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Monitoring of Juvenile Yearling Chinook Salmon and Steelhead Survival and Passage at John Day Dam, Spring 2010

Summary Report

Pacific Northwest National Laboratory
University of Washington
Pacific States Marine Fisheries Commission

November 2012

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Preface

This study was conducted by the Pacific Northwest National Laboratory (PNNL), the Pacific States Marine Fisheries Commission (PSMFC), and the University of Washington (UW) for the U.S. Army Corps of Engineers, Portland District (USACE). The PNNL and UW project managers are Drs. Thomas J. Carlson and John R. Skalski, respectively. The USACE technical lead is Mr. Brad Eppard. The study was designed using a single-release model to estimate rates of survival and passage of juvenile salmonids passing John Day Dam at two spill treatment levels, 30% and 40% of total project discharge, and to provide additional performance measures as stipulated in the Columbia Basin Fish Accords for yearling Chinook salmon (*Oncorhynchus tshawytscha*) and steelhead (*O. mykiss*). The study was not intended to formally evaluate survival rates relative to performance standards set forth in the 2008 Federal Columbia River Power System Biological Opinion, because long-term juvenile salmonid protection measures at John Day Dam had yet to be finalized at the time of the study.

This report focuses on spring out-migrating yearling Chinook salmon and steelhead. A separate monitoring report will present the findings of the survival studies of subyearling Chinook salmon at John Day Dam during 2010. A comprehensive technical report of the spring and summer 2010 tagging studies at John Day Dam, including behavior and fish passage results, for yearling and subyearling Chinook salmon, and steelhead will be presented in a separate report.

Executive Summary

The purpose of the study reported herein was to evaluate dam passage survival of yearling Chinook salmon (*Oncorhynchus tshawytscha*; CH1) and steelhead (*O. mykiss*; STH) at John Day Dam (JDA) during spring 2010. The study was conducted by researchers from the Pacific Northwest National Laboratory (PNNL) in collaboration with the Pacific States Marine Fisheries Commission (PSMFC) and the University of Washington (UW). It was designed to estimate the effects of 30% and 40% spill treatment levels on single-release survival rates of CH1 and STH passing through two reaches: 1) the dam and 40 km of tailwater, and 2) the forebay, dam, and 40 km of tailwater. The study also estimated additional passage performance measures, which are stipulated in the Columbia Basin Fish Accords.

This study was not an official compliance test as described by the 2008 Federal Columbia River Power System (FCRPS) Biological Opinion (BiOp, NOAA 2008), because passage conditions for the dam had not yet been finalized. Changes in 2010 at JDA to improve fish passage and survival rates included relocating the top-spill weirs (TSWs) from spill bays 15 and 16 to spill bays 18 and 19, modifying the deflector at spill bay 20, and installing avian wires in the tailrace.

Juvenile Salmon Acoustic Telemetry System (JSATS) cabled arrays were monitored for the spring season at JDA until June 12 for detection of CH1 and STH tagged with JSATS micro-transmitters. The last CH1 at JDA used in the survival analysis was detected at the dam on June 5 and the last STH used was detected at the dam on June 10. Two spill treatments were tested at JDA in spring 2010 (April 28–June 3)—30% and 40% spill out of total project discharge. Passage survival rates at JDA is estimated from the upstream face of JDA at river kilometer (rkm) 349 (Columbia River 349 [CR349]) to the cabled array at the upstream face of The Dalles Dam (TDA, CR309), 40 rkm downstream. Under the 2008 FCRPS BiOp, the dam passage survival rates for CH1 and STH should be greater than or equal to 96% and estimated with a standard error (SE) less than or equal to 1.5%. Also estimated were forebay residence time, tailrace egress time, and spill passage efficiency (SPE), as required in the Columbia Basin Fish Accords. However, this study was not an official BiOp compliance test because the long-term passage measures at JDA had yet to be finalized at the time of this study, and the study design was based on a single-release survival model instead of the virtual-paired reference release model.

A virtual/single-release model was used to estimate dam-and-tailwater-passage and forebay-dam-and-tailwater-passage survival rates for fish passing through JDA. The approach included releases of CH1 and STH, tagged with JSATS acoustic micro-transmitters, 41 rkm above JDA that contributed to the formation of a virtual release if released fish were detected on the forebay entrance array or at the face of the dam. All survival rates are single-release estimates. A total of 2287 CH1 and 2288 STH were tagged and released into the river near Roosevelt, Washington (CR390). Survival rates were estimated from the detection array in the forebay and on the upstream face of JDA through Lake Celilo to the detection array on the upstream face of TDA. The JSATS micro-transmitter, tag model number ATS-156 dB, weighing 0.438 g in air, was used in this investigation.

The study methods and environmental and operational conditions are summarized in Tables ES.1. Study results for survival and performance metrics are summarized in Table ES.2 for CH1 and Table ES.3 for STH.

Table ES.1. Summary of Methods and Conditions at John Day Dam, Spring 2010

Study Objectives: Estimate single-release dam passage survival rates and other performance measures for CH1 and STH for 30% and 40% spill treatments.

Unique Study Conditions: Top-spill weirs were installed in spill bays 18 and 19 and the deflector at spill bay 20 to improve egress conditions and survival rates for downstream migrating juvenile salmon. A new avian array was installed across the tailrace.

Hypothesis (H0):	
30% spill passage survival ≥40% spill passage survival	H1: 30% <40%
30% spill forebay residence time ≥40% spill residence time	H1: 30% <40%
30% spill egress rate ≥40% spill egress rate	H1: 30% <40%
30% spill passage efficiency ≥40% spill passage efficiency	H1: 30% <40%

Fish: yearling Chinook salmon (CH1), steelhead (STH), Implant Procedure: surgical
Source: John Day Dam Smolt Monitoring Facility

Size (median):	CH1	STH	Sample Size:	CH1	STH
Weight:	32.1 g	80.0 g	# release sites:	1	1
Length:	132 mm	215 mm	# releases:	32	32
			Total # released:	2287	2288

Tag Type/Model: Advanced Telemetry Systems ATS-156 dB Weight (g): 0.438 g (air)
Analytical Model: virtual/single release
Characteristics of Estimate: direct effects, relative survival estimates

Environmental/Operating Conditions	
Study period	April 28 through June 12, 2010
Daily total project discharge (kcfs)	Mean 232, min 154, max 408
Spill operations	30% versus 40% spill treatments
Temperature (°C):	Mean 12.7, min 10.9, max 14.8
Total dissolved gas (tailrace)	Mean 107%, min 100%, max 114%

Table ES.2. Summary of Survival Rates and Other Performance Metrics for CH1 at John Day Dam During Spring 2010. Travel time median and means (respectively) are provided in hours.

Metric	Combined Spill	30% Spill	40% Spill
Survival: dam passage to TDA	0.937 ($\widehat{SE}$ = 0.005)	0.940 ($\widehat{SE}$ = 0.007)	0.944 ($\widehat{SE}$ = 0.007)
Survival: forebay entrance array to TDA	0.934 ($\widehat{SE}$ = 0.005)	0.935 ($\widehat{SE}$ = 0.008)	0.941 ($\widehat{SE}$ = 0.007)
Forebay Residence Time	2.15; 5.32	2.38; 5.28	1.89; 4.99
100-m Forebay Residence Time	0.58; 3.26	0.66; 2.95	0.52; 3.04
Tailrace Egress Time	0.74; 2.31	0.73; 2.02	0.74; 2.59
Fish Passage Efficiency	0.963 ($\widehat{SE}$ = 0.004)	0.969 ($\widehat{SE}$ = 0.005)	0.958 ($\widehat{SE}$ = 0.006)
Spill Passage Efficiency	0.900 ($\widehat{SE}$ = 0.007)	0.917 ($\widehat{SE}$ = 0.008)	0.884 ($\widehat{SE}$ = 0.010)

Table ES.3. Summary of Survival Rates and Other Performance Metrics for Juvenile STH at John Day Dam During Spring 2010. Travel time median and means (respectively) are provided in hours.

Metric	Combined Spill	30% Spill	40% Spill
Survival: dam passage to TDA	0.950 ($\widehat{SE}$ = 0.005)	0.942 ($\widehat{SE}$ = 0.008)	0.975 ($\widehat{SE}$ = 0.005)
Survival: forebay entrance array to TDA	0.948 ($\widehat{SE}$ = 0.005)	0.931 ($\widehat{SE}$ = 0.008)	0.962 ($\widehat{SE}$ = 0.006)
Forebay Residence Time	4.44; 13.70	5.10; 13.96	3.97; 13.42
100-m Forebay Residence Time	1.37; 8.12	1.66; 8.30	1.21; 7.85
Tailrace Egress Time	0.63; 2.49	0.64; 2.50	0.62; 2.48
Fish Passage Efficiency	0.982 ($\widehat{SE}$ = 0.003)	0.982 ($\widehat{SE}$ = 0.004)	0.982 ($\widehat{SE}$ = 0.004)
Spill Passage Efficiency	0.888 ($\widehat{SE}$ = 0.007)	0.871 ($\widehat{SE}$ = 0.011)	0.904 ($\widehat{SE}$ = 0.009)

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Many people from the Pacific Northwest National Laboratory (PNNL), the Pacific States Marine Fisheries Commission (PSMFC), the U.S. Army Corps of Engineers, Portland District (USACE), and the University of Washington (UW) made valuable contributions to this study and deserve acknowledgment.

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- UW: J Lady, A Seaburg, and P Westhagen.

We also wish to acknowledge the manufacturers of the tags, hydrophones, and hardware required to accomplish testing.

- Advanced Telemetry Systems (ATS), Inc. manufactured the JSATS acoustic tags.
- Autonomous and dam-mounted hydrophones were produced by Sonic Concepts, Seattle, Washington.
- Precision Acoustic Systems, Seattle, Washington, manufactured the quad channel receivers and conducted node acceptance tests for PNNL.
- Cascade Aquatics, Inc., Ellensburg, Washington, activated and delivered the acoustic tags.
- The Dalles Ironworks, The Dalles, Oregon, fabricated anchors for autonomous nodes and frames for star clusters that were deployed in the spillway forebay.

Acronyms and Abbreviations

°C	degree(s) Celsius
2D	two-dimensional
3D	three-dimensional
AT	acoustic telemetry
BiOp	Biological Opinion
BON	Bonneville Dam
BRZ	boat-restricted zone
CH0	subyearling Chinook salmon
CH1	yearling Chinook salmon
CR234	Bonneville Dam dam-face array; John Day Dam tertiary survival-detection array
CR275	Hood River, Oregon autonomous node array; John Day Dam secondary survival-detection array
CR309	The Dalles Dam dam-face array; John Day Dam primary survival-detection array
CR346	John Day Dam tailwater-egress array
CR349	John Day Dam dam-face array
CR351	John Day Dam forebay entrance array
CR390	Roosevelt, Washington release location (R_1)
d	day(s)
FCRPS	Federal Columbia River Power System
FPE	fish passage efficiency
ft	foot(feet)
g	gram(s)
h	hour(s)
HA	hydroacoustic
JBS	juvenile bypass system
JSATS	Juvenile Salmon Acoustic Telemetry System
JDA	John Day Dam
kcfs	thousand cubic feet per second
km	kilometer(s)
L	liter(s)
m	meter(s)
mg	milligram(s)
mm	millimeter(s)
MOA	Memorandum of Agreement
MS-222	tricaine methanesulfonate
PIT	passive integrated transponder

PNNL	Pacific Northwest National Laboratory
PRI	pulse repetition interval
PSMFC	Pacific States Marine Fisheries Commission
rkm	river kilometer(s)
RME	research, monitoring, and evaluation
ROR	run-of-river
RPA	Reasonable and Prudent Alternative
RT	radio telemetry
s	second(s)
SE	standard error
SPE	spill passage efficiency
STH	steelhead
TDA	The Dalles Dam
TSW	top-spill weir
USACE	U.S. Army Corps of Engineers
UW	University of Washington

Contents

Figures

Tables

1.0 Introduction

Researchers at the Pacific Northwest National Laboratory (PNNL), the Pacific States Marine Fisheries Commission (PSMFC), and the University of Washington (UW) conducted a juvenile fish passage and survival study for the U.S. Army Corps of Engineers, Portland District (USACE). The study, reported herein, was primarily designed to estimate the survival rates of yearling Chinook salmon (*Oncorhynchus tshawytscha*; CH1) and steelhead (*O. mykiss*; STH) passing through John Day Dam (JDA) by the various routes and 40 km of tailwater using a single-release survival model. Additional passage performance measures were estimated, most of which were stipulated in the Columbia Basin Fish Accords.

The 2010 study was not an official compliance test as described by the 2008 Federal Columbia River Power System (FCRPS) Biological Opinion (BiOp; NOAA 2008), because passage conditions for the dam had not been finalized. The primary goal of the current study was to estimate the survival rates of CH1 and STH passing through the dam by various routes and 40 km of tailwater using a single-release survival model. The effects of two spillway discharge treatments (30% and 40% spill) and the performance of JDA surface flow outlets on survival rates and passage performance measures were also evaluated. The Portland District and regional fisheries managers will use the data to adaptively manage the configuration and operation of JDA to maximize the survival rate of juvenile salmonids.

1.1 Background

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

> Juvenile Dam Passage Performance Standards – The Action Agencies' juvenile performance standards are an average across Snake River and lower Columbia River dams of 96% average dam passage survival for spring Chinook and steelhead and 93% average across all dams for Snake River subyearling Chinook. Dam passage survival is defined as survival from the upstream face of the dam to a standardized reference point in the tailrace.

The Memorandum of Agreement (MOA) between the three lower river tribes and the Action Agencies (known informally as the Fish Accords), contains three additional requirements relevant to the 2010 survival studies:

> Dam Survival Performance Standard – Meet the 96% dam passage survival standard for yearling Chinook and steelhead and the 93% standard for subyearling Chinook. Achievement of the standard is based on 2 years of empirical survival data….
>
> Spill Passage Efficiency and Delay Metrics − Spill passage efficiency (SPE) and delay metrics under current spill conditions … are not expected to be degraded ("no backsliding") with installation of new fish passage facilities at the dams….

Future Research, Monitoring, and Evaluation − The Action Agencies' dam survival studies for purposes of determining juvenile dam passage performance will also collect information about SPE, survival and delay between boat-restricted zones (BRZs), 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 2010 spring acoustic-telemetry study of CH1 and STH at JDA. Only single-release survival estimates were calculated because there were no paired reference releases of fish downstream of JDA in 2010. Therefore, BiOp performance standards were not explicitly tested.

1.2 Study Objectives

The purpose of the spring 2010 spill treatment study at JDA was to estimate performance measures outlined in the 2008 FCRPS BiOp and the Fish Accords for CH1 and STH using a single-release passage and survival model under 30% and 40% spill-discharge treatments, and evaluate the performance of the top-spill weirs (TSWs) at spill bays 18 and 19. The following metrics were estimated using the Juvenile Salmon Acoustic Telemetry System (JSATS) technology for CH1 and STH:

- Dam passage survival, defined as the rate of survival from the upstream face of JDA (CR349) to the acoustic array at The Dalles Dam (TDA, CR309). Performance[1] should be ≥96% survival rate for CH1 and STH. Survival rates were estimated with a standard error (SE) ≤1.5%. A single-release point estimate ≥96% also would exceed the BiOp standard for a paired-release estimate, because the single-release estimate is more conservative than the paired-release estimate.
- Survival rate from the forebay entrance array to the primary array 40 km downstream of the dam was estimated instead of forebay-to-tailrace survival rate, which was specified as BRZ-to-BRZ survival in the Fish Accords. Forebay to tailrace survival rate estimates require tailrace and tailwater reference releases that were not part of the 2010 study.
- SPE, defined as the fraction of the total number of fish going through the dam via the spillway.
- Fish passage efficiency (FPE), defined as the fraction of fish going through the dam via the spillway and guided fish at the turbines.
- Forebay residence time, defined by the median, mean, and standard error that juvenile salmonids take to travel from the forebay entrance array 2 km upstream of the dam to when they pass into the dam (i.e., from 2 km upstream of the dam to the dam face)
- Tailrace egress time, defined as the median or mean time that juvenile salmonids take to travel through the dam to the downstream tailrace boundary 2 km downstream of the dam.

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

Results are reported for each performance measure. This report is designed to provide a succinct summary of BiOp/Fish Accords performance measures by treatment. A subsequent, comprehensive technical report will provide more detailed data about survival rates and fish passage at JDA in 2010.

1.3 Report Contents

Chapter 2.0 describes the methods used to evaluate salmonid passage, including handling, fish collection; tagging and release procedures; signal processing; and statistical methods. Study results are presented in Chapter 3.0, followed by a discussion of the results in Chapter 4.0, and references in Chapter 5.0. Fish capture histories are presented in the Appendix.

2.0 Methods

Study methods include fish handling, tagging, and release procedures; acoustic-tag detection and signal processing; and statistical and analytical approaches.

2.1 Release-Recapture Design

The release-recapture design used to estimate dam passage survival rates at JDA was based on a single-release model, whereby detected fish are regrouped as a virtual release (V_2) at the face of the dam (Figure 2.1) (Skalski et al. 2010). Tagged fish released above JDA at CR390 near Roosevelt, Washington, were used as the source of fish known to have arrived alive at the face of JDA. By releasing the fish far enough upstream, they should arrive at the dam in a spatial pattern typical of run-of-river (ROR) fish. This virtual-release group was then used to estimate survival of fish passing through the forebay, dam, and to 40 km downstream of the dam or the dam and 40 km of tailwater. We were unable to account for tailwater mortalities because there were no paired releases of fish below JDA. In the survival model, the dam-face detection array at the face of TDA was the primary array; the autonomous array (CR275), near Hood River, Oregon, was the secondary array; and the dam-face detection array at the face of Bonneville Dam (BON; CR234) was the tertiary array. The release sample sizes of fish tagged with JSATS acoustic micro-transmitters used in the dam passage survival estimates are summarized in Table 2.1.

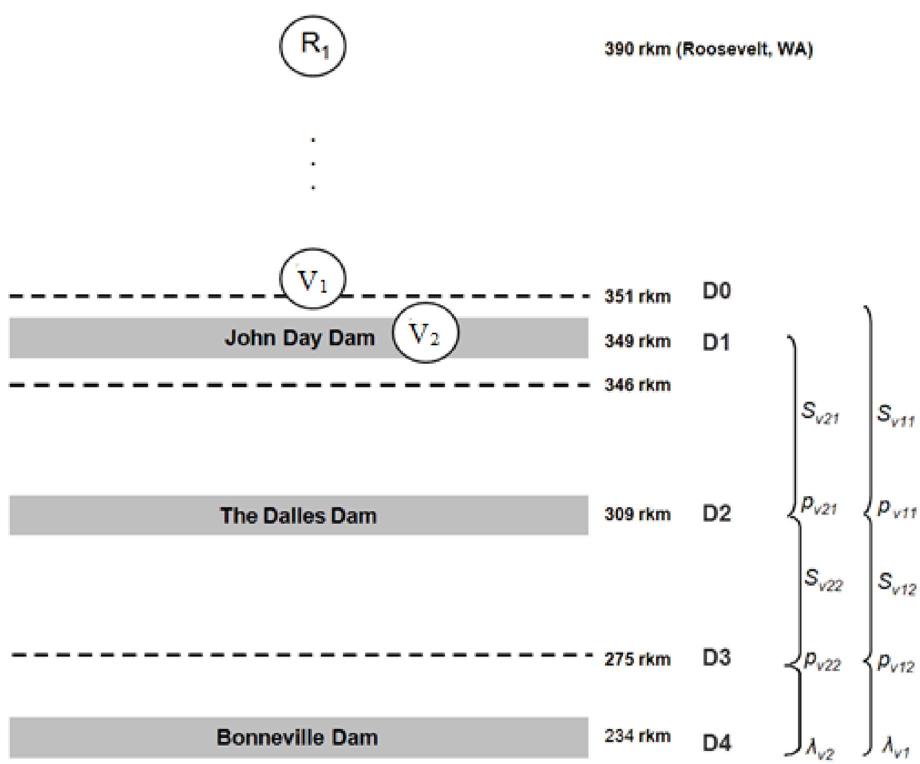

Figure 2.1. Schematic of the Single-Release Model Design Used to Estimate Dam Passage Survival from the John Day Dam Forebay and Dam Face to The Dalles Dam (S_{v11}). The virtual releases (V_1, V_2) were composed of fish arriving at the forebay array or dam face from fish released at CR390 (R_1).

Table 2.1. Sample Sizes of CH1 and STH Tagged with Acoustic Micro-Transmitters Released Above JDA Near Roosevelt, Washington (CR390) and Regrouped as a Virtual Release at the JDA Dam Face (V_2) in Spring 2010 and Used to Estimate Dam Passage Survival

Species	Total Released	Virtual Release	
		30% Spill	40% Spill
Yearling Chinook salmon	2287	1060	1104
Juvenile steelhead	2288	973	1164

A three-dimensional (3D) double-detection array at the face of JDA (CR349) was used to construct the virtual–release group, and to identify powerhouse and spillway passage routes taken by fish passing through the dam. These passage-route data were used to calculate SPE at JDA. A total of 49 acoustic tags were randomly sampled from the tags used in the spring season for a tag-life assessment. The tags were activated, held in river water, and monitored continuously until they stopped transmitting. 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).

2.1.1 Spill Treatments

The effects of the 30% and 40% spill treatments on fish passage and survival rates during the spring study period were evaluated using a randomized block experimental design (Figure 2.2). The data collection period was designed to be from April 28 to June 12, 2010, but 30% and 40% spill treatments were only realized between April 28 and June 3, 2010. The design called for nine 4-d blocks, each block consisting of a 2-d treatment randomly chosen to be 30% or 40% spill, followed by 2 d of the alternate treatment. Treatment order within a given block was randomized. Treatment changes were made at 0600 hours on a given day.

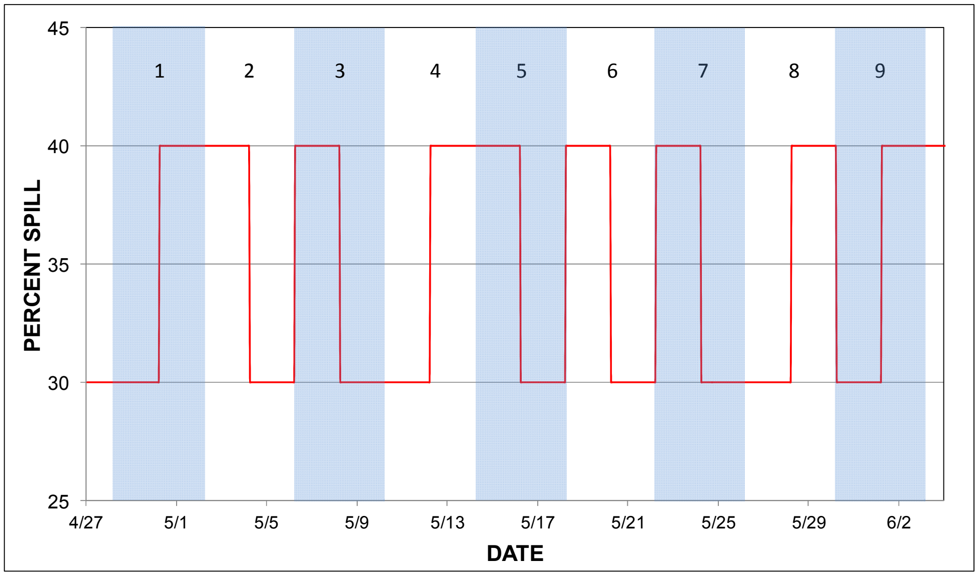

Figure 2.2. Spill Treatment Schedule for the Spring Season (April 28–June 3, 2010) at JDA. The design calls for nine treatment blocks (numbered) with two 2-d treatments (30% or 40% spill) per block.

2.2 Handling, Tagging, and Release Procedures

Fish obtained from the JDA juvenile bypass system (JBS) were surgically implanted with JSATS tags, held for 24 h, and transported to Roosevelt, Washington (CR390), where they were released into the river, as described in the following sections.

2.2.1 Acoustic Tags

The acoustic tags used in the spring 2010 study were manufactured by Advanced Telemetry Systems. Each tag, model number ATS-156 dB, measured 12.02 mm in length, 5.21 mm in width, 3.72 mm in thickness, and weighed 0.438 g in air. The tags had a nominal transmission rate of 1 pulse every 3 s. Nominal tag life was expected to be about 25 d.

2.2.2 Fish Collection

The CH1 and STH used in the study were obtained from the JDA JBS. The PSMFC diverted fish from the JBS into an examination trough, as described by Martinson et al. (2006). Fish were evaluated and accepted for tagging using the following criteria:

- Qualifying (Acceptable) Conditions
  - size ≥95 mm
  - visible elastomer tag(s) present or absent
  - adipose-fin clipped or unclipped
  - presence of trematodes, copepods, leeches
  - short operculum
  - healed (moderate) injuries (e.g., bird strikes)
  - ≤3% fungal patch
  - minor fin blood
  - partial descaling (3–19%)
  - eroded pectoral or ventral fins
- Disqualifying Conditions
  - ≥20% descaling
  - body punctures (showing blood, e.g., predator marks, bird strikes, head wounds, nose/snout injuries)
  - obvious signs of bacterial kidney disease
  - eye hemorrhage or pop eye
  - >3% coverage with fungus
  - deformed or emaciated
  - passive integrated transponder (PIT)- or radio-tagged or other post-surgical fishes

– notable operculum damage (except short operculum)
– presence of columnaris, furuncles
– injured caudal peduncles
– injured caudal fins
– fin hemorrhage.

2.2.3 Tagging Procedure

Prior to surgery, fish were anesthetized in an 18.9-L “knockdown” bucket containing fresh river water and MS-222 (tricaine methanesulfonate; 80 mg/L). Anesthesia buckets were refreshed repeatedly to maintain the temperature within ±2°C of river temperature. Each fish was weighed and measured before tagging.

During surgery, each fish was placed ventral side up and a gravity-fed anesthesia supply line was placed into its mouth. The dilution of the “maintenance” anesthesia was 40 mg/L. Using a surgical blade, a 6- to 8-mm incision was made in the body cavity between the pelvic girdle and pectoral fin. A PIT tag was inserted followed by an acoustic tag. Both tags were inserted toward the anterior end of the fish. The incision was closed using 5-0 Monocryl suture.

After closing the incision, the fish were placed in a light occlusive 18.9-L transport bucket filled with aerated river water. Fish were held in these buckets for 18 to 24 h before being transported for release into the river. The loading rate was five fish per bucket.

2.2.4 Release Procedures

All fish were tagged at JDA and transported by truck to CR390, upstream for release into the river at R_1 (Figure 2.1). Upon arriving at a release site, fish buckets were transferred to a boat for transport to the in-river release location. Fish were released at each of five release locations across the width of the river channel, one bucket at a time. The purpose of this release strategy was to distribute fish in a way that better represents the actual spatial distribution of ROR fish.

Releases occurred for 32 d (from April 28 to May 29, 2010). Releases alternated between daytime and nighttime, every other day, over the course of the study. The timing of the releases was staggered to help facilitate downstream mixing (Table 2.2).

Table 2.2. Release Times for the Fish Tagged with Acoustic Micro-Transmitters near Roosevelt, Washington

	Relative Release Times	
Release Location	Daytime Start	Nighttime Start
R_1, Roosevelt, WA (CR390)	Day 1: 0900 h	Day 2: 2000 h

2.3 Acoustic Signal Processing

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

- Multipath filter: For data from each individual cabled hydrophone, all tag-code receptions that occur within 0.156 s after an initial identical tag code reception were deleted under the assumption that closely lagging signals are multipath. Initial code receptions were retained. The delay of 0.156 s was the maximum acceptance window width for evaluating a pulse repetition interval (PRI) and was computed as 2 (PRI_Window+12×PRI_Increment). Both PRI_Window and PRI_Increment were set at 0.006, which was chosen to be slightly larger than the potential rounding error in estimating PRI to two decimal places.
- Multi-detection filter: Receptions were retained only if the same tag code was received at another hydrophone in the same array within 0.3 s because receptions on separate hydrophones within 0.3 s (about 450 m of range) were likely from a single tag transmission.
- PRI filter: Only those series of receptions of a tag code (or "messages") that were consistent with the pattern of transmissions from a properly functioning JSATS acoustic tag were retained. Filtering rules were evaluated for each tag code individually, and it was assumed that only a single tag would be transmitting that code at any given time. For the cabled system, the PRI filter operated on a message, which included all receptions of the same transmission on multiple hydrophones within 0.3 s. Message time was defined as the earliest reception time across all hydrophones for that message. Detection required that at least six messages were received with an appropriate time interval between the leading edges of successive messages.

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

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

An important quality control step was examination of the sequence of detections for 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 more 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 are deleted from the event data set before survival analysis.

JSATS-tagged fish were tracked in 3D in the immediate forebay of JDA to determine routes of passage and to estimate SPE. Acoustic tracking is a common technique in bioacoustics based on time-of-arrival differences among different hydrophones. Usually, the process requires a three-hydrophone array for 2D tracking and a four-hydrophone array for 3D tracking. For this study, only 3D tracking was performed; methods used were similar to those described by Weiland et al. (2011).

2.4 Statistical Methods

Dam passage survival rates were estimated, tag life was analyzed, assumptions were tested, and SPE and FPE were estimated as described in the following sections.

2.4.1 Estimation of Dam Passage Survival Rates

Maximum likelihood estimation was used to estimate rates of dam passage survival at JDA. The capture histories from all replicate releases, both daytime and nighttime, were pooled for the analysis to produce a single season-wide estimate of survival. A joint likelihood model was used to estimate dam passage survival rates based on the virtual/single-release model corrected for tag life.

The estimate of dam passage survival was computed as a function of estimated survival rate from the dam-face array at JDA to the dam-face array at TDA (Figure 2.1) and corrected for the probabilities that the acoustic tags were still active, i.e.,

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

where $\hat{L}_1$ is the estimated probability an acoustic tag is still active associated with the survival estimate $\hat{S}_1$. The variance estimate for $\hat{S}_{\text{Dam}}$ takes into account both the release-recapture sampling error and the error in the tag-life estimates according to Townsend et al. (2006). All calculations were performed using Program ATLAS (2012a) and cross-verified using Statistical Analysis Systems software and/or Program USER (2012b).

2.4.2 Tag-Life Analysis

The 49 acoustic tags systematically sampled from the tags used in the CH1 and STH survival studies were monitored continuously until tag failure. The failure times were fit to the four-parameter vitality model of Li and Anderson (2009). The vitality model tends to fit acoustic-tag failure times well, because it allows for both early onset of random failure due to manufacturing as well as systematic battery failure later on.

The probability density function for the vitality model can be rewritten as

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

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

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

For the virtual-release group (V_1) based on fish known to have arrived at the dam and with active tags, the conditional probability of tag activation, given that the tag was active at the detection array at rkm 309, was used in the tag-life adjustment for that release group. The conditional probability of tag activation at time t_1, given that it was active at time t_0, was computed by the following quotient:

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

2.4.3 Tests of Assumptions

Detections at multiple locations downstream of the single fish release site at Roosevelt, Washington, provided data required to estimate virtual-release reach survival rates based on the single release-recapture model. Tests of assumptions are described in the following sections.

2.4.3.1 Burnham et al. (1987) Tests

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

2.4.3.2 Tests of Mixing

There were no downstream reference releases of fish downstream of JDA; therefore, there was no need to test for mixing in the common tailwater.

2.4.3.3 Tagger Effects

Subtle differences in handling and tagging techniques can have an effect on the survival rate of juvenile salmonids tagged with acoustic micro-transmitters used in the estimation of dam passage survival. For this reason, tagger effects on CH1 and STH were evaluated as part of the study at JDA. In that analysis, the single release-recapture model was used to estimate reach survival rates for fish tagged by different individuals. The analysis evaluated whether any consistent pattern of reduced reach survival rates existed for fish tagged by any of the tagging staff.

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

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

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

The F-test was used in evaluating tagger effects.

2.4.4 Estimation of Travel Times

Median and mean travel times associated with forebay residence time, 100-m forebay residence time, and tailrace egress time were calculated. The variance of $\bar{t}$ was estimated by

$$\widehat{\mathrm{Var}}(\bar{t}) = \frac{\sum_{i=1}^{n}\left(t_i - \bar{t}\right)^2}{n(n-1)}, \tag{2.5}$$

where t_i was the travel time of the ith fish $(i = 1,\ldots,n)$.

Methods for estimating travel times were as follows:

1. Forebay residence time was calculated as the difference between the time of last detection on the dam-face array and the time of first detection on the forebay entrance array.
2. The 100-m forebay residence time was calculated as the difference between the time of last detection on the dam-face array and the time of first detection 100 m upstream of the dam on the dam-face array.
3. Tailrace egress time was calculated as the difference between the time of last detection on the dam-face array and the time of last detection on the egress array.

2.4.5 Estimation of Spill Passage Efficiency

By definition in the Fish Accords, SPE is the number of fish passing at the spillway relative to the number of fish passing the entire dam. Consequently, SPE was estimated by the fraction

$$\widehat{\text{SPE}} = \frac{\hat{N}_{SP}}{\hat{N}_{SP} + \hat{N}_{PH}}, \tag{2.6}$$

where $\hat{N}_i$ is the estimated abundance of fish tagged with JSATS acoustic micro-transmitters through the ith route (i = spillway [SP] or powerhouse [PH]). The dam-face detection array was used to estimate absolute abundance (N) through a route using the single mark-recapture model (Seber 1982, p. 60) independently at each route. We calculated the variance as follows:

$$\text{Var}\left(\widehat{\text{SPE}}\right) = \frac{\widehat{\text{SPE}}\left(1-\widehat{\text{SPE}}\right)}{\sum_{i=1}^{3}\hat{N}_i} + \widehat{\text{SPE}}^2\left(1-\widehat{\text{SPE}}\right)^2 \cdot \left[\frac{\text{Var}\left(\hat{N}_{SP}\right)}{\left(\hat{N}_{SP}\right)^2} + \frac{\widehat{\text{Var}}\left(\hat{N}_{PH}\right)}{\hat{N}_{PH}^2}\right]. \tag{2.7}$$

2.4.6 Estimation of Fish Passage Efficiency

Fish passage was estimated from several passage efficiencies (e.g., SPE, TSW-passage efficiency, and JBS-passage efficiency). FPE is defined as the proportion of fish that pass through the dam through non-turbine routes (i.e., spill, TSW, or JBS). FPE was estimated by the sum of the proportions of non-turbine passage proportions:

$$\widehat{\text{FPE}} = \hat{P}_{\text{SP}} + \hat{P}_{\text{TSW}} + \hat{P}_{\text{JBS}} \tag{2.8}$$

The variance of FPE was estimated as

$$\widehat{\text{Var}}\left(\widehat{\text{FPE}}\right) = \frac{\widehat{\text{FPE}}\left(1-\widehat{\text{FPE}}\right)}{\hat{N}} + \widehat{\text{FPE}}^2\left(1-\widehat{\text{FPE}}\right)^2 \cdot \left[\frac{\widehat{\text{Var}}\left(\hat{N}_{\text{PH}}\right)}{\hat{N}_{\text{PH}}^2} + \frac{\widehat{\text{Var}}\left(\hat{N}_{\text{SP}}\right) + \widehat{\text{Var}}\left(\hat{N}_{\text{TSW}}\right) + \widehat{\text{Var}}\left(\hat{N}_{\text{JBS}}\right)}{\left(\hat{N}_{\text{SP}} + \hat{N}_{\text{TSW}} + \hat{N}_{\text{JBS}}\right)^2}\right]. \tag{2.9}$$

3.0 Results

This section contains study findings, including discharge and spill conditions; fish size distribution; handling mortality and tag shedding; tagger effects; tag-life corrections; arrival distributions; dam passage survival; forebay, 100-m forebay residence times; tailrace egress, and metrics of passage efficiency.

3.1 Project Discharge

The total project and spill discharge during the spring 2010 survival study at JDA was approximately 20% lower than the 10-y average conditions (Figure 3.1). Daily total project discharge averaged 232 kcfs and ranged between 154 and 408 kcfs (April 28 to June 12, 2010).

Forebay elevation averaged 263.3 ft during the study period, referenced to mean sea level.

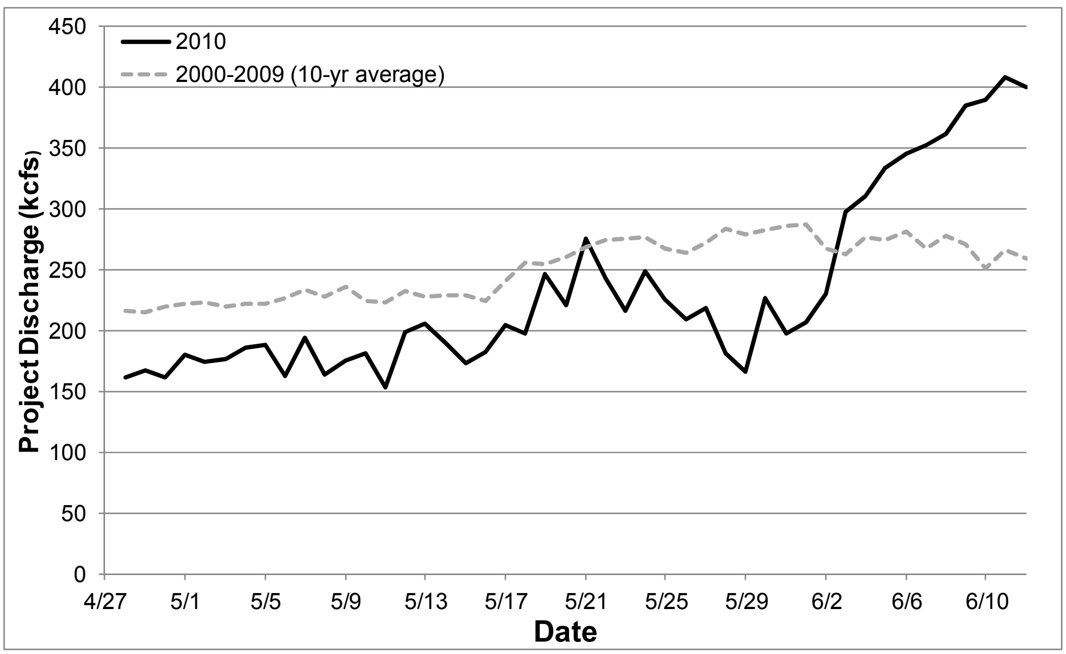

Figure 3.1. Average Daily Water Discharge (kcfs) from JDA During the Spring 2010 Study and for the Preceding 10-Year Period (2000 to 2009)

3.2 Spill Treatments

During the spring 2010 tagging effort, treatment conditions were generally maintained at each of the designated spill levels for 2 d during each block. During block 6, dam operations required treatments to be maintained for 4 d rather than 2 d; consequently, there were eight treatment blocks rather than nine (Figure 3.2).

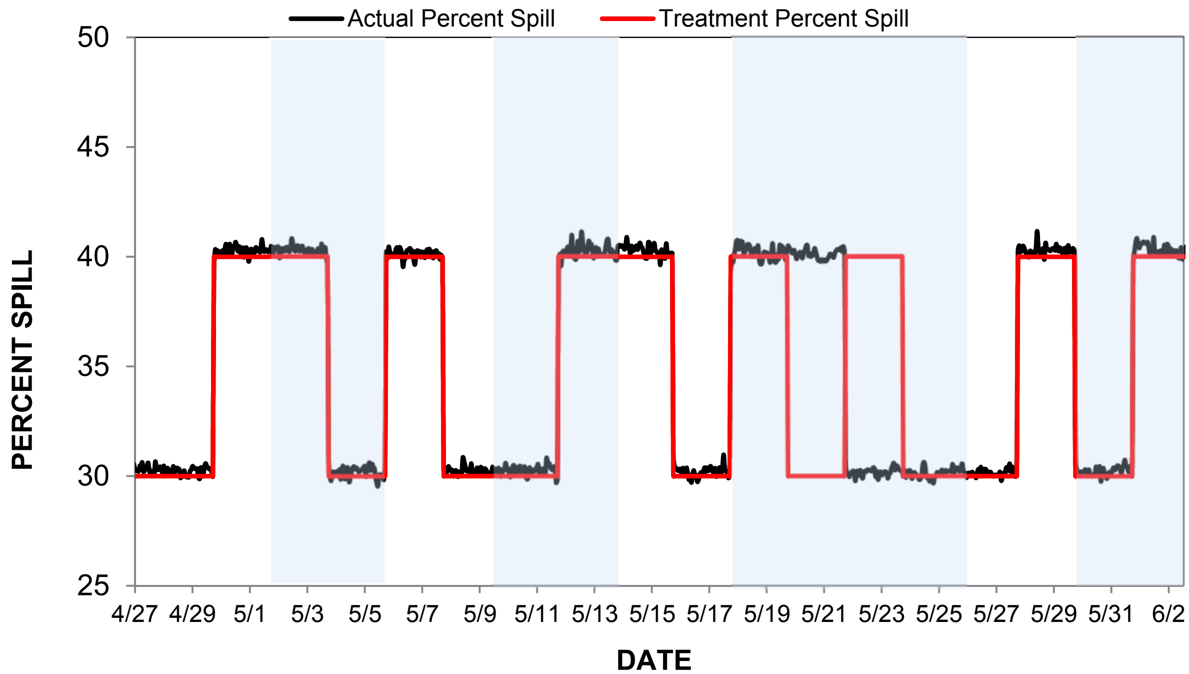

Figure 3.2. Spill Treatments for the Spring Study at JDA, April 28 Through June 3, 2010. There were eight treatment blocks with two 2-d treatments per block, with the exception of block 6, which had a 4-d treatment length.

3.3 Assessment of Assumptions

This section of the report covers the assessment of assumptions, including fish size distribution, tag-life corrections, handling mortality and tag shedding, and tagger effects. Downstream mixing and arrival distributions were not included in the test of assumptions because a single-release survival model was used.

3.3.1 Fish Size Distribution

Comparison of fish, tagged with acoustic micro-transmitters, with ROR fish sampled at JDA as part of the Smolt Monitoring Program shows that the length frequency distributions were generally well matched for CH1 (Figure 3.3) and STH (Figure 3.4). Median length for a CH1 tagged with acoustic micro-transmitters was 132 mm and for STH, it was 215 mm.

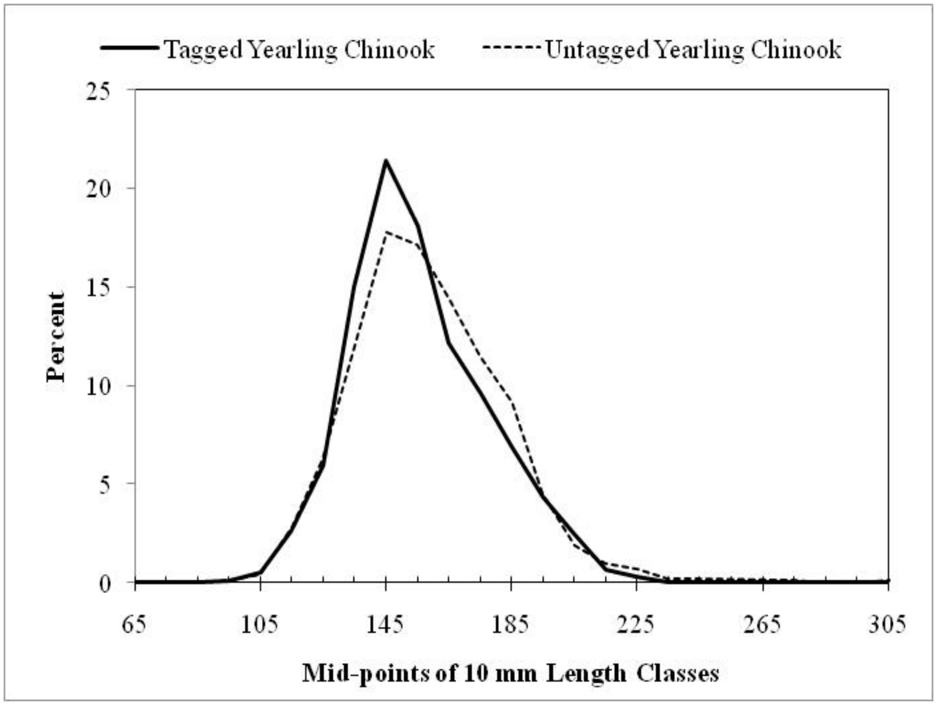

Figure 3.3. Relative Frequency Distributions for Fish Length (mm) of CH1 Sampled at JDA, Spring 2010

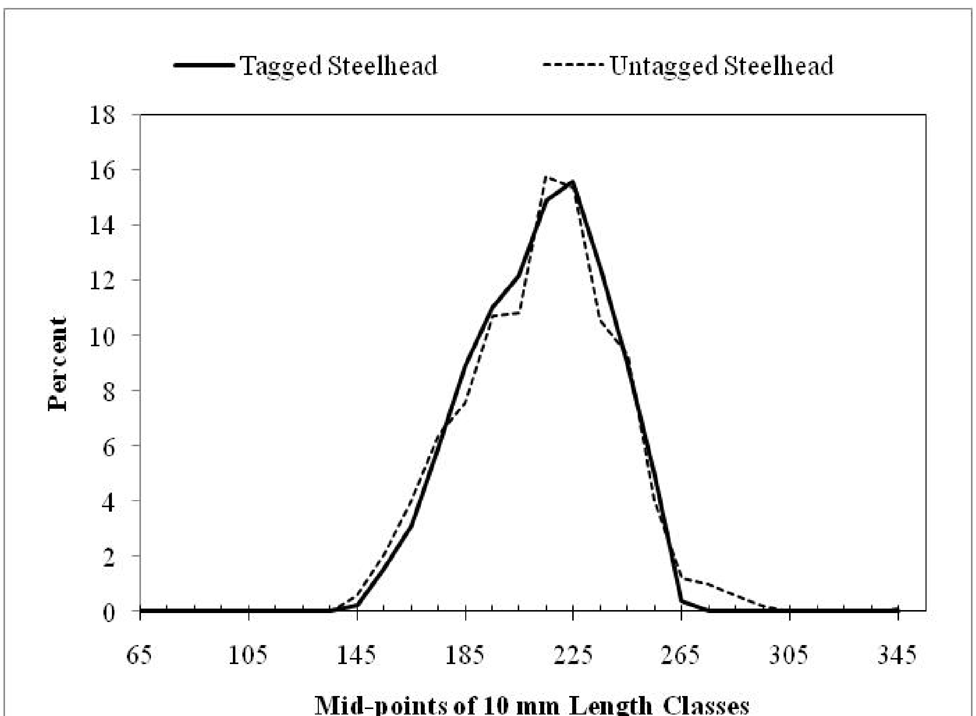

Figure 3.4. Relative Frequency Distributions for Fish Length (mm) of Juvenile STH Sampled at JDA, Spring 2010

3.4 Fish Collection

Of the 4601 CH1 and 4805 STH collected in spring 2010, 3880 CH1 and 3885 STH were tagged and released alive for the survival studies at JDA, TDA, and BON. In addition, 33 CH1 and 37 STH were tagged and released dead to validate that dead fish were not being detected on downstream arrays. Table 3.1 provides a summary of all CH1 and STH collected for the studies and their fates. The number of fish rejected due to maladies and the reasons for their rejection are provided in Table 3.2 and the number of and reasons that fish were excluded for other reasons are provided in Table 3.3.

Table 3.1. Summary of the Number and Percent of Fish Rejected, Excluded, Tagged, and Released Alive, Tagged and Released Dead, and that Exceeded Collection Needs. Totals represent the number and percent collected in 2010.

Fate	CH1		STH		Total	
Statistics	n	%	n	%	n	%
Rejected[(a)]	297	6.5	427	8.9	724	7.7
Excluded[(b)]	209	4.5	309	6.4	518	5.5
Tagged and Released Live	3880	84.3	3885	80.9	7765	82.6
Tagged and Released Dead[(c)]	33	0.7	37	0.8	70	0.7
Extra Fish[(d)]	182	4.0	147	3.1	329	3.5
Collected	**4601**	**100.0**	**4805**	**100.0**	**9406**	**100.0**

(a) Because of maladies.
(b) Too short, too long, previously tagged, dead, wrong species, dropped, or jumped.
(c) Beyond overnight mortalities, others were sacrificed.
(d) Collected but not evaluated before the tagging quota was met.

Table 3.2. Rejection Numbers and Percentages Due to Fish Maladies

	CH1		STH		Total	
Malady Description	n	%	n	%	n	%
Bacterial Kidney Disease	2	0.7	0	0.0	2	0.3
Descaling (≥20%)	148	49.8	212	49.6	360	49.7
Emaciated	1	0.3	0	0.0	1	0.1
Exophthalmia	16	5.4	5	1.2	21	2.9
Fin Rot	5	1.7	1	0.2	6	0.8
Fungus	49	16.5	60	14.1	109	15.1
Hemorrhaging	9	3.0	2	0.5	11	1.5
Lacerations	25	8.4	50	11.7	75	10.4
Lesions	12	4.0	22	5.2	34	4.7
Operculum Damage	13	4.4	41	9.6	54	7.5
Other	8	2.7	23	5.4	31	4.3
Parasites	0	0.0	4	0.9	4	0.6
Skeletal Deformities	9	3.0	7	1.6	16	2.2
Total	**297**	**100.0**	**427**	**100.0**	**724**	**100.0**

Table 3.3. Exclusion Numbers and Percentages Due to Failure to Meet Study Criteria

	CH1		STH		Total	
Reason for Exclusion	n	%	n	%	n	%
Moribund	0	0.0	0	0.0	0	0.0
Previously Tagged	168	80.4	156	50.5	324	62.5
<95 or >260 mm	1	0.5	150	48.5	151	29.2
Wrong Species	40	19.1	3	1.0	43	8.3
Dropped/Jumped	0	0.0	0	0.0	0	0.0
Total	**209**	**100.0**	**309**	**100.0**	**518**	**100.0**

3.5 Handling Mortality and Tag Shedding

Fish were held for 24 h prior to release. The 24-h tagging mortality in spring was 0.10% for CH1 and 0.10% for STH. No tags were shed during the 24-h holding period.

3.6 Tag-Life Corrections

Mean tag life (n = 49) was 32.73 d. The earliest tag failure was at 7.8 d and the longest at 39.6 d. The failure-time data for the acoustic tags was fit to a four-parameter vitality model of Li and Anderson (2009). The maximum likelihood estimates for the four model parameters were $\hat{r} = 0.02963$, $\hat{s} = -5.59145\times10^{-9}$, $\hat{k} = 0.00173$, and $\hat{u} = 0.05730$ (Figure 3.5). This tag-life survivorship model was subsequently used to estimate the probabilities of tag failure and provide tag-life-adjusted estimates of juvenile salmonid survival rates.

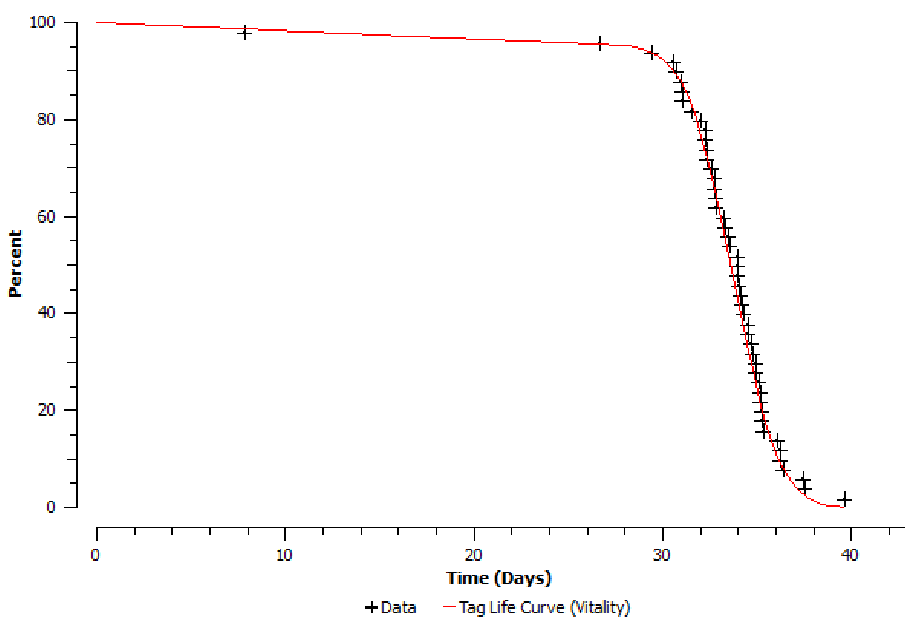

Figure 3.5. Individual Failure Times for the Acoustic Tags Used in the Tag-Life Study (n = 49), Along with the Fitted Four-Parameter Vitality Model of Li and Anderson (2009)

3.7 Arrival Distributions

The estimated probability an acoustic tag was active when fish arrived at a downstream detection array depended on the tag-life curve and the distribution of observed travel times. These probabilities were calculated by integrating the tag survivorship curve (Figure 3.5) with the observed distribution of fish arrival times (i.e., time from tag activation to arrival).

The last detection array used in the survival analysis was CR234 (the BON dam-face array). Plots of the arrival distributions of each virtual-release group to that array indicate both the CH1 (Figure 3.6) and STH (Figure 3.7) should have arrived well before tag failure became problematic. Tag-life adjustments to survival rate estimates would be incomplete if fish had arrival times beyond the range of observed tag lives.

A total of 13.7 d was required for more than 99% of the CH1 to pass the tertiary survival-detection array; juvenile steelhead required 15 d.

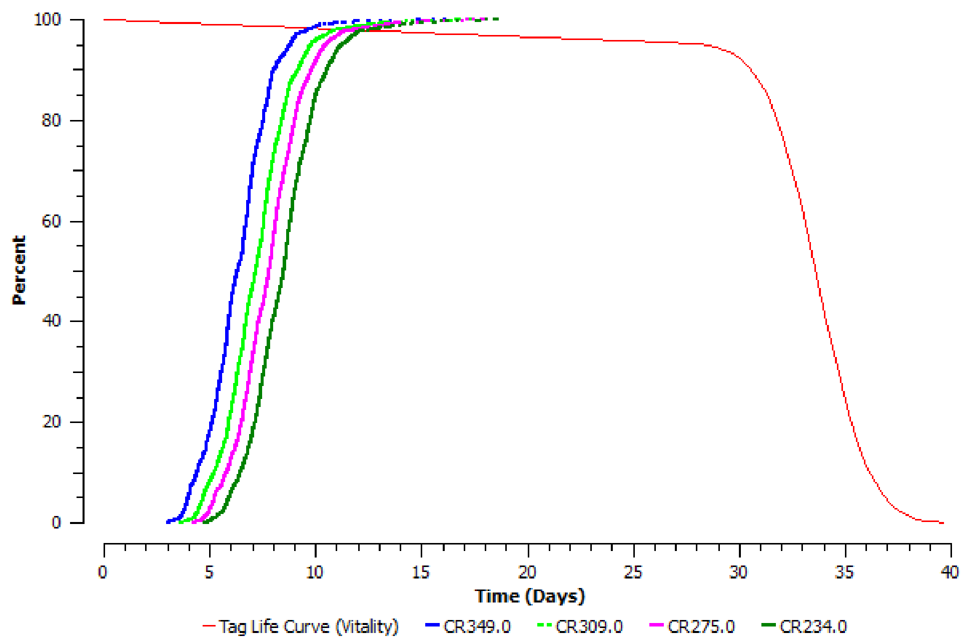

Figure 3.6. Cumulative Time of Arrival of Tagged CH1 Regrouped at the JDA Face to Form a Virtual Dam Passage Release at All Downstream Detection Sites Versus Tag-Life Curve

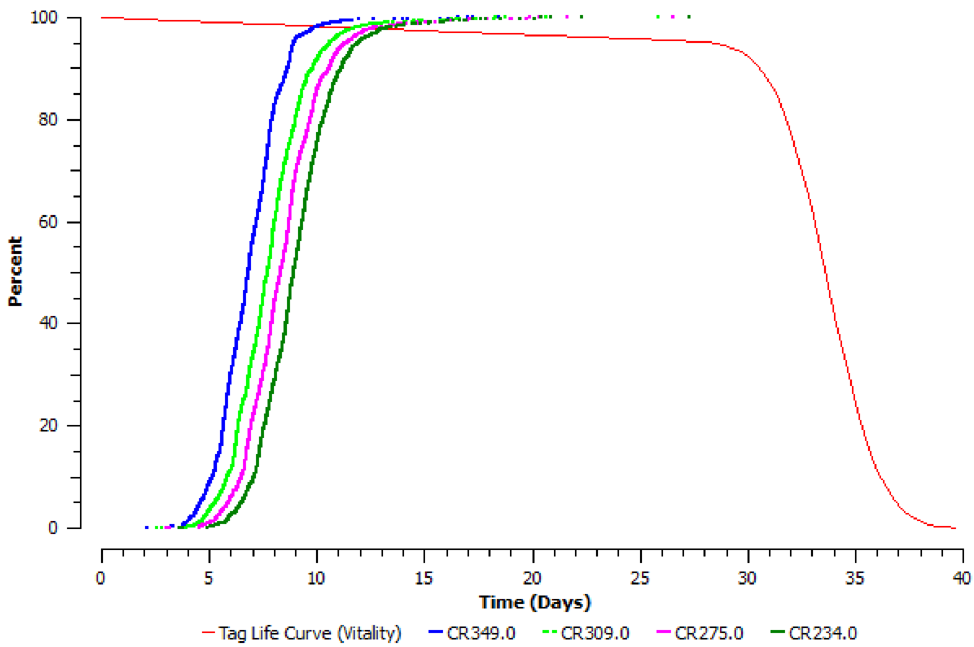

Figure 3.7. Cumulative Time of Arrival of Tagged STH Regrouped at the JDA Face to Form a Virtual Dam Passage Release at All Downstream Detection Sites Versus Tag-Life Curve

3.8 Examination of Tagger Effects

Having various fish surgeons tag the same proportions of fish helped minimize but did not necessarily eliminate handling effects during the survival study. The study was therefore designed to balance tagger effort across locations. Implementation of balancing tagging proportions among surgeons produced a good balance for both the CH1 and STH releases (Table 3.4).

To further assess whether tagger effects may have occurred, reach survival rates for the fish tagged by the different staff were calculated using the Cormack-Jolly-Seber single release-recapture model. For both CH1 (Table 3.5) and STH (Table 3.6), reach survival rates were found to be homogeneous ($P > 0.05$) across all reaches examined. For this reason, all fish, regardless of fish tagger, were included in the survival analyses.

Table 3.4. Number of CH1 and Juvenile STH Tagged for Release at R_1 by Tagger. Tagger effort was homogeneous.

	Tagger						
Stock	A	B	C	D	E	F	**Total**
Yearling Chinook	441	356	311	350	372	457	**2287**
Steelhead	430	359	331	354	365	449	**2288**

Table 3.5. Cormack-Jolly-Seber Estimates of Reach Survival Rates by Tagger for CH1. Standard errors in parentheses; *F*-tests test for homogeneity of survival rate across taggers. No tests were significant ($\alpha < 0.05$).

Tagger	Release to Rkm 309	Rkm 309 to 275	Rkm 275 to 234
#1	0.8912 (0.015)	0.9364 (0.012)	0.9790 (0.008)
#2	0.8934 (0.016)	0.9527 (0.012)	0.9910 (0.006)
#3	0.8489 (0.020)	0.9318 (0.016)	0.9797 (0.009)
#4	0.8943 (0.016)	0.9457 (0.013)	0.9767 (0.009)
#5	0.9140 (0.015)	0.9382 (0.013)	0.9906 (0.005)
#6	0.9059 (0.014)	0.9348 (0.012)	0.9798 (0.007)
F-test	1.9448	0.3597	0.7243
P-value	0.0828	0.8763	0.6051

Table 3.6. Cormack-Jolly-Seber Estimates of Reach Survival Rates by Tagger for STH. Standard errors in parentheses; *F*-tests test for homogeneity of survival rates across taggers. No tests were significant ($\alpha < 0.05$).

Tagger	Release to Rkm 309	Rkm 309 to 275	Rkm 275 to 234
#1	0.8930 (0.015)	0.9505 (0.011)	0.9699 (0.009)
#2	0.8831 (0.017)	0.9621 (0.011)	0.9671 (0.010)
#3	0.9063 (0.016)	0.9600 (0.011)	0.9831 (0.008)
#4	0.8729 (0.018)	0.9320 (0.014)	0.9725 (0.010)
#5	0.9151 (0.015)	0.9372 (0.013)	0.9776 (0.008)
#6	0.9065 (0.014)	0.9656 (0.009)	0.9804 (0.007)
F-test	1.0452	1.4044	0.5128
P-value	0.3890	0.2192	0.7668

3.9 Survival and Passage Estimates

Dam passage survival rates were calculated from the dam face at JDA to the dam face at TDA. Survival rates from the forebay to TDA were calculated from the forebay array 2 rkm upstream of JDA, past the dam to the dam face at TDA. Survival estimates were based on the virtual/single-release model using capture-history data and the fitted tag-life curve (Figure 3.5).

3.9.1 Yearling Chinook Salmon

3.9.1.1 Passage Survival to TDA

The estimates of dam passage survival were based on the virtual/single-release model using capture-history data (Appendix). Single-release survival estimates [$\hat{S}$ (±SE)] were calculated for the 2287 CH1 released at Roosevelt, Washington (CR390). These fish were regrouped at the face of JDA (V_2) or the forebay entrance array (V_1) to form virtual-release groups. The rate of survival from JDA to TDA was similar whether fish were virtually released from the face of JDA (0.937 ±0.005; CR349) or JDA forebay entrance (0.934 ±0.006; CR351) (Table 3.7). Survival rates through the JBS decreased after the repair of a loose steel plate in the passage channel; however, the difference in survival rate before and after the repair was not significant ((P >0.05); Table 3.8).

Table 3.7. Estimates of Survival Rates for CH1 Passing JDA Through Various Routes and Traveling to the Upstream Face of TDA in Spring 2010. Estimates were not corrected for tag life.

Route	Survival Estimate
Dam passage to TDA	0.937 ($\widehat{SE}$ = 0.005)
Forebay entrance array to TDA	0.934 ($\widehat{SE}$ = 0.006)

Table 3.8. Juvenile Bypass System Survival Rates of CH1 Before and After Repair of a Loose Steel Plate in the Bypass Channel

Metric	All Spring	SE	Prior to 5/20	SE	After 5/21	SE
JDA forebay array to TDA (CR351 to CR309)	0.901	0.026	0.909	0.030	0.880	0.051

3.9.1.2 Spill Treatment Effects on Survival Rates

There was no significant difference between single-release estimates (P >0.5) for the 30% and 40% spill treatments for CH1 (Table 3.9).

Table 3.9. Estimates of Survival Rates for CH1 Passing JDA Through Various Routes and Traveling to the Upstream Face of TDA (CR309) During 30% and 40% Spill Treatments in Spring 2010

Metric	Combined Spill	30% Spill	40% Spill
Dam passage to TDA	0.937 ($\widehat{SE}$ = 0.005)	0.940 ($\widehat{SE}$ = 0.007)	0.944 ($\widehat{SE}$ = 0.007)
Forebay entrance array to TDA	0.934 ($\widehat{SE}$ = 0.005)	0.935 ($\widehat{SE}$ = 0.008)	0.941 ($\widehat{SE}$ = 0.007)

3.9.2 Steelhead

3.9.2.1 Passage Survival to TDA

The estimates of dam passage survival were based on the virtual/single-release model using capture-history data (Appendix). Single-release survival estimates [$\hat{S}$ (±S.E.)] were calculated for the 2288 STH released at Roosevelt, Washington (CR390), and regrouped at the face of JDA (V_2) or the forebay entrance array (V_1) to form virtual releases. STH survival rates from JDA to TDA were 95% for fish released from the face of JDA (0.950 ± 0.005) or the forebay entrance (0.948 ± 0.005) (Table 3.10). Survival rates through the JBS were similar before and after the repair of a loose steel plate in the juvenile bypass channel (Table 3.11).

Table 3.10. Estimates of Survival Rates for STH Passing JDA Through Various Routes and Traveling to the Upstream Face of TDA in Spring 2010

Route	Survival Estimate
Dam passage to TDA	0.950 ($\widehat{SE}$ = 0.005)
Forebay entrance array to TDA	0.948 ($\widehat{SE}$ = 0.005)
Spillway to TDA	0.967 ($\widehat{SE}$ = 0.004)

Table 3.11. STH Juvenile Bypass System Survival Rates Before and After Repair of a Loose Steel Plate in the Bypass Channel

Metric	All Spring	SE	Prior to 5/20	SE	After 5/21	SE
JDA forebay array to TDA (CR351 to CR309)	0.943	0.017	0.944	0.021	0.941	0.030

3.9.2.2 Spill Treatment Effects on Survival Rates

STH dam passage survival was significantly higher during the 40% spill treatment than during the 30% spill treatment. Mean survival rates were 97.5 ± 0.5% and 94.2 ± 0.8%, respectively (P <0.05; Table 3.12). The difference was most evident for treatment blocks 3, 5, 6, and 7, when survival rates for the 40% spill treatment were 2 to 6% higher than that of the 30% spill treatment (Table 3.13). A Shapiro-Wilk Normality Test was performed to determine if the data from 30% and 40% spill conditions were normally distributed. The W statistic (alpha = 0.05:W = 0.80) indicates that the data are normally distributed and the difference in the means is greater than would be expected by chance.

Table 3.12. Estimates of Survival Rate for STH Passing JDA Through Various Routes and Traveling to the Upstream Face of TDA (CR309) During 30% and 40% Spill Treatments in Spring 2010

Metric	Combined Spill	30% Spill	40% Spill
Dam passage to TDA	0.950 ($\widehat{SE}$ = 0.005)	0.942 ($\widehat{SE}$ = 0.008)	0.975 ($\widehat{SE}$ = 0.005)
Forebay entrance array to TDA	0.948 ($\widehat{SE}$ = 0.005)	0.931 ($\widehat{SE}$ = 0.008)	0.962 ($\widehat{SE}$ = 0.006)

Table 3.13. Estimates of JDA Dam-Face to TDA Dam-Face Passage Survival Rates by Two-Day Block and Spill Treatment for STH (CR349 to CR309)

Block	30% Spill	1/2 95% CI	40% Spill	1/2 95% CI
1	-	-	0.930	0.052
2	0.957	0.036	0.959	0.037
3	0.932	0.045	0.951	0.034
4	0.945	0.037	0.942	0.038
5	0.927	0.050	0.985	0.019
6	0.929	0.031	0.971	0.018
7	0.915	0.051	0.971	0.030
8	0.896	0.066	-	-

3.10 Forebay Residence Time

The forebay residence time is calculated as the time elapsed from the first detection on the forebay entrance array until the last detection on the dam-face array. Median forebay residence times for CH1 were less than 2.5 h and for STH residence times were less than 5.5 h (Table 3.14).

Table 3.14. Median and Mean Estimated Forebay Residence Time (h) for CH1 and STH at JDA in 2010

	CH1			STH		
Treatment	Median Time (h)	Mean Time (h)	SE	Median Time (h)	Mean Time (h)	SE
All	2.15	5.32	0.24	4.44	13.70	0.51
30% Spill	2.38	5.28	0.28	5.10	13.96	0.74
40% Spill	1.89	4.99	0.29	3.97	13.42	0.70

3.11 100-m Forebay Residence Time

The 100-m forebay residence times were based on the time elapsed from the first detection within 100 m of the dam face to the last detection at the double array in front of JDA. The timing of the first detection within 100 m of the dam was based on 3D tracking of the fish tagged with acoustic micro-transmitters and interpretation of the time when the fish first crossed the 100-m distance threshold.

Median residence times for CH1 were less than 0.7 h and STH residence times were less than 1.7 h, irrespective of spill treatment (Table 3.15).

Table 3.15. Median and Mean Estimated 100-m Forebay Residence Time (h) for CH1 and STH at JDA in 2010

	CH1			STH		
Treatment	Median Time (h)	Mean Time (h)	SE	Median Time (h)	Mean Time (h)	SE
All	0.58	3.26	0.28	1.37	8.12	0.46
30% Spill	0.66	2.95	0.26	1.66	8.30	0.69
40% Spill	0.52	3.04	0.32	1.21	7.85	0.62

3.12 Tailrace Egress Time

Tailrace egress times were calculated from the last detection on the dam face array (CR349) to the last detection on the egress array (CR346). For both CH1 and STH, median egress times were estimated to be less than 0.8 h (Table 3.16).

Table 3.16. Median and Mean Estimated Tailrace Egress Times (h) for CH1 and STH at JDA in 2010

	CH1			STH		
Treatment	Median Time (h)	Mean Time (h)	SE	Median Time (h)	Mean Time (h)	SE
All	0.74	2.31	0.32	0.63	2.49	0.33
30% Spill	0.73	2.02	0.50	0.64	2.50	0.42
40% Spill	0.74	2.59	0.42	0.62	2.48	0.49

3.13 Passage Efficiency Metrics

During spring 2010, the FPE for CH1 at JDA was 0.963±0.004 and for STH it was 0.982±0.003, relative to total dam passage. SPE for CH1 was 0.900±0.007 and 0.888±0.007 for STH. Efficiency estimates can be found in Table 3.17 for CH1 and Table 3.18 for STH.

Table 3.17. Estimates of Major Passage Metrics for CH1 at JDA, Spring 2010

Metric	Combined Spill	30% Spill	40% Spill
Fish Passage Efficiency	0.963 ($\widehat{SE}$ = 0.004)	0.969 ($\widehat{SE}$ = 0.005)	0.958 ($\widehat{SE}$ = 0.006)
Spill Passage Efficiency	0.900 ($\widehat{SE}$ = 0.007)	0.917 ($\widehat{SE}$ = 0.009)	0.884 ($\widehat{SE}$ = 0.010)

Table 3.18. Estimates of Major Passage Metrics for STH at JDA, Spring 2010

Metric	Combined Spill	30% Spill	40% Spill
Fish Passage Efficiency	0.982 ($\widehat{SE}$ = 0.003)	0.982 ($\widehat{SE}$ = 0.004)	0.982 ($\widehat{SE}$ = 0.004)
Spill Passage Efficiency	0.888 ($\widehat{SE}$ = 0.007)	0.871 ($\widehat{SE}$ = 0.011)	0.904 ($\widehat{SE}$ = 0.009)

4.0 Discussion

This section briefly discusses the reasonableness of primary survival model assumptions, the historical context for estimates, and the statistical performance of the double array and spill-treatment results.

4.1 Reasonableness of Model Assumptions

The survival study at JDA was a precursor to a full-scale application of the virtual/paired-release model (Skalski et al. 2010) in 2011, because the single-release survival model used in this study has some of the same assumptions as the virtual/paired-release survival model.

Overall, the primary assumptions of the single-release survival model used for this study were reasonable. Analyses found no tagger effects that might confound estimation of dam passage survival. Handling and tagging mortalities during the study were minimal and no tags were shed during the 24 h post-surgery holding period. Travel times were sufficiently short relative to tag life to adequately adjust the release-recapture data for tag failure. In all cases, the probability that an acoustic tag was active at a downstream detection location was >0.99%. The distribution of fish lengths for CH1 and STH used in the tagging study was comparable to the ROR sampled at JDA by the Fish Passage Center.

4.2 Historical Context

Historically, telemetry studies have been used to estimate survival rates for CH1 and STH passing JDA. In the early 2000s, radio telemetry (RT) was the primary mode for estimating survival rates throughout the lower Columbia River; more recently acoustic telemetry (AT), specifically JSATS, has become the primary mode for obtaining these estimates.

During 2008 and 2009, Weiland et al. (2009 and 2011, respectively) conducted acoustic telemetry studies to estimate fish passage and survival rates at JDA. Tagged fish were released near Arlington, Oregon (rkm 390), and regrouped on the JDA forebay entrance array to create virtual releases for estimating single-release dam passage survival rates. Tag-life-corrected survival rates, from 2 km upstream of JDA to the TDA forebay, were estimated for CH1 and STH using a single-release model and are listed in Table 4.1 and Table 4.2, respectively, along with estimates from the current study for comparison. Dam passage survival estimates for 2010, 0.937 ± 0.005 for CH1 and 0.950 ± 0.005 for STH are comparable to previous estimates. Although this study was not an official compliance test, survival estimates for both CH1 and STH did not meet the ≥96% survival requirements as stipulated in the 2008 BiOp, but they did meet precision requirements (±1.5% SE).

Current study estimates show no difference in survival rates for the 30% and 40% spill treatments for CH1. However, Weiland et al. (2009) reported that CH1 survival rates were significantly higher during the 30% spill treatment than they were during the 40% spill treatment for treatment blocks 1−5. Current results indicate significantly higher STH survival rates for the 40% spill treatment (0.975 ± 0.005) than for the 30% spill treatment (0.942 ± 0.008), contrasting findings in 2009 in which no significant difference in STH survival rates between the 30% and 40% spill treatments were observed.

Table 4.1. Single-Release Survival Estimates of CH1 at JDA from 2008 to 2010

Year	Survival	30% Spill	40% Spill
2008	0.944 ± 0.011	-	-
2009	0.927 ± 0.010	0.943 ± 0.018[(a)]	0.925 ± 0.010[(a)]
2010	0.937 ± 0.005	0.940 ± 0.007	0.944 ± 0.007

(a) Estimates for spill treatment blocks 1−5 were significantly different.

Table 4.2. Single Release Survival Estimates of STH at JDA from 2008 to 2010

Year	Survival	30% Spill	40% Spill
2008	0.959 ± 0.011	-	-
2009	0.953 ± 0.008	0.955 ± 0.019	0.947 ± 0.016
2010	0.950 ± 0.005	0.942 ± 0.008[(a)]	0.975 ± 0.005[(a)]

(a) Significantly different.

SPE has ranged widely since 2002 at JDA; the lowest reported comparable SPE was the 2002 study year, in which RT was the telemetry system used with spill treatments of 30% and 30% (day/night) and with an observed SPE of 56.7% and 54.3% for CH1 and STH, respectively (Table 4.3 and Table 4.4). Concurrently in 2002, a hydroacoustic (HA) study estimated SPEs of 72.2% for both CH1 and STH with the same spill treatments. However, in recent years (2008−2010) SPE has ranged from ~76% to ~90% for CH1 and ~72% to ~81% for STH depending on spill treatment levels. For the current study, SPE for CH1 ranged from 87.1% to 90.4%, and for STH it ranged from 74.1% to 81.0%.

From 2008 to 2010, AT estimates of FPE at JDA has ranged from ~91% to ~98% for CH1 and ~88% to ~97% for STH depending on spill treatment levels. For the 2002 study year and for both RT and HA, FPE for CH1 ranged from 82.4% to 89.3% and for STH was approximately 89% dependent on the data collection system used.

Table 4.3. Estimates of Spill Passage Efficiency and Fish Passage Efficiency for CH1 from Current and Previous Radio Telemetry (RT), Acoustic Telemetry (AT), and Hydroacoustic (HA) Studies at JDA from 2002 to 2010. TSWs were installed in 2008 and 2010.

Year	Study Type	SPE	FPE	References
2002	RT − (30/30%)	56.7%	82.4%	Beeman et al. (2007)
	HA – (30/30%)	72.2%	89.3%	Moursund et al. (2003)
2008	AT Combined	76.24 ± 2.4%	92.1 ± 1.3%	Weiland et al. (2009)
	AT 30%	75.9 ± 3.9%	92.9 ± 1.9%	
	AT 40%	76.8 ± 4.1%	91.1 ± 2.4%	
2009	AT Combined	80.6 ± 1.8%	93.4 ± 0.9%	Weiland et al. (2011)
	AT 30%	75.9 ± 1.5%[(a)]	92.6 ± 0.8%	
	AT 40%	85.4 ± 1.1%[(a)]	94.3 ± 0.6%	
2010	AT Combined	88.8 ± 0.7%	98.2 ± 0.3%	Current Study
	AT 30%	87.1 ±1.1%	98.2 ± 0.4%	
	AT 40%	90.4 ± 0.9%	98.2 ± 0.4%	

(a) Significantly different.

Table 4.4. Estimates of Spill Passage Efficiency and Fish Passage Efficiency for STH from Current and Previous Radio Telemetry (RT), Acoustic Telemetry (AT), and Hydroacoustic (HA) Studies at JDA from 2002 to 2010. TSWs were installed in 2008 and 2010.

Year	Study Type	SPE	FPE	References
2002	RT – (30/30%)	54.3%	88.4%	Beeman et al. (2007)
	HA – (30/30%)	72.2%	89.3%	Moursund et al. (2003)
2008	AT Combined	74.4 ± 2.6%	97.2 ± 0.7%	Weiland et al. (2009)
	AT 30%	75.8 ± 3.7%	97.4 ± 0.9%	
	AT 40%	72.4 ± 5.0%	96.7 ± 1.3%	
2009	AT Combined	76.3 ± 1.7%	97.4 ± 0.6%	Weiland et al. (2011)
	AT 30%	71.5 ± 1.3%[a]	96.8 ± 0.5%	
	AT 40%	81.2 ± 1.2%[a]	98.0 ± 0.4%	
2010	AT Combined	77.6 ± 0.8%	88.3 ± 0.6%	Current Study
	AT 30%	74.1 ±1.2%	85.7 ± 1.0%	
	AT 40%	81.0 ± 1.1%	90.8 ± 0.8%	

(a) Significantly different.

4.3 Statistical Performance

The single-release survival study at JDA in 2010 was a precursor to a full-scale application of the virtual/paired-release study design planned for the dam in 2011. The double array at each dam face provided a combined detection probability of 100%, indicating that dam-face deployments are ready for the full BiOp study in 2011.

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Appendix

Capture-History Data

Table A.1. Capture Histories at the John Day Dam Dam-Face Array (V_2; CR349), TDA Dam-Face Array (CR309), the Hood River Autonomous Node Array (CR275), and the BON Dam-Face Array (CR234) for Release Group V_2 for Yearling Chinook Salmon and Steelhead Used in Estimating Dam Passage Survival. A "1" denotes detection, "0" denotes non-detection, and "2" denotes detection and censoring due to removal.

Capture History	Yearling Chinook Salmon (V_2)	Juvenile Steelhead (V_2)
1 1 1 2:	0	0
1 1 1 1:	1873	1893
0 1 1 1:	1	1
1 0 1 1:	0	0
0 0 1 1:	0	0
1 1 0 1:	1	3
0 1 0 1:	0	0
1 0 0 1:	0	1
0 0 0 1:	0	0
1 1 2 0:	0	0
0 1 2 0:	0	0
1 0 2 0:	0	0
0 0 2 0:	0	0
1 1 1 0:	43	53
0 1 1 0:	0	0
1 0 1 0:	0	1
0 0 1 0:	0	0
1 2 0 0:	0	0
0 2 0 0:	0	0
1 1 0 0:	123	99
0 1 0 0:	0	0
2 0 0 0:	0	0
1 0 0 0:	141	113
0 0 0 0:	105	124

Table A.2. Capture Histories for 30% Spill Treatments at the John Day Dam Dam-Face Array (V_2; CR349), TDA Dam-Face Array (CR309), the Hood River Autonomous Node Array (CR275), and the BON Dam-Face Array (CR234) for Release Group V_2 for Yearling Chinook Salmon and Steelhead Used in Estimating Dam Passage Survival. A "1" denotes detection, "0" denotes non-detection, and "2" denotes detection and censoring due to removal.

Capture History	Yearling Chinook Salmon (V_2)	Juvenile Steelhead (V_2)
1 1 1 2:	0	0
1 1 1 1:	902	850
0 1 1 1:	0	0
1 0 1 1:	0	0
0 0 1 1:	0	0
1 1 0 1:	1	1
0 1 0 1:	0	0
1 0 0 1:	0	0
0 0 0 1:	0	0
1 1 2 0:	0	0
0 1 2 0:	0	0
1 0 2 0:	0	0
0 0 2 0:	0	0
1 1 1 0:	28	21
0 1 1 0:	0	0
1 0 1 0:	0	1
0 0 1 0:	0	0
1 2 0 0:	0	0
0 2 0 0:	0	0
1 1 0 0:	64	42
0 1 0 0:	0	0
2 0 0 0:	0	0
1 0 0 0:	71	70
0 0 0 0:	-	-

Table A.3. Capture Histories for 40% Spill Treatments at the John Day Dam Dam-Face Array (V_2; CR349), TDA Dam-Face Array (CR309), the Hood River Autonomous Node Array (CR275), and the BON Dam-Face Array (CR234) for Release Group V_2 for Yearling Chinook Salmon and Steelhead Used in Estimating Dam Passage Survival. A "1" denotes detection, "0" denotes non-detection, and "2" denotes detection and censoring due to removal.

Capture History	Yearling Chinook Salmon (V_2)	Juvenile Steelhead (V_2)
1 1 1 2:	0	0
1 1 1 1:	970	1043
0 1 1 1:	0	0
1 0 1 1:	0	0
0 0 1 1:	0	0
1 1 0 1:	0	2
0 1 0 1:	0	0
1 0 0 1:	0	1
0 0 0 1:	0	0
1 1 2 0:	0	0
0 1 2 0:	0	0
1 0 2 0:	0	0
0 0 2 0:	0	0
1 1 1 0:	15	31
0 1 1 0:	0	0
1 0 1 0:	0	0
0 0 1 0:	0	0
1 2 0 0:	0	0
0 2 0 0:	0	0
1 1 0 0:	59	57
0 1 0 0:	0	0
2 0 0 0:	0	0
1 0 0 0:	68	41
0 0 0 0:	0	-

Table A.4. Capture Histories at the John Day Dam Forebay Array (V_1; CR351), TDA Dam-Face Array (CR309), the Hood River Autonomous Node Array (CR275), and the BON Dam-Face Array (CR234) for Release Group V_1 for Yearling Chinook Salmon and Juvenile Steelhead Used in Estimating Forebay Entrance Array to The Dalles Dam Survival. A "1" denotes detection, "0" denotes non-detection, and "2" denotes detection and censoring due to removal.

Capture History	Yearling Chinook Salmon (V_1)	Juvenile Steelhead (V_1)
1 1 1 2:	0	0
1 1 1 1:	1874	1894
0 1 1 1:	0	0
1 0 1 1:	0	0
0 0 1 1:	0	0
1 1 0 1:	1	3
0 1 0 1:	0	0
1 0 0 1:	0	1
0 0 0 1:	0	0
1 1 2 0:	0	0
0 1 2 0:	0	0
1 0 2 0:	0	0
0 0 2 0:	0	0
1 1 1 0:	43	53
0 1 1 0:	0	0
1 0 1 0:	0	1
0 0 1 0:	0	0
1 2 0 0:	0	0
0 2 0 0:	0	0
1 1 0 0:	123	99
0 1 0 0:	0	0
2 0 0 0:	0	0
1 0 0 0:	149	119
0 0 0 0:	97	118

Table A.5. Capture Histories 30% Spill Treatments at the John Day Dam Forebay Entrance Array (V_1; CR351), TDA Dam-Face Array (CR309), the Hood River Autonomous Node Array (CR275), and the BON Dam-Face Array (CR234) for Release Group V_1 for Yearling Chinook Salmon and Juvenile Steelhead Used in Estimating Forebay Entrance Array to The Dalles Dam Survival. A "1" denotes detection, "0" denotes non-detection, and "2" denotes detection and censoring due to removal.

Capture History	Yearling Chinook Salmon (V_1)	Juvenile Steelhead (V_1)
1 1 1 2:	0	0
1 1 1 1:	902	850
0 1 1 1:	0	0
1 0 1 1:	0	0
0 0 1 1:	0	0
1 1 0 1:	1	1
0 1 0 1:	0	0
1 0 0 1:	0	0
0 0 0 1:	0	0
1 1 2 0:	0	0
0 1 2 0:	0	0
1 0 2 0:	0	0
0 0 2 0:	0	0
1 1 1 0:	28	21
0 1 1 0:	0	0
1 0 1 0:	0	1
0 0 1 0:	0	0
1 2 0 0:	0	0
0 2 0 0:	0	0
1 1 0 0:	64	42
0 1 0 0:	0	0
2 0 0 0:	0	0
1 0 0 0:	71	67
0 0 0 0:	-	0

Table A.6. Capture Histories for 40% Spill Treatments Level at John Day Dam Forebay Entrance Array (V_1; CR351), TDA Dam-Face Array (CR309), the Hood River Autonomous Node Array (CR275), and the BON Dam-Face Array (CR234) for Release Group V_1 for Yearling Chinook Salmon and Juvenile Steelhead Used in Estimating Forebay Entrance Array to The Dalles Dam Survival. A "1" denotes detection, "0" denotes non-detection, and "2" denotes detection and censoring due to removal.

Capture History	Yearling Chinook Salmon (V_1)	Juvenile Steelhead (V_1)
1 1 1 2:	0	0
1 1 1 1:	970	1043
0 1 1 1:	0	0
1 0 1 1:	0	0
0 0 1 1:	0	0
1 1 0 1:	0	2
0 1 0 1:	0	0
1 0 0 1:	0	1
0 0 0 1:	0	0
1 1 2 0:	0	0
0 1 2 0:	0	0
1 0 2 0:	0	0
0 0 2 0:	0	0
1 1 1 0:	15	31
0 1 1 0:	0	0
1 0 1 0:	0	0
0 0 1 0:	0	0
1 2 0 0:	0	0
0 2 0 0:	0	0
1 1 0 0:	59	57
0 1 0 0:	0	0
2 0 0 0:	0	0
1 0 0 0:	68	41
0 0 0 0:	-	-

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