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Prepared for the U.S. Army Corps of Engineers, Portland District,
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Survival Rates of Juvenile Salmonids Passing Through the Bonneville Dam and Spillway in 2008

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FINAL REPORT

December 2009

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Executive Summary

In 2008, the Portland District of the U.S. Army Corps of Engineers (USACE) contracted with the Pacific Northwest National Laboratory (PNNL) to conduct an acoustic telemetry study to estimate the survival rates of juvenile Chinook salmon and steelhead passing through Bonneville Dam (BON) and its spillway. Of particular interest was the relative survival rate of smolts detected passing through end spill bays 1-3 and 16-18, which had deep flow deflectors immediately downstream of spill gates, versus the survival rate of smolts passing through middle spill bays 4-15, which had shallow flow deflectors.

Yearling Chinook salmon (YC), steelhead (STH), and fall Chinook salmon (FC) longer than 95 mm were collected from routine smolt monitoring samples at John Day Dam (JDA) and held overnight before surgery so that they were not overly stressed. Smolts longer than 95 mm were surgically implanted with Juvenile Acoustic Telemetry System (JSATS) and passive integrated transponder (PIT) tags and held another night to allow time for fish to recover from surgery. Fish tagged the previous day were released by a PNNL team three times per day (morning, midday, and night) in the JDA pool near Arlington, Oregon, and about 2.5 km below JDA in spring and summer. The team also released FC about 3 km below The Dalles Dam (TDA) in summer. Releases of live JSATS-tagged smolts in the Columbia River upstream of BON totaled 3431 YC and 3430 STH in spring. In summer, 5909 FC were released upstream of BON. Releases were spread out over 28 consecutive days (April 29 through May 27) during spring and over 29 consecutive days (June 15 through July 13) in summer. All of the “treatment” fish released above BON had the opportunity to be detected and regrouped by a BON forebay entrance array of autonomous nodes or by dam-face arrays at the BON spillway (this study) or BON Powerhouse 2 (B2) (Faber et al. 2009) before they passed the BON project. An array is a group of underwater listening devices deployed to detect acoustic tags in fish passing through a forebay or an entire cross section of the river above or below a dam. Non-spillway passage routes were assigned based on detections of PIT tags in the B2 Corner Collector (B2CC) and B2 Juvenile Bypass System (B2 JBS) and acoustic detections on a cabled JSATS array in the B2 forebay (from Faber et al. 2009). Routes of spillway passage included end bays 1-3 and 16-18 with deep flow deflectors downstream of spill gates and middle bays 4-15 with shallow flow deflectors. Powerhouse 1 was not monitored.

A National Marine Fisheries Service (NMFS) team released 826 live and 50 dead tagged YC in spring and 1020 live and 52 dead tagged FC smolts in summer into the downstream end of the BON tailrace near the USACE boat launch three times per day (about 0600, 1300, and 2100 hours PST) to serve as reference releases (controls) for virtual releases of treatment fish from upstream of the dam. Reference releases were made daily from April 30 through June 2 and from June 16 through July 22. The NMFS team also released 826 live YC and 1020 live FC smolts directly into the B2CC on the same days and at roughly the same times that fish were released in the tailrace. Pairing the B2CC-specific releases and tailwater releases provided a means of scaling paired-release estimates of dam-passage survival rates using a triple-release model (see Faber et al. 2009).

The common tailwater that both treatment and reference releases of tagged smolts swam through was from the tailrace-release site 2 km downstream of the dam through three survival-detection arrays located about 31, 42, and 148 km downstream. Some treatment fish were detected by the forebay entrance array located about 2 km upstream of BON and classified as a virtual release of fish that passed through 2 to 3 km of forebay, the dam, 2.2 to 2.6 km of tailrace, and the common tailwater. Tagged smolts passing through the spillway were detected and tracked by a dense array of 36 hydrophones. Two hydrophones were mounted on each of 18 spillway piers south of spill bays at elevations 12.2 and 18.3 m above mean sea level (MSL). Smolts were tracked passing into specific spill bays and were classified as virtual releases of fish passing through end or middle spill bays. End and middle bay virtual releases were pooled to define a virtual release for the entire spillway. These virtual releases of spillway-passed smolts were exposed to passage through about 100 m of spillway forebay, spill bays, 2.2 km of tailrace, and the tailwater. In contrast to treatment fish, tailrace reference releases of fish experienced passage through the tailwater only and therefore were used as controls that did not pass the forebay, dam, or tailrace. Single-release, Cormack-Jolly-Seber (CJS) estimates of survival rates were calculated from detection histories on the three tailwater survival-detection arrays for each virtual or reference release of fish. Single-release survival estimates were for the river reach from the virtual or tailrace release sites to the primary detection array or from the primary array to the secondary array and included all mortality that occurred in the common tailwater. Paired-release survival estimates for dam-passed or spillway-passed fish to the tailrace-release site were calculated as the ratio of the survival rates of virtual releases of treatment fish to the survival rates of fish in tailrace reference releases. The paired-release estimate is designed to remove the mortality of fish that occurs in the common tailwater.

Major Findings

Detection performance of autonomous node arrays was best upstream of BON and generally decreased with the increasing distance of arrays downstream of the dam.

An examination of tailwater egress rates revealed the following:

1. The STH smolts traveled faster than YC and FC smolts regardless of passage route, although the variability in travel times also was higher for STH than for YC or FC.
2. Travel times and rates were lower in summer than they were in spring, undoubtedly due to reduced water discharge through the project in late summer.
3. Smolts passing through the spillway and the B2CC had similar travel times and rates that were significantly faster than times and rates of smolts passing through B2 turbines and the B2 JBS.
4. Egress times and rates for fish passing through the B2 JBS were the slowest and most variable for each stock of fish.
5. The projected time required for all B2-passed fish to reach the downstream end of the tailrace was only 8 to 11 minutes longer than that of spillway-passed fish, although the estimate for B2-passed fish was biased low by substantial numbers of fish quickly passing through the B2CC.
6. Smolts passing through middle bays of the spillway had slightly longer travel times (8.5 to 34 minutes) and slower travel rates than smolts passing through end bays. The median travel time to the primary array for the slowest 10% of FC passing through middle bays after July 2 was 63 minutes longer than that of the slowest 10% of FC passing through end bays. Observations about fish with the slowest egress times are important because these fish should have a lower probability of survival than fish with fast egress times.

Estimates of spill passage efficiency and effectiveness in 2008 were very similar to historical estimates by radio telemetry and fixed-aspect hydroacoustic studies during non-drought years. A logit regression line fitted to historical hydroacoustic and radio-telemetry estimates of spill passage efficiency as a function of percent spill predicted that spill efficiency would be about 50% when spill discharge was

46% of project discharge, as it was in spring 2008. Our 2008 spill passage efficiency estimate was 50.6% for YC and 49.1% for STH. The same logit regression forecasted a spill efficiency of about 40% for summer 2008, and our estimate of spill passage efficiency was 45.1%. Spill passage effectiveness estimates of 1.084 for YC, 1.051 for STH, and 1.145 for FC in 2008 also were similar to the average of radio-telemetry estimates for non-drought years: 1.075 for YC, 0.975 for STH, and 1.1 for FC.

The 2008 tag-life-corrected survival estimates summarized in Table ES.1 were high relative to most previously reported estimates. The most obvious factor that could cause survival rates to be high was above-average Columbia River water discharge which sped smolts downstream and kept water temperatures below average each season. The probability of implanted acoustic tags being detected on the primary and secondary survival-detection arrays below BON was inversely related to river discharge; i.e., detection probabilities were lowest when discharge was high and were highest when discharge was low.

Table ES.1. Survival and detection probabilities by fish stock, release location, and river reach along with information on numbers of fish, the effect of interest, and the type of survival model

Fish Stock	Release Location	N	Reach	Effect of Interest	Model	Survival Probability	Detection Probability
YC	LGR TR	2,611	A4CR237 to A5CR203	Dam Passage	Single	0.960 (0.015)	0.827 (0.047)
YC	BON TR	660	BON TR to A5CR203	Tailwater Passage	Single	0.962 (0.032)	0.869 (0.019)
YC			A4CR237 to BON TR	Dam Passage	Paired	0.969 (0.042)*	
YC	JDA	3,016	A4CR237 to A5CR203	Dam Passage	Single	0.966 (0.008)	0.879 (0.012)
YC	BON TR	778	BON TR to A5CR203	Tailwater Passage	Single	0.965 (0.023)	0.862 (0.021
YC			A4CR237 to BON TR	Dam Passage	Paired	0.972 (0.028)*	
YC	JDA	1,525	Spillway to A5CR203	Spillway Passage	Single	0.962 (0.012)	0.860 (0.015)
YC	BON TR	707	BON TR to A5CR203	Tailwater Passage	Single	0.963 (0.024)	0.849 (0.023)
YC			Spillway to BON TR	Spillway Passage	Paired	0.970 (0.030)*	
YC	End Bays	693	Spillway to A5CR203	Deep Deflector Bay Passage	Single	0.964 (0.016)	0.848 (0.022)
YC	Mid Bays	832	Spillway to A5CR203	Shallow Deflector Bay Passage	Single	0.960 (0.020)	0.870 (0.019)
YC			Spillway to A5CR203	Ratio of Deep/Shallow	Paired	1.016 (0.036)	
STH	JDA	3,016	A4CR237 to A5CR203	Dam Passage	Single	0.972 (0.010)	0.892 (0.012)
STH	JDA	1,482	Spillway to A5CR203	Spillway Passage	Single	0.962 (0.016)	0.876 (0.016)
STH	End Bays	633	Spillway to A5CR203	Deep Deflector Bay Passage	Single	0.948 (0.027)	0.892 (0.025)
STH	Mid Bays	859	Spillway to A5CR203	Shallow Deflector Bay Passage	Single	0.965 (0.018)	0.865 (0.021)
STH			Spillway to A5CR203	Ratio of Deep/Shallow	Paired	0.984 (0.038)	
FC	JDA/TDA	5,110	A4CR237 to A5CR203	Dam Passage	Single	0.953 (0.011)	0.909 (0.007)
FC	BON TR	918	BON TR to A5CR203	Tailwater Passage	Single	0.982 (0.008)	0.884 (0.012)
FC			A4CR237 to BON TR	Dam Passage	Paired	0.970 (0.014)	
FC	JDA/TDA	2,304	Spillway to A5CR203	Spillway Passage	Single	0.952 (0.014)	0.911 (0.010)
FC	BON TR	918	BON TR to A5CR203	Tailwater Passage	Single	0.982 (0.008)	0.884 (0.012)
FC			Spillway to BON TR	Spillway Passage	Paired	0.969 (0.016)	
FC	End Bays	1,018	Spillway to A5CR203	Deep Deflector Bay Passage	Single	0.957 (0.013)	0.915 (0.014)
FC	Mid Bays	1,286	Spillway to A5CR203	Shallow Deflector Bay Passage	Single	0.948 (0.023)	0.907 (0.013)
FC			Spillway to A5CR203	Ratio Deep/Shallow	Paired	1.021 (0.032)	
FC	JDA/TDA	563/469	Spillway to A5CR203	Ratio Deep/Shallow after July 2	Paired	1.065 (0.063)	

(a) Numbers in parentheses after probabilities are ½ width of a 95% confidence interval (CI). Arrays are named by concatenating an "A" for autonomous, the array's number, "CR" for Columbia River, and the river km where the array was located. Autonomous arrays deployed from JDA to the BON tailwater were numbered consecutively according to their location from upstream to downstream. Accordingly, the forebay entrance array was A4CR237, the primary survival-detection array was A5CR203, the secondary was A6CR192, and the tertiary was A7CR086. Tailrace is abbreviated as TR. Release locations identified as End Bays or Mid Bays were virtual releases at those spill bays. A "JDA" release location refers to releases in the JDA pool near Arlington, Oregon, and in the JDA tailrace; a "TDA" release location refers to TDA tailrace releases.

*Corrected for a dead-fish detection probability ($\hat{D}$) = 0.0126.

We confirmed that three testable assumptions of survival models were reasonable. First, tagged and untagged smolts of each stock were properly identified and had reasonably similar length frequency distributions. None of the STH or YC smolts were excluded from tagging based on their length, and only 9% of the FC smolts were excluded because they were <95 mm long. Second, 97% of the Burnham et al. (1987) tests (Test 2 and Test 3) for spring and 95% of the tests for summer were not significant at α=0.05. Non-significant tests indicate that upstream detection histories did not affect downstream detection and survival probabilities. Third, the timing of three releases of reference fish in the tailrace each day allowed for adequate mixing with treatment fish that passed through the dam. Mixing is an important assumption for estimating paired-release survival rates.

We did not find significant differences between weighted-average survival estimates of YC, STH, or FC smolts passing through end bays with deep deflectors and middle bays with shallow deflectors for entire seasons. This result was not surprising, given high discharge and tailrace elevations during most of the spring and summer, and the absence of mechanisms that might have caused differences except during the second half of summer.

We found that FC smolts passing through spill bays with deep flow deflectors had significantly higher survival rates than smolts passing through bays with shallow deflectors during the second half of summer 2008 when project discharge and tailrace elevations were declining. The unweighted relative survival rate (Deep/Shallow) during this period was 1.065 (95% confidence interval = $1.002 \leq S \leq 1.132$). An analysis of deviance confirmed that the survival rate of FC smolts passing through end bays with deep flow deflectors was higher than that of their counterparts passing through middle bays with shallow flow deflectors (t = 3.573; P(>|t|)=0.0034). These results are consistent with the alternative hypothesis that the survival rate of FC passing through spill bays containing the deep flow deflectors would be better than that of FC passing through middle bays with shallow flow deflectors when discharge and tailrace elevations are low.

The following recommendations are derived from the study results:

1. Paired releases matching veteran smolts in virtual releases with fresh smolts in reference releases probably should end in favor of a more sophisticated survival model, such as that proposed by Skalski (2009).
2. The density of autonomous nodes in arrays downstream of the primary survival-detection array should be increased to increase the probability of detecting acoustic tags in future studies. The cost of increasing node density and detection probabilities is less than the cost of procuring more tags to obtain the required precision of survival estimates.
3. At least 50 dead fish should be released in the tailrace each season during the next survival study at BON to better quantify the probability of detecting dead fish on downstream arrays. This was recommended in the 2007 study year report (Ploskey et al. 2008), and the importance of continuing the practice is underscored by a single dead fish detected in 2008. Detection of dead fish implanted with acoustic tags causes a positive bias in survival estimates that can be corrected if researchers have an accurate estimate of the dead fish detection probability $(\hat{D})$.
4. To avoid sacrificing a lot of fish for future dead-fish releases, we recommend using dead specimens found before rigor mortis is obvious during routine smolt-monitoring operations as well as any fish that happen to die as a result of tagging. Recently deceased fish also could be collected from the

Bonneville Hatchery, although reasonable condition criteria would have to be established. If fish must be sacrificed, we recommend sacrificing individuals that would otherwise be rejected for tagging because of injury or descaling, as these individuals would be much less likely to survive than healthy fish.

5. Tag-life studies should be improved by testing 100 tags of each nominal pulse repetition interval (PRI). Tags must be drawn from all production lots and preferably would be delivered before the tagging season begins so that tag-life results do not delay derivation and application of tag-life corrections. Having 100 tags will minimize the impact of the premature failure of one or two tags on the tag-life curves because each tag will represent only 1% of the study tags. Implementation of this recommendation will require the early purchase, production, and delivery of all tags before the start of each migration season so that researchers can randomly sample 100 tags from all tags with each PRI.
6. For most years and particularly years with above-average discharge, tagging at JDA should start by April 20 to be more representative of run timing at BON. The tagging schedule for 2008 did a good job representing run timing for STH and FC at BON and probably would not require alteration for a similar water year.

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Many people made valuable contributions to this study and deserve to be acknowledged. A team assembled by the National Marine Fisheries Service (NMFS) was responsible for tagging and releasing juvenile Chinook salmon smolts into the Bonneville Dam tailrace and second Powerhouse Corner Collector during this study. The team was led by Lynn McComas and Jason Everett (NMFS) and included Jeff Moser, Galan Wolf, and Steve Brewer (also from NMFS) as well as Dennis Quaempts, Caren Dittbrenner, Mike Jenkins, and Linda McPhetridge from the Pacific States Marine Fisheries Commission (PSMFC). Greg Kovalchuk and Dean Ballinger, the respective PSMFC supervisors at the John Day Dam Smolt Monitoring Facility (SMF) and at the Bonneville Dam Juvenile Monitoring Facility, were helpful in coordinating fish collections with daily fish sampling at the respective locations. Seasonal staff with the PSMFC who also helped with tagging fish at the JDA SMF included Laura Daniel, Steve Goss, Kenneth Kenny, John Mathieus, and Randy Wall.

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Many PNNL staff assisted in project management (Geoff McMichael), surgery training (Rich Brown and Kate Deters), fish collection (Robin Durham), fish transport and release, tag-life monitoring (Rich Brown and Kathleen Carter), Juvenile Salmon Acoustic Telemetry System development (Eric Choi, Brian LaMarche, Daniel Deng, Tao Fu, Thomas Seim, and Thomas Carlson), deployment and retrieval of spillway hydrophones (Fenton Kahn), and database entry and management (Jessica Carter). Dr. Kenneth Ham was very helpful in implementing filters for autonomous node data. Dr. David Geist was the Ecology Group Manager within PNNL, and Dr. Dennis Dauble was the line manager during this study.

Advanced Telemetry Systems (ATS), Inc. manufactured the Juvenile Salmon Acoustic Telemetry System acoustic tags. Autonomous and dam-mounted hydrophones were manufactured by Sonic Concepts, Seattle, Washington. Precision Acoustic Systems, also in Seattle, make the quad channel receivers and conducted node acceptance tests for PNNL. Cascade Aquatics, Inc. in Ellensburg, Washington, activated and delivered the acoustic tags. Schlosser Machine Shop, Hood River, Oregon, fabricated anchors for autonomous nodes and frames for star clusters that were deployed in the spillway forebay.

Acronyms and Abbreviations

ANODEV	analysis of deviance
ATS	Advanced Telemetry Systems®
B1	Bonneville Powerhouse 1
B2	Bonneville Powerhouse 2
B2CC	Bonneville Powerhouse 2 Corner Collector
B2 JBS	Bonneville Powerhouse 2 Juvenile Bypass System
BiOp	Biological Opinion
BON	Bonneville Dam
BPA	Bonneville Power Administration
BPSK	Binary Phase Shift Keying
A4CR237	Bonneville forebay entrance array
A5CR203	primary survival-detection array located at Columbia River km 203 near Reed Island
A6CR192	secondary survival-detection array located at Columbia River km 192 near Lady Island
A7CR086	tertiary survival-detection array located at Columbia River km 86 near Oak Point, Washington
BPA	Bonneville Power Administration
°C	degree(s) Celsius or Centigrade
CENWP	Corps of Engineers, Northwest, Portland
CF	CompactFlash (card)
cfs	cubic feet per second
CI	confidence interval (95% unless specified otherwise)
CJS	Cormack-Jolly-Seber model
CL	confidence limit
cm	centimeter(s)
CSV	comma-separated variables
3D	three dimensional
$\hat{D}$	dead-fish detection probability
DART	Data Access in Real Time
FC	fall Chinook salmon
FCRPS	Federal Columbia River Power System
g	gram(s)
GB	gigabyte(s)
GPS	global positioning system
h	hour(s)
JBS	Juvenile Bypass System
JDA	John Day Dam
JMF	Juvenile Monitoring Facility below the Second Powerhouse (B2)

JSATS	Juvenile Salmon Acoustic Telemetry System
kg	kilogram(s)
km	kilometer(s)
l	liter(s)
LED	light-emitting diode
LRT	likelihood ratio test
m	meter
mg/l	milligram(s) per liter
ml	milliliter(s)
mm	millimeter(s)
m/s	meter(s) per second
MS-222	tricaine methanesulfonate
MSL	mean sea level
NMFS	National Marine Fisheries Service
NOAA	National Oceanic and Atmospheric Administration
O_2	oxygen
p_{11} p_{12}	mean detection probability for virtual releases at the primary and secondary arrays
p_{21} p_{22}	mean detection probability for tailrace releases at the primary and secondary arrays
PAS	Precision Acoustic System
PIT	passive integrated transponder
PNNL	Pacific Northwest National Laboratory
PRI	pulse repetition interval
PSMFC	Pacific States Marine Fisheries Commission
PST	Pacific Standard Time
PVC	polyvinyl chloride
rkm	river kilometer
RS	relative survival rate
s	second(s)
S_{11} S_{12}	Survival of virtual releases of fish through the primary and secondary reaches
S_{21} S_{22}	Survival of virtual releases of fish passing through the primary and secondary reaches
SAS	Statistical Analysis System
SE	standard error
SMF	Smolt Monitoring Facility
STH	steelhead
SURPH	Survival under Proportional Hazards
TDG	total dissolved gas
USACE	U.S. Army Corps of Engineers
UTM	Universal Transverse Mercator (a global positioning grid system)
YC	yearling Chinook salmon

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1.0 Introduction

In continually seeking to improve the conditions juvenile anadromous fish experience when passing through the dams that it operates on the lower Columbia River, the U.S. Army Corps of Engineers (USACE) Portland District (CENWP) has funded numerous evaluations of fish passage and survival. In 2008, the CENWP asked Pacific Northwest National Laboratory (PNNL)[1] to conduct an acoustic telemetry study to estimate the survival rates of juvenile yearling Chinook salmon (YC), steelhead (STH), and fall Chinook salmon (FC) smolts passing through Bonneville Dam (BON) and its spillway.

1.1 Background

Several factors govern the discharge and pattern of spill at BON, including total dissolved gas (TDG) limitations and effects on adult and juvenile salmonid passage. The Biological Opinions (BiOp) for the Federal Columbia River Power System (FCRPS) issued in 2000 and 2004 called for agencies to continue to provide spill for juvenile salmonid passage, because “spill is the option that provides dam passage with the least mortality.” The States of Oregon and Washington granted water-quality waivers to allow TDG levels in the tailwater to rise above 110% of saturation (state water-quality standards) to 120% of saturation over a maximum 12-hour daily average (a gas cap). Before the construction of additional spillway flow deflectors in 2002, the BON spillway was recognized as being one of the biggest TDG producers on the Columbia River. During winter 2001–2002, six new spillway flow deflectors were constructed at BON to reduce the production of TDG during spillway discharge. The new flow deflectors in spill bays 1 through 3 and 16 through 18 were placed 2.134 m deeper than the existing flow deflectors located in spill bays 4 through 15. A new spill pattern was implemented in conjunction with the addition of the new flow deflectors. A study was conducted throughout the 2002 spill season to determine the TDG exchange characteristics of spill operations at BON (Schneider et al. 2003). The study found that the addition of six new flow deflectors and the corresponding change in spill pattern significantly reduced the TDG saturation when compared to similar spill rates observed prior to the 2002 spill season. However, the degree of improvement over pre-2002 conditions declined with increasing discharge. The estimated reduction in TDG saturation for a spill discharge of 75,000 cfs was 10% of saturation. For low tailwater elevations, ranging from 3.1 to 4.18 m above mean sea level (MSL), the new flow deflectors generated considerably lower TDG pressures than the old deflectors.

In terms of biological effects, Johnson and Dawley (1974) found that FC passing through bays without flow deflectors had higher survival rates (95.8%) than FC passing through bays with flow deflectors (86.8%). The effects of the two types of spillway deflectors have been evaluated in direct survival studies using balloon tags (Normandeau and Associates et al. 1996, 2003) and indirect survival studies using radio telemetry (Counihan et al. 2006a, b). In both cases, trends were apparent, although usually not significant, and further evaluations were needed to identify effects and confirm results. The 2002 balloon-tag data suggested that when tailwater surface elevations were low, injury rates increased and survival rates decreased. The survival rates of fish released at bays with deflectors at the 4.267-m elevation were compared with rates for fish released at bays with deflectors at the 2.134-m elevation, but estimates of precision were low (Normandeau et al. 2003). Radio-telemetry survival studies conducted in 2004 and 2005 showed a trend of decreasing fish survival rates with decreasing spill volumes, and bays

[1]PNNL is operated by Battelle Memorial Institute for the U.S. Department of Energy under Contract DE-AC05-76RL01830.

equipped with the shallow flow deflectors usually had lower fish survival rates than bays with the deep flow deflectors. Most results were not statistically significant, but there was some consistency in trends. One operational explanation for reduced survival rates was a new spill pattern that used smaller gate openings and more spill bays for the 75,000-cfs spill during the daytime. In 2006, a total survival evaluation looked at 100,000-cfs spill for 24 hours/day in spring and a modified BiOp spill with larger gate openings in summer. Unfortunately, the effects of spill condition were confounded by a typical decline in the survival rate of FC as summer progressed (Ploskey et al. 2007b).

In summer 2007, a Juvenile Salmon Acoustic Telemetry System (JSATS) acoustic telemetry study found that juvenile fish passing through middle bays with shallow flow deflectors had significantly lower survival rates ($t_{26} = -2.538$, $P = 0.0087$) through the first reach but not in the second reach ($P = 0.9736$) than did counterparts passing through end bays with deep flow deflectors. The first-reach result was expected under the alternative hypothesis that fish have higher passage survival rates in the deep deflector spill bays than in the shallow deflector spill bays. For the shallow flow deflector releases, a weighted-average survival rate from BON to the primary downstream array was 0.936 ($\widehat{SE} = 0.008$). For the deep flow deflector releases, the weighted-average survival rate for that same initial reach was 0.999 ($\widehat{\mathrm{SE}} = 0.002$). For both treatment groups, reach survival rates between primary and secondary arrays was estimated to be 1.0. Estimates of single-release survival rates were based on tracking 1105 FC smolts to bays with shallow flow deflectors and another 892 to bays with deep flow deflectors. The most likely environmental conditions that are reducing survival rates of FC passing through bays with shallow flow deflectors are the below-average project discharge and low-tailrace elevations in summer. Below-average project discharge resulted in low tailwater elevations that were often within 1 m of shallow flow deflectors in summer. For FC in summer, we found that the mean travel time to the egress array located 9 km downstream of the dam was 20 minutes longer (P = 0.0105) for fish passing through middle bays with shallow flow deflectors (2.58 hours) than it was for fish passing through end bays with deep deflectors (2.26 hours).

For spring 2007, there was no effect of spill-bay deflector type on survival rates because estimates were based on very small sample sizes of tracked fish (167 yearlings tracked to middle bays and 114 tracked to end bays), and 95% confidence intervals (CIs) were very wide ($0.849 \leq$ relative survival rate to Array 1 [RS_1] ≤ 1.089). Detection probabilities for the dam-face array were poor until cone-shaped sound-absorbing baffles were added to hydrophones during the third week of sampling in spring 2007. The addition of baffles to pier-mounted hydrophones greatly improved signal-to-noise ratios during the last week of spring and all of summer 2007. However, it was also true that project discharge was similar to the 10-year average in spring, and tailrace elevations were mostly in the range of 6.1 to 7.0 m above MSL, making it unlikely that survival differences would occur.

1.2 Definitions

In this report, we define estimates of single-release reach survival rates by the upstream and downstream boundaries of the reach of interest. Some additional definitions are needed to clarify paired-release survival metrics:

Forebay is the reach of river immediately upstream of the dam where operations at the dam are the primary contributing factor to the velocity and direction of water flow. The upstream boundary of a forebay is where a significant alteration in water-flow allocation through dam operational changes affects water velocity or direction. The downstream boundary is the upstream face of a dam structure. The BON forebay entrance array was located 2 km upstream of BON Powerhouse 2 (B2). Hydrophones making up the spillway forebay array were mounted on piers south of every bay.

Tailrace is the reach of river immediately downstream of the dam where dam operations are the primary factor affecting the velocity and direction of water flow. The upstream boundary of the tailrace is the downstream face of the dam and the downstream boundary is where operational changes at the dam no longer affect the direction of water flow, and mixing from the spillway and powerhouse is complete. The National Marine Fisheries Service (NMFS) release site was about 2 km downstream of the spillway adjacent to the USACE boat launch and near the downstream boundary of the tailwater.

Tailwater in this study is the reach of river downstream of the tailrace to the point where saltwater mixing occurs. Tailwater is synonymous with reservoir or pool when it lies between two dams, but BON is the last dam on the lower Columbia River.

Passage-route survival is the probability of survival for fish passing through any individual route (e.g., spillway, B2 Corner Collector [B2CC], B2 turbines, or B2 Juvenile Bypass System [JBS]) to the boundary between the tailrace and tailwater where reference fish were released. In this study, passage route survival rates were estimated for fish passing through spill bays with deep flow deflectors (end bays 1 through 3 and 16 through 18) and through bays with shallow flow deflectors (bays 4 through 15). The numbers of fish tracked to individual bays were too low to warrant calculation of survival rates by individual spill bay. The estimates of bay-specific survival rates lacked the precision required to detect significant differences in survival rates among individual spill bays.

1.3 2008 Study Objectives and Tasks

The primary objective of the acoustic telemetry study reported here was to conduct spring and summer spillway survival studies each with sufficient statistical power to test the null hypothesis that the survival rates of YC, STH, and FC smolts passing through end spill bays with deep flow deflectors was no higher than the survival rates of their counterparts passing through middle bays with shallow flow deflectors. We also estimated survival rates for YC, STH, and FC passing through the entire spillway.

Tasks undertaken to accomplish the objectives included the following:

1. Juvenile salmonids were collected in the John Day Dam (JDA) Smolt Monitoring Facility (SMF) and surgically implanted with JSATS acoustic and passive integrated transponder (PIT) tags. There were 3425 YC and 3427 STH tagged in spring and 5909 FC tagged in summer. Fish were tagged and released three times per day over a period of 28 consecutive days at two sites in spring and over a period of 29 consecutive days at three sites in summer. These releases of treatment fish above BON provided the opportunity for tagged fish to be detected on a BON spillway array and regrouped into virtual releases through end bays or middle bays.
2. Juvenile Chinook salmon smolts were collected at the BON Juvenile Monitoring Facility below B2 (JMF) and surgically implanted 1654 YC and 2040 FC with JSATS and PIT tags. This task was accomplished by a NMFS team. The fish were released into the BON tailrace three times per day over a 34-day period in spring (826 YC) and over a 37-day period in summer (1020 FC) to serve as reference release groups for treatment fish described in Task 1 above. The team also released fish

(826 YC and 1020 FC) directly into the B2CC on a similar schedule so that B2CC and tailwater releases could be used to scale paired-release estimates of dam survival rates.

3. A cabled system of 36 hydrophones on 18 spillway piers was installed and maintained to detect the passage of tagged fish migrating downstream. Hydrophone detections were used to assign a bay of passage for fish based upon the location of the last of at least four detections within 60 seconds. Detections of PIT tags in the B2 JBS and the B2CC and of acoustic detections on hydrophones in a B2 dam-face array were used to assign non-spillway routes of passage.
4. Primary, secondary, and tertiary survival-detection arrays were deployed in the BON tailwater and maintained to detect acoustically tagged smolts downstream of BON. The tertiary array was deployed by a post-FCRPS survival study team. Detections of coded acoustic tag signals on nodes in these arrays were used to complete detection histories for making route-specific survival estimates using single- and paired-release survival models.
5. Distribution statistics were calculated with respect to the time required for fish to pass from a forebay entrance array located 2 km upstream of B2 to the final bay of passage.
6. Survival rates by route of passage were estimated based upon detection histories of treatment and reference fish at the primary, secondary, and tertiary tailwater arrays, using paired-release survival models. Routes were pooled by type (e.g., spill bays with deflectors at the 2.134 m elevation above MSL; spill bays 1 through 3 and 16 through 18) and bays with deflectors at the 4.267 m elevation above MSL (spill bays 4 through 15). All survival estimates were accompanied by an estimate of the one-half 95% CI.
7. The null hypothesis that the survival rate of YC and FC passing through spill bays with deep flow deflectors (end spill bays 1 through 3 and 16 through 18) was no higher than the survival rate of fish passing through bays with shallow deflectors (middle spill bays 4 through 15) was tested.
8. Survival results from this study were compared with previous estimates based upon acoustic- and radio-telemetry studies.

1.4 Site Descriptions

The distance between the uppermost release site at Arlington, Oregon, and the last survival-detection array at Oak Point, Washington, was 304 km. Excluding distances traveled by fish released at upstream sites to BON, the study area covered about 150 km of the lower Columbia River from BON to Oak Point, Washington at river kilometer (rkm) 86 (Figure 1.1). Cabled underwater hydrophones were deployed on 18 spillway piers and in the spillway forebay to detect the passage of tagged fish and assign the last detections of tags to the bay where fish passed the spillway. Two survival-detection arrays of underwater listening devices were deployed at Reed Island and Lady Island to detect passing smolts. These data and detection data from a third array deployed at Oak Point by a post-FCRPS survival study were used to create detection histories and estimate the survival rates of smolts through the dam and spillway.

Bonneville Lock and Dam consist of several structures that together span the Columbia River between Oregon and Washington near rkm 234.3, about 64 km east of Portland, Oregon (Figure 1.1). From the Oregon shore north toward Washington, BON is composed of a navigation lock, the 10-turbine Powerhouse 1 (B1), Bradford Island, an 18-bay spillway, Cascades Island, and the 8-turbine B2 (Figure 1.2). The spillway and B1 were constructed between 1933 and 1937 without specific regard for protecting juvenile salmonids migrating downstream. Construction of B2 began in 1974 and was completed in 1982. The CENWP operates BON for hydroelectric power generation for the Bonneville Power Administration (BPA) and the Bonneville Lock for navigation.

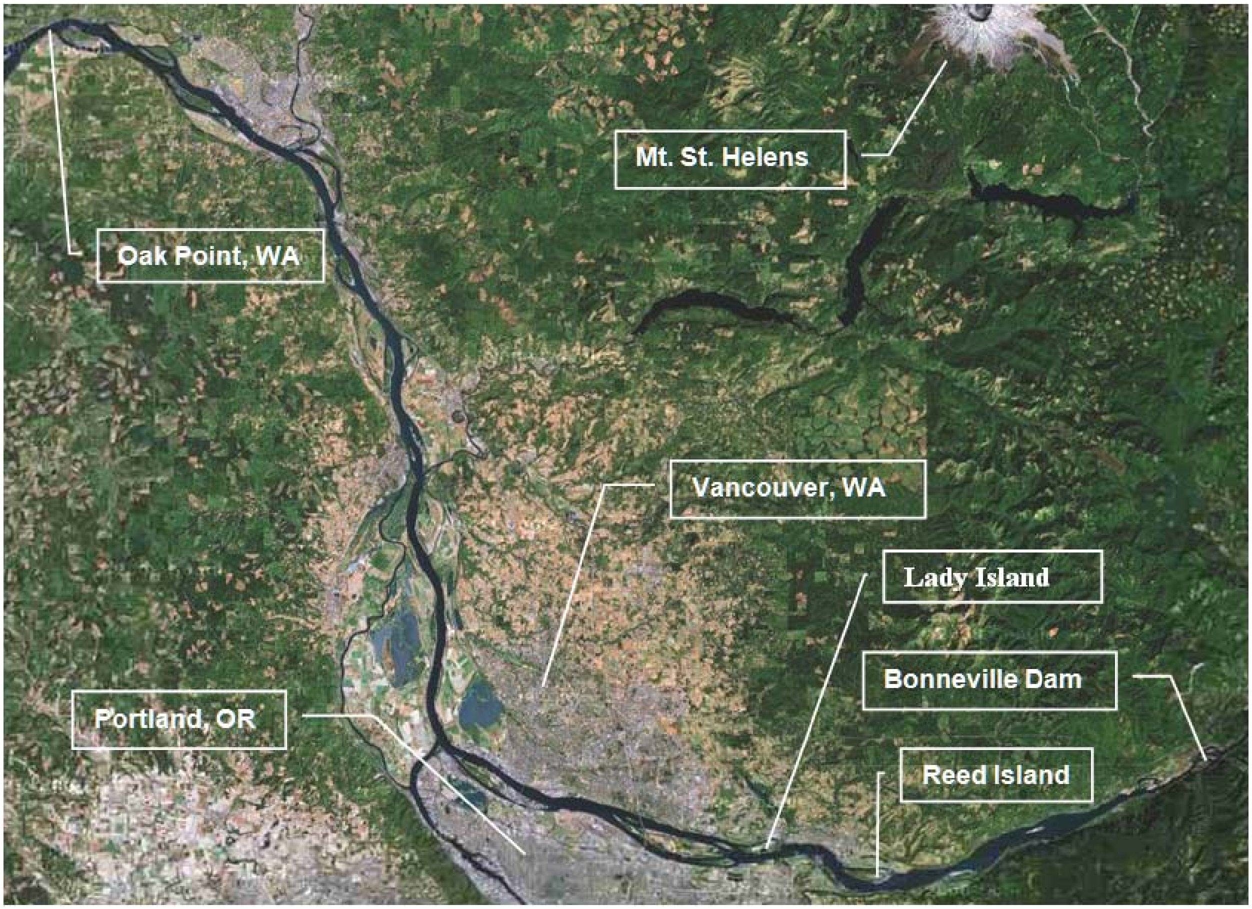


Figure 1.1. Study area from Bonneville Dam downstream to Oak Point, Washington. The background image was copied from Google Maps.

1.5 Report Contents and Organization

The ensuing sections of this report present the materials and methods used in conducting the study (Section 2.0) and the study results (Section 3.0). Section 4.0 discusses environmental and 2007 outmigration conditions and other study findings, including length frequencies of tagged and untagged fish, a tag-life study, array detection performance, spillway passage efficiency and effectiveness, egress rates, and the detection and survival rates of YC, STH, and FC smolts. Recommendations are provided in Section 5.0, followed by references in Section 6.0. There are three appendices. Appendix A provides data from tagging, releases, dam operations, and capture-history datasets. Appendix B provides results of Burnham et al. (1987) Tests 2 and Test 3 that were used to evaluate the survival model assumption that downstream detection and survival rates are independent of upstream detection rates. Appendix C is a report on the effect of dead-fish detections on the variance of survival estimates.

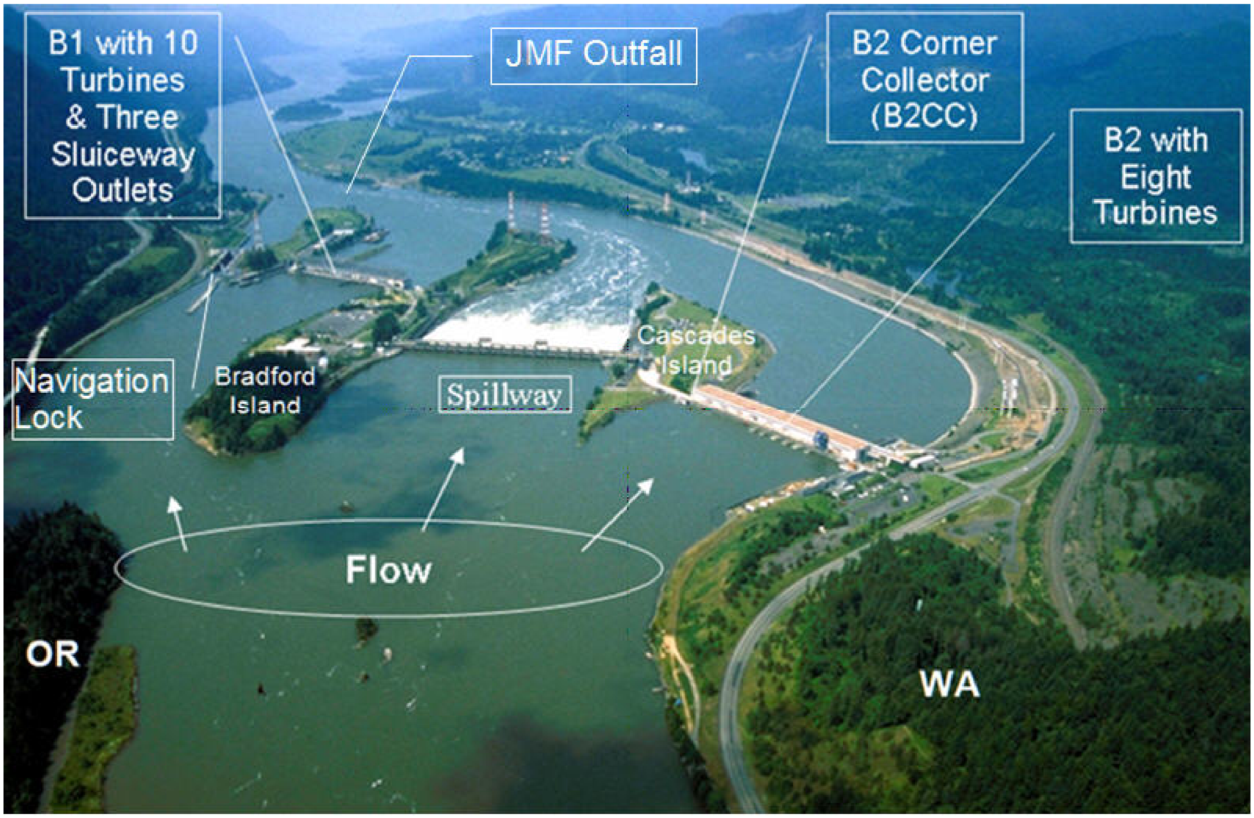


Figure 1.2. Aerial view of Bonneville Dam. JMF = Juvenile Monitoring Facility; B1 = Powerhouse 1; B2 = Powerhouse 2.

2.0 Materials and Methods

This chapter describes materials and methods related to a number of tasks that together comprise the 2008 dam and spillway survival study at Bonneville Dam. Tasks included fish collection, tagging, release, and detection of tagged migrating fish followed by data processing and analysis. We also describe methods used in a tag-life study that supported all JSATS acoustic tag studies conducted in 2008.

2.1 Fish Collections

Fish were collected for this study in accordance with established permitting requirements using the sampling methods commonly used at smolt-monitoring facilities, as described below.

2.1.1 Description of Tagging Sites

Treatment fish were collected and tagged at the JDA SMF for release above BON, and reference fish released into the BON tailrace or B2CC were collected and tagged at the BON JMF. Monitoring facilities at both locations receive fish passing through a JBS. Juvenile salmonids begin moving through each JBS after they are screened from the upper third of 16 turbines at JDA or eight B2 turbines at BON. Most smolts are diverted into gatewell slots located above each turbine intake (three per turbine), and from the gatewell slot, most smolts pass through a 0.305-m-diameter orifice into a collection channel that runs the length of the powerhouse. After considerable dewatering, insulated pipes deliver smolts to monitoring facilities where they may be sampled and examined to evaluate their health or condition. Sampled fish typically were returned to the river in an outfall pipe emptying into fast water in the tailrace. A small percentage of JBS-passed fish at either monitoring site were selected for inclusion in this survival study, and those fish were held 2 days longer than their counterparts to allow time for surgical implantation of PIT and acoustic tags and recovery prior to their release.

2.1.2 Federal and State Permitting

Records were kept on all smolts handled and collected (both target and non-target species) for permit accounting purposes. Collections were conducted in conjunction with routine sampling at the monitoring facilities to minimize the impacts of handling. Fish selected as tagging candidates were taken from routine target sample sizes and accounted for under permits issued to the monitoring facilities. Additional fish required to meet research needs (beyond typical sampling goals) were accounted for under separate federal and state permits.

All permitting requirements were met by the PNNL and NMFS teams. A federal scientific permit (SS-08 PNNL-40) issued by the National Oceanic and Atmospheric Administration (NOAA) Fisheries Hydropower Division's FCRPS Branch under the 2004 FCRPS BiOp authorized PNNL researchers to take juvenile salmonids at the JDA SMF. The Oregon Department of Fish and Wildlife also authorized the take of fish for this study under permit number OR2008-4600. The NMFS team that tagged juvenile salmonids at the BON JMF also obtained a federal permit (16-08-NWFSC16 from the Hydropower Division, FCRPS Branch), and a state permit (Washington Department of Fish and Wildlife Permit 08-178).

2.1.3 Sampling Methods

Pacific States Marine Fisheries Commission (PSMFC) staff diverted fish from the JBS at JDA and BON using detailed methods described by Martinson et al. (2006). Several samples of about 250 fish were anesthetized using a tricaine methanesulfonate (MS-222) solution prepared at a concentration of 44 mg/l. Once fish were in the examination trough, MS-222 was added as necessary to maintain induction.

PNNL staff evaluated the candidate fish for inclusion in the survival study using the following specific acceptance and rejection criteria:

- **Accept if the fish** is from the correct run and the adipose-fin is clipped or unclipped and length is >95 mm.
- **Reject if the fish is a non-target species or exhibits any of the following:**
  - descaling greater than 20% on any one side
  - signs of prior surgery (for instance: radio tags, sutures, or PIT-tag scars)
  - positive readings when put through a PIT-tag reader
  - physical injuries, such as to the head (injury on the head or in the eye); operculum damage (torn or folded); popeye; body injury; or fin hemorrhage
  - evidence of infections or parasites, such as fungus (infection on the body surface); bacterial kidney disease; columnaris (yellow rimmed sores, ulcers, or open lesions on the body or fins); or trematodes (subdermal parasites)
  - signs of predation, such as bird strikes or injuries inflicted by other fish or mammals that result in punctures or abrasions.

The NMFS team tagging at BON used similar acceptance and rejection criteria, but it only tagged clipped YC and FC smolts and tagged no STH in 2008. Non-target and rejected fish were released to the river after a 30-minute recovery period. Accepted fish were counted into transfer buckets containing fresh river water, and moved to one of two, 511-l pre-surgical holding tanks. Fish were held in the tanks for 24 hours so that their gut contents would be evacuated before surgery.

2.2 Fish Tagging

Acoustic tags were surgically implanted in the fish, which were held for recovery as described here, prior to being released.

2.2.1 JSATS Acoustic Micro-Transmitter

The size of JSATS acoustic micro-transmitters surgically implanted in fish differed between spring and summer. In spring, the mean weight of tags was 0.485 g in air and 0.324 g in water, and tag were nominally 12.46 mm long, 5.30 mm wide, and 3.70 mm high. In summer, the mean weight of tags was 0.425 g in air and 0.29 g in water. Summer tags averaged 12.04 mm long, 5.27 mm wide, and 3.74 mm high (Figure 2.1). Fish collected at JDA were implanted with tags that had nominal transmission rates of about 1 pulse every 3 seconds (3-s tags), and fish tagged at BON received tags transmitting once every 5 seconds (5-s tags). Each pulse from a JSATS tag contains a complex phase-encoded signal that uniquely identifies the transmitting tag without varying pulse duration. Within 1 to 5 days of being implanted in fish, each tag was acoustically activated by Cascade Aquatics, Inc., using a Pinger dish designed by ATS to activate or deactivate tags. Nominal tag life was about 30 days for 3-s tags and 45 days for 5-s tags.

Figure 2.1. The ATS JSATS Acoustic Micro-Transmitter (top) and a PIT Tag (bottom)

2.2.2 Fish Collection and Tagging Procedures

The tagging process involved several steps taken to minimize handling impacts. Sterilization of all surgical instruments was a continuous and emphasized protocol. Each surgeon used three to four complete sets of instruments. Once used, the instruments were placed in a 70% ethanol solution for approximately 10 minutes. All instruments were rotated into distilled water for 10 minutes to "wash" off the residual ethanol prior to their use during the next surgery. This procedure reduced the introduction of bacteria and other harmful particulates into the incision and suture site. A synthetic fish slime (Poly-Aqua) was liberally used on the surgical pad to counteract the disruption to mucus membranes during surgical procedures (Table 2.1). Local anesthetic was not used on the incision site because of its characteristic of further disrupting the mucus membrane. The proximity of the incision to the midline was closely monitored to ensure that neither the incision nor the suture went through the midline.

Table 2.1. Dilution of Poly-Aqua used in surgical procedures

Volume (l)	Poly-Aqua
1	0.15
2	0.30
3	0.45
4	0.60
5	0.75
6	0.90
10	1.50
2	3.00
5	7.50

The day before tagging, one person sub-sampled fish from the routine smolt-monitoring sample. Fish were placed in three 511-l tanks with inflowing and outflowing river water and held overnight to provide time for gut contents to be eliminated. The use of routine smolt-monitoring samples usually provided enough fish to meet our quota each day except occasionally near the beginning or at the end of a migration season when numbers in routine samples may have been low.

A team of eight people participated in the tagging process to reduce handling time from netting to post-surgery recovery. The "Surgical Implantation of Acoustic Transmitters in Juvenile Salmonids within the Columbia River Basin: Guidelines for Corps of Engineers Contractors and Staff" was used as a guide in every aspect of the tagging process. On many days all fish were tagged within a 4- to 5-hour period. The procedure started with one technician netting enough fish (usually five) from the 511-l holding tanks to fill one 18.9-l transport bucket. These fish were anesthetized in an 18.9-l "knockdown" bucket with fresh river water and MS-222 at a concentration between 80 and 100 mg/l. After fish lost equilibrium and rolled over, they were monitored closely to assure that breathing, as indicated by gill movements, was continuous and did not weaken before the fish were moved into the tagging process. Anesthesia buckets were refreshed regularly to maintain the ±2°C of the current river temperatures. Anesthesia solutions were either replaced or cooled with ice when temperatures exceeded protocols. On rare occasions when the surgery routine was delayed, a few fish may have remained in the knockdown bucket minutes longer than usual and exhibited slowed breathing. They were promptly transferred to an adjacent bucket of cool freshwater until their breathing rates returned to normal. Anesthetized fish were transferred one-at-a time into a 0.25-l plastic container of knockdown solution and handed to a second person who measured (fork length ±1 mm) and weighed (±0.1 g) them. A digitizing board and electronic scale with serial connections to a computer facilitated accurate recording of lengths and weights. The person measuring and weighing fish was stationed at the end of a line of three or four surgeons so that they could see who was available to tag the next fish. The digitizing board had buttons with the names of all surgeons so each fish could be assigned to the next available surgeon with the push of one button. A third individual scanned PIT and acoustic tag codes into the computer, assigned tags to each specific fish, and recorded fish species, run, and adipose fin status (clipped or unclipped). After a fish was weighed and measured, it was placed back into its plastic transfer container along with an assigned PIT tag, activated acoustic tag, and a colored cork matching the color of a piece of foam stationed above the 18.9-l transport bucket receiving fish. The container with fish, tags, and colored cork were then handed to one of three or four surgeons for tag implantation.

During surgery (Figure 2.2), each fish was placed ventral side up and a gravity-fed anesthesia supply line was placed into its mouth. The dilution of this “maintenance” line was 40 mg/l. A 6- to 8-mm incision, using a #10 or #15 stainless-steel surgical blade, was made ventrally, 3 mm from and parallel to the mid-ventral line and equidistant from 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. Two interrupted sutures were made using 5-0 monocryl suture with a RB-1 needle. After closing the incision, the surgeon would check to see whether the colored cork with the fish matched the color of a piece of foam set up near the transport bucket being filled. If the colors were the same, the surgeon placed the tagged fish and colored cork into an opening in the top of a 20-ft long, 76-mm-diameter polyvinyl chloride (PVC) pipe that sluiced the tagged fish and cork along the line of surgeon stations (Figure 2.2) down to a dark 18.9-l transport bucket filled with oxygenated river water. If the cork and foam colors were different, the surgeon waited for the transport bucket and colored foam indicator to be switched to the next available bucket and color that matched, or walked the fish down the line to the next bucket to be filled. At the end

Figure 2.2. Picture of a line of four surgery stations. Each station had an elevated bucket of maintenance anesthetic solution with a plastic line that fed solution to the fish throughout the operation. Tagged fish and colored corks were dropped into one of four openings along a 20-ft-long, 76-mm-diameter PVC pipe that ran the length of the four tagging stations. River water supplied to one end of the pipe swept fish and corks to a transport bucket.

of the line of surgeons, another technician was responsible for closely observing and counting the number of fish and corks accumulating in the transport bucket, for letting surgeons know what transport bucket was being filled (verbally and by setting out a colored piece of foam), and for switching out transport buckets and colored foam indicators after each bucket was filled to its quota (usually five fish). When fish in transport buckets regained equilibrium, as indicated by vertical posture and active swimming, a lid was added to the bucket, and it was hand carried outside and placed in one of several large holding tanks with flowing river water for 18 to 24 hours.

2.2.3 Transport and Holding

Each transport bucket had many 3/8th-inch-diameter holes drilled through the upper half of its height and around its circumference (Figure 2.3), but while being filled with recently tagged fish, it was nested inside another 18.9-l bucket without holes so that it could be filled to capacity. The location of holes in the upper half of the buckets allowed water to flow through each bucket when submerged in a large post-surgery holding tank that had fresh river water flowing through it (Figure 2.4). The solid bottom half of transport buckets provided a sanctuary that retained about 9 l of water when the bucket was being transported, and this protected fish and reduced the weight of the bucket by half. Most transport buckets were loaded with five fish, although the last bucket for a release site may have had fewer than five or as many as seven if the fish were small.

Figure 2.3. Transport bucket with 15-inch-long ruler to indicate scale

Figure 2.4. Large insulated tanks for holding transport buckets at the BON JMF (top) and JDA SMF (bottom). Holding tanks were plumbed to allow flowing river water to pass through the tanks that each held 32 transport buckets, and holes in the upper half of transport buckets allowed water freshwater to enter and leave individual buckets.

When fish regained equilibrium after surgery, the 18.9-l buckets were covered with a fitted lid and hand carried outside to a larger holding tank with a continuous supply of river water (Figure 2.4). Fish were held for at least 18 hours prior to release in the river. A sensor for monitoring water level, temperature, and dissolved oxygen was installed and set up to automatically telephone staff if

Water-quality conditions were undesirable for the fish. Alert limits were set to a maximum of 21.7°C and a minimum of 7 mg/l of oxygen. The inside of the tanks was sectioned off by an aluminum or PVC pipe to keep buckets upright (Figure 2.5).

Figure 2.5. View inside the large holding tanks at BON (left) and JDA (right) showing aluminum or PVC grids for keeping transport buckets upright

2.3 Transport and Release

To transport fish from the JDA tagging site to release locations, the PNNL team secured 681-l and 265-l Bonar insulated totes in the bed of a pickup truck. The large tote held water and ten 18.9-l transport buckets and the 265-l tote held water and four buckets. Totes had locking lids and extra space to accommodate a wood-frame separator so that ice could be added for cooling on hot days. A network of valves and plastic tubing was attached to oxygen (O_2) tanks for delivering oxygen to the water in each tote from a 2200 psi O_2 tank secured in the truck bed. Fish buckets were removed two at a time from the post-surgery holding tank and loaded into insulated totes. Dissolved oxygen concentration and temperature in Bonar totes were measured before and after transport with a Yellow Springs Instruments (YSI) meter to assure that levels remained satisfactory during transport. Procedures used by the NMFS team were similar, although the specific vehicle and transport tank were different and the need to measure oxygen concentration and temperature before and after transport was eliminated by short distances from the BON JMF to the B2CC.

We minimized handling impacts during transport and release in several ways. Dark buckets reduced stress associated with holding fish in confined spaces and transport vehicles. Before loading fish transport buckets into insulated tanks on transport vehicles, each insulated tank was flushed with river water to cool and clean. On boats, transport buckets were shaded to reduce solar heating.

Tagged fish were hauled from tagging sites to release locations (Figure 2.6) three times every day (morning, afternoon, and at night). Fish were released into the B2CC by a hose induction system (Figure 2.7). Fish usually were released by boat along a transect line across the river at the BON tailrace (Figure 2.8), upper TDA tailwater, upper JDA tailwater, and above JDA at Arlington, Oregon (e.g., see Figure 2.9). Buckets were opened to check for dead fish, and all dead fish were scanned with a BioMark portable transceiver PIT-tag scanner so that their identities could be established and recorded. Following established protocol, biologists cut through gill arches of all dead fish before releasing them. Boat operators used an onboard global positioning system (GPS) to move the boat to specific latitudes and longitudes and put the motor in neutral while the crew gently poured fish into the river and recorded the location, bucket number, and time of release. Acoustic tags and PIT tags in each bucket were part of the tagging database, so records indicate release time to the nearest minute (Pacific Standard Time).

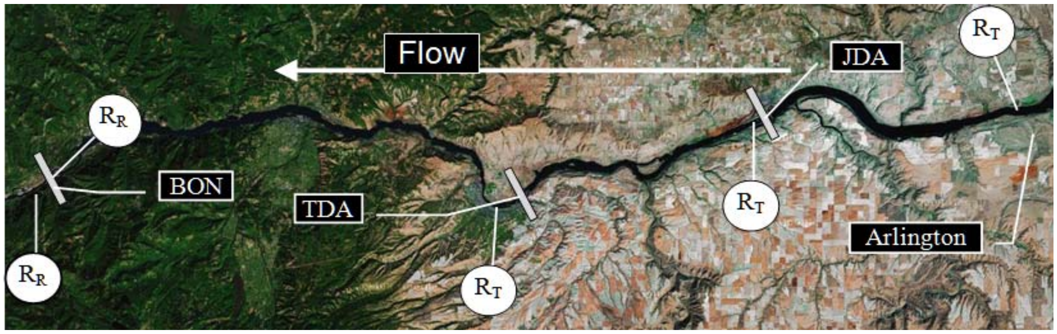


Figure 2.6. Plan view of the reach of the Columbia River with fish release sites. The approximate locations of dams are indicated by gray rectangles. Reference releases (R_R) were into the B2CC at BON or in the BON tailwater 2 km downstream of the dam. Treatment releases (R_T) were made 3 km below TDA in summer only and 2 km below JDA and near Arlington, Oregon, above JDA in spring and summer.

Figure 2.7. Photo of fish release apparatus at the B2CC (Courtesy of Jason Everett with the NMFS). Fish were poured into an induction tank (left) and flushed through a 102-mm-diameter plastic hose into the B2CC entrance.

Figure 2.8. Photo of the fish release barge maneuvering along a line transect 2 km downstream of Bonneville Dam. (This photo was provided by Jason Everett with the NMFS Team.)

Figure 2.9. Photo of fish being released from a boat moving along a line transect above JDA. Fish were gently poured into the river from each transport bucket.

All survival estimates in this study were defined by virtual releases of tagged smolts coming downstream to BON from upstream release sites (treatment fish that passed the dam) or by releases of tagged smolts in the BON tailrace (reference fish that did not pass the dam). Virtual releases were defined by detections on the forebay entrance array or spillway array to identify groups of fish for estimating dam-passage and spillway-passage survival rates, respectively. Weiland et al. (2009)

presented tables describing tagging and release data for YC, STH, and FC released in the JDA pool, JDA tailrace, and TDA tailrace. Similar data for YC and FC released in the BON tailrace by the NMFS are presented in Table 2.2.

Table 2.2. Numbers of smolts released alive and dead by date, release location, and run in the BON tailrace by the NMFS. These reference fish did not pass through the dam and were paired with virtual releases of treatment fish that did pass through the dam or spillway to calculate paired-release estimates of dam-passage or spillway-passage survival rates. The ratio of survivals of fish released in the B2CC and tailrace was used to scale a dam survival estimate in a triple release model (Faber et al. 2009).

Yearling Chinook Salmon in Spring				Fall Chinook Salmon in Summer			
	B2CC	Tailrace			B2CC	Tailrace	
Date	Alive	Alive	Dead	Date	Alive	Alive	Dead
				6/15/2008	26	26	
4/30/2008	25	26		6/16/2008	26	26	
5/1/2008	23	22		6/17/2008	30	30	
5/2/2008	23	23		6/18/2008	30	30	
5/3/2008	24	24		6/19/2008	30	30	3
5/4/2008	24	24	3	6/20/2008	30	30	3
5/5/2008	23	24	3	6/21/2008	30	30	3
5/6/2008	24	23	4	6/22/2008	30	30	3
5/7/2008	18	19	3	6/23/2008	30	30	
5/8/2008	30	28		6/24/2008	30	30	
5/9/2008	24	25		6/25/2008	30	29	1
5/10/2008	25	25		6/26/2008	30	30	4
5/11/2008	24	24	2	6/27/2008	30	30	2
5/12/2008	24	24	3	6/28/2008	31	30	3
5/13/2008	23	24	3	6/29/2008	30	30	3
5/14/2008	25	24	3	6/30/2008	30	30	
5/15/2008	24	24		7/1/2008	30	30	
5/16/2008	24	24		7/2/2008	30	30	
5/17/2008	24	24		7/3/2008	30	30	3
5/18/2008	12	4	3	7/4/2008	30	30	3
5/19/2008	24	24		7/5/2008	30	30	3
5/20/2008	26	30	3	7/6/2008	29	30	6
5/21/2008	32	34	4	7/7/2008	30	30	
5/22/2008	32	31	4	7/8/2008	31	30	
5/23/2008	27	30		7/9/2008	30	30	
5/24/2008	27	25		7/10/2008	30	30	
5/25/2008	26	28		7/11/2008	30	30	2
5/26/2008	24	24		7/12/2008	30	30	3
5/27/2008	24	24	3	7/13/2008	30	29	3
5/28/2008	24	24	3	7/14/2008	30	31	3
5/29/2008	24	24	3	7/15/2008	28	29	
5/30/2008	24	24	3	7/16/2008	25	25	
5/31/2008	24	24		7/17/2008	25	25	
6/1/2008	23	23		7/18/2008	25	25	
6/2/2008	22	22		7/19/2008	24	25	1
Spring Total	826	826	50	Summer Total	1020	1020	52

2.4 Detection of Tagged Fish

Underwater listening devices (called nodes) were deployed in groups (called arrays) to detect tagged fish moving downstream from release locations. The following sections describe the nodes, arrays, array locations, node deployment, retrieval, servicing, and redeployment practices.

2.5 Nodes and Arrays

The Sonic Concepts' autonomous acoustic telemetry receiver (node) used in this study consisted of two coupled parts. The top was made from Schedule 40 10.16-cm-diameter PVC pipe that was capped at the top and had a fitting with male threading at the bottom (Figure 2.10). The cap was modified for water-tight seating of a hydrophone, and the body below the cap housed the analog and digital boards for processing detected tag signals. A lubricated 10.16-cm-diameter rubber O-ring was fitted over the lower threaded end so that it would form a water-tight seal when the node top was screwed together with the bottom. The node bottom was made from approximately 1 m of 10.16-cm-diameter PVC pipe and the upper end had a fitting with female threads for coupling it to the node top. The lower end of the node bottom was capped and a stainless-steel harness was located just below the upper fitting so the node could be attached to an anchor system, which is described later. An acoustic beacon that transmitted a signal four times louder than acoustic tags once every 15 seconds was attached to the outside of the battery housing just below the threaded end of the housing. This beacon was used to determine the location of a node if it did not surface after it was acoustically released from an anchor. Beacons also could be used to determine when an adjacent node disappeared. All autonomous nodes were received with version 2006 software and were thoroughly tested by Precision Acoustic Systems (PAS) to ensure that nodes met acceptance-testing criteria. Node functionality also was verified just before each was deployed in the river.

Figure 2.10. Side (left) and bottom (right) view of a node top

Before the deployment of each node, two 30-day lithium-ion batteries were gently lowered into the node bottom and secured in place with a battery-retention device. Wires from the batteries were attached to connectors from the analog board in the node top. One end of a serial cable was connected to a plug from the board set in the node top and the other end was plugged into a laptop computer so that staff could communicate with the node, set its date and time, and verify detection of a beacon tag. Next, a 1-GB SanDisk Extreme III Compact Flash (CF) card was mounted in a slot on the board set, and the node top and bottom were screwed together until beveled edges of each piece compressed the O-ring to form a watertight seal. Just before putting the node into the water, we verified that a light-emitting diode (LED) on the node top housing was flashing, which indicated that the node was functioning properly and data would be written to the CF card. In the water, air space within the sealed node provided positive buoyancy, while the batteries in the node bottom provided ballast to help keep the node upright.

An array is defined as a group of nodes deployed within 1 km of a specific river cross section to detect passing acoustically tagged fish. Nodes in line transects were deployed at distances ≤ 150 m from each other and ≤ 90 m from the shore. However, additional nodes sometimes had to be deployed in entrances to or exits from side channels formed by islands downstream of BON.

2.5.1 Array Locations

Figure 2.11 shows the location of all arrays deployed to detect fish and estimate survival rates for this study. The spillway array was composed of nine receiver systems, each cabled to four hydrophones and running on 110-volt alternating current. All other arrays located away from the dam were composed of autonomous nodes running on two lithium battery packs. Internal clocks in autonomous nodes were set based upon GPS time each week that they were serviced but time could drift several minutes per week so those nodes were only used to detect fish and not to track them.

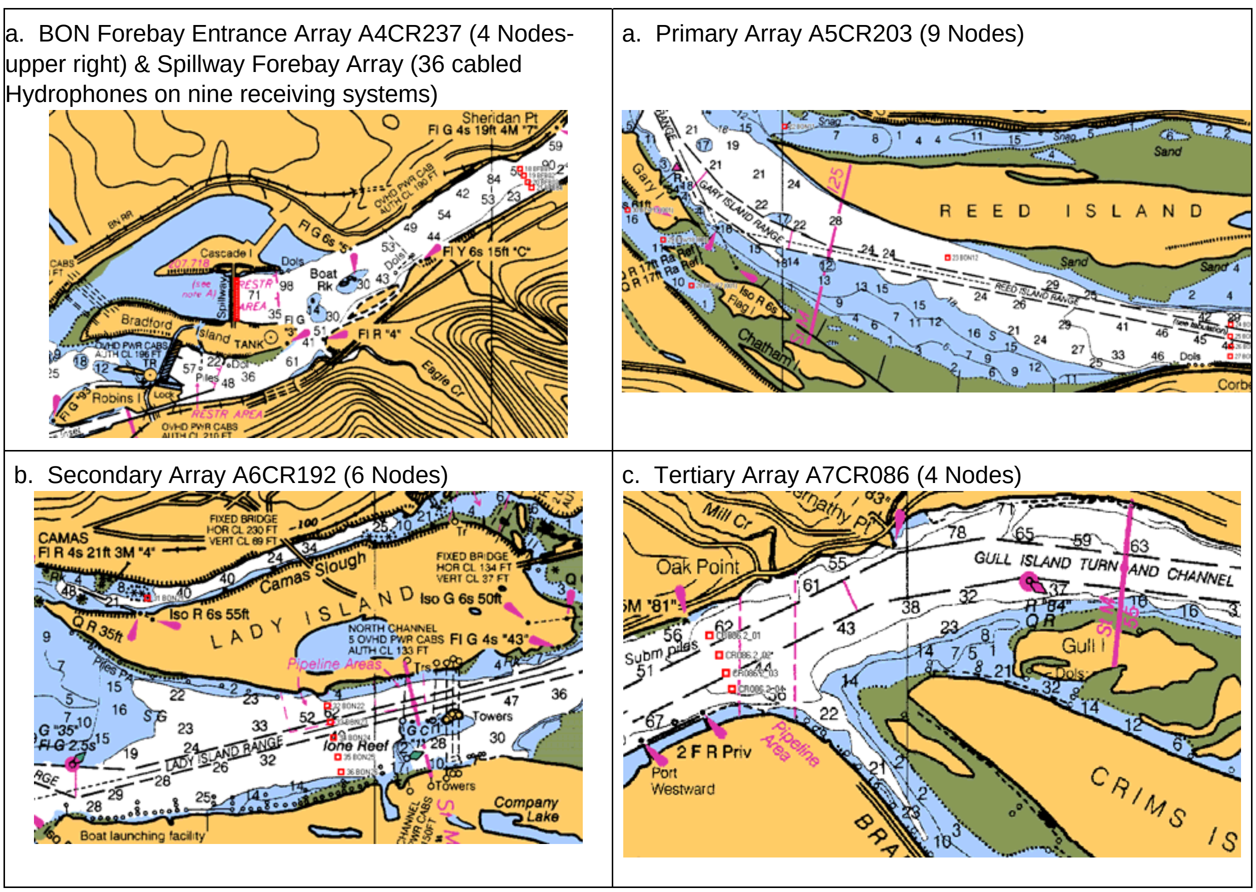


Figure 2.11. Fugawi maps showing approximate locations of underwater listening devices in arrays deployed for this study. Twenty-three autonomous node locations are marked with red squares, and the 36 cabled hydrophones deployed on spillway piers appear as a thick red line on the forebay side of the spillway. Flow is from right to left in all panels.

2.5.1.1 Bonneville Spillway Array

Individual hydrophones on spillway piers were baffled by plastic cones lined with an anechoic material throughout sampling in 2008 to exclude loud noises emanating from spill gates downstream of hydrophones. Baffling greatly increased the ratio of tag signals relative to background noise levels, and significantly increased the percentage of successful tag decodes. These hydrophones were used to track tagged juvenile salmonids from about 50 m upstream of the spillway to the spill bay that each fish passed. Tracking successive positions of tagged fish required us to synchronize digital signal processing (DSP) cards to within 0.4 μs using five GPSs and Meinberg GPS time cards. Fish passing through bays 1 through 3 or 16 through 18 were assigned to an end-bay-passage treatment, whereas fish passing through middle bays (4 through 15) were assigned to a middle-bay-passage treatment. Table 2.3 provides GPS coordinates and depths of cabled hydrophones deployed in the spillway forebay. Two hydrophones were deployed on each pier south of a spill bay at water depths averaging 2.7 and 10.35 m below the average pool elevation (22.554 m above MSL).

Table 2.3. GPS coordinates (WGS84 datum; latitude and longitude) of cabled hydrophones deployed in the forebay of the Bonneville Dam spillway in 2008. Depths are referenced to average pool elevation (22.554 m above mean sea level).

Location Name	Number of Hydrophones	Latitude (Deg)	Longitude (Deg)	Deep Hydrophone (m)	Shallow Hydrophone (m)
P1	2	45.645632	-121.940627	10.4	2.8
P2	2	45.645468	-121.940632	10.4	2.8
P3	2	45.645304	-121.940636	10.4	2.7
P4	2	45.645139	-121.940641	10.3	2.7
P5	2	45.644974	-121.940646	10.3	2.7
P6	2	45.644810	-121.940651	10.3	2.6
P7	2	45.644645	-121.940656	10.4	2.7
P8	2	45.644481	-121.940661	10.3	2.7
P9	2	45.644316	-121.940666	10.4	2.7
P10	2	45.644152	-121.940671	10.3	2.7
P11	2	45.643987	-121.940676	10.3	2.6
P12	2	45.643822	-121.940681	10.3	2.7
P13	2	45.643660	-121.940686	10.4	2.7
P14	2	45.643494	-121.940691	10.4	2.8
P15	2	45.643330	-121.940696	10.4	2.7
P16	2	45.643165	-121.940701	10.4	2.7
P17	2	45.643000	-121.940706	10.4	2.6
P18	2	45.642859	-121.940707	10.4	2.6

2.5.1.2 Survival-Detection Arrays

Table 2.4 lists GPS coordinates and approximate depths of each autonomous node deployed in arrays above and below BON. The primary survival-detection array with nine autonomous nodes was centered on rkm 203 near Reed Island (Figure 2.11a). The secondary array with six autonomous nodes was centered on rkm 192 near Lady Island and Camas, Washington (Figure 2.11c). The tertiary array located at rkm 86.2 had four autonomous nodes and was deployed by the post-FCRPS (estuary) survival study.

Table 2.4. Approximate GPS coordinates of autonomous nodes deployed in 2008 by array. The Universal Transverse Mercator (UTM) zone was 10T. Primary, secondary, and tertiary arrays were used to estimate survival rates.

Array Name	Array Function	Latitude (Deg)	Longitude (Deg)	Approximate Depth (m)
A4CR237_01	Forebay Entrance	45.6526278	-121.9140195	19.8
A4CR237_02	Forebay Entrance	45.6521960	-121.9136593	28.2
A4CR237_03	Forebay Entrance	45.6517643	-121.9132991	22.9
A4CR237_04	Forebay Entrance	45.6514046	-121.9129389	16.4
A5CR203_01	Primary	45.5589048	-122.3330537	6.0
A5CR203_02	Primary	45.5496636	-122.3167645	12.8
A5CR203_03	Primary	45.5449652	-122.2884518	15.9
A5CR203_04	Primary	45.5441388	-122.2885033	18.1
A5CR203_05	Primary	45.5434062	-122.2884599	19.4
A5CR203_06	Primary	45.5427175	-122.2885132	20.8
A5CR203_07	Primary	45.5476987	-122.3423970	9.8
A5CR203_08	Primary	45.5508925	-122.3452551	10.0
A5CR203_09	Primary	45.5530010	-122.3488051	8.3
A6CR192_01	Secondary	45.5750091	-122.4352865	11.1
A6CR192_02	Secondary	45.5687937	-122.4205678	21.9
A6CR192_03	Secondary	45.5678520	-122.4203114	19.8
A6CR192_04	Secondary	45.5669466	-122.4200549	17.2
A6CR192_05	Secondary	45.5658238	-122.4196958	10.4
A6CR192_06	Secondary	45.5649545	-122.4194395	11.5
A7CR086_01	Tertiary	46.1859280	-123.1802780	21.3
A7CR086_02	Tertiary	46.1849910	-123.1796010	20.8
A7CR086_03	Tertiary	46.1841270	-123.1791320	15.8
A7CR086_04	Tertiary	46.1833700	-123.1787150	20.6

2.5.2 Autonomous Node Rigging

The length of autonomous node rigging (Figure 2.12) varied with water depth at deployment sites. A 1.5-m section of line with three 2.72-kg buoyancy floats was attached to a strap half way between the node tip and node bottom. An InterOcean Systems Model 11 acoustic release was attached to the other end of the 1.5-m line. The length of the 0.48-cm-diameter wire rope anchor line deployed varied with water depth, from 0.3- to 2-m long. One end of the anchor line was swaged to a 76.2-mm ring that fit into the mechanical latch end of the acoustic release and the other end was shackled to a 34-kg anchor. In water <5.5 m deep, we bound the node, float line, and acoustic release together with 1-m-long zip-ties and used a short (0.3-m) anchor line to keep the entire package under 1.5 m long.

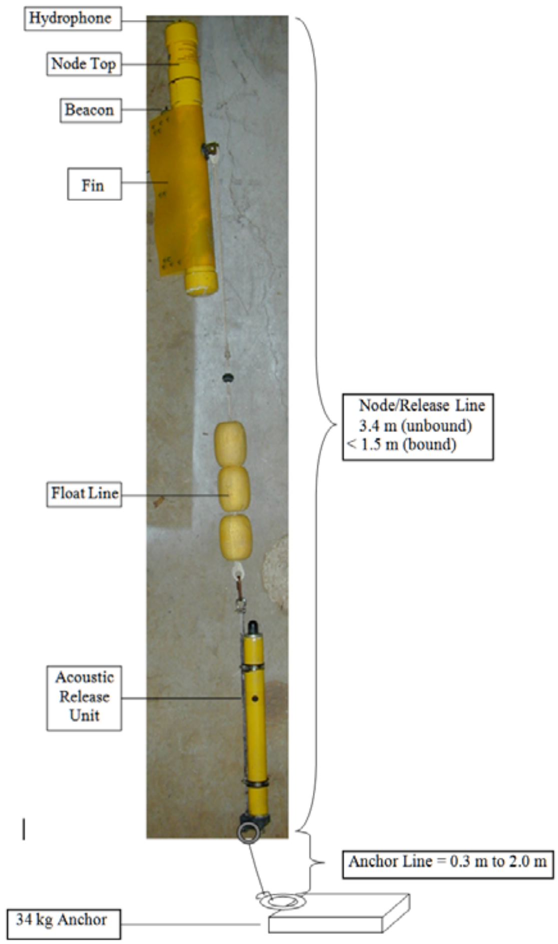


Figure 2.12. Autonomous node rigging

Figure 2.13. Autonomous node retrieval

2.5.3 Node Retrieval, Servicing, and Redeployment

Autonomous nodes were deployed between April 4 and May 1, 2008, retrieved weekly to download data, and redeployed until about July 25, 2008. The post-FCRPS study deployed the Oak Point array, which we used as a tertiary survival-detection array, on April 14, 2008 and removed it on September 3, 2008. The first step in servicing a node was to trigger its acoustic release by entering a release-specific code into a transceiver to transmit an acoustic signal to the release mechanism to free the acoustic release and node from the anchor. After the node, floats, and acoustic release surfaced, they were retrieved by boat (Figure 2.13). The next step was to dry the node with a towel, open it, eject the CF card, and download data from the card to a laptop computer. We checked the data file to verify that the node collected data throughout its deployment, records were continuous, and records included time stamps and tag detections. We replaced the CF card every time nodes were retrieved and replaced batteries at about 28-day intervals. When data were corrupt, the node top was replaced with a new one and the faulty top was sent to Sonic Concepts in Seattle for repair. The most common problem was damage to the hydrophone tip.

2.6 Project Discharge and Water Temperature

Project discharge data by spill bay and turbine unit and forebay and tailwater elevations were acquired in 5-minute increments by the automated data-acquisition systems at BON and provided to us by the Portland District. Average discharge and forebay water temperature data from 1999 through 2008 were downloaded from the DART (Data Access in Real Time) website (http://www.cbr.washington.edu/dart) and plotted. Water discharge for the entire project and spillway that were automatically recorded at 5-minute intervals were averaged by day and plotted along with 10-year averages. Average hourly tailrace elevation data were plotted by date so show seasonal trends.

2.7 Data Processing and Validation

As in previous studies (Ploskey et al. 2007b; 2008), tag-detection data from JSATS autonomous nodes were processed in two ways as a quality-control measure, and we found no significant difference in detection and survival estimates based upon detection histories. One method involved using TagViz software, and the other involved processing data with programs written in the Statistical Analysis System (SAS) code.

Tag, release, and detection data were merged together into separate datasets for autonomous and cabled systems, and system-specific filtering rules were applied to decoded data to identify detections and generate detection histories for every tag. To filter out false positive detections, which are detections of otherwise valid tag codes, we ran post-processing programs according to specific rules for autonomous and cabled systems.

The rules for autonomous nodes were as follows:

1. Tag codes were among those assigned to tags that were implanted in released fish.
2. Tag codes were detected after the release date and time.
3. Decodes of the same tag within 0.156 seconds of the previous decode were deleted (multipath filter).
4. A detection event was initiated when the time interval between any four identical decodes was ≤47.8 seconds (3-s tags) or 79 seconds (5-s tags). Once started, the event continued until the time lapse between any two successive decodes exceeded the same respective time intervals.
5. The time spacing between these detections had to match the pulse repetition interval (PRI) of the tag, or be a multiple of the PRI for the detections to be kept in the valid detection file.

The data collected by the JSATS cabled hydrophones were binary time-domain waveform files that had a high probability of containing Binary Phase Shift Keying (BPSK) to representing tag codes. BPSK is a digital modulation technique that transmits messages by altering the phase of the carrier wave. Waveform data were post-processed with software to produce comma-separated variable files with decodes and time-of-arrival data. Several filtering algorithms were then applied to the raw results from the decoding utilities to exclude spurious data and false positives.

The rules for cabled hydrophones at the spillway were as follows:

1. Tag codes were among those assigned to tags that were implanted in released fish.
2. Tag codes detected were downstream of the release site.
3. Tag codes were detected after the release date and time.
4. The signal-to-noise ratio of decoded signals was at least 3:1.
5. The time gap between two consecutive decodes by one hydrophone had to be longer than 0.5 seconds or the second decode of a pair was eliminated as multipath.
6. A minimum of four decodes in 36 seconds for 3-s tags and in 60 seconds for 5-s tags.

Tracking of fish movements in the forebay was based on differences in time-of-arrival data for each tag from four hydrophones, as required to solve three-dimensional (3D) source location (Watkins and Schevill 1972; Foy 1976; Spiesberger and Fristrup 1990; Wahlberg et al. 2001). If more than four hydrophones detected the same tag signal, the four with the best geometric configuration for 3D tracking were then selected (Wahlberg et al. 2001; Ehgrenberg and Steig 2002).

2.8 Tag-Life Study

As part of the 2008 Tag Effects Study, Dr. Richard Brown and colleagues implanted tags sub-sampled from all tags used in this study into juvenile Chinook salmon from Priest Rapids Hatchery and monitored transmissions from those tags until every tag quit transmitting. When a tagged fish died, the tag was re-implanted in another fish until the tag died. A JSATS mobile node was used to listen for tags daily and tag-life history data were compiled to produce tag-life curves, which indicate the percent of each tag type transmitting as a function of days since its activation. There were 44 ATS 3-s tags, 40 ATS 5-s tags, and 27 10-s tags. There also were 94 5-s tags recovered when fish were removed from the river at smolt monitoring facilities using a sort-by-code diversion.

2.9 Egress Rates

Egress rates to the primary survival-detection array were calculated as the time of detection on the primary array minus the time of last detection on the spillway or B2 forebay arrays for fish passing through all routes, including the B2 JBS. We estimated a standardized egress rate to the tailrace release site by dividing the distance (m) from the point of last detection in the forebay to the tailrace release site by the median rate of travel (m / s) from point of last detection to the primary array. These standardized estimates likely are more conservative (slower) than actual travel times through the tailrace because the median rate of travel to the primary array is slower than the rate of travel from the dam to the tailrace release site. Linear flow rates vary with river width and depth, and cross sections with the highest linear flow rates were in the tailrace.

2.10 Statistical Methods for Estimating Survival Rates

Using upstream releases of acoustic-tagged YC, STH, and FC smolts in conjunction with onsite smolt releases, passage dynamics, and survival rates through BON and its spillway were examined. Specific statistical objectives included the following:

1. Estimate dam-passage survival rates of YC and FC smolts using a paired-release-recapture model based on fish arriving at the forebay and a tailrace release at BON.
2. Estimate dam-passage survival rates of STH, YC, and FC smolts using a single release-recapture model based on fish of the same stocks arriving at the forebay of BON.
3. Estimate the relative survival rate for STH, YC, and FC smolts passing through deep flow deflector spill bays (4 through 15) versus shallow deflector spill bays (1 through 3, 16 through 18).

Analyses for YC and FC smolts (Objective 1) were similar for both fish stocks. The STH survival estimates in Objectives 2 and 3 were limited to single-release models because there was no tailrace release of STH in 2008.

2.10.1 Release-Recapture Designs and Analyses

All release-recapture analyses described below are based upon estimating the survival rates of virtual releases of treatment fish relative to the survival rates of reference releases or other virtual releases. Treatment fish were detected on upstream arrays and passed through the dam, spillway, or spill bays with deep or shallow flow deflectors, whereas reference fish were released in the tailrace and did not pass through the dam or spillway. Detections on the forebay entrance array were grouped by fish stock and blocks of two or more days to form virtual releases of fish for estimating dam survival rates. Virtual releases also were formed by species/run, blocks of two or more days, and end-or-middle bay of passage to form treatments for fish passing through end bays with deep flow deflectors and middle bays with shallow deflectors. The number of days pooled to form virtual releases depended on the rate of fish passage and the number of fish required for a reasonably precise estimate of survival rates. We tried to pool the same number of days (most virtual releases pooled over 2 days, except at the beginning or end of seasons when there were insufficient numbers of fish to make reasonably precise estimates of survival rates).

In the next section, we use dam passage survival rates to describe most of the details, including a description of model assumptions and tag-life corrections. These descriptions also apply to subsequent sections on the relative survival rate of fish passing through spill bays with deep and shallow flow deflectors and to spillway survival estimates but are not reiterated each time.

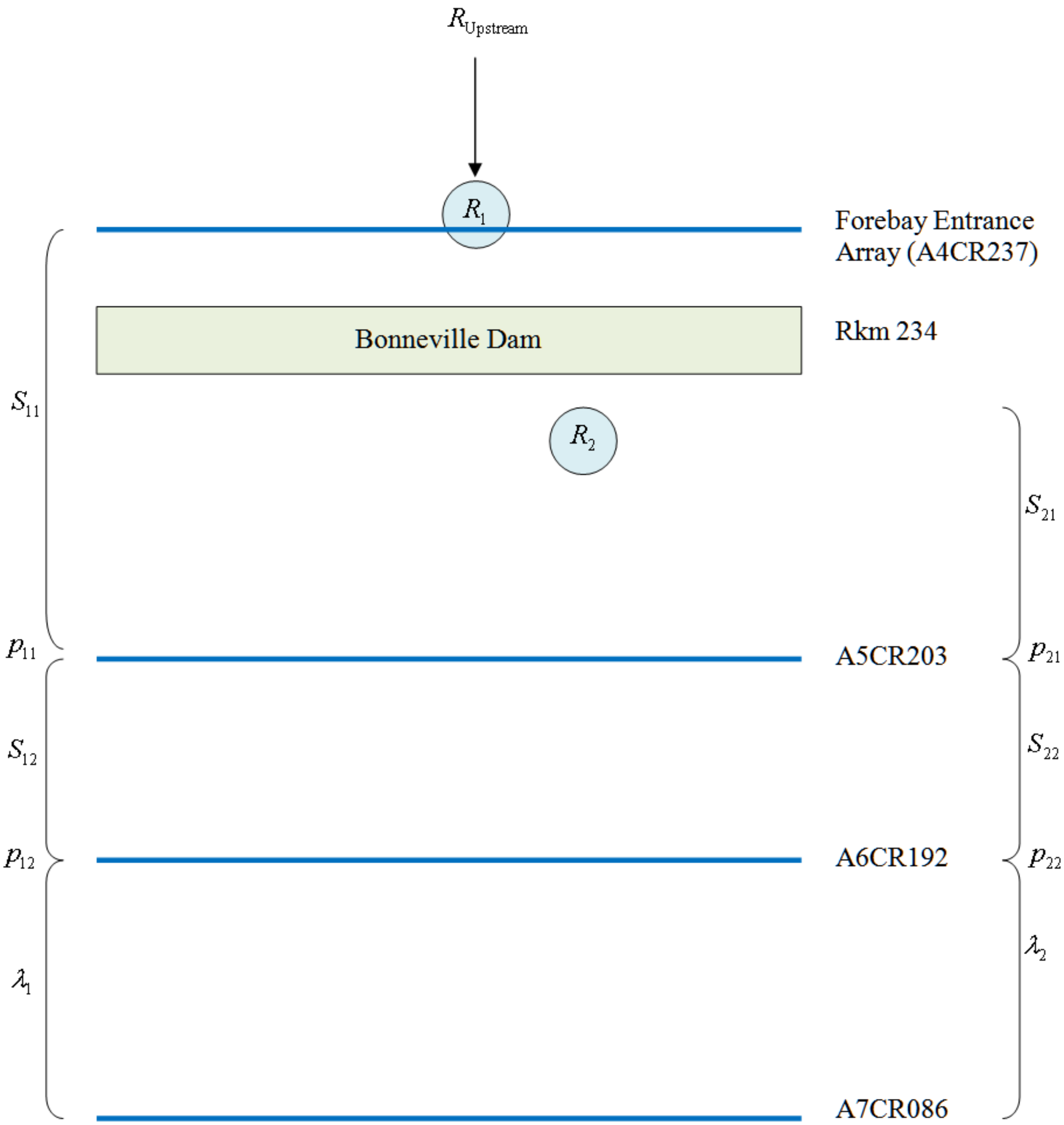
When a Chi-square goodness-of-fit test indicated that detection probabilities on three survival-detection arrays were homogeneous over time (χ^2 not significant), we reported pooled survival estimates for the season. When capture histories were heterogeneous (significant χ^2), we reported weighted averages of the trial-specific relative survival estimates:

$$\hat{S}_i = \frac{\sum_{j=1}^{n} w_j \hat{S}_{ij}}{\sum_{j=1}^{n} w_j}$$

The first choice for calculating weights was the sample size of individual release trials.

2.10.1.1 Estimation of the Dam-Passage Survival Rates of Juvenile Chinook Salmon

A paired-release-recapture design was used to estimate dam passage survival rates at BON. Using the forebay entrance array, fish known to have arrived at BON from upstream releases were regrouped to form virtual releases (R_1) and were paired with tailrace releases (R_2; Figure 2.14). Capture data also were pooled or averaged over the course of the season. Downstream detections at three survival downstream arrays below BON were used to make single- and paired-release survival estimates (Figure 2.14). The three downstream arrays produced $2^3 = 8$ possible capture histories.



$$\text{Dam passage survival rate } \hat{S}_{\text{Dam}} = \frac{\hat{S}_{11}}{\hat{S}_{21}} \qquad (2.1)$$

Figure 2.14. Schematic of the release-recapture design used to estimate BON dam-passage survival probabilities in 2008. The forebay entrance array was located about 2 km upstream of B2, and the downstream arrays of autonomous nodes were located 31, 42, and 148 km downstream of the dam.

The joint likelihood for the model is as follows:

$$
\begin{aligned}
L = &\binom{R_1}{\underset{\sim}{n}}\left(S_{11}p_{11}S_{12}p_{12}\right)^{n_{111}}\left(S_{11}\left(1-p_{11}\right)S_{12}p_{12}\lambda_1\right)^{n_{011}} \\
&\cdot\left(S_{11}p_{11}S_{12}\left(1-p_{12}\right)\lambda_1\right)^{n_{101}}\left(S_{11}\left(1-p_{11}\right)S_{12}\left(1-p_{12}\right)\lambda_1\right)^{n_{011}} \\
&\cdot\left(S_{11}p_{11}S_{12}p_{12}\left(1-\lambda_1\right)\right)^{n_{110}}\left(S_{11}\left(1-p_{11}\right)S_{12}p_{12}\left(1-\lambda_1\right)\right)^{n_{010}} \\
&\cdot\left(S_{11}p_{11}\left(\left(1-S_{12}\right)+S_{12}\left(1-p_{12}\right)\left(1-\lambda_1\right)\right)\right)^{n_{100}} \\
&\cdot\left(\left(1-S_{11}\right)+S_{11}\left(1-p_{11}\right)\left(\left(1-S_{12}\right)+S_{12}\left(1-p_{12}\right)\left(1-\lambda_1\right)\right)\right)^{n_{000}} \\
&\cdot\binom{R_2}{\underset{\sim}{m}}\left(S_{21}p_{21}S_{22}p_{22}\lambda_2\right)^{m_{111}}\left(S_{21}\left(1-p_{21}\right)S_{22}p_{22}\lambda_2\right)^{m_{011}} \\
&\cdot\left(S_{21}p_{21}S_{22}\left(1-p_{22}\right)\lambda_2\right)^{m_{101}}\left(S_{21}\left(1-p_{21}\right)S_{22}\left(1-p_{22}\right)\lambda_2\right)^{m_{011}} \\
&\cdot\left(S_{21}p_{21}S_{22}p_{22}\left(1-\lambda_2\right)\right)^{m_{110}}\left(S_{21}\left(1-p_{21}\right)S_{22}p_{22}\left(1-\lambda_2\right)\right)^{m_{010}} \\
&\cdot\left(S_{21}p_{21}\left(\left(1-S_{22}\right)+S_{22}\left(1-p_{22}\right)\left(1-\lambda_2\right)\right)\right)^{m_{100}} \\
&\cdot\left(\left(1-S_{21}\right)+S_{21}\left(1-p_{21}\right)\left(\left(1-S_{22}\right)+S_{22}\left(1-p_{22}\right)\left(1-\lambda_2\right)\right)\right)^{m_{000}},
\end{aligned}
\tag{2.2}
$$

where $\underset{\sim}{n}$ and $\underset{\sim}{m}$ are the vector of counts associated with the downstream capture histories of releases R_1 and R_2, respectively. For example, n_{101} is the number of R_1 fish detected at A5CR203, not detected at A6CR192, and subsequently detected at A7CR086 (Figure 2.14).

For historical release-recapture studies like this, modeling could be performed to simplify the likelihood for common survival or detection probabilities downriver between the two release groups. However, modeling was not conducted because of the need to apply a different tag-life correction to the tags detected at each array for each release; also, release sizes and detection probabilities were sufficient to meet precision requirements. Tag-life corrections were applied to the individual release Cormack (1964), Jolly (1965), and Seber (1965) survival estimates (CJS).

Model Assumptions. Each release group (i.e., R_1 and R_2) provides the data to estimate reach survival rates based on the single release-recapture model (Skalski et al. 1998). The assumptions of the single release-recapture model include the following:

1. Individuals marked for the study are a representative sample from the population of interest.
2. Survival and capture probabilities are not affected by tagging or sampling. That is, tagged animals have the same probabilities as untagged animals.
3. All sampling events are “instantaneous.” That is, sampling occurs over a negligible distance relative to the length of the intervals between sampling events.
4. The fate of each tagged individual is independent of the fate of all others.
5. All tagged individuals alive at a sampling location have the same probability of surviving until the end of that event.

6. All tagged individuals alive at a sampling location have the same probability of being detected at that event.
7. All tags are correctly identified and the status of the smolt (i.e., alive or dead), correctly assessed.

The first assumption above deals with making inferences from the sample to the target population. For example, if inferences are sought to Chinook salmon smolts, then the sample of tagged fish should be drawn from that class of fish. Otherwise, non-statistical inferences would be necessary to show that the acoustically tagged fish were representative of the target population. These assumptions could also be violated if smolts selected for acoustic tagging are, on the average, larger than the population of smolts in general.

Assumption 2 again relates to making inferences to the population of interest (i.e., untagged fish). If tagging has a detrimental effect on survival rates, then survival estimates from the single release-recapture design will tend to be negatively biased (i.e., underestimated).

The third assumption specifies that mortality is negligible immediately in the vicinity of the sampling stations, so that the estimated mortality is related to the river reaches in question and not during the sampling event. In the case of outmigrating smolts, the time they spend in the vicinity of a hydrophone array is brief and small, relative to the size of the river reaches in question. This assumption is for the sake of mathematical convenience and should be fulfilled by the nature of the outmigration dynamics and deployment of the hydrophone array.

The assumption of independence (4) implies that the survival or death of one smolt has no effect on the fates of others. In the larger river system with tens of thousands of smolts, this is likely true. Furthermore, this assumption is common to all tag analyses with little or no evidence collected to suggest that it is not generally true. Nevertheless, violations of assumption 4 have little effect on the point estimate but might bias the variance estimate with precision being less than calculated.

Assumption 5 specifies that a smolt's prior detection history has no effect on subsequent survival rates. This could be violated if some smolts were self-trained to repeatedly go through turbine or spill routes or, alternatively, avoid routes because of prior experience. This occurrence is unlikely and can be accessed from the detection histories of the individual smolts. The lack of handling following initial release of acoustic-tagged smolts further minimizes the risk that subsequent detections influence survival rates. Similarly, assumption 6 could be violated if downstream detections are influenced by upstream passage routes taken by the smolts. Violation of this assumption is minimized by placing hydrophone arrays across the breadth of the river or below the mixing zones for smolts following different passages at the dam.

Assumption 7 implies that the smolts do not lose their tags and are not subsequently misidentified as dead or not captured, nor are dead fish falsely recorded as alive at detection locations. The use of surgically implanted tags should minimize the change of tag loss. Tag loss and tag failure would tend to result in a negative bias (i.e., underestimation) of smolt survival rates. The possibility of tag failure depends on travel time relative to battery life. Dead fish drifting downstream could also result in a false-positive detections and upwardly bias survival estimates. For this reason, tailrace hydrophone arrays are not proposed for this set of analyses.

To estimate survival components from the paired releases, two additional assumptions for valid survival estimates are necessary:

A8. The survival rate in the lower river segment of the first reach is conditionally independent of the survival rate in the upper river segment.

A9. Releases R_1 and R_2 experience the same survival probabilities in the lower river segment of the first reach they share in common.

Assumption 8 implies that there is no synergistic relationship between survival processes in the two river segments within the first reach. In other words, smolts that survive the first river segment are no more or less susceptible to mortality in the second river segment than smolts released in the second river segment. Assumption 9 is satisfied by the in river mixing of the release groups but can also be satisfied if the survival processes are stable over the course of smolt passage by the releases. A stable survival process might well be expected for one to a few days under similar flow and spill conditions. Furthermore, unlike the paired-release methods of the earlier Mid-Columbia survival studies, the assumption of equal capture probabilities is unnecessary for estimation.

In this study, juvenile Chinook salmon smolts known to have arrived at BON were paired with a fresh release of fish in the tailrace. If the downstream controls experienced post-release handling mortality that had already been expressed in fish released upstream, dam-passage or spillway-passage survival estimates would be positively biased. This was the impetus for making specific releases of juvenile Chinook salmon smolts into the B2CC to provide a means of scaling paired-release estimates of dam-passage survival rates using a triple-release model, as presented by Faber et al. (2009).

Tests of Assumptions within a Release. For the single release-recapture model to be valid, certain data patterns should be evident from the capture histories. Both releases R_1 and R_2 permit tests of goodness-of-fit to the release-recapture model. A series of tests of assumptions was performed to determine the validity of the model (i.e., goodness-of -fit). The data from release R_1 can be summarized by an m-array matrix of the form below:

	Recovery Site		
Release Site	A5CR203(2)	A6CR192 (3)	A7CR086 (4)
Forebay (1)	m_{12}	m_{13}	m_{14}
A5CR203 (2)		m_{23}	m_{24}
A6CR192 (3)			m_{34}

The value of m_{ij} are the number of smolts detected at site i that are next detected at site j.

Burnham et al. (1987; 65:71-74) present a series of tests of assumptions called Test 2 that examine whether upstream detections affect downstream survival and/or detection. For release R_1, a contingency table test was performed, as follows:

Test 2.2

m_{13}	m_{14}	
m_{23}	m_{24}	χ_1^2

(2.3)

Burnham et al. (1987; 65:71-74) also present a series of tests of assumptions called Test 3 that examine whether upstream capture histories affect downstream survival and/or capture.

For release R_1, a contingency table can be constructed of the following form:

Capture History at A7CR086		Capture History to A6CR192: 101	111	
	1			
	0			χ_1^2

(2.4)

This contingency table tested whether detection at A5CR203 has a subsequent effect on the capture history at A7CR086.

Tests of Mixing. For the estimates of project survival rates to be valid, the detection data need to conform to the assumptions of the statistical model. One assumption is the downstream mixing of release groups. Chi-squared R × C contingency tables were used to test the assumption of homogeneous arrival distributions for releases R_1 and R_2 at A5CR203, A6CR192, and A7CR086. The chi-squared contingency table tests of homogeneity were of the following form:

Arrival Date		Release: R_1	R_2
	1		
	2		
	⋮	⋮	⋮
	D		

(2.5)

The chi-square test of homogeneous arrival timing was calculated for the paired releases (e.g., R_1 and R_2) at each detection location. Each test was performed at $\alpha = 0.10$. Because of multiple tests across release pairs, Type I error rates were adjusted for an overall experimental-wise error rate of 0.10.

Tag-Life Correction. Acoustic tags were used to characterize tag life from systematically sampling tags used in the survival studies. The tags were initiated and continually monitored in ambient river water until they failed. The failure times or tag lives were recorded for tags with 3-s and 5-s ping rates. We plotted the fraction of transmitting tags remaining against days since tag activation (also known as a Kaplan-Meier estimator). We used this non-parametric estimation of tag life to derive tag-life corrections, rather than fitting curvilinear regression models to observed data. Some early tag failures in the tag-life study made it difficult to accurately fit observed data.

In the case of potential tag failure, additional parameters need to be added to the above model (Equation 2.2) based on methods of Townsend et al. (2006). Table 2.5 presents the expected probabilities of occurrence for each of the possible capture histories under tag failure where

L_{11} = probability a tag from release R_1 survives the first reach

L_{12} = probability a tag from release R_1 survives both reach 1 and reach 2

L_{13} = probability a tag from release R_1 survives reaches 1 through 3

L_{21} = probability a tag from release R_2 survives the first reach

L_{22} = probability a tag from release R_2 survives both reach 1 and reach 2

L_{23} = probability a tag from release R_1 survives reaches 1 through 3.

The joint likelihood can be expressed as

$$L = L\left(S_{11}, p_{11}, S_{12}, p_{12}, \lambda_1 \middle| R_1, \underset{\sim}{n}, \underset{\sim}{L}_1\right) \cdot L\left(S_{21}, p_{21}, S_{22}, p_{22}, \lambda_2 \middle| R_2, \underset{\sim}{m}, \underset{\sim}{L}_2\right) \quad (2.9)$$

The estimates of survival rates from the likelihood model (Equation 2.8) should be more reliable because it takes into account possible tag failure and tag-life probabilities less than one.

The estimates of the survival and capture parameters in the likelihood model (Equation 2.9) were calculated, treating the estimates of tag life (i.e., $\hat{L}_{11}$, $\hat{L}_{12}$, $\hat{L}_{21}$, and $\hat{L}_{22}$) as known constants. However, to calculate a realistic variance estimator for the survival parameters, the error in the estimation of the tag-life probabilities must be incorporated into an overall variance calculation. The variance of the survival estimates was calculated using the total variance formula:

$$\text{Var}\left(\hat{S}_{PR}\right) = \text{Var}_{\underset{\sim}{\hat{L}}}\left[E\left(\hat{S}_{PR} \middle| \underset{\sim}{\hat{L}}\right)\right] + E_{\underset{\sim}{\hat{L}}}\left[\text{Var}\left(\hat{S}_{PR} \middle| \underset{\sim}{\hat{L}}\right)\right] \quad (2.10)$$

The above variance can therefore be estimated in stages using the following expression:

$$\text{Var}\left(\hat{S}_{PR}\right) = s^2_{\hat{S}_{PR}|\underset{\sim}{\hat{L}}} + \text{Var}\left(\hat{S}_{PR} \middle| \underset{\sim}{\hat{L}}\right) \quad (2.11)$$

Table 2.5. Detection histories and expected probabilities of occurrences for releases R_1 and R_2 in the presence of tag failure

Release	Detection History	Expected Probabilities
R_1	111	$S_{11}p_{11}S_{12}p_{12}\lambda_1 L_{13}$
	011	$S_{11}(1-p_{11})S_{12}p_{12}\lambda_1 L_{13}$
	101	$S_{11}p_{11}S_{12}(1-p_{12})\lambda_1 L_{13}$
	001	$S_{11}(1-p_{11})S_{12}(1-p_{12})\lambda_1 L_{13}$
	110	$S_{11}p_{11}S_{12}p_{12}(L_{12}-L_{13}\lambda_1)$
	010	$S_{11}(1-p_{11})S_{12}p_{12}(L_{12}-L_{13}\lambda_1)$
	100	$S_{11}p_{11}\left[(L_{11}-L_{12}S_{12})+S_{12}(1-p_{12})(L_{12}-L_{13}\lambda_1)\right]$
	000	$(1-L_{11}S_{11})+S_{11}(1-p_{11})\left\lfloor(L_{11}-L_{12}S_{12})+S_{12}(1-p_{12})(L_{12}-L_{13}\lambda_1)\right\rfloor$
R_2	111	$S_{21}p_{21}S_{22}p_{22}\lambda_2 L_{23}$
	011	$S_{21}(1-p_{21})S_{22}p_{22}\lambda_2 L_{23}$
	101	$S_{21}p_{21}S_{22}(1-p_{22})\lambda_2 L_{23}$
	001	$S_{21}(1-p_{21})S_{22}(1-p_{22})\lambda_2 L_{23}$
	110	$S_{21}p_{21}S_{22}p_{22}(L_{22}-L_{23}\lambda_2)$
	010	$S_{21}(1-p_{21})S_{22}p_{22}(L_{22}-L_{23}\lambda_2)$
	100	$S_{21}p_{21}\left[(L_{21}-L_{22}S_{22})+S_{22}(1-p_{22})(L_{22}-L_{23}\lambda_2)\right]$
	000	$(1-L_{21}S_{21})+S_{21}(1-p_{21})\left[(L_{21}-L_{22}S_{22})+S_{22}(1-p_{22})(L_{22}-L_{23}\lambda_2)\right]$

The second term in Equation (2.11) was derived from the maximum likelihood model (Equation [2.9]) conditioning on the tag-life probabilities (i.e., $\underset{\sim}{\hat{L}}$). The first variance component in Equation (2.11) was calculated using bootstrap resampling techniques (Efron and Tibshirani 1993). Alternative estimates of $\underset{\sim}{\hat{L}}$ were computed by bootstrapping both the observed tag-life data and travel-time data. For each estimated vector of tag-life parameters, a survival rate was estimated using likelihood model (Equation [2.11]). One thousand bootstrap estimates of the tag-life parameters were calculated along with the corresponding conditional maximum likelihood estimates of survival rates.

The first variance component in Equation (2.11) was then estimated by the quantity, as follows:

$$s^2_{\hat{S}_{PR}|\hat{\underset{\sim}{L}}} = \frac{\sum_{b=1}^{1000}\left(\hat{S}_b - \hat{\bar{S}}\right)^2}{(1000-1)}$$

where $\hat{S}_b$ = the bth bootstrap estimate of survival rates $(b = 1,\ldots,1000)$,

$$\hat{\bar{S}} = \frac{\sum_{b=1}^{1000}\hat{S}_b}{1000}.$$

2.10.1.2 Estimation of the Dam-Passage Survival Rates of Steelhead

No tailrace release of steelhead was performed in 2008. Dam passage survival rates from the forebay array to the first downstream detection site at A5CR203 was estimated using the single release-recapture model (Figure 2.14). The three downstream detection sites produced $2^3 = 8$ capture histories that were analyzed using the following likelihood model:

$$\begin{aligned}
&\binom{R_1}{\underset{\sim}{n}}\left(S_{11}p_{11}S_{12}p_{12}\lambda_1\right)^{n_{111}}\left(S_{11}(1-p_{11})S_{12}p_{12}\lambda_1\right)^{n_{011}} \\
&\cdot\left(S_{11}p_{11}S_{12}(1-p_{12})\lambda_1\right)^{n_{101}}\left(S_{11}(1-p_{11})S_{12}(1-p_{12})\lambda_1\right)^{n_{001}} \\
&\cdot\left(S_{11}p_{11}S_{12}p_{12}(1-\lambda_1)\right)^{n_{110}}\left(S_{11}(1-p_{11})S_{12}p_{12}(1-\lambda_1)\right)^{n_{010}} \\
&\cdot\left(S_{11}p_{11}\left[(1-S_{12})+S_{12}(1-p_{12})(1-\lambda_1)\right]\right)^{n_{100}} \\
&\cdot\left((1-S_{11})+S_{11}(1-p_{11})\left[(1-S_{12})+S_{12}(1-p_{12})\lambda_1\right]\right)^{n_{000}},
\end{aligned} \tag{2.12}$$

where n_{ijk} is the number of smolts with capture history ijk (0 = not detected, 1 = detected). This estimation procedure also was used to analyze YC and FC data for comparison with STH results. Tests of assumptions were the same as those described in Section 2.8.2.1.

2.10.1.3 Relative Survival Estimates for Smolts Passing Through the Shallow and Deep Deflector Bays

Within each trial, smolts known to have passed through shallow versus deep flow deflector spill bays were compared using the paired-release models of Burnham et al. (1987). For each trial, the relative survival rate (RS) of smolt passage through deep to shallow flow deflectors was estimated as follows:

$$\text{RS}_{\text{Deep/Shallow}} = \frac{\hat{S}_{\text{Deep}}}{\hat{S}_{\text{Shallow}}}$$

The estimates of RS were calculated for the first downstream reach between BON and the primary array and for the second reach between the primary and secondary arrays (Figure 2.15). With three detector locations, there were eight (2^3) possible capture histories used in modeling the release-recapture data from each release group. The release-recapture model had the following parameters:

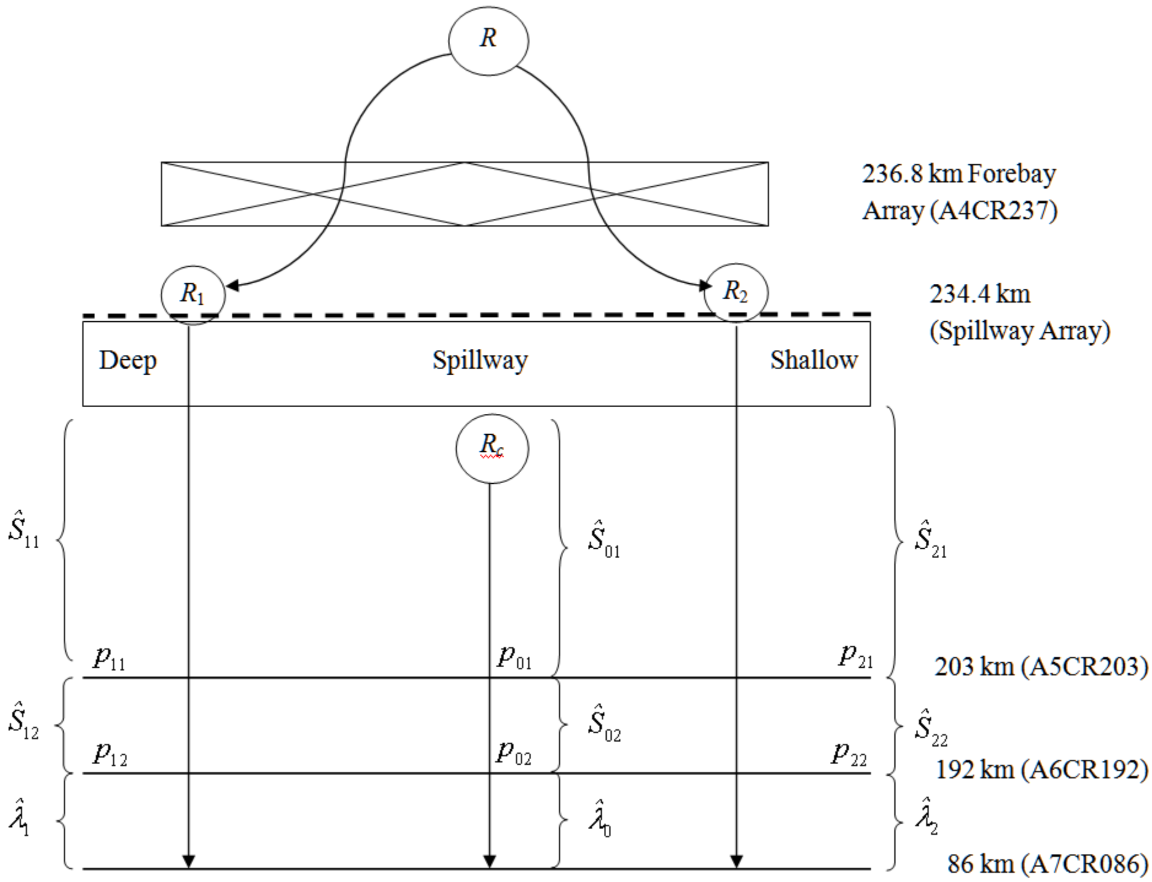


Figure 2.15. Schematic of spillway survival studies at BON in 2008, showing virtual treatment releases formed from smolt passage detections at the spillway array, deep flow deflector bays (1-3 and 16-18), and shallow flow deflector bays (4-15) and corresponding reference releases at the downstream end of the tailrace. Three autonomous arrays located 31, 42, and 148 km downstream provided capture histories to populate CJS survival models.

S_{1j} = survival rate in the first reach for the *j*th treatment group $(j = 1,2)$

p_{1j} = probability of being detected at the first downstream detection array, given that fish survived to that location for the *j*th treatment group $(j = 1,2)$

S_{2j} = conditional probability of survival to the second reach, given that fish survived the first reach for the *j*th treatment group $(j = 1,2)$

p_{2j} = probability of being detected at the second downstream detection array, given that fish survived to that location for the *j*th treatment group $(j = 1,2)$

λ_j = joint probability of a fish surviving to and being detected at the third downstream detection array, given that fish survived to the second detection array for the *j*th treatment group $(j = 1,2)$.

A joint likelihood model was used to estimate these parameters and estimate the relative survival rate of fish through the deep flow $(\hat{S}_{i1})$ versus shallow flow deflector $(\hat{S}_{i2})$ spill bays, i.e.,

$$\widehat{\text{RS}}_1 = \frac{\hat{S}_{11}}{\hat{S}_{12}} \tag{2.13}$$

for reach 1 and

$$\widehat{\text{RS}}_2 = \frac{\hat{S}_{21}}{\hat{S}_{22}}$$

for reach 2.

The variance of the RS can be estimated by the following expression:

$$\begin{aligned}\widehat{\text{Var}}\left(\widehat{\text{RS}}_i\right) &= \left(\frac{\hat{S}_{i1}}{\hat{S}_{i2}}\right)^2 \left[\frac{\widehat{\text{Var}}\left(\hat{S}_{i1}\right)}{\hat{S}_{i1}^2} + \frac{\widehat{\text{Var}}\left(\hat{S}_{i2}\right)}{\hat{S}_{i2}^2}\right] \\ &= \widehat{\text{RS}}_i^2 \left[\widehat{\text{CV}}\left(\hat{S}_{i1}\right)^2 + \widehat{\text{CV}}\left(\hat{S}_{i2}\right)^2\right]\end{aligned} \tag{2.14}$$

and where

$$\widehat{\text{CV}}\left(\hat{\theta}\right) = \frac{\sqrt{\widehat{\text{Var}}\left(\hat{\theta}\right)}}{\hat{\theta}}$$

Initially, we tested whether there were significant differences in the survival rates of fish passing through end bays with deep flow deflectors relative to the survival rates of fish passing through middle bays with shallow flow deflectors by season and fish run using Z-tests on proportions. We also ran similar tests for the first and second halves of each season because tailrace elevations were only low enough to affect survival rates in early spring and late summer. This was a logical next step in the analysis because tailrace elevations were above average most of spring and summer, and significant differences are not expected under these conditions.

We also used analysis of deviance (ANODEV) procedures (McCullagh and Nelder 1989) to test the null hypothesis that survival rates through the deep flow deflector spill bays (S_{DF}) were less than or equal to survival rates through the shallow flow deflector (S_{DF}) spill bays:

$$\mathrm{H_o{:}S_{DF} \le S_{SF}}$$

versus the alternative hypothesis

$$\mathrm{H_a{:}S_{DF} > S_{SF}} \tag{2.15}$$

at $\alpha = 0.05$, one-tailed. The ANODEV was used because it accounted for the variation in response between replicate releases conducted over the season. The ANODEV was used to assess whether spill-bay effects persisted through not only the first downriver reach but also through the second reach. Separate analyses were performed for STH, YC, and FC trials. Note that testing for spill deflector bay differences in survival rates did not require reference-release groups. Reference releases are only required for estimating absolute passage survival rates.

2.10.1.4 Estimation of Absolute Spillway-Passage Survival Rates

The tailrace releases below BON were used in conjunction with virtual releases formed from detections by the spillway array to estimate absolute spillway passage survival rates (Figure 2.15). The ratio of reach survival rates for known spill-bay-passed fish to survival rates of tailrace-released fish was used to estimate survival rates through the spillway. This is essentially the same paired-release-recapture model described in Sections 2.8.3.1 and 2.8.3.2. Estimates were made on a per-trial basis and a weighted average (Equation 2.14) was calculated across trials with an associated variance estimator. The three downstream arrays produced eight (2^3) possible capture histories. The joint likelihood for the model was formulated as follows:

$$\begin{aligned}
L = &\binom{R_1}{\underset{\sim}{n}}\left(S_{11}p_{11}S_{12}p_{12}\right)^{n_{111}}\left(S_{11}(1-p_{11})S_{12}p_{12}\lambda_1\right)^{n_{011}} \\
&\cdot\left(S_{11}p_{11}S_{12}(1-p_{12})\lambda_1\right)^{n_{101}}\left(S_{11}(1-p_{11})S_{12}(1-p_{12})\lambda_1\right)^{n_{011}} \\
&\cdot\left(S_{11}p_{11}S_{12}p_{12}(1-\lambda_1)\right)^{n_{110}}\left(S_{11}(1-p_{11})S_{12}p_{12}(1-\lambda_1)\right)^{n_{010}} \\
&\cdot\left(S_{11}p_{11}\left((1-S_{12})+S_{12}(1-p_{12})(1-\lambda_1)\right)\right)^{n_{100}} \\
&\cdot\left((1-S_{11})+S_{11}(1-p_{11})\left((1-S_{12})+S_{12}(1-p_{12})(1-\lambda_1)\right)\right)^{n_{000}} \\
&\cdot\binom{R_2}{\underset{\sim}{m}}\left(S_{21}p_{21}S_{22}p_{22}\lambda_2\right)^{m_{111}}\left(S_{21}(1-p_{21})S_{22}p_{22}\lambda_2\right)^{m_{011}} \\
&\cdot\left(S_{21}p_{21}S_{22}(1-p_{22})\lambda_2\right)^{m_{101}}\left(S_{21}(1-p_{21})S_{22}(1-p_{22})\lambda_2\right)^{m_{011}} \\
&\cdot\left(S_{21}p_{21}S_{22}p_{22}(1-\lambda_2)\right)^{m_{110}}\left(S_{21}(1-p_{21})S_{22}p_{22}(1-\lambda_2)\right)^{m_{010}} \\
&\cdot\left(S_{21}p_{21}\left((1-S_{22})+S_{22}(1-p_{22})(1-\lambda_2)\right)\right)^{m_{100}} \\
&\cdot\left((1-S_{21})+S_{21}(1-p_{21})\left((1-S_{22})+S_{22}(1-p_{22})(1-\lambda_2)\right)\right)^{m_{000}},
\end{aligned} \tag{2.16}$$

where $\underset{\sim}{n}$ and $\underset{\sim}{m}$ are the vector of counts associated with the downstream capture histories of releases R_1 and R_2, respectively. For example, n_{101} would be the number of R_1 fish detected at A5CR203, not detected at A6CR192, and subsequently detected at A7CR086 (Equation 2.16).

The spillway survival rate was estimated as the following ratio:

$$\hat{S}_{\text{Spill}} = \frac{\hat{S}_{11}}{\hat{S}_{21}} \tag{2.17}$$

with associated variance estimator

$$\widehat{\text{Var}}\left(\hat{S}_{\text{Spill}}\right) = \hat{S}^2_{\text{Spill}} \left[\frac{\widehat{\text{Var}}\left(\hat{S}_{11}\right)}{\hat{S}^2_{11}} + \frac{\widehat{\text{Var}}\left(\hat{S}_{21}\right)}{\hat{S}^2_{21}} \right] \tag{2.18}$$

2.10.1.5 Model Fitting

Unless otherwise noted, straight lines and curves on graphs are linear and quadratic fits using ordinary least-squares regression. We only considered the use of higher-order polynomials when r^2 increased by ≥ 0.05.

3.0 Results

The 2008 outmigration conditions described below precede the discussion of study results, which include the detection of dead fish by survival-detection arrays, detection performance of the spillway cabled array, downstream arrays, egress rates, and detection and survival of juvenile STH, YC, and FC salmon. The results of tests on some survival-model assumptions are also described in this section.

3.1 2008 Outmigration Conditions

The description of environmental conditions during the 2008 study includes seasonal changes in river and spill discharge, water temperature, and tailrace elevation. Seasonal trends in discharge and temperature were plotted alongside averages for the previous 10 years. We also looked at the species composition of all juvenile salmonids in the JDA SMF samples, and plotted length frequencies of tagged and un-tagged smolts of each stock of fish.

3.1.1 Project Discharge, Temperature, and Tailrace Elevation

Project discharge in 2008 was much higher than the 10-year average during the second half of spring releases and the first half of summer releases, and the same was true of spillway discharge (Figure 3.1). Relative to discharge, daily average dissolved gas concentrations were relatively constant, ranging from 116.1 to 124.3 (median = 121.3). Forebay water temperatures in 2008 usually were below the previous 10-year average and the maximum observed water temperature during releases was 19.7°C (Figure 3.2). Tailrace elevations usually were at least 2 m higher than the elevation of shallow flow deflectors in bays 4 through 15 most of spring and summer (after May 7 and before July 10; Figure 3.3). This means that the depth of water over shallow flow deflectors was close to flow-deflector elevations only for about 5 days in early spring and 10 days in late summer.

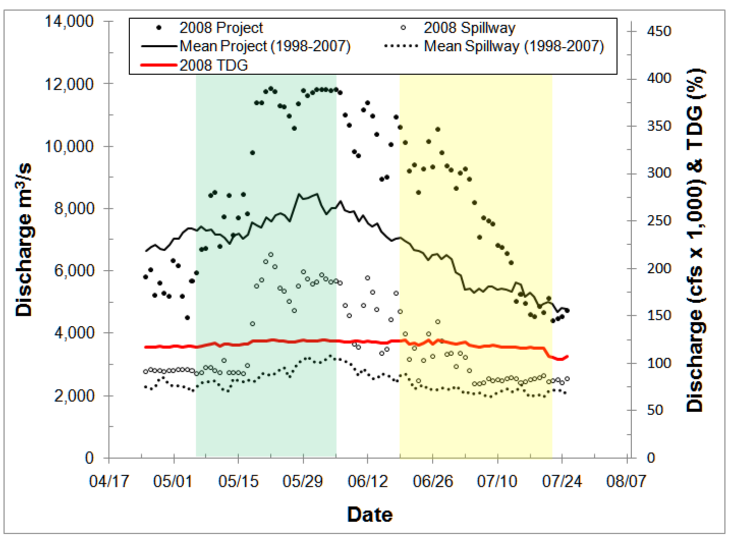


Figure 3.1. Ten-year average daily project discharge (solid black line) and spill discharge (dotted line) relative to 2008 daily project and spill discharge for the Bonneville project during the study period. Total dissolved gas percentages in 2008 are in red.

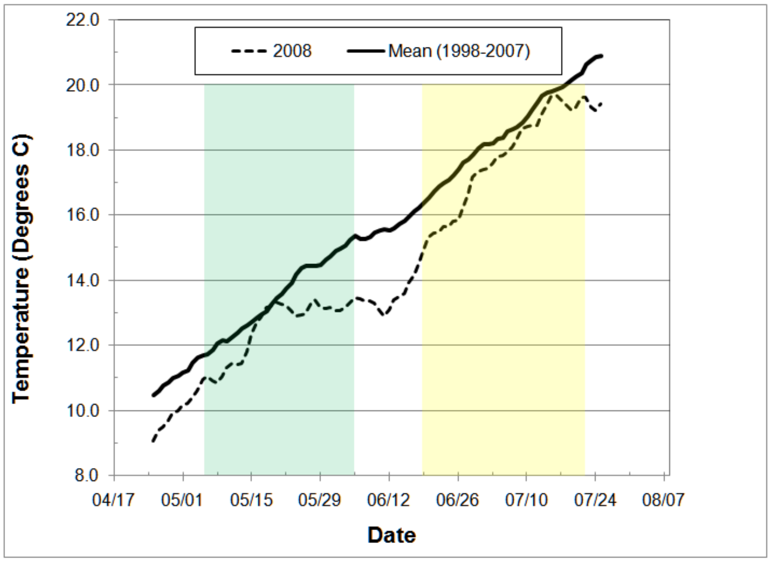


Figure 3.2. Ten-year mean and 2008 daily water temperatures in the BON forebay

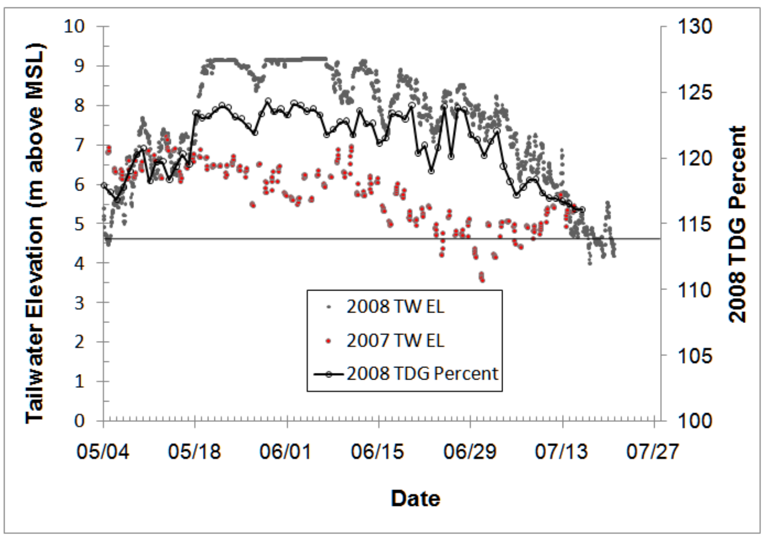


Figure 3.3. Mean tailrace elevations in meters above MSL in 2007 (red dots) and 2008 (gray dots) and TDG concentrations as a percent of saturation. The horizontal reference line at 4.3 m above MSL marks the elevation of shallow flow deflectors at spill bays 4 through 15.

3.1.2 Run Timing and Smolt Species Composition

Treatment fish tagged upstream arrived at BON during the peak of the runs for YC, STH, and FC according to smolt monitoring data collected by the PSMFC (Figure 3.4). Arrivals of tagged YC from upstream began when 28% of run-of-river YC had passed BON and ended by the time 98% had passed, so arrivals covered about 70% of the YC run. May 2, 2008 was the first day that tagged yearling Chinook began to arrive from upstream release locations and by then 28% of the run had passed. An average of 27% would have passed in an average year from 1998 to 2007, so the late arrival of the first tagged fish was anticipated. Dam arrays were fully functional and ready to detect tagged fish a few days later than we had planned, and there was no reason to release tagged fish until all arrays were functional. Given travel times ranging from about 1.5 to 2.5 days, tagging of YC at JDA would have to start by April 19 for most arrivals to reach BON by April 21, when 8% of the run had passed (Figure 3.5). Arrivals of tagged STH and FC from upstream locations occurred during 93% and over 95% of the respective runs.

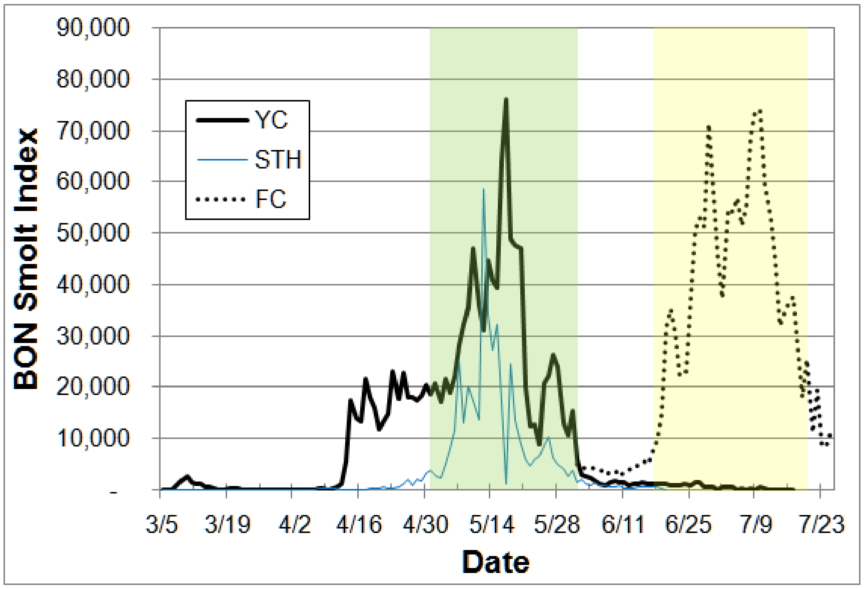


Figure 3.4. Smolt monitoring program passage index (lines) for March 5 through July 25, 2008, based on data from the BON JMF. Shading indicates dates that acoustically tagged fish released upstream of BON arrived at the dam. Smolt index data were obtained from http://www.fpc.org/smolt/historicsmpsubmitdata.html.

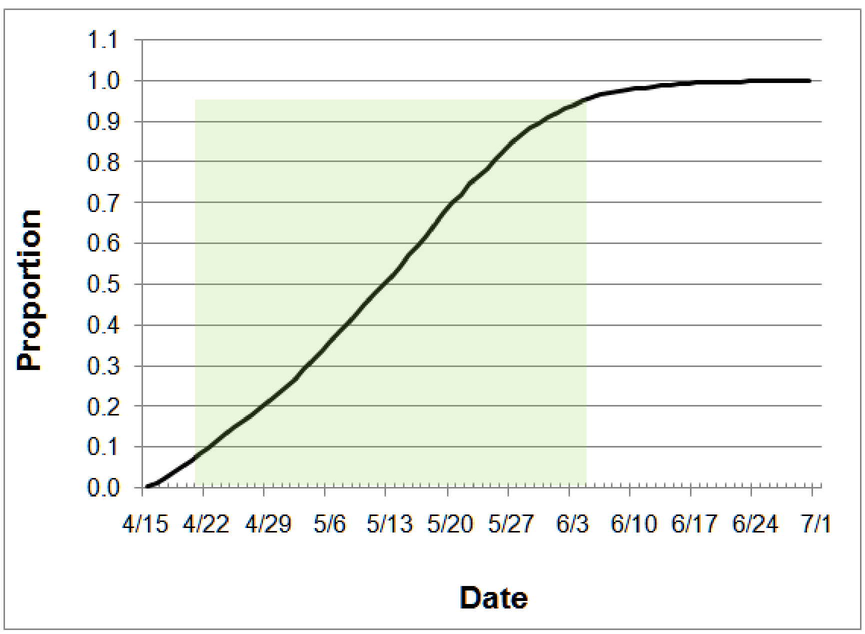


Figure 3.5. Average proportion of yearling Chinook salmon smolts arriving at BON by date from 1998 through 2007. Data source http://www.fpc.org/smolt/historicsmpsubmitdata.html.

3.1.3 Fish Rejection Rates and Lengths of Tagged and Untagged Smolts

The percent of smolts rejected for tagging at JDA SMF was low: 0.8% for YC salmon (299 out of 3763), 0.7% for STH (361 out of 3815), and 0.7 % for FC salmon (212 out of 6170). Rejection percentages were slightly higher at the BON JMF (3.6% for YC and 1.9% for FC).

Length frequency distributions of tagged fish were slightly skewed (6 to 11 mm) toward longer fish more than the respective distributions of untagged fish passing through the JDA SMF (Figure 3.6). The median length of tagged STH (217 mm) was 11 mm longer than that of untagged STH (206 mm). The median length of 3447 tagged YC was 8 mm longer than that of untagged YC, and the difference was greater for unclipped YC (21 mm) than it was for clipped YC (7 mm). The median length of 5931 tagged FC (115 mm) was 6 mm longer than that of untagged FC (109 mm) in routine SMF samples. The lower end of the distribution of length frequencies of 5931 tagged FC smolts was truncated at 95 mm relative to the length frequency distribution of run-of-river subyearlings handled at the JDA SMF in summer because of a minimum length limit of 95 mm for using JSATS tags (Figure 3.6). Only about 9% of subyearlings in routine samples could not be tagged because they were too small.

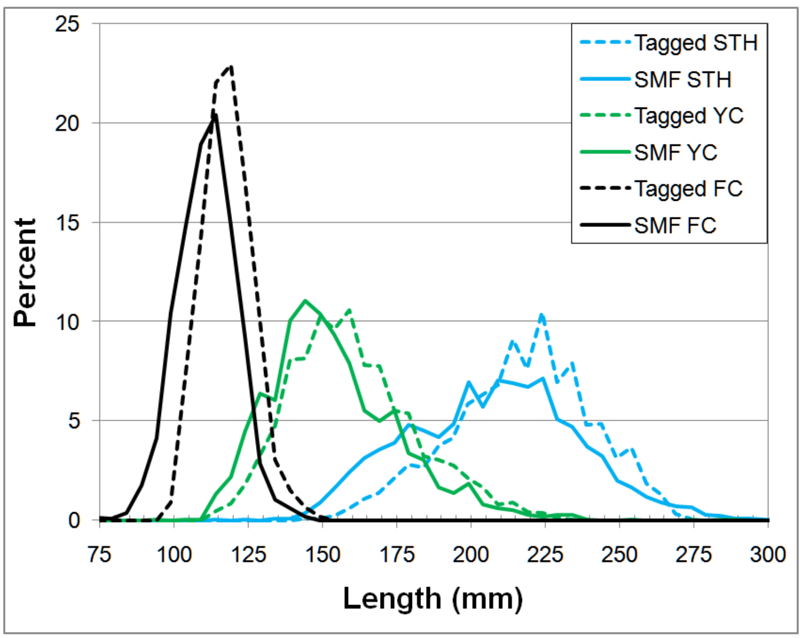


Figure 3.6. Length frequencies of tagged and untagged STH, YC, and FC at the JDA SMF

Additional information about fish in virtual releases at the forebay entrance array, spillway array, and reference releases in the tailrace are presented in Appendix A. Tables A.1 and A.2 describe comma-separated variable (CSV) files for spring and summer that are on a CD that accompanies printed versions of this report. The CSV files contain detailed data associated with every fish that was regrouped to form virtual releases at the BON forebay entrance array and spillway or that was released in the BON tailrace, including season, release date, release time, PIT-tag code, acoustic-tag code, acoustic-tag activation date, fork length, weight, mortality status, and release location, as well as BON dam operations at the time of each virtual release.

3.2 Tag-Life Study

Forty-four 3-s tags that were activated and implanted in fish had a mean tag life of 30 days, and the range was from 9 to 48 days. The 40 tags with a 5-s PRI rate that were recovered at LGR or from Cascade Aquatics, after activation, had a tag life that ranged from 8 to 56 days with a mean tag life of 42 days. Another 94 tags recovered through sort by code with a 5-s PRI rate had a tag life that ranged from 20 to 56 days with a mean of 46 days.

3.3 Detection Performance of Entrance and Survival-Detection Arrays

In general, detection probabilities declined for successive river reaches downstream of BON relative to the upstream reach from the TDA forebay to the BON forebay entrance array (Figure 3.7). We examined the distribution of detections among autonomous nodes deployed in each array and found that mid-river nodes or those near the navigation channel usually detected more acoustic tags in each of the sampled fish stocks (Figure 3.8). The BON forebay array was located at a narrow cross section about 2 km upstream of B2. More juvenile Chinook salmon and steelhead smolts were detected on the north side of the channel than on the south side at the forebay array. Part of this may have been due to the difficulty we had in keeping four nodes deployed during each season. Most node losses occurred at location N3 in both seasons, but even if you assume that N3 detections were like N4 detections, the distribution would be skewed to the north. The deepest and usually fastest part of the river channel was closest to nodes 2, 3, 4, 5, and 6 on the primary array at Reed Island, nodes 3, 4, and 5 on the secondary array near Lady Island, and all nodes on the tertiary array at Oak Point.

Another indicator of performance is the frequency of multi-node detections within arrays (Figure 3.9). The forebay array had at least 90% of detections on 2 or more nodes each season. In contrast, the percent of detections on multiple nodes was only 50 to 58% at the primary survival-detection array (A5CR203), 20 to 30% on the secondary array (A6CR192), and 40 to 49% on the tertiary array (A7CR086).

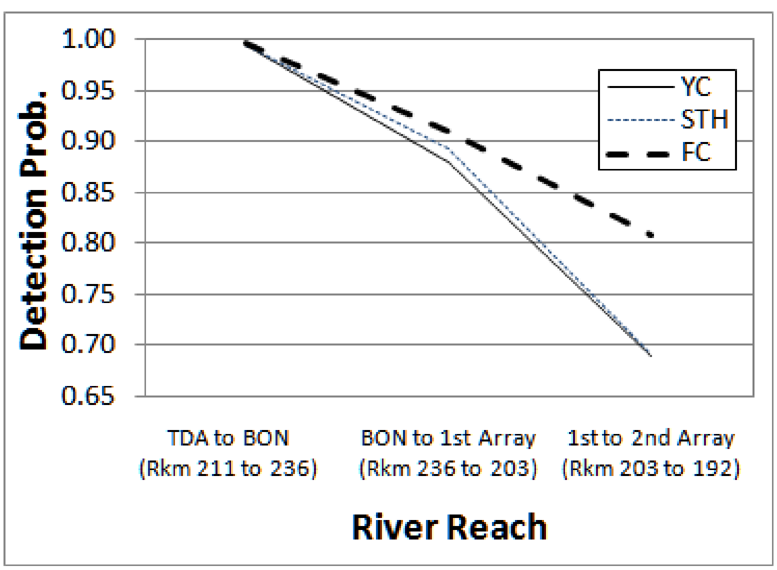


Figure 3.7. Detection probabilities by river reach and stock of juvenile salmonids

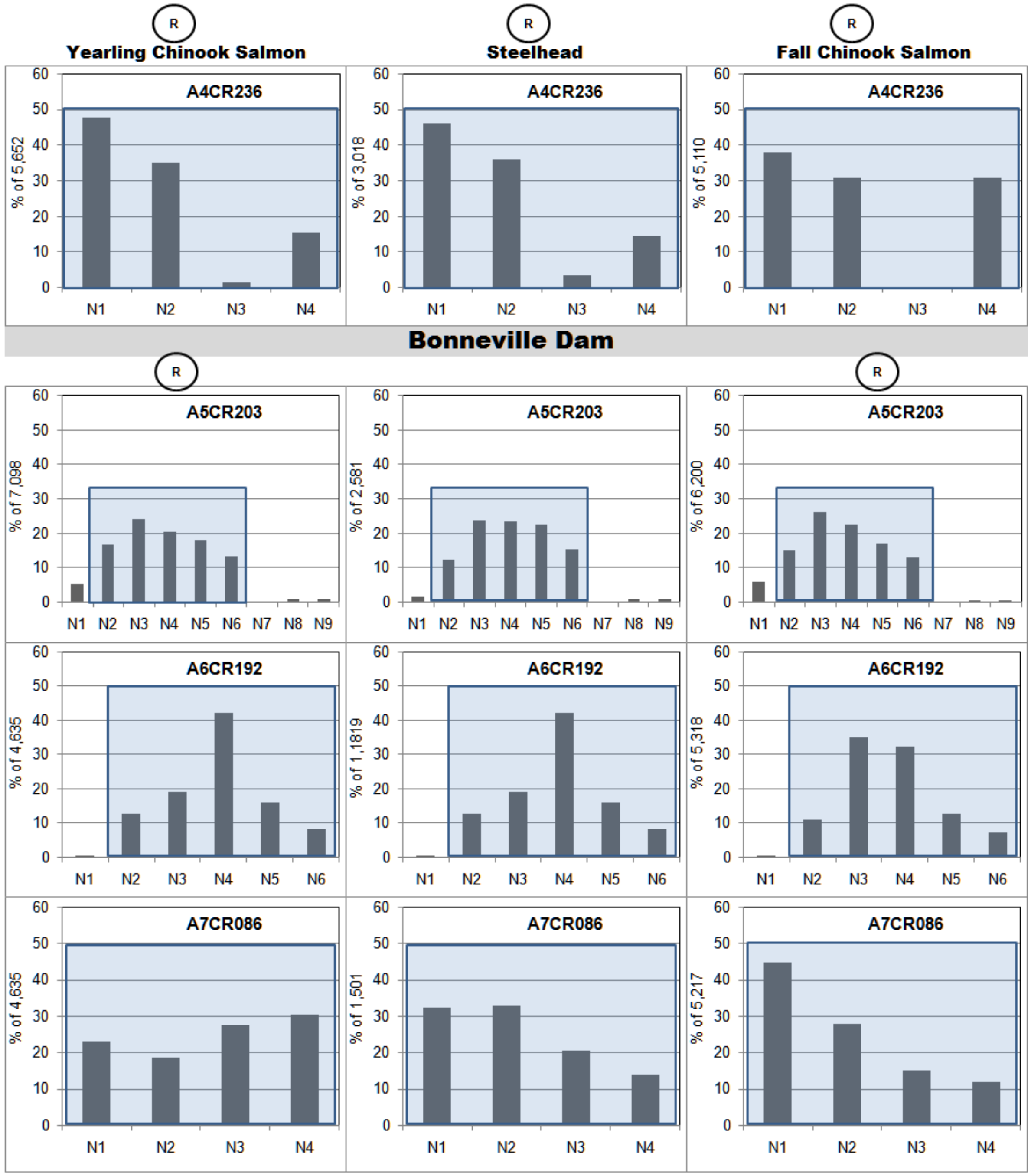


Figure 3.8. Percent of acoustic tag detections on autonomous nodes deployed in arrays immediately above and below BON in spring and summer 2008. The three arrays below the dam were used to estimate survival rates. In general, the Washington shore is on the left side of each panel and the Oregon shore is on the right as if the reader were looking upstream. The shaded rectangle overlays nodes deployed in the main channel and un-shaded nodes were outside of the main channel behind islands. See Figure 2.11 for mapped locations of autonomous nodes.

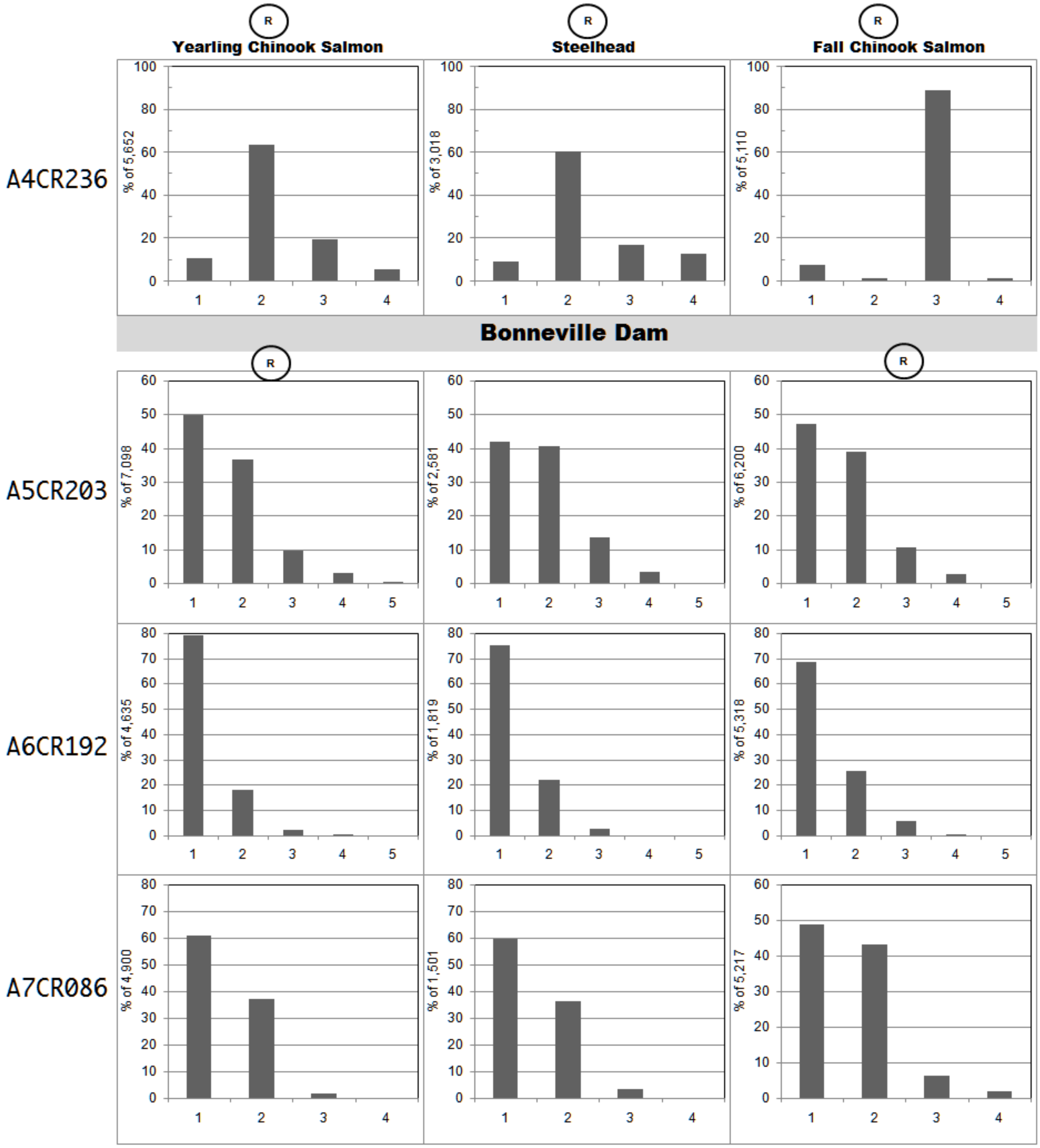


Figure 3.9. Frequency of detections on multiple autonomous nodes in survival-detection arrays (A5CR203, A6CR192, and A7CR086)

The probability of implanted acoustic tags being detected on the primary and secondary survival-detection arrays below BON were clearly a function of river discharge, and detection probabilities were higher when BON discharge was low than they were when discharge was high (Figure 3.10). Detection probabilities on the primary array were mostly above 80%, whereas detection probabilities on the secondary array ranged widely from 30% to 100% for YC, from about 40 to 100% for STH, and about 60% to 100% for FC depending on discharge.

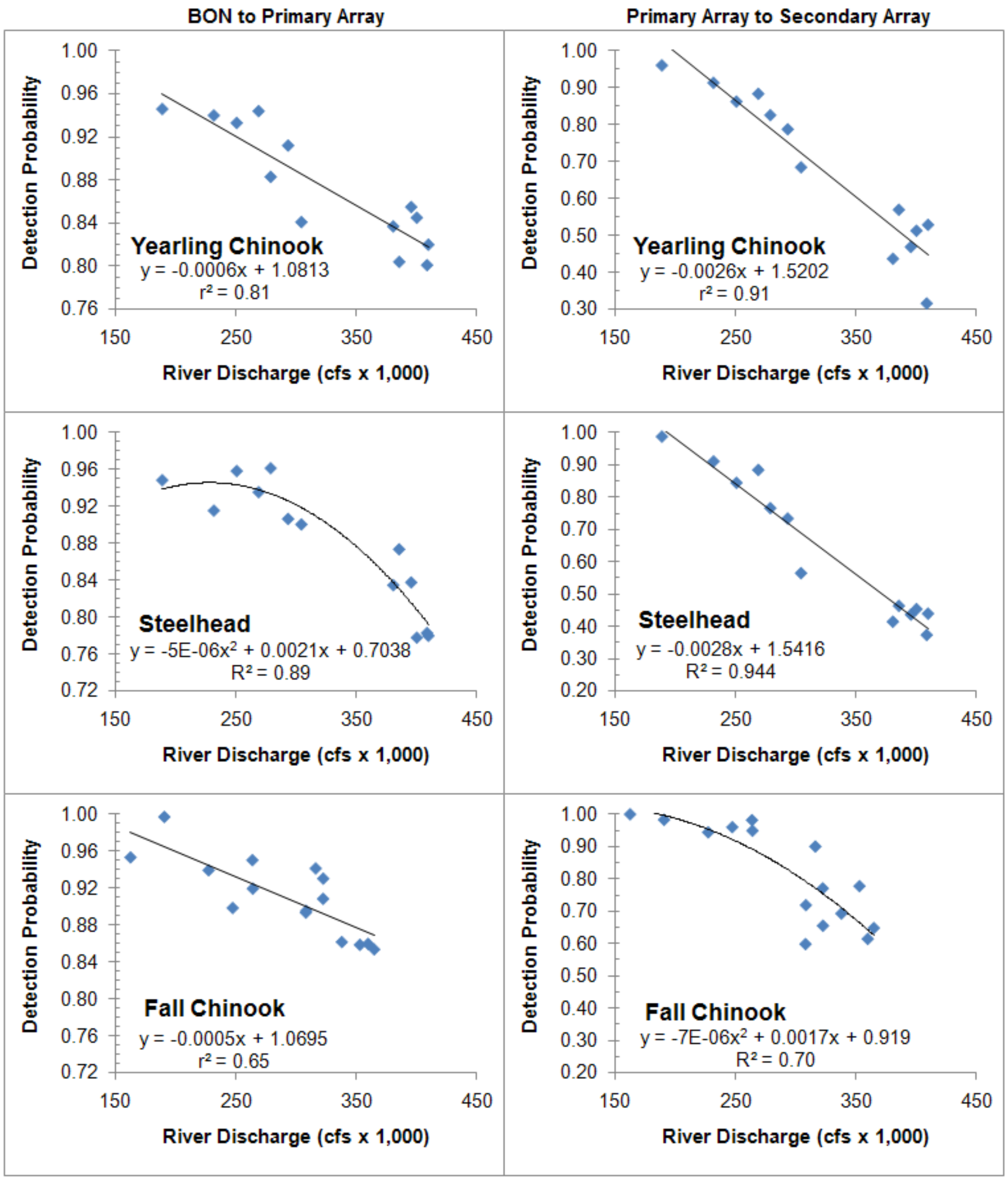


Figure 3.10. Detection probabilities by river reach and discharge

3.4 Spill Passage Efficiency and Effectiveness

Of fish detected on the BON forebay entrance array, 50.6% of YC, 49.1% of STH, and 45.1% of FC were subsequently detected by the spillway dam-face array. These percentages would equate to spill passage efficiencies. The average percent discharge passing through the spillway was 46.7% from May 2 through June 4, 2008, and 39.4% from June 17 through July 17, 2008. Dividing spill-passage efficiencies by the percent of project flow passing through the spillway provides estimates of spill passage-effectiveness, as follows: 1.084 for YC, 1.051 for STH, and 1.145 for FC.

3.5 Egress Rates

We did not have an egress array installed in 2008, so we instead report a variety of statistics on travel time and the median travel rate for fish passing through the spillway or B2 to the primary survival-detection array located 31.4 km from the spillway or 31.8 km from B2 (Table 3.1). Median travel times for juvenile Chinook salmon traveling from the spillway were 8.35 hours in spring to 8.87 hours in summer. Steelhead smolts passing through the spillway took fewer hours to reach the primary array and traveled faster (1.31 m/s) than Chinook salmon smolts in spring (1.04 m/s) and summer (0.98 m/s), and STH only required a median 6.85 hours to reach the primary array. However, STH travel times were much more variable than those of YC or FC. The standard deviation in STH travel time was 3.0 times higher than that estimated for YC smolts and 2.6 times higher than that of FC smolts. Travel times for B2-passed fish were longer than those of spillway passed fish of each fish stock, and they traveled slightly slower than spillway passed fish (Table 3.1). Median projected egress times to the tailrace release site were 8 to 11 minutes longer for B2-passed fish than for spillway passed fish.

Table 3.1. Median travel time and rate statistics for fish traveling from the BON spillway or B2 to the primary survival-detection array (A5CR203). Projected egress times from B2 or the spillway to the end of the tailrace assume that median travel rates from the dam to the primary array are similar to rates for the tailrace and therefore probably are conservative relative to actual tailrace transit times.

Statistic	Yearling Chinook	Steelhead	Fall Chinook
From the Spillway to the Primary Array (31.4 km)			
1st Percentile Travel Time (hours)	5.78	4.9	6.26
Median and Standard Deviation in Travel Time (hours)	8.35 ± 3.05	6.85 ± 9.17	8.87 ± 3.59
99th Percentile Travel Time (hours)	20.80	19.16	23.1
Median Travel Rate (m/s)	1.04	1.27	0.98
Projected Egress Time (Spillway to the Tailrace End = 2.2 km)	0.59	0.48	0.62
From B2 to the Primary Array (31.8 km)			
1st Percentile Travel Time (hours)	6.23	4.90	6.46
Median and Standard Deviation in Travel Time (hours)	9.37 ± 6.14	7.60 ± 3.37	9.36 ± 5.37
99th Percentile Travel Time (hours)	34.88	22.43	31.36
Median Travel Rate (m/s)	0.94	1.16	0.94
Projected Egress Time from B2 to the Tailrace End (2.6 km)	0.77	0.62	0.77

On average and regardless of stock, fish passing through the B2CC and spillway reach the primary array in less time and traveled faster than smolts passing through turbines or through the JBS (Table 3.2). Also, B2 turbine-passed fish reached the primary array before smolts passing through the JBS. Passage through the JBS was confirmed by PIT-tag detections of tagged smolts acoustically detected entering a B2 turbine, but passage time began with the last acoustic detection on the B2 forebay array. Therefore, egress time for JBS-passed smolts included time in the turbine, gatewell, bypass channel, and tailwater. Steelhead smolts traveled faster from B2 to the primary array and therefore took fewer hours to reach the primary array than did the juvenile Chinook salmon smolts (Table 3.2).

Table 3.2. Egress time and rates by route of passage at BON in 2008

Statistic	B2CC	Spillway	Turbine	JBS	B2 Routes Combined
Yearling Chinook Smolts					
1st Percentile	6.2	5.8	6.3	7.3	6.2
Median Hours to Primary	8.9	8.3	9.2	12.5	9.4
Mean Hours to Primary	9.8	9.0	10.6	15.2	11.1
99th Percentile	22.9	20.8	26.3	51.9	34.9
m/s	1.0	1.0	1.0	0.7	0.9
Projected Hours to Tailrace End	0.7	0.6	0.8	1.0	0.8
Steelhead Smolts					
1st Percentile	4.8	4.9	5.3	7.0	4.9
Median Hours to Primary	7.2	6.8	8.3	10.2	7.6
Mean Hours to Primary	7.4	7.9	8.5	12.7	8.2
99th Percentile	13.1	19.2	16.3	46.1	22.4
m/s	1.2	1.3	1.1	0.9	1.2
Projected Hours to Tailrace End	0.6	0.5	0.7	0.8	0.6
Fall Chinook Smolts					
1st Percentile	6.4	6.3	6.6	6.9	6.5
Median Hours to Primary	8.7	8.9	9.3	13.2	9.4
Mean Hours to Primary	9.5	9.9	10.4	15.8	11.0
99th Percentile	21.3	23.1	24.7	48.9	31.4
m/s	1.0	1.0	0.9	0.7	0.9
Projected Hours to Tailrace End	0.7	0.6	0.8	1.1	0.8

The average time for fish to reach the primary array was slightly longer for smolts passing through middle bays than it was for fish passing through end bays. On average, smolts passing through middle bays took from 8.5 to 34.1 minutes longer to reach the primary survival-detection array than did smolts passing through end bays (YC = 8.5 minutes; STH = 34.1 minutes; FC = 18.1 minutes). After July 2, 2008, FC smolts passing through middle bays took an average of 11 minutes longer to reach the primary array than did counterparts passing through end bays. However, for the slowest 10 percent of fish passing through each type of spill bay, subyearling smolts passing through middle bays took from 30 minutes (the mean difference) to 63 minutes (median difference) longer to reach the primary array than did smolts passing through end bays.

3.6 Detection and Survival of Yearling Chinook Salmon in Spring

In this section, we describe the results of the tag-life study relative to arrival times of tagged smolts at downstream survival-detection arrays, the survival rates of dam-passed and spillway-passed yearlings, and compare survival rates of yearlings passing through deep and shallow flow deflector bays.

3.6.1 Tag-Life Effects

We plotted the fraction of transmitting tags remaining against days since tag activation and this non-parametric Kaplan-Meier estimator of actual tag-life survival rates was used to derive tag-life corrections.

Over 99.5% of YC bearing 3-s tags passed the primary survival-detection array below BON within 16 days, the secondary within 17 days, and the tertiary within 18 days when tags were just slightly beyond their half life (Figure 3.11). A plot of the probability that a 3-s tag released at Arlington above JDA or in the tailrace below JDA would still be working by the time it reached the BON survival-detection arrays is shown in Figure 3.12. Similar plots by spillway passage route and fish released in the BON tailwater are presented in Figure 3.13. In every plot, the average probability that a tag was still working by the time fish reached survival-detection arrays exceeded 99% and the average was about 0.1% to 0.2% lower at successive downstream arrays.

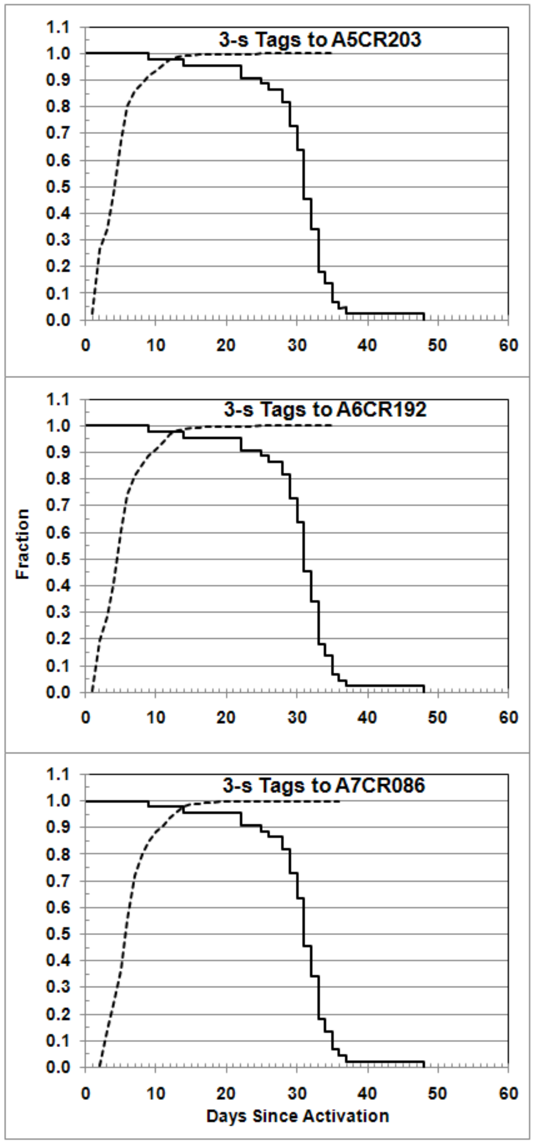


Figure 3.11. Fraction of tag-life study tags transmitting (solid lines) and the cumulative fraction of detected yearling Chinook salmon smolts arriving at the BON primary, secondary, and tertiary survival-detection arrays (dashed lines) as a function of days since tag activation. Arrays were as follows: A5CR203 in the BON tailwater near Reed Island, A6CR192 in the tailwater near Lady Island at Camas, Washington, and A7CR086 near Oak Point, Washington.

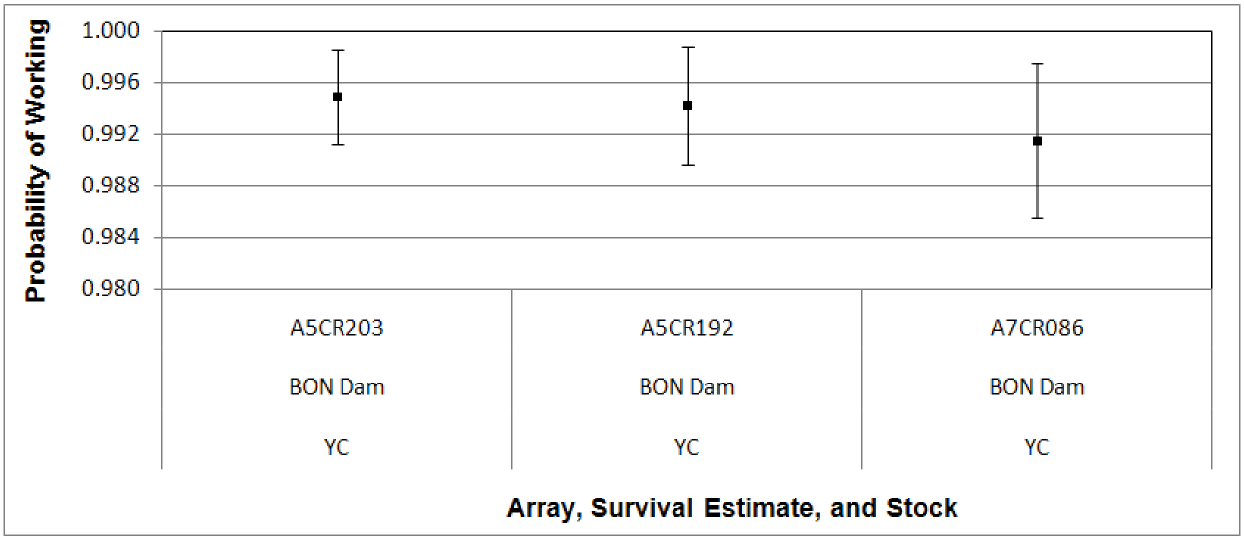


Figure 3.12. Plot of the probability of a tag implanted in YC working by the time fish arrived at survival-detection arrays for BON survival estimates. Array abbreviations are as follows: A5CR203 = BON Tailwater 1 (Primary at Reed Island), A6CR192 = BON Tailwater 2 (Secondary at Camas, Washington), A7CR086 = BON Tailwater 3 (Tertiary at Oak Point, Washington). Vertical bars are ± 1 standard error.

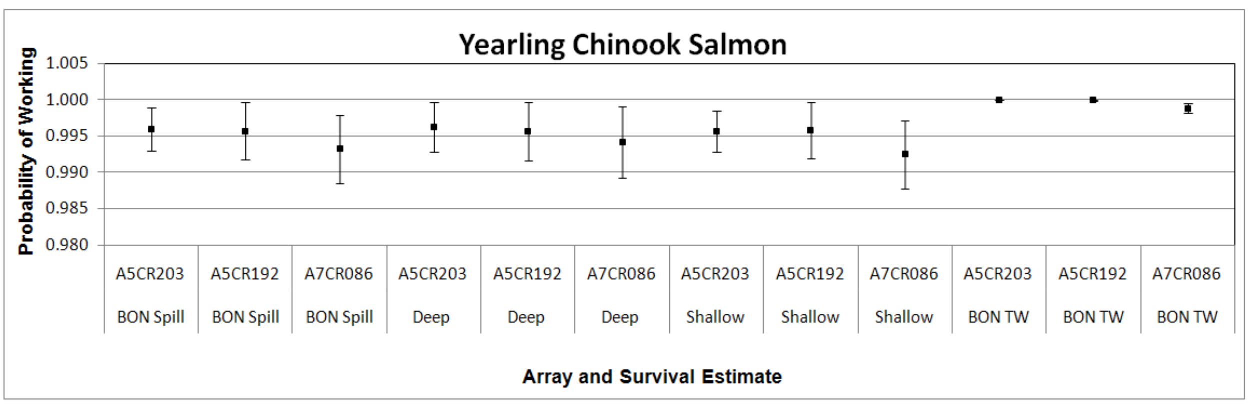


Figure 3.13. Plot of the probability of a tag implanted in YC smolts working by the time fish arrived at survival-detection arrays for estimating BON spillway and tailwater (TW) survival rates. Array abbreviations are as follows: A5CR203 = BON Tailwater 1 (Primary at Reed Island), A6CR192 = BON Tailwater 2 (Secondary at Camas, Washington), A7CR086 = BON Tailwater 3 (Tertiary at Oak Point, Washington). Survival rate abbreviations by passage route are as follows: BON Spill = Bonneville Spillway; Deep = spill bays with deep flow deflectors (Bays 1-3 and 16-18); Shallow = spill bays with shallow flow deflectors (Bays 4-15); BON TW = Bonneville Tailwater. Fish released in the BON tailwater had 5-s tags, whereas fish released at Arlington above JDA or in the JDA tailwater had 3-s tags. Vertical bars are ± 1 standard error.

Tag-life corrections were more critical for YC released below LGR on the Snake River (see Figure 3.14 and Figure 3.15) than they were for fish released in the lower Columbia River (Figure 3.12

and Figure 3.13). The average probability of a tag still working by the time it reached the BON primary, secondary, and tertiary arrays was between 0.96 and 0.97 (Figure 3.15).

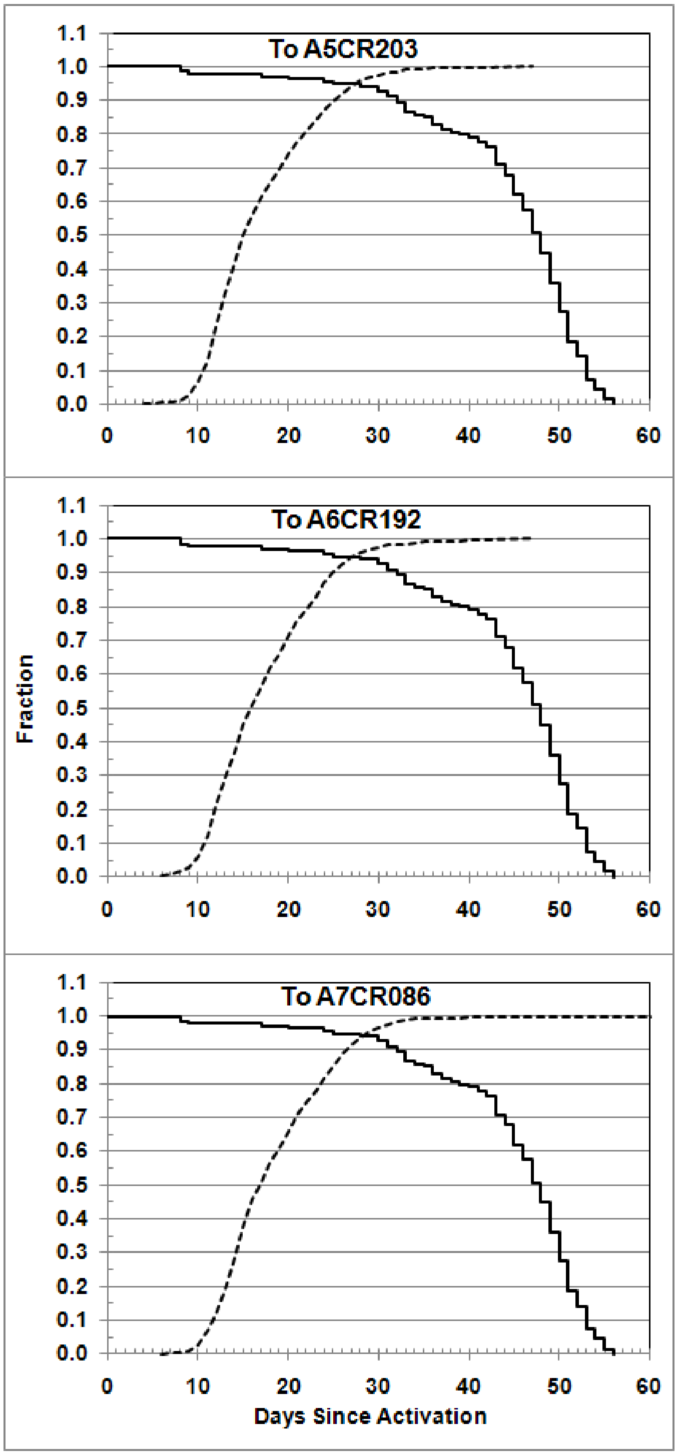


Figure 3.14. Fraction of tag-life study tags transmitting (solid lines) and the cumulative fraction of detected LGR YC smolts arriving at the BON primary, secondary, and tertiary survival-detection arrays (dashed lines) as a function of days since tag activation. Arrays were as

follows: A5CR203 in the BON tailwater near Reed Island, A6CR192 in the tailwater near Lady Island at Camas, Washington, and A7CR086 near Oak Point, Washington.

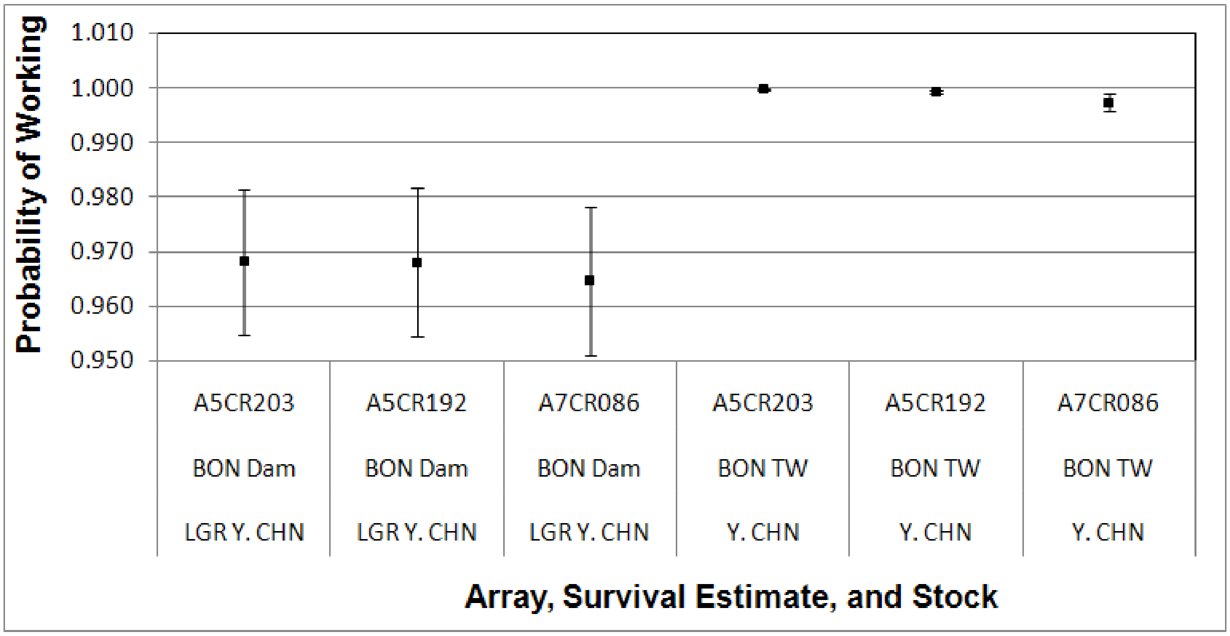


Figure 3.15. Plot of the probability of a tag implanted in YC smolts working by the time fish arrived at survival-detection arrays for estimating BON and tailwater survival rates. These tagged yearlings were released at LGR on the Snake River and in the BON tailwater. Array abbreviations are as follows: A5CR203 = BON Tailwater 1 (Primary at Reed Island), A6CR192 = BON Tailwater 2 (Secondary at Camas, Washington), A7CR086 = BON Tailwater 3 (Tertiary at Oak Point, Washington). Vertical bars are ± 1 standard error.

3.6.2 Survival Rates of Yearling Chinook Salmon Passing Through Bonneville Dam

In this section of the report, we first describe the BON dam-passage survival rate for YC released in the JDA pool and tailrace and then describe the BON dam-passage survival rate for YC released in the Lower Granite tailrace on the Snake River.

3.6.2.1 Yearling Chinook Released in the JDA Pool and Tailrace

Yearlings released in the JDA pool and tailrace that were detected by the BON forebay array were identified and their downstream capture probabilities were recorded for each of 13 consecutive time blocks in spring (Table 3.3), as were capture histories of BON tailrace reference releases (Table 3.4). Tag-life-corrected CJS estimates of reach survival rates were calculated for each virtual release from the BON forebay array (Table 3.3; Table 3.5) and tailrace release (Table 3.4; Table 3.6). For each daily release pair, estimates of spillway passage survival rates were calculated using the fully parameterized CJS model (Table 3.7). Across the 13 paired-release trials, we estimated that the weighted mean, paired-release dam survival rate was $\hat{S}_{Dam} = 0.997$ ($\widehat{\text{SE}} = 0.014$). A 95% CI would be $0.970 \le S \le 1.024$.

Table 3.3. Detection histories for YC smolts released above and below JDA and detected at the BON forebay entrance array to form virtual releases to estimate BON dam passage survival rates. The headings of columns 2 through 9 have three digits and each digit represents a detection (1) or non-detection (0) at three successive survival-detection arrays (A5CR203, A6CR192, and A7CR086), respectively. A Chi-square test for homogeneity, excluding pooled estimates, columns with <5 pooled detections, and totals, was significant (P < 0.0010).

Date	P_111	P_011	P_101	P_001	P_110	P_010	P_100	P_000	Total
5/02-5/06	94	6	3	1	26	0	1	8	139
5/07-5/08	144	9	11	2	62	3	7	7	245
5/09-5/10	128	14	35	3	43	3	14	18	258
5/11-5/12	150	9	21	4	39	2	9	6	240
5/13-5/14	127	11	17	1	57	0	7	5	225
5/15-5/16	114	15	25	2	42	7	12	10	227
5/17-5/18	94	22	46	7	35	4	27	11	246
5/19-5/20	61	9	68	11	42	9	49	25	274
5/21-5/22	43	10	39	8	41	9	64	24	238
5/23-5/24	41	6	37	8	53	10	50	15	220
5/25-5/26	41	11	28	11	46	6	36	14	193
5/27-5/28	44	8	71	15	52	8	47	26	271
5/29-6/04	29	9	70	21	33	2	53	23	240
Pooled	1110	139	471	94	571	63	376	192	3016

Table 3.4. Detection histories for YC smolts released in the upper end of the BON tailwater as reference releases for estimating BON dam passage survival rates. The headings of columns 2 through 9 have three digits and each digit represents a detection (1) or non-detection (0) at three successive survival-detection arrays (A5CR203, A6CR192, and A7CR086), respectively. A Chi-square test for homogeneity, excluding pooled estimates, columns with <5 pooled detections, and totals, was not significant (P < 0.0010).

Date	P_111	P_011	P_101	P_001	P_110	P_010	P_100	P_000	Total
5/02-5/06	80	5	2	1	21	3	4	2	118
5/07-5/08	24	3	6	2	7	0	3	2	47
5/09-5/10	31	3	6	0	6	0	3	1	50
5/11-5/12	37	1	2	0	7	0	1	0	48
5/13-5/14	27	1	6	0	11	0	2	1	48
5/15-5/16	24	2	14	0	4	0	4	0	48
5/17-5/18	8	1	4	3	5	0	7	0	28
5/19-5/20	5	1	15	7	5	3	12	6	54
5/21-5/22	3	3	17	6	7	1	15	13	65
5/23-5/24	6	1	11	2	10	2	14	9	55
5/25-5/26	7	1	11	7	7	4	9	6	52
5/27-5/28	7	5	9	4	5	0	13	5	48
5/29-6/04	11	4	30	5	13	1	37	16	117
Pooled	270	31	133	37	108	14	124	61	778

Table 3.5. Tag-life-corrected, single-release estimates of dam passage survival rates (S) and detection probabilities for YC smolts based on capture history data in Table 3.3. Lambda is the product of survival and detection probabilities for the third array, and CI = confidence interval. The N-Wt Mean (weighted by numbers of fish in each virtual release) is preferred over the pooled estimate when capture histories are not homogeneous.

Virtual Release Dates	S to 1st Array	1/2 95% CI	S from 1st to 2nd Array	1/2 95% CI	Detect. Prob. To 1st Array	1/2 95% CI	Detect. Prob. from 1st to 2nd Array	1/2 95% CI	Lambda	1/2 95% CI
5/02-5/06	0.960	0.051	1.000	0.000	0.946	0.051	0.962	0.000	0.794	0.069
5/07-5/08	0.984	0.028	1.000	0.001	0.940	0.028	0.915	0.001	0.707	0.059
5/09-5/10	0.949	0.041	0.988	0.041	0.912	0.041	0.789	0.041	0.758	0.062
5/11-5/12	0.981	0.021	0.987	0.030	0.933	0.021	0.864	0.030	0.796	0.056
5/13-5/14	0.981	0.019	1.000	0.000	0.944	0.019	0.885	0.000	0.709	0.060
5/15-5/16	0.964	0.027	0.985	0.042	0.883	0.027	0.827	0.042	0.726	0.066
5/17-5/18	0.977	0.029	0.941	0.060	0.841	0.029	0.686	0.060	0.751	0.069
5/19-5/20	0.941	0.038	1.000	0.000	0.855	0.038	0.470	0.000	0.579	0.062
5/21-5/22	0.959	0.049	0.853	0.125	0.820	0.049	0.530	0.125	0.515	0.096
5/23-5/24	0.975	0.040	1.000	0.000	0.845	0.040	0.514	0.000	0.430	0.068
5/25-5/26	0.973	0.045	0.969	0.130	0.804	0.045	0.571	0.130	0.500	0.096
5/27-5/28	0.944	0.040	1.000	0.015	0.837	0.040	0.438	0.015	0.540	0.064
5/29-6/04	0.975	0.047	1.000	0.000	0.801	0.047	0.317	0.000	0.563	0.069
Pooled	0.958	0.012	0.952	0.020	0.879	0.012	0.689	0.020	0.665	0.021
N-Wt Mean	0.966	0.008	0.978	0.023						

Table 3.6. Tag-life-corrected, single-release estimates of survival rates (S) and detection probabilities for YC smolts in reference releases for estimating BON dam passage survival rates. Releases were in the upper end of the BON tailwater. Lambda is the product of survival and detection probabilities for the third array, and CI = confidence interval. The N-Wt Mean (weighted by numbers of fish in each virtual release) is preferred over the pooled estimate when capture histories are not homogeneous.

Virtual Release Dates	S to 1st Array	1/2 95% CI	S from 1st to 2nd Array	1/2 95% CI	Detect. Prob. To 1st Array	1/2 95% CI	Detect. Prob. from 1st to 2nd Array	1/2 95% CI	Lambda	1/2 95% CI
5/02-5/06	0.986	0.024	0.971	0.037	0.920	0.024	0.966	0.037	0.784	0.078
5/07-5/08	0.966	0.060	0.971	0.098	0.881	0.060	0.771	0.098	0.797	0.136
5/09-5/10	0.984	0.040	0.956	0.077	0.935	0.040	0.850	0.077	0.852	0.111
5/11-5/12	1.000	0.000	0.987	0.042	0.979	0.000	0.950	0.042	0.845	0.106
5/13-5/14	0.980	0.040	1.000	0.000	0.978	0.040	0.829	0.000	0.723	0.128
5/15-5/16	1.000	0.013	0.962	0.097	0.958	0.013	0.650	0.097	0.867	0.122
5/17-5/18	1.000	0.016	0.889	0.257	0.857	0.016	0.563	0.257	0.643	0.251
5/19-5/20	1.000	0.093	1.000	0.046	0.685	0.093	0.259	0.046	0.519	0.136
5/21-5/22	0.895	0.131	1.000	0.054	0.722	0.131	0.241	0.054	0.499	0.142
5/23-5/24	0.888	0.115	1.000	0.059	0.840	0.115	0.389	0.059	0.410	0.143
5/25-5/26	1.000	0.000	1.000	0.040	0.654	0.000	0.365	0.040	0.500	0.135
5/27-5/28	1.000	0.055	0.738	0.206	0.708	0.055	0.480	0.206	0.706	0.217
5/29-6/04	0.922	0.079	0.896	0.277	0.844	0.079	0.300	0.277	0.517	0.182
Pooled	0.947	0.021	0.898	0.041	0.862	0.021	0.639	0.041	0.713	0.043
N-Wt Mean	0.965	0.023	0.952	0.038						

Table 3.7. Tag-life-corrected, paired-release estimates of dam survival rates (S) for YC smolts released above and below JDA and regrouped to form virtual releases traveling from the BON forebay entrance array to the uppermost end of the BON tailwater

Paired Release	S to Tailrace	1/2 95% CI
5/02-5/06	0.974	0.057
5/07-5/08	1.019	0.069
5/09-5/10	0.964	0.057
5/11-5/12	0.981	0.021
5/13-5/14	1.001	0.046
5/15-5/16	0.964	0.030
5/17-5/18	0.977	0.033
5/19-5/20	0.941	0.095
5/21-5/22	1.072	0.166
5/23-5/24	1.098	0.150
5/25-5/26	0.973	0.045
5/27-5/28	0.944	0.065
5/29-6/04	1.058	0.104
Pooled	1.012	0.025
N-Wt Mean	0.997	0.027

3.6.2.2 Yearling Chinook Released in the Snake River in the LGR Tailrace

We made similar single- and paired-release, tag-life-corrected estimates of dam survival rates just for YC released below LGR on the Snake River to see how those estimates might comport with those for YC released in the JDA pool and tailrace. These paired-release estimates were based on single-release estimates for LGR-released fish regrouped on the forebay array (Table 3.8 and Table 3.9) relative to single-release estimates for reference releases of YC in the BON tailwater (Table 3.10 and Table 3.11). Based on the point estimates for the passage season and associated 95% CIs, the virtual release survival estimates for Snake River-released YC (Table 3.12) and JDA-released YC (Table 3.7) did not differ significantly.

Table 3.8. Detection histories for YC smolts released below lower granite dam (Snake River) and detected at the BON forebay entrance array to form virtual releases to estimate BON dam passage survival rates. The headings of columns 2 through 9 have three digits and each digit represents a detection (1) or non-detection (0) at three successive survival-detection arrays (A5CR203, A6CR192, and A7CR086), respectively. A Chi-square test for homogeneity, excluding pooled estimates, columns with <5 pooled detections, and totals, was significant ($P < 0.0010$).

Date	P_111	P_011	P_101	P_001	P_110	P_010	P_100	P_000	Total
5/07-5/14	58	4	17	2	28	1	11	16	137
5/15-5/16	74	10	29	4	36	2	18	26	199
5/17-5/18	53	13	47	8	24	6	53	32	236
5/19-5/20	41	6	79	22	38	13	91	45	335
5/21-5/22	24	7	75	15	47	8	128	49	353
5/23-5/24	33	11	55	14	45	14	75	44	291
5/25-5/26	75	16	120	23	84	26	158	73	575
5/27-5/28	30	3	66	19	42	10	101	21	292
5/29-5/30	7	0	30	6	6	0	37	14	100
5/31-6/04	7	1	32	8	13	3	18	11	93
Pooled	402	71	550	121	363	83	690	331	2611

Table 3.9. Tag-life-corrected, single-release estimates of dam passage survival rates (S) and detection probabilities for YC smolts released below LGR, based on capture history data in Table 3.8. Lambda is the product of survival and detection probabilities for the third array, and CI = confidence interval. The N-Wt Mean (weighted by numbers of fish in each virtual release) is preferred over the pooled estimate when capture histories are not homogeneous.

Virtual Release Dates	S to 1st Array	1/2 95% CI	S from 1st to 2nd Array	1/2 95% CI	Detect. Prob. to 1st Array	1/2 95% CI	Detect. Prob. from 1st to 2nd Array	1/2 95% CI	Lambda	1/2 95% CI
5/07-5/14	0.920	0.063	1.000	0.012	0.937	0.063	0.748	0.012	0.669	0.084
5/15-5/16	0.911	**0.057**	1.000	0.001	0.898	0.057	0.698	0.001	0.672	0.071
5/17-5/18	0.950	0.062	0.817	0.096	0.821	0.062	0.546	0.096	0.689	0.093
5/19-5/20	0.972	0.057	0.986	0.174	0.794	0.057	0.318	0.174	0.481	0.099
5/21-5/22	0.969	0.057	1.000	0.004	0.829	0.057	0.260	0.004	0.367	0.055
5/23-5/24	0.954	0.061	1.000	0.006	0.774	0.061	0.383	0.006	0.422	0.061
5/25-5/26	0.961	0.044	0.958	0.119	0.811	0.044	0.389	0.119	0.455	0.069
5/27-5/28	1.000	0.000	1.000	0.000	0.837	0.000	0.297	0.000	0.412	0.057
5/29-5/30	0.942	0.092	0.882	0.417	0.878	0.092	0.163	0.417	0.538	0.271
5/31-6/04	0.976	0.088	1.000	0.000	0.796	0.088	0.273	0.000	0.548	0.112
Pooled	0.959	0.031	0.917	0.047	0.827	0.031	0.414	0.047	0.516	0.032
N-Wt Mean	0.960	0.015	0.968	0.035						

Table 3.10. Detection histories for YC smolts released in the BON tailrace as reference releases for estimating paired-release dam passage survival rates for fish released below LGR. The headings of columns 2 through 9 have three digits and each digit represents a detection (1) or non-detection (0) at three successive survival-detection arrays (A5CR203, A6CR192, and A7CR086), respectively. A Chi-square test for homogeneity, excluding pooled estimates, columns with <5 pooled detections, and totals, was not significant ($P < 0.0010$).

Date	P_111	P_011	P_101	P_001	P_110	P_010	P_100	P_000	Total
5/07-5/14	119	8	20	2	31	0	9	4	193
5/15-5/16	24	2	14	0	4	0	4	0	48
5/17-5/18	8	1	4	3	5	0	7	0	28
5/19-5/20	5	1	15	7	5	3	12	6	54
5/21-5/22	3	3	17	6	7	1	15	13	65
5/23-5/24	6	1	11	2	10	2	14	9	55
5/25-5/26	7	1	11	7	7	4	9	6	52
5/27-5/28	7	5	9	4	5	0	13	5	48
5/29-5/30	2	1	12	2	7	1	13	10	48
5/31-6/04	9	3	18	3	6	0	24	6	69
Pooled	190	26	131	36	87	11	120	59	660

Table 3.11. Tag-life-corrected, single-release estimates of survival rates (S) and detection probabilities for YC smolts in reference releases for estimating BON dam passage survival rates based on capture histories in Table 3.10. Releases were in the Upper End of the BON tailwater. Lambda is the product of survival and detection probabilities for the third array, and CI = confidence interval. The N-Wt Mean (weighted by numbers of fish in each virtual release) is preferred over the pooled estimate when capture histories are not homogeneous.

Virtual Release Dates	S to 1st Array	1/2 95% CI	S from 1st to 2nd Array	1/2 95% CI	Detect. Prob. To 1st Array	1/2 95% CI	Detect. Prob. from 1st to 2nd Array	1/2 95% CI	Lambda	1/2 95% CI
5/07-5/14	0.982	0.020	0.978	0.036	0.944	0.020	0.852	0.036	0.806	0.062
5/15-5/16	1.000	0.013	0.962	0.097	0.958	0.013	0.650	0.097	0.867	0.122
5/17-5/18	1.000	0.016	0.889	0.257	0.857	0.016	0.563	0.257	0.643	0.251
5/19-5/20	1.000	0.089	1.000	0.046	0.686	0.089	0.259	0.046	0.519	0.136
5/21-5/22	0.895	0.131	1.000	0.054	0.722	0.131	0.241	0.054	0.499	0.142
5/23-5/24	0.888	0.115	1.000	0.059	0.840	0.115	0.389	0.059	0.410	0.143
5/25-5/26	1.000	0.000	1.000	0.040	0.654	0.000	0.365	0.040	0.500	0.135
5/27-5/28	1.000	0.055	0.738	0.206	0.708	0.055	0.480	0.206	0.706	0.217
5/29-5/30	0.854	0.142	1.000	0.046	0.829	0.142	0.268	0.046	0.415	0.159
5/31-6/04	0.976	0.092	0.735	0.228	0.846	0.092	0.364	0.228	0.667	0.218
Pooled	0.949	0.019	0.902	0.038	0.869	0.019	0.665	0.038	0.725	0.041
N-Wt Mean	0.962	0.032	0.939	0.063						

Table 3.12. Tag-life-corrected, paired-release estimates of dam passage survival rates (S) for YC smolts released below LGR (Snake River), regrouped in virtual releases at the BON forebay entrance array, and traveling to the upper end of the BON tailwater

Paired Release	S to Tailrace	1/2 95% CI
5/07-5/14	0.937	0.067
5/15-5/16	0.911	0.059
5/17-5/18	0.950	0.064
5/19-5/20	0.972	0.104
5/21-5/22	1.084	0.171
5/23-5/24	1.075	0.156
5/25-5/26	0.961	0.044
5/27-5/28	1.000	0.055
5/29-5/30	1.103	0.212
5/31-6/04	1.000	0.131
Pooled	1.011	0.038
N-Wt Mean	0.989	0.041

3.6.3 Survival Rates of Spillway-Passed Yearling Chinook Salmon

Survival rates were estimated for spillway-passed YC across the entire spillway and for those passing through the deep and shallow deflector bays.

3.6.3.1 Composite Spillway-Passage Estimates

Yearling Chinook salmon released in the JDA pool and tailrace were regrouped to form virtual releases of fish through the BON spillway and their downstream capture probabilities were recorded (Table 3.13) and used to populate a tag-life-corrected CJS (single-release survival) model (Table 3.14). Similarly, capture histories were generated for BON tailrace releases (Table 3.15) and were used to make tag-life-corrected, single-release survival estimates for reference releases (Table 3.16). For each daily release pair, estimates of spillway passage survival rates were calculated using the fully parameterized CJS model (Table 3.17). Across the 13 paired-release trials, we estimated a weighted-average spillway survival rate of $\hat{S}_{Spill}$ = 0.999 ($\widehat{SE}$ = 0.015). A 95% CI would be $(0.970 \le S \le 1.028)$. This estimate of survival from the spillway to the upper tailwater release site was very similar to the dam survival estimate from the BON forebay array to the upper tailwater release site ($\hat{S}_{Dam}$ =0.997; $\widehat{SE}$ = 0.014).

Table 3.13. Detection histories for YC smolts released above and below JDA and detected and regrouped to form virtual releases at the BON spillway in spring. The headings of columns 2 through 9 have three digits and each digit represents a detection (1) or non-detection (0) at three successive survival-detection arrays (A5CR203, A6CR192, and A7CR086), respectively. A Chi-square test for homogeneity, excluding pooled estimates, columns with <5 pooled detections, and totals, was significant (P < 0.0010).

Date	P_111	P_011	P_101	P_001	P_110	P_010	P_100	P_000	Total
5/05-5/06	29	3	1	0	8	0	1	6	48
5/07-5/08	58	5	2	1	30	1	4	5	106
5/09-5/10	49	8	15	0	20	2	3	8	105
5/11-5/12	67	9	9	2	20	1	4	3	115
5/13-5/14	55	3	9	1	21	0	2	3	94
5/15-5/16	38	9	9	2	18	5	5	6	92
5/17-5/18	42	13	24	4	14	1	10	6	114
5/19-5/20	43	5	37	4	22	5	29	12	157
5/21-5/22	26	3	27	3	20	5	41	16	141
5/23-5/24	23	4	23	5	34	7	34	11	141
5/25-5/26	20	7	18	8	22	3	22	4	104
5/27-5/28	19	7	42	8	30	4	28	11	149
5/29-6/04	20	6	50	13	21	2	33	14	159
Pooled	489	82	266	51	280	36	216	105	1525

Table 3.14. Tag-life-corrected, single-release estimates of BON spillway passage survival rates (S) and detection probabilities for YC smolts in virtual releases at the spillway based on capture histories in Table 3.13. Lambda is the product of survival and detection probabilities for the third array, and CI = confidence interval. The N-Wt Mean (weighted by numbers of fish in virtual releases) is preferred over the pooled estimate when capture histories are not homogeneous and some variance estimates approach zero and would overly weight high survival estimates.

Virtual Release Dates	S to 1st Array	1/2 95% CI	S from 1st to 2nd Array	1/2 95% CI	Detect. Prob. To 1st Array	1/2 95% CI	Detect. Prob. from 1st to 2nd Array	1/2 95% CI	Lambda	1/2 95% CI
5/05-5/06	0.893	0.101	0.980	0.051	0.927	0.101	0.970	0.051	0.799	0.124
5/07-5/08	0.968	0.047	0.973	0.045	0.928	0.047	0.955	0.045	0.680	0.096
5/09-5/10	0.941	0.056	1.000	0.000	0.892	0.056	0.810	0.000	0.741	0.088
5/11-5/12	0.983	0.030	0.987	0.044	0.889	0.030	0.874	0.044	0.783	0.082
5/13-5/14	0.971	0.036	1.000	0.016	0.955	0.036	0.867	0.016	0.748	0.090
5/15-5/16	0.950	0.053	0.990	0.079	0.803	0.053	0.810	0.079	0.672	0.110
5/17-5/18	0.969	0.045	0.959	0.083	0.816	0.045	0.663	0.083	0.788	0.096
5/19-5/20	0.950	0.046	0.933	0.118	0.879	0.046	0.539	0.118	0.641	0.109
5/21-5/22	0.931	0.063	0.837	0.166	0.869	0.063	0.492	0.166	0.537	0.133
5/23-5/24	0.971	0.054	1.000	0.000	0.833	0.054	0.497	0.000	0.402	0.084
5/25-5/26	1.000	0.000	0.982	0.182	0.789	0.000	0.509	0.182	0.519	0.136
5/27-5/28	0.976	0.052	1.000	0.000	0.818	0.052	0.413	0.000	0.523	0.085
5/29-6/04	0.972	0.054	1.000	0.000	0.809	0.054	0.317	0.000	0.583	0.083
Pooled	0.958	0.015	0.948	0.031	0.860	0.015	0.643	0.031	0.645	0.032
N-Wt Mean	0.962	0.012	0.970	0.027						

Table 3.15. Detection histories for YC smolts released in the upper end of the BON tailwater as reference releases for estimating spillway passage survival rates, end bay passage survival rates (Bays 1-3 and 16-18), and middle bay passage survival rates (bays 4-15). The headings of columns 2 through 9 have three digits and each digit represents a detection (1) or non-detection (0) at three successive survival-detection arrays (A5CR203, A6CR192, and A7CR086), respectively. A Chi-square test for homogeneity, excluding pooled estimates, columns with <5 pooled detections, and totals, was significant (P < 0.0010).

Date	P_111	P_011	P_101	P_001	P_110	P_010	P_100	P_000	Total
5/05-5/06	27	3	1	1	9	2	3	1	47
5/07-5/08	24	3	6	2	7	0	3	2	47
5/09-5/10	31	3	6	0	6	0	3	1	50
5/11-5/12	37	1	2	0	7	0	1	0	48
5/13-5/14	27	1	6	0	11	0	2	1	48
5/15-5/16	24	2	14	0	4	0	4	0	48
5/17-5/18	8	1	4	3	5	0	7	0	28
5/19-5/20	5	1	15	7	5	3	12	6	54
5/21-5/22	3	3	17	6	7	1	15	13	65
5/23-5/24	6	1	11	2	10	2	14	9	55
5/25-5/26	7	1	11	7	7	4	9	6	52
5/27-5/28	7	5	9	4	5	0	13	5	48
5/29-6/04	11	4	30	5	13	1	37	16	117
Pooled	217	29	132	37	96	13	123	60	707

Table 3.16. Tag-life-corrected, single-release estimates of survival rates (S) and detection probabilities for YC smolts in reference releases for estimating BON survival rates of fish passing through the BON spillway, the end bays (1-3 and 16-18), and middle bays (4-15). Reference releases were in the upper end of the BON tailwater. Lambda is the product of survival and detection probabilities for the third array, and CI = confidence interval. The N-Wt Mean (weighted by numbers of fish in each virtual release) is preferred over the pooled estimate when capture histories are not homogeneous.

Virtual Release Dates	S to 1st Array	1/2 95% CI	S from 1st to 2nd Array	1/2 95% CI	Detect. Prob. To 1st Array	1/2 95% CI	Detect. Prob. from 1st to 2nd Array	1/2 95% CI	Lambda	1/2 95% CI
5/05-5/06	0.989	0.044	0.941	0.086	0.861	0.044	0.938	0.086	0.735	0.136
5/07-5/08	0.966	0.060	0.971	0.098	0.881	0.060	0.771	0.098	0.797	0.136
5/09-5/10	0.984	0.040	0.956	0.077	0.935	0.040	0.850	0.077	0.853	0.111
5/11-5/12	1.000	0.000	0.987	0.042	0.979	0.000	0.950	0.042	0.846	0.106
5/13-5/14	0.980	0.040	1.000	0.000	0.978	0.040	0.829	0.000	0.723	0.128
5/15-5/16	1.000	0.013	0.962	0.097	0.958	0.013	0.650	0.097	0.867	0.122
5/17-5/18	1.000	0.016	0.889	0.257	0.857	0.016	0.563	0.257	0.643	0.251
5/19-5/20	1.000	0.089	1.000	0.046	0.686	0.089	0.259	0.046	0.519	0.136
5/21-5/22	0.895	0.131	1.000	0.054	0.722	0.131	0.241	0.054	0.499	0.142
5/23-5/24	0.888	0.115	1.000	0.059	0.840	0.115	0.389	0.059	0.410	0.143
5/25-5/26	1.000	0.000	1.000	0.040	0.654	0.000	0.365	0.040	0.500	0.135
5/27-5/28	1.000	0.055	0.738	0.206	0.708	0.055	0.480	0.206	0.706	0.217
5/29-6/04	0.922	0.079	0.896	0.277	0.844	0.079	0.300	0.277	0.517	0.182
Pooled	0.946	0.023	0.896	0.048	0.849	0.023	0.593	0.048	0.694	0.048
N-Wt Mean	0.963	0.024	0.948	0.039						

Table 3.17. Tag-life-corrected, paired-release estimates of survival rates (S) for YC smolts released above and below JDA, regrouped in virtual releases at the BON spillway, and traveling to the upper end of the BON tailwater. Treatment virtual release data were derived from Table 3.13 and Table 3.14, and reference release data were derived from Table 3.15 and Table 3.16.

Paired Release	S to Tailrace	1/2 95% CI
5/05-5/06	0.902	0.109
5/07-5/08	1.001	0.079
5/09-5/10	0.956	0.069
5/11-5/12	0.983	0.030
5/13-5/14	0.991	0.055
5/15-5/16	0.950	0.054
5/17-5/18	0.969	0.047
5/19-5/20	0.950	0.096
5/21-5/22	1.041	0.168
5/23-5/24	1.094	0.155
5/25-5/26	1.000	0.000
5/27-5/28	0.976	0.074
5/29-6/04	1.055	0.108
Pooled	1.013	0.029
N-Wt Mean	0.999	0.029

3.6.3.2 Relative Survival Rates for YC Passing Through Deep and Shallow Deflector Bays

We found no significant difference in the survival rates of YC passing through end bays with deep flow deflectors and counterparts passing through middle bays with shallow flow deflectors for the entire spring season ($t = 0.8961$; $P > | t | = 0.3868$), the first half of the spring season ($t = 1.1538$; $P > | t | = 0.2730$), or the second half of the spring season ($t = 0.2162$; $P > | t | = 0.8328$). May 15 was selected as the first day of the second half of the spring season. Capture histories and associated survival estimates are presented in Table 3.18 and Table 3.18, respectively, for YC passing through end bays with deep flow deflectors and in Table 3.20 and Table 3.21 for YC passing through middle bays with shallow deflectors. Ratio estimates (deep deflector bay passage survival/shallow deflector bays passage survival) are presented in Table 3.22.

Table 3.18. Detection histories for YC smolts released above and below JDA and detected and regrouped to form virtual releases at BON end spill bays (1-3 and 16-18) in spring. The headings of columns 2 through 9 have three digits and each digit represents a detection (1) or non-detection (0) at three successive survival-detection arrays (A5CR203, A6CR192, and A7CR086), respectively. A Chi-square test for homogeneity, excluding pooled estimates, columns with <5 pooled detections, and totals, was significant (P < 0.0010).

Date	P_111	P_011	P_101	P_001	P_110	P_010	P_100	P_000	Total
5/05-5/06	14	1	0	0	5	0	1	1	22
5/07-5/08	23	3	1	1	12	1	1	4	46
5/09-5/10	22	4	5	0	16	1	1	3	52
5/11-5/12	29	6	3	1	13	0	3	2	57
5/13-5/14	31	2	3	1	9	0	0	1	47
5/15-5/16	18	5	7	1	12	3	2	3	51
5/17-5/18	19	6	10	3	7	1	4	2	52
5/19-5/20	18	2	21	2	6	4	12	6	71
5/21-5/22	11	1	14	2	7	2	17	7	61
5/23-5/24	8	2	13	2	16	3	16	9	69
5/25-5/26	4	3	5	4	14	1	8	2	41
5/27-5/28	4	3	14	1	12	1	11	3	49
5/29-6/04	9	3	22	6	10	2	18	5	75
Pooled	210	41	118	24	139	19	94	48	693

Table 3.19. Tag-life-corrected, single-release estimates of BON spillway passage survival rates (S) and detection probabilities for YC smolts passing through end spill bays (1-3 and 16-18) based on detection histories in Table 3.18. Lambda is the product of survival and detection probabilities for the third array, and CI = confidence interval. The N-Wt Mean (weighted by numbers of fish in each virtual release) is preferred over the pooled estimate when capture histories are not homogeneous.

Virtual Release Dates	S to 1st Array	1/2 95% CI	S from 1st to 2nd Array	1/2 95% CI	Detect. Prob. To 1st Array	1/2 95% CI	Detect. Prob. from 1st to 2nd Array	1/2 95% CI	Lambda	1/2 95% CI
5/05-5/06	0.977	0.095	0.950	0.095	0.950	0.095	1.000	0.095	0.749	0.190
5/07-5/08	0.927	0.086	1.000	0.001	0.878	0.086	0.926	0.001	0.675	0.145
5/09-5/10	0.960	0.069	1.000	0.000	0.894	0.069	0.873	0.000	0.632	0.136
5/11-5/12	0.977	0.050	0.964	0.077	0.865	0.050	0.897	0.077	0.729	0.126
5/13-5/14	0.981	0.041	1.000	0.000	0.934	0.041	0.912	0.000	0.805	0.115
5/15-5/16	0.958	0.067	1.000	0.000	0.799	0.067	0.779	0.000	0.636	0.138
5/17-5/18	0.984	0.059	0.981	0.126	0.783	0.059	0.658	0.126	0.759	0.147
5/19-5/20	0.947	0.072	0.960	0.190	0.849	0.072	0.465	0.190	0.668	0.169
5/21-5/22	0.929	0.095	0.865	0.266	0.865	0.095	0.429	0.266	0.571	0.212
5/23-5/24	0.920	0.094	1.000	0.000	0.836	0.094	0.458	0.000	0.395	0.124
5/25-5/26	1.000	0.025	1.000	0.037	0.757	0.025	0.537	0.037	0.390	0.149
5/27-5/28	1.000	0.001	1.000	0.035	0.837	0.001	0.408	0.035	0.450	0.139
5/29-6/04	1.000	0.000	1.000	0.000	0.788	0.000	0.320	0.000	0.534	0.113
Pooled	0.959	0.022	0.968	0.049	0.848	0.022	0.639	0.049	0.615	0.047
N-Wt Mean	0.964	0.016	0.978	0.022						

Table 3.20. Detection histories for YC smolts released above and below JDA and detected and regrouped to form virtual releases at BON spillway middle bays (4-15) in spring. The headings of columns 2 through 9 have three digits and each digit represents a detection (1) or non-detection (0) at three successive survival-detection arrays (A5CR203, A6CR192, and A7CR086), respectively. A Chi-square test for homogeneity, excluding pooled estimates, columns with <5 pooled detections, and totals, was significant (P < 0.0010).

Date	P_111	P_011	P_101	P_001	P_110	P_010	P_100	P_000	Total
5/05-5/06	15	2	1	0	3	0	0	5	26
5/07-5/08	35	2	1	0	18	0	3	1	60
5/09-5/10	27	4	10	0	4	1	2	5	53
5/11-5/12	38	3	6	1	7	1	1	1	58
5/13-5/14	24	1	6	0	12	0	2	2	47
5/15-5/16	20	4	2	1	6	2	3	3	41
5/17-5/18	23	7	14	1	7	0	6	4	62
5/19-5/20	25	3	16	2	16	1	17	6	86
5/21-5/22	15	2	13	1	13	3	24	9	80
5/23-5/24	15	2	10	3	18	4	18	2	72
5/25-5/26	16	4	13	4	8	2	14	2	63
5/27-5/28	15	4	28	7	18	3	17	8	100
5/29-6/04	11	3	28	7	11	0	15	9	84
Pooled	279	41	148	27	141	17	122	57	832

Table 3.21. Tag-life-corrected, single-release estimates of BON spillway passage survival rates (S) and detection probabilities for YC smolts passing through middle spill bays (4-15) based on detection histories in Table 3.20. Lambda is the product of survival and detection probabilities for the third array, and CI = confidence interval. The N-Wt Mean (weighted by numbers of fish in each virtual release) is preferred over the pooled estimate when capture histories are not homogeneous.

Virtual Release Dates	S to 1st Array	1/2 95% CI	S from 1st to 2nd Array	1/2 95% CI	Detect. Prob. To 1st Array	1/2 95% CI	Detect. Prob. from 1st to 2nd Array	1/2 95% CI	Lambda	1/2 95% CI
5/05-5/06	0.821	0.156	1.000	0.020	0.904	0.156	0.952	0.020	0.856	0.150
5/07-5/08	1.000	0.012	0.956	0.061	0.964	0.012	0.974	0.061	0.683	0.126
5/09-5/10	0.921	0.083	0.987	0.075	0.891	0.083	0.756	0.075	0.864	0.113
5/11-5/12	0.989	0.034	1.000	0.000	0.910	0.034	0.858	0.000	0.840	0.095
5/13-5/14	0.960	0.058	1.000	0.000	0.977	0.058	0.821	0.000	0.690	0.136
5/15-5/16	0.947	0.085	0.929	0.113	0.800	0.085	0.889	0.113	0.750	0.150
5/17-5/18	0.955	0.065	0.941	0.111	0.846	0.065	0.667	0.111	0.813	0.126
5/19-5/20	0.951	0.058	0.904	0.148	0.905	0.058	0.609	0.148	0.623	0.142
5/21-5/22	0.932	0.083	0.807	0.208	0.872	0.083	0.548	0.208	0.515	0.171
5/23-5/24	1.000	0.000	0.957	0.230	0.847	0.000	0.567	0.230	0.435	0.155
5/25-5/26	1.000	0.019	0.881	0.171	0.810	0.019	0.541	0.171	0.667	0.169
5/27-5/28	0.970	0.064	1.000	0.025	0.805	0.064	0.413	0.025	0.557	0.104
5/29-6/04	0.947	0.076	1.000	0.037	0.830	0.076	0.315	0.037	0.630	0.114
Pooled	0.958	0.019	0.932	0.041	0.870	0.019	0.647	0.041	0.672	0.042
N-Wt Mean	0.960	0.020	0.947	0.034						

Table 3.22. Tag-life-corrected, relative survival rates for YC smolts passing through deep deflector bays 1-3 and 16-18 and shallow deflector bays 4-14. The ratio estimates tabulated below were calculated by dividing deep deflector bay passage survival rates (Table 3.19) by shallow deflector bay passage survival rates (Table 3.21).

Paired Release	$\hat{S}_{Deep/Shallow}$	1/2 95% CI
5/05-5/06	1.190	0.254
5/07-5/08	0.927	0.087
5/09-5/10	1.042	0.120
5/11-5/12	0.988	0.061
5/13-5/14	1.022	0.075
5/15-5/16	1.012	0.115
5/17-5/18	1.030	0.093
5/19-5/20	0.996	0.097
5/21-5/22	0.997	0.135
5/23-5/24	0.920	0.094
5/25-5/26	1.000	0.031
5/27-5/28	1.031	0.068
5/29-6/04	1.056	0.085
Arith. Mean	1.016	0.036

3.6.4 Effect of Detecting a Dead Tagged Fish on Survival-Detection Arrays

We detected one dead tagged spring Chinook salmon smolt released in the BON tailrace on the primary and secondary survival-detection arrays and on a Kalama array located 113 km downstream of the dam. This fish was not detected on the tertiary array located at Oak Point 148 km downstream of BON. The travel rate of this dead fish to the primary array was 26.4 hours compared to a rate of 26.6 hours for tagged fish released live at the same time into the BON tailrace. Its travel rate from the dam to the secondary array (30.90 hours) also was very similar to that of live fish released at the same time (30.94 hours). The single dead fish detection brought the cumulative dead fish detection rate $(\hat{D})$ to 0.0126, which is 2 dead fish detections out of 159 dead fish released over 3 years of acoustic telemetry study.

According to Equations 3 and 4 in Appendix C, assuming $\hat{D}$ = 0.0126, the average tag-life- and dead-fish-corrected dam survival rates for YC was 0.972 [0.944 ≤ S ≤ 1.001 = 0.95] instead of a weighted average of 0.997 [0.963 ≤ S ≤ 1.019 = 0.95], which received a tag-life correction only, as described in Section 3.6.2.1. For YC released in the LGR tailrace and regrouped at the forebay entrance array, the average tag-life- and dead-fish corrected dam survival rate was 0.969 [0.927 ≤ S ≤ 1.011 = 0.95], down 3% from 0.999 (see Section 3.6.2.2). The average tag-life- and dead-fish-corrected survival rate for YC passing through the BON spillway was 0.970 [0.940 ≤ S ≤ 1.000 = 0.95] instead of the tag-life-corrected estimate without a dead-fish detection correction, which was 0.999 [0.970 ≤ S ≤ 1.028 = 0.95], as described in Section 3.6.3.1.

3.7 Detection and Survival of Steelhead Smolts

In this section, we describe the results of the arrival times of STH smolts at downstream survival-detection arrays relative to acoustic tag life as determined in a tag-life study, the survival rates of dam-passed and spillway-passed STH smolts, and compare survival rates of STH passing through spill bays with deep and shallow flow deflectors.

3.7.1 Tag-Life Effects

We plotted the fraction of transmitting tags remaining against days since tag activation, and the non-parametric Kaplan-Meier estimator of actual tag survival rate was used to derive tag-life corrections. Over 99.5% of STH bearing 3-s tags passed the primary and secondary survival-detection arrays below BON within 17 days and the tertiary survival-detection array within 19 days. These preceded significant roll-off in the Kaplan-Meir tag-life curve (Figure 3.16). Figure 3.17 shows a plot of the probability that a 3-s tag released at Arlington above JDA or in the tailrace below JDA would still be working by the time that a tagged STH smolt reached the BON survival-detection arrays. Figure 3.18 is a similar plot for spillway passage routes. The average probability that a tag was still working by the time fish reached survival-detection arrays exceeded 99%, and the average was only tenths of a percent lower at each successive array.

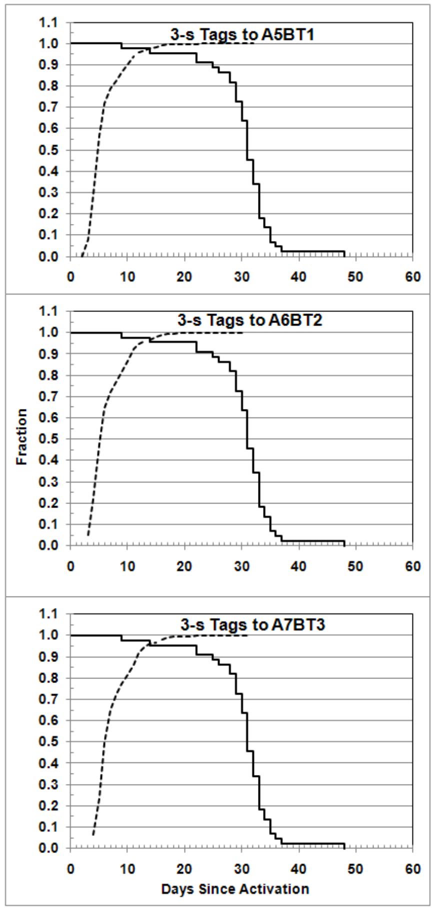


Figure 3.16. Fraction of tag-life study tags transmitting (solid lines) and the cumulative fraction of detected steelhead smolts arriving at the Bonneville Dam primary, secondary, and tertiary survival-detection arrays (dashed lines) as a function of days since tag activation. Arrays were as follows: A5CR203 in the BON tailwater near Reed Island, A6CR192 in the tailwater near Lady Island at Camas, Washington, and A7CR086 near Oak Point, Washington.

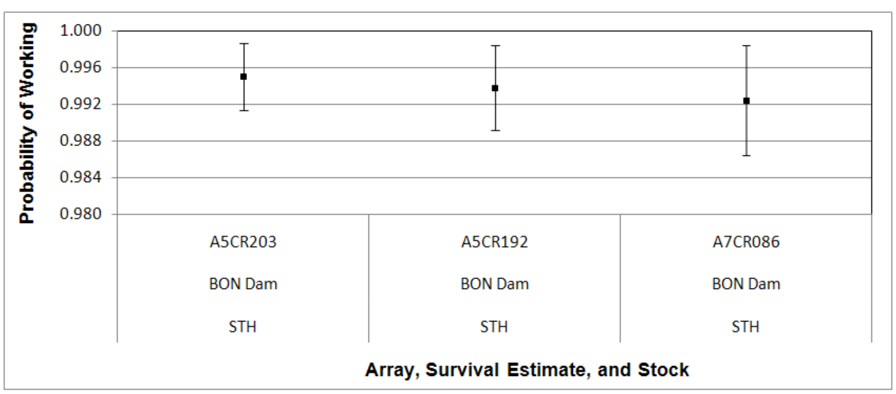


Figure 3.17. Plot of the probability of a tag implanted in STH smolts working by the time fish arrived at survival-detection arrays for BON survival estimates. Array abbreviations are as follows: A5CR203 = Bonneville Tailwater 1 (Primary at Reed Island), A6CR192 = Bonneville Tailwater 2 (Secondary at Camas, Washington), A7CR086 = Bonneville Tailwater 3 (Tertiary at Oak Point, Washington). Vertical bars are ± 1 standard error.

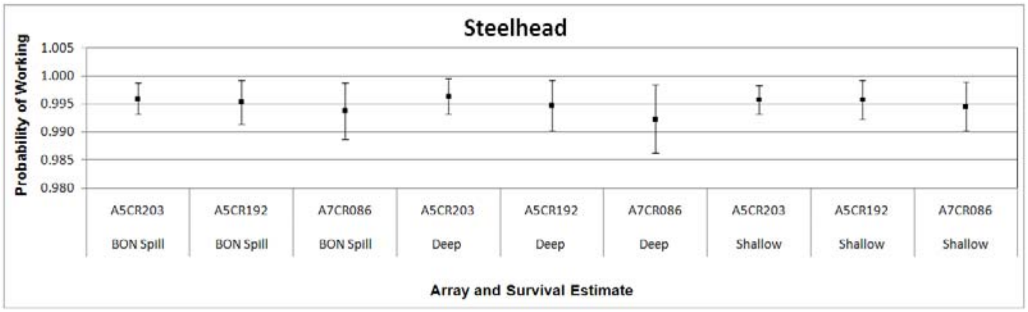


Figure 3.18. Plot of the probability of a tag implanted in STH smolts working by the time fish arrived at survival-detection arrays for estimating BON spillway survival rates. No STH was released in the BON tailwater in 2008. Array abbreviations are as follows: A5CR203 = Bonneville Tailwater 1 (Primary at Reed Island), A6CR192 = Bonneville Tailwater 2 (Secondary at Camas, Washington), A7CR086 = Bonneville Tailwater 3 (Tertiary at Oak Point, Washington). Survival rate abbreviations by passage route are as follows: BON Spill = Bonneville Spillway; Deep = spill bays with deep flow deflectors (Bays 1-3 and 16-18); Shallow = spill bays with shallow flow deflectors (Bays 4-15). Vertical bars are ± 1 standard error.

3.7.2 Survival Rates of Steelhead Smolts Passing Through Bonneville Dam

Steelheads released in the JDA pool and tailwater detected by the BON forebay array were identified and their downstream capture probabilities were recorded for each of 13 consecutive time blocks in spring (Table 3.23). Tag-life-corrected CJS estimates of reach survival were calculated for each virtual release from the BON forebay array (Table 3.23; Table 3.24). Across the 13 single-release trials, we estimated that the n-weighted mean, single-release dam survival rate was $\hat{S}_{Dam} = 0.972$ ($\widehat{SE} = 0.005$). A 95% CI would be $0.967 \leq S \leq 0.977$. A paired-release estimate could not be made because there were no releases of STH in the BON tailwater in 2008.

Table 3.23. Detection histories for STH smolts released above and below JDA, detected and regrouped at the BON forebay entrance array to form virtual releases for estimating dam passage survival rates. The headings of columns 2 through 9 have three digits and each digit represents a detection (1) or non-detection (0) at three successive survival-detection arrays (A5CR203, A6CR192, and A7CR086), respectively. A Chi-square test for homogeneity, excluding pooled estimates, columns with ≤ 5 pooled detections, and totals, was significant ($P < 0.0010$).

Date	P_111	P_011	P_101	P_001	P_110	P_010	P_100	P_000	Total
5/02-5/06	150	10	2	0	71	2	1	7	243
5/07-5/08	116	11	12	1	47	4	4	7	202
5/09-5/10	129	12	55	5	57	7	12	11	288
5/11-5/12	141	6	29	2	67	2	8	14	269
5/13-5/14	108	8	17	0	68	5	7	8	221
5/15-5/16	68	4	22	1	61	1	17	10	184
5/17-5/18	66	3	43	10	45	4	54	13	238
5/19-5/20	38	4	42	12	39	7	79	29	250
5/21-5/22	19	11	29	10	57	10	66	18	220
5/23-5/24	22	8	26	10	50	10	63	24	213
5/25-5/26	31	6	39	4	55	8	63	21	227
5/27-5/28	32	5	46	6	43	13	86	21	252
5/29-6/04	21	3	30	10	32	10	78	25	209
Pooled	941	91	392	71	692	83	538	208	3016

Table 3.24. Tag-life-corrected, single-release estimates of dam survival rates (S) and detection probabilities for STH smolts in virtual releases at the BON forebay entrance array based on detection histories in Table 3.23. Lambda is the product of survival and detection probabilities for the third array, and CI = confidence interval. The N-Wt Mean and CI (weighted by numbers of fish in virtual releases) is preferred over the pooled estimate when capture histories are not homogeneous and some variance estimates approach zero and would overly weight high survival estimates.

Virtual Release Dates	S to 1st Array	1/2 95% CI	S from 1st to 2nd Array	1/2 95% CI	Detect. Prob. To 1st Array	1/2 95% CI	Detect. Prob. from 1st to 2nd Array	1/2 95% CI	Lambda	1/2 95% CI
5/02-5/06	0.996	0.030	0.999	0.020	0.949	0.030	0.988	0.020	0.687	0.060
5/07-5/08	0.977	0.031	1.000	0.017	0.916	0.031	0.911	0.017	0.723	0.064
5/09-5/10	0.978	0.028	1.000	0.000	0.907	0.028	0.735	0.000	0.722	0.053
5/11-5/12	0.953	0.027	1.000	0.000	0.959	0.027	0.845	0.000	0.697	0.057
5/13-5/14	0.968	0.025	1.000	0.014	0.936	0.025	0.885	0.014	0.623	0.065
5/15-5/16	0.951	0.033	1.000	0.000	0.962	0.033	0.767	0.000	0.544	0.074
5/17-5/18	0.972	0.033	0.905	0.101	0.901	0.033	0.566	0.101	0.586	0.089
5/19-5/20	0.946	0.052	0.851	0.152	0.838	0.052	0.438	0.152	0.477	0.104
5/21-5/22	1.000	0.000	1.000	0.000	0.780	0.000	0.441	0.000	0.314	0.061
5/23-5/24	0.972	0.061	0.957	0.216	0.778	0.061	0.455	0.216	0.334	0.098
5/25-5/26	0.948	0.044	1.000	0.097	0.874	0.044	0.465	0.097	0.372	0.068
5/27-5/28	0.985	0.049	0.902	0.181	0.835	0.049	0.416	0.181	0.398	0.100
5/29-6/04	0.985	0.071	0.855	0.229	0.783	0.071	0.375	0.229	0.364	0.116
Pooled	0.957	0.012	0.912	0.024	0.892	0.012	0.690	0.024	0.572	0.023
N-Wt Mean	0.972	0.010	0.959	0.032						

3.7.3 Survival Rates of Spillway-Passed Steelhead

Survival rates were estimated for spillway-passed STH across the entire spillway and for those passing through the deep and shallow deflector bays.

3.7.3.1 Composite Spillway-Passage Estimates

Some of the tagged STH smolts released in the JDA pool and upper tailwater were detected by the BON spillway array and regrouped to form virtual releases of fish passing through that spillway, and their downstream capture probabilities were recorded (Table 3.25) and used to populate a tag-life-corrected CJS (single-release survival rate) model (Table 3.26). Across the 13 single-release trials, we estimated that the n-weighted mean, single-release spillway survival rate was $\hat{S}_{Spill} = 0.962$ ($\widehat{SE} = 0.008$). A 95% CI would be ($0.945 \leq S \leq 0.978$). A paired-release estimate for STH passing through the spillway could not be made because there were no releases of STH in the BON tailwater in 2008.

Table 3.25. Detection histories for STH smolts released above and below JDA and detected and regrouped to form virtual releases at the BON spillway in spring. The headings of columns 2 through 9 have three digits and each digit represents a detection (1) or non-detection (0) at three successive survival-detection arrays (A5CR203, A6CR192, and A7CR086), respectively. A Chi-square test for homogeneity, excluding pooled estimates, columns with <5 pooled detections, and totals, was significant (P < 0.0010).

Date	P_111	P_011	P_101	P_001	P_110	P_010	P_100	P_000	Total
5/04-5/06	41	5	0	0	23	1	0	2	72
5/07-5/08	36	3	6	0	17	2	1	3	68
5/09-5/10	42	4	22	2	30	2	0	7	109
5/11-5/12	53	3	8	0	22	1	0	7	94
5/13-5/14	29	3	5	0	10	1	2	6	56
5/15-5/16	39	2	5	1	40	1	9	9	106
5/17-5/18	40	1	29	5	27	3	28	6	139
5/19-5/20	26	1	28	5	25	4	50	12	151
5/21-5/22	10	6	19	9	35	8	41	9	137
5/23-5/24	17	4	16	5	35	8	35	18	138
5/25-5/26	20	2	23	3	35	6	38	13	140
5/27-5/28	15	3	21	2	23	10	48	10	132
5/29-6/04	12	2	21	7	23	6	52	17	140
Pooled	380	39	203	39	345	53	304	119	1482

Table 3.26. Tag-life-corrected, single-release estimates of BON spillway passage survival rates (S) and detection probabilities for STH smolts in virtual releases at the spillway based on capture histories in Table 3.25. Lambda is the product of survival and detection probabilities for the third array, and CI = confidence interval. The N-Wt mean (weighted by numbers of fish in virtual releases) is preferred over the pooled estimate when capture histories are not homogeneous.

Virtual Release Dates	S to 1st Array	1/2 95% CI	S from 1st to 2nd Array	1/2 95% CI	Detect. Prob. To 1st Array	1/2 95% CI	Detect. Prob. from 1st to 2nd Array	1/2 95% CI	Lambda	1/2 95% CI
5/04-5/06	1.000	0.020	1.000	0.011	0.914	0.020	1.000	0.011	0.657	0.111
5/07-5/08	0.970	0.054	1.000	0.000	0.921	0.054	0.890	0.000	0.696	0.113
5/09-5/10	0.950	0.049	1.000	0.009	0.916	0.049	0.760	0.009	0.685	0.091
5/11-5/12	0.932	0.054	1.000	0.010	0.953	0.054	0.907	0.010	0.737	0.093
5/13-5/14	0.898	0.082	0.990	0.071	0.917	0.082	0.865	0.071	0.746	0.131
5/15-5/16	0.921	0.054	0.965	0.084	0.955	0.054	0.872	0.084	0.502	0.109
5/17-5/18	0.977	0.037	0.957	0.135	0.914	0.037	0.547	0.135	0.579	0.115
5/19-5/20	0.964	0.054	0.855	0.186	0.888	0.054	0.450	0.186	0.482	0.131
5/21-5/22	1.000	0.000	1.000	0.000	0.770	0.000	0.430	0.000	0.321	0.078
5/23-5/24	0.933	0.071	0.995	0.254	0.800	0.071	0.500	0.254	0.329	0.115
5/25-5/26	0.947	0.056	1.000	0.000	0.875	0.056	0.475	0.000	0.362	0.083
5/27-5/28	1.000	0.025	0.880	0.251	0.811	0.025	0.439	0.251	0.353	0.131
5/29-6/04	0.979	0.085	0.942	0.342	0.789	0.085	0.333	0.342	0.326	0.140
Pooled	0.953	0.016	0.917	0.041	0.876	0.016	0.634	0.041	0.514	0.034
N-Wt Mean	0.962	0.016	0.962	0.028						

3.7.3.2 Relative Survival Rates for STH Passing Through Deep and Shallow Deflector Bays

We found no significant difference in the survival rates of STH passing through end bays with deep flow deflectors and their counterparts passing through middle bays with shallow flow deflectors for the entire spring season (t = -0.8243; P > | t | = 0.4258), the first half of the spring season (t = 0.5374; P > | t | = 0.6017), or the second half of the spring season (t = -1.4908; P > | t | = 0.1641). As for YC, May 15 was selected as the first day of the second half of the spring season. Capture histories and associated survival estimates are presented in Table 3.27 and Table 3.28, respectively, for STH passing through end bays with deep flow deflectors and in Table 3.29 and Table 3.30 for STH passing through middle bays with shallow deflectors. Ratio estimates (deep deflector bay passage survival rates/shallow deflector bays passage survival rates) are presented in Table 3.31. The arithmetic mean and 95% CI for the ratio estimate for the spring season were 0.984 and 0.945 ≤ S ≤ 1.026, respectively.

Table 3.27. Detection histories for STH smolts released above and below JDA and detected and regrouped to form virtual releases of fish passing through BON spillway end bays with deep flow deflectors in (1-3 and 16-18) in spring. The headings of columns 2 through 9 have three digits and each digit represents a detection (1) or non-detection (0) at three successive survival-detection arrays (A5CR203, A6CR192, and A7CR086), respectively. A Chi-square test for homogeneity, excluding pooled estimates, columns with <5 pooled detections, and totals, was significant (P < 0.0010).

Date	P_111	P_011	P_101	P_001	P_110	P_010	P_100	P_000	Total
5/04-5/06	23	4	0	0	14	0	0	2	43
5/07-5/08	19	2	3	0	8	2	0	0	34
5/09-5/10	20	1	9	1	19	2	0	1	53
5/11-5/12	28	1	2	0	14	0	0	4	49
5/13-5/14	6	0	2	0	8	0	2	3	21
5/15-5/16	11	0	2	0	17	1	7	7	45
5/17-5/18	9	1	8	2	6	2	8	3	39
5/19-5/20	10	0	11	4	13	2	20	5	65
5/21-5/22	5	0	4	3	18	4	21	4	59
5/23-5/24	7	2	10	2	16	2	15	8	62
5/25-5/26	9	0	6	2	15	2	21	5	60
5/27-5/28	9	2	4	0	13	2	19	5	54
5/29-6/04	5	0	6	0	8	2	20	8	49
Pooled	161	13	67	14	169	21	133	55	633

Table 3.28. Tag- life corrected, single-release estimates of BON spillway passage survival rates (S) and detection probabilities for STH smolts passing through end spill bays (1-3 and 16-18) based on detection histories in Table 3.27. Lambda is the product of survival and detection probabilities for the third array, and CI = confidence interval. The N-Wt mean (weighted by numbers of fish in each virtual release) is preferred over the pooled estimate when capture histories are not homogeneous.

Virtual Release Dates	S to 1st Array	1/2 95% CI	S from 1st to 2nd Array	1/2 95% CI	Detect. Prob. To 1st Array	1/2 95% CI	Detect. Prob. from 1st to 2nd Array	1/2 95% CI	Lambda	1/2 95% CI
5/04-5/06	0.976	0.072	1.000	0.014	0.902	0.072	1.000	0.014	0.658	0.145
5/07-5/08	1.000	0.015	1.000	0.015	0.882	0.015	0.912	0.015	0.712	0.154
5/09-5/10	0.997	0.039	1.000	0.000	0.917	0.039	0.802	0.000	0.595	0.134
5/11-5/12	0.923	0.077	1.000	0.000	0.978	0.077	0.955	0.000	0.691	0.136
5/13-5/14	0.858	0.150	1.000	0.000	1.000	0.150	0.777	0.000	0.445	0.230
5/15-5/16	0.850	0.107	0.896	0.192	0.968	0.107	0.846	0.192	0.380	0.177
5/17-5/18	0.968	0.102	0.953	0.298	0.821	0.102	0.500	0.298	0.558	0.231
5/19-5/20	0.977	0.085	0.984	0.375	0.850	0.085	0.400	0.375	0.400	0.192
5/21-5/22	1.000	0.028	1.000	0.080	0.814	0.028	0.458	0.080	0.204	0.103
5/23-5/24	0.919	0.098	1.000	0.051	0.842	0.098	0.474	0.051	0.369	0.129
5/25-5/26	0.963	0.090	0.850	0.328	0.882	0.090	0.529	0.328	0.346	0.183
5/27-5/28	0.962	0.102	0.683	0.212	0.867	0.102	0.733	0.212	0.423	0.190
5/29-6/04	0.880	0.126	0.766	0.431	0.905	0.126	0.455	0.431	0.333	0.239
Pooled	0.942	0.025	0.899	0.062	0.892	0.025	0.682	0.062	0.479	0.051
N-Wt Mean	0.948	0.027	0.929	0.059						

Table 3.29. Detection histories for STH smolts released above and below JDA and detected and regrouped to form virtual releases of fish passing through BON spillway middle bays (1-3 and 16-18) in spring. The headings of columns 2 through 9 have three digits and each digit represents a detection (1) or non-detection (0) at three successive survival-detection arrays (A5CR203, A6CR192, and A7CR086), respectively. A Chi-square test for homogeneity, excluding pooled estimates, columns with <5 pooled detections, and totals, was significant (P < 0.0010).

Date	P_111	P_011	P_101	P_001	P_110	P_010	P_100	P_000	Total
5/04-5/06	18	1	0	0	9	1	0	0	29
5/07-5/08	17	1	3	0	9	0	1	3	34
5/09-5/10	22	3	13	1	11	0	0	6	56
5/11-5/12	25	2	6	0	8	1	0	3	45
5/13-5/14	23	3	3	0	2	1	0	3	35
5/15-5/16	28	2	3	1	23	0	2	2	61
5/17-5/18	31	0	21	3	21	1	20	3	100
5/19-5/20	16	1	17	1	12	2	30	7	86
5/21-5/22	5	6	15	6	17	4	20	5	78
5/23-5/24	10	2	6	3	19	6	20	10	76
5/25-5/26	11	2	17	1	20	4	17	8	80
5/27-5/28	6	1	17	2	10	8	29	5	78
5/29-6/04	7	2	15	7	15	4	32	9	91
Pooled	219	26	136	25	176	32	171	64	849

Table 3.30. Tag-life-corrected, single-release estimates of BON spillway passage survival rates (S) and detection probabilities for STH smolts passing through middle spill bays (1-3 and 16-18) based on detection histories in Table 3.29. Lambda is the product of survival and detection probabilities for the third array, and CI = confidence interval. The N-Wt mean (weighted by numbers of fish in each virtual release) is preferred over the pooled estimate when capture histories are not homogeneous.

Virtual Release Dates	S to 1st Array	1/2 95% CI	S from 1st to 2nd Array	1/2 95% CI	Detect. Prob. To 1st Array	1/2 95% CI	Detect. Prob. from 1st to 2nd Array	1/2 95% CI	Lambda	1/2 95% CI
5/04-5/06	1.000	0.000	1.000	0.000	0.931	0.000	1.000	0.000	0.656	0.173
5/07-5/08	0.924	0.098	1.000	0.000	0.966	0.098	0.869	0.000	0.681	0.166
5/09-5/10	0.904	0.083	1.000	0.000	0.915	0.083	0.716	0.000	0.780	0.117
5/11-5/12	0.941	0.074	1.000	0.014	0.926	0.074	0.855	0.014	0.786	0.125
5/13-5/14	0.918	0.093	1.000	0.000	0.874	0.093	0.905	0.000	0.907	0.102
5/15-5/16	0.972	0.045	1.000	0.000	0.947	0.045	0.896	0.000	0.576	0.127
5/17-5/18	0.983	0.036	0.959	0.151	0.948	0.036	0.564	0.151	0.585	0.133
5/19-5/20	0.951	0.068	0.780	0.204	0.918	0.068	0.486	0.204	0.549	0.175
5/21-5/22	1.000	0.016	1.000	0.036	0.736	0.016	0.409	0.036	0.409	0.109
5/23-5/24	0.951	0.105	0.896	0.295	0.761	0.105	0.571	0.295	0.325	0.151
5/25-5/26	0.938	0.075	1.000	0.000	0.867	0.075	0.494	0.000	0.414	0.114
5/27-5/28	1.000	0.018	1.000	0.051	0.795	0.018	0.321	0.051	0.333	0.105
5/29-6/04	1.000	0.000	1.000	0.000	0.759	0.000	0.308	0.000	0.341	0.097
Pooled	0.960	0.021	0.925	0.054	0.865	0.021	0.604	0.054	0.542	0.046
N-Wt Mean	0.965	0.018	0.964	0.039						

Table 3.31. Tag-life-corrected, relative survival rates for STH smolts passing through deep deflector bays 1-3 and 16-18 and shallow deflector bays 4-14. The ratio estimates tabulated below were calculated by dividing deep deflector bay passage survival rates (Table 3.28) by shallow deflector bay passage survival rates (Table 3.30).

Paired Release	S to Tailrace	1/2 95% CI
5/04-5/06	0.976	0.072
5/07-5/08	1.082	0.116
5/09-5/10	1.103	0.110
5/11-5/12	0.981	0.112
5/13-5/14	0.935	0.189
5/15-5/16	0.874	0.117
5/17-5/18	0.985	0.110
5/19-5/20	1.027	0.116
5/21-5/22	1.000	0.032
5/23-5/24	0.966	0.148
5/25-5/26	1.027	0.126
5/27-5/28	0.962	0.103
5/29-6/04	0.880	0.126
Pooled	0.981	0.034
Arith. Mean	0.984	0.038

3.8 Detection and Survival Rates of Fall Chinook Salmon in Summer

In this section, we describe the time of arrival of FC smolts at downstream survival-detection arrays relative to acoustic tag life, as determined in the tag-life study, the survival rates of dam-passed and spillway-passed FC smolts, and compare survival rates of subyearlings passing through bays with deep and shallow flow deflectors.

3.8.1 Tag-Life Effects

Over 99.5% of FC bearing 3-s tags passed the primary survival-detection array below BON within 8 days, the secondary within 8 days, and the tertiary within 10 days, long before acoustic tags showed any appreciable failure (Figure 3.19). A plot of the probability that a 3-s tag released at Arlington above JDA or in the tailrace below JDA would still be working by the time it reached the BON survival-detection arrays is shown in Figure 3.20. Similar plots by spillway passage route and fish released in the BON tailwater are presented in Figure 3.21. In every plot, the average probability that a tag was still working by the time fish reached survival-detection arrays exceeded 99.6% and the average tended to be tenths of a percent lower at each successive array.

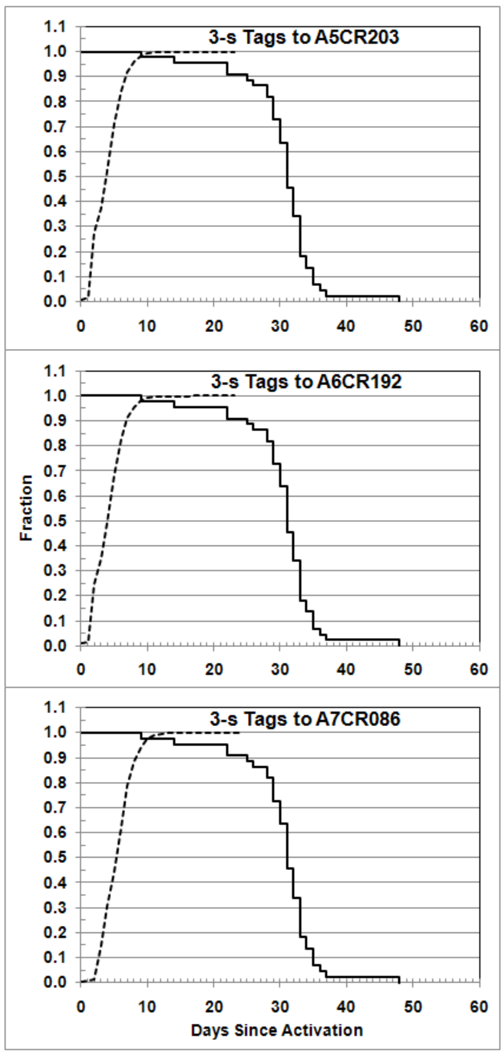


Figure 3.19. Fraction of tag-life study tags transmitting (solid lines) and the cumulative fraction of detected FC smolts arriving at the BON primary, secondary, and tertiary survival-detection arrays (dashed lines) as a function of days since tag activation. Arrays were as follows: A5CR203 in the Bonneville tailwater near Reed Island, A6CR192 in the tailwater near Lady Island at Camas, Washington, and A7CR086 near Oak Point, Washington.

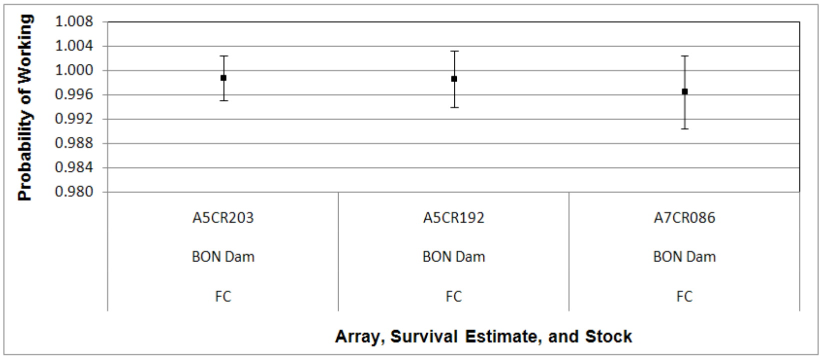


Figure 3.20. Plot of the probability of a tag implanted in FC smolts working by the time fish arrived at survival-detection arrays for BON survival estimates. Array abbreviations are as follows: A5CR203 = Bonneville Tailwater 1 (Primary at Reed Island), A6CR192 = Bonneville Tailwater 2 (Secondary at Camas, Washington), A7CR086 = Bonneville Tailwater 3 (Tertiary at Oak Point, Washington). Vertical bars are ± 1 standard error.

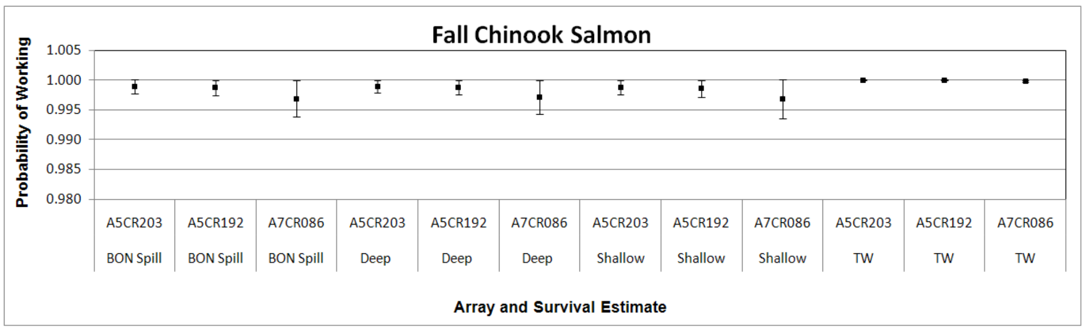


Figure 3.21. Plot of the probability of a tag implanted in FC smolts working by the time fish arrived at survival-detection arrays for estimating BON spillway survival rates. Array abbreviations are as follows: A5CR203 = Bonneville Tailwater 1 (Primary at Reed Island), A6CR192 = Bonneville Tailwater 2 (Secondary at Camas, Washington), A7CR086 = Bonneville Tailwater 3 (Tertiary at Oak Point, Washington). Survival rates were estimated for fish passing via four routes: BON Spill = Bonneville Spillway; Deep = spill bays with deep flow deflectors (Bays 1-3 and 16-18); Shallow = spill bays with shallow flow deflectors (Bays 4-15); TW = Bonneville Tailwater. Vertical bars are ± 1 standard error.

3.8.2 Survival Rates of Fall Chinook Salmon Passing Through Bonneville Dam

Fall Chinook Salmon smolts released in the JDA pool and tailwater and detected by the BON forebay array were identified and their downstream capture probabilities were recorded for each of 15 consecutive time blocks in summer (Table 3.32), as were capture histories of BON tailwater reference releases (Table 3.33). Tag-life-corrected CJS estimates of reach survival rates were calculated for each virtual release from the BON forebay array (Table 3.32; Table 3.34) and tailrace release (Table 3.33; Table 3.35). For each daily release pair, estimates of spillway passage survival rates from the forebay entrance array to the tailwater release site were calculated using the fully parameterized CJS model (Table 3.36). Across the 15 paired-release trials, we estimated that tag-life-corrected, n-weighted-mean dam survival rates for subyearlings traveling from the forebay entrance array to the tailrace release site was $\hat{S}_{Dam} = 0.970$ ($\widehat{SE} = 0.007$). A 95% CI was $0.956 \le S \le 0.984$.

Table 3.32. Detection histories for FC smolts released above and below JDA or below TDA, and detected at the BON forebay entrance array to form virtual releases to estimate BON passage survival rates. The headings of columns 2 through 9 have three digits and each digit represents a detection (1) or non-detection (0) at three successive survival-detection arrays (A5CR203, A6CR192, and A7CR086), respectively. A Chi-square test for homogeneity, excluding pooled estimates, columns with <5 pooled detections, and totals, was significant (P < 0.0010).

Date	P_111	P_011	P_101	P_001	P_110	P_010	P_100	P_000	Total
6/17-6/18	99	11	55	8	34	13	19	12	251
6/19-6/20	140	22	87	18	56	6	31	14	374
6/21-6/22	162	11	88	8	33	2	13	17	334
6/23-6/24	146	17	97	13	50	5	39	12	379
6/25-6/26	183	30	80	15	60	7	28	18	421
6/27-6/28	169	29	50	7	77	13	25	18	388
6/29-6/30	145	13	42	8	62	4	15	19	308
7/01-7/02	161	20	61	10	69	4	26	17	368
7/03-7/04	231	12	25	2	62	6	14	19	371
7/05-7/06	257	12	5	0	59	5	5	17	360
7/07-7/08	242	22	14	1	49	4	2	20	354
7/09-7/10	236	27	10	1	36	4	3	29	346
7/11-7/12	272	14	13	4	38	3	5	31	380
7/13-7/14	280	1	5	0	41	0	5	23	355
7/15-7/17	75	4	0	0	26	1	2	13	121
Pooled	2798	245	632	95	752	77	232	279	5110

Table 3.33. Detection histories for FC smolts released in the upper end of the BON tailwater as reference releases for making paired-release estimates of BON passage survival rates and spillway passage survival rates. The headings of columns 2 through 9 have three digits and each digit represents a detection (1) or non-detection (0) at three successive survival-detection arrays (A5CR203, A6CR192, and A7CR086), respectively. A Chi-square test for homogeneity, excluding pooled estimates, columns with <5 pooled detections, and totals, was not significant (P < 0.0010).

Date	P_111	P_011	P_101	P_001	P_110	P_010	P_100	P_000	Total
6/17-6/18	18	3	16	3	7	0	11	2	60
6/19-6/20	14	6	17	5	8	3	4	3	60
6/21-6/22	22	3	15	3	10	0	7	0	60
6/23-6/24	16	1	22	3	6	1	7	4	60
6/25-6/26	14	1	8	4	9	0	18	5	59
6/27-6/28	23	3	12	2	7	2	9	2	60
6/29-6/30	17	6	15	1	14	2	4	1	60
7/01-7/02	21	1	17	0	8	3	8	2	60
7/03-7/04	33	3	7	1	12	1	2	1	60
7/05-7/06	34	3	3	0	17	1	2	0	60
7/07-7/08	37	7	4	0	8	2	1	1	60
7/09-7/10	34	8	5	0	11	1	0	1	60
7/11-7/12	34	6	8	1	5	2	2	2	60
7/13-7/14	41	0	1	1	14	1	1	1	60
7/15-7/17	54	0	1	0	19	0	2	3	79
Pooled	412	51	151	24	155	19	78	28	918

Table 3.34. Tag-life-corrected, single-release estimates of dam passage survival rates (S) and detection probabilities for FC smolts based on capture history data in Table 3.32. Lambda is the product of survival and detection probabilities for the third array, and CI = confidence interval. The N-Wt Mean (weighted by numbers of fish in each virtual release) is preferred over the pooled estimate when capture histories are not homogeneous.

Virtual Release Dates	S to 1st Array	1/2 95% CI	S from 1st to 2nd Array	1/2 95% CI	Detect. Prob. To 1st Array	1/2 95% CI	Detect. Prob. from 1st to 2nd Array	1/2 95% CI	Lambda	1/2 95% CI
6/17-6/18	0.967	0.028	1.000	0.019	0.853	0.028	0.647	0.019	0.713	0.058
6/19-6/20	0.977	0.020	1.000	0.000	0.859	0.020	0.613	0.000	0.732	0.047
6/21-6/22	0.953	0.024	1.000	0.000	0.930	0.024	0.654	0.000	0.847	0.040
6/23-6/24	0.982	0.019	0.982	0.052	0.893	0.019	0.597	0.052	0.753	0.058
6/25-6/26	0.970	0.020	0.994	0.039	0.861	0.020	0.692	0.039	0.764	0.050
6/27-6/28	0.971	0.025	0.992	0.040	0.858	0.025	0.777	0.040	0.688	0.054
6/29-6/30	0.945	0.027	1.000	0.000	0.908	0.027	0.770	0.000	0.718	0.053
7/01-7/02	0.965	0.023	1.000	0.000	0.895	0.023	0.718	0.000	0.715	0.048
7/03-7/04	0.953	0.023	0.979	0.024	0.941	0.023	0.900	0.024	0.782	0.046
7/05-7/06	0.954	0.022	0.988	0.014	0.950	0.022	0.982	0.014	0.809	0.042
7/07-7/08	0.945	0.024	1.000	0.000	0.919	0.024	0.949	0.000	0.836	0.040
7/09-7/10	0.917	0.029	0.995	0.012	0.898	0.029	0.960	0.012	0.869	0.038
7/11-7/12	0.920	0.028	0.992	0.014	0.939	0.028	0.944	0.014	0.876	0.036
7/13-7/14	0.935	0.026	0.987	0.013	0.997	0.026	0.983	0.013	0.873	0.036
7/15-7/17	0.895	0.055	0.981	0.027	0.953	0.055	1.000	0.027	0.748	0.083
Pooled	0.951	0.007	0.988	0.008	0.909	0.007	0.807	0.008	0.788	0.013
N-Wt Mean	0.953	0.011	0.993	0.004						

Table 3.35. Tag-life-corrected, single-release estimates of dam passage survival rates (S) and detection probabilities for FC smolts based on capture histories of reference releases in Table 3.33. These survival estimates also were used as reference releases for estimating BON spillway passage survival rates and survival rates of FC smolts passing through end and middle spill bays. Lambda is the product of survival and detection probabilities for the third array, and CI = confidence interval. The N-Wt Mean (weighted by numbers of fish in each virtual release) is preferred over the pooled estimate when capture histories are not homogeneous.

Virtual Release Dates	S to 1st Array	1/2 95% CI	S from 1st to 2nd Array	1/2 95% CI	Detect. Prob. To 1st Array	1/2 95% CI	Detect. Prob. from 1st to 2nd Array	1/2 95% CI	Lambda	1/2 95% CI
6/17-6/18	0.994	0.054	0.895	0.160	0.872	0.054	0.525	0.160	0.750	0.161
6/19-6/20	0.988	0.064	1.000	0.023	0.726	0.064	0.523	0.023	0.709	0.123
6/21-6/22	1.000	0.011	1.000	0.086	0.900	0.011	0.583	0.086	0.718	0.118
6/23-6/24	0.948	0.066	1.000	0.039	0.896	0.066	0.422	0.039	0.739	0.118
6/25-6/26	0.965	0.090	0.759	0.201	0.861	0.090	0.556	0.201	0.625	0.194
6/27-6/28	0.992	0.053	0.905	0.135	0.857	0.053	0.650	0.135	0.743	0.145
6/29-6/30	1.000	0.024	1.000	0.020	0.833	0.024	0.650	0.020	0.650	0.121
7/01-7/02	0.978	0.048	0.997	0.162	0.920	0.048	0.564	0.162	0.667	0.161
7/03-7/04	0.987	0.033	1.000	0.028	0.912	0.033	0.827	0.028	0.743	0.112
7/05-7/06	1.000	0.011	0.991	0.055	0.933	0.011	0.925	0.055	0.673	0.124
7/07-7/08	0.986	0.033	0.995	0.043	0.845	0.033	0.917	0.043	0.815	0.104
7/09-7/10	0.986	0.033	1.000	0.000	0.845	0.033	0.913	0.000	0.794	0.103
7/11-7/12	0.973	0.047	0.986	0.063	0.839	0.047	0.816	0.063	0.851	0.102
7/13-7/14	0.984	0.032	0.995	0.039	0.966	0.032	0.954	0.039	0.732	0.116
7/15-7/17	0.962	0.042	0.978	0.037	1.000	0.042	0.982	0.037	0.740	0.101
Pooled	0.981	0.012	0.975	0.027	0.884	0.012	0.726	0.027	0.727	0.035
N-Wt Mean	0.982	0.008	0.967	0.033						

Table 3.36. Tag-life-corrected, paired-release estimates of dam survival rates (S) for FC smolts released above and below JDA, below TDA, and regrouped to form virtual releases traveling from the BON forebay entrance array to the uppermost end of the BON tailwater. Treatment virtual release data were derived from Table 3.34, and reference release data were derived from Table 3.35.

Paired Release	S to Tailrace	1/2 95% CI
6/17-6/18	0.973	0.060
6/19-6/20	0.989	0.067
6/21-6/22	0.953	0.026
6/23-6/24	1.035	0.075
6/25-6/26	1.006	0.096
6/27-6/28	0.979	0.058
6/29-6/30	0.945	0.036
7/01-7/02	0.986	0.054
7/03-7/04	0.965	0.039
7/05-7/06	0.954	0.024
7/07-7/08	0.958	0.040
7/09-7/10	0.930	0.043
7/11-7/12	0.945	0.053
7/13-7/14	0.951	0.041
7/15-7/17	0.930	0.070
Pooled	0.970	0.013
N-Wt Mean	0.970	0.014

3.8.3 Survival Rates of Spillway-Passed Fall Chinook Salmon Smolts

We made composite estimates of FC smolt survival rates for the entire spillway and for those smolts passing through the deep and shallow deflector bays.

3.8.3.1 Composite Spillway-Passage Estimates

During 15 releases of smolts, we identified 2304 acoustic-tagged FC smolts as passing through the BON spillway, tallied their capture history probabilities (Table 3.37), and estimated detection probabilities and single-release survival rates (Table 3.38). These 15 virtual releases of smolts passing through the spillway were paired daily with 15 reference releases in the tailrace totaling 918 fish (Table 3.33 and Table 3.35) to produce paired-release survival rate estimates shown in Table 3.39. The n-weighted-mean paired-release survival rates for FC passing through the spillway and traveling to the tailrace release site was 0.969 (95% CI = $0.953 \le S \le 0.985$).

Table 3.37. Detection histories for FC smolts released above and below JDA, below TDA, and detected and regrouped to form virtual releases at the BON spillway in summer. The headings of columns 2 through 9 have three digits and each digit represents a detection (1) or non-detection (0) at three successive survival-detection arrays (A5CR203, A6CR192, and A7CR086), respectively. A Chi-square test for homogeneity, excluding pooled estimates, columns with <5 pooled detections, and totals, was significant ($P < 0.0010$).

Date	P_111	P_011	P_101	P_001	P_110	P_010	P_100	P_000	Total
6/17-6/18	53	7	28	2	10	5	9	4	118
6/19-6/20	77	11	47	11	21	6	18	7	198
6/21-6/22	79	2	48	4	11	1	7	7	159
6/23-6/24	57	3	36	4	24	2	14	6	146
6/25-6/26	76	18	33	4	29	3	19	8	190
6/27-6/28	78	11	27	3	33	4	13	6	175
6/29-6/30	64	7	14	3	34	3	7	8	140
7/01-7/02	57	9	23	4	30	2	11	10	146
7/03-7/04	100	4	10	1	23	1	3	3	145
7/05-7/06	100	8	1	0	17	2	3	11	142
7/07-7/08	91	11	8	0	19	1	1	10	141
7/09-7/10	97	11	4	1	22	1	2	10	148
7/11-7/12	129	6	9	2	22	3	2	19	192
7/13-7/14	152	1	3	0	22	0	2	14	194
7/15-7/17	45	1	0	0	15	1	2	6	70
Pooled	1255	110	291	39	332	35	113	129	2304

Table 3.38. Tag-life-corrected, single-release estimates of BON spillway passage survival rates (S) and detection probabilities for FC smolts in virtual releases at the spillway based on capture histories in Table 3.37. Lambda is the product of survival and detection probabilities for the third array, and CI = confidence interval. The N-Wt Mean (weighted by numbers of fish in virtual releases) is preferred over the pooled estimate when capture histories are not homogeneous and some variance estimates approach zero and would overly weight high survival estimates.

Virtual Release Dates	S to 1st Array	1/2 95% CI	S from 1st to 2nd Array	1/2 95% CI	Detect. Prob. To 1st Array	1/2 95% CI	Detect. Prob. from 1st to 2nd Array	1/2 95% CI	Lambda	1/2 95% CI
6/17-6/18	0.978	0.034	0.975	0.073	0.867	0.034	0.667	0.073	0.800	0.091
6/19-6/20	0.982	0.028	0.981	0.069	0.838	0.028	0.603	0.069	0.766	0.078
6/21-6/22	0.959	0.032	1.000	0.000	0.952	0.032	0.611	0.000	0.874	0.054
6/23-6/24	0.968	0.033	1.000	0.000	0.928	0.033	0.609	0.000	0.714	0.076
6/25-6/26	0.978	0.031	0.947	0.064	0.847	0.031	0.718	0.064	0.749	0.076
6/27-6/28	0.983	0.032	0.987	0.061	0.885	0.032	0.748	0.061	0.707	0.080
6/29-6/30	0.950	0.039	1.000	0.000	0.896	0.039	0.813	0.000	0.664	0.081
7/01-7/02	0.944	0.042	1.000	0.000	0.880	0.042	0.713	0.000	0.679	0.080
7/03-7/04	0.982	0.023	0.996	0.028	0.957	0.023	0.904	0.028	0.813	0.068
7/05-7/06	0.925	0.044	0.977	0.028	0.922	0.044	0.991	0.028	0.851	0.062
7/07-7/08	0.930	0.042	1.000	0.015	0.907	0.042	0.930	0.015	0.840	0.063
7/09-7/10	0.934	0.041	0.992	0.023	0.904	0.041	0.956	0.023	0.825	0.065
7/11-7/12	0.902	0.042	1.000	0.001	0.936	0.042	0.925	0.001	0.845	0.054
7/13-7/14	0.928	0.036	0.991	0.016	0.994	0.036	0.981	0.016	0.874	0.049
7/15-7/17	0.915	0.066	0.968	0.044	0.968	0.066	1.000	0.044	0.745	0.109
Pooled	0.950	0.010	0.984	0.012	0.911	0.010	0.805	0.012	0.790	0.019
N-Wt Mean	0.952	0.014	0.988	0.008						

Table 3.39. Tag-life-corrected, paired-release estimates of survival rates (S) for FC smolts released above and below JDA or below TDA, regrouped in virtual releases at the BON spillway, and traveling to the upper end of the BON tailwater. Treatment virtual release data were derived from Table 3.36 and Table 3.37, and reference release data were derived from Table 3.33 and Table 3.35.

Paired Release	S to Tailrace	1/2 95% CI
6/17-6/18	0.984	0.064
6/19-6/20	0.995	0.071
6/21-6/22	0.959	0.034
6/23-6/24	1.020	0.079
6/25-6/26	1.014	0.100
6/27-6/28	0.991	0.062
6/29-6/30	0.950	0.045
7/01-7/02	0.965	0.064
7/03-7/04	0.994	0.041
7/05-7/06	0.925	0.045
7/07-7/08	0.943	0.053
7/09-7/10	0.947	0.052
7/11-7/12	0.927	0.062
7/13-7/14	0.943	0.048
7/15-7/17	0.951	0.080
Pooled	0.969	0.015
N-Wt Mean	0.969	0.016

3.8.3.2 Relative Survival Rates for FC Passing Through Deep and Shallow Deflector Bays

During 15 summer trials, 1018 FC smolts were identified going through deep flow deflector bays (Table 3.40) and 1286 were identified going through shallow flow deflector bays (Table 3.41). Chi-square tests of homogeneity found the survival and detection processes for the replicate trials to be significantly different ($P < 0.001$), precluding pooling of the data over the season. Using the single-release-recapture model, reach survival estimates were calculated for each of the virtual releases formed for deep flow deflector bays (Table 3.42) and shallow flow deflector bays (Table 3.43). For the deep flow deflector releases, the weighted-average survival from BON to the primary downstream array was 0.957 ($\widehat{SE} = 0.007$). For the shallow flow deflector releases, a weighted-average survival for that same initial reach was 0.946 ($\widehat{SE} = 0.012$). For both treatment groups, reach survival rates between primary and secondary arrays were high (0.974-0.988).

An ANODEV using the estimates of relative survival rates (Table 3.44), based on a log-link, normal error structure and no weighting, revealed that relative survival rates for FC smolts passing through deep and shallow deflector bays did not differ significantly in summer [$t = 1.3243$; $P(>|t|)=0.2066$]. However, splitting the analysis into two parts, depending on tailwater elevation, suggested that the survival rates of smolts passing through bays with deep flow deflectors was significantly higher than that of smolts passing through bays with shallow flow deflectors during the period from July 3 through July 17, 2008 (Figure 3.22). For the first reach, five out of seven ratio estimates exceeded 1 and two were slightly below 1. The unweighted relative survival rate (Deep/Shallow) during this period was 1.065 [95% CI = $1.002 \leq S \leq 1.132$). An ANODEV confirmed that the survival rates of FC smolts passing through end bays with deep flow deflectors was higher than that of their counterparts passing through middle bays with shallow flow deflectors ($t = 3.573$; $P(>|t|)=0.0034$). These results are consistent with the alternative hypothesis that survival rates of FC passing through spill bays containing the deep flow deflectors would be better than through those containing shallow flow deflectors.

Table 3.40. Detection histories for FC smolts released above and below JDA or below TDA, detected passing through spill bays with deep flow deflectors (bays 1-3 and 16-18), and regrouped to form virtual releases there in summer. The headings of columns 2 through 9 have three digits and each digit represents a detection (1) or non-detection (0) at three successive survival-detection arrays (A5CR203, A6CR192, and A7CR086), respectively. A Chi-square test for homogeneity, excluding pooled estimates, columns with <5 pooled detections, and totals, was significant (P < 0.0010).

Date	P_111	P_011	P_101	P_001	P_110	P_010	P_100	P_000	Total
6/17-6/18	18	1	5	1	4	2	4	1	36
6/19-6/20	28	4	23	4	4	2	8	4	77
6/21-6/22	29	2	19	1	4	1	3	3	62
6/23-6/24	27	1	12	2	12	0	9	3	66
6/25-6/26	34	10	20	0	15	1	12	6	98
6/27-6/28	25	6	10	1	14	0	6	4	66
6/29-6/30	31	2	6	2	14	1	2	4	62
7/01-7/02	27	4	16	3	21	1	4	6	82
7/03-7/04	44	2	6	1	10	1	1	0	65
7/05-7/06	51	2	0	0	9	1	3	1	67
7/07-7/08	37	7	2	0	8	0	0	5	59
7/09-7/10	53	4	4	0	10	0	1	1	73
7/11-7/12	66	3	2	1	8	2	2	7	91
7/13-7/14	71	1	0	0	11	0	1	7	91
7/15-7/17	19	0	0	0	4	0	0	0	23
Pooled	560	49	125	16	148	12	56	52	1018

Table 3.41. Detection histories for FC smolts released above and below JDA or below TDA, and detected and regrouped to form virtual releases at BON spillway middle bays (4-15) in summer. The headings of columns 2 through 9 have three digits and each digit represents a detection (1) or non-detection (0) at three successive survival-detection arrays (A5CR203, A6CR192, and A7CR086), respectively. A Chi-square test for homogeneity, excluding pooled estimates, columns with <5 pooled detections, and totals, was significant (P < 0.0010).

Date	P_111	P_011	P_101	P_001	P_110	P_010	P_100	P_000	Total
6/17-6/18	35	6	23	1	6	3	5	3	82
6/19-6/20	49	7	24	7	17	4	10	3	121
6/21-6/22	50	0	29	3	7	0	4	4	97
6/23-6/24	30	2	24	2	12	2	5	3	80
6/25-6/26	42	8	13	4	14	2	7	2	92
6/27-6/28	53	5	17	2	19	4	7	2	109
6/29-6/30	33	5	8	1	20	2	5	4	78
7/01-7/02	30	5	7	1	9	1	7	4	64
7/03-7/04	56	2	4	0	13	0	2	3	80
7/05-7/06	49	6	1	0	8	1	0	10	75
7/07-7/08	54	4	6	0	11	1	1	5	82
7/09-7/10	44	7	0	1	12	1	1	9	75
7/11-7/12	63	3	7	1	14	1	0	12	101
7/13-7/14	81	0	3	0	11	0	1	7	103
7/15-7/17	26	1	0	0	11	1	2	6	47
Pooled	695	61	166	23	184	23	57	77	1286

Table 3.42. Tag-life-corrected, single-release estimates of survival rates (S) and detection probabilities for FC smolts passing through end spill bays with deep flow deflectors (bays 1-3 and 16-18) based on detection histories in Table 3.40. Lambda is the product of survival and detection probabilities for the third array, and CI = confidence interval. The N-Wt Mean (weighted by numbers of fish in each virtual release) is preferred over the pooled estimate when capture histories are not homogeneous.

Virtual Release Dates	S to 1st Array	1/2 95% CI	S from 1st to 2nd Array	1/2 95% CI	Detect. Prob. To 1st Array	1/2 95% CI	Detect. Prob. from 1st to 2nd Array	1/2 95% CI	Lambda	1/2 95% CI
6/17-6/18	0.989	0.059	0.924	0.140	0.871	0.059	0.760	0.140	0.760	0.167
6/19-6/20	0.967	0.054	0.941	0.108	0.846	0.054	0.542	0.108	0.843	0.116
6/21-6/22	0.955	0.054	1.000	0.123	0.929	0.054	0.608	0.123	0.862	0.116
6/23-6/24	0.964	0.052	0.944	0.126	0.944	0.052	0.667	0.126	0.705	0.143
6/25-6/26	0.961	0.052	0.930	0.100	0.863	0.052	0.688	0.100	0.736	0.112
6/27-6/28	0.958	0.062	0.970	0.111	0.875	0.062	0.738	0.111	0.689	0.135
6/29-6/30	0.940	0.062	1.000	0.000	0.909	0.062	0.824	0.000	0.705	0.118
7/01-7/02	0.941	0.058	1.000	0.000	0.883	0.058	0.689	0.000	0.652	0.109
7/03-7/04	1.000	0.000	1.000	0.000	0.939	0.000	0.877	0.000	0.816	0.094
7/05-7/06	0.988	0.029	0.952	0.053	0.952	0.029	1.000	0.053	0.841	0.090
7/07-7/08	0.916	0.071	1.000	0.013	0.870	0.071	0.962	0.013	0.852	0.095
7/09-7/10	0.987	0.027	0.995	0.031	0.944	0.027	0.934	0.031	0.852	0.085
7/11-7/12	0.926	0.055	0.980	0.036	0.927	0.055	0.958	0.036	0.876	0.074
7/13-7/14	0.923	0.055	0.988	0.023	0.988	0.055	1.000	0.023	0.868	0.073
7/15-7/17	1.000	0.018	1.000	0.018	1.000	0.018	1.000	0.018	0.827	0.155
Pooled					0.915	0.014	0.812	0.019	0.793	0.029
N-Wt Mean	0.957	0.013	0.974	0.014						

Table 3.43. Tag-life-corrected, single-release estimates of survival rates (S) and detection probabilities for FC smolts passing through middle spill bays (1-3 and 16-18) in summer based on detection histories in Table 3.41. Lambda is the product of survival and detection probabilities for the third array, and CI = confidence interval. The N-Wt Mean (weighted by numbers of fish in each virtual release) is preferred over the pooled estimate when capture histories are not homogeneous.

Virtual Release Dates	S to 1st Array	1/2 95% CI	S from 1st to 2nd Array	1/2 95% CI	Detect. Prob. To 1st Array	1/2 95% CI	Detect. Prob. from 1st to 2nd Array	1/2 95% CI	Lambda	1/2 95% CI
6/17-6/18	0.973	0.042	0.994	0.084	0.865	0.042	0.631	0.084	0.820	0.107
6/19-6/20	0.992	0.031	0.997	0.086	0.833	0.031	0.644	0.086	0.728	0.100
6/21-6/22	0.961	0.040	1.000	0.000	0.966	0.040	0.612	0.000	0.882	0.066
6/23-6/24	0.972	0.043	1.000	0.000	0.914	0.043	0.592	0.000	0.752	0.099
6/25-6/26	0.995	0.034	0.968	0.081	0.831	0.034	0.746	0.081	0.760	0.104
6/27-6/28	0.998	0.028	0.999	0.072	0.890	0.028	0.751	0.072	0.715	0.099
6/29-6/30	0.958	0.050	0.994	0.089	0.884	0.050	0.809	0.089	0.635	0.122
7/01-7/02	0.957	0.063	0.905	0.102	0.868	0.063	0.814	0.102	0.780	0.122
7/03-7/04	0.965	0.042	0.985	0.039	0.973	0.042	0.936	0.039	0.818	0.090
7/05-7/06	0.867	0.077	1.000	0.012	0.892	0.077	0.984	0.012	0.862	0.084
7/07-7/08	0.940	0.052	1.000	0.026	0.934	0.052	0.908	0.026	0.832	0.085
7/09-7/10	0.882	0.074	0.987	0.035	0.862	0.074	0.981	0.035	0.797	0.099
7/11-7/12	0.882	0.063	1.000	0.000	0.943	0.063	0.909	0.000	0.832	0.078
7/13-7/14	0.932	0.049	0.994	0.021	1.000	0.049	0.964	0.021	0.880	0.066
7/15-7/17	0.875	0.096	0.949	0.069	0.949	0.096	1.000	0.069	0.696	0.146
Pooled	0.946	0.013	0.991	0.016	0.907	0.013	0.800	0.016	0.787	0.026
N-Wt Mean	0.948	0.023	0.988	0.012						

Table 3.44. Tag-life-corrected, relative survival rates (S) of FC smolts passing through deep flow deflector bays (1-3 and 16-18) and shallow deflector bays (4-15). The ratio estimates tabulated below were calculated by dividing deep deflector bay passage survival rates (Table 3.42) by shallow deflector bay passage survival rates (Table 3.43).

Release Dates	$\hat{S}_{Deep/Shallow}$	1/2 95% CI
6/17-6/18	1.016	0.075
6/19-6/20	0.975	0.062
6/21-6/22	0.994	0.070
6/23-6/24	0.992	0.069
6/25-6/26	0.966	0.062
6/27-6/28	0.960	0.068
6/29-6/30	0.981	0.083
7/01-7/02	0.983	0.089
7/03-7/04	1.036	0.045
7/05-7/06	1.140	0.107
7/07-7/08	0.974	0.093
7/09-7/10	1.119	0.099
7/11-7/12	1.050	0.098
7/13-7/14	0.990	0.079
7/15-7/17	1.143	0.127
Pooled	1.010	0.020
Arith. Mean	1.021	0.032

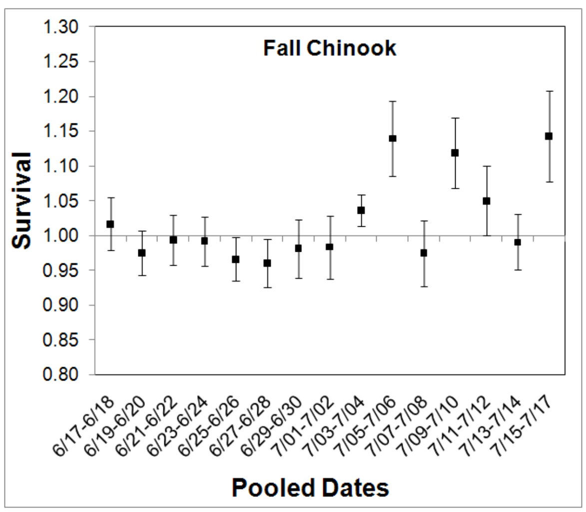


Figure 3.22. Plot of the trend in relative survival rates (deep deflector bay survival rates/shallow deflector bay survival rates) during summer 2008. Vertical error bars are estimated standard deviations.

3.9 Tests of Survival-Model Assumptions

Results from Burnham and arrival distribution tests are described in the following sections.

3.9.1 Burnham Test Results

A major assumption of the survival models used in this study are that upstream detections do not affect downstream detection or survival probabilities, and this can be tested using Burnham Test 2 and Test 3. Appendix B presents tables of two-tailed probabilities from Fischer's Exact Test on 2 × 2 contingency tables for every release by fish stock and survival metric for BON and its spillway.

Results of Burnham tests do not indicate that there was a problem with this study. Fewer than 10% of the tests were significant at α=0.1, and at this α level, we could expect to reject a true null hypothesis (H0: no effect) up to 10% of the time. For YC smolts, only 3 of 77 (3.9%) calculated Test 2 statistics and 3 of 78 (3.9%) of calculated Test 3 statistics were significant at α=0.1. For STH smolts, 3 of 48 (6.3%) Test 2 statistics and 2 of 51 (3.9%) Test 3 statistics were significant at α=0.1. For FC smolts, 5 of 67 (7.5%) Test 2 statistics and 3 of 73 (4.1%) Test 3 statistics were significant at α=0.1.

3.9.2 Arrival Distribution Test Results

We examined the cumulative frequency of arrivals of tagged fish in virtual and reference releases at the primary survival-detection array to determine whether the model assumption of mixing of fish in the common tailwater was violated. For YC and FC smolts, cumulative frequencies of arrivals were very similar and no consistent large deviation of arrival times of the two releases was evident (Figure 3.23 and Figure 3.24). Scatter plots of arrival hour at the primary array showed that arrivals of virtually released fish were relatively uniform throughout each day, whereas arrivals of tailrace-released reference fish were loosely (±3 hours) clustered around three times of day (roughly 1200, 2000, and 0400 hours).

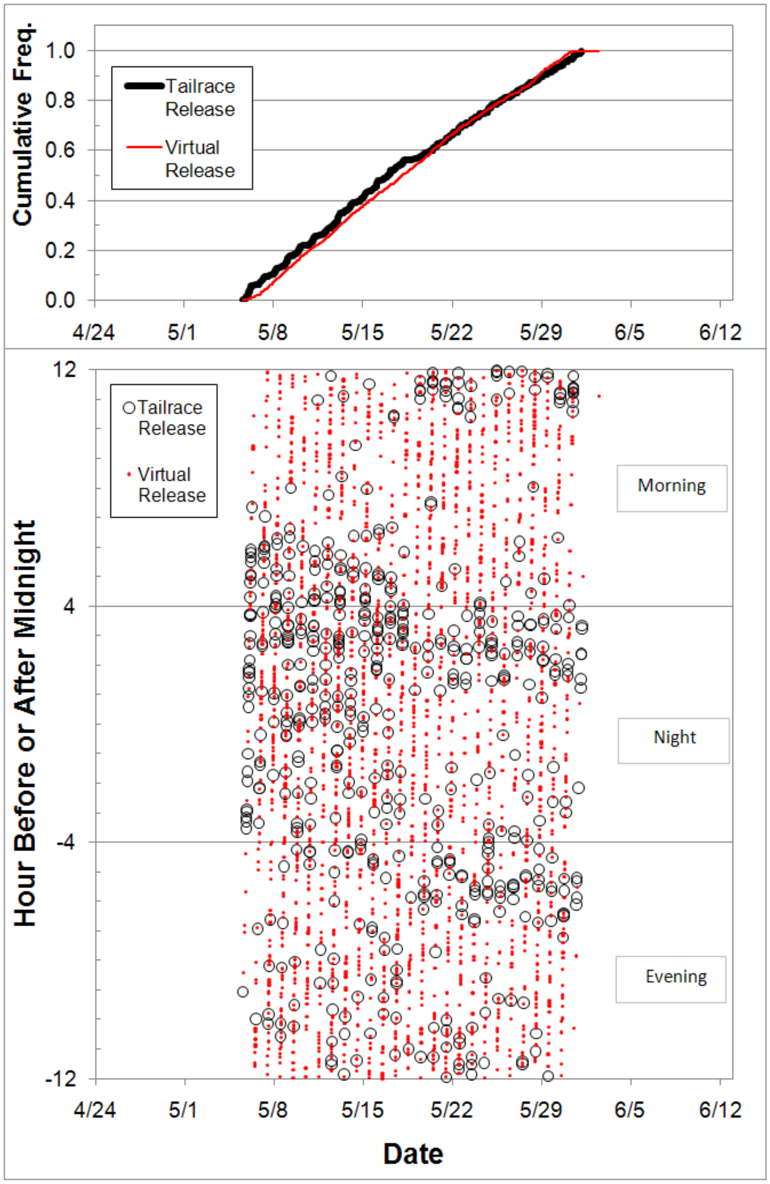


Figure 3.23. Cumulative frequency of primary array arrivals of tagged spring Chinook salmon smolts in virtual releases at BON and references releases below BON (top) and a scatter plot of arrival hour of each released fish before or after midnight by date (bottom)

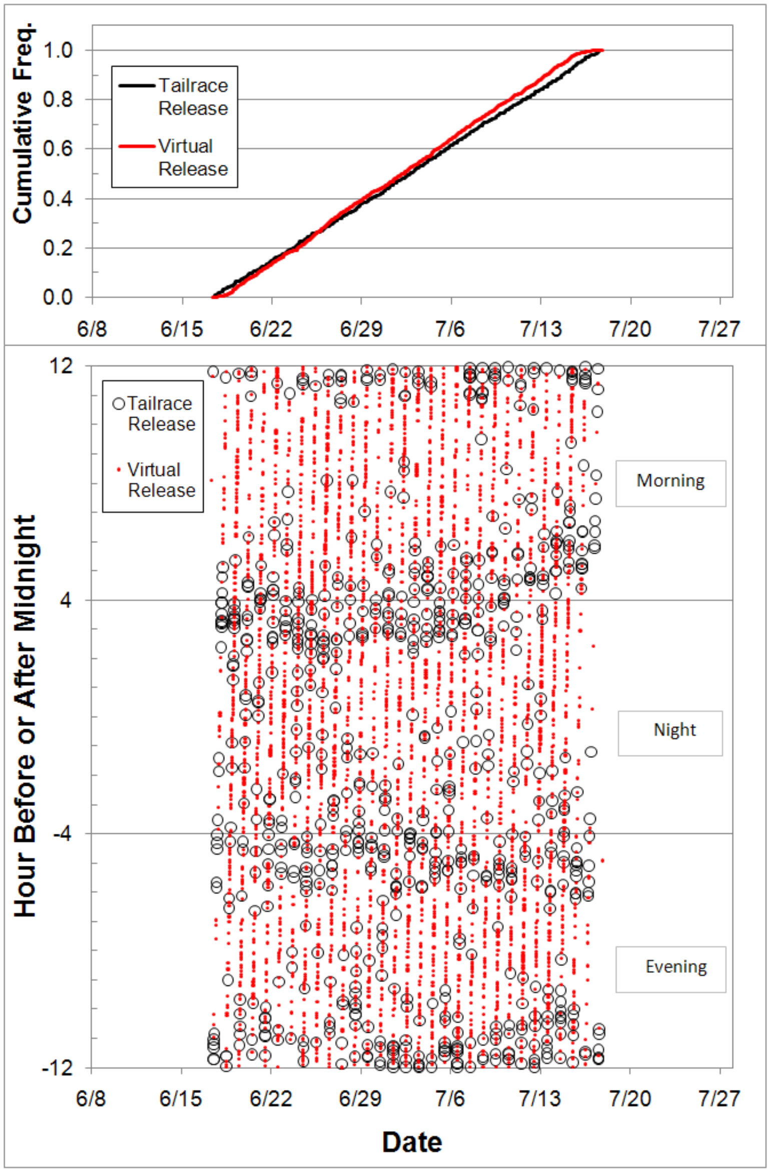


Figure 3.24. Cumulative frequency of primary array arrivals of tagged FC smolts in virtual releases at BON and references releases below BON (top) and a scatter plot of arrival hour of each released fish before or after midnight by date (bottom)

4.0 Discussion

The environment and 2008 outmigration conditions are discussed first in this section, followed by discussion of spill passage efficiency and effectiveness, the detection performance of the downstream arrays of autonomous nodes, fish egress rates, detection and survival, and survival-model assumptions.

4.1 Environment and 2008 Outmigration Conditions

Environmental conditions include discharge, temperature, and tailrace elevation, and 2008 outmigration conditions include run timing, smolt species composition, and length frequencies of run-of-river and tagged fish.

4.1.1 Project Discharge, Temperature, and Tailrace Elevation

Above-average project and spill discharge and tailrace water-surface elevations during most of spring and summer 2008 eliminated mechanisms that might have caused differences in survival rates for smolts passing through spill bays with deep and shallow flow deflectors. Based on results of Counihan et al. (2006a) and Ploskey et al. (2007b), we hypothesized that the most likely environmental conditions reducing the survival rates of juvenile salmonids passing through bays with shallow flow deflectors were below-average project discharge and low tailrace elevations. Neither of these conditions was common until late summer 2008 (see Figure 3.1 and Figure 3.3). Project discharge was below the 10-year average for only 3 days in early May and 7 days after mid-July, and spill discharge was above the previous 10-year average throughout 2008 (Figure 3.1). Below-average project discharge resulted in low-tailwater elevations that were often within 2 m of shallow flow deflectors in summer only after July 6 (Figure 3.3).

Mechanisms for increased mortality when tailrace elevations are near the elevation of shallow flow deflectors at middle bays are unknown, but it seems obvious that fish get closer to deflector surfaces as the amount of water passing over deflectors decreases. Any injury or loss of equilibrium associated with abrasion or shear could increase the susceptibility of fish to predation or disease so there could be immediate or delayed mortality. Johnson and Dawley (1974) reported that FC passing through BON spill bays without flow deflectors had a higher survival rate (95.8%) than FC passing through bays with flow deflectors (86.8%) and all flow deflectors at that time were located at middle bays where shallow flow deflectors are located today. Muir et al. (2001) reported that spillway deflectors did not significantly affect survival rates of PIT-tagged YC and STH passing through spill bays at Little Goose and Lower Monumental dams with the sample sizes used, although point estimates were higher for fish passing through spill bays without flow deflectors than they were for fish passing through bays with deflectors.

Observed water temperatures were 1 to 2 degrees below the previous 10-year average during most of spring and summer 2008 (Figure 3.2) and well below critical levels for juvenile Chinook salmon (Brett 1952). Above-average river discharge in 2008 undoubtedly explains depressed water temperatures and above-average project and spillway survival rates, as discussed in the following sections of this report. Higher water temperatures may increase susceptibility to disease (Tiffan et al. 2000) and may be an additional stressor on young salmon, particularly those that are not well fed (Cobleigh 2003). Water temperatures probably had less effect on survival rates in 2008 because temperatures did not reach 20°C during this study.

4.1.2 Run Timing and Smolt Species Composition

Arrivals of STH and FC at BON occurred throughout the central 93% and 95% of the respective runs but only occurred during the last 70% of the YC run (Figure 3.4). This means that the timing of releases and associated arrivals was highly representative for 2008 STH and FC runs but did not represent the early 30% of the YC run. The 2008 study exceeded its goal of releasing fish during the central 80% of each of the STH and FC runs, but missed the goal by 10% for YC. Dam arrays were fully functional and ready to detect tagged fish a few days later than we had planned, and there was no reason to release tagged fish until all arrays were functional. Given travel times ranging from about 1.5 to 2.5 days, tagging of YC at JDA would have to start by April 19 for most arrivals to reach BON by April 21, when 8% of the run had passed (Figure 3.5). The tagging and release season would have to be different for STH and YC to obtain enough fish and to be representative of the respective timing of each run.

4.1.3 Differences in Length Distributions of Tagged and Untagged Smolts

Part of the explanation for a small but fairly consistent difference in the lengths of tagged and untagged fish (Figure 3.6) likely relates to preferential selection of clipped individuals for tagging. Unclipped fish, which tended to be smaller than clipped fish, were more common in the routine SMF samples than they were in the tagging samples (Weiland et al. 2009). Figure 3.6 shows that the median lengths of tagged fish tended to be 6 to 11 mm longer than the median lengths of untagged fish. The slightly offset length frequency distributions suggest that the bias in fish size selection was systematic, but it was not caused by measurement methods (fork length was measured in both cases) or differences in the start and end dates for sampling.

No YC or STH were intentionally rejected from tagging based on length because all fish in routine SMF samples exceeded the 95-mm minimum length requirement for tagging, but the minimum tagging length did eliminate about 4.16% of the run-of-river FC from the tagging sample, because these fish were deemed too small for tagging. This was a great improvement over 2007, when 40% of run-of-river subyearlings were below the 95-mm length limit, and comparison of length frequencies in the 2 years shows how much length frequencies can vary among years. River discharge was below average in summer 2007 and water temperatures were higher and average lengths of subyearlings shorter than in 2008, when river discharge was above average most of the summer. Tagging would have needed to include 75- to 95-mm-long FCs to be fully representative of the population passing through BON in summer 2007, whereas 96% of FC in the 2008 run exceeded 95 mm. Tagging 75-mm-long FC will require further miniaturization of tags and reduction in tag weight, according to results of a 2007 tag-effects study (Richard Brown, Personal Communication, 2007). Length-related detection biases associated with acoustic telemetry have not yet been documented like those for PIT-tag detection systems (Zabel et al. 2005).

If a bias is introduced by relying solely on bypassed fish for acoustic telemetry studies, it likely is negative because bypassed fish are exposed to in-turbine screens, gatewells, and a bypass system that prolongs dam passage. Fish collected from the JDA SMF represented only 16% of YC, 23% of STH, and 15% of FC passing through JDA in 2008. Reliance on JBS-passed smolts could yield a tagged population with a lower level of fitness than that of fish passing through other routes, except perhaps for turbines.

4.2 Tag-Life Study

The tag-life study conducted in 2008 was adequate to correct survival estimates for premature failure of tags or for late detections of tags implanted in fish that migrated too slowly to pass survival-detection arrays before a tag had a high probability of failure. Nevertheless, the tag-life study can be improved by testing 100 tags of each nominal PRI. Tags must be randomly drawn from all production lots, and all tags preferably would be delivered before the tagging season begins so that tag-life results to not delay derivation and application of tag-life corrections. Having 100 tags from a single production lot will minimize the impact of the premature failure of one or two tags on the tag-life curves because each tag will represent only 1% of the study tags. This will require the early purchase, production, and delivery of all tags before the start of each migration season so that researchers can randomly sample 100 tags from all tags with each nominal PRI.

4.3 Detection Performance of Forebay and Survival-Detection Arrays

In general, channel width tends to increase and shallow water areas, sand bars, and islands occur more frequently at downstream array locations than at locations above BON, and this probably explains why detectability decreases downstream (Figure 3.7). The best array in the forebay of BON was located at relatively deep constricted cross section and had a lot of bottom scoured by flow to expose rock, which can reflect sound. Except for instances where a single node failed or was not redeployed continuously, most detections of each stock occurred in the main channel with the most flow (Figure 3.8), and off-channel detections made up <6% of detections on a single array. However, at 6%, researchers could not afford to stop sampling side channels that occur at an array cross section. Detections of the same tag on multiple nodes within an array also tended to decline on arrays downstream of BON (Figure 3.9), indicating the need to increase node densities at downstream arrays to compensate for poor acoustic conditions. This is a recommendation of this study.

Detection probabilities were adequate to estimate survival rates with reasonable precision. Pooled detection probabilities exceeded 69%, and the pooled estimate for the primary array was 89% in spring and 91% in summer. The pooled estimates were within 1.7% of average in spring 2007 (92.7%) and within 7.8% of the average in summer 2007 (98.8%). Pooled estimates of detection probability for the secondary array at Camas were 69% in spring and 81% in summer. Detection probabilities were higher in summer than in spring, because detection probabilities were inversely related to river discharge (Figure 3.10). River discharge determined the rate at which fish passed the autonomous hydrophone arrays. Given the relationship between detectability and river discharge, which is a surrogate for the rate at which fish pass through an array, we believe that it logically follows that tags with faster transmission rates would maintain high detection probabilities when river discharge peaks. Of course, the choice of tag transmission rate depends on study objectives.

4.4 Spillway Passage Efficiency and Effectiveness

Estimates of spill passage efficiency and effectiveness in 2008 were very similar to historical estimates by radio telemetry and fixed-aspect hydroacoustic studies during non-drought years, as summarized by Ploskey et al. (2007a). A logit regression line fitted to hydroacoustic and radio-telemetry estimates of spill passage efficiency as a function of percent spill (Figure 3.2 in Ploskey et al. 2007a) predicts that spill efficiency would be about 50% when spill discharge is 46% of project discharge, as it was in spring 2008. Our 2008 spill passage efficiency estimate was 50.6% for YC and 49.1% for STH. The same logit regression forecasted a spill efficiency of about 40% for summer 2008, and our estimate of spill passage efficiency was 45.1%. Spill passage effectiveness estimates of 1.084 for YC, 1.051 for STH, and 1.145 for FC in 2008 were similar to the average of radio-telemetry estimates for non-drought years: 1.075 for YC, 0.975 for STH, and 1.1 for FC (from Table 3.3, Table 3.4, and Table 3.5 in Ploskey et al. 2007a). As noted by Ploskey et al. (2007a), for effectiveness to be much above 1:1 at BON, fish would have to preferentially select the spillway over either powerhouse, but this does not happen because islands funnel fish to the three forebays before they are exposed to forebay conditions that might allow them to make a choice.

4.5 Egress Rates

We were able to provide a variety of egress statistics to allow comparison of travel times and rates among smolts passing through the spillway and B2, specific routes within those structures, and among stocks of fish based upon recorded travel times to the primary array. Projected times of travel from the point of last detection to the tailrace release site (Table 3.1 and Table 3.2) were based upon median travel rates to the primary array, which likely would be slightly slower than the actual rates of travel to the tailrace release site. Our projected tailrace egress times are therefore conservative relative measures. We readily acknowledge that future plans to locate an egress array at the tailrace release site will produce better estimates of tailrace egress times than the projected estimates presented in Table 3.1 and Table 3.2.

The key points to take away from travel times and rates presented in Section 3.5 of the results are as follows:

1. The STH smolts traveled faster than YC and FC smolts regardless of passage route, although the variability in travel times also was higher for STH than for YC or FC.
2. Travel times and rates were lower in summer than they were in spring, undoubtedly due to reduced water discharge through the project in late summer.
3. Smolts passing through the spillway and the B2CC had similar travel times and rates that were significantly faster than the times and rates of smolts passing through B2 turbines and the B2 JBS.
4. Egress times and rates for fish passing through the B2 JBS were the slowest and most variable for each stock of fish.
5. The projected time required for all B2-passed fish to reach the downstream end of the tailrace was only 8 to 11 minutes longer than that of spillway-passed fish, although the estimate for B2-passed fish was biased low by substantial numbers of fish quickly passing through the B2CC.
6. Smolts passing through middle bays of the spillway had slightly longer travel times (8.5 to 34 minutes) and slower travel rates than smolts passing through end bays. The median travel time to the primary array for the slowest 10% of FC passing through middle bays after July 2 was 63 minutes longer than that of the slowest 10% of FC passing through end bays. Observations about fish with the slowest egress times are important because these fish should have a lower probability of survival than fish with fast egress times.

Observing slower egress rates for FC through middle spill bays (Point 6 above) is consistent with findings in 2007. In 2007, Ploskey et al. (2008) found that the mean travel time from spillway passage to an egress array located 9 km downstream of the dam was 20 minutes longer (P = 0.0105) for fish passing through middle bays (2.58 hours) than it was for fish passing through end bays (2.26 hours). In 2008, travel time to the primary array was 18 minutes longer for FC passing through middle bays than it was for FC passing through end bays. Comparison of travel times for the slowest 10% of smolts passing through end and middle bays after July 2 is important because the slowest fish are less likely to survive than the fastest fish. The median travel time to the primary array for the slowest 10% of FC was 63 minutes longer for smolts passing through middle bays than for smolts passing through end bays. In addition to injury associated with passing too close to shallow flow deflectors in late summer, delayed egress for smolts passing through middle bays could expose that group to increased predation and delayed mortality in the tailwater and help explain why we found lower survival rates for FC passing through middle bays than for FC passing through end bays after July 2, 2008.

Mean travel times to the array at Reed Island (rkm 203) were shortest in 2008 and shorter in 2006 and 2008 than in 2007 (Table 4.1), but this is directly related to river discharge in each year. Discharge was above average in 2006 and 2008, average in spring 2007 and below average in summer 2007.

Table 4.1. Median travel times from the BON spillway to the primary array location in 2008 (A5CR203). The primary array in 2008 was the same as the secondary array location in 2006 and 2007.

Year/Stock	Time (hours)	N
2006/YC	9.2	470
2007/YC	11.2	764
2008/YC	8.4	1,250
2008/STH	6.9	1,232
2006/FC	9.9	1,236
2007/FC	11.3	964
2008/FC	8.9	1,991

4.6 Detection and Survival of Yearling Chinook Salmon in Spring

Activities related to the detection and survival of YC in spring involved conducting the spring tag-life study, estimating the survival rates of spillway-passed yearlings, and comparing survival rates through deep versus shallow flow deflector bays in spring, and assessing the effect of detecting a dead tagged fish on survival-detection arrays as discussed briefly in the following sections.

4.6.1 Tag-Life Effects

The tag-life study verified that most tags lasted about as long as expected, and most survival estimates required only minor corrections to adjust for the low probability that a tag would fail before tagged fish passed survival-detection arrays. For example, uncorrected pooled single-release survival estimates for YC traveling to the primary array were increased by 0.0049 (0.49%) for releases in the JDA pool and tailrace and passing through BON, and by 0.0039 (3.9%) for the same smolts passing through the spillway. Tag-life corrections varied greatly among release trials depending on travel times and the probability that a tag would be working on a given date. For example, the difference in uncorrected and corrected survival rates of JDA-released YC ranged from 0.0007 (0.07%) for the May 21 to 22 virtual release to 0.0174 (1.74%) for the May 2 to 6 virtual release. Estimates of BON survival rates for YC released on the Snake River below LGR had a greater adjustment (0.0306 or 3.06%), although we did not use YC from Snake River releases to make official estimates of BON dam-passage survival rates.

4.6.2 Survival Rates of Yearling Chinook Salmon Passing Through Bonneville Dam

The paired-release estimate of dam survival rate (forebay entrance to tailrace release site) in 2008 (0.997; $\widehat{SE}$ = 0.014) was high but within the range of 95% confidence limits estimated in previous studies. Most comparable estimates were based on radio-telemetry studies. In the drought year of 2001, dam survival estimates for YC were 0.928 (n = 8, $\widehat{SE}$ = 0.023) before spill began and 0.946 (n = 7, $\widehat{SE}$ = 0.015) after spill began (Counihan et al. 2002). The estimate for spring 2002, which was a normal water year, was 0.977 ($\widehat{SE}$ = 0.019). Thedam survival rate for YC was estimated to be 0.951 ($\widehat{SE}$ = 0.008) under a 56,000-cfs day spill and spill-to-the-gas night spill operation and 0.979 ($\widehat{SE}$ = 0.015) under high spill (to the gas cap) at night (Counihan et al. 2006a). Spill was very high throughout 2008 and therefore the nighttime estimate for 2004 would be most comparable to the 2008 estimate. Thedam survival rate was estimated to be 0.966 ($\widehat{SE}$ = 0.007) in 2005 (Counihan et al. 2006b). An acoustic telemetry study in 2006 (Ploskey et al. 2007b) produced a paired-release YC dam survival estimate of 1.057 ($\widehat{SE}$ = 0.045).

We compared tag-life-corrected survival estimates for YC released on the Snake River with estimates for YC released in the JDA pool and tailrace. Based on point estimates and overlapping 95% CIs and on a Z test using individual release trials in Table 3.7 and Table 3.12 [P(Z<=z) two-tail = 0.8020], the two estimates did not differ significantly. We did not use YC released below LGR on the Snake River to bolster sample sizes for 2008 dam survival estimates because the fish came from different sources, and we did not tag or release the LGR fish. However, comparison of virtual release estimates of dam survival suggests that these releases could have been pooled.

The high dam survival estimates for YC in 2008 likely relate to above-average river discharge in spring 2008, which sped smolts downstream and reduced their exposure time to predators in the forebay and tailrace. In 2008, survival estimates for YC passing through all routes including the spillway (this report), the B2CC, B2 turbines, and the B2 JBS, were high.

4.6.3 Survival Rates of Spillway-Passed Yearling Chinook Salmon

As indicated previously, survival rates were estimated for spillway-passed YC across the entire spillway and for those passing through the deep and shallow deflector bays.

4.6.3.1 Composite Spillway-Passage Estimates

The paired-release survival estimate of YC smolts passing through the spillway was high (0.999; $\widehat{SE}$ = 0.015), similar to the 2008 dam survival estimate (0.997; $\widehat{SE}$ = 0.014), and exceeded four previously reported spillway survival estimates based on point estimates and non-overlap of 95% CIs (Table 4.2). The 2008 estimate appears to be greater than a 2004 estimate for a 56,000 cfs daytime spill condition

(Counihan et al. 2006a), two 2005 estimates (Counihan et al. 2006b), and daytime release estimates in 2007 (Ploskey et al. 2008). Based on the overlap of 95% CIs, the 2008 weighted-average survival estimate of YC passing through the spillway did not differ from the 2002 estimate by Counihan et al. (2003) or from end and middle bay estimates in 2004 (Counihan et al. 2006a), although the variability in previous estimates was high (Table 4.2).

Table 4.2. Spillway-passage survival estimates for YC smolts from previous studies and this 2008 study

Species/Study	Condition	Study Year	Survival Rate	Lower 95% CL[a]	Upper 95% CL[a]	Over-lap[b]
Counihan et al. 2003	Spillway under all conditions; route specific	2002	0.977	0.951	1.004	=
Counihan et al. 2006a	56 kcfs daytime; route specific	2004	0.891	0.840	0.936	<
	56 kcfs daytime; deep deflector bays	2004	0.937	0.818	1.036	=
	56 kcfs daytime; shallow deflector bays	2004	0.773	0.650	1.050	=
	Ratio deep/shallow	2004	1.212			
Counihan et al. 2006b	All conditions; route specific	2005	0.930	0.912	0.947	<
	75 kcfs spill;	2005	0.897	0.872	0.921	<
Ploskey et al. 2008	Daytime release; entire spillway	2007	0.937[c]	0.911	0.964	<
	Ratio deep/shallow (ratio of single releases)	2007	0.969			
This study	24-h per day virtual releases	2008	0.999	0.970	1.028	

(a) CL = confidence limit.
(b) Overlap refers to overlapping 95% CIs; estimates followed by an = symbol had 95% CIs that overlapped with those of 2008 estimates, and estimates followed by a < symbol were less than 2008 estimates based on the non-overlap of 95% CIs.
(c) Adjustment for one dead-fish detection applied; 0.957 [0.931, 0.970; 95% CL] without the adjustment.

4.6.3.2 Relative Survival Rates for YC Passing Through Deep and Shallow Deflector Bays

We found no effect of spill-bay deflector elevation on the survival rates of YC in spring, likely because project discharge was above average on all but 3 days and tailrace water surface elevations were so high that even deflectors at middle bays usually were deep (see Figure 3.1 and Figure 3.3). Unlike the 2007 test for differences, the test in 2008 had sufficient power, but there was likely no causal mechanism to produce differences. The median travel time of YC passing through middle bays until they reached the primary array was only 8 minutes slower than that of YC passing through end bays. The only time significant differences in survival rates have been observed for YC was in spring 2004 (Counihan et al. 2006a) when tailrace elevations averaged 5.44 m and were within 0.87 m of shallow flow deflector elevations.

4.6.4 Effect of Detecting a Dead Tagged Fish on Survival-Detection Arrays

The travel rate of the single dead fish detected on the primary and secondary arrays was very similar to that of the live fish, and this suggests that the dead fish travelled unimpeded at about the same speed as the current and other live fish in that release. Previous experience indicates that dead fish usually travel much slower than live fish because they typically sink for a few days before they float and travel at the speed of prevailing river currents (Counihan et al. 2006a, 2006b; Ploskey et al. 2008). The tendency of dead fish to travel slower than live fish led Counihan et al. (2006a) to exclude data for fish with long egress times (>99.7 percentile) from survival calculations. However, protocols for releasing dead fish in 2008 included cutting through gill arches, and if this protocol was strictly followed and there was no recording error, then we cannot unequivocally rule out the possibility that this fish was dead when released even though its egress rate was uncharacteristically fast. River discharge in 2008 was significantly above average during most of spring 2008, including the day that the dead fish was released.

Pooling all data from 2006, 2007, and 2008, there have been two dead-fish detections out of 159 dead-fish released at BON ($\hat{D}$ = 0.0126). Previous radio-telemetry studies also detected dead fish on survival-detection arrays below BON (Counihan et al. 2006a, b), and, although detection rates for dead radio-tagged fish may differ from those of acoustically tagged fish, those detection probabilities are interesting. Counihan et al. (2006b) estimated a dead-fish-detection probability of 0.0206 for YC, and approximately 0.0103 for dead STH, and 0.0102 for dead subyearling Chinook salmon. The average of those estimates, assuming that the species of dead fish does not matter, was 0.014, and this is within 1.4% of our estimate based on all dead-fish releases and detections from 2006 through 2008.

One approach to handling the dead-fish-detection problem in 2004 (Counihan et al. 2006a) was to exclude data for fish with long egress times (>99.7 percentile) from survival calculations. A second approach involved recalculating survival rates after removing release and detection data for all releases of fish that happened to have dead-fish detections (Counihan et al. 2006b). The latter approach assumes that conditions during some releases may increase the probability of detecting dead fish on survival-detection arrays. These conditions could include river discharge and water temperature as well as population levels of scavengers (avian and fish) and time of day, which could affect the probability of birds or fish seeing and removing a body before it reached survival-detection arrays.

Previous methods of guarding against bias resulting from false positive detections of dead fish were not practicable in 2008. Dropping fish with very slow travel times (after Counihan et al. 2006a) would not have eliminated the dead fish detected in 2008 and did not alter YC survival estimates significantly. Dropping the May 11-12 virtual release, during which the dead fish was detected (after Counihan et al. 2006b) actually increased the average survival estimate for yearlings by 0.002, from 0.997 to 0.999 instead of reducing it. Clearly, dropping releases with dead-fish detections is not enough. Releases of fish the day before or after a day that included a dead-fish detection likely would have had similar environmental conditions. In 2008, only one dead fish was detected out of 99 released in spite of very high river flows that should have greatly increased $\hat{D}$. This indicates that river discharge may not be the primary factor influencing the probability that a dead fish will float to the water's surface and then travel >42 km downstream undetected by scavengers. The probability is so low that it appears to occur by chance alone and, as such, probably should be corrected by using a cumulative estimate of $\hat{D}$.

Corrections based on the cumulative estimate of $\hat{D}$ ranged from 2.5 to 3.0% but did not reduce the survival estimates below the targets prescribed by the 2008 BiOp. The tag-life-corrected survival estimate for YC was biased upward by 2.5 to 3.0% because it did not account for the probability that a dead tagged fish might be detected. The upward bias to survival estimates due to detection of dead fish in 2008 was slightly higher than that estimated for spring 2007 (about 2%).

We recommend releasing at least 50 dead fish each season during future survival studies conducted at BON to better quantify the rate of dead-fish detections for acoustic tags. We arrived at this sample size based upon a preliminary dead-fish-detection probability of 0.0126, and calculations provided to us by Drs. John Skalski and Rebecca Buchanan (see Appendix C). At about $185 per tag, releasing 150 dead fish (50 each of YC, STH, and FC) would cost about $27,750. To avoid sacrificing a lot of fish for future dead-fish releases, we recommend using dead specimens found before rigor mortis is obvious during routine smolt-monitoring operations as well as any fish that happen to die as a result of tagging (a common practice). If fish must be sacrificed, we recommend sacrificing individuals that would otherwise be rejected for tagging because of injury or descaling. These individuals would be much less likely to survive than healthy fish.

4.7 Detection and Survival of Steelhead in Spring

Activities related to the detection and survival of STH in spring largely involved making tag-life corrections to the STH survival estimates, estimating the survival rates of spillway-passed STH, and comparing survival rates through deep versus shallow flow deflector bays in spring, as discussed briefly in the following sections.

4.7.1 Tag-Life Effects

Tag-life corrections to STH survival estimates were very small because most fish passed the three BON survival-detection arrays before there was significant roll-off in the tag-life curve. The uncorrected, pooled, single-release STH dam-passage survival estimate was increased by 0.0048 (0.48%) after the tag-life correction was applied. The correction applied to the uncorrected spillway-passage survival estimate added just 0.0038 (0.38%).

4.7.2 Survival Rates of Steelhead Passing Through Bonneville Dam

We were limited to estimating single-release survival rates of STH because the study did not include tailrace reference releases in 2008. Even though the 2008 single-release estimate of dam-passage survival rates included mortality that occurred as smolts traveled through the tailwater 31.4 to 31.8 km downstream, it did not differ significantly from most previous paired-release estimates based on overlapping 95% CIs (Table 4.3).

4.7.3 Survival of Spillway-Passed Steelhead

As indicated previously, survival was estimated for spillway-passed STH across the entire spillway and for those passing through the deep and shallow deflector bays.

4.7.3.1 Composite Spillway-Passage Estimates

Most single-release estimates of spillway survival rates in 2008 were so high that they did not differ from the paired-release estimates available provided by previous studies (see Table 4.3). Even if paired-release estimates were possible in 2008, they likely would not have exceeded most of the previous estimates, all of which had upper 95% CIs >1.

4.7.3.2 Relative Survival Rates for STH Passing Through Deep and Shallow Deflector Bays

We found no effect of spill-bay deflector elevation on survival rates of STH in spring, likely because project discharge was above average on all but 3 days and only 95.1% of hourly tailwater elevations were over 1 m above the depth of the shallow flow deflectors (see Figure 3.1). The median travel time of STH passing through middle bays until they reached the primary array was 34 minutes slower than that of smolts passing through end bays, but tailrace elevations were high enough that an injury mechanism probably was lacking for middle bays with shallow flow deflectors. In 2004, Counihan et al. (2006a) found that point estimates of survival rates for STH were higher for smolts passing through end bays with the deep flow deflectors (0.927) than for STH passing through middle bays with shallow flow deflectors (0.850), and this only occurred during the 56,000-cfs day spill treatment. Tailrace elevations averaged 5.44 m and often were within 0.87 m of shallow flow deflector elevations during this spill treatment.

Table 4.3. Dam and spillway-passage survival estimates for STH smolts from previous studies and this 2008 study. Estimates for 2004 and 2005 are based on pairs of releases, whereas the estimate in this study was a single-release estimate that includes dam or spillway passage survival rates and survival rates through the tailwater down to the primary array about 31.4 km downstream of the spillway.

Species/Study	Condition	Study Year	Survival Rate	Lower 95% CL[(a)]	Upper 95% CL[(a)]	Over-lap[(b)]
Counihan et al. 2006a	Dam Passage in Spring	2004	0.991	0.975	1.008	=
	Spillway Passage in Spring	2004	0.979	0.956	1.002	=
	Spillway Passage under Gas-Cap Spill	2004	1.020	0.992	1.050	=
	Deep Deflector; 56,000 cfs day	2004	0.927	0.818	1.036	=
	Shallow Deflector; 56,000 cfs day	2004	0.850	0.650	1.050	=
	Ratio deep/shallow deflectors	2004	1.091			
Counihan et al. 2006b	Dam Passage under Gas-Cap Spill	2005	0.970	0.953	0.987	=
	Spillway Passage under Gas-Cap Spill	2005	0.986	0.968	1.005	=
This study	Dam Passage (Single Release)	2008	0.972	0.967	0.977	
	Spillway Survival (Single Release)	2008	0.962	0.945	0.978	
	Deep Deflector; High Spill 24 h	2008	0.948	0.921	0.975	
	Shallow Deflector; High Spill 24 h	2008	0.965	0.950	0.986	
	Ratio deep/shallow deflectors	2008	0.982			

(a) CL = confidence limit.
(b) Overlap refers to overlapping 95% CIs; estimates followed by an = symbol had 95% CIs that overlapped with those of 2008 estimates, and estimates followed by a < symbol were less than 2008 estimates based on the non-overlap of 95% CIs.

4.8 Detection and Survival of Fall Chinook Salmon in Summer

Activities related to the detection and survival of subyearling Chinook salmon during the summer involved the tag-life study, spillway-passed FC, and comparison of the fish passage survival rates of fish passing through spill bays containing deep and shallow flow deflectors, as described in the following sections.

4.8.1 Tag-Life Effects

Tag-life corrections for FC were very small because over 99.5% of FC passed the primary survival-detection array below BON within 8 days, the secondary within 8 days, and the tertiary within 10 days, which is less than half of the expected tag life. Tag-life corrections increased the uncorrected estimate of dam survival rates by 0.12% and the uncorrected estimate of spillway survival rates by just 0.11%.

4.8.2 Survival Rates of Fall Chinook Salmon Passing Through Bonneville Dam

Three previously reported estimates of dam-passage survival rates for FC at BON were lower than the estimates for 2008 (Table 4.4), and high project discharge is the most logical explanation for this. High river discharge speeds smolts past the dam and through the tailwater and keeps water temperatures below average. Columbia River discharge was above 300,000 cfs on most days during the first half of summer 2008, and was above the previous 10-year average during most of the summer. The previous high water year with survival estimates was in 2006, but river discharge at BON was only above 300,000 cfs for the first quarter of summer in 2006, and discharge was below the previous 10-year average during the entire second half of summer releases that year. Project discharge was below the previous 10-year averages on most days in 2004 and 2005, the other two years with reported dam survival estimates for subyearlings.

4.8.3 Survival Rates of Spillway-Passed Fall Chinook Salmon

As indicated previously, we made composite passage survival estimates for the entire spillway and for FC passing through the deep and shallow deflector bays.

4.8.3.1 Composite Spillway-Passage Estimates

Our weighted-average survival estimate of FC smolts passing through the BON spillway in summer was 0.969 and that point estimate was higher than summer survival estimates in 2004, 2005, 2006, and 2007 (Table 4.4). The only previous estimates that had 95% CIs that overlapped with the summer 2008 estimates occurred during high spill conditions such as gas-cap night spilling 2004 and 2005 or deep-deflector bay spill in 2007. As explained in the previous paragraph, we attribute higher spillway survival rates in 2008 to above average discharge during most of summer 2008. Higher subyearling survival rates under daytime spill in 2007 and throughout summer 2008 over rates observed in 2005 may be explained by differences in spill patterns between the years. After 2005, spill consisted of 100,000-cfs spill for 24 hours/day in spring and a modified BiOp spill that provided larger gate openings in summer than had been used in prior years. Smaller gate openings used in 2005 may have increased mortality.

Table 4.4. Survival estimates for FC smolts from previous studies and this 2008 study. Survival estimates are based on paired releases unless noted otherwise.

Species/Study	Condition	Study Year	Survival Rate	Lower 95% CL[(a)]	Upper 95% CL[(a)]	Over-lap[(b)]
Counihan et al. 2006a	Dam Passage (Gas Cap Night Spill)	2004	0.887	0.847	0.925	<
	Spillway Passage (56,000 cfs Day & Gas-Cap Night Spill)	2004	0.877	0.848	0.902	<
	Spillway Passage (Gas Cap Night)	2004	0.913	0.869	0.953	=
	Deep Deflector; 56,000 cfs day	2004	0.920	0.899	0.941	<
	Shallow Deflector; 56,000 cfs day	2004	0.803	0.749	0.857	<
Counihan et al. 2006b	Dam Passage in summer	2005	0.938	0.924	0.952	<
	Spillway Passage in summer	2005	0.911	0.893	0.928	<
	Spillway Passage under Gas-Cap Spill	2005	0.986	0.960	1.011	=
Ploskey et al. 2007b	Dam Passage (Calculated Paired Release)	2006	0.919	0.890	0.948	<
	Spillway-Passage (Paired Release)	2006	0.906	0.869	0.944	<
Ploskey et al. 2008	Spill-Passage for summer	2007	0.930	0.917	0.945	<
	Deep-Deflector Passage (Single Release)	2007	0.999	0.995	1.003	>
	Shallow Deflector Passage (Single Release)	2007	0.936	0.922	0.950	=
This study	Dam-Passage	2008	0.970	0.956	0.984	
	Spillway-Passage	2008	0.969	0.953	0.985	
	Deep Flow Deflector (Single Release)	2008	0.957	0.943	0.971	
	Shallow Flow Deflector (Single Release)	2008	0.946	0.923	0.970	

(a) CL = confidence limit.
(b) Overlap refers to overlapping 95% CIs; estimates followed by an = symbol had 95% CIs that overlapped with those of 2008 estimates, and estimates followed by a < symbol were less than 2008 estimates based on the non-overlap of 95% CIs.
(c) Adjustment for one dead-fish detection applied; 0.957 [0.931, 0.970; 95% CL] without the adjustment.

4.8.3.2 Relative Survival Rates for FC Passing Through Deep and Shallow Deflectors Bays

We found that smolts passing through bays with deep flow deflectors had significantly higher survival rates than smolts passing through middle bays with shallow deflectors in the second half of summer 2008, but not for the entire summer season. River discharge and tailrace water surface elevations were so high during most of summer 2008 that a causal mechanism in the form of smolts passing close to shallow flow deflectors did not exist until late summer. The ability to detect within-season differences is a testament to the precision of survival estimates for individual virtual releases. Statistical tests on 2007 data showed that deep flow deflector spill bays had 6.3% higher passage survival rates in the first reach than shallow flow deflector spill bays, and this result was consistent with findings in summer 2004 by Counihan et al. (2006a). Conditions in summer 2004 were exacerbated by low spill discharge during the day (56,000 cfs compared to 80,000 cfs in 2007) and low tailrace elevations that averaged just 4.24 m above MSL. In contrast, mean tailrace elevations in summer 2007 were closer to 5.34 m above MSL.

Low tailrace elevations and spill discharge in 2004 probably explain why the deep-to-shallow ratio of survival rates for FC was much higher in 2004 (1.146) than it was in 2007 (1.067) or after July 2, 2008 (1.065).

The body of evidence from this study and earlier studies indicates that the most likely environmental conditions reducing survival rates of FC passing through bays with shallow flow deflectors are below-average project discharge and low tailrace elevations in summer. These conditions occurred in summer 2004, summer 2007, and late summer 2008. If future studies happen to be conducted during a drought, evidence suggests that significant differences will be detected again. Mechanisms for increased mortality when tailrace elevations are near the elevations of shallow flow deflectors in middle bays are unknown, but obviously the proximity of fish to deflector surfaces must decrease as the amount of water passing over deflectors decreases. In the early 1970s, Johnson and Dawley (1974) found that FC passing through bays without flow deflectors had higher survival percentages (95.8%) than FC passing through bays with flow deflectors (86.8%). Any injury or loss of equilibrium associated with abrasion or shear could increase the susceptibility of fish to predation or disease so there could be immediate or delayed mortality. For FC in summer 2007, we found that the mean travel time to the egress array located 9 km downstream of the dam was 20 minutes longer (P = 0.0105) for fish passing through middle bays with shallow flow deflectors than it was for fish passing through end bays with deep deflectors. In late summer 2008, the smolts passing through middle bays took about 18 minutes longer than smolts passing through end bays to reach the primary array. More importantly, the middle-bay-passage delay relative to end-bay passage was about 1 hour for the slowest 10% of smolts passing through each route. Smolts with slow egress times are less likely to survive than smolts with fast egress times, because slow-moving smolts have more exposure to predation.

4.9 Tests of Survival-Model Assumptions

Nine assumptions of mark, release, and recapture survival models were described under Model Assumptions in Section 2.8.1.1, and out of those, only a few could be tested by examining empirical data.

The first assumption concerns making inferences from the sampled population to the target population. Is the sample of smolts from a JBS representative of the run at large passing through lower Columbia River projects? There are few other options for sampling large numbers of fish without stress or injury, and it is therefore unlikely that sampling methods will change regardless of the answer. If smolts are sampled with other methods in a given year, researchers certainly should take the opportunity to compare lengths of sampled smolts from the JBS with those of smolts taken in other samples. Other quantifiable measures of fish condition should be examined as well.

The first assumption also could be violated if smolts selected for tagging were, on average, significantly larger than the run-of-river population of smolts. In this study, the length frequency distributions of tagged and untagged smolts were similar, although median lengths of tagged fish were 8 mm (YC), 11 mm (STH), and 6 mm (FC) longer than those of smolts in routine smolt-monitoring samples in 2008. We suspect that this was mostly because clipped smolts, which often were slightly longer than unclipped fish, were preferentially selected for tagging in 2008. Nevertheless, slight differences in median lengths were not large enough for us to conclude that inferences made from the tagged populations would not generally apply to the run at large. In 2008, no YC or STH smolts and only 9% of FC smolts were excluded from tagging because they were shorter than the 95-mm minimum length required for tagging. Until miniaturization of acoustic tags reaches a point where 75-mm smolts can be tagged, the length bias in summer will remain a problem in some years. It also is possible that the length frequency of smolts collected from a JBS might differ from that of smolts passing by non-JBS routes.

We found no significant differences between virtual-release estimates of survival rates for YC released in the Snake River below LGR and rates for YC released in the JDA pool or tailrace. This suggests that if tag effects occurred, they manifested themselves before smolts reached the BON forebay. If tagging had a detrimental effect on survival rates (Assumption 2; Section 2.8.1.1), then survival estimates from the single-release model tend to be negatively biased (i.e., underestimated).

Results of Burnham tests did not indicate that there was a problem with upstream detection histories affecting downstream detection or survival probabilities in this study (see Assumption 5 described under Section 2.8.1.1). For each stock of fish tested under Test 2 or Test 3, less than 10% was significant at α=0.1. At an alpha (α) level of 0.1, either test could incorrectly reject a true null hypothesis (of no effect) up to 10% of the time.

Assumption 7 implies that the smolts do not lose their tags and are subsequently misidentified as dead or not captured, nor are dead fish falsely recorded as alive at detection locations. Tag failure will depend on travel times relative to battery life, and was not a serious concern for this study because over 99% of smolts exited survival-detection arrays before the probability of tag failure was significant. Also, we adjusted survival estimates to account for what little premature tag failure was observed before smolts passed the three downstream survival-detection arrays. Acoustically tagged dead fish drifting downstream could result in false positive detections and upwardly bias survival estimates. We also adjusted survival estimates for YC to account for the probability of detecting dead fish on survival-detection arrays and the correction decreased survival estimates by 2.5 to 3.0%. There is a need to better estimate the probability of detecting dead fish on survival-detection arrays, as discussed earlier in this section, and this can be done in future studies by releasing more dead fish implanted with acoustic transmitters.

Assumption 8 implies that there is no synergistic relationship between survival processes in the two river reaches. In other words, smolts that survive the first river reach are no more or less susceptible to mortality in the second river reach than smolts released in the second river reach. This could be a problem when virtual releases of veteran smolts are paired with reference releases of recently tagged smolts and the latter group suffered higher mortality than the former group. Faber et al. (2009) found no evidence of post handling mortality of control fish when they compared paired- and triple-release survival estimates for YC smolts. Similarly, Faber et al. (2009) found no significant difference between survival estimates for FC smolts from the paired- and triple-release models.

The assumption of mixing treatment and reference releases of fish (Assumption 9) is important for paired-release estimates in this study. This assumption was tested by examining cumulative frequency distributions of the arrival times of each release group at downstream arrays. We examined the distributions of arrivals of treatment and reference fish at the primary array and found both groups to be well mixed with no significant deviation in cumulative time of arrival (see Figure 3.23 and Figure 3.24). Both YC and FC were well represented traversing the common tailwater during morning, afternoon, and evening, which means that they were exposed to similar conditions that might influence survival rates (e.g., avian or piscivorous predation).

5.0 Recommendations

The following recommendations are derived from the study results:

1. Reliance on paired releases that match veteran smolts in virtual releases with fresh smolts in references releases probably should end in favor of a more sophisticated survival model such as the one proposed by Skalski (2009).
2. The density of autonomous nodes in arrays downstream of the primary survival-detection array should be increased to increase the probability of detecting acoustic tags in future studies. The cost of increasing node density and detection probabilities is less than the cost of procuring more tags to obtain the required precision of survival estimates.
3. Arrays of autonomous nodes downstream of the primary survival-detection array should be more densely populated with nodes to increase the probability of detecting acoustic tags there in future studies. The cost of increasing node density and detection probabilities is less than the cost of procuring many more tags to increase the precision of survival estimates.
4. We recommend releasing at least 50 dead fish each season during the next survival study at this dam to better quantify the probability of detecting dead fish on survival-detection arrays below BON. This was a recommendation for 2007 study year report and the importance of continuing the practice is underscored by a single dead fish being detected in 2008. Detection of dead tagged fish implanted with acoustic tags causes a positive bias in survival estimates that can be corrected if researchers have an accurate estimate of the dead fish detection probability ($\hat{D}$).
5. To avoid sacrificing a lot of fish for future dead-fish releases, we recommend using dead specimens found before rigor mortis is obvious during routine smolt-monitoring operations as well as any fish that happen to die as a result of tagging. Recently deceased fish also could be collected from the Bonneville Hatchery, although reasonable condition criteria would have to be established. If fish must be sacrificed, we recommend sacrificing individuals that would otherwise be rejected for tagging because of injury or descaling. These individuals would be much less likely to survive than healthy fish.
6. Tag-life studies should be improved by testing 100 tags of each nominal PRI from all production lots delivered before the tagging season begins. Having 100 tags will minimize the impact of the premature failure of one or two tags on the tag-life curves because each tag will represent only 1% of the study tags. Implementation of this recommendation will require the early purchase, production, and delivery of all tags before the start of each migration season so that researchers can randomly sample 100 tags from all tags with each PRI.
7. For most years and particularly years with above-average discharge, tagging at JDA should start by April 20 to be more representative of run timing at BON. The tagging schedule for 2008 did a good job representing run timing for STH and FC at BON and probably would not require alteration for a similar water year.

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Appendix A

Tables on Tagging, Release, BON Virtual Releases, Dam Operations Data, and Capture History (at or below BON)

Appendix A

Tables on Tagging, Release, BON Virtual Releases, Dam Operations Data, and Capture History (at or below BON)

Table A.1. List of comma-separated-variable (CSV) files on an accompanying compact disc.[a] Variables in the first row of the CSV files are defined in Tables A.2 through A.6 below.

File	Description
Appendix A1.xlsx	BON Virtual Releases, Reference Releases, Hourly Dam Operations Data, and Capture History at or Below BON (All Species)
Appendix A2.xlsx	Tagging, Release, and Capture History Data for Steelhead
Appendix A3.xlsx	Tagging, Release, and Capture History Data for Spring Chinook Salmon Released in the John Day and The Dalles Pools
Appendix A4.xlsx	Tagging, Release, and Capture History Data for Fall Chinook Salmon Released in the John Day, The Dalles, and Bonneville Pools
Appendix A5.xlsx	Tagging, Release, and Capture History Data for Spring Chinook Salmon Released in the Lower Granite Tailrace

(a) A compact disc accompanying the report has six files: A Portable Document (PDF) file of this report and comma-separated-variable files with tagging, release, virtual release, and capture-history data.

Table A.2. Variable names and definitions in Appendix A1.csv

Variable	Definition
SEASON	Spring or Summer
TAGGER	Name of Surgeon Implanting Tags
SP	Species Name
SPP	PTAGIS Species Code
LENGTH	Fork Length (mm)
WEIGHT	Fish weight (g)
MORT	0=Alive; >0 = Dead
ACTAGCODE	Acoustic Tag Code
PRI	Pulse Repetition Interval of Acoustic Tag
PIT	PIT Tag Code
ADATETIME	Acoustic Tag Activation Date and Time (mm/dd/yyyy hh:mm)
TDATETIME	Tagging Date and Time (mm/dd/yyyy hh:mm)
RDATETIME	Release date and time (mm/dd/yyyy hh:mm)
REL_LOC	Release Location
Rkm	Release River Kilometer (km)
A4CR237	Regrouped at BON Forebay Entrance Array (1 = detected; 0 = not detected; . or blank = missing)
DATE	Date Released (if REL_LOC=BON_T) or Date of Forebay Virtual Release (if A4CR237=1), or Date of Spillway Virtual Release (if BROUTE='SPILL')
HOUR	Hour Released (if REL_LOC=BON_T) or Hour of Forebay Virtual Release (if A4CR237=1), or Hour of Spillway Virtual Release (if BROUTE='SPILL')
BROUTE	Route of Passage (Spill or blank)
BSUB_ROUTE	Sub Route of Passage (End Bay = SP_END; Middle Bay = SP_MID)
FU_01	Fish Unit 1 Discharge (cfs × 1,000)
FU_02	Fish Unit 2 Discharge (cfs × 1,000)
SP_01	Spill bay 1 Discharge (cfs × 1,000)
SP_02	Spill bay 2 Discharge (cfs × 1,000)
SP_03	Spill bay 3 Discharge (cfs × 1,000)
SP_04	Spill bay 4 Discharge (cfs × 1,000)
SP_05	Spill bay 5 Discharge (cfs × 1,000)
SP_06	Spill bay 6 Discharge (cfs × 1,000)
SP_07	Spill bay 7 Discharge (cfs × 1,000)
SP_08	Spill bay 8 Discharge (cfs × 1,000)
SP_09	Spill bay 9 Discharge (cfs × 1,000)
SP_10	Spill bay 10 Discharge (cfs × 1,000)
SP_11	Spill bay 11 Discharge (cfs × 1,000)
SP_12	Spill bay 12 Discharge (cfs × 1,000)
SP_13	Spill bay 13 Discharge (cfs × 1,000)
SP_14	Spill bay 14 Discharge (cfs × 1,000)
SP_15	Spill bay 15 Discharge (cfs × 1,000)
SP_16	Spill bay 16 Discharge (cfs × 1,000)
SP_17	Spill bay 17 Discharge (cfs × 1,000)
SP_18	Spill bay 18 Discharge (cfs × 1,000)
TU_01	Turbine 1 Discharge (cfs × 1,000)
TU_02	Turbine 2 Discharge (cfs × 1,000)

Table A.2. (contd)

Variable	Definition
TU_03	Turbine 3 Discharge (cfs × 1,000)
TU_04	Turbine 4 Discharge (cfs × 1,000)
TU_05	Turbine 5 Discharge (cfs × 1,000)
TU_06	Turbine 6 Discharge (cfs × 1,000)
TU_07	Turbine 7 Discharge (cfs × 1,000)
TU_08	Turbine 8 Discharge (cfs × 1,000)
TU_09	Turbine 9 Discharge (cfs × 1,000)
TU_10	Turbine 10 Discharge (cfs × 1,000)
TU_11	Turbine 11 Discharge (cfs × 1,000)
TU_12	Turbine 12 Discharge (cfs × 1,000)
TU_13	Turbine 13 Discharge (cfs × 1,000)
TU_14	Turbine 14 Discharge (cfs × 1,000)
TU_15	Turbine 15 Discharge (cfs × 1,000)
TU_16	Turbine 16 Discharge (cfs × 1,000)
TU_17	Turbine 17 Discharge (cfs × 1,000)
TU_18	Turbine 18 Discharge (cfs × 1,000)
SPILL_Q	Spillway Discharge (cfs × 1,000)
B1_Q	Powerhouse 1 Discharge (cfs × 1,000)
B2_Q	Powerhouse 2 Discharge (cfs × 1,000)
B2CC_Q	B2CC Discharge (cfs × 1,000)
BON_Q	Bonneville Project Discharge (cfs × 1,000)
P_SPILL	Percent Spill
HEAD	Difference in forebay and tailrace water surface elevations
FB_EL	Forebay Water Surface Elevation (ft)
TR_EL	Tailrace Water Surface Elevation (ft)
A5CR203	Tag Detected at Primary Array = 1; Not Detected = 0
A6CR192	Tag Detected at Secondary Array = 1; Not Detected = 0
A7CR086	Tag Detected at Tertiary Array = 1; Not Detected = 0
A5CR203_TIME	Date and Time of Detection on Primary Array
A6CR192_TIME	Date and Time of Detection on Secondary Array
A7CR086_TIME	Date and Time of Detection on Tertiary Array

Table A.3. Variable names and definitions in Appendix A2.csv

Variable Name	Definition
SEASON	Spring or summer outmigration season defined by type of fish and release date
SP	Species or run of juvenile salmon (SPR_STH = steelhead)
REL_LOC	Release Location (ARLINGTON=Arlington, OR; JDA_TW = upper end of the John Day Tailwater)
RDATETIME	Release date and time (mm/dd/yyyy hh:mm)
ADATETIME	Acoustic tag activation date and time (mm/dd/yyyy hh:mm)
PIT	Passive Integrated Transponder tag code
ACTAGCODE	Acoustic tag code
A1CR351	Detection indicator for the JDA Forebay Entrance Array (1 = detected; 0 = not detected; blank = missing)
JDA_ARRAY	Detection indicator for the JDA Dam-Face Array (1 = detected; 0 = not detected; blank = missing)
A2CR346	Detection indicator for the JDA Tailwater Array (1 = detected; 0 = not detected; blank = missing)
A3CR312	Detection indicator for The Dalles Forebay Entrance Array (1 = detected; 0 = not detected; blank = missing)
A4CR237	Detection indicator for the Bonneville Forebay Entrance Array (1 = detected; 0 = not detected; blank = missing)
B2_ARRAY	Detection indicator for the Bonneville Powerhouse 2 Dam-Face Array (1 = detected; 0 = not detected; blank = missing)
BSPILL_ARRAY	Detection indicator for the Bonneville Spillway Array (1 = detected; 0 = not detected; blank = missing)
A5CR203	Detection indicator for the first Bonneville Tailwater Array at Reed Island (1 = detected; 0 = not detected; blank = missing)
A6CR192	Detection indicator for the second Bonneville Tailwater Array at Lady Island (1 = detected; 0 = not detected; blank = missing)
A7CR086	Detection indicator for the third Bonneville Tailwater Array at Oak Point (1 = detected; 0 = not detected; blank = missing)
A1CR351_TIME	Date and time of arrival at the JDA Forebay Entrance Array
JDATETIME	Date and time of arrival at the JDA Dam-Face Array
A2CR346_TIME	Date and time of arrival at the JDA Tailwater Array
A3CR312_TIME	Date and time of arrival at The Dalles Forebay Entrance Array
A4CR237_TIME	Date and time of arrival at the BON Forebay Entrance Array
B2DATETIME	Date and time of last detection on the Bonneville Powerhouse 2 Array
BSDATETIME	Date and time of last detection on the Bonneville Spillway Array
A5CR203_TIME	Date and time of arrival at the first Bonneville Tailwater Array at Reed Island
A6CR192_TIME	Date and time of arrival at the second Bonneville Tailwater Array at Lady Island
A7CR086_TIME	Date and time of arrival at the third Bonneville Tailwater Array at Oak Point
JROUTE	Route of passage through John Day Dam (Powerhouse or Spillway)
JSUB_ROUTE	Sub-route of passage through John Day Dam [TSW (spill) , NonTSW (spill), Turbine, JBS]
JHOLE	Specific route of passage (Spill bays S1-S20; Turbines T1-T16; blank = missing)
BROUTE	Route of passage through BON (B2 or SPILL)
BSUB_ROUTE	Sub-route of passage through BON (SP_MID = spill bays 4-15; SP_END = spill bays 1-3 or 16-18; BCC = B2CC; Turbine = B2 turbines; JBS = juvenile bypass system)
BHOLE	Specific route of passage through BON (Spill bays = SB1-SB18; Turbines = TU11-TU18 or Unknown Turbine = UnkTurb; B2CC=BCC; Juvenile Bypass System = JBS)
J	Assigned pool of dates for virtual releases at JDA for estimating dam passage survival rate

Table A.3. (contd)

Variable Name	Definition
J_TW	Assigned pool of dates for reference releases in the upper JDA Tailwater for pairing with variable J above
J_NON_TSW	Assigned pool of dates for virtual releases at non-TSW spill bays at JDA
J_NON_TSW_TW	Assigned pool of dates for reference releases in the upper JDA Tailwater for pairing with J_NON_TSW above
J_TSW	Assigned pool of dates for virtual releases at JDA TSW spill bays (bays 15 and 16 in 2008)
J_TSW_TW	Assigned pool of dates for reference releases in the upper JDA Tailwater for pairing with J_TSW above
J_TUR	Assigned pool of dates for virtual releases at JDA turbines
J_TUR_TW	Assigned pool of dates for reference releases in the upper JDA Tailwater for pairing with J_TUR above
J_JBS	Assigned pool of dates for virtual releases at the JDA JBS
J_JBS_TW	Assigned pool of dates for reference releases in the upper JDA Tailwater for pairing with J_JBS above
T_FB	Assigned pool of dates for virtual releases at The Dalles Forebay Entrance Array
B_FB	Assigned pool of dates for reference releases in the upper JDA Tailwater for pairing with J_TUR above
B2	Assigned pool of dates for virtual releases at Bonneville Powerhouse 2
B2CC	Assigned pool of dates for virtual releases at the BON B2CC
B2_JBS	Assigned pool of dates for virtual releases at the BON B2 JBS
B2_TUR	Assigned pool of dates for virtual releases at BON B2 Turbines
BSPILL	Assigned pool of dates for virtual releases at the BON Spillway
BS_END	Assigned pool of dates for virtual releases at end bays (1-3 and 16-18) at the BON Spillway
BS_MID	Assigned pool of dates for virtual releases at middle spill bays at the BON Spillway

Table A.4. Variable names and definitions in Appendix A3.csv

Variable Name	Definition
SEASON	Spring or summer outmigration season defined by type of fish and release date
SP	Species or run of juvenile salmon (SPR_CHN = spring Chinook salmon)
REL_LOC	Release Location (ARLINGTON=Arlington, OR; JDA_TW = upper end of the John Day Tailwater; BON_T = the upper end of the Bonneville Tailwater)
RDATETIME	Release date and time (mm/dd/yyyy hh:mm)
ADATETIME	Acoustic tag activation date and time (mm/dd/yyyy hh:mm)
PIT	Passive Integrated Transponder tag code
ACTAGCODE	Acoustic tag code
A1CR351	Detection indicator for the JDA Forebay Entrance Array (1 = detected; 0 = not detected; blank = missing)
JDA_ARRAY	Detection indicator for the JDA Dam-Face Array (1 = detected; 0 = not detected; blank = missing)
A2CR346	Detection indicator for the JDA Tailwater Array (1 = detected; 0 = not detected; blank = missing)
A3CR312	Detection indicator for The Dalles Forebay Entrance Array (1 = detected; 0 = not detected; blank = missing)
A4CR237	Detection indicator for the Bonneville Forebay Entrance Array (1 = detected; 0 = not detected; blank = missing)
B2_ARRAY	Detection indicator for the Bonneville Powerhouse 2 Dam-Face Array (1 = detected; 0 = not detected; blank = missing)
BSPILL_ARRAY	Detection indicator for the Bonneville Spillway Array (1 = detected; 0 = not detected; blank = missing)
A5CR203	Detection indicator for the first Bonneville Tailwater Array at Reed Island (1 = detected; 0 = not detected; blank = missing)
A6CR192	Detection indicator for the second Bonneville Tailwater Array at Lady Island (1 = detected; 0 = not detected; blank = missing)
A7CR086	Detection indicator for the third Bonneville Tailwater Array at Oak Point (1 = detected; 0 = not detected; blank = missing)
A1CR351_TIME	Date and time of arrival at the JDA Forebay Entrance Array
JDATETIME	Date and time of arrival at the JDA Dam-Face Array
A2CR346_TIME	Date and time of arrival at the JDA Tailwater Array
A3CR312_TIME	Date and time of arrival at The Dalles Forebay Entrance Array
A4CR237_TIME	Date and time of arrival at the BON Forebay Entrance Array
B2DATETIME	Date and time of last detection on the Bonneville Powerhouse 2 Array
BSDATETIME	Date and time of last detection on the Bonneville Spillway Array
A5CR203_TIME	Date and time of arrival at the first Bonneville Tailwater Array at Reed Island
A6CR192_TIME	Date and time of arrival at the second Bonneville Tailwater Array at Lady Island
A7CR086_TIME	Date and time of arrival at the third Bonneville Tailwater Array at Oak Point
JROUTE	Route of passage through John Day Dam (Powerhouse or Spillway)
JSUB_ROUTE	Sub-route of passage through John Day Dam [TSW (spill) , NonTSW (spill), Turbine, JBS]
JHOLE	Specific route of passage (Spill bays S1-S20; Turbines T1-T16; blank = missing)
BROUTE	Route of passage through BON (B2 or SPILL)

Table A.4. (contd)

Variable Name	Definition
BSUB_ROUTE	Sub-route of passage through BON (SP_MID = spill bays 4-15; SP_END = spill bays 1-3 or 16-18; BCC = B2CC; Turbine = B2 turbines; JBS = juvenile bypass system)
BHOLE	Specific route of passage through BON (Spill bays = SB1-SB18; Turbines = TU11-TU18 or Unknown Turbine = UnkTurb; B2CC=BCC; Juvenile Bypass System = JBS)
J	Assigned pool of dates for virtual releases at JDA for estimating dam-passage survival rate
J_TW	Assigned pool of dates for reference releases in the upper JDA Tailwater for pairing with variable J above
J_NON_TSW	Assigned pool of dates for virtual releases at non-TSW spill bays at JDA
J_NON_TSW_TW	Assigned pool of dates for reference releases in the upper JDA Tailwater for pairing with J_NON_TSW above
J_TSW	Assigned pool of dates for virtual releases at JDA TSW spill bays (bays 15 and 16 in 2008)
J_TSW_TW	Assigned pool of dates for reference releases in the upper JDA Tailwater for pairing with J_TSW above
J_TUR	Assigned pool of dates for virtual releases at JDA turbines
J_TUR_TW	Assigned pool of dates for reference releases in the upper JDA Tailwater for pairing with J_TUR above
J_JBS	Assigned pool of dates for virtual releases at the JDA JBS
J_JBS_TW	Assigned pool of dates for reference releases in the upper JDA Tailwater for pairing with J_JBS above
T_FB	Assigned pool of dates for virtual releases at The Dalles Forebay Entrance Array
B_FB	Assigned pool of dates for virtual releases at the BON Forebay Entrance Array for estimating BON Dam-Passage Survival Rate
B_FB_TW	Assigned pool of date for reference releases for pairing with B_FB above
B2	Assigned pool of dates for virtual releases at Bonneville Powerhouse 2
B2_TW	Assigned pool of dates for reference releases for pairing with B2 above
B2CC	Assigned pool of dates for virtual releases at the BON B2CC
B2CC_TW	Assigned pool of dates for reference releases for pairing with B2 above
B2CC_R	Assigned pool of dates for releases directly into the B2CC
B2CC_R_TW	Assigned pool of dates for reference releases in the BON Tailwater for pairing with B2CC_R
B2_JBS	Assigned pool of dates for virtual releases at the BON B2 JBS
B2_JBS_TW	Assigned pool of dates for reference releases in the BON Tailwater for pairing with B2_JBS above
B2_TUR	Assigned pool of dates for virtual releases at BON B2 Turbines
B2_TUR_TW	Assigned pool of dates for reference releases in the BON Tailwater for pairing with B2_TUR above
BSPILL	Assigned pool of dates for virtual releases at the BON Spillway
BSPILL_TW	Assigned pool of dates for references releases in the BON Tailwater for pairing with BSPILL above
BS_END	Assigned pool of dates for virtual releases at end bays (1-3 and 16-18) at the BON Spillway
BS_END_TW	Assigned pool of dates for references releases in the BON Tailwater for pairing with BS_END above
BS_MID	Assigned pool of dates for virtual releases at middle spill bays at the BON Spillway
BS_MID_TW	Assigned pool of dates for references releases in the BON Tailwater for pairing with BS_MID above

Table A.5. Variable names and definitions in Appendix A4.csv

Variable Name	Definition
SEASON	Spring or summer outmigration season defined by type of fish and release date
SP	Species or run of juvenile salmon (FALL_CHN = fall Chinook salmon)
REL_LOC	Release Location (ARLINGTON=Arlington, OR; JDA_TW = upper end of the John Day Tailwater; TDA_TW = the upper end of The Dalles Tailwater; BON_T = the upper end of the Bonneville Tailwater)
RDATETIME	Release date and time (mm/dd/yyyy hh:mm)
ADATETIME	Acoustic tag activation date and time (mm/dd/yyyy hh:mm)
PIT	Passive Integrated Transponder tag code
ACTAGCODE	Acoustic tag code
A1CR351	Detection indicator for the JDA Forebay Entrance Array (1 = detected; 0 = not detected; blank = missing)
JDA_ARRAY	Detection indicator for the JDA Dam-Face Array (1 = detected; 0 = not detected; blank = missing)
A2CR346	Detection indicator for the JDA Tailwater Array (1 = detected; 0 = not detected; blank = missing)
A3CR312	Detection indicator for The Dalles Forebay Entrance Array (1 = detected; 0 = not detected; blank = missing)
A4CR237	Detection indicator for the Bonneville Forebay Entrance Array (1 = detected; 0 = not detected; blank = missing)
B2_ARRAY	Detection indicator for the Bonneville Powerhouse 2 Dam-Face Array (1 = detected; 0 = not detected; blank = missing)
BSPILL_ARRAY	Detection indicator for the Bonneville Spillway Array (1 = detected; 0 = not detected; blank = missing)
A5CR203	Detection indicator for the first Bonneville Tailwater Array at Reed Island (1 = detected; 0 = not detected; blank = missing)
A6CR192	Detection indicator for the second Bonneville Tailwater Array at Lady Island (1 = detected; 0 = not detected; blank = missing)
A7CR086	Detection indicator for the third Bonneville Tailwater Array at Oak Point (1 = detected; 0 = not detected; blank = missing)
A1CR351_TIME	Date and time of arrival at the JDA Forebay Entrance Array
JDATETIME	Date and time of arrival at the JDA Dam-Face Array
A2CR346_TIME	Date and time of arrival at the JDA Tailwater Array
A3CR312_TIME	Date and time of arrival at The Dalles Forebay Entrance Array
A4CR237_TIME	Date and time of arrival at the BON Forebay Entrance Array
B2DATETIME	Date and time of last detection on the Bonneville Powerhouse 2 Array
BSDATETIME	Date and time of last detection on the Bonneville Spillway Array
A5CR203_TIME	Date and time of arrival at the first Bonneville Tailwater Array at Reed Island
A6CR192_TIME	Date and time of arrival at the second Bonneville Tailwater Array at Lady Island
A7CR086_TIME	Date and time of arrival at the third Bonneville Tailwater Array at Oak Point
JROUTE	Route of passage through John Day Dam (Powerhouse or Spillway)
JSUB_ROUTE	Sub-route of passage through John Day Dam [TSW (spill) , NonTSW (spill), Turbine, JBS]
JHOLE	Specific route of passage (Spill bays S1-S20; Turbines T1-T16; blank = missing)
BROUTE	Route of passage through BON (B2 or SPILL)

Table A.5. (contd)

Variable Name	Definition
BSUB_ROUTE	Sub-route of passage through BON (SP_MID = spill bays 4-15; SP_END = spill bays 1-3 or 16-18; BCC = B2CC; Turbine = B2 turbines; JBS = juvenile bypass system)
BHOLE	Specific route of passage through BON (Spill bays = SB1-SB18; Turbines = TU11-TU18 or Unknown Turbine = UnkTurb; B2CC=BCC; Juvenile Bypass System = JBS)
J	Assigned pool of dates for virtual releases at JDA for estimating dam-passage survival rate
J_TW	Assigned pool of dates for reference releases in the upper JDA Tailwater for pairing with variable J above
J_NON_TSW	Assigned pool of dates for virtual releases at non-TSW spill bays at JDA
J_NON_TSW_TW	Assigned pool of dates for reference releases in the upper JDA Tailwater for pairing with J_NON_TSW above
J_TSW	Assigned pool of dates for virtual releases at JDA TSW spill bays (bays 15 and 16 in 2008)
J_TSW_TW	Assigned pool of dates for reference releases in the upper JDA Tailwater for pairing with J_TSW above
J_TUR	Assigned pool of dates for virtual releases at JDA turbines
J_TUR_TW	Assigned pool of dates for reference releases in the upper JDA Tailwater for pairing with J_TUR above
J_JBS	Assigned pool of dates for virtual releases at the JDA JBS
J_JBS_TW	Assigned pool of dates for reference releases in the upper JDA Tailwater for pairing with J_JBS above
T_FB	Assigned pool of dates for virtual releases at The Dalles Forebay Entrance Array
T_FB	Assigned pool of dates for reference releases in the upper tailwater of The Dalles Dam
B_FB	Assigned pool of dates for virtual releases at the BON Forebay Entrance Array for estimating BON Dam-Passage Survival Rate
B_FB_TW	Assigned pool of date for reference releases for pairing with B_FB above
B2	Assigned pool of dates for virtual releases at Bonneville Powerhouse 2
B2_TW	Assigned pool of dates for reference releases for pairing with B2 above
B2CC	Assigned pool of dates for virtual releases at the BON B2CC
B2CC_TW	Assigned pool of dates for reference releases for pairing with B2 above
B2CC_R	Assigned pool of dates for releases directly into the B2CC
B2CC_R_TW	Assigned pool of dates for reference releases in the BON Tailwater for pairing with B2CC_R
B2_JBS	Assigned pool of dates for virtual releases at the BON B2 JBS
B2_JBS_TW	Assigned pool of dates for reference releases in the BON Tailwater for pairing with B2_JBS above
B2_TUR	Assigned pool of dates for virtual releases at BON B2 Turbines
B2_TUR_TW	Assigned pool of dates for reference releases in the BON Tailwater for pairing with B2_TUR above
BSPILL	Assigned pool of dates for virtual releases at the BON Spillway
BSPILL_TW	Assigned pool of dates for references releases in the BON Tailwater for pairing with BSPILL above
BS_END	Assigned pool of dates for virtual releases at end bays (1-3 and 16-18) at the BON Spillway
BS_END_TW	Assigned pool of dates for references releases in the BON Tailwater for pairing with BS_END above
BS_MID	Assigned pool of dates for virtual releases at middle spill bays at the BON Spillway
BS_MID_TW	Assigned pool of dates for references releases in the BON Tailwater for pairing with BS_MID above

Table A.6. Variable names and definitions in Appendix A5.csv

Variable Name	Definition
SEASON	Spring or summer outmigration season defined by type of fish and release date
SP	Species or run of juvenile salmon (SPR_CHN = spring Chinook salmon)
REL_LOC	Release Location (LGR=Lower Granite Tailwater; JDA_TW = upper end of the John Day Tailwater; BON_T = the upper end of the Bonneville Tailwater)
RDATETIME	Release date and time (mm/dd/yyyy hh:mm)
ADATETIME	Acoustic tag activation date and time (mm/dd/yyyy hh:mm)
PIT	Passive Integrated Transponder tag code
ACTAGCODE	Acoustic tag code
A1CR351	Detection indicator for the JDA Forebay Entrance Array (1 = detected; 0 = not detected; blank = missing)
JDA_ARRAY	Detection indicator for the JDA Dam-Face Array (1 = detected; 0 = not detected; blank = missing)
A2CR346	Detection indicator for the JDA Tailwater Array (1 = detected; 0 = not detected; blank = missing)
A3CR312	Detection indicator for The Dalles Forebay Entrance Array (1 = detected; 0 = not detected; blank = missing)
A4CR237	Detection indicator for the Bonneville Forebay Entrance Array (1 = detected; 0 = not detected; blank = missing)
B2_ARRAY	Detection indicator for the Bonneville Powerhouse 2 Dam-Face Array (1 = detected; 0 = not detected; blank = missing)
BSPILL_ARRAY	Detection indicator for the Bonneville Spillway Array (1 = detected; 0 = not detected; blank = missing)
A5CR203	Detection indicator for the first Bonneville Tailwater Array at Reed Island (1 = detected; 0 = not detected; blank = missing)
A6CR192	Detection indicator for the second Bonneville Tailwater Array at Lady Island (1 = detected; 0 = not detected; blank = missing)
A7CR086	Detection indicator for the third Bonneville Tailwater Array at Oak Point (1 = detected; 0 = not detected; blank = missing)
A1CR351_TIME	Date and time of arrival at the JDA Forebay Entrance Array
JDATETIME	Date and time of arrival at the JDA Dam-Face Array
A2CR346_TIME	Date and time of arrival at the JDA Tailwater Array
A3CR312_TIME	Date and time of arrival at The Dalles Forebay Entrance Array
A4CR237_TIME	Date and time of arrival at the BON Forebay Entrance Array
B2DATETIME	Date and time of last detection on the Bonneville Powerhouse 2 Array
BSDATETIME	Date and time of last detection on the Bonneville Spillway Array
A5CR203_TIME	Date and time of arrival at the first Bonneville Tailwater Array at Reed Island
A6CR192_TIME	Date and time of arrival at the second Bonneville Tailwater Array at Lady Island
A7CR086_TIME	Date and time of arrival at the third Bonneville Tailwater Array at Oak Point
JROUTE	Route of passage through John Day Dam (Powerhouse or Spillway)
JSUB_ROUTE	Sub-route of passage through John Day Dam [TSW (spill) , NonTSW (spill), Turbine, JBS]
JHOLE	Specific route of passage (Spill bays S1-S20; Turbines T1-T16; blank = missing)
BROUTE	Route of passage through BON (B2 or SPILL)
BSUB_ROUTE	Sub-route of passage through BON (SP_MID = spill bays 4-15; SP_END = spill bays 1-3 or 16-18; BCC = B2CC; Turbine = B2 turbines; JBS = juvenile bypass system)
BHOLE	Specific route of passage through BON (Spill bays = SB1-SB18; Turbines = TU11-TU18 or Unknown Turbine = UnkTurb; B2CC=BCC; Juvenile Bypass System = JBS)

Table A.6. (contd)

Variable Name	Definition
J	Assigned pool of dates for virtual releases at JDA for estimating dam-passage survival rate
J_TW	Assigned pool of dates for reference releases in the upper JDA Tailwater for pairing with variable J above
B_FB	Assigned pool of dates for virtual releases at the BON Forebay Entrance Array for estimating the BON dam-passage survival rate
B_FB_TW	Assigned pool of date for reference releases for pairing with B_FB above

Appendix B

Two-Tailed Probabilities for Fischer's Exact Test on 2 × 2 Contingency Tables Populated with Counts According to Burnham Test 2 and Test 3 Configurations

Appendix B

Two-Tailed Probabilities for Fischer's Exact Test on 2 × 2 Contingency Tables Populated with Counts According to Burnham Test 2 and Test 3 Configurations

Table B.1. Burnham et al. (1987) Test 2 and Test 3 p-values for goodness-of-fit to the single-release-recapture data for YC smolts passing BON. Cells with NC could not be calculated because of high detection rates on the primary and secondary arrays. Shaded cells had P-values <0.10, which suggests that model Assumption 4 was violated.

Virtual Release Date	2 Sided Prob ≤ P (Fischer's Exact Test)	
	Test 2.2	Test 3.1
5/02-5/06	0.2007	0.3438
5/07-5/08	0.1813	1.0000
5/09-5/10	1.0000	0.7675
5/11-5/12	0.0696	1.0000
5/13-5/14	1.0000	0.0356
5/15-5/16	0.7474	0.6174
5/17-5/18	0.8661	0.3210
5/19-5/20	0.6651	0.6059
5/21-5/22	1.0000	1.0000
5/23-5/24	0.6295	0.7868
5/25-5/26	0.1543	0.2888
5/27-5/28	0.5599	0.7922
5/29-6/04	0.2367	0.0483

Table B.2. Burnham et al. (1987) Test 2 and Test 3 p-values for goodness-of-fit to the single-release-recapture data for yc smolts released in the Bonneville Tailrace as reference releases. Cells with NC could not be calculated because of high detection rates on the primary and secondary arrays. Shaded cells had P-values <0.10, which suggests that model Assumption 4 was violated.

Virtual Release Date	2 Sided Prob ≤ P (Fischer's Exact Test)	
	Test 2.2	Test 3.1
5/02-5/06	0.2241	0.3705
5/07-5/08	0.2368	1.0000
5/09-5/10	1.0000	1.0000
5/11-5/12	1.0000	1.0000
5/13-5/14	1.0000	1.0000
5/15-5/16	1.0000	1.0000
5/17-5/18	0.0877	1.0000
5/19-5/20	1.0000	0.5804
5/21-5/22	1.0000	0.2448
5/23-5/24	1.0000	1.0000
5/25-5/26	0.4951	0.3378
5/27-5/28	1.0000	0.2445
5/29-6/04	1.0000	0.3295

Table B.3. Burnham et al. (1987) Test 2 and Test 3 p-values for goodness-of-fit to the single-release-recapture data for YC smolts passing through the Bonneville spillway. Cells with NC could not be calculated because of high detection rates on the primary and secondary arrays. Shaded cells had P-values <0.10, which suggests that model Assumption 4 was violated.

Virtual Release Date	2 Sided Prob ≤ P (Fischer's Exact Test)	
	Test 2.2	Test 3.1
5/05-5/06	1.0000	1.0000
5/07-5/08	0.2032	0.6598
5/09-5/10	0.3556	0.7174
5/11-5/12	0.3520	0.6851
5/13-5/14	0.3846	0.5610
5/15-5/16	1.0000	1.0000
5/17-5/18	0.5784	0.2733
5/19-5/20	0.7675	0.4804
5/21-5/22	0.7387	0.4487
5/23-5/24	1.0000	1.0000
5/25-5/26	0.2686	0.2957
5/27-5/28	0.8044	0.1825
5/29-6/04	0.6312	0.2541

Table B.4. Burnham et al. (1987) Test 2 and Test 3 p-values for goodness-of-fit to the single-release-recapture data for YC smolts released in the Bonneville tailrace as reference releases for spillway passed fish. Cells with NC could not be calculated because of high detection rates on the primary and secondary arrays. Shaded cells had P-values <0.10, which suggests that model Assumption 4 was violated.

Virtual Release Date	2 Sided Prob ≤ P (Fischer's Exact Test)	
	Test 2.2	Test 3.1
5/05-5/06	0.2625	0.5977
5/07-5/08	0.2368	1.0000
5/09-5/10	1.0000	1.0000
5/11-5/12	1.0000	1.0000
5/13-5/14	1.0000	1.0000
5/15-5/16	1.0000	1.0000
5/17-5/18	0.0877	1.0000
5/19-5/20	1.0000	0.5804
5/21-5/22	1.0000	0.2448
5/23-5/24	1.0000	1.0000
5/25-5/26	0.4951	0.3378
5/27-5/28	1.0000	0.2445
5/29-6/04	1.0000	0.3295

Table B.5. Burnham et al. (1987) Test 2 and Test 3 p-values for goodness-of-fit to the single-release-recapture data for yc smolts through Bonneville spillway end bays with deep flow deflectors. Cells with NC could not be calculated because of high detection rates on the primary and secondary arrays. Shaded cells had P-values <0.10, which suggests that model Assumption 4 was violated.

Virtual Release Date	2 Sided Prob ≤ P (Fischer's Exact Test)	
	Test 2.2	Test 3.1
5/05-5/06	NC	1.0000
5/07-5/08	0.2317	1.0000
5/09-5/10	1.0000	0.6327
5/11-5/12	0.4496	0.1707
5/13-5/14	0.2437	1.0000
5/15-5/16	1.0000	1.0000
5/17-5/18	1.0000	0.6518
5/19-5/20	0.4415	0.1413
5/21-5/22	1.0000	0.5534
5/23-5/24	1.0000	1.0000
5/25-5/26	0.1845	0.0766
5/27-5/28	0.3650	0.1011
5/29-6/04	1.0000	1.0000

Table B.6. Burnham et al. (1987) Test 2 and Test 3 p-values for goodness-of-fit to the single-release-recapture data for yc smolts passing through Bonneville spillway middle bays with deep flow deflectors. Cells with NC could not be calculated because of high detection rates on the primary and secondary arrays. Shaded cells had P-values <0.10, which suggests that model Assumption 4 was violated.

Virtual Release Date	2 Sided Prob ≤ P (Fischer's Exact Test)	
	Test 2.2	Test 3.1
5/05-5/06	1.0000	1.0000
5/07-5/08	1.0000	1.0000
5/09-5/10	0.5703	0.5493
5/11-5/12	0.5008	0.5220
5/13-5/14	1.0000	1.0000
5/15-5/16	0.4995	0.6248
5/17-5/18	0.4121	0.3056
5/19-5/20	1.0000	1.0000
5/21-5/22	0.6532	0.6562
5/23-5/24	0.6739	0.6790
5/25-5/26	1.0000	1.0000
5/27-5/28	1.0000	0.6889
5/29-6/04	0.4989	0.2300

Table B.7. Burnham et al. (1987) Test 2 and Test 3 p-values for goodness-of-fit to the single-release-recapture data for STH smolts passing BON. Cells with NC could not be calculated because of high detection rates on the primary and secondary arrays. Shaded cells had P-values <0.10, which suggests that model Assumption 4 was violated.

Virtual Release Date	2 Sided Prob ≤ P (Fischer's Exact Test)	
	Test 2.2	Test 3.1
5/02-5/06	1.0000	0.3493
5/07-5/08	1.0000	1.0000
5/09-5/10	1.0000	0.6076
5/11-5/12	0.3641	1.0000
5/13-5/14	0.6067	1.0000
5/15-5/16	1.0000	0.3726
5/17-5/18	0.0130	0.4472
5/19-5/20	0.1601	0.5264
5/21-5/22	0.6542	0.0306
5/23-5/24	0.3516	0.2769
5/25-5/26	0.5857	0.7665
5/27-5/28	0.2536	0.2931
5/29-6/04	0.6280	0.3454

Table B.8. Burnham et al. (1987) Test 2 and Test 3 p-values for goodness-of-fit to the single-release-recapture data for STH smolts passing through the Bonneville spillway. Cells with NC could not be calculated because of high detection rates on the primary and secondary arrays. Shaded cells had P-values <0.10, which suggests that model Assumption 4 was violated.

Virtual Release Date	2 Sided Prob ≤ P (Fischer's Exact Test)	
	Test 2.2	Test 3.1
5/04-5/06	NC	0.6565
5/07-5/08	1.0000	1.0000
5/09-5/10	1.0000	1.0000
5/11-5/12	1.0000	1.0000
5/13-5/14	1.0000	1.0000
5/15-5/16	0.2499	1.0000
5/17-5/18	0.1452	0.3038
5/19-5/20	0.4899	0.3533
5/21-5/22	0.4421	0.1717
5/23-5/24	0.7538	1.0000
5/25-5/26	1.0000	0.7020
5/27-5/28	0.1250	0.3359
5/29-6/04	0.5617	1.0000

Table B.9. Burnham et al. (1987) Test 2 and Test 3 p-values for goodness-of-fit to the single-release-recapture data for STH smolts passing through Bonneville spillway end bays with deep flow deflectors. Cells with NC could not be calculated because of high detection rates on the primary and secondary arrays. Shaded cells had P-values <0.10, which suggests that model Assumption 4 was violated.

Virtual Release Date	P-values from Fisher's Exact Test	
	Test 2.2	Test 3.1
5/04-5/06	NC	0.2802
5/07-5/08	1.0000	0.5773
5/09-5/10	1.0000	1.0000
5/11-5/12	1.0000	1.0000
5/13-5/14	NC	NC
5/15-5/16	1.0000	1.0000
5/17-5/18	1.0000	0.5588
5/19-5/20	0.1737	0.5000
5/21-5/22	0.1346	0.5613
5/23-5/24	1.0000	0.5815
5/25-5/26	0.2291	0.5292
5/27-5/28	1.0000	1.0000
5/29-6/04	1.0000	0.5238

Table B.10. Burnham et al. (1987) Test 2 and Test 3 p-values for goodness-of-fit to the single-release-recapture data for STH smolts passing through Bonneville spillway middle bays with shallow flow deflectors. Cells with NC could not be calculated because of high detection rates on the primary and secondary arrays. Shaded cells had P-values <0.10, which suggests that model Assumption 4 was violated.

Virtual Release Date	P-values from Fisher's Exact Test	
	Test 2.2	Test 3.1
5/04-5/06	NC	1.0000
5/07-5/08	1.0000	1.0000
5/09-5/10	1.0000	0.5378
5/11-5/12	1.0000	1.0000
5/13-5/14	1.0000	0.3706
5/15-5/16	0.1994	0.4993
5/17-5/18	0.0871	0.4151
5/19-5/20	1.0000	0.5764
5/21-5/22	1.0000	0.0557
5/23-5/24	0.6643	1.0000
5/25-5/26	0.4058	1.0000
5/27-5/28	0.0808	0.3548
5/29-6/04	0.5204	1.0000

Table B.11. Burnham et al. (1987) Test 2 and Test 3 p-values for goodness-of-fit to the single-release-recapture data for FC smolts passing BON. Cells with NC could not be calculated because of high detection rates on the primary and secondary arrays. Shaded cells had P-values <0.10, which suggests that model Assumption 4 was violated.

Virtual Release Date	P-values from Fisher's Exact Test	
	Test 2.2	Test 3.1
6/17-6/18	0.6787	0.0075
6/19-6/20	0.3061	0.5047
6/21-6/22	0.4782	1.0000
6/23-6/24	0.7054	1.0000
6/25-6/26	0.6063	0.5381
6/27-6/28	0.8356	1.000
6/29-6/30	0.0975	0.7832
7/01-7/02	0.2747	0.2363
7/03-7/04	0.6675	0.2420
7/05-7/06	1.0000	0.3383
7/07-7/08	1.0000	1.0000
7/09-7/10	1.0000	1.0000
7/11-7/12	0.0146	0.4573
7/13-7/14	1.0000	1.0000
7/15-7/17	NC	1.0000

Table B.12. Burnham et al. (1987) Test 2 and Test 3 p-values for goodness-of-fit to the single-release-recapture data for FC smolts released in the Bonneville tailrace as reference releases for estimating dam survival rates. Cells with NC could not be calculated because of high detection rates on the primary and secondary arrays. Shaded cells had P-values <0.10, indicating that model Assumption 4 was violated.

Virtual Release Date	P-values from Fisher's Exact Test	
	Test 2.2	Test 3.1
6/17-6/18	0.6739	0.5513
6/19-6/20	0.7552	1.0000
6/21-6/22	0.3965	0.5416
6/23-6/24	1.0000	0.5072
6/25-6/26	0.0336	1.0000
6/27-6/28	1.0000	0.5855
6/29-6/30	0.2576	0.4318
7/01-7/02	0.2855	0.0968
7/03-7/04	0.5446	1.0000
7/05-7/06	1.0000	0.4101
7/07-7/08	1.0000	0.6667
7/09-7/10	1.0000	0.6652
7/11-7/12	1.0000	0.5850
7/13-7/14	0.0684	0.2679
7/15-7/17	NC	1.0000

Table B.13. Burnham et al. (1987) Test 2 and Test 3 p-values for goodness-of-fit to the single-release-recapture data for FC smolts passing through the Bonneville spillway. Cells with NC could not be calculated because of high detection rates on the primary and secondary arrays. Shaded cells had P-values <0.10, which suggests that model Assumption 4 was violated.

Virtual Release Date	P-values from Fisher's Exact Test	
	Test 2.2	Test 3.1
6/17-6/18	0.3406	0.0555
6/19-6/20	0.5155	0.2251
6/21-6/22	0.2502	0.3425
6/23-6/24	0.4634	0.6360
6/25-6/26	0.4495	0.2756
6/27-6/28	1.0000	1.0000
6/29-6/30	0.3840	1.0000
7/01-7/02	0.7379	0.4958
7/03-7/04	0.3960	1.0000
7/05-7/06	1.0000	0.6446
7/07-7/08	1.0000	0.6882
7/09-7/10	0.3997	0.6912
7/11-7/12	0.1504	0.1490
7/13-7/14	1.0000	1.0000
7/15-7/17	NC	0.4527

Table B.14. Burnham et al. (1987) Test 2 and Test 3 p-values for goodness-of-fit to the single-release-recapture data for FC smolts passing through end bays with deep flow deflectors. Cells with NC could not be calculated because of high detection rates on the primary and secondary arrays. Shaded cells had P-values <0.10, which suggests that model Assumption 4 was violated.

Virtual Release Date	P-values from Fisher's Exact Test	
	Test 2.2	Test 3.1
6/17-6/18	1.0000	0.1326
6/19-6/20	1.0000	0.2341
6/21-6/22	1.0000	0.3704
6/23-6/24	0.1614	1.0000
6/25-6/26	0.0570	0.2586
6/27-6/28	1.0000	0.1555
6/29-6/30	0.1442	1.0000
7/01-7/02	0.4273	0.3886
7/03-7/04	0.3783	0.4812
7/05-7/06	NC	0.4101
7/07-7/08	1.0000	0.5779
7/09-7/10	1.0000	1.0000
7/11-7/12	0.2062	0.1178
7/13-7/14	NC	1.0000
7/15-7/17	NC	NC

Table B.15. Burnham et al. (1987) Test 2 and Test 3 p-values for goodness-of-fit to the single-release-recapture data for FC smolts passing through middle bays with shallow flow deflectors. Cells with NC could not be calculated because of high detection rates on the primary and secondary arrays. Shaded cells had P-values <0.10, which suggests that model Assumption 4 was violated.

Virtual Release Date	P-values from Fisher's Exact Test	
	Test 2.2	Test 3.1
6/17-6/18	0.1519	0.3337
6/19-6/20	0.3917	0.4791
6/21-6/22	0.0437	0.5745
6/23-6/24	1.0000	1.0000
6/25-6/26	0.4707	0.2647
6/27-6/28	1.0000	1.0000
6/29-6/30	1.0000	1.0000
7/01-7/02	1.0000	1.0000
7/03-7/04	1.0000	1.0000
7/05-7/06	1.0000	1.0000
7/07-7/08	1.0000	1.0000
7/09-7/10	0.1385	1.0000
7/11-7/12	0.3827	0.5668
7/13-7/14	NC	NC
7/15-7/17	NC	0.5263

Appendix C

Estimating the Additional Contribution of “Dead-Fish Releases” to the Overall Variance of Project Survival Estimates

Estimating the Additional Contribution of “Dead-Fish Releases” to the Overall Variance of Project Survival Estimates

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Introduction

Tagged dead fish that pass through BON and are detected downriver must be accounted for in estimation of project or dam-passage survival rates. To adjust for this potential source of positive bias, releases of "tagged dead fish" must be conducted to independently estimate the probability such fish float downriver and are subsequently detected. This report addresses the issue of how many "tagged dead fish" must be released (*n*) in order to retain a precise estimate of dam-passage survival.

Methods

The bias-adjusted, paired-release estimates of project/dam survival $(\tilde{S})$ has a variance composed of two components as follows:

$$\mathrm{Var}(\tilde{S}) = \mathrm{Var}_{\hat{D}}\left(E(\tilde{S}|\hat{D})\right) + E_{\hat{D}}\left(\mathrm{Var}(\tilde{S}|\hat{D})\right) \tag{1}$$

The first component is the contribution associated with estimating the dead fish detection probability $(\hat{D})$ and the second component, the contribution due to the paired-release-recapture model estimation of project-passage survival (S). For a paired-release-recapture study with two downstream detection sites, the bias-adjusted estimator of survival can be written as

$$\tilde{S} = \frac{\left[\dfrac{n_1 + n_3}{R_1} - D\right]}{\left[\dfrac{n_1}{n_1 + n_2} - D\right]\hat{S}_2}, \tag{2}$$

where

R_1 = release size for upstream group,

n_1 = number of fish from release R_1 with history 11,

n_2 = number of fish from release R_1 with history 01,

n_3 = number of fish from release R_1 with history 10,

$\hat{S}_2$ = estimated survival probability of fish from downstream release R_2 to the first detection array.

In expectation, $\tilde{S}$ has the value

$$E(\tilde{S}|\hat{D}) = \frac{S_1 + (1 - S_1)\hat{D} - \dfrac{\hat{D}}{p}}{S_2\left(1 - \dfrac{\hat{D}}{p}\right)}, \tag{3}$$

where

S_1 = survival probability for fish from upstream release R_1 to the first detection array,

S_2 = survival probability for fish from downstream release R_2 to the first detection array,

p = probability of detecting a tagged fish at the first array,

$\hat{D}$ = probability a dead fish from release R_1 migrates and is detected at the first array,

such that, if $\hat{D}$ = 0, $\tilde{S} = \frac{S_1}{S_2} = S_{\text{Project}}$.

The variance of Eq. (3) with respect to $\hat{D}$ can be estimated by the delta method to be

$$\text{Var}_{\hat{D}}\left[E\left(\tilde{S}|\hat{D}\right)\right] = \frac{D(1-D)}{n}\left[\frac{\left[(1-S_1)p-1\right]}{S_2(p-D)} + \frac{\left[S_1^2 p + S_1(1-S_1)Dp - S_1 D\right]}{S_2^2(p-D)}\right], \qquad (4)$$

where n = number of dead tagged fish released below the dam. Using Eq. (4), the contribution of estimating the dead-fish detection rate $(\hat{D})$ on the overall variance of a project-passage survival (1) estimate can be calculated. The square root of Eq. (4) provides a rough approximate value of how much the standard error ($\widehat{SE}$) of a project-passage survival estimate will increase due to dead-fish detections, since

$$\sqrt{\sigma_1^2 + \sigma_2^2} < \sqrt{\sigma_1^2} + \sqrt{\sigma_2^2} = \sigma_1 + \sigma_2 .$$

A more accurate interpretation is to add the value of Eq. (4) to the anticipated variance of $\hat{S}$ without dead-fish problems and then take the square root of the sum to see what the expected $\widehat{SE}$ might be with release size n.

Results

One release-recapture scenario was investigated using Eq. (4) (Figure C.1). The scenario consisted of a paired release above and below BON with two downstream detection arrays. It was assumed dead, tagged fish might be detected at the first array but not the second. Reach survival rates were set at S_1 = 0.83, S_2 = 0.87 for a paired-release survival value of S_1/S_2 = 0.95. Detection of the first array was set at p = 0.80, consistent with values observed in 2006.

The square root of Eq. (4) (i.e., appropriate additional contribution to $\widehat{SE}$ of $\hat{S}_{\text{Project}}$) was plotted against the release size (n) of dead, tagged fish for various values of $\hat{D}$ = 0.01, 0.05, … , 0.30. Results indicate (Figure C.2) sample size can be quite large if the contributions to the overall $\widehat{SE}\left(\hat{S}\right)$ are to be small. For example, if $\hat{D}$ = 0.05, release size must be n = 100 for the $\widehat{SE}$ of the survival estimate to be inflated by 0.01. For the $\widehat{SE}$ of the project-passage survival rate to be inflated by no more than 0.005 when $\hat{D}$ = 0.05, release size of dead, tagged fish is $n \approx$ 500. Release sizes increase substantially as the value of $\hat{D}$ increases.

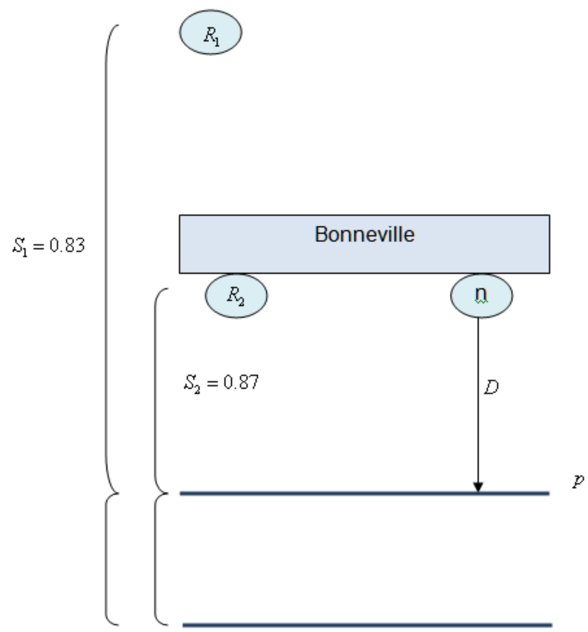
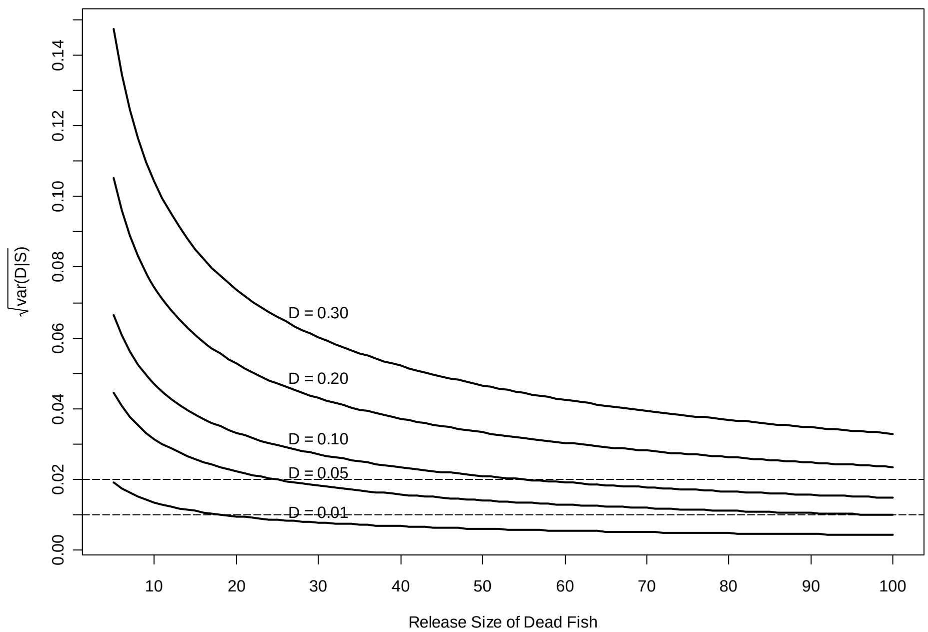


Figure C.1. Schematic of paired-release-recapture scenario used in sample size calculations

a. Release size n where $n \leq 100$



a. Release size $n \geq 100$

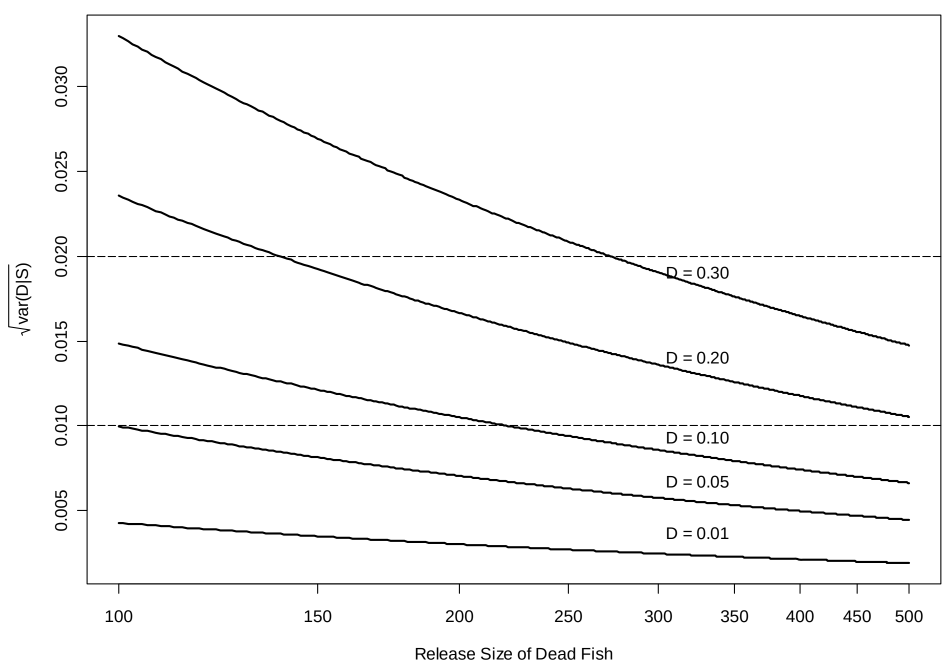


Figure C.2. Appropriate additional contributions to the standard error of project survival estimates as a function of the number of dead, tagged fish released (n) and the probability that a dead fish migrates to and is detected at the first downstream array (d) for (a) $n \leq 100$ and (b) $n \geq 100$

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