PNNL-23979

US Army Corps
of Engineers®

Prepared for the U.S. Army Corps of Engineers, Walla Walla District,
under an Interagency Agreement with the U.S. Department of Energy
Contract DE-AC05-76RL01830

Compliance Monitoring of Yearling and Subyearling Chinook Salmon and Juvenile Steelhead Survival and Passage at McNary Dam, 2014

FINAL COMPLIANCE REPORT

JR Skalski
RL Townsend
MA Weiland
CM Woodley
J Kim

March 2015

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Contract DE-AC05-76RL01830

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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 (USACE), Walla Walla District (NWW). The PNNL project managers were Mark A. Weiland and Christa M. Woodley; the UW project manager was John R. Skalski. The USACE-NWW technical lead was Mr. Eric Hockersmith. The study was designed to estimate dam passage survival at McNary Dam as stipulated by the 2008 Federal Columbia River Power System (FCRPS) Biological Opinion (BiOp) and provide additional performance measures as specified in the Columbia Basin Fish Accords.

This report summarizes the results of the 2014 spring and summer compliance studies of yearling and subyearling Chinook salmon (*Oncorhynchus tshawytscha*) and juvenile steelhead (*O. mykiss*) at McNary Dam in 2014.

Suggested citation for this report:

Skalski, JR, RL Townsend, MA Weiland, CM Woodley, and J Kim. 2014. *Compliance Monitoring of Yearling and Subyearling Chinook Salmon and Juvenile Steelhead Survival and Passage at McNary Dam, 2014*. PNNL-23979, Pacific Northwest National Laboratory, Richland, Washington.

Executive Summary

The objective of this compliance study was to estimate dam passage survival of yearling and subyearling Chinook salmon and juvenile steelhead at McNary Dam (MCN) during spring and summer outmigration in 2014. Under the 2008 Federal Columbia River Power System (FCRPS) Biological Opinion (BiOp), dam passage survival should be greater than or equal to 0.96 for spring migrants and greater than or equal to 0.93 for summer migrants, estimated with a standard error (SE) less than or equal to 0.015. The study also estimated juvenile salmonid passage survival for the estimated zone of hydraulic influence of the dam from 2 km upstream of the dam (forebay) to 2 km downstream of the dam (tailrace),[1] as well as the forebay residence time, tailrace egress time, spill passage efficiency (SPE), and fish passage efficiency (FPE), as required in the Columbia Basin Fish Accords (Fish Accords).

A virtual/paired-release design was used to estimate dam passage survival at McNary Dam. The approach included releases of yearling and subyearling Chinook salmon and juvenile steelhead above McNary Dam, tagged with both acoustic transmitters and passive integrated transponders, that contributed to the formation of a virtual release at the face of McNary Dam. A survival estimate from this release was adjusted by a paired release below McNary Dam. A total of 2,391 yearling Chinook salmon, 2,376 juvenile steelhead, and 2,412 subyearling Chinook salmon were used in the virtual releases. Sample sizes for the below-dam paired releases used in the analyses were 2,000 and 1,988 for yearling Chinook salmon, 1,998 and 1,995 for juvenile steelhead, and 1,995 and 1,989 for subyearling Chinook salmon for the R_2 and R_3 released fish, respectively. The Juvenile Salmon Acoustic Telemetry System (JSATS) acoustic transmitters (ATs) (model SS300, 0.308 g in air, Advanced Telemetry Systems, Isanti, Minnesota) were surgically implanted in the yearling and subyearling Chinook salmon and juvenile steelhead, along with passive integrated transponders (PITs) (model HPT12, Biomark, Boise Idaho) to differentiate between turbine and juvenile bypass guided fish at the powerhouse.

The 2014 Fish Passage Plan called for 40% spill in spring and 50% spill in summer. The spring spill target could not be maintained, due to a combination of high river discharge and turbine outages for maintenance. The 50% spill objective was met for all, but the first few days of the survival study in summer. Dam passage survival was estimated seasonally, regardless of spill conditions. Temporary spill weirs (TSWs) were installed in spillbays 19 and 20 in spring, but were removed for the summer study in accordance with the 2014 Fish Passage Plan.

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

The study results are summarized in the following tables.

Table ES.1. Estimates of dam passage survival(a) at McNary Dam in 2014. Standard errors in parentheses.

Spill Operations	Yearling Chinook Salmon	Juvenile Steelhead	Subyearling Chinook Salmon
Spring at 40% spill	0.9610 (0.0127)	0.9698 (0.0136)	
Summer at 50% spill			0.9239 (0.0180)

(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 at McNary Dam in 2014 for yearling and subyearling Chinook salmon and juvenile steelhead. Standard errors in parentheses.

Performance Measures	Yearling Chinook Salmon	Juvenile Steelhead	Subyearling Chinook Salmon
Forebay-to-tailrace survival (season-wide)	0.9575 (0.0127)	0.9663 (0.0136)	0.9215 (0.0180)
Forebay residence time (mean/median) b	3.06/1.73 h (0.30)	5.07/2.57 h (0.17)	3.76/2.22 h (0.16)
Tailrace egress rate (mean/median)b	0.74/0.44 h (0.20)	0.60/0.37 h (0.09)	1.07/0.54 h (0.18)
Spill passage efficiency(a)	0.7140 (0.0092)	0.8433 (0.0075)	0.5380 (0.0102)
Fish passage efficiency	0.9118 (0.0058)	0.9730 (0.0033)	0.8090 (0.0080)

(a) The estimate of spill passage efficiency includes the fraction of fish going through the temporary spill weir (TSW) and non-TSW spill bays in spring, when they were installed.
(b) Standard error on mean.

Table ES.3. Survival study summary.

Year: 2014

Study Site(s): McNary Dam

Objective(s) of study: Estimate dam passage survival and other performance measures for yearling Chinook salmon, juvenile steelhead, and subyearling Chinook salmon.

Hypothesis (if applicable): Not applicable; this is a compliance study.

Fish: Species-race: yearling Chinook salmon (CH1), steelhead (STH), subyearling Chinook salmon (CH0) Source: John Day Dam Smolt Monitoring Facility	Implant Procedure: Surgical: Yes Injected: No

Size (median):	CH1	STH	CH0
Weight (g):	26.5	79.2	12.4
Length (mm):	143	211	106

Sample Size:	CH1	STH	CH0
# Release Sites:	3	3	3
Total # Released[a]:	6,488	6,492	6,501

Tag Type: Advanced Telemetry Systems (ATS)-156dB Model: SS300 Weight (air): 0.308 g	Analytical Model: Virtual/paired-release model	Characteristics of Estimate: Effects Reflected (direct, total, etc.): Direct Absolute or Relative: Absolute

Environmental/Operating Conditions (daily from 27 April 2014 through 30 May 2014):

Statistic	Mean	Min	Max
River Discharge (kcfs):	305.9	252.1	375.5
Spill Discharge (kcfs):	162.8	108.2	227.9
Percent Spill (24 h/d):	52.6	41.8	61.7
Temperature (°C):	12.0	9.2	13.6
Total Dissolved Gas % (tailrace):	118.2	113.8	123.7

Treatment(s): None

Unique Study Characteristics: None

Environmental/Operating Conditions (daily from 11 June 2014 through 11 July 2014):

Statistic	Mean	Min	Max
River Discharge (kcfs):	261.5	207.4	299.4
Spill Discharge (kcfs):	127.8	86.1	149.9
Percent Spill (24 h/d):	48.8	40.1	50.2
Temperature (°C):	16.7	15.1	19.4
Total Dissolved Gas % (tailrace):	117.8	115.5	119.7

Treatment(s): None

Unique Study Characteristics: None

Survival and Passage Estimates:	CH1	STH	CH0
Dam survival			
• Spring	0.9610 (0.0127)	0.9698 (0.0136)	
• Summer			0.9239 (0.0180)
Forebay-to-tailrace survival (season-wide)	0.9575 (0.0127)	0.9663 (0.0136)	0.9215 (0.0180)
Forebay residence time (median)	1.73 h	2.57 h	2.22 h
Tailrace egress rate (median)	0.44 h	0.37 h	0.54 h
Spill passage efficiency	0.7140 (0.0092)	0.8433 (0.0075)	0.5380 (0.0102)
Fish passage efficiency	0.9118 (0.0058)	0.9730 (0.0033)	0.8090 (0.0080)

Compliance Results: Estimates of dam passage survival met compliance requirements for CH1 and STH for both point estimates and standard errors. The point estimate and standard error for CH0 did not meet compliance requirements.

(a) Total release size for R_1, R_2, and R_3 used in the survival analysis.

Acknowledgments

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

- PNNL: E Arntzen, B Bellgraph, C Brandt, C Campbell, T Carlson, E Choi, D Deng, G Dirkes, E Fischer, A Flory, T Fu, N Fuller, D Geist, E Green, M Greiner, K Hall, K Ham, K Hand, J Hughes, B Jeide, B Jones, K Jung, R Karls, B Lamarche, K Lavender, X Li, T Linley, J Martinez, J Morasutti, R Mueller, E Oldenburg, D Parr, A Phillips, N Phillips, B Rayamajhi, S Saranovich, N Sather, S Southard, J Stephenson, A Stott, A Thronas, S Titzler, N Trimble, J Vavrinec, J Vazquez, C Vernon, K Wagner, Y Yuan, and S Zimmerman.

- PSMFC: R Martinson, G Kolvachuk, D Ballinger, and C Golden, along with the helpful staff at the John Day Dam and Bonneville Dam juvenile smolt facilities. We also thank those at PTAGIS (Passive Integrated Transponder Information System) for their continued assistance. In addition, L Baker, A Barnes, G Batten, L Belcher, R Blanchard, S Carpenter, D Etherington, C Grady, K Klebes, T Mitchell, A Montgomery, T Royal, and R Wall.

- Cascade Aquatics: B James, P James, and Z Jaques.

- USACE: E Hockersmith, D Fryer, M Shutters, and T Wik with NWW; electricians, mechanics, riggers, operators, and biologists at McNary Dam (C Dugger), and John Day Dam (M Zyndol, E Grosvenor) and B Eppard, S Fielding, and M Langeslay with the NWP.

- UW: J Lady, T Lockhart, and C Helfrich.

Acronyms and Abbreviations

°C	degree(s) Celsius
3D	three-dimensional
AT	acoustic transmitter
ATS	Advanced Telemetry Systems
BiOp	biological opinion
BRZ	boat-restricted zone
CH0	subyearling Chinook salmon
CH1	yearling Chinook salmon
CI	confidence interval
CR	Columbia River
FCRPS	Federal Columbia River Power System
FPC	Fish Passage Center
FPE	fish passage efficiency
g	gram(s)
h	hours(s)
JBS	juvenile bypass system
JSATS	Juvenile Salmon Acoustic Telemetry System
kcfs	thousand cubic feet per second
km	kilometer(s)
L	liter(s)
m	meter(s)
mg	milligram(s)
mm	millimeter(s)
MS-222	tricaine methanesulfonate
N	absolute abundance
NTSW	non-temporary spill weir
PIT	passive integrated transponder
PNNL	Pacific Northwest National Laboratory
PRI	pulse repetition interval
PSMFC	Pacific States Marine Fisheries Commission
R	release
rkm	river kilometer(s)
RME	research, monitoring, and evaluation
ROR	run-of-river
RPA	reasonable and prudent alternative
s	second(s)

SE	standard error
SPE	spill passage efficiency
STH	juvenile steelhead
TSW	temporary spill weir
TUR	turbine(s)
USACE	U.S. Army Corps of Engineers
UW	University of Washington
V	virtual release

Contents

Preface iii
Executive Summary v
Acknowledgments ix
Acronyms and Abbreviations xi
1.0 Introduction 1.1
  1.1 Background 1.1
  1.2 Study Objectives 1.2
  1.3 Report Contents and Organization 1.2
2.0 Methods 2.1
  2.1 Release-Recapture Design 2.1
  2.2 Handling, Tagging, and Release Procedures 2.3
    2.2.1 Acoustic Transmitters 2.3
    2.2.2 Fish Source 2.3
    2.2.3 Tagging Procedure 2.4
    2.2.4 Release Procedures 2.4
  2.3 Acoustic Signal Processing 2.5
  2.4 Statistical Methods 2.6
    2.4.1 Estimation of Dam Passage Survival 2.6
    2.4.2 Tag-Life Analysis 2.7
    2.4.3 Tests of Assumptions 2.8
    2.4.4 Forebay-to-Tailrace Survival 2.9
    2.4.5 Estimation of Travel Times 2.10
    2.4.6 Estimation of Spill Passage Efficiency 2.10
    2.4.7 Estimation of Fish Passage Efficiency 2.11
3.0 Results 3.1
  3.1 Fish Collection, Rejection, and Tagging 3.1
  3.2 Discharge and Spill Conditions 3.2
  3.3 Run Timing 3.3
  3.4 Assessment of Assumptions 3.4
    3.4.1 Examination of Tagger Effects 3.4
    3.4.2 Examination of Tag-Lot Effects 3.5
    3.4.3 Handling Mortality and Tag Shedding 3.5
    3.4.4 Effects of Tailrace and Tailwater Release Locations on Survival 3.5
    3.4.5 Fish Size Distributions 3.9
    3.4.6 Tag-Life Corrections 3.9
    3.4.7 Arrival Distributions 3.9

3.4.8 Downstream Mixing 3.15
3.4.9 Dead Tagged Fish Releases 3.15
3.5 Survival and Passage Performance 3.19
3.5.1 Dam Passage Survival 3.19
3.5.2 Forebay-to-Tailrace Passage Survival 3.22
3.5.3 Forebay Residence Time 3.23
3.5.4 Tailrace Egress Time 3.23
3.5.5 Spill Passage Efficiency 3.23
3.5.6 Fish Passage Efficiency 3.23
4.0 Discussion 4.1
4.1 Study Conduct 4.1
4.2 Study Performance 4.1
4.3 Comparison to Previous Studies at McNary Dam 4.1
5.0 References 5.1
Appendix A − Tests of Assumptions A.3
Appendix B − Capture Histories Used in Estimating Dam Passage Survival B.1
Appendix C − Bias Corrections for Detections of Dead Tagged Fish C.1

Figures

2.1. Schematic of the virtual/paired-release design used to estimate dam passage survival at McNary Dam 2.2

2.2. Front view schematic of hydrophone deployments at three turbines showing the double-detection arrays 2.3

3.1. Daily average total discharge and percent spill at McNary Dam during the a) spring and b) summer JSATS survival studies in 2014. ..... 3.3

3.2. Cumulative percent of a) yearling Chinook salmon and juvenile steelhead and b) subyearling Chinook salmon that passed McNary Dam in 2014 based on Fish Passage Center smolt indices 3.4

3.3. Single-release estimates of survival probabilitiesfor yearling Chinook salmon released across the Columbia River downstream of McNary Dam at three or five locations from the Washington to the Oregon side of the channel 3.6

3.4. Single-release estimates of survival probabilities for juvenile steelhead released across the Columbia River downstream of McNary Dam at three or five locations from the Washington to the Oregon side of the channel 3.7

3.5. Single-release estimates of survival probabilities for subyearling Chinook salmon released across the Columbia River at three or five locations from the Washington to the Oregon side of the channel 3.8

3.6. Relative frequency distributions for fish lengths of yearling Chinook salmon used in a) release V_1, b) release R_2, c) release R_3, and d) ROR fish sampled at McNary Dam by the Fish Passage Center in 2014 ..... 3.10

3.7. Relative frequency distributions for fish lengths of juvenile steelhead used in a) release V_1, b) release R_2, c) release R_3, and d) ROR fish sampled at McNary Dam by the Fish Passage Center in 2014 ..... 3.11

3.8. Relative frequency distributions for fish lengths of subyearling Chinook salmon used in a) release V_1, b) release R_2, c) release R_3, and d) ROR fish sampled during the study period at John Day Dam by the Fish Passage Center in 2014. ..... 3.12

3.9. Range and median lengths of tagged a) yearling Chinook salmon, b) juvenile steelhead, and c) subyearling Chinook salmon used in the 2014 survival studies 3.13

3.10. Observed time of tag failure and fitted survivorship curves using a) the Weibull model for the spring tagging study and b) the vitality model of Li and Anderson (2009) for the summer tagging study in 2014. ..... 3.14

3.11. Fitted tag-life survivorship curve and the arrival-time distributions of a) yearling Chinook salmon, b) juvenile steelhead, and c) subyearling Chinook salmon for releases V_1, R_2, and R_3 at the acoustic-detection array located at rkm 325. ..... 3.15

3.12. Frequency distributions of downstream arrival timing for yearling Chinook salmon releases V_1, R_2, and R_3 at detection arrays located at a) rkm 449, b) rkm 349, and c) rkm 325 ..... 3.17

3.13. Frequency distributions of downstream arrival timing for juvenile steelhead releases V_1, R_2, and R_3 at detection arrays located at a) rkm 449, b) rkm 349, and c) rkm 325 ..... 3.17

3.14. Frequency distributions of downstream arrival timing for subyearling Chinook salmon releases V_1, R_2, and R_3 at detection arrays located at a) rkm 449, b) rkm 349, and c) rkm 325 .... 3.18

3.15. Distribution of forebay residence times for a) yearling Chinook salmon, b) juvenile steelhead, and c) subyearling Chinook salmon at McNary Dam, 2014. .... 3.24

3.16. Distribution of tailrace egress times for a) yearling Chinook salmon, b) juvenile steelhead, and c) subyearling Chinook salmon at McNary Dam, 2014. .... 3.26

Tables

ES.1 Estimates of dam passage survival at McNary Dam in 2014. vi

ES.2 Fish Accords performance measures at McNary Dam in 2014. vi

ES.3 Survival study summary. vii

2.1. Sample sizes of yearling and subyearling Chinook salmon and juvenile steelhead tagged with AT and PIT used in the survival study at McNary Dam in 2014. .... 2.3

2.2. Relative release times for fish implanted with AT and PIT to accommodate downstream mixing 2.4

3.1. Total number of fish handled by PNNL during the spring and summer of 2014 and counts of fish retained for tagging and rejected based on condition. 3.1

3.2. Observed malady types and percentage of yearling and subyearling Chinook salmon and juvenile steelhead rejected by malady type during spring and summer of 2014. .... 3.2

3.3. Estimated probabilities (*L*) of an AT being active at a downstream detection site for a) yearling Chinook salmon, b) juvenile steelhead, and c) subyearling Chinook salmon by release group 3.16

3.4. Survival, detection, and λ parameters for the final model used to estimate dam passage survival for yearling Chinook salmon during the season-wide spring study (27 April to 30 May 2014) 3.20

3.5. Survival, detection, and λ parameters for the final model used to estimate dam passage survival for juvenile steelhead during the season-wide spring study (29 April to 28 May 2014) 3.21

3.6. Survival, detection, and λ parameters for the final model used to estimate dam passage survival for subyearling Chinook salmon during the summer study 3.22

3.7. Estimated mean and median forebay residence times (h) and mean and median tailrace egress times for yearling Chinook salmon, juvenile steelhead, and subyearling Chinook salmon at McNary Dam in 2014 .... 3.25

3.8. Estimated spill passage efficiency (SPE) and fish passage efficiency (FPE) for yearling Chinook salmon, juvenile steelhead, and subyearling Chinook salmon at McNary Dam in 2014 .... 3.25

4.1. Comparison of dam passage survival estimates of tagged fish at McNary Dam in 2012 and 2014 .... 4.2

4.2. Comparison of spill passage efficiency (SPE) and fish passage efficiency (FPE) estimates at McNary Dam between 2012 and 2014 by fish stock 4.2

1.0 Introduction

The compliance monitoring studies reported herein were conducted by researchers at the Pacific Northwest National Laboratory (PNNL) and the University of Washington for the U.S. Army Corps of Engineers, (USACE) Walla Walla District (NWW) and Portland District (NWP) in spring and summer 2014. The purpose of these studies was to estimate dam passage survival of yearling and subyearling Chinook salmon and juvenile steelhead at McNary Dam as stipulated by the 2008 Federal Columbia River Power System (FCRPS) Biological Opinion (BiOp; NMFS 2008) and provide additional performance measures at the dam as stipulated in the Columbia Basin Fish Accords for yearling and subyearling Chinook salmon and juvenile steelhead (3 Treaty Tribes-Action Agencies 2008).

1.1 Background

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

> <u>Juvenile Dam Passage Performance Standards</u> – The Action Agencies juvenile performance standards are an average across Snake River and lower Columbia River dams of 96% average dam passage survival for spring Chinook 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), contains three additional requirements relevant to the 2014 survival studies (after Attachment A to the Memorandum of Agreement):

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

standard, SPE and delay metrics may be monitored coincidentally with dam survival testing.

This report summarizes the results of the 2014 acoustic telemetry studies of yearling and subyearling Chinook salmon and juvenile steelhead at McNary Dam to assess the Action Agencies' compliance with the performance criteria of the BiOp and Fish Accords.

1.2 Study Objectives

The purpose of the 2014 compliance monitoring at McNary Dam was to estimate performance measures for yearling and subyearling Chinook salmon and juvenile steelhead as outlined in the FCRPS BiOp and Fish Accords. McNary Dam operations during the study were to be maintained at 40% spill during the spring and 50% spill during the summer portions of the study. For each fish species/run, the following metrics were estimated using the Juvenile Salmon Acoustic Telemetry System (JSATS) technology:

- Dam passage survival, defined as survival from the upstream face of the dam to a standardized reference point in the tailrace. Performance[1] should be ≥96% survival for spring species/run (i.e., yearling Chinook salmon and juvenile steelhead) and ≥93% survival for summer species/run (i.e., subyearling Chinook salmon). Survival should be estimated with a standard error (SE) ≤1.5% (i.e., 95% confidence interval [CI] with a half-width of ±3%; 3% = 1.96 SE ≈ 2 SE or SE = 1.5%).
- Forebay-to-tailrace survival, defined as survival from a forebay array 2 km upstream of the dam to a tailrace array 2 km downstream of the dam. The forebay-to-tailrace survival estimate satisfies the "BRZ-to-BRZ" survival estimate called for in the Fish Accords.
- Forebay residence time, defined as the time from first detection on the forebay entrance array, 2 km upstream of the dam, to the time of last detection on the dam-face array.
- Tailrace egress time, defined as the average travel time from last detection on the dam-face array to the last detection on the tailrace array 2 km downstream of the dam.
- Spill passage efficiency (SPE), defined as the fraction of fish going through the dam via the spillway.
- Fish passage efficiency (FPE), defined as the fraction of fish going through the dam via non-turbine routes.

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

1.3 Report Contents and Organization

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

---

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

2.0 Methods

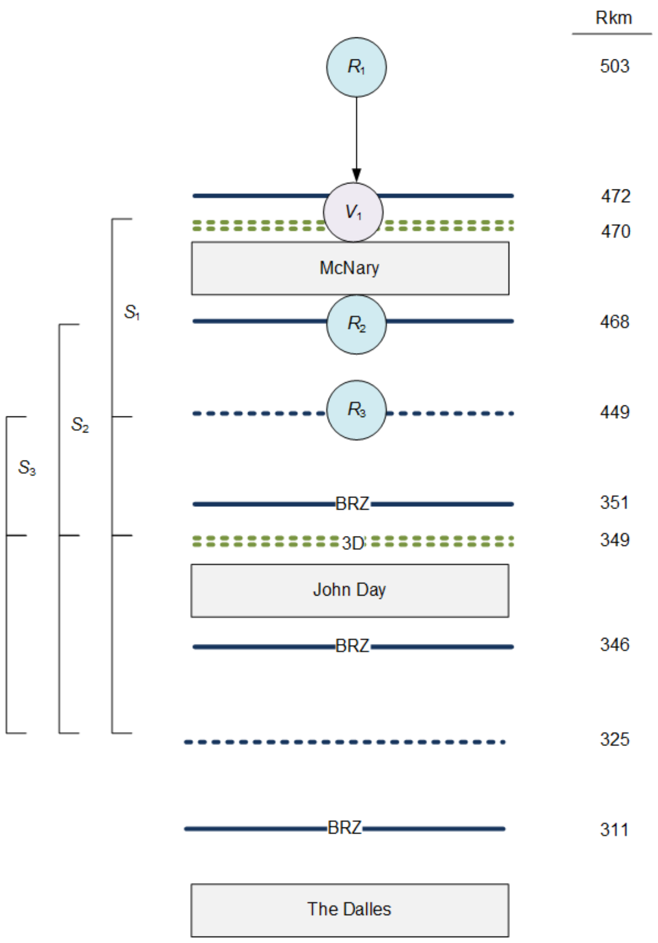
The study methods cover four topics: 1) fish collection, rejection, tagging, 2) fish release, 3) acoustic signal processing, and 4) statistical and analytical approaches.

2.1 Release-Recapture Design

The release-recapture design used to estimate dam passage survival at McNary Dam consisted of the combination of a virtual release (V_1) of fish at the face of the dam and a paired release below the dam (Figure 2.1) (Skalski et al. 2010a, 2010b). Fish tagged with both acoustic transmitters (ATs) and passive integrated transponders (PITs) were released above McNary Dam to supply a source of fish known to have arrived alive at the face of the dam. By releasing the fish far enough upstream, the fish should have arrived at the dam in a spatial pattern typical of run-of-river (ROR) fish. This virtual-release group was then used to estimate survival through the dam and part of the way through the next reservoir (i.e., river kilometer [rkm] 449) (Figure 2.1). To account and adjust for this extra reach mortality, a paired release below McNary Dam (i.e., R_2 and R_3) (Figure 2.1) was used to estimate survival in the segment of the reservoir below the dam. Dam passage survival was estimated as the quotient of the survival estimates for the virtual release to that of the paired release. The sample sizes of the releases of the fish tagged with ATs and PITs used in the dam passage survival estimates are summarized in Table 2.1. PITs were implanted to differentiate between turbine and juvenile bypass guided fish passing at the powerhouse.

The same release-recapture design was used to estimate forebay-to-tailrace survival, except that the virtual-release group was constructed of fish known to have arrived at the forebay array (rkm 472). The same below-dam paired release was used to adjust for the extra release mortality below the dam as was used to estimate dam passage survival. The double-detection arrays at the face of the dam (Figure 2.2) were analyzed as two independent arrays to allow estimation of detection probabilities by route of passage and assign the location of the last detection (i.e., the passage route). These passage-route data were used to calculate SPE and FPE at McNary Dam. Also, the fish used in the virtual release at the face of the dam were used to estimate tailrace egress time.

One manufacturing tag lot was used during the spring 2014 JSATS study, and another tag lot was used for the summer 2014 study. A total of 100 tags from spring and 99 tags from summer were randomly sampled for the tag-life assessments. The tags were activated, held in river water, and monitored continuously until they failed. The information from the tag-life study was used to adjust the perceived survival estimates from the Cormack-Jolly-Seber release-recapture model according to the methods of Townsend et al. (2006).



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

Figure 2.1. Schematic of the virtual/paired-release design used to estimate dam passage survival at McNary Dam. The virtual release (V_1) was composed of fish that arrived at the dam face from releases at rkm 503. The below-dam release pair was composed of releases R_2 and R_3 with detection arrays used in the survival analysis denoted by dashed lines.

Table 2.1. Sample sizes of yearling and subyearling Chinook salmon and juvenile steelhead tagged with AT and PIT used in the survival study at McNary Dam in 2014.

Release Location	Yearling Chinook Salmon	Juvenile Steelhead	Subyearling Chinook Salmon
Above McNary Dam (R_1)	2,500	2,499	2,517
Virtual Release–McNary Dam (V_1)	2,391	2,376	2,412
McNary Dam Tailrace (R_2)	2,000	1,998	1,995
Rkm 449, downstream of Irrigon, OR (R_3)	1,988	1,995	1,989

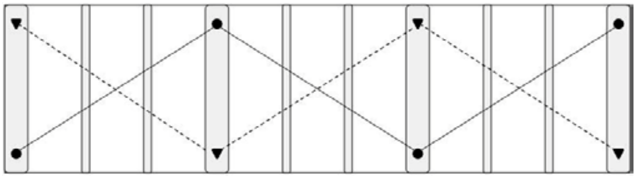


Figure 2.2. Front view schematic of hydrophone deployments at three turbines showing the double-detection arrays. The circles denote the hydrophones of Array 1 and the triangles denote the hydrophones of Array 2.

2.2 Handling, Tagging, and Release Procedures

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

2.2.1 Acoustic Transmitters

The ATs used in the 2014 studies were manufactured by Advanced Telemetry Systems, Inc. (ATS, Isanti, Minnesota). The yearling and subyearling Chinook salmon and juvenile steelhead were tagged with ATS model SS300 ATs that were 10.71 mm long, 5.19 mm wide, 3.04 mm thick, and weighed 0.308 g in air. These transmitters had a nominal transmission rate of 1 pulse every 3 s and nominal tag life was expected to be about 24 d.

2.2.2 Fish Source

The yearling and subyearling Chinook salmon and juvenile steelhead used in the studies were all obtained from the John Day Dam JBS. The Pacific States Marine Fisheries Commission/Fish Passage Center (FPC) diverted fish from the JBS into an examination trough, as described by Martinson et al. (2006). Fish ≥95 and <300 mm in length without severe maladies, excessive descaling (>20%), or skeletal deformity that prevented surgical implantation of tags or impaired swimming were selected for tagging.

2.2.3 Tagging Procedure

The fish to be tagged were anesthetized in an 18.9-L “knockdown” bucket that contained fresh river water and MS-222 (tricaine methanesulfonate; 80 to 100 mg/L). Anesthesia buckets were refreshed repeatedly to maintain the temperature within ±2°C of ambient river temperature. Each fish was weighed and measured before tagging, its condition was described, and it was assigned a set of tags and a release location.

During surgery, each fish was placed ventral side up and a gravity-fed “maintenance” anesthesia (40 mg/L) supply line was placed into its mouth. Using a micro-sharp, a 5- to 7-mm incision was made in the body cavity between the pelvic girdle and pectoral fin. A PIT was inserted, followed by an AT, both toward the anterior end of the fish. The incision was closed using a 5-0 Monocryl® suture.

After surgery, fish were placed in a dark, 18.9-L, flow-through transport bucket with aerated river water to recover. Upon recovery from the anesthesia, each bucket was placed in a holding tank supplied with flow-through water. Fish were held for 12 to 36 h in the assigned bucket before being transported for release into the river. The loading rate was five fish per bucket.

2.2.4 Release Procedures

All fish were tagged at John Day Dam and transported by truck to the release locations (Figure 2.1). Transportation routes were adjusted to provide equal travel times to each release location from John Day Dam. Upon arriving at a release site, fish buckets were transferred to a boat for transport to the in-river release locations. There were five release locations at each release site across the river, and equal numbers of buckets of fish were released at each of the five locations.

Releases occurred daily in spring from 27 April to 30 May for yearling Chinook salmon and from 27 April to 28 May for juvenile steelhead for the R_1 releases. The last day of the R_3 release was 30 May and 28 May, respectively, for yearling Chinook salmon and juvenile steelhead. Releases alternated days between daytime and nighttime over the course of the study (Table 2.2).

In the summer, releases occurred from 11 June for the R_1 releases to 11 July for the R_1, R_2 and R_3 releases. Again, releases occurred on alternating days, and every other release was day or night. The timing of the releases at the release sites was staggered to help facilitate downstream mixing (Table 2.2).

Table 2.2. Relative release times for fish implanted with ATs and PITs to accommodate downstream mixing. The virtual release occurred continuously from upstream release sites. Releases were timed to accommodate the approximately 21-h travel time between R_1 and R_2 and 14-h travel time between R_2 and R_3.

	Relative Release Times	
Release Location	Daytime Start	Nighttime Start
R_1 (rkm 503)	Day 1: 1000	Day 1: 0000
R_2 (rkm 468)	Day 2: 0700	Day 1: 2200
R_3 (rkm 449)	Day 2: 2100	Day 2: 1200

2.3 Acoustic Signal Processing

Transmissions of JSATS AT codes received on cabled and autonomous hydrophones were recorded in raw data files. These files were downloaded periodically and transported to PNNL's North Bonneville office for processing. Receptions of AT codes within raw data files were processed to produce a data set of accepted AT-detection events. For cabled arrays, detections from all hydrophones at a dam were combined for processing. The following three filters were used:

- Multipath filter: For data from each individual cabled hydrophone, all AT code receptions that occurred within 0.156 s after an initial identical AT code reception were deleted under the assumption that closely lagging signals are multipath. Initial code receptions were retained. The delay of 0.156 s was the maximum acceptance window width for evaluating a pulse repetition interval (PRI) and was computed as 2 × (PRI_Window + 12 × PRI_Increment). Both PRI_Window and PRI_Increment were set at 0.006 s, which was chosen to be slightly larger than the potential rounding error in estimating PRI to two decimal places.
- Multi-detection filter: Receptions were retained if the same AT 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 AT transmission.
- PRI filter: Only those series of receptions of an AT code (or "messages") that were consistent with the pattern of transmissions from a properly functioning JSATS AT were retained. Filtering rules were evaluated for each AT code individually, and it was assumed that only a single AT would be transmitting that code at any given time. For the cabled system, the PRI filter operated on a message, which included all receptions of the same transmission on multiple hydrophones within 0.3 s. Message time was defined as the earliest reception time across all hydrophones for that message. Detection required that at least six messages were received with an appropriate time interval between the leading edges of successive messages.

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

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

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

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

2.4 Statistical Methods

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

2.4.1 Estimation of Dam Passage Survival

Maximum likelihood estimation was used to estimate dam passage survival at McNary Dam based on the virtual/paired-release design. The capture histories from all the replicate releases, both daytime and nighttime, were pooled to produce the estimate of dam passage survival. A joint likelihood model was constructed of a product multinomial with separate multinomial distributions describing the capture histories of the separate release groups (i.e., V_1, R_2, and R_3).

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

Dam passage survival was estimated by the function

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

where $\hat{S}_i$ is the tag-life-corrected survival estimate for the *i*th release group $(i = 1, \ldots, 3)$ (Figure 2.1). The variance of $\hat{S}_{\text{Dam}}$ was estimated in a two-step process that incorporated both the uncertainty in the tag-life corrections and the release-recapture processes.

2.4.2 Tag-Life Analysis

A total of 100 and 99 ATs were systematically sampled over the course of the spring and summer survival studies, respectively, for tag-life analysis. The ATs were continuously monitored from activation to failure in ambient river water.

For the spring tag lot, the failure times were fit to the three-parameter Weibull distribution. The Weibull model tends to fit AT data that only exhibit battery failure and no mechanical failure. The three-parameter Weibull distribution (Elandt-Johnson and Johnson 1980) with scale (λ), shape (β), and shift (γ) parameters has a probability density function of

$$f(t)=\frac{\beta}{\lambda}\left(\frac{t-\gamma}{\lambda}\right)^{\beta-1}e^{-\left(\frac{t-\gamma}{\lambda}\right)^{\beta}} \tag{2.2}$$

with survivorship function

$$S(t)=e^{-\left(\frac{t-\gamma}{\lambda}\right)^{\beta}} \tag{2.3}$$

cumulative density function

$$F(t)=1-e^{-\left(\frac{t-\gamma}{\lambda}\right)^{\beta}} \tag{2.4}$$

and hazard function

$$h(t)=\frac{\beta}{\lambda}\left(\frac{t-\gamma}{\lambda}\right)^{\beta-1}. \tag{2.5}$$

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

For the summer AT lot, the failure times were fit to the four-parameter vitality model of Li and Anderson (2009). The vitality model tends to fit AT failure times well because it allows for both early onset of random failure due to manufacturing as well as systematic battery failure later on.

The survivorship function for the vitality model can be rewritten as

$$S(t)=1-\left(\Phi\left(\frac{1-rt}{\sqrt{u^2+s^2t}}\right)-e^{\left(\frac{2u^2r^2}{s^4}+\frac{2r}{s^2}\right)}\Phi\left(\frac{2u^2r+rt+1}{\sqrt{u^2+s^2t}}\right)\right)^{e^{-kt}} \tag{2.6}$$

where Φ = cumulative normal distribution
r = average wear rate of components

s = standard deviation in wear rate
k = rate of accidental failure
u = standard deviation in quality of original components.

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

For the virtual-release group (V_1) based on fish known to have arrived at the dam and with active ATs, the conditional probability of AT activation, given the AT was active at the detection array at rkm 470, was used in the tag-life adjustment for that release group. The conditional probability of AT activation at time t_1, given it was active at time t_0, was computed by the quotient:

$$P\left(t_1 \middle| t_0\right) = \frac{P\left(t_1\right)}{P\left(t_0\right)} \qquad (2.7)$$

where $P\left(t_0\right)$ is the average unconditional probability that the AT is active when detected at the V_1 detection array (rkm 470), and $P\left(t_1\right)$ is the average unconditional probability that the AT is active when detected at the first downstream survival detection array (rkm 449).

2.4.3 Tests of Assumptions

Approaches to assumption testing are described below.

2.4.3.1 Burnham et al. (1987) Tests

Tests 2 and 3 of Burnham et al. (1987) have been used to assess whether upstream detection history has an effect on downstream survival. Such tests are most appropriate when fish are physically recaptured or segregated during capture as in the case with PIT-tagged fish going through the JBS. However, AT studies do not use physical recapture techniques to detect fish. Consequently, there is little or no relevance of these tests in acoustic telemetry studies. Furthermore, the very high detection probabilities present in acoustic telemetry 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 juvenile salmonids used in the estimation of dam passage survival. For this reason, tagger effects were evaluated. The single release-recapture model was used to estimate reach survivals for fish tagged by different individuals. The analysis evaluated whether any consistent pattern of reduced reach survivals existed for fish tagged by any of the tagging staff.

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

$$F_{k-1,\infty} = \frac{s_{\hat{S}}^2}{\left(\frac{\sum_{i=1}^{k} \widehat{\text{Var}}\left(\hat{S}_i \middle| S_i\right)}{k} \right)} \tag{2.8}$$

where

$$s_{\hat{S}}^2 = \frac{\sum_{i=1}^{k} \left(\hat{S}_i - \hat{\bar{S}}\right)^2}{k-1} \tag{2.9}$$

and

$$\hat{\bar{S}} = \frac{\sum_{i=1}^{k} \hat{S}_i}{k} \tag{2.10}$$

The *F*-test was used in evaluating tagger effects as well as delayed tag effects.

2.4.3.4 Tag-Lot Effects

Because only one tag lot was used in each survival study, examination of tag-lot effects was unnecessary.

2.4.3.5 Dead Tagged Fish Releases

To assure the detection array at the R_3 release (i.e., rkm 449) was sufficiently far downstream to avoid detections of fish that died during dam passage with still active tags, dead tagged fish releases were performed during each survival study. A total of 25 yearling Chinook salmon, 25 juvenile steelhead, and 50 subyearling Chinook salmon were released into the McNary Dam tailrace at the spillway over the course of their respective studies. Dead tagged fish were released weekly throughout the study to cover the range of flows during the season.

2.4.4 Forebay-to-Tailrace Survival

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

2.4.5 Estimation of Travel Times

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

$$\bar{t} = \frac{\sum_{i=1}^{n} t_i}{n}, \tag{2.11}$$

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

$$\widehat{\text{Var}}(\bar{t}) = \frac{\sum_{i=1}^{n} \left(t_i - \bar{t}\right)^2}{n(n-1)}, \tag{2.12}$$

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

Tailrace egress time for fish passing McNary Dam was calculated differently for bypassed fish and all other fish before their data were pooled. For bypassed fish, tailrace egress time was calculated from the last detection in the fish bypass to the last detection at the tailrace array below the dam. For all other fish, tailrace egress time was calculated from the last detection at the dam-face array to the last detection at the tailrace array below the dam. Both the arithmetic average and the median egress times were calculated. Only fish that passed the dam alive were used in the calculations, based on detection of the fish on arrays downstream of the tailrace array.

The estimated forebay residence times were based on the time from the first detection at the forebay BRZ array 2 km above the dam to the last detection at the double array on the upstream face of McNary Dam.

2.4.6 Estimation of Spill Passage Efficiency

Spill passage efficiency was estimated by the fraction

$$\widehat{\text{SPE}} = \frac{\hat{N}_{NTSW} + \hat{N}_{TSW}}{\hat{N}_{NTSW} + \hat{N}_{TSW} + \hat{N}_{TUR} + \hat{N}_{JBS}}, \tag{2.13}$$

where $\hat{N}_i$ is the estimated abundance of tagged fish through the *i*th route (temporary spill weir [TSW], i = non-TSW [NTSW], 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. The perfect or near-perfect detection probabilities allowed estimates based on direct counts and the binomial sampling model. Calculating the variance in stages, the variance of $\widehat{\mathrm{SPE}}$ was estimated as

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

$$\cdot\left[\frac{\operatorname{Var}\left(\hat{N}_{NTSW}\right)+\operatorname{Var}\left(\hat{N}_{TSW}\right)}{\left(\hat{N}_{NTSW}+\hat{N}_{TSW}\right)^{2}}+\frac{\widehat{\operatorname{Var}}\left(\hat{N}_{TUR}\right)+\operatorname{Var}\left(\hat{N}_{JBS}\right)}{\left(\hat{N}_{TUR}+\hat{N}_{JBS}\right)^{2}}\right]. \tag{2.14}$$

2.4.7 Estimation of Fish Passage Efficiency

Fish passage efficiency was estimated by the fraction

$$\widehat{\mathrm{FPE}}=\frac{\hat{N}_{NTSW}+\hat{N}_{TSW}+\hat{N}_{JBS}}{\hat{N}_{NTSW}+\hat{N}_{TSW}+\hat{N}_{JBS}+\hat{N}_{TUR}}\ , \tag{2.15}$$

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

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

$$\cdot\left[\frac{\operatorname{Var}\left(\hat{N}_{NTSW}\right)+\operatorname{Var}\left(\hat{N}_{TSW}\right)+\operatorname{Var}\left(\hat{N}_{JBS}\right)}{\left(\hat{N}_{NTSW}+\hat{N}_{TSW}+\hat{N}_{JBS}\right)^{2}}+\frac{\widehat{\operatorname{Var}}\left(\hat{N}_{TUR}\right)}{\hat{N}_{TUR}^{2}}\right]. \tag{2.16}$$

In the case of detection probabilities of 1.0 at the dam face, the estimates of SPE and FPE reduce to binomial proportions and the variances are estimated based on a binomial distribution.

3.0 Results

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

3.1 Fish Collection, Rejection, and Tagging

The total number of fish handled by PNNL in spring and summer 2014, and the counts and percentages of fish by handling category are listed in Table 3.1. During the study, 23,469 yearling and subyearling Chinook salmon and juvenile steelhead were handled. Of the fish retained for tagging 6,498 yearling Chinook salmon, 6,492 juvenile steelhead, and 6,501 subyearling Chinook salmon were tagged and released alive for these studies. After every tagging day, excess fish that were retained for tagging, to ensure adequate sample numbers, were released back into the river.

Table 3.1. Total number of fish handled by PNNL during the spring and summer of 2014 and counts of fish retained for tagging and rejected based on condition.

Handling Category	CH1	%CH1	STH	%STH	CH0	%CH0
Retained for Tagging	6,893	98.0	6,912	96.8	9,105	98.0
Non-Candidate Based on Condition	138	2.0	231	3.2	190	2.0
Total Handled	**7,031**		**7,143**		**9,295**	

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

Observed fish maladies were recorded by staff prior to tagging. Maladies that resulted in fish rejection prior to tagging are listed in Table 3.2. Conditions for fish rejection were based on the general recommendations of the Columbia Basin Rejection Criteria (CBSPSC 2011) and confirmed by the Studies Review Work Group and National Oceanic and Atmospheric Administration in meetings during spring 2012 (B Eppard, personal communication, April 20, 2012). Fish were not accepted for the project if they were moribund, or showed obvious signs of progressed infections/diseases (e.g., fungus or furunculosis presence greater than 5% on one side of fish flank), open wounds that perforated the stomach cavity, skeletal deformities that would inhibit tag insertion or swimming ability, and descaling greater than 20% where there was no indication of scale regrowth or mucous coat present. PNNL broadened the criteria to minimize the rejection rate of fish. If a particular malady/infection was observed in more than 5% of the sample on a specific day, the following day’s fish affected by that malady were accepted only after approval by the fish condition study manager.

Table 3.2. Observed malady types and percentage of yearling and subyearling Chinook salmon and juvenile steelhead rejected by malady type during spring and summer of 2014.

	CH1	Rejected CH1 (%)	STH	Rejected STH (%)	CH0	Rejected CH0 (%)	**Total**
Descaling >20%	30	21.7	23	10.0	28	14.7	**81**
Caudal Fin Missing	5	3.6	3	1.3	1	0.5	**9**
Diseases	55	39.9	138	59.7	65	34.2	**258**
Damage/Injury	65	47.1	96	41.6	109	57.4	**270**
Skeletal Deformity	6	4.6	6	2.6	2	1.1	**14**
Total Fish[(a)]	**138**		**231**		**190**		**632**

(a) Each species averaged >1 malady per fish; 13.7% CH1, 13.4% STH, and 7.4% CH0 had more than one malady.

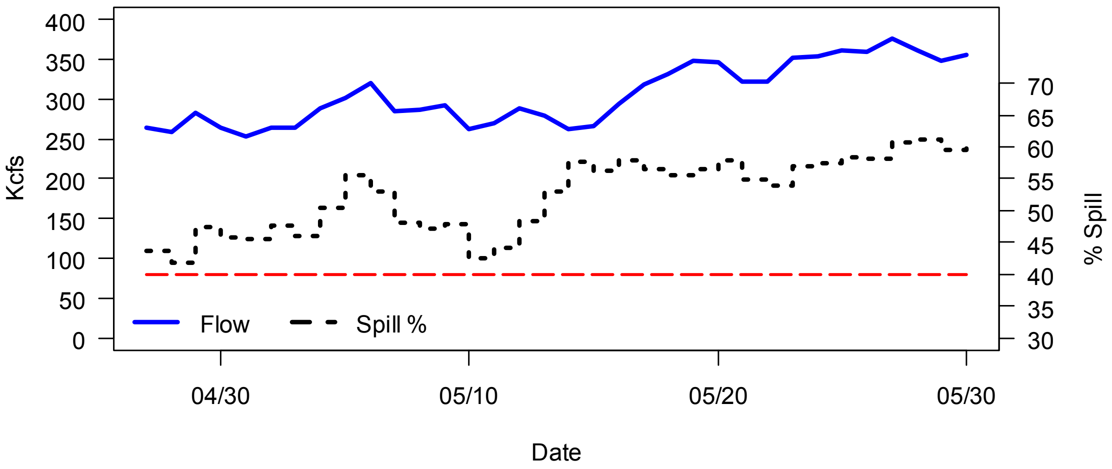
CH1 = yearling Chinook salmon, STH = juvenile steelhead, CH0 = subyearling Chinook salmon.

3.2 Discharge and Spill Conditions

From the start of the spring study on 27 April 2014 through the end on 30 May 2014 (28 May for juvenile steelhead), the percent spill at McNary Dam exceeded the 40% target due to a combination of high river discharge and turbine outages for maintenance. For the majority of the time, the percent spill also exceeded 40% ±5% of the spill target (Figure 3.1a). For this reason, no attempt was made to identify and isolate days where spill was 35–45% and separately estimate dam passage survival for that period. Instead, dam passage survival was estimated season-wide during spring regardless of spill level.

During the summer survival study (9 June – 11 July), spill levels largely met the 50% spill target. Spill levels were below the 50% target for the first eight days of the study and then leveled off at 50% spill for the remainder of the investigation (Figure 3.1b).

a. Spring



b. Summer

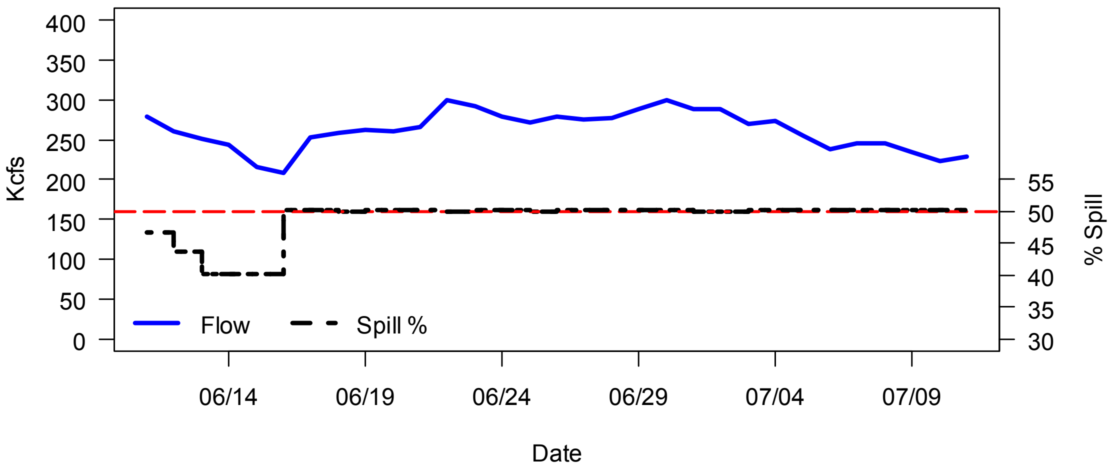
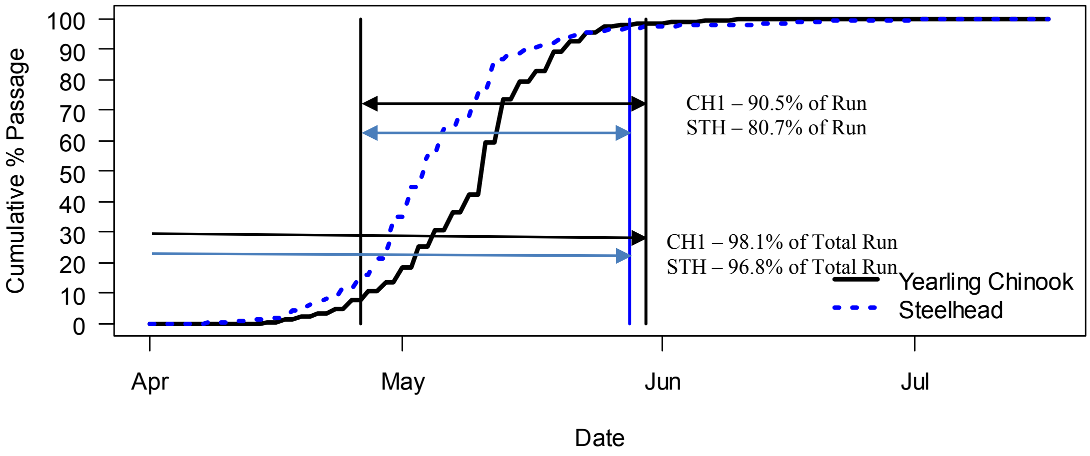


Figure 3.1. Daily average total discharge and percent spill at McNary Dam during the a) spring and b) summer JSATS survival studies in 2014. The red dashed line denotes the targeted spill level.

3.3 Run Timing

The cumulative percentage of yearling Chinook salmon, juvenile steelhead, and subyearling Chinook salmon that passed McNary Dam by date was calculated from smolt index data obtained from the FPC (Figure 3.2). Between 27 April and 30 May when yearling Chinook salmon were released, 90.5% of the yearling Chinook salmon run passed through McNary Dam (Figure 3.2a). Between 27 April and 28 May, when the juvenile steelhead study was performed, 80.7% of the juvenile steelhead run passed through McNary Dam (Figure 3.2a). From 11 June, when the first subyearling Chinook salmon were released, through 11 July 2014, 69.0% of subyearling Chinook salmon had passed McNary Dam. By the end of the study on 11 July 2014, 72.2% of subyearling Chinook salmon run had passed McNary Dam (Figure 3.2b).

a. Spring



b. Summer

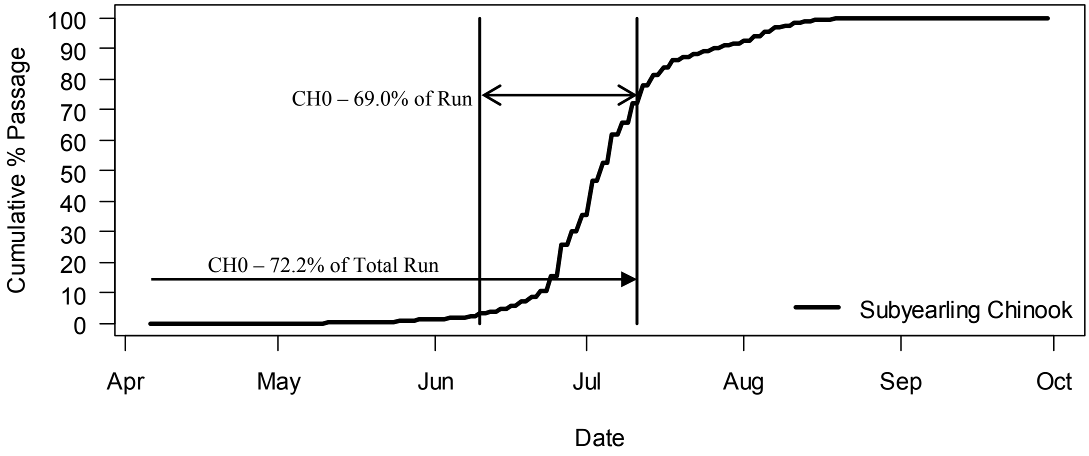


Figure 3.2. Cumulative percent of a) yearling Chinook salmon (CH1) and juvenile steelhead (STH) and b) subyearling Chinook salmon (CH0) that passed McNary Dam in 2014 based on Fish Passage Center smolt indices. Vertical lines mark the beginning and end of the survival studies.

3.4 Assessment of Assumptions

Assumption assessment includes tagger effects, tag-lot effects, delayed handling effects, fish size distributions, tag-life corrections, arrival distributions, and downstream mixing.

3.4.1 Examination of Tagger Effects

A total of eight different taggers assisted in tagging all juvenile steelhead and yearling Chinook salmon associated with the JSATS survival studies at McNary Dam in spring 2014. Six of the eight taggers from the spring study tagged all subyearling Chinook salmon during the summer 2014 study. During both the spring and summer studies, tagger effort was found to be homogeneously distributed across all locations within a replicate release or within the project-specific releases within a replicate

(Appendix A). Examination of reach survivals and cumulative survivals from above McNary Dam to below John Day Dam found no consistent evidence that fish tagged by different staff members had different in-river survival rates (Appendix A). Therefore, fish tagged by all taggers were included in the estimation of survival and other performance measures.

3.4.2 Examination of Tag-Lot Effects

Because only one tag lot was used in the spring study and one tag lot was used in the summer study in 2014, it was not necessary to test for tag-lot effects.

3.4.3 Handling Mortality and Tag Shedding

Fish were held for 12 to 36 h prior to release. The post-tagging mortality in spring was 0.15% and 0.06% for yearling Chinook salmon and juvenile steelhead, respectively. One PIT tag was shed during the post-tagging holding period in spring. In summer, post-tagging mortality was 0.20% for subyearling Chinook salmon and no tags were shed.

3.4.4 Effects of Tailrace and Tailwater Release Locations on Survival

Survival rates for yearling Chinook salmon, juvenile steelhead, and subyearling Chinook salmon released at three or five adjacent sites across the tailrace and tailwater did not appear to differ significantly based upon overlap of 95% CIs (Figure 3.3, Figure 3.4, and Figure 3.5, respectively). The uppermost plot in each of the figures shows survival rates for dam-passed fish regrouped on tailrace autonomous nodes to form three virtual releases across the tailrace. Regrouping dam-passed fish (V_1) on the tailrace array is problematic because it has the real potential to include some tagged fish that died during dam passage, which would violate survival model assumptions and underestimate survival in downstream reaches. Our intent was to provide some indication of the relative distribution of survival rates for fish regrouped at sites across the tailrace. An underlying assumption is that the probability of regrouping dead fish along with live fish is low and similar across the tailrace, but this assumption may not be valid.

The distribution of numbers of fish released across the tailrace was uniform (see numbers and percentages in middle plots in Figure 3.3, Figure 3.4, and Figure 3.5). The distribution of numbers of fish released at the five sites (Sites 1–5) across the tailwater near Irrigon, Oregon (CR449) also was uniform (see numbers and percentages in the bottom plots in Figure 3.3, Figure 3.4, and Figure 3.5). We did not specify the number of V_1 fish regrouped on each autonomous node because that distribution can be highly biased by differences in tag detectability, which is inversely related to linear water velocity where each node was deployed.

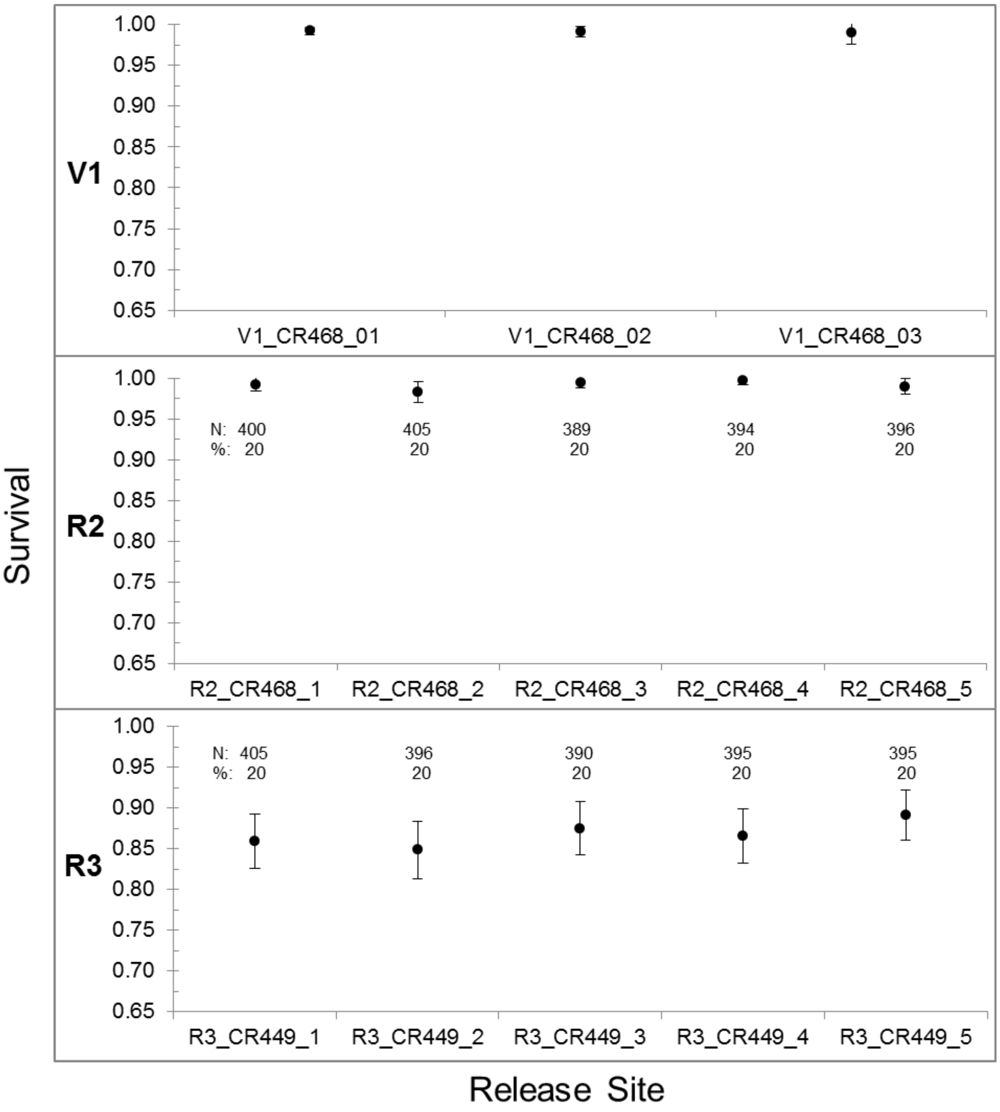


Figure 3.3. Single-release estimates of survival probabilities (y-axis) for yearling Chinook salmon released across the Columbia River downstream of McNary Dam at three or five locations from the Washington to the Oregon side of the channel (x-axis). The top plot shows survival probabilities for the reach from the tailrace (CR468) to Irrigon, OR (CR449) for three virtual releases of fish formed by regrouping dam-passed fish (V_1) on the tailrace autonomous node that received the most receptions of each tag code. The middle plot shows reach survival probabilities of tailrace-released fish (R_2 at CR468) to John Day Dam (CR349), and the bottom plot shows reach survivals of tailwater-released fish (Irrigon, OR at CR449) to John Day Dam (CR349). The numbers above and below the survival bars show the number of fish (*N*) and percent (%) of fish released at each site. Vertical error bars represent the extent of the 95% CIs.

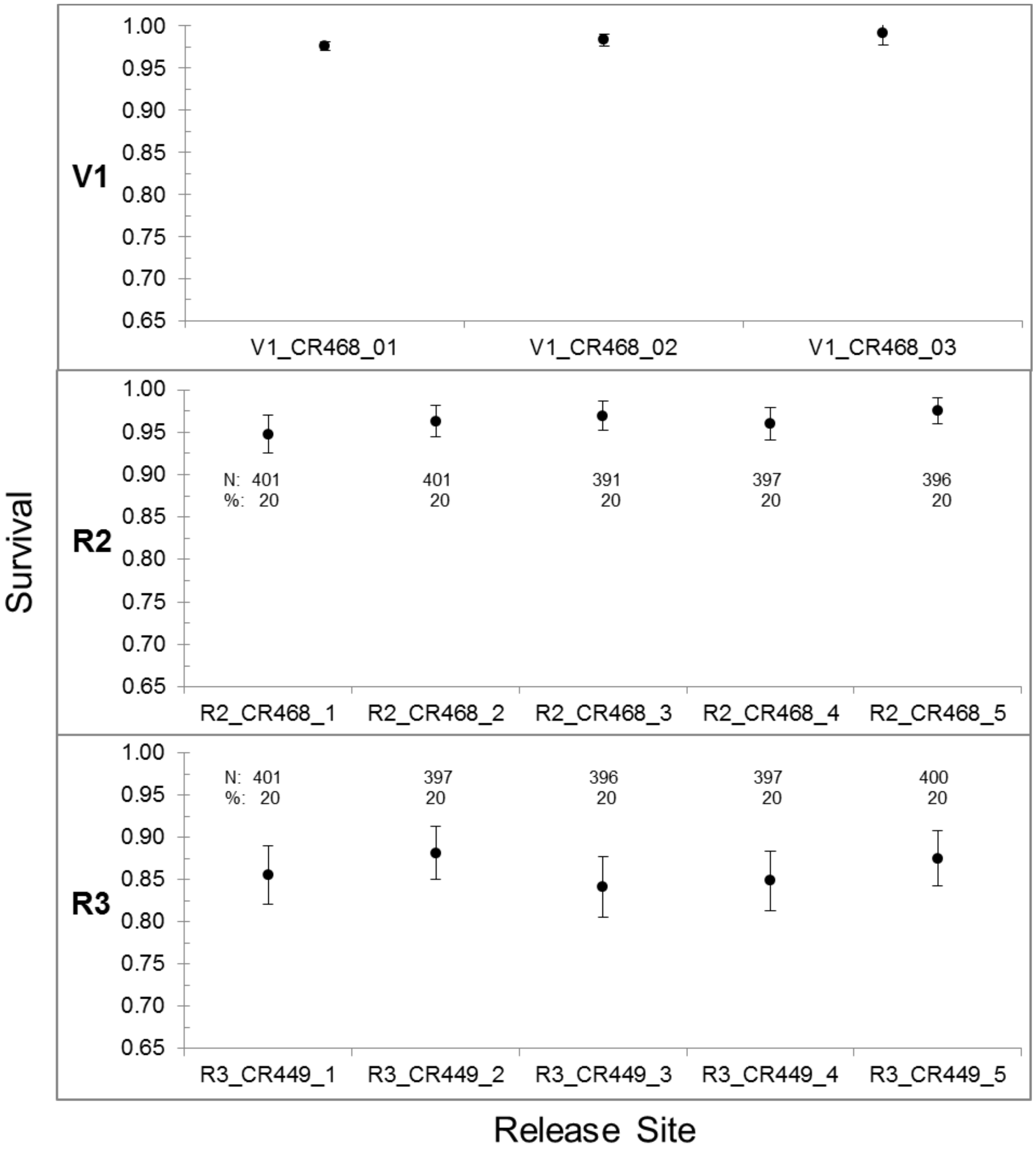


Figure 3.4. Single-release estimates of survival probabilities (y-axis) for juvenile steelhead released across the Columbia River downstream of McNary Dam at three or five locations from the Washington to the Oregon side of the channel (x-axis). The top plot shows survival probabilities for the reach from CR468 to CR449 for three virtual releases of fish formed by regrouping dam-passed fish (V_1) on the tailrace autonomous node that received the most receptions of each tag code. The middle plot shows reach survival probabilities of tailrace-released fish (R_2 at CR468) to Irrigon, Oregon (CR449), and the bottom plot shows reach survivals of tailwater-released fish (Irrigon, Oregon at CR449) to John Day Dam (CR349). The numbers above and below the survival bars show the number (N) and percent (%) of fish released at each site. Vertical error bars represent the extent of the 95% CI.

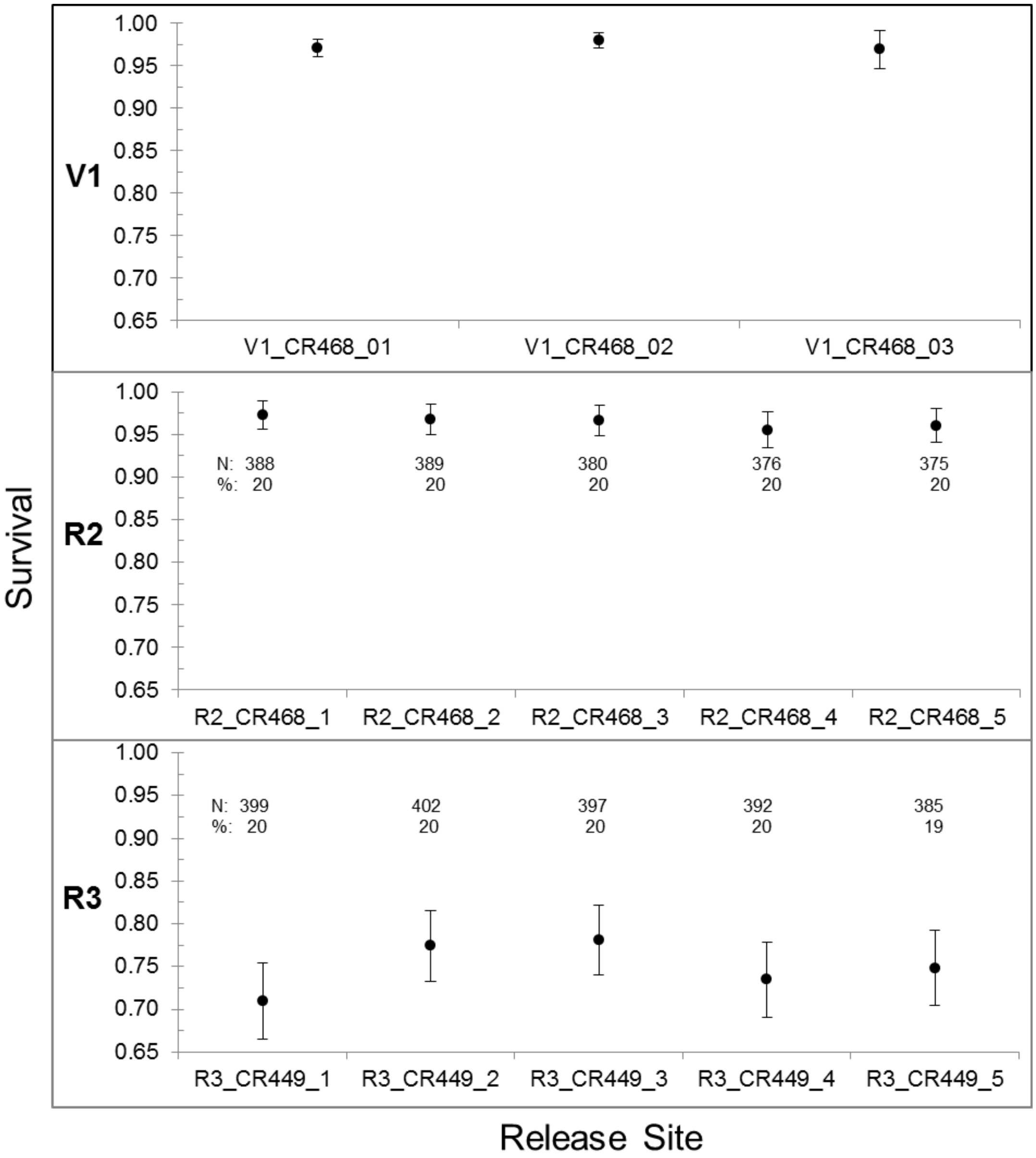


Figure 3.5. Single-release estimates of survival probabilities (y-axis) for subyearling Chinook salmon released across the Columbia River at three or five locations from the Washington to the Oregon side of the channel (x-axis). The top plot shows survival probabilities for the reach from CR468 to CR449 for three virtual releases of fish formed by regrouping dam-passed fish on the tailrace autonomous node that received the most receptions of a tag code. The middle plot shows survival probabilities of tailrace-released fish from the tailrace (CR468) to near Irrigon, Oregon (CR449), and the bottom chart shows the survival rates for tailwater-released fish (Irrigon, Oregon at CR449) to John Day Dam (CR349).). The numbers above and below the survival bars show the number (*N*) and percent (%) of fish released at each site. Vertical error bars represent the extent of the 95% CI.

3.4.5 Fish Size Distributions

Comparison of tagged fish with ROR fish sampled at McNary Dam through the Smolt Monitoring Program shows that the length frequency distributions were well matched for yearling Chinook salmon (Figure 3.6) and juvenile steelhead (Figure 3.7). The size of tagged subyearling Chinook salmon was somewhat larger than the fish sampled by the FPC (Figure 3.8). This was due to the restriction of tagging fish ≥95 mm in length. Using the condition data generated by the FPC at the JDA SMF, during the summer study sampling period, it was estimated that 17.5% of the subyearling Chinook salmon were less than 95 mm in length and excluded from study due to size. Mean lengths for the tagged fish were 144.8 mm for yearling Chinook salmon, 211.7 mm for juvenile steelhead, and 107.4 mm for subyearling Chinook salmon. Mean lengths for yearling Chinook salmon, juvenile steelhead, and subyearling Chinook salmon sampled by the FPC at the McNary Dam juvenile sampling facility were 137.5 mm, 208.7 mm, and 99.3 mm, respectively. The length frequency distributions for yearling Chinook salmon releases (Figure 3.6), juvenile steelhead releases (Figure 3.7), and subyearling Chinook salmon releases (Figure 3.8) were quite similar. Median fish size for yearling Chinook salmon and juvenile steelhead showed a slight decline over the course of the study (Figure 3.9a, b). No trend in fish size was noted for subyearling Chinook salmon (Figure 3.9c).

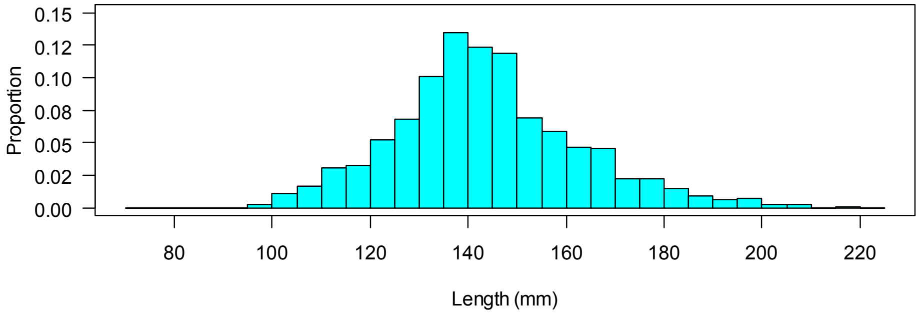
3.4.6 Tag-Life Corrections

For the 2014 studies, separate tag lots were used in the spring and the summer studies. During spring and summer, 100 and 99 ATs, respectively, were systematically sampled to conduct independent tag-life studies. A three-parameter Weibull curve was used to fit the tags during the spring study, and the vitality curve of Li and Anderson (2009) was used for the summer study (Figure 3.10). Average tag life was 23.2 d for the juvenile steelhead and yearling Chinook salmon studies, and 24.3 d for the subyearling Chinook salmon tag lot, respectively.

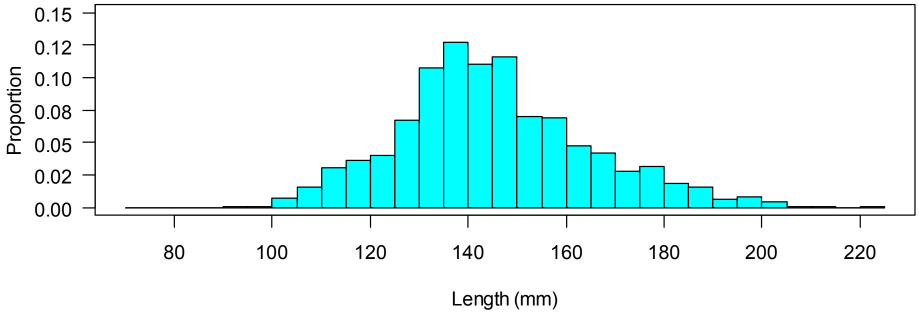
3.4.7 Arrival Distributions

The estimated probability that an AT was active when fish arrived at a downstream detection array depends on the tag-life curve and the distribution of observed travel times for yearling Chinook salmon, juvenile steelhead, and subyearling Chinook salmon (Figure 3.11). Examination of the fish arrival distributions to the last detection array used in the survival analyses (i.e., rkm 325) indicated all fish had passed through the study area before tag failure became important. These probabilities were calculated by integrating the tag survivorship curve over the observed distribution of fish arrival times (i.e., time from tag activation to arrival; Figure 3.11). The probabilities of an AT being active at a downstream detection site was specific to release location, fish stock, and season (Table 3.3). In all cases, the probability that an AT was active at a downstream detection site as far as rkm 325 was >0.999% for yearling Chinook salmon, juvenile steelhead, and subyearling Chinook salmon (Table 3.3).

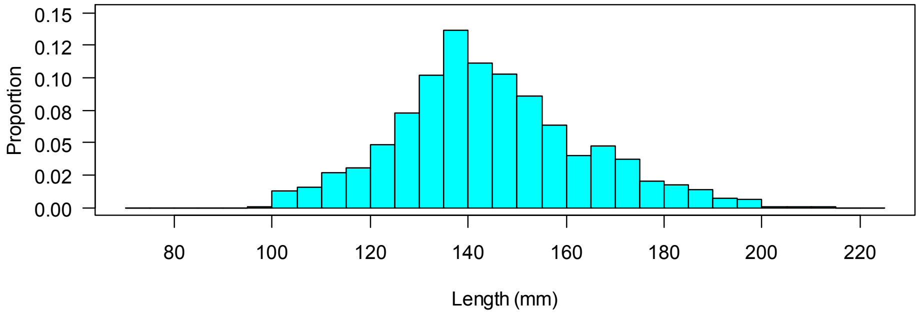
a. McNary Dam (Release V_1)



b. McNary Tailrace (Release R_2)



c. Mid-Reservoir (Release R_3)



d. ROR Yearling Chinook Salmon at McNary Dam

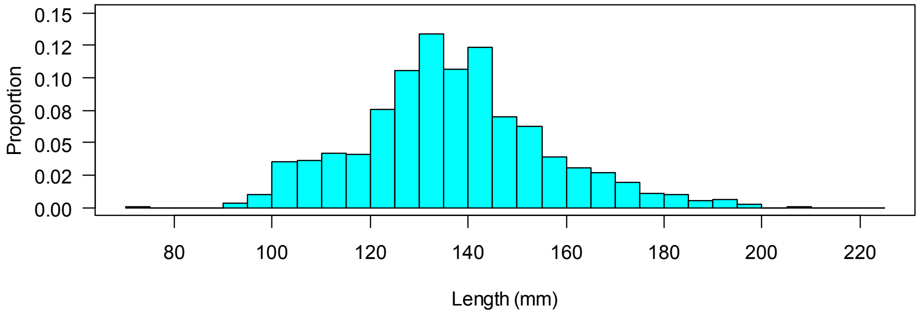
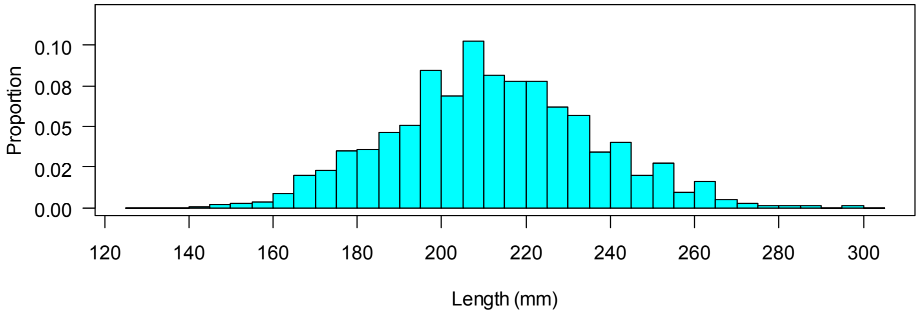
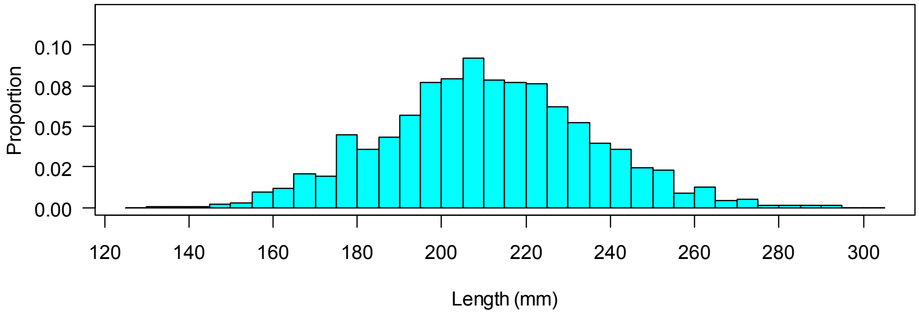


Figure 3.6. Relative frequency distributions for fish lengths (mm) of yearling Chinook salmon used in a) release V_1, b) release R_2, c) release R_3, and d) ROR fish sampled at McNary Dam by the Fish Passage Center in 2014.

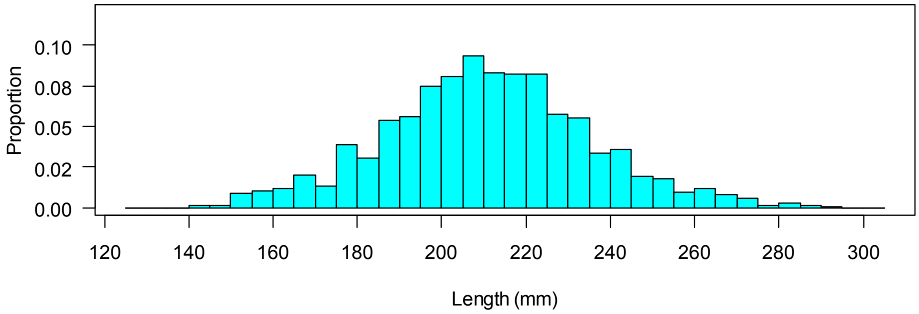
a. McNary Dam (Release V_1)



b. McNary Tailrace (Release R_2)



c. Mid-Reservoir (Release R_3)



d. ROR Juvenile Steelhead at McNary Dam

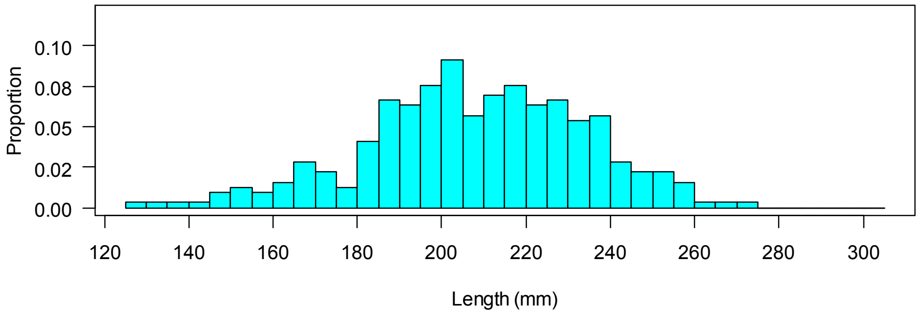
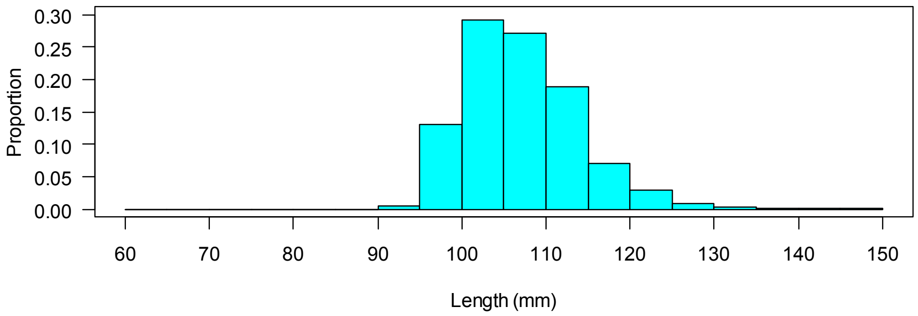
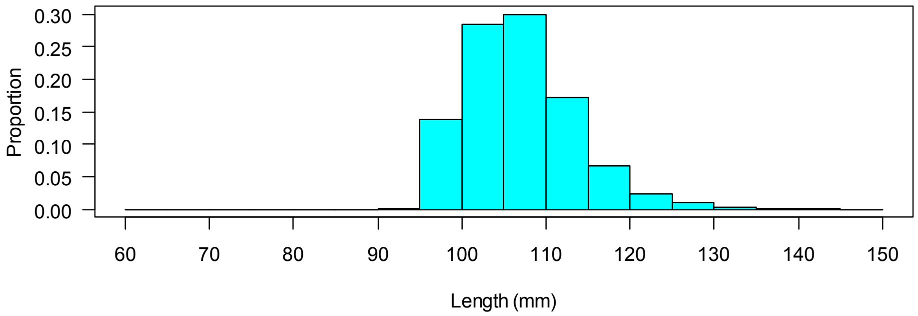


Figure 3.7. Relative frequency distributions for fish lengths (mm) of juvenile steelhead used in a) release V_1, b) release R_2, c) release R_3, and d) ROR fish sampled at McNary Dam by the Fish Passage Center in 2014.

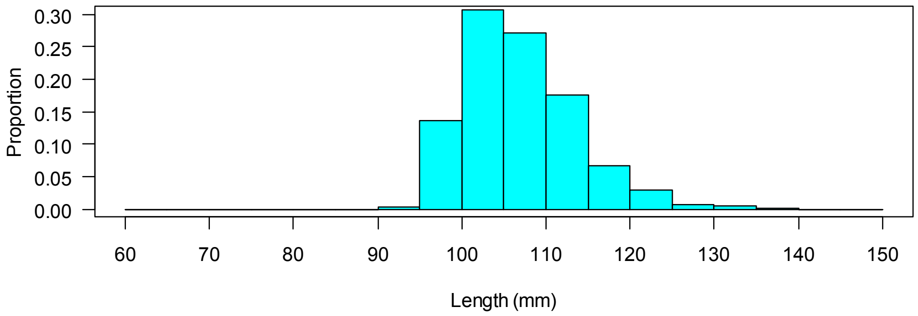
a. McNary Dam (Release V_1)



b. McNary Tailrace (Release R_2)



c. Mid-Reservoir (Release R_3)



d. ROR Subyearling Chinook Salmon at John Day Dam

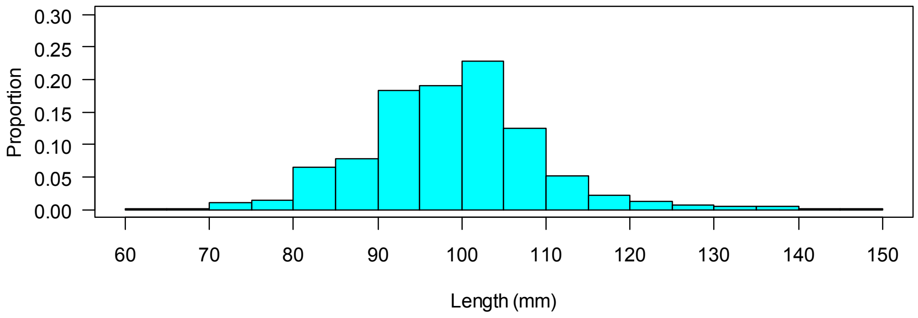
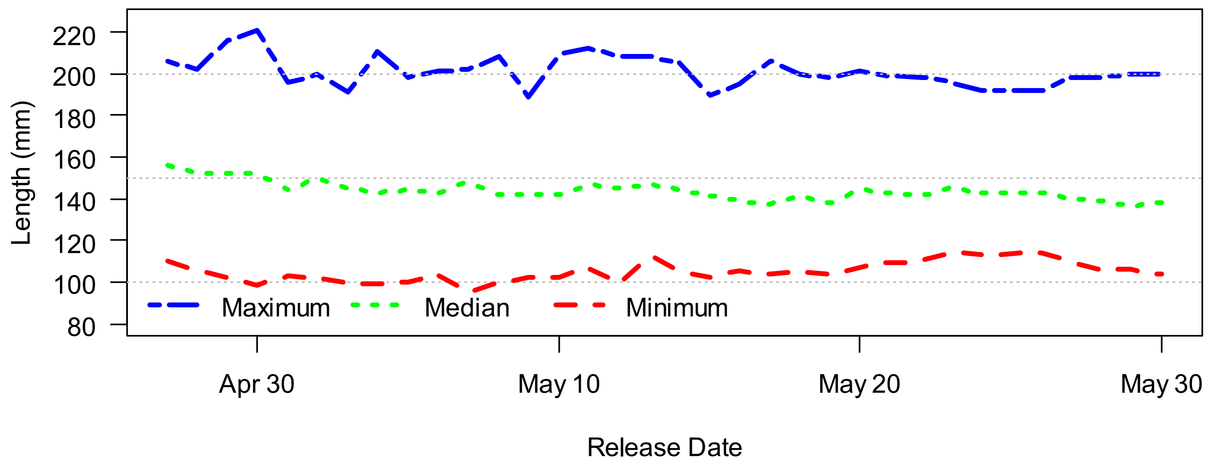
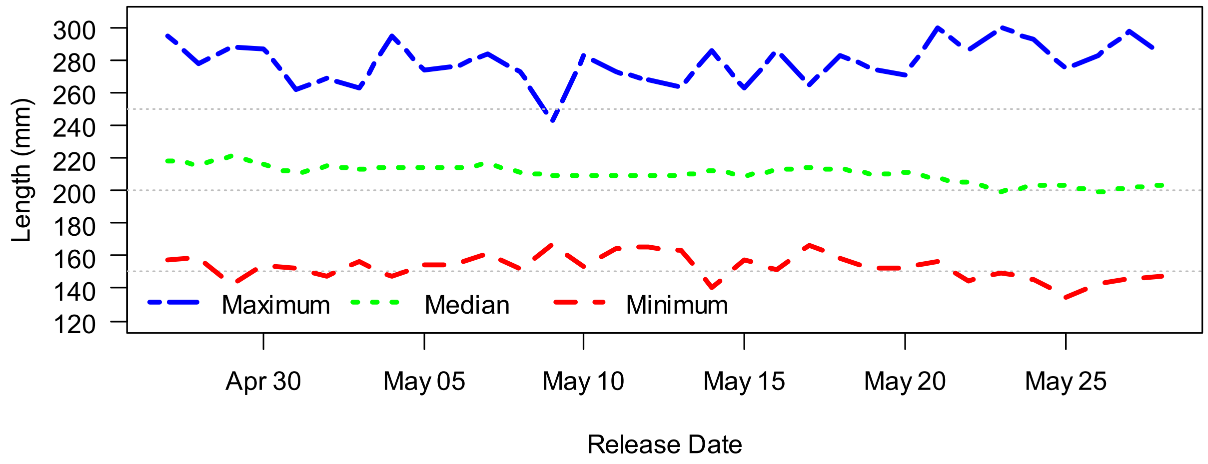


Figure 3.8. Relative frequency distributions for fish lengths (mm) of subyearling Chinook salmon used in a) release V_1, b) release R_2, c) release R_3, and d) ROR fish sampled during the study period at John Day Dam by the Fish Passage Center in 2014.

a. Yearling Chinook Salmon



b. Juvenile Steelhead



c. Subyearling Chinook Salmon

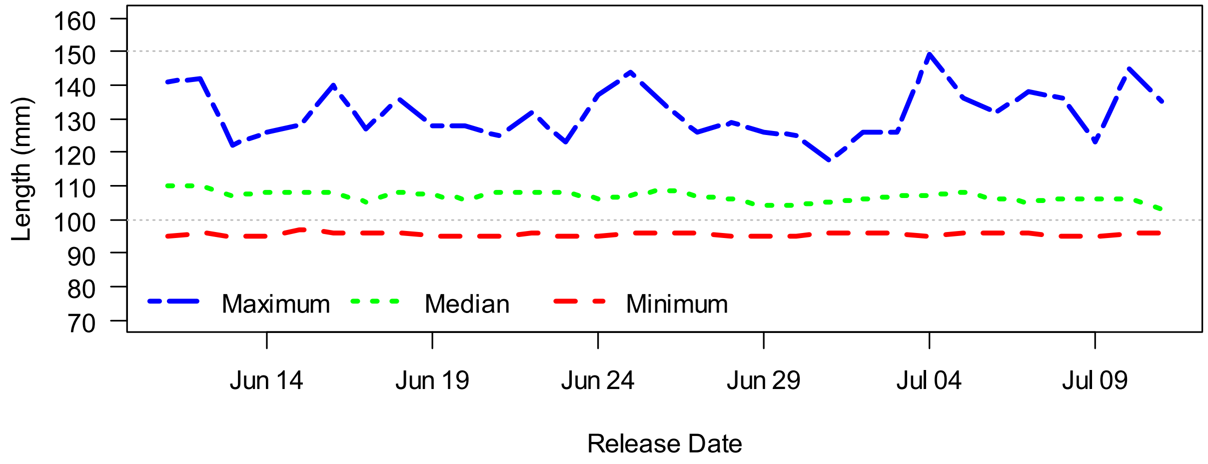
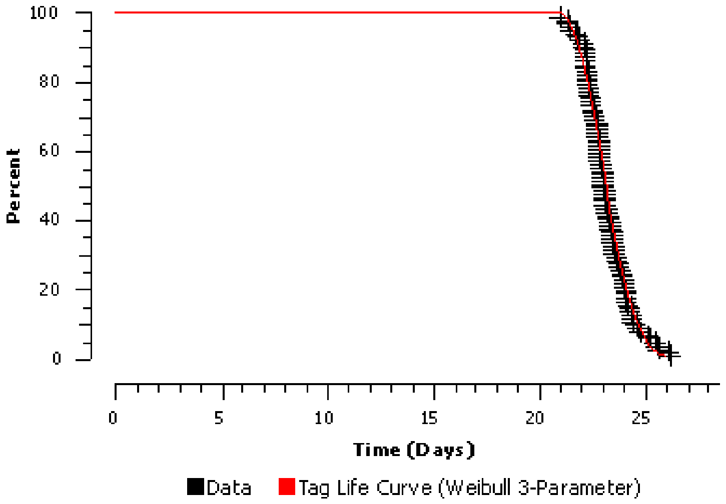


Figure 3.9. Range and median lengths of tagged a) yearling Chinook salmon, b) juvenile steelhead, and c) subyearling Chinook salmon used in the 2014 survival studies.

a. Spring – Yearling Chinook Salmon and Juvenile Steelhead



b. Summer – Subyearling Chinook Salmon

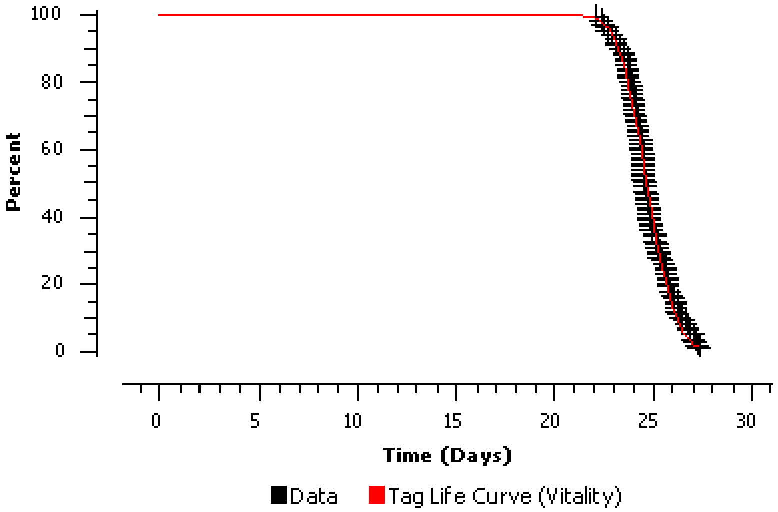
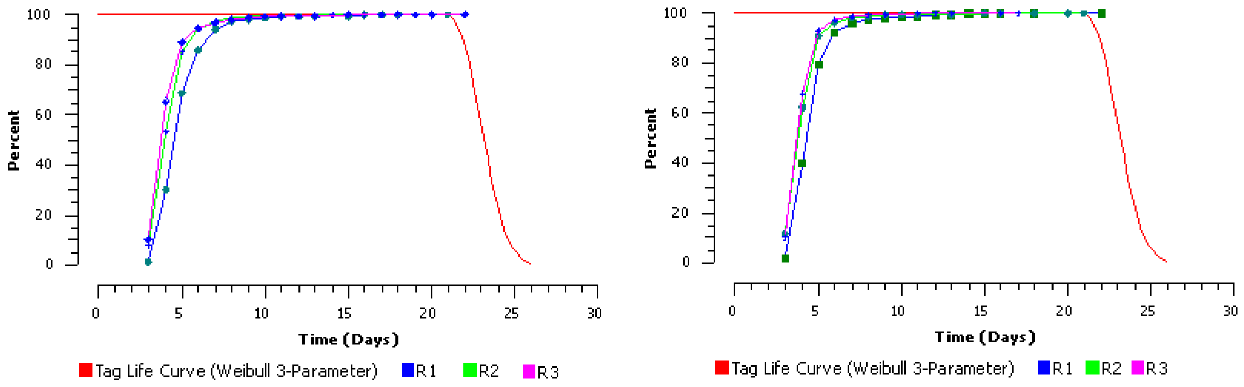
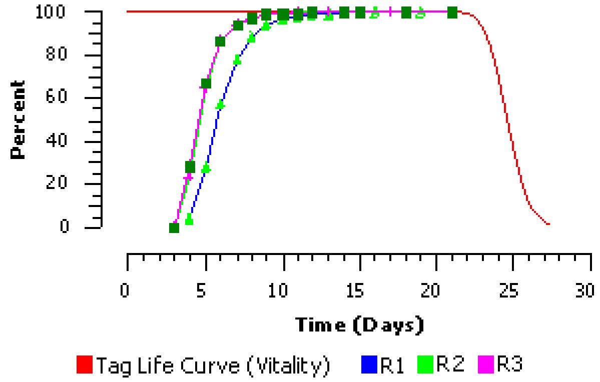


Figure 3.10. Observed time of tag failure and fitted survivorship curves using a) the Weibull model for the spring tagging study and b) the vitality model of Li and Anderson (2009) for the summer tagging study in 2014.



a. Yearling Chinook Salmon

b. Juvenile Steelhead



c. Subyearling Chinook Salmon

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

3.4.8 Downstream Mixing

To help induce downstream mixing of the release groups, the R_1 release was 21 h before the R_2 release for all three fish stocks. The R_2 release occurred 14 h before the R_3 release in both spring and summer. Plots of the arrival timing of the various release groups at downstream detection sites indicate reasonable mixing for yearling Chinook salmon (Figure 3.12), juvenile steelhead (Figure 3.13), and subyearling Chinook salmon (Figure 3.14). The arrival modes for V_1, R_2, and R_3 were synchronous for all three fish stocks.

3.4.9 Dead Tagged Fish Releases

During the spring yearling Chinook salmon study, 2 of 25 dead tagged fish released into the tailrace of McNary Dam were detected at the array located at rkm 449. As such, the survival estimate for the V_1 release of yearling Chinook salmon must be adjusted for the probability of fish that died during dam passage with still active ATs at detection array rkm 449. Consequently, the estimate of dam passage survival and forebay-to-tailrace survival of yearling Chinook salmon at McNary Dam was bias corrected (Appendix C).

None of the dead tagged fish releases for juvenile steelhead or subyearling Chinook salmon was detected downstream at study arrays. Consequently, no adjustments were required for these two fish stocks.

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

Release Group		Detection Site			
Stock	rkm	rkm 470	rkm 449	rkm 349	rkm 325
a. Yearling Chinook Salmon					
$V_1^{(a)}$	472	1.0000 (<0.0001)	1.0000 (<0.0001)	1.0000 (<0.0001)	1.0000 (<0.0001)
R_2	468			1.0000 (<0.0001)	0.9999 (<0.0001)
R_3	449			0.9999 (<0.0001)	0.9998 (<0.0001)
b. Juvenile Steelhead					
$V_1^{(a)}$	472	1.0000 (<0.0001)	1.0000 (<0.0001)	1.0000 (<0.0001)	≥0.9999 (<0.0001)
R_2	468			≥0.9996 (<0.0001)	≥0.9999 (<0.0001)
R_3	449			1.0000 (<0.0001)	1.0000 (<0.0001)
c. Subyearling Chinook Salmon					
$V_1^{(a)}$	472	0.9997 (0.0005)	1.0000 (0.0001)	0.9997 (0.0006)	0.9997 (0.0007)
R_2	468			0.9995 (0.0009)	0.9995 (0.0010)
R_3	449			0.9995 (0.0009)	0.9995 (0.0010)

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

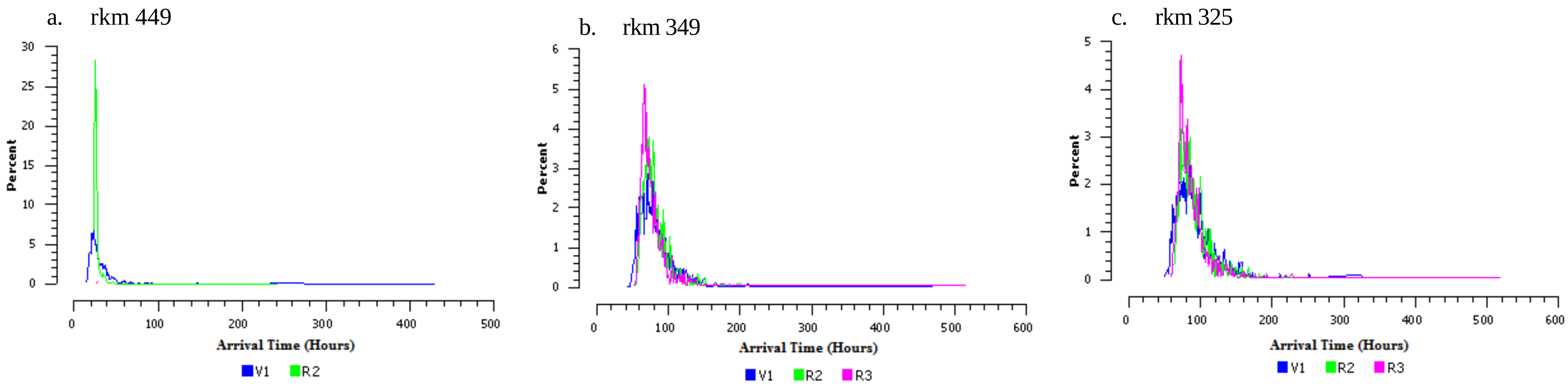

a. rkm 449
b. rkm 349
c. rkm 325

Figure 3.12. Frequency distributions of downstream arrival timing (expressed as percentages) for yearling Chinook salmon releases V_1, R_2, and R_3 at detection arrays located at a) rkm 449, b) rkm 349, and c) rkm 325 (see Figure 2.1). All times were adjusted relative to the release time of V_1.

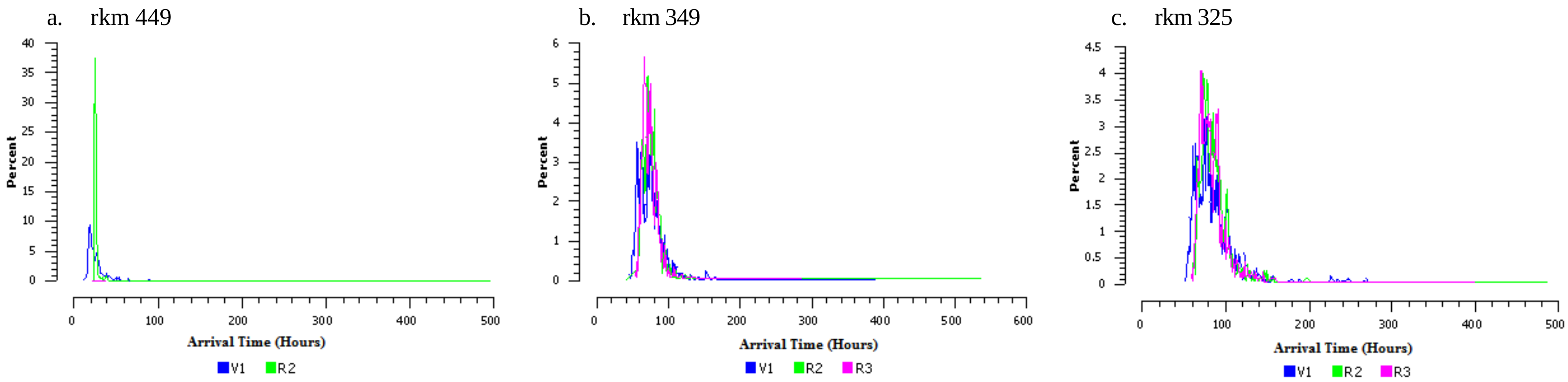
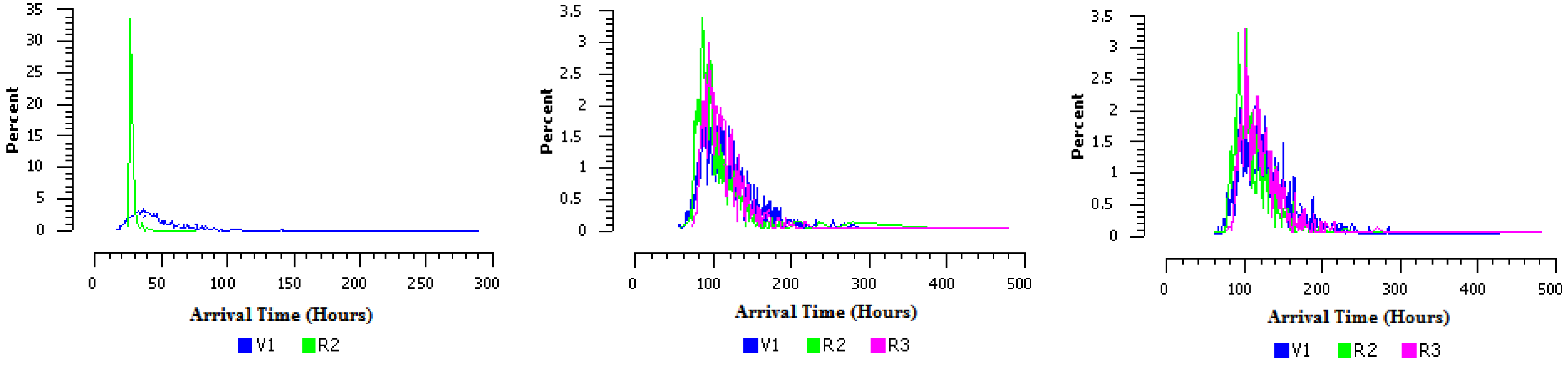

a. rkm 449
b. rkm 349
c. rkm 325

Figure 3.13. Frequency distributions of downstream arrival timing (expressed as percentages) for juvenile steelhead releases V_1, R_2, and R_3 at detection arrays located at a) rkm 449, b) rkm 349, and c) rkm 325 (see Figure 2.1). All times were adjusted relative to the release time of V_1.



a. rkm 449

b. rkm 349

c. rkm 325

Figure 3.14. Frequency distributions 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 449, b) rkm 349, and c) rkm 325 (see Figure 2.1). All times were adjusted relative to the release time of V_1.

3.5 Survival and Passage Performance

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

3.5.1 Dam Passage Survival

The high river flows in 2014 disrupted the planned 40% spill in spring. During the summer study, the 50% spill target was achieved for the majority of the study period. Season-wide survival estimates were calculated over the prevailing spill conditions. Detection histories used in the survival analyses can be found in Appendix B.

3.5.1.1 Yearling Chinook Salmon

The estimate of dam passage survival for yearling Chinook salmon must be adjusted for the observed frequency of dead tagged fish detections at array rkm 449. The unadjusted reach survival for the V_1 release group was $\hat{S}_1 = 0.9628$ ($\widehat{\text{SE}} = 0.0039$). After adjustment for the observed rate of dead tagged fish detected (i.e., 2/25), the reach survival estimate reduced to 0.9595 ($\widehat{\text{SE}} = 0.0048$) (Appendix C).

The estimate of dam passage survival was calculated after adjustment for the dead tagged fish release to be

$$\hat{S} = \frac{0.9595}{\left(\frac{0.8701}{0.8714}\right)} = \frac{0.9595}{0.9985} = 0.9610 \tag{3.1}$$

with an estimated standard error of $\widehat{\text{SE}} = 0.0127$ (Table 3.4). Consequently, the point estimate and standard error for dam passage survival of yearling Chinook salmon at McNary Dam in 2014 met the BiOp standards.

Table 3.4. Survival, detection, and λ parameters for the final model used to estimate dam passage survival for yearling Chinook salmon during the season-wide spring study (27 April to 30 May 2014). Standard errors are based on both the inverse Hessian matrix and bootstrapping for key parameters (†) and only the inverse Hessian matrix for associated parameters (*).

	CR470 to 449		CR449 to 349		Release to CR349	
Release	$\hat{S}$	$\widehat{\text{SE}}$ †	$\hat{S}$	$\widehat{\text{SE}}$ *	$\hat{S}$	$\widehat{\text{SE}}$ †
V_1	0.9628$^{(a)}$	0.0039	0.8946	0.0064		
R_2					0.8701	0.0075
R_3					0.8714	0.0075

(a) Reach survival for V1 not adjusted for detections of dead tagged fish

	CR449		CR349	
Release	$\hat{p}$	$\widehat{\text{SE}}$ *	$\hat{p}$	$\widehat{\text{SE}}$ *
V_1	1.0000	0.0000	0.9975	0.0011
R_2			0.9994	0.0006
R_3			0.9994	0.0006

	CR349–325	
Release	$\hat{\lambda}$	$\widehat{\text{SE}}$ *
V_1	0.9623	0.0042
R_2	0.9699	0.0041
R_3	0.9692	0.0042

3.5.1.2 Juvenile Steelhead

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

$$\hat{S}_{\text{Dam}} = \frac{0.9478}{\left(\frac{0.8426}{0.8622}\right)} = \frac{0.9478}{0.9773} = 0.9698 \qquad (3.2)$$

with an estimated standard error of $\widehat{\text{SE}}$ = 0.0136 (Table 3.5). Consequently, the juvenile steelhead tagging study in 2014 meet BiOp standards for dam passage survival and precision.

Table 3.5. Survival, detection, and λ parameters for the final model used to estimate dam passage survival for juvenile steelhead during the season-wide spring study (29 April to 28 May 2014). Standard errors are based on both the inverse Hessian matrix and bootstrapping for key parameters (†) and only the inverse Hessian matrix for associated parameters (*).

	CR470 to 449		CR449 to 349		Release to CR349	
Release	$\hat{S}$	$\widehat{\text{SE}}$ †	$\hat{S}$	$\widehat{\text{SE}}$ *	$\hat{S}$	$\widehat{\text{SE}}$ †
V_1	0.9478	0.0046	0.9045	0.0062		
R_2					0.8426	0.0082
R_3					0.8622	0.0077

	CR449		CR349	
Release	$\hat{p}$	$\widehat{\text{SE}}$ *	$\hat{p}$	$\widehat{\text{SE}}$ *
V_1	1.0000	0.0000	1.0000	0.0000
R_2			1.0000	0.0000
R_3			0.9994	0.0006

	CR349–325	
Release	$\hat{\lambda}$	$\widehat{\text{SE}}$ *
V_1	0.9828	0.0029
R_2	0.9740	0.0039
R_3	0.9825	0.0032

3.5.1.3 Subyearling Chinook Salmon

The estimate of season-wide dam passage survival for subyearling Chinook salmon during summer 2014 was calculated to be

$$\hat{S}_{\text{Dam}} = \frac{0.9101}{\left(\frac{0.7417}{0.7530}\right)} = \frac{0.9101}{0.9850} = 0.9239 \qquad (3.3)$$

with a standard error of $\widehat{\text{SE}}$ = 0.0180 (Table 3.6). Because the precision standard was exceeded (i.e., SE >0.015), a reduced model was also fit to the data that assumed homogeneous detection probabilities at CR349 and homogeneous λ ’s between CR349–325. However, because of the extremely high detection rates, the reduced model produced the same results as the fully parameterized model with no gain in precision. Neither the point estimate nor the standard error met the BiOp requirements for this subyearling Chinook salmon survival study at McNary Dam in 2014.

Table 3.6. Survival, detection, and λ parameters for the final model used to estimate dam passage survival for subyearling Chinook salmon during the summer study. Standard errors are based on both the inverse Hessian matrix and bootstrapping for key parameters (†) and only the inverse Hessian matrix for associated parameters (*).

	CR470 to 449		CR449 to 349		Release to CR349	
Release	$\hat{S}$	$\widehat{\text{SE}}^{\dagger}$	$\hat{S}$	$\widehat{\text{SE}}^{*}$	$\hat{S}$	$\widehat{\text{SE}}^{\dagger}$
V_1	0.9101	0.0058	0.7606	0.0091		
R_2					0.7417	0.0098
R_3					0.7530	0.0097

	CR449		CR349	
Release	$\hat{p}$	$\widehat{\text{SE}}^{*}$	$\hat{p}$	$\widehat{\text{SE}}^{*}$
V_1	0.9982	0.0010	1.0000	0.0000
R_2			1.0000	0.0000
R_3			1.0000	0.0000

	CR349–325	
Release	$\hat{\lambda}$	$\widehat{\text{SE}}^{*}$
V_1	0.8949	0.0076
R_2	0.9152	0.0073
R_3	0.9075	0.0075

3.5.2 Forebay-to-Tailrace Passage Survival

The estimates of forebay-to-tailrace passage survival were calculated analogously to those of dam passage survival except the virtual-release group (V_1) was composed of fish known to have arrived at the forebay (i.e., detection array rkm 472, Figure 2.1) rather than at the dam face. These survival estimates were based on the release data across the season. The forebay-to-tailrace survival was estimated using the same statistical model as was used in estimating dam passage survival. Yearling Chinook survival was

$$\hat{S}_{\text{forebay-to-tailrace}} = 0.9575\left(\widehat{\text{SE}} = 0.0127\right)^{1} \tag{3.4}$$

juvenile steelhead was

$$\hat{S}_{\text{forebay-to-tailrace}} = 0.9663\left(\widehat{\text{SE}} = 0.0136\right) \tag{3.5}$$

and subyearling Chinook salmon was

$$\hat{S}_{\text{forebay-to-tailrace}} = 0.9215\left(\widehat{\text{SE}} = 0.0180\right). \tag{3.6}$$

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[1] Adjusted for the probability of detecting dead tagged yearling Chinook salmon at the McNary tailwater array.

3.5.3 Forebay Residence Time

The forebay residence time was calculated from the first detection at the forebay BRZ array (rkm 472) to the last detection at the dam (rkm 470). For yearling Chinook salmon, the mean forebay residence time was estimated to be 3.06 h ($\widehat{\text{SE}}$ = 0.30), for juvenile steelhead it was estimated to be 5.07 h ($\widehat{\text{SE}}$ = 0.17), and for subyearling Chinook salmon it was estimated to be 3.76 h ($\widehat{\text{SE}}$ = 0.16) (Table 3.7). The distribution of forebay residence times indicates the mode for forebay residence times was 1–1.5 h for yearling Chinook salmon, 1.5–2 h for juvenile steelhead, and 1–1.5 h for subyearling Chinook salmon (Figure 3.15). Median forebay residence times were 1.73 h, 2.57 h, and 2.22 h for yearling Chinook salmon, juvenile steelhead, and subyearling Chinook salmon, respectively (Table 3.7).

3.5.4 Tailrace Egress Time

The tailrace egress time was calculated based on the time from the last fish detection at the double array at the face of McNary Dam to the last detection at the BRZ tailrace array (Figure 3.16). However, for bypassed fish, tailrace egress time was calculated from the last detection in the fish bypass to the last detection at the BRZ tailrace array. Mean tailrace egress time for yearling Chinook salmon was estimated to be 0.74 h ($\widehat{\text{SE}}$ = 0.20). For juvenile steelhead, mean tailrace egress time was estimated to be 0.60 h ($\widehat{\text{SE}}$ = 0.09). Mean tailrace egress time for subyearling Chinook salmon was estimated to be 1.07 h ($\widehat{\text{SE}}$ = 0.18). Median egress times were 0.44, 0.37, and 0.54 h for yearling Chinook salmon, juvenile steelhead, and subyearling Chinook salmon, respectively (Table 3.7). For yearling Chinook and juvenile steelhead, the mode for tailrace egress time was 0–0.5 h; egress time was 0.5–1.0 h for subyearling Chinook salmon (Figure 3.16).

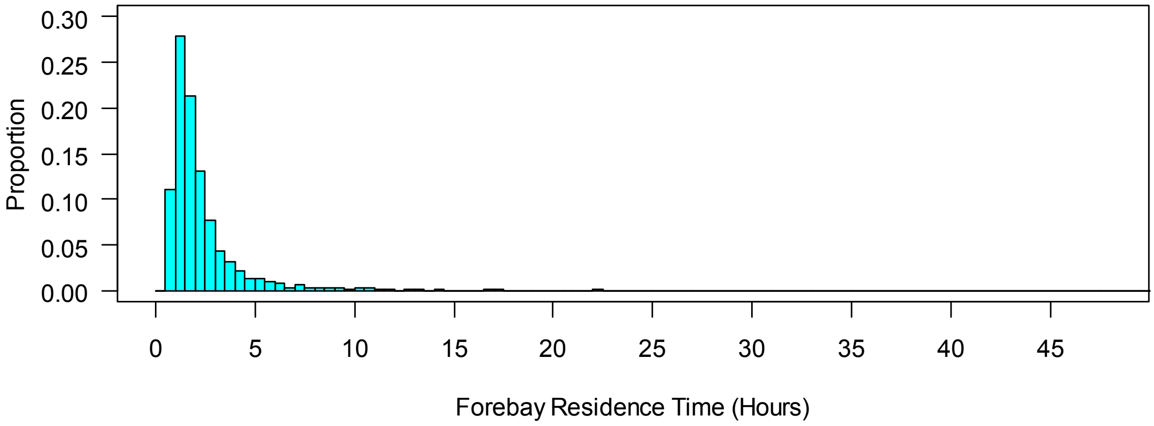
3.5.5 Spill Passage Efficiency

Spill passage efficiency is defined as the fraction of the fish that passed through a hydroproject by the spillway and temporary spill weirs. The double-detection array at the face of McNary Dam was used to identify and track fish as they approached and passed at the dam. Because detection efficiency was constant (100%) across the dam, the numbers of fish entering the various routes at McNary Dam were used to estimate SPE based on a binomial sampling model. For yearling Chinook salmon, $\widehat{\text{SPE}}$ = 0.7140 (0.0092); for juvenile steelhead, $\widehat{\text{SPE}}$ = 0.8433 (0.0075); and for subyearling Chinook salmon, $\widehat{\text{SPE}}$ = 0.5380 (0.0102) (Table 3.8).

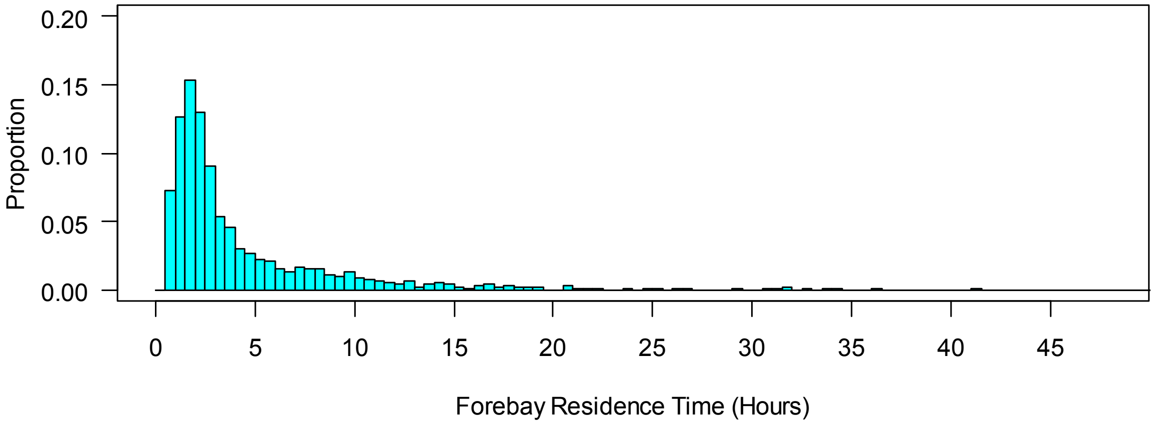
3.5.6 Fish Passage Efficiency

Fish passage efficiency, termed SPE in the Fish Accords, is the fraction of the fish that passed through non-turbine routes at the dam. As with SPE, the double-detection array at the face of McNary Dam was used to identify and track fish as they entered the dam. Because detection efficiency was constant (100%) for all routes, the number of fish entering the various routes at McNary Dam were used to estimate FPE based on a binomial sampling model. For yearling Chinook salmon at McNary Dam in 2014, fish passage efficiency is estimated to be $\widehat{\text{FPE}}$ = 0.9118 (0.0058); for juvenile steelhead, $\widehat{\text{FPE}}$ = 0.9730 (0.0033); and for subyearling Chinook salmon, $\widehat{\text{FPE}}$ = 0.8090 (0.0080) (Table 3.8).

a. Yearling Chinook Salmon



b. Juvenile Steelhead



c. Subyearling Chinook Salmon

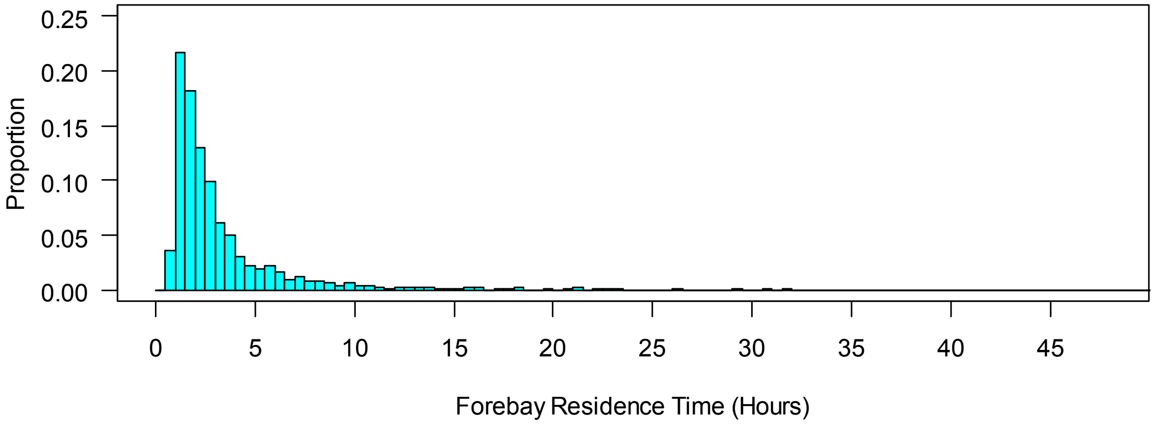


Figure 3.15. Distribution of forebay residence times for a) yearling Chinook salmon, b) juvenile steelhead, and c) subyearling Chinook salmon at McNary Dam, 2014.

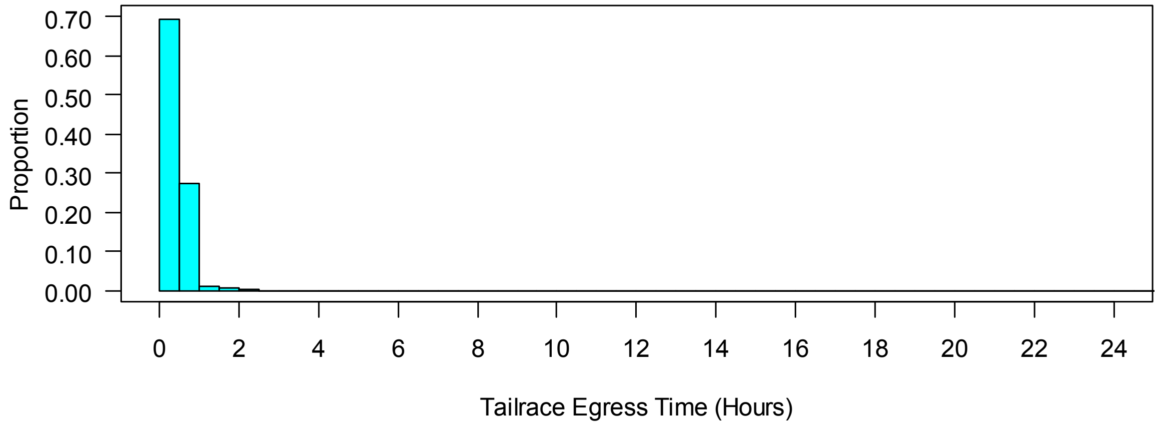
Table 3.7. Estimated mean and median forebay residence times (h) and mean and median tailrace egress times for yearling Chinook salmon, juvenile steelhead, and subyearling Chinook salmon at McNary Dam in 2014. Standard errors are in parentheses.

Performance Measure	Yearling Chinook Salmon	Juvenile Steelhead	Subyearling Chinook Salmon
Forebay Residence Time			
• Mean	3.06 h (0.30)	5.07 h (0.17)	3.76 h (0.16)
• Median	1.73 h	2.57 h	2.22 h
Tailrace Egress Time			
• Mean	0.74 h (0.20)	0.60 h (0.09)	1.07 h (0.18)
• Median	0.44 h	0.37 h	0.54 h

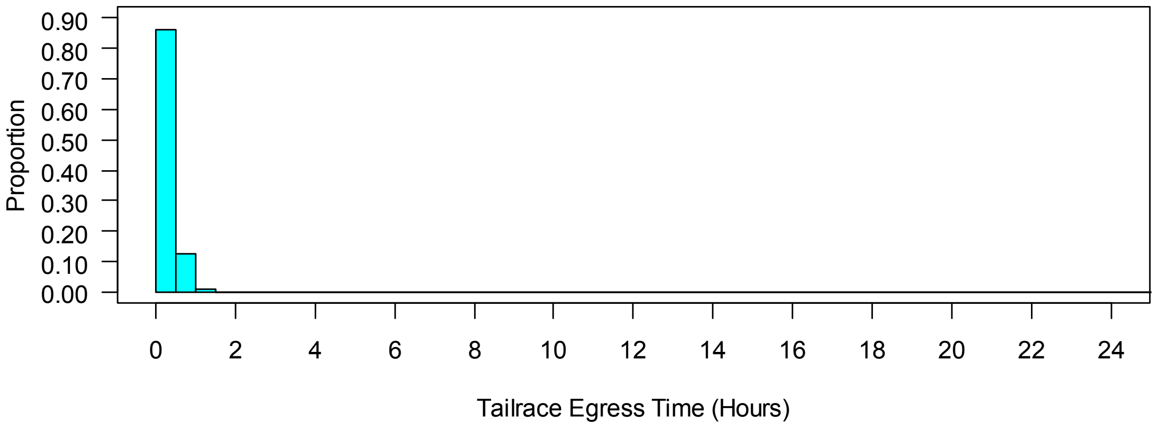
Table 3.8. Estimated spill passage efficiency (SPE) and fish passage efficiency (FPE) for yearling Chinook salmon, juvenile steelhead, and subyearling Chinook salmon at McNary Dam in 2014. Standard errors are in parentheses.

Performance Measure	Yearling Chinook Salmon	Juvenile Steelhead	Subyearling Chinook Salmon
SPE	0.7140 (0.0092)	0.8433 (0.0075)	0.5380 (0.0102)
FPE	0.9118 (0.0058)	0.9730 (0.0033)	0.8090 (0.0080)

a. Yearling Chinook Salmon



b. Juvenile Steelhead



c. Subyearling Chinook Salmon

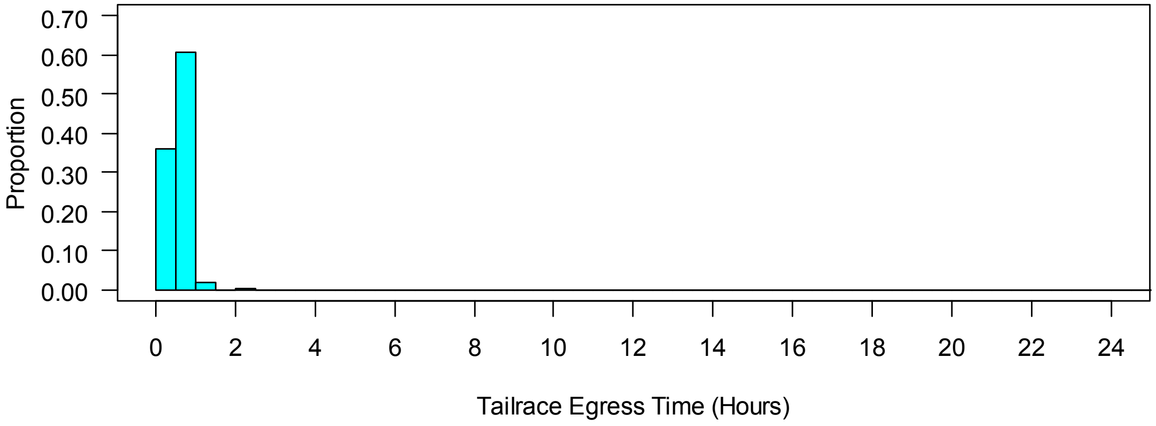


Figure 3.16. Distribution of tailrace egress times for a) yearling Chinook salmon, b) juvenile steelhead, and c) subyearling Chinook salmon at McNary Dam, 2014.

4.0 Discussion

This section describes the conduct of the 2014 study, study performance, and compares the 2014 compliance study estimates with previous studies at McNary Dam. A detailed analysis of the route of passage, behavior, and passage distribution will be provided in a follow up technical report (Weiland et al. in preparation).

4.1 Study Conduct

The many tests of assumptions (Appendix A) found the acoustic telemetry study achieved good downstream mixing (Figure 3.12–Figure 3.154), with adequate tag-life (Figure 3.11) and no evidence of adverse tagger effects. Those results suggest the assumptions of the virtual/paired-release model were fulfilled, permitting valid estimation of dam passage survival and related parameters.

The one model violation was the detection of dead tagged fish at the tailwater array during the yearling Chinook salmon study. However, a bias adjustment (see Appendix C) was applied to provide a valid estimate of dam passage survival. No similar problem occurred during the juvenile steelhead or subyearling Chinook salmon studies.

The spring spill target of 40% could not be maintained because of a combination of high river discharge and turbine outages for maintenance. The summer 50% spill target was met and maintained starting on June 15, 2014.

4.2 Study Performance

Yearling Chinook salmon, juvenile steelhead, and subyearling Chinook salmon dam passage survival studies were conducted at McNary Dam in 2014. For the spring studies, yearling Chinook salmon ($\hat{S}$ = 0.9610, $\widehat{\mathrm{SE}}$ = 0.0127) and juvenile steelhead ($\hat{S}$ = 0.9698, $\widehat{\mathrm{SE}}$ = 0.0136) both met the 2008 BiOp standards for dam passage survival (i.e., $\hat{S} \geq 0.96$) and precision ($\widehat{\mathrm{SE}} \leq 0.015$). For the subyearling Chinook salmon study, neither the point estimate nor the standard error (i.e., $\hat{S}$ = 0.9239, $\widehat{\mathrm{SE}}$ = 0.0180) met the 2008 BiOp standards of $\hat{S} \geq 0.93$ and $\widehat{\mathrm{SE}} \leq 0.015$ for summer migrants. Failure to meet the precision level for subyearling Chinook salmon was due, in part, to the unexpectedly low survival rate between rkm 449 and 349 of approximately 75%.

4.3 Comparison to Previous Studies at McNary Dam

Comparison of survival between 2012 and 2014 (Table 4.1) shows no significant difference for yearling Chinook salmon (*P* = 0.9747) or juvenile steelhead (*P* = 0.3570). However, there was a significant difference between years (*P* = 0.0171) for subyearling Chinook salmon, with an estimated 5-percentage-point drop in 2014. Accompanying this decrease in survival was approximately a 25-percentage-point drop in SPE and 10-percentage-point drop in FPE (Table 4.2). No similar declines in SPE and FPE were observed for yearling Chinook salmon or juvenile steelhead in spring 2014.

Table 4.1. Comparison of dam passage survival estimates of tagged fish at McNary Dam in 2012 and 2014. Standard errors are in parentheses. Spill levels exceeded; 40% ±5% in spring and 50% ±5% in summer of 2012, and 40% ±5% in spring of 2014.

Fish Stock	2012	2014
Yearling Chinook salmon	0.9616 (0.0140)	0.9610 (0.0127)
Juvenile steelhead	0.9908 (0.0183)	0.9698 (0.0136)
Subyearling Chinook salmon	0.9747 (0.0114)	0.9239 (0.0180)

Table 4.2. Comparison of spill passage efficiency (SPE) and fish passage efficiency (FPE) estimates at McNary Dam between 2012 and 2014 by fish stock. Standard errors are in parentheses.

		Year	
Performance Measure	Stock	2012	2014
SPE	Yearling Chinook salmon	0.7246 (0.0121)	0.7140 (0.0092)
	Juvenile steelhead	0.8215 (0.0104)	0.8433 (0.0075)
	Subyearling Chinook salmon	0.7832 (0.0083)	0.5380 (0.0102)
FPE	Yearling Chinook salmon	0.9676 (0.0048)	0.9118 (0.0058)
	Juvenile steelhead	0.9768 (0.0042)	0.9730 (0.0033)
	Subyearling Chinook salmon	0.9089 (0.0058)	0.8090 (0.0080)

5.0 References

3 Treaty Tribes-Action Agencies. 2008. *Memorandum of Agreement Among the Umatilla, Warm Springs and Yakama Tribes, Bonneville Power Administration, U.S. Army Corps of Engineers, and U.S. Bureau of Reclamation*, Portland, Oregon, April 4, 2008. Available at http://www.salmonrecovery.gov/Files/BiologicalOpinions/3-tribe-AA-MOA-Final.pdf.

Burnham KP, DR Anderson, GC White, C Brownie, and KH Pollock. 1987. "Design and Analysis Methods for Fish Survival Experiments Based on Release-Recapture." *American Fisheries Society Monograph* 5.

CBSPSC (Columbia Basin Surgical Protocol Steering Committee). 2011. *Surgical Protocols for Implanting JSATS Transmitters into Juvenile Salmonids for Studies Conducted for the U.S. Army Corps of Engineers*. V1, U.S. Army Corps of Engineers, Portland District, Portland, Oregon.

Elandt-Johnson RC and NL Johnson. 1980. *Survival Models and Data Analysis*. Wiley, New York.

Li T and JJ Anderson. 2009. "The Vitality Model: A Way to Understand Population Survival and Demographic Heterogeneity." *Theoretical Population Biology* 76:118–131.

Martinson R, G Kovalchuk, and D Ballinger. 2006. *Monitoring of Downstream Salmon and Steelhead at Federal Hydroelectric Facilities.* 2005–2006 Annual Report, Project No. 198712700, BPA Report DOE/BP-00022085-2, Portland, Oregon.

NMFS (National Marine Fisheries Service). 2008. *Biological Opinion – Consultation on Remand for Operation of the Federal Columbia River Power System, 11 Bureau of Reclamation Projects in the Columbia Basin and ESA Section 10(a)(1)(A) Permit for Juvenile Fish Transportation Program.* National Marine Fisheries Service (NOAA Fisheries) – Northwest Region, Seattle, Washington. Available at: http://www.salmonrecovery.gov/.

Seber GAF. 1982. *The Estimation of Animal Abundance*. MacMillan, New York.

Skalski, J. R., A. G. Seaburg, and R. A. Buchanan. 2013. The Effects of High Detection Probabilities on Model Selection in Paired Release-Recapture Studies in the Era of Electronic Tagging Studies. *Animal Biotelemetry* 1:12 (DOI: 10.1186/10.1186/2050-3385-1-12).

Skalski JR, GE Johnson, and TJ Carlson. 2010a. Compliance *Monitoring of Juvenile Yearling Chinook Salmon and Steelhead Survival and Passage at The Dalles Dam, Spring 2010*. PNNL-19819, summary report submitted to the U.S. Army Corps of Engineers, Portland District, Portland, Oregon, by Pacific Northwest National Laboratory, Richland, Washington.

Skalski JR, RL Townsend, TW Steig, and S Hemstrom. 2010b. "Comparison of Two Alternative Approaches for Estimating Dam Passage Survival using Acoustic-tagged Sockeye Salmon Smolts." *North American Journal of Fisheries Management* 30:831–839.

Townsend RL, JR Skalski, P Dillingham, and TW Steig. 2006. “Correcting Bias in Survival Estimation Resulting from Tag Failure in Acoustic and Radiotelemetry Studies.” *Journal of Agricultural Biology and Environmental Statistics* 11(2):183–196.

Weiland MA, GR Ploskey, JS Hughes, and fifteen co-authors. 2009. *Acoustic Telemetry Evaluation of Juvenile Salmonid Passage and Survival at John Day Dam with Emphasis on the Prototype Surface Flow Outlet, 2008*. PNNL-18890, final report submitted to the U.S. Army Corps of Engineers, Portland District, Portland, Oregon, by Pacific Northwest National Laboratory, Richland, Washington.

Weiland MA, GR Ploskey, JS Hughes, and sixteen co-authors. 2011. *Acoustic Telemetry Evaluation of Juvenile Salmonid Passage and Survival Proportions at John Day Dam, 2009*. PNNL-20766, final report submitted to the U.S. Army Corps of Engineers, Portland District, Portland, Oregon, by Pacific Northwest National Laboratory, Richland, Washington.

Weiland MA, GR Ploskey, CM Woodley, and twenty-three co-authors. 2013. *Acoustic Telemetry Evaluation of Juvenile Salmonid Passage and Survival at John Day Dam, 2010*. PNNL-22177, final report submitted to the U.S. Army Corps of Engineers, Portland District, Portland, Oregon, by Pacific Northwest National Laboratory, Richland, Washington.

Weiland MA, CM Woodley, JS Hughes, and co-authors. In preparation. *Survival and Passage of Yearling and Subyearling Chinook Salmon and Juvenile Steelhead at McNary Dam, 2014.* Pacific Northwest National Laboratory, Richland, Washington.

Appendix A

Tests of Assumptions

Appendix A

Tests of Assumptions

A.1 Tagger Effort

Data from all three release locations in the McNary Dam spring and summer studies were examined as far downriver as possible for tagger effects. This was done to maximize the statistical power to detect tagger effects.

To minimize any tagger effects that might go undetected, tagger effort should be balanced across release locations and within replicates. A total of eight taggers participated in tagging the yearling Chinook salmon and juvenile steelhead during the spring study. Tagger effort was found to be balanced across the three release locations for yearling Chinook salmon $\left(P\left(\chi_{14}^2 \geq 0.4246\right) \approx 1.0\right)$ and juvenile steelhead $\left(P\left(\chi_{14}^2 \geq 0.4254\right) \approx 1.0\right)$ (Table A.1a, Table A.2a).

For the six taggers during the summer subyearling Chinook salmon study, tagger effort was found to be balanced across release locations for the McNary and John Day releases, respectively (Table A.3) $\left(P\left(\chi_{20}^2 \geq 25.4875\right) = 0.1709\right)$.

A.2 Tagger Effects – Spring

Reach survivals and cumulative reach survivals were calculated for the fish tagged by the eight different staff in spring. Of the 12 tests of significance for reach survivals for yearling Chinook salmon and juvenile steelhead (Table A.2), only 1 was significant at $\alpha = 0.10$ (i.e., 8.3%). For cumulative survivals, 2 of 12 tests were significant at $\alpha = 0.10$ (i.e., 16.6%). However, the pattern of results did not identify any tagger as consistently having poor fish performance. Therefore, all fish tagged by all staff were used in the spring analysis.

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

a. Replicates 1-16

Release	A	B	C	D	E	F	G	H	*P*-value
R1_CR503	318	350	367	274	321	279	297	294	
R2_CR468	257	279	291	217	260	218	239	239	
R3_CR449	256	282	291	215	255	223	236	244	
Chi-square = 0.4246				df = 14					1.0000

b. Replicate 1

Release	C	E	F	G	*P*-value
R1_CR503	39	40	40	38	
R2_CR468	32	33	32	29	
R3_CR449	33	33	31	28	
Chi-square = 0.2101		df = 6			0.9998

c. Replicate 2

Release	B	C	E	G	*P*-value
R1_CR503	41	40	42	35	
R2_CR468	33	32	31	30	
R3_CR449	32	32	34	28	
Chi-square = 0.2784		df = 6			0.9996

d. Replicate 3

Release	A	B	C	D	*P*-value
R1_CR503	39	38	43	37	
R2_CR468	33	30	35	28	
R3_CR449	31	31	35	29	
Chi-square = 0.1517		df = 6			0.9999

e. Replicate 4

Release	A	B	D	H	*P*-value
R1_CR503	40	39	35	44	
R2_CR468	33	32	27	34	
R3_CR449	31	32	26	36	
Chi-square = 0.2098		df = 6			0.9998

f. Replicate 5

Release	C	E	F	G	*P*-value
R1_CR503	42	39	40	38	
R2_CR468	32	34	31	29	
R3_CR449	30	29	30	29	
Chi-square = 0.3210		df = 6			0.9994

g. Replicate 6

Release	C	E	F	G	*P*-value
R1_CR503	40	40	40	38	
R2_CR468	32	32	31	31	
R3_CR449	31	30	31	30	
Chi-square = 0.0519		df = 6			1.0000

h. Replicate 7

Release	A	B	D	H	*P*-value
R1_CR503	41	39	34	44	
R2_CR468	34	32	26	34	
R3_CR449	34	33	26	35	
Chi-square = 0.1384		df = 6			0.9999

i. Replicate 8

Release	A	B	D	H	*P*-value
R1_CR503	41	40	36	41	
R2_CR468	31	32	29	34	
R3_CR449	34	33	27	33	
Chi-square = 0.2718		df = 6			0.9996

j. Replicate 9

Release	C	E	F	G	*P*-value
R1_CR503	40	40	40	38	
R2_CR468	32	32	30	30	
R3_CR449	32	34	32	30	
Chi-square = 0.1128		df = 6			1.0000

k. Replicate 10

Release	C	E	F	G	*P*-value
R1_CR503	40	39	40	38	
R2_CR468	32	33	30	31	
R3_CR449	33	31	33	31	
Chi-square = 0.2292		df = 6			0.9998

l. Replicate 11

Release	A	B	D	H	A
R1_CR503	40	38	34	46	40
R2_CR468	33	30	29	34	33
R3_CR449	32	31	29	36	32
Chi-square = 0.2348		df = 6			0.9998

m. Replicate 12

Release	A	B	D	H	*P*-value
R1_CR503	41	39	36	40	
R2_CR468	33	32	28	33	
R3_CR449	33	31	29	34	
Chi-square = 0.0849		df = 6			1.0000

n. Replicate 13

Release	C	E	F	G	*P*-value
R1_CR503	43	41	38	36	
R2_CR468	33	33	31	29	
R3_CR449	33	33	33	29	
Chi-square = 0.1549		df = 6			0.9999

o. Replicate 14

Release	C	E	F	G	*P*-value
R1_CR503	40	40	41	36	
R2_CR468	31	32	33	30	
R3_CR449	32	31	33	31	
Chi-square = 0.1268		df = 6			1.0000

p. Replicate 15

Release	A	B	D	H	*P*-value
R1_CR503	35	36	28	36	
R2_CR468	27	26	23	30	
R3_CR449	29	27	24	32	
Chi-square = 0.3168		df = 6			0.9994

q. Replicate 16

Release	A	B	D	H	*P*-value
R1_CR503	41	40	34	43	
R2_CR468	33	32	27	40	
R3_CR449	32	32	25	38	
Chi-square = 0.4725		df = 6			0.9982

Table A.2. Numbers of juvenile steelhead tagged by each staff member by release location (i.e., R_1, R_2, ...). Chi-square tests of homogeneity were not significant.

a. Replicates 1-16

Release	A	B	C	D	E	F	G	H	*P*-value
R1_CR503	313	349	363	274	323	276	304	297	
R2_CR468	253	281	290	220	252	222	244	237	
R3_CR449	256	280	288	214	254	222	242	244	
Chi-square = 0.4254					df = 14				1.0000

b. Replicate 1

Release	C	E	F	G	*P*-value
R1_CR503	41	40	39	38	
R2_CR468	32	32	32	30	
R3_CR449	34	32	34	26	
Chi-square = 0.6299		df = 6			0.9959

c. Replicate 2

Release	B	C	E	G	*P*-value
R1_CR503	40	41	40	37	
R2_CR468	32	33	30	31	
R3_CR449	32	32	31	31	
Chi-square = 0.1377		df = 6			0.9999

d. Replicate 3

Release	A	B	C	D	*P*-value
R1_CR503	38	39	44	37	
R2_CR468	29	32	34	30	
R3_CR449	33	32	31	30	
Chi-square = 0.5809		df = 6			0.9967

e. Replicate 4

Release	A	B	D	H	*P*-value
R1_CR503	40	40	35	43	
R2_CR468	33	33	26	34	
R3_CR449	32	33	26	35	
Chi-square = 0.1736		df = 6			0.9999

f. Replicate 5

Release	C	E	F	G	*P*-value
R1_CR503	40	40	40	38	
R2_CR468	32	32	32	30	
R3_CR449	32	32	32	30	
Chi-square = 0.0031		df = 6			1.0000

g. Replicate 6

Release	C	E	F	G	*P*-value
R1_CR503	40	40	40	38	
R2_CR468	31	31	32	31	
R3_CR449	32	32	31	31	
Chi-square = 0.0657		df = 6			1.0000

h. Replicate 7

Release	A	B	D	H	*P*-value
R1_CR503	41	40	33	44	
R2_CR468	33	33	26	35	
R3_CR449	33	33	26	34	
Chi-square = 0.0505		df = 6			1.0000

i. Replicate 8

Release	A	B	D	H	*P*-value
R1_CR503	40	40	37	41	
R2_CR468	33	32	28	33	
R3_CR449	33	32	26	35	
Chi-square = 0.3724		df = 6			0.9991

j. Replicate 9

Release	C	E	F	G	*P*-value
R1_CR503	40	41	39	38	
R2_CR468	32	32	32	29	
R3_CR449	32	32	32	30	
Chi-square = 0.0595		df = 6			1.0000

k. Replicate 10

Release	C	E	F	G	*P*-value
R1_CR503	39	40	39	40	
R2_CR468	31	32	32	32	
R3_CR449	32	31	31	31	
Chi-square = 0.0633		df = 6			1.0000

l. Replicate 11

Release	A	B	D	H	A
R1_CR503	40	36	36	46	40
R2_CR468	31	30	29	35	31
R3_CR449	32	30	28	36	32
Chi-square = 0.1204		df = 6			1.0000

m. Replicate 12

Release	A	B	D	H	*P*-value
R1_CR503	39	39	36	44	
R2_CR468	33	32	29	33	
R3_CR449	32	30	28	36	
Chi-square = 0.2775		df = 6			0.9996

n. Replicate 13

Release	C	E	F	G	*P*-value
R1_CR503	39	40	40	37	
R2_CR468	33	32	31	30	
R3_CR449	31	32	31	32	
Chi-square = 0.2092		df = 6			0.9998

o. Replicate 14

Release	C	E	F	G	*P*-value
R1_CR503	39	42	39	38	
R2_CR468	32	31	31	31	
R3_CR449	32	32	31	31	
Chi-square = 0.1371		df = 6			0.9999

p. Replicate 15

Release	A	B	D	H	*P*-value
R1_CR503	41	42	33	42	
R2_CR468	32	30	29	36	
R3_CR449	32	31	27	36	
Chi-square = 0.5309		df = 6			0.9974

q. Replicate 16

Release	A	B	D	H	*P*-value
R1_CR503	34	33	27	37	
R2_CR468	29	27	23	31	
R3_CR449	29	27	23	32	
Chi-square = 0.0367		df = 6			1.0000

Table A.3. Numbers of subyearling Chinook salmon tagged by each staff member by release location (i.e., R_1, R_2, ...). Chi-square tests of homogeneity were not significant.

a. Replicates 1-16

Release location	A	B	C	D	E	F	*P*-value
R1_CR503	392	427	430	356	401	510	1
R2_CR468	311	335	335	286	326	402	
R3_CR449	304	334	336	284	326	406	
R4_CR346	173	140	149	156	138	225	0.9998
R5_CR325	172	141	146	159	141	224	

b. Replicate 1

Release location	A	B	C	D	E	F	*P*-value
R1_CR503	0	52	52	0	53	0	0.9998
R2_CR468	0	41	42	0	41	0	
R3_CR449	0	42	41	0	41	0	
R4_CR346	19	0	0	19	0	24	1
R5_CR325	19	0	0	19	0	24	

c. Replicate 2

Release location	A	B	C	D	E	F	*P*-value
R1_CR503	0	54	52	0	51	0	0.9956
R2_CR468	0	41	43	0	42	0	
R3_CR449	0	41	43	0	39	0	
R4_CR346	20	0	0	17	0	25	0.9776
R5_CR325	19	0	0	17	0	26	

d. Replicate 3

Release location	A	B	C	D	E	F	*P*-value
R1_CR503	51	0	0	48	0	59	0.9896
R2_CR468	39	0	0	39	0	46	
R3_CR449	36	0	0	38	0	48	
R4_CR346	0	21	22	0	21	0	1
R5_CR325	0	21	22	0	21	0	

e. Replicate 4

Release location	A	B	C	D	E	F	*P*-value
R1_CR503	49	0	0	46	0	63	0.9922
R2_CR468	40	0	0	35	0	51	
R3_CR449	40	0	0	33	0	52	
R4_CR346	0	20	22	0	19	0	0.9919
R5_CR325	0	21	22	0	19	0	

f. Replicate 5

Release location	A	B	C	D	E	F	*P*-value
R1_CR503	0	56	55	0	46	0	0.9517
R2_CR468	0	41	42	0	41	0	
R3_CR449	0	41	41	0	41	0	
R4_CR346	20	0	0	16	0	26	0.9754
R5_CR325	20	0	0	17	0	25	

g. Replicate 6

Release location	A	B	C	D	E	F	*P*-value
R1_CR503	0	54	54	0	49	0	0.9954
R2_CR468	0	42	42	0	42	0	
R3_CR449	0	42	42	0	42	0	
R4_CR346	20	0	0	16	0	28	0.9760
R5_CR325	20	0	0	17	0	27	

h. Replicate 7

Release location	A	B	C	D	E	F	*P*-value
R1_CR503	49	0	0	44	0	65	0.9957
R2_CR468	36	0	0	36	0	52	
R3_CR449	36	0	0	36	0	50	
R4_CR346	0	21	20	0	21	0	0.9305
R5_CR325	0	20	22	0	20	0	

i. Replicate 8

Release location	A	B	C	D	E	F	*P*-value
R1_CR503	51	0	0	42	0	65	0.9925
R2_CR468	41	0	0	32	0	53	
R3_CR449	38	0	0	34	0	54	
R4_CR346	0	20	22	0	20	0	0.9092
R5_CR325	0	20	20	0	22	0	

j. Replicate 9

Release location	A	B	C	D	E	F	*P*-value
R1_CR503	0	55	54	0	49	0	1
R2_CR468	0	43	42	0	39	0	
R3_CR449	0	43	42	0	39	0	
R4_CR346	20	0	0	18	0	26	1
R5_CR325	20	0	0	18	0	26	

k. Replicate 10

Release location	A	B	C	D	E	F	*P*-value
R1_CR503	0	53	53	0	52	0	0.9985
R2_CR468	0	44	42	0	40	0	
R3_CR449	0	42	42	0	42	0	
R4_CR346	19	0	0	17	0	26	0.9726
R5_CR325	18	0	0	18	0	26	

l. Replicate 11

Release location	A	B	C	D	E	F	*P*-value
R1_CR503	47	0	0	45	0	66	0.9996
R2_CR468	37	0	0	35	0	51	
R3_CR449	38	0	0	34	0	52	
R4_CR346	0	20	22	0	19	0	0.9747
R5_CR325	0	19	22	0	20	0	

m. Replicate 12

Release location	A	B	C	D	E	F	*P*-value
R1_CR503	48	0	0	44	0	65	0.9934
R2_CR468	39	0	0	38	0	49	
R3_CR449	38	0	0	37	0	50	
R4_CR346	0	21	23	0	20	0	0.8488
R5_CR325	0	22	20	0	22	0	

n. Replicate 13

Release location	A	B	C	D	E	F	*P*-value
R1_CR503	0	51	56	0	50	0	0.9905
R2_CR468	0	42	40	0	40	0	
R3_CR449	0	42	42	0	39	0	
R4_CR346	18	0	0	18	0	25	0.9391
R5_CR325	20	0	0	17	0	25	

o. Replicate 14

Release location	A	B	C	D	E	F	*P*-value
R1_CR503	0	52	54	0	51	0	0.9999
R2_CR468	0	41	42	0	41	0	
R3_CR449	0	41	43	0	42	0	
R4_CR346	18	0	0	19	0	24	0.9906
R5_CR325	19	0	0	19	0	24	

p. Replicate 15

Release location	A	B	C	D	E	F	*P*-value
R1_CR503	50	0	0	44	0	63	0.9990
R2_CR468	38	0	0	36	0	50	
R3_CR449	38	0	0	35	0	51	
R4_CR346	19	17	18	16	18	21	0.9992
R5_CR325	17	18	18	17	17	21	

q. Replicate 16

Release location	A	B	C	D	E	F	*P*-value
R1_CR503	47	0	0	43	0	64	0.9901
R2_CR468	41	0	0	35	0	50	
R3_CR449	40	0	0	37	0	49	

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

a. Yearling Chinook salmon

1) Release 1 (CR503) – Reach survival

	Release to CR470.0		CR470.0 to CR449.0		CR449.0 to CR349.0	
	Est	SE	Est	SE	Est	SE
A	0.9692	0.0098	0.9503	0.0125	0.8789	0.0192
B	0.9659	0.0098	0.9669	0.0098	0.9072	0.0162
C	0.9702	0.0089	0.9632	0.0100	0.9268	0.0141
D	0.9639	0.0113	0.9615	0.0119	0.8889	0.0198
E	0.9751	0.0087	0.9744	0.0089	0.8493	0.0205
F	0.9713	0.0100	0.9704	0.0103	0.9077	0.0180
G	0.9764	0.0088	0.9689	0.0102	0.9070	0.0174
H	0.9679	0.0106	0.9416	0.0142	0.8839	0.0196
P-value	0.9874		0.4398		0.1021	

2) Release 1 (CR503) – Cumulative survival

	Release to CR470.0		Release to CR449.0		Release to CR349.0	
	Est	SE	Est	SE	Est	SE
A	0.9692	0.0098	0.9211	0.0152	0.8095	0.0221
B	0.9659	0.0098	0.9339	0.0133	0.8473	0.0193
C	0.9702	0.0089	0.9345	0.0129	0.8661	0.0178
D	0.9639	0.0113	0.9269	0.0157	0.8239	0.0231
E	0.9751	0.0087	0.9502	0.0121	0.8069	0.0220
F	0.9713	0.0100	0.9425	0.0139	0.8555	0.0211
G	0.9764	0.0088	0.9460	0.0131	0.8580	0.0203
H	0.9679	0.0106	0.9114	0.0166	0.8056	0.0231
P-value	0.9874		0.5432		0.1889	

3) Release 2 (CR468) – Reach survival

	Release to CR449.0		CR449.0 to CR349.0	
	Est	SE	Est	SE
A	0.9883	0.0067	0.8972	0.0191
B	0.9964	0.0036	0.8582	0.0210
C	0.9931	0.0048	0.8893	0.0185
D	0.9816	0.0091	0.8864	0.0219
E	0.9962	0.0038	0.8833	0.0200
F	1.0000	0.0000	0.8761	0.0223
G	0.9916	0.0059	0.8856	0.0207
H	0.9833	0.0083	0.8803	0.0212
P-value	0.3006		0.9500	

4) Release 2 (CR468) – Cumulative survival

	Release to CR470.0		Release to CR449.0		Release to CR349.0	
	Est	SE	Est	SE	Est	SE
A			0.9883	0.0067	0.8868	0.0198
B			0.9964	0.0036	0.8551	0.0212
C			0.9931	0.0048	0.8832	0.0188
D			0.9816	0.0091	0.8701	0.0229
E			0.9962	0.0038	0.8799	0.0202
F			1.0000	0.0000	0.8761	0.0223
G			0.9916	0.0059	0.8782	0.0212
H			0.9833	0.0083	0.8656	0.0221
P-value			0.3006		0.9756	

5) Release 3 (CR449) – Reach survival

	Release to CR349.0	
	Est	SE
A	0.8543	0.0221
B	0.8684	0.0202
C	0.8690	0.0198
D	0.9108	0.0195
E	0.8740	0.0208
F	0.8959	0.0205
G	0.8462	0.0236
H	0.8607	0.0222
P-value	0.4104	

6) Release 3 (CR449) – Cumulative survival

	Release to CR470.0		Release to CR449.0		Release to CR349.0	
	Est	SE	Est	SE	Est	SE
A					0.8543	0.0221
B					0.8684	0.0202
C					0.8690	0.0198
D					0.9108	0.0195
E					0.8740	0.0208
F					0.8959	0.0205
G					0.8462	0.0236
H					0.8607	0.0222
P-value					0.4104	

b. Juvenile Steelhead

1) Release 1 (CR503) – Reach survival

	Release to CR470.0		CR470.0 to CR449.0		CR449.0 to CR349.0	
	Est	SE	Est	SE	Est	SE
A	0.9621	0.0109	0.9398	0.0138	0.9223	0.0159
B	0.9543	0.0112	0.9547	0.0114	0.9117	0.0159
C	0.9697	0.0090	0.9487	0.0118	0.9189	0.0150
D	0.9380	0.0146	0.9531	0.0132	0.9262	0.0167
E	0.9628	0.0105	0.9453	0.0129	0.8878	0.0184
F	0.9640	0.0113	0.9356	0.0151	0.9150	0.0177
G	0.9507	0.0125	0.9547	0.0123	0.8764	0.0198
H	0.9360	0.0142	0.9460	0.0136	0.8783	0.0202
P-value	0.3678		0.9587		0.2220	

2) Release 1 (CR503) – Cumulative survival

	Release to CR470.0		Release to CR449.0		Release to CR349.0	
	Est	SE	Est	SE	Est	SE
A	0.9621	0.0109	0.9042	0.0166	0.8339	0.0210
B	0.9543	0.0112	0.9110	0.0153	0.8306	0.0201
C	0.9697	0.0090	0.9200	0.0143	0.8454	0.0190
D	0.9380	0.0146	0.8940	0.0186	0.8280	0.0228
E	0.9628	0.0105	0.9102	0.0159	0.8080	0.0219
F	0.9640	0.0113	0.9019	0.0179	0.8253	0.0229
G	0.9507	0.0125	0.9076	0.0166	0.7954	0.0232
H	0.9360	0.0142	0.8855	0.0185	0.7778	0.0241
P-value	0.3678		0.8984		0.3929	

3) Release 2 (CR468) – Reach survival

	Release to CR449.0		CR449.0 to CR349.0	
	Est	SE	Est	SE
A	0.9526	0.0134	0.8382	0.0237
B	0.9715	0.0099	0.9011	0.0181
C	0.9621	0.0112	0.8889	0.0188
D	0.9543	0.0141	0.8852	0.0221
E	0.9881	0.0068	0.8956	0.0194
F	0.9595	0.0132	0.8404	0.0251
G	0.9508	0.0138	0.8913	0.0205
H	0.9620	0.0124	0.8553	0.0233
P-value	0.4117		0.1908	

4) Release 2 (CR468) – Cumulative survival

	Release to CR449.0		Release to CR349.0	
	Est	SE	Est	SE
A	0.9526	0.0134	0.7984	0.0252
B	0.9715	0.0099	0.8754	0.0197
C	0.9621	0.0112	0.8552	0.0207
D	0.9543	0.0141	0.8447	0.0245
E	0.9881	0.0068	0.8849	0.0201
F	0.9595	0.0132	0.8063	0.0265
G	0.9508	0.0138	0.8475	0.0231
H	0.9620	0.0124	0.8228	0.0248
P-value	0.4117		0.0861	

5) Release 3 (CR449) – Reach survival

	Release to CR349.0	
	Est	SE
A	0.7992	0.0251
B	0.8817	0.0193
C	0.8921	0.0183
D	0.9061	0.0200
E	0.8701	0.0211
F	0.8423	0.0245
G	0.8512	0.0229
H	0.8525	0.0227
P-value	0.0216	

6) Release 3 (CR449) – Cumulative survival

	Release to CR349.0	
	Est	SE
A	0.7992	0.0251
B	0.8817	0.0193
C	0.8921	0.0183
D	0.9061	0.0200
E	0.8701	0.0211
F	0.8423	0.0245
G	0.8512	0.0229
H	0.8525	0.0227
P-value	0.0216	

A.3 Tagger Effects – Summer

Six taggers tagged all the fish associated with the summer subyearling Chinook salmon studies at McNary and John Day dams in 2014. Of the 15 tests of homogeneous reach survival, 4 (27%) were significant at $\alpha = 0.10$. One-third of the 15 tests of cumulative survival were significant at $\alpha = 0.10$, but these tests were not independent. However, once again, there was no one tagger who was consistently the worst or never had top performing fish. For these reasons, all fish from all taggers were used in the summer analysis.

Table A.5. Estimates of reach 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 (CR503) – Reach survival

	Release to CR470.0		CR470.0 to CR449.0		CR449.0 to CR349.0		CR349.0 to CR325.0		CR325.0 to CR311.0	
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE
A	0.9826	0.0067	0.9146	0.0145	0.6753	0.0251	0.9064	0.0190	0.9858	0.0081
B	0.9841	0.0062	0.9031	0.0146	0.7713	0.0217	0.8783	0.0193	0.9720	0.0104
C	0.9775	0.0073	0.9251	0.0129	0.7870	0.0209	0.9461	0.0131	0.9786	0.0086
D	0.9614	0.0103	0.9172	0.0150	0.7923	0.0229	0.8735	0.0212	0.9958	0.0047
E	0.9835	0.0066	0.9103	0.0145	0.7675	0.0224	0.8864	0.0192	0.9752	0.0100
F	0.9708	0.0075	0.8925	0.0140	0.7534	0.0206	0.8906	0.0172	0.9966	0.0034
P-value	0.2124		0.6665		**0.0025**		**0.0607**		0.1241	

b. Release 1 (CR503) – Cumulative survival

	Release to CR470.0		Release to CR449.0		Release to CR349.0		Release to CR325.0		Release to CR311.0	
	Est	SE	Est	SE	Est	SE	Est	SE	Est	SE
A	0.9826	0.0067	0.8988	0.0154	0.6069	0.0248	0.5501	0.0252	0.5423	0.0253
B	0.9841	0.0062	0.8888	0.0154	0.6855	0.0225	0.6020	0.0238	0.5852	0.0239
C	0.9775	0.0073	0.9043	0.0142	0.7117	0.0219	0.6734	0.0228	0.6590	0.0230
D	0.9614	0.0103	0.8818	0.0171	0.6987	0.0244	0.6103	0.0259	0.6077	0.0260
E	0.9835	0.0066	0.8953	0.0153	0.6871	0.0232	0.6091	0.0244	0.5940	0.0246
F	0.9708	0.0075	0.8665	0.0151	0.6528	0.0212	0.5814	0.0219	0.5794	0.0219
P-value	0.2124		0.5648		**0.0173**		**0.0136**		**0.0272**	

c. Release 2 (CR468) – Reach survival

	Release to CR449.0		CR449.0 to CR349.0		CR349.0 to CR325.0		CR325.0 to CR311.0	
	Est	SE	Est	SE	Est	SE	Est	SE
A	0.9678	0.0100	0.7291	0.0257	0.9062	0.0200	0.9844	0.0090
B	0.9612	0.0106	0.8313	0.0209	0.9235	0.0165	0.9838	0.0083
C	0.9493	0.0120	0.7848	0.0231	0.9353	0.0157	0.9918	0.0061
D	0.9696	0.0104	0.7645	0.0255	0.9095	0.0198	0.9529	0.0153
E	0.9693	0.0096	0.8057	0.0223	0.9240	0.0168	0.9870	0.0074
F	0.9711	0.0085	0.7242	0.0227	0.9071	0.0173	0.9567	0.0128
P-value	0.6508		**0.0059**		0.8209		**0.0216**	

d. Release 2 (CR468) – Cumulative survival

	Release to CR449.0		Release to CR349.0		Release to CR325.0		Release to CR311.0	
	Est	SE	Est	SE	Est	SE	Est	SE
A	0.9678	0.0100	0.7057	0.0259	0.6394	0.0274	0.6295	0.0276
B	0.9612	0.0106	0.7990	0.0220	0.7379	0.0242	0.7259	0.0245
C	0.9493	0.0120	0.7450	0.0239	0.6968	0.0252	0.6910	0.0254
D	0.9696	0.0104	0.7413	0.0259	0.6742	0.0278	0.6424	0.0284
E	0.9693	0.0096	0.7810	0.0230	0.7217	0.0249	0.7123	0.0252
F	0.9711	0.0085	0.7033	0.0228	0.6380	0.0240	0.6104	0.0244
P-value	0.6508		**0.0226**		**0.0214**		**0.0049**	

e. Release 3 (CR449) – Reach survival

	Release to CR349.0		CR349.0 to CR325.0		CR325.0 to CR311.0	
	Est	SE	Est	SE	Est	SE
A	0.7336	0.0254	0.8909	0.0210	0.9910	0.0072
B	0.7006	0.0251	0.9145	0.0183	0.9907	0.0066
C	0.7827	0.0225	0.8881	0.0196	0.9869	0.0075
D	0.7430	0.0259	0.9282	0.0179	0.9897	0.0073
E	0.7754	0.0231	0.9191	0.0174	0.9918	0.0063
F	0.7734	0.0208	0.9164	0.0157	0.9860	0.0070
P-value	0.1173		0.5625		0.9891	

f. Release 3 (CR449) – Cumulative survival

	Release to CR349.0		CR349.0 to CR325.0		CR325.0 to CR311.0	
	Est	SE	Est	SE	Est	SE
A	0.7336	0.0254	0.6535	0.0274	0.6477	0.0275
B	0.7006	0.0251	0.6407	0.0263	0.6347	0.0263
C	0.7827	0.0225	0.6951	0.0252	0.6860	0.0254
D	0.7430	0.0259	0.6896	0.0275	0.6825	0.0277
E	0.7754	0.0231	0.7127	0.0252	0.7068	0.0254
F	0.7734	0.0208	0.7087	0.0226	0.6988	0.0228
P-value	0.1173		0.2495		0.2930	

g. Release 4 (CR346) – Reach survival

	Release to CR325.0		CR325.0 to CR311.0	
	Est	SE	Est	SE
A	0.9827	0.0099	0.9941	0.0059
B	0.9857	0.0100	1.0015	0.0016
C	1.0000	0.0000	1.0000	0.0000
D	1.0000	0.0000	0.9808	0.0110
E	0.9856	0.0102	0.9926	0.0074
F	0.9956	0.0044	0.9955	0.0045
P-value	0.3333		0.2179	

h. Release 4 (CR346) – Cumulative survival

	Release to CR325.0		Release to CR311.0	
	Est	SE	Est	SE
A	0.9827	0.0099	0.9769	0.0114
B	0.9857	0.0100	0.9872	0.0102
C	1.0000	0.0000	1.0000	0.0000
D	1.0000	0.0000	0.9808	0.0110
E	0.9856	0.0102	0.9783	0.0124
F	0.9956	0.0044	0.9911	0.0063
P-value	0.3333		0.5058	

i. Release 5 (CR325) – Reach survival

	Release to CR311.0	
	Est	SE
A	0.9893	0.0082
B	0.9858	0.0100
C	0.9942	0.0069
D	0.9874	0.0088
E	1.0000	0.0000
F	0.9970	0.0046
P-value	0.6917	

j. Release 5 (CR325) – Cumulative survival

	Release to CR311.0	
	Est	SE
A	0.9893	0.0082
B	0.9858	0.0100
C	0.9942	0.0069
D	0.9874	0.0088
E	1.0000	0.0000
F	0.9970	0.0046
P-value	0.6917	

Appendix B

Capture Histories Used in Estimating Dam Passage Survival

Appendix B

Capture Histories Used in Estimating Dam Passage Survival

B.1 Yearling Chinook Salmon

Capture History	V_1 (Season-Wide) Dam Passage Survival	BRZ-to-BRZ Survival
111	1,964	1,983
011	0	0
101	5	5
001	0	0
120	6	6
020	0	0
110	77	77
010	0	0
200	8	8
100	242	245
000	89	98
Total	2,391	2,422

Capture History	Season-Wide Dam Passage Survival R_2	R_3
11	1,676	1,665
01	1	1
20	11	13
10	52	53
00	260	256
Total	2,000	1,988

B.2 Juvenile Steelhead

Capture History	V_1 (Season-Wide) Dam Passage Survival	BRZ-to-BRZ Survival
111	1,990	1,995
011	0	0
101	0	0
001	0	0
120	11	11
020	0	0
110	35	35
010	0	0
200	1	1
100	215	215
000	124	133
Total	2,376	2,390

Capture History	Season-Wide Dam Passage Survival R_2	R_3
11	1,630	1,682
01	0	1
20	10	7
10	43	30
00	315	275
Total	1,998	1,995

B.3 Subyearling Chinook Salmon

Capture History	V1 (Season-Wide)	
	Dam Passage Survival	BRZ-to-BRZ Survival
111	1,471	1,484
011	2	2
101	0	0
001	0	0
120	17	17
020	0	0
110	172	174
010	1	1
200	8	8
100	523	525
000	218	226
Total	2,412	2,437

Capture History	Season-Wide Dam Passage Survival	
	R2	R3
11	1,337	1,343
01	0	0
20	18	17
10	124	137
00	516	492
Total	1,995	1,989

Appendix C

Bias Corrections for Detections of Dead Tagged Fish

Appendix C

Bias Corrections for Detections of Dead Tagged Fish

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

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

In this estimation approach, a single detection array downstream is used and relative recovery data on release V_1 are collected (Figure C.1).

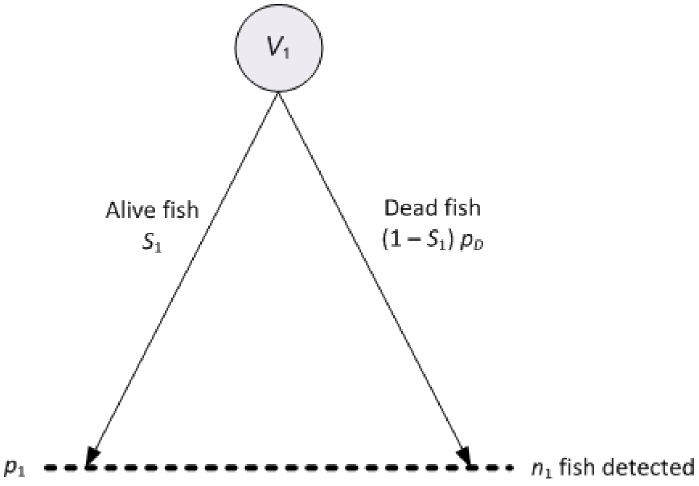


Figure C.2. Schematic of a single-reach relative recovery study with detections of both live and dead tagged fish at the array.

Let n_1 be the number of V_1 fish detected downriver regardless of alive or dead. Then the expected value of $\hat{R} = n_1 / V_1$ is

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

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

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

The variance of $\tilde{S}$ is estimated by the delta method as

$$\widehat{\mathrm{Var}}\left(\tilde{S}_1\right) \doteq \frac{\widehat{\mathrm{Var}}\left(\hat{R}\right)}{\left(\hat{p}_1 - \hat{p}_D\right)^2} + \frac{\widehat{\mathrm{Var}}\left(\hat{p}_D\right)\left(\hat{R} - \hat{p}_1\right)^2}{\left(\hat{p}_1 - \hat{p}_D\right)^4} + \frac{\widehat{\mathrm{Var}}\left(\hat{p}_1\right)\left(\hat{R} - \hat{p}_D\right)^2}{\left(\hat{p}_1 - \hat{p}_D\right)^4}$$

where $\widehat{\mathrm{Var}}\left(\hat{p}_1\right)$ comes from the fitted Cormack-Jolly-Seber model and where

$$\widehat{\mathrm{Var}}\left(\hat{R}\right) = \frac{\hat{R}\left(1 - \hat{R}\right)}{V_1}$$

$$\widehat{\mathrm{Var}}\left(\hat{p}_D\right) = \frac{\hat{p}_D\left(1 - \hat{p}_D\right)}{d}$$

and where *d* is the dead tagged fish release size.

In the case of yearling Chinook salmon during the 2014 McNary Dam investigation, the adjusted estimate of reach survival for V_1 is calculated to be

$$\hat{S}_1 = \frac{\left(\frac{2,302}{2,391}\right) - 0.08}{1.0 - 0.08} = 0.9595 \ \left(\widehat{\mathrm{SE}} = 0.0048\right)$$

The estimate of standard error is based on the delta method.

Similarly, the adjusted estimate of reach survival used in estimating BRZ-to-BRZ survival for yearling Chinook salmon is

$$\hat{S}_1 = \frac{\left(\frac{2,324}{2,422}\right) - 0.08}{1.0 - 0.08} = 0.9560 \ \left(\widehat{\mathrm{SE}} = 0.0051\right).$$

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