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BiOp Performance Testing: Passage and Survival of Subyearling Chinook Salmon at Little Goose and Lower Monumental Dams, 2013

DRAFT BiOp Performance Testing Report

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RL Townsend
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CR Vernon

December 2013

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Pacific Northwest National Laboratory
Richland, Washington 99352

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Preface

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

This report summarizes the performance and survival studies performed at Little Goose and Lower Monumental dams during summer 2013.

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Executive Summary

The purpose of this passage and survival study was to estimate fish performance metrics associated with passage through Little Goose and Lower Monumental dams for emigrating subyearling Chinook salmon smolts during 2013. The metrics estimated during this study included dam passage survival, forebay-to-tailrace survival, forebay residence time, tailrace egress time, and spill passage efficiency (SPE). Under the 2008 Federal Columbia River Power System (FCRPS) Biological Opinion (BiOp), dam passage survival is required to be greater than or equal to 0.93 for summer migrants, estimated with a standard error (SE) less than or equal to 0.015. The study also estimated smolt passage survival from the forebay to the hydraulic extent of the tailrace, also known as "BRZ-to-BRZ survival."[1] Forebay residence time, tailrace egress time, and SPE were estimated also, as required in the Columbia Basin Fish Accords (Fish Accords).

A virtual-paired-release design was used to estimate dam passage survival at Little Goose and Lower Monumental dams. The approach included releases of acoustic-tagged smolts above Little Goose Dam that contributed to the formation of a virtual release at the face of Little Goose Dam. A survival estimate from the virtual release was adjusted using a paired release below Little Goose Dam. Acoustic-tagged fish arriving at the face of Lower Monumental Dam formed the virtual release for that project. The survival estimate from that virtual release was adjusted using a paired release below Lower Monumental Dam. The release sizes at the five locations were 2,998, 2,099, 2,099, 1,901, and 1,906 upriver to downriver, respectively. The Juvenile Salmon Acoustic Telemetry System (JSATS) tag used in these evaluations was model number SS300, which weighs 0.346 g in air.

All Little Goose and Lower Monumental dam passage and survival metrics measured during 2013 for subyearling Chinook are presented in Tables ES.1 through ES.4.

Table ES.1. Estimates of dam passage survival[(a)] for subyearling Chinook salmon at Little Goose and Lower Monumental dams during 2013. Parentheses denote standard error.

Period	Little Goose Dam	Lower Monumental Dam
Season-wide summer	0.9076 (0.0139)	0.9297 (0.0105)

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

Table ES.2. Fish Accords performance measures for subyearling Chinook salmon at Little Goose and Lower Monumental dams during 2013. Parentheses denote standard error.

Performance Measures	Little Goose Dam	Lower Monumental Dam
Forebay residence time (mean/median)	12.27 h (0.67)/3.66 h	17.44 h (0.66)/2.99 h
Tailrace egress time (mean/median)	3.37 h (0.55)/1.23 h	1.16 h (0.20)/0.67 h
Spill passage efficiency (SPE)[(a)]	0.7683 (0.0083)	0.8910 (0.0043)

(a) SPE includes both spillway and adjustable spillway weir passage.

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

Table ES.3. Little Goose Dam 2013 survival study summary.

<table>
<tr><td colspan="3">Year: 2013</td></tr>
<tr><td colspan="3">Study Site(s): Little Goose Dam</td></tr>
<tr><td colspan="3">Objective(s) of study: Estimate dam passage survival and other performance measures for subyearling Chinook salmon.</td></tr>
<tr><td colspan="3">Hypothesis (if applicable): Not applicable; this is a performance standard study.</td></tr>
<tr><td colspan="2">Fish:
Species-race: Subyearling Chinook salmon (CH0)
Source: Lower Monumental Dam juvenile fish collection facility</td><td>Implant Procedure:
Surgical: Yes
Injected: No</td></tr>
<tr><td colspan="2">Size (median):
Weight (g): 12.5
Length (mm): 109.0</td><td>Sample Size:
release sites[(a)]: 3
Total # released: 7196</td></tr>
<tr><td>Tags:
Type/model: Advanced Telemetry Systems (ATS) − SS300 and Biomark HPT12 PIT tag
Weight (g): SS300 = 0.346 g (air), HPT12 = 0.100 g (air)</td><td>Analytical Model:
Virtual-paired-release model</td><td>Characteristics of Estimate:
Effects Reflected (direct, total, etc.): Direct
Absolute or Relative: Absolute</td></tr>
<tr><td colspan="3">Summer Environmental/Operating Conditions (daily from 4 June 2013 through 6 July 2013):
Discharge (kcfs): Mean 52.2, minimum 36.3, maximum 74.2
Temperature (°C): Mean 16.2, minimum 13.2, maximum 19.4
Total Dissolved Gas (tailrace): Mean 112.1%, minimum 109.9%, maximum 114.0%
Spill: Mean 30.4%, minimum 29.5%, maximum 38.1% (target spill 30%)
Unique Study Characteristics: None</td></tr>
</table>

Survival and Passage Estimates (value and SE):	CH0
• Season-wide summer	0.9076 (0.0139)
Forebay-to-tailrace survival (season-wide)	0.9007 (0.0139)
Forebay residence time (mean/median)	12.27 h (0.67)/3.66 h
Tailrace egress time (mean/median)[(b)]	3.37 h (0.55)/1.23 h
Spill passage efficiency (SPE)	0.7683 (0.0083)
Fish passage efficiency (FPE)	0.9498 (0.0043)

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

Table ES.4. Lower Monumental Dam 2013 survival study summary.

<table>
<tr><td colspan="3">Year: 2013</td></tr>
<tr><td colspan="3">Study Site(s): Lower Monumental Dam</td></tr>
<tr><td colspan="3">Objective(s) of study: Estimate dam passage survival and other performance measures for subyearling Chinook salmon.</td></tr>
<tr><td colspan="3">Hypothesis (if applicable): Not applicable; this is a performance standard study.</td></tr>
<tr><td colspan="2">Fish:
Species-race: Subyearling Chinook salmon (CH0)
Source: Lower Monumental Dam juvenile fish collection facility</td><td>Implant Procedure:
Surgical: Yes
Injected: No</td></tr>
<tr><td colspan="2">Size (median):
Weight (g): 12.6
Length (mm): 109.0</td><td>Sample Size:
release sites[(a)]: 5
Total # released: 11003</td></tr>
<tr><td>Tags:
Type/model: Advanced Telemetry Systems (ATS) − SS300 and Biomark HPT12 PIT tag
Weight (g): SS300 = 0.346 g (air), HPT12 = 0.100 g (air)</td><td>Analytical Model:
Virtual-paired-release model</td><td>Characteristics of Estimate:
Effects Reflected (direct, total, etc.): Direct
Absolute or Relative: Absolute</td></tr>
<tr><td colspan="3">Summer Environmental/Operating Conditions (daily from 6 June 2013 through 8 July 2013):
Discharge (kcfs): Mean 51.7, minimum 34.7, maximum 74.8
Temperature (°C): Mean 16.5, minimum 13.7, maximum 18.9
Total Dissolved Gas (tailrace): Mean 115.4%, minimum 112.6%, maximum 117.6%
Spill (kcfs): Mean 19.8, minimum 16.5, maximum 26.0% (target spill 25.5 and 17 kcfs)
Unique Study Characteristics: None</td></tr>
</table>

Survival and Passage Estimates (value and SE):	CH0
• Season-wide summer	0.9297 (0.0105)
Forebay-to-tailrace survival (season-wide)	0.9161 (0.0105)
Forebay residence time (mean/median)	17.44 h (0.66)/2.99 h
Tailrace egress time (mean/median) [(b)]	1.16 h (0.20)/0.67 h
Spill passage efficiency (SPE)	0.8910 (0.0043)
Fish passage efficiency (FPE)	0.9514 (0.0030)

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

Acknowledgments

This study was the result of hard work by dedicated scientists and field support from Cascade Aquatics, 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 regarding the study objectives, the schedule, and the budget were essential for our success in providing high-quality, timely results to decision-makers.

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- UW: C. Helfrich
- WDFW: S. Lind
- Cascade Aquatics: A. LeBarge and N. Mucha

Acronyms and Abbreviations

°C	degree(s) Celsius
ATS	Advanced Telemetry Systems
BFL	Bio-Acoustics & Flow Laboratory
BiOp	Biological Opinion
BRZ	boat-restricted zone
CH0	subyearling Chinook salmon
FCRPS	Federal Columbia River Power System
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
RPA	reasonable and prudent alternative
s	second(s)
SE	standard error
SMP	Smolt Monitoring Program
SPE	spill passage efficiency
USACE	U.S. Army Corps of Engineers
UW	University of Washington
VPR	virtual-paired-release

Contents

Figures

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 summer of 2013. The purpose of the study was to estimate dam passage survival at Little Goose and Lower Monumental dams as stipulated by the 2008 Federal Columbia River Power System (FCRPS) Biological Opinion (BiOp) (NOAA Fisheries 2008) and provide additional performance measures at the dams as stipulated in the Columbia Basin Fish Accords (Fish Accords) for subyearling Chinook salmon (Three Treaty Tribes-Action Agencies 2008 [Memorandum of Agreement]).

1.1 Background

The 2008 FCRPS 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 described below (after the RME Strategy 2 of the RPA):

> *Juvenile Dam Passage Performance Standards* – The Action Agencies juvenile performance standards are an average across Snake River and lower Columbia River dams of 96% average dam passage survival for spring Chinook salmon and steelhead and 93% average across all dams for Snake River subyearling Chinook salmon. 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) (Three Treaty Tribes-Action Agencies 2008), contains three additional requirements relevant to the 2013 survival studies (after Attachment A to the Memorandum of Agreement):

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

This report summarizes the results of the 2013 summer acoustic-telemetry studies of subyearling Chinook salmon at Little Goose and Lower Monumental dams to assess the Action Agencies' compliance with the performance criteria of the BiOp and Fish Accords.

1.2 Study Objectives

The purpose of the summer 2013 performance and survival monitoring at Little Goose Dam and Lower Monumental Dam was to estimate performance measures for subyearling Chinook salmon smolts as outlined in the FCRPS BiOp and Fish Accords. At each hydropower project, 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 ≥93% for the summer stock (i.e., subyearling Chinook salmon) with an estimated standard error (SE) ≤1.5%. Note that an SE 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 to the tailrace array. At Little Goose Dam, these arrays are located 0.9 km upstream and 1.5 km downstream of the dam. At Lower Monumental Dam, these arrays are located 0.8 km upstream and 2.0 km downstream of the dam. The forebay-to-tailrace survival estimate satisfies the "BRZ-to-BRZ" survival estimated called for in the Fish Accords.
- Forebay residence time is defined as the average (median) time smolts take to travel from the forebay BRZ (located 0.9 km upstream of Little Goose Dam and 0.8 km upstream of Lower Monumental Dam) to the entrance into the dam.
- Tailrace egress time is defined as the average (median) time smolts take to travel from the dam to the tailrace array (located 1.5 km downstream of Little Goose Dam and 2.0 km downstream of Lower Monumental Dam).
- Spill passage efficiency (SPE) is defined as the fraction of fish going through the dam via the spillway, including the spillway weir.
- Fish passage efficiency (FPE) is defined as the fraction of fish going through the dam via non-turbine routes, including the spillway, the spillway weir, and the juvenile bypass system (JBS).

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

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

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

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

The intent of the summer 2013 studies was, in part, to evaluate performance under operational conditions called for in the Fish Operations Plans (Appendix E in USACE 2013). Flows during the summer of 2013 allowed spill targets at Little Goose and Lower Monumental dams to be met throughout the course of the study.

1.3 Report Contents and Organization

This report is designed to provide a succinct and timely summary of BiOp/Fish Accords performance measures. Study results are reported by performance measure for each hydropower project. The ensuing chapters present study methods, results, and associated discussions. Appendices contain tables of acoustic receiver locations (Appendix A), supplementary information about tests of assumptions (Appendix B), and capture histories used in estimating dam passage survival (Appendix C).

2.0 Methods

Study methods included fish collection, tagging, and release; acoustic signal detection and processing; and statistical approaches.

2.1 Study Design

The study design used to estimate dam passage survival at Little Goose and Lower Monumental dams consisted of a combination of a virtual release (V_1) of fish at the face of each dam and a paired release below each dam (Figure 2.1) (Skalski et al. 2010a, b). An initial release above Little Goose Dam at river kilometer (rkm as measured from the mouth of the Snake River) 133 provided the source of tagged fish to form the virtual-release group at the face of Little Goose Dam. Below Little Goose Dam, releases at rkm 112 and 80 completed the virtual-paired-release design for the first project. At Lower Monumental Dam, the virtual release was formed using fish released from upstream release locations (rkm 133, 112, and 80) (Figure 2.2). Lower Monumental Dam then had its own tailrace and reservoir release pair (rkm 65 and 30) (Figure 2.2). The acoustic-tagged fish sample sizes used to estimate dam passage survival are summarized in Table 2.1. This multi-dam-design configuration has four advantages. First, investigations at the two dams can be performed using five rather than six release groups, as would be the case in two independent dam investigations. Second, the increased sample sizes benefit the downstream dam investigation by contributing to that virtual-release group (e.g., V_2, Figure 2.2). Third, the corresponding below-dam releases at the downstream dam can be reduced because of the precision advantage of the larger virtual release. Finally, there are multiple detection arrays available for the upstream study at Little Goose Dam to use in its investigation, potentially improving study precision.

The same study design was used to estimate forebay-to-tailrace survival, except that the virtual-release group was composed of fish known to have arrived at the forebay arrays at each dam (i.e., rkm 114 and 68). The below-dam paired releases used to adjust for the extra release mortality below the dams also was used to estimate dam passage survival. The double-detection arrays at the face of each dam (Figure 2.2) were analyzed as two independent arrays. This allowed estimation of detection probabilities by route-of-passage and assignment of passage route for individual fish using three-dimensional tracks and the location of the last detections. These passage-route data were used to calculate SPE and FPE at each dam. Tailrace egress time was estimated using the fish included in the virtual release at the face of each dam.

Tags used during the summer 2013 JSATS study were from a single manufacturing lot. A total of 77 tags were randomly sampled for tag-life assessment. These tags were activated, held in water, and monitored continuously until they failed. The information from the tag-life study was used to adjust the survival estimates from the Cormack-Jolly-Seber release-recapture model using the methods of Townsend et al. (2006).

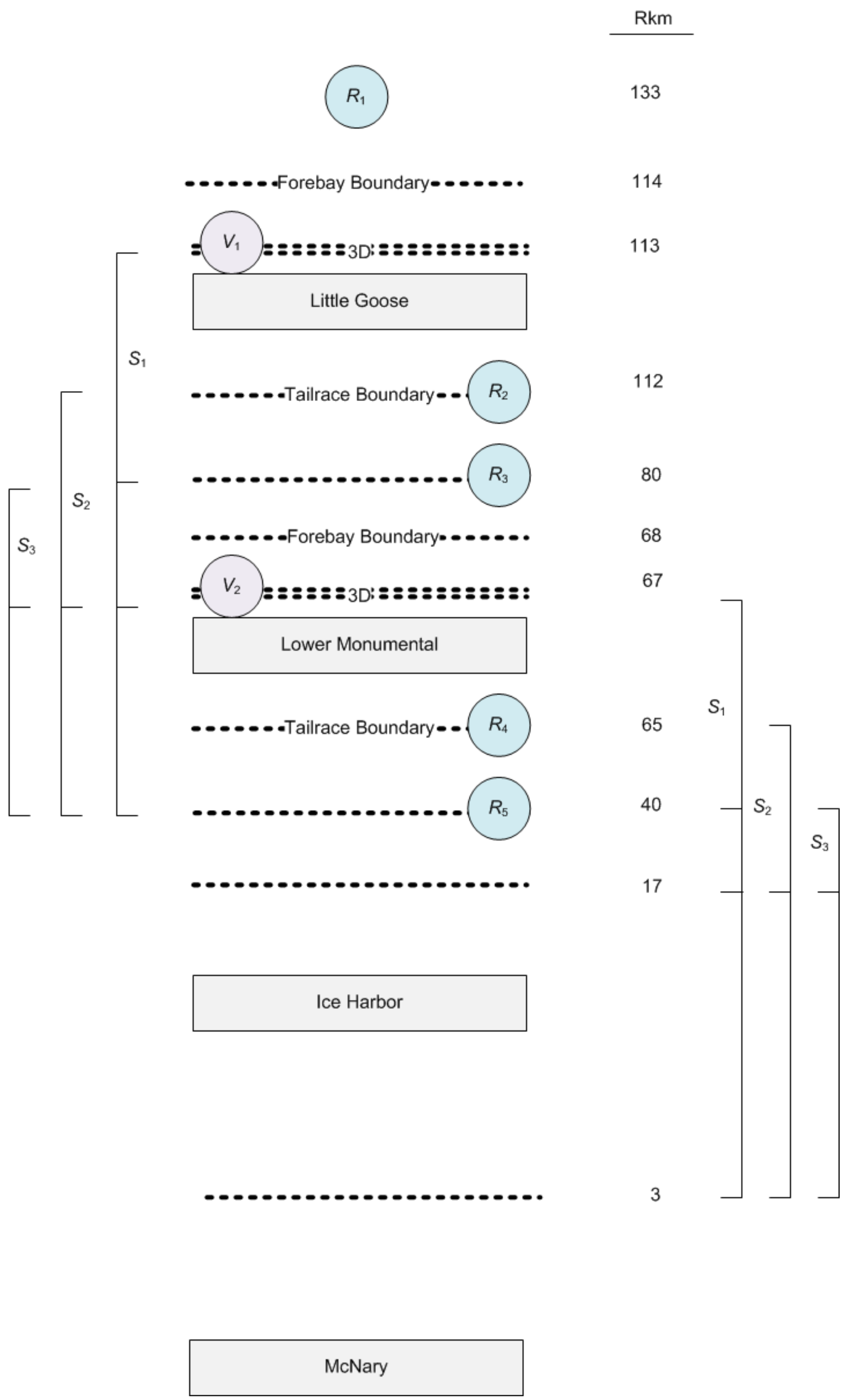


Figure 2.1. Schematic of JSATS survival studies at Little Goose and Lower Monumental dams using the virtual-paired-release design. Releases denoted by *R*, virtual releases denoted by *V*, and hydrophone arrays by dashed lines. Arrays used in the analyses are denoted by brackets.

Table 2.1. Locations and sample sizes of acoustic-tagged fish releases used in the subyearling Chinook salmon survival studies at Little Goose and Lower Monumental dams during 2013.

Project	Release Location	rkm	Subyearling Chinook Salmon
Little Goose	Above Little Goose (R_1)	133	2998
	Virtual Release (V_1)	113	2539
	Tailrace (R_2)	112	2099
	Mid-Reservoir (R_3)	80	2099
Lower Monumental	Virtual Release (V_2)	67	5156
	Tailrace (R_4)	65	1901
	Mid-Reservoir (R_5)	40	1906

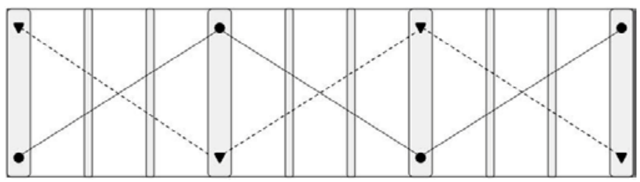


Figure 2.2. Front view schematic of hydrophone deployments at three turbines showing the double-detection arrays. The circles denote the hydrophones of Array 1 and the triangles denote the hydrophones of Array 2.

2.2 Handling, Tagging, and Release Procedures

Fish were surgically implanted with acoustic tags, and then transported to the five different release points, as described in the following sections.

2.2.1 Acoustic Tags

The acoustic tags used in the summer 2013 study were manufactured by Advanced Telemetry Systems (ATS, Isanti, Minnesota). Each tag (model number SS300) was 10.79 mm long, 5.26 mm wide, 3.65 mm high, and weighed 0.346 g in air. The tags had a nominal transmission rate of 1 pulse per 4.2 s. Nominal tag life was expected to be about 45 days.

2.2.2 Fish Source

The 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 examined these fish as described by Lind and Price (2009). After SMP examination, subyearling Chinook salmon that were ≥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 pre-determined acceptance/exclusion criteria outlined by the Columbia Basin Surgical Protocol Steering Committee (USACE 2011) for BiOp testing as follows. These criteria are described below:

Fish was accepted if it:

- Was a subyearling fall Chinook salmon
- 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 passive integrated transponder [PIT-tag] scars)
- Indicated a positive reading when put through a 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; symptoms include:
  - 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 maintained in holding tanks for 18 to 30 h prior to surgery. Non–sorted or excluded fish were returned to the river below the dam or were routed directly onto barge on transport days or diverted to a recovery tank on non-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 to 100 mg/L). In this “knockdown” solution, fish reached stage-4 anesthesia within 2 to 3 min (Summerfelt and Smith 1990). Anesthesia containers were refreshed repeatedly to maintain the temperature within ±2°C of current river temperatures. Sedated fish were weighed, measured, assessed for noteworthy abnormalities (e.g., minor descaling, fin erosion, predation marks, etc.), assigned tag codes, and assigned to a surgeon.

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 to the pelvic girdle. A PIT tag was inserted into the coelom followed by the acoustic transmitter (battery end inserted toward the head of the fish). Both tags were inserted slightly anterior and parallel to the incision. The incision was closed using 5-0 absorbable monofilament with two simple, interrupted sutures tied with reinforced square knots (Deters et al. 2012). Knots were made with one wrap on each of four throws.

After closing the incision, the fish were placed in a partially perforated dark-colored 22.7-L transport bucket filled with aerated river water. Fish were held in these buckets within a trough of flow-through river water for 12 to 30 h before being transported for release into the river. The loading rate was typically five fish per bucket.

2.2.4 Release Procedures

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

Releases at R_1 occurred for 32 consecutive days (from 3 June to 4 July 2013) for the study, alternating between daytime and nighttime, every other day. The timing of the releases at $R_1,\ldots,R_5$ were staggered to help facilitate downstream mixing (Table 2.2).

Table 2.2. Relative release times for the acoustic-tagged fish to accommodate downstream mixing.

	Relative Release Times	
Release Location	Daytime Start	Nighttime Start
R_1 (rkm 133)	Day 1: 1500	Day 1: 0400
R_2 (rkm 112)	Day 2: 1200	Day 2: 0000
R_3 (rkm 80)	Day 3: 1300	Day 3: 0100
R_4 (rkm 65)	Day 1: 1600	Day 1: 0400
R_5 (rkm 40)	Day 2: 1700	Day 2: 0500

2.3 Acoustic Signal Detection and Processing

Prior to deployment, all hydrophones and receivers were evaluated in an acoustic tank lined with anechoic materials at the PNNL Bio-Acoustics & Flow Laboratory (BFL) (Deng et al. 2010). The BFL is accredited by the American Association for Laboratory Accreditation to ISO/IEC 17025:2005, which is the international standard for calibration and testing laboratories. The accreditation scope (Certificate Number 3267.01) includes hydrophone sensitivity measurements and power-level measurements of sound sources for frequencies from 50 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 receivers) or bi-weekly (autonomous receivers). These files were transported to PNNL's Richland offices for processing. Receptions of tag codes within data files were processed to produce a data set of accepted tag-detection events. For cabled arrays, tag-code receptions from all hydrophones at a dam were combined for processing. Autonomous node receptions were processed by node, without information on receptions at other nodes within the array. The following filters were used:

- *Multipath filter* – For data from each individual autonomous receiver, all tag-code receptions that occurred within 0.156 s after an initial identical tag-code reception were deleted under the assumption that closely lagging signals are multipath. Initial code receptions were retained. The delay of 0.156 s was the maximum acceptance window width for evaluating a pulse repetition interval (PRI) and was computed as 2(PRI_Window+12 × PRI_Increment). Both PRI_Window and PRI_Increment were set at 0.006 s, which was chosen to be slightly larger than the potential rounding error in estimating PRI to two decimal places. For cabled data, tag-code receptions occurring within 0.3 s were deleted. This larger window for multipath in cabled data is consistent with previous studies at dams in the lower Columbia River.
- *Multi-detection filter (cabled data only)* – Receptions were retained only if the same tag code was received at another hydrophone in the same array within 0.3 s because receptions on separate hydrophones within 0.3 s (about 450 m of range) were likely from a single tag transmission.
- *PRI filter* – Only those series of receptions of a tag code (or "hits") that are consistent with the pattern of transmissions from a properly functioning JSATS acoustic tag were retained. Filtering rules are evaluated for each tag code individually, and it is assumed that only a single tag will be transmitting that code at any given time. For a cabled system, the PRI filter operates on a message that includes all receptions of the same transmission on multiple hydrophones within 0.3 s. Each autonomous receiver is processed independently, so each hit represents a message. Message time is defined as the earliest reception time across all hydrophones for that message. Detection requires that at least four (autonomous) or six messages (cabled) are received with an appropriate time interval between the leading edges of successive messages.
- *Mimic filter* – Detection events were checked to see if they occurred simultaneously with receptions of three to four codes that have been identified to have similar characteristics. Rarely, tags emitting these codes have been found to generate what are referred to as "mimic" receptions of the code of interest. Events were deleted if there was evidence that this was occurring.

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

We added another quality control step by examining 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 resulting from 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 acoustic-tagged fish in the immediate forebays of Little Goose and Lower Monumental dams was used to determine routes-of-passage to estimate SPE. Acoustic tracking, a common technique in used in bio-acoustics, is 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 three-dimensional tracking. For this study, only three-dimensional tracking was performed. The methods were similar to those described by Deng et al. (2011) and Weiland et al. (2011). For example, route-of-passage was assigned a value for the events that immediately precede passage at a dam based on spatial tracking of tagged fish movements to a location of last detection.

2.4 Statistical Methods

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

2.4.1 Estimation of Dam Passage Survival

Maximum likelihood estimation was used to estimate dam passage survival at Little Goose and Lower Monumental dams based on the virtual-paired-release design. The capture histories from all the replicate releases, both daytime and nighttime, were pooled to produce the estimates of dam passage survival. A joint likelihood model was constructed as 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; V_2, R_4, and R_5;

Figure 2.1).

The joint likelihood used to model the three release groups was initially fully parameterized. Each of the three releases was allowed to have unique survival and detection parameters. If precision was adequate (i.e., $SE \leq 0.015$) with the fully parameterized model, no further modeling was performed. If initial precision was inadequate, then likelihood ratio tests were used to assess the homogeneity of parameters across release groups to identify the best parsimonious model to describe the capture-history data. This approach was used to help preserve both the precision and robustness of the survival results (Skalski et al. 2013). All calculations were performed using Program ATLAS.[1]

Dam passage survival was estimated by the following function:

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

where $\hat{S}_i$ is the tag-life-corrected survival estimate for the ith release group ($i = 1,\ldots,3$). 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.

During 2013, 30% spill was planned as the dam operating condition for the passage and survival study at Little Goose Dam. The spill target at Lower Monumental Dam was 25.5 kcfs (to the gas cap) between 6 and 20 June and 17 kcfs spill from 21 June through 8 July. Spill targets were maintained, so a season-wide survival was estimated for each dam.

2.4.2 Tag-Life Analysis

A random sample of 77 JSATS tags was selected from the tag lot. The reception of messages from those individual tags was continuously monitored from activation to failure time in water. 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 resulting from manufacturing defects as well as subsequent systematic battery failure.

The survivorship function for the vitality model can be rewritten as follows:

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

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.

[1] Available at http://www.cbr.washington.edu/paramest/atlas/.

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 groups (V_1 sand V_2), based on fish known to have arrived at the dam faces with active tags, the conditional probability of a tag being active downstream, given the tag was active at the dam face, was used in the tag-life adjustment for these release groups. The conditional probability of tag activation at time t_1, given it was active at time t_0, was computed by the following quotient:

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

2.4.3 Tests of Assumptions

Approaches to assumption testing are described below.

2.4.3.1 Burnham et al. (1987) Tests

Tests 2 and 3 of Burnham et al. (1987) have been used to assess whether upstream detection history has an effect on downstream survival. Such tests are most appropriate when fish are physically recaptured or segregated during capture as in the case of PIT-tagged fish going through the JBS. However, acoustic-tag studies do not use physical recaptures to detect fish. Consequently, there is little or no relevance of these tests in acoustic-tag studies. Furthermore, the very high detection probabilities present in acoustic-tag studies frequently preclude calculation of these tests. For these reasons, these tests were not performed.

2.4.3.2 Tests of Mixing

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

2.4.3.3 Tagger Effects

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

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

where

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

and

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

This F-test was used in evaluating tagger effects.

2.4.3.4 Tag Lot Effects

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

2.4.4 Forebay-to-Tailrace Survival

The same virtual-paired-release methods used to estimate dam passage were also used to estimate forebay-to-tailrace survival. The only distinction was that the virtual-release group (V_1) was composed of fish known to have arrived alive at the forebay array (rkm 114) of Little Goose Dam and the forebay array (rkm 68) of Lower Monumental Dam instead of at the dam faces (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, as follows:

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

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

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

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

Tailrace egress time for fish arriving at a dam was calculated differently for bypassed fish and all other fish before their data were pooled. For bypassed fish, tailrace egress time was measured from the last detection in the fish bypass to the last detection at the tailwater array below the dam. For all other fish, tailrace egress time was measured from the last detection at the dam face array to the last detection at the tailwater array below the dam. Both the arithmetic average and the median were calculated. Only fish known to have passed the dam alive were used in the calculations, based on fish observed to be alive downstream.

2.4.6 Estimation of Spill Passage Efficiency

At each dam, SPE was estimated by the following fraction:

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

where $\hat{N}_i$ is the estimated abundance of acoustic-tagged fish through the *i*th route (*i* = spill [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) independently at each route. Calculating the variance in stages, the variance of SPE was estimated as

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

2.4.7 Estimation of Fish Passage Efficiency

At each dam, FPE was estimated by the following fraction:

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

Calculating the variance in stages, the variance of FPE was estimated as:

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

To expedite this report, we assumed that all routes had equal probability of detection and calculations of SPE and FPE were based on a binomial sampling model.

3.0 Results

The results section 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 15,000 subyearling Chinook salmon were handled as part of the BiOp passage and survival studies at Little Goose and Lower Monumental dams during 2013 (Table 3.1). Fish for studies at both dams were collected simultaneously 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 subyearling Chinook salmon (CH0) handled by PNNL during the 2013 season 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		CH0
Total handled		15,462
	Previously tagged	64
	Did not meet fork length (<95 mm)	2,110
Not available for tagging		2,174
	% Not available for tagging	14.1%
Met all acceptance criteria		13,288
Excluded for condition		694
	% Excluded	5.2%
Number tagged for live release		11,047
Post-tagging mortality		41
	% Mortality	0.4%
Pre-release tag failure (N=2) and PIT tag loss (N=1)		3
		0.03%

All fish used in this study were evaluated based on a set of pre-determined criteria outlined by the USACE Surgical Protocols Committee. Overall, 5.2% 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 reasons for exclusion of subyearling Chinook salmon were descaling over 20% of one side of the body and physical injuries that impede performance.

Table 3.2. Total number of subyearling Chinook salmon (CH0) and reasons for exclusion for tagging by PNNL during the summer of 2013. Percentages are based on the total number of fish that met all acceptance criteria.

Reason for Exclusion	CH0	%CH0
Moribund/Emaciated	5	0.0%
Skeletal Deformities	3	0.0%
>20% Descaling	312	2.3%
Physical Injuries	313	2.4%
Disease and Infection	61	0.5%
Total	**694**	**5.2%**

A total of 11,003 live fish were released as part of the BiOp passage and survival study at Little Goose and Lower Monumental dams (Table 3.3). In addition, 64 tagged dead fish (n = 32 LGS, and n = 32 LMN) were released from the spillway weir at Little Goose (LGS) and Lower Monumental (LMN) dams to evaluate the assumptions of the virtual paired-release survival estimate.

Table 3.3. Total number of acoustic-tagged subyearling Chinook salmon (CH0) released at $R_1,\ldots,R_5$ locations by PNNL during the summer of 2013 as part of the studies at Little Goose (LGS) Dam and Lower Monumental (LMN) Dam.

Release Location (rkm)	CH0
133	2,998
112	2,099
80	2,099
65	1,901
40	1,906
LGS dead fish releases	32
LMN dead fish releases	32
Total	**11,067**

3.2 Discharge and Spill Conditions

3.2.1 Little Goose Dam

The spill operations at Little Goose Dam were targeted at 30% for the summer study. For the vast majority of the summer study, the spill was 30% (Figure 3.1). Therefore, only a season-wide estimate of survival was calculated for the summer of 2013. The Little Goose Dam project discharge averaged 52.2 kcfs (within a range of 36.3 to 74.2 kcfs) during the summer study period. This was within the middle 90th percentile of the previous 70-year record (5th to 95th percentile) in the Snake River, which was 30.9 to 128.5 kcfs during the study period.

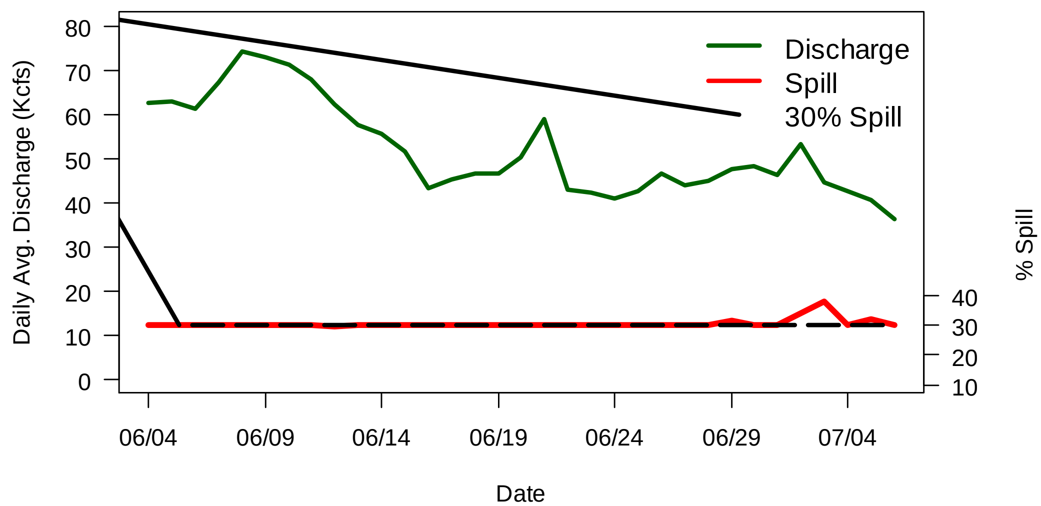


Figure 3.1. Daily average total discharge (kcfs) (green line) and percent spill (red line) at Little Goose Dam during the summer subyearling Chinook salmon study, 4 June to 6 July 2013. The black dashed line represents 30% spill.

3.2.2 Lower Monumental Dam

The spill operations at Lower Monumental Dam were targeted at 25.5 kcfs for the first half, and 17 kcfs for the second half of the summer study. Actual spill levels averaged 23.1 kcfs for the first half and 17.0 kcfs for the second half of the study (Figure 3.2). Because spill targets were met, only a season-wide estimate of survival was calculated for summer 2013. Lower Monumental Dam project discharge averaged 51.7 kcfs (range 34.7–74.8 kcfs) during the summer study period.

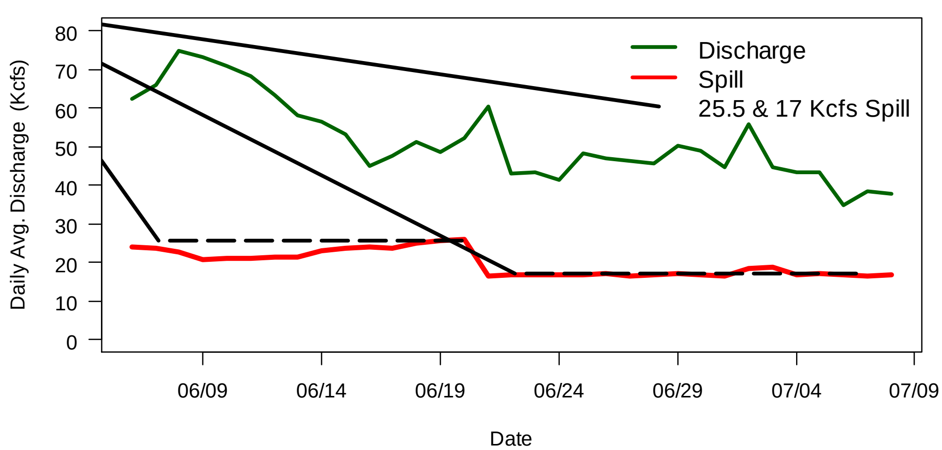


Figure 3.2. Daily average total discharge (kcfs) (green line) and percent spill (red line) at Lower Monumental Dam during the summer subyearling Chinook salmon study, 6 June to 8 July 2013. The black dashed line represents the 25.5 and 17 kcfs spill targets.

3.3 Run Timing

The cumulative percent of subyearling Chinook salmon that passed Little Goose and Lower Monumental dams by date were calculated from smolt index data obtained from the Fish Passage Center (Figure 3.3, Figure 3.4).

3.3.1 Little Goose Dam

From 4 June to 6 July, 68.9% of the subyearling Chinook salmon passed through Little Goose Dam based on Fish Pass Center index counts (Figure 3.3).

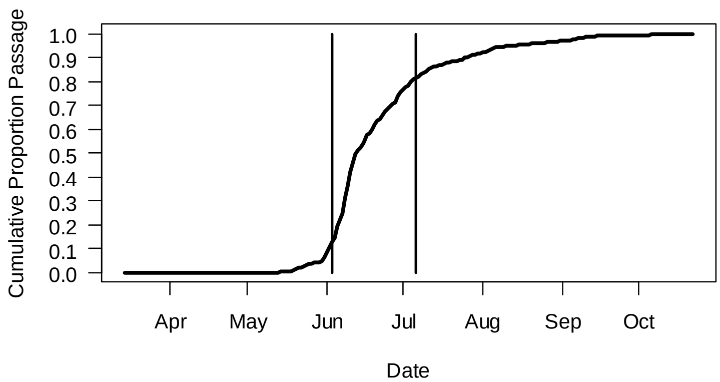


Figure 3.3. Plot of the cumulative proportion of subyearling Chinook salmon that passed Little Goose Dam during 2013. Vertical lines indicate start and stop times of the survival study.

3.3.2 Lower Monumental Dam

From 6 June to 8 July, 73.5% of the subyearling Chinook salmon passed through Lower Monumental Dam based on Fish Passage Center index counts (Figure 3.4).

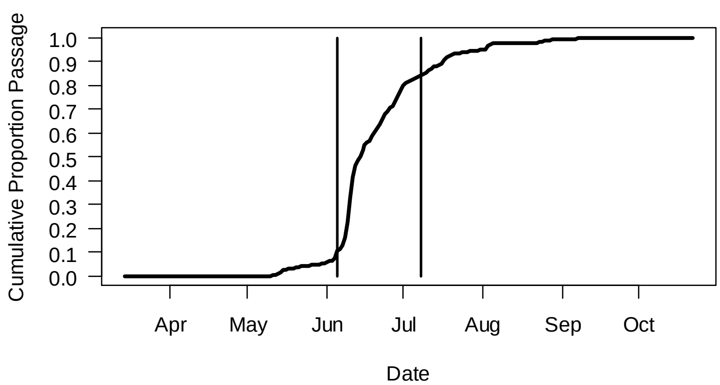


Figure 3.4. Plot of the cumulative proportion of subyearling Chinook salmon that passed Lower Monumental Dam during 2013. Vertical lines indicate start and stop times of the survival study.

3.4 Assessment of Assumptions

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

3.4.1 Examination of Tagger Effects

Eight different taggers assisted in tagging the subyearling Chinook salmon associated with the acoustic-telemetry survival studies at Little Goose and Lower Monumental dams during 2013. Analyses found tagger the effort was homogenously distributed either across all locations within a replicate release or within the project-specific releases within a replicate (Appendix B). Examination of reach survivals and cumulative survivals from above Little Goose Dam to below Ice Harbor Dam found no consistent or reproducible evidence that fish tagged by different staff members had different in-river survival rates (Appendix B). Therefore, fish tagged by all taggers were included in the estimation of survival and other performance measures during the summer study.

3.4.2 Examination of Tag-Lot Effects

Because only one tag lot was used in the 2013 studies, no examination of tag-lot effects was performed.

3.4.3 Handling Mortality and Tag Shedding

Fish were held for 12 to 30 h between tagging and release. The probability of mortality during the post-surgery holding period was 0.4% (n = 41 of 11,047 fish) for subyearling Chinook salmon. No acoustic tags and were shed during the holding period, but one PIT tag was. The fish that shed its PIT tag and the fish with the two acoustic tags that failed during the holding period were removed from the study.

3.4.4 Effect of Tailrace Release Positions on Survival

Each release location included five adjacent release positions distributed across the river channel. This section reports the results of the evaluation of whether those release positions influenced survival.

3.4.4.1 Little Goose Dam

The survival probabilities for subyearling Chinook salmon released at five adjacent locations across the Little Goose Dam tailrace did not differ significantly among release positions across the channel (Figure 3.5 and Figure 3.6).

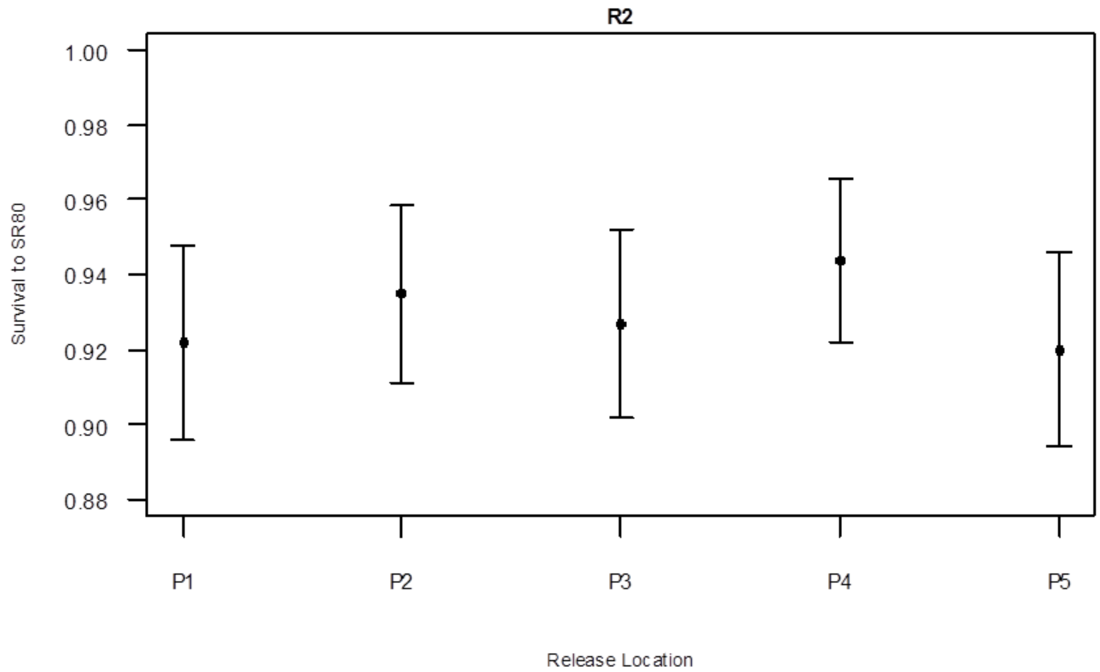


Figure 3.5. Single-release survival estimates (±2 SE) of subyearling Chinook salmon (CH0) from each position (P1 to P5) in the tailrace release location downstream of Little Goose Dam (R2; rkm 112) to the first array downstream (rkm 80). See Figure 3.6 for a map of the release positions.

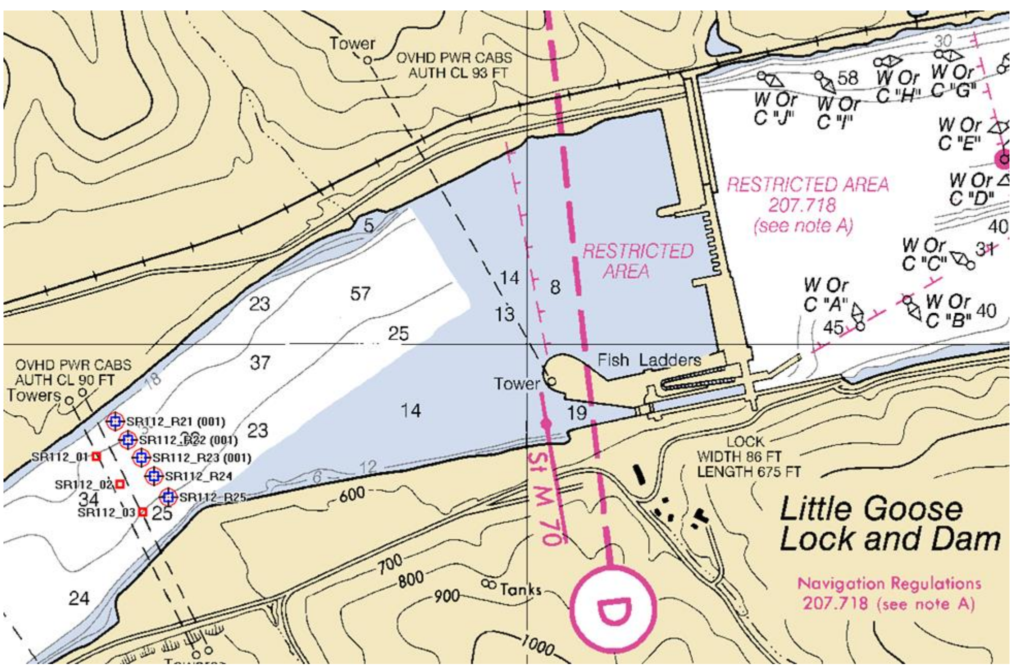


Figure 3.6. Little Goose Dam tailrace fish release locations (red circle with blue square). Release position 1 (SR112_R21) is near the north shore and release position number 5 (SR112__R25) is near the south shore.

3.4.4.2 Lower Monumental Dam

The survival rates for subyearling Chinook salmon released at five adjacent locations across the Lower Monumental Dam tailrace did not differ significantly among release positions across the channel (Figure 3.7 and Figure 3.8).

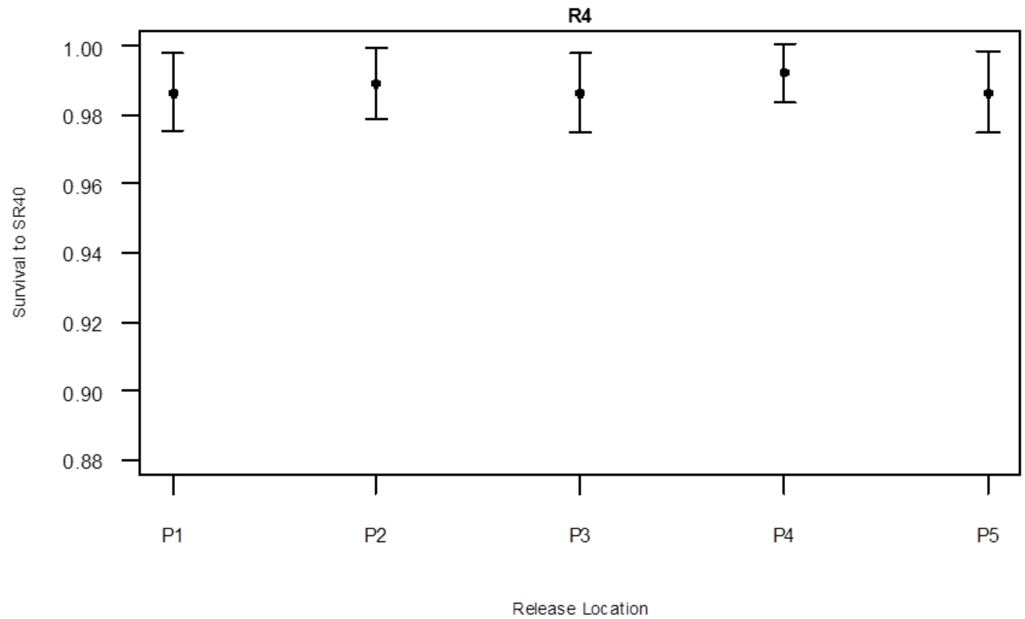


Figure 3.7. Single-release survival estimates (±2 SE) of subyearling Chinook salmon (CH0) from each position (P1-P5) in the tailrace release location downstream of Lower Monumental Dam (R4; rkm 65) to the first array downstream (rkm 40). See Figure 3.8 for a map of the release positions.

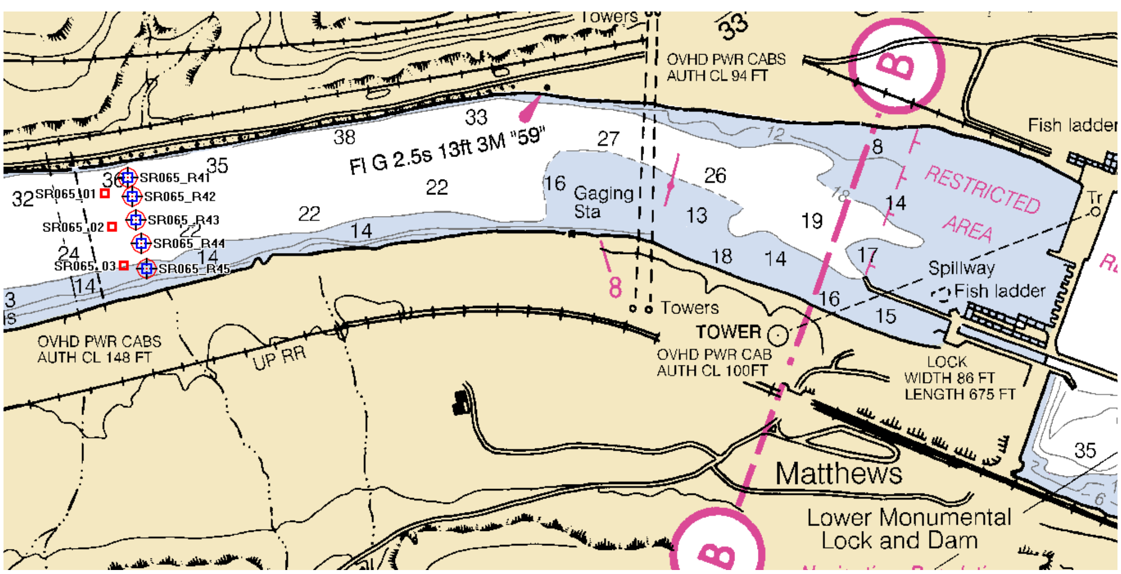


Figure 3.8. Lower Monumental Dam tailrace fish release locations (red circle with blue square). Release position 1 (SR065_R41) is near the north shore and release position number 5 (SR065_R45) is near the south shore.

3.4.5 Fish Size Distributions

Comparison of acoustic-tagged fish with run-of-river fish sampled at Little Goose and Lower Monumental dams by the SMP shows that the length frequency distributions were generally well matched for the subyearling Chinook salmon releases (Figure 3.9 and Figure 3.10). Length distributions among subyearling Chinook salmon released at different locations also were quite similar. Mean length for the acoustic-tagged subyearling Chinook salmon was 109.0 mm. The length of tagged subyearling Chinook salmon increased slightly over the course of the summer study (Figure 3.11).

Mean length for subyearling Chinook salmon sampled by the SMP at the Little Goose Dam juvenile sampling facility during the study was 105.0 mm. Mean length for subyearling Chinook salmon sampled by the SMP at the Lower Monumental Dam juvenile sampling facility was 107.5 mm.

3.4.6 Tag-Life Corrections

During the 2013 summer studies, one tag lot was used at both Little Goose and Lower Monumental dams. A vitality curve of Li and Anderson (2009) was fit to the tag-life data (Figure 3.12). Average tag life was 48.9 days.

3.4.7 Arrival Distributions

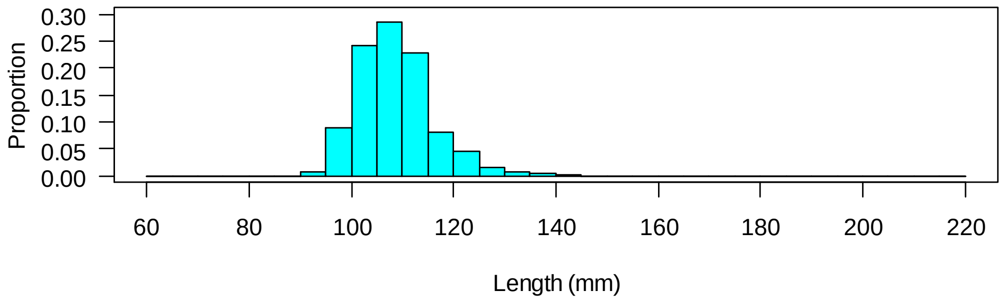
The estimated probability an acoustic tag was active when fish arrived at a downstream detection array depended on the tag-life curve and the distribution of observed travel times for subyearling Chinook salmon (Figure 3.13). Examination of the fish arrival distributions to the last detection array (rkm 3) used in the survival analyses indicated all fish that arrived had passed through the study area before tag failure became important. These probabilities of tag activation were calculated by integrating the tag survivorship curve (Figure 3.13) over the observed distribution of fish arrival times (i.e., time from tag activation to arrival). The probabilities of a JSATS tag being active at a downstream detection site were specific to release group and detection locations (Table 3.4). In all cases, the probability that a tag was active at a downstream detection site as far as rkm 3 was greater than 0.9964 for subyearling Chinook salmon released for these assessments (Table 3.4).

3.4.8 Downstream Mixing

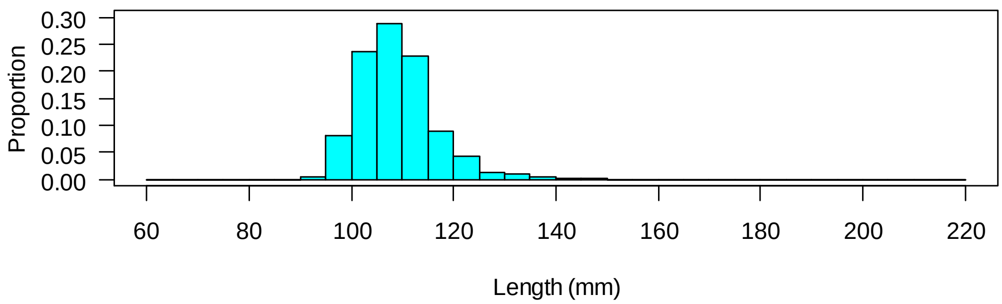
To help induce downstream mixing of the release groups associated with the Little Goose Dam survival study, the R_2 release occurred 20 to 21 h after the R_1 release, and the R3 release occurred 25 h after the R_2 release. Plots of the arrival timing of the three release groups at rkm 67 and rkm 40 indicate reasonable downstream mixing (Figure 3.14). Arrival modes for releases V_1, R_2, and R_3 were nearly synchronous.

The V_2 release from the face of Lower Monumental Dam was continuous over the course of the study and, as such, covered the release times of the R_4 and R_5 releases. However, release R_4 occurred 25 h after the R_3 release to facilitate downstream mixing of this paired release. Plots of the arrival times of these two release groups at rkm 17 and rkm 3 indicate reasonable downstream mixing (Figure 3.15). The arrival modes for releases R_4 and R_5 were nearly synchronous.

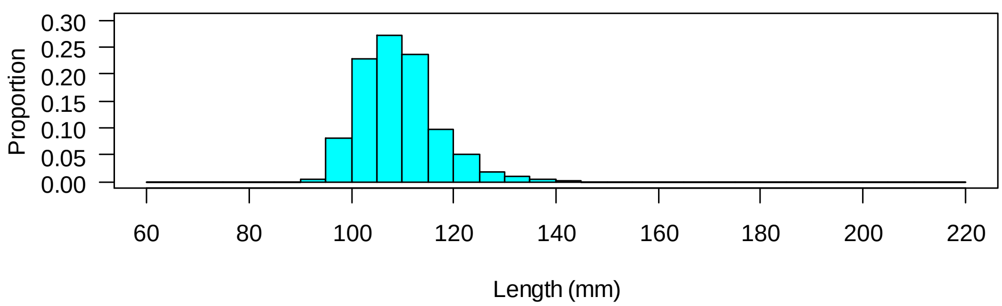
a. Little Goose Dam (Release V_1)



b. Little Goose Tailrace (Release R_2)



c. Mid-Reservoir (Release R_3)



d. Run-of-River Yearling Chinook Salmon at Little Goose Dam

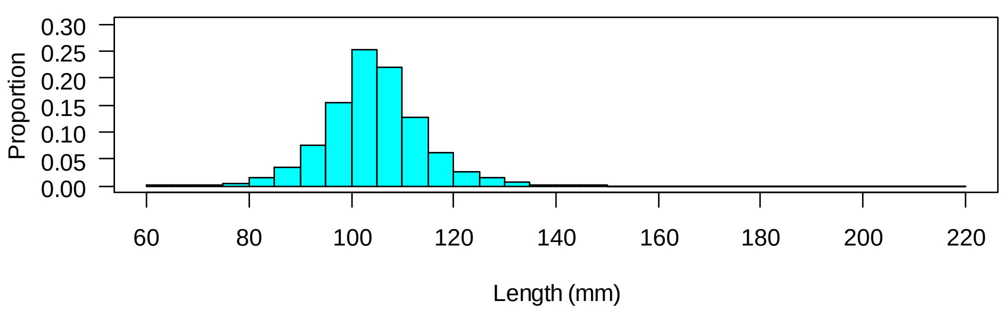
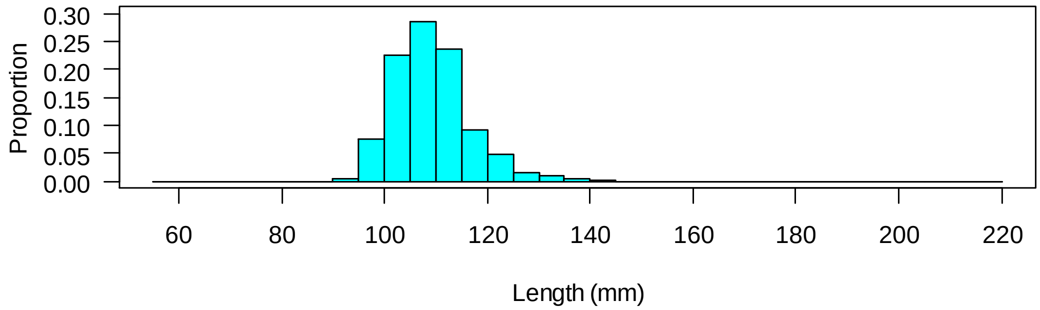
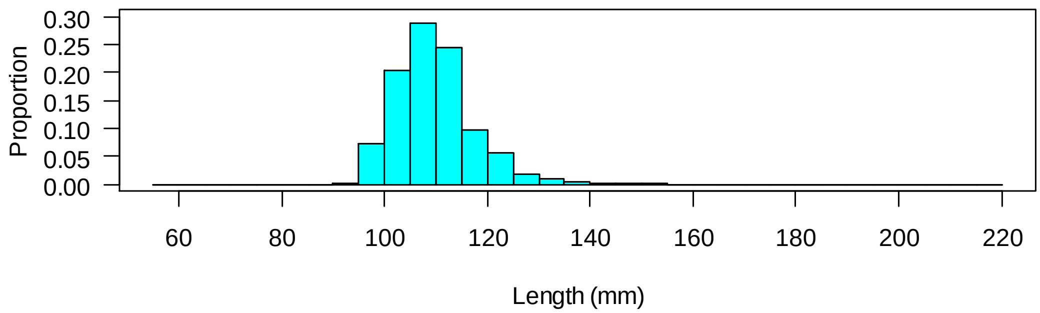


Figure 3.9. Frequency distributions for fish lengths (5-mm bins) of subyearling Chinook salmon smolts used in a) release V_1, b) release R_2, c) release R_3, and d) run-of-river fish sampled at Little Goose Dam by the Smolt Monitoring Program.

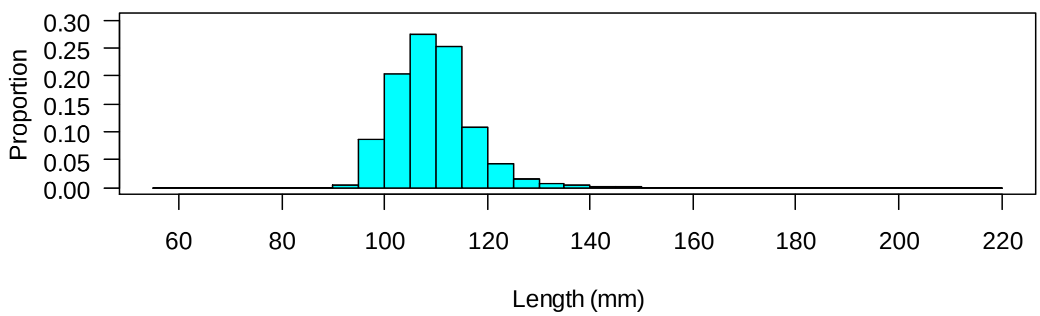
a. Lower Monumental Dam (Release V_2)



b. Lower Monumental Tailrace (Release R_4)



c. Mid-Reservoir (Release R_5)



d. Run-of-River Subyearling Chinook Salmon at Lower Monumental Dam

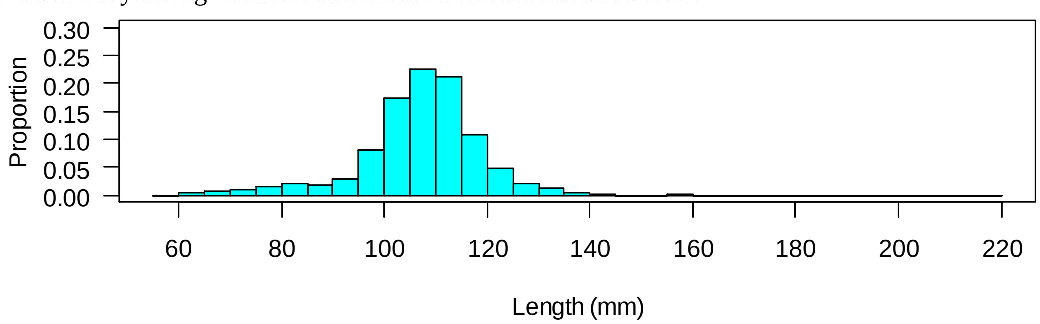
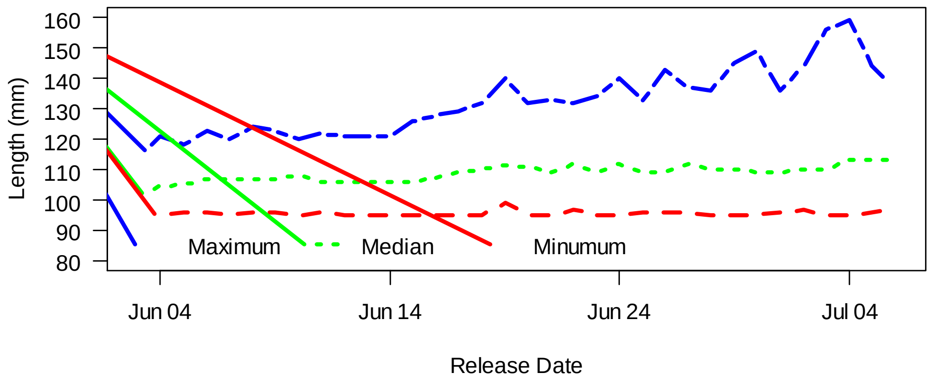


Figure 3.10. Frequency distributions for fish lengths (mm) of subyearling Chinook salmon smolts used in a) release V_2, b) release R_4, c) release R_5, and d) run-of-river fish sampled at Lower Monumental Dam by the Smolt Monitoring Program.

a. Little Goose Dam



b. Lower Monumental Dam

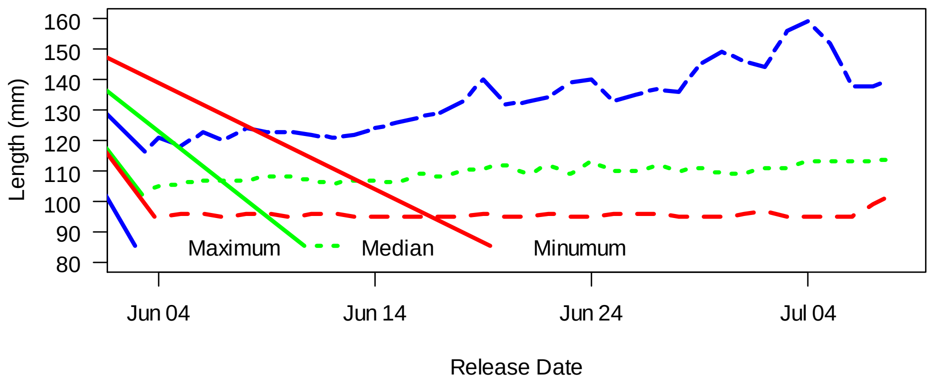


Figure 3.11. Range and median lengths of acoustic-tagged subyearling Chinook salmon used in the 2013 survival studies at a) Little Goose Dam and b) Lower Monumental Dam. R_1 releases were made daily from 3 June through 4 July in the summer study.

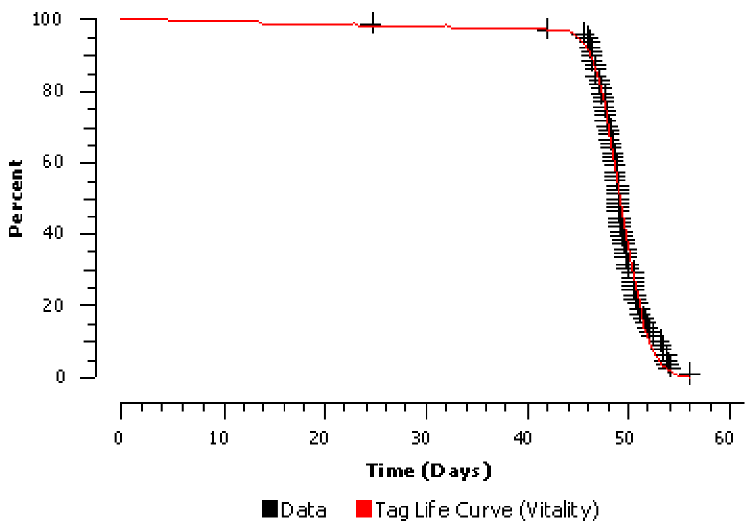


Figure 3.12. Observed time of tag failures (+) and fitted survivorship curves using the vitality model of Li and Anderson (2009) for the 2013 study. Average tag life was 48.9 days.

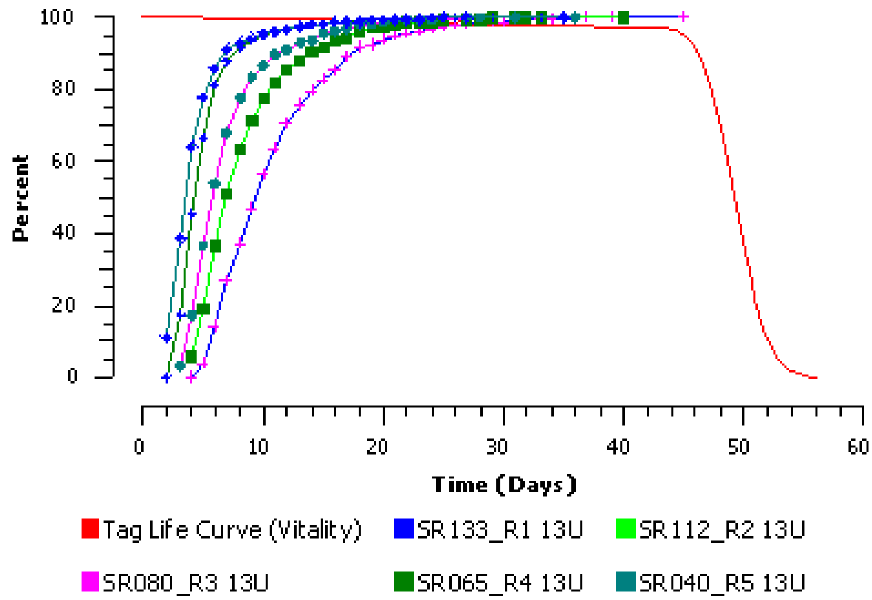
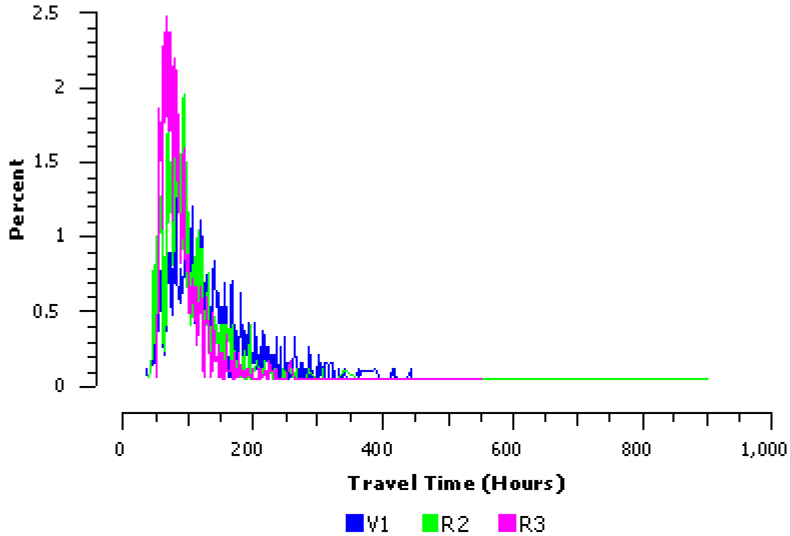


Figure 3.13. Fitted tag-life survivorship curve and the arrival-time distributions of subyearling Chinook salmon smolts from releases V_1, R_2, and R_3 and V_2, R_4, and R_5 at the acoustic-detection array located at rkm 3 (Figure 2.1).

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

Release Group	rkm 80	rkm 67	rkm 40	rkm 17	rkm 3
V_1 (rkm 113)	0.9989 (0.0004)	0.9978 (0.0008)	0.9972 (0.0011)	--	--
R_2 (rkm 112)	--	0.9967 (0.0012)	0.9961 (0.0015)	--	--
R_3 (rkm 80)	--	0.9976 (0.0009)	0.9969 (0.0012)	--	--
V_2 (rkm 67)	--	--	0.9993 (0.0002)	0.9979 (0.0007)	0.9976 (0.0009)
R_4 (rkm 65)	--	--	--	0.9968 (0.0011)	0.9964 (0.0013)
R_5 (rkm 40)	--	--	--	0.9973 (0.0010)	0.9968 (0.0011)

a. rkm 67



b. rkm 40

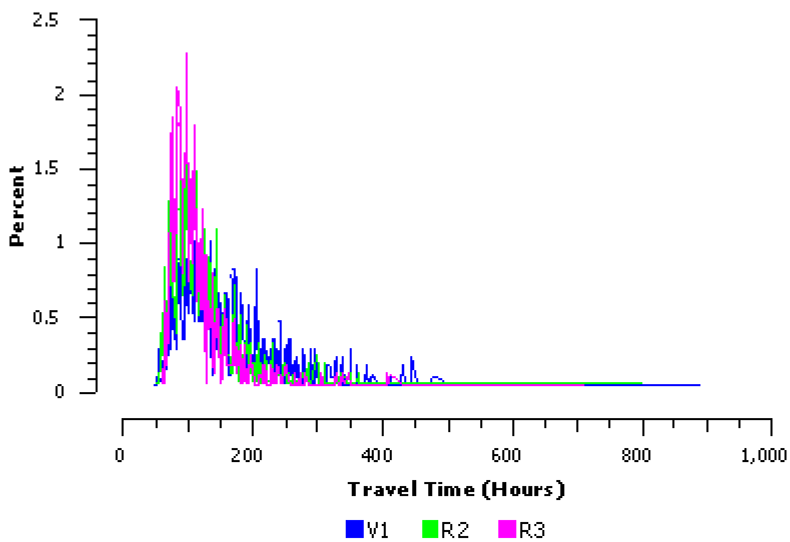
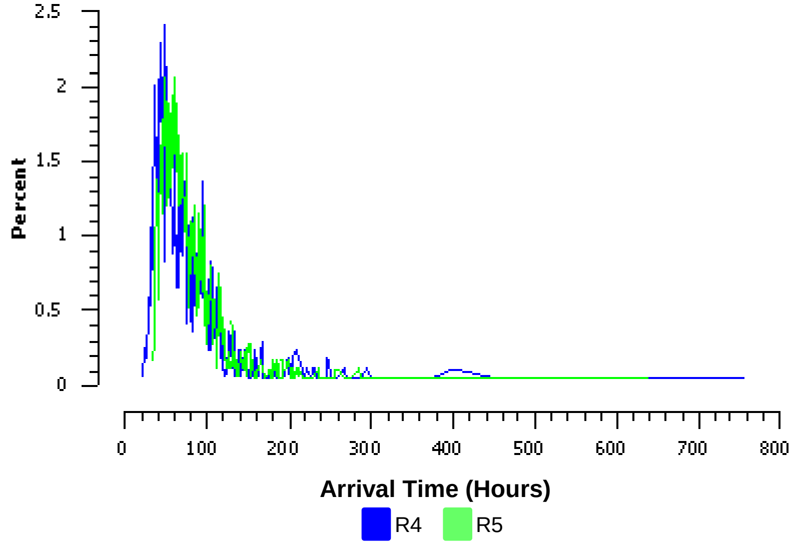


Figure 3.14. Frequency distribution plots of downstream arrival timing (expressed as percentages) for subyearling Chinook salmon releases V_1, R_2, and R_3 at detection arrays located at a) rkm 67 and b) rkm 40 (see Figure 2.1) over the period from 4 June to 6 July 2013. All times are adjusted relative to the release time of R_1.

a. rkm 17



b. rkm 3

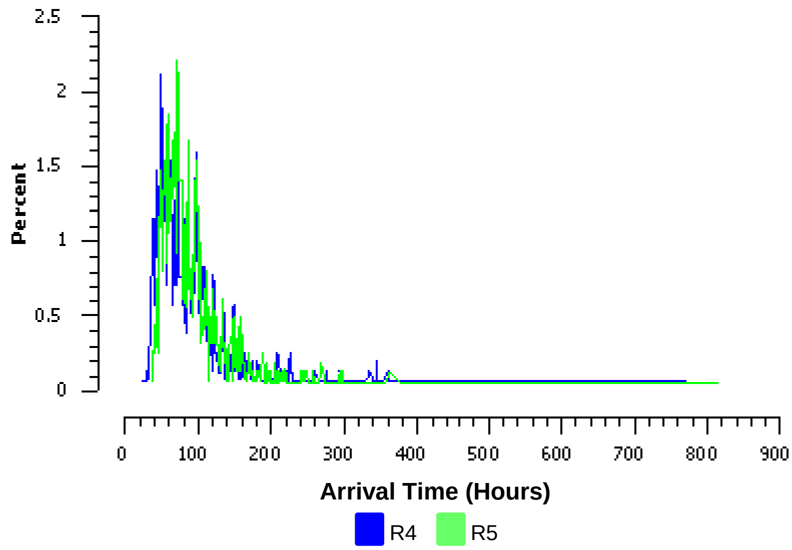


Figure 3.15. Frequency distribution plots of downstream arrival timing (expressed as percentages) for subyearling Chinook salmon releases R_4 and R_5 at detection arrays located at a) rkm 17 and b) rkm 3 (see Figure 2.1) during the period from 6 June to 8 July 2013. All times are adjusted relative to the release time of R_4.

3.5 Survival and Passage Performance

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

3.5.1 Dam Passage Survival

3.5.1.1 Little Goose Dam

A season-wide estimate of dam passage survival was calculated for subyearling Chinook salmon at Little Goose Dam as follows (Table 3.5):

$$\hat{S}_{\text{LGS}} = \frac{0.8635}{\left(\frac{0.8297}{0.8720}\right)} = \frac{0.8635}{0.9514} = 0.9076 \tag{3.1}$$

with an associated standard error of $\widehat{\text{SE}}$ = 0.0139.

Table 3.5. Survival, detection, and λ parameters for the fitted model used to estimate dam passage survival for subyearling Chinook salmon during the summer 2013 study at Little Goose Dam. Standard errors are based on both the inverse Hessian matrix and bootstrapping for key parameters (†) and only the inverse Hessian matrix for associated parameters (*). Bolded numbers were used in virtual paired release survival estimate.

Release	SR 113 to 80 $\hat{S}(\widehat{\text{SE}})$	SR 112 to 67 $\hat{S}(\widehat{\text{SE}})$	SR 80 to 67 $\hat{S}(\widehat{\text{SE}})$
V_1	**0.8635 (0.0069)**†		0.8724 (0.0072)*
R_2		**0.8297 (0.0083)**†	
R_3			**0.8720 (0.0074)** †

Release	SR 80 $\hat{p}(\widehat{\text{SE}})^*$	SR 67 $\hat{p}(\widehat{\text{SE}})^*$	SR 40 $\hat{\lambda}(\widehat{\text{SE}})^*$
V_1	1.0000 (<0.0001)	1.0000 (<0.0001)	0.8987 (0.0070)
R_2		1.0000 (<0.0001)	0.9119 (0.0069)
R_3		0.9994 (0.0006)	0.9012 (0.0071)

While sampling precision was adequate (i.e., $\widehat{\text{SE}}$ = 0.0139 ≤0.015), the 2013 estimate of dam passage survival for subyearling Chinook salmon was below the BiOp threshold (i.e., $\hat{S}_{Dam}$ = 0.9076 < 0.93).

3.5.1.2 Lower Monumental Dam

A season-wide estimate of dam passage survival was calculated for subyearling Chinook salmon at Lower Monumental Dam as follows (Table 3.6):

$$\hat{S}_{\text{LMN}} = \frac{0.9091}{\left(\frac{0.8992}{0.9196}\right)} = \frac{0.9091}{0.9778} = 0.9297 \tag{3.2}$$

with an associated standard error of $\widehat{\text{SE}} = 0.0105$.

Table 3.6. Survival, detection, and λ parameters for final model used to estimate dam passage survival for subyearling Chinook salmon during the summer 2013 study at Lower Monumental Dam. Standard errors are based on both the inverse Hessian matrix and bootstrapping for key parameters (†) and only the inverse Hessian matrix for associated parameters (*). Bolded numbers were used in virtual paired release survival estimate.

Release	SR 67 to 40 $\hat{S}(\widehat{\text{SE}})$	SR 65 to 17 $\hat{S}(\widehat{\text{SE}})$	SR 40 to 17 $\hat{S}(\widehat{\text{SE}})$
V_1	**0.9091 (0.0040)**†		0.9167 (0.0041)*
R_2		**0.8992 (0.0071)**†	
R_3			**0.9196 (0.0064)**†

Release	SR 40 $\hat{p}(\widehat{\text{SE}})^*$	SR 17 $\hat{p}(\widehat{\text{SE}})^*$	SR 3 $\hat{\lambda}(\widehat{\text{SE}})^*$
V_1	1.0000 (< 0.0001)	1.0000 (< 0.0001)	0.9343 (0.0038)
R_2		1.0000 (< 0.0001)	0.9194 (0.0066)
R_3		1.0000 (< 0.0001)	0.9335 (0.0060)

The sampling precision was adequate (i.e., $\widehat{\text{SE}} = 0.0105 < 0.015$), but the point estimate of dam passage survival for subyearling Chinook salmon in 2013 at Lower Monumental Dam was just below the BiOp standard (i.e., $\hat{S}_{\text{Dam}} = 0.9297 < 0.93$).

3.5.2 Forebay-to-Tailrace Passage Survival

The estimates of forebay-to-tailrace passage survival were calculated analogously to that of dam passage survival except the virtual-release group (V_1) was composed of fish known to have arrived at the forebay BRZs rather than at the dam face. These season-wide survival estimates were based on all release data across the study period. Using the same statistical model as was used in estimating dam passage survival, forebay-to-tailrace survival for subyearling Chinook salmon at Little Goose Dam was as follows

$$\text{LGS } \hat{S}_{\text{Forebay-to-tailrace}} = 0.9007 \left(\widehat{\text{SE}} = 0.0139\right). \tag{3.3}$$

At Lower Monumental Dam, forebay-to-tailrace survival was estimated to be:

$$\text{LMN } \hat{S}_{\text{Forebay-to-tailrace}} = 0.9161\left(\text{SE} = 0.0105\right). \tag{3.4}$$

3.5.3 Forebay Residence Time

The forebay residence time was calculated from the first detection of a smolt at the forebay BRZ array to the last detection at the dam (0.9 km). For Little Goose Dam, this distance is 0.9 km and for Lower Monumental Dam, the distance is 0.8 km. The mean forebay residence times for subyearling Chinook salmon smolts at Little Goose Dam was 12.26 h ($\widehat{\text{SE}}$ = 0.67) (Table 3.7). The median residence time was 3.66 h, and the mode occurred between 0.5-1 h (Figure 3.16). At Lower Monumental Dam, the mean residence time was estimated to be 17.44 h ($\widehat{\text{SE}}$ = 0.66). The median residence time was 2.99 h, and the mode occurred between 0.5-1 h (Figure 3.16).

Table 3.7. Estimated mean and median forebay residence time (h) and mean and median tailrace egress times for subyearling Chinook salmon smolts at Little Goose and Lower Monumental dams during 2013. Standard errors are in parentheses.

Performance Measure	Little Goose Dam	Lower Monumental Dam
Forebay Residence Time		
Mean	12.26 (0.67)	17.44 (0.66)
Median	3.66	2.99
Tailrace Egress Time[(a)]		
Mean	3.37 (0.55)	1.16 (0.20)
Median	1.23	0.67

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

3.5.4 Tailrace Egress Time

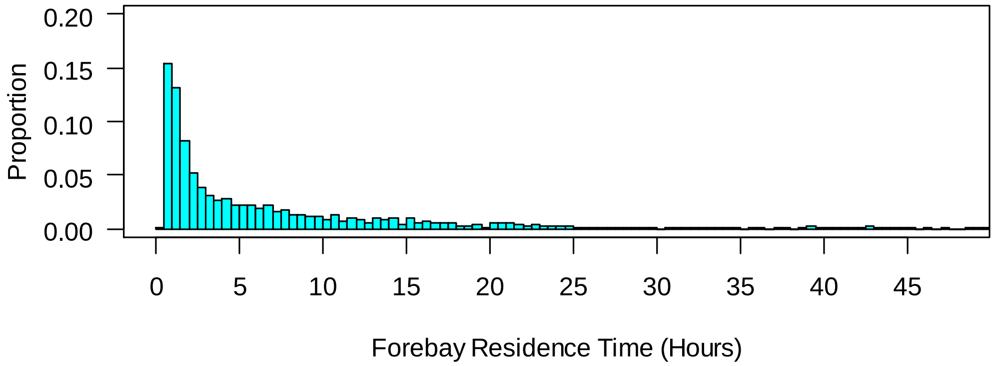
The tailrace egress time was calculated based on the time from the last detection of fish at the double array at the face of the dam to the last detection at the tailrace mixing zone array (

Figure 2.1). However, for bypassed fish, the time was from the last detection in the bypass to the last detection at the tailrace mixing zone array. In all cases, only fish known to be alive during dam passage were used in the calculations, based on detections at the rkm 17 array (

Figure 2.1).

At Little Goose Dam, the mean tailrace egress time was $\bar{t}$ = 3.37 h ($\widehat{\text{SE}}$ = 0.55) (Table 3.7). The median time was calculated to be 1.23 h, with the mode occurring between 0.5 and 1 h (Figure 3.17). At Lower Monumental Dam, the mean tailrace egress time was $\bar{t}$ = 1.16 h ($\widehat{\text{SE}}$ = 0.20). The median time was calculated to be 0.67 h, with the mode occurring between 0.5 h and 1 h (Figure 3.17).

a. Little Goose Dam



b. Lower Monumental Dam

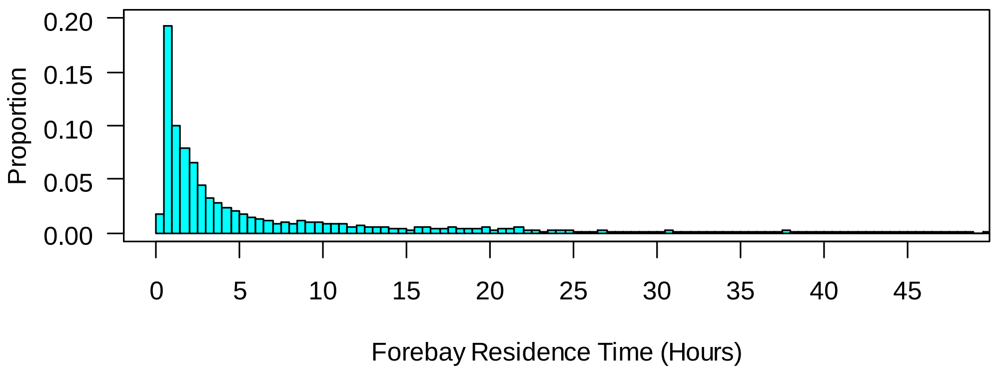
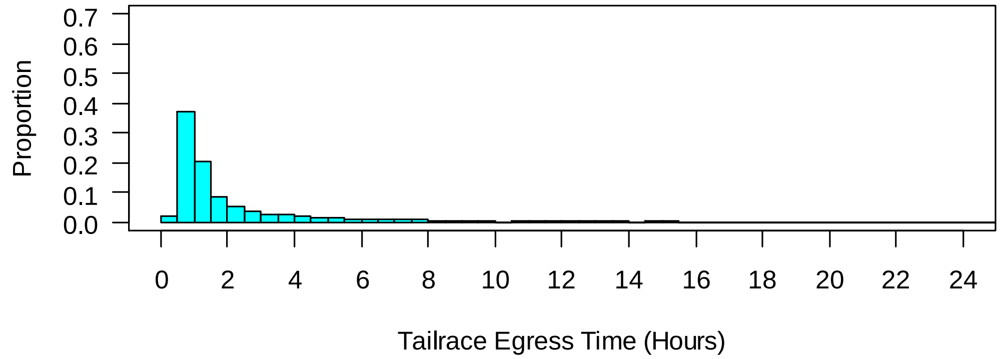


Figure 3.16. Distribution of forebay residence times (0.5-h bins) for subyearling Chinook salmon smolts at a) Little Goose Dam and b) Lower Monumental Dam, 2013.

a. Little Goose Dam



b. Lower Monumental Dam

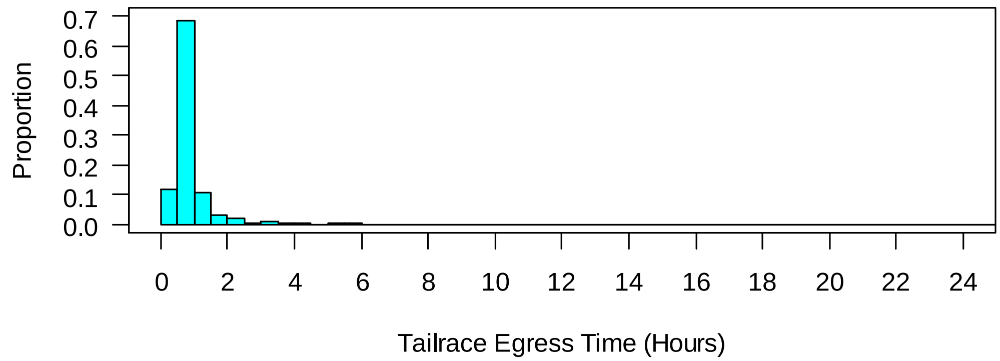


Figure 3.17. Distribution of tailrace egress times (0.5-h bins) for subyearling Chinook salmon smolts at a) Little Goose Dam and b) Lower Monumental Dam, 2013.

3.5.5 Spill Passage Efficiency

SPE is defined as the fraction of the fish that passed through a dam by the spillway or spillway weir. The double-detection arrays at the faces of Little Goose and Lower Monumental dams were used to identify and track fish as they entered the forebays. Using the observed counts and assuming detection efficiency was constant across the dam, the numbers of fish entering the various routes at a dam were used to estimate SPE based on a binomial sampling model. At Little Goose Dam, SPE was estimated to be $\widehat{\text{SPE}} = 0.7683$ ($\widehat{\text{SE}} = 0.0083$). For Lower Monumental Dam, SPE was estimated to be $\widehat{\text{SPE}} = 0.8910$ ($\widehat{\text{SE}} = 0.0043$).

3.5.6 Fish Passage Efficiency

FPE is the fraction of the fish that passed through non-turbine routes at the dam. As with SPE, the double-detection array at the face of Little Goose Dam was used to identify and track fish as they entered the dam. Using the observed counts and assuming constant detection efficiency across the face of the dam, the number of fish entering the various routes at Little Goose Dam was used to estimate FPE based on a binomial sampling model. For subyearling Chinook salmon smolts at Little Goose Dam in 2013, FPE was estimated to be $\text{FPE} = 0.9498$ ($\text{SE} = 0.0043$). At Lower Monumental Dam, FPE was estimated to be $\text{FPE} = 0.9514$ ($\text{SE} = 0.0030$).

4.0 Discussion

This chapter describes the conduct of the 2013 acoustic-telemetry survival studies, study performance, and compares the 2013 results with the 2012 results.

4.1 Study Conduct

The many tests of assumptions (Section 3.4 and Appendix B) found the acoustic-tag study achieved good downstream mixing, with adequate tag-life and no evidence of adverse tagger effects. There also was no evidence of delayed handling/tagger effects within the realm of the study. The results suggest the assumptions of the virtual-paired-release model were fulfilled.

4.2 Study Performance

The sample sizes were adequate in 2013 to achieve the required precision levels (i.e., SE <0.015) for subyearling Chinook salmon at both Little Goose and Lower Monumental dams. The estimates of dam passage survival at both Little Goose and Lower Monumental dams failed to achieve the 2008 BiOp standard for subyearling migrants of $S_{Dam} \geq 0.93$. However, the survival estimate of Lower Monumental Dam (i.e., $\hat{S}_{Dam} = 0.9297$) was 0.0003 less than the BiOp standard.

4.3 Cross-Year Comparison of Study Results

Only subyearling Chinook salmon smolts were evaluated during both 2012 and 2013. Estimates of dam passage survival were approximately 0.05 (i.e., 5 percentage points) lower in 2013 compared to 2012 (Table 4.1). The observed reduction in survival occurred despite SPE and FPE values in 2013 that were as high or higher than in 2012 (Table 4.2). There were, however, longer tailrace egress times in 2013 compared to 2012. These observations suggest the lower 2013 survival rates may be a function of higher tailrace losses once the smolts passed through the dams.

Table 4.1. Comparison of estimates of dam passage survival from performance testing in 2012 and 2013 at Little Goose and Lower Monumental dams. Standard errors are in parentheses.

Project	Stock	2012	2013
Little Goose	Yearling Chinook salmon	0.9822 (0.0076)	N/A
	Steelhead	0.9948 (0.0081)	N/A
	Subyearling Chinook salmon	0.9508 (0.0097)	0.9076 (0.0139)
Lower Monumental	Yearling Chinook salmon	0.9869 (0.0090)	N/A
	Steelhead	0.9826 (0.0021)	N/A
	Subyearling Chinook salmon	0.9789 (0.0079)	0.9297 (0.0079)

Table 4.2. Comparison of Fish Accord performance measures based on results for 2012 and 2013 at Little Goose and Lower Monumental dams. Standard errors are in parentheses.

Project	Performance Measure	2012	2013
	Forebay Residence Time	2.80 h	3.66 h
	Tailrace Egress Time	0.80 h	1.23 h
	Spill Passage Efficiency	0.7249 (0.0086)	0.7683 (0.0083)
	Fish Passage Efficiency	0.9507 (0.0042)	0.9498 (0.0043)
Lower Monumental	$S_{\text{Forebay-to-Tailrace}}$	0.9721 (0.0079)	0.9161 (0.0105)
	Forebay Residence Time	2.60 h	2.99 h
	Tailrace Egress Time	0.53 h	0.67 h
	Spill Passage Efficiency	0.8356 (0.0048)	0.8910 (0.0043)
	Fish Passage Efficiency	0.9236 (0.0034)	0.9514 (0.0030)

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Appendix A

Acoustic Receiver and Fish Release 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
SR114.0_01	46.5893617	-118.0168600
SR114.0_02	46.5881717	-118.0163783
SR114.0_03	46.5871217	-118.0156550
SR114.0_04	46.5859900	-118.0152617
SR112.0_01	46.5809067	-118.0466483
SR112.0_02	46.5802900	-118.0459133
SR112.0_03	46.5797783	-118.0450533
SR080.0_01	46.5817333	-118.3941533
SR080.0_02	46.5806967	-118.3941633
SR080.0_03	46.5797183	-118.3940400
SR080.0_04	46.5787450	-118.3943917
SR068.0_01	46.5675433	-118.5313817
SR068.0_02	46.5669633	-118.5299383
SR068.0_03	46.5658267	-118.5288367
SR068.0_04	46.5649450	-118.5281267
SR065.0_01	46.5474267	-118.5553867
SR065.0_02	46.5465683	-118.5560433
SR065.0_03	46.5470317	-118.5534017
SR040.0_01	46.3789667	-118.6953717
SR040.0_02	46.3788100	-118.6941700
SR040.0_03	46.3784350	-118.6931433
SR040.0_04	46.3783383	-118.6923083
SR017.0_01	46.2528817	-118.8699250
SR017.0_02	46.2519400	-118.8689633
SR017.0_03	46.2510250	-118.8685350
SR017.0_04	46.2498933	-118.8679233
SR003.0_01	46.2161733	-119.0243817
SR003.0_02	46.2153100	-119.0231867
SR003.0_03	46.2148083	-119.0227250
SR003.0_04	46.2143767	-119.0218217

Table A.2. Little Goose Dam (SR113) and Lower Monumental Dam (SR067) cabled receiver locations, WGS84 Datum (degrees.decimal degrees for latitude/longitude NAD83 vertical datum [feet above mean sea level] for elevations).

Waypoint Name	Latitude	Longitude	Elevation
SR113.0_01	46.58616543	-118.0273789	596.88
SR113.0_02	46.58616543	-118.0273789	623.95
SR113.0_03	46.58599119	-118.0273299	596.98
SR113.0_04	46.58599119	-118.0273299	623.72
SR113.0_05	46.58581759	-118.0272810	597.01
SR113.0_06	46.58581759	-118.0272810	623.88
SR113.0_07	46.58564690	-118.0272337	624.02
SR113.0_08	46.58564690	-118.0272337	597.11
SR113.0_09	46.58547392	-118.0271846	596.98
SR113.0_10	46.58547392	-118.0271846	624.02
SR113.0_11	46.58530149	-118.0271363	624.08
SR113.0_12	46.58530149	-118.0271363	597.21
SR113.0_13	46.58512963	-118.0270884	596.88
SR113.0_14	46.58512963	-118.0270884	623.82
SR113.0_15	46.58495583	-118.0270391	622.51
SR113.0_16	46.58495583	-118.0270391	595.41
SR113.0_17	46.58478224	-118.0269909	597.18
SR113.0_18	46.58478224	-118.0269909	624.34
SR113.0_19	46.58468104	-118.0268229	539.76
SR113.0_20	46.58467372	-118.0268723	622.93
SR113.0_21	46.58443898	-118.0267560	540.42
SR113.0_22	46.58443168	-118.0268053	623.42
SR113.0_23	46.58419772	-118.0266880	540.12
SR113.0_24	46.58419034	-118.0267375	623.46
SR113.0_25	46.58395377	-118.0266201	540.51
SR113.0_26	46.58394647	-118.0266694	623.45
SR113.0_27	46.58371143	-118.0265519	540.32
SR113.0_28	46.58370405	-118.0266013	623.36
SR113.0_29	46.58346926	-118.0264836	540.19
SR113.0_30	46.58346188	-118.0265329	623.13
SR113.0_31	46.58322679	-118.0264129	540.38
SR113.0_32	46.58321938	-118.0264624	623.52
SR113.0_33	46.58292047	-118.0263206	626.41
SR067.0_01	46.56455186	-118.5401841	531.12
SR067.0_02	46.56420973	-118.5396080	443.26
SR067.0_03	46.56418889	-118.5396474	527.32
SR067.0_04	46.56402340	-118.5394062	443.36
SR067.0_05	46.56400256	-118.5394456	527.28

Table A.2 (contd)

Waypoint Name	Latitude	Longitude	Elevation
SR067.0_06	46.56382662	-118.5391931	443.06
SR067.0_07	46.56380569	-118.5392326	527.18
SR067.0_08	46.56362800	-118.5389782	443.19
R067.0_09	46.56360717	-118.5390175	527.18
SR067.0_10	46.56343068	-118.5387648	443.33
SR067.0_11	46.56340984	-118.5388042	527.35
SR067.0_12	46.56323260	-118.5385501	443.33
SR067.0_13	46.56323363	-118.5377934	425.69
SR067.0_14	46.56321168	-118.5385895	527.41
SR067.0_15	46.56325183	-118.5377829	424.66
SR067.0_16	46.56323932	-118.5377650	423.75
SR067.0_17	46.56324192	-118.5377768	430.02
SR067.0_18	46.56301586	-118.5376513	433.61
SR067.0_19	46.56303591	-118.5383368	443.36
SR067.0_20	46.56300257	-118.5376657	429.38
SR067.0_21	46.56301395	-118.5376419	428.69
SR067.0_22	46.56302216	-118.5376618	428.36
SR067.0_23	46.56301499	-118.5383762	527.42
SR067.0_24	46.56261439	-118.5380490	526.79
SR067.0_25	46.56261439	-118.5380490	497.92
SR067.0_26	46.56247364	-118.5378969	497.95
SR067.0_27	46.56247364	-118.5378969	526.76
SR067.0_28	46.56233307	-118.5377448	526.83
SR067.0_29	46.56233307	-118.5377448	497.92
SR067.0_30	46.56219314	-118.5375935	497.99
SR067.0_31	46.56219314	-118.5375935	526.89
SR067.0_32	46.56205257	-118.5374415	526.86
SR067.0_33	46.56205257	-118.5374415	497.89
SR067.0_34	46.56191116	-118.5372882	497.66
SR067.0_35	46.56191116	-118.5372882	526.66
SR067.0_36	46.56176912	-118.5371344	526.92
SR067.0_37	46.56176912	-118.5371344	497.99
SR067.0_38	46.56159715	-118.5369512	531.32

Table A.3. Fish release locations in WGS84 Datum (degrees.decimal degrees).

Waypoint Name	Latitude	Longitude
SR133_R11	46.6257000	-117.8067312
SR133_R12	46.6250599	-117.8066040
SR133_R13	46.6243462	-117.8064644
SR133_R14	46.6236451	-117.8062759
SR133_R15	46.6226597	-117.8060713
SR112_R21	46.5818138	-118.0461879
SR112_R22	46.5814000	-118.0457965
SR112_R23	46.5810042	-118.0453007
SR112_R24	46.5805184	-118.0448571
SR112_R25	46.5800686	-118.0444135
SR080_R31	46.5819569	-118.3928509
SR080_R32	46.5810934	-118.3928248
SR080_R33	46.5801939	-118.3927987
SR080_R34	46.5792584	-118.3927726
SR080_R35	46.5783769	-118.3927465
SR065_R41	46.5479037	-118.5553757
SR065_R42	46.5477762	-118.5548458
SR065_R43	46.5475853	-118.5542203
SR065_R44	46.5474246	-118.5535669
SR065_R45	46.5472445	-118.5528696
SR040_R51	46.3792661	-118.6954810
SR040_R52	46.3791309	-118.6947417
SR040_R53	46.3789430	-118.6938351
SR040_R54	46.3787842	-118.6929942
SR040_R55	46.3786472	-118.6920096

Appendix B

Tests of Assumptions

Appendix B

Tests of Assumptions

B.1 Tagger Effects

Data from all five release locations in the two dam studies were examined for tagger effects. This maximized the statistical power to detect tagger effects that might have influenced either or both of the Little Goose Dam and Lower Monumental Dam studies.

A total of eight taggers participated in tagging the subyearling Chinook salmon during the study. To minimize tagger effects that might go undetected, tagger effort should be balanced across release locations and within replicates. Over the course of the current study, tagger effort was balanced between taggers across release locations on a season-wide basis (Table B.1). Tagger effort also was examined within each of the 32 replicate releases and was found to be conditionally balanced among releases R1 through R3 and releases R4 and R5 (Table B.2). This allocation of effort is sufficient to assure balance within each of the separate survival studies at Little Goose and Lower Monumental dams. To test for tagger effects, reach survivals and cumulative survivals were calculated for fish tagged by different staff members on a release-location basis (i.e., $R_1,\ldots,R_5$) (Table B.3). Of the 15 tests of homogeneous reach survivals, two were significant at $\alpha = 0.10$ (i.e., 2/15 or 13.33%). Of the 15 tests of homogeneous cumulative reach survivals, three were significant at $\alpha = 0.10$ (i.e., 3/15 or 20%). However, examination of the individual tests that were significant indicated no consistent pattern where one tagger always performed worse than the other taggers. Consequently, while there was variability in performance between taggers, no one tagger stands out as having uniformly the worst performance. All fish from all taggers were therefore included in the survival analyses.

Table B.1. 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.

	Tagger							
Release Location	Alina	Andy	Brett	Brian	Kateh	Kathleen	Ricardo	Sadie
SR133_R1	367	375	377	376	374	373	379	377
SR112_R2	255	266	266	256	266	261	262	267
SR080_R3	260	258	263	260	265	261	264	268
SR065_R4	238	236	240	240	239	233	238	237
SR040_R5	235	237	239	238	240	238	238	241
Chi-square = 0.6976				df = 28				*P*-value = 1

Table B.2. Contingency tables with numbers of subyearling Chinook salmon tagged by each staff member per release location within a replicate release. A total of 32 replicate day or night releases was performed over the course of the summer 2013 study. Results of the chi-square tests of homogeneity are presented in the form of *P*-values.

a. Replicate 1

Release	Alina	Andy	Brett	Brian	Kateh	Kathleen	Ricardo	Sadie	P-value
SR133_R1	11	13	0	0	0	0	12	13	
SR112_R2	16	17	0	0	0	0	16	17	1
SR080_R3	12	13	0	0	0	0	13	13	
SR065_R4	0	0	15	16	14	15	0	0	0.9955
SR040_R5	0	0	15	15	15	15	0	0	
Chi-square = 286.2979				df = 28					<0.0001

b. Replicate 2

Release	Alina	Andy	Brett	Brian	Kateh	Kathleen	Ricardo	Sadie	P-value
SR133_R1	23	23	0	0	0	0	23	24	
SR112_R2	13	13	0	0	0	0	13	13	1
SR080_R3	16	17	0	0	0	0	16	17	
SR065_R4	0	0	15	15	15	15	0	0	1
SR040_R5	0	0	15	15	15	15	0	0	
Chi-square = 331.0637				df = 28					<0.0001

c. Replicate 3

Release	Alina	Andy	Brett	Brian	Kateh	Kathleen	Ricardo	Sadie	P-value
SR133_R1	0	0	20	17	19	19	0	0	
SR112_R2	0	0	17	15	17	17	0	0	0.9994
SR080_R3	0	0	16	17	16	16	0	0	
SR065_R4	15	15	0	0	0	0	15	15	1
SR040_R5	15	15	0	0	0	0	15	15	
Chi-square = 326.4992				df = 28					<0.0001

d. Replicate 4

Release	Alina	Andy	Brett	Brian	Kateh	Kathleen	Ricardo	Sadie	P-value
SR133_R1	0	0	24	23	24	23	0	0	
SR112_R2	0	0	17	16	17	16	0	0	1
SR080_R3	0	0	17	16	17	16	0	0	
SR065_R4	15	15	0	0	0	0	15	15	1
SR040_R5	15	15	0	0	0	0	15	15	
Chi-square = 346.0069				df = 28					<0.0001

Table B.2. (contd)

e. Replicate 5

Release	Alina	Andy	Brett	Brian	Kateh	Kathleen	Ricardo	Sadie	P-value
SR133_R1	0	0	24	24	24	24	0	0	1
SR112_R2	0	0	17	16	17	16	0	0	
SR080_R3	0	0	17	16	17	16	0	0	
SR065_R4	15	15	0	0	0	0	15	14	0.9825
SR040_R5	13	15	0	0	0	0	15	15	
Chi-square = 345.5750				df = 28					<0.0001

f. Replicate 6

Release	Alina	Andy	Brett	Brian	Kateh	Kathleen	Ricardo	Sadie	P-value
SR133_R1	0	0	23	24	23	24	0	0	0.9999
SR112_R2	0	0	17	16	17	16	0	0	
SR080_R3	0	0	16	17	17	16	0	0	
SR065_R4	15	14	0	0	0	0	15	15	0.9953
SR040_R5	14	15	0	0	0	0	15	15	
Chi-square = 344.4234				df = 28					<0.0001

g. Replicate 7

Release	Alina	Andy	Ricardo	Sadie	P-value
SR133_R1	24	25	25	26	1
SR112_R2	17	16	16	17	
SR080_R3	17	17	17	17	
SR065_R4	15	15	14	15	1
SR040_R5	15	15	14	15	
Chi-square = 0.1521			df = 12		1

h. Replicate 8

Release	Alina	Andy	Ricardo	Sadie	P-value
SR133_R1	23	23	25	23	1
SR112_R2	17	16	17	17	
SR080_R3	16	16	17	17	
SR065_R4	14	15	15	14	0.9924
SR040_R5	15	14	15	15	
Chi-square = 0.1911			df = 12		1

Table B.2. (contd)

i. Replicate 9

Release	Alina	Andy	Brett	Brian	Kateh	Kathleen	Ricardo	Sadie	P-value
SR133_R1	25	25	0	0	0	0	25	25	0.9959
SR112_R2	16	17	0	0	0	0	17	16	
SR080_R3	18	14	0	0	0	0	18	18	
SR065_R4	0	0	15	15	15	14	0	0	0.9953
SR040_R5	0	0	14	15	15	15	0	0	
Chi-square = 353.1536				df = 28					<0.0001

j. Replicate 10

Release	Alina	Andy	Brett	Brian	Kateh	Kathleen	Ricardo	Sadie	P-value
SR133_R1	24	23	0	0	0	0	24	23	1
SR112_R2	16	17	0	0	0	0	17	17	
SR080_R3	16	17	0	0	0	0	16	17	
SR065_R4	0	0	15	15	14	15	0	0	0.9953
SR040_R5	0	0	15	15	15	14	0	0	
Chi-square = 345.4068				df = 28					<0.0001

k. Replicate 11

Release	Brett	Brian	Kateh	Kathleen	P-value
SR133_R1	25	24	24	23	0.9999
SR112_R2	16	16	17	16	
SR080_R3	17	15	17	17	
SR065_R4	15	15	15	14	0.9924
SR040_R5	15	14	14	15	
Chi-square = 0.3173			df = 12		1

l. Replicate 12

Release	Brett	Brian	Kateh	Kathleen	P-value
SR133_R1	23	24	23	24	0.9999
SR112_R2	16	17	17	16	
SR080_R3	15	16	17	17	
SR065_R4	15	15	15	14	1
SR040_R5	15	15	15	14	
Chi-square = 0.2975			df = 12		1

Table B.2. (contd)

m. Replicate 13

Release	Alina	Andy	Brett	Brian	Kateh	Kathleen	Ricardo	Sadie	P-value
SR133_R1	0	0	22	24	24	24	0	0	
SR112_R2	0	0	16	16	16	17	0	0	0.9999
SR080_R3	0	0	17	16	17	16	0	0	
SR065_R4	15	15	0	0	0	0	15	14	0.9983
SR040_R5	14	14	0	0	0	0	15	14	
Chi-square = 341.3844				df = 28					<0.0001

n. Replicate 14

Release	Alina	Andy	Brett	Brian	Kateh	Kathleen	Ricardo	Sadie	P-value
SR133_R1	0	0	24	23	24	23	0	0	
SR112_R2	0	0	16	16	16	17	0	0	1
SR080_R3	0	0	16	17	16	17	0	0	
SR065_R4	14	15	0	0	0	0	14	15	0.9989
SR040_R5	15	15	0	0	0	0	14	15	
Chi-square = 342.2821				df = 28					<0.0001

o. Replicate 15

Release	Alina	Andy	Ricardo	Sadie	P-value
SR133_R1	24	24	23	25	
SR112_R2	16	16	16	17	1
SR080_R3	16	16	17	17	
SR065_R4	15	15	15	15	1
SR040_R5	15	15	15	15	
Chi-square = 0.1121			df = 12		1

p. Replicate 16

Release	Alina	Andy	Ricardo	Sadie	P-value
SR133_R1	24	23	24	23	
SR112_R2	15	17	18	16	0.9998
SR080_R3	16	16	17	16	
SR065_R4	15	15	15	15	0.9989
SR040_R5	15	14	15	15	
Chi-square = 0.3029			df = 12		1

Table B.2. (contd)

q. Replicate 17

Release	Alina	Andy	Brett	Brian	Kateh	Kathleen	Ricardo	Sadie	P-value
SR133_R1	25	25	0	0	0	0	24	24	
SR112_R2	16	17	0	0	0	0	15	17	1
SR080_R3	17	17	0	0	0	0	17	17	
SR065_R4	0	0	15	15	15	14	0	0	0.9989
SR040_R5	0	0	15	15	15	15	0	0	
Chi-square = 350.2719				df = 28					<0.0001

r. Replicate 18

Release	Alina	Andy	Brett	Brian	Kateh	Kathleen	Ricardo	Sadie	P-value
SR133_R1	24	23	0	0	0	0	24	23	
SR112_R2	17	17	0	0	0	0	17	17	1
SR080_R3	16	16	0	0	0	0	16	17	
SR065_R4	0	0	14	15	15	15	0	0	0.9953
SR040_R5	0	0	15	15	15	14	0	0	
Chi-square = 345.3160				df = 28					<0.0001

s. Replicate 19

Release	Brett	Brian	Kateh	Kathleen	P-value
SR133_R1	25	23	24	24	
SR112_R2	17	16	17	16	1
SR080_R3	17	16	16	17	
SR065_R4	15	15	15	15	1
SR040_R5	15	15	15	15	
Chi-square = 0.1126			df = 12		1

t. Replicate 20

Release	Brett	Brian	Kateh	Kathleen	P-value
SR133_R1	23	24	23	24	
SR112_R2	16	17	17	16	0.9999
SR080_R3	17	16	17	16	
SR065_R4	15	15	15	15	1
SR040_R5	15	15	15	15	
Chi-square = 0.1522			df = 12		1

Table B.2. (contd)

u. Replicate 21

Release	Alina	Andy	Brett	Brian	Kateh	Kathleen	Ricardo	Sadie	P-value
SR133_R1	0	0	25	24	24	22	0	0	
SR112_R2	0	0	16	16	16	17	0	0	0.9997
SR080_R3	0	0	16	17	16	16	0	0	
SR065_R4	15	13	0	0	0	0	15	15	0.9907
SR040_R5	15	15	0	0	0	0	15	15	
Chi-square = 343.6909				df = 28					<0.0001

v. Replicate 22

Release	Alina	Andy	Brett	Brian	Kateh	Kathleen	Ricardo	Sadie	P-value
SR133_R1	0	0	23	24	23	23	0	0	
SR112_R2	0	0	17	15	17	16	0	0	0.9998
SR080_R3	0	0	17	16	16	16	0	0	
SR065_R4	15	15	0	0	0	0	15	15	0.9990
SR040_R5	15	15	0	0	0	0	15	16	
Chi-square = 344.3748				df = 28					<0.0001

w. Replicate 23

Release	Alina	Andy	Ricardo	Sadie	P-value
SR133_R1	24	25	26	26	
SR112_R2	15	17	16	17	1
SR080_R3	17	17	17	17	
SR065_R4	15	15	15	15	0.9955
SR040_R5	14	15	15	16	
Chi-square = 0.1986			df = 12		1

x. Replicate 24

Release	Alina	Andy	Ricardo	Sadie	P-value
SR133_R1	22	24	24	24	
SR112_R2	17	17	17	17	0.9997
SR080_R3	17	15	17	16	
SR065_R4	15	15	15	15	0.9989
SR040_R5	15	14	15	15	
Chi-square = 0.2923			df = 12		1

Table B.2. (contd)

y. Replicate 25

Release	Alina	Andy	Brett	Brian	Kateh	Kathleen	Ricardo	Sadie	P-value
SR133_R1	24	26	0	0	0	0	26	26	1
SR112_R2	15	17	0	0	0	0	16	17	
SR080_R3	16	17	0	0	0	0	17	17	
SR065_R4	0	0	15	15	15	14	0	0	0.9644
SR040_R5	0	0	15	13	15	16	0	0	
Chi-square = 352.8856				df = 28					<0.0001

z. Replicate 26

Release	Alina	Andy	Brett	Brian	Kateh	Kathleen	Ricardo	Sadie	P-value
SR133_R1	23	24	0	0	0	0	24	22	0.9999
SR112_R2	17	17	0	0	0	0	16	17	
SR080_R3	16	17	0	0	0	0	16	17	
SR065_R4	0	0	15	15	15	14	0	0	0.9989
SR040_R5	0	0	14	15	15	14	0	0	
Chi-square = 343.3370				df = 28					<0.0001

aa. Replicate 27

Release	Brett	Brian	Kateh	Kathleen	P-value
SR133_R1	25	25	24	23	0.9999
SR112_R2	17	16	17	16	
SR080_R3	16	16	16	17	
SR065_R4	15	15	15	15	1
SR040_R5	15	15	15	15	
Chi-square = 0.1980			df = 12		1

bb. Replicate 28

Release	Brett	Brian	Kateh	Kathleen	P-value
SR133_R1	23	24	23	24	0.9999
SR112_R2	17	16	17	16	
SR080_R3	16	17	17	16	
SR065_R4	15	15	15	14	0.9989
SR040_R5	15	15	15	15	
Chi-square = 0.1831			df = 12		1

Table B.2. (contd)

cc. Replicate 29

Release	Alina	Andy	Brett	Brian	Kateh	Kathleen	Ricardo	Sadie	P-value
SR133_R1	0	0	25	26	25	25	0	0	
SR112_R2	0	0	17	16	15	17	0	0	0.9998
SR080_R3	0	0	16	16	17	16	0	0	
SR065_R4	15	15	0	0	0	0	15	15	0.9990
SR040_R5	15	16	0	0	0	0	15	15	
Chi-square = 352.4252				df = 28					<0.0001

dd. Replicate 30

Release	Alina	Andy	Brett	Brian	Kateh	Kathleen	Ricardo	Sadie	P-value
SR133_R1	0	0	23	23	23	24	0	0	
SR112_R2	0	0	17	16	16	16	0	0	1
SR080_R3	0	0	17	16	16	16	0	0	
SR065_R4	15	14	0	0	0	0	15	15	0.9989
SR040_R5	15	15	0	0	0	0	15	15	
Chi-square = 342.1887				df = 28					<0.0001

ee. Replicate 31

Release	Alina	Andy	Brett	Brian	Kateh	Kathleen	Ricardo	Sadie	P-value
SR133_R1	25	26	0	0	0	0	26	27	
SR112_R2	16	17	0	0	0	0	17	17	0.9999
SR080_R3	18	16	0	0	0	0	17	18	
SR065_R4	0	0	15	14	15	15	0	0	0.9989
SR040_R5	0	0	15	15	15	15	0	0	
Chi-square = 359.3534				df = 28					<0.0001

ff. Replicate 32

Release	Alina	Andy	Brett	Brian	Kateh	Kathleen	Ricardo	Sadie	P-value
SR133_R1	22	23	0	0	0	0	24	23	
SR112_R2	16	18	0	0	0	0	18	18	1
SR080_R3	16	17	0	0	0	0	16	17	
SR065_R4	0	0	16	15	16	15	0	0	0.9984
SR040_R5	0	0	16	16	16	16	0	0	
Chi-square = 354.2609				df = 28					<0.0001

Table B.3. 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 SR080.0		SR080.0 to SR067.0		SR067.0 to SR040.0		SR040.0 to SR017.0	
Tagger	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE
Alina	0.8942	0.0161	0.8665	0.0190	0.8607	0.0207	0.9114	0.0185	0.9074	0.0197
Andy	0.8667	0.0176	0.8766	0.0185	0.8845	0.0192	0.8703	0.0217	0.9183	0.0190
Brett	0.8462	0.0186	0.8371	0.0209	0.8736	0.0206	0.9022	0.0198	0.9261	0.0184
Brian	0.8697	0.0174	0.8896	0.0176	0.8759	0.0196	0.8898	0.0200	0.9450	0.0154
Kateh	0.8770	0.0170	0.8457	0.0201	0.8576	0.0212	0.8995	0.0200	0.9220	0.0187
Kathleen	0.8981	0.0157	0.8359	0.0204	0.8905	0.0189	0.8926	0.0199	0.9256	0.0179
Ricardo	0.8522	0.0182	0.8742	0.0186	0.8597	0.0208	0.9185	0.0179	0.9393	0.0163
Sadie	0.8806	0.0167	0.8611	0.0192	0.8710	0.0201	0.8833	0.0207	0.9245	0.0181
P-value	0.3352		0.4044		0.9294		0.7529		0.8876	

b. Release 1 (SR133) – Cumulative Survival

	Release to SR113.0		Release to SR080.0		Release to SR067.0		Release to SR040.0		Release to SR017.0	
Tagger	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE
Alina	0.8942	0.0161	0.7747	0.0219	0.6668	0.0247	0.6077	0.0257	0.5515	0.0262
Andy	0.8667	0.0176	0.7597	0.0222	0.6719	0.0245	0.5848	0.0258	0.5370	0.0262
Brett	0.8462	0.0186	0.7083	0.0235	0.6187	0.0252	0.5582	0.0258	0.5170	0.0260
Brian	0.8697	0.0174	0.7737	0.0217	0.6776	0.0244	0.6030	0.0256	0.5698	0.0259
Kateh	0.8770	0.0170	0.7417	0.0227	0.6360	0.0250	0.5721	0.0258	0.5274	0.0261
Kathleen	0.8981	0.0157	0.7507	0.0225	0.6685	0.0246	0.5967	0.0256	0.5523	0.0260
Ricardo	0.8522	0.0182	0.7450	0.0225	0.6405	0.0248	0.5883	0.0255	0.5526	0.0258
Sadie	0.8806	0.0167	0.7583	0.0222	0.6605	0.0246	0.5834	0.0257	0.5394	0.0260
P-value	0.3352		0.5081		0.6639		0.9027		0.8977	

Table B.3. (contd)

c. Release 2 (SR112) – Reach Survival

Tagger	Release to SR080.0		SR080.0 to SR067.0		SR067.0 to SR040.0		SR040.0 to SR017.0	
	Est	SE	Est	SE	Est	SE	Est	SE
Alina	0.9449	0.0143	0.8542	0.0228	0.9109	0.0200	0.9130	0.0208
Andy	0.9361	0.0150	0.9355	0.0156	0.9079	0.0192	0.9565	0.0142
Brett	0.9361	0.0150	0.8795	0.0206	0.9065	0.0199	0.8814	0.0232
Brian	0.8945	0.0192	0.8908	0.0206	0.9250	0.0186	0.8919	0.0228
Kateh	0.9286	0.0158	0.8826	0.0205	0.8832	0.0220	0.8836	0.0233
Kathleen	0.9234	0.0165	0.8755	0.0213	0.9275	0.0180	0.9267	0.0189
Ricardo	0.9389	0.0148	0.8862	0.0202	0.9202	0.0186	0.9337	0.0178
Sadie	0.9363	0.0149	0.9120	0.0179	0.9107	0.0191	0.9020	0.0208
P-value	0.4360		0.1613		0.8272		0.1091	

d. Release 2 (SR112) – Cumulative Survival

Tagger	Release to SR080.0		Release to SR067.0		Release to SR040.0		Release to SR017.0	
	Est	SE	Est	SE	Est	SE	Est	SE
Alina	0.9449	0.0143	0.8071	0.0248	0.7352	0.0278	0.6712	0.0296
Andy	0.9361	0.0150	0.8757	0.0203	0.7950	0.0249	0.7605	0.0263
Brett	0.9361	0.0150	0.8233	0.0234	0.7464	0.0268	0.6579	0.0293
Brian	0.8945	0.0192	0.7969	0.0251	0.7371	0.0276	0.6574	0.0298
Kateh	0.9286	0.0158	0.8195	0.0236	0.7238	0.0275	0.6396	0.0296
Kathleen	0.9234	0.0165	0.8084	0.0244	0.7498	0.0269	0.6949	0.0286
Ricardo	0.9389	0.0148	0.8321	0.0231	0.7657	0.0263	0.7149	0.0281
Sadie	0.9363	0.0149	0.8539	0.0216	0.7777	0.0255	0.7014	0.0282
P-value	0.4360		0.2610		0.5838		0.0734	

Table B.3. (contd)

e. Release 3 (SR82) – Reach Survival

Tagger	Release to SR067.0		SR067.0 to SR040.0		SR040.0 to SR017.0	
	Est	SE	Est	SE	Est	SE
Alina	0.8346	0.0230	0.8884	0.0215	0.8848	0.0231
Andy	0.8527	0.0221	0.9263	0.0177	0.9104	0.0201
Brett	0.8593	0.0214	0.9022	0.0198	0.9212	0.0189
Brian	0.8808	0.0201	0.8884	0.0210	0.9548	0.0147
Kateh	0.8833	0.0198	0.9304	0.0168	0.9023	0.0202
Kathleen	0.8885	0.0195	0.9115	0.0189	0.9272	0.0181
Ricardo	0.8788	0.0201	0.8745	0.0218	0.8762	0.0232
Sadie	0.8806	0.0198	0.8836	0.0211	0.8634	0.0240
P-value	0.5653		0.3867		0.0379	

f. Release 3 (SR82) – Cumulative Survival

Tagger	Release to SR067.0		Release to SR040.0		Release to SR017.0	
	Est	SE	Est	SE	Est	SE
Alina	0.8346	0.0230	0.7414	0.0272	0.6560	0.0295
Andy	0.8527	0.0221	0.7898	0.0254	0.7191	0.0281
Brett	0.8593	0.0214	0.7753	0.0258	0.7142	0.0279
Brian	0.8808	0.0201	0.7825	0.0257	0.7471	0.0271
Kateh	0.8833	0.0198	0.8219	0.0236	0.7416	0.0270
Kathleen	0.8885	0.0195	0.8098	0.0245	0.7509	0.0270
Ricardo	0.8788	0.0201	0.7685	0.0260	0.6734	0.0289
Sadie	0.8806	0.0198	0.7781	0.0255	0.6718	0.0289
P-value	0.5653		0.4691		0.0848	

Table B.3. (contd))

g. Release 4 (SR65) – Reach Survival

Tagger	Release to SR040.0		SR040.0 to SR017.0	
	Est	SE	Est	SE
Alina	0.9958	0.0042	0.9325	0.0163
Andy	0.9915	0.0060	0.9316	0.0165
Brett	0.9833	0.0083	0.8517	0.0231
Brian	0.9917	0.0059	0.8950	0.0199
Kateh	0.9791	0.0093	0.9316	0.0165
Kathleen	0.9828	0.0085	0.8821	0.0213
Ricardo	0.9874	0.0072	0.9191	0.0178
Sadie	0.9958	0.0042	0.9110	0.0185
P-value	0.5748		0.0218	

h. Release 4 (SR65) – Cumulative Survival

Tagger	Release to SR040.0		Release to SR017.0	
	Est	SE	Est	SE
Alina	0.9958	0.0042	0.9286	0.0167
Andy	0.9915	0.0060	0.9237	0.0173
Brett	0.9833	0.0083	0.8375	0.0238
Brian	0.9917	0.0059	0.8875	0.0204
Kateh	0.9791	0.0093	0.9121	0.0183
Kathleen	0.9828	0.0085	0.8670	0.0222
Ricardo	0.9874	0.0072	0.9076	0.0188
Sadie	0.9958	0.0042	0.9072	0.0188
P-value	0.5748		0.0157	

Table B.3. (contd)

i. Release 5 (SR40) – Reach Survival

Tagger	Release to SR017.0	
	Est	SE
Alina	0.9191	0.0178
Andy	0.9494	0.0142
Brett	0.8996	0.0194
Brian	0.9286	0.0167
Kateh	0.8875	0.0204
Kathleen	0.9286	0.0167
Ricardo	0.9202	0.0176
Sadie	0.9046	0.0189
P-value	0.2993	

j. Release 5 (SR40) – Cumulative Survival

Tagger	Release to SR017.0	
	Est	SE
Alina	0.9191	0.0178
Andy	0.9494	0.0142
Brett	0.8996	0.0194
Brian	0.9286	0.0167
Kateh	0.8875	0.0204
Kathleen	0.9286	0.0167
Ricardo	0.9202	0.0176
Sadie	0.9046	0.0189
P-value	0.2993	

B.2 Examination of Delayed Handling Effects

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

One of the four tests (i.e., 25%) of reach survival was significant at $\alpha = 0.10$ (Table B.4). Comparisons of cumulative survival in reaches common to multiple release groups found two of five tests (i.e., 40%) significant at $\alpha = 0.10$ (Table B.5, Table B.6). In several instances, the R_1 release had higher survival than some of the downstream release groups (i.e., R_2 and R_5), suggesting no specific pattern of delayed/handling effects. Consequently, no convincing evidence was found in the spring 2013 study 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.

Table B.4. Comparison of reach survival of subyearling Chinook salmon by release location (i.e., R_1, R_2,…)

	R_1 (SR133)		R_2 (SR112)		R_3 (SR080)		R_4 (SR065)		R_5 (SR040)		
Reach	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE	*P* (*F*-test)
Release to SR113	0.8754	0.0062									
SR113 to SR080	0.8616	0.0069	0.9319	0.0056							
SR080 to SR067	0.8726	0.0071	0.8908	0.0071	0.8720	0.0074					0.0669
SR067 to SR040	0.8963	0.0070	0.9119	0.0069	0.9012	0.0071	0.9902	0.0025			0.2729
SR040 to SR017	0.9275	0.0064	0.9129	0.0072	0.9063	0.0073	0.9082	0.0067	0.9196	0.0064	0.1249
SR017 to SR003 (λ)	0.9320	0.0064	0.9352	0.0066	0.9336	0.0065	0.9194	0.0066	0.9335	0.0060	0.4034

Table B.5. Comparison of cumulative reach survival of subyearling Chinook salmon by release location (i.e., R_1, R_2)

	R_1 (SR133)		R_2 (SR112)		
Reach	Est	SE	Est	SE	P (*F*-test)
SR080 to SR067	0.8726	0.0071	0.8908	0.0071	0.0659
SR080 to SR040	0.7821	0.0089	0.8123	0.0090	0.0308
SR080 to SR017	0.7255	0.0097	0.7416	0.0101	0.3199

Table B.6. Comparison of cumulative reach survival of subyearling Chinook salmon by release location (i.e., R_1, R_2, R_3)

	R_1 (SR133)		R_2 (SR112)		R_3 (SR080)		
Reach	Est	SE	Est	SE	Est	SE	*P* (*F*-test)
SR067 to SR040	0.8963	0.0070	0.9119	0.0069	0.9012	0.0071	0.2729
SR067 to SR017	0.8314	0.0087	0.8325	0.0091	0.8167	0.0092	0.4121

Appendix C

Capture Histories Used in Estimating Dam Passage Survival

Appendix C

Capture Histories Used in Estimating Dam Passage Survival

C.1 Little Goose Dam

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

	V_1 (Season-Wide)	
Capture History	Dam Passage Survival	Forebay-to-Tailrace Survival
111	1,684	1,685
011	0	0
101	0	0
001	0	0
120	31	31
020	0	0
110	191	192
010	0	0
200	3	3
100	281	281
000	349	369
Total	**2,539**	**2,561**

	Season-Wide Dam Passage Survival	
Capture History	R_2	R_3
11	1,551	1,621
01	0	1
20	33	24
10	151	179
00	363	273
Total	**2,098**	**2,098**

C.2 Lower Monumental Dam

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

	V_2 (Season-Wide)	
Capture History	Dam Passage Survival	Forebay-to-Tailrace Survival
111	4,003	4,006
011	0	0
101	0	0
001	0	0
120	0	0
020	0	0
110	283	283
010	0	0
200	2	2
100	396	396
000	472	550
Total	**5,156**	**5,237**

	Season-Wide Dam Passage Survival	
Capture History	R_4	R_5
11	1,566	1,631
01	0	0
20	0	0
10	138	117
00	197	158
Total	**1,901**	**1,906**

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