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

FINAL BiOp Performance Testing Report

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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 Lower Monumental Dam as stipulated by the 2008 Federal Columbia River Power System (FCRPS) Biological Opinion (BiOp) and provide additional performance measures at that site as stipulated in the Columbia Basin Fish Accords.

This report summarizes performance and survival studies performed at Lower Monumental 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 Lower Monumental Dam for emigrating yearling and subyearling Chinook salmon and steelhead smolts in 2012. The performance 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, 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 (0.8 km upstream of the dam) to the tailrace (2 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 Lower Monumental Dam. The approach included releases of acoustic-tagged smolts above Lower Monumental Dam that contributed to the formation of a virtual release at the face of Lower Monumental Dam. A survival estimate from the virtual release was adjusted by a paired release below Lower Monumental Dam. A total of 3,964 yearling Chinook salmon, 3,928 steelhead, and 6,013 subyearling Chinook salmon smolts were used in the virtual releases. Sample sizes for the below-dam paired releases were composed of 1,000 and 1,001 yearling Chinook salmon, 1,000 and 1,000 for steelhead, and 1,889 and 1,885 for 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 Lower Monumental 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 Lower Monumental Dam in 2012.

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

Spill Operations	Yearling Chinook Salmon	Steelhead	Subyearling Chinook Salmon
Season-wide spring	0.9868 (0.0090)	0.9826 (0.0021)[(b)]	NA
≤9 May 2012	0.9692 (0.0175)	0.9802 (0.0040)[(b)]	NA
≥10 May 2012	0.9939 (0.0105)	0.9838 (0.0025)[(b)]	NA
Season-wide summer	NA	NA	0.9789 (0.0079)

(a) Dam passage survival is defined as survival from the upstream face of the dam to a standardized reference point in the tailrace.
(b) Survival is based on V_1 single-release estimate only.

[1] The forebay-to-tailrace survival estimate is analogous to the "BRZ-to-BRZ" (boat-restricted zone) survival estimate referred to in the Fish Accords.

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

Performance Measures	Yearling Chinook Salmon	Steelhead	Subyearling Chinook Salmon
Forebay residence time (mean/median)	4.81 h (0.15)/2.35 h	5.65 h (0.16)/2.17 h	14.56 h (0.58)/2.60 h
Spill passage efficiency (SPE)[b]	0.7889 (0.0065)	0.6585 (0.0075)	0.8356 (0.0048)

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

Table ES.3. Lower Monumental Dam survival study summary.

Year: 2012							
Study Site(s): Lower Monumental 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 fish collection facility				Implant Procedure: Surgical: Yes Injected: No			
Size (median):	CH1	STH	CH0	Sample Size:	CH1	STH	CH0
Weight:	25.0	86.4	13.6	# release sites[a]:	5	5	5
Length:	137	215	109	Total # in est[b]:	5,965	5,928	9,787

Tag:	Analytical Model:	Characteristics of Estimate:
Type/model: Advanced Telemetry Systems (ATS) – SS300 and Biomark HPT12 PIT tag Weight (g): SS300 = 0.346 g (air), HPT12 = 0.100 g (air	Virtual-paired-release model	Effects Reflected (direct, total, etc.): Direct Absolute or Relative: Absolute

Spring Environmental/Operating Conditions (daily from 30 April 2012 through 28 May 2012):
Discharge (kcfs): mean 108.4, minimum 76.1, maximum 136.3
Temperature (°C): mean 11.4, minimum 9.1, maximum 13.0
Total Dissolved Gas (tailrace): mean 116.7%, minimum 112.5%, maximum 120.8%
Spill: mean 29.9 kcfs, minimum 23.6 kcfs, maximum 43.7 (target spill 20–29 kcfs)
Unique Study Characteristics: None

Summer Environmental/Operating Conditions (daily from 6 June 2012 through 8 July 2012):
Discharge (kcfs): mean 78.9, minimum 48.2, maximum 128.9
Temperature (°C): mean 15.0, minimum 12.6, maximum 18.2
Total Dissolved Gas (tailrace): mean 117.1%, minimum 113.9%, maximum 119.5%
Spill: mean 25.2 kcfs, minimum 16.6 kcfs, maximum 60.8 kcfs (target spill 6–20 June 25.5 kcfs, 21 June–8 July 17 kcfs)
Unique Study Characteristics: None

Survival and Passage Estimates (value & SE):	CH1	STH	CH0
Dam survival			
• Season-wide spring	0.9868 (0.0090)	0.9826 (0.0021)[c]	NA
• ≤9 May 2012	0.9692 (0.0175)	0.9802 (0.0040)[c]	NA
• ≥10 May 2012	0.9939 (0.0105)	0.9838 (0.0025)[c]	NA
• Season-wide summer	NA	NA	0.9789 (0.0079)
Forebay-to-tailrace survival (season-wide)	0.9859 (0.0090)	0.9815 (0.0022)[c]	0.9721 (0.0079)
Forebay residence time (mean/median)	4.81 h (0.15)/2.35 h	5.65 h (0.16)/2.17 h	14.56 h (0.58)/2.60 h
Tailrace egress time (mean/median)[d]	0.64 h (0.05)/0.40 h	0.73 h (0.04)/0.40 h	0.66 h (0.01)/0.53 h
Spill passage efficiency (SPE)	0.7889 (0.0065)	0.6585 (0.0075)	0.8356 (0.0048)
Fish passage efficiency (FPE)	0.9484 (0.0035)	0.9653 (0.0029)	0.9236 (0.0034)

(a) Includes all locations that contributed fish to the survival estimate.
(b) Includes only those fish directly used in estimation of dam passage survival. Except, see below for steelhead.
(c) Survival is based on V_1 single-release estimate only.
(d) Based on PIT-tag detections for bypassed fish, acoustic-tag detections for remaining fish.

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 Lower Monumental 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 and subyearling Chinook salmon and steelhead (3 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), contains three additional requirements relevant to the 2012 survival studies (after Attachment A to the Memorandum of Agreement):

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

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

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

This report summarizes the results of the 2012 spring and summer acoustic-telemetry studies of yearling Chinook salmon, steelhead, and subyearling Chinook salmon at Lower Monumental Dam to assess the Action Agencies' compliance with the performance criteria of the BiOp and Fish Accords.

1.2 Study Objectives

The purpose of 2012 passage and survival monitoring at Lower Monumental 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 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 0.8 km upstream of the dam) to the tailrace array (located 2 km downstream of the dam). The forebay-to-tailrace survival estimate satisfies the "BRZ-to-BRZ" survival estimate called for in the Fish Accords.
- Forebay residence time is defined as the average time smolts take to travel from the forebay BRZ (located 0.8 km upstream of the dam) to the entrance to the dam.
- Tailrace egress time is defined as the average time smolts take to travel from the dam to the tailrace array (located 2 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 Lower Monumental Dam are shown in Table 1.1.

Table 1.1. Fish Accords passage metrics for Lower Monumental 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	58–75	2006–2007	2.2–3.0 h
Steelhead	48–64	2006–2007	5.5–19.0 h
Subyearling Chinook	81–>90	2005–2007	2.7–3.0 h

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

1.3 Report Contents and Organization

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

2.0 Methods

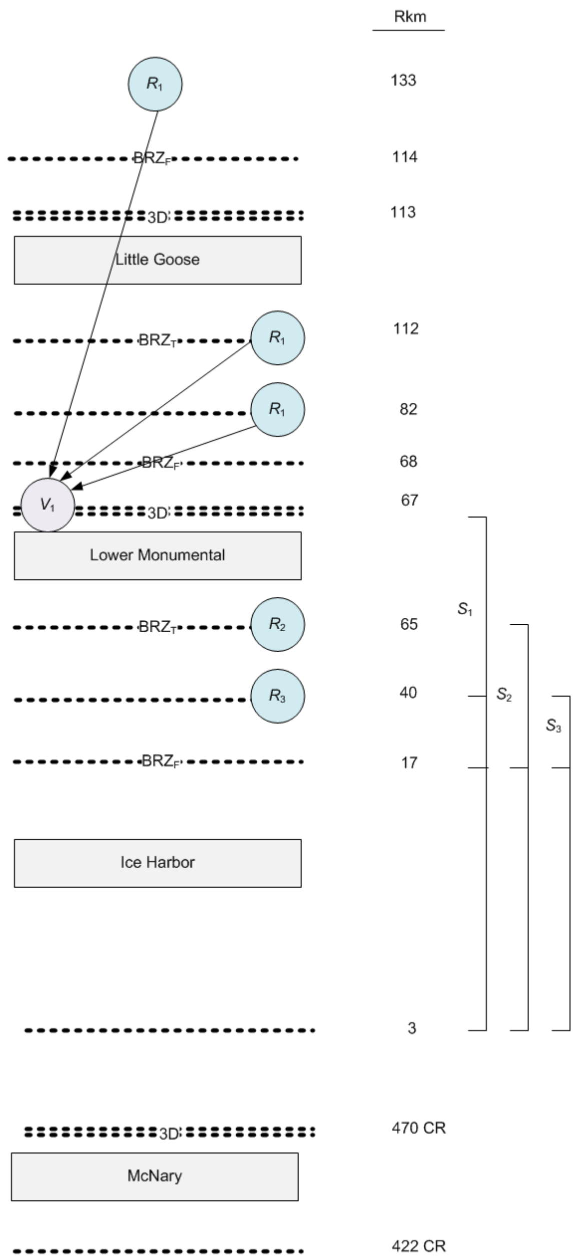
Study methods involved fish release and recapture; the associated fish handling, tagging, and release procedures; acoustic signal processing; and statistical and analytical approaches.

2.1 Release-Recapture Design

The release-recapture design used to estimate dam passage survival at Lower Monumental 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 above Lower Monumental 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 on the immediate 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] 40) (Figure 2.1). To account and adjust for this mortality downstream of the tailrace boundary, a paired release below Lower Monumental 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 for 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 Lower Monumental 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 in 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 according to 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 Lower Monumental Dam. The virtual release (V_1) was composed of fish that arrived at the dam face from releases at rkm 133, 112, and 82. 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. Sample sizes of acoustic-tagged fish releases used in the yearling Chinook salmon, steelhead, and subyearling Chinook salmon survival studies at Lower Monumental Dam in 2012.

Release Location	rkm	Yearling Chinook Salmon	Steelhead	Subyearling Chinook Salmon
Above Lower Monumental (R_1)	133, 112, 82	4,199	4,202	7,189
Virtual Release (V_1)	67	3,964	3,928	6,013
Lower Monumental Dam Tailrace (R_2)	65	1,000	1,000	1,889
Mid-Reservoir (R_3)	40	1,001	1,000	1,885

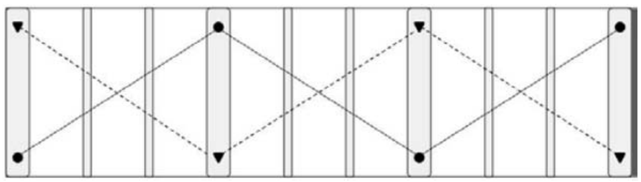


Figure 2.2. Front view schematic of hydrophone deployments at three turbines showing the double-detection arrays. The circles denote the hydrophones of Array 1 and the triangles denote the hydrophones of Array 2.

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 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 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; and 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 Was moribund or emaciated Showed signs of prior surgery (e.g., radio tags, sutures or PIT-tag scars) Indicated a positive reading when put through PIT-tag reader 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 infections 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 or were diverted to a recovery tank on non-transport days or routed directly onto 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, and assessed for noteworthy abnormalities (e.g., minor descaling, fin erosion, predation marks, etc.) 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 Monocryl 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 dark-colored 22.7-L transport bucket filled with aerated river water. Fish were held in partially perforated buckets within a trough of flow-through river water for 12 to 36 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 boat ramps located nearest 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 all fish release locations. Upon arriving at the boat ramp, 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 at R_2 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 acoustic-tagged fish to accommodate downstream mixing. Releases were timed to accommodate the approximately travel time between releases that made up the V_1 and R_2 and the 8-h (spring) or 12-h (summer) travel time between R_2 and R_3.

Release Location	Relative Release Times	
Spring	Daytime Start	Nighttime Start
V_1 (rkm 67)	Continuous	Continuous
R_2 (rkm 65)	Day 1: 1545	Day 2: 0000
R_3 (rkm 40)	Day 2: 0400	Day 2: 1145
Summer	Daytime Start	Nighttime Start
V_1 (rkm 67)	Continuous	Continuous
R_2 (rkm 65)	Day 1: 1545	Day 2: 0330
R_3 (rkm 40)	Day 2: 0400	Day 2: 1500

2.3 Acoustic Detection and Signal Processing

Prior to field 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 individual node, without information of 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, which 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, and under the right conditions, 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 occurred.

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 precede passage at a dam based on spatial tracking of tagged fish movements to a location of last detection. Multiple receptions of messages within an event can be used to triangulate successive tag position relative to hydrophone locations.

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 Lower Monumental 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 Lower Monumental 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 contribution from different releases in V_1 had separate tag-life corrections.

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

Dam passage survival was estimated by the function

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

where $\hat{S}_i$ is the tag-life-corrected survival estimate for the *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 Lower Monumental Dam were planned for dam operation conditions that included a 20- to 29-kcfs spill target in spring. The target spill was 25.5 kcfs between 6 and 20 June and 17-kcfs spill from 21 June through 8 July. High flow conditions in spring and summer 2012 resulted in spill targets being exceeded. Consequently, season-wide estimates of dam passage survival were calculated based on prevailing spill conditions.

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

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

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

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

For the virtual-release group (V_1) based on fish known to have arrived at the dam and with active tags, the conditional probability of tag activation, given the tag was active at the detection array at rkm 67, 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 with 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 Delayed Handling/Tag Effects

The fish forming the virtual release at the face of Lower Monumental Dam (V_1) came from three upriver release groups (Figure 2.1; rkm 133, 112, and 82). Tests of homogeneity of survival were performed (Equation (2.4)) by comparing downriver reach survivals for fish from different upstream release locations (Appendix B). Heterogeneity in survival at downriver reaches with a descending pattern of survivals with distance upriver would be evidence of time-dependent tag effects, in which case, only downstream releases with homogeneous survival would be used in forming the V_1 release groups.

2.4.3.5 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 the virtual-release group (V_1) was composed of fish known to have arrived alive at the forebay array (rkm 67) of Lower Monumental Dam instead of at the dam face (Figure 2.1).

2.4.5 Estimation of Travel Times

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

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

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

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

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

The tailrace egress was calculated two different ways to correspond to current and historical methods of calculation. The first method estimated tailrace egress time based on the time from last detection of a fish at the double array at the dam face at Lower Monumental Dam to the last detection at the tailrace array 2 km downstream of the dam (rkm 65). The second method, which has been used in past, used the time of the last detection in the fish bypass system rather the dam face for those 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 0.8 km above the dam to the last detection at the double array in front of Lower Monumental Dam.

2.4.6 Estimation of Spill Passage Efficiency

SPE was estimated by the fraction

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

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

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

2.4.7 Estimation of Fish Passage Efficiency

FPE was estimated by the fraction

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

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

$$\operatorname{Var}\left(\widehat{\mathrm{FPE}}\right)=\frac{\widehat{\mathrm{FPE}}\left(1-\widehat{\mathrm{FPE}}\right)}{\sum_{i=1}^{4}\hat{N}_i}+\widehat{\mathrm{FPE}}^{2}\left(1-\widehat{\mathrm{FPE}}\right)^{2}$$

$$\cdot\left[\frac{\operatorname{Var}\left(\hat{N}_{SP}\right)+\operatorname{Var}\left(\hat{N}_{SW}\right)+\operatorname{Var}\left(\hat{N}_{JBS}\right)}{\left(\hat{N}_{SP}+\hat{N}_{SW}+\hat{N}_{JBS}\right)^{2}}+\frac{\widehat{\operatorname{Var}}\left(\hat{N}_{TUR}\right)}{\hat{N}_{TUR}^{2}}\right]. \tag{2.12}$$

To expedite this report, it was assumed all routes had equal probability of detection and calculations of $\widehat{\mathrm{SPE}}$ and $\widehat{\mathrm{FPE}}$ 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

More than 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 and Lower Monumental Dam 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 Little Goose and Lower Monumental dams. 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 Lower Monumental Dam 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 their 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**	**2.2**	**1,134**

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

A total of 23,369 live fish were released as part of the BiOp passage and survival study at Lower Monumental Dam (Table 3.3). In addition, 58 dead fish (n = 15 CH1, n = 14 STH, and n = 29 CH0) were released from the spillway weir at Lower Monumental Dam (LMN) to evaluate the assumptions of the virtual-paired-release survival estimate.

Table 3.3. Total number of fish released at five locations by PNNL during the spring and summer of 2012. For the purposes of the LMN study, releases from rkm 133–82 contributed to release group V_1, and the releases at rkm 65 and 40 were considered the R_2 and R_3 releases, respectively.

Release Location	Species			
(rkm)	CH1	STH	CH0	**Total**
133	1,800	1,799	2,998	**6,597**
112	1,198	1,201	2,095	**4,494**
82	1,200	1,204	2,096	**4,500**
65	1,000	1,000	1,889	**3,889**
40	1,001	1,003	1,885	**3,889**
Dead fish releases	15	14	29	**58**
Total	**6,214**	**6,221**	**10,991**	**23,427**

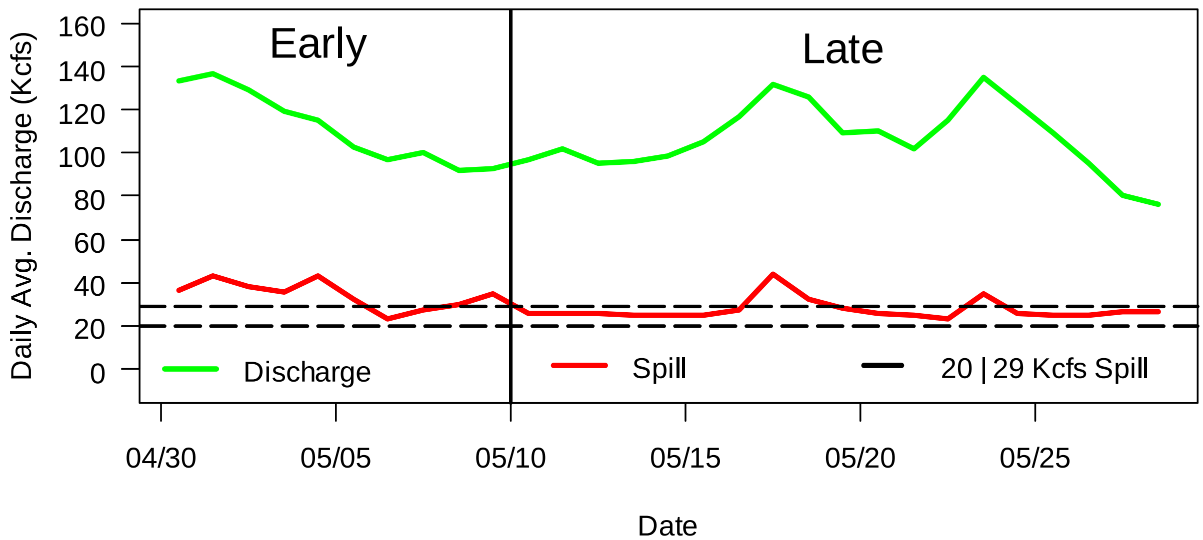
CH1 = yearling Chinook salmon; STH = juvenile steelhead; CH0 = subyearling Chinook salmon.

3.2 Discharge and Spill Conditions

The spring spill target at Lower Monumental Dam was 20–29 kcfs to gas cap. Because of high spring flows in 2012, that target was not approached until midway into the spring survival study (Figure 3.1a). Survival analyses for the spring study were therefore performed before and after 10 May 2012 to examine dam passage survival above and near the spring spill target. However, Lower Monumental Dam project discharge averaged 108 kcfs (range 76–136 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 study period.

The summer spill targets were close to being met for all but the earliest part of the summer survival study (Figure 3.1b). Consequently, only a season-wide survival estimate was calculated for the summer survival study. Lower Monumental Dam project discharge averaged 78.9 kcfs (range 48–129 kcfs) during the summer 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 30.9 to 128.5 kcfs during the study period.

a. Spring



b. Summer

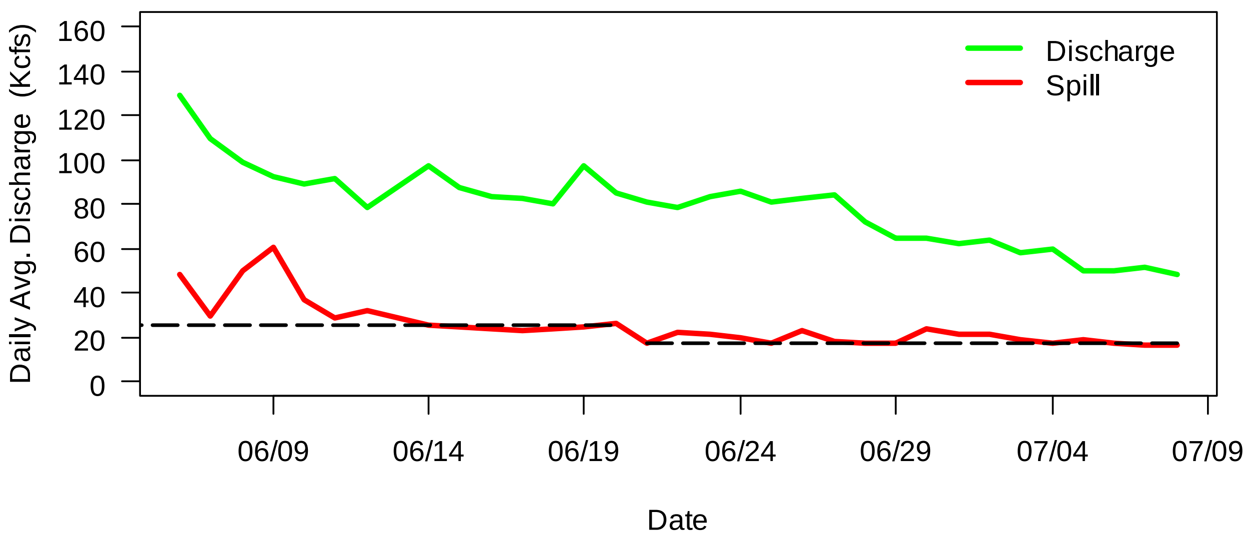
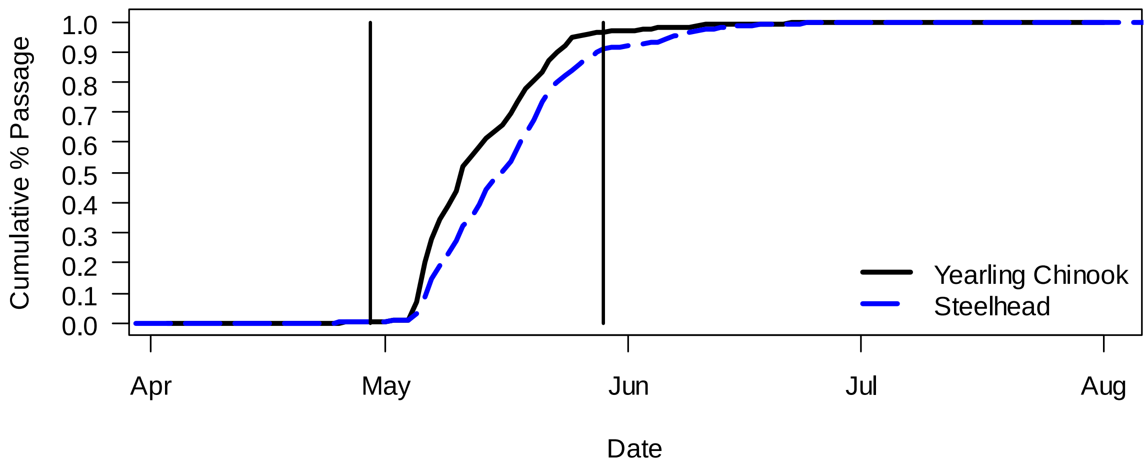


Figure 3.1. Daily average total discharge (kcfs) (green line) and spill volume (red line) at Lower Monumental Dam during the a) spring JSATS yearling Chinook salmon and steelhead study, 30 April to 28 May 2012, and b) summer JSATS subyearling Chinook salmon study, 6 June to 8 July 2012. Target spill is denoted by black dashed lines.

3.3 Run Timing

From 30 April to 28 May 2012, 96.1% of the yearling Chinook salmon and 89.7% of the steelhead smolts passed through Lower Monumental Dam based on Fish Passage Center (FPC) index counts. From 6 June to 8 July 2012, 84.7% of the subyearling Chinook salmon passed through Lower Monumental Dam based on FPC index counts (see Figure 3.2). However, the manner in which the smolt facility was operated influenced the passage distribution data. Appendix C describes how the cumulative passage information presented above may be inaccurate due to the smolt facility not sampling fish during the early portion of the run.

a. Spring



b. Summer

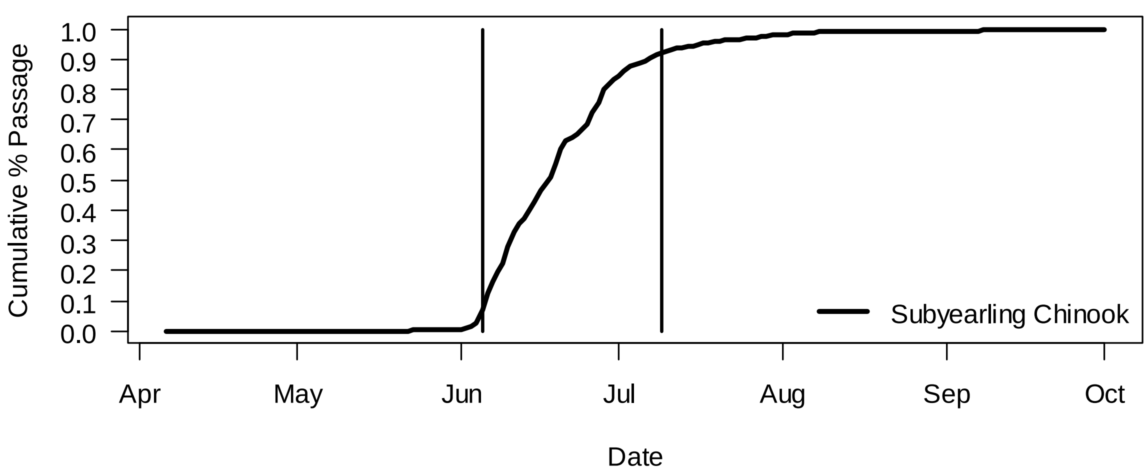


Figure 3.2. Plots of the cumulative percent of a) juvenile steelhead (dashed line) and yearling Chinook salmon (solid line), and b) subyearling Chinook salmon that passed Lower Monumental Dam in 2012. Vertical lines indicate start and stop times of the survival studies.

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

A total of eight different taggers assisted in tagging all of the yearling Chinook salmon, steelhead, and subyearling Chinook salmon smolts associated with the JSATS survival studies at Little Goose and Lower Monumental dams in spring and summer 2012. Analyses found tagger effort was homogeneously distributed either across all locations within a replicate release or within the project-specific releases within a replicate for both spring and summer studies (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 during the spring studies (Appendix B). Initially, tests of homogeneity found differences in survival for fish tagged by different staff members in summer. However, closer examination of the data found seasonal trends in subyearling Chinook salmon survival confounded with tagger scheduling. Elimination of the confounding time period resulted in homogeneity of the survival of subyearling Chinook salmon tagged by different staff members. Therefore, fish tagged by all taggers were included in the estimation of survival and other performance measures.

3.4.2 Examination of Tag-Lot Effects

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

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 Lower Monumental Dam tailrace did not appear to differ significantly among release positions across the channel (Figure 3.3 and Figure 3.4).

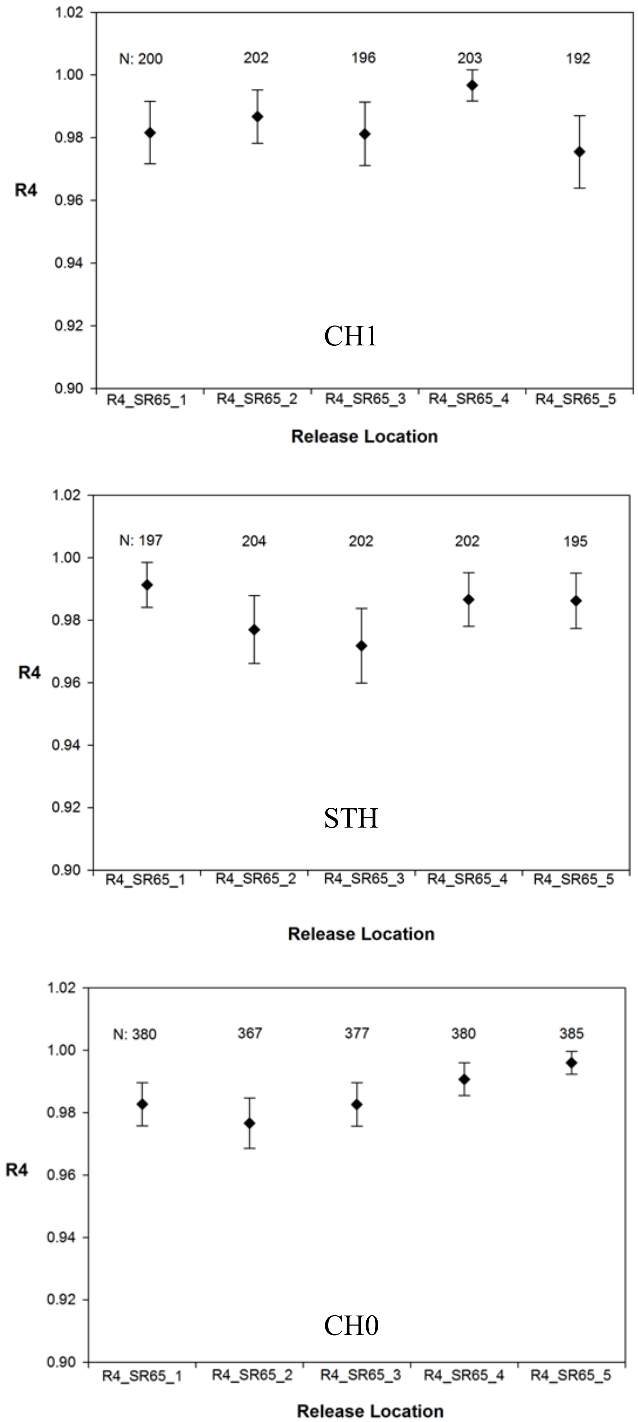


Figure 3.3. Single-release survival estimates (±1 SE) of yearling Chinook salmon (CH1), steelhead (STH), and subyearling Chinook salmon (CH0) from each position in the tailrace release location downstream of Lower Monumental Dam (R4; rkm 65) to the first array downstream (rkm 40). See Figure 3.4 for a map of the release positions.

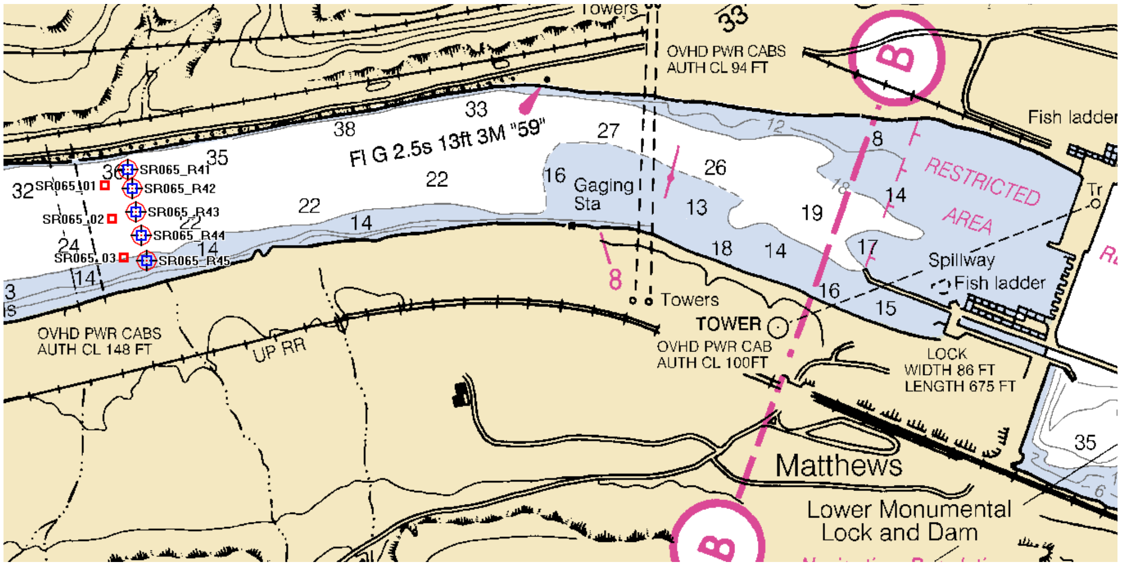


Figure 3.4. Lower Monumental Dam tailrace fish release locations (red circle with blue square). Release position 1 is near the north shore and release position number 5 is near the south shore.

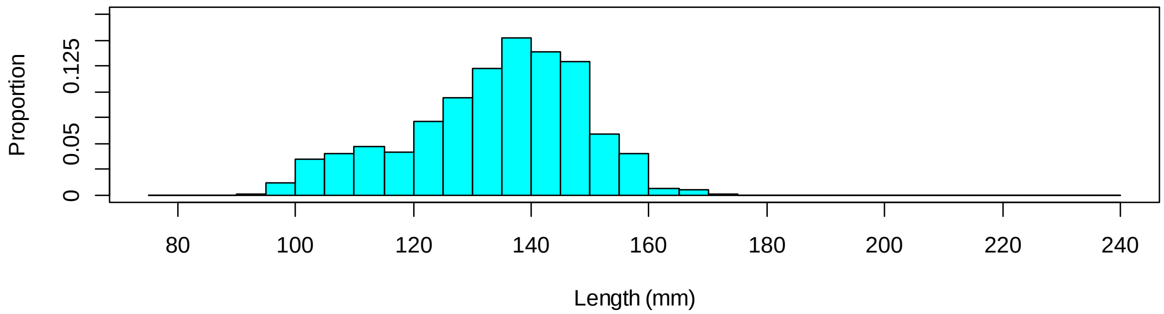
3.4.5 Examination of Time In-River on Survivals of Different Release Groups

The virtual release formed from the detections of different upriver releases at the face of the dam could result in biased survival estimates if fish from the various upriver release locations had differential downriver survival rates. For this reason, reach survivals and cumulative survivals were compared across fish from the different upriver release locations (i.e., rkm 133, 112, 82). There was no consistent or reproducible evidence to suggest that the amount of time (i.e., distance) in-river had a subsequent effect on downriver smolt survival for yearling Chinook salmon, steelhead, or subyearling Chinook salmon (Appendix B). Therefore, in constructing the virtual releases at the face of the dam, fish from all available upriver release locations were used in subsequent survival and other parameter estimation.

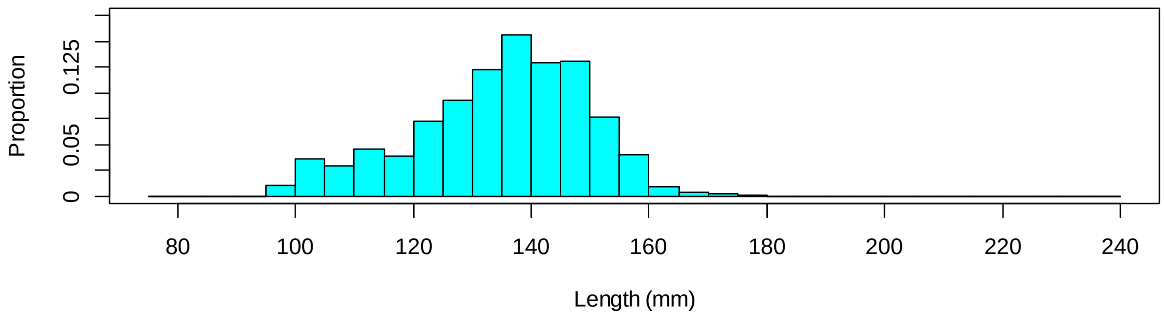
3.4.6 Fish Size Distributions

Comparison of JSATS-tagged fish with ROR fish sampled at Lower Monumental Dam by the SMP shows that the length frequency distributions were reasonably well matched for yearling Chinook salmon (Figure 3.5). Examination of length frequency histograms indicates there was a higher frequency of smaller steelhead in the ROR sample than those tagged (Figure 3.6). The subyearling Chinook salmon ROR and JSATS tagged fish were well matched (Figure 3.7). The discrepancy between fish lengths for JSATS and SMP-sampled steelhead is due in large part to the way fish are sampled at the juvenile collection facility at Lower Monumental Dam. Appendix C describes how the operation of the facility results in the collection of fish size data for yearling Chinook salmon and steelhead smolts that is not representative of the run at large.

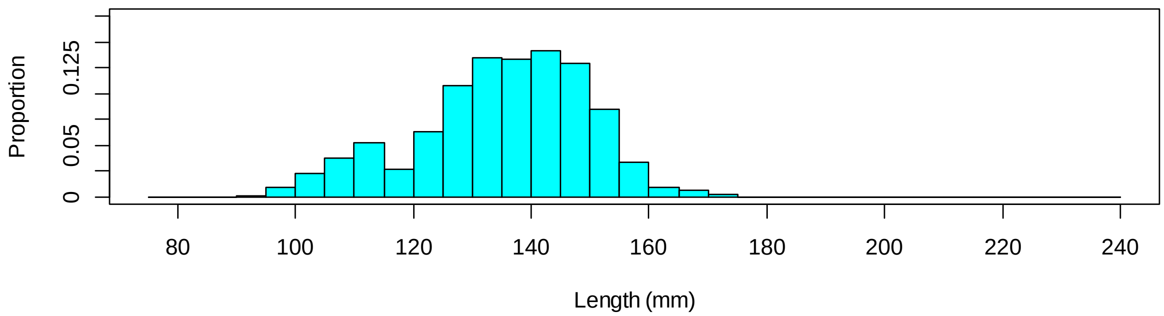
a. Lower Monumental Dam (Release V_1)



b. Lower Monumental tailrace (Release R_2)



c. Mid-reservoir (Release R_3)



d. ROR yearling Chinook salmon at Lower Monumental Dam

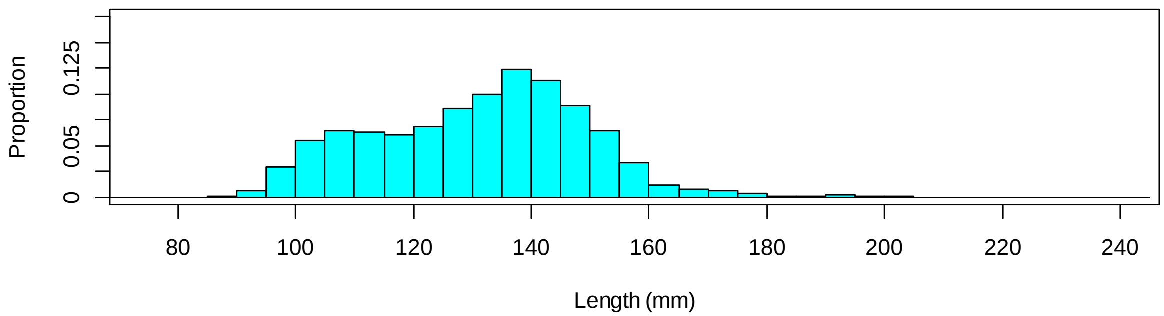
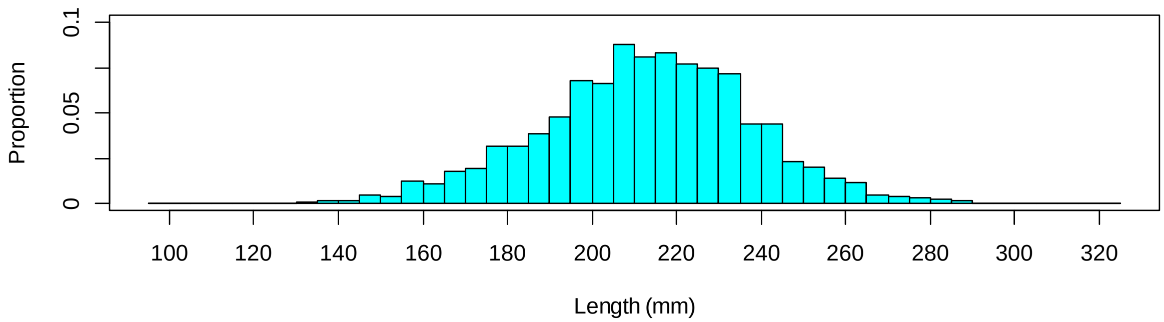
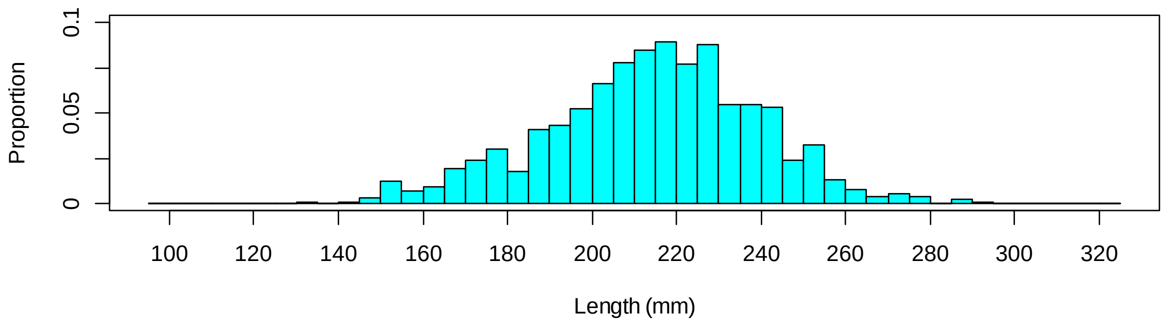


Figure 3.5. Frequency distributions for fish lengths (5-mm bins) of yearling Chinook salmon smolts used in a) release V_1, b) release R_2, c) release R_3, and d) ROR fish sampled at Lower Monumental Dam by the Smolt Monitoring Program.

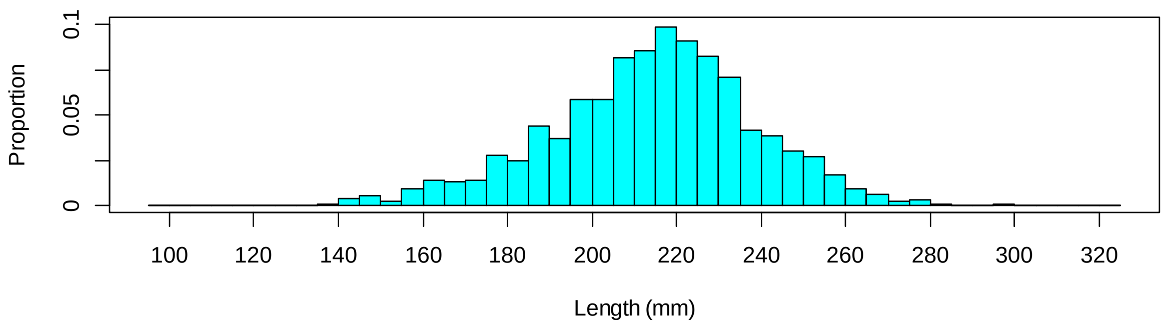
a. Lower Monumental Dam (Release V_1)



b. Lower Monumental tailrace (Release R_2)



c. Mid-reservoir (Release R_3)



d. ROR steelhead at Lower Monumental Dam

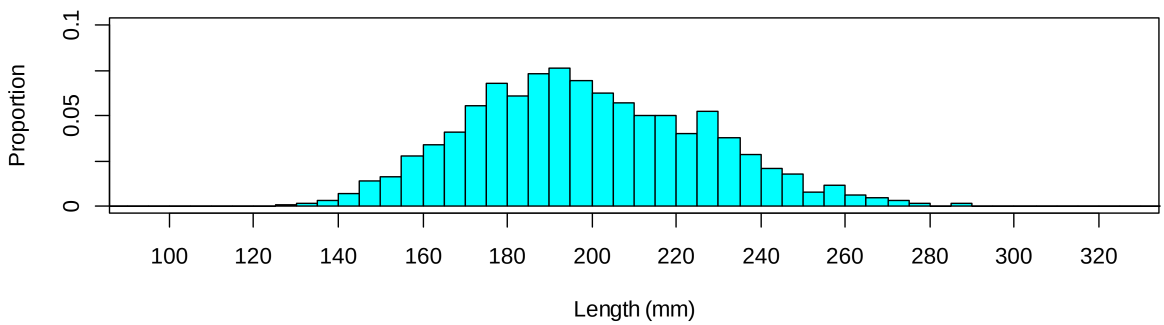


Figure 3.6. Frequency distributions for fish lengths (mm) of steelhead smolts used in a) release V_1, b) release R_2, c) release R_3, and d) ROR fish sampled at Lower Monumental Dam by the Smolt Monitoring Program.

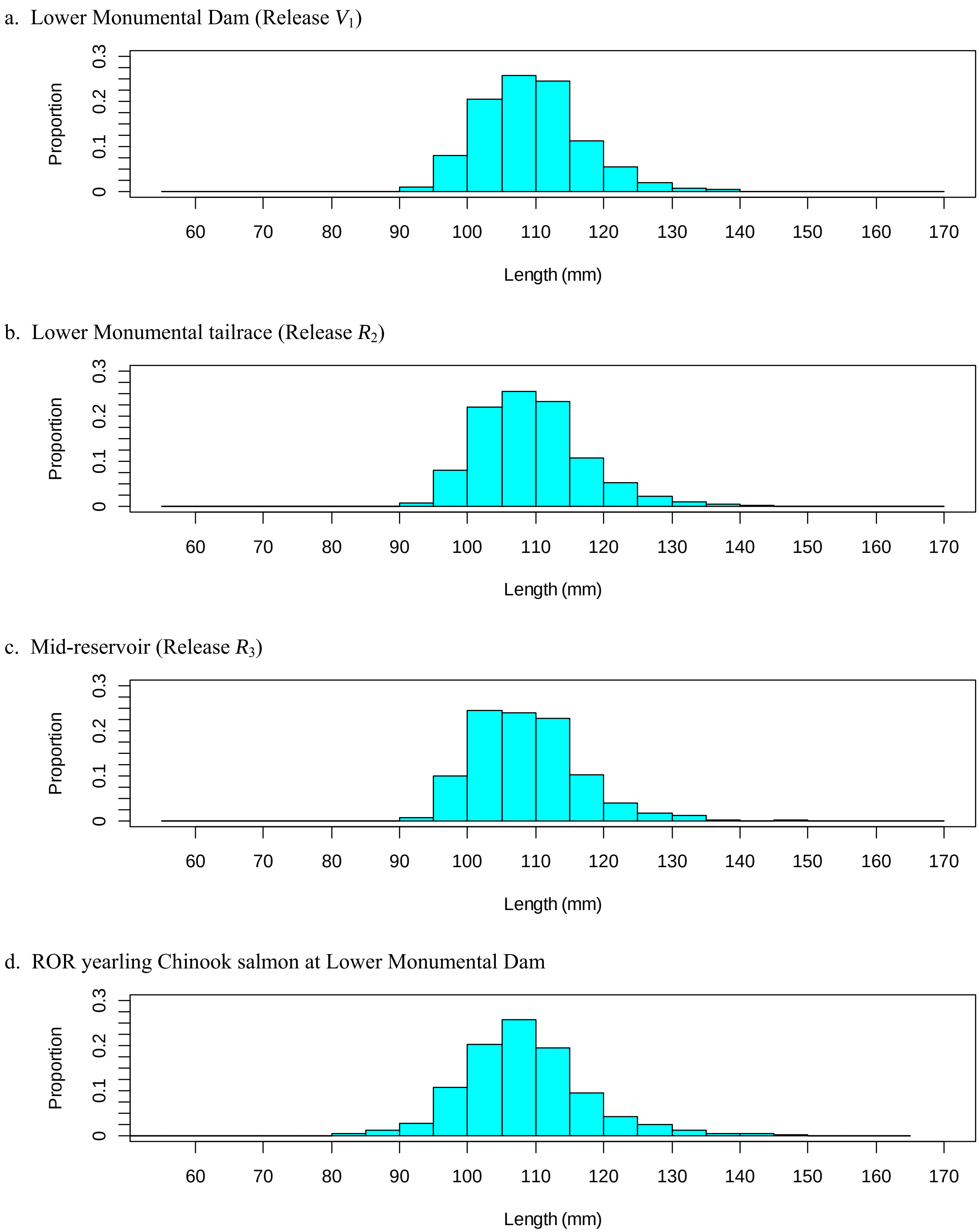
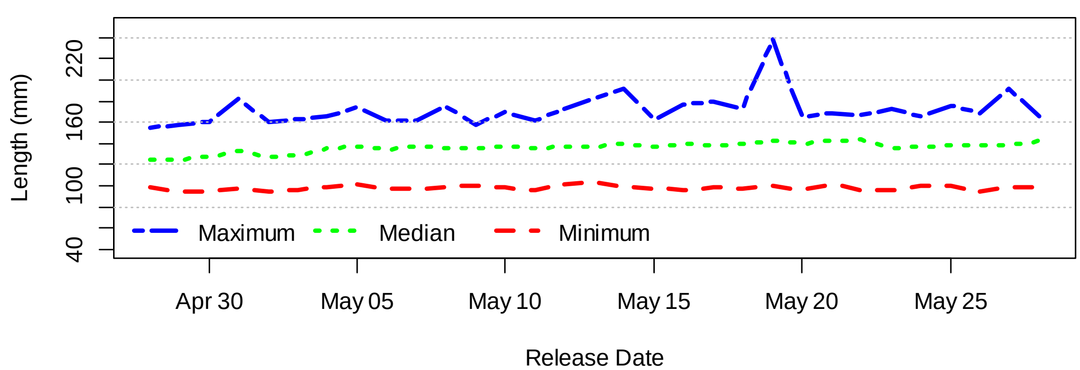


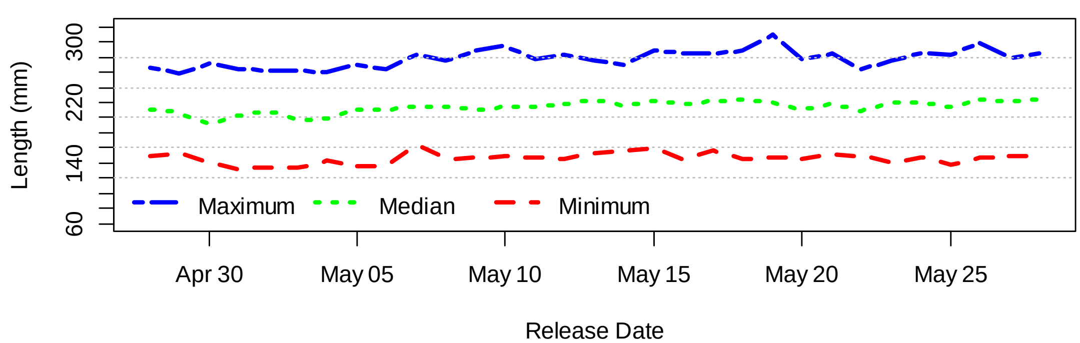
Figure 3.7. Frequency distributions for fish lengths (mm) of subyearling Chinook salmon smolts used in a) release V_1, b) release R_2, c) release R_3, and d) ROR fish sampled at Lower Monumental Dam by the Smolt Monitoring Program.

The length distributions for the three yearling Chinook salmon release locations (Figure 3.5), the three steelhead release locations (Figure 3.6), and the three subyearling Chinook salmon release locations (Figure 3.7) were similar. Mean lengths for the acoustic-tagged yearling Chinook salmon were 134.9 mm; for the steelhead, 213.7 mm; and for the subyearling Chinook salmon, 110.0 mm. Mean lengths for yearling Chinook salmon, steelhead, and subyearling Chinook salmon sampled by the FPC at the Lower Monumental Dam juvenile sampling facility were 129.5 mm, 203.2 mm, and 119.8 mm, respectively. Mean fish size increased slightly over the course of the study for yearling Chinook salmon and steelhead but not subyearling Chinook salmon (Figure 3.8).

a. Yearling Chinook salmon smolts



b. Steelhead smolts



c. Subyearling Chinook salmon smolts

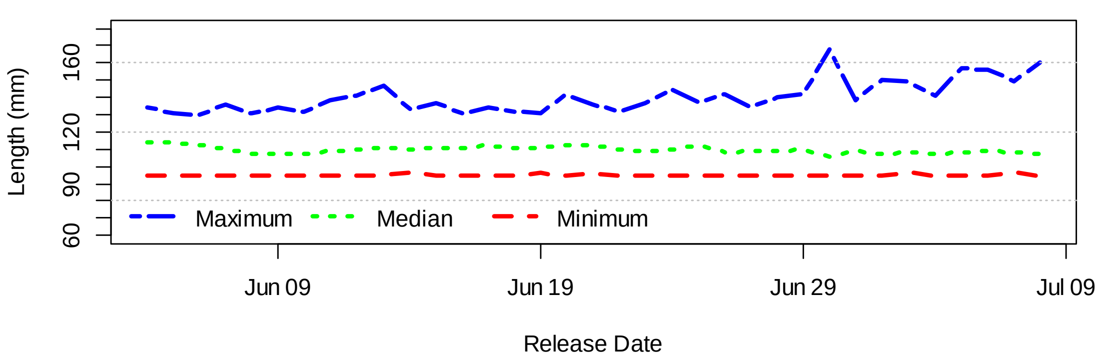


Figure 3.8. Range and median lengths of acoustic-tagged a) yearling Chinook salmon, b) steelhead, and c) subyearling Chinook salmon used in the 2012 survival studies. Releases were made daily from 30 April through 28 May and 6 June through 8 July 2012.

3.4.7 Tag-Life Corrections

During the 2012 spring study, one tag lot was used in tagging both the yearling Chinook salmon and steelhead smolts. A different tag lot was used for the summer study of subyearling Chinook salmon. 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 d for the spring and summer tag lots, respectively.

(a) Spring (b) Summer

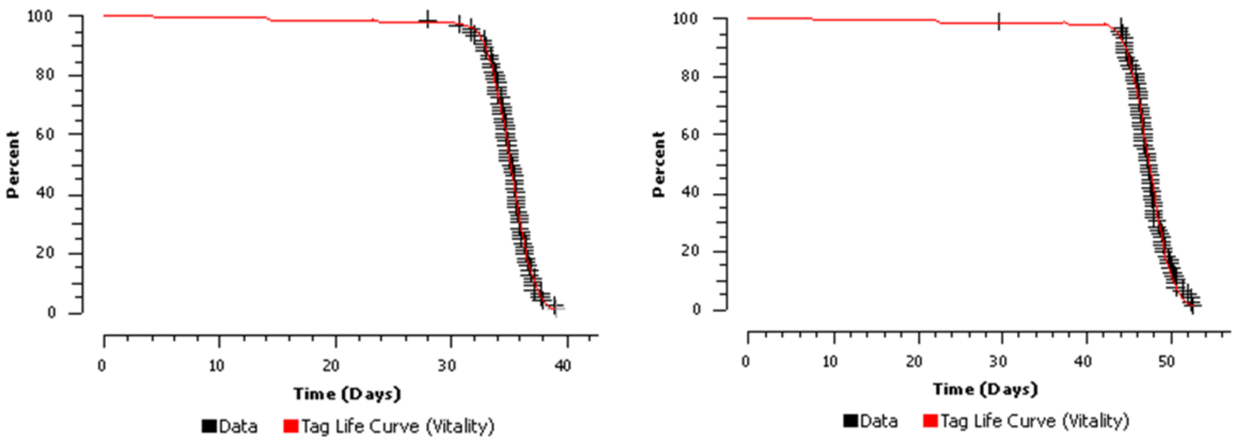


Figure 3.9. Observed time of tag failure (+) and fitted survivorship curves using the vitality model of Li and Anderson (2009) for the a) spring and b) summer tag lots.

3.4.8 Arrival Distributions

The estimated probability that an acoustic tag was active when fish arrived at a downstream detection array depends on the tag-life curve and the distribution of observed travel times for yearling Chinook salmon (Figure 3.10), steelhead (Figure 3.11), and subyearling Chinook salmon (Figure 3.12). Examination of the fish arrival distributions to the last detection array used in the survival analyses indicated all fish had passed through the study area before tag failure became important. The probabilities of a tag being active 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 3.3). In all cases, the probability that a tag was active at a downstream detection site as far as rkm 3 was >0.9977 for yearling Chinook salmon smolts; >0.9973 for steelhead smolts; and, >0.9983 (Table 3.4) for subyearling Chinook salmon.

3.4.9 Downstream Mixing

To help induce downstream mixing of the release groups, the R_2 release occurred 12 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 R_2 and R_3 were nearly synchronous for yearling Chinook salmon and steelhead smolts. For subyearling Chinook salmon, the R_2 released fish arrived a few hours earlier than the R_3 on average (Figure 3.15).

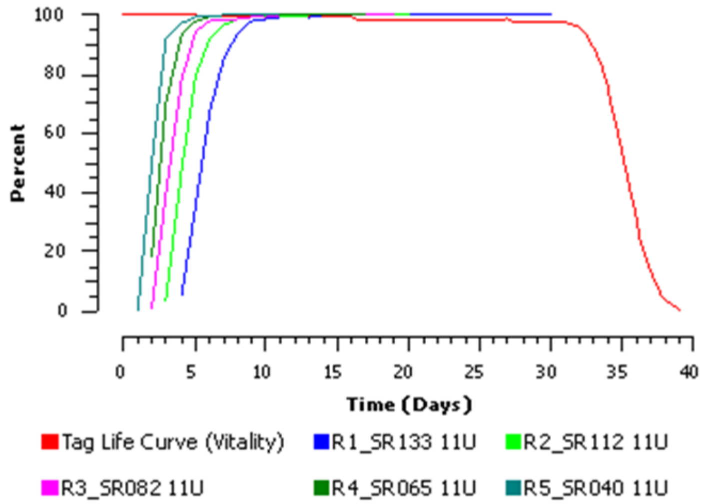


Figure 3.10. Plot of the fitted tag-life survivorship curve and the arrival-time distributions of yearling Chinook salmon smolts for releases V_1, R_2, and R_3 at the acoustic-detection array located at rkm 3 from the Snake River confluence (Figure 2.1). For the purposes of the LMN study, releases between rkm 133 and 82 contributed to the virtual release (V_1), and the releases at rkm 65 and 40 were considered the R_2, and R_3 releases, respectively.

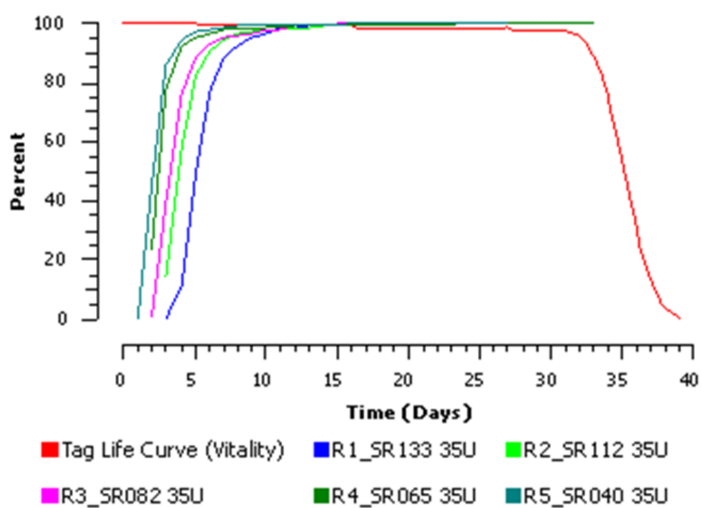


Figure 3.11. Plot of the fitted tag-life survivorship curve and the arrival-time distributions of steelhead smolts for releases V_1, R_2, and R_3 at the acoustic-detection array located at rkm 3 from the Snake River confluence (Figure 2.1). For the purposes of the LMN study, releases between rkm 133 and 82 contributed to the virtual release (V_1), and the releases at rkm 65 and 40 were considered the R_2, and R_3 releases, respectively.

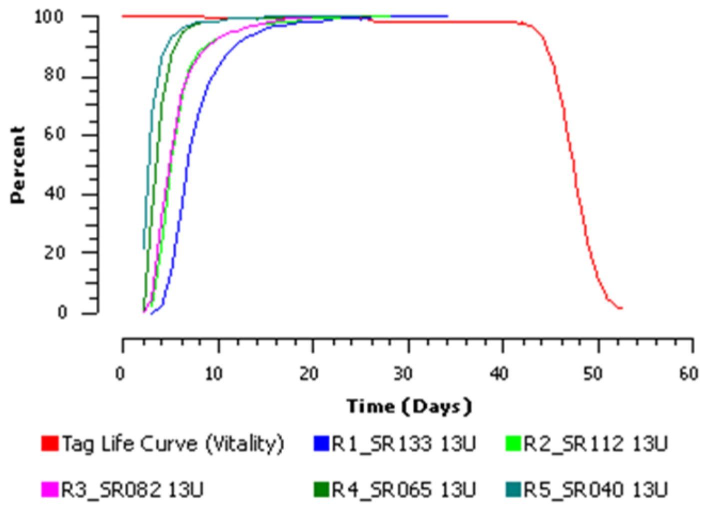


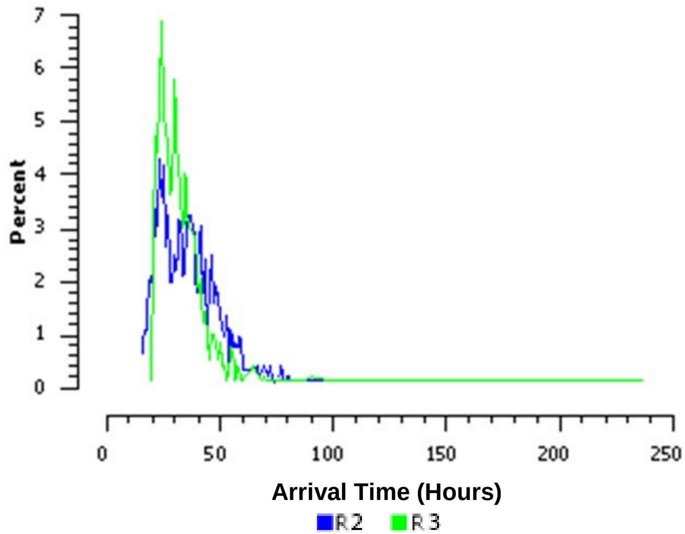
Figure 3.12. Plot of the fitted tag-life survivorship curve and the arrival-time distributions of subyearling Chinook salmon smolts for releases V_1, R_2, and R_3 at the acoustic-detection array located at rkm 3 from the Snake River confluence (Figure 2.1). For the purposes of the LMN study, releases between rkm 133 and 82 contributed to the virtual release (V_1), and the releases at rkm 65 and 40 were considered the R_2, and R_3 releases, respectively.

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

	Detection Site		
Release Group	rkm 40	rkm 17	rkm 3
a. Yearling Chinook Salmon			
V_1 (rkm 133)[(a)]	0.9996 (0.000176)	0.9991 (0.000348)	0.9989 (0.000424)
V_1 (rkm 112)[(a)]	0.9995 (0.000188)	0.9991 (0.000367)	0.9989 (0.000442)
V_1 (rkm 82)[(a)]	0.9995 (0.000208)	0.9990 (0.000396)	0.9988 (0.000479)
R_2 (rkm 65)	--	0.9979 (0.000849)	0.9977 (0.000934)
R_3 (rkm 40)	--	0.9983 (0.000685)	0.9981 (0.000780)
b. Steelhead			
V_1 (rkm 133)[(a)]	0.9996 (0.000164)	0.9991 (0.000335)	0.9988 (0.000432)
V_1 (rkm 112)[(a)]	0.9995 (0.000170)	0.9991 (0.000348)	0.9987 (0.000465)
V_1 (rkm 82)[(a)]	0.9995 (0.000183)	0.9990 (0.000362)	0.9987 (0.000469)
R_2 (rkm 65)	--	0.9979 (0.000760)	0.9973 (0.000888)
R_3 (rkm 40)	--	0.9982 (0.000674)	0.9979 (0.000790)
c. Subyearling Chinook Salmon			
V_1 (rkm 133)[(a)]	0.9977 (0.000296)	0.9995 (0.000060)	0.9990 (0.000125)
V_1 (rkm 112)[(a)]	0.9984 (0.000200)	0.9995 (0.000059)	0.9991 (0.000122)
V_1 (rkm 82)[(a)]	0.9987 (0.000173)	0.9995 (0.000067)	0.9989 (0.000137)
R_2 (rkm 65)	--	--	0.9983 (0.000221)
R_3 (rkm 40)	--	--	0.9986 (0.000177)

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

a. rkm 17



b. rkm 3

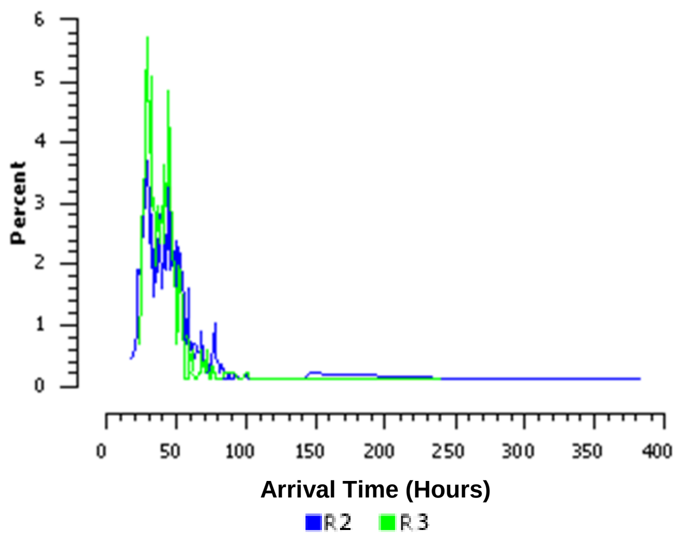
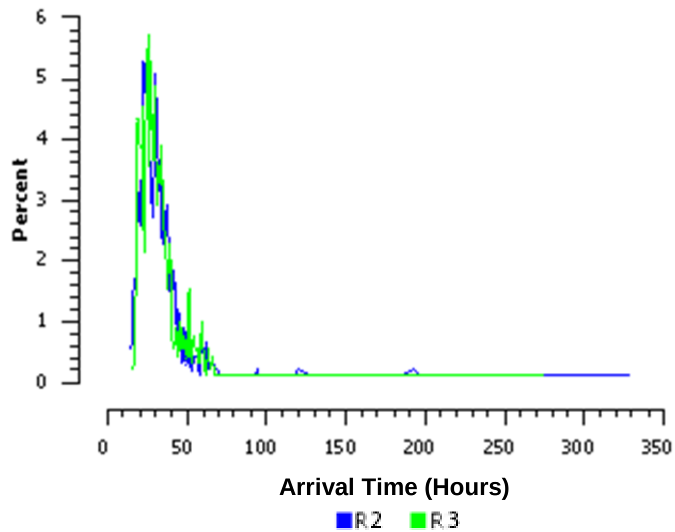


Figure 3.13. Frequency distribution plots of downstream arrival timing (expressed as percentages) for yearling Chinook salmon releases R_2 and R_3 at detection arrays located at a) rkm 17 and b) rkm 3 (see Figure 2.1) during the period from 30 April to 28 May 2012. All times adjusted relative to the release time of R_2.

a. rkm 17



b. rkm 3

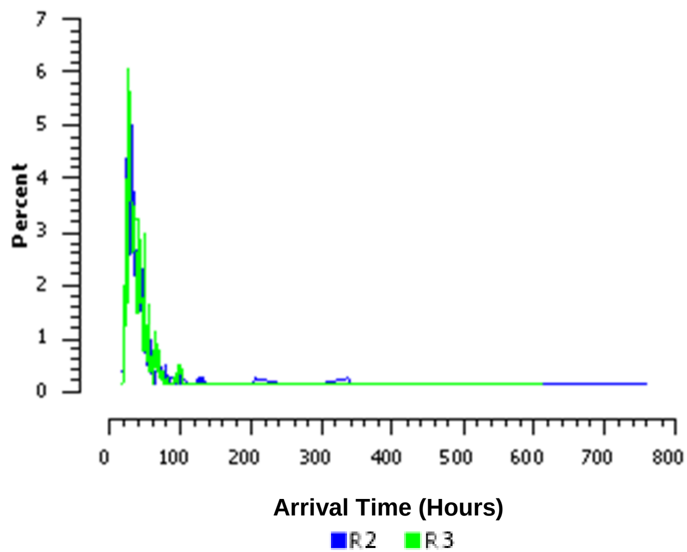
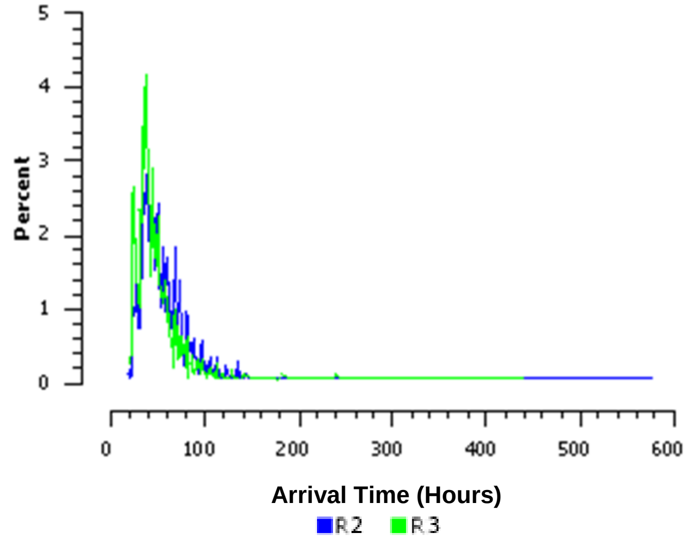


Figure 3.14. Frequency distribution plots of downstream arrival timing (expressed as percentages) for steelhead salmon releases R_2 and R_3 at detection arrays located at a) rkm 17 and b) rkm 3 (see Figure 2.1) during the period from 30 April to 28 May 2012. All times adjusted relative to the release time of R_2.

a. rkm 17



b. rkm 3

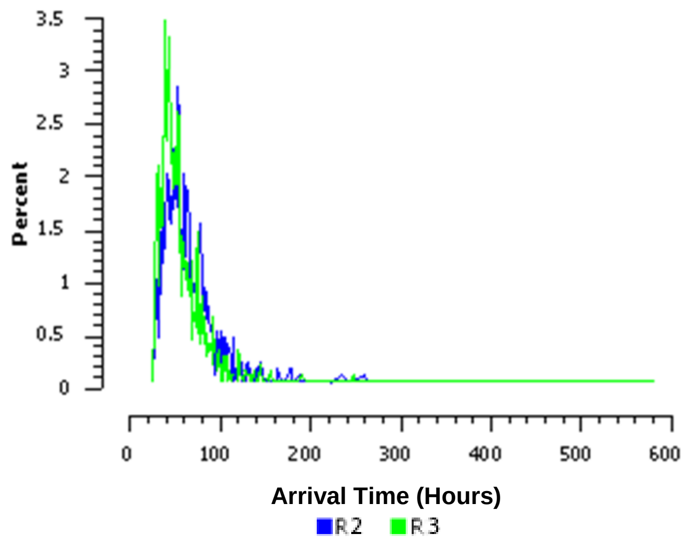


Figure 3.15. Frequency distribution plots of downstream arrival timing (expressed as percentages) for subyearling Chinook salmon releases R_2 and R_3 at detection arrays located at a) rkm 17 and b) rkm 3 (see Figure 2.1) during the period from 6 June to 8 July 2012. All times adjusted relative to the release time of R_2.

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 Lower Monumental Dam were calculated over three different periods of time. One period was from the beginning of the study on 24 April through 9 May 2012, when spill generally exceeded the 20- to 29-kcfs spill target. The second time period was 10 May 2012 through the end of the spring study, when spill volume was near the target. The final survival estimate was calculated for the entire spring study.

For the early part of the spring study, when spill volume was above the 20- to 29-kcfs target, dam passage survival was estimated to be

$$\hat{S}_{\text{Dam}} = \frac{0.9686}{\left(\frac{0.9588}{0.9594}\right)} = \frac{0.9686}{0.9994} = 0.9692 \tag{3.1}$$

with a standard error of $\widehat{\text{SE}} = 0.0175$ (Table 3.5). The estimate is based on a fully parameterized likelihood model. For the second half of the spring study, when spill volume was close to the 20- to 29-kcfs target, dam passage survival was estimated to be

$$\hat{S}_{\text{Dam}} = \frac{0.9719}{\left(\frac{0.9576}{0.9793}\right)} = \frac{0.9719}{0.9778} = 0.9939 \tag{3.2}$$

with a standard error of $\widehat{\text{SE}} = 0.0105$ (Table 3.6).

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

$$\hat{S}_{\text{Dam}} = \frac{0.9709}{\left(\frac{0.9580}{0.9737}\right)} = \frac{0.9709}{0.9839} = 0.9868 \tag{3.3}$$

with a standard error of $\widehat{\text{SE}} = 0.0090$ (Table 3.7). It should be noted the virtual release (i.e., V_1), uncorrected for below dam survival, was also in excess of 96%. The single-release estimate of survival for V_1 includes survival in 25 km of Ice Harbor reservoir with an estimated standard error of $\widehat{\text{SE}} = 0.0027$.

Table 3.5. Survival, detection, and λ parameters for final model used to estimate dam passage survival for yearling Chinook salmon during the early part of the spring study (i.e., ≤9 May 2012). 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 (*).

	SR67 to 40		SR40 to 17		Release to 17	
Release	$\hat{S}$	$\widehat{\mathrm{SE}}^{\dagger}$	$\hat{S}$	$\widehat{\mathrm{SE}}^{*}$	$\hat{S}$	$\widehat{\mathrm{SE}}^{\dagger}$
R_1	0.9686	0.005087	0.9893	0.003103	---	---
R_2	---	---	---	---	0.9588	0.011446
R_3	---	---	---	---	0.9594	0.012035

	SR40		SR17	
Release	$\hat{p}$	$\widehat{\mathrm{SE}}^{*}$	$\hat{p}$	$\widehat{\mathrm{SE}}^{*}$
R_1	1.0000	<0.0001	1.0000	<0.0001
R_2	---	---	1.0000	<0.0001
R_3	---	---	1.0000	<0.0001

	SR3	
Release	$\hat{\lambda}$	$\widehat{\mathrm{SE}}^{*}$
R_1	0.9529	0.006277
R_2	0.9645	0.010576
R_3	0.9485	0.013448

Table 3.6. Survival, detection, and λ parameters for final model used to estimate dam passage survival for yearling Chinook salmon during the later part of the spring study (i.e., ≥10 May 2012). 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 (*).

	SR67 to 40		SR40 to 17		Release to 17	
Release	$\hat{S}$	$\widehat{\mathrm{SE}}^{\dagger}$	$\hat{S}$	$\widehat{\mathrm{SE}}^{*}$	$\hat{S}$	$\widehat{\mathrm{SE}}^{\dagger}$
R_1	0.9719	0.003169	0.9826	0.002554	---	---
R_2	---	---	---	---	0.9576	0.007947
R_3	---	---	---	---	0.9793	0.005549

	SR40		SR17	
Release	$\hat{p}$	$\widehat{\mathrm{SE}}^{*}$	$\hat{p}$	$\widehat{\mathrm{SE}}^{*}$
R_1	1.0000	<0.0001	1.0000	<0.0001
R_2	---	---	1.0000	<0.0001
R_3	---	---	1.0000	<0.0001

	SR3	
Release	$\hat{\lambda}$	$\widehat{\mathrm{SE}}^{*}$
R_1	0.9411	0.004588
R_2	0.9246	0.010388
R_3	0.9333	0.009436

Table 3.7. Survival, detection, and λ parameters for final model used to estimate dam passage survival for yearling Chinook salmon during the season-wide spring study (30 April–28 May 2012). 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 (*).

	SR67 to 40		SR40 to 17		Release to 17	
Release	$\hat{S}$	$\widehat{\mathrm{SE}}^{\dagger}$	$\hat{S}$	$\widehat{\mathrm{SE}}^{*}$	$\hat{S}$	$\widehat{\mathrm{SE}}^{\dagger}$
R_1	0.9709	0.002695	0.9846	0.002015	---	---
R_2	---	---	---	---	0.9580	0.006549
R_3	---	---	---	---	0.9737	0.005262

	SR40		SR17	
Release	$\hat{p}$	$\widehat{\mathrm{SE}}^{*}$	$\hat{p}$	$\widehat{\mathrm{SE}}^{*}$
R_1	1.0000	<0.0001	1.0000	<0.0001
R_2	---	---	1.0000	<0.0001
R_3	---	---	1.0000	<0.0001

	SR3	
Release	$\hat{\lambda}$	$\widehat{\mathrm{SE}}^{*}$
R_1	0.9447	0.003723
R_2	0.9374	0.007846
R_3	0.9375	0.007773

3.5.1.2 Steelhead

For the early part of the spring study (i.e., ≤9 May 2012), dam passage survival for steelhead was estimated to be over 100%, when corrected for below dam survival, i.e.,

$$\hat{S}_{\mathrm{Dam}} = \frac{0.9802}{\left(\frac{0.9430}{0.9669}\right)} = \frac{0.9808}{0.9753} = 1.0050 \tag{3.4}$$

with a standard error of $\widehat{\mathrm{SE}} = 0.01852$ (Table 3.8). A more conservative estimate would be to use just the virtual release (V_1), which estimated survival from the dam face to rkm 40 (i.e., including 25 km of Ice Harbor reservoir) of 0.9802 ($\widehat{\mathrm{SE}} = 0.0040$).

For the late part of the spring study (i.e., ≥10 May 2012), dam passage survival is estimated to be

$$\hat{S}_{\mathrm{Dam}} = \frac{0.9838}{\left(\frac{0.9267}{0.9176}\right)} = \frac{0.9838}{1.0099} = 0.9741 \tag{3.5}$$

with a standard error estimate of $\widehat{\text{SE}} = 0.0155$ (Table 3.9). In this case, the data from the paired release result in an unrealistic survival estimate of 1.0099 in the 25 km below Lower Monumental Dam. Using just the virtual release again, a conservative and recommended estimate of dam passage survival would be 0.9838 ($\widehat{\text{SE}} = 0.0025$).

The season-wide spring estimate of dam passage survival for steelhead smolts is estimated using the virtual-paired-release model to be

$$\hat{S}_{\text{Dam}} = \frac{0.9826}{\left(\frac{0.9319}{0.9317}\right)} = \frac{0.9826}{1.0002} = 0.9824 \tag{3.6}$$

with a standard error of $\widehat{\text{SE}} = 0.0122$) (Table 3.10). Again, because the paired release is estimating an unrealistic survival value of 1.0002 in the 25 km below Lower Monumental Dam, the conservative estimate of survival for the virtual release is recommended, $\hat{S}_{\text{Dam}} = 0.9826$ ($\widehat{\text{SE}} = 0.0021$).

Table 3.8. Survival, detection, and λ parameters for final model used to estimate dam passage survival for steelhead during the early part of the spring study (i.e., ≤ 9 May 2012). 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 (*).

	SR67 to 40		SR40 to 17		Release to 17	
Release	$\hat{S}$	$\widehat{\text{SE}}^{\dagger}$	$\hat{S}$	$\widehat{\text{SE}}^{*}$	$\hat{S}$	$\widehat{\text{SE}}^{\dagger}$
R_1	0.9802	0.004035	0.9781	0.004269	---	---
R_2	---	---	---	---	0.9430	0.013245
R_3	---	---	---	---	0.9669	0.010918

	SR40		SR17	
Release	$\hat{p}$	$\widehat{\text{SE}}^{*}$	$\hat{p}$	$\widehat{\text{SE}}^{*}$
R_1	1.0000	<0.0001	1.0000	<0.0001
R_2	---	---	1.0000	<0.0001
R_3	---	---	1.0000	<0.0001

	SR3	
Release	$\hat{\lambda}$	$\widehat{\text{SE}}^{*}$
R_1	0.9085	0.008417
R_2	0.9315	0.014654
R_3	0.8952	0.018463

Table 3.9. Survival, detection, and λ parameters for final model used to estimate dam passage survival for steelhead during the later part of the spring study (i.e., ≥10 May 2012). 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 (*).

	SR67 to 40		SR40 to 17		Release to 17	
Release	$\hat{S}$	$\widehat{SE}^{\dagger}$	$\hat{S}$	$\widehat{SE}^{*}$	$\hat{S}$	$\widehat{SE}^{\dagger}$
R_1	0.9838	0.0025	0.9503	0.0042	---	---
R_2	---	---	---	---	0.9267	0.0102
R_3	---	---	---	---	0.9176	0.0104

	SR40		SR17	
Release	$\hat{p}$	$\widehat{SE}^{*}$	$\hat{p}$	$\widehat{SE}^{*}$
R_1	1.0000	<0.0001	1.0000	<0.0001
R_2	---	---	1.0000	<0.0001
R_3	---	---	1.0000	<0.0001

	SR3	
Release	$\hat{\lambda}$	$\widehat{SE}^{*}$
R_1	0.8506	0.0071
R_2	0.8617	0.0138
R_3	0.8609	0.0136

Table 3.10. Survival, detection, and λ parameters for final model used to estimate dam passage survival for steelhead during the spring study (30 April–28 May 2012). 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 (*).

	SR67 to 40		SR40 to 17		Release to 17	
Release	$\hat{S}$	$\widehat{SE}^{\dagger}$	$\hat{S}$	$\widehat{SE}^{*}$	$\hat{S}$	$\widehat{SE}^{\dagger}$
R_1	0.9826	0.002139	0.9590	0.003212	---	---
R_2	---	---	---	---	0.9319	0.008219
R_3	---	---	---	---	0.9317	0.008187

	SR40		SR17	
Release	$\hat{p}$	$\widehat{SE}^{*}$	$\hat{p}$	$\widehat{SE}^{*}$
R_1	1.0000	<0.0001	1.0000	<0.0001
R_2	---	---	1.0000	<0.0001
R_3	---	---	1.0000	<0.0001

	SR3	
Release	$\hat{\lambda}$	$\widehat{SE}^{*}$
R_1	0.8691	0.005554
R_2	0.8844	0.010512
R_3	0.8711	0.011007

3.5.1.3 Subyearling Chinook Salmon

A single season-wide estimate of dam passage survival was calculated for subyearling Chinook salmon at Lower Monumental Dam where

$$\hat{S}_{\text{Dam}} = \frac{0.9424}{\left(\frac{0.9344}{0.9706}\right)} = \frac{0.9424}{0.9627} = 0.9789 \tag{3.7}$$

with an associated standard error of $\widehat{\text{SE}} = 0.0079$. It should be also noted the survival estimate from the virtual-release group (V_1) from the face of Lower Monumental Dam to rkm 40 (i.e., 25 km into the Ice Harbor reservoir) of $\hat{S}_1 = 0.09424$ ($\widehat{\text{SE}} = 0.0030$) also exceeds 93% (Table 3.11).

Table 3.11. Survival, detection, and λ parameters for final model used to estimate dam passage survival for subyearling Chinook salmon during the spring study (6 June–8 July 2012). 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 (*).

	SR67 to 40		SR40 to 17		Release to 17	
Release	$\hat{S}$	$\widehat{\text{SE}}^{\dagger}$	$\hat{S}$	$\widehat{\text{SE}}^{*}$	$\hat{S}$	$\widehat{\text{SE}}^{\dagger}$
R_1	0.9424	0.0030	0.9541	0.0028	---	---
R_2	---	---	---	---	0.9344	0.0058
R_3	---	---	---	---	0.9706	0.0040

	SR40		SR17	
Release	$\hat{p}$	$\widehat{\text{SE}}^{*}$	$\hat{p}$	$\widehat{\text{SE}}^{*}$
R_1	1.0000	<0.0001	1.0000	<0.0001
R_2			1.0000	<0.0001
R_3			1.0000	<0.0001

	SR3	
Release	$\hat{\lambda}$	$\widehat{\text{SE}}^{*}$
R_1	0.9639	0.0025
R_2	0.9547	0.0050
R_3	0.9597	0.0046

3.5.2 Forebay-to-Tailrace Passage Survival

The estimates of forebay-to-tailrace passage survival were calculated analogously to that of dam passage survival except the virtual-release group (V_1) was composed of fish known to have arrived at the forebay (i.e., detection array rkm 67, Figure 2.1) rather than at the dam face. These season-wide survival estimates were based on all release data across the season, regardless of spill conditions.

Using the same statistical model that was used in estimating dam passage survival, forebay-to-tailrace survival for yearling Chinook salmon was

$$\hat{S}_{\text{forebay-to-tailrace}} = 0.9859\,(0.0090) \tag{3.8}$$

for steelhead it was

$$\hat{S}_{\text{forebay-to-tailrace}} = 0.9815\,(0.0022) \tag{3.9}$$

and for subyearling Chinook salmon it was

$$\hat{S}_{\text{forebay-to-tailrace}} = 0.9721\,\left(0.0079\right). \tag{3.10}$$

3.5.3 Forebay Residence Time

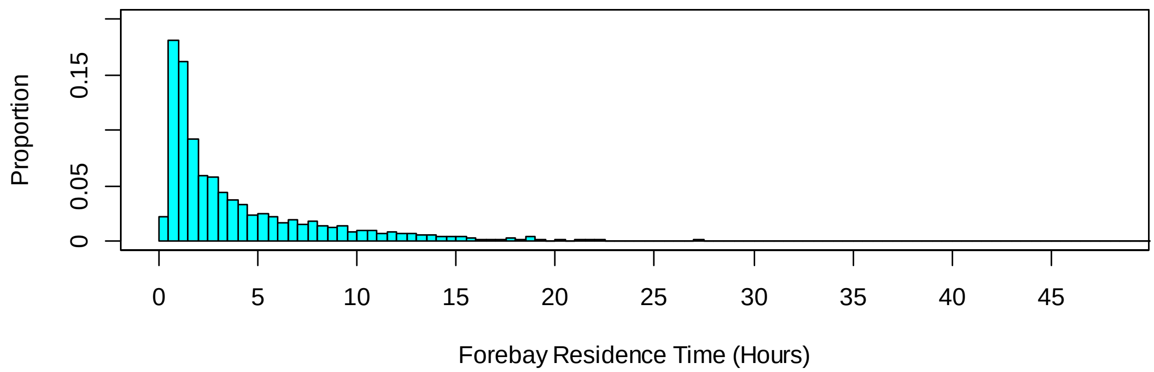
The forebay residence time was calculated from the first detection of a smolt at the forebay BRZ array to the last detection at the dam (0.8 km). For yearling Chinook salmon, the mean forebay residence time was estimated to be 4.81 h (SE = 0.15); for steelhead, it was estimated to be 5.65 h (SE = 0.16); and for subyearling Chinook salmon, it was estimated to be 14.56 h (SE = 0.58) (Table 3.12). The distribution of forebay residence times indicates the modes for forebay residence time were 1 h for yearling Chinook salmon, 1.5 h for steelhead, and 1 h for subyearling Chinook salmon (Figure 3.16). Median residence times were 2.35 h, 2.17 h, and 2.60 h for yearling Chinook salmon, steelhead, and subyearling Chinook salmon, respectively (Table 3.12).

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

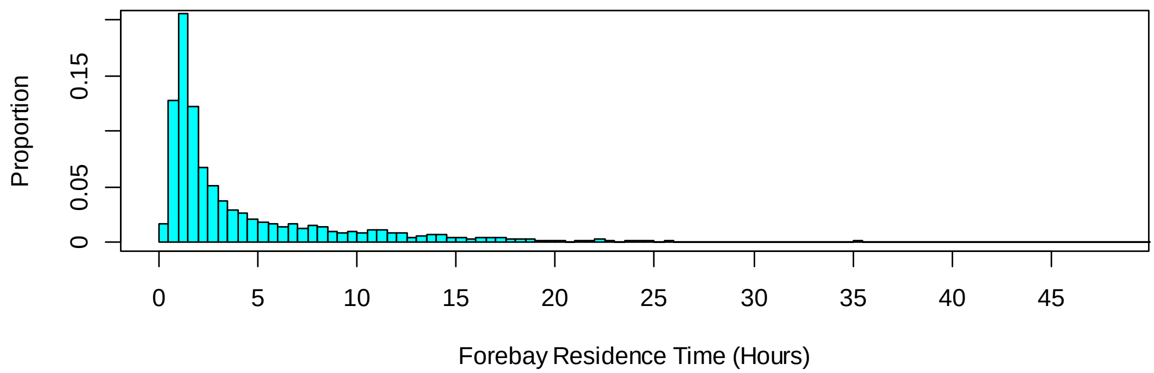
Performance Measure	Yearling Chinook Salmon	Steelhead	Subyearling Chinook Salmon
Forebay Residence Time			
Mean	4.81 (0.15)	5.65 (0.16)	14.56 (0.58)
Median	2.35	2.17	2.60
Tailrace Egress Time[(a)]			
Mean	1.57 (0.22)	6.02 (0.38)	1.28 (0.12)
Median	0.40	0.40	0.53
Tailrace Egress Time[(b)]			
Mean	0.64 (0.05)	0.73 (0.04)	0.66 (0.01)
Median	0.40	0.40	0.53

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

a. Yearling Chinook salmon



b. Steelhead



c. Subyearling Chinook salmon

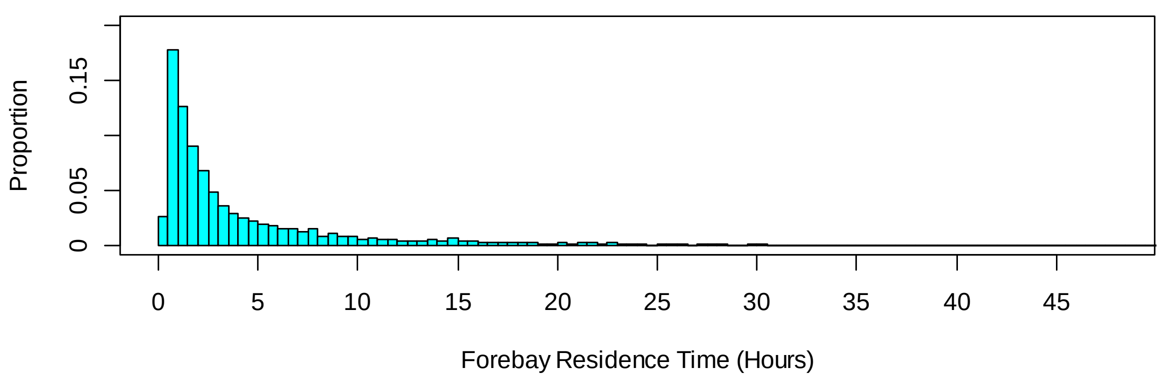


Figure 3.16. Distribution of forebay residence times (half-hour bins) for a) yearling Chinook salmon, b) steelhead, and c) subyearling Chinook salmon smolts at Lower Monumental Dam, 2012.

3.5.4 Tailrace Egress Time

The first method of calculating tailrace egress time was calculated based on the time from the last detection of fish at the double array at the face of Lower Monumental Dam to the last detection at the BRZ tailrace array (Figure 3.17). Mean tailrace egress time for yearling Chinook salmon smolts was estimated to be $\bar{t}$ = 1.57 h ($\widehat{\mathrm{SE}}$ = 0.22). For steelhead smolts, mean tailrace egress time was estimated to be $\bar{t}$ = 6.02 h ($\widehat{\mathrm{SE}}$ = 0.38). For subyearling Chinook salmon smolts, mean tailrace egress time was estimated to be $\bar{t}$ = 1.28 h ($\widehat{\mathrm{SE}}$ = 0.12). Median egress times were 0.40, 0.40, and 0.53 hours for yearling Chinook salmon, steelhead, and subyearling Chinook salmon, respectively (Table 3.12).

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 based on the time 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 0.40, 0.40, and 0.53 hours for yearling Chinook salmon, steelhead, and subyearling Chinook salmon, respectively (Table 3.12). Modes for tailrace egress time were 0.5 h each for yearling Chinook salmon, steelhead, and subyearling Chinook salmon (Figure 3.17).

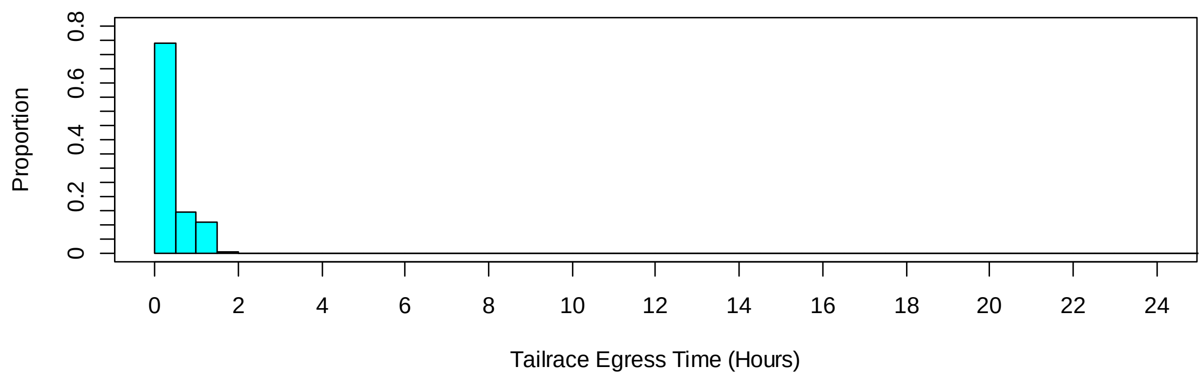
3.5.5 Spill Passage Efficiency

SPE is defined as the fraction of the fish that passed through a hydroproject by the spillway. The double-detection array at the face of Lower Monumental 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 Lower Monumental Dam were used to estimate SPE based on a binomial sampling model. For yearling Chinook salmon smolts, $\widehat{\mathrm{SPE}}$ = 0.7889 (0.0065); and for steelhead smolts, $\widehat{\mathrm{SPE}}$ = 0.6585 (0.0075); and for subyearling Chinook salmon smolts, $\widehat{\mathrm{SPE}}$ = 0.8356 (0.0048).

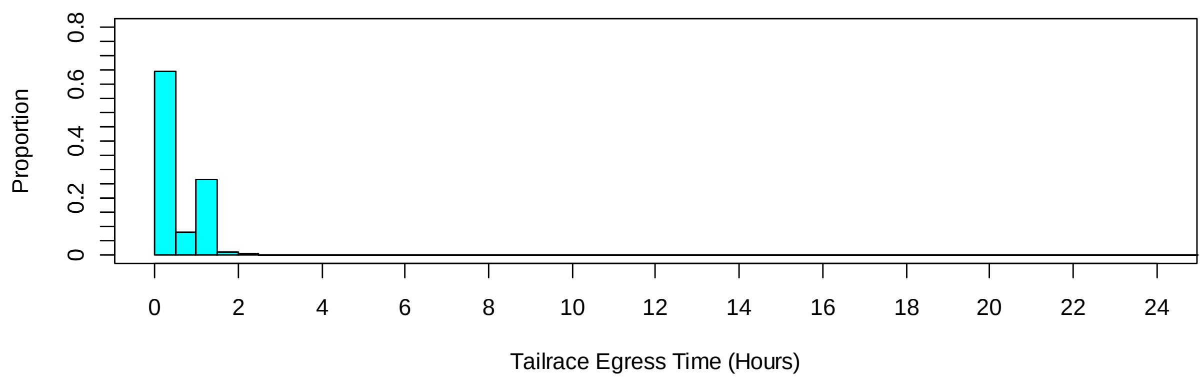
3.5.6 Fish Passage Efficiency

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 Lower Monumental 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 Lower Monumental Dam were used to estimate FPE based on a binomial sampling model. For yearling Chinook salmon smolts at Lower Monumental Dam in 2012, FPE is estimated to be $\widehat{\mathrm{FPE}}$ = 0.9484 (0.0035); for steelhead smolts, $\widehat{\mathrm{FPE}}$ = 0.9653 (0.0029); and for subyearling Chinook salmon smolts, $\widehat{\mathrm{FPE}}$ = 0.9236 (0.0034).

a. Yearling Chinook salmon



b. Steelhead



c. Subyearling Chinook salmon

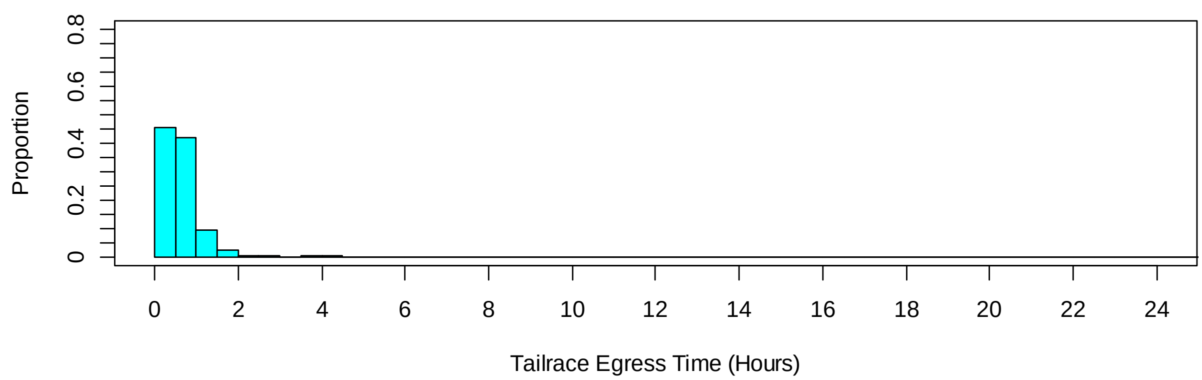


Figure 3.17. Distribution of tailrace egress times (half-hour bins) for a) yearling Chinook salmon, b) steelhead, and c) subyearling Chinook salmon smolts at Lower Monumental Dam, 2012.

3.5.7 Route-Specific Survival

The majority of acoustic-tagged yearling Chinook salmon (62%), steelhead (53%), and subyearling Chinook salmon (58%) that passed Lower Monumental Dam during the study period did so over the spillway weir (Table 3.13). Estimated survival for fish that passed Lower Monumental Dam over the spillway weir exceeded 99% for all three species/stocks. The next most commonly used route of passage was through traditional (deep) spill for yearling (17%) and subyearling (25%) Chinook salmon. About 13% of acoustic-tagged steelhead passed Lower Monumental Dam through deep spill routes in 2012. Survival of fish that passed via deep spill ranged from 95% for yearling Chinook salmon to 98% for subyearling Chinook salmon. Considering the spillway weir and traditional deep spill routes together, 79% of yearling Chinook salmon, 66% of steelhead, and 84% of subyearling Chinook salmon passed Lower Monumental Dam via the spillway, with 98% to 99% survival.

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

		Route				
	Measure	Deep Spill	Spillway Weir	(All Spill)	Turbine	JBS
Yearling Chinook	Proportion	0.1663 (0.0059)	0.6226 (0.0077)	0.7889 (0.0065)	0.0516 (0.0035)	0.1595 (0.00588)
	Survival	0.9460 (0.0130)	0.9979 (0.0091)	0.9870 (0.0091)	0.9321 (0.0213)	1.0071 (0.0096)
Steelhead	Proportion	0.1262 (0.0053)	0.5323 (0.0079)	0.6585 (0.0075)	0.0347 (0.0029)	0.3068 (0.0073)
	Survival	0.9744 (0.0071)[a]	0.9913 (0.0021)[a]	0.9881 (0.0022)[a]	0.8139 (0.0359)[a]	0.9906 (0.0029)[a]
Subyearling Chinook	Proportion	0.2517 (0.0056)	0.5839 (0.0064)	0.8365 (0.0048)	0.0764 (0.0034)	0.0880 (0.0037)
	Survival	0.9794 (0.0096)	0.9859 (0.0083)	0.9839 (0.0080)	0.8989 (0.0179)	1.0115 (0.0105)

(a) Steelhead survival estimates are single release estimates.

4.0 Discussion

This section describes the conduct of the 2012 JSATS studies at Lower Monumental Dam, study performance, and compares 2012 estimates to historical information.

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 or delayed tagging/ handling effects. The results suggest the assumptions of the virtual-paired-release model were fulfilled, permitting valid estimation of dam passage survival and related parameters. The size distribution of tagged steelhead appears to be shifted to the right (i.e., larger sizes) compared to fish sampled by the SMP at Lower Monumental Dam. However, the size comparison appears to be flawed due to an unrepresentative, size-biased sample collected by the SMP at Lower Monumental Dam because of the way fish are sorted upon arriving at the sampling room.

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 Lower Monumental Dam were conducted during relatively high river flow conditions. Spill levels generally exceeded the target spill level during the first part of the study (i.e., ≤9 May 2012) and at times ≥10 May 2012. The point estimate of survival for yearling Chinook salmon was higher in the later part of the spring study compared to the earlier part. The opposite pattern occurred for steelhead. However, survival estimates were not significantly different between early and later periods of spring for yearling Chinook salmon ($P = 0.2262$) or steelhead ($P = 0.7032$). Season-wide estimates of dam passage survival exceeded the 96% for both species (i.e., 0.9868 [0.0090]) for yearling Chinook salmon; 0.9826 [0.0021] for steelhead). Also, the mean Lower Monumental Dam project discharge (108 kcfs) was within the middle 90th percentile of the previous 70-year average spring flow record (54.9 to 154.9 kcfs).

The summer study began with spill exceeding the operational target of 25.5 kcfs through 20 June, but by midway through the subyearling Chinook salmon study, the spill target of 17 kcfs for 21 June through 8 July was generally met. The season-wide estimate of dam passage survival for subyearling Chinook salmon was in excess of 93% and had very good precision (i.e., $\hat{S}_{\text{Dam}} = 0.9789$ [$\widehat{\text{SE}} = 0.0079$]). The mean Lower Monumental Dam project discharge (78.9 kcfs) during the summer study period was within the middle 90th percentile of the previous 70-year average spring flow record (30.9 to 128.5 kcfs).

Mortality per kilometer rates of PIT-tagged fish between Lower Monumental Dam and McNary Dam were similar to those for acoustic-tagged fish between the Lower Monumental Dam tailrace and the Ice Harbor Dam forebay during the study period in 2012 (Appendix E).

4.3 Comparison to Previous Studies

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). The greatest difference between the 2012 study and those conducted previously is the study design and survival model used to estimate dam passage survival. Previous studies used the standard paired-release design, which may bias survival estimates high. In 2012, the virtual-paired-release model was used to minimize or eliminate this bias. In addition, multiple treatment conditions were evaluated during several of the previous studies (e.g., 2004 and 2009). 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 later in Table 4.3 through 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).

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

	2004[a]	2006[b]	2007[c]	2008[d]	2009[e]	2012[f]
Design	PR	PR	PR	PR	PR	VPR
Telemetry system	Radio	Radio	Radio	Radio	Radio	JSATS
Treatment	Bulk spill	Bulk spill	Bulk spill	Overall	Bulk spill	Overall
Mean discharge (kcfs)	72	139	79	99	102	107
Percent spill	38	26	27	34	27	28
SW present	No	No	No	Yes	Yes	Yes
SW percent spill	NA	NA	NA	7	7	7
FA to dam dist. (km)	0.7	0.7	0.7	0.7	0.7	0.8
TA to dam dist. (km)	0.5	0.5	0.5	0.5	0.5	2.1
R_2 to dam dist. (km)	1.3	1.3	1.3	1.3	1.3	2.1
CH1 mean FL (mm)	150	148	145	142	141	135
STH mean FL (mm)	NA	220	219	207	211	214

(a) Hockersmith et al. (2005).
(b) Hockersmith et al. (2008a).
(c) Hockersmith et al. (2008b).
(d) Hockersmith et al. (2010a).
(e) Hockersmith et al. (2010b).
(f) This study.
PR = paired release; VPR = virtual-paired-release; SW = spillway weir; FA = forebay array; TA = tailrace array; R_2 = paired tailrace release; CH1 = yearling Chinook salmon; STH = juvenile steelhead; FL = fork length; NR = not reported; NA = not applicable.

Dam passage survival is the estimated survival from the immediate dam face to the tailrace release location (termed R_2 in this study). The tailrace release location was 1.3 km downstream of Lower Monumental Dam during previous studies conducted to estimate dam passage survival (Hockersmith et al. 2005, 2008a, 2008b, 2010a, 2010b; Absolon et al. 2007, 2008a, 2008b, 2010; Dumdei et al. 2010). However, recent modeling indicated the hydraulic extent of Lower Monumental Dam was located 2.1 km downstream from the dam (Rakowski et al. 2010). Therefore, this location was used as the R_2 tailrace release location in 2012. Thus, dam passage survival estimates from previous studies included only the first 1.3 km of the tailrace, whereas estimates from 2012 included the entire 2.1-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 also differed between the 2012 study and previous studies. The forebay array was located 0.68 km upstream of Lower Monumental Dam during previous studies and was placed 0.78 km upstream of Lower Monumental Dam during 2012 to match the upstream hydraulic extent (Rakowski et al. 2010). Therefore, forebay-to-tailrace survival was estimated over a longer reach in 2012 compared to previous studies.

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

	2005[a]	2006[b]	2007[c]	2008[d]	2009[e]	2012[f]
Design	PR	PR	PR	PR	PR	VPR
Telemetry system	Radio	Radio	Radio	Radio	Radio	JSATS
Treatment	Bulk spill	Bulk spill	Bulk spill	Bulk spill	Bulk spill	Overall
Mean discharge (kcfs)	37	51	38	106	87	78
Percent spill	59	32	50	24	22	33
SW present?	No	No	No	Yes	Yes	Yes
SW percent spill	NA	NA	NA	NR	NR	9
FA to dam dist. (km)	0.7	0.7	0.7	0.7	0.7	0.8
TA to dam dist. (km)	0.5	0.5	0.5	0.5	0.5	2.1
R_2 to dam dist. (km)	1.3	1.3	1.3	1.3	1.3	2.1
CH0 mean FL (mm)	116	118	116	108	113	110

(a) Absolon et al. (2007).
(b) Absolon et al. (2008a).
(c) Absolon et al. (2008b).
(d) Absolon et al. (2010).
(e) Dumdei et al. (2010).
(f) This study.
PR = paired release; VPR = virtual-paired-release; SW = spillway weir; FA = forebay array; TA = tailrace array; R_2 = paired tailrace release; CH0 = subyearling Chinook salmon; FL = fork length; NR = not reported; NA = not applicable.

On average, estimated dam passage and forebay-to-tailrace survival has been higher for yearling Chinook salmon, juvenile steelhead, and subyearling Chinook salmon after installation of the spillway weir at Lower Monumental Dam during the winter of 2007/2008 (Table 4.3). Estimated yearling Chinook salmon dam passage and forebay-to-tailrace survival has increased each study year from 2006 to 2012. During this same time period steelhead survival has been characterized by relatively high survival and precision. The highest estimated dam passage survival was observed in 2012 for subyearling Chinook salmon.

The JBS outfall downstream of Lower Monumental Dam was relocated about 650 m downstream from its previous location in the tailrace prior to the 2012 migration season in an effort to reduce avian and piscivorous predation on bypassed individuals. A relatively high percentage of acoustic-tagged steelhead passed Lower Monumental Dam via the JBS (31%) compared to yearling (16%) and subyearling (9%) Chinook salmon. Estimated survival was high, ranging from 99% to 100%, for JBS groups. These point estimates exceeded those observed in most previous studies that estimated JBS route-specific survival for yearling Chinook salmon and steelhead (Hockersmith et al. 2008, 2010a, 2010b) and subyearling Chinook salmon (Absolon et al. 2010; Dumdei et al. 2010). It is possible the improved JBS survival observed in 2012 resulted from this alteration. Acoustic-tagged fish that passed Lower Monumental Dam through turbines had the lowest probability of surviving dam passage, ranging from 81% for steelhead to 93% for yearling Chinook salmon. However, the turbines were the least commonly used route for all three species/stocks: 5% of yearling Chinook salmon, 3% of steelhead, and 8% of subyearling Chinook salmon passed Lower Monumental Dam through the turbines during the study period.

Table 4.3. Dam passage survival and forebay-to-tailrace survival among years. Parentheses denote standard error.

	Year	Yearling	Steelhead	Subyearling
Dam passage survival	2004	NR	NA	NA
	2005	NA	NA	NR
	2006	0.943 (0.009)	1.001 (0.010)	0.943 (0.003)
	2007	0.952 (0.011)	0.955 (0.013)	0.845 (0.018)
	2008	0.963 (0.016)	1.006 (0.009)	0.932 (0.023)
	2009	0.975 (0.018)	0.976 (0.009)	0.929 (0.010)
	2012	0.987 (0.009)	0.983 (0.002)[a]	0.979 (0.008)
Forebay-to-tailrace survival	2004	0.919 (0.019)	NA	NA
	2005	NA	NA	0.722 (0.025)
	2006	0.924 (0.009)	0.980 (0.012)	0.896 (0.013)
	2007	0.930 (0.016)	0.888 (0.017)	0.762 (0.036)
	2008	0.934 (0.016)	0.982 (0.011)	0.879 (0.022)
	2009	0.949 (0.014)	0.977 (0.009)	0.862 (0.012)
	2012	0.986 (0.009)	0.982 (0.002)[a]	0.972 (0.008)

(a) Single-release survival estimate (includes 25 km of the river downstream from Lower Monumental Dam).
NR = not reported; NA = not applicable.

Median forebay residence times were generally similar among all species and stocks in 2012, ranging from 2.2 h for steelhead to 2.6 h for subyearling Chinook salmon (Table 4.4). In addition, results from 2012 were generally similar to those obtained in previous studies.

Median tailrace egress times were similar for yearling Chinook salmon and steelhead in 2012 (Table 4.5). Subyearling Chinook salmon took an additional 8 min on average to exit the tailrace compared to spring migrants. This difference was likely caused by the lower discharge observed during the summer portion of the study. Also, median tailrace egress times were markedly higher in 2012 than those observed in previous years. This difference may have been caused by the location of the tailrace array, which was located 0.8 km farther downstream from Lower Monumental Dam in 2012 compared to previous years. Another potential cause of the difference between years is related to the method by which egress times were calculated. For fish passing Lower Monumental Dam via deep spill, the spillway weir, and turbines, the method of calculation was similar among years. However, for fish passing Lower Monumental Dam through the JBS, the time of last detection on the cabled dam-face acoustic array was used as the start time for calculating tailrace egress time during this study, whereas the last PIT-tag detection in the outfall pipe was used in previous studies. Therefore, the present study includes time spent within the JBS in the egress time estimate.

Table 4.4. Mean (SE) and median forebay residence times (h) among years.

	Year	Yearling	Steelhead	Subyearling
Mean forebay residence time	2004	NR	NA	NA
	2005	NA	NA	NR
	2006	7.8 (NR)	14.0 (NR)	7.8 (NR)
	2007	6.3 (NR)	28.2 (NR)	9.0 (NR)
	2008	6.8 (NR)	5.8 (NR)	6.9 (NR)
	2009	7.4 (NR)	7.7 (NR)	3.9 (NR)
	2012	4.8 (0.15)	5.7 (0.16)	14.6 (0.58)
Median forebay residence time	2004	2.2	NA	NA
	2005	NA	NA	3.8
	2006	2.5	5.5	3.0
	2007	2.5	17.8	4.1
	2008	2.2	2.2	2.6
	2009	3.6	3.2	1.3
	2012	2.4	2.2	2.6

NA = not applicable; NR = not reported.

Table 4.5. Mean (SE) and median tailrace egress times (h) among years.

	Year	Yearling	Steelhead	Subyearling
Mean tailrace egress time	2004	NR	NA	NA
	2005	NA	NA	NR
	2006	1.0 (NR)	0.9 (NR)	0.1 (NR)
	2007	4.2 (NR)	1.8 (NR)	5.0 (NR)
	2008	2.9 (NR)	0.3 (NR)	6.0 (NR)
	2009	1.3 (NR)	1.0 (NR)	3.0 (NR)
	2012	0.64 (0.05)	0.73 (0.04)	0.66 (0.01)
Median tailrace egress time	2004	0.17	NA	NA
	2005	NA	NA	0.03
	2006	0.10	0.10	0.17
	2007	0.12	0.14	0.32
	2008	0.11	0.09	0.14
	2009	0.09	0.10	0.13
	2012	0.40	0.40	0.53

NR = not reported; NA = not applicable.

SPE was higher in 2012 than it was in the other post-spillway weir installation study years (2008, 2009) for both yearling and subyearling Chinook salmon (Table 4.6). Conversely, SPE was lower in 2012 than it was in 2008 or 2009 for juvenile steelhead. Spill passage efficiency was positively correlated with percent spill for all three species/stocks over all study years. This relationship was strongest for steelhead and weakest for yearling Chinook salmon. The FPE observed in 2012 was within the range observed during previous study years for all three species/stocks investigated (Table 4.6).

Table 4.6. Spill passage efficiency (SPE) and fish passage efficiency (FPE) among years. Parentheses denote standard error.

	Year	Yearling	Steelhead	Subyearling
SPE	2004	0.893 (NR)	NA	NA
	2005	NA	NA	0.874 (0.019)
	2006	0.600 (0.014)	0.489 (0.015)	0.820 (0.030)
	2007	0.752 (0.012)	0.673 (NR)	0.914 (0.018)
	2008	0.646 (0.016)	0.818 (0.012)	0.404 (0.012)
	2009	0.730 (0.020)	0.688 (0.019)	0.615 (0.022)
	2012	0.789 (0.007)	0.659 (0.008)	0.836 (0.005)
FPE	2004	0.984 (NR)	NA	NA
	2005	NA	NA	0.955 (0.015)
	2006	0.907 (0.008)	0.981 (0.004)	0.947 (0.010)
	2007	0.928 (0.007)	0.963 (0.006)	0.982 (0.005)
	2008	0.938 (0.008)	0.987 (0.004)	0.866 (0.008)
	2009	0.970 (0.008)	0.986 (0.005)	0.918 (0.013)
	2012	0.948 (0.004)	0.965 (0.003)	0.924 (0.003)

NR = not reported; NA = not applicable.

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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 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 homogeneous 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 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 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 (CR112) – 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 was performed over the course of the summer 2012 study. 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	

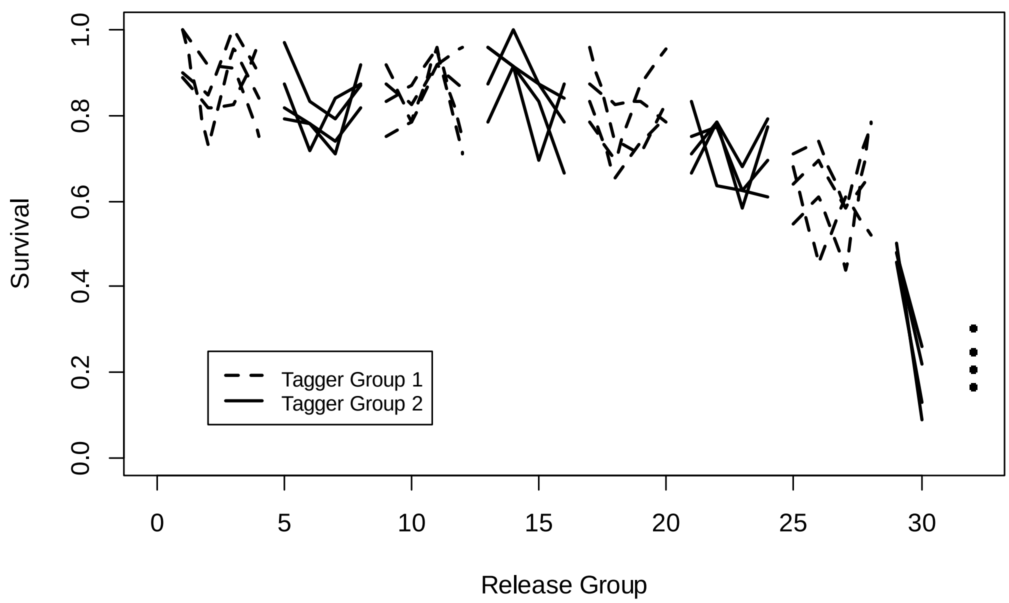

Figure B.1. Estimates of survival from the release location of R_1 to SR017 by tagger and tag team (solid vs. dashed lines) plotted against replicate release groups over time (i.e., 1–32) for the summer 2012 subyearling Chinook salmon study. Plot shows considerable seasonality in the survival estimates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

B.2 Examination of Delayed Handling Effects

B.2.1 Spring Study

The purpose of these tests was to assess whether downstream reach survivals were affected by how far upstream smolts were released. The results were used to determine which release groups were used in the construction of a virtual-release group at Lower Monumental Dam.

Four of the eight tests (i.e., 50%) of the reach comparisons were significant at $\alpha = 0.10$. However, in all cases, the most upstream release never had the lowest survival, and in two cases had the highest survival (Table B.9), contrary to the expected pattern if handling effects had occurred. Comparisons of cumulative survivals in reaches common to multiple release groups found 3 of 10 tests significant at $\alpha = 0.10$ (Table B.10). However, once again, there was no relationship between time in-river and cumulative downriver survival.

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

B.2.2 Summer Study

Tests of delayed tagging/handling effects for subyearling Chinook salmon found none of the four tests to be significant for reach survival (Table B.11). Of the five tests of homogeneous cumulative survival, one was significant at $\alpha = 0.10$ (i.e., 20%; Table B.12). However, the upper release group had higher survival than the lower release groups, opposite of the expected pattern if delayed tagging effects were present.

Table B.9. Comparison of reach survivals between tag releases from different upstream locations for a) yearling Chinook salmon and b) steelhead smolts during the 2012 spring JSATS survival study in the Snake River. Newly released and previously released fish were not compared within a reach (shaded).

a. Yearling Chinook salmon

	SR133		SR112		SR082		SR065		SR040		
Reach	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	P (F-test)
Release to SR113	0.9888	0.0029									
SR113 to SR082	0.9578	0.0048	0.9767	0.0046							
SR082 to SR067	0.9909	0.0024	0.9936	0.0024	0.9941	0.0026					0.4263
SR067 to SR040	0.9688	0.0043	0.9762	0.0045	0.9692	0.0051	0.9846	0.0041			0.4482
SR040 to SR017	0.9881	0.0027	0.9809	0.0041	0.9821	0.0040	0.9730	0.0052	0.9737	0.0053	0.0755
SR017 to SR003 (λ)	0.9478	0.0056	0.9377	0.0073	0.9468	0.0067	0.9374	0.0078	0.9375	0.0078	0.6828

b. Steelhead

	SR133		SR112		SR082		SR065		SR040		
Reach	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	P (F-test)
Release to SR113	0.9772	0.0035									
SR113 to SR082	0.9702	0.0041	0.9783	0.0044							
SR082 to SR067	0.9917	0.0022	0.9833	0.0038	0.9859	0.0036					0.0557
SR067 to SR040	0.9812	0.0033	0.9890	0.0032	0.9764	0.0045	0.9825	0.0044			0.0533
SR040 to SR017	0.9518	0.0053	0.9692	0.0052	0.9557	0.0061	0.9485	0.0071	0.9317	0.0081	0.0737
SR017 to SR003 (λ)	0.8761	0.0084	0.8637	0.0104	0.8622	0.0105	0.8844	0.0105	0.8711	0.0110	0.5216

Table B.10. Comparison of cumulative reach survivals between tag releases from different upstream locations for a) yearling Chinook salmon and b) steelhead smolts in spring survival 2012.

a. Yearling Chinook salmon

	SR133		SR112		
Reach	Est	SE	Est	SE	P (F-test)
SR082 to SR067	0.9909	0.0024	0.9936	0.0024	0.4263
SR082 to SR040	0.9601	0.0048	0.9700	0.0051	0.1575
SR082 to SR017	0.9486	0.0055	0.9514	0.0064	0.7400

	SR133		SR112		SR082		
Reach	Est	SE	Est	SE	Est	SE	P (F-test)
SR067 to SR040	0.9688	0.0043	0.9762	0.0045	0.9692	0.0051	0.4482
SR067 to SR017	0.9573	0.0050	0.9576	0.0060	0.9519	0.0063	0.7360

b. Steelhead

	SR133		SR112		
Reach	Est	SE	Est	SE	P (F-test)
SR082 to SR067	0.9921	0.0022	0.9833	0.0038	0.0451
SR082 to SR040	0.9745	0.0039	0.9725	0.0049	0.7495
SR082 to SR017	0.9280	0.0064	0.9425	0.0069	0.1234

	SR133		SR112		SR082		
Reach	Est	SE	Est	SE	Est	SE	P (F-test)
SR067 to SR040	0.9817	0.0033	0.9890	0.0032	0.9764	0.0045	0.0549
SR067 to SR017	0.9348	0.0061	0.9585	0.0060	0.9331	0.0074	0.0089

Table B.11. Comparison of reach survivals between tag releases from different upstream locations for subyearling Chinook salmon during the 2012 summer JSATS survival study in the Snake River. Newly released and previously released fish were not compared within a reach.

	SR133		SR112		SR082		SR065		SR040		
Reach	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	*P* (*F*-test)
Release to SR113	0.9397	0.0044									
SR113 to SR082	0.9141	0.0053	0.9658	0.0040							
SR082 to SR067	0.9500	0.0044	0.9590	0.0044	0.9532	0.0047					0.1481
SR067 to SR040	0.9456	0.0047	0.9304	0.0058	0.9354	0.0056	0.9858	0.0028			0.1265
SR040 to SR017	0.9571	0.0043	0.9466	0.0054	0.9461	0.0053	0.9478	0.0052	0.9706	0.0040	0.3711
SR017 to SR003 (λ)	0.9595	0.0042	0.9622	0.0047	0.9691	0.0042	0.9547	0.0050	0.9597	0.0046	0.2537

Table B.12. Comparison of cumulative reach survivals between tag releases from different upstream locations for subyearling Chinook salmon in summer 2012.

	SR133		SR112		
Reach	Est	SE	Est	SE	*P* (*F*-test)
SR082 to SR067	0.9501	0.0044	0.9590	0.0044	0.1526
SR082 to SR040	0.8987	0.0060	0.8927	0.0069	0.5117
SR082 to SR017	0.8602	0.0069	0.8450	0.0081	0.1531

	SR133		SR112		SR082		
Reach	Est	SE	Est	SE	Est	SE	*P* (*F*-test)
SR067 to SR040	0.9456	0.0047	0.9304	0.0058	0.9354	0.0056	0.1265
SR067 to SR017	0.9050	0.0060	0.8807	0.0074	0.8850	0.0072	0.0291

Appendix C

Representativeness of the Sample

Appendix C

Representativeness of the Sample

Traditionally, researchers have used Smolt Monitoring Program (SMP) data to describe characteristics (e.g., fish length distributions and run timing) of runs of outmigrating salmonid smolts. The SMP data have been thought of as being representative of the run. Thus, our goal was to compare data from the fish used during this study (the Multi-dam Performance Study [MPS]) to data collected under the Lower Monumental Dam (LMN) SMP to evaluate whether or not MPS fish were representative of the runs-at-large of yearling Chinook salmon, steelhead, and subyearling Chinook salmon passing LMN. Specifically, we evaluated fish length distributions and run timing during the time periods that fish passing through the dams were mixing with run-of-river fish. During this process, we discovered that LMN SMP data were collected with goals related to fish transportation. Thus, for certain run characteristics, LMN SMP data were not representative of the run-at-large making it imperative that these data are interpreted correctly when making inferences regarding the run-at-large. Thus, the following sections describe the fish length and run timing distributions of fish used in the MPS and fish sampled by the LMN SMP, and interprets how well the MPS fish represented the run-at-large with regard to fish length and run timing distributions.

C.1 Fish Length Distribution

The length distributions of fish evaluated for the MPS were likely representative of the runs-at-large of yearling Chinook salmon, steelhead, and subyearling Chinook salmon passing Little Goose Dam (LGS) and LMN. The length distributions of subyearling Chinook salmon were similar between MPS and LMN SMP fish (Figure C.1). The length distributions of yearling Chinook salmon were bimodal and

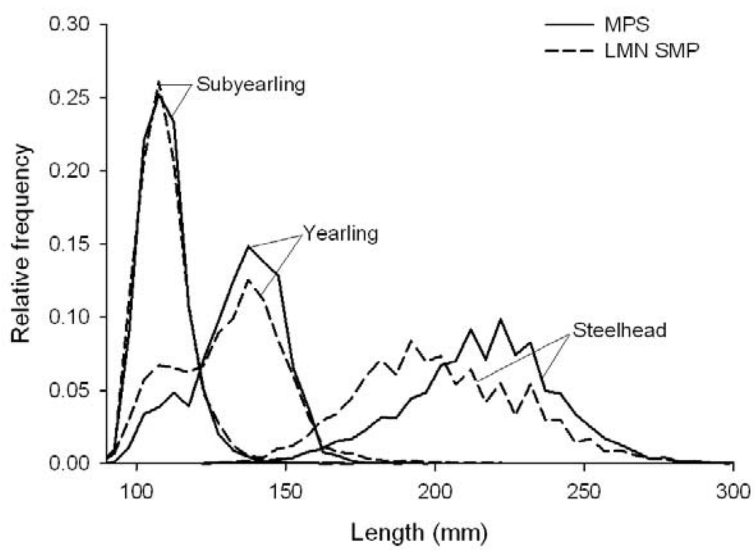

Figure C.1. Length-relative-frequency distributions of yearling Chinook salmon, steelhead, and subyearling Chinook salmon used in the Multi-dam Performance study (MPS) compared to those of fish that were measured for length under the LMN SMP.

similar in range between the two studies. However, the MPS used a higher proportion of fish from the mode of larger fish and a smaller proportion of fish from the smaller mode compared to the fish evaluated for length under the LMN SMP. For steelhead, MPS fish were generally larger than the LMN SMP fish that were measured for length.

C.1.1 Yearling Chinook Salmon

The bimodal distribution of yearling Chinook salmon was primarily caused by the combination of fish with clipped adipose fins (hatchery fish) and fish with unclipped adipose fins (mostly wild fish), where clipped fish compose the majority of the larger mode and unclipped fish compose the majority of the smaller mode. When the length distributions were broken down and compared independently within clipped and unclipped fish, the length distributions of MPS fish were virtually identical to those of fish measured for length under the SMP (Figure C.2). Thus, it was likely that within clipped or unclipped fish, fish from both studies were representative of the run-at-large, and that the proportion of clipped to unclipped fish explained the difference in distributions between the studies.

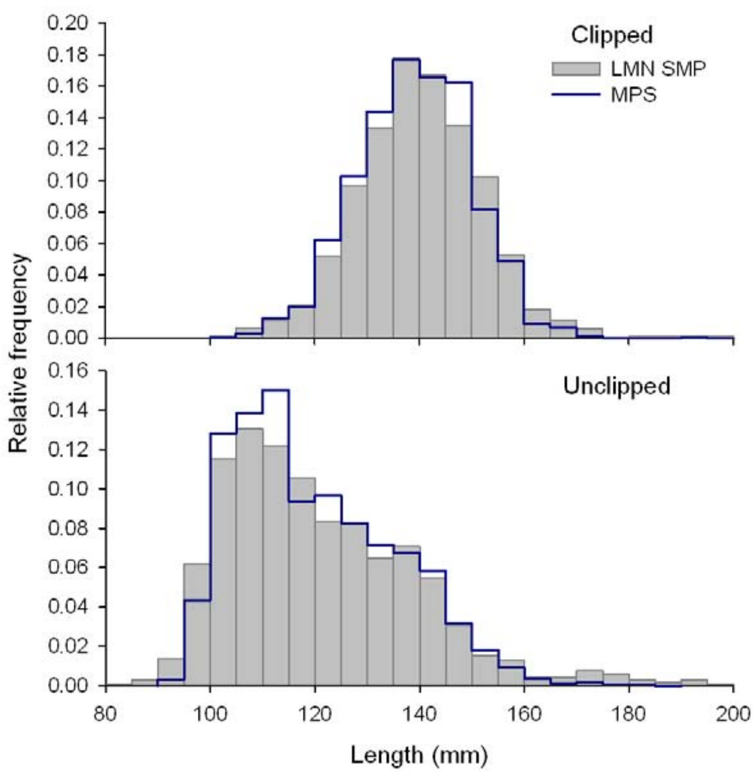

Figure C.2. Relative-length-frequency distributions of clipped and unclipped Multi-dam Performance Study (MPS) yearling Chinook salmon compared to fish measured for length under the Lower Monumental Dam (LMN) Smolt Monitoring Program (SMP).

Upon further investigation, it was discovered that fish measured for length under the LMN SMP (N = 4,572) were sampled with a goal of measuring equal numbers of clipped and unclipped fish rather than randomly sampling these fish. Thus, 51% of these fish were clipped (the other 49% were unclipped). MPS fish were randomly selected (i.e., sampled without regard to being clipped or unclipped) and were composed of 70% clipped fish (total clipped plus unclipped N = 6,177). Beyond the fish that were measured for length under the LMN SMP, the clipped status of all fish that came through the sample room was also recorded (i.e., the measured fish were a non-random sample of all the fish that came through the sample room). Within the total sample of fish that came through the sample room, 69% were clipped. In addition, fish measured for length under the LGS SMP were sampled without regard to being clipped or unclipped and were composed of 73% clipped fish. The overall length distribution of these LGS fish was nearly identical to that of MPS fish (Figure C.3). Thus, based on the identical distributions observed within clipped and unclipped fish, the random selection of MPS fish, the proportion of clipped to unclipped fish that came through the LMN SMP sample room, and the length distribution of LGS fish, it is highly likely that the length distribution of MPS fish were representative of the run-at-large (technically, they were representative of the sample of fish that came through the juvenile bypass system [JBS]).

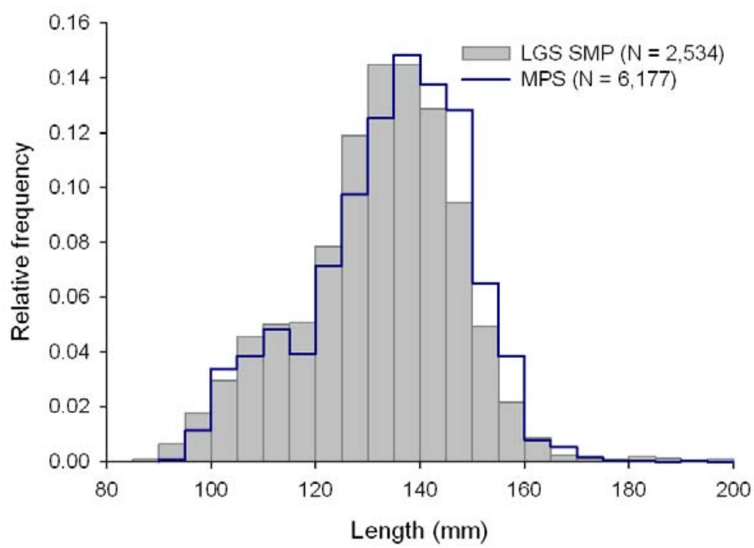

Figure C.3. Length-relative-frequency distributions of Multi-dam Performance Study (MPS) yearling Chinook salmon compared to fish measured for length under the Little Goose Dam (LGS) Smolt Monitoring Program (SMP).

C.1.2 Steelhead

The difference between the MPS and LMN SMP steelhead length distributions was related to the separator in the JBS. The separator uses bars of a fixed width to allow only smaller fish to pass to one side (called the "A side") and any fish (consisting mostly of larger fish because most of the smaller fish pass to the A side) to pass to the other side (called the "B side"). Similar to the "clipped vs. unclipped" issue observed for yearling Chinook salmon, rather than randomly sampling fish regardless of the side of the separator, the goals of the LMN SMP called for certain numbers of fish from each side of the separator to be sampled. Thus, 57% of the steelhead measured for length under the LMN SMP came from the B side (total A and B side $N = 3{,}824$). However, total count data were also recorded under the LMN SMP and indicated that 86% of the total steelhead sample were routed through the B side of the separator. MPS fish were selected in proportion to the total count of A versus B side fish. This resulted in 82% of the fish evaluated during the MPS being collected from the B side (total A and B side $N = 6{,}192$). Not surprisingly, the length distribution of MPS fish is nearly identical to that of the fish measured for length under the LMN SMP that came from the B side (Figure C.4). In addition, under the

LGS SMP, steelhead that were measured for length were sampled in proportion to the number of fish that went to each side of the separator. Not surprisingly, the length distribution of fish measured for length under the LGS SMP was similar to that of the MPS fish (and thus dissimilar to that of LMN SMP fish; Figure C.5). Therefore, the length distribution of MPS steelhead was likely representative of the run-at-large. It is interesting to note that the side of the separator did not bias the length distribution of yearling Chinook salmon measured under the LMN SMP. This is because approximately 50% of yearling Chinook salmon passed through each side of the separator and because most yearlings were small enough to pass freely to either side.

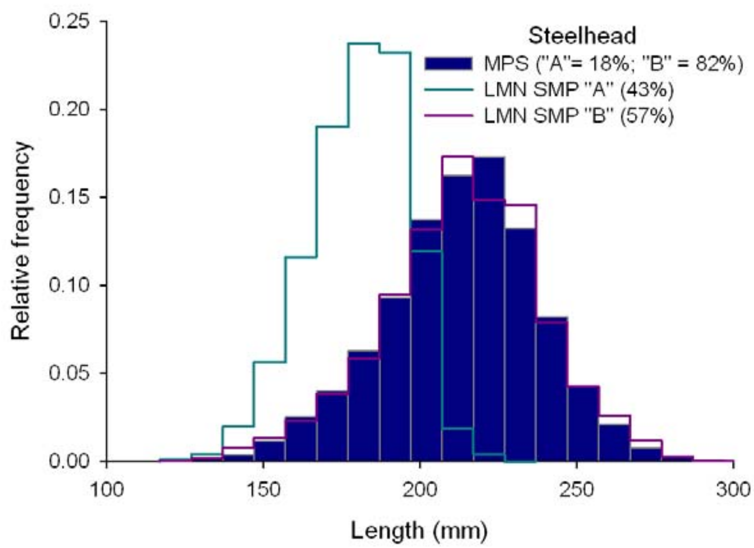

Figure C.4. Length-relative-frequency distributions of all Multi-dam Performance Study (MPS) steelhead compared to the distributions of steelhead measured for length under the Lower Monumental Dam (LMN) Smolt Monitoring Program (SMP) that passed through the A and B sides of the separator.

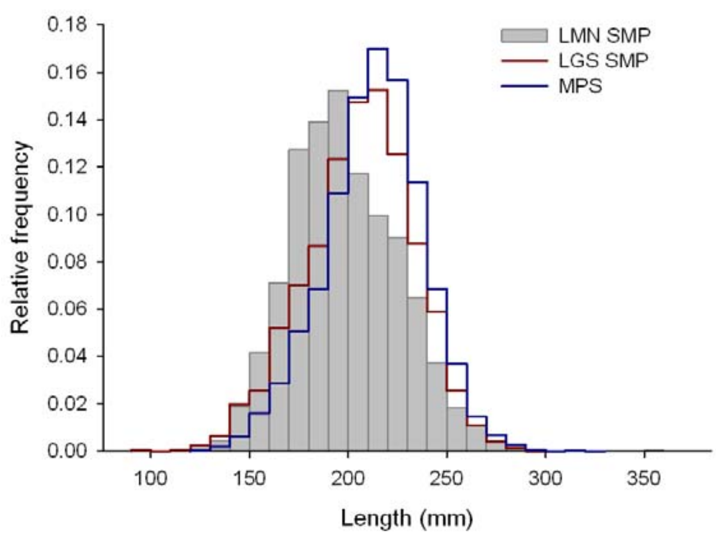

Figure C.5. Length-relative frequency distribution of Multi-dam Performance Study (MPS) steelhead compared to the distributions of fish sampled for length under the Little Goose Dam (LGS) and Lower Monumental Dam (LMN) Smolt Monitoring Programs (SMP).

C.1.3 Subyearling Chinook Salmon

The length distribution of subyearling Chinook salmon used for the MPS study was similar to the distribution of fish measured for length under the LMN SMP, and both were likely representative of the run-at-large. The reason the clipped versus unclipped issue did not influence the LMN SMP sample is that approximately half of the fish were clipped and half were unclipped. Similarly, the side of the separator did not influence the length distribution of LMN SMP fish. Although 90% of subyearlings passed through to the A side of the separator, while only 67% of those measured for length came from the A side, all subyearlings were small enough that the separator yielded no length-specific effect.

C.2 Run Timing

The Smolt Monitoring Index (SMI) based on the fish count data and sampling rates of the LMN SMP are likely the most useful index of the run timing of smolts through LMN and were thus used to compare the timing of the MPS. Upon comparison of the time of mixing of MPS fish with run-of-river fish (using the LMN SMI), it first appeared that the MPS overrepresented the beginning of the runs (and thus, underrepresented the end of the runs) of both spring stocks (yearling Chinook salmon and steelhead) of fish but appropriately represented the spring stock (subyearling Chinook salmon; Figure C.6). However,

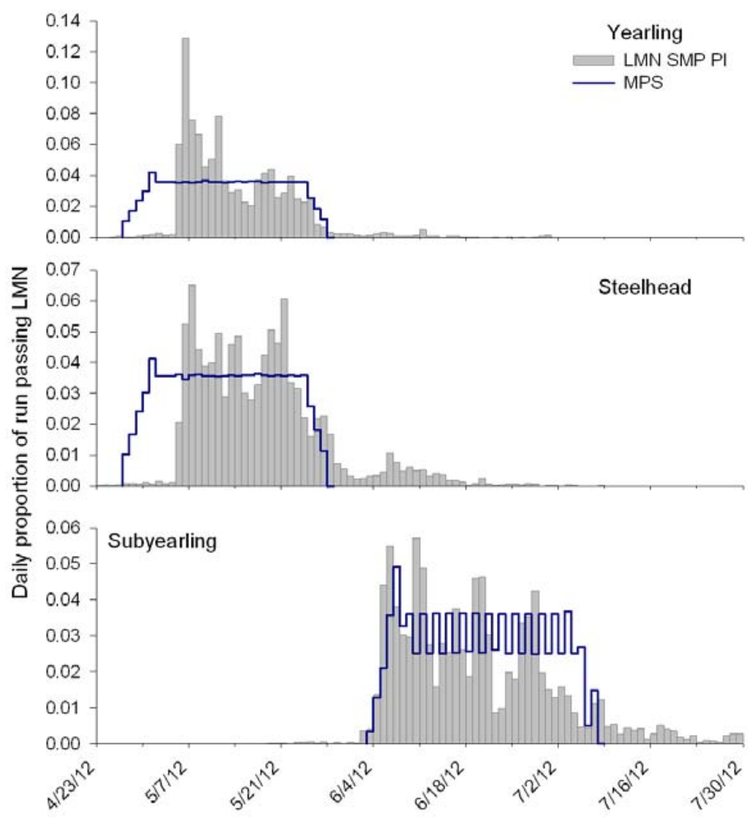

Figure C.6. Run timing distributions of yearling Chinook salmon, steelhead, and subyearling Chinook salmon studied in the Multi-dam Performance Study (MPS) compared to the runs-at-large passing Lower Monumental Dam (LMN) in 2012. LMN data are from the Smolt Monitoring Program (SMP) Passage Index (PI).

it is likely that the MPS represented the run timing of all three stocks well, and that the LMN SMI did not accurately represent the beginning of the yearling Chinook salmon and steelhead runs. This is because the LMN SMP was not effectively sampling until transportation began (~May 5) and therefore skewed the run timing distributions of the spring stocks. Although the exact dates and magnitudes of passage of the run-at-large for LMN cannot be precisely quantified for yearling Chinook salmon and steelhead, evaluating the passage timing at Lower Granite Dam and LGS allows one to deduce what the run timing distribution may have looked like at LMN (Figure C.7 and Figure C.8). Based on these data, it is reasonable to assume that the timing of the MPS represented the run timing of the runs-at-large for all three stocks.

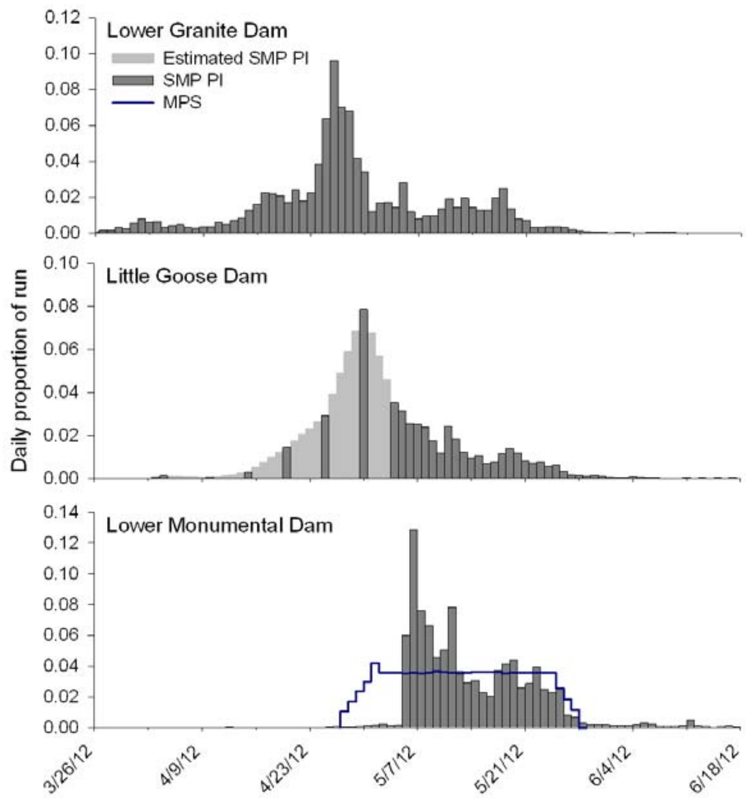

Figure C.7. Run timing distributions of yearling Chinook salmon studied during the Multi-dam Performance Study (MPS) compared to the runs-at-large passing Lower Granite, Little Goose, and Lower Monumental dams in 2012. Dam data are from the Smolt Monitoring Program (SMP) Passage Index (PI). Sampling was not conducted every day during the first half of the run at Little Goose Dam. Thus, SMP PI data are represented by dark grey bars and linear interpolations between these data points are presented as light grey bars.

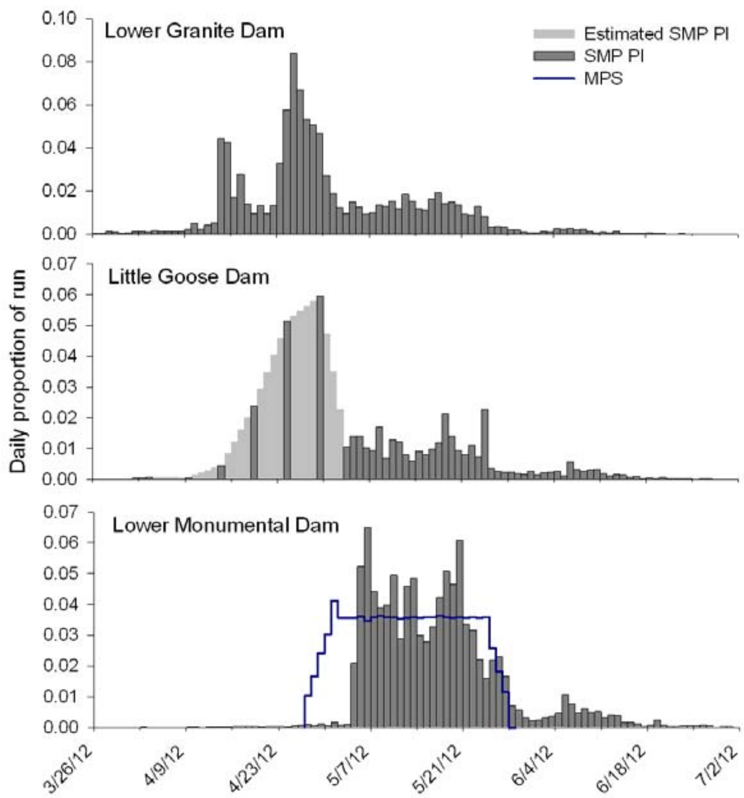

Figure C.8. Run timing distributions of steelhead studied during the Multi-dam Performance Study (MPS) compared to the runs-at-large passing Lower Granite, Little Goose, and Lower Monumental dams in 2012. Dam data are from the Smolt Monitoring Program (SMP) Passage Index (PI). Sampling was not conducted every day during the first half of the run at Little Goose Dam. Thus, SMP PI data are represented by dark grey bars and linear interpolations between these data points are presented as light grey bars.

Appendix D

Capture Histories Used in Estimating Dam Passage Survival

Appendix D

Capture Histories Used in Estimating Dam Passage Survival

D.1 Yearling Chinook Salmon

Table D.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.

	V1 (Season-Wide)		V1 (Early Season)	V1 (Late Season)
Capture History	Dam Passage Survival	BRZ-to-BRZ Survival	Dam Passage Survival	Dam Passage Survival
111	3574	3576	1089	2485
011	0	0	0	0
101	0	0	0	0
001	0	0	0	0
120	1	1	0	1
020	0	0	0	0
110	210	210	54	156
010	0	0	0	0
200	1	1	0	1
100	61	61	13	48
000	117	121	38	79
Total	3964	3970	1194	2770

	Season-Wide Dam Passage Survival		V1 (Early Season)		V1 (Late Season)	
Capture History	R2	R3	R2	R3	R2	R3
11	896	912	297	257	599	655
01	0	0	0	0	0	0
20	0	0	0	0	0	0
10	60	61	11	14	49	47
00	44	28	14	12	30	16
Total	1000	1001	322	283	678	718

D.2 Steelhead

Table D.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)		V1 (Early Season)	V1 (Late Season)
	Dam Passage Survival	BRZ-to-BRZ Survival	Dam Passage Survival	Dam Passage Survival
111	3212	3215	1069	2143
011	0	0	0	0
101	0	0	0	0
001	0	0	0	0
120	0	0	0	0
020	0	0	0	0
110	485	486	108	377
010	0	0	0	0
200	1	1	0	1
100	160	161	27	133
000	70	75	25	45
Total	3928	3938	1229	2699

Capture History	Season-Wide Dam Passage Survival		V1 (Early Season)		V1 (Late Season)	
	R2	R3	R2	R3	R2	R3
11	822	809	281	247	541	562
01	0	0	0	0	0	0
20	0	1	0	0	0	1
10	108	120	21	29	87	91
00	70	70	19	10	51	60
Total	1000	1000	321	286	679	714

D.3 Subyearling Chinook Salmon

Table D.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.

Capture History	V1 (Season-Wide) Dam Passage Survival	V1 (Season-Wide) BRZ-to-BRZ Survival
111	5205	5211
011	0	0
101	0	0
001	0	0
120	0	0
020	0	0
110	196	196
010	0	0
200	0	0
100	263	264
000	349	392
Total	6013	6063

Capture History	Season-Wide Dam Passage Survival R2	Season-Wide Dam Passage Survival R3
11	1682	1753
01	0	0
20	0	0
10	80	74
00	127	58
Total	1889	1885

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 R4 and R5 release sites in the 2012 acoustic-tag survival study to the array above Ice Harbor 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, passive integrated transponder (PIT)-tagged fish detected in the bypass system of Lower Monumental Dam during the acoustic-tag study period were regrouped into a virtual release group and their survival to McNary 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 R4 and R5 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 Biological Opinion performance tests. The single-release survival estimates, survival per kilometer, mortality per kilometer, and 95% confidence intervals are presented for each stock/species for both tailrace groups (R4 and R5) downstream of Lower Monumental 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	LMN-MCN	4/30 to 5/28	0.9117	0.955604	0.867796	0.999224761	0.999619102	0.998811122	0.07752387	0.118887842	0.038089789		
STH	LMN-MCN	4/30 to 5/29	0.8374	0.983812	0.690988	0.998512404	0.999863093	0.996903856	0.148759566	0.309614352	0.013690721		
CH0	LMN-MCN	6/6 to 7/8	0.8507	0.962616	0.738784	0.998644412	0.999680414	0.997463376	0.135558824	0.253662369	0.031958567		
CH1													
R4	LMN Tailrace to IHR	4/30 to 5/28	0.958	0.97074	0.94526	0.999106493	0.999381512	0.99882787	0.089350686	0.117213037	0.061848807	no	yes
R5	LMN Tailrace to IHR	4/30 to 5/28	0.9737	0.984088	0.963312	0.998841887	0.999302854	0.998376192	0.115811283	0.162380768	0.069714623	no	yes
STH													
R4	LMN Tailrace to IHR	4/30 to 5/28	0.9319	0.947972	0.915828	0.998531709	0.998887488	0.99816987	0.146829113	0.183012962	0.111251222	yes	yes
R5	LMN Tailrace to IHR	4/30 to 5/28	0.9317	0.947772	0.915628	0.996928882	0.997670487	0.996174938	0.307111811	0.382506184	0.232951342	no	yes
CH0													
R4	LMN Tailrace to IHR	6/6 to 7/8	0.9344	0.945768	0.923032	0.998587443	0.99883905	0.998332821	0.141255696	0.166717903	0.116095022	no	yes
R5	LMN Tailrace to IHR	6/6 to 7/8	0.9706	0.97844	0.96276	0.998703413	0.999052805	0.998351312	0.129658662	0.164868809	0.094719514	yes	yes

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