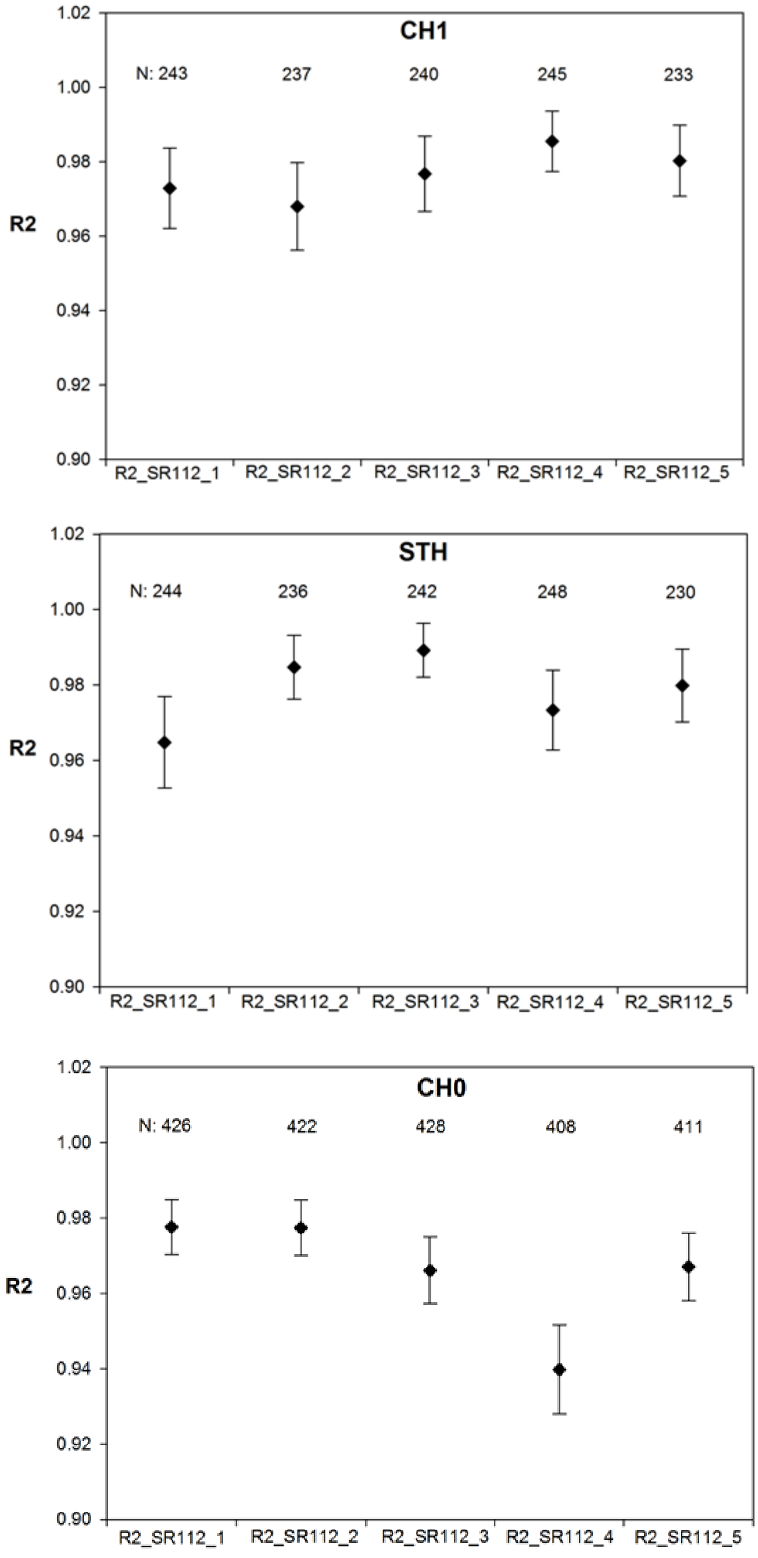


Figure 3.3. Single-release survival estimates (±1 SE) of yearling Chinook salmon (CH1), steelhead (STH), and subyearling Chinook salmon (CH0) from each position in the tailrace release location downstream of Little Goose Dam (R2; rkm 112) to the first array downstream (rkm 82). See Figure 3.4 for a map of the release positions.

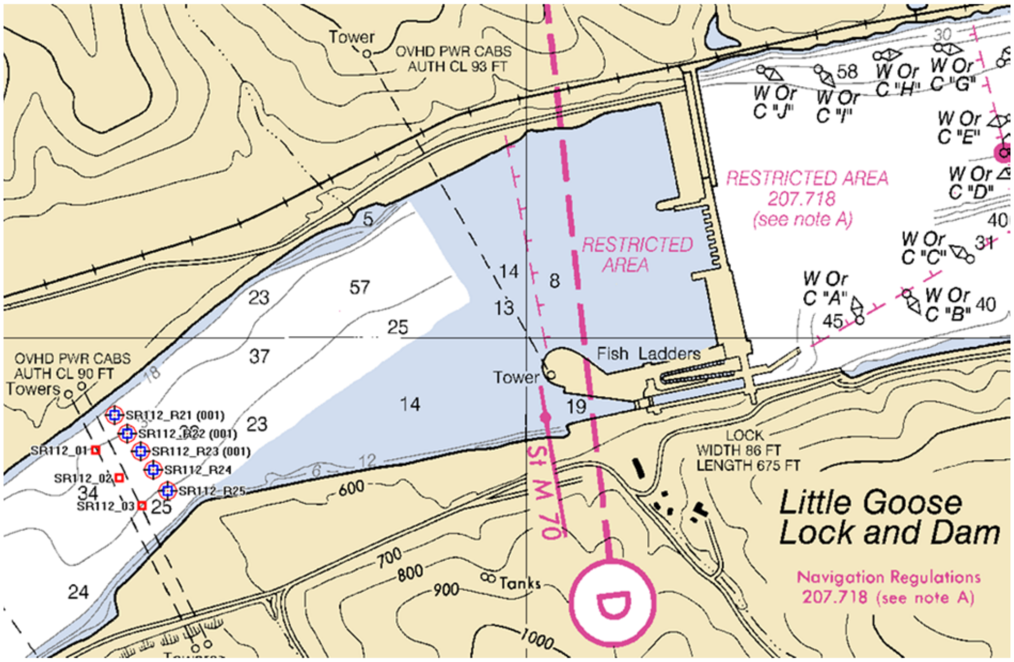
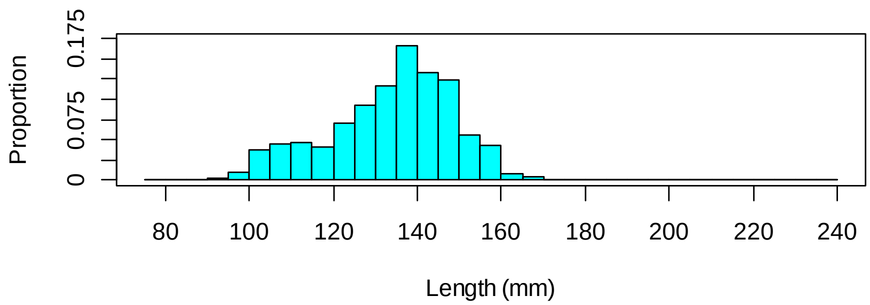


Figure 3.4. Little Goose Dam tailrace fish release locations (red circle with blue square). Release position 1 is near the north shore and release position number 5 is near the south shore.

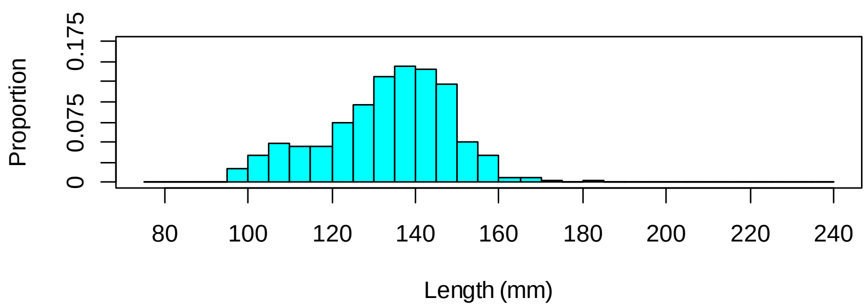
3.4.5 Fish Size Distributions

Comparison of JSATS-tagged fish with ROR fish sampled at Little Goose Dam by the SMP shows that the length frequency distributions were generally well matched for yearling Chinook salmon (Figure 3.5), steelhead (Figure 3.6), and subyearling Chinook salmon (Figure 3.7). The length distributions for the three yearling Chinook salmon releases (Figure 3.5), the three steelhead releases (Figure 3.4), and three subyearling Chinook salmon releases (Figure 3.5) also were quite similar. Mean length for the acoustic-tagged yearling Chinook salmon was 134.5 mm; for the steelhead, 213.1 mm; and for the subyearling Chinook salmon, 109.8 mm. Mean lengths for yearling Chinook salmon, steelhead, and subyearling Chinook salmon sampled by the SMP at the Little Goose Dam juvenile sampling facility were 132.3 mm, 210.5 mm, and 106.5 mm, respectively. Fish size increased almost imperceptibly over the course of the spring studies (Figure 3.8). The length of tagged subyearling Chinook salmon did not change over the course of the summer study (Figure 3.8).

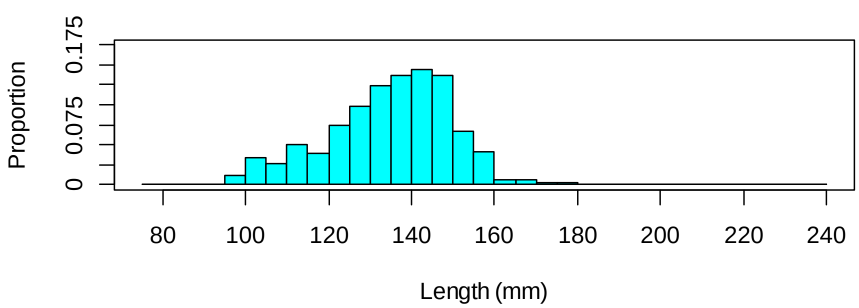
a. Little Goose Dam (Release V_1)



b. Little Goose Tailrace (Release R_2)



c. Mid-Reservoir (Release R_3)



d. ROR Yearling Chinook salmon at Little Goose Dam

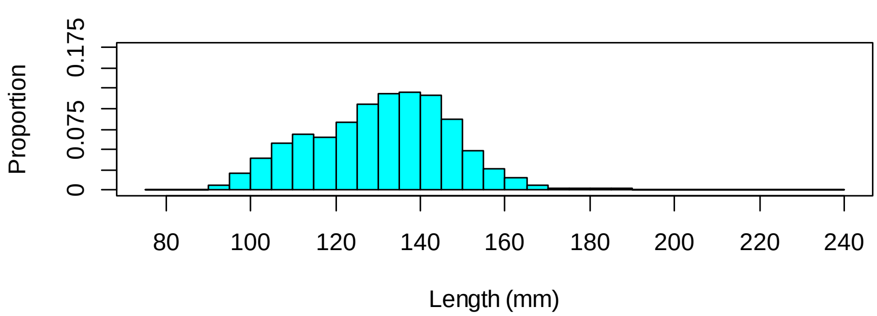
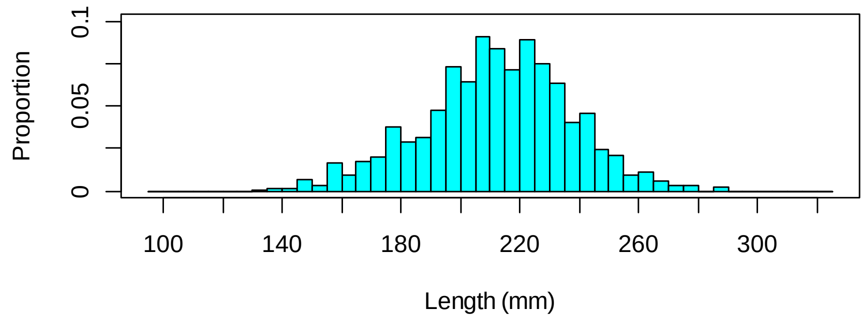
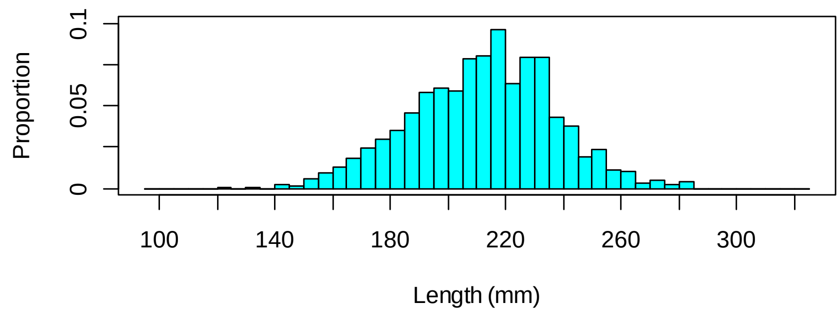


Figure 3.5. Frequency distributions for fish lengths (5-mm bins) of yearling Chinook salmon smolts used in a) release V_1, b) release R_2, c) release R_3, and d) ROR fish sampled at Little Goose Dam by the Smolt Monitoring Program.

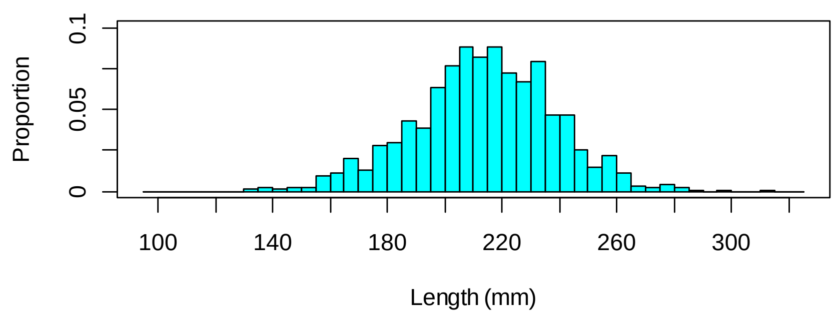
a. Little Goose Dam (Release V_1)



b. Little Goose Tailrace (Release R_2)



c. Mid-Reservoir (Release R_3)



d. ROR steelhead at Little Goose Dam

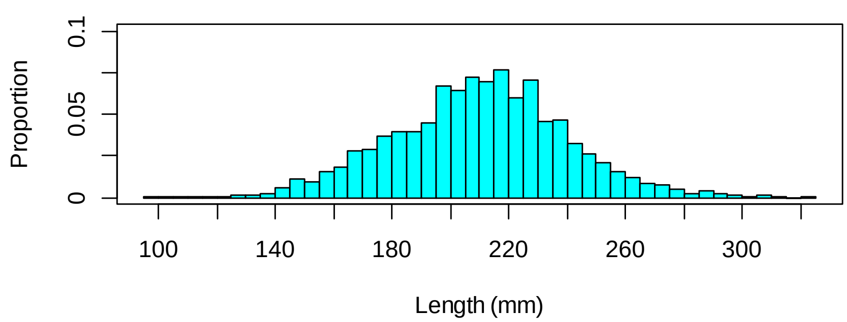
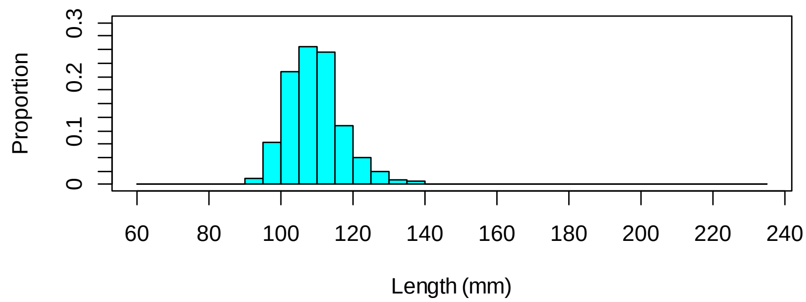
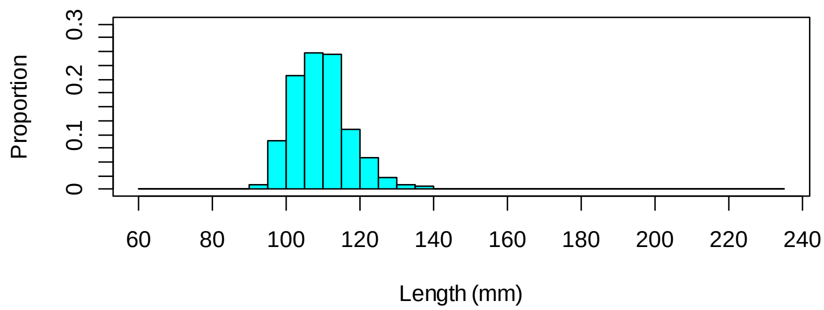


Figure 3.6. Frequency distributions for fish lengths (5-mm bins) of steelhead smolts used in a) release V_1, b) release R_2, c) release R_3, and d) ROR fish sampled at Little Goose Dam by the Smolt Monitoring Program.

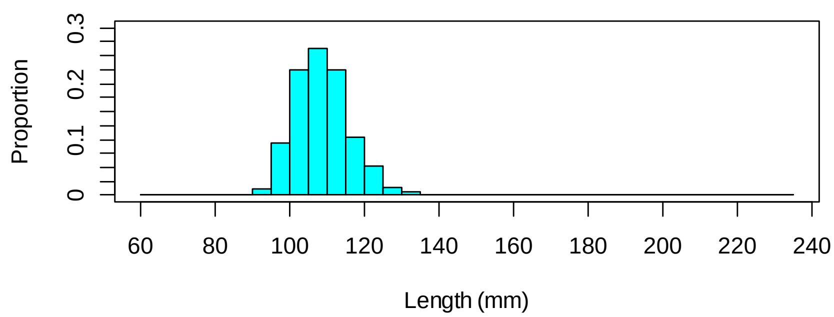
a. Little Goose Dam (Release V_1)



b. Little Goose Tailrace (Release R_2)



c. Mid-Reservoir (Release R_3)



d. ROR subyearling Chinook salmon at Little Goose Dam

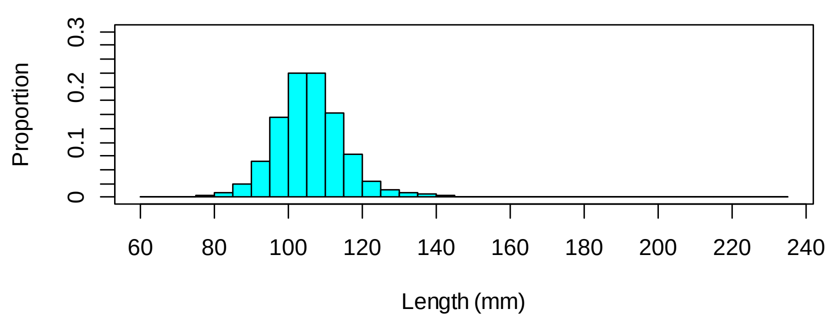
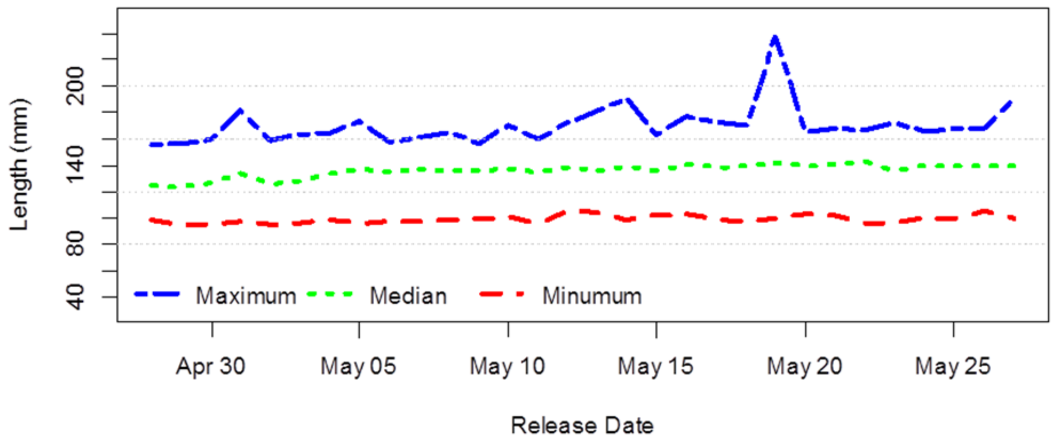
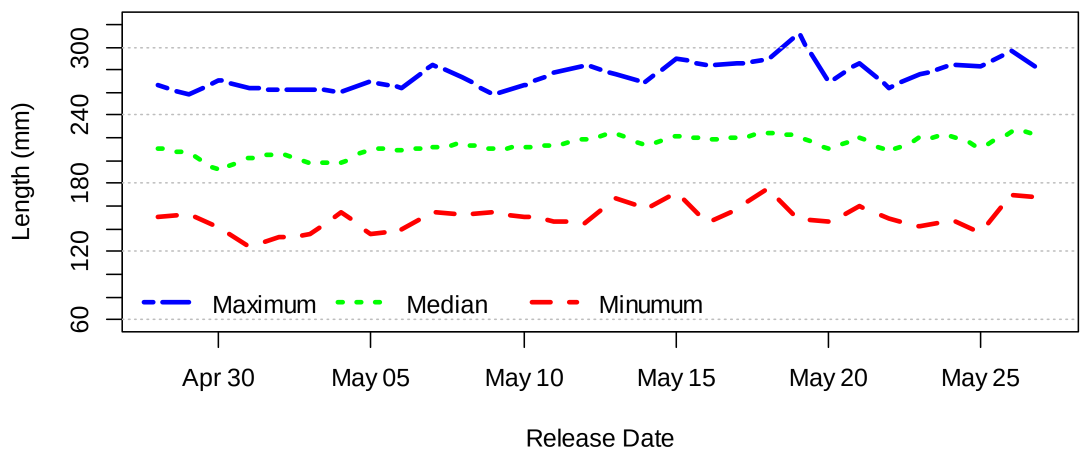


Figure 3.7. Frequency distributions for fish lengths (5-mm bins) of subyearling Chinook salmon smolts used in a) release V_1, b) release R_2, c) release R_3, and d) ROR fish sampled at Little Goose Dam by the Smolt Monitoring Program.

a. Yearling Chinook salmon smolts



b. Steelhead smolts



c. Subyearling Chinook salmon smolts

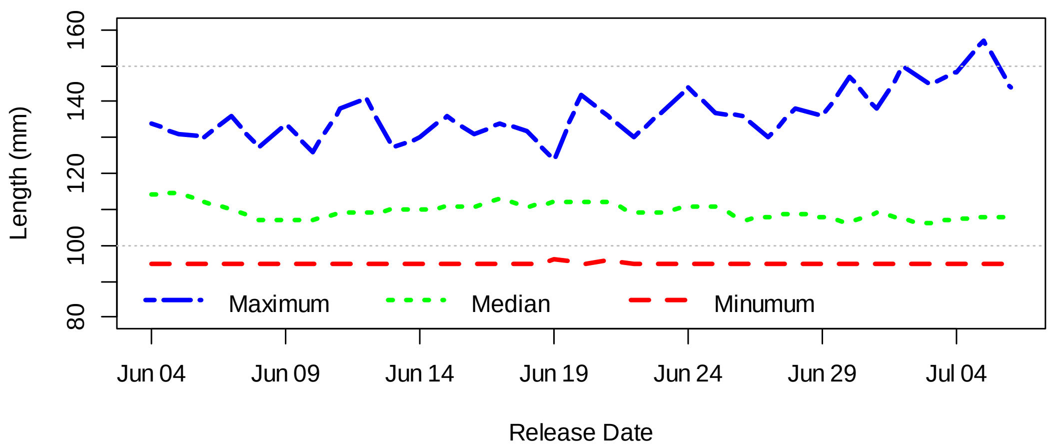


Figure 3.8. Range and median lengths of acoustic-tagged a) yearling Chinook salmon, b) steelhead, and c) subyearling Chinook salmon used in the 2012 survival studies. R_1 releases were made daily from 28 April through 25 May in spring and from 4 June through 5 July in the summer study.

3.4.6 Tag-Life Corrections

During the 2012 spring study, one tag lot was used for both the yearling Chinook salmon and steelhead smolts. A different tag lot was used for the summer subyearling Chinook salmon smolt study. Vitality curves of Li and Anderson (2009) were fit independently to each tag lot (Figure 3.9). Average tag lives were 34.5 and 46.4 days, respectively, for the spring and summer studies.

(a) Spring (b) Summer

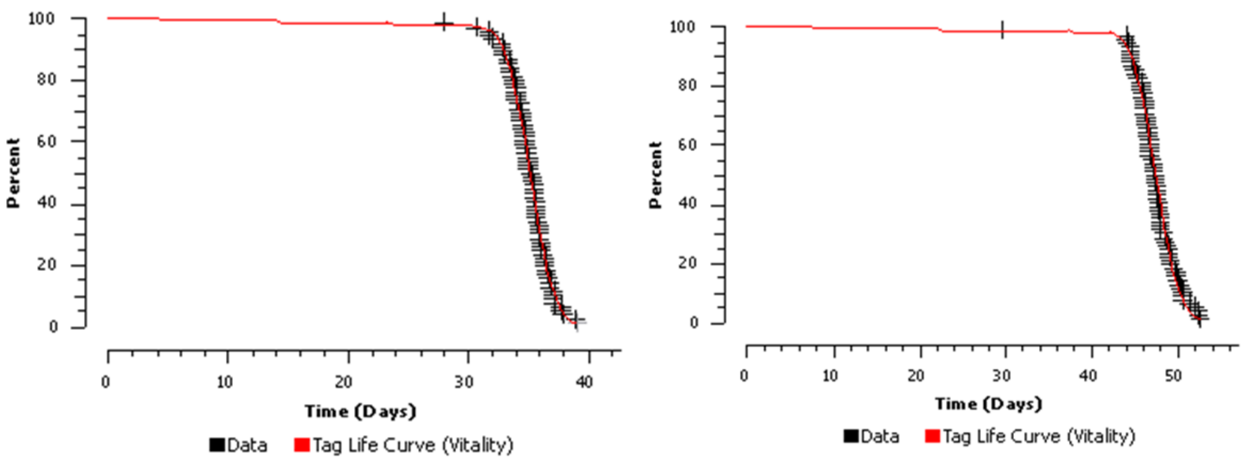


Figure 3.9. Observed time of tag failure (+) and fitted survivorship curves using the vitality model of Li and Anderson (2009) for a) spring and b) summer tagging studies.

3.4.7 Arrival Distributions

The estimated probability an acoustic tag was active when fish arrived at a downstream detection array depended on the tag-life curve and the distribution of observed travel times for yearling Chinook salmon (Figure 3.10), steelhead (Figure 3.11), and subyearling Chinook salmon (Figure 3.12). Examination of the fish arrival distributions to the last detection array (rkm 40) used in the survival analyses indicated all fish that arrived had passed through the study area before tag failure became important. These probabilities were calculated by integrating the tag survivorship curve (Figure 3.10–Figure 3.12) divided by the observed distribution of fish arrival times (i.e., time from tag activation to arrival). The probabilities of a JSATS tag being active at a downstream detection site were specific to release location and species (Table 3.4). In all cases, the probability that a tag was active at a downstream detection site as far as rkm 40 was >0.9973 for yearling Chinook salmon smolts, >0.9975 for steelhead smolts, and >0.9984 for subyearling Chinook salmon smolts (Table 3.4).

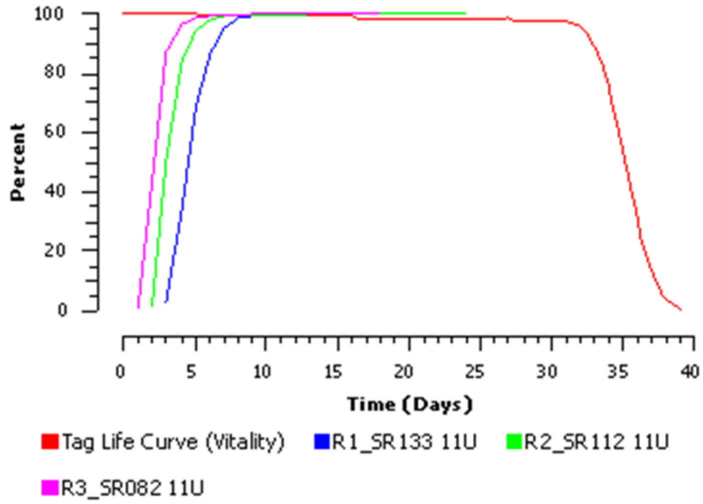


Figure 3.10. Plot of the fitted tag-life survivorship curve and the arrival-time distributions of yearling Chinook salmon smolts for releases V_1, R_2, and R_3 at the acoustic-detection array located at rkm 40 from the Snake River confluence (Figure 2.1).

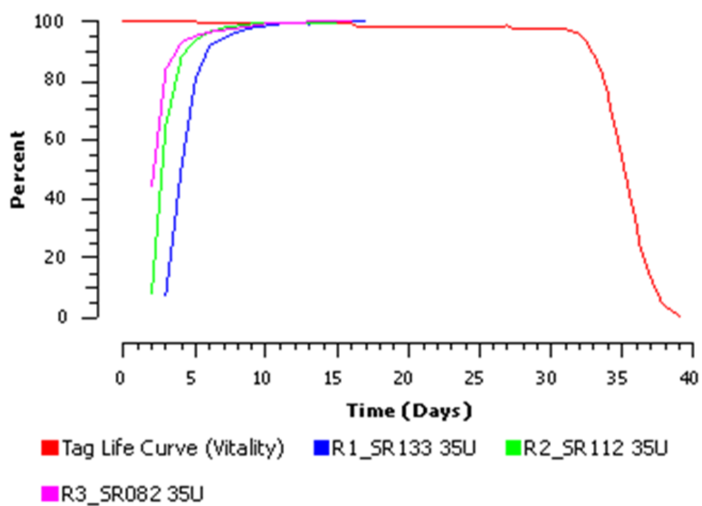


Figure 3.11. Plots of the fitted tag-life survivorship curve and the arrival-time distributions of steelhead smolts for releases V_1, R_2, and R_3 at the acoustic-detection array located at rkm 40 from the Snake River confluence (Figure 2.1).

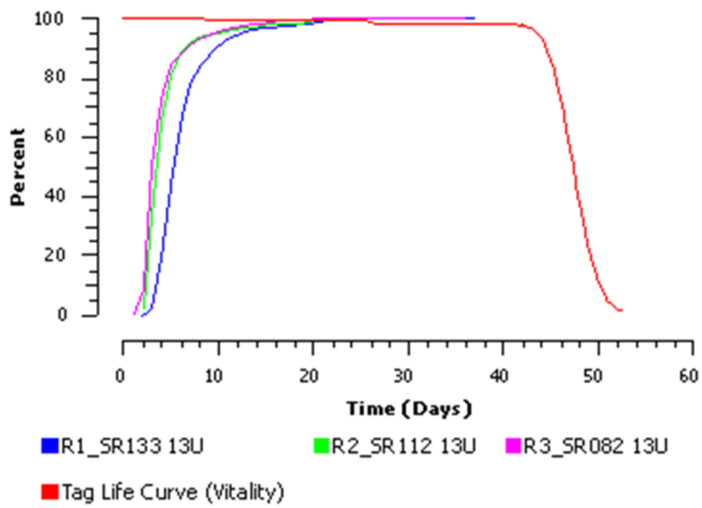


Figure 3.12. Plots of the fitted tag-life survivorship curve and the arrival-time distributions of subyearling Chinook salmon smolts for releases V_1, R_2, and R_3 at the acoustic-detection array located at rkm 40 from the Snake River confluence (Figure 2.1).

Table 3.4. Estimated probabilities (L) of an acoustic tag being active at a downstream detection site for a) yearling Chinook salmon smolts, b) steelhead smolts, and c) subyearling Chinook salmon smolts by release group. (Standard errors are in parentheses.)

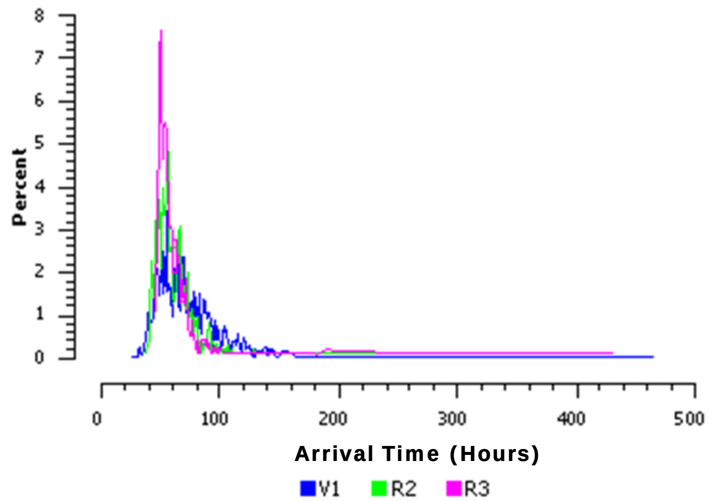
Release Group	rkm 82	rkm 67	rkm 40
a. Yearling Chinook salmon			
V_1 (rkm 113)[(a)]	0.9993 (0.0003)	0.9989 (0.0004)	0.9985 (0.0006)
R_2 (rkm 112)	--	0.9978 (0.0009)	0.9973 (0.0011)
R_3 (rkm 82)	--	0.9984 (0.0006)	0.9979 (0.0008)
b. Steelhead			
V_1 (rkm 113)[(a)]	0.9994 (0.0002)	0.9990 (0.0004)	0.9986 (0.0005)
R_2 (rkm 112)	--	0.9979 (0.0008)	0.9975 (0.0010)
R_3 (rkm 82)	--	0.9983 (0.0006)	0.9978 (0.0008)
c. Subyearling Chinook salmon			
V_1 (rkm 113)[(a)]	0.9985 (0.0002)	0.9995 (0.0001)	0.9991 (0.0001)
R_2 (rkm 112)	--	--	0.9984 (0.0002)
R_3 (rkm 82)	--	--	0.9986 (0.0002)

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

3.4.8 Downstream Mixing

To help induce downstream mixing of the release groups, the R_1 release was 20 h before the R_2 release, which, in turn, occurred 21 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 3.13), steelhead (Figure 3.14), and subyearling Chinook salmon smolts (Figure 3.15). The arrival modes for releases V_1, R_2, and R_3 were nearly synchronous in the spring yearling Chinook salmon and steelhead studies and the summer subyearling Chinook salmon study.

a. rkm 67



b. rkm 40

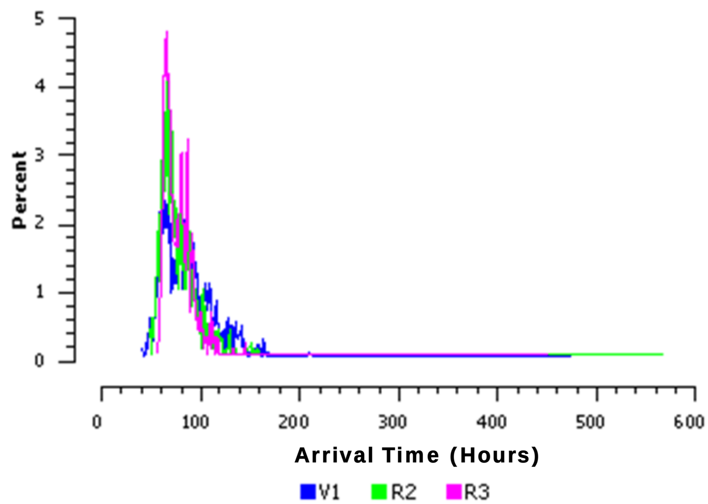
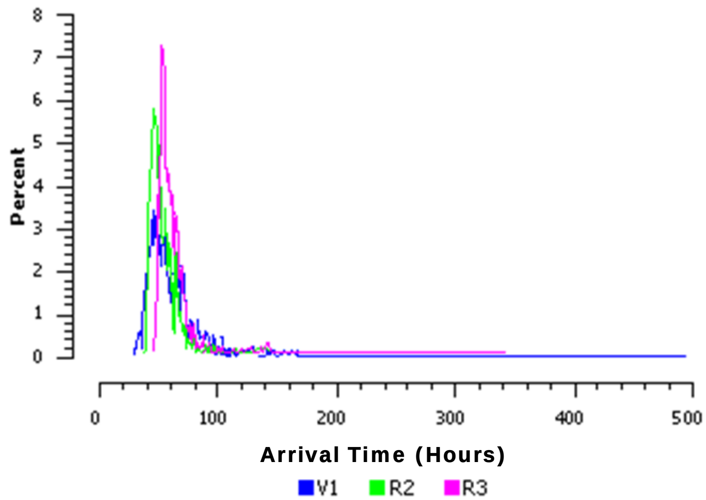


Figure 3.13. Frequency distribution plots of downstream arrival timing (expressed as percentages) for yearling Chinook salmon releases V_1, R_2, and R_3 at detection arrays located at a) rkm 67 and b) rkm 40 (see Figure 2.1) over the period 29 April to 27 May. All times are adjusted relative to the release time of V_1.

a. rkm 67



b. rkm 40

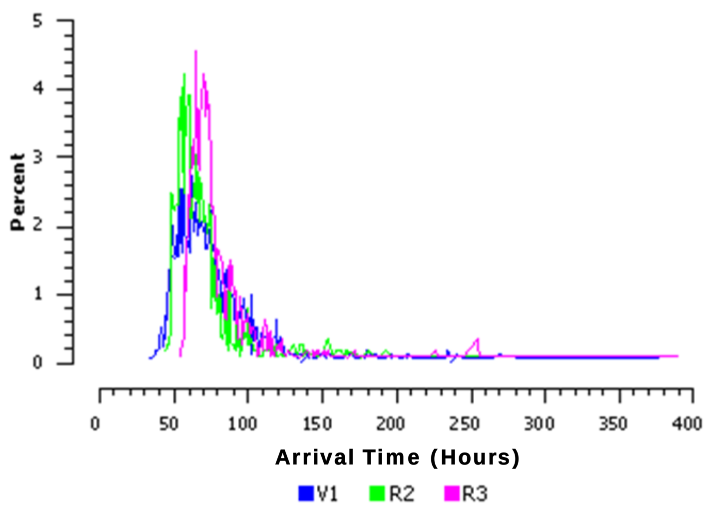
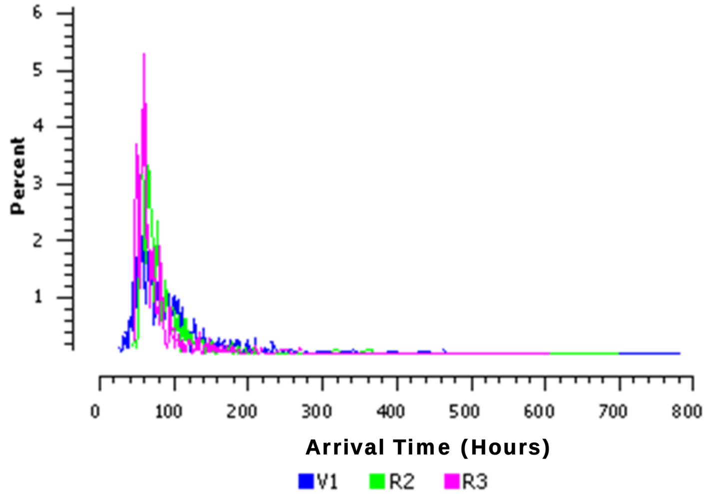


Figure 3.14. Frequency distribution plots of downstream arrival timing (expressed as percentages) for steelhead releases V_1, R_2, and R_3 at detection arrays located at a) rkm 67 and b) rkm 40 (see Figure 2.1) over the period 29 April to 27 May. All times are adjusted relative to the release time of V_1.

a. rkm 67



b. rkm 40

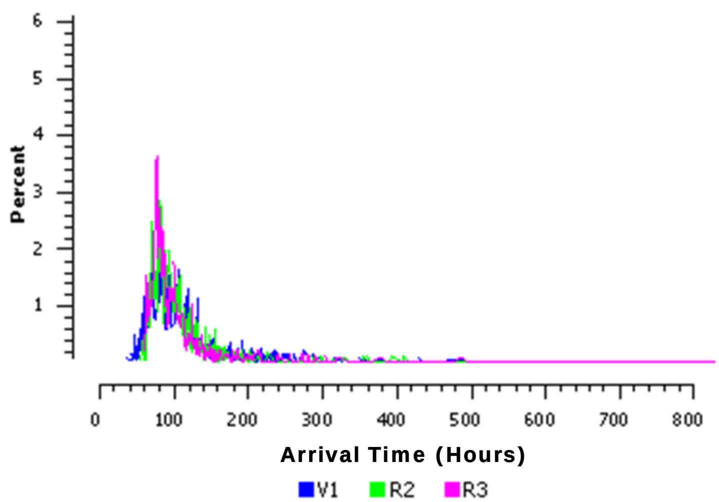


Figure 3.15. Frequency distribution plots of downstream arrival timing (expressed as percentages) for subyearling Chinook salmon releases V_1, R_2, and R_3 at detection arrays located at a) rkm 67, and b) rkm 40 (see Figure 2.1) over the period 5 June to 6 July. All times are adjusted relative to the 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, FPE, and route-specific survival.

3.5.1 Dam Passage Survival

3.5.1.1 Yearling Chinook Salmon

The estimates of dam passage survival for yearling Chinook salmon smolts at Little Goose Dam were calculated over three different periods of time. One period was from the beginning of the study on 29 April through 9 May 2012, when spill generally exceeded 30%. The second time period was 10 May 2012 through the end of the spring study, when percent spill was near the 30% target. The final survival estimate was calculated for the entire spring study.

For the early part of the spring study, when spill was above 30%, dam passage survival was estimated to be

$$\hat{S}_{\text{Dam}} = \frac{0.9600}{\left(\frac{0.9728}{0.9878}\right)} = \frac{0.9600}{0.9488} = 0.9748 \quad , \tag{3.1}$$

with a standard error of $\widehat{\text{SE}} = 0.0126$ (Table 3.5). This estimate is based on a fully parameterized likelihood model, because achieved precision with the model was adequate (i.e., $\widehat{\text{SE}} \le 0.015$). For the second half of the study, when spill levels were near the 30% target, dam passage survival was estimated to be

$$\hat{S}_{\text{Dam}} = \frac{0.9570}{\left(\frac{0.9675}{0.9976}\right)} = \frac{0.9570}{0.9698} = 0.9867 \quad , \tag{3.2}$$

with a standard error of $\widehat{\text{SE}} = 0.0098$ (Table 3.6).

The season-wide spring estimate of dam passage survival for yearling Chinook salmon smolts was estimated to be

$$\hat{S}_{\text{Dam}} = \frac{0.9581}{\left(\frac{0.9696}{0.9941}\right)} = \frac{0.9581}{0.9754} = 0.9822 \quad , \tag{3.3}$$

with an estimated standard error of $\widehat{\text{SE}} = 0.0076$ (Table 3.7).

This yearling Chinook salmon study estimated dam passage survival at Little Goose Dam had a point estimate ≥0.96 and estimated standard error ≤0.015. The semi-seasonal estimates also exceeded 96%

with a precision of less than 1.5%. The late season estimate of survival during approximate 30% spill was higher than the early season estimate when spill often greatly exceed 30%, but not significantly so $\left(P(|Z| \geq 0.6578) = 0.5107\right)$.

Table 3.5. Survival, detection, and λ parameters for the final model used to estimate dam passage survival for yearling Chinook salmon during the first half (i.e., ≤9 May 2012) of the spring study. Standard errors (SE) are based on both the inverse Hessian matrix and bootstrap for key parameter (†) and only the inverse Hessian matrix for associated parameters (*).

	SR113 to 82		SR82 to 67		Release to 67	
Release	$\hat{S}$	$\widehat{\text{SE}}^{\dagger}$	$\hat{S}$	$\widehat{\text{SE}}^{*}$	$\hat{S}$	$\widehat{\text{SE}}^{\dagger}$
V_1	0.9600	0.0080	0.9937	0.0034	---	---
R_2	---	---	---	---	0.9728	0.0079
R_3	---	---	---	---	0.9878	0.0058

	SR82		SR67		SR40	
Release	$\hat{p}$	$\widehat{\text{SE}}^{*}$	$\hat{p}$	$\widehat{\text{SE}}^{*}$	λ	$\widehat{\text{SE}}^{*}$
V_1	1.0000	< 0.0001	1.0000	< 0.0001	0.9628	0.0079
R_2	---	---	1.0000	< 0.0001	0.9830	0.0062
R_3	---	---	1.0000	< 0.0001	0.9623	0.0094

Table 3.6. Survival, detection, and λ parameters for the final model used to estimate dam passage survival for yearling Chinook salmon during the last half (i.e., ≥10 May 2012) of the spring study. Standard errors (SE) are based on both the inverse Hessian matrix and bootstrap for key parameter (†) and only the inverse Hessian matrix for associated parameters (*).

	SR113 to 82		SR82 to 67		Release to 67	
Release	$\hat{S}$	$\widehat{\text{SE}}^{\dagger}$	$\hat{S}$	$\widehat{\text{SE}}^{*}$	$\hat{S}$	$\widehat{\text{SE}}^{\dagger}$
V_1	0.9570	0.0060	0.9894	0.0031	---	---
R_2	---	---	---	---	0.9675	0.0068
R_3	---	---	---	---	0.9976	0.0023

	SR82		SR67		SR40	
Release	$\hat{p}$	$\widehat{\text{SE}}^{*}$	$\hat{p}$	$\widehat{\text{SE}}^{*}$	λ	$\widehat{\text{SE}}^{*}$
V_1	1.0000	< 0.0001	1.0000	< 0.0001	0.9717	0.0051
R_2	---	---	1.0000	< 0.0001	0.9718	0.0063
R_3	---	---	1.0000	< 0.0001	0.9730	0.0059

Table 3.7. Survival, detection, and λ parameters for the final model used to estimate dam passage survival for yearling Chinook salmon during the season-wide spring 2012 study. Standard errors (SE) are based on both the inverse Hessian matrix and bootstrapping for key parameters (†) and only the inverse Hessian matrix for associated parameters (*).

	SR113 to 82		SR82 to 67		Release to 67	
Release	$\hat{S}$	$\widehat{\text{SE}}^{\dagger}$	$\hat{S}$	$\widehat{\text{SE}}^{*}$	$\hat{S}$	$\widehat{\text{SE}}^{\dagger}$
V_1	0.9581	0.0048	0.9909	0.0024	---	---
R_2	---	---	---	---	0.9696	0.0052
R_3	---	---	---	---	0.9941	0.0026

	SR82		SR67		SR40	
Release	$\hat{p}$	$\widehat{\text{SE}}^{*}$	$\hat{p}$	$\widehat{\text{SE}}^{*}$	λ	$\widehat{\text{SE}}^{*}$
V_1	1.0000	<0.0001	1.0000	<0.0001	0.9686	0.0043
R_2	---	---	1.0000	<0.0001	0.9762	0.0045
R_3	---	---	1.0000	<0.0001	0.9692	0.0051

3.5.1.2 Steelhead

Survival estimation for steelhead smolts was performed over the same three time periods used in the yearling Chinook salmon analyses. For the early spring period (i.e., ≤9 May 2012), dam passage survival was estimated to be

$$\hat{S}_{\text{Dam}} = \frac{0.9706}{\left(\frac{0.9554}{0.9811}\right)} = \frac{0.9706}{0.9738} = 0.9967 \quad , \tag{3.4}$$

with a standard error of $\widehat{\text{SE}} = 0.0142$ (Table 3.8). For the later part of spring (i.e., ≥ 10 May 2012), dam passage survival was estimated to be

$$\hat{S}_{\text{Dam}} = \frac{0.9708}{\left(\frac{0.9663}{0.9886}\right)} = \frac{0.9708}{0.9774} = 0.9932 \quad , \tag{3.5}$$

with a standard error of $\widehat{\text{SE}} = 0.0098$ (Table 3.9).

Across the entire spring study, dam passage survival for steelhead smolts through Little Goose Dam was estimated to be

$$\hat{S}_{\text{Dam}} = \frac{0.9707}{\left(\frac{0.9620}{0.9859}\right)} = \frac{0.9707}{0.9758} = 0.9948 \quad , \tag{3.6}$$

with a standard error of $\widehat{\mathrm{SE}} = 0.0081$ (Table 3.10). It is useful to note, not only the season-wide estimate, but also each of the semi-seasonal estimates of dam passage survival was ≥0.96 with standard errors ≤0.015. Furthermore, the reach survival estimates from the virtual releases (i.e., V_1, dam face to rkm 82), which include 30 km of survival in the Lower Monumental reservoir, exceeded 0.96. The standard errors for the virtual releases, V_1, were 0.0068, 0.0054, and 0.0041 for early spring, late spring, and season-wide, respectively.

Estimates of dam passage survival during early and late spring were not significantly different $\left(P(|Z| \geq 0.3014) = 0.7631\right)$.

Table 3.8. Survival, detection, and λ parameters for the final model used to estimate dam passage survival for steelhead during the first half (i.e., ≤ 9 May 2012) of the spring study. Standard errors (SE) are based on both the inverse Hessian matrix and bootstrap for key parameter (†) and only the inverse Hessian matrix for associated parameters (*).

	SR113 to 82		SR82 to 67		Release to 67	
Release	$\hat{S}$	$\widehat{\mathrm{SE}}^{\dagger}$	$\hat{S}$	$\widehat{\mathrm{SE}}^{*}$	$\hat{S}$	$\widehat{\mathrm{SE}}^{\dagger}$
V_1	0.9706	0.0068	0.9890	0.0043	---	---
R_2	---	---	---	---	0.9554	0.0098
R_3	---	---	---	---	0.9811	0.0070

	SR82		SR67		SR40	
Release	$\hat{p}$	$\widehat{\mathrm{SE}}^{*}$	$\hat{p}$	$\widehat{\mathrm{SE}}^{*}$	λ	$\widehat{\mathrm{SE}}^{*}$
V_1	0.9984	0.0016	1.0000	<0.0001	0.9788	0.0059
R_2	---	---	1.0000	<0.0001	0.9893	0.0050
R_3	---	---	0.9951	0.0035	0.9645	0.0092

Table 3.9. Survival, detection, and λ parameters for the final model used to estimate dam passage survival for steelhead during the last half (i.e., ≥ 10 May 2012) of the spring study. Standard errors (SE) are based on both the inverse Hessian matrix and bootstrap for key parameter (†) and only the inverse Hessian matrix for associated parameters (*).

	SR113 to 82		SR82 to 67		Release to 67	
Release	$\hat{S}$	$\widehat{\mathrm{SE}}^{\dagger}$	$\hat{S}$	$\widehat{\mathrm{SE}}^{*}$	$\hat{S}$	$\widehat{\mathrm{SE}}^{\dagger}$
V_1	0.9708	0.0051	0.9938	0.0025	---	---
R_2	---	---	---	---	0.9663	0.0069
R_3	---	---	---	---	0.9886	0.0041

	SR82		SR67		SR40	
Release	$\hat{p}$	$\widehat{\mathrm{SE}}^{*}$	$\hat{p}$	$\widehat{\mathrm{SE}}^{*}$	λ	$\widehat{\mathrm{SE}}^{*}$
V_1	1.0000	< 0.0001	1.0000	< 0.0001	0.9833	0.0040
R_2	---	---	1.0000	< 0.0001	0.9888	0.0041
R_3	---	---	1.0000	< 0.0001	0.9831	0.0048

Table 3.10. Survival, detection, and λ parameters for the final model used to estimate dam passage survival for steelhead during the season-wide spring 2012 study. Standard errors (SE) are based on both the inverse Hessian matrix and bootstrapping for key parameters (†) and only the inverse Hessian matrix for associated parameters (*).

	SR113 to 82		SR82 to 67		Release to 67	
Release	$\hat{S}$	$\widehat{\mathrm{SE}}^{\dagger}$	$\hat{S}$	$\widehat{\mathrm{SE}}^{*}$	$\hat{S}$	$\widehat{\mathrm{SE}}^{\dagger}$
V_1	0.9707	0.0041	0.9921	0.0022	---	---
R_2	---	---	---	---	0.9620	0.0057
R_3	---	---	---	---	0.9859	0.0037

	SR82		SR67		SR40	
Release	$\hat{p}$	$\widehat{\mathrm{SE}}^{*}$	$\hat{p}$	$\widehat{\mathrm{SE}}^{*}$	λ	$\widehat{\mathrm{SE}}^{*}$
V_1	0.9994	0.0006	1.0000	<0.0001	0.9816	0.0033
R_2	---	---	1.0000	<0.0001	0.9890	0.0032
R_3	---	---	0.9983	0.0012	0.9764	0.0045

3.5.1.3 Subyearling Chinook Salmon

A season-wide estimate of dam passage survival was calculated for subyearling Chinook salmon regardless of spill level. The standard calculation for dam passage survival is as follows (Table 3.11):

$$\hat{S}_{\text{Dam}} = \frac{0.9239}{\left(\frac{0.9257}{0.9527}\right)} = \frac{0.9239}{0.9717} = 0.9508\,, \tag{3.7}$$

with a standard error of $\widehat{\mathrm{SE}} = 0.0097$. This estimate of dam passage survival is based on a bias-adjusted estimate of S_1 from the virtual release. In summer, during the subyearling Chinook salmon survival study, 1 of 32 dead tagged fish released into the Little Goose tailrace was detected at the R_3 detection array at rkm 82. Such false-positive detections from fish that died during dam passage with still active tags could bias our estimate of dam passage survival. The unadjusted estimate of S_1 from the Cormack-Jolly-Seber model was 0.9267 ($\widehat{\mathrm{SE}} = 0.0051$) (Table 3.11). Adjusting for a dead tagged-fish detection rate of 1/32 yielded a bias-corrected value of 0.9239 ($\widehat{\mathrm{SE}} = 0.0058$) (Appendix D). The bias correction is small because the study estimates most fish survived between the dam and the detection array at rkm 82. Consequently, there were few actual opportunities for false-positive detections due to dead fish.

Table 3.11. Survival, detection, and λ parameters for the final model used to estimate dam passage survival for subyearling Chinook salmon during the summer 2012 study. Standard errors (SE) are based on both the inverse Hessian matrix and bootstrapping for key parameters (†) and only the inverse Hessian matrix for associated parameters (*).

	SR113 to 82		SR112 to 67		Release to 67	
Release	$\hat{S}$	$\widehat{\mathrm{SE}}^{\dagger}$	$\hat{S}$	$\widehat{\mathrm{SE}}^{*}$	$\hat{S}$	$\widehat{\mathrm{SE}}^{\dagger}$
V_1	0.9267	0.0051	0.9558	0.0042	---	---
R_2	---	---	---	---	0.9257	0.0058
R_3	---	---	--	---	0.9527	0.0047

	SR82		SR67		SR40	
Release	$\hat{p}$	$\widehat{\mathrm{SE}}^{*}$	$\hat{p}$	$\widehat{\mathrm{SE}}^{*}$	λ	$\widehat{\mathrm{SE}}^{*}$
V_1	0.9992	0.0006	0.9987	0.0008	0.9473	0.0046
R_2	---	---	0.9989	0.0008	0.9304	0.0058
R_3	---	---	1.0000	<0.0001	0.9354	0.0056

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 BRZ (i.e., detection array rkm 113, Figure 2.1) rather than at the dam face. These season-wide survival estimates were based on all release data across the season. Using the same statistical model as was used in estimating dam passage survival, forebay-to-tailrace survival for yearling Chinook salmon was

$$\hat{S}_{\text{forebay-to-tailrace}} = 0.9813 \left(\widehat{\mathrm{SE}} = 0.0076\right); \tag{3.8}$$

for steelhead it was

$$\hat{S}_{\text{forebay-to-tailrace}} = 0.9943 \left(\widehat{\mathrm{SE}} = 0.0081\right); \tag{3.9}$$

and for subyearling Chinook salmon it was

$$\hat{S}_{\text{forebay-to-tailrace}} = 0.9454 \left(\widehat{\mathrm{SE}} = 0.0098\right). \tag{3.10}$$

In the case of subyearling Chinook salmon, the estimate of forebay-to-tailrace survival was corrected for the dead tagged fish detection, analogous to that of dam passage survival.

3.5.3 Forebay Residence Time

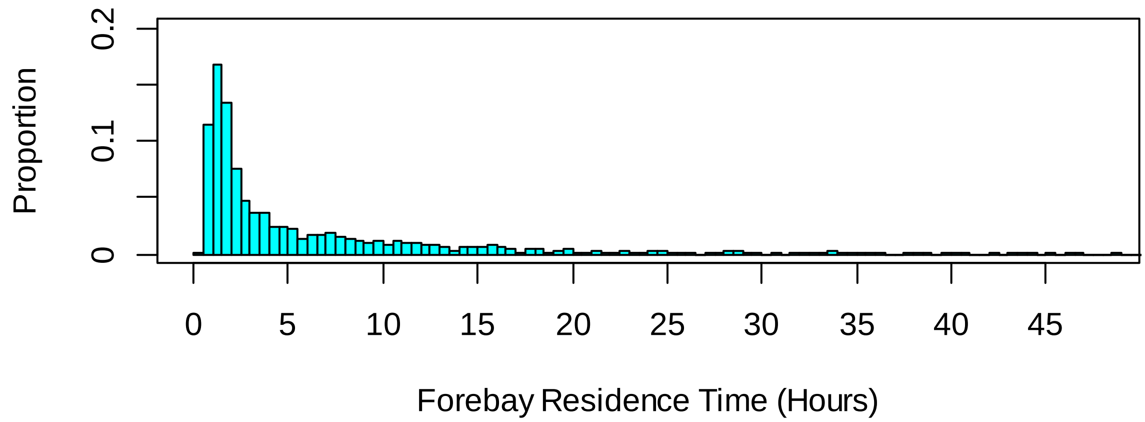
The forebay residence time was calculated from the first detection of a smolt at the forebay BRZ array to the last detection at the dam (0.9 km). For yearling Chinook salmon, the mean forebay residence time was estimated to be 6.34 h (SE = 0.22); for steelhead, it was estimated to be 5.84 h (SE =0.23); and for subyearling Chinook salmon, it was estimated to be 7.86 h (SE = 0.56) (Figure 3.16, Table 3.12). The distribution of forebay residence times indicates the modes for forebay residence times were 1.5, 2, and 1 h for yearling Chinook salmon, steelhead, and subyearling Chinook salmon, respectively. Median residence times were 2.58 h, 2.67 h, and 2.80 h for yearling Chinook salmon, steelhead, and subyearling Chinook salmon, respectively (Table 3.12).

3.5.4 Tailrace Egress Time

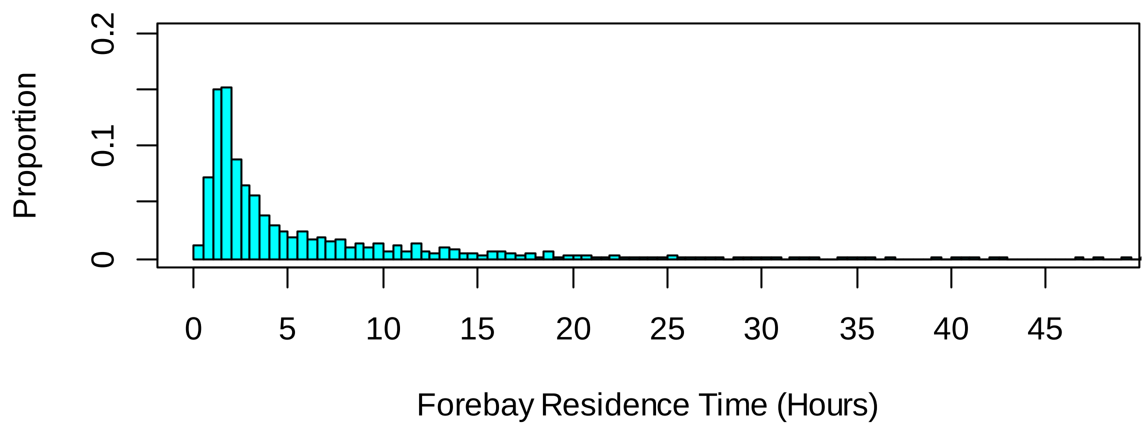
The first method of calculating tailrace egress time was based on the time from the last detection of fish at the double array at the face of Little Goose Dam to the last detection at the BRZ tailrace array (Figure 2.1). Mean tailrace egress time was estimated to be $\bar{t}$ = 3.26 h ($\widehat{\mathrm{SE}}$ = 0.34) for yearling Chinook salmon smolts, $\bar{t}$ = 3.37 h ($\widehat{\mathrm{SE}}$ = 0.33) for steelhead smolts, and $\bar{t}$ = 2.47 h ($\widehat{\mathrm{SE}}$ = 0.27) for subyearling Chinook salmon smolts. Median egress times were 0.60, 0.69, and 0.80 h for yearling Chinook salmon, steelhead, and subyearling Chinook salmon, respectively (Table 3.12). The modes were 0.5 h, 1.0 h, and 1.0 h for yearling Chinook salmon, steelhead, and subyearling Chinook salmon, respectively (Figure 3.17).

The second method of calculating tailrace egress time was adjusted for the fish that went through the juvenile bypass system. For those fish, tailrace egress was from the last detection in the bypass system to the last detection at the BRZ tailrace array. Based on these calculations, median egress times were 0.58, 0.68, and 0.78 hours for yearling Chinook salmon, steelhead, and subyearling Chinook salmon, respectively (Table 3.12).

a. Yearling Chinook salmon



b. Steelhead



c. Subyearling Chinook salmon

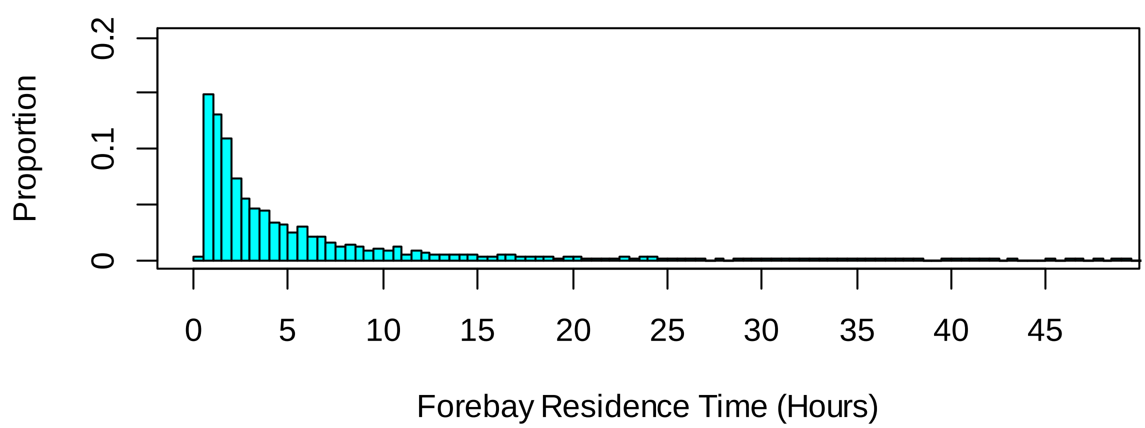


Figure 3.16. Distribution of forebay residence times (half-hour bins) for a) yearling Chinook salmon, b) steelhead, and c) subyearling Chinook salmon smolts at Little Goose Dam, 2012.

Table 3.12. Estimated mean and median forebay residence time (h) and mean and median tailrace egress times for yearling Chinook salmon, steelhead, and subyearling Chinook salmon smolts at Little Goose Dam in 2012. Standard errors are in parentheses.

Performance Measure	Yearling Chinook Salmon	Steelhead	Subyearling Chinook Salmon
Forebay Residence Time			
Mean	6.34 (0.22)	5.84 (0.23)	7.86 (0.56)
Median	2.58	2.67	2.80
Tailrace Egress Time[(a)]			
Mean	3.26 (0.34)	3.37 (0.33)	2.47 (0.27)
Median	0.60	0.69	0.80
Tailrace Egress Time[(b)]			
Mean	1.35 (0.06)	1.12 (0.10)	1.41 (0.05)
Median	0.58	0.68	0.78

(a) Egress time based on acoustic-tag detections for all fish.
(b) Egress time based, in part, on PIT-tag detections for bypassed fish.

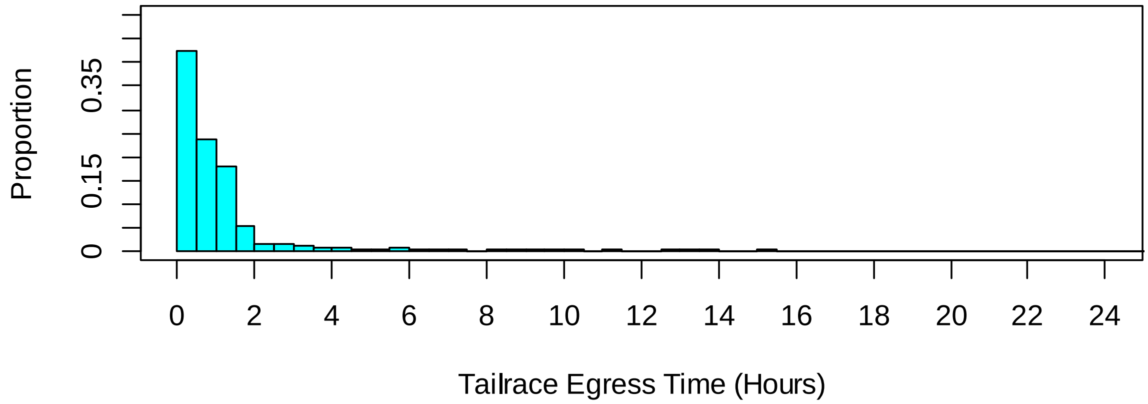
3.5.5 Spill Passage Efficiency

SPE is defined as the fraction of the fish that passed through a dam by the spillway. The double-detection array at the face of Little Goose Dam was used to identify and track fish as they entered the forebay. Using the observed counts and assuming detection efficiency was constant across the dam, the numbers of fish entering the various routes at Little Goose Dam were used to estimate SPE based on a binomial sampling model. For yearling Chinook smolts, $\widehat{\text{SPE}}$ = 0.6528 (0.0113); for steelhead smolts, $\widehat{\text{SPE}}$ = 0.5609 (0.0119); and for subyearling Chinook salmon smolts, $\widehat{\text{SPE}}$ = 0.7249 (0.0086).

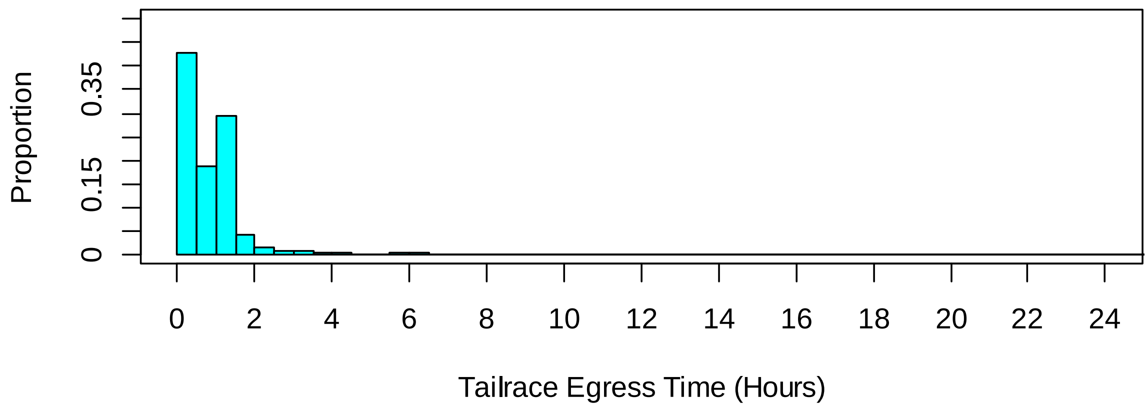
3.5.6 Fish Passage Efficiency

FPE 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 Little Goose Dam was used to identify and track fish as they entered the dam. Using the observed counts and assuming constant detection efficiency across the face of the dam, the number of fish entering the various routes at Little Goose Dam was used to estimate FPE based on a binomial sampling model. For yearling Chinook salmon smolts at Little Goose Dam in 2012, FPE is estimated to be $\widehat{\text{FPE}}$ = 0.9625 (0.0045); for steelhead smolts, $\widehat{\text{FPE}}$ = 0.9800 (0.0033); and for subyearling Chinook salmon smolts, $\widehat{\text{FPE}}$ = 0.9507 (0.0042).

a. Yearling Chinook Salmon



b. Steelhead



c. Subyearling Chinook Salmon

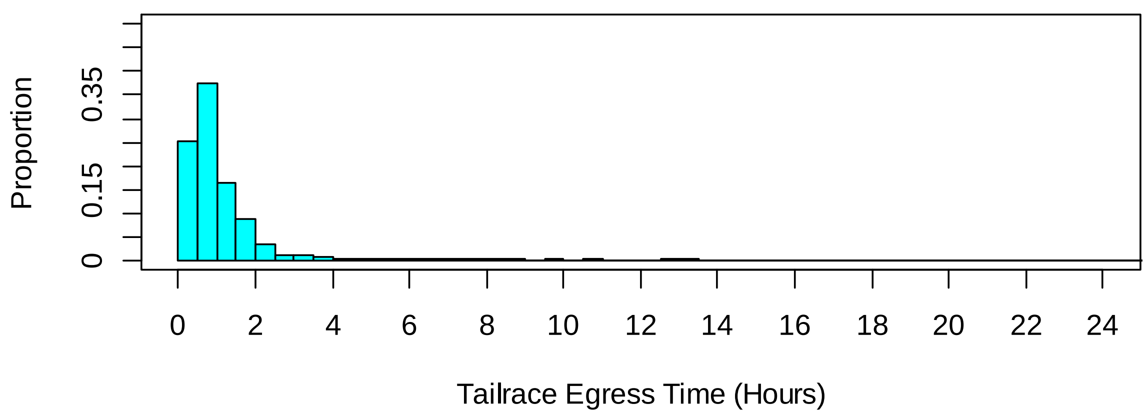


Figure 3.17. Distribution of tailrace egress times (half-hour bins) for a) yearling Chinook salmon, b) steelhead, and c) subyearling Chinook salmon smolts at Little Goose Dam, 2012.

3.5.7 Route-Specific Survival

High percentages of fish from all three stocks passed LGS through the spillway weir where survival was near 100% for yearling Chinook salmon (44% passed via this route) and steelhead (40% passed via this route), and 96% for subyearling Chinook salmon (48% passed via this route; Table 3.12). High percentages of fish (31% of yearling Chinook salmon, 42% of steelhead, and 23% of subyearling Chinook salmon) passed LGS through the JBS where survival was greater than 98% for each stock. Survival through the turbines was markedly lower (i.e., 81%–87%) than survival through all other routes; however, less than 5% of any stock passed LGS through the turbines.

Table 3.13. Proportion of fish passing and survival by route at Little Goose Dam in 2012. Standard errors are in parentheses.

		Route				
Species	Measure	Deep Spill	Spillway Weir	All Spill	Turbine	JBS
Yearling Chinook	Proportion	0.2114 (0.0097)	0.4415 (0.0118)	0.6528 (0.0113)	0.0375 (0.0045)	0.3097 (0.0110)
	Survival	0.9486 (0.0151)	1.0048 (0.0078)	0.9866 (0.0082)	0.8704 (0.0456)	0.9882 (0.0101)
Steelhead	Proportion	0.1572 (0.0087)	0.4037 (0.0117)	0.5609 (0.0119)	0.0200 (0.0033)	0.4191 (0.0118)
	Survival	0.9918 (0.0129)	1.0006 (0.0091)	0.9981 (0.0087)	0.8055 (0.0797)	0.9973 (0.0093)
Subyearling Chinook	Proportion	0.2484 (0.0083)	0.4765 (0.0096)	0.7249 (0.0086)	0.0493 (0.0042)	0.2258 (0.0081)
	Survival	0.9421 (0.0134)	0.9623 (0.0105)	0.9554 (0.0097)	0.8128 (0.0370)	0.9807 (0.0119)

4.0 Discussion

This section describes the conduct of the 2012 study, study performance, and compares 2012 estimates to comparable estimates in previous telemetry studies at Little Goose Dam.

4.1 Study Conduct

The many tests of assumptions (Section 3.4 and Appendix B) found the acoustic-tag study achieved good downstream mixing, with adequate tag-life and no evidence of adverse tagger effects. There was also no evidence of delayed handling/tagger effects within the realm of the study. The results suggest the assumptions of the virtual-paired-release model were fulfilled with one exception, permitting valid estimation of dam passage survival and related parameters. One of 32 dead tagged fish released during the summer survival study was detected at detection array SR82. The subyearling Chinook salmon survival estimate had to be bias-corrected for this rate of dead fish detections (Appendix D).

Despite the high river velocities, detection probabilities at downriver detection sites were extremely high (i.e., estimated at 1.0). The result was all estimates of dam passage survival were in excess of 96% in spring and 93% in summer and had very good precision (i.e., SE ≤ 0.015).

4.2 Study Performance

The 2012 spring passage and survival studies at Little Goose Dam were conducted during relatively high river flow conditions. Spill levels generally exceeded the target spill level of 30% prior to 10 May 2012. Spill levels were closer to the 30% target from 10 May 2012 and beyond. Early ($\hat{S}_{\text{Dam}}$ = 0.9748 [0.0126]) and later season ($\hat{S}_{\text{Dam}}$ = 0.9867 [0.0098]) survival estimates for yearling Chinook salmon were not significantly different (*P* = 0.5107). Similarly for steelhead, early ($\hat{S}_{\text{Dam}}$ = 0.9967 [0.0142]) and later season ($\hat{S}_{\text{Dam}}$ = 0.9932 [0.0098]) estimates of dam passage survival were not significantly different (*P* = 0.7631). All of these semi-seasonal estimates of dam passage survival exceeded 96% and had very good precision. Also, the mean discharge during the spring study period (106.7 kcfs) was well within the middle 90% of the previous 70-year average for spring of 54.9 to 154.9.

In summer 2012, spill levels exceeded the 30% spill target for most for the study. No attempt was made to dissect the summer study into periods where spill was within ±5% of the targeted 30% or not. The season-wide estimate of dam passage survival for subyearling Chinook salmon exceed 93% and had very good precision (i.e., $\hat{S}_{\text{Dam}}$ = 0.9508 [$\widehat{\text{SE}}$ = 0.0097]).

Mortality per kilometer rates of PIT-tagged and acoustic-tagged fish were similar between the Little Goose tailrace and Lower Monumental Dam during the study period in 2012 (Appendix E).

4.3 Comparison to Previous Survival Study Results

Differences in dam operations, environmental conditions, and experimental designs necessitate caution in the comparison of performance metrics among study years (Table 4.1 and Table 4.2). Multiple treatment conditions were evaluated during the two pre-spillway weir study years (i.e., 2006 and 2007).

Thus, the estimated performance metrics (e.g., dam passage survival, etc.) associated with the pre-spillway weir study years were estimated using the treatment conditions (e.g., bulk spill) most similar to those observed during the two post-spillway weir years (i.e., 2009 and 2012), and not necessarily representative of standard operations during those years. All performance metrics presented in Table 4.3–Table 4.6 are related to the conditions denoted in Table 4.1 (yearling Chinook salmon and steelhead) and Table 4.2 (subyearling Chinook salmon) unless otherwise noted.

Table 4.1. Study design and conditions among study years during spring (yearling Chinook salmon and steelhead) migrations.

	2006[a]	2007[b]	2009[c]	2012[d]
Design	PR	PR	PR	VPR
Telemetry system	Radio	Radio	Radio	JSATS
Treatment	Bulk spill	Bulk2 spill	Overall	Overall
Mean discharge (kcfs)	125	76	112	115
Percent spill	24	29	29	32
SW operation	NA	NA	Low	Low
Percent SW	NA	NA	11.1	10.5
FA to dam dist. (km)	2	2	2	0.86
TA to dam dist. (km)	1.4	1.4	1.4	1.50
R_2 to dam dist. (km)	0.50	0.50	0.50	1.42

(a) Beeman et al. (2008a).
(b) Beeman et al. (2008b).
(c) Beeman et al. (2010).
(d) This study.
PR = paired release; VPR = virtual-paired-release; FA = forebay array; TA = tailrace array; R_2 = tailrace "control" release).

Dam passage survival is the estimated survival from the time fish enter the dam until they reach the tailrace release location (termed R_2 in this study and *Rc* in previous studies). The tailrace release location was 0.5 km below the dam during 2006, 2007, and 2009 (Beeman et al. 2008a, 2008b, 2010). Recent modeling indicated that the hydraulic extent of Little Goose Dam was located 0.92 km downstream of this tailrace release location (Rakowski et al. 2010). Therefore, the tailrace release was located near the hydraulic extent (1.42 km below the dam) in 2012. Thus, dam passage survival estimates for 2006, 2007, and 2009 represent survival through the dam and the first 0.50 km of the tailrace; whereas, dam passage survival estimates for 2012 represent survival through the dam and the entire 1.5-km tailrace.

Forebay-to-tailrace survival is the estimated survival from the forebay detection array to the tailrace release location. The location of the forebay detection array was also changed for the 2012 sampling year. The forebay detection array was located 2 km upstream of the dam during 2006, 2007, and 2009, and was placed 0.9 km upstream of the dam during 2012 in response to modeling of the hydraulic extent (Rakowski et al. 2010). Thus, the 2012 forebay-to-tailrace survival estimates were based on a slightly different reach of river than estimates from the previous three study years.

Table 4.2. Study design and conditions among study years during the summer (subyearling Chinook salmon) migration.

	2006[a]	2007[b]	2009[c]	2012[d]
Design	PR	PR	PR	VPR
Telemetry system	Radio	Radio	Radio	JSATS
Treatment	Bulk spill	Uniform spill	Overall	Overall
Mean discharge (kcfs)	49	37	94	81
Percent spill	31	31	30	39
SW operation	NA	NA	Low	High
Percent SW	NA	NA	11.2	8.5
FA to dam dist. (km)	2	2	2	0.86
TA to dam dist. (km)	1.4	1.4	1.4	1.50
R_2 to dam dist. (km)	0.50	0.50	0.50	1.42

(a) Beeman et al. (2008a).
(b) Beeman et al. (2008b).
(c) Beeman et al. (2010).
(d) This study.
PR = paired release; VPR = virtual-paired-release; FA = forebay array; TA = tailrace array; R_2 = tailrace "control" release).

Estimates of dam passage survival were generally consistent among study years, and characterized by high survival and precision levels during both post-spillway weir study years (Table 4.3). There were notable increases in dam passage survival and associated precision for yearling Chinook salmon and steelhead following the 2006 study year. Subyearling Chinook salmon showed a marked increase in dam passage survival and associated precision after the construction of the spillway weir (i.e., after 2007). Forebay-to-tailrace survival was generally similar among study years for yearling Chinook salmon and steelhead (Table 4.3). There was a notable increase in subyearling Chinook salmon forebay-to-tailrace survival after construction of the spillway weir.

Forebay residence times were markedly lower during 2012 than during the previous study years for all three species/stocks (Table 4.4). As previously mentioned, the forebay detection array was located 2 km above Little Goose Dam during the 2006, 2007, and 2009 study years, while it was located at the hydraulic extent (Rakowski et al. 2010) of the forebay (0.9 km above the dam) during 2012. Thus, the times observed during 2012 were expected to be less than those observed during the previous three study years.

Table 4.3. Dam passage survival and forebay-to-tailrace survival of yearling Chinook salmon, steelhead, and subyearling Chinook salmon at Little Goose Dam among years. Parentheses denote standard error.

	Year	Yearling	Steelhead	Subyearling
Dam passage survival	2006[(a)]	0.949 (0.014)	0.959 (0.012)	0.894 (0.033)
	2007[(b)]	1.005 (0.018)	0.986 (0.013)	0.905 (0.023)
	2009[(b)]	0.994 (0.010)	0.998 (0.004)	0.952 (0.013)
	2012	0.982 (0.008)	0.995 (0.008)	0.951 (0.010)[(c)]
Forebay-to-tailrace survival	2006	NE	NE	NE
	2007[(d)]	1.001 (0.009)	0.984 (0.015)	0.834 (0.023)
	2009[(d)]	0.992 (0.010)	0.994 (0.004)	0.936 (0.013)
	2012	0.981 (0.008)	0.994 (0.008)	0.945 (0.010)

(a) "S dam" (average survival probability of dam passage through all routes weighted by the probability of passing each route) estimates (note: "S dam" has a different definition in 2006 than in subsequent study years).
(b) "S concrete" (average survival probability of dam passage through all routes weighted by the probability of passing each route) estimates.
(c) Dead fish detection correction applied.
(d) "S dam" (joint probability of forebay and S concrete survival) estimates
NE = not estimated.

Table 4.4. Mean (SE) and median forebay residence times (h) of yearling Chinook salmon, steelhead, and subyearling Chinook salmon at Little Goose Dam among years.

	Year	Yearling	Steelhead	Subyearling
Mean forebay residence time	2006[(a)]	11.96 (0.86)	14.42 (1.11)	29.70 (3.85)
	2007[(a)]	9.97 (0.76)	48.36 (3.29)	37.55 (2.72)
	2009[(a)]	10.00 (0.52)	12.11 (0.50)	13.98 (0.61)
	2012[(b)]	6.34 (0.22)	5.84 (0.23)	7.86 (0.56)
Median forebay residence time	2006[(a)]	6.13	7.69	11.02
	2007[(a)]	5.01	20.91	14.51
	2009[(a)]	6.02	7.80	5.43
	2012[(b)]	2.58	2.67	2.80

(a) Forebay array located 2 km upstream of the dam.
(b) Forebay array located 0.9 km upstream of the dam.

Tailrace egress time is the duration between the last detection at Little Goose Dam until detection at the tailrace array. The tailrace array was located 1.4 km downstream from Little Goose Dam during the first three study years, but it was located 1.5 km below the dam during the 2012 study in response to the aforementioned hydraulic extent model. Mean and median tailrace egress times were highly variable among years for all three species/stocks (Table 4.5). Because of the highly skewed distributions of tailrace egress times, median egress time may be a more accurate measure of central tendency than mean egress time. Tailrace egress times estimated for yearling Chinook salmon and steelhead were markedly greater during 2012 than during the previous three study years. However, this disparity is likely related to the method by which egress time was calculated, rather than to the rate of fish movement. For fish passing Little Goose Dam via deep spill, the spillway weir, and turbines, the method of calculation was similar among years. However, for fish passing the dam through the JBS, the time of last detection on the cabled acoustic array was used as the start time for tailrace egress during this study, whereas, the last PIT-tag detection in the outfall pipe was used for the previous three study years. Thus, the present study accounts for time spent within the JBS in the tailrace egress time estimate. In addition, differences in detection range between radio- and acoustic-tagged fish may have contributed to the differences observed between 2012 and the previous three study years.

Table 4.5. Mean (SE) and median tailrace egress times (h) of yearling Chinook salmon, steelhead, and subyearling Chinook salmon at Little Goose Dam among years.

	Year	Yearling	Steelhead	Subyearling
Mean tailrace egress time	2006[a]	0.57 (0.07)	0.96 (0.51)	2.68 (0.85)
	2007[a]	2.63 (0.24)[b]	0.86 (0.08)[b]	2.53 (0.16)
	2009[a]	0.92 (0.09)	0.68 (0.10)	0.87 (0.09)
	2012[c]	1.35 (0.06)	1.12 (0.10)	1.41 (0.05)
Median tailrace egress time	2006[a]	0.28	0.26	0.82
	2007[a]	0.40[b]	0.27[b]	1.09
	2009[a]	0.26	0.24	0.30
	2012[c]	0.58	0.68	0.78

(a) Tailrace array located 1.4 km downstream of the dam.
(b) Tailrace egress times under Bulk2 spill conditions were not available, so "overall" values are reported.
(c) Tailrace array located 1.5 km downstream of the dam.

A smaller percentage of fish (18% fewer yearling Chinook salmon, 9% fewer steelhead, and 17% fewer subyearling Chinook salmon) passed LGS via the spillway weir in 2012 than in 2009 (Beeman et al. 2010). Conversely, greater percentages of fish (11% more yearling Chinook salmon, 7% more steelhead, and 18% more subyearling Chinook salmon) passed LGS via deep spill in 2012 than in 2009. Operations were slightly different between these 2 years (e.g., percent spill was greater in 2012 than in 2009 during both seasons) and may have contributed to the differences observed in route of passage. Survival rates were similar between years (i.e., 2009 and 2012) for all yearling Chinook salmon and steelhead routes of passage with one exception: steelhead survival through the turbines was markedly higher in 2009 than in 2012. However, the survival of steelhead through the turbines was estimated to be near 100% and was likely biased because very few steelhead passed using this route (Beeman et al. 2010). For subyearling Chinook salmon, survival through the spillway weir and turbine was generally similar between years. However, survival through deep spill (9% difference) and the JBS (7% difference) was greater in 2012 than in 2009.

Spill and fish passage efficiencies at Little Goose Dam were generally similar among the 2007, 2009, and 2012 study years for each stock of fish (Table 4.6). SPE and FPE were systematically lower during 2006 when compared to all other study years and for all species. These differences may be partly attributed to the installation of the spillway weir and the proportion of discharge passing deep spill and/or the spillway weir. Interestingly, SPE and FPE were generally high during the other pre-spillway weir year (i.e., 2007).

Table 4.6. Spill passage efficiency (SPE) and fish passage efficiency (FPE) of yearling Chinook salmon, steelhead, and subyearling Chinook salmon at Little Goose Dam among years. Parentheses denote standard error.

	Year	Yearling	Steelhead	Subyearling
SPE	2006	0.605 (0.023)	0.370 (0.023)	0.512 (0.031)
	2007	0.834 (0.018)	0.592 (0.024)	0.698 (0.015)
	2009	0.724 (0.015)	0.581 (0.017)	0.714 (0.010)
	2012	0.653 (0.011)	0.561 (0.012)	0.725 (0.009)
FPE	2006	0.946 (0.011)	0.952 (0.011)	0.870 (0.023)
	2007	0.970 (0.008)	0.974 (0.008)	0.956 (0.007)
	2009	0.961 (0.007)	0.987 (0.004)	0.958 (0.004)
	2012	0.963 (0.005)	0.980 (0.003)	0.951 (0.004)

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Appendix A

Acoustic Receiver Locations

Appendix A

Acoustic Receiver Locations

Table A.1. Lower Snake River autonomous receiver locations in WGS84 Datum, degrees.decimal degrees.

Waypoint Name	Latitude	Longitude
SR114_01	46.5889564	-118.0184757
SR114_02	46.5875171	-118.0178234
SR114_03	46.5862577	-118.0172493
SR114_04	46.5848363	-118.0166491
SR112_01	46.5809322	-118.0466576
SR112_02	46.5803385	-118.0459269
SR112_03	46.5797448	-118.0452224
SR082_01	46.5911858	-118.3755769
SR082_02	46.5907001	-118.3746375
SR082_03	46.5901964	-118.3736199
SR082_04	46.5896747	-118.3727327
SR068_01	46.5672095	-118.5316793
SR068_02	46.5663607	-118.5305463
SR068_03	46.5654662	-118.5294642
SR068_04	46.5645629	-118.5283688
SR065_01	46.5473658	-118.5554116
SR065_02	46.5465922	-118.5559747
SR065_03	46.5468807	-118.5532997
SR040_01	46.3788405	-118.6951954
SR040_02	46.3786799	-118.6943578
SR040_03	46.3784853	-118.6933323
SR040_04	46.3784119	-118.6924432
SR017_01	46.2527095	-118.8703623
SR017_02	46.2517000	-118.8697856
SR017_03	46.2506759	-118.8692885
SR017_04	46.2494470	-118.8688160
SR003_01	46.2160281	-119.0244908
SR003_02	46.2151988	-119.0232769
SR003_03	46.2148091	-119.0226624
SR003_04	46.2142781	-119.0218841

Table A.2. Little Goose Dam cabled receiver locations, WGS84 Datum in degrees.decimal degrees for latitude/longitude NAD83 vertical datum for elevations.

Phone Name	Latitude	Longitude	Elevation
FLS	46.58292046	-118.0263206	626.439
P00_01S	46.5832194	-118.0264623	623.518
P01_02D	46.58346927	-118.0264836	540.158
P02_03S	46.58370407	-118.0266013	623.358
P03_04D	46.58395382	-118.02662	540.413
P00_01D	46.58322677	-118.0264129	540.444
P01_02S	46.5834619	-118.026533	623.233
P02_03D	46.58371146	-118.0265517	540.057
P03_04S	46.58394645	-118.0266694	623.446
P04_05S	46.58419037	-118.0267375	623.443
P05_06D	46.58443904	-118.0267558	540.257
P06S	46.5846737	-118.0268722	622.764
S01D	46.58478223	-118.0269909	597.505
P04_05D	46.58419775	-118.026688	540.204
P05_06S	46.58443167	-118.0268053	623.413
P06D	46.58468107	-118.0268228	539.731
S01S	46.58478223	-118.0269909	624.31
S01_02S	46.58495583	-118.0270391	622.604
S02_03D	46.58512962	-118.0270884	597.079
S03_04S	46.5853015	-118.0271363	624.179
S04_05D	46.58547392	-118.0271846	596.948
S01_02D	46.58495583	-118.0270391	595.602
S02_03S	46.58512962	-118.0270884	624.08
S03_04D	46.5853015	-118.0271363	597.276
S04_05S	46.58547392	-118.0271846	624.015
S05_06S	46.5856469	-118.0272337	624.179
S06_07D	46.58581759	-118.027281	597.079
S07_08S	46.58599116	-118.02733	624.119
S08D	46.58616544	-118.0273788	597.003
S05_06D	46.5856469	-118.0272337	597.21
S06_07S	46.58581759	-118.027281	624.08
S07_08D	46.5859912	-118.0273299	597.112
S08S	46.58616544	-118.0273788	624.086

Appendix B

Tests of Assumptions

Appendix B

Tests of Assumptions

B.1 Tagger Effects

B.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 Little Goose Dam and Lower Monumental 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 $\left(P\left(\chi^2_{28} \geq 1.0167\right) \approx 1\right)$ or analyzed separately by yearling Chinook salmon $\left(P\left(\chi^2_{28} \geq 0.8507\right) \approx 1\right)$ or steelhead $\left(P\left(\chi^2_{28} \geq 0.8004\right) \approx 1\right)$ (Table B.1).

Tagger effort was also examined within each of the 28 replicate releases conducted over the course of the spring study (Table B.2, Table B.3). Tagger effort was found to be balanced within replicates 2, 5, 6, 9, 10, 13, 14, 17, 18, 21, 22, 25, 26, and 28 $(P \approx 1)$. 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 and R_4–R_5) for the remainder of the release groups (Table B.2, Table B.3). The conditional and unconditional balance within replicates is the reason for the overall balance observed in Table B.1.

To test for tagger effects, reach survivals and cumulative survivals were calculated for fish tagged by different staff members on a release location (i.e., $R_1, \ldots, R_5$) and species basis (Table B.4). Of the 30 tests of homogeneous reach survivals, 1 (i.e., 3.3%) was found to be significant at $\alpha = 0.10$. By chance alone, we might expect 10% of the 30 tests (i.e., 3) to be significant at $\alpha = 0.10$ when no effect exists. Similarly, we found 0 of 28 tests of homogeneous cumulative survival to be significant at $\alpha = 0.10$. Therefore, fish tagged by all taggers were considered acceptable for inclusion in the survival analyses.

B.1.2 Summer Study

During the 2012 summer subyearling Chinook salmon survival study, the same eight taggers were used as during the spring study. Tagger effort was found to be homogeneous across release locations $\left(P\left(\chi^2_{28} \geq 9.466\right) = 0.9996\right)$ (Table B.5). Tagger effort was also examined within each of the 32 replicate releases conducted over the course of the summer study (Table B.6). Tagger effort was found to be homogeneous in replicates 1, 2, 5, 6, 9, 10, 13, 14, 17, 18, 21, 22, 25, 26, 29, and 30 $(P \approx 1)$. 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 and R_4–R_5) for the remainder of the release groups (Table B.6). The combination of conditional and unconditional balance within replicates is the reason for the overall balance observed in Table B.5.

Tagger effects were examined on a reach and cumulative reach basis (Table B.7). The results of these tests initially suggested tagger effects, with one team having lower fish survivals than the other. However, further examination found appreciable seasonality associated with the subyearling outmigration. Reach survivals started to appreciably decline after replicate 20 (Figure B.1). Figure B.1 also indicated one tagging team was responsible for tagging the fish at the end of the study when survivals were the lowest. Hence, the initial tests of homogenous fish survival across taggers were confounded by seasonal survival trends. Table B.8 repeats the test of homogeneity for release R_1 using only replicates 1–20 before the seasonal decline in survival began. While previously R_1 had 3/5 tests of reach survival and 5/5 tests of cumulative survival significant ($P < 0.10$), the reanalysis using only replicates 1–20 found only 1 of these 10 tests to be significant ($P < 0.10$). The perceived heterogeneity was eliminated when the confounding of taggers with seasonality was eliminated. Similar results occur for releases R_2 to R_5 when only replicate releases 1–20 are analyzed.

This reanalysis indicates the prior analysis was misleading, and after removing seasonal effects, no tagger effects are evident. Therefore, all fish from all taggers were used in the analysis of the subyearling Chinook salmon survival at Little Goose and Lower Monumental dams.

Table B.1. Number 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.

a. Combined yearling Chinook salmon and steelhead

	Tagger							
Release location	ANDY	BEN	KATHLEEN	RICARDO	AMANDAO	ASHLIE	AUSTIN	GINA
R1_SR133	452	450	451	455	451	443	442	455
R2_SR112	298	298	296	300	304	305	298	300
R3_SR082	300	297	300	296	303	303	305	298
R4_SR065	248	249	248	252	255	245	253	250
R5_SR040	249	245	251	252	252	250	249	253
Chi-square = 1.0167				df = 28				P-value = 1

b. Yearling Chinook salmon

	Tagger							
Release location	ANDY	BEN	KATHLEEN	RICARDO	AMANDAO	ASHLIE	AUSTIN	GINA
R1_SR133	227	228	223	226	225	223	220	228
R2_SR112	151	148	147	149	152	152	151	148
R3_SR082	151	149	147	148	153	151	152	149
R4_SR065	123	126	124	125	129	122	126	125
R5_SR040	124	122	127	126	126	127	124	125
Chi-square = 0.8507				df = 28				P-value = 1

c. Steelhead

	Tagger							
Release location	ANDY	BEN	KATHLEEN	RICARDO	AMANDAO	ASHLIE	AUSTIN	GINA
R1_SR133	225	222	228	229	226	220	222	227
R2_SR112	147	150	149	151	152	153	147	152
R3_SR082	149	148	153	148	150	152	153	149
R4_SR065	125	123	124	127	126	123	127	125
R5_SR040	125	123	124	126	126	123	125	128
Chi-square = 0.8004				df = 28				P-value = 1

Table B.2. Contingency tables with numbers of yearling Chinook salmon tagged by each staff member per release location within a replicate release. A total of 28 replicate day or night 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	ANDY	BEN	KATHLEEN	RICARDO	AMANDAO	ASHLIE	AUSTIN	GINA	P-value
R1_SR133	16	16	16	16	0	0	0	0	
R2_SR112	11	11	10	10	0	0	0	0	1
R3_SR082	11	11	10	11	0	0	0	0	
R4_SR065	0	0	0	0	9	9	9	9	1
R5_SR040	0	0	0	0	9	9	9	9	
Chi-square = 221.1364				df = 28					<0.0001

b. Replicate 2

Release	AMANDAO	ASHLIE	AUSTIN	GINA	P-value
R1_SR133	16	16	16	15	
R2_SR112	11	11	11	10	1
R3_SR082	11	11	10	11	
R4_SR065	9	9	9	9	1
R5_SR040	9	9	9	9	
Chi-square = 0.1390		df = 12			1

c. Replicate 3

Release	ANDY	BEN	KATHLEEN	RICARDO	AMANDAO	ASHLIE	AUSTIN	GINA	P-value
R1_SR133	0	0	0	0	16	14	15	15	
R2_SR112	0	0	0	0	11	11	11	10	0.9999
R3_SR082	0	0	0	0	11	11	10	11	
R4_SR065	9	9	9	9	0	0	0	0	1
R5_SR040	9	9	9	9	0	0	0	0	
Chi-square = 218.2873				df = 28					<0.0001

d. Replicate 4

Release	ANDY	BEN	KATHLEEN	RICARDO	AMANDAO	ASHLIE	AUSTIN	GINA	P-value
R1_SR133	0	0	0	0	16	16	14	17	0.9990
R2_SR112	0	0	0	0	11	11	11	10	
R3_SR082	0	0	0	0	11	11	11	10	
R4_SR065	9	9	8	9	0	0	0	0	0.9896
R5_SR040	9	8	9	9	0	0	0	0	
Chi-square = 219.9183				df = 28					<0.0001

Table B.2. (contd)

e. Replicate 5

Release	ANDY	BEN	KATHLEEN	RICARDO	P-value
R1_SR133	16	17	16	16	
R2_SR112	11	10	11	11	0.9985
R3_SR082	11	11	12	9	
R4_SR065	9	9	9	9	0.9975
R5_SR040	9	8	9	9	
Chi-square = 0.5587		df = 12			1

f. Replicate 6

Release	ANDY	BEN	KATHLEEN	RICARDO	P-value
R1_SR133	16	17	16	16	0.9999
R2_SR112	11	10	11	11	
R3_SR082	11	11	11	10	
R4_SR065	9	9	9	9	1
R5_SR040	9	9	9	9	
Chi-square = 0.1724		df = 12			1

g. Replicate 7

Release	ANDY	BEN	KATHLEEN	RICARDO	AMANDAO	ASHLIE	AUSTIN	GINA	P-value
R1_SR133	15	16	17	16	0	0	0	0	
R2_SR112	11	11	10	10	0	0	0	0	0.9997
R3_SR082	11	10	11	10	0	0	0	0	
R4_SR065	0	0	0	0	9	10	9	9	0.9965
R5_SR040	0	0	0	0	8	9	9	9	
Chi-square = 220.5571				df = 28					<0.0001

h. Replicate 8

Release	ANDY	BEN	KATHLEEN	RICARDO	AMANDAO	ASHLIE	AUSTIN	GINA	P-value
R1_SR133	16	15	16	17	0	0	0	0	1
R2_SR112	11	11	10	11	0	0	0	0	
R3_SR082	11	10	10	11	0	0	0	0	
R4_SR065	0	0	0	0	9	7	9	9	0.8938
R5_SR040	0	0	0	0	10	9	7	8	
Chi-square = 219.1129				df = 28					<0.0001

i. Replicate 9

Release	AMANDAO	ASHLIE	AUSTIN	GINA	P-value
R1_SR133	16	16	16	16	
R2_SR112	11	11	11	11	0.9999
R3_SR082	11	9	10	11	
R4_SR065	9	9	9	9	0.9970
R5_SR040	10	9	10	9	
Chi-square = 0.2907		df = 12			1

Table B.2. (contd)

j. Replicate 10

Release	AMANDAO	ASHLIE	AUSTIN	GINA	P-value
R1_SR133	16	16	16	17	
R2_SR112	11	11	10	11	1
R3_SR082	11	11	11	11	
R4_SR065	9	9	9	8	0.9828
R5_SR040	9	9	9	10	
Chi-square = 0.2454		df = 12			1

k. Replicate 11

Release	ANDY	BEN	KATHLEEN	RICARDO	AMANDAO	ASHLIE	AUSTIN	GINA	P-value
R1_SR133	0	0	0	0	15	16	17	16	
R2_SR112	0	0	0	0	11	11	11	10	1
R3_SR082	0	0	0	0	11	11	11	11	
R4_SR065	9	9	9	9	0	0	0	0	1
R5_SR040	9	9	9	9	0	0	0	0	
Chi-square = 223.1815				df = 28					<0.0001

l. Replicate 12

Release	ANDY	BEN	KATHLEEN	RICARDO	AMANDAO	ASHLIE	AUSTIN	GINA	P-value
R1_SR133	0	0	0	0	16	15	15	17	
R2_SR112	0	0	0	0	11	11	10	11	0.9997
R3_SR082	0	0	0	0	11	11	11	10	
R4_SR065	9	8	9	9	0	0	0	0	0.9896
R5_SR040	8	9	9	9	0	0	0	0	
Chi-square = 219.7202				df = 28					<0.0001

m. Replicate 13

Release	ANDY	BEN	KATHLEEN	RICARDO	P-value
R1_SR133	16	16	16	17	
R2_SR112	11	11	11	11	0.9995
R3_SR082	11	10	11	9	
R4_SR065	9	9	9	9	1
R5_SR040	9	9	9	9	
Chi-square = 0.2972		df = 12			1

n. Replicate 14

Release	ANDY	BEN	KATHLEEN	RICARDO	P-value
R1_SR133	16	17	16	16	
R2_SR112	10	11	10	11	1
R3_SR082	10	11	10	11	
R4_SR065	9	9	9	9	1
R5_SR040	9	9	9	9	
Chi-square = 0.1142		df = 12			1

Table B.2. (contd)

o. Replicate 15

Release	ANDY	BEN	KATHLEEN	RICARDO	AMANDAO	ASHLIE	AUSTIN	GINA	P-value
R1_SR133	17	16	16	16	0	0	0	0	
R2_SR112	11	10	11	10	0	0	0	0	1
R3_SR082	11	10	11	11	0	0	0	0	
R4_SR065	0	0	0	0	10	9	9	8	0.9536
R5_SR040	0	0	0	0	8	10	9	9	
Chi-square = 223.1450				df = 28					<0.0001

p. Replicate 16

Release	ANDY	BEN	KATHLEEN	RICARDO	AMANDAO	ASHLIE	AUSTIN	GINA	P-value
R1_SR133	16	16	16	15	0	0	0	0	
R2_SR112	11	11	10	11	0	0	0	0	0.9998
R3_SR082	11	11	10	12	0	0	0	0	
R4_SR065	0	0	0	0	9	9	9	9	0.9975
R5_SR040	0	0	0	0	9	9	9	8	
Chi-square = 221.4650				df = 28					<0.0001

q. Replicate 17

Release	AMANDAO	ASHLIE	AUSTIN	GINA	P-value
R1_SR133	15	17	16	16	
R2_SR112	10	11	11	11	1
R3_SR082	11	11	12	11	
R4_SR065	9	9	9	9	1
R5_SR040	9	9	9	9	
Chi-square = 0.1545		df = 12			1

r. Replicate 18

Release	AMANDAO	ASHLIE	AUSTIN	GINA	P-value
R1_SR133	17	16	16	16	
R2_SR112	11	10	11	10	1
R3_SR082	11	11	11	10	
R4_SR065	10	7	10	10	0.9414
R5_SR040	9	9	9	9	
Chi-square = 0.6984		df = 12			1

s. Replicate 19

Release	ANDY	BEN	KATHLEEN	RICARDO	AMANDAO	ASHLIE	AUSTIN	GINA	P-value
R1_SR133	0	0	0	0	16	16	16	17	
R2_SR112	0	0	0	0	11	10	11	11	1
R3_SR082	0	0	0	0	11	10	11	11	
R4_SR065	8	9	9	9	0	0	0	0	0.9975
R5_SR040	9	9	9	9	0	0	0	0	
Chi-square = 222.2294				df = 28					<0.0001

Table B.2. (contd)

t. Replicate 20

Release	ANDY	BEN	KATHLEEN	RICARDO	AMANDAO	ASHLIE	AUSTIN	GINA	P-value
R1_SR133	0	0	0	0	16	17	16	16	
R2_SR112	0	0	0	0	11	11	11	11	1
R3_SR082	0	0	0	0	11	11	11	10	
R4_SR065	8	9	9	9	0	0	0	0	1
R5_SR040	8	9	9	9	0	0	0	0	
Chi-square = 222.0931				df = 28					<0.0001

u. Replicate 21

Release	ANDY	BEN	KATHLEEN	RICARDO	P-value
R1_SR133	17	16	15	17	
R2_SR112	10	10	10	10	0.9999
R3_SR082	10	11	10	10	
R4_SR065	8	9	9	9	0.9896
R5_SR040	9	8	9	9	
Chi-square = 0.3780		df = 12			1

v. Replicate 22

Release	ANDY	BEN	KATHLEEN	RICARDO	P-value
R1_SR133	17	17	15	16	
R2_SR112	11	10	11	11	0.9999
R3_SR082	11	11	10	11	
R4_SR065	9	10	9	8	0.9904
R5_SR040	9	9	9	9	
Chi-square = 0.4105		df = 12			1

w. Replicate 23

Release	ANDY	BEN	KATHLEEN	RICARDO	AMANDAO	ASHLIE	AUSTIN	GINA	P-value
R1_SR133	16	16	16	17	0	0	0	0	
R2_SR112	10	11	11	11	0	0	0	0	1
R3_SR082	11	10	11	11	0	0	0	0	
R4_SR065	0	0	0	0	9	8	9	9	0.9896
R5_SR040	0	0	0	0	9	9	8	9	
Chi-square = 221.5390				df = 28					<0.0001

Table B.2. (contd)

x. Replicate 24

Release	ANDY	BEN	KATHLEEN	RICARDO	AMANDAO	ASHLIE	AUSTIN	GINA	P-value
R1_SR133	17	16	16	16	0	0	0	0	
R2_SR112	11	10	11	10	0	0	0	0	1
R3_SR082	11	11	10	11	0	0	0	0	
R4_SR065	0	0	0	0	9	9	9	9	1
R5_SR040	0	0	0	0	9	9	9	9	
Chi-square = 222.1964				df = 28					<0.0001

y. Replicate 25

Release	AMANDAO	ASHLIE	AUSTIN	GINA	P-value
R1_SR133	17	16	16	16	
R2_SR112	11	11	11	10	0.9999
R3_SR082	10	11	11	11	
R4_SR065	9	9	8	9	1
R5_SR040	9	9	8	9	
Chi-square = 0.3088		df = 12			1

z. Replicate 26

Release	AMANDAO	ASHLIE	AUSTIN	GINA	P-value
R1_SR133	16	17	15	17	
R2_SR112	10	11	11	11	0.9997
R3_SR082	11	11	11	10	
R4_SR065	10	9	9	9	0.9912
R5_SR040	9	9	10	9	
Chi-square = 0.4588		df = 12			1

aa. Replicate 27

Release	ANDY	BEN	KATHLEEN	RICARDO	AMANDAO	ASHLIE	AUSTIN	GINA	P-value
R1_SR133	0	0	0	0	17	15	16	17	
R2_SR112	0	0	0	0	11	11	10	11	1
R3_SR082	0	0	0	0	11	11	11	11	
R4_SR065	9	9	8	9	0	0	0	0	0.9661
R5_SR040	9	8	10	9	0	0	0	0	
Chi-square = 224.0380				df = 28					<0.0001

bb. Replicate 28

Release	ANDY	BEN	KATHLEEN	RICARDO	P-value
R1_SR133	16	17	16	15	
R2_SR112	11	11	10	11	0.9999
R3_SR082	10	11	10	11	
R4_SR065	9	9	9	9	1
R5_SR040	9	9	9	9	
Chi-square = 0.2046		df = 12			1

Table B.3. Contingency tables with numbers of steelhead tagged by each staff member per release location within a replicate release. A total of 28 replicate day or nighttime releases were performed over the course of the spring season. Results of chi-square tests of homogeneity are presented in the form of *P*-values.

a. Replicate 1

Release	ANDY	BEN	KATHLEEN	RICARDO	AMANDAO	ASHLIE	AUSTIN	GINA	P-value
R1_SR133	16	16	16	16	0	0	0	0	
R2_SR112	10	10	10	10	0	0	0	0	1
R3_SR082	10	11	11	11	0	0	0	0	
R4_SR065	0	0	0	0	9	9	9	9	0.9904
R5_SR040	0	0	0	0	10	8	9	9	
Chi-square = 219.4136				df = 28					<0.0001

b. Replicate 2

Release	AMANDAO	ASHLIE	AUSTIN	GINA	P-value
R1_SR133	17	16	15	16	
R2_SR112	11	11	10	11	0.9998
R3_SR082	10	11	11	10	
R4_SR065	9	9	9	9	1
R5_SR040	9	9	9	9	
Chi-square =	0.2416	df = 12			1

c. Replicate 3

Release	ANDY	BEN	KATHLEEN	RICARDO	AMANDAO	ASHLIE	AUSTIN	GINA	P-value
R1_SR133	0	0	0	0	16	16	16	16	0.9999
R2_SR112	0	0	0	0	12	11	11	12	
R3_SR082	0	0	0	0	10	11	11	11	
R4_SR065	9	8	9	9	0	0	0	0	0.9975
R5_SR040	9	9	9	9	0	0	0	0	
Chi-square = 224.3428				df = 28					<0.0001

d. Replicate 4

Release	ANDY	BEN	KATHLEEN	RICARDO	AMANDAO	ASHLIE	AUSTIN	GINA	P-value
R1_SR133	0	0	0	0	16	16	16	16	
R2_SR112	0	0	0	0	9	10	10	11	0.9997
R3_SR082	0	0	0	0	11	11	11	10	
R4_SR065	9	9	8	9	0	0	0	0	1
R5_SR040	9	9	8	9	0	0	0	0	
Chi-square = 217.3693				df = 28					<0.0001

Table B.3. (contd)

e. Replicate 5

Release	ANDY	BEN	KATHLEEN	RICARDO	P-value
R1_SR133	17	16	16	16	
R2_SR112	11	10	11	11	0.9992
R3_SR082	10	12	11	10	
R4_SR065	9	9	9	9	1
R5_SR040	9	9	9	9	
Chi-square = 0.3576		df = 12			1

f. Replicate 6

Release	ANDY	BEN	KATHLEEN	RICARDO	P-value
R1_SR133	16	16	16	17	
R2_SR112	10	11	11	11	1
R3_SR082	11	10	11	11	
R4_SR065	9	9	9	9	0.9852
R5_SR040	9	8	10	10	
Chi-square = 0.3090		df = 12			1

g. Replicate 7

Release	ANDY	BEN	KATHLEEN	RICARDO	AMANDAO	ASHLIE	AUSTIN	GINA	P-value
R1_SR133	15	15	17	16	0	0	0	0	
R2_SR112	10	11	10	11	0	0	0	0	0.9998
R3_SR082	10	11	10	11	0	0	0	0	
R4_SR065	0	0	0	0	9	9	8	9	0.9481
R5_SR040	0	0	0	0	7	9	9	10	
Chi-square = 218.4659				df = 28					<0.0001

h. Replicate 8

Release	ANDY	BEN	KATHLEEN	RICARDO	AMANDAO	ASHLIE	AUSTIN	GINA	P-value
R1_SR133	15	16	16	17	0	0	0	0	
R2_SR112	10	11	11	11	0	0	0	0	1
R3_SR082	11	11	12	11	0	0	0	0	
R4_SR065	0	0	0	0	8	9	10	8	0.9904
R5_SR040	0	0	0	0	8	9	9	9	
Chi-square = 222.5030				df = 28					<0.0001

i. Replicate 9

Release	AMANDAO	ASHLIE	AUSTIN	GINA	P-value
R1_SR133	16	16	15	16	
R2_SR112	11	11	11	10	0.9999
R3_SR082	10	11	11	11	
R4_SR065	10	8	9	10	0.9548
R5_SR040	9	10	9	9	
Chi-square = 0.5505		df = 12			1

Table B.3. (contd)

j. Replicate 10

Release	AMANDAO	ASHLIE	AUSTIN	GINA	P-value
R1_SR133	14	13	15	15	
R2_SR112	11	12	11	11	0.9994
R3_SR082	11	11	11	10	
R4_SR065	9	9	10	9	0.9846
R5_SR040	9	8	8	9	
Chi-square = 0.4923		df = 12			1

k. Replicate 11

Release	ANDY	BEN	KATHLEEN	RICARDO	AMANDAO	ASHLIE	AUSTIN	GINA	P-value
R1_SR133	0	0	0	0	17	16	16	16	
R2_SR112	0	0	0	0	11	11	11	10	1
R3_SR082	0	0	0	0	11	11	11	10	
R4_SR065	9	9	9	10	0	0	0	0	0.9980
R5_SR040	9	9	9	9	0	0	0	0	
Chi-square = 224.2098				df = 28					<0.0001

l. Replicate 12

Release	ANDY	BEN	KATHLEEN	RICARDO	AMANDAO	ASHLIE	AUSTIN	GINA	P-value
R1_SR133	0	0	0	0	16	16	16	17	
R2_SR112	0	0	0	0	11	11	11	11	1
R3_SR082	0	0	0	0	11	10	11	11	
R4_SR065	9	8	9	9	0	0	0	0	0.9896
R5_SR040	9	9	9	8	0	0	0	0	
Chi-square = 222.4662				df = 28					<0.0001

m. Replicate 13

Release	ANDY	BEN	KATHLEEN	RICARDO	P-value
R1_SR133	16	16	16	16	
R2_SR112	11	11	11	10	1
R3_SR082	11	11	10	11	
R4_SR065	9	9	9	9	1
R5_SR040	9	9	9	9	
Chi-square = 0.1224		df = 12			1

n. Replicate 14

Release	ANDY	BEN	KATHLEEN	RICARDO	P-value
R1_SR133	16	14	16	17	
R2_SR112	10	10	10	12	0.9994
R3_SR082	11	10	11	10	
R4_SR065	9	9	9	9	0.9975
R5_SR040	8	9	9	9	
Chi-square = 0.5267		df = 12			1

Table B.3. (contd)

o. Replicate 15

Release	ANDY	BEN	KATHLEEN	RICARDO	AMANDAO	ASHLIE	AUSTIN	GINA	P-value
R1_SR133	16	16	16	16	0	0	0	0	
R2_SR112	11	11	11	9	0	0	0	0	0.9999
R3_SR082	11	11	11	10	0	0	0	0	
R4_SR065	0	0	0	0	9	9	9	9	1
R5_SR040	0	0	0	0	9	9	9	9	
Chi-square = 221.2697				df = 28					<0.0001

p. Replicate 16

Release	ANDY	BEN	KATHLEEN	RICARDO	AMANDAO	ASHLIE	AUSTIN	GINA	P-value
R1_SR133	16	16	16	17	0	0	0	0	
R2_SR112	10	11	11	11	0	0	0	0	0.9999
R3_SR082	11	11	11	10	0	0	0	0	
R4_SR065	0	0	0	0	9	9	8	9	0.9835
R5_SR040	0	0	0	0	9	8	9	8	
Chi-square = 220.7584				df = 28					<0.0001

q. Replicate 17

Release	AMANDAO	ASHLIE	AUSTIN	GINA	P-value
R1_SR133	16	16	16	17	
R2_SR112	11	11	9	11	0.9997
R3_SR082	11	12	11	11	
R4_SR065	9	9	9	9	1
R5_SR040	10	10	10	10	
Chi-square = 0.2970		df = 12			1

r. Replicate 18

Release	AMANDAO	ASHLIE	AUSTIN	GINA	P-value
R1_SR133	16	16	16	17	
R2_SR112	12	11	9	11	0.9990
R3_SR082	11	10	11	11	
R4_SR065	9	9	9	8	0.9165
R5_SR040	10	7	9	10	
Chi-square = 1.0183		df = 12			1

Table B.3. (contd)

s. Replicate 19

Release	ANDY	BEN	KATHLEEN	RICARDO	AMANDAO	ASHLIE	AUSTIN	GINA	P-value
R1_SR133	0	0	0	0	16	16	16	16	
R2_SR112	0	0	0	0	10	11	11	11	1
R3_SR082	0	0	0	0	10	11	10	11	
R4_SR065	9	9	9	9	0	0	0	0	1
R5_SR040	9	9	9	9	0	0	0	0	
Chi-square = 221.1364				df = 28					<0.0001

t. Replicate 20

Release	ANDY	BEN	KATHLEEN	RICARDO	AMANDAO	ASHLIE	AUSTIN	GINA	P-value
R1_SR133	0	0	0	0	17	16	16	17	
R2_SR112	0	0	0	0	11	11	10	11	1
R3_SR082	0	0	0	0	11	10	11	11	
R4_SR065	9	9	8	9	0	0	0	0	0.9896
R5_SR040	9	8	9	9	0	0	0	0	
Chi-square = 222.5154				df = 28					<0.0001

u. Replicate 21

Release	ANDY	BEN	KATHLEEN	RICARDO	P-value
R1_SR133	16	16	17	16	
R2_SR112	11	11	11	11	0.9999
R3_SR082	11	9	11	10	
R4_SR065	9	8	9	9	0.9975
R5_SR040	9	8	8	9	
Chi-square = 0.3235		df = 12			1

v. Replicate 22

Release	ANDY	BEN	KATHLEEN	RICARDO	P-value
R1_SR133	16	16	16	17	
R2_SR112	11	11	10	11	1
R3_SR082	10	11	11	11	
R4_SR065	9	9	9	9	1
R5_SR040	9	9	9	9	
Chi-square = 0.1373		df = 12			1

Table B.3. (contd)

w. Replicate 23

Release	ANDY	BEN	KATHLEEN	RICARDO	AMANDAO	ASHLIE	AUSTIN	GINA	P-value
R1_SR133	16	17	16	16	0	0	0	0	
R2_SR112	11	11	10	11	0	0	0	0	0.9990
R3_SR082	11	9	11	11	0	0	0	0	
R4_SR065	0	0	0	0	9	8	9	9	0.9896
R5_SR040	0	0	0	0	9	9	9	8	
Chi-square = 220.9250				df = 28					<0.0001

x. Replicate 24

Release	ANDY	BEN	KATHLEEN	RICARDO	AMANDAO	ASHLIE	AUSTIN	GINA	P-value
R1_SR133	17	16	17	16	0	0	0	0	
R2_SR112	10	11	11	11	0	0	0	0	0.9999
R3_SR082	10	11	11	11	0	0	0	0	
R4_SR065	0	0	0	0	9	9	9	9	1
R5_SR040	0	0	0	0	9	9	9	9	
Chi-square = 224.2211				df = 28					<0.0001

y. Replicate 25

Release	AMANDAO	ASHLIE	AUSTIN	GINA	P-value
R1_SR133	16	16	16	16	
R2_SR112	11	11	11	11	1
R3_SR082	11	11	11	10	
R4_SR065	9	8	9	9	0.9896
R5_SR040	9	9	8	9	
Chi-square = 0.2285			df = 12		1

z. Replicate 26

Release	AMANDAO	ASHLIE	AUSTIN	GINA	P-value
R1_SR133	17	15	17	16	
R2_SR112	11	10	11	11	1
R3_SR082	11	10	11	11	
R4_SR065	9	9	10	9	0.9912
R5_SR040	9	9	9	10	
Chi-square = 0.2069		df = 12			1

Table B.3. (contd)

aa. Replicate 27

Release	ANDY	BEN	KATHLEEN	RICARDO	AMANDAO	ASHLIE	AUSTIN	GINA	P-value
R1_SR133	0	0	0	0	16	16	16	16	
R2_SR112	0	0	0	0	10	11	11	10	1
R3_SR082	0	0	0	0	11	12	11	11	
R4_SR065	8	9	9	9	0	0	0	0	0.9896
R5_SR040	9	9	8	9	0	0	0	0	
Chi-square = 221.5008				df = 28					<0.0001

bb. Replicate 28

Release	ANDY	BEN	KATHLEEN	RICARDO	P-value
R1_SR133	17	16	17	16	
R2_SR112	11	10	11	11	1
R3_SR082	11	10	11	10	
R4_SR065	9	9	9	9	1
R5_SR040	9	9	9	9	
Chi-square = 0.1055		df = 12			1

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

a. Yearling Chinook salmon smolts

1) Release 1 (SR133) – Reach survival

	Release to SR113.0		SR113.0 to SR082.0		SR082.0 to SR067.0		SR067.0 to SR040.0		SR040.0 to SR017.0	
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE
Amandao	0.9867	0.0076	0.9640	0.0125	0.9953	0.0047	0.9714	0.0115	0.9853	0.0084
Andy	0.9868	0.0076	0.9596	0.0132	0.9907	0.0066	0.9811	0.0093	0.9952	0.0048
Ashlie	0.9778	0.0099	0.9585	0.0135	0.9952	0.0048	0.9567	0.0141	0.9799	0.0099
Austin	0.9818	0.0090	0.9491	0.0150	0.9951	0.0049	0.9608	0.0136	0.9847	0.0088
Ben	0.9825	0.0087	0.9821	0.0088	0.9955	0.0045	0.9498	0.0148	0.9952	0.0048
Gina	0.9912	0.0062	0.9292	0.0171	0.9762	0.0105	0.9805	0.0097	0.9851	0.0086
Kathleen	0.9910	0.0063	0.9545	0.0140	0.9810	0.0094	0.9756	0.0108	0.9750	0.0110
Ricardo	0.9956	0.0044	0.9598	0.0131	0.9953	0.0046	0.9720	0.0113	1.0000	0.0000
P-value	0.7700		0.3038		0.2333		0.4985		0.3993	

2) Release 1 (SR133) – Cumulative survival

	Release to SR113.0		Release to SR082.0		Release to SR067.0		Release to SR040.0		Release to SR017.0	
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE
Amandao	0.9867	0.0076	0.9511	0.0144	0.9467	0.0150	0.9196	0.0182	0.9061	0.0195
Andy	0.9868	0.0076	0.9470	0.0149	0.9381	0.0160	0.9204	0.0180	0.9160	0.0184
Ashlie	0.9778	0.0099	0.9372	0.0162	0.9327	0.0168	0.8924	0.0208	0.8744	0.0222
Austin	0.9818	0.0090	0.9318	0.0170	0.9273	0.0175	0.8909	0.0210	0.8773	0.0221
Ben	0.9825	0.0087	0.9649	0.0122	0.9605	0.0129	0.9123	0.0187	0.9079	0.0192
Gina	0.9912	0.0062	0.9211	0.0179	0.8991	0.0199	0.8816	0.0214	0.8684	0.0224
Kathleen	0.9910	0.0063	0.9460	0.0152	0.9280	0.0173	0.9053	0.0197	0.8827	0.0216
Ricardo	0.9956	0.0044	0.9556	0.0137	0.9511	0.0144	0.9245	0.0176	0.9245	0.0176
P-value	0.7700		0.5641		0.2393		0.6964		0.3653	

3) Reach 2 (SR112) – Reach survival

	Release to SR082.0		SR082.0 to SR067.0		SR067.0 to SR040.0		SR040.0 to SR017.0	
	Est	SE	Est	SE	Est	SE	Est	SE
Amandao	0.9803	0.0113	0.9932	0.0067	0.9796	0.0117	0.9792	0.0119
Andy	1.0000	0.0000	0.9868	0.0093	0.9797	0.0116	0.9586	0.0165
Ashlie	0.9539	0.0170	1.0000	0.0000	0.9655	0.0152	0.9928	0.0072
Austin	0.9735	0.0131	1.0000	0.0000	0.9863	0.0096	0.9861	0.0098
Ben	0.9730	0.0133	0.9931	0.0069	0.9650	0.0154	0.9710	0.0143
Gina	0.9730	0.0133	0.9722	0.0137	0.9786	0.0122	0.9854	0.0102
Kathleen	0.9592	0.0163	1.0000	0.0000	0.9714	0.0141	0.9779	0.0126
Ricardo	0.9866	0.0094	1.0000	0.0000	0.9796	0.0117	0.9931	0.0069
P-value	0.3272		0.4008		0.9303		0.4276	

Table B.4. (contd)

4) Reach 2 (SR112) – Cumulative survival

	Release to SR082.0		Release to SR067.0		Release to SR040.0		Release to SR017.0	
	Est	SE	Est	SE	Est	SE	Est	SE
Amandao	0.9803	0.0113	0.9736	0.0130	0.9538	0.0171	0.9339	0.0202
Andy	1.0000	0.0000	0.9868	0.0093	0.9668	0.0146	0.9268	0.0213
Ashlie	0.9539	0.0170	0.9539	0.0170	0.9211	0.0219	0.9144	0.0227
Austin	0.9735	0.0131	0.9735	0.0131	0.9602	0.0159	0.9468	0.0183
Ben	0.9730	0.0133	0.9662	0.0149	0.9324	0.0206	0.9054	0.0241
Gina	0.9730	0.0133	0.9459	0.0186	0.9257	0.0216	0.9122	0.0233
Kathleen	0.9592	0.0163	0.9592	0.0163	0.9318	0.0208	0.9112	0.0235
Ricardo	0.9866	0.0094	0.9866	0.0094	0.9664	0.0148	0.9597	0.0161
P-value	0.3272		0.3821		0.4039		0.5750	

5) Release 3 (SR082) – Reach survival

	Release to SR067.0		SR067.0 to SR040.0		SR040.0 to SR017.0	
	Est	SE	Est	SE	Est	SE
Amandao	0.9869	0.0092	0.9799	0.0115	0.9863	0.0096
Andy	0.9934	0.0066	0.9733	0.0132	0.9795	0.0117
Ashlie	0.9934	0.0066	0.9867	0.0094	0.9865	0.0095
Austin	0.9934	0.0066	0.9536	0.0171	0.9931	0.0069
Ben	0.9933	0.0067	0.9724	0.0136	0.9787	0.0122
Gina	1.0000	0.0000	0.9595	0.0162	0.9789	0.0121
Kathleen	0.9864	0.0096	0.9580	0.0168	0.9854	0.0102
Ricardo	0.9932	0.0067	0.9658	0.0151	0.9645	0.0156
P-value	0.9439		0.7239		0.7793	

6) Reach 3 (SR082) – Cumulative survival

	Release to SR067.0		Release to SR040.0		Release to SR017.0	
	Est	SE	Est	SE	Est	SE
Amandao	0.9869	0.0092	0.9671	0.0145	0.9538	0.0171
Andy	0.9934	0.0066	0.9669	0.0146	0.9470	0.0182
Ashlie	0.9934	0.0066	0.9801	0.0114	0.9669	0.0146
Austin	0.9934	0.0066	0.9474	0.0181	0.9408	0.0191
Ben	0.9933	0.0067	0.9659	0.0150	0.9453	0.0188
Gina	1.0000	0.0000	0.9595	0.0162	0.9392	0.0196
Kathleen	0.9864	0.0096	0.9450	0.0189	0.9312	0.0210
Ricardo	0.9932	0.0067	0.9592	0.0163	0.9252	0.0217
P-value	0.9439		0.8202		0.8546	

Table B.4. (contd)

7) Release 4 (SR065) – Reach survival

	Release to SR040.0		SR040.0 to SR017.0	
	Est	SE	Est	SE
Amandao	0.9922	0.0077	0.9688	0.0154
Andy	0.9919	0.0081	0.9754	0.0140
Ashlie	0.9918	0.0082	0.9752	0.0141
Austin	0.9762	0.0136	0.9756	0.0139
Ben	1.0000	0.0000	0.9921	0.0079
Gina	0.9680	0.0157	0.9504	0.0197
Kathleen	0.9677	0.0159	0.9833	0.0117
Ricardo	0.9760	0.0137	0.9590	0.0179
P-value	0.4150		0.5886	

8) Reach survival (SR065) – Cumulative survival

	Release to SR040.0		Release to SR017.0	
	Est	SE	Est	SE
Amandao	0.9922	0.0077	0.9612	0.0170
Andy	0.9919	0.0081	0.9675	0.0160
Ashlie	0.9918	0.0082	0.9672	0.0161
Austin	0.9762	0.0136	0.9524	0.0190
Ben	1.0000	0.0000	0.9921	0.0079
Gina	0.9680	0.0157	0.9200	0.0243
Kathleen	0.9677	0.0159	0.9516	0.0193
Ricardo	0.9760	0.0137	0.9360	0.0219
P-value	0.4150		0.1923	

9) Release 5 (SR040) – Reach survival

	Release to SR017.0	
	Est	SE
Amandao	0.9841	0.0111
Andy	0.9839	0.0113
Ashlie	0.9606	0.0173
Austin	0.9597	0.0177
Ben	0.9754	0.0140
Gina	0.9760	0.0137
Kathleen	0.9606	0.0173
Ricardo	0.9762	0.0136
P-value	0.8416	

Table B.4. (contd)

b. Steelhead smolts

1) Release 1 (SR133) – Reach survival

	Release to SR113.0		SR113.0 to SR082.0		SR082.0 to SR067.0		SR067.0 to SR040.0		SR040.0 to SR017.0	
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE
Amandao	0.9779	0.0098	0.9724	0.0111	0.9905	0.0067	0.9806	0.0096	0.9554	0.0145
Andy	0.9822	0.0088	0.9772	0.0101	1.0000	0.0000	0.9858	0.0081	0.9522	0.0148
Ashlie	0.9591	0.0134	0.9809	0.0095	0.9951	0.0049	0.9901	0.0070	0.9447	0.0162
Austin	0.9820	0.0089	0.9720	0.0113	0.9904	0.0068	0.9804	0.0097	0.9500	0.0154
Ben	0.9775	0.0100	0.9584	0.0136	0.9903	0.0068	0.9653	0.0129	0.9846	0.0088
Gina	0.9648	0.0122	0.9861	0.0080	0.9906	0.0066	0.9855	0.0083	0.8971	0.0213
Kathleen	0.9825	0.0087	0.9688	0.0116	0.9908	0.0065	0.9858	0.0081	0.9665	0.0124
Ricardo	0.9913	0.0061	0.9471	0.0149	0.9860	0.0080	0.9757	0.0107	0.9652	0.0129
P-value	0.3667		0.3000		0.9113		0.6921		0.0048	

2) Release 1 (SR133) – Cumulative survival

	Release to SR113.0		Release to SR082.0		Release to SR067.0		Release to SR040.0		Release to SR017.0	
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE
Amandao	0.9779	0.0098	0.9508	0.0145	0.9418	0.0157	0.9235	0.0178	0.8824	0.0217
Andy	0.9822	0.0088	0.9598	0.0131	0.9598	0.0131	0.9462	0.0151	0.9009	0.0201
Ashlie	0.9591	0.0134	0.9407	0.0159	0.9361	0.0165	0.9268	0.0176	0.8756	0.0224
Austin	0.9820	0.0089	0.9545	0.0141	0.9453	0.0154	0.9267	0.0176	0.8804	0.0220
Ben	0.9775	0.0100	0.9368	0.0164	0.9277	0.0174	0.8956	0.0206	0.8818	0.0218
Gina	0.9648	0.0122	0.9514	0.0143	0.9424	0.0155	0.9288	0.0172	0.8332	0.0251
Kathleen	0.9825	0.0087	0.9518	0.0142	0.9430	0.0154	0.9296	0.0170	0.8985	0.0201
Ricardo	0.9913	0.0061	0.9389	0.0158	0.9258	0.0173	0.9033	0.0196	0.8718	0.0222
P-value	0.3667		0.9499		0.8647		0.5906		0.5067	

3) Release 2 (SR112) – Reach survival

	Release to SR082.0		SR082.0 to SR067.0		SR067.0 to SR040.0		SR040.0 to SR017.0	
	Est	SE	Est	SE	Est	SE	Est	SE
Amandao	0.9737	0.0130	1.0000	0.0000	0.9861	0.0098	0.9648	0.0155
Andy	0.9864	0.0096	1.0000	0.0000	0.9860	0.0098	0.9929	0.0071
Ashlie	0.9804	0.0112	0.9667	0.0147	0.9790	0.0120	0.9643	0.0157
Austin	0.9796	0.0117	0.9653	0.0153	0.9854	0.0102	0.9556	0.0177
Ben	0.9667	0.0147	0.9862	0.0097	0.9787	0.0122	0.9710	0.0143
Gina	0.9868	0.0092	0.9733	0.0132	1.0000	0.0000	0.9510	0.0180
Kathleen	0.9732	0.0132	0.9724	0.0136	0.9928	0.0072	0.9927	0.0073
Ricardo	0.9669	0.0146	1.0000	0.0000	1.0000	0.0000	0.9583	0.0167
P-value	0.8963		0.2385		0.7091		0.2995	

Table B.4. (contd)

4) Release 2 (SR112) – Cumulative survival

	Release to SR082.0		Release to SR067.0		Release to SR040.0		Release to SR017.0	
	Est	SE	Est	SE	Est	SE	Est	SE
Amandao	0.9737	0.0130	0.9737	0.0130	0.9602	0.0159	0.9264	0.0214
Andy	0.9864	0.0096	0.9864	0.0096	0.9726	0.0135	0.9657	0.0151
Ashlie	0.9804	0.0112	0.9477	0.0180	0.9278	0.0210	0.8947	0.0249
Austin	0.9796	0.0117	0.9456	0.0187	0.9318	0.0208	0.8904	0.0259
Ben	0.9667	0.0147	0.9533	0.0172	0.9331	0.0205	0.9060	0.0239
Gina	0.9868	0.0092	0.9605	0.0158	0.9605	0.0158	0.9135	0.0229
Kathleen	0.9732	0.0132	0.9463	0.0185	0.9395	0.0196	0.9326	0.0206
Ricardo	0.9669	0.0146	0.9669	0.0146	0.9669	0.0146	0.9266	0.0213
P-value	0.8963		0.5412		0.4388		0.3093	

5) Release 3 (SR082) – Reach survival

	Release to SR067.0		SR067.0 to SR040.0		SR040.0 to SR017.0	
	Est	SE	Est	SE	Est	SE
Amandao	0.9869	0.0094	0.9720	0.0138	0.9571	0.0171
Andy	0.9733	0.0132	0.9859	0.0099	0.9645	0.0156
Ashlie	0.9868	0.0092	0.9655	0.0152	0.9357	0.0207
Austin	0.9804	0.0112	0.9933	0.0066	0.9530	0.0173
Ben	0.9865	0.0095	0.9726	0.0135	0.9507	0.0182
Gina	0.9732	0.0132	0.9720	0.0138	0.9353	0.0209
Kathleen	0.9935	0.0065	0.9735	0.0131	0.9864	0.0096
Ricardo	0.9932	0.0067	0.9722	0.0137	0.9571	0.0171
P-value	0.7469		0.8319		0.5183	

6) Release 3 (SR082) – Cumulative survival

	Release to SR067.0		Release to SR040.0		Release to SR017.0	
	Est	SE	Est	SE	Est	SE
Amandao	0.9869	0.0094	0.9593	0.0163	0.9181	0.0226
Andy	0.9733	0.0132	0.9595	0.0162	0.9255	0.0216
Ashlie	0.9868	0.0092	0.9528	0.0174	0.8916	0.0256
Austin	0.9804	0.0112	0.9739	0.0129	0.9281	0.0209
Ben	0.9865	0.0095	0.9595	0.0162	0.9122	0.0233
Gina	0.9732	0.0132	0.9459	0.0186	0.8847	0.0263
Kathleen	0.9935	0.0065	0.9671	0.0144	0.9540	0.0170
Ricardo	0.9932	0.0067	0.9657	0.0151	0.9243	0.0220
P-value	0.7469		0.9563		0.4790	

Table B.4. (contd)

7) Release 4 (SR065) – Reach survival

	Release to SR040.0		SR040.0 to SR017.0	
	Est	SE	Est	SE
Amandao	0.9762	0.0136	0.9837	0.0114
Andy	0.9760	0.0137	0.9590	0.0179
Ashlie	0.9837	0.0114	0.9339	0.0226
Austin	0.9921	0.0078	0.9524	0.0190
Ben	0.9837	0.0114	0.9339	0.0226
Gina	0.9840	0.0112	0.9675	0.0160
Kathleen	0.9758	0.0138	0.9339	0.0226
Ricardo	0.9764	0.0135	0.9194	0.0245
P-value	0.9774		0.3305	

8) Release 4 (SR065) – Cumulative survival

	Release to SR040.0		Release to SR017.0	
	Est	SE	Est	SE
Amandao	0.9762	0.0136	0.9603	0.0174
Andy	0.9760	0.0137	0.9360	0.0219
Ashlie	0.9837	0.0114	0.9187	0.0246
Austin	0.9921	0.0078	0.9449	0.0203
Ben	0.9837	0.0114	0.9187	0.0246
Gina	0.9840	0.0112	0.9520	0.0191
Kathleen	0.9758	0.0138	0.9113	0.0255
Ricardo	0.9764	0.0135	0.8976	0.0269
P-value	0.9774		0.4939	

9) Release 5 (SR040) – Reach survival

	Release to SR017.0	
	Est	SE
Amandao	0.9127	0.0251
Andy	0.9440	0.0206
Ashlie	0.9350	0.0222
Austin	0.9600	0.0175
Ben	0.9350	0.0222
Gina	0.9141	0.0248
Kathleen	0.9516	0.0193
Ricardo	0.8889	0.0280
P-value	0.3800	

Table B.5. Number 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.

Release	AMANDAO	ANDY	ASHLIE	AUSTIN	BEN	GINA	KATHLEEN	RICARDO	P-value
R1_SR133	396	356	387	394	358	391	353	363	
R2_SR112	264	261	262	261	261	262	261	263	1
R3_SR082	257	273	256	252	265	254	268	271	
R4_SR065	233	237	236	233	239	231	239	241	0.9972
R5_SR040	233	241	229	228	236	234	243	241	
Chi-square = 9.466				df = 28					0.9996

Table B.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. The results of the chi-square tests of homogeneity are presented in the form of *P*-values.

a. Replicate 1

Release	ANDY	BEN	KATHLEEN	RICARDO	*P*-value
R1_SR133	9	10	9	10	
R2_SR112	7	6	7	6	0.9993
R3_SR082	18	16	18	18	
R4_SR065	22	23	22	23	0.9992
R5_SR040	20	20	20	20	
Chi-square = 0.4502		df = 12			1

b. Replicate 2

Release	ANDY	BEN	KATHLEEN	RICARDO	*P*-value
R1_SR133	11	13	11	12	0.9995
R2_SR112	16	17	17	18	
R3_SR082	18	18	16	17	
R4_SR065	19	20	20	20	0.9993
R5_SR040	20	20	20	20	
Chi-square = 0.4018		df = 12			1

c. Replicate 3

Release	AMANDAO	ANDY	ASHLIE	AUSTIN	BEN	GINA	KATHLEEN	RICARDO	*P*-value
R1_SR133	0	23	0	0	23	0	23	22	
R2_SR112	0	23	0	0	22	0	23	21	1
R3_SR082	0	22	0	0	21	0	22	22	
R4_SR065	20	0	20	20	0	21	0	0	0.9937
R5_SR040	15	0	14	15	0	14	0	0	
Chi-square = 406.384				df = 28					<0.0001

d. Replicate 4

Release	AMANDAO	ANDY	ASHLIE	AUSTIN	BEN	GINA	KATHLEEN	RICARDO	*P*-value
R1_SR133	0	31	0	0	30	0	31	32	
R2_SR112	0	20	0	0	22	0	22	23	0.9998
R3_SR082	0	22	0	0	22	0	21	22	
R4_SR065	15	0	15	14	0	14	0	0	0.9953
R5_SR040	15	0	14	14	0	15	0	0	
Chi-square = 414.522				df = 28					<0.0001

Table B.6. (contd)

e. Replicate 5

Release	AMANDAO	ASHLIE	AUSTIN	GINA	*P*-value
R1_SR133	33	29	32	32	
R2_SR112	22	21	22	22	0.9999
R3_SR082	16	15	15	17	
R4_SR065	14	14	14	13	0.9921
R5_SR040	15	14	14	15	
Chi-square = 0.3242		df = 12			1

f. Replicate 6

Release	AMANDAO	ASHLIE	AUSTIN	GINA	*P*-value
R1_SR133	32	32	32	30	
R2_SR112	16	16	16	16	1
R3_SR082	16	16	15	16	
R4_SR065	15	15	14	14	0.9953
R5_SR040	14	15	15	14	
Chi-square = 0.1870		df = 12			1

g. Replicate 7

Release	AMANDAO	ANDY	ASHLIE	AUSTIN	BEN	GINA	KATHLEEN	RICARDO	*P*-value
R1_SR133	24	0	23	25	0	24	0	0	
R2_SR112	16	0	17	16	0	17	0	0	0.9998
R3_SR082	16	0	16	15	0	15	0	0	
R4_SR065	0	14	0	0	13	0	14	14	0.9989
R5_SR040	0	15	0	0	14	0	15	14	
Chi-square = 337.392				df = 28					<0.0001

h. Replicate 8

Release	AMANDAO	ANDY	ASHLIE	AUSTIN	BEN	GINA	KATHLEEN	RICARDO	*P*-value
R1_SR133	24	0	22	24	0	23	0	0	
R2_SR112	16	0	16	16	0	14	0	0	0.9999
R3_SR082	16	0	16	16	0	16	0	0	
R4_SR065	0	14	0	0	15	0	14	15	1
R5_SR040	0	14	0	0	15	0	14	15	
Chi-square = 335.294				df = 28					<0.0001

Table B.6. (contd)

i. Replicate 9

Release	ANDY	BEN	KATHLEEN	RICARDO	*P*-value
R1_SR133	24	24	24	24	
R2_SR112	16	16	16	16	1
R3_SR082	16	16	16	16	
R4_SR065	12	13	13	13	0.9988
R5_SR040	14	14	15	15	
Chi-square = 0.0952		df = 12			1

j. Replicate 10

Release	ANDY	BEN	KATHLEEN	RICARDO	*P*-value
R1_SR133	23	23	23	23	
R2_SR112	16	16	16	16	1
R3_SR082	16	16	16	16	
R4_SR065	14	14	15	15	0.9953
R5_SR040	15	14	15	14	
Chi-square = 0.1141		df = 12			1

k. Replicate 11

Release	AMANDAO	ANDY	ASHLIE	AUSTIN	BEN	GINA	KATHLEEN	RICARDO	*P*-value
R1_SR133	0	24	0	0	24	0	24	24	
R2_SR112	0	16	0	0	16	0	17	16	1
R3_SR082	0	17	0	0	16	0	16	16	
R4_SR065	14	0	14	14	0	14	0	0	0.9957
R5_SR040	15	0	14	16	0	15	0	0	
Chi-square = 342.302				df = 28					<0.0001

l. Replicate 12

Release	AMANDAO	ANDY	ASHLIE	AUSTIN	BEN	GINA	KATHLEEN	RICARDO	*P*-value
R1_SR133	0	24	0	0	24	0	22	24	
R2_SR112	0	16	0	0	17	0	15	17	1
R3_SR082	0	16	0	0	16	0	16	16	
R4_SR065	15	0	15	15	0	14	0	0	0.9989
R5_SR040	14	0	14	14	0	14	0	0	
Chi-square = 338.235				df = 28					<0.0001

m. Replicate 13

Release	AMANDAO	ASHLIE	AUSTIN	GINA	*P*-value
R1_SR133	24	24	24	23	
R2_SR112	16	16	15	16	1
R3_SR082	16	16	16	16	
R4_SR065	14	14	15	15	0.9953
R5_SR040	14	15	15	14	
Chi-square = 0.2052		df = 12			1

Table B.6. (contd)

n. Replicate 14

Release	AMANDAO	ASHLIE	AUSTIN	GINA	*P*-value
R1_SR133	23	23	23	23	
R2_SR112	17	16	15	17	0.9999
R3_SR082	16	17	15	16	
R4_SR065	14	15	14	15	0.9953
R5_SR040	15	14	14	15	
Chi-square = 0.2578		df = 12			1

o. Replicate 15

Release	AMANDAO	ANDY	ASHLIE	AUSTIN	BEN	GINA	KATHLEEN	RICARDO	*P*-value
R1_SR133	24	0	23	24	0	24	0	0	
R2_SR112	15	0	15	17	0	16	0	0	0.9999
R3_SR082	17	0	16	16	0	16	0	0	
R4_SR065	0	14	0	0	14	0	14	13	0.9989
R5_SR040	0	15	0	0	14	0	15	14	
Chi-square = 336.328					df = 28				<0.0001

p. Replicate 16

Release	AMANDAO	ANDY	ASHLIE	AUSTIN	BEN	GINA	KATHLEEN	RICARDO	*P*-value
R1_SR133	25	0	24	23	0	24	0	0	
R2_SR112	16	0	16	16	0	16	0	0	1
R3_SR082	16	0	15	16	0	16	0	0	
R4_SR065	0	15	0	0	14	0	14	15	0.9953
R5_SR040	0	14	0	0	15	0	14	15	
Chi-square = 339.326					df = 28				<0.0001

q. Replicate 17

Release	ANDY	BEN	KATHLEEN	RICARDO	*P*-value
R1_SR133	24	24	23	25	
R2_SR112	16	15	16	17	1
R3_SR082	17	16	16	16	
R4_SR065	15	14	15	13	0.9866
R5_SR040	14	15	14	14	
Chi-square = 0.4678		df = 12			1

r. Replicate 18

Release	ANDY	BEN	KATHLEEN	RICARDO	*P*-value
R1_SR133	23	23	23	23	
R2_SR112	16	17	16	16	1
R3_SR082	16	15	16	16	
R4_SR065	15	15	14	15	0.9924
R5_SR040	15	14	15	14	
Chi-square = 0.2050		df = 12			1

Table B.6. (contd)

s. Replicate 19

Release	AMANDAO	ANDY	ASHLIE	AUSTIN	BEN	GINA	KATHLEEN	RICARDO	*P*-value
R1_SR133	0	24	0	0	23	0	24	24	
R2_SR112	0	17	0	0	17	0	17	17	0.9999
R3_SR082	0	15	0	0	15	0	17	17	
R4_SR065	14	0	14	14	0	14	0	0	0.9922
R5_SR040	15	0	14	13	0	15	0	0	
Chi-square = 340.536					df = 28				<0.0001

t. Replicate 20

Release	AMANDAO	ANDY	ASHLIE	AUSTIN	BEN	GINA	KATHLEEN	RICARDO	*P*-value
R1_SR133	0	23	0	0	24	0	22	24	
R2_SR112	0	17	0	0	17	0	17	16	1
R3_SR082	0	16	0	0	16	0	15	16	
R4_SR065	15	0	14	14	0	14	0	0	0.9925
R5_SR040	14	0	15	14	0	15	0	0	
Chi-square = 338.471					df = 28				<0.0001

u. Replicate 21

Release	AMANDAO	ASHLIE	AUSTIN	GINA	*P*-value
R1_SR133	24	24	24	24	
R2_SR112	16	17	16	17	1
R3_SR082	16	16	16	16	
R4_SR065	14	14	13	14	0.9982
R5_SR040	14	15	14	14	
Chi-square = 0.1087		df = 12			1

v. Replicate 22

Release	AMANDAO	ASHLIE	AUSTIN	GINA	*P*-value
R1_SR133	23	22	23	22	
R2_SR112	16	16	16	16	1
R3_SR082	17	16	16	16	
R4_SR065	14	15	15	15	0.9924
R5_SR040	15	14	14	15	
Chi-square = 0.1858		df = 12			1

w. Replicate 23

Release	AMANDAO	ANDY	ASHLIE	AUSTIN	BEN	GINA	KATHLEEN	RICARDO	*P*-value
R1_SR133	22	0	24	24	0	24	0	0	
R2_SR112	16	0	16	16	0	16	0	0	0.9999
R3_SR082	16	0	16	15	0	15	0	0	
R4_SR065	0	14	0	0	14	0	14	14	0.9984
R5_SR040	0	14	0	0	15	0	14	15	
Chi-square = 334.338					df = 28				<0.0001

Table B.6. (contd)

x. Replicate 24

Release	AMANDAO	ANDY	ASHLIE	AUSTIN	BEN	GINA	KATHLEEN	RICARDO	*P*-value
R1_SR133	24	0	23	22	0	23	0	0	
R2_SR112	17	0	16	16	0	16	0	0	0.9999
R3_SR082	15	0	16	16	0	16	0	0	
R4_SR065	0	14	0	0	15	0	14	15	0.9989
R5_SR040	0	14	0	0	14	0	14	15	
Chi-square = 335.293					df = 28				<0.0001

y. Replicate 25

Release	ANDY	BEN	KATHLEEN	RICARDO	*P*-value
R1_SR133	22	25	24	25	
R2_SR112	16	16	16	17	0.9996
R3_SR082	16	15	16	15	
R4_SR065	14	13	14	14	0.9989
R5_SR040	15	14	15	14	
Chi-square = 0.4387		df = 12			1

z. Replicate 26

Release	ANDY	BEN	KATHLEEN	RICARDO	*P*-value
R1_SR133	23	22	23	23	
R2_SR112	16	15	16	15	1
R3_SR082	16	16	16	16	
R4_SR065	13	14	15	15	0.9821
R5_SR040	15	13	15	15	
Chi-square = 0.3307		df = 12			1

aa. Replicate 27

Release	AMANDAO	ANDY	ASHLIE	AUSTIN	BEN	GINA	KATHLEEN	RICARDO	*P*-value
R1_SR133	0	25	0	0	23	0	24	24	
R2_SR112	0	16	0	0	17	0	16	16	0.9998
R3_SR082	0	16	0	0	15	0	15	17	
R4_SR065	12	0	14	14	0	14	0	0	0.9805
R5_SR040	15	0	15	14	0	15	0	0	
Chi-square = 337.891					df = 28				<0.0001

bb. Replicate 28

Release	AMANDAO	ANDY	ASHLIE	AUSTIN	BEN	GINA	KATHLEEN	RICARDO	*P*-value
R1_SR133	0	23	0	0	23	0	23	24	
R2_SR112	0	17	0	0	15	0	14	16	0.9994
R3_SR082	0	16	0	0	16	0	16	15	
R4_SR065	15	0	14	15	0	14	0	0	0.9983
R5_SR040	15	0	15	15	0	15	0	0	
Chi-square = 336.578					df = 28				<0.0001

Table B.6. (contd)

cc. Replicate 29

Release	AMANDAO	ASHLIE	AUSTIN	GINA	*P*-value
R1_SR133	23	23	24	24	
R2_SR112	16	17	17	16	1
R3_SR082	16	16	17	16	
R4_SR065	14	14	14	12	0.9805
R5_SR040	14	14	13	14	
Chi-square = 0.3677		df = 12			1

dd. Replicate 30

Release	AMANDAO	ASHLIE	AUSTIN	GINA	*P*-value
R1_SR133	23	23	23	23	
R2_SR112	16	16	16	16	1
R3_SR082	16	17	16	16	
R4_SR065	14	15	14	14	0.9825
R5_SR040	14	13	14	15	
Chi-square = 0.2284		df = 12			1

ee. Replicate 31

Release	AMANDAO	ANDY	ASHLIE	AUSTIN	BEN	GINA	KATHLEEN	RICARDO	*P*-value
R1_SR133	24	0	24	24	0	24	0	0	
R2_SR112	17	0	16	16	0	16	0	0	1
R3_SR082	16	0	15	16	0	15	0	0	
R4_SR065	0	14	0	0	14	0	13	14	0.9790
R5_SR040	0	13	0	0	12	0	14	14	
Chi-square = 331.676				df = 28					<0.0001

ff. Replicate 32

Release	AMANDAO	ANDY	ASHLIE	AUSTIN	BEN	GINA	KATHLEEN	RICARDO	*P*-value
R1_SR133	24	0	24	23	0	24	0	0	
R2_SR112	16	0	15	15	0	15	0	0	1
R3_SR082	16	0	17	16	0	16	0	0	
R4_SR065	0	14	0	0	14	0	14	13	0.9988
R5_SR040	0	14	0	0	13	0	14	13	
Chi-square = 330.198				df = 28					<0.0001

Table B.7. Estimates of reach survival and cumulative survival for subyearling Chinook salmon, along with *P*-values associated with the *F*-tests of homogeneous survival across fish tagged by different staff members.

a. Release 1 (SR133) – Reach survival

	Release to SR113.0		SR113.0 to SR082.0		SR082.0 to SR067.0		SR067.0 to SR040.0		SR040.0 to SR017.0	
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE
AMANDAO	0.9369	0.0122	0.8940	0.0160	0.9027	0.0163	0.9422	0.0136	0.9675	0.0107
ANDY	0.9579	0.0106	0.9286	0.0141	0.9777	0.0084	0.9572	0.0116	0.9724	0.0096
ASHLIE	0.9096	0.0146	0.8911	0.0167	0.9260	0.0148	0.9201	0.0160	0.9396	0.0146
AUSTIN	0.9137	0.0141	0.9088	0.0154	0.9404	0.0133	0.9493	0.0127	0.9291	0.0153
BEN	0.9553	0.0109	0.9208	0.0146	0.9713	0.0094	0.9605	0.0112	0.9384	0.0141
GINA	0.9028	0.0150	0.9003	0.0160	0.9211	0.0152	0.9266	0.0154	0.9624	0.0117
KATHLEEN	0.9718	0.0088	0.9462	0.0124	0.9810	0.0077	0.9542	0.0119	0.9760	0.0090
RICARDO	0.9669	0.0094	0.9227	0.0143	0.9783	0.0082	0.9486	0.0125	0.9662	0.0105
P-value	<0.0001		0.1313		<0.0001		0.2967		0.0333	

b. Release 1 (SR133) – Cumulative survival

	Release to SR113.0		Release to SR082.0		Release to SR067.0		Release to SR040.0		Release to SR017.0	
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE
AMANDAO	0.9369	0.0122	0.8376	0.0186	0.7561	0.0216	0.7124	0.0228	0.6892	0.0234
ANDY	0.9579	0.0106	0.8894	0.0167	0.8696	0.0180	0.8324	0.0199	0.8094	0.0210
ASHLIE	0.9096	0.0146	0.8105	0.0200	0.7506	0.0221	0.6906	0.0236	0.6489	0.0243
AUSTIN	0.9137	0.0141	0.8304	0.0190	0.7809	0.0210	0.7414	0.0223	0.6888	0.0236
BEN	0.9553	0.0109	0.8797	0.0172	0.8545	0.0187	0.8207	0.0203	0.7701	0.0223
GINA	0.9028	0.0150	0.8128	0.0198	0.7487	0.0220	0.6937	0.0234	0.6676	0.0239
KATHLEEN	0.9718	0.0088	0.9195	0.0146	0.9021	0.0160	0.8608	0.0187	0.8402	0.0198
RICARDO	0.9669	0.0094	0.8922	0.0163	0.8728	0.0175	0.8279	0.0199	0.8000	0.0211
P-value	<0.0001		<0.0001		<0.0001		<0.0001		<0.0001	

Table B.7. (contd)

c. Release 2 (SR112) – Reach survival

	Release to SR082.0		SR082.0 to SR067.0		SR067.0 to SR040.0		SR040.0 to SR017.0	
	Est	SE	Est	SE	Est	SE	Est	SE
AMANDAO	0.9548	0.0128	0.9442	0.0145	0.9030	0.0192	0.9439	0.0157
ANDY	0.9655	0.0113	0.9803	0.0088	0.9588	0.0127	0.9786	0.0095
ASHLIE	0.9618	0.0118	0.9405	0.0149	0.8793	0.0214	0.9265	0.0183
AUSTIN	0.9655	0.0113	0.9524	0.0134	0.9289	0.0166	0.9189	0.0183
BEN	0.9617	0.0119	0.9522	0.0135	0.9622	0.0124	0.9432	0.0153
GINA	0.9733	0.0100	0.9490	0.0138	0.8987	0.0196	0.9061	0.0200
KATHLEEN	0.9693	0.0107	0.9646	0.0116	0.9587	0.0128	0.9871	0.0074
RICARDO	0.9658	0.0112	0.9842	0.0078	0.9472	0.0143	0.9571	0.0133
P-value	0.9771		0.1043		0.0004		0.0012	

d. Release 2 (SR112) – Cumulative survival

	Release to SR082.0		Release to SR067.0		Release to SR040.0		Release to SR017.0	
	Est	SE	Est	SE	Est	SE	Est	SE
AMANDAO	0.9548	0.0128	0.9015	0.0183	0.8140	0.0240	0.7684	0.0260
ANDY	0.9655	0.0113	0.9465	0.0140	0.9076	0.0180	0.8882	0.0196
ASHLIE	0.9618	0.0118	0.9046	0.0182	0.7954	0.0251	0.7369	0.0274
AUSTIN	0.9655	0.0113	0.9195	0.0168	0.8541	0.0219	0.7849	0.0255
BEN	0.9617	0.0119	0.9157	0.0172	0.8811	0.0200	0.8311	0.0232
GINA	0.9733	0.0100	0.9237	0.0164	0.8301	0.0233	0.7522	0.0269
KATHLEEN	0.9693	0.0107	0.9350	0.0153	0.8964	0.0189	0.8849	0.0198
RICARDO	0.9658	0.0112	0.9505	0.0134	0.9003	0.0186	0.8616	0.0214
P-value	0.9771		0.2779		0.0002		<0.0001	

Table B.7. (contd)

e. Release 3 (SR82) – Reach survival

	Release to SR067.0		SR067.0 to SR040.0		SR040.0 to SR017.0	
	Est	SE	Est	SE	Est	SE
AMANDAO	0.9494	0.0137	0.9076	0.0188	0.9259	0.0178
ANDY	0.9560	0.0124	0.9459	0.0141	0.9714	0.0106
ASHLIE	0.9531	0.0132	0.9461	0.0146	0.9035	0.0196
AUSTIN	0.9286	0.0162	0.9348	0.0163	0.9256	0.0179
BEN	0.9623	0.0117	0.9360	0.0155	0.9701	0.0111
GINA	0.9291	0.0161	0.9267	0.0171	0.9349	0.0168
KATHLEEN	0.9592	0.0121	0.9453	0.0143	0.9586	0.0128
RICARDO	0.9742	0.0096	0.9349	0.0153	0.9672	0.0114
P-value	0.1955		0.7006		0.0057	

f. Release 3 (SR82) – Cumulative survival

	Release to SR067.0		Release to SR040.0		Release to SR017.0	
	Est	SE	Est	SE	Est	SE
AMANDAO	0.9494	0.0137	0.8617	0.0217	0.7978	0.0253
ANDY	0.9560	0.0124	0.9044	0.0178	0.8785	0.0198
ASHLIE	0.9531	0.0132	0.9017	0.0187	0.8147	0.0244
AUSTIN	0.9286	0.0162	0.8680	0.0214	0.8034	0.0252
BEN	0.9623	0.0117	0.9007	0.0185	0.8737	0.0206
GINA	0.9291	0.0161	0.8611	0.0218	0.8050	0.0250
KATHLEEN	0.9592	0.0121	0.9067	0.0178	0.8692	0.0206
RICARDO	0.9742	0.0096	0.9107	0.0174	0.8809	0.0198
P-value	0.1955		0.2779		0.0064	

Table B.7. (contd)

g. Release 4 (SR65) – Reach survival

	Release to SR040.0		SR040.0 to SR017.0	
	Est	SE	Est	SE
AMANDAO	0.9957	0.0043	0.9052	0.0192
ANDY	0.9831	0.0084	0.9742	0.0104
ASHLIE	0.9703	0.0110	0.9432	0.0153
AUSTIN	0.9871	0.0074	0.9043	0.0194
BEN	0.9874	0.0072	0.9746	0.0102
GINA	0.9913	0.0061	0.9389	0.0158
KATHLEEN	0.9833	0.0083	0.9745	0.0103
RICARDO	0.9793	0.0092	0.9619	0.0125
P-value	0.4716		0.0002	

h. Release 4 (SR65) – Cumulative survival

	Release to SR040.0		Release to SR017.0	
	Est	SE	Est	SE
AMANDAO	0.9957	0.0043	0.9013	0.0195
ANDY	0.9831	0.0084	0.9578	0.0131
ASHLIE	0.9703	0.0110	0.9153	0.0181
AUSTIN	0.9871	0.0074	0.8927	0.0203
BEN	0.9874	0.0072	0.9623	0.0123
GINA	0.9913	0.0061	0.9307	0.0167
KATHLEEN	0.9833	0.0083	0.9582	0.0130
RICARDO	0.9793	0.0092	0.9419	0.0151
P-value	0.4716		0.0071	

Table B.7. (contd)

i. Release 5 (SR40) – Reach survival

	Release to SR017.0	
	Est	SE
AMANDAO	0.9657	0.0119
ANDY	0.9710	0.0108
ASHLIE	0.9476	0.0147
AUSTIN	0.9649	0.0122
BEN	0.9831	0.0084
GINA	0.9615	0.0126
KATHLEEN	0.9835	0.0082
RICARDO	0.9751	0.0100
P-value	0.3521	

j. Release 5 (SR40) – Cumulative survival

	Release to SR017.0	
	Est	SE
AMANDAO	0.9657	0.0119
ANDY	0.9710	0.0108
ASHLIE	0.9476	0.0147
AUSTIN	0.9649	0.0122
BEN	0.9831	0.0084
GINA	0.9615	0.0126
KATHLEEN	0.9835	0.0082
RICARDO	0.9751	0.0100
P-value	0.3521	

Table B.8. Estimates of a) reach and b) cumulative reach survival for subyearling Chinook salmon for release R_1 for the replicate release groups 1–20, along with *P*-values associated with the *F*-test of homogeneous fish tagged by different staff members.

a. Reach Survival

	Release to SR113.0		SR113.0 to SR082.0		SR082.0 to SR067.0		SR067.0 to SR040.0		SR040.0 to SR017.0	
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE
AMANDAO	0.9856	0.0082	0.9466	0.0157	0.9487	0.0158	0.9836	0.0094	0.9833	0.0095
ANDY	0.9734	0.0099	0.9606	0.0122	0.9837	0.0081	0.9791	0.0093	0.9742	0.0104
ASHLIE	0.9900	0.0070	0.9388	0.0171	0.9783	0.0108	0.9556	0.0154	0.9535	0.0161
AUSTIN	0.9855	0.0083	0.9453	0.0160	0.9841	0.0091	0.9892	0.0076	0.9617	0.0142
BEN	0.9736	0.0099	0.9416	0.0146	0.9793	0.0091	0.9746	0.0102	0.9609	0.0128
GINA	0.9803	0.0098	0.9188	0.0195	0.9946	0.0055	0.9718	0.0125	0.9827	0.0099
KATHLEEN	0.9925	0.0054	0.9562	0.0129	0.9875	0.0072	0.9530	0.0138	0.9821	0.0089
RICARDO	0.9850	0.0074	0.9428	0.0144	0.9798	0.0090	0.9580	0.0130	0.9782	0.0097
P-value	0.6723		0.7071		0.0614		0.2167		0.4278	

b. Cumulative Reach Survival

	Release to SR113.0		Release to SR082.0		Release to SR067.0		Release to SR040.0		Release to SR017.0	
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE
AMANDAO	0.9856	0.0082	0.9330	0.0173	0.8852	0.0221	0.8707	0.0232	0.8561	0.0243
ANDY	0.9734	0.0099	0.9351	0.0152	0.9198	0.0168	0.9006	0.0185	0.8774	0.0203
ASHLIE	0.9900	0.0070	0.9294	0.0182	0.9092	0.0204	0.8688	0.0240	0.8284	0.0268
AUSTIN	0.9855	0.0083	0.9316	0.0177	0.9168	0.0193	0.9069	0.0203	0.8722	0.0234
BEN	0.9736	0.0099	0.9168	0.0170	0.8978	0.0186	0.8750	0.0204	0.8408	0.0225
GINA	0.9803	0.0098	0.9007	0.0211	0.8958	0.0215	0.8705	0.0237	0.8554	0.0248
KATHLEEN	0.9925	0.0054	0.9490	0.0138	0.9371	0.0152	0.8931	0.0195	0.8771	0.0207
RICARDO	0.9850	0.0074	0.9287	0.0158	0.9099	0.0176	0.8717	0.0206	0.8527	0.0218
P-value	0.6723		0.6872		0.6545		0.8161		0.7788	

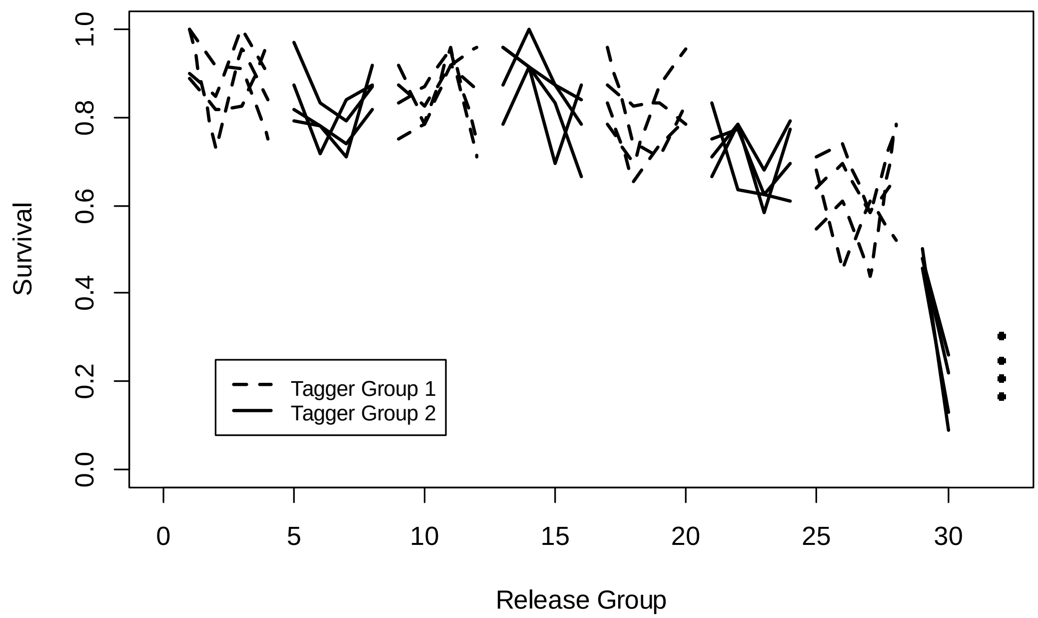

Figure B.1. Estimates of survival from the release location of R_1 to SR017 by tagger and tag team (solid vs. dashed lines) plotted against replicate release groups over time (i.e., 1–32) for the summer 2012 subyearling Chinook salmon study. Plot shows considerable seasonality in the survival estimates and one team tagging all the fish at the end of the study.

Appendix C

Capture Histories Used in Estimating Dam Passage Survival

Appendix C

Capture Histories Used in Estimating Dam Passage Survival

C.1 Yearling Chinook Salmon

Table C.1. Numbers of yearling Chinook salmon per capture history by release group used in the survival analyses of dam passage survival and BRZ-to-BRZ survival. "1" denotes detection, "0" denotes nondetection, and "2" denotes detection and subsequent censoring at each detection array.

Capture History	V1 (Season-Wide) Dam Passage Survival	V1 (Season-Wide) BRZ-to-BRZ Survival	V1 (Early Season) Dam Passage Survival	V1 (Late Season) Dam Passage Survival
111	1613	1617	563	1050
011	0	0	0	0
101	0	0	0	0
001	0	0	0	0
120	4	4	1	3
020	0	0	0	0
110	53	53	22	31
010	0	0	0	0
200	0	0	0	0
100	16	16	4	12
000	75	77	25	50
Total	1761	1767	615	1146

Capture History	Season-Wide Dam Passage Survival R2	Season-Wide Dam Passage Survival R3	V1 (Early Season) R2	V1 (Early Season) R3	V1 (Late Season) R2	V1 (Late Season) R3
11	1128	1145	449	403	679	742
01	0	0	0	0	0	0
20	3	9	1	2	2	7
10	28	37	8	16	20	21
00	39	9	14	6	25	3
Total	1198	1200	472	427	726	773

C.2 Steelhead

Table C.2. Numbers of steelhead per capture history by release group used in the survival analyses of dam passage survival and BRZ-to-BRZ survival. "1" denotes detection, "0" denotes nondetection, and "2" denotes detection and subsequent censoring at each detection array.

Capture History	V1 (Season-Wide) Dam Passage Survival	V1 (Season-Wide) BRZ-to-BRZ Survival	V1 (Early Season) Dam Passage Survival	V1 (Late Season) Dam Passage Survival
111	1619	1619	588	1031
011	0	0	0	0
101	0	0	0	0
001	0	0	0	0
120	26	26	7	19
020	0	0	0	0
110	30	30	12	18
010	1	1	1	0
200	0	0	0	0
100	14	14	7	7
000	52	53	19	33
Total	1742	1743	634	1108

	Season-Wide Dam Passage Survival		V1 (Early Season)		V1 (Late Season)	
Capture History	R2	R3	R2	R3	R2	R3
11	1120	1136	441	400	679	736
01	0	2	0	2	0	0
20	20	17	3	4	17	13
10	13	28	5	15	8	13
00	48	19	22	9	26	10
Total	1201	1202	471	430	730	772

C.3 Subyearling Chinook Salmon

Table C.3. Numbers of subyearling Chinook salmon per capture history by release group used in the survival analyses of dam passage survival and BRZ-to-BRZ survival. “1” denotes detection, “0” denotes nondetection, and “2” denotes detection and subsequent censoring at each detection array.

	V1 (Season-Wide)	
Capture History	Dam Passage Survival	BRZ-to-BRZ Survival
111	2227	2227
011	1	1
101	3	3
001	0	0
120	17	17
020	0	0
110	124	125
010	1	1
200	2	2
100	111	113
000	198	213
Total	2684	2702

	Season-Wide Dam Passage Survival	
Capture History	R2	R3
11	1780	1838
01	2	0
20	20	28
10	134	128
00	159	102
Total	2095	2096

Appendix D

Bias Corrections for Detections of Dead Tagged Fish

Appendix D

Bias Corrections for Detections of Dead Tagged Fish

D.1 Detections of Dead Tagged Fish

Fish that died during dam passage and are detected at the R_3 array with active acoustic tags will bias the estimate of $\hat{S}_1$ used in calculating dam passage survival. Consequently, dead tagged fish are released into the tailrace to verify the assumption that this does not occur. The downstream detections of dead tagged fish can also be used to provide a correction if the problem occurs.

This appendix derives a bias-corrected estimator for S_1 in the presence of dead fish detections. Only $\hat{S}_1$ needs to be adjusted for dead fish corrections in the estimate of dam passage survival, because the estimates of $\hat{S}_2$ and $\hat{S}_3$ are based on detections farther downriver. The derivation is performed in two comparable approaches, providing complementary estimators.

D.2 Approach 1: CJS Model

Figure D.1 illustrates a single release-recapture study with two downstream detection arrays. The closed-form estimator of survival in the first reach from the Cormack-Jolly-Seber (CJS) model will be used as the basis of the bias-corrected estimator of S_1 from the virtual release V_1.

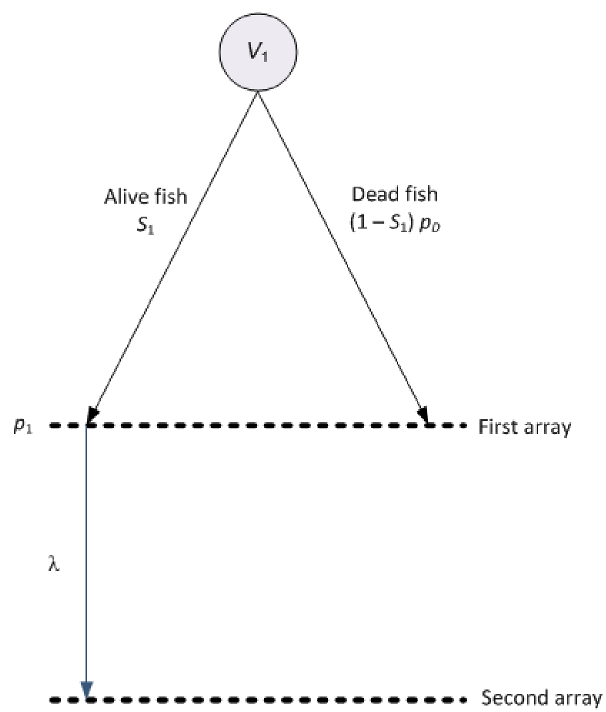

Figure D.1. Schematic of a two-reach Cormack-Jolly-Seber release-recapture study with the detection of live fish and dead fish at the first array. No dead tagged fish are washed downriver and detected at the second array.

The CJS estimator of survival S_1 for this simple two-reach study is

$$\hat{S}_1 = \frac{(n_{11} + n_{10})(n_{11} + n_{01})}{n_{11}} \quad . \tag{D.1}$$

In the case of detections of dead tagged fish, the counts have the following expected values:

$$\begin{aligned}
E(n_{11}) &= V_1 S_1 p_1 \lambda \\
E(n_{01}) &= V_1 S_1 (1 - p_1) \lambda \\
E(n_{10}) &= V_1 \left[S_1 p_1 (1 - \lambda) + (1 - S_1) p_D \right] \\
E(n_{00}) &= V_1 \left[S_1 (1 - p_1)(1 - \lambda) + (1 - S_1)(1 - p_D) \right]
\end{aligned}$$

where p_D = probability of a dead fish being washed downriver and being detected at the first array. This correction is based on the assumption dead tagged fish are not washed downriver to the second array.

Substituting in expected values of n_{ij} into the reach survival estimate (D.1) yields

$$E\left(\hat{S}_1\right) \doteq S_1 + \frac{p_D (1 - S_1)}{p_1} \quad . \tag{D.2}$$

Hence, the biased estimator is a function of the true survival probability (S_1) and a function of the probability of false-positive detections of dead tagged fish. Using the method of moments, a bias-corrected estimator of reach survival, a function of the biased estimator, is then

$$\tilde{S}_1 = \frac{\hat{p}_1 \hat{S}_{\text{Bias}} - \hat{p}_D}{\hat{p}_1 - \hat{p}_D} \tag{D.3}$$

where $\hat{S}_{\text{Bias}}$ = estimate of S_1 ignoring the problem with dead tagged fish detections
$\hat{p}_1$ = estimate of the detection probability at the first array
$\hat{p}_D$ = estimated probability of detecting a dead tagged fish at the first array.

Note, using the CJS estimator of

$$\hat{p}_1 = \frac{n_{11}}{n_{11} + n_{01}} \; ,$$

the $E(\hat{p}_1) = p_1$ in the presence of dead tagged fish detections. Hence, the estimate $\hat{p}_1$ is unaffected by dead tagged fish detections and can be estimated directly from the capture data by ignoring the problem.

D.3 Approach 2

In this approach, a single detection array downstream is used and relative recovery data on release V_1 are collected (Figure D.2).

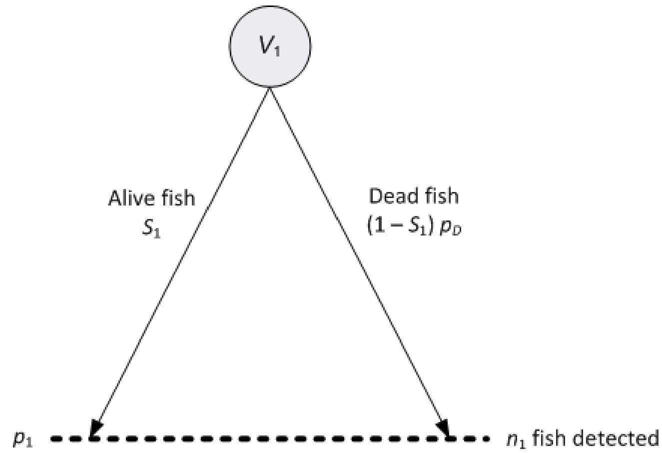

Figure D.2. Schematic of a single-reach relative recovery study with detections of both live and dead tagged fish at the array.

Let n_1 be the number of V_1 fish detected downriver regardless of alive or dead. Then the expected value of n_1/V_1 is

$$E\left(\frac{n_1}{V_1}\right)=S_1 p_1+\left(1-S_1\right)p_D .$$

Using the method of moments, an estimator of actual survival in the reach is

$$\tilde{S}_1=\frac{\left(\frac{n_1}{V_1}-\hat{p}_D\right)}{\left(\hat{p}_1-\hat{p}_D\right)} . \tag{D.4}$$

Estimator (D.4) is the same form as (D.3), noting that

$$E\left(\frac{n_1}{V_1}\right)=p_1 S_{\text{Bias}}$$

or, in other words, n_1/V_1 is an estimator of $p_1 S_{\text{Bias}}$.

In the specific case of the subyearling Chinook salmon at Little Goose Dam in 2012, the bias corrected estimator of S_1 is calculated as follows:

$$\tilde{S}_1 = \frac{\left(\left(\frac{n_1}{V_1}\right) - \hat{p}_D\right)}{\hat{p}_1 - \hat{p}_D}$$

$$= \frac{\left(\left(\frac{2484}{2684}\right) - \frac{1}{32}\right)}{0.9992 - \frac{1}{32}} = 0.9239\ \left(\widehat{\mathrm{SE}} = 0.0058\right)$$

where $\hat{p}_D$ = dead tagged fish recovery rate (i.e., 1/32)

$\hat{p}_1$ = probability of detection of alive fish at array (i.e., 0.9992, Table 3.11)

$\frac{n_1}{V_1}$ = observed recovery rate of V_1 (i.e., $\frac{2484}{2684}$) at detection array.

The variance of $\tilde{S}_1$ is calculated using the delta method as described below.

D.4 Variance Estimator for $\tilde{S}_1$

Assuming the three inputs into $\tilde{S}_1$ are uncorrelated, the variance of $\tilde{S}_1$ can be calculated using the delta method (Seber 1982), where

$$\widehat{\mathrm{Var}}\left(\tilde{S}_1\right) = \widehat{\mathrm{Var}}\left(\frac{n_1}{V_1}\right)\left(\frac{1}{\hat{p}_1 - \hat{p}_D}\right)^2 + \widehat{\mathrm{Var}}\left(\hat{p}_D\right)\left(\frac{\left(\frac{n_1}{V_1} - \hat{p}_1\right)}{\left(\hat{p}_1 - \hat{p}_D\right)^2}\right)^2 + \widehat{\mathrm{Var}}\left(\hat{p}_1\right)\left(\frac{\left(\frac{n_1}{V_1} - \hat{p}_D\right)}{\left(\hat{p}_1 - \hat{p}_D\right)^2}\right)^2 \tag{D.5}$$

where $\widehat{\mathrm{Var}}\left(\frac{n_1}{V_1}\right) = \frac{\frac{n_1}{V_1}\left(1 - \frac{n_1}{V_1}\right)}{V_1}$ (i.e., binomial variance),

$\widehat{\mathrm{Var}}\left(\hat{p}_D\right) = \widehat{\mathrm{Var}}\left(\frac{d}{D}\right) = \frac{\frac{d}{D}\left(1 - \frac{d}{D}\right)}{D}$ (i.e., binomial variance),

$\widehat{\mathrm{Var}}\left(\hat{p}_1\right) = \widehat{\mathrm{SE}}\left(\hat{p}_1\right)^2$ from the likelihood model.

D.5 $\mathrm{Var}\left(\hat{S}_{\mathrm{Dam}}\right)$

Using the biased-corrected point estimator for S_1 (D.4), and associated variance estimator (D.5), the delta method would be used to estimate the variance of the estimate of dam passage survival.

Appendix E

Single-Release PIT- and Acoustic-Tag Survival Estimates of Tailrace Release Groups

Appendix E

Single-Release PIT- and Acoustic-Tag Survival Estimates of Tailrace Release Groups

Single-release survivals were estimated from the R2 and R3 release sites in the 2012 acoustic-tag survival study to the array above Lower Monumental Dam for all three species in the study. These single-release survival estimates may include handling mortality that had not been expressed prior to release. For comparison, PIT-tagged fish detected in the bypass system of Little Goose Dam during the acoustic-tag study period were regrouped into a virtual release group and their survival to the Lower Monumental Dam was estimated. These survivals are considered a "tailrace to tailrace" survival estimates. Table E.1 shows the PIT tag- and acoustic-tag-based survival estimates as well as the survival and mortality per kilometer during the 2012 study period. In all six comparisons, the estimated PIT tag per kilometer mortality was either higher than the acoustic-tag-based estimate, or the 95% confidence intervals of the PIT tag and acoustic-tag estimates overlapped for the both the R2 and R3 estimates.

Table E.1. Single release survival estimates based on PIT and acoustic tags for yearling Chinook salmon (CH1), steelhead (STH), and subyearling Chinook salmon (CH0) for the reaches of the lower Snake and mid-Columbia rivers during the study period of the 2012 lower Snake River BiOp performance tests. The single release survival estimates, survival per kilometer, mortality per km, and 95% confidence intervals are presented for each stock/species for both tailrace groups (R2 and R3) downstream of Little Goose Dam.

	Reach	Dates	Survival	Upper 95% CI	Lower 95% CI	Survival/km	Upper 95% CI	Lower 95% CI	Mortality/km	Upper 95% CI	Lower 95% CI	Mortality/km PIT > AT	Mortality/km CI overlap
PIT Survival Estimates													
CH1	LGS-LMN	4/29 to 5/27	0.8873	0.917092	0.857508	0.99742078	0.99813247	0.996685316	0.25792196	0.331468369	0.186753012		
STH	LGS-LMN	4/29 to 5/27	0.838	0.872104	0.803896	0.996190059	0.997048714	0.995296509	0.380994136	0.470349064	0.295128639		
CH0	LGS-LMN	6/5 to 7/6	0.919	1.005436	0.832564	0.998177275	1.000117097	0.996050042	0.182272465	0.394995765	-0.01170971		
AT Survival Estimates													
CH1													
R2	LGS Tailrace to LMN	4/29 to 5/27	0.9696	0.979792	0.959408	0.999314198	0.999546437	0.999079561	0.06858017	0.09204395	0.045356321	yes	no
R3	LGS Tailrace to LMN	4/29 to 5/27	0.9941	0.999196	0.989004	0.99960558	0.99994638	0.999263145	0.039442045	0.073685525	0.005362012	yes	no
STH													
R2	LGS Tailrace to LMN	4/29 to 5/27	0.962	0.973172	0.950828	0.999139463	0.999395862	0.998880137	0.086053682	0.111986349	0.060413831	yes	no
R3	LGS Tailrace to LMN	4/29 to 5/27	0.9859	0.993152	0.978648	0.999053758	0.999542001	0.998562151	0.094624199	0.143784875	0.045799876	yes	no
CH0													
R2	LGS Tailrace to LMN	6/5 to 7/6	0.9257	0.937068	0.914332	0.998285803	0.998556611	0.998011723	0.171419732	0.198827709	0.144338903	yes	yes
R3	LGS Tailrace to LMN	6/5 to 7/6	0.9527	0.961912	0.943488	0.996774864	0.997414528	0.996129401	0.322513606	0.38705987	0.258547247	no	yes

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