Comparative Survival Study of PIT-tagged Spring/Summer/Fall Chinook, Summer Steelhead, and Sockeye

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GLOSSARY OF TERMS

ADMB	AD Model Builder optimization software (free to download at www.admb-project.org)
AIC	Akaike Information Criterion: -2 ln (Likelihood) + 2p, where p = #parameters.
AICc	Akaike's information criterion for small sample sizes: $$AIC + [2p(p + 1)]/[n - p - 1],$$ where p = # parameters/ n = sample size.
ANCOVA	Analysis of covariation.
AP	Refers to acclimation ponds used as smolt acclimation and release sites for certain hatchery programs. For example, CATH AP refers to the Lookingglass hatchery AP at Catherine Creek.
A-run steelhead	Summer steelhead distributed throughout the Columbia Interior Domain distinguished from B-run steelhead by earlier adult migration timing, younger ocean-age (primarily 1-salt adults), and smaller adult size.
BH	Beverton-Holt
BKD	Bacterial Kidney Disease: a serious salmonid disease which can cause death or health impairment in both juveniles and adults.
BLUPs	Best Least Unbiased Predictions
BOA	Bonneville Dam adult fish ladder
BON	Bonneville Dam

BPA	Bonneville Power Administration
B-run steelhead	Summer steelhead originating from the Clearwater and Salmon rivers of Idaho that differ from A-run stocks in their later adult migration timing, older ocean-age (primarily 2-salt adults), and larger adult size.
BY	Brood Year
C0, C_0	Refers to the group of in-river control PIT-tagged smolts, (i.e., the number of PIT-tagged smolts at LGR that migrate through the hydrosystem without being bypassed at any of the Snake River collector dams). This group includes both fish that survived to reach the ocean and fish that may have died before reaching the ocean. This group of fish is most representative of the untagged run of the river.
C1, C_1	Refers to untransported PIT-tagged smolts which enter the detection/collection facility at one or more of the collector projects. Unlike untagged smolts, they are returned to the river so reach survival estimates are possible.
C_1_t	C_1 fish within Group T are bypassed fish that are representative of the untagged run of the river. They are detected at the Snake River detection/collection facility mostly prior to the start of transportation program.
C_1_r	C_1 fish within Group R are bypassed both prior and during the transportation season. They are used in the evaluation of the effects of detection and bypass passage relative to passage without detection at the three Snake River collection facilities (LGR, LGS, and LMN).
Capture history	The record of detections of PIT-tagged fish including date/sequence, location, and disposition.
CATH	Catherine Creek Acclimation Pond

CBFWA	Columbia Basin Fish and Wildlife Authority
CC	Catherine Creek
CH0, CH_0	Subyearling Chinook
CH1, CH_1	Yearling Chinook
CHH	Hatchery Chinook salmon
CHW	Wild Chinook salmon
CI	Confidence Interval
CJS	Cormack-Jolly-Seber. The multiple mark-recapture survival estimation method that is employed using the PIT-tag detections from the array of detection sites in the Snake and Columbia Rivers.
CLW	Clearwater River
CLWH-SP	Clearwater Hatchery Spring Chinook
CO	Coho
CRI	Cumulative Risk Initiative
CRITFC	Columbia River Inter-Tribal Fish Commission
CSS	Comparative Survival Study
CSSOC	CSS Oversight Committee
CTUIR	Confederated Tribes of the Umatilla Indian Reservation
CTWSRO	Confederated Tribes of the Warm Springs Reservation of Oregon

CV	Coefficient of variation
CWT	Coded-Wire Tag
D	The estuary and ocean survival rate of Snake River transported fish relative to fish that migrate in-river through the FCRPS. It is a ratio of SARs similar to the *TIR*, except the starting point for juvenile outmigrating fish is below Bonneville Dam. This is an index of the post-Bonneville survival of transported and non-transported fish.
Delayed mortality	Delayed mortality is the component of mortality that takes place in the estuary and during early ocean residence that is related to earlier life stage anthropogenic impacts downstream migration. Delayed mortality is expressed after fish pass through the hydrosystem.
Detection history	The record of detections of PIT-tagged fish including date/sequence, location, and disposition.
DEV	Productivity Deviate Model
Differential delayed mortality	*D*, the estuary and ocean survival rate of Snake River transported fish relative to fish that migrate in-river through the FCRPS. It is a ratio of SARs similar to the *TIR*, except the starting point for juvenile outmigrating fish is below Bonneville Dam.
Differential mortality	Difference in instantaneous mortality rates between Snake River populations and downriver populations of stream-type Chinook salmon that migrate through fewer dams. Measured as the difference in ln(recruit/spawner) or ln(SAR) between population groups.
Direct mortality	Mortality incurred within the hydrosystem.
DPS	Distinct Population Segment

DWOR	Dworshak National Fish Hatchery
ENT	Entiat River
ESA	Endangered Species Act
ESU	An Evolutionarily Significant Unit. A population that is considered distinct for purposes of conservation and is defined under the Endangered Species Act.
FCRPS	Federal Columbia River Power System
FGE	Fish Guidance Efficiency: Proportion of the living fish passing the powerhouse that were detected in the smolt collection system.
FPC	Fish Passage Center
FSR	Freshwater spawning and rearing
FTT	Fish Travel Time. The number of days a fish spends migrating through the reservoirs and past dams or through defined reaches.
FWP	NPCC's Fish and Wildlife Program
Group R	PIT-tagged fish that have been pre-assigned to follow the default return-to-river operations at all transportation facilities (LGR, LGS, LMN, and MCN) throughout the entire migration season.
Group T	PIT-tagged fish that have been pre-assigned to the monitor-mode operations which routes the PIT-tagged fish to pathways identical to the untagged run of the river fish (e.g., back to river prior to the initiation of transportation and to raceways during transportation) at all transportation facilities (LGR, LGS, LMN, and MCN) throughout the entire migration season.

GR, GRN	Grand Ronde River or Basin
GRA	Lower Granite Dam adult fish ladder
GRI	Grand Ronde/Imnaha
GRIMPG	Grand Ronde/Imnaha Major Population Group
HCD	Hells Canyon Dam
HO (Holdover)	Juvenile fall Chinook salmon that does not actively migrate through the hydrosystem during the summer or fall after emergence, or in the year released, and instead passes after the PIT-tag detection systems have shut down for winter at the dams, or during the following spring.
HSOX	Hatchery sockeye
ICTRT	Interior Columbia Basin Technical Recovery Team
IDFG	Idaho Department of Fish and Game
IHR	Ice Harbor Dam
IMN	Imnaha River or basin
Instantaneous mortality rate	Denoted as '*Z*', the rate of exponential population decline.
IPC	Idaho Power Company
ISAB	Independent Scientific Advisory Board
ISRP	Independent Scientific Review Panel
JDA	John Day Dam
JDMA	John Day Mainstem

JMMF	John Day Middle Fork
JDNF	John Day North Fork
JOH	Johnson Creek
LC model	Life-Cycle Model
LCX model	Environmentally influenced life-cycle model
LCH	Life Cycle Hydro Model
LGO	Little Goose Dam adult fish ladder
LGR	Lower Granite Dam
LGR equivalents	An estimate of the number of smolts at LGR for each of the three study categories (C_0, C_1, and T_0 or T_X_t) that includes the fish that perish before reaching and passing Little Goose and Lower Monumental dams.
LGS	Little Goose Dam
LM	Linear regression model
LMN	Lower Monumental Dam
LOS	Lostine River
LSRCP	Lower Snake River Compensation Plan
MAR	Marsh Creek
MAT	Minimum Abundance Threshold
MCA	McNary Dam adult fish ladder

MCMC	Markov Chain Monte Carlo (simulations using a Metropolis Hastings algorithm native to AD Model Builder software)
MCN	McNary Dam
ME	Mixed effects model
MET	Methow River
MFS	Middle Fork, Salmon River
MIN	Minam River
MLE	Maximum Likelihood Estimation
MP	Pacific Macropthalmia
MPG	Major Population Group. A subgroup or stratum of populations within a salmon ESU or steelhead DPS distinguished from other populations by similar genetic and demographic characteristics.
MY	Smolt migration year
NFH	National Fish Hatchery
NMFS	National Marine Fisheries Service
NOAA-Fisheries	National Oceanic and Atmospheric Administration, Fisheries
NPCC	Northwest Power and Conservation Council, present name of the Northwest Power Planning Council
NPH	Number of Power House passages for smolts
NPT	Nez Perce Tribe

ODFW	Oregon Department Fish and Wildlife
OE Model	Observation error form of the LCH model
Overall SAR	The SAR that includes the survival of all outmigrating smolts weighted across their different in-river and transport route experiences; the SAR of an entire brood of smolts, irrespective of their route of passage through the hydrosystem.
OXBH	Oxbow Hatchery
PATH	Plan for Analyzing and Testing Hypotheses
Pathway probability	The probability an individual smolt faces at LGR of falling into a particular outmigration pathway. The pathways are: (1) transported at LGR; (2) transported at LGS; (3) transported at LMN; or (4) migrate in-river through the entire hydrosystem.
PDO	Pacific Decadal Oscillation
PE	Process error estimation model
PIT-tag	Passive Integrated Transponder tag. Glass-encapsulated transponders, 11–12 mm in length with a unique identification code, which can be implanted into a fish's abdomen using a hand-held syringe. These tags are generally retained and function throughout the life of the fish. The tag's code can be read and recorded with an electronic scanner installed at a fixed site or hand held.
PITPH	Powerhouse contact rate derived from PIT-tag data.
POV	Poverty Flat
PRD	Priest Rapids Dam

PTAGIS	PIT-tag Information System. Regional depository and clearing house for the Columbia Basin PIT-tag release and detection information.
PTES	PIT Tag Effects Study
PTRANS	Index used to predict the fraction of juveniles that are transported.
RIS	Rock Island Dam
RAPH	Rapid River Hatchery
RM&E	Research, Monitoring and Evaluation
RMIS	Regional Mark Information System
RR	Run Reconstruction
RRE	Rocky Reach Dam
R/S	Recruits per spawner or mature fish at the point of recruitment (R) divided by the number of spawners in the parent generation (S).
Rsg	Spawning grounds recruits
RSWs	Removable spillway weirs
RY	Adult return year
SAL	Salmon River or Salmon River Basin
Salt (e.g. 1-salt, 2-salt, etc.)	Refers to adult return age as the number of years in the ocean. Used similarly for all species in the CSS reports. A "1-salt" for Chinook is also a jack adult return.

S	Reach- or life-stage specific survival. Estimates can be made from hatchery of release to Lower Granite Dam, Lower Granite Dam to Little Goose Dam, Lower Granite Dam to Bonneville Dam, and so forth.
SAR	Smolt-to-Adult-Return rate. The survival rate of a population from a beginning point as smolts to an ending point as adults. SARs are calculated from LGR to LGR and can also be estimated at BON to BON or LGR, or below BON to BON. SARs for populations could be for wild only, hatchery-origin, or both combined. The populations can be defined as those being transported, being left in the river to migrate, or all smolts combined regardless of their route of passage.
SAWT	Sawtooth Hatchery
SBT	Shoshone-Bannock Tribes
SFS	South Fork of Salmon River
SFTAFM	State, Federal, and Tribal Anadromous Fish Managers
SMP	Smolt Monitoring Program
SOX	Sockeye
S.o1, SO1	Survival during the first year of ocean life.
S.oa	Marine survival rates from the stage smolts enter the estuary to adult return.
SPS	Salmon population summaries
S_R	In-River Survivals
S-R, S/R	Spawner-Recruit data.

SRI	Survival Rate Index: The residuals from a fit of stock recruitment function to a given period of brood years.
SRP	Scientific Review Panel
ST	Steelhead
S_T	S_T is the assumed direct transportation survival rate (0.98) adjusted for in-river survival to the respective transportation sites for those fish transported from LGS or LMN.
STUFA	State Tribal and U.S. Fisheries Agencies
STH	Hatchery summer steelhead
STW	Wild summer steelhead
SUL	Sulphur Creek
Survival Rate	Number of fish alive after a specific time interval or life stage, divided by the initial number.
T_0	Refers to LGR equivalent transported smolts. First-time detected fish in the transported from LGR, LGS, or LMN pathways form this category. The numbers of fish transported from LGS or LMN are expanded by the inverse of the in-river survival rates from LGR to the respective transport sites.
TDA	The Dalles Dam

T_X_t	Refers to LGR equivalent transported smolts in pre-assigned Group T. Both first-time and prior detected fish in the transported from LGR, LGS, or LMN pathways form this category. The numbers of fish transported from LGS or LMN are expanded by the inverse of the in-river survival rates from LGR to the respective transport sites. This group of fish is directly representative of the untagged run of the river fish being transported in years with the later start of transportation.
TIR	Transport/In-river, the ratio of SARs that relates survival of transported fish to in-river migrants. The ratio is the SAR of fish transported from LGR to BON and returning as adults, divided by the SAR of fish outmigrating from LGR to BON and returning to LGR as adults.
TSWs	Temporary spillway weirs
TWX	Trawling operation by NMFS in the lower Columbia River in the vicinity of Jones Beach that detects PIT-tagged fish.
UCOL	Upper Columbia River
UPW	Upwelling
USACE	U.S. Army Corp of Engineers
USFWS	U.S. Fish and Wildlife Service
USR	Upper Salmon River
WDFW	Washington Department of Fish and Wildlife
WEN	Wenaha River (Snake Basin) or Wenatchee River (Upper Columbia Basin)

WTT	Water Travel Time. Water velocity in the mainstem migratory corridor is generally expressed as the average time (in days) it takes for a water particle to travel through a river reach (water travel time) during a specified period.
YIN	Yakama Indian Nation
Z	The total instantaneous mortality rate (rate of exponential population decline) of a population cohort. Mathematically, *Z* is the negative natural logarithm of survival divided by median fish travel time.

EXECUTIVE SUMMARY

The 2017 Comparative Survival Study Annual Report continues to update the historical time series life-cycle monitoring data and includes enhancements to analyses based upon review comments and recommendations from the fishery management agencies, tribes, and the Northwest Power and Conservation Council's Independent Scientific Advisory Board (ISAB).

This CSS Annual Report includes 22 years of SAR data for wild Snake River spring/summer Chinook (1994–2015), 19 years of SAR data for Snake River hatchery spring/summer Chinook (1997–2015), 18 years of SAR data for Snake River wild and hatchery steelhead (1997–2014), and seven years of SAR data for Snake River sockeye (2009–2015). There are seven years of SAR data for Snake River hatchery fall Chinook (2006–2012), and seven years of Snake River wild fall SAR data spanning the years 2006–2011. For mid-Columbia and upper-Columbia fall Chinook there are varying numbers of years available. There are 15 years of SAR data for Hanford Reach wild fall Chinook (2000–2014), four years of SAR data for wild Deschutes River fall Chinook (2011–2014), and seven years of SAR data for both Spring Creek NFH and Little White Salmon NFH fall Chinook (2008–2014). Spring and summer Chinook and sockeye returns from outmigration year 2015 should be considered preliminary, as they include only 2-salt returns and may change with the addition of 3-salt returns next year. Similarly, 2014 migration year fall Chinook returns include only 2-salt adults. The CSS has actively provided Passive Integrated Transponder (PIT) tags for most of these groups since outmigration year 1997.

Mark groups in 2017 were consistent with groups utilized in past years. In addition to overall smolt-to-adult return rates (SARs) for aggregate Snake River wild steelhead and Chinook salmon, the CSS has continued to pursue the development of SAR and life cycle metrics at the Major Population Group (MPG) level when sample size was adequate. These MPG-level SARs are provided for both Lower Granite to Lower Granite and from Lower Granite to Bonneville with and without jacks (1-salt) for Chinook salmon. In addition, Chapter 4 now includes estimates of overall SARs (MCN-to-MCN) for Yakima River wild Chinook salmon, Yakima River hatchery Chinook salmon (i.e., Cle Elum Hatchery), and Yakima River wild steelhead. The CSS continue to strive to improve life cycle monitoring metrics for wild populations of

salmon and steelhead, and continue to work with fishery managers to improve tagging coverage of wild populations from tributary traps.

The long-term objective of the CSS is to link stages of the salmon life cycle, the factors influencing survival at each life stage, and understanding how each factor affects survival at later life stages, resulting in smolt-to adult return rates. The analyses presented in Chapter 2 utilize the life cycle model to predict the long-term effects of four experimental spill alternatives under a dam breach scenario of the four lower Snake River dams, and a non-breach scenario, on population recovery. The experimental spill levels are defined in terms of the limits of total dissolved gas (TDG) produced at each project. The prospective analyses considered the relative benefit in adult return and smolt-to-adult return of four operation scenarios, the BiOp, 115%/120%, 120%, and 125% spill levels under high, average and low flow conditions. The analyses do not predict absolute SARs but rather examines the relative change among the four scenarios with increasing spill for fish passage under breach and non-breach scenarios. This analysis predicts that average return abundances and SARs increase at higher levels of spill and when dams are breached, owing to the empirical finding that survival is higher when powerhouse passage and water transit times are lower. The predicted outcomes represent approximations of the relative magnitude of increased survival and return abundance that are predicted relative to expected passage and water transit time values under flow, spill, and breach conditions. In a fully impounded river, we predict a 2-2.5 fold increase in return abundance above BiOp spill levels when spill is increased to 125% TDG. If the lower four Snake River dams are breached and the remaining four lower Columbia dams operate at BioP spill levels, we predict approximately a 2-3 fold increase in abundance above that predicted at BiOp spill levels in an impounded system, and up to a 4 fold increase if spill is increased to the 125% TDG limit. This analysis predicts that higher SARs and long-term abundances can be achieved by reducing powerhouse passage and water transit time, both of which are reduced by increasing spill, and

The time series analyses 1998-2016 of juvenile fish passage characteristics, including fish travel times, instantaneous mortality rates, and reach survival probabilities relative to environmental variables, were updated to include data from the 2016 juvenile outmigration year. Multiple regression analyses, mixed effect model structures, and multi-model inference methods were utilized to evaluate juvenile fish passage characteristics relative to environmental variables. These data time series incorporate a high degree of contrast in the environmental conditions and juvenile fish passage metrics, both within- and across-years. New in this report is the inclusion of Total Dissolved Gas as an environmental variable. Analyses indicated that total dissolved gas was not an important variable affecting instantaneous mortality or survival probabilities. Consistent with past years' findings, conclusions from the 2017 analyses of 2016 migration conditions and migration metrics are that water travel time, spill proportion, Julian date, and water temperature are important variables for predicting fish travel time, instantaneous mortality, and reach survival probability. One exception to this was the 2016 Springfield Hatchery sockeye mark group. The instantaneous mortality rate for Snake River sockeye in 2016 was the highest rate ever observed and was much higher than the average rate in 1998-2014. The survival probability for Snake River sockeye in 2016 was about half the average survival probability 1998-2014. Concerns have been raised over the poor condition and survival of sockeye released from the Springfield Hatchery in 2015 and 2016 (Hassemer 2016). Due to these concerns, only data from 1998-2014 was used to examine the effects of environmental variables on fish travel

time, instantaneous mortality rates, and survival probabilities for hatchery sockeye in the LGR-MCN reach.

Overall SARs are the net effect of SARs for the different routes of in-river passage and juvenile transportation. Overall SAR and route of passage SARs are consistent with past year's findings. None of the passage routes have resulted in SARs that met the NPCC SAR objectives for Snake River wild spring/summer Chinook and steelhead. The relative effectiveness of transportation has been observed to decline as in-river conditions and survival rates improve. PIT-tag SARs for Middle Columbia wild spring Chinook and wild steelhead generally fell within the 2%–6% range of the NPCC SAR objectives. Incorporating the 2016 adult returns in this Annual Report shows that the trends seen in all but two past years of CSS monitoring continue. The overall SARs for Upper Columbia and Snake River populations of salmon and steelhead are not meeting the 2%–6% regional goal, while middle Columbia populations are meeting the regional SAR goals in most years.

In this report the analyses of SARs relative to estimates of population productivity which began in the 2015 CSS Annual Report has been expanded and is presented in Chapter 5. In 2016 the CSS began a comparison of Snake River SARs and steelhead population productivity for Fish Creek (Clearwater Major Population Group (MPG)) and Rapid River (Salmon MPG), which complement those for Snake River spring/summer Chinook. We have added comparable data for Pahsimeroi River steelhead (Salmon MPG) in this report. In 2017 we have also updated the analysis of pre-harvest SARs and historical productivity for Snake River spring/summer Chinook salmon. This represents the continuation of a longer-term effort, which will incorporate effects of density dependence on observed productivity to evaluate population responses relative to SAR rates. Analyses in this Chapter support objectives of the Columbia River Basin Fish and Wildlife Program (NPCC 2014), encouraging a regional review of the NPCC SAR objectives relative the survival of populations needed to achieve salmon and steelhead recovery and harvest goals. Major population declines of Snake River wild spring/summer Chinook were associated with SARs less than 1% and increased life-cycle productivity occurred when SARs exceeded 2%. Snake River wild steelhead population declines were associated with brood year SARs less than 1%, and increased life-cycle productivity occurred in the years that brood year SARs exceeded 2%. Pre-harvest SARs in the range of 4% to 6% are associated with historical levels of productivity for Snake River wild spring/summer Chinook. Although there are fewer SAR estimates for John Day River spring Chinook, historical levels of productivity appear to be achieved with pre-harvest SARs in the range of 4%-7%

Results of analyses of smolt to adult return, TIR, and delayed mortality for fall chinook were consistent with past year's analyses. These results indicate that the smolt transportation program for juvenile fall Chinook salmon does not adequately mitigate for the adverse effects of development and operation of the Snake and Columbia rivers hydropower projects on fall Chinook survival and adult return. Consistent with past years analyses, overall SARs of fall Chinook salmon were low compared to SARs for spring/summer Chinook salmon and steelhead. As in past years, the need to increase marking of fall chinook in order to address the entire passage distribution and population is needed. The CSS continues to work with the Nez Perce Tribe to improve fall chinook marking coverage.

An update of earlier analyses of age-at-maturity is included in this report. Both stock effects and common year effects were important factors for explaining patterns in mean age-at-maturity and

the proportion returning at Age-3, Age-4, and Age-5. Stocks with the highest proportions returning at Age-5 included the wild stocks from the Snake and John Day rivers and hatchery stocks from Leavenworth and Dworshak hatcheries. Stocks with the lowest proportions returning at Age-5 included the Cle Elum, Imnaha, and Catherine Creek hatchery stocks. Across stocks, the proportions returning at Age-5 decreased over the 1997- 2011 juvenile outmigration years analyzed. There was considerable year-to-year variability in age-at-maturity that was shared across stocks, with the oldest age-at-maturity occurring in the 2000, 2004, and 2005 juvenile outmigration years and the youngest age-at-maturity occurring in the 2007, 2008, and 2010 juvenile outmigration years.

New in this CSS Annual Report is analyses of adult upstream migration success. The Comparative Survival Study (CSS) has been assessing adult salmon and steelhead upstream migration success through the Federal Columbia River Power System (FCRPS) beginning with the 2010 Annual Report. These analyses were included in response to regional concerns regarding high stray rates of Snake River steelhead (Oncorhynchus mykiss) and salmon that were transported as juveniles. Early analyses indicated that salmon and steelhead that were transported downstream in the smolt transportation program had lower upstream migration success and higher stray rates. This was considered problematic for some middle Columbia River listed steelhead stocks which were affected by Snake River steelhead straying. National Oceanic and Atmospheric Administration (NOAA) has established performance standards for adult salmon migration success in the Biological Opinions for the FCRPS. In the earlier Biological Opinions, NOAA included Reasonable and Prudent Alternatives that addressed water temperature thresholds for salmon migration corridors. In addition, the Environmental Protection Agency began a basin wide evaluation to establish Total Maximum Daily Load (TMDL) for water temperature. All three species in our analyses showed that the upstream survivals for transported fish were lower than fish that had migrated in-river as juveniles. In addition survival of fish transported as juveniles started to decrease at a lower temperature compared to fish that migrated in-river. These analyses indicate that summer chinook upstream survival began to decrease when water temperatures exceeded 17 degrees centigrade and sockeye and steelhead survival began to decrease when water temperature began to exceed 18 degrees centigrade.

CHAPTER 1
INTRODUCTION

The Comparative Survival Study (CSS; BPA Project 199602000) began in 1996 with the objective of establishing a long-term data set of annual estimates of the survival probability of generations of salmon from their outmigration as smolts to their return to freshwater as adults to spawn (smolt-to-adult return rate; SAR). The study was implemented to address the question of whether collecting juvenile fish at dams, transporting them downstream of Bonneville Dam (BON), and then releasing them was compensating for the effect of the Federal Columbia River Power System (FCRPS) on the survival of Snake Basin spring/summer Chinook salmon that migrate through the hydrosystem.

The CSS is a long-term study within the Northwest Power and Conservation Council's Columbia Basin Fish and Wildlife Program (NPCC FWP) and is funded by the Bonneville Power Administration (BPA). Study design and analyses are conducted through a CSS Oversight Committee (CSSOC) with representation from Columbia River Inter-Tribal Fish Commission (CRITFC), Idaho Department of Fish and Game (IDFG), Oregon Department of Fish and Wildlife (ODFW), U.S. Fish and Wildlife Service (USFWS), and Washington Department of Fish and Wildlife (WDFW). The Fish Passage Center (FPC) coordinates the PIT-tagging efforts, data management and preparation, and CSSOC work. All draft and final written work products are subject to regional technical and public review and are available electronically on FPC and BPA websites: FPC: http://www.fpc.org/documents/CSS.html and BPA: https://www.cbfish.org/PiscesPublication.mvc/SearchByTitleDescriptionAuthorOrDate.

This CSS Annual Report includes 22 years of SAR data for wild Snake River spring/summer Chinook (1994–2015), 19 years of SAR data for Snake River hatchery spring/summer Chinook (1997–2015), 18 years of SAR data for Snake River wild and hatchery steelhead (1997–2014), and seven years of SAR data for Snake River sockeye (2009–2015). There are seven years of SAR data for Snake River hatchery fall Chinook (2006–2012), and seven years of Snake River wild fall SAR data spanning the years 2006–2011. For mid-Columbia and upper-Columbia fall Chinook there are varying numbers of years available. There are 15 years of SAR data for Hanford Reach wild fall Chinook (2000–2014), four years of SAR data for wild Deschutes River fall Chinook (2011–2014), and seven years of SAR data for both Spring Creek NFH and Little White Salmon NFH fall Chinook (2008–2014). Spring and summer Chinook and sockeye returns from outmigration year 2015 should be considered preliminary, as they include only 2-salt returns and may change with the addition of 3-salt returns next year. Similarly, 2014 migration year fall Chinook returns include only 2-salt adults. The CSS has actively provided Passive Integrated Transponder (PIT) tags for most of these groups since outmigration year 1997.

The primary purpose of the 2017 Annual Report is to update the time series of smolt-to-adult survival probability data and related parameters with additional years of data since the completion of the CSS 10-year Retrospective Summary Report (Schaller et al. 2007). The 10-year report provided a synthesis of the results from this ongoing study, the analytical approaches

employed, and the evolving improvements incorporated into the study as reported in CSS annual progress reports. This current report specifically addresses the constructive comments of the regional technical review conducted by the Independent Scientific Advisory Board and Independent Scientific Review Panel (ISAB and ISRP 2007) and recent comments on the CSS study from the ISAB (2016).

All study fish used in this report were uniquely identifiable based on a PIT tag implanted in the body cavity during (or before) the smolt life stage and retained through their return as adults. These tagged fish can then be detected as juveniles and adults at many locations of the Snake and Columbia rivers. The number of individuals detected from a population of tagged fish declines, on average, over time, allowing estimation of survival probability. Comparisons of estimated survival probability over different life stages between fish with different experiences in the hydro-system (e.g., transportation vs. in-river migrants and migration through various numbers of dams) are possible as illustrated in Figure 1.1. The locations of commonly used tagging and release sites are identified in Figures 1.2 through 1.5.

Throughout this report we organized groups of stocks primarily according to major population group (MPG)/evolutionarily significant unit (ESU) boundaries (e.g., Snake River, Mid-Columbia River, and Upper Columbia River). However, we add the caveat that our presentations of Snake River aggregate stocks do not include stocks below Lower Granite Dam. Also, Carson National Fish Hatchery is actually located within the Lower Columbia Chinook ESU but we present it here as a Mid-Columbia group, partly for simplicity, as it is the only Lower Columbia group presented, but also because its lineage is from upriver stocks and its location is upstream of Bonneville Dam.

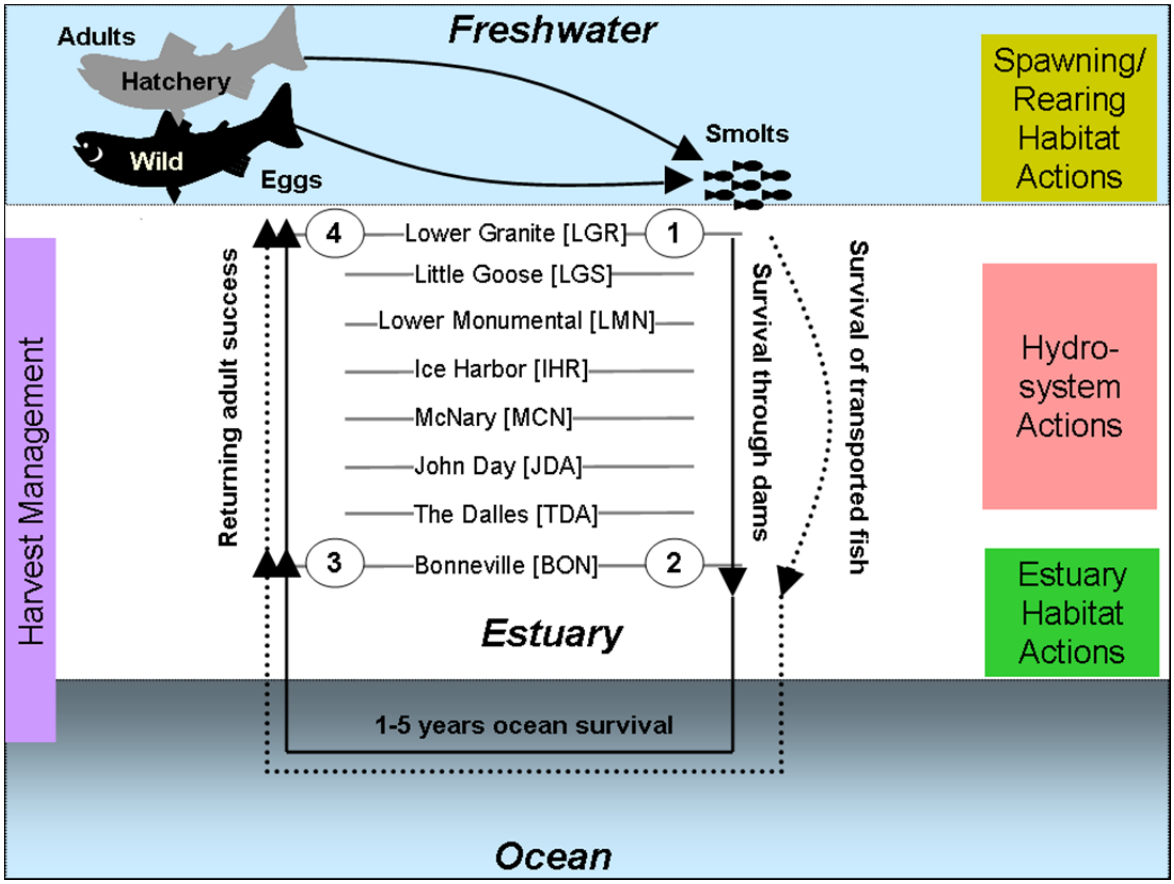

Figure 1.1. A simplified sketch of salmonid life cycle originating in the Snake River basin above LGR. Survival metrics from different portions of the life cycle inform various management questions (e.g., regarding hydrosystem, estuary, or habitat actions, etc.). Both naturally spawned and hatchery produced smolts arrive at LGR dam. The four reference points are: (1) smolts at LGR tailrace; (2) smolts at tailrace of BON/barge release; (3) adults at BON; and (4) adults at LGR. Although the study is not limited to these, some key parameters in the CSS are: (1) Overall SAR calculated from 1 to 3 and 1 to 4; (2) SAR by out-migration type (transported, and in-river) from 1 to 4; (3) differential survival (transport, in-river) from 1 to 4 is TIR; (4) differential survival (transport, in-river) from 2 to 4 is D; (5) adult success is often estimated from 3 to 4.

Development of the Comparative Survival Study

Beginning in 1981, collection of fish at lower Snake River dams and transportation to below Bonneville dam was institutionalized as an operational program by the U.S. Army Corps of Engineers (USACE). The intention was to mitigate for mortality impacts associated with the FCRPS, and thus to increase survival of spring/summer Chinook salmon. However, abundance of Snake River spring/summer Chinook salmon continued to decline. Fisheries that had been conducted at moderate levels in the Columbia River mainstem during the 1950s and 1960s were all but closed by the mid-1970s. In 1992, the Snake River spring/summer Chinook salmon ESU was listed under the federal Endangered Species Act (ESA). Spawning ground survey results in the mid-1990s indicated virtually complete brood year failure for some wild populations. For hatchery fish, low abundance of returning hatchery adults was a concern as the Lower Snake River Compensation Plan (LSRCP) hatcheries began to collect program brood stock and produce juveniles.

The motivation for the CSS began with the region's fishery managers expressing concern that the benefits of transportation were less than anticipated (Olney et al. 1992, Mundy et al. 1994, and Ward et al. 1997). Experiments conducted by the National Marine Fisheries Service (NMFS) prior to the mid-1990s sought to assess whether transportation increased survival beyond that of smolts that migrated in-river through the dams and impoundments.

Regional opinions concerning the efficacy of transportation ranged from transportation being the best option to mitigate for the impacts of the FCRPS, to the survival of transported fish was insufficient to overcome those FCRPS impacts. Although the survival of fish transported around the FCRPS could be demonstrated to be generally higher than the survival of juveniles that migrated in the river, evidence on whether transportation contributed to significant increases in adult abundance of wild populations was unavailable. If the overall survival probability (egg to spawner) was insufficient for populations to at least persist, the issue would be moot (Mundy et al. 1994).

The foundational objectives of the CSS design translate these issues about the efficacy of transportation into key response variables. The CSS uses the following two aspects for evaluating the efficacy of transportation: (1) empirical SARs compared to those needed for survival and recovery of the ESU; and (2) SAR comparisons between transport and in-river migration routes. In this broader context, the primary objective is to answer: "Are the direct and delayed impacts of the configuration and operation of the FCRPS sufficiently low to ensure that cumulative life-cycle survival is high enough to recover threatened and endangered populations?" The secondary objective is to answer: "Is the survival of transported fish (SAR) higher than the survival (SAR) of fish migrating in-river?" Beginning in 2003, the NPCC Fish and Wildlife Program adopted the goal to achieve smolt-to-adult survival probabilities (SARs) in the range of 2% to 6% (average 4%) for federal ESA-listed Snake and Upper Columbia river salmon and steelhead. The objective continued through 2009 and most recently the amended 2014 Fish and Wildlife Program (NPCC 2003, 2009, 2014). Combining these objectives, effectiveness of transportation is assessed by whether (1) the overall $SAR_{(LGR\text{-}to\text{-}LGR)}$ meets the NPCC regional objective (2%–6% with 4% average) for the ESU and (2) the SAR of fish collected at Snake River dams and diverted into barges is higher than that of fish that migrate through reservoirs and pass these dams via the spillways and turbines.

The design and implementation of the CSS improved upon shortcomings of the methods that had previously been used to estimate and compare survival probability for transported fish and non-transported (in-river migrating) fish. These shortcomings resulted from the collection and handling protocols, the marking and recovery technology, the study objectives, the definition and use of a control population, and the inconsistency and duration of survival studies (Olney et al. 1992, Mundy et al. 1994, and Ward et al.1997). Transported and in-river groups were handled differently in the first juvenile fish studies. Whereas transported fish were captured at dams, tagged, and placed in trucks or barges, some in-river control groups of fish were transported back upstream for release. Thus, unlike the unmarked outmigrating run-at-large, these marked in-river fish were therefore subjected to the same hydrosystem impacts multiple times whether they were subsequently collected and transported or remained in-river. The early mark-recapture studies used coded-wire tags (CWT) and freeze brands to mark juveniles collected at the dams. Therefore, Snake River basin origin of individuals could not be identified, and CWT information could be obtained only from sacrificed fish. Evidence suggested that the process of guiding and collecting fish for either transport or bypass contributed to juvenile fish

mortality and was cumulative when fish were bypassed multiple times. If such mortality differentially impacted the study fish, and was not representative of the in-river migrant run-at-large, measures of the efficacy of transportation would be biased.

All CSS study fish are uniquely identified with a PIT tag, and the use of this technology has provided substantial improvements in the evaluation of the efficacy of transportation. To ensure that all CSS study fish, whether transported or migrating in-river, experience the same effects from handling (thus improving the utility of an in-river control group relative to transportation), hatchery-reared fish are tagged at hatcheries and wild fish are tagged at subbasin and mainstem outmigrant traps upstream of the FCRPS (Figures 1.2–1.5). PIT-tagged juveniles are released near their marking station, allowing the numbers of fish and distribution across subbasins of origin to be predetermined. Recapture information can be collected without sacrificing fish, and automated detection stations reduce impacts from trapping and handling.

PIT-tag detectors at mainstem dams in the Columbia and Snake rivers now allow passage dates and locations to be recorded for both juvenile and adult PIT-tagged fish and provide the ability to link that information to the characteristics of each fish at time and location of release (Figures 1.2–1.5). With sufficient numbers of fish tagged, survival probability throughout the life-cycle can be compared across release groups, subbasins, ESUs, species or race, major population group, rearing type (i.e., hatchery vs. wild), unique life history experiences (e.g., transported vs. in-river), and outmigration seasons. The CSS PIT-tagging design and application allows the use of the Cormack-Jolly-Seber (CJS; see Appendix A) method with multiple mark-recapture information. This method is used to estimate a population of PIT-tagged smolts alive in the tailrace of Lower Granite Dam and to estimate their survival through the hydrosystem.

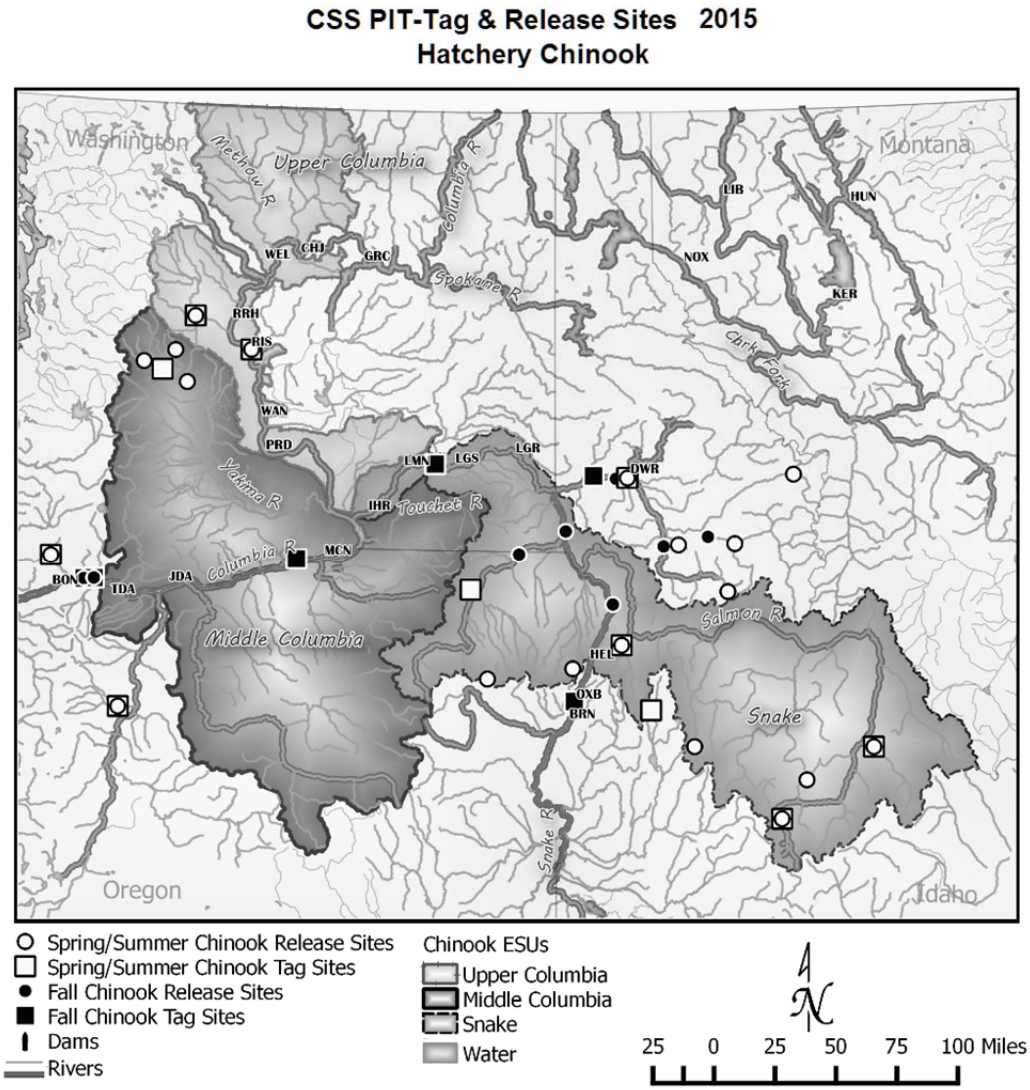

Figure 1.2. CSS PIT-tag release locations for Hatchery spring/summer Chinook and fall Chinook in the Columbia River Basin.

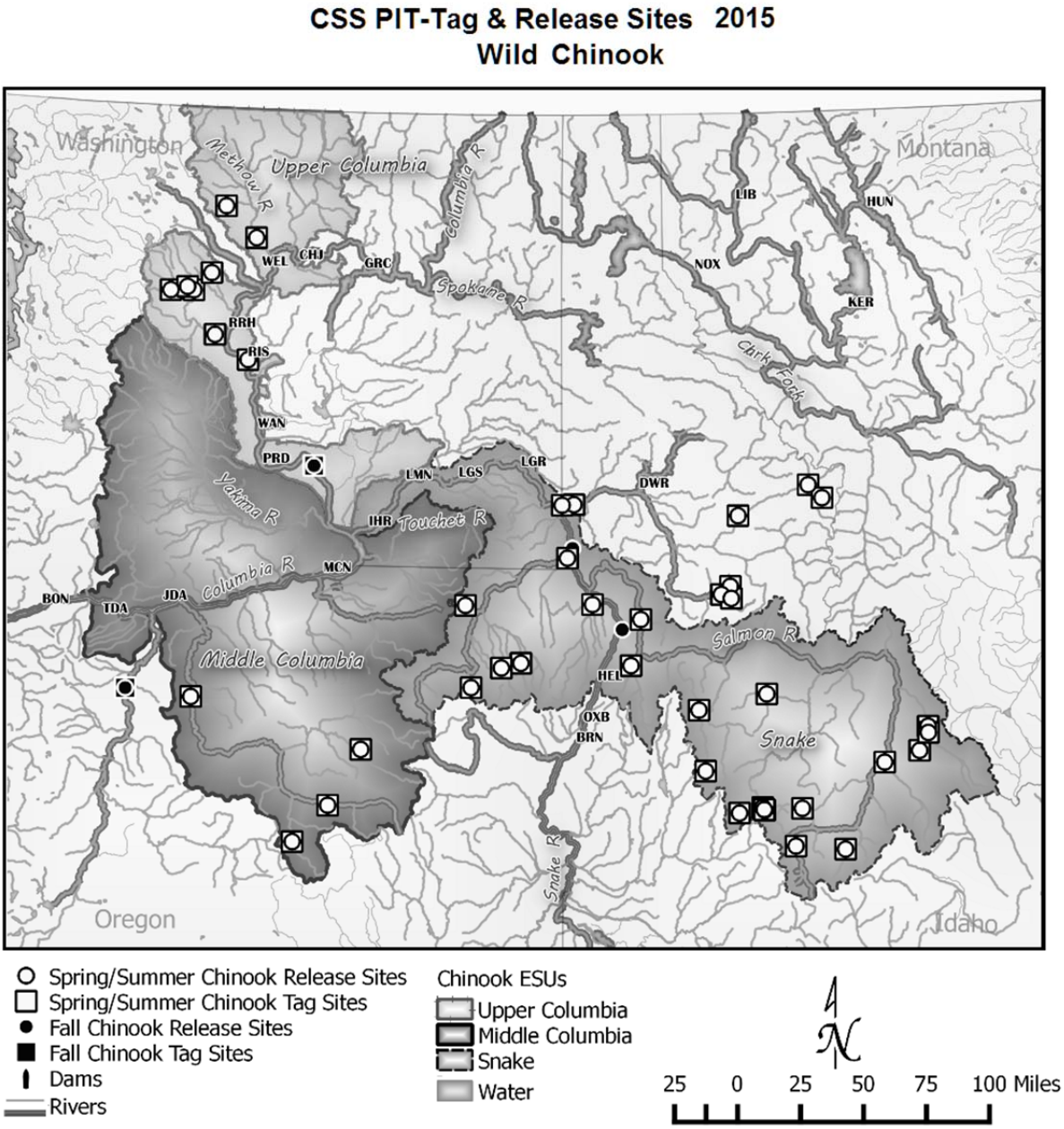

Figure 1.3. CSS PIT-tag release locations for wild spring/summer Chinook and fall Chinook in the Columbia River Basin.

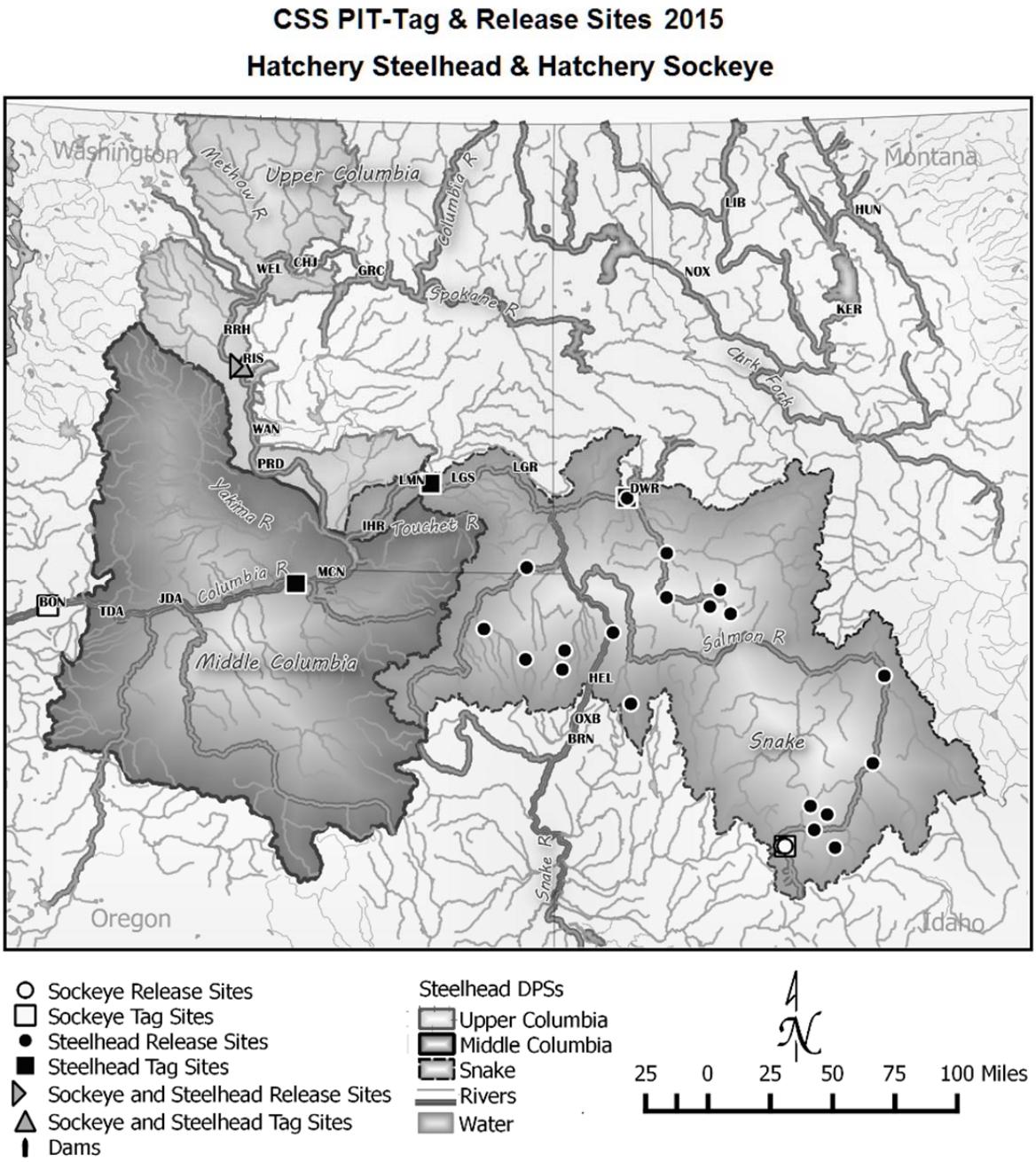

Figure 1.4. CSS PIT-tag release locations for hatchery steelhead and sockeye in the Columbia River Basin.

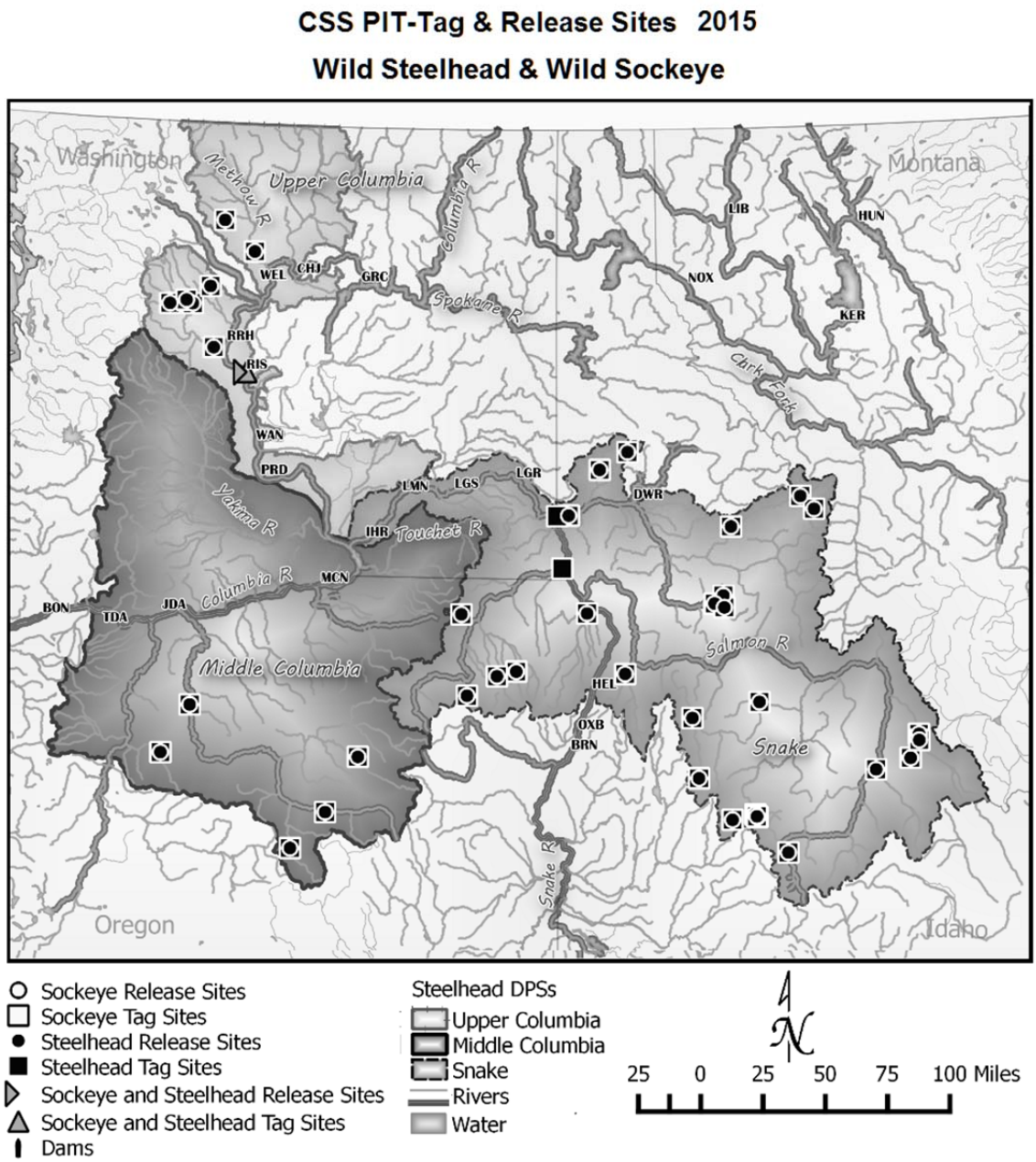

Figure 1.5. CSS PIT-tag release locations for wild steelhead and sockeye in the Columbia River Basin.

Data generated in the Comparative Survival Study

The Comparative Survival Study (CSS) is a management-oriented, large scale monitoring study of spring/summer/fall Chinook, steelhead, and sockeye. The CSS was designed to address several of the basin-wide monitoring needs and to provide demographic and other data for Snake

River and Columbia River wild and hatchery salmon and steelhead populations. One product of the CSS is annual estimates of SARs for Snake River hatchery and wild steelhead and salmon. Estimation of the overall, aggregate SARs of fish that are transported and those that migrate entirely in-river is key to evaluation of avoidance of jeopardy (i.e., put at risk of extinction) as well as progress toward recovery goals. Monitoring survival probability over the entire life-cycle can help identify where survival bottlenecks are occurring, which is critical input for informed management decisions (Good et al. 2007). The CSS also examines environmental factors associated with life-cycle survival probability and evaluates the hypothesized mechanisms for variations in those probabilities.

Generally we estimated the survival of various life stages through known release and detected return numbers of PIT-tagged fish. The PIT tags in juvenile fish are potentially read as the fish pass through the coils of detectors installed in the collection/bypass channels at six Snake and Columbia River dams, including Lower Granite (LGR), Little Goose (LGS), Lower Monumental (LMN), McNary (MCN), John Day (JDA), and Bonneville (BON) (Figure 1.2–Figure 1.5). When tags are read, their fish identification number and the time/date of detection is recorded. Upon arrival at LGR, LGS and LMN, Snake River smolts can travel through three different routes of passage: (1) over the spillway via typical spillway, removable spillway weir (RSW), or temporary spillway weir (TSW), or (2) into the powerhouse where smolts either subsequently pass through the turbines, or (3) are diverted with screens and pipes into the collection and bypass facility. Those smolts that pass over the spillway or through the turbines are not detected. Juvenile detection probabilities for each dam can range from 5%–90% and depend on interactions between species, dam, environmental conditions, and facility operations while smolts are passing.

The first three dams in the Lower Snake River (LGR, LGS, and LMN) have facilities for holding and transporting smolts. During transportation operations, smolts without PIT tags that enter the collection facility are generally put in trucks or barges and transported to below BON. Transportation at MCN used to begin in July after the completion of the spring outmigration and did not affect the Columbia River groups currently studied in the CSS (e.g., spring out-migrating steelhead and Chinook). Transportation has been discontinued at McNary Dam. There is not a transportation program at JDA or BON. Additional PIT-tag detections can be obtained from a special trawling operation (TWX) by NMFS in the lower Columbia River in the vicinity of Jones Beach. Returning adults with PIT tags are detected in the fish ladders at LGR with nearly 100% probability. PIT-tag detection capability for returning adults has been added at BON, TDA, Ice Harbor (IHR), MCN, LMN, and LGS over the past several years, allowing for additional analyses. PIT-tag detection capability also exists in nearly all major tributaries such as the Deschutes and John Day rivers.

A specific goal of the CSS has been to develop long-term indices of SAR ratios between transported and in-river fish. A common comparison, termed “Transport: In-river” ratio, or TIR, is the SAR of transported fish divided by the SAR of in-river fish, with SAR being estimated for smolts passing LGR and returning as adults back to the adult detector at LGR (GRA). Additionally, overall SARs from LGR to the adult detector at BON (BOA) are provided (see Chapter 4). Estimates of TIR address the question of whether transportation provides an overall benefit to smolt-to-adult survival, compared to leaving smolts to migrate in-river, through the hydrosystem, as currently configured. The overall value of transportation in avoiding jeopardy and promoting recovery depends on the extent to which it circumvents direct mortality (i.e., to

smolts within the hydrosystem) and indirect mortality (i.e., to smolts after passing BON) caused as a result of passage through the hydrosystem. In the CSS, this indirect mortality is referred to as "delayed" or "latent" mortality. Because TIR compares SARs starting from collector projects, it does not by itself provide a direct estimate of delayed mortality specific to transported fish (see below for a description and use of "*D*", which is an estimate of transportation-related delayed mortality).

Related to TIR is *D*, the ratio between SARs of transported fish and in-river fish from downstream of BON as smolts back to LGR as adults (BON-to-GRA SARs). *D* excludes mortality occurring during juvenile salmon passage between Lower Granite and Bonneville dams and captures any differences in mortality between transported smolts and in-river migrants that occurs after BON juvenile passage (i.e., from ocean residence through return as adults to LGR). $D = 1$ indicates that there is no difference in the survival probability of transported or in-river fish after hydrosystem passage. $D < 1$ indicates that transported smolts die at a higher rate after passing BON compared to in-river smolts that have migrated through the hydrosystem. $D > 1$ indicates that transported fish have higher survival after passing BON compared to in-river fish. *D* has been used extensively in modeling the effects of the hydrosystem on Snake River Chinook salmon (Kareiva et al. 2000; Peters and Marmorek 2001; Wilson 2003; Zabel et al. 2008).

Estimation and comparison of annual SARs for hatchery and wild groups of smolts with different hydrosystem experiences between common start and end points are made for three categories of fish passage:

1. tagged fish that are collected at Snake River dams (LGR, LGS or LMN), and transported (T);
2. tagged fish collected at Snake River dams and returned to the river (C_1), or
3. tagged fish that have not been collected at the Snake River dams (C_0).

The year 2006 marked an important change in fish transportation operations within the FCRPS. Transportation operations from 1997–2005 began ~ April 1st and encompassed most of the emigrating groups of CSS-marked fish. In 2006, the transportation operational protocol was altered at the three Snake River collector dams. The start of transportation was delayed at LGR until April 20 in 2006 and generally until on or about May 1 from 2007 through 2016. During 2010, as an example, transportation began on April 25. The start of transportation at LGS and LMN was delayed further to account for smolt travel time between projects, typically ranging from 4 to 12 days later than LGR depending on the year and fish travel times. This change in operations affected the CSS study because the transportation protocol now allows a portion of the population to migrate entirely in-river through the hydrosystem before transportation begins.

This 2006 management change coincided with the CSS change in methods that pre-assigned fish to bypass or transport routes, rather than forming transport and in-river cohorts at Snake River collector projects as was done through 2005. The new CSS approach facilitated evaluation of the 2006 change in transportation strategy. Prior to 2006, computers at the dams selected which fish were to be routed to transportation during the out-migration based on order of passage; an example would be one of every four fish detected would be routed to transport. This would occur when the transportation proportion was 0.25 and then every fourth fish was chosen to be transported while the other three were returned to river. The new method randomly pre-assigns the tagged fish to two different study groups prior to their emigration through the

hydrosystem. This is accomplished through FPC coordination with various marking agencies. By knowing what PIT tags are used for marking, FPC randomly assigns individual PIT tags to two groups, and passes this information on to the separation-by-code facilities at each dam. One group (denoted as Group T in this report) reflects the untagged population. These tagged fish are routed in "Monitor-Mode," which means they are routed the same way as the untagged smolts at each of the collector dams where transportation occurs. The other group (denoted as Group R in this report) follows the default return-to-river routing for PIT-tagged fish at each collector dam throughout the season. The primary utility of the R group is to augment the sample size used in the CJS model, but these PIT tags are also included in other analyses where applicable. During the emigration, upon entering the bypass facilities at the transportation sites, two things can happen. If transportation is taking place, Group T fish are transported and Group R fish are bypassed. If transportation is not taking place, both groups are bypassed. Combining Groups T and R provides a composite group (Group CRT) comparable to what has been used in the CSS in all migration years through 2005. For the analyses in this report, we use Group CRT to estimate CJS reach survival probability and detection probabilities. See Appendix A for a detailed description as well as diagrams showing how R and T group assignments are used in computations.

The transport category can fall into two subcategories. The first is termed T_0 and includes those smolts that were detected for the first time at a collector dam in the hydrosystem and transported. This action was typical for nearly all transported smolts prior to 2006 — before the transportation delay began. After the initiation of the delayed transportation protocol, transported smolts included both those *never previously detected* and those that *were previously detected*. Concordant with this operational change, the CSS included both types in the transport category and referred to these as T_X in most cases for years after 2005. The estimation of TIRs and *D* will have T_X replace T_0 smolts in migration years after 2005, while C_0 smolts are estimated the same in all years (i.e., the total smolt population at LGR minus LGR equivalents of detected fish at LGR, LGS, and LMN; see Appendix A for formulas).

The SARs and the ratios of SARs in this report are estimated for the entire migration year. For years prior to 2006, the SARs developed for each of the study categories (transported, C_0 and C_1) are weighted by the proportion of the run-at-large (untagged and tagged fish) represented by these categories to provide overall annual SARs (see Chapter 2 in Tuomikoski et al. 2009 for formulas). A direct estimation of overall annual SARs is possible beginning in 2006 where PIT-tagged study fish are pre-assigned prior to release into a monitor-mode group (Group T) that passes through the collector dams in the same manner as untagged smolts. Both the estimated smolt numbers and adult return data for Group T provide a direct estimation of the annual overall SARs beginning with the 2006 migrants. Because no transported smolts and only a small number of in-river smolts are enumerated at BON, the BON-to-GRA SAR is estimated from the LGR-to-GRA SAR, adjusted by annual in-river survival probability estimates (through the hydrosystem) and assumed average direct transport survival probability from empirical studies.

Overview of Bootstrapping Estimation Approach

Over the years, we have developed a computer program to estimate the following quantities with confidence intervals: survival from hatchery release to LGR; reach survival estimates between each of the dams equipped with PIT-tag detectors; survival from smolt arrival

at LGR dam until return to LGR or BON as adults ($SAR_{LGR\text{-}to\text{-}GRA}$ and $SAR_{LGR\text{-}to\text{-}BOA}$); survival from smolt at BON to LGR as adults (BON-to-GRA SAR); and the ratio of these SARs for smolts with different hydrosystem passage experience (TIR and *D*). Assessment of the variance of estimates of survival probability and ratios is necessary to describe the precision of these estimates for statistical inference and to help monitor actions to mitigate effects of the hydro-system. For a number of the quantities described above, theoretical estimates of variance are tractable. However, variance components of other quantities are often unknown or are extremely complicated and thus impracticable to estimate using theoretical variances. Therefore, a naïve bootstrap method was used to describe uncertainty around parameter estimates, where the point estimate was first calculated from the original sample, then the PIT-tag data were re-sampled with replacement to create 1,000 bootstrap replications. These 1,000 simulated samples were used to produce a distribution of values that describe the mean and variance associated with the point estimate. From the set of 1,000 iterations, 80%, 90%, and 95% non-parametric bootstrap confidence intervals (Efron and Tibshirani 1993) were computed for each parameter of interest. Peterman (1990) argued that in fisheries, the cost associated with wrong decisions resulting from Type II errors can exceed those from Type I errors and, in part, recommended using an alpha of 0.10 instead of 0.05. The 90% confidence intervals used in the CSS annual reports were chosen in an attempt to better balance the making of Type I (rejecting a true null hypothesis) and Type II (accepting a false null hypothesis) errors for comparison among study groups of fish for the various parameters of interest.

The CSS has begun exploring the use of a weighted bootstrap for use with groups of fish that have unequal marking across the population. In particular, PIT-tag marking at McCall National Fish Hatchery is done unequally among smolts from two different brood stock breeding types. Half the PIT-tags are implanted in each sub-population although those populations are unequal (making up one third and two thirds of the total release). The CSS has developed a prototype method (McCann et al 2015 Appendix H) that reweights the bootstrap draws so that each iteration reflects the proportions of the population. The resulting bootstrap population of tags reflects the underlying population proportions. Testing to date has shown the method works as expected. The method is still in development.

CSS PIT-tagging operations and sources of study fish

An overall goal of CSS is to emphasize marking wild fish and to mark wild populations as representatively as possible. Part of that effort involves marking wild fish at finer geographic scales by largely relying more on screw traps located in tributaries and reducing marking at mainstem traps. This allows marking wild fish at the Major Population Group (MPG) level versus at the Ecologically Significant Unit (ESU) level. Although truly representative marking is likely impossible, given constraints on fish handling, trapping operations during peak runoff and other limitations to sampling, the CSS has implemented changes to marking to attempt to improve representativeness of major population groups, transition toward finer geographic scale marking, and reduce the handling of listed hatchery stocks. To accomplish these goals, CSS reduced or eliminated marking at mainstem traps in the Clearwater and Salmon rivers in 2015, and transitioned those tags to screw traps in tributaries higher up in the watersheds.

The Clearwater River trap (operated by IDFG) was located near the confluence of the Clearwater and Snake rivers. Operations at this trap were ceased in 2015 and tags were moved to traps in the Lochsa River (operated by IDFG) and South Fork Clearwater River (operated by

Nez Perce Tribe). Two other new traps began operation in 2016 in these rivers (with PTAGIS release site codes LOCTRP and CLWRSF). The emphasis for these new traps is marking wild steelhead throughout the Clearwater Basin MPG. The CSS Oversight Committee worked with IDFG and NPT to reallocate tags from the Clearwater trap to these new locations. Similarly, marking at the Salmon River trap was modified in 2015 in an attempt to reduce handling of listed hatchery Chinook at the trap. Marking was modified by implementing a weekly quota, thus assuring that tags were available for marking into late May.

Also, some tagging was moved from the Salmon River Trap to new traps operated by IDFG and the Shoshone-Bannock Tribe (SBT) higher up in tributaries. These new traps include, Valley Creek, East Fork Salmon River, and North Fork Salmon River. This allows more targeted marking of MPG-level populations of both wild yearling spring/summer Chinook as well as wild steelhead. Finally, approximately 10,000 tags previously allocated for hatchery Chinook at Dworshak NFH were reallocated to marking of wild Chinook and wild steelhead at tributary traps throughout the Clearwater and Salmon river basins.

Trap operations at the Grande Ronde River trap (rkm 2) were modified in 2015 in an attempt to reduce handling of listed hatchery Chinook. Because these modifications had the potential to reduce wild Chinook and steelhead marking at this trap, the CSS coordinated with ODFW to include two additional Grande Ronde River tributary traps into the CSS analyses. These two traps are the Upper Grande Ronde trap (rkm 299) and the Grande Ronde trap near Elgin (rkm 160).

Wild and hatchery smolts are marked with glass-encapsulated, passive integrated transponders (PIT) that are 9 to 12 mm in length and have a unique code to identify individual fish. These PIT tags are normally implanted into the fish's body cavity using a hand-held syringe, and are generally retained and function throughout the life of the fish. Snake River basin wild and hatchery Chinook and steelhead used in the CSS analyses were obtained from all available marking efforts above LGR. Wild Chinook from each tributary (plus fish tagged at the Snake River trap near Lewiston) were represented in the PIT-tag aggregates for migration years 1994 to 2015. The sample sizes for each group with tags provided by the CSS from 1994–2015 are presented in Appendix C at the end of this report.

During 2010, tagging operations began in cooperation with WDFW on wild Chinook and steelhead in the Upper Columbia basin. These cooperative tagging efforts are ongoing at the time of this report.

Snake River hatchery yearling spring and summer Chinook were PIT-tagged for the CSS at specific hatcheries within the four drainages above LGR including the Clearwater, Salmon, Imnaha, and Grande Ronde rivers. Hatcheries that accounted for a major portion of Chinook production in their respective drainages were selected. Since study inception in 1997, the CSS has PIT-tagged juvenile Chinook at Rapid River, Dworshak, McCall, and Lookingglass hatcheries. Two Chinook stocks are tagged for the CSS at Lookingglass Hatchery: an Imnaha River stock released into the Imnaha River and a Catherine Creek stock released in the Grand Ronde River drainage. This latter stock became available to the CSS in 2001 after the Lookingglass Hatchery complex changed its operation to rear only stocks endemic to the Grande Ronde River basin. The CSS has also contributed PIT tags to additional Lower Snake River Compensation Plan (LSRCP) hatcheries including spring (since 2006) and summer (since 2011) Chinook from Clearwater Hatchery in the Clearwater River basin, summer Chinook from

Pahsimeroi Hatchery (since 2008), and spring Chinook from Sawtooth Hatchery (since 2007) in the Salmon River basin.

From 2009 to 2012, Snake River hatchery sockeye were tagged at Oxbow (Oregon) and Sawtooth hatcheries as part of a short-term Corps of Engineers study. These have been the only available marks for hatchery sockeye in the Snake River basin in large enough numbers to estimate SARs. The total number of tagged sockeye smolts from Oxbow has been approximately one-fifth of that from Sawtooth, and thus the Oxbow group provided a more limited data set with respect to the CSS. However, the Sawtooth group sample size has been adequate for estimation of various CSS parameters. To maintain a time-series of PIT-tagged Snake River Basin hatchery sockeye amenable to the CSS study design, the CSS and IDFG began cooperatively marking Sawtooth hatchery sockeye in 2013, and this was continued through 2015. In 2015, sockeye hatchery operations transitioned to Springfield Hatchery. In 2015, the CSS and IDFG PIT-tagged hatchery sockeye from both Sawtooth and Springfield hatcheries. Beginning in 2016, CSS tags will be provided for releases of sockeye from Springfield Hatchery, as sockeye will no longer be reared at Sawtooth Hatchery. This tagging program meets hatchery monitoring needs for the Snake River sockeye salmon hatchery program and maintains the CSS time-series for Snake River Basin hatchery sockeye.

Wild steelhead smolts from each tributary (plus fish tagged at the Snake River trap near Lewiston) were represented in the PIT-tag aggregates for migration years beginning in 1997. Hatchery steelhead from each tributary, plus PIT-tag releases in the mainstem Snake River at the Lewiston trap and below Hells Canyon Dam, were represented in the PIT-tag aggregates for migration years 1997 to 2007 with more extensive PIT-tagging of hatchery steelhead beginning in 2008. This increased again in 2009 with the addition of the Niagara Springs Hatchery production. With the greater coverage of hatchery steelhead above LGR, separation of metrics into A- and B-runs and by basin are now possible. Snake River stocks designated as B-run differ from A-run stocks in their later adult migration timing, older ocean-age (primarily 2-salt adults), and larger adult size.

The PIT-tagged wild Chinook and wild steelhead used in the CSS may be PIT-tagged as part of the CSS or for other research (discussed further in the next section) and at certain times of the year, multiple age classes of fish were being PIT-tagged. We employed date and/or length constraints specific to the migration year, species, and basin of interest to exclude cohorts of smolts that outmigrated in other years. This was necessary since estimates of collection efficiency and survival must reflect a single year. We used information on the year fish are observed outmigrating through the FCRPS along with tagging size and tagging date to identify where multiple cohorts occur and the constraints that should be applied. As a general example, for Snake River wild Chinook, we often found that limiting the tagging season to a 10-month period from ~ July 25 to ~ May 20 the following year reduced the instances of overlapping age classes. For Snake River wild steelhead, we typically found that size at tagging was a useful parameter for removing a high proportion of fish that reside an extra year or two in freshwater beyond the desired migration year of study (Berggren et al. 2005; Berggren et al. 2008). Generally for Snake River wild steelhead, excluding smolts marked below 130 mm and above 300 mm reduced the instances of multiple year classes and allowed the tagging season to be a full 12 months. These base constraints were adjusted for individual outmigration years. For John Day wild Chinook, limiting the tagging season from October until June often was enough to exclude other year classes of fish.

Similar methods were used for Deschutes River steelhead (marked at Trout Creek) and John Day River steelhead. To assemble the data for Deschutes River steelhead, we found very little evidence of multiple year classes being marked in a single calendar year and utilized nearly all marks until early June from the spring of each calendar year with a lower length constraint of approximately 100 mm in certain years. To assemble the John Day wild steelhead marks we included wild steelhead marked at sites within the John Day River south fork, middle fork, and mainstem. For these groups, we used smolts marked from July through June when available (up to 11 months) and length constraints that increased from approximately 90 mm to 120 mm across this date range.

Some new groups were added in the 2014 Annual Report (McCann et al. 2014). In addition to overall SARs for aggregate Snake River wild Steelhead and Chinook, when sample sizes allowed, Chapter 4 now includes overall SAR estimates for wild steelhead and Chinook at the MPG level. These MPG-level SARs are provided for both LGR-to-GRA and LGR-to-BOA, and with and without jacks (1-salt) for Chinook. In addition, Chapter 4 now includes estimates of overall SARs (MCN-to-MCA and MCN-to-BOA) for Yakima River wild Chinook and Yakima River hatchery Chinook (i.e., Cle Elum Hatchery), and Yakima River wild steelhead. Additional fall Chinook groups in Chapter 5 include the Little White Salmon, Spring Creek hatchery fall Chinook releases, Hanford Reach wild fall Chinook, and Deschutes River wild fall Chinook. Finally, in cooperation with the Nez Perce Tribe, CSS provided funding for marking Lyons Ferry hatchery subyearling fall Chinook in 2015. Approximately 44,400 PIT-tagged juveniles were released at two acclimation facilities (Captain John Rapids and Pittsburgh Landing) located on the Snake River.

Two new groups were added to the 2016 CSS Report. Wild Okanogan River sockeye were added; marking this group is a joint project of CRITFC and Okanogan Nation Alliance. This has been a pilot project for CSS since MY 2013. The 2016 CSS report will have SARs (RRE-BOA, MCN-BOA) for MY 2013 & 2014. In addition, wild summer Chinook from above Wells Dam have been added. Upon request from Colville Tribe, beginning in 2017 CSS will include SARs for upper Columbia wild summer Chinook (RRE-BOA, MCN-BOA) beginning with MY 2011.

Coordination and pre-assignments during 2017

Marked fish utilized in the CSS may be from groups PIT-tagged specifically for this program or may be from marked groups planned for other research studies. Wherever possible the CSS makes use of mark groups from other research and coordinates with other marking programs to meet CSS requirements in order to reduce costs and handling of fish. To that end, the CSS has a history of collaboration and is currently cooperating with several other agencies in the marking and pre-assignment of smolts. All of the smolts marked and pre-assigned during the 2017 migration year are outlined in Tables 1.1–1.3 (these releases will be analyzed in future reports).

The CSS will continue coordination efforts to avoid redundancy and save costs as recommended by the ISAB/ISRP reviews (2007 and 2009). Collaboration on Snake River basin hatchery fish in recent years includes those with the marking programs of the LSRCP. Specifically this includes IDFG, ODFW, and WDFW (Table 1.1). Additionally, the CSS has collaborated with Idaho Power Company (IPC), Nez Perce Tribe, USFWS, and many others.

Wild fish marking in tributaries relies heavily upon screw traps operated by several state, federal and tribal agencies.

Table 1.1. Snake River hatchery groups marked for the 2017 smolt outmigration that have all or part of their PIT tags provided by the CSS. Many groups have tags cooperatively provided by the CSS and other entities. The hatchery, species, tag funding sources and tag totals are shown for each. Through cooperative efforts pre-assignments are carried out by either the CSS or the other associated agencies.

		PIT-Tag Funding Source [1]							
Hatchery	Species	IDFG/ LSRCP	CSS	IPC	ODFW/ LSRCP	USFWS	WDFW/ LSRCP	NPT/ LSRCP	Total
Rapid River	Sp. Chinook		32,000	20,000					52,000
McCall	Su. Chinook	20,000	32,000						52,000
Clearwater	Sp. & Su. Chinoo	59,400	27,200						86,600
Kooskia	Sp. Chinook		3,100			4,900			8,000
Pahsimeroi	Su. Chinook		6,400	15,000					21,400
Sawtooth	Sp. Chinook	15,000	6,400						21,400
Magic Valley	Steelhead	16,000	18,800						34,800
Hagerman	Steelhead	12,000	5,200						17,200
Niagara Springs	Steelhead		9,700	13,000					22,700
Clearwater	Steelhead	12,700	5,400					3,400	21,500
Lookingglass (Imnaha AP)	Sp. Chinook		21,000						21,000
Lookingglass (Catherine Creek)	Sp. Chinook		21,000						21,000
Irrigon (Grande Ronde, Imnaha)	Steelhead		14,000		20,000				34,000
Dworshak	Sp. Chinook		42,000						42,000
Dworshak	Steelhead		11,400			21,500			32,900
Lyons Ferry (Cottonwood AP)	Steelhead		2,000				4,000		6,000
Springfield	Sockeye	12,200	39,800						52,000
Lyons Ferry (Captain Johns and Pittsburg Landing)	Fa. Chinook		52,000					4,000	56,000
Lyons Ferry (Big Canyon Creek)	Fa. Chinook		11,100					2,000	13,100
Grand Total		147,300	360,500	48,000	20,000	26,400	4,000	9,400	615,600

[1] Tag funding Sources are: Idaho Fish and Game (IDFG), Idaho Power Company (IPC), Oregon Department of Fish and Wildlife (ODFW), U.S. Fish and Wildlife Service (USFWS), Washington Department of Fish and Wildlife (WDFW), Comparative Survival Study (CSS), the Nez Perce Tribe (NPT), and Lower Snake River Compensation Plan (LSRCP).

Coordination and cooperation have been part of the marking efforts on wild fish throughout the history of the CSS. The CSS has coordinated with the Smolt Monitoring Program (SMP) over several years of both studies. During the 2010 marking, a new study group was added to the CSS through collaboration with WDFW: wild steelhead and Chinook marked in the upper Columbia are now included in the study (Table 1.2). Metrics and analyses on these groups are included in Chapter 4 of this report.

Table 1.2. Wild fish marked for the 2017 smolt outmigration that have all or part of their PIT tags provided by the CSS. Many groups have tags cooperatively provided by the CSS and other studies. The location of marking, species, tag funding sources and tag totals are shown for each. Through cooperative efforts pre-assignments are carried out by the CSS on these groups except for the Chiwawa Trap and Lower Wenatchee Trap (i.e., Upper Columbia Basin).

		PIT-Tag Funding Source [1]					
Location	Wild Species	SMP	CSS	IDFG	ODFW	WDFW	Total
Clearwater/Salmon Tributaries	CH/St		46,000	40,000			86,000
Snake and Salmon Traps	CH/St	8,800	6,200				15,000
Grande Ronde Trap	CH/St	4,000	1,400				5,400
Grande Ronde Tributaries	CH/St		4,600		8,200		12,800
Asotin Creek Trap	St		1,500			3,500	5,000
Entiat, Methow, Chiwawa, Wenatchee Tributaries	CH/St/SK		30,000				30,000
Grand Total		12,800	89,700	40,000	8,200	3,500	154,200

[1] Tag funding sources are: Smolt Monitoring Program (SMP), Idaho Fish and Game (IDFG), Oregon Department of Fish and Wildlife (ODFW), Washington Department of Fish and Wildlife (WDFW). PIT-tags are provided for both wild Chinook and

wild steelhead at some locations but the actual numbers captured and tagged by species are not known until after the outmigration is complete.

Fish to be utilized in the CSS from groups planned for other research studies during 2017 are shown in Table 1.3. In the future, the CSS will continue to review on-going and planned programs in the Middle and Upper Columbia River regions, to establish stock-specific or aggregate groups of marks in those regions to support CSS analysis and develop demographic survival data for those stocks.

Table 1.3. Groups marked in 2017 (through August 1) that do not include PIT tags provided by the CSS but are included in the study. The location of marking/hatchery, species, primary marking agency and tag totals are shown for each.

		PIT-tag Marking Agency[1]							
Location/Hatchery	**Species**	**NPT[2]**	**ODFW**	**USFWS**	**YINN**	**SMP**	**COLV**	**ONA**	**Total**
Wild Groups									
Imnaha Trap (Imnaha Basin)	CH/ST	5,300							5,300
Above Wells/Okanogan River	Su. Chinook						23,000		23,000
Okanogan River	Sockeye							11,500	11,500
John Day River	CH/ST		7,000						7,000
Trout Creek (Deschutes Basin)	Steelhead		2,500						2,500
Deschutes River	Fa. Chinook		25,000						25,000
Yakima (Satus, Toppenish, and Ahtanum Creeks)	Steelhead				250				250
Hatchery Groups									0
Carson NFH	Sp. Chinook			15,000					15,000
Little White Salmon NFH	Fa. Chinook			15,000					15,000
Spring Creek NFH	Fa. Chinook			15,000					15,000
Cle Elum	Sp. Chinook				40,000				40,000
Leavenworth NFH	Sp. Chinook					15,000			15,000
Warm Springs NFH	Sp. Chinook			15,000					15,000
Entiat NFH	Su. Chinook			20,000					20,000
Winthrop NFH	Sp. Chinook			20,000					20,000
Hatchery + Wild									0
RIS Yearling	Chinook					4,000			4,000
RIS subyearling	Chinook					4,800			4,800
RIS	Steelhead					4,000			4,000
RIS	Sockeye					3,400			3,400
Grand Total		5,300	34,500	100,000	40,250	31,200	23,000	11,500	245,750

[1] Tag funding sources are: Nez Perce Tribe (NPT), Oregon Department of Fish and Wildlife (ODFW), U.S. Fish and Wildlife (USFWS), Yakama Indian Nation (YINN), Smolt Monitoring Program (SMP), Colville Tribes (COLV), and Okanogan Nation Alliance (ONA). PIT-tags are provided for both wild Chinook and wild steelhead at some locations but the actual numbers captured and tagged by species is not known until after the outmigration is complete.

[2] Pre-assigned by NPT.

[1] Tag funding sources are: Nez Perce Tribe (NPT), Oregon Department of Fish and Wildlife (ODFW), U.S. Fish and Wildlife (USFWS), Yakama Indian Nation (YINN), Smolt Monitoring Program (SMP), Colville Tribes (COLV), and Okanagan Nation Alliance (ONA). PIT-tags are provided for both wild Chinook and wild steelhead at some locations, but the actual numbers captured and tagged by species is not known until after the outmigration is complete.

[2] Pre-assigned by NPT.

Historic in-river conditions and transportation

The environmental conditions experienced by out-migrating juvenile yearling Chinook and steelhead have varied considerably over the 22-year historical context of the CSS (Figure 1.6). The spring spill program has been in place since 1996 though some years with low flows (2001, 2004, and 2005) also had the lowest median spill percentages over these years. In 2007, low flows were accompanied by high spring spill percentages and low transportation percentages. This was the first time that spill was provided under such low flows. Migration

years 2010 and 2013 were similar in this regard. In contrast, 2008, 2009 and 2012 had medium flows and 2011 had high flows, all of which were accompanied with high spill.

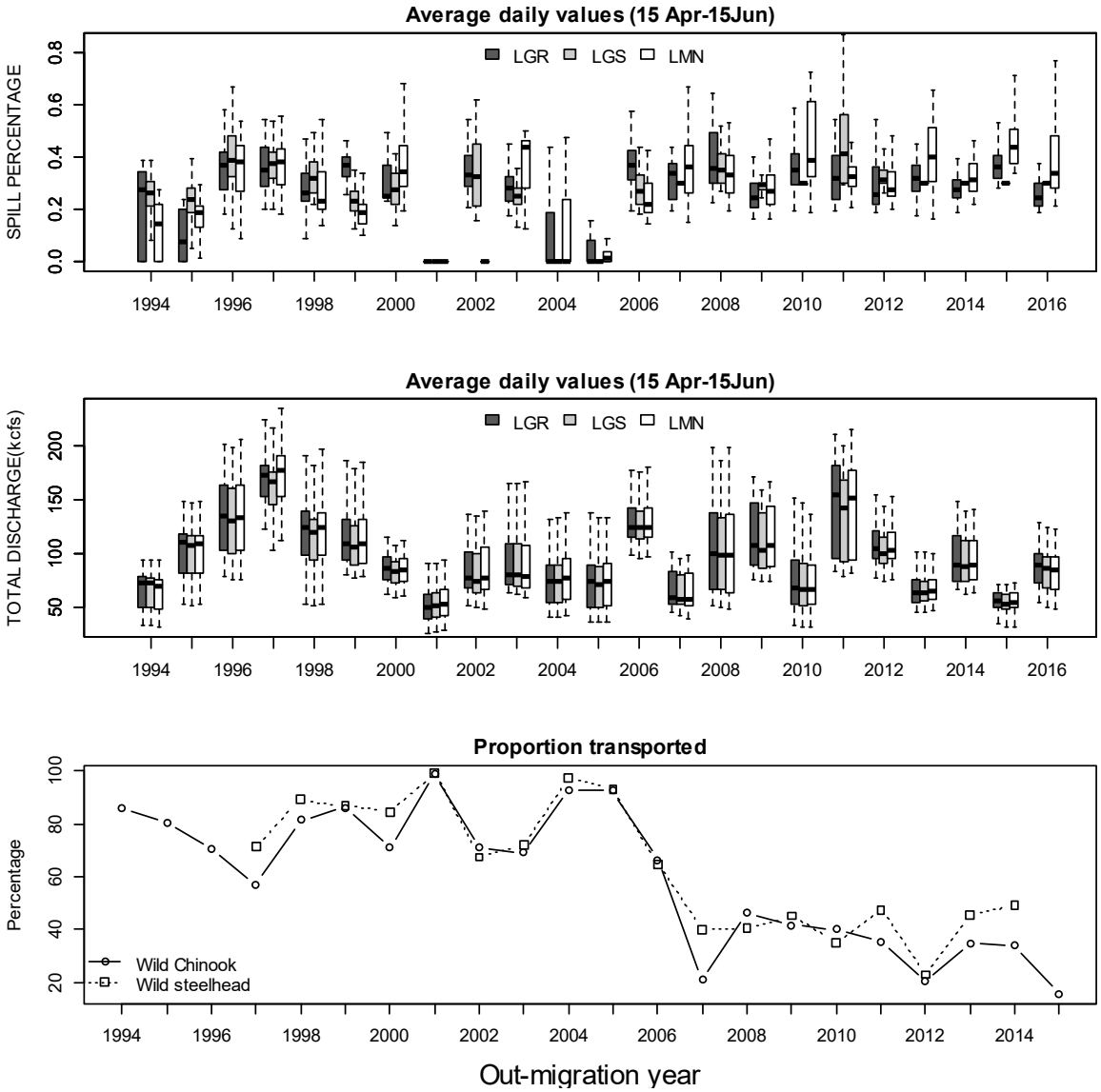

Figure 1.6 The top, middle, and bottom panels are summaries of spill percentage, flow, and the proportion transported over the historical context of the CSS at Lower Granite (LGR), Little Goose (LGS), and Lower Monumental (LMN) dams. The top two panels are boxplot summaries of average daily spill percentages and average daily flows at the three primary transportation dams. The proportion transported is shown for the wild Snake River stocks involved in the CSS as expressed by population proportion of T_0 fish in migration years before 2006 (Table 7.7 and Table 7.13 in the 2009 CSS annual report, and Appendix D of 2016 CSS annual report). The proportion transported for migration year 2015 Wild Chinook was estimated for this report.

Transportation protocol has varied over the years of the study as well. The transportation program underwent a change in operations during 2006. Transportation was delayed at LGR

until April 20 in 2006, April 25 in 2010, May 1 in 2007–2009 and 2011, and May 2 in 2012–2016. These years included a similar (but lagged) start date at LGS and LMN. The delayed start date was combined with an increased spill percentage as compared with 2004 and 2005, and resulted in a lower proportion of wild smolts being transported. Smolt outmigration timing also should affect transportation percentage and these results vary by stock. The highest transport percentages of CSS PIT-tagged wild smolts occurred in 2001, 2004, and 2005. Conversely, 2015 had one of the lowest transportation percentages in recent years (for wild Chinook) and much lower than other years with comparable flows. The higher spill percentage and delay of transportation contributed to a lower percentage of wild smolts transported. Typically for years after 2005 about 40 percent of the PIT-tagged Snake River wild stocks were transported.

Draft Report Organization

The draft report has eight chapters, including this introduction, followed by several appendices. Each of the following sections addresses a specific question or set of questions relating to the objectives of the CSS, its constituent data, analytical methods, and the comments by the ISAB as well as other reviewers.

Chapter 2 presents a life cycle modeling analysis that relies on the statistical results obtained from the 2015 life cycle model fitting to examine how alternative spill levels can help population recovery. The effects of breaching four Lower Snake River dams are modeled as a possible ESA recovery strategy for the BiOp. Four alternative spill scenarios are examined. Each spill scenario predicts a rate of powerhouse passage at low flow, average flow, and high flow. The effect of powerhouse passage on in-river and ocean survival is predicted as a consequence of each spill/flow combination, and the life cycle model is used to predict the effect of each spill scenario on SARs and long term abundances for six Snake River Spring Chinook populations. Results are preliminary and SARs should be viewed as relative estimates of the effects of different spill scenarios.

Chapter 3 updates the time series of data on juvenile travel time, instantaneous mortality, and survival with data from 2016. Models are developed to evaluate the relationships between water transit time, spill proportions, spillway weirs, water temperature, and seasonality to juvenile travel time, instantaneous mortality rates, and survival. The species evaluated include juvenile yearling Chinook salmon, subyearling Chinook salmon, sockeye salmon, and steelhead as they migrate through the reaches from Lower Granite Dam to McNary Dam, Rock Island Dam to McNary Dam, and McNary Dam to Bonneville Dam.

Chapter 4 summarizes overall smolt-to-adult return rates (SARs) for wild and hatchery salmon and steelhead populations from the Snake River, Mid-Columbia and Upper Columbia regions. Overall SARs of Snake River wild spring/summer Chinook and steelhead fell well short of the Northwest Power and Conservation council's (NPCC) 2% - 6% SAR objectives, while those from the mid-Columbia region generally fell within this range. For Snake River populations, none of the passage routes (in-river or juvenile transportation) have provided SARs within the range of the NPCC objectives; the relative effectiveness of transportation decreases as in-river conditions improve and survivals increase. SARs of wild and hatchery populations were highly correlated within and among regions, suggesting that common environmental factors were influencing survival rates.

Chapter 5 examines the association of SARs to life-cycle productivity for wild spring/summer Chinook and steelhead populations. Major population declines of Snake River spring/summer Chinook and steelhead are associated with SARs less than 1%, and increased life-cycle productivity has occurred in years that SARs exceeded 2%. Pre-harvest SARs in the range of 4% to 6% are associated with historical (pre-FCRPS) productivity for Snake River spring/summer Chinook. Historical levels of productivity for John Day river spring Chinook are associated with pre-harvest SARs in the range of 4% to 7%.

Chapter 6 presents updates for SARs by route of passage and TIRs for Snake River fall Chinook from migration years 2006 to 2012. The chapter also includes overall SAR data for hatchery and wild subyearling Chinook from the Mid-Columbia Region.

Chapter 7 examines PIT-tag-based data on age-at-maturity for eleven stocks of spring/summer Chinook salmon in the Columbia River Basin. Data across these eleven stocks are analyzed by a series of models to determine whether there are commonalities or differences in patterns of age-at-maturity across stocks, across rear types, and across juvenile outmigration years 1994-2011. For comparison purposes and to provide additional context for these data, age-at-maturity data for the overall spring Chinook salmon returns to the Columbia River from juvenile outmigration years 1980-2012 are compared to the more recent, PIT-tag-based data.

Chapter 8 examines PIT-tag-based adult passage success from Bonneville Dam upstream. Date of passage, flow and spill conditions as well as juvenile passage experience (transport or in-river migrant) are used to predict passage success. The analysis estimates the relationship between temperature, juvenile transport, and salmon survival using models in generalized regression, mixed effects, and Cormack-Jolly-Seber (CJS) framework. The analysis focuses on three salmonid species in the Snake River: summer run Chinook salmon, sockeye salmon, and steelhead, using temperature and PIT-tag data from 2003 to 2016.

Appendix A updates the CSS time series of juvenile in-river survival from LGR to BON (termed SR), transported and in-river SARs, TIRs and *D* for Snake River hatchery and wild spring/summer Chinook, steelhead, and sockeye. Prior to the 2012 CSS Annual Report, these data were presented in Chapter 2 (SR) and Chapter 4 (SARs, TIR, and *D*). Patterns of TIR and in-river survival probability are also updated for Snake River wild spring/summer Chinook and steelhead.

Appendix B contains tables of the overall SARs that are presented in Chapter 4.

Appendix C describes sources of PIT-tagged fish in the study.

Appendix D contains the dam-specific transportation SARs in terms of adult returns to LGR for Snake River transported fish from LGR, LGS, and LMN.

Appendix E includes the estimates of the proportion of the run-at-large that experiences passage through transportation, bypass, or without detection for Snake River groups.

Appendix F updates the returning age composition of adults for the Snake, Upper Columbia, and Lower Columbia river groups.

Appendix G presents BOA-GRA adult upstream passage success rates by return year for wild Snake River spring/summer Chinook.

Appendix H presents a weighted bootstrap procedure that can be used to estimate SARs for PIT-tag groups that are marked disproportionately. The weighted approach uses a population

proportions as weights for drawing tags for each bootstrap run. The method is underdevelopment and is proposed to be used for hatchery release groups where known proportions of sub-populations are disproportionately marked. The weighted bootstrap allows the estimation of confidence intervals using the bootstrap methodology.

Appendix I summarizes the 2017 CSS annual meeting held on April 3, 2017, at the Water Resource Center in Vancouver, Washington.

Appendix J includes the CSS Oversight Committee responses to comments on the draft 2017 CSS report.

Appendix K As requested by ODFW, attached is the supplemental analysis for the breach option using the models for the long-time series data sets. Prospective models are the same as were used for the documentation of spill management experiment (CSSOC 2017).

CHAPTER 2
LIFE CYCLE MODELING EVALUATION OF ALTERNATIVE SPILL AND BREACH SCENARIOS

The CSS began developing life cycle models in 2013 for the purpose of examining survival at specific life stages, which is an important component of Adaptive Management (Holling 1978), and also a key element of NOAA's Biological Opinion (BiOp) on the operation of the Federal Columbia River Power System (FCRPS). Since its inception, the life cycle modeling initiative has explored the potential to assess tributary smolt production, mainstem passage survival, ocean survival, and adult return rates. Empirical validation to abundance data and environmental time series has provided a detailed perspective of spatial and temporal variability in SAR estimates, while separating survival into freshwater and ocean components. Detailed separation of life stages included separating the juvenile migrants into transported and untransported fish for downstream migration, as well as the distinction that transported and untransported fish experience different survivals upon ocean entry.

The life cycle model was used to compare the predicted relative impacts that two key factors would have on long-term abundance increases: 1. Freshwater production as a function of habitat restoration, and 2. Survival in the mainstem as a function of hydrosystem operations. Through 2016, life cycle modeling analyses examined the potential for abundance to increase as a result of how these two factors can influence survival across the life cycle. Freshwater productivity is of interest because numerous habitat improvement activities are underway, and the benefits of those activities can likely be expected to result in increases in productivity and capacity. Hydrosystem operations are of interest because they have been shown to affect survival during juvenile migration and also survival at ocean entry. Analyses relying on empirical parameter estimates derived from historical life cycle reconstructions examined how alternative spill levels influence SARs and long-term return abundances. Alternative spill levels were examined, with each spill level predicting a rate of powerhouse passage at three characteristic flow levels (high flow, average flow, and low flow). The effect of powerhouse passage on in-river and ocean survival was predicted, and the life cycle model was used to predict SARs and long-term abundances of six Snake River Spring Chinook populations.

In a recent court Opinion (NWF v. NMFS 2016), Judge Simon ruled that NMFS, in its 2014 FCRPS BiOp, had violated the National Environmental Policy Act (NEPA) by failing to have a "hard look" at all reasonable alternatives to the recovery of listed salmon populations. Specifically, Judge Simon stated that federal agencies had ignored previous calls by federal Judges Marsh and Redden that federal agencies needed to consider a "major overhaul" of the FCRPS, including potentially breaching or removing one or more of the lower Snake River dams, the implication being that breach should be considered a reasonable alternative for recovery. NEPA requires that all agencies of the Federal Government complete an environmental impact statement (EIS) in connection with every recommendation in a BiOp. Judge Simon ordered that NMFS produce produce and file a BiOp by March 1, 2018 that complies with the Endangered Species Act (ESA), and prepare an EIS that complies with NEPA. A complete EIS will involve a comprehensive cost and benefit analysis of alternatives to avoid jeopardy under ESA. Given the

likelihood that breach will need to be examined in one way or another, an initial investigation focussed solely on the fish survival benefits of dam breaching seems warranted.

The CSS aims to provide meaningful and relevant perspectives on Columbia Basin salmonid recovery, and the 2016 NWF v. NMFS Court Opinion puts a spotlight on dam breaching as a potential subject of investigation. This analysis is a step toward bringing dam breach alternatives into the assessment of impacts on salmon population recovery. Specifically, it uses a life cycle model to examine the potential fish survival benefits of breaching the lower four Snake River dams. We present a prospective contrast of spill and breach scenarios by simulating future population trends using an empirically validated life cycle model sensitive to hydrosystem conditions affected by flow, spill, and breach. In like fashion to previous life cycle analyses the CSS has produced, we simulate population trends using predicted powerhouse passage rates under each spill and breach scenario. The analysis compares simulated return abundances and smolt to adult rates (SARs) to the physical location of Lower Granite dam when each spill and breach scenario is evaluated under a range of flow conditions.

Introduction and background

Since 2013, the CSS has been developing life cycle modeling analyses that link freshwater spawning and rearing (FSR) dynamics with historical records of survival rates and smolt-to-adult return rates. Relative numbers of 3, 4, and 5-year old fish were used to infer survival during the time between juvenile outmigration past Bonnevile Dam (BON) and the end of the first year in the ocean. We focussed on the combined estuary and first year ocean survival (S.o.1) because early ocean survival is considered very crucial in the life history of salmonids. Ocean survival probabilities have been associated with indices of ocean conditions such as the Pacific Decadal Oscillation (PDO) (Mantua et al., 1997), upwelling indices indicative of primary production, and sea surface temperature (Petrosky and Schaller 2010). Additionally, evidence has emerged that environmental conditions in the river affect the physical condition of out-migrating fish, and influence the rate of mortality after the fish enter the ocean (Petrosky et al. 2001; Budy et al. 2002). Petrosky and Schaller (2010) showed that S.o.1 varied with PDO, upwelling and a variable describing juvenile interaction with powerhouses. An index powerhouse passage was created (termed NPH) where each powerhouse that fish come into contact with is discounted by the spill amount and spill efficiency. For example, a 50% spill can reduce a powerhouse passage rate from as high as 1.0 without spill to as low as 0.5 with spill (see Petrosky and Schaller (2010)). The study found that the sum of the spill-adjusted powerhouse passage values (NPH) was negatively correlated with survival below BON and during the first year in the ocean.

Life cycle modeling analyses were refined by partitioning mainstem passage survival into transported and untransported life histories, and accounting for survival differences both during these two routes of passage, as well as survival differences that occur upon ocean entry. The 2015 life cycle modeling analysis provided a quantitative assessment of the relative life cycle production benefits of improving survival conditions in the spawning and rearing versus improving survival conditions during juvenile outmigration through the mainstem. It used the same basic population prediction methods and statistical fitting methods developed in previous years analyses, but the 2015 analysis included additional years of abundance and survival data, and reconstructed population specific in-river harvest using US v OR Technical Advisory

Committee (TAC) estimates of Zone 6 and commercial harvest, and included brood stock removals and upstream conversion rates. The 2015 analysis provided a comparison of the potential benefits of managing FSR habitat for increased productivity and capacity versus the potential benefit of managing the hydrosystem. The analysis was a retrospective simulation of potential FSR and hydrosystem actions evaluated at historically observed mainstem and ocean conditions. It contrasted a predicted reconstruction of present day return abundances across a range of possible alternative FSR and hydrosystem actions. The 2016 analysis built upon the 2015 framework, but with the distinction that the 2016 analysis evaluated long-term projected return abundances prospectively, rather than retrospectively. Simulated freshwater, hydrosystem, and ocean factors were used as the basis for predicting life stage survivals. Future unobserved environmental conditions were randomly simulated to produce time series of in-river and ocean variables similar to historical or expected future conditions. The analysis evaluated the potential for increased spill levels to produce survival and recovery benefits. Population trends under BiOp level spills were compared to three increasingly higher spill levels, and each spill level was evaluated at a historical flow level representative of high, average, and low flow levels.

This 2017 analysis uses the life cycle model to explore the effect of breaching the lower four Snake River dams. Ice Harbor (ICH), Lower Monumental (LMN), Little Goose (LGS), and Lower Granite (LGR) each contribute the overall powerhouse passage experience of juvenile migrating fish, and each dam creates a reservoir volume that affects how water transit times are predicted by discharge and spill volumes. Just as powerhouse passage probability can be predicted from spill percentages at known discharge levels for each project, and just as water transit time can be calculated from reservoir volume, spill, and discharge for each project, passage and travel can be predicted through the entire mainstem when breach conditions are assumed at the lower four Snake River dams. The lower four Snake River breach scenario predicts reductions in powerhouse passage and water transit time, which provides a further contrast in life stage survivals to those already examined across alternative spill levels.

Data

There are three types of data used in this analysis: 1. forcing variables used to predict survival (environmental and anthropogenic data), 2. empirical abundances (juvenile and adult) used for comparison with predicted abundances, and 3. survival rates used to compare to the predicted trends in survival.

This analysis focuses on spring/summer Chinook salmon in the Grande Ronde basin. The Snake River spring/summer chinook ESU contains several major population aggregates in Idaho, Washington and Oregon. The Grande Ronde/Imnaha Major Population Group (MPG) consists of several populations migrating into the Snake river. The Grande Ronde River (GR), Catherine Creek (CC), Lostine/Wallowa (LOS), Minam (MIN), Wenaha (WEN), and Imnaha (IMN) are six populations making up the MPG, and are the focus of this analysis. The Northwest Fisheries Science Center of the National Marine Fisheries Service (NMFS) publishes salmon population summaries annually (SPS[1]). These summaries include annual estimates of the number of spawners, the age compositions of spawners, the proportion of hatchery fish on spawning

[1] https://www.webapps.nwfsc.noaa.gov/apex/f?p=261:home:0

grounds, and harvest rates. The annual record can be used to account for the number of fish of each age from each spawning year (or brood year) that later return to spawn, including those that were caught in fisheries or collected for hatchery brood stock. The full account of this is called a brood table and is used in this analysis for each of the six listed populations of the MPG. We selected the time period for which all populations were monitored and environmental data were available. Thus, early years where not all populations were monitored were not included. Adult returns were available up until 2013, meaning that three year old returns from brood year 2010 were accounted for, along with four year old returns from 2009, and five year olds from 2008. This results in a multi-population brood table spanning the brood years 1964 to 2008, where 2008 is the most recent brood year where all ages of adults have been observed on spawning grounds (2013). We used conversion rates, Zone 6 harvest estimates, and commercial harvest estimates from US v. OR TAC Biological Assessment Tables to reconstruct the number of adults that would have been present at the mouth of the Columbia, based on the number that were observed on the spawning grounds. Those numbers are used to compare to predicted returns to the mouth. Tributary harvest rates and collection for brood stock, which are also used in this back-calculation, were obtained from ODFW population reconstruction tables.

One facet of this analysis is focussed on the effects of environmental conditions in the Columbia River during smolt outmigration, and environmental conditions in the ocean when smolts enter their ocean residency stage. We use a powerhouse passage rate derived from PIT tag data (PITPH) to predict in-river and ocean survival (Appendix J, McCann et al., 2015). The PITPH index uses the PIT tag detection rate and an estimated fish guidance efficiency to estimate the fraction of fish passing through the powerhouse (bypass and turbine routes combined). This is predicated on the fact that the actual number passing through the powerhouse is the number of bypass detections divided by the guidance efficiency. PITPH implicitly captures traditional spill and surface passage. The index is the sum of the fractions passing through the powerhouses of all projects combined.

We also used an index of water travel time (WTT) to predict in-river survival. WTT is obtained by dividing the total volume of reservoirs by the flow rate, with adjustments in McNary pool to account for Columbia River versus Snake River flows (Tuomikoski et al., 2012). Breach scenario WTT was re-evaluated using transit times where reservoir volumes between IHR and LGR were based on tailrace elevations 90-100 ft below current minimum operating pool elevations. WTT was then calculated by dividing reservoir volumes by rates of discharge for low, average, and high flow conditions. Elevation (ft) and storage (af) used for for LGR, LGS, LMN, and IHR calculations were (in ft/af) 640/41K, 540/119K, 440/73K, and 340/40K respectively. To predict the fraction of juveniles that are transported, we use an index (PTRANS) that was reported in Appendix E of McCann et al. (2016). PTRANS is the proportion of outmigrating smolts alive at Lower Granite Dame that are likely to be transported at LGR, LGS or LMN dams. For early ocean survival, we use the PDO in May, the upwelling index (UPW) in April, and additionally, we formulated a mechanism by which the ocean survival of in-river migrants is also affected by PITPH. The time series of environmental conditions is shown in Figure 2.1. PITPH appears to generally reflect the number of powerhouses in place and the proportion of total flow that has occurred as spill at each project over the time series. This time series encompasses a period of time when several changes took place in the hydrosystem. Fewer powerhouses were operational in the hydrosystem until the mid 1970's, so PITPH was lower. The transmission capabilities were

limited prior to the construction of the DC and AC Intertie transmission lines, which resulted in a considerable amount of uncontrolled spill. As a consequence of this construction, the occurrence of uncontrolled spill declined. Full transportation as a mitigation measure was implemented for several years and no spill occurred at the transport projects. In addition, several planned spill programs were in place, including the Spill Memorandum of Agreement prior to the 1992 BiOp. Subsequent increases in spill levels occurred through the series of Biological Opinions until the 2008 BiOp. The most significant changes in spill came after 2005, when a court opinion granted the summer spill portion of the National Wildlife Federation's request for injunctive relief to provide spill to gas cap limits at LGR, LGS, LMN, and McNary (MCN) dams.

Juvenile data (Favrot 2012[2]) are available for four of the six populations in the MPG: Catherine Creek, the Grande Ronde River, the Lostine/Wallowa and the Minam river. Data are not available for each year for each population, but the range was between 1992 to 2009, and some missing years are excluded from model fitting procedures. Additional years of smolt data were obtained from ODFW for brood years years 2010-2013.

We use SAR and in-river survival rates s_R obtained from PIT tag data for migration years 1994 to 2013. Prior to 1992, SARs were obtained by dividing the returns to the mouth of the Columbia River by number of smolts at the upper dam (Petrosky and Schaller, 2010). For 1980 and prior migration years, data from Williams et al. (2001) were used for in-river survival rates. 1981-1984 in-river survival rates are from Marmorek and Peters (1998).

Methods

A life cycle model was constructed that predicts smolt production and life stage survivals in relation to environmental conditions in the mainstem during smolt migration and in the ocean. We estimated model parameters that predict life stage survivals in order to best fit trends in abundance, trends in life stage survivals, and route of passage SARs. We then use the results of statistical fitting as the basis for predicting abundance trends under alternative potential changes to both tributary and mainstem survival. We use an Alternative Treatment Evaluation (ATE) method that compares the potential relative benefit of a level of improvement to juvenile passage survival (as a result of spill and/or breach) to a level of improvement in freshwater spawning and rearing productivity. The ATE method factors the uncertainty in parameter estimates into predictions, and therefore predicts the range of possible outcomes from each alternative spill level or breach scenario.

Models

Typically, freshwater salmonid production is described in terms of spawners, eggs, fry, parr and smolts. The Beverton-Holt (BH) stock recruitment relationship (Beverton and Holt 1957) is a density dependent production and survival model, which does not assume overcompensation (diminishing production above an abundance threshold). We use a BH function to characterize survival between stages, though density dependence is only modeled at the smolt

[2]https://pisces.bpa.gov/release/documents/documentviewer.aspx?doc=P128637

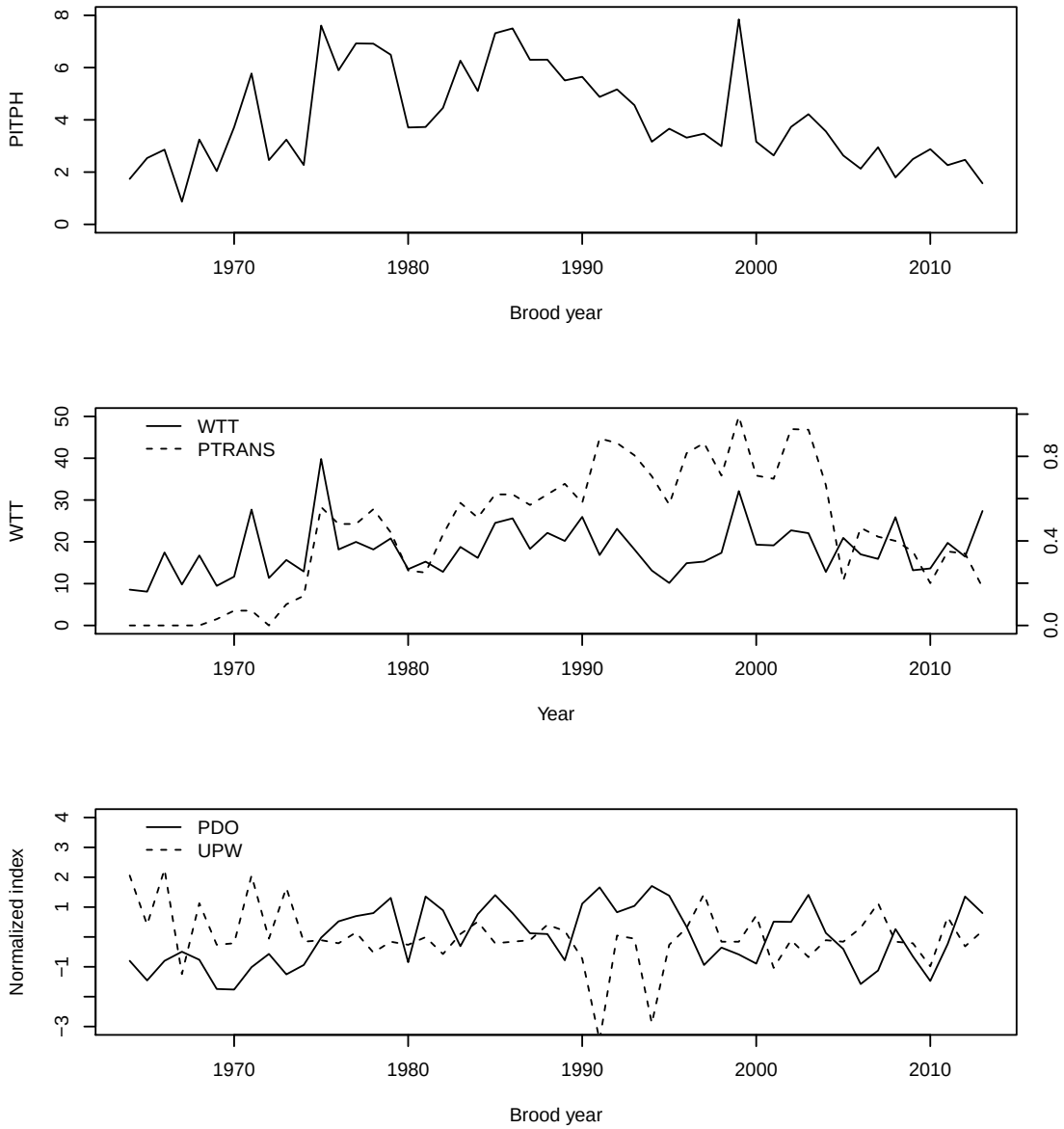

Figure 2.1: PITPH (upper panel) WTT and Transport (middle panel) and ocean environmental conditions (lower panel) used in model predictions.

production stage, not in the mainstem, nor ocean stages. We limit density dependence to the smolt production stage because populations are isolated from each other at that stage, i.e., many populations interact in later life stages, and it is difficult to isolate the source of density effects.

The potential effect of distinct population migration timing is not considered. We predict freshwater smolt production of distinct populations and merge those populations together into a single migration unit, sharing common outmigration dynamics and a combined in-river/first year ocean survival, before maturing on a common maturation schedule and returning to spawn after 1, 2, or 3 winters in the ocean. Migration through the mainstem explicitly distinguishes between transported and in-river juveniles migrating through the hydrosystem. This distinction is clearly formulated in the model description (Equations [2.9]-[2.11]), where it can be seen that each population has a transported and an in-river survival probability, and once the fish enter the ocean, the transported and in-river fish have different survival probabilities.

To estimate parameters, brood years 1964-2008 of observed spawners are used to predict age class returns from each brood year, and the predicted returns from observed data are compared to observed returns. The statistical estimation assumes that the age of returns are measured without error, and differences between observations and predictions are the result of errors in prediction, known as a process error model (Quinn and Deriso, 1999). We fit the model to empirical juvenile abundance data, adult abundance data, empirical in-river survival, and empirical SARs. We predict smolts from the combined natural and hatchery spawners on the spawning grounds, but the returning adults are compared to natural returns only, meaning that hatchery fish on the spawning ground contribute to production and their offspring are counted as natural production. We perform the model fitting using maximum likelihood estimation (MLE) techniques, and we additionally explore the variability in the estimated rates using Markov Chain Monte Carlo simulations.

Equations [2.1] - [2.8] describe the life cycle from spawners to adults for a single brood year. Upper case letters are state variables of predicted (indicated by ˆ) or observed life history stages. Lower case letters and Greek symbols are either estimated parameters, fixed parameters, or derived parameters. Table 2.1 describes each parameter and variable in the model, and whether it's estimated, fixed, derived, or predicted. Smolts in brood year t from population p are predicted from spawners as

$$\hat{M}_{p,t+2} = \frac{a_p S_{p,t}}{1 + a_p S_{p,t}/b_p} \qquad [2.1]$$

where a_p is the productivity for population p. Adults in the ocean following one winter in the ocean are predicted by the relationship

$$\hat{O}_{1,p,t+3} = \overbrace{\tau_{t+2} \underbrace{0.98}_{Barge} \underbrace{s_{T,t+2}}_{Ocean} \hat{M}_{p,t+2}}^{Transported} + \overbrace{(1-\tau_{t+2}) \underbrace{s_{R,t+2}}_{River} \underbrace{s_{H,t+2}}_{Ocean} \hat{M}_{p,t+2}} \qquad [2.2]$$

where τ_t is the proportion of juveniles transported estimated from PIT tag data. Transported fish are assumed to have transportation survival probability of 98% (McMichael et. al 2010). $s_{T,t}$ is the survival in year t of ocean entry from the tailrace of Bonneville dam for transported juveniles. $s_{R,t}$ is the in-river survival in year t of non-transported fish. $s_{H,t}$ is the survival in year t of ocean

Table 2.1: Description of variables and parameters used in Equations [2.1] to [2.12]. All variables are time-indexed to brood year t. Parameters and variables indexed by population p have dimension 6. Parameters estimated directly are indicated. Parameters derived from auxiliary data and estimated parameters indicate equation of origin.

Variable	Parameter	Description (year t, population p)	Value
$\hat{M}_{p,t+2}$		Brood year t Smolts	Equation [2.1][1]
$\hat{O}_{1,p,t+3}$		Brood year t first year ocean resident	Equation [2.2]
$\hat{R}_{3,p,t+3}$		Brood year t 1-salt returns	Equation [2.3][1]
$\hat{O}_{2,p,t+4}$		Brood year t second year ocean residents	Equation [2.4]
$\hat{R}_{4,p,t+4}$		Brood year t 2-salt returns	Equation [2.5][1]
$\hat{O}_{3,p,t+5}$		Brood year t third year ocean residents	Equation [2.6]
$\hat{R}_{5,p,t+5}$		Brood year t 3-salt returns	Equation [2.7][1]
${}_{C0}\hat{R}_{a,p,t+a}$		C0 group returns of age a in year t+a	
${}_{TX}\hat{R}_{a,p,t+a}$		TX group returns of age a in year t+a	
$\hat{S}_{p,t}$		Brood year t spawners	Equation [2.8][1]
$S\hat{A}R_t$		Brood year t SAR	Equation [2.12][1]
$\bar{R}_{p,j,i}$		Mean recruitment for spill scenario j, MCMC iteration i	Calculated
	$h_{p,t}$	Harvest rate for population p year t	Derived[2]
	$\lambda_{p,t}$	Adult migration conversion rate for population p year t	Derived[4]
	a_p	Spawner to smolt productivity for population p	Estimated
	b_p	Spawner to smolt capacity for population p	Estimated
	$s_{R,t}$	Survival of in-river migrants from LGR to BON	Equation [2.9]
	$s_{H,t}$	Early ocean survival of in-river migrants	Equation [2.10]
	$s_{T,t}$	Early ocean survival of transported fish	Equation [2.11]
	τ_t	Proportion of fish transported	CSS estimate[3]
	s_2	Survival through second ocean winter	0.8[5]
	s_3	Survival through third ocean winter	0.8[5]
	m_1	Maturation rate after first ocean winter	0.02[5]
	m_2	Maturation rate after second ocean winter	Estimated
	δ_R	$s_{R,t}$ In-river logistic intercept	Estimated
	δ_{PH}	$s_{R,t}$ In-river logistic PITPH coefficient	Estimated
	δ_{WTT}	$s_{R,t}$ In-river logistic WTT coefficient	Estimated
	δ_{PW}	$s_{R,t}$ In-river logistic PITPH WTT interaction coefficient	Estimated
	γ_H	$s_{H,t}$ Early ocean logistic in-river intercept	Estimated
	γ_T	$s_{T,t}$ Early ocean logistic transport intercept	Estimated
	γ_{PDO}	$s_{1,t}$ Early ocean logistic PDO coefficient	Estimated
	γ_{UPW}	$s_{1,t}$ Early ocean logistic UPW coefficient	Estimated
	γ_{PH}	$s_{1,t}$ Early ocean logistic PITPH coefficient	Estimated

[1] Observed quantities (without ˆ) also represented for these variables.
[2] https://www.webapps.nwfsc.noaa.gov/apex/f?p=261:home:0
[3] CSS 2016 annual report.
[4] US v. OR Biological Assessment Tables.
[5] Fixed value.

entry from the tailrace of Bonneville dam for in-river migrants. Note that $\hat{O}_{1,p,t}$ can be apportioned to transported and in-river fish with $\phi_{T,t} = .98\tau_t s_{T,t}/(.98\tau_t s_{T,t} + (1-\tau_t)s_{R,t}s_{H,t})$ being the transported fraction and $\phi_{R,t} = (1-\tau_t)s_{R,t}s_{H,t}/(.98\tau_t s_{T,t} + (1-\tau_t)s_{R,t}s_{H,t})$ being the in-river fraction for migration year t.

The number of 1-salt fish (three years old) that mature and return to spawn is given by

$$\hat{R}_{3,p,t+3} = m_1 \hat{O}_{1,p,t+3} \qquad [2.3]$$

where m_1 is the maturation rate of 1-salt fish. The predicted abundance of 2-salt fish after the second year in the ocean is

$$\hat{O}_{2,p,t+4} = s_2(1-m_1)\hat{O}_{1,p,t+3} \qquad [2.4]$$

where s_2 is the survival probability in the second year. The number of maturing 2-salt fish (four years old) that return to spawn is

$$\hat{R}_{4,p,t+4} = m_2 \hat{O}_{2,p,t+4} \qquad [2.5]$$

where m_2 is the maturation rate of 2-salt fish. The predicted abundance of 3-salt fish after the third year in the ocean is

$$\hat{O}_{3,p,t+5} = s_3(1-m_2)\hat{O}_{2,p,t+4} \qquad [2.6]$$

All fish are assumed to return after the third winter (five years old) in the ocean, i.e,

$$\hat{R}_{5,p,t+5} = \hat{O}_{3,p,t+5} \qquad [2.7]$$

The number of spawners is the sum of the run of each age class of fish not harvested that survive migration passage, where there is a harvest rate $h_{p,t}$ and a migration conversion rate $\lambda_{p,t}$ for each population p and each year t.

$$\hat{S}_{p,t} = \sum_{a=3}^{5} \hat{R}_{a,p,t}(1-h_{p,t})\lambda_{p,t} \qquad [2.8]$$

The model predicts three survival probabilities through the hydrosystem until the end of the first year in the ocean: 1. the in-river survival probability $s_{R,t}$, 2. the first year ocean survival probability of in-river migrating fish that are exposed to conditions in the hydrosystem $s_{H,t}$, and 3. the first year ocean survival probability of transported fish $s_{T,t}$. The predicted SAR to Lower Granite Dam (or its location if breached) is calculated from transported and untransported smolts and returns after harvest and dam passage. The predicted C0SAR is calculated using untransported smolts and C0 returns excluding jacks. The predicted TXSAR is calculated using transported smolts and TX returns excluding jacks.

$$logit(s_{R,t}) = \delta_R + \delta_{PH}PITPH_t + \delta_{WTT}WTT_t + \delta_{PW}PITPH_tWTT_t \qquad [2.9]$$

$$logit(s_{H,t}) = \gamma_H + \gamma_{PDO}PDO_t + \gamma_{UPW}UPW_t + \gamma_{PH}PITPH_t \qquad [2.10]$$

$$logit(s_{T,t}) = \gamma_T + \gamma_{PDO}PDO_t + \gamma_{UPW}UPW_t \qquad [2.11]$$

$$SAR_{p,t} = \frac{\sum_{a=3}^{5} \hat{R}_{a,p,t+a}(1-h_{p,t+a})\lambda_{p,t+a}}{\hat{M}_{p,t+2}} \qquad [2.12]$$

$$C0SAR_{p,t} = \frac{\sum_{a=3}^{5} {}_{C0}\hat{R}_{a,p,t+a}(1-h_{p,t+a})\lambda_{p,t+a}}{(1-\tau_{t+2})\hat{M}_{p,t+2}} \quad [2.13]$$

$$TXSAR_{p,t} = \frac{\sum_{a=3}^{5} {}_{TX}\hat{R}_{a,p,t+a}(1-h_{p,t+a})\lambda_{p,t+a}}{\tau_{t+2}\hat{M}_{p,t+2}} \quad [2.14]$$

Survivals are linear in logit space, with intercepts δ_R, γ_H, and γ_T. $\delta_{PH,WTT}$ and $\gamma_{PH,PDO,UPW}$ are slope coefficients that predict the magnitude of influence of environmental factors. PITPH is implemented in such a way as to allow the parameter estimation to predict if it is significant in both in-river and early ocean survivals. The logit transform is used here because it allows the search algorithm in the statistical fitting procedure to choose values of the δs and γs in the range $(-\infty, \infty)$ without causing the survival estimate to leave the range (0,1).

Model fitting

Parameters are estimated by comparing the predicted to observed smolt and adult abundances, as well as comparing predicted to observed in-river survival, overall SARs, C0 (in-river migrant) SARs, and Tx (transported) SARs. In previous lifecycle analyses, we did not include likelihoods specifically for C0 and transported SARs. We include these extra likelihood terms to provide a more detailed perspective on survival distinctions between transported and in-river routes of passage. The abundance comparisons include comparing the total returning adult fish of each age $R_{a,t}$ to the returns of each age in the NMFS population summary data, and comparing the predicted smolts to observed smolts. The returns at age for each year in the NMFS data are obtained by adding the spawners of a given age to the catch and hatchery broodstock collection, if any. The parameter estimates are obtained by minimizing the negative log-likelihoods of the following Equations:

$$\mathscr{L}_{R_{p,a}}\left(R_{a,t}|\Theta_p\right) = \prod_{t=1}^{n} \frac{1}{\sigma_{R_{p,a}}\sqrt{2\pi}} \exp\left[-\frac{\left(log(R_{p,a,t}) - log(\hat{R}_{p,a,t})\right)^2}{2\sigma^2_{R_{p,a}}}\right] \quad [2.15]$$

where Θ_p is the set of parameters a_p and b_p for p=1...6, m_1, and m_2, and also the δs and γs that predict survivals in Equations [2.9]-[2.11]. $\sigma^2_{R_{p,a}}$ is the process error variance of the prediction of returning spawners at age. The likelihood term for smolts (Equation [2.16]) uses the same form, but uses observed and predicted juvenile numbers for the populations that had juvenile surveys and is given by

$$\mathscr{L}_{M_p}\left(M_{p,t}|\Theta_p\right) = \prod_{t=1}^{n} \frac{1}{\sigma_{M_p}\sqrt{2\pi}} \exp\left[-\frac{\left(log(M_{p,t}) - log(\hat{M}_{p,t})\right)^2}{2\sigma^2_{M_p}}\right] \quad [2.16]$$

We treat the prediction of the returns at age and smolt data as having unknown σ^2_R and σ^2_M and we minimize the negative log-likelihood while substituting the maximum likelihood estimate for σ^2 into the likelihood equations. The substitution of this "nuisance parameter" with its MLE

reduces the number of parameters that need to be estimated, and places more emphasis on observed quantities instead of discounting observations with high estimated variances. The MLE for $\hat{\sigma}_R^2$ is given by

$$\hat{\sigma}^2_{R_{p,a}} = \sum_{t=1}^{n} \frac{(log(R_{a,p,t}) - log(\hat{R}_{a,p,t}))^2}{n} \qquad [2.17]$$

The same assumption was made for juvenile data, so $\hat{\sigma}^2_{M_p}$ is estimated using a similar substitution. The empirical in-river survival probability estimates (s_R) and the overall, transported, and C0 SARs are also included in likelihoods. The in-river survival likelihood is given by

$$\mathscr{L}_{s_R}\left(s_{R,t}|\Theta_R\right) = \prod_{t=1}^{T_R} \frac{1}{\sigma_{s_{R,t}}\sqrt{2\pi}} \exp\left[-\frac{\left(log(s_{R,t}) - log(\hat{s}_{R,t})\right)^2}{2\sigma^2_{s_{R,t}}}\right] \qquad [2.18]$$

where $\sigma_{s_{R,t}}$ is obtained by substituting the maximum likelihood estimate into the likelihood (as in [2.17]). The likelihoods for the overall SARs, C0SARs, and TXSARs are given by

$$\mathscr{L}_{SAR}\left(SAR_t|\Theta_{SAR}\right) = \prod_{t=1}^{T_{SAR}} \frac{1}{\sigma_{SAR}\sqrt{2\pi}} \exp\left[-\frac{\left(log(SAR_t) - log(S\hat{A}R_t)\right)^2}{2\sigma^2_{SAR}}\right] \qquad [2.19]$$

where σ_{SAR} is again obtained by substituting the maximum likelihood estimate into the likelihood (again like [2.17]). We note that adding C0 and transported SAR likelihoods changes the statistical statistical and numerical balance of how potential parameter values influence empirical model fitting. Specifically, the additional terms provide a basis for predicting the relative effect of environmental factors on survivals of in-river and transported fish.

The likelihoods and the life cycle model were coded and implemented using the AD Model Builder optimization software (ADMB, free to download at www.admb-project.org). The package is designed for large scale non-linear optimization problems and is commonly used in fisheries stock assessments. We obtained the best fit to the data by minimizing the sum of all the negative logarithms of the likelihoods, which is equivalent to maximizing the product of the likelihoods. Rather than report the values of the maximum likelihood parameter estimates, we report the range of variability in parameter estimates by performing Markov Chain Monte Carlo (MCMC) simulations using a Metropolis Hastings algorithm native to the ADMB package. The MCMC simulations produce samples of the posterior probability densities of each parameter. We simulated a chain of 1,000,000 samples after a burn-in period of 100,000 samples, and sampled the chain 1,000 times to obtain a posterior density estimate. We assumed an uninformative prior distribution for each parameter, so the limits of the range of the sampling distributions are bounded, but the shape of the distribution is predicted by the data. Sampling from the chain of parameter estimates obtained from the MCMC simulations, we produced frequency histograms that show the shapes of the distributions of parameter estimates. Whereas the maximum likelihood estimation provides estimates of each parameter at the mode, and an estimate of the variance in each parameter evaluated near the mode, the posterior densities reflect the frequency with which given parameter values are chosen at random and found to explain the data better than alternative random choices (the essence of MCMC simulation). We present the posterior

distributions in lieu of point estimates because this provides a better sense of how well the model was able to fit all abundance and survival data sources, and gives us a relative sense of how well the data might have been explained by parameter values higher and lower than the most probable combination of parameters.

Prospective simulation

Parameters determine survival rates in relation to environmental conditions, as well as how recruitment differs among populations because of estimated productivities and capacities. We can use estimated parameter values to simulate projected future population trends by initializing the model with recent spawning abundances. Once the model predicts the adult returns, it can propagate population trends multiple generations into the future without the need for additional empirical spawning abundances. We can use the projected population trends as the basis for evaluating the relative benefits of alternative spill and breach scenarios. Further, we can project the population trend response to these spill and breach scenarios across ranges of potential changes to freshwater habitat conditions, and therefore the effect habitat restoration could have on freshwater productivity and capacity. Further still, by looking at the predicted response across ranges of variability in parameter estimates, we can examine the variability in the population trend response to spill, breach, and habitat restoration.

We use the life cycle model to predict the long-term effects of four experimental spill alternatives on population recovery, and reevaluate those spill levels under the scenario where the lower four Snake River dams are breached. The experimental spill levels are defined in terms of the limits of total dissolved gas (TDG) produced at each project.

BiOp Maintain spill levels according to the regulations consistent with the current Biological Opinion.

115%/120% Increase spill up to limits of 120% TDG in the tailraces and 115% TDG in the forebay.

120% Increase spill up to a limit of 120% TDG in tailraces and forebays.

125% Increase spill up to a limit of 125% TDG in tailraces and forebays.

The actual spill percentage or volume to produce specified TDG levels depends on flows at each project (Appendix J, McCann et al., 2015). Since the goal of evaluating different spill and breach scenarios is to evaluate the effect of spill on PITPH, each experimental level is evaluated at three flow levels (high, average, and low flow), which produces a total of twelve spill scenarios with the four lower Snake River dams in place, and twelve scenarios with the four dams breached. Each scenario predicts a different value of PITPH, which was evaluated with spill caps applied to the hourly flow data at all eight projects from April 1 through August 31. We used flow levels from specific years as surrogates for high, average, and low years. We used 2011 to represent a typical high flow year, 2009 to represent an average year, and 2010 to represent a low flow year. These three years represent a range of flow conditions relative to the historic data (1929 to 2012). The three years also represent operations that reflect the most recent configuration and operation of the FCRPS. While 2010 was not a low flow year when the whole spring and summer period is considered, the flows that took place during the spring period being modeled were considerably less than other years. We also used historical water transit times from 2011, 2009, and 2010 for

Table 2.2: PITPH and WTT values used for each spill and flow level.

			No breach		Breach	
Scenario	Spill level	Flow[1]	PITPH	WTT	PITPH	WTT
1	BIOP	High	2.99	13	1.38	7.8
2	BIOP	Average	3.06	16	1.48	9.8
3	BIOP	Low	1.95	26	1.14	14.7
4	115%/120%	High	2.37	13	1.16	7.8
5	115%/120%	Average	2.16	16	1.07	9.8
6	115%/120%	Low	0.87	26	0.64	14.7
7	120%	High	2.12	13	1.18	7.8
8	120%	Average	1.88	16	1.11	9.8
9	120%	Low	0.80	26	0.66	14.7
10	125%	High	1.01	13	0.57	7.8
11	125%	Average	0.44	16	0.14	9.8
12	125%	Low	0.28	26	0.18	14.7

[1] Flow were assumed to correspond to observed years
High=2011, Average=2009, Low=2010

the high, average, and low flow scenarios. The breach scenarios involved assuming the lower four Columbia dams continued to operate at the proposed TDG spill levels, but compensating for the fact that the four breached dams no longer contributed to powerhouse passage rates, and that the absence of four reservoirs decreases water travel time. The resulting values are in Table 2.2 and are displayed in Figure 2.2. Since the future projections lack the historical record of environmental conditions that existed during the statistical model fitting, time series of environmental variables need to be provided as model inputs. These inputs include: powerhouse passage (PITPH) water transit time (WTT) from Table 2.2, PDO, upwelling (UPW), harvest rates, proportion transported, and conversion rates. Transport was set at 20% for all future years of non-breach scenarios. The choice Breach scenarios set transportation to 0%, since collection facilities would no longer exist. Specific variable derivation methods are described below.

PITPH The prospective simulations use powerhouse passage index values predicted for each of the twelve spill scenarios. PITPH values were produced using an estimate obtained from a statistical fitting of passage rates at known spill levels and known flow levels. Historical passage rates derived from PIT tag data were compared to flow and spill data to estimate the effectiveness of spill levels across a range of flow levels for each project. The cumulative powerhouse passage rate PITPH was obtained by summing the individual project rates. A powerhouse passage index specific to a combination of spill alternatives and flows was used for all future years, e.g., a BiOp spill at low flow would yield a value of PITPH, which would be assumed every year into the future. The methods to obtain these values are discussed in Appendix J of McCann et al. (2015). Breach scenarios subtracted the contributions of LGR, LGS, LMN, and IHR from PITPH when evaluated at breached flow levels.

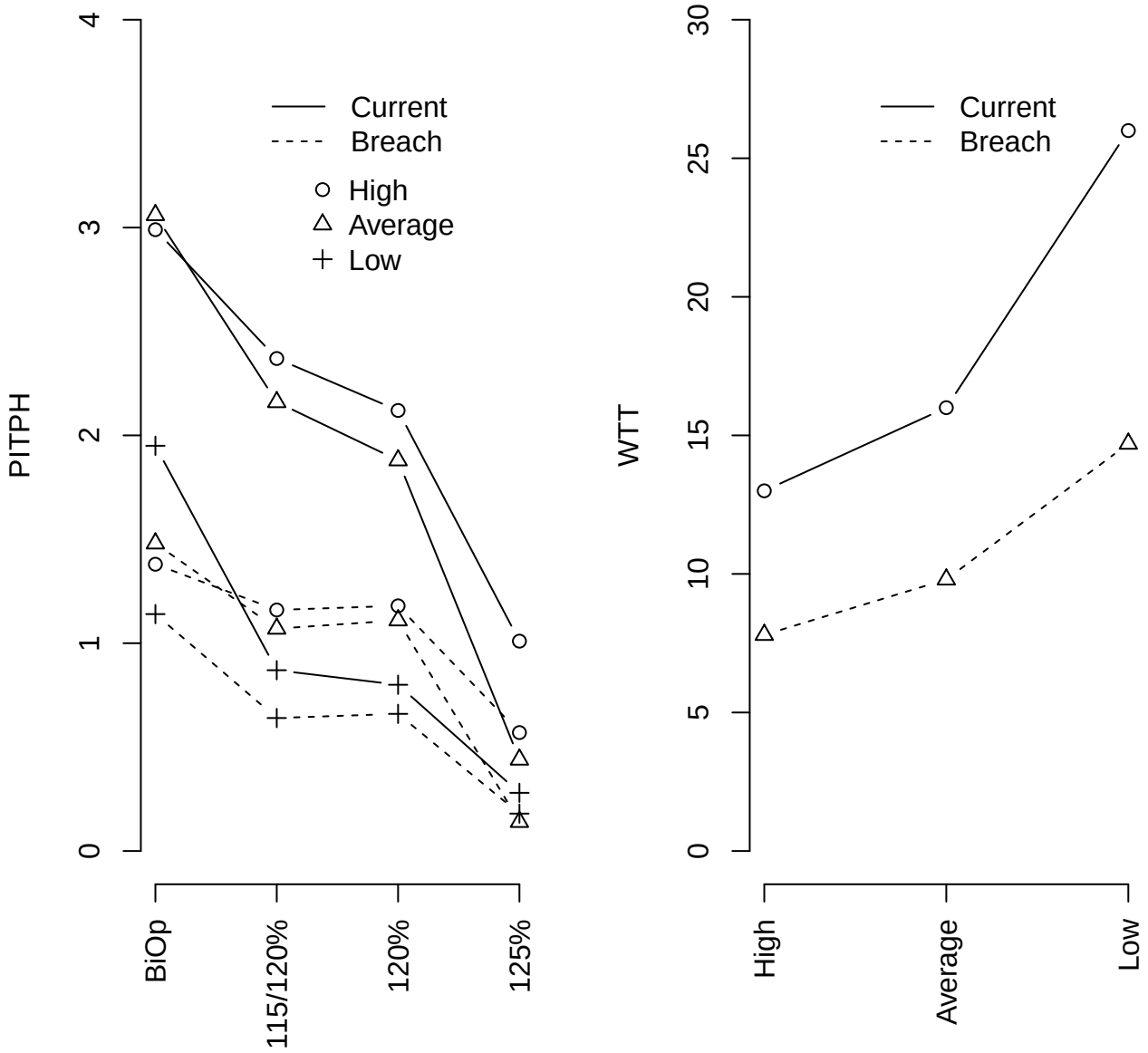

Figure 2.2: PITPH (left) and WTT (right) values for breached and non-breached scenarios.

WTT We used the water transit times calculated from historical flow, spill and reservoir volumes in 2011, 2009, and 2010 to represent WTT in high flow, average flow, and low flow. Breach scenarios were re-evaluated using transit times where reservoir volumes between IHR and LGR were based on tailrace elevations 90-100 ft below current minimum operating pool elevations.

PDO The Pacific Decadal Oscillation is a statistical calculation of oceanographic conditions that does not have a mechanism for prospective prediction, but the historical record can be described as a temporally autocorrelated time series. In order to simulate future population trends in relation to the PDO effect that was estimate in the statistical fitting, something other than an average value needs to be used, otherwise none of the inter-annual variability in its effect on ocean survival will be simulated. To produce a "PDO-like" time series we note that the PDO is normalized and roughly generates decadal cycles, but the predominant factor relevant to producing simulated future time series is that they vary from year to year, reach similar peaks and valleys to the historical record, and sustain increases and decreases predominantly for about 5 years before reversing direction. Ultimately, a simulated PDO need only produce a cyclical trend similar in frequency and magnitude to the PDO. We simulate PDO time series by creating a time series of random draws from a normal distribution $\epsilon_t \sim N(0,1)$. We then generate an AR(1) autocorrelation sequence, setting $\text{PDO}_1 = \epsilon_1$, and $\text{PDO}_t = 0.5\text{PDO}_{t-1} + 0.7\epsilon_t$ for $t \in (2, n)$. We then normalized the simulated PDO index to ensure the range of values was on the same scale as the empirical PDO.

UPW The upwelling index has no cyclical trend, nor is it correlated with the PDO, nor does it have a discernible temporal trend. To generate a future time series, we simply sampled the historical time series at random.

Harvest Historical harvest rates of Snake River Spring Chinook have varied from as high as 70% in the late 1960's to under 10% in recent years. Those ranges of total exploitation rates are a combination of sequential harvests in commercial and sport sectors in the lower Columbia, Zone 6 harvest, tributary harvests, and brood stock removal. Regulations at current return abundances call for lower river and Zone 6 rates not to exceed 17%. Since we are simulating population recovery potential, return abundances can be expected to increase if management scenarios are effective. We therefore modeled harvest rates to increase as return abundances increase. We modeled the harvest rate to increase asymptotically to 40%, and to reach 20% at an aggregate run abundance of 5000 for all populations.

Conversion Rate Conversion rates represent adult losses net of harvest, e.g., a conversion rate of 0.5 means that 2 adults would need to return to the mouth of the Columbia so that 1 adult could make it to the spawning ground. Those losses represent all factors not related to harvest, including predation loss, pre-spawn mortality, adult passage related mortality, and other causes. In recent years, conversion rates have been fairly high, and historically they were comparatively low because less passage infrastructure was in place. In an attempt to capture the variability, but contain the rate in the range of values of recent years where passage infrastructure is more representative of future conversion rates, we drew values at random from the most recent 20 years of conversions rates, which produced simulated future time series of conversion rates in the range of 60% to nearly 100%. To approximate

the effect of breach, we assumed that four fewer dams would result in a 50% improvement in upstream mortality arising from dam passage, i.e., λ_{Breach} = 1.0 - 0.5(1-λ).

Each prospective simulation draws upon several things: 1. the underlying parameters that predict survival in relation to environmental conditions, 2. the projected environmental conditions, and 3. the alterations to underlying conditions (i.e., TDG level spill on PITPH and WTT for breach and non-breach) that make up the basis for an alternative management scenario. In the hydrosystem, those are the four spill alternatives evaluated under three flow and breach conditions. In freshwater, the alterations are presumed levels of productivity or capacity that could be achieved via habitat improvements. Prospective simulations can capture all combinations of these alterations to the full life cycle, and represent the predicted outcomes in terms of the predicted uncertainty that arises from the underlying uncertainty in parameter estimates.

Alternative Treatment Evaluation

The MCMC simulations build a sequence of parameter vectors by generating values at random, and accepting or rejecting randomly generated vectors in proportion to the relative likelihoods of predicting empirical data. The sequence building proposes a potential improvement to the fit with a randomly generate alternative parameter vector. The proposed new vector is accepted or rejected based on relative likelihoods. Eventually, a sequence of a desired number of samples is produced, which contains many combinations of parameters. The more likely combinations appear in the chain more frequently than the less likely ones, so if we draw randomly from the posterior chain thousands of times, we tend to draw the more likely ones more often. Each draw produces a simulated population trend that is different. Drawing and predicting thousands of times produces thousands of different population predictions, and the predictions themselves take on distributions. As a result, we can simulate a population trend where the conditions can be the same as historical conditions, i.e., similar environmental and anthropogenic conditions, or we can simulate a trend where we manipulate key underlying aspects of the system to mimic a condition of interest. The result of simulating contrasting scenarios provides a sense of how much change to overall system behavior can be expected from relative changes to underlying conditions. Those can either be natural biotic (change in food or competitors), natural abiotic (changes to climate and the environment), or anthropogenic (changes in exploitation or hydrosystem operations).

We used the posterior densities (MCMC parameter vectors) as the basis for simulating ranges of possible population trends when alternative spill levels are assumed under the three flow levels. The Alternative Treatment Evaluation (ATE) uses 1,000 samples of parameter values drawn from the MCMC posterior chain to simulate future population trends until 2050. It initializes population projections with empirical spawners from 2010-2013 and parameters from a posterior sample, and uses simulated conditions in future years (PITPH, WTT, PDO, UPW, TRANS, commercial and Zone 6 harvest, and upstream migration survival) to predict subsequent spawners of each age in years 2015-2050. Predicted returning spawners in each year after the first complete brood year returns in 2015 are used to predict successive generations, meaning the model spawns new generations from predicted returns and does not require empirical spawners past 2013.

For our ATE analysis, we posed two questions: 1. What is the potential for changes to spawning and rearing productivity to increase long-term adult return abundance?, and 2. What is the potential for changes to hydrosystem operations (TDG spill levels for breach and non-breach scenarios) to increase average long-term adult return abundance and SARs? To address these questions, we simulated prospective population trends and looked at average long-term return abundances and SARs. We simulated population trends 1,000 times by drawing parameter values randomly from the posterior chain saved from the MCMC simulations. 1,000 simulated population trends were produced for each of the twelve spill scenarios, which produces 1,000 population trends for each population, and therefore an average return abundance for each of the six population for each of the twelve scenarios. Comparing relative return abundance averages provides an indication of the relative benefits of the spill scenarios to each of the populations. We simulated for 35 years and used the last 10 years of complete brood returns to evaluate performance. We report averages over the period 2036 to 2045.

We also examined the potential for the relative benefits of spill scenarios to differ among populations. To examine the effect of different spill levels, we simulated average long-term abundances and calculated the average recruitment abundance and SARs from each population . We used the following logic for the breach and non-breach scenarios:

1. Start with scenario $j = 1$
2. Get PITPH$_j$ and WTT$_j$ for scenario j from Table 2.2
3. Set PITPH$_t$ = PITPH$_j$ for all years t
4. Set WTT$_t$ = WTT$_j$ for all years t
5. Draw a set of parameters Θ_i from the posterior chain
6. Simulate population trends from initial spawning abundances and calculate $\bar{R}_{p,j,i}$ for each population p, where $\bar{R}_{p,j,i}$ is the average recruitment to the spawning ground indexed by brood year, and averaged over the last ten years simulated.
7. Calculate $S\bar{A}R_{p,j,i}$ for each population p, where $S\bar{A}R_{p,j,i}$ is the average SAR in the last ten years simulated.
8. Return to step 5 until i = 1,000 draws of Θ_i
9. Return to step 1 and set j = j + 1 until the 12th scenario
10. Use the 6 x 12 x 1,000 $\bar{R}_{p,j,i}$ and $S\bar{A}R_{p,j,i}$ arrays to show the quantile ranges of predicted average abundance and SARs from 2036 to 2045 for each population p of each spill and breach scenario j.

To examine the potential effect of changes in productivity, we simulated $\bar{R}_{p,j,i}$ at four different spill levels across a productivity range of 50-250 smolts per spawner. Simulations were evaluated at average flow conditions only. Similar predictions at high or low flows would be relative to $\bar{R}_{p,j,i}$s evaluated at the MLE of productivity (i.e., $\bar{R}_{p,j,i}$ would be higher for low flows and lower for high flows). We stepped through the following procedure:

1. Get PITPH$_j$ and WTT$_j$ for scenario j = 2 from Table 2.2
2. Set PITPH$_t$ = PITPH$_j$ for all years t
3. Set WTT$_t$ = WTT$_j$ for all years t
4. Set a_p = 50 for each of the 6 population productivities and replace the value drawn from the chain with a_p.

5. Draw a set of parameters Θ_i from the posterior chain.
6. Simulate population trends from initial spawning abundances and calculate $\bar{R}_{p,j,i}$ for each population p, where $\bar{R}_{p,j,i}$ is the average recruitment to the spawning ground indexed by brood year, and averaged over the last ten years simulated, where i is the iteration, and j is the level of a_p.
7. Go back to step 5 and repeat for 1,000 draws of Θ_i.
8. Go back to step 4 using a_p+10 until all 21 values the range $a_p \in$ [50-250] have been simulated.
9. Return to step 1 and set j equal to scenarios 5, 8, and 11
10. Use the 6 x 21 x 1,000 $\bar{R}_{p,j,i}$ array to show the quantile range of predicted average abundance from 2036 to 2045 for each population p of each level j.

To examine the potential effect of changes in capacity, we used a capacity range of 5000-50000 smolts, and simulated $\bar{R}_{p,j,i}$ at four different spill levels evaluated at average flow conditions. We stepped through the following procedure:

1. Get PITPH$_j$ and WTT$_j$ for scenario j = 2 from Table 2.2
2. Set PITPH$_t$ = PITPH$_j$ for all years t
3. Set WTT$_t$ = WTT$_j$ for all years t
4. Set b_p = 5000 for each of the 6 population productivities and replace the value drawn from the chain with b_p.
5. Draw a set of parameters Θ_i from the posterior chain.
6. Simulate population trends from initial spawning abundances and calculate $\bar{R}_{p,j,i}$ for each population p, where $\bar{R}_{p,j,i}$ is the average recruitment to the spawning ground indexed by brood year, and averaged over the last ten years simulated, where i is the iteration, and j is the level of a_p.
7. Go back to step 5 using b_p+5000 until all 10 values the range $b_p \in$ [5000-50000] have been simulated.
8. Go back to step 4 and repeat for 1,000 draws of Θ_i.
9. Return to step 1 and set j equal to scenarios 5, 8, and 11
10. Use the 6 x 21 x 1,000 $\bar{R}_{p,j,i}$ array to show the quantile range of predicted average abundance from 2036 to 2045 for each population p of each level j.

Results

We fit the life cycle model to juvenile abundance data, adult abundance data, in-river survival, and SARs using likelihood Equations [2.15]-[2.19]. We examined possible model combinations of including or excluding PITPH and WTT for predicting s_R with PITPH and WTT, and for predicting s_H and s_T with PDO, UPW, and PITPH (only s_H). Using AIC comparisons to evaluate the top fitting model, the best fit occurred when PITPH and WTT were both included in the prediction of s_R, when PDO, UPW, and PITPH were included in the prediction of s_H, and when PDO and UPW were included in the prediction of s_T. This implies that the overall SAR has an in-river survival component that is affected by PITPH as well as an ocean survival that is affected by PITPH, i.e., hydrosystem effects predict variability in early ocean survival (a.k.a: delayed mortality). The model with the lowest AIC was used as the basis for doing MCMC

simulations and performing the ATE analysis. We did not find a significant interaction between PITPH and WTT.

Rather than present the point estimates of each variable, we present the posterior distributions from samples of the MCMC chain (see Figure 2.3). The histograms show the relative frequency of parameter draws from the posterior density when 1,000 samples are drawn at random from an MCMC simulation chain of one million estimates after a burn-in of one hundred thousand samples. Means and standard deviations are shown above each histogram. The MCMC plots illustrate the relative probability of parameter values. Narrower ranges imply less variation around the mode of the density. In general, parameter estimation was bounded to restrict the search algorithm to look within biologically plausible ranges. In the case of productivity parameters like the Imnaha and Minam productivities, the estimates indicate that productivities might be higher than the allowed range, but the productivity was bounded to search between about 20 and 1000 smolts per spawner (actually, between 3 and 7 in log-space), which should be broad enough to fit any spawner to smolt relationship (approximately 0.4-40% egg to smolt survival). Possible explanations for this are under-reported spawners, strong hatchery influence on spawning grounds, or over reported smolt abundance, all of which would elevate apparent smolts per spawner. Figure 2.4 shows the correlations between parameters when the joint posterior is drawn at random. Positive correlations between random draws imply that when one parameter improves the likelihood, the other does so as well, meaning that the underlying effect is not independent. It is not uncommon for environmental variables to have an underlying signal correlation (eg: flow and temperature), but unless the correlation is very high, it is still possible that the improvement in fit is worth the correlation redundancy. The correlations do not appear to be very high.

Figure 2.5 shows the correlations between environmental indices and predicted survivals and SARs. Predicted $s_{R,t}$ is negatively correlated with PITPH and WTT. There are strong correlations between PITPH and both $s_{R,t}$ and $s_{H,t}$. $s_{T,t}$ shows a very strong correlation with PDO and also with UPW – stronger than the correlation between $s_{H,t}$ and UPW.

By separating hydro passage into transported and in-river migrants, we were able to further examine the effect of transportation. Predicted $s_{H,t}$ and $s_{T,t}$ are shown in Figure 2.6, and $s_{T,t}$ is consistently predicted to be lower than $s_{H,t}$. The predicted ocean survival of in-river migrants are shown along with empirical data as well. The predicted C0 SAR in Figure 2.6 is higher than the empirical C0 SAR derived from the aggregate of the Snake River PIT tag data, possibly indicating that the Grande Ronde / Imnaha populations survive better than the Snake aggregate, but alternatively, this could be compensation for the fact that the predicted in-river survival is lower than the empirical trend in recent years. The Snake River aggregate SAR is composed of only approximately 35% Grande Ronde / Imnaha PIT tags. Figure 2.5 indicates that lower early ocean survival of transported fish may be attributable to the PDO, which is seen to have a higher correlation with $s_{T,t}$ than with $s_{H,t}$. The upwelling index is also only somewhat correlated with $s_{T,t}$, not with $s_{H,t}$. These two correlations suggest that transported fish are more sensitive to ocean conditions than in-river migrants.

The model fitting results are shown in Figures 2.7 and 2.8. Since all populations are forced to follow the same mainstem and ocean dynamics, yet do not experience the same FSR dynamics, we do not expect that all models fit their respective abundance data in the same way. CC and GR predicted recruits are negatively biased in the first half of of the time series. The remaining

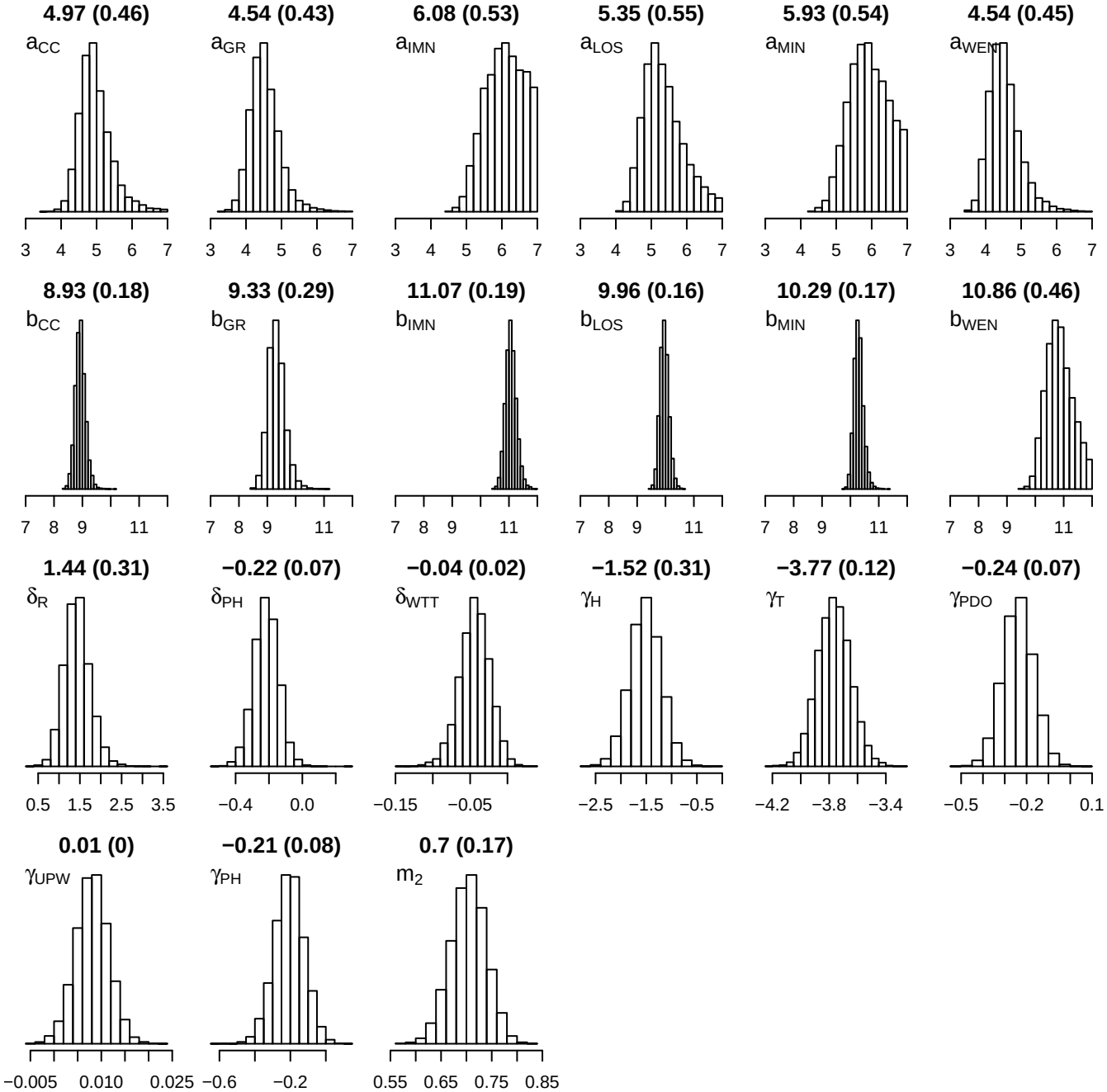

Figure 2.3: Posterior estimates of the model parameters for the model. Each histogram shows frequency of samples from parameter values coming from a Markov chain of length 1,000,000, sampled 1,000 times. Estimated means (and standard deviations) for each posterior sample appear at the top of each histogram. The top row contains the log productivities for CC, GR, IMN, LOS, MIN and WEN respectively. The second row contains log capacities for the same populations. The remaining posterior panels are labeled with corresponding symbols.

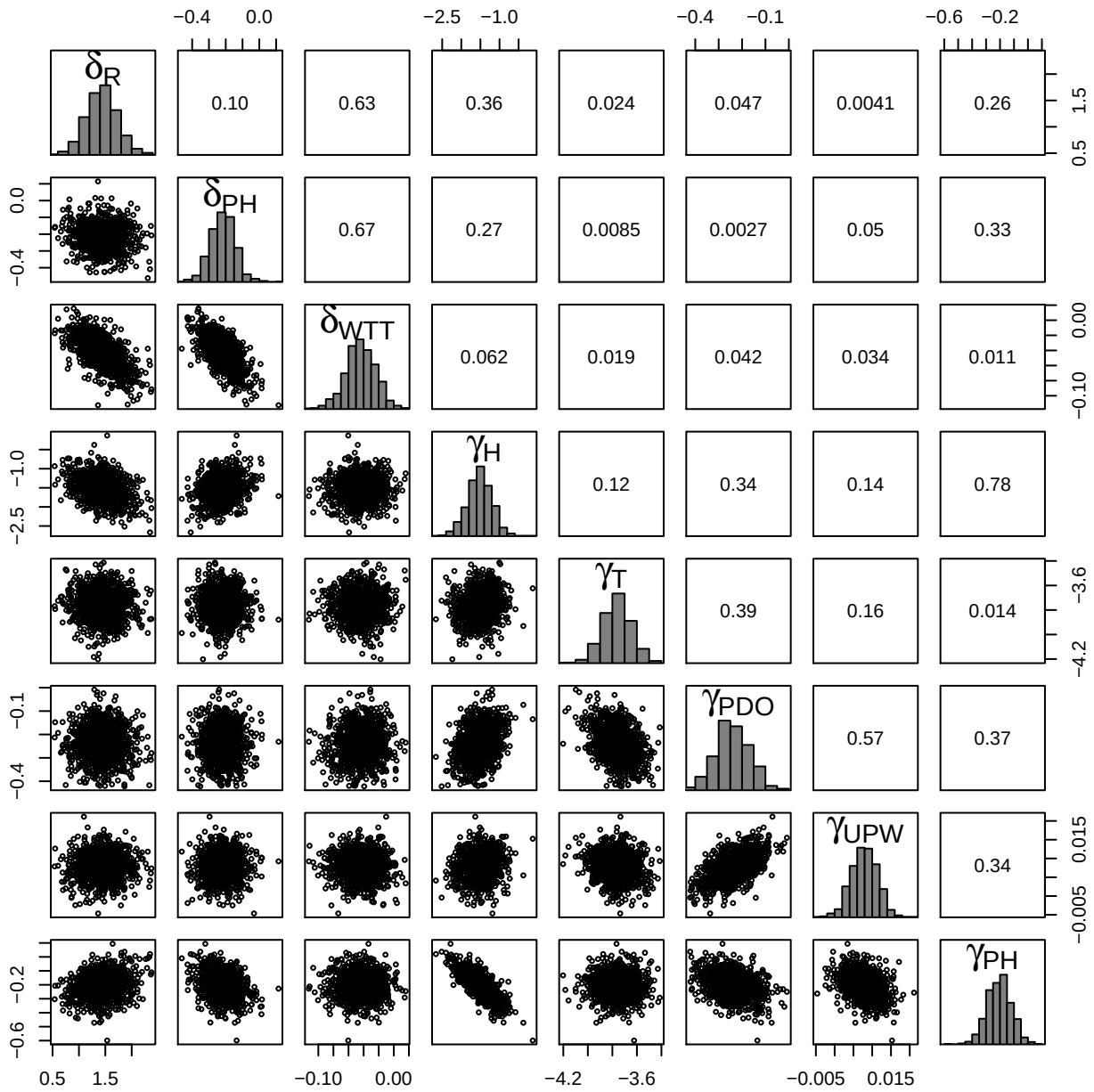

Figure 2.4: Correlation s of posterior draws from MCMC simulations. Plot shows correlations between key parameters predicting effect of environmental variables on survival rates.

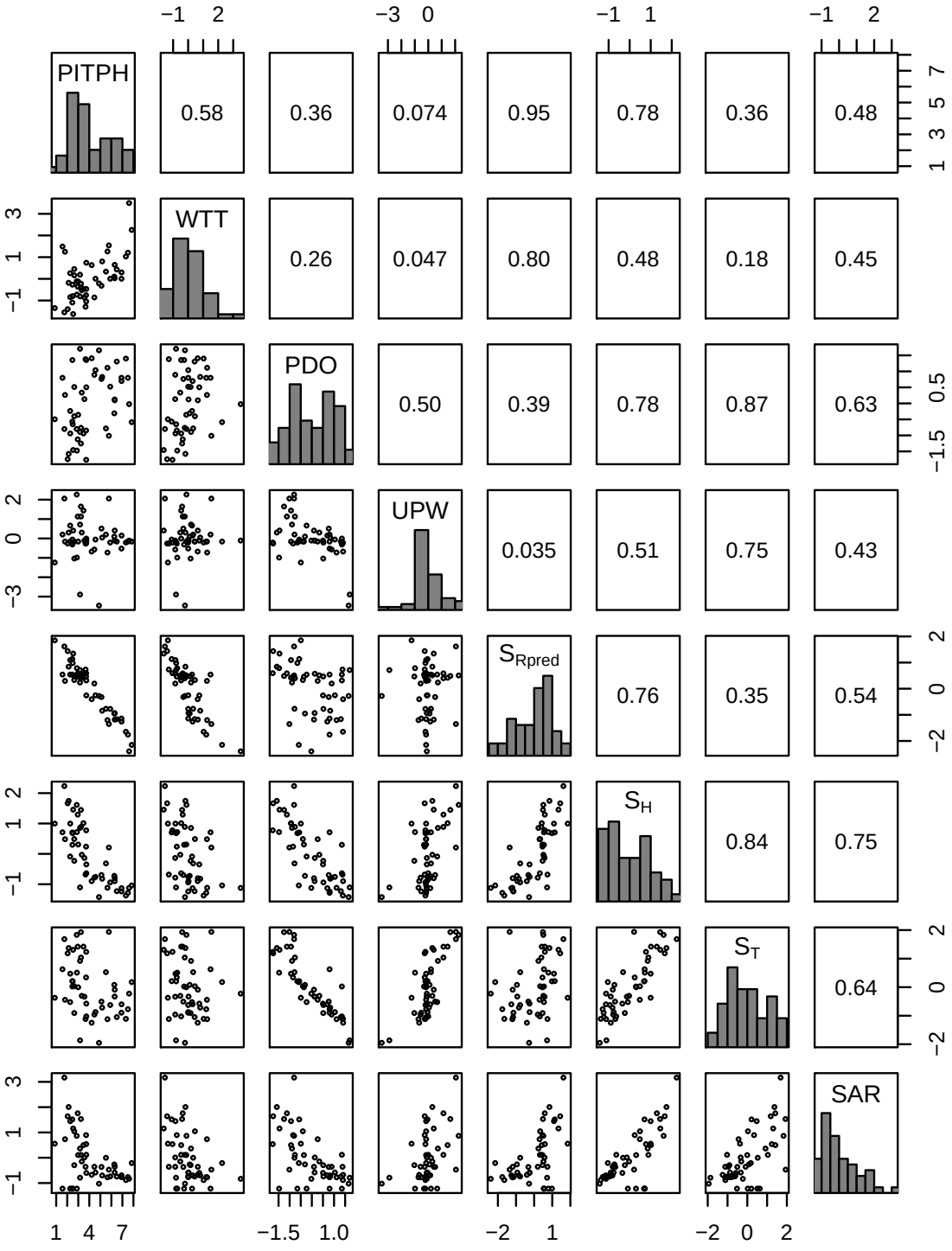

Figure 2.5: Correlations between estimated in-river, transported, and early ocean survival, and environmental indices. The lower diagonal shows the scatter plots between variables. The upper diagonal shows the correlation coefficients.

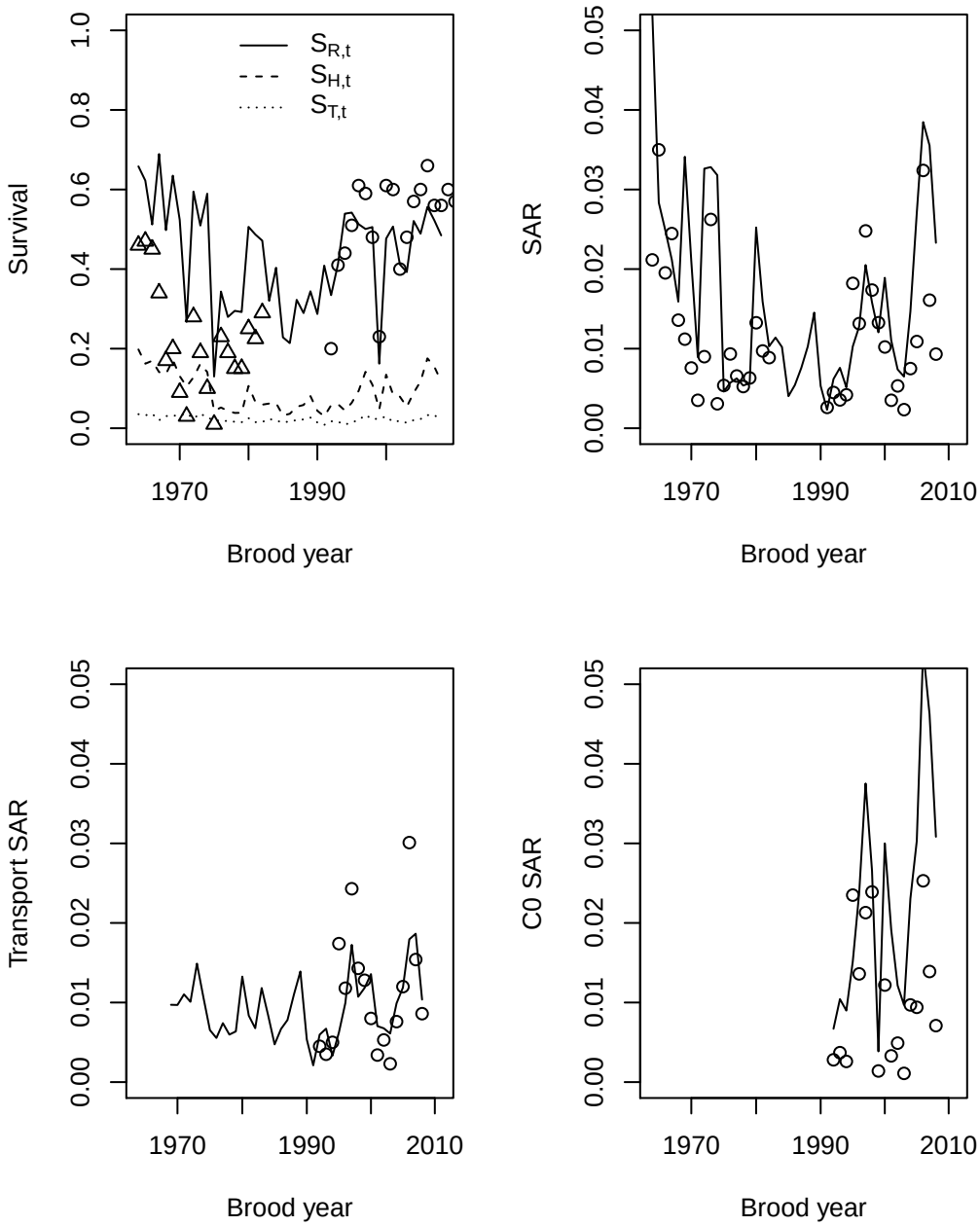

Figure 2.6: Upper left panel shows observed in-river survival (circles) and predicted in-river survival s_R, early ocean survival for in-river s_H migrants, and early ocean survival for transported fish s_T. Circles show the PIT tag derived estimates of in-river survival. Triangles show the pre 1985 migration year in-river survival rates from Williams et al. (2001) and Marmorek and Peters (1998). Upper right panel shows observed (circles) and predicted SAR (line). Lower left panel shows observed (circles) and predicted transport SAR (line). Lower right shows observed (circles) and predicted in-river (C0) SAR (line).

populations do not appear to have the same negative temporal bias in the same early time period, and overall the IMN, LOS, MIN, and WEN predicted population trends are consistent with empirical observations, i.e., a declining trend from the late 1960's until around 1990, then an increase. The smolts per spawner fit (Figure 2.8) shows density dependence in all four populations for which smolt data were available.

Figure 2.9 shows the relative average predicted in-river survival at breach and non-breach experimental spill and flow levels when evaluated across 1,000 draws from the posterior at scenario PITPH and WTT values. Breach scenarios predict in-river survivals between 65% and 75%, as opposed to non-breach spill predictions between 50% and 65%. Figure 2.10 shows the predicted average SARs for all six populations to LGA with and without dam breach. The average SARs are adjusted for harvest, meaning that the rate assumes adult returns to LGR after harvest and adult interdam losses. Interdam losses are assumed to be lower with breach (50% lower total dam passage mortality). The SARs reflect the simulated harvest where the harvest rate increases asymptotically to a maximum of 40%, attaining a rate of 20% at 5000 total Grand Ronde / Imnaha returns to the mouth. The SAR can be viewed as more than a smolt to spawner ratio, because it also captures what would otherwise have been considered tributary harvest and broodstock removals. Spilling to higher TDG levels is predicted to increase SARs in both breached and unbreached scenarios.With dam breaching, there is approximately a two fold increase in the SAR compared to scenarios without breach.

Figures 2.11 and 2.12 show the relative performance of the twelve spill scenarios across all six populations. The three assumed flow levels are represented in clusters of three (high, average, and low flow) in each four of the BiOp, 115%/120%, 120%, and 125% spill levels. The general pattern for the non-breach case is that increasing the spill level produces an increase in the total average number of returning spawners. The breach scenario shows abundances reaching non-breach 125% spill levels at BiOp level spills. The shaded boxes represent the 25% to 50% quartiles of average adult return abundances ($\bar{R}$) from a sample of 1,000 simulations drawing parameters from the joint posterior distribution of parameters.

Relative performances of simulated spill scenarios can also be evaluated using the ratio of the median of long-term average return abundance to the BiOp level spill predicted long-term return abundance at one of the flow levels. Figure 2.13 shows the relative median $\bar{R}$ (of the 1,000 predicted $\bar{R}$s) at a given breached or non-breached spill level for each flow level compared to the median BiOp level spill at average flow in a non-breached system. There is nearly a 50% gain from BiOp to 115%/120% for all flow levels. This perspective illustrates what performance would look like if spill were increased relative to BiOp at average flow in an impounded system, and only if spill levels were sustained every year, and flows remained at the same level every year. The benefit of spill relative to each flow level's BiOp abundance prediction is shown for the non-breached scenarios in Figure 2.14 and for the breach scenarios in Figure 2.15. The prediction is that under non-breached conditions, relative abundances increase with spill to approximately 1.5 to 2.5 times the level expected at BiOp level spills for a given flow level. Under breached conditions, BiOp level spills predict return abundances 2-3 times higher than under non-breached conditions, and increasing spill to 125% only provides and additional 40% more abundance above that predicted by BiOp level spill under breached conditions.

Figures 2.16 and 2.17 show the effect of spilling alternatives under non-breach and breach

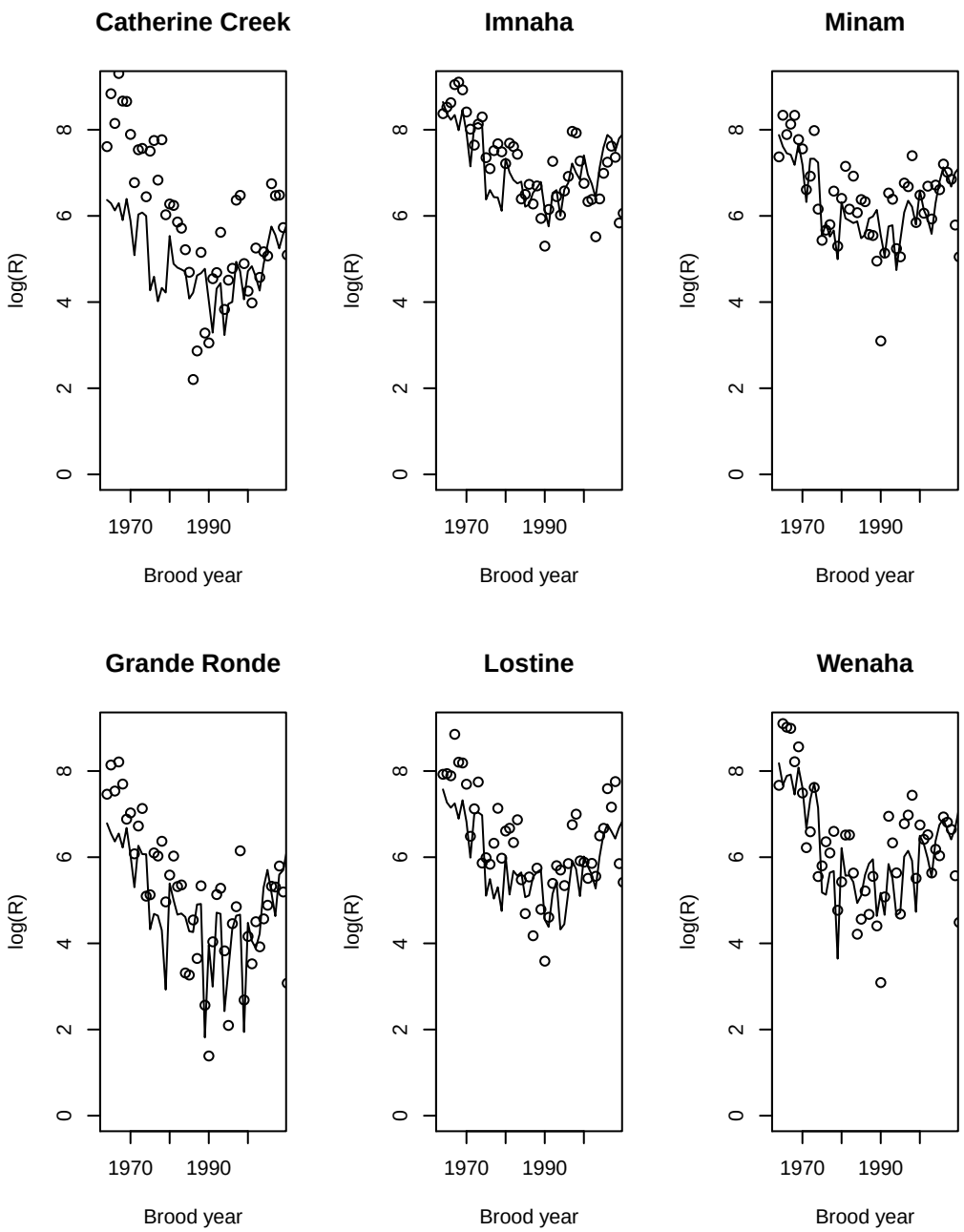

Figure 2.7: Observed (circles) and the predicted (line) recruits for each brood year.

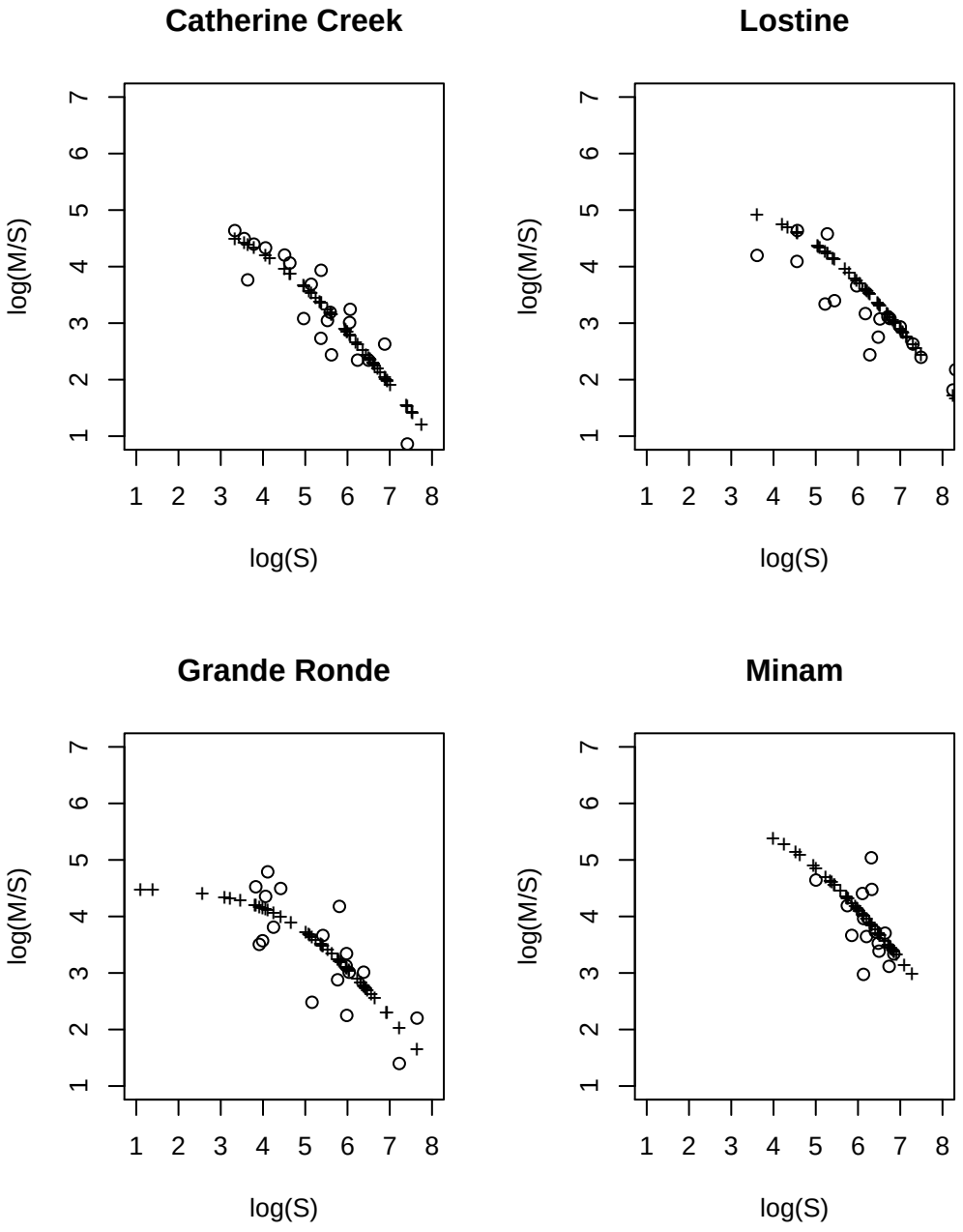

Figure 2.8: Observed (circles) and the predicted (plus symbols) smolts per spawner vs spawners.

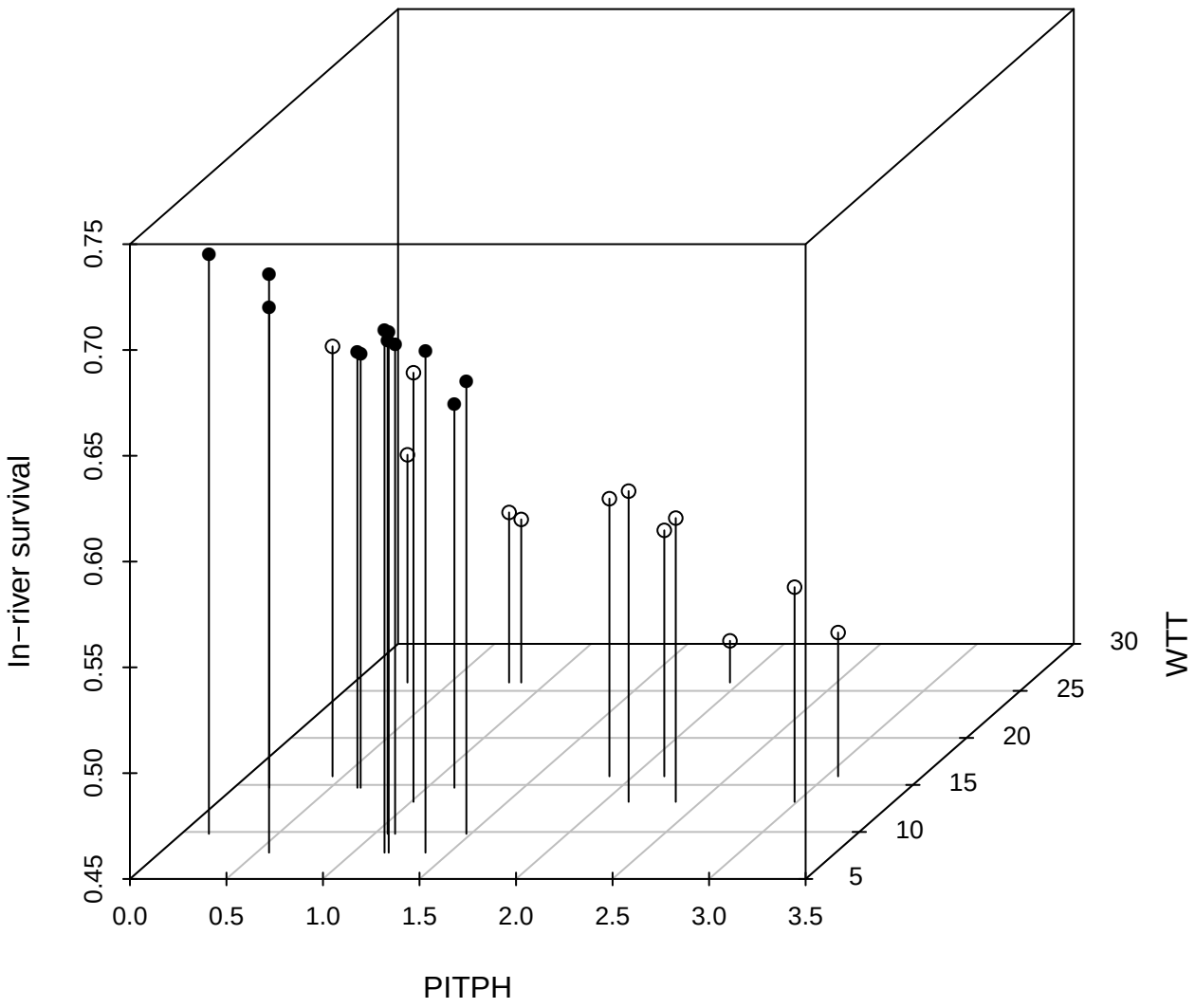

Figure 2.9: Relative predicted in-river survival at breach and non-breach experimental spill and flow levels. Open circles show predicted in-river survival at PITPH and WTT levels of non-breach scenarios. Closed circles show predicted in-river survival at PITPH and WTT levels of breach scenarios. Values shows are average of values predicted from 1,000 draws from the posterior.

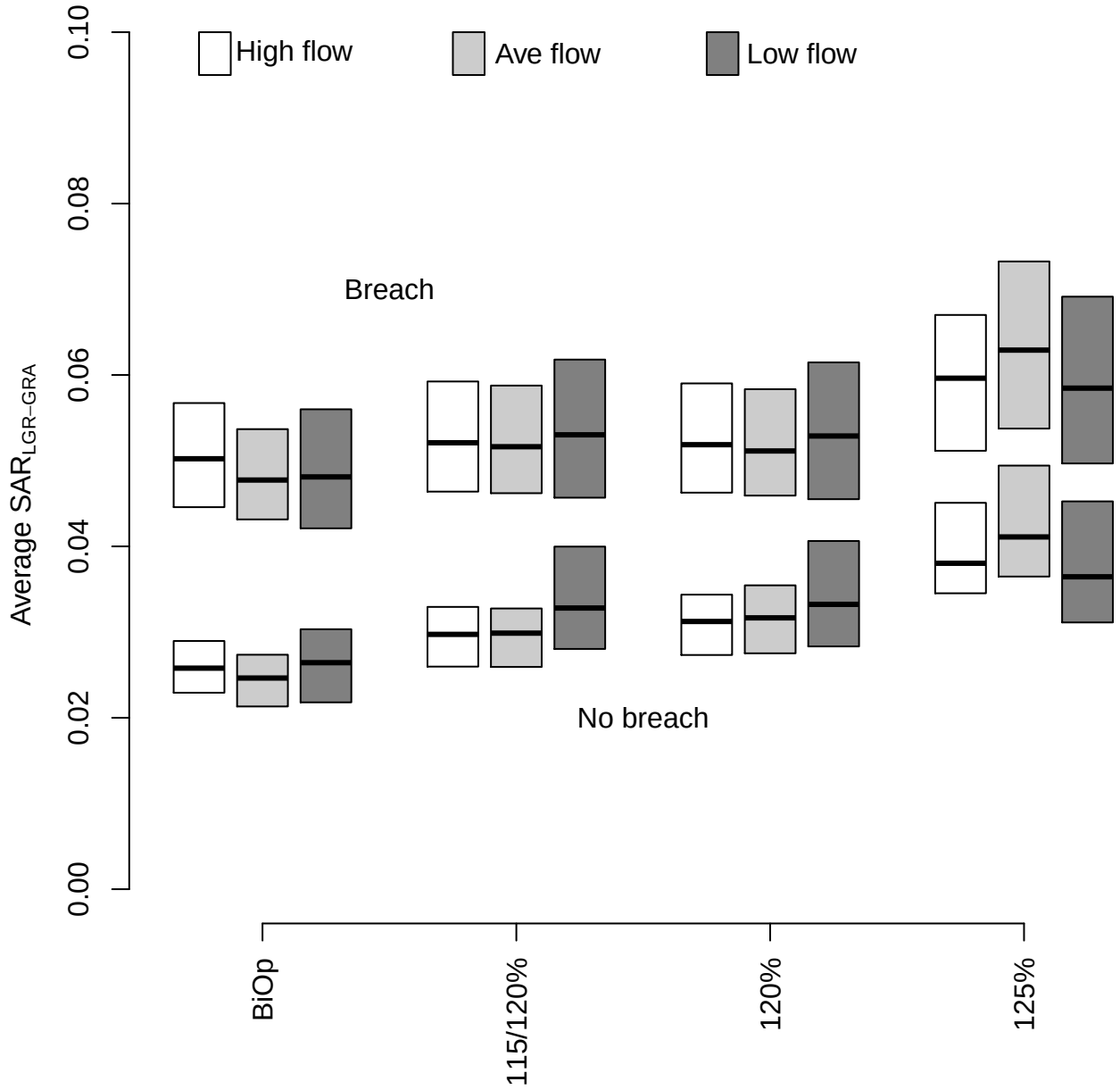

Figure 2.10: Sensitivity analysis of predicted long-term average SAR at LGR between 2036 and 2045 at all combinations of spill levels and flow levels. Each cluster of three bars represent high flow (white boxes), average flow (light grey boxes), and low flow (dark grey boxes). Boxes represent the 25%-75% quartiles. Median values are shown with dark horizontal lines inside boxes.

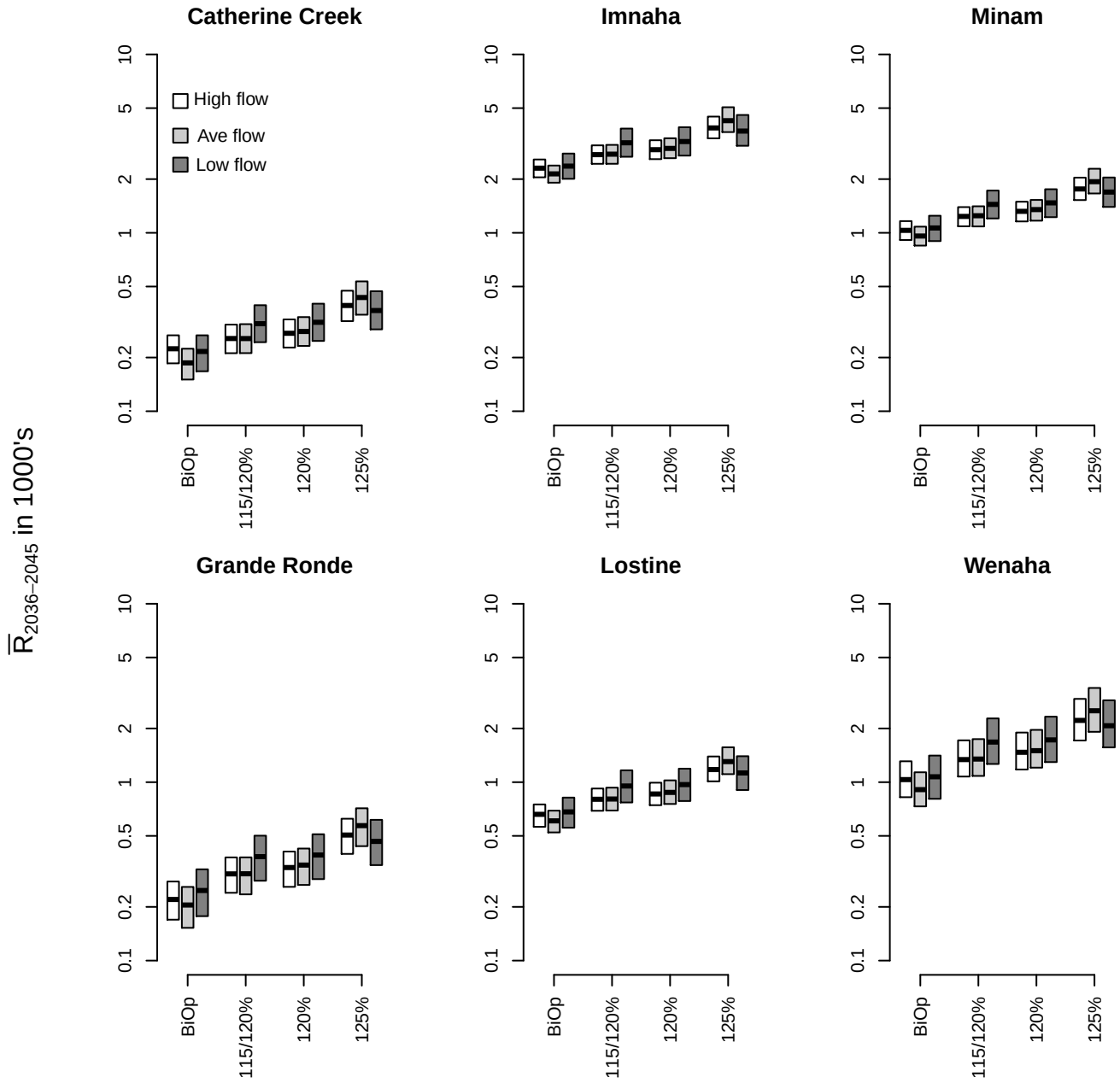

Figure 2.11: Sensitivity analysis of predicted long-term average predicted average abundance between 2036 and 2045 ($\bar{R}$ in log scale) at all non-breach combinations of spill levels and flow levels. Each cluster of three bars represent high flow (white boxes), average flow (light grey boxes), and low flow (dark grey boxes). Boxes represent the 25%-75% quartiles. Median values are shown with dark horizontal lines inside boxes.

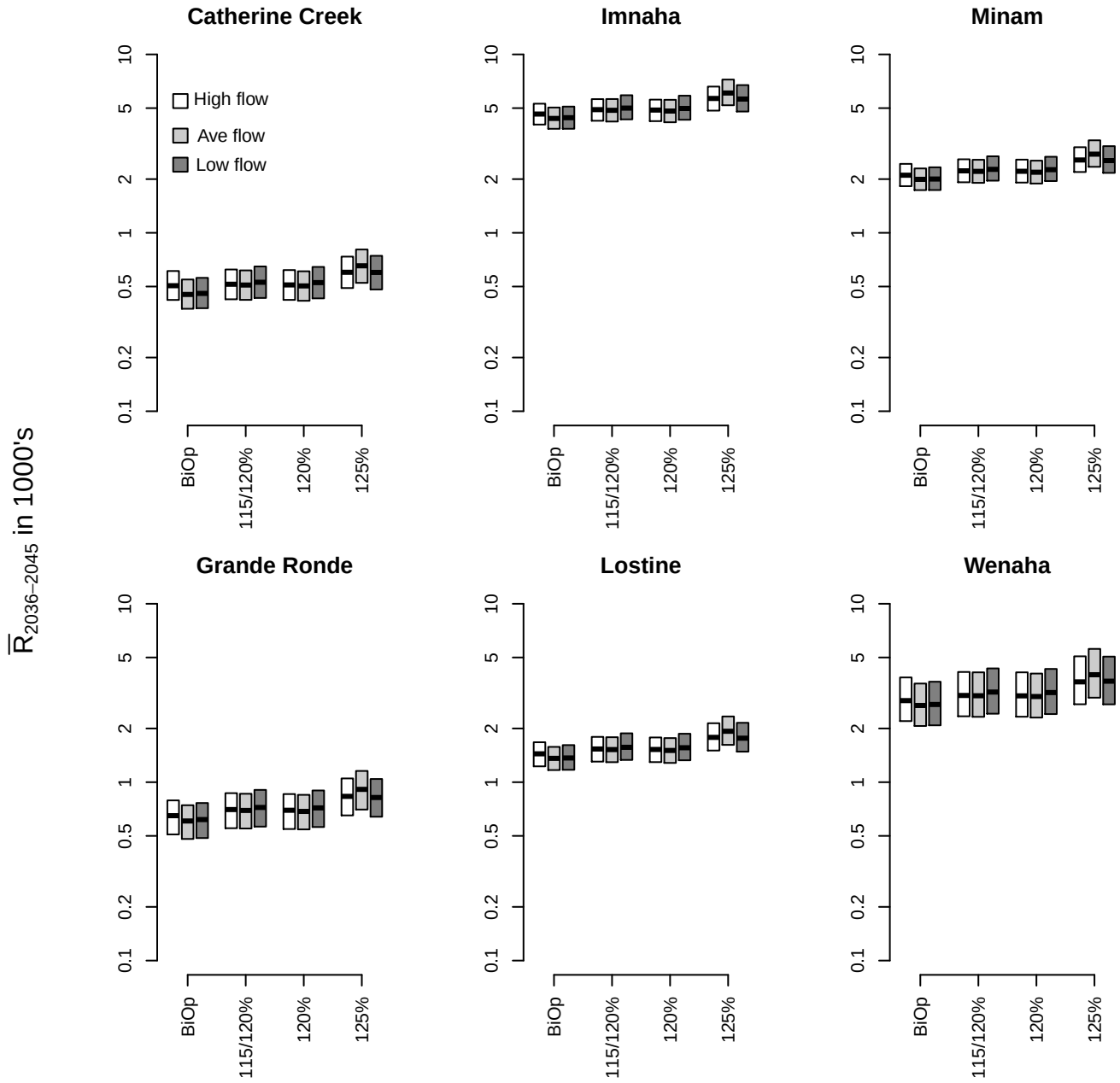

Figure 2.12: Sensitivity analysis of predicted long-term average predicted average abundance between 2036 and 2045 ($\bar{R}$ in log scale) at all breach combinations of spill levels and flow levels. Each cluster of three bars represent high flow (white boxes), average flow (light grey boxes), and low flow (dark grey boxes). Boxes represent the 25%-75% quartiles. Median values are shown with dark horizontal lines inside boxes.

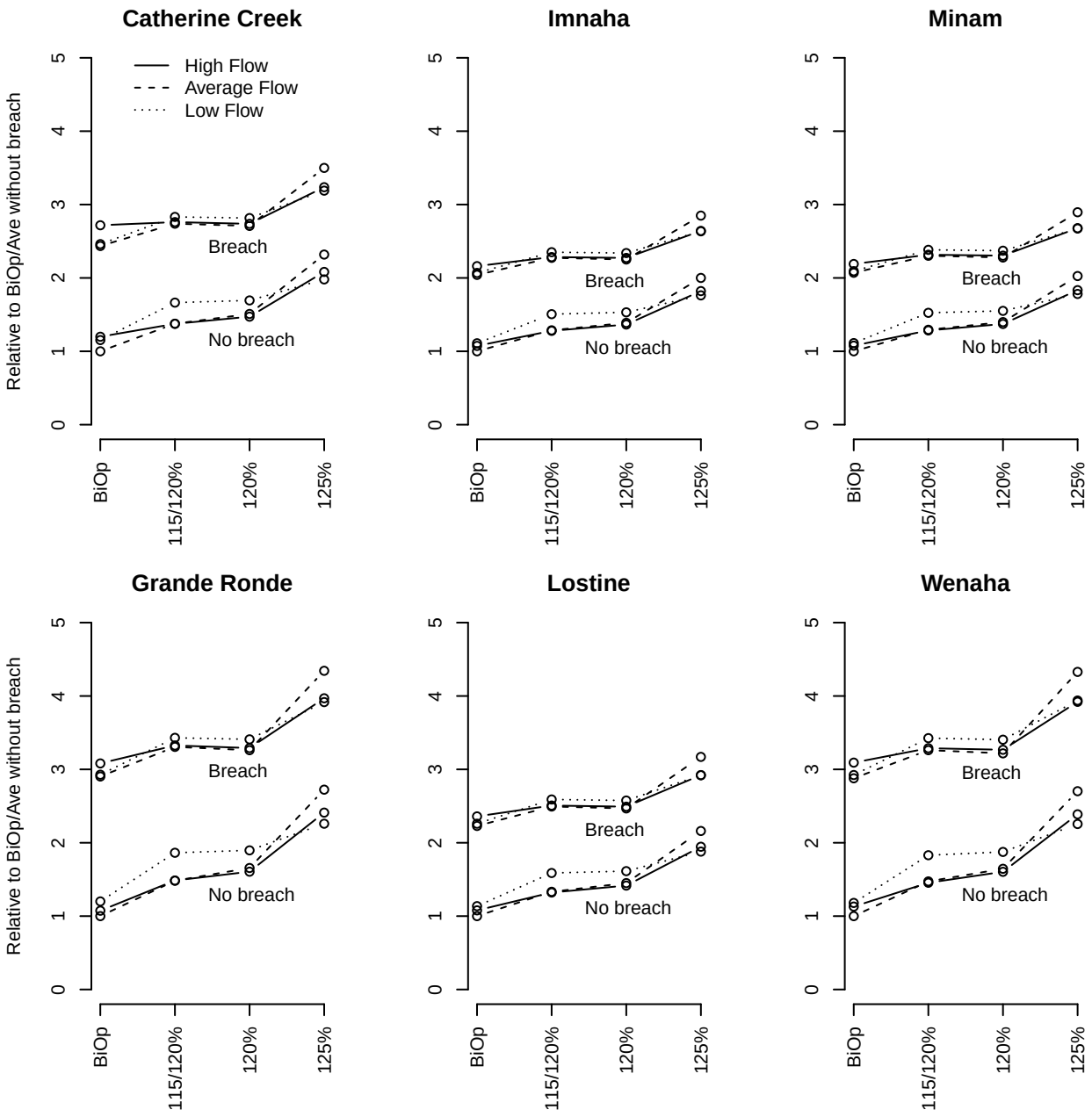

Figure 2.13: Sensitivity analysis of predicted non-breached and breached long-term average return abundance between 2036 and 2045 at each flow level when compared to non-breach BiOp spill at average flow

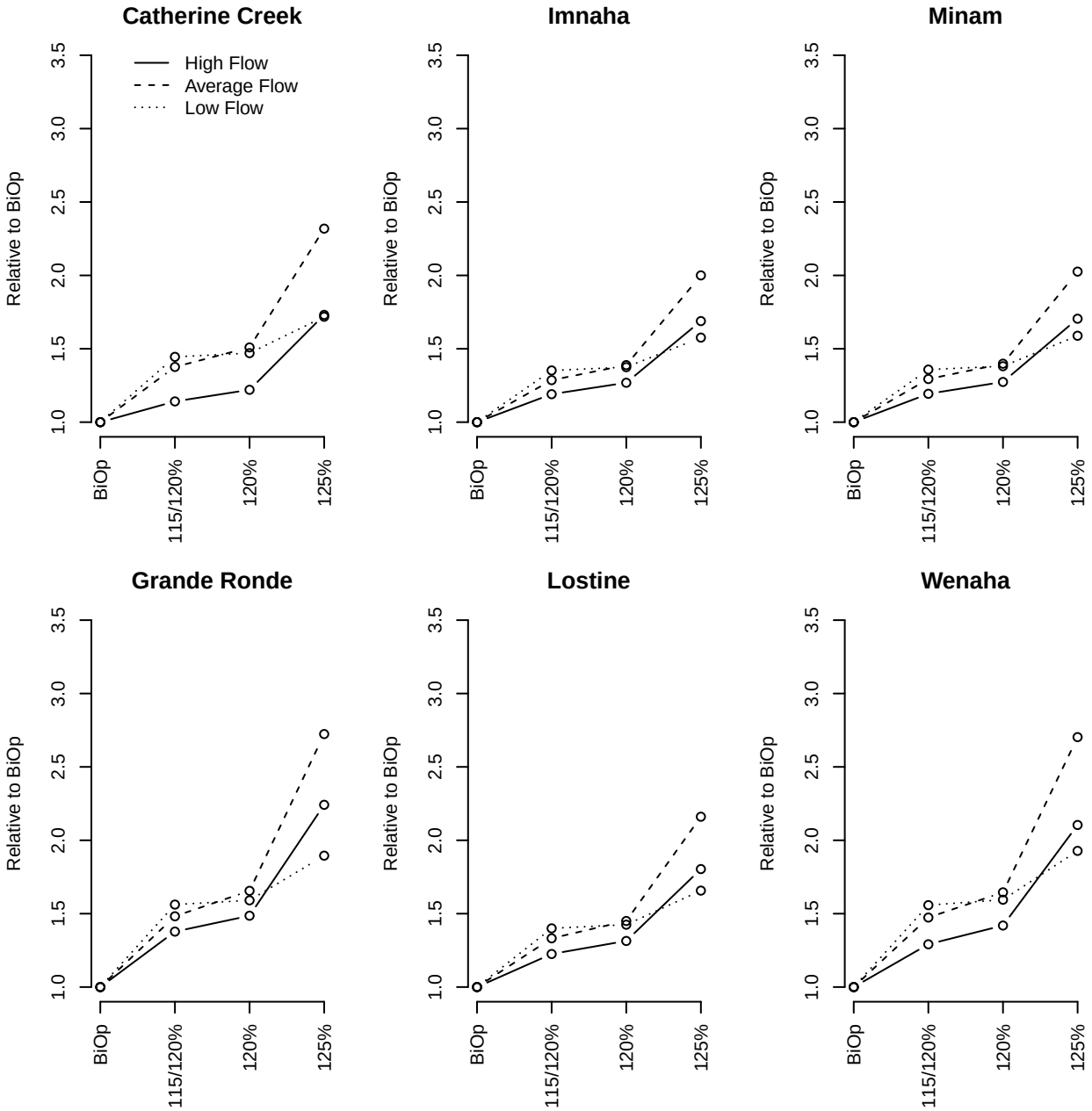

Figure 2.14: Sensitivity analysis of predicted non-breached long-term average return abundance between 2036 and 2045 at each flow level when compared to non-breach BiOp spill.

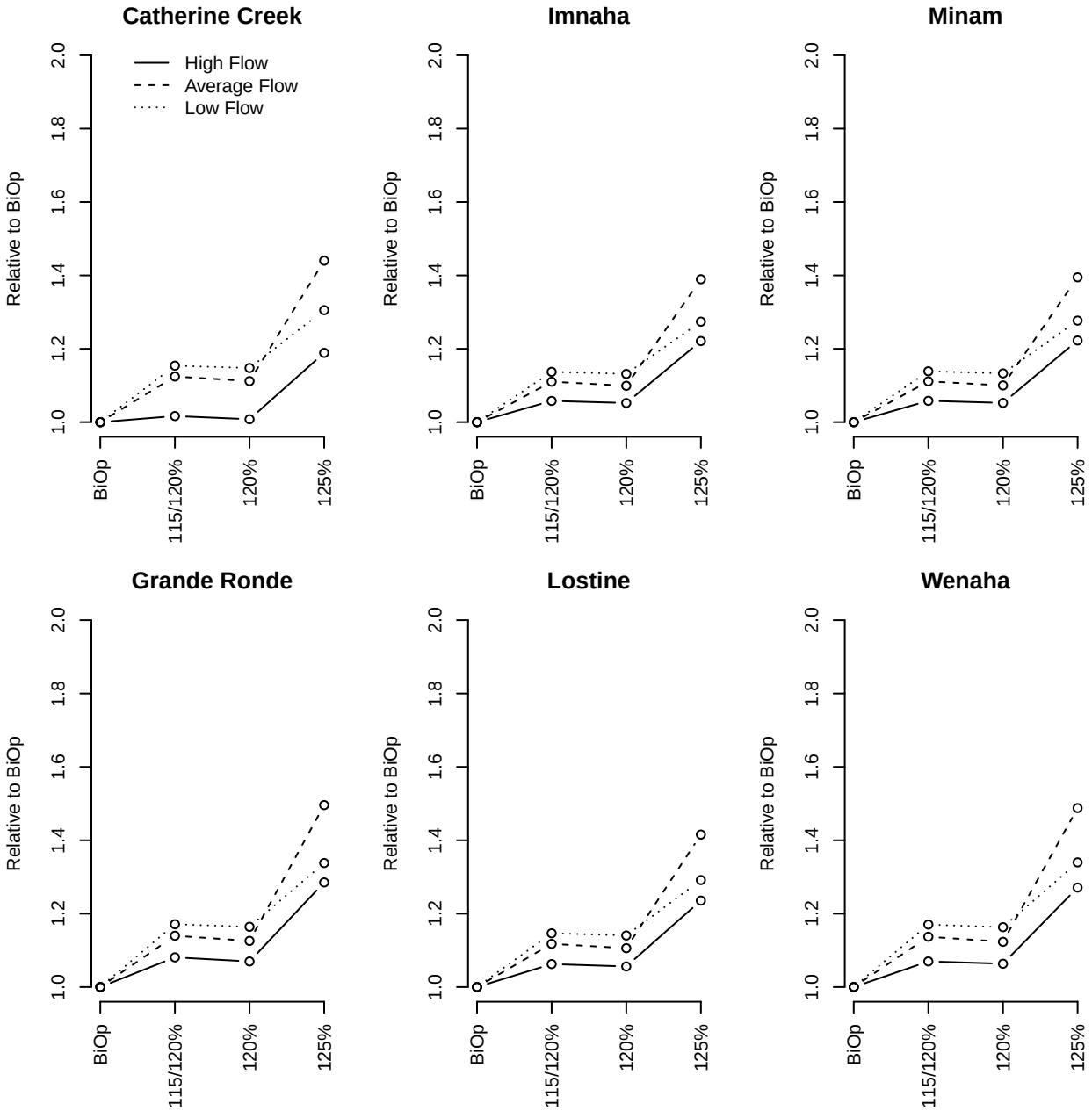

Figure 2.15: Sensitivity analysis of predicted breached long-term average return abundance between 2036 and 2045 at each flow level when compared to breach BiOp spill for each flow level.

conditions, but evaluated across a range of productivities for each population. Each line represents one of the four spill levels evaluated at average flows for each of the spill levels (BiOp, 115%/120%, 120%, and 125%). The lines represent the median predicted $\bar{R}$ from 1,000 simulations. The figure is intended to demonstrate the relative change in $\bar{R}$ across a range of productivities at four spill levels. The general pattern is that larger gains from increased spill are realized by populations that have high capacity (Imnaha and Wenaha), and that the gain is greater still if the productivity is high (Imnaha). Breach conditions predict higher returns because of higher overall lifecycle survivals arising from higher in-river survivals and overall SARs.

In all six population, there is a predicted increase in $\bar{R}$ if productivity is increased, but unless capacity is relatively high, the gains are not very significant. The Imnaha, Minam, and Wenaha have the highest capacities, and therefore predict larger gains in average abundance from increases in productivity. There are no cases where increasing freshwater productivity has more influence on $\bar{R}$ than increasing spill levels.

Figure 2.18 shows the effect of spilling under non-breach and breach conditions, but evaluated across a range of capacities for each population. The result is shown for Catherine Creek, but differs for other populations only in slope, where it is steeper for higher productivities. Like the productivity comparisons, the lines represent the median predicted $\bar{R}$ from 1,000 simulations at four spill scenarios. Capacity estimates for the six populations ranged from as low as about 9,000 to as high as about 60,000, which translates to returning spawner abundances of between 500 and 3,000 (at and assumed 5% SAR), so clearly capacities are limiting and were likely higher historically.

Discussion

This analysis demonstrates the potential survival benefits to Snake River spring/summer chinook as a result of increased spill and dam breach in the lower Snake River. Using a statistically validated life cycle model, we simulated population trends under breached and impounded hydrosystem conditions involving a variety of spill levels and flow levels. We found that predicted SARs and long-term average return abundances responded positively to increased spill, with a breached system predicting the largest positive response in survival benefits and return abundances. Results indicate that in-river survival increases with reduced powerhouse passage and reduced water transit times, and also that early ocean survival increases as powerhouse passage decreases. We found that the most significant benefits to in-river survival rates and SARs occurred at the highest TDG limit spill levels, and that benefits under breached conditions at BiOp spill levels were higher than under impounded conditions at 125% spill levels.

Results indicate that if habitat could be improved to increase freshwater productivity, an increase in return abundance is predicted. Increasing spill levels predicts an even greater response in abundance, but abundances are ultimately limited by tributary capacity. The range of benefit from additional spill and breach is predicted to be a two to three fold increase in average return abundance, with the highest increase being approximately a 2.5 fold increase in average return abundance from a BiOp spill level at average flows compared to a 125% TDG spill level in the Imnaha and Wenaha (which were estimated to have the highest capacities). Looking more closely at how increased spill interacts with changes to productivity and capacity, we found that most of

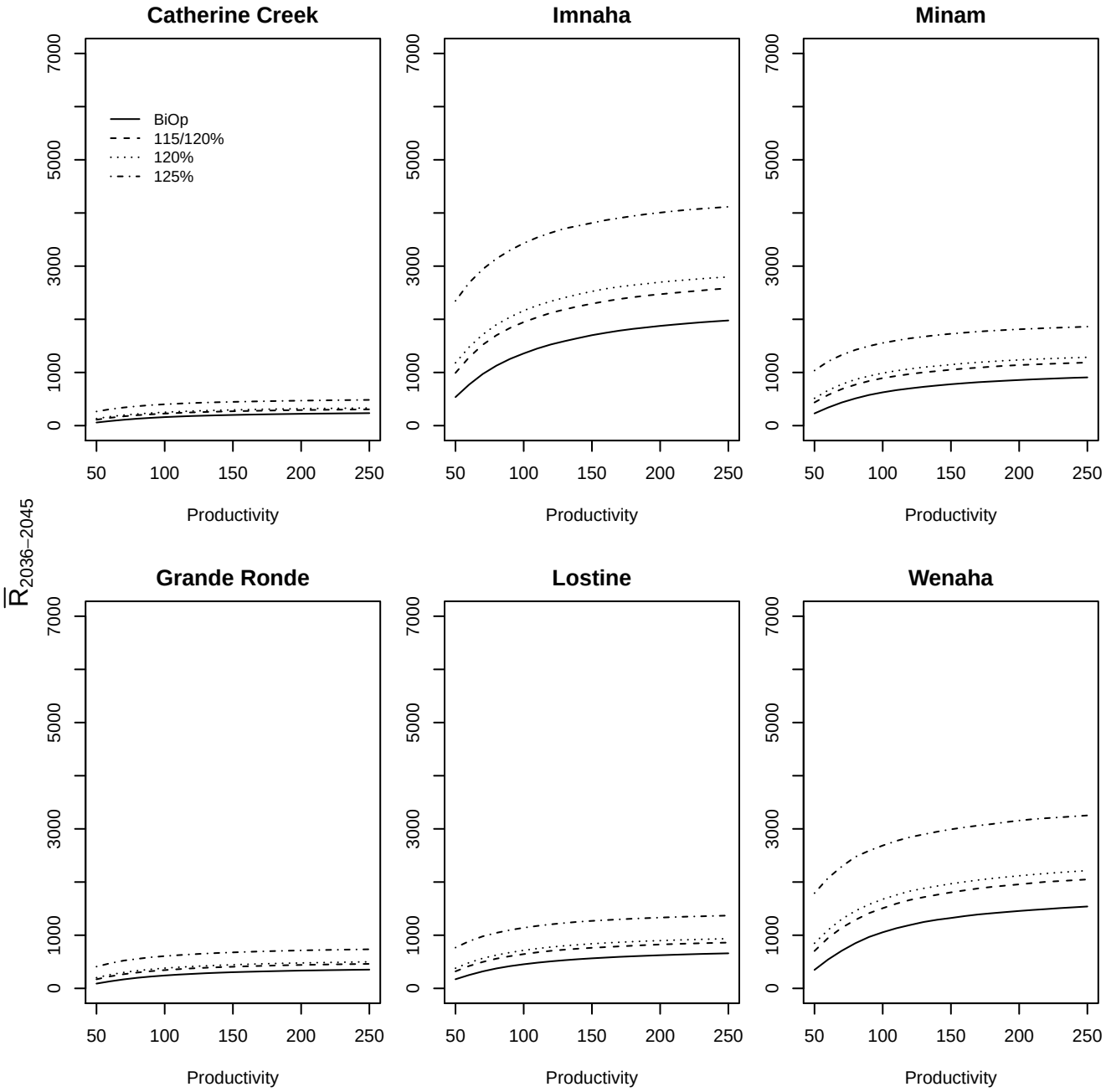

Figure 2.16: Sensitivity analysis of predicted long-term average return abundance between 2036 and 2045 when tributary productivities span the range from 50 to 250 smolts per spawner. The lines are the median ($\bar{R}$) predicted average return abundance at four spill levels under non-breached conditions evaluated at average flows.

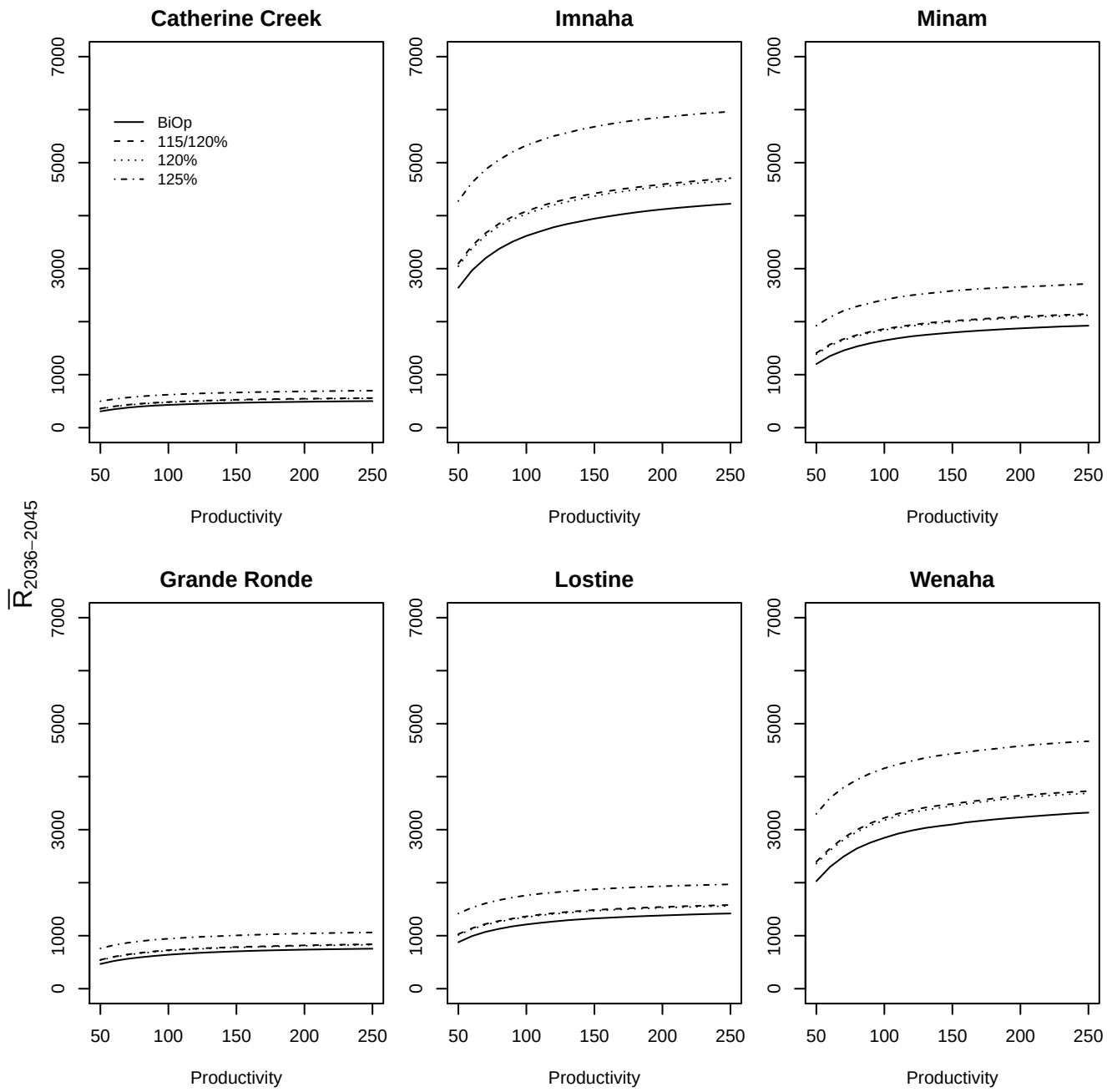

Figure 2.17: Sensitivity analysis of predicted long-term average return abundance between 2036 and 2045 when tributary productivities span the range from 50 to 250 smolts per spawner. The lines are the median ($\bar{R}$) predicted average return abundance at four spill levels under breached conditions evaluated at average flows.

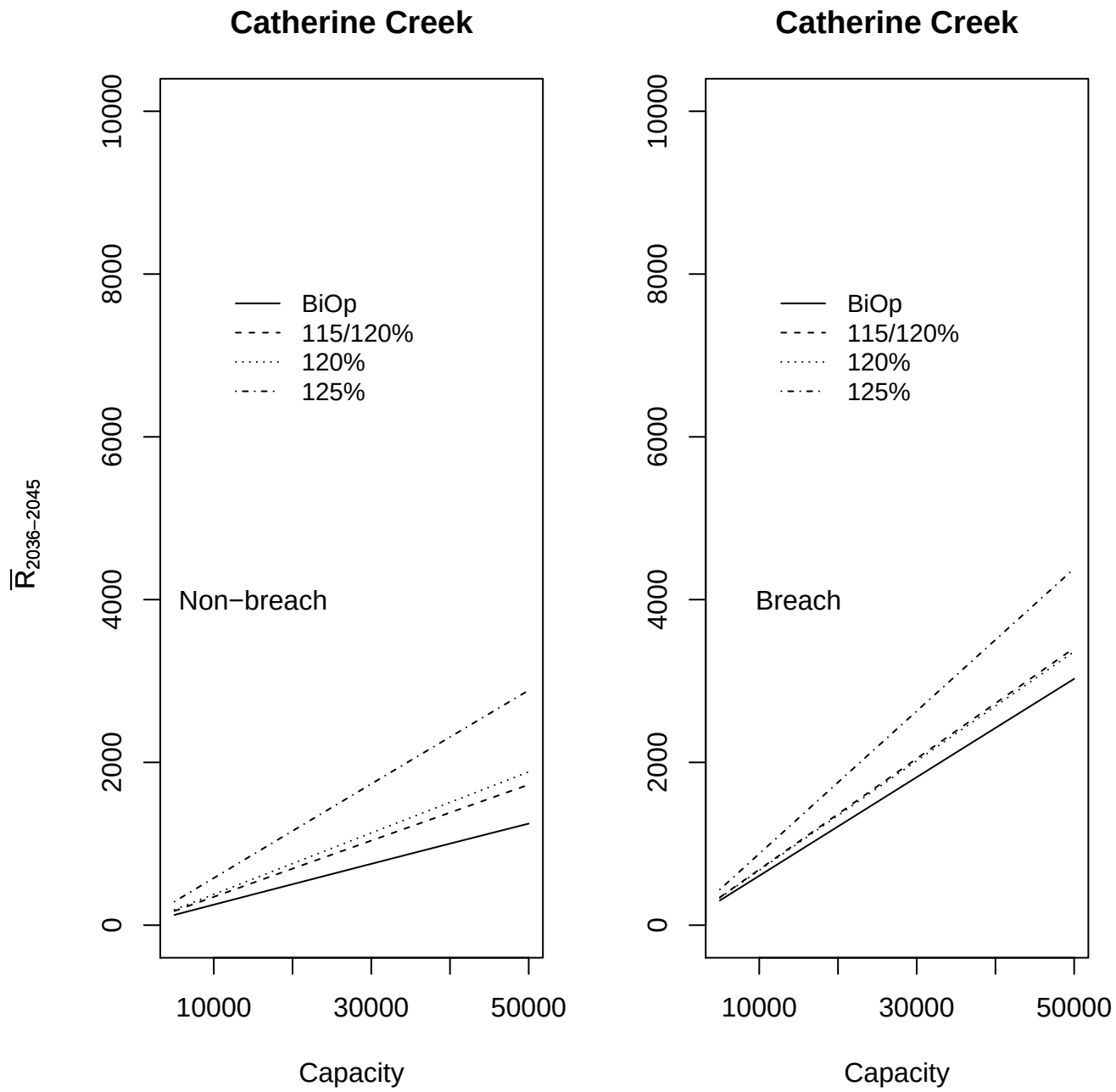

Figure 2.18: Sensitivity analysis of predicted long-term average abundance between 2036 and 2045 ($\bar{R}$) when capacity spans the range from 5000 to 50000 smolts. The lines are the median ($\bar{R}$) predicted return average abundance at four spill levels under breached and non-breached conditions evaluated at average flows.

the potential gains from productivity came from populations that have low productivities and high capacities.

Capacity ultimately limits the attainable population size, but low productivity and life cycle survival hamper a population's growth by suppressing the rate at which it can increase in abundance, so recovery depends on increasing productivity as well as capacity. Habitat improvements have the potential to bring population abundances back to historical levels if the habitat actions increase productivities and/or capacities, but benefits have the potential to lag many years following implementation of habitat improvement. Spill and breach scenarios provide a relatively immediate means of increasing life cycle survival, both during in-river migration, and upon ocean entry. Looking at the results on a case by case basis for each population, the circumstances and conditions for habitat actions are different. The Imnaha and Minam have significant portions of habitat within Wilderness Areas, so they are not as disturbed relative to other populations. Habitat restoration is not something that would be expected to have a large effect on freshwater spawning and rearing conditions. The Upper Grande Ronde and Catherine Creek, on the other hand, have very low estimated capacities, and the Upper Grande Ronde has a very low estimated productivity as well. Both populations could benefit from habitat improvements, but private land ownership within the drainages impedes and delays habitat restoration action on significant portions of the drainages, making it difficult to effect change with the speed and intensity required to create measurable benefits. Breach and increased spill, on the other hand, could return immediate survival benefits to both disturbed and undisturbed populations, providing the means for populations to return more spawners per smolt, which would provide more eggs for improved habitats to hatch into rearing juveniles. We have shown that increasing from BiOp to 115%/120% levels could lead to about a 50% increase in return abundances without breach, and spill to a 125% TDG level could lead to about a 2.5 to 3 fold increase depending on productivity and capacity. Predicted increases are higher with the water travel times and powerhouse passage rates that apply with breach scenarios.

We have illustrated how increases in $\bar{R}$ can be effected by productivity improvements, capacity improvements, faster water travel times, and powerhouse passage reduction, and that the relative gains can be limited by freshwater spawning and rearing capacities. We have shown that increasing spill levels can increase predicted median $\bar{R}$ by several fold if capacity is high enough, and generally by 2 fold or more. Our results predict SARs in the 2-4% range under most breached spill levels, where the variable PITPH is below 1.5 and the variable WTT is in the 8-15 day range, but we note that observed SARs have rarely exceeded 2% in recent years and non-breached BiOp predictions are in the 2-3% range. This indicates a potential small positive bias to predictions, but we emphasize that the pattern of predicted results relative to PITPH and WTT is consistent with empirical patterns, so the predictions of returns and survivals are supported by empirical evidence in relative terms, i.e., survival and abundance predictions at higher spills should be viewed in relative terms. Breached scenario SARs are comparable to the historical SARs of John Day chinook (2-8%), which is interesting because John Day chinook experience a 3/8 fraction of the powerhouses of Snake River chinook and do not travel as far. A John Day PITPH value would be about 1.1 if taken to be 3/8 of a Snake River BiOp average PITPH. Since WTT would also be lower than for Snake River migrants, John Day chinook have historically been experiencing similar conditions to the alternatives predicted for Snake River chinook under breached condition.

Parameter estimates in this analysis predict slightly different dynamics than those of the estimates obtained in 2016. This is due to the fact that the 2016 analysis included fewer likelihood terms for SARs and compared fewer years of smolt data. Most notably, the estimates of $\delta_{PH}$and δ_{WTT}in this analysis still imply that in-river survivals are higher for lower flows at a given spill level, but not to the same degree as in 2016. The estimated $\delta_{PH}$and δ_{WTT}parameters in the 2016 analysis implied that the shorter water transit times at high flows were insufficient to compensate for the fact that lower spill efficiency at higher flows predicted higher powerhouse passage than at lower flows. The estimates in this analysis indicate that the effect of faster water transit times is strong enough to compensate for increased powerhouse passage relative to low flows. Overall, the main conclusions are no different than in 2016. This analysis shows that reduced powerhouse passage predicts higher in-river survival, whether by means of increased spill or dam breach. It is always the case when fitting models to data that there is some uncertainty around parameter estimates, and the inclusion of new sources of data can affect the range of uncertainty. Adding new data and refining validation procedures is an integral part of adaptive management research and evaluation.

The CSS life cycle model has evolved to balance realism and precision against the need to align predictions with data, and the need to make predictions that identify potential benefits from operational alternatives. There will always be another mechanism that can be modeled to make a more precise prediction or to examine the problem at a finer resolution, but in doing so, the ability to discern differences between policy alternatives can be lost. The CSS life cycle model analysis is presented as though some factors remain constant even though they may be known to vary (eg: transportation or flow), but keeping them constant makes it easier to see relative changes in survival and abundance across a range of alternative spills. We used 2009, 2010, and 2011 as a contrast of flow conditions because those years are on record with known PIT tag detection rates, which are the product of finer scale migration patterns. The corresponding PITPH and WTT values used in the analysis are based on actual measurements of fish passing dams at known flow and spill. PITPH and WTT are the net results of non-hypothetical fish migration patterns, spill volumes, flow volumes, and spill timing. The fact that the same values for PITPH and WTT are used for every year of future simulations may at first seem simplistic, but predicted survivals are in a sense not constant because random draws from the posterior chain of $\delta_{PH}$and δ_{WTT}predict different in-river survivals for each of the 1,000 simulated trends. Survivals remain constant over time, but not across simulations. Keeping PITPH and WTT constant for all simulations of a scenario avoids conflating variability in spill and flow with variability in the estimated effects of spill and flow on survival, i.e., arising from $\delta_{PH}$and δ_{WTT}uncertainty.

Results need to be interpreted in relation to mechanistic assumptions (eg: unimpounded Snake river benefit to adult migration survival). We assumed that dam breaching would decrease adult migration mortality by 50%. This assumption was predicated on the fact that if the lower Snake River was no longer impounded, adult migration would be reduced by 50% because half of the dams would no longer be in place. This assumption may be optimistic because not all mortality is dam induced. There will still be mortality in a free flowing or unimpounded river. It also assumes the remaining infrastructure has no effect on passage survival, when in fact a river drawdown study by the Army Corps of Engineers in 2002 found that above 170 kcfs, passage enhancement would be required at some dams, though flow records indicate those flow levels are rarely attained. The results presented in this analysis need to be considered in a relative sense -

relative to transportation assumptions, relative to harvest assumptions, and relative to downstream and upstream passage assumptions. The model's assumptions are clearly stated, however, and predictions can be interpreted in relation to the scale of bias.

Conclusions

This analysis provides insight into the potential for dam breach to play a role in the recovery of Snake River spring/summer chinook. The results presented illustrate how survival and long-term return abundance respond to changes in hydrosystem operations. Relying on the empirical estimates of life cycle model parameters, and particularly the finding that powerhouse passage is a significant determinant of in-river survival and early ocean survival, we demonstrated that dam breaching and increased spill can benefit population recovery in relative proportion to the productivities and capacities of the populations. This analysis predicts that average return abundances and SARs increase at higher levels of spill and when dams are breached, owing to the empirical finding that survival is higher when powerhouse passage and water transit times are lower. The results are preliminary in the sense that the simulated future conditions are speculative and have a strong influence on predicted survival, and also that predicted powerhouse passage under breach conditions has not been empirically validated, but the results present a contrast of alternatives. The predicted outcomes represent approximations of the relative magnitude of increased survival and return abundance that are predicted relative to expected passage and water transit time values under flow, spill, and breach conditions. In a fully impounded river, we predict a 2-2.5 fold increase in return abundance above BiOp spill levels when spill is increased to 125% TDG. If the lower four Snake River dams are breached and the remaining four lower Columbia dams operate at BioP spill levels, we predict approximately a 2-3 fold increase in abundance above that predicted at BiOp spill levels in an impounded system, and up to a 4 fold increase if spill is increased to the 125% TDG limit. This analysis predicts that higher SARs and long-term abundances can be achieved by reducing powerhouse passage and water transit time, both of which are reduced by increasing spill, and reduced further when the lower four Snake River dams are breached.

CHAPTER 3
EFFECTS OF THE IN-RIVER ENVIRONMENT ON JUVENILE TRAVEL TIME, INSTANTANEOUS MORTALITY RATES AND SURVIVAL

The CSS is an important component of ongoing Research, Monitoring and Evaluation (RM&E) and Data Management studies in the Columbia River Basin. This long-term study provides specific information on management actions in the region, specifically the role of the smolt transportation program, flow augmentation, and spill for the recovery of listed salmon and steelhead stocks. In addition to providing a time series of SAR data, the CSS provides data on smolt out-migration timing, juvenile migration rates and travel times, juvenile reach survivals, and evaluates these parameters for the purpose of informing management and recovery decisions related to those stocks.

As a long-term study, the CSS has included PIT-tagged smolts from a variety of basins, locations, species and rear-types in an effort to arrive at, among other goals, a holistic view of juvenile demographic parameters and their relationships to hydrosystem management actions in the FCRPS. This chapter summarizes data collected on groups of juvenile salmonids from the Snake River basin, which consisted of yearling spring/summer Chinook salmon, subyearling (fall) Chinook salmon, steelhead and sockeye salmon. We also summarize and analyze groups of yearling spring/summer Chinook salmon, sockeye salmon, and steelhead originating in the upper Columbia River, from Rock Island Dam to McNary Dam.

This chapter uses information-theoretic model selection techniques (Burnham and Anderson 2002) to update the multiple regression models of fish travel time, instantaneous mortality rates and survival probabilities from Chapter 3 of the 2016 Annual Report (McCann et al. 2014). These analyses address an interest of the ISAB/ISRP for finer-scale analyses of the relationships between survival and specific operational actions or environmental features (ISAB 2006). In this chapter we continue the process of summarizing and synthesizing the results that have been obtained to date through the CSS on the responses of juvenile yearling (spring/summer) and subyearling (fall) Chinook salmon, sockeye salmon and steelhead to conditions experienced within the hydrosystem. These analyses evaluate the effects of management actions on fish travel times and in-river juvenile survival probabilities, while directly accounting for model uncertainty, measurement uncertainty, and environmental variation.

Methods

Study area and definitions

In this chapter, we define the Snake Basin migration corridor as the overall reach between Lower Granite Dam (LGR) and Bonneville (BON) Dam (Figure 3.1). There are six dams between LGR and BON: Little Goose (LGS), Lower Monumental (LMN), Ice Harbor (IHR), McNary (MCN), John Day (JDA), and The Dalles (TDA). We divided the Snake Basin migration corridor into two reaches for summarizing fish travel time, instantaneous mortality rates, and survival probabilities: LGR–MCN and MCN–BON. We also define the upper Columbia River migration corridor as the river reach between Rock Island Dam (RIS) and

McNary Dam. There are two dams between RIS and MCN: Wanapum Dam and Priest Rapids Dam. We define fish travel time (FTT) as the time spent migrating the LGR–MCN, RIS–MCN or MCN–BON reach and expressed this in days. We used Cormack-Jolly-Seber (CJS) methods to estimate survival probabilities through the three reaches based on detections at the dams and in a PIT-tag trawl operating below BON (Cormack 1964, Jolly 1965, Seber 1965, Burnham et al. 1987).

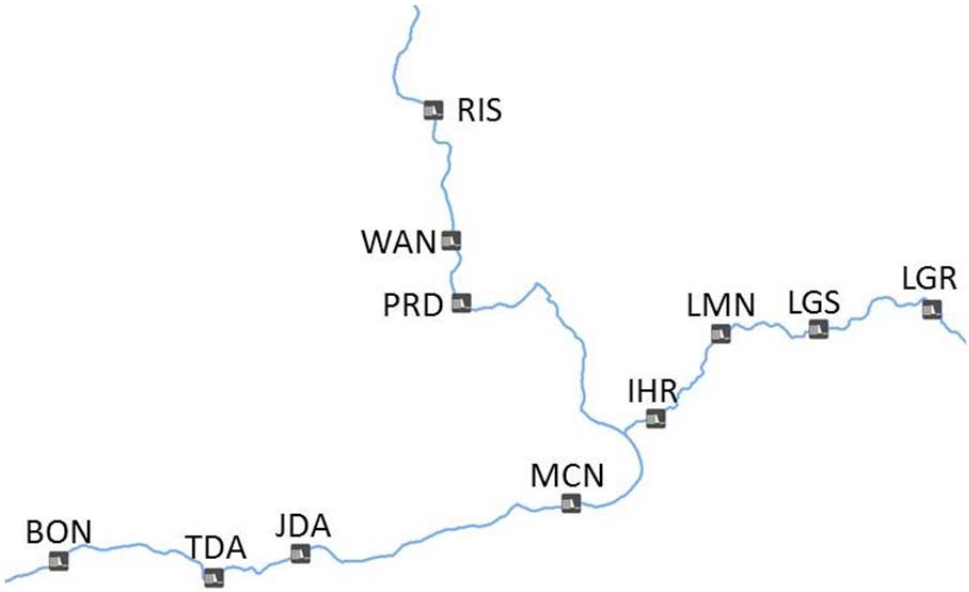

Figure 3.1 Location of dams and river reaches analyzed. Labels refer to Lower Granite Dam (LGR), Little Goose Dam (LGS), Lower Monumental Dam (LMN), Ice Harbor Dam (IHR), Rock Island Dam (RIS), Wanapum Dam (WAN), Priest Rapids Dam (PRD), McNary Dam (MCN), John Day Dam (JDA), The Dalles Dam (TDA), and Bonneville Dam (BON).

Multiple regression modeling

The goal of the multiple regression models is to evaluate finer-scale analyses of the relationships between survival probabilities and specific operational actions or environmental features during the juvenile outmigration. Toward this goal, we calculated and summarized within-year (weekly or multi-weekly) fish travel time, instantaneous mortality rate, and survival probability estimates for juvenile yearling Chinook, subyearling Chinook, and steelhead across years of the CSS. We also calculated and summarized seasonal estimates of fish travel time, instantaneous mortality rate, and survival probabilities for sockeye salmon in the LGR–MCN and RIS–MCN reaches. The yearling Chinook, steelhead and sockeye used in this analysis consisted of fish PIT-tagged both at hatcheries and fish traps upstream of LGR and those tagged and released at LGR. Due to sufficient numbers of PIT-tagged hatchery and wild yearling Chinook available, analyses in the LGR–MCN reach were conducted separately for hatchery and

wild yearling Chinook. Due to the limited number of PIT-tagged steelhead available, hatchery and wild steelhead were combined for analyses in the LGR–MCN reach. Similarly, hatchery and wild sockeye were combined for analyses in the LGR–MCN and RIS–MCN reaches. The subyearling fall Chinook analyzed in the LGR–MCN reach were tagged at hatcheries. Analyses on yearling Chinook and steelhead in the RIS–MCN reach consisted of both hatchery and wild fish. Analyses on the MCN–BON reach included hatchery and wild yearling Chinook and steelhead from the Snake River, hatchery-marked fish from the Mid-Columbia River, and fish marked and released at MCN.

Fish travel time

We utilized a cohort-based approach for characterizing mean fish travel times for weekly or bi-weekly groups of juvenile Chinook salmon and steelhead. Individual fish detected at LGR with PIT tags were assigned to a weekly cohort group (i) according to the week of their detection. Cohorts were identified by the Julian day of the midpoint of the weekly cohort. For example, the April 1–7 release cohort was identified by Julian day 94 (April 4). We calculated mean fish travel time as the mean number of days between release at LGR until detection at MCN for each fish subsequently detected at MCN. In preliminary analyses, we used Box-Cox power transformations to determine whether the FTT_i data needed to be transformed in order to better approximate normality of the residuals and reduce heteroscedasticity in subsequent regressions. These preliminary analyses indicated that a log-transformation was most appropriate. We calculated mean FTT_i for each weekly release cohort of both yearling Chinook and steelhead, in both the LGR–MCN and MCN–BON reaches. Because the number of PIT-tagged sockeye was low and the juvenile sockeye migration season is relatively narrow, we calculated annual estimates of LGR–MCN FTT and RIS–MCN FTT for sockeye. For yearling Chinook and steelhead in the RIS–MCN reach, three 2-week release cohorts were used and were defined based on detection date at RIS. Similarly, for hatchery subyearling fall Chinook in the LGR–MCN reach, four 2-week release cohorts were used and were defined based on detection date at LGR.

For yearling Chinook, we calculated mean FTT_i for eight weekly cohorts from April 1 through May 26 in the LGR–MCN reach. Separate estimates were developed for hatchery and wild rearing types of yearling Chinook. In the MCN–BON reach, hatchery and wild yearling Chinook were combined and we calculated mean FTT_i for six weekly cohorts from April 26 through June 5. For steelhead, we calculated mean FTT_i for six weekly cohorts from April 17 through May 28 in the LGR–MCN reach. In the MCN–BON reach, we calculated mean FTT_i for six weekly cohorts of steelhead from April 27 through June 7. Hatchery and wild rearing types of steelhead were combined for both reaches. The number of cohorts by reach, species, and rearing type are summarized in Table 3.1.

Table 3.1 Reaches, species, rearing type, and number of FTT cohorts that were analyzed for the 2016 Annual Report.

Reach	Species	Rearing type	Cohorts	Cohort Period
LGR-MCN	steelhead	hatchery and wild	114	1-week
LGR-MCN	yearling Chinook	wild	148	1-week
LGR-MCN	yearling Chinook	hatchery	145	1-week
LGR-MCN	sockeye	hatchery and wild	18	annual
LGR-MCN	subyearling Chinook	hatchery and wild	61	2-week
RIS-MCN	steelhead	hatchery and wild	54	2-week
RIS-MCN	yearling Chinook	hatchery and wild	54	2-week
RIS-MCN	sockeye	hatchery and wild	18	annual
MCN-BON	steelhead	hatchery and wild	107	1-week
MCN-BON	yearling Chinook	hatchery and wild	108	1-week

Because FTT_i is calculated only using individuals that survive the migration, under conditions of a constant instantaneous mortality rate, the observed travel times will be underestimated to some degree due to the loss (i.e., mortality) of individuals with long travel times (i.e., those with slower migration speeds). As a result, the estimates of mean *FTT* can exhibit a small degree of negative bias relative to the expected travel times of all fish in the release cohort, which includes both the observed individuals that survive and unobserved individuals that do not survive (Tuomikoski et al. 2013, Appendix J). This effect has been observed and known since 1989 (FPC 1990). The degree of bias appears to be a function of both the travel times of the release cohort and the instantaneous mortality rate, with higher levels of bias expected under conditions of long travel times and high mortality rates (Tuomikoski et al. 2013, Appendix J). Simulations indicate that the degree of bias is less than 10% under most conditions that have been observed within the FCRPS (Tuomikoski et al. 2013, Appendix J).

Survival Probabilities

We estimated the survival probabilities for each weekly cohort of wild Chinook, hatchery Chinook and the combined hatchery and wild steelhead in the LGR–MCN reach using standard CJS methods over migration years 1998–2016. We also estimated annual survival probabilities for sockeye in the LGR–MCN reach over 1998–2016. Due to lower numbers of PIT-tagged fish detected and released at MCN, we developed survival probability estimates for three, 2-week cohorts for yearling Chinook and two 3-week cohorts for steelhead in the MCN–BON reach over migration years 1999–2016. For hatchery subyearling Chinook in the LGR–MCN reach we developed survival probability estimates for four 2-week release cohorts over migration years 1998–2016. In the RIS–MCN reach, we developed survival probability estimates for three 2-week release cohorts of yearling Chinook and steelhead. We calculated Chi-square adjusted variances (using the ĉ variance inflation factor, the ratio of the deviance divided by the degrees of freedom) for each survival probability estimate ($\hat{S}$) (Burnham et al. 1987:244–246). The number of cohorts by reach, species, and rearing type are summarized in Table 3.2.

Table 3.2 Reaches, species, rearing type, and number of survival cohorts that were analyzed for the 2016 Annual Report.

Reach	Species	Rearing type	Cohorts	Cohort Period
LGR-MCN	steelhead	hatchery and wild	103	1-week
LGR-MCN	yearling Chinook	wild	120	1-week
LGR-MCN	yearling Chinook	hatchery	118	1-week
LGR-MCN	sockeye	hatchery and wild	18	annual
LGR-MCN	subyearling Chinook	hatchery and wild	53	2-week
RIS-MCN	steelhead	hatchery and wild	51	2-week
RIS-MCN	yearling Chinook	hatchery and wild	43	2-week
RIS-MCN	sockeye	hatchery and wild	18	annual
MCN-BON	steelhead	hatchery and wild	29	3-week
MCN-BON	yearling Chinook	hatchery and wild	44	2-week

Instantaneous mortality rates

In 2003, the ISAB offered the suggestion that "an interpretation of the patterns observed in the relation between reach survival and travel time or flow requires an understanding of the relation between reach survival, instantaneous mortality, migration speed, and flow" (ISAB 2003). Consistent with that suggestion, we developed an approach for estimating instantaneous mortality rates for juvenile salmonids (Schaller et al. 2007). Ricker (1975) provides a numerical characterization of survival, also known as the exponential law of population decline (Quinn and Deriso 1999):

$$S = \frac{N_t}{N_0} = e^{-Zt}, \qquad [3.1]$$

where S is a survival probability, N_t is the number of individuals alive at time t, N_0 is the number of individuals alive at time $t = 0$, and Z is the instantaneous mortality rate, in units of t^{-1}. The exponential law of population decline provides a useful framework for understanding the interrelationships between instantaneous mortality rates, time, and survival. If instantaneous mortality rates vary over time, Z represents the arithmetic mean mortality rate over the time period (Keyfitz 1985:18–19). This property of Z may be useful for capturing mortality rates for smolts in the Columbia Basin, which may experience different mortality rates over time. For example, if mortality rates experienced through a reservoir differ from mortality experienced through a dam, then the instantaneous mortality rate Z represents the arithmetic mean mortality rate over that period of migration through the reservoir and dam combination. Rearranging Eqn. 3.1, we estimated Z using

$$\hat{Z} = \frac{-\log_e(\hat{S})}{t} \qquad [3.2]$$

In our application, we calculated instantaneous mortality rates (in units of d^{-1}) for each survival cohort using Eqn. 3.2. We used the CJS estimates of survival probability for each cohort ($\hat{S}_i$) in the numerator and used the mean $F\hat{T}T_i$ in the denominator of Eqn. 3.2. This approach for estimating instantaneous mortality rates incorporates the variability in cohort

migration rates, which can vary substantially over the migration season. This approach for estimating instantaneous mortality also differs from most applications where the instantaneous mortality rate is defined for a fixed time step, such as a year or fixed within-year period. In our application, the mean *FTT* for each cohort determines the time step over which the instantaneous mortality rate is calculated and defined.

While individuals in each release cohort have variable individual *FTT's*, we used the mean $F\hat{T}T_i's$ in the denominator of Eqn. 3.2 to characterize the cohort-level central tendency in the amount of time required to travel a reach. Combining the cohort-level survival probability estimates ($\hat{S}_i$) with the cohort-level mean $F\hat{T}T_i$ estimates, we estimated the cohort-level instantaneous mortality rates ($\hat{Z}_i$) using Eqn. 3.2. As discussed above, estimates of mean *FTT* can exhibit a small degree of negative bias due to the loss of individuals with long travel times. This can, in turn, result in a small degree of positive bias in the instantaneous mortality rate estimates (Tuomikoski et al. 2013, Appendix J). However, simulation results indicate that the degree of bias is less than 5% under most conditions that have been observed within the FCRPS (Tuomikoski et al. 2013, Appendix J).

Both $-\log_e(\hat{S}_i)$ and mean $F\hat{T}T_i$ are random variables subject to sampling and process error. To calculate the variance of $\hat{Z}_i$, we used the formula for the variance of the quotient of two random variables (Mood et al. 1974):

$$\mathrm{var}(\hat{Z}_i) = \mathrm{var}\left(\frac{-\log(\hat{S})}{F\hat{T}T}\right) \cong \left(\frac{-\log(\hat{S})}{F\hat{T}T}\right)^2 \left(\frac{\mathrm{var}[-\log(\hat{S})]}{-\log(\hat{S})^2} + \frac{\mathrm{var}[F\hat{T}T]}{F\hat{T}T^2} - \frac{2cor(-\log(\hat{S}), F\hat{T}T)\cdot\sqrt{\mathrm{var}[-\log(\hat{S})]\cdot\mathrm{var}[F\hat{T}T]}}{-\log(\hat{S})\cdot F\hat{T}T}\right), \quad [3.3]$$

Empirical (Peterman 1981) and theoretical (Hilborn and Walters 1992) analyses support the assumption that $\hat{S}$ tends to be log-normally distributed, and therefore $-\log_e(\hat{S})$ would tend to be normally distributed. To estimate the variance of $-\log_e(\hat{S}_i)$ we used the approximation provided by Blumenfeld (2001) for log-normally distributed random variables:

$$\mathrm{var}[-\log_e(\hat{S})] = \log_e(1 + [CV(\hat{S})]^2). \quad [3.4]$$

Environmental variables

The environmental variables associated with each cohort were generated based on fish travel time and conditions at each dam along the reaches. Travel time for each cohort between dams was estimated, and we calculated the average spill percentage, temperature (based on tailwater total dissolved gas monitoring data, downloaded from the USACE website: www.nwd-wc.usace.army.mil/cgi-bin/dataquery.pl), and total water transit time (WTT) as indicators of conditions each group experienced while passing through the reach. Water transit time was calculated by dividing the total volume of reservoirs by the flow rate, and with adjustments in McNary pool to account for Columbia River versus Snake River flows. Conditions at downstream dams were averaged over a 7-day window around the median passage date at each dam, and the travel time to the next dam was used to adjust the start date of the calculations. For example, steelhead travel time from LGR to LGO for the earliest release cohort in 2005 (detected at LGR from 4/17 to 4/23) was estimated to be 5.0 days based on 378 detections. Average environmental variables over the time period of April 22 to April 28 at LGO were then

calculated. At each downstream dam, environmental variables were calculated in a similar manner. The rationale behind using the 7-day window around the median passage date is to develop an index of exposure to the environmental variables analyzed (e.g., spill, water transit time, temperature) that aligns with the timing of smolt passage at each dam. The 7-day windows were selected because the vast majority of smolts pass during these 7-day windows around the median passage date and experience the spill, temperature, and water transit times that occur within these windows. Since no PIT-tag detection data were available until 2005 at IHR, travel time to IHR was estimated as 43% of the total travel time from LMN to MCN (corresponding to the distance to IHR relative to the distance to MCN). The overall reach environmental variables were the average of these dam-specific calculated values for spill percentage and temperature, whereas for water transit time the sub-reach values were summed to estimate the total reach water transit time. In addition to these environmental predictor variables, we also used Julian date as a predictor variable to help capture seasonal effects not reflected in these environmental variables. We use Julian date of release to characterize effects such as degree of smoltification, photoperiod, predator abundance/activity, or fish length that may demonstrate a consistent pattern within- and across-years, but is not already captured by the other environmental variables. The use of Julian date of release as an attempt to capture seasonal effects is a common modeling strategy for these data (Berggren and Filardo 1993, Smith et al. 2002, Williams et al. 2005). Building on the results of McCann et al. 2015 (Appendix J), we also developed an index of the expected number of powerhouse passage experiences based on the project-specific spill proportions, flow levels, and the presence of spillway weirs for spring/summer Chinook salmon and steelhead. Due to a lack of available information on fish passage routes at Priest Rapids and Wanapum dams, average spill levels were used to characterize spill operations at those dams. At these dams, we also developed a variable that enumerated the number of dams with spillway surface passage structures (e.g., removable spillway weirs [RSWs], temporary spillway weirs [TSWs], or adjustable spillway weirs [ASWs]) in place over the years of observation.

Multi-model inference

We used multi-model inference techniques (Burnham and Anderson 2002) to evaluate the associations between the environmental variables and mean *FTT* and instantaneous mortality (*Z*). Our objectives were to account for model selection uncertainty and to synthesize results on the relative importance of environmental factors on fish travel time and instantaneous mortality across the set of species and reaches that have been monitored. We evaluated seven environmental factors that have previously been identified (Tuomikoski et al. 2013) as being associated with *FTT* and/or *Z*: Julian day of fish release from the dam at the starting point of the reach (LGR, RIS, or MCN), Julian day squared, average proportion spill, expected number of powerhouse passage experiences, total water transit time, average water temperature, and the number of dams with spillway surface passage structures. Based on previous results, evaluations of the quadratic effect of Julian day was limited to the yearling Chinook salmon fish travel time models. Because each environmental factor was considered plausible based on previous evaluations, we evaluated all possible model combinations of the predictor variables (all subsets regression). We calculated Akaike's information criterion for small sample sizes (AIC_C) for each combination of the predictor variables. In cases where all six variables were applicable, there were 64 possible model combinations of the predictor variables. In cases where some of the variables were not applicable (e.g., Julian day for sockeye) there were fewer possible model combinations of the variables.

As mentioned above, Box-Cox power transformations indicated that a $\log_e$-transformation was most appropriate for the *FTT* data. Therefore we modeled $\log_e(FTT)$ as the response variable in all analyses. The $\log_e$ transformations were also implemented to help reduce heteroscedasticity and improve linearity.

During the smolt outmigration, individuals within each release cohort tend to spread out as they migrate downstream (Zabel and Anderson 1997). With sequential release cohorts, fast-migrating individuals within one release cohort may overlap to some degree with the slower-migrating individuals of the previous cohort in downstream reaches and vice versa (Tuomikoski et al. 2013, Appendix J). In addition, prior growth and rearing conditions may similarly influence the migration rates of individuals across cohorts within a migration year. As a result, the cohorts may lack complete independence and share some degree of correlation. However, mixed-effects models (Pinheiro and Bates 2000) can be used to properly account for the lack of independence among sample units (Millar and Anderson 2004, Chavez 2010). Preliminary analyses indicated that mixed-effects models with migration year (i.e., random intercept) and Julian day (i.e., random slope) as random effects frequently improved model fit based on AIC_C. The full model for evaluating the effects of environmental and management factors on FTT was of the form:

$$\log_e(F\hat{T}T_{y,j}) = \beta_0 + \beta_1 \cdot X_{1,y,j} + ...\beta_6 \cdot X_{6,y,j} + b_y + b_j \cdot X_{1,y,j} + \varepsilon_{y,j}, \qquad [3.5]$$

where $\beta_0, \beta_1, ..., \beta_6$ are fixed-effect parameters used to describe the relationship between environmental variables $X_1, X_2, ..., X_6$ and $\log_e(FTT)$, b_y is a random effect of migration year (y) with $b_y \sim N(0, \sigma_y^2)$, b_j is a random effect of Julian day (j) with $b_j \sim N((0, \sigma_j^2)$, and $\varepsilon_{y,j} \sim N(0, \sigma_\varepsilon^2)$. This full, mixed-effects model is termed the "MY + Day" model, as it includes all of the environmental variables as fixed effects, plus a random intercept for Migration Year (MY) and a random slope for the effect of Julian day of release (Day). In addition to the full model described above, we also considered simpler, reduced-model forms with: (1) only the random intercept for Migration Year, termed the "MY" model, and (2) a standard Linear Regression model without random effects, termed the "LR" model. The model form with the lowest AIC_C among the three forms evaluated (i.e., the MY + Day, MY, or LR model forms) was selected for use in subsequent analyses.

We also utilized Box-Cox power transformations to determine the most appropriate transformation of the $\hat{Z}_i$ for each of the ten species-reach combinations that have been monitored. The Box-Cox analyses indicated that either a natural log or a square-root transformation was most appropriate for the instantaneous mortality rate models. Preliminary analyses indicated that mixed-effects models with migration year (i.e., random intercept) and Julian day (i.e., random slope) as random effects occasionally improved model fit based on AIC_C. The full model for evaluating the effects of environmental and management factors on Z were of the form:

$$\log_e(\hat{Z}_{y,j}) = \beta_0 + \beta_1 \cdot X_{1,y,j} + ...\beta_5 \cdot X_{5,y,j} + b_y + b_j \cdot X_{1,y,j} + \varepsilon_{y,j}, \qquad [3.6]$$

where $\beta_0, \beta_1, ..., \beta_5$ are fixed-effect parameters used to describe the relationship between environmental variables $X_1, X_2, ..., X_5$ and $\log_e(Z)$, b_y is a random effect of migration year (y)

with $b_y \sim N(0, \sigma_y^2)$, b_j is a random effect of Julian day (j) with $b_j \sim N((0, \sigma_j^2)$, and $\varepsilon_{y,j} \sim N(0, \sigma_\varepsilon^2)$. This full, mixed-effects model is termed the "MY + Day" model, as it includes all of the environmental variables as fixed effects, plus a random intercept for Migration Year (MY) and a random slope for the effect of Julian day of release (Day). In addition to the full model described above, we also considered simpler, reduced-model forms with: (1) only the random intercept for Migration Year, termed the "MY" model, and (2) a standard Linear Regression model without random effects, termed the "LR" model. The model form with the lowest AIC_C among the three forms evaluated (i.e., the MY + Day, MY, or LR model forms) was selected for use in subsequent analyses. Because there were large differences in the precision of the $\hat{Z}_i$, we used inverse coefficient of variation weighting in the fitting process for modeling instantaneous mortality rates.

The models were ranked according to AIC_C, the model with the minimum AIC_C was identified, and Akaike weights (w_i) were calculated for each model (Burnham and Anderson 2002). Using the AIC_C-ranked set, we calculated model-averaged predictions for the FTT and Z of each of the ten species-reach combinations. Model-averaged predictions were calculated using:

$$\hat{\bar{\theta}} = \sum_{i=1}^{R} w_i \hat{\theta}, \qquad [3.7]$$

where $\hat{\bar{\theta}}$ denotes the model-averaged prediction of $\hat{\theta}$ (i.e., *FTT* or *Z*) across the R models and w_i denotes the Akaike weight for model i = 1, 2, …, R (Burnham and Anderson 2002). Model-averaged coefficients were calculated in a similar manner, along with unconditional variance estimates for the coefficients using the methods described in Burnham and Anderson (2002).

The sets of best fitting models were also used to evaluate the relative importance of each predictor variable used in the regressions (Burnham and Anderson 2002). The relative variable importance is a quantitative measure of the degree to which variables are consistently included among the best-fitting models based on AIC_C, relative to the other variables that were considered. The relative variable importance for variable j among a set of R models is calculated as

$$\sum_{i=1}^{R} w_i I_j(g_i), \qquad [3.8]$$

where w_i is the Akaike weight for model i and $I_j(g_i)$ is an indicator variable equal to one if variable j is in model i (g_i) and equal to zero otherwise. Variables with relative variable importance values near one are consistently in the top fitting models while variables with relative variable importance values near zero are rarely, if ever, included in the top fitting models.

Survival modeling approach

Our approach for modeling survival probabilities utilized the exponential mortality model (Eqn. 3.1), allowing the predicted instantaneous mortality rates Z_i and the mean $FTT_i's$ to vary in response to environmental factors. Using our best-fitting model predictions for Z^*_i and FTT^*_i (Eqns. 3.5 and 3.6), predicted survival probabilities were calculated as:

$$S^*_i = e^{-Z^*_i \cdot FTT^*_i}, \qquad [3.9]$$

where Z^*_i is the predicted instantaneous mortality rate, FTT^*_i is the predicted mean FTT_i, and S^*_i is the predicted survival probability for period *i*, calculated by exponentiating the negative product of Z^*_i and FTT^*_i. It is important to note that although the estimates of *FTT* and *Z* may include a small degree of bias due to the loss of individuals with long travel times, the survival probability predictions generated using Eqn. 3.9 show no evidence for bias (Tuomikoski et al. 2013, Appendix J).

Summarizing goodness of fit

We used the coefficient of determination (R^2) to characterize the goodness of fit for the models used to predict fish travel time, instantaneous mortality and survival. The coefficient of determination was calculated as the squared Pearson correlation coefficient between estimates of fish travel times and instantaneous mortality rates and the back-transformed, model-averaged predictions for fish travel times and instantaneous mortality rates. For survival probabilities, the coefficient of determination was calculated as the squared Pearson correlation coefficient between estimates of survival and the survival predictions generated using Eqn. 3.9. The coefficient of determination reflects the proportion of variance explained by the models.

Evaluations of Total Dissolved Gas (TDG) on Mortality Rates and Survival Probabilities

Using yearling Chinook salmon and steelhead that were tagged with acoustic transmitters in 2011, Elder et al. (2016) concluded that Total Dissolved Gas (TDG) levels strongly influenced juvenile survival. However, numerous issues and concerns over the data, analytical methods, and conclusions of this single-year study have been raised with this study (FPC 2016). To comprehensively examine the effects of TDG on yearling Chinook salmon and steelhead, we employed the long time series of instantaneous mortality rates and survival probabilities that have been collected through the CSS project to evaluate the effects of TDG. Over the 1998-2016 timeframe, there are 103-120 estimates of instantaneous mortality and survival probabilities for juvenile yearling Chinook salmon and steelhead in the LGR-MCN reach and 29-44 estimates in the MCN-BON reach (Table 3.2). These estimates have been collected over a wide range of TDG levels, providing an opportunity to comprehensively evaluate the effects of TDG on instantaneous mortality rates and survival probabilities.

In addition to potential TDG effects, several other co-occurring factors have been shown to be associated with mortality rates and survival probabilities including seasonality, water transit time, powerhouse passage rates, and water temperatures (McCann et al. 2016). In similar cases, residual analyses have been applied to examine the effects of co-occurring factors on survival rates of Chinook salmon populations (Schaller et al. 1999, Schaller et al. 2014). Multiple regression approaches could also be used to examine the influence of multiple factors, but regression approaches do not easily provide a sense of the scale or range of the factors that are considered. In this application, we calculated instantaneous mortality rate and survival probability residuals and compared those residuals to measures of the average and maximum TDG levels that were experienced by the juvenile outmigrants to comprehensively evaluate the effects of TDG on yearling Chinook salmon and steelhead.

Using methods described earlier, we generated model-averaged predictions of the instantaneous mortality rate using combinations of Julian Day, water transit time, powerhouse passage rates, and water temperature. Instantaneous mortality rate residuals were calculated as

$$log_e(\hat{Z}) - log_e(\hat{\theta})$$

where $\hat{Z}$ is the observed instantaneous mortality rate and $\hat{\theta}$ is the model-averaged prediction of the instantaneous mortality rate. Positive residuals indicate that observed mortality rates are higher than expectations based on the Julian Day, water transit time, powerhouse passage rate, and water temperature experienced by the cohort. Similarly, negative residuals indicate that mortality rates are lower than expectations.

To account for potential correlations between TDG and the other variables, we also developed instantaneous mortality rate models that included TDG along with Julian Day, water transit time, powerhouse passage rates, and water temperatures. Using the information theoretic methods described previously, we calculated the model-averaged coefficients and unconditional standard errors for the effects of average and maximum TDG on instantaneous mortality rates. Model-averaged coefficients near zero and coefficient confidence intervals that overlap zero would indicate that TDG had little effect on instantaneous mortality rates. We also calculated the Relative Variable Importance for the TDG variables in the instantaneous mortality rate models.

A similar approach was applied for calculating survival residuals. The full model for estimating the effects of environmental variables on survival was of the form

$$\log_e\left(\frac{\hat{S}}{1-\hat{S}}\right) = \beta_0 + \beta_1 \cdot X_{1,y,j} + ...\beta_4 \cdot X_{5,y,j} + b_y + b_j \cdot X_{1,y,j} + \varepsilon_{y,j}$$

where β_0, β_1,..., β_4 are fixed-effect parameters used to describe the relationship between environmental variables $X_1, X_2, ..., X_4$ and $log_e\left(\frac{\hat{S}}{1-\hat{S}}\right)$, b_y is a random effect of migration year (y) with $b_y \sim N(0, \sigma_y^2)$, b_j is a random effect of Julian day (j) with $b_j \sim N((0, \sigma_j^2)$, and $\varepsilon_{y,j} \sim N(0, \sigma_\varepsilon^2)$. Selection of a standard linear model without random effects, a mixed effects model with only a random effect of migration year, or a mixed effects model with both a migration year random effect and a Julian day random effect was based on AICc. Once the model form had been identified, model averaging was used to generate a model-averaged prediction of the logit transform of survival. Survival residuals were calculated as

$$log_e\left(\frac{\hat{S}}{1-\hat{S}}\right) - log_e\left(\frac{\hat{\theta}}{1-\hat{\theta}}\right)$$

where $\hat{S}$ is the observed survival probability and $\hat{\theta}$ is the model-averaged prediction of the survival probability. Positive residuals indicate that survival probabilities are higher than expectations based on the Julian Day, water transit time, powerhouse passage rate, and water temperature experienced by the cohort. Similarly, negative residuals indicate that survival probabilities are lower than expectations.

Once the instantaneous mortality rate and survival probability residuals were calculated, those residuals were plotted against the average and maximum TDG experienced by the cohort

during outmigration. If the instantaneous mortality rate residuals are increasingly positive at high TDG levels, this would suggest that TDG is having a detrimental effect on mortality rates beyond expectations based on Julian day, water transit time, powerhouse passage rates, and water temperature. The opposite is true for the survival residuals. If the survival residuals are increasingly negative at high TDG levels, this would suggest that TDG is having a detrimental effect on survival beyond expectations based on Julian day, water transit time, powerhouse passage rates, and water temperature.

Results

Estimates of mean $F\hat{T}T_i$, $\hat{Z}_i$ and $\hat{S}_i$ of cohorts of juvenile yearling and subyearling Chinook, steelhead, and annual estimates of sockeye along with predicted values for these parameters are shown in Figures 3.2, 3.3, and 3.4. In the LGR–MCN reach, mean $F\hat{T}T_i$, $\hat{Z}_i$ and $\hat{S}_i$ varied considerably over the period of 1998–2015, both within- and across-years. While there were some special cases, mean $F\hat{T}T_i$ generally decreased over the season, $\hat{S}_i$ both increased and decreased over the season, and $\hat{Z}_i$ increased over the season. Within-year estimates of $\hat{S}_i$ varied by up to 39 percentage points for both wild yearling Chinook and steelhead, and by up to 32 percentage points for hatchery yearling Chinook. Across all years and cohorts, estimates of $\hat{S}_i$ varied by up to 64 percentage points for yearling Chinook and 76 percentage points for steelhead. The large within- and across-year variation in $\hat{S}_i$ demonstrates a high degree of contrast in $\hat{S}_i$ over this 1998–2016 timeframe. It is important to note that although water transit times in 2015 were similar to 2001, estimates of mean $F\hat{T}T_i$, $\hat{Z}_i$ and $\hat{S}_i$ were not dramatically different than recent years and showed marked improvements over the estimates from 2001. The primary difference in the outmigration conditions between 2001 and 2015 was the provision of spill.

In the MCN–BON reach, cohorts of yearling Chinook and steelhead demonstrated within-year mean $F\hat{T}T_i$, $\hat{Z}_i$ and $\hat{S}_i$ patterns similar to those observed in the LGR–MCN reach, varying considerably both within- and across-years (Figures 3.2, 3.3, and 3.4). For both species, mean $F\hat{T}T_i$ generally decreased over the migration season. Yearling Chinook in 2001 demonstrated the largest within-year variation in mean $F\hat{T}T_i$, ranging from 22 days early in the season to 8 days late in the season (Figure 3.2). Due to imprecision in the estimates of $\hat{S}_i$, general patterns in the estimates of $\hat{S}_i$ and $\hat{Z}_i$ in the MCN–BON reach were difficult to discern (Figures 3.3 and 3.4). For both Chinook and steelhead, $\hat{Z}_i$ generally increased over the season. Steelhead $\hat{S}_i$ generally decreased over the season, but no general patterns were evident for Chinook $\hat{S}_i$.

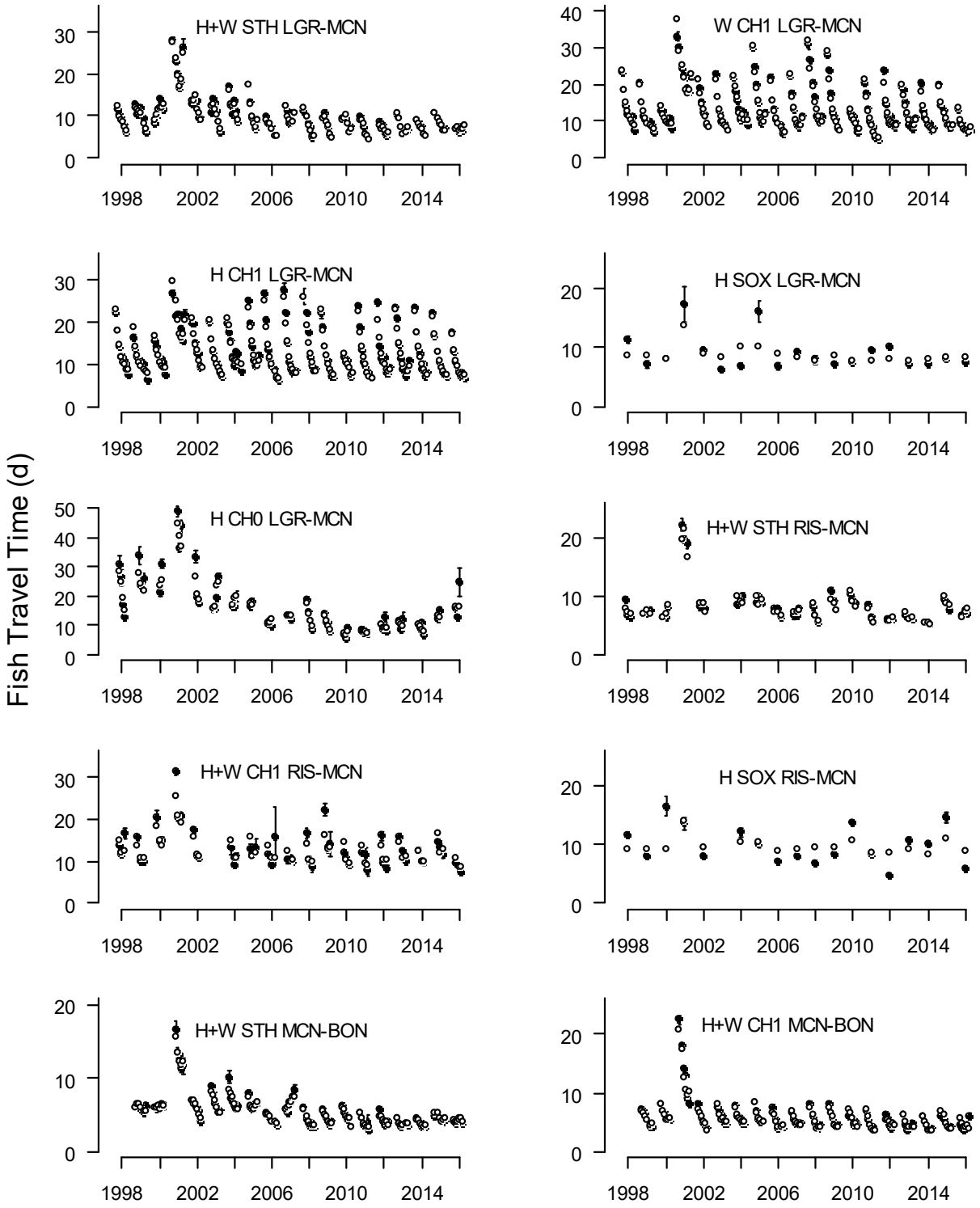

Figure 3.2 Estimates of mean Fish Travel Time (in days, black circles) and predicted mean Fish Travel Time (open circles) for release cohorts of hatchery (H) and wild (W) steelhead (STH), yearling Chinook (CH1), subyearling Chinook (CH0), sockeye (SOX) in the LGR–MCN, RIS–MCN and MCN–BON reaches, 1998–2016. The error bars represent +/- 1 SE.

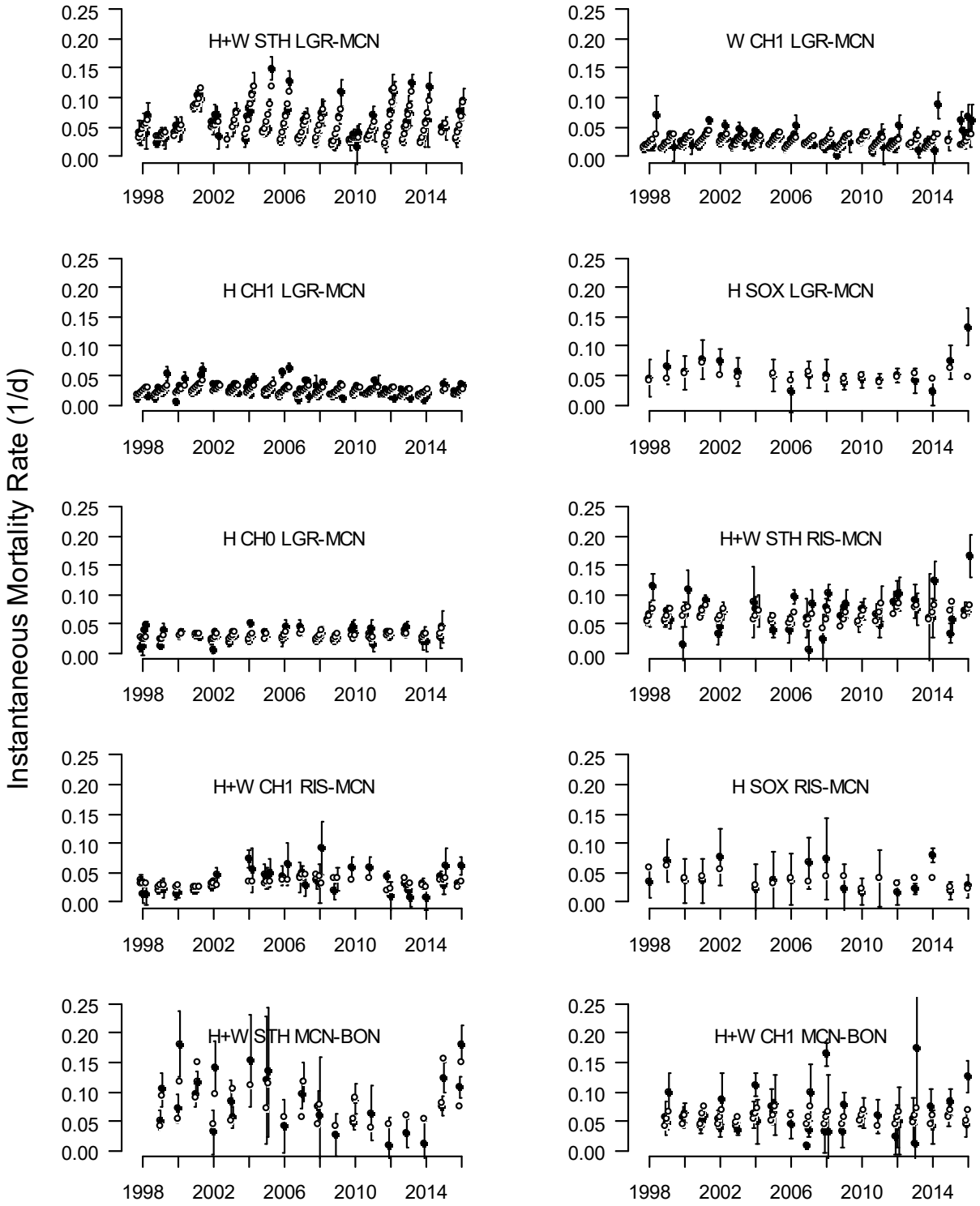

Figure 3.3 Estimates of instantaneous mortality rates, *Z* (y-axis, d^{-1}, black circles) and predicted *Z* (open circles) for release cohorts of hatchery (H) and wild (W) steelhead (STH), yearling Chinook (CH1), subyearling Chinook (CH0), sockeye (SOX) in the LGR–MCN, RIS–MCN and MCN–BON reaches, 1998–2016. The error bars represent +/- 1 SE.

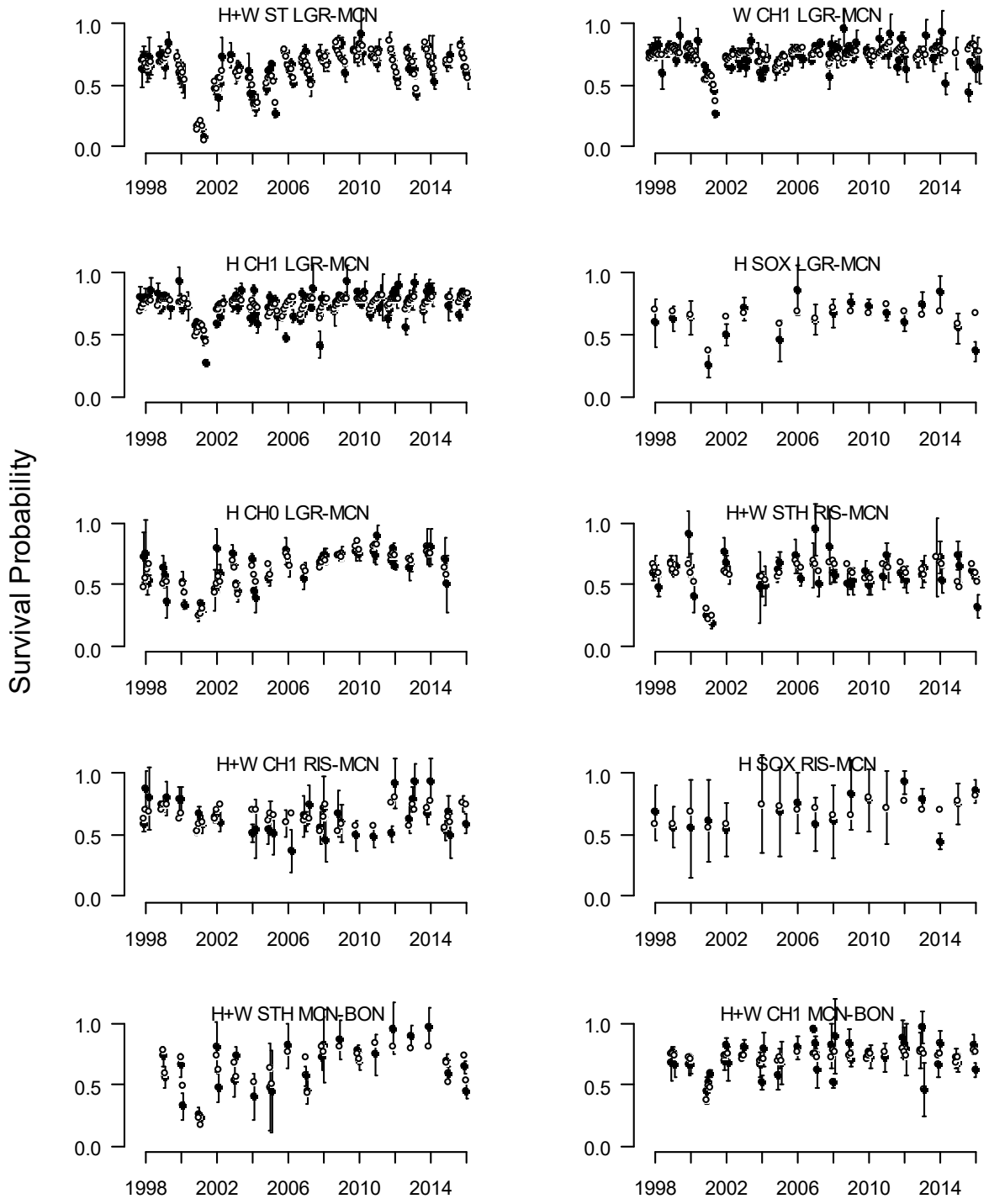

Figure 3.4 Estimates of in-river survival probability (black circles) and predicted in-river survival probability (open circles) for release cohorts of hatchery (H) and wild (W) steelhead (STH), yearling Chinook salmon (CH1), subyearling Chinook salmon (CH0), and sockeye salmon (SOX) in the LGR–MCN, RIS–MCN and MCN–BON reaches, 1998–2016. The error bars represent +/- 1 SE.

In the RIS–MCN reach, cohorts of yearling Chinook, steelhead, and sockeye demonstrated within-year mean $F\hat{T}T_i$, $\hat{Z}_i$ and $\hat{S}_i$ patterns similar to those observed in the LGR–MCN and MCN–BON reaches, varying considerably both within- and across-years (Figures 3.2, 3.3, and 3.4). For yearling Chinook and steelhead, mean $F\hat{T}T_i$ generally decreased over the migration season. Yearling Chinook in 2001 demonstrated the largest within-year variation in mean $F\hat{T}T_i$, ranging from 31 days early in the season to 20 days late in the season (Figure 3.2). Due to imprecision in the estimates of $\hat{S}_i$, general patterns in the estimates of $\hat{S}_i$ and $\hat{Z}_i$ in the RIS–MCN reach were difficult to discern (Figures 3.3 and 3.4). For both Chinook and steelhead, $\hat{Z}_i$ generally increased over the season. Steelhead $\hat{S}_i$ generally decreased over the season, but no general patterns were evident for Chinook $\hat{S}_i$.

Model-averaged coefficients and relative variable importance values indicated that Julian day, water transit time, spill, and the number of dams with spillway surface passage structures frequently were important factors for describing variability in *FTT* (Figure 3.5). The signs of the model coefficients for these variables indicated that juvenile yearling and subyearling Chinook, steelhead and sockeye migrated faster as water velocity increased (i.e., WTT was reduced) and when powerhouse passage rates were reduced. Relative variable importance values and the signs of the model coefficients indicated that juvenile yearling Chinook and steelhead also migrated faster as the season progressed. Because we were not able to develop within-season estimates of *FTT* for sockeye, we were not able to determine whether sockeye share similar increases in migration speed as Julian day increases. Model-averaged coefficients and relative variable importance values indicated that steelhead, sockeye and yearling Chinook in the RIS–MCN reach all had faster FTT when WTT was reduced. Model-averaged predictions captured a very high degree of the variation in mean *FTT* of all species and reaches (Table 3.4).

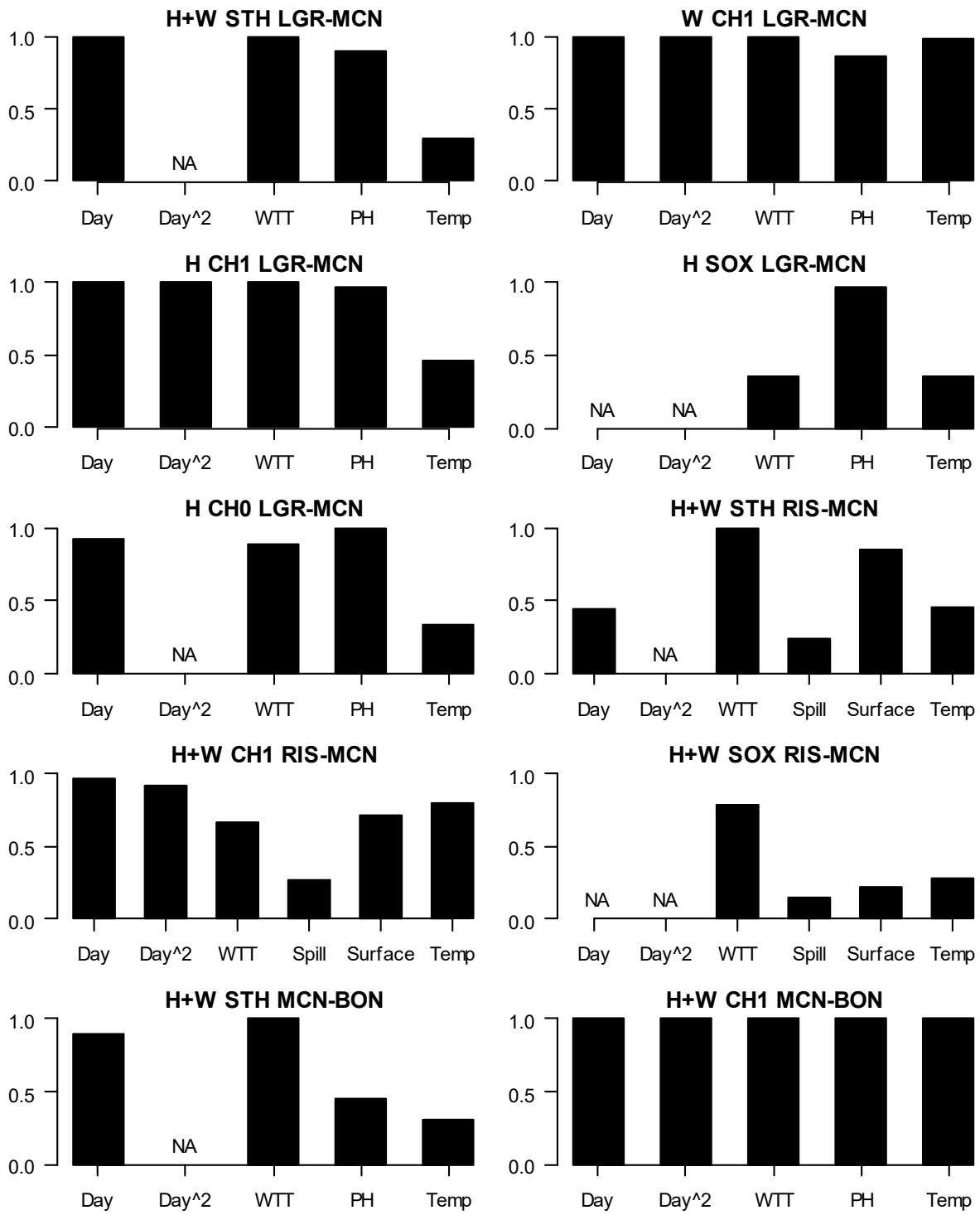

Figure 3.5 Relative variable importance values (y-axis) for fish travel time (FTT) models on release cohorts of hatchery (H) and wild (W) steelhead (STH), yearling Chinook salmon (CH1), subyearling Chinook salmon (CH0), and sockeye salmon (SOX) in the LGR–MCN, RIS–MCN and MCN–BON reaches, 1998–2016. Model variables included: Julian day of cohort release (Day), the quadratic effect of Julian day of cohort release (Day^2), water transit time (WTT), powerhouse passage (PH), average spill proportion (Spill), the number of dams with spillway surface weirs (Surface), and water temperature (Temp). NA represents variables that were not fit in the model for that species and reach.

Table 3.4 Coefficient of determination values (R^2) in models characterizing yearling and subyearling Chinook salmon, steelhead, and sockeye salmon fish travel time (FTT), instantaneous mortality rates (*Z*) and in-river survival probabilities within the LGR–MCN, RIS–MCN and MCN–BON reaches. Model forms with the lowest AIC_C are identified and include the standard linear regression model (LR), a mixed-effect model with migration year as a random effect (MY), and a mixed-effect model with both migration year and Julian day as random effects (MY + Day).

			FTT		Z		Survival
Reach	Species	Rearing type	Model form	R^2	Model form	R^2	R^2
LGR-MCN	steelhead	hatchery and wild	MY + Day	0.97	MY + Day	0.86	0.91
LGR-MCN	yearling Chinook	wild	MY + Day	0.97	MY	0.27	0.32
LGR-MCN	yearling Chinook	hatchery	MY + Day	0.95	MY	0.29	0.51
LGR-MCN	sockeye	hatchery and wild	LR	0.64	LR	0.43	0.64
LGR-MCN	subyearling Chinook	hatchery and wild	MY + Day	0.91	LR	0.19	0.69
RIS-MCN	steelhead	hatchery and wild	MY	0.90	LR	0.32	0.47
RIS-MCN	yearling Chinook	hatchery and wild	MY	0.82	LR	0.13	0.17
RIS-MCN	sockeye	hatchery and wild	LR	0.24	LR	0.33	0.29
MCN-BON	steelhead	hatchery and wild	MY + Day	0.97	LR	0.51	0.73
MCN-BON	yearling Chinook	hatchery and wild	MY	0.95	MY	0.19	0.30

Model-averaged coefficients and relative variable importance values indicated that Julian day of release, spill, and water temperature were frequently the most important factors for characterizing the variability in *Z* (Figure 3.6). The signs of the model-averaged coefficients indicated that *Z* tended to increase over the migration season and as water temperatures increased, and tended to decrease when powerhouse passage rates were reduced. Exceptions to these patterns included sockeye in both the RIS–MCN and LGR–MCN reaches, where the sign of the model-averaged coefficient suggested that *Z* decreased with increasing water temperatures. Model-averaged predictions captured a moderate-high degree of the variation in *Z* across species and reaches (Table 3.4).

Combining the models for predicting mean FTT and *Z* resulted in generally high accuracy in predicting reach survival probabilities for the species-reach combinations that we examined (Table 3.4). As mentioned above, the models developed for FTT explained a very high proportion of the observed variation in FTT. Although the models for *Z* explained a lower proportion of the variability in *Z*, when the models for FTT and *Z* were combined to make predictions for survival probabilities, a relatively high proportion of the variation was captured. These results show that the models developed by the CSS are effective for characterizing and understanding sources of variation in the migration rates, mortality rates and survival probabilities of yearling and subyearling Chinook, steelhead and sockeye.

Concerns have been raised over the poor condition and survival of sockeye released from the Springfield Hatchery in 2015 and 2016 (Hassemer 2016). Due to these concerns, only data from 1998-2014 was used to examine the effects of environmental variables on fish travel time, instantaneous mortality rates, and survival probabilities for hatchery sockeye in the LGR-MCN reach. Using those models that were developed, we generated predictions of the fish travel time,

instantaneous mortality rates, and survival probabilities that would have been expected for sockeye in 2015 and 2016 (Figures 3.2-3.4). Those predictions indicated that fish travel times were consistent with expectations in 2015 and 2016 based on the water transit times, powerhouse passage rates, and water temperatures that were present in those years. Instantaneous mortality rates and survival probabilities were also consistent with expectations in 2015. This result may be due to the fact that the PIT tag releases in 2015 consisted of 49,772 sockeye released from Sawtooth Hatchery and 49,307 sockeye released from Springfield Hatchery. Releases in 2016 were only from the Springfield Hatchery. The instantaneous mortality rate in 2016 (Z = 0.132) was the highest rate ever observed and was much higher than the average rate 1998-2014 (average Z = 0.049). The survival probability in 2016 ($\hat{S}$ = 0.369) was about half the average survival probability 1998-2014 (average S = 0.644).

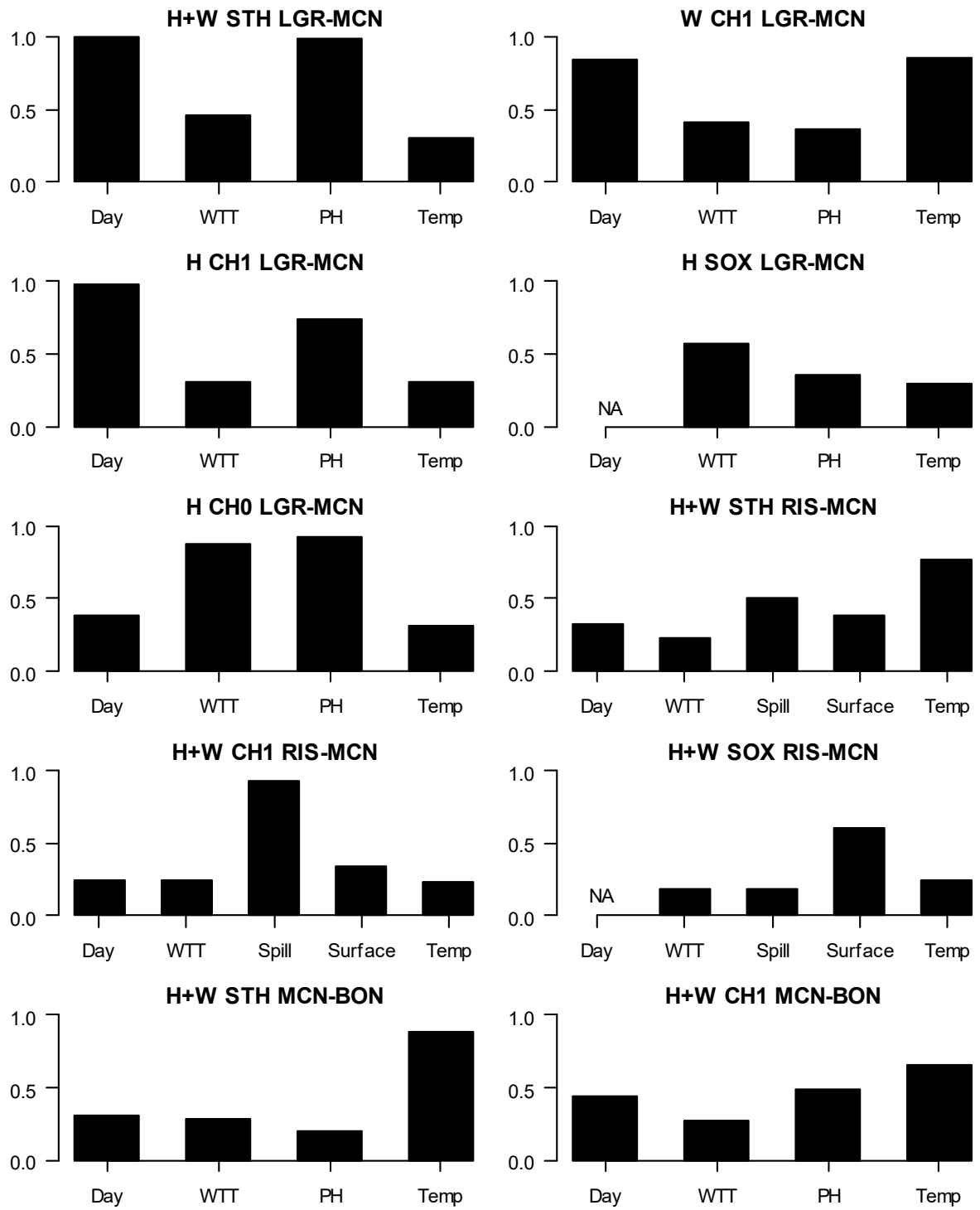

Figure 3.6 Relative variable importance values (y-axis) for instantaneous mortality rate (*Z*) models on release cohorts of hatchery (H) and wild (W) steelhead (STH), yearling Chinook salmon (CH1), subyearling Chinook salmon (CH0), and sockeye salmon (SOX) in the LGR–MCN, RIS–MCN and MCN–BON reaches, 1998–2016. Model variables included: Julian day of cohort release (Day), water transit time (WTT), powerhouse passage (PH), average spill proportion (Spill), the number of dams with spillway surface weirs (Surface), and water temperature (Temp). NA represents variables that were not fit for that species and reach.

Results of TDG Evaluations

Residual plots of instantaneous mortality rates and survival probabilities against average and maximum TDG levels that were experienced by outmigrating yearling Chinook salmon and steelhead indicated no detrimental effects of high TDG over the range of TDG levels observed 1998-2016 (Figures 3.7-3.10). The majority of the observations were collected under TDG levels of less than 120%, which is the current tailrace limit. However, a number of observations were collected under involuntary spill levels where the TDG levels were above 120% and up to a maximum of 135%. Those observations that were collected when TDG levels were over 120% also showed no indications that TDG was having a detrimental effect on instantaneous mortality rates or survival probabilities.

Similar results were found for the instantaneous mortality rate models that included average or maximum TDG along with Julian Day, water transit time, water temperature, and powerhouse passage rates. The Relative Variable Importance values for the TDG variables were low compared to the other variables, indicating that the TDG variables were not consistently included in the top fitting models based on AICc (Figures 3.11-3.12). Consistent with these Relative Variable Importance results, the model-averaged coefficients of the effects of average and maximum TDG were near zero and confidence intervals overlapped zero for all species and reaches (Figure 3.13), indicating that TDG had little influence on instantaneous mortality rates.

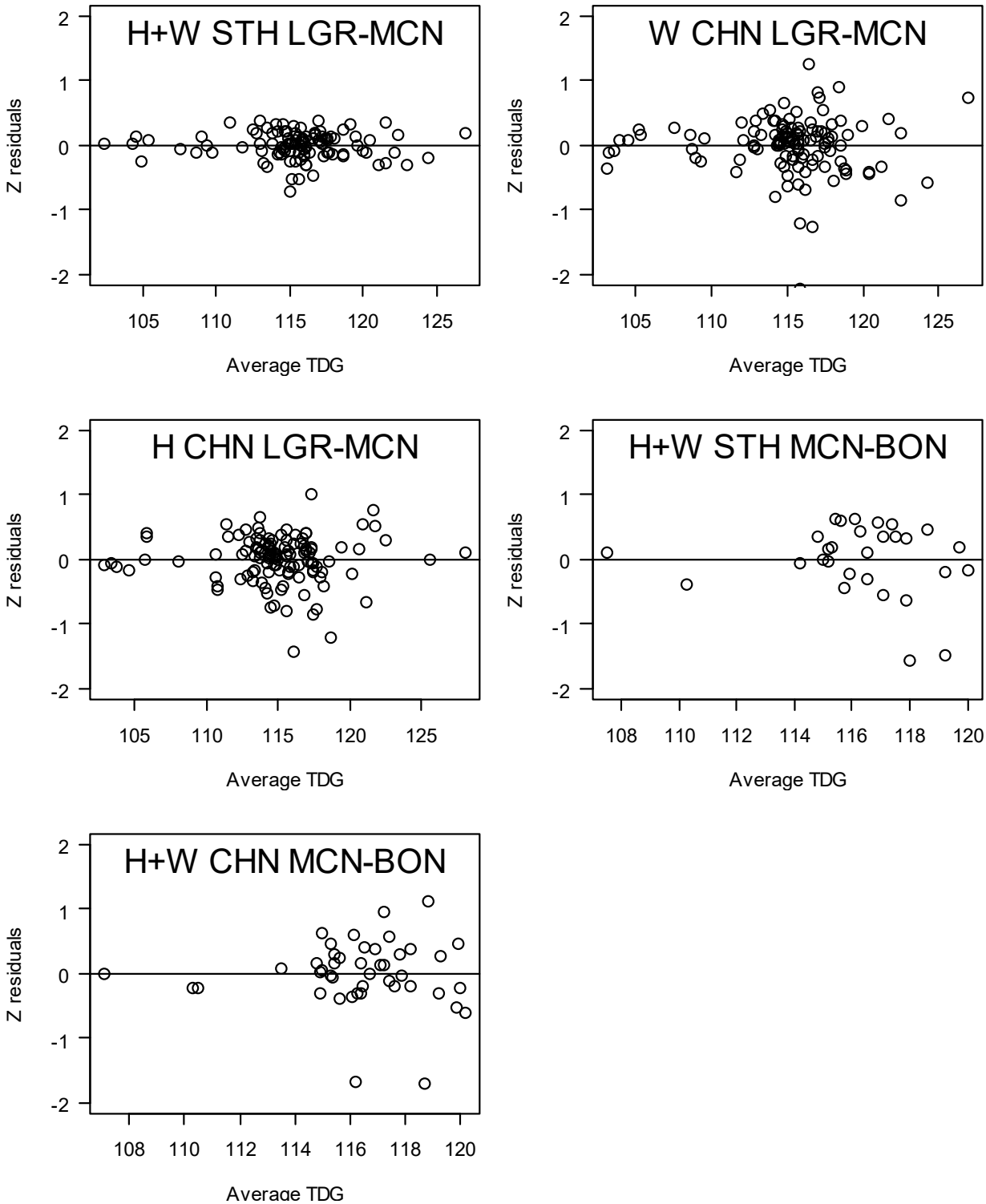

Figure 3.7 Instantaneous mortality rate (Z) residuals plotted against average Total Dissolved Gas (TDG) levels experienced by hatchery (H) and wild (W) yearling Chinook salmon (CHN) and steelhead (STH) in the LGR-MCN and MCN-BON reaches 1998-2016.

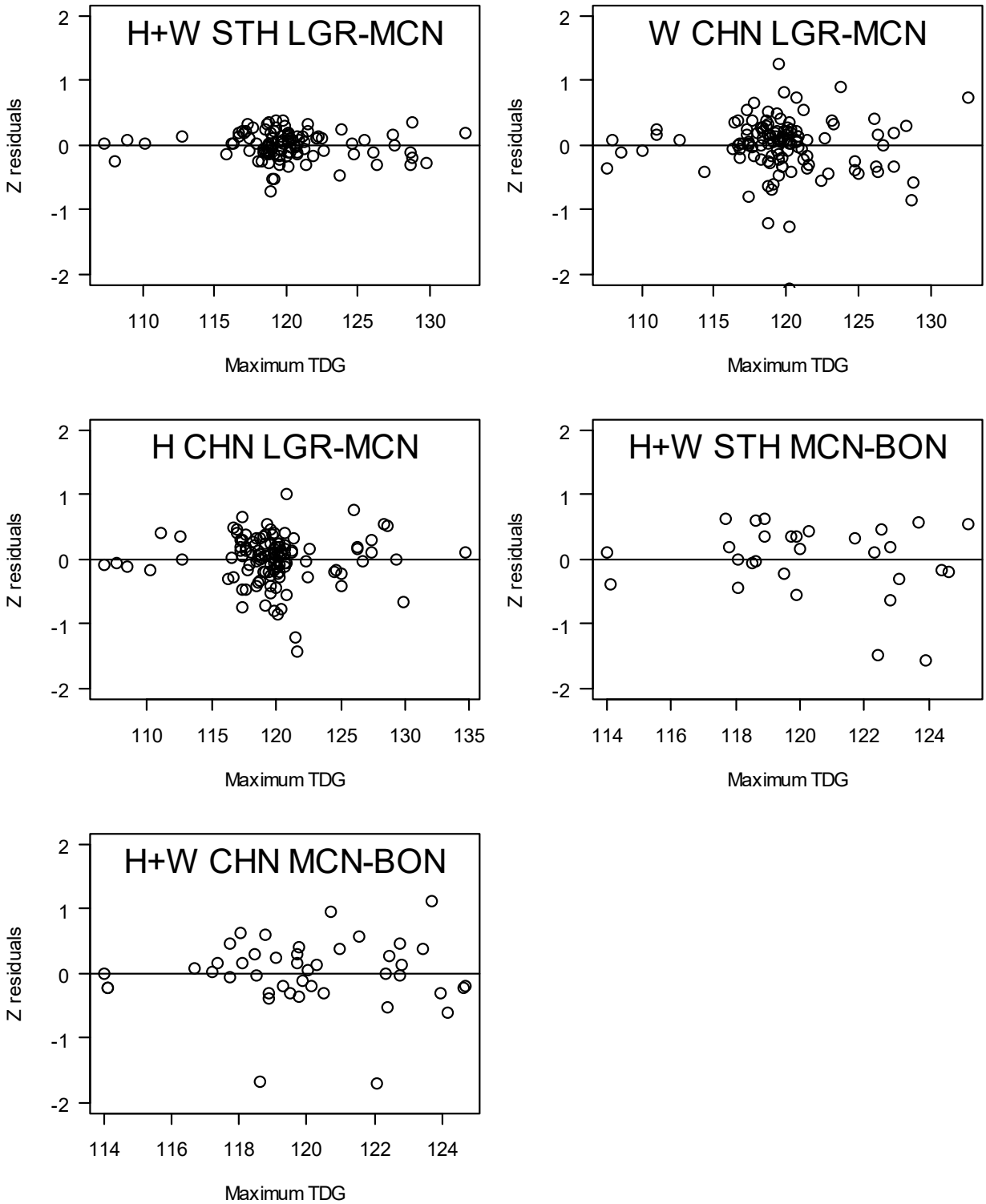

Figure 3.8 Instantaneous mortality rate (Z) residuals plotted against maximum Total Dissolved Gas (TDG) levels experienced by hatchery (H) and wild (W) yearling Chinook salmon (CHN) and steelhead (STH) in the LGR-MCN and MCN-BON reaches 1998-2016.

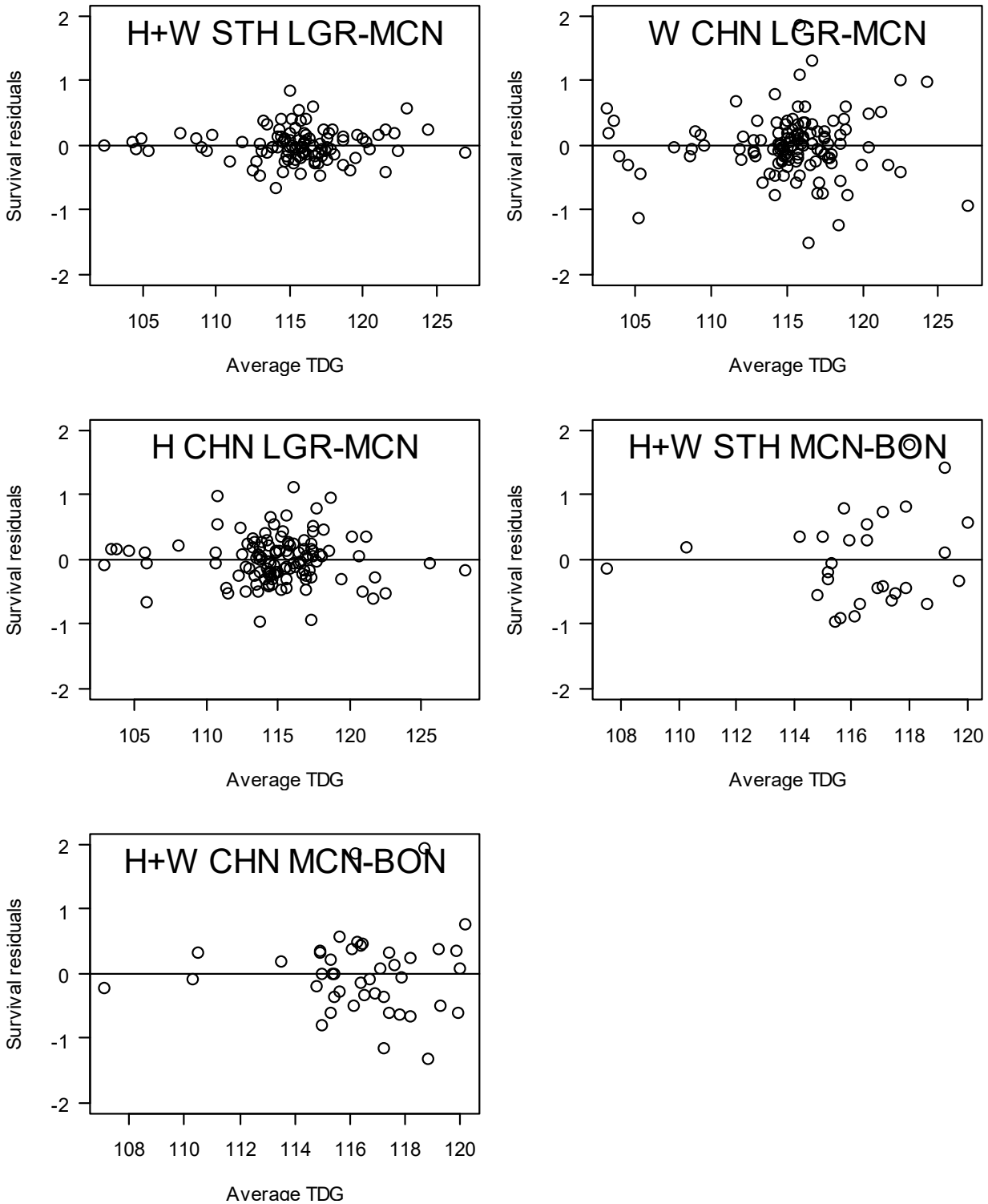

Figure 3.9 Survival residuals plotted against average Total Dissolved Gas (TDG) levels experienced by hatchery (H) and wild (W) yearling Chinook salmon (CHN) and steelhead (STH) in the LGR-MCN and MCN-BON reaches 1998-2016.

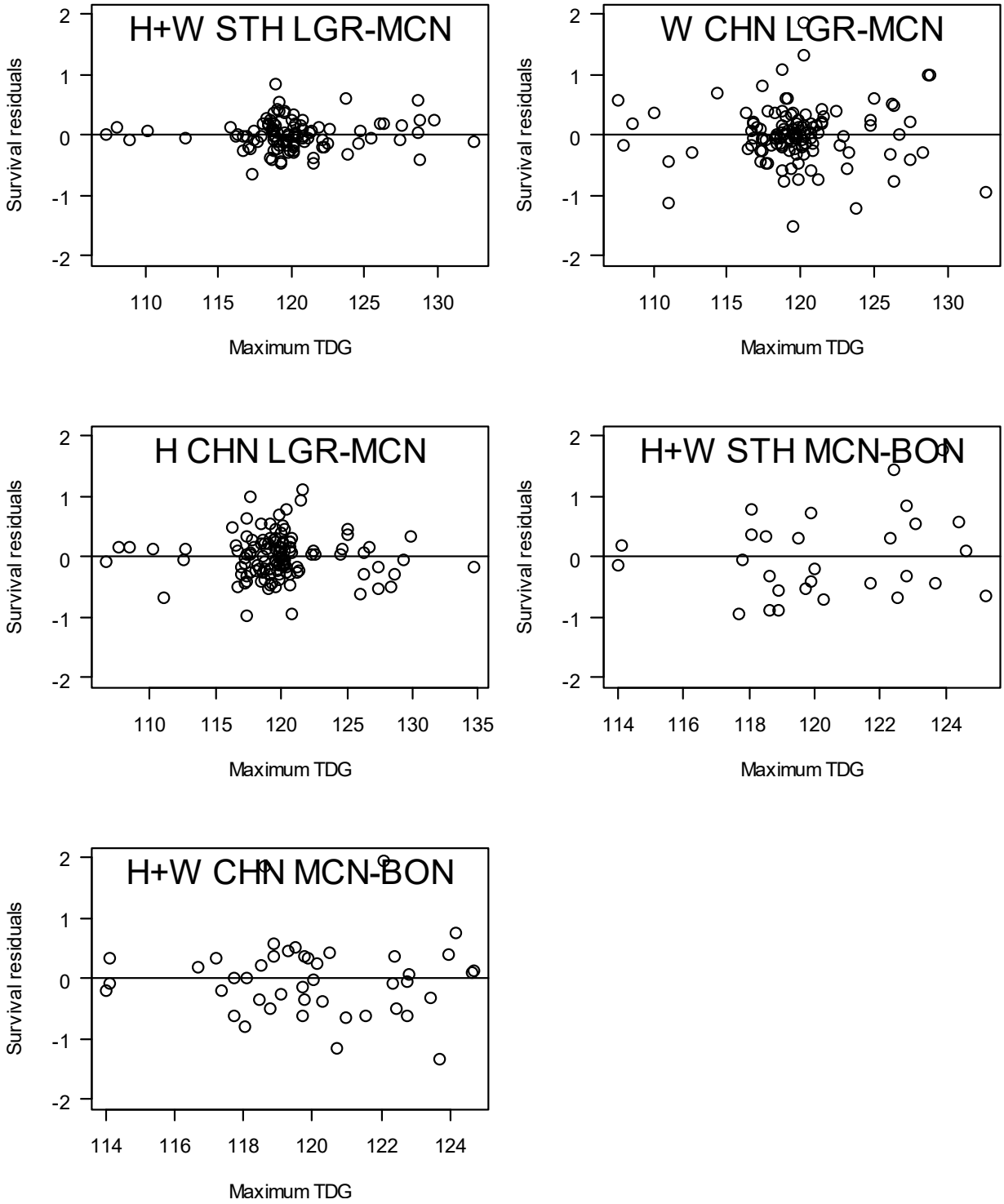

Figure 3.10 Survival residuals plotted against maximum Total Dissolved Gas (TDG) levels experienced by hatchery (H) and wild (W) yearling Chinook salmon (CHN) and steelhead (STH) in the LGR-MCN and MCN-BON reaches 1998-2016.

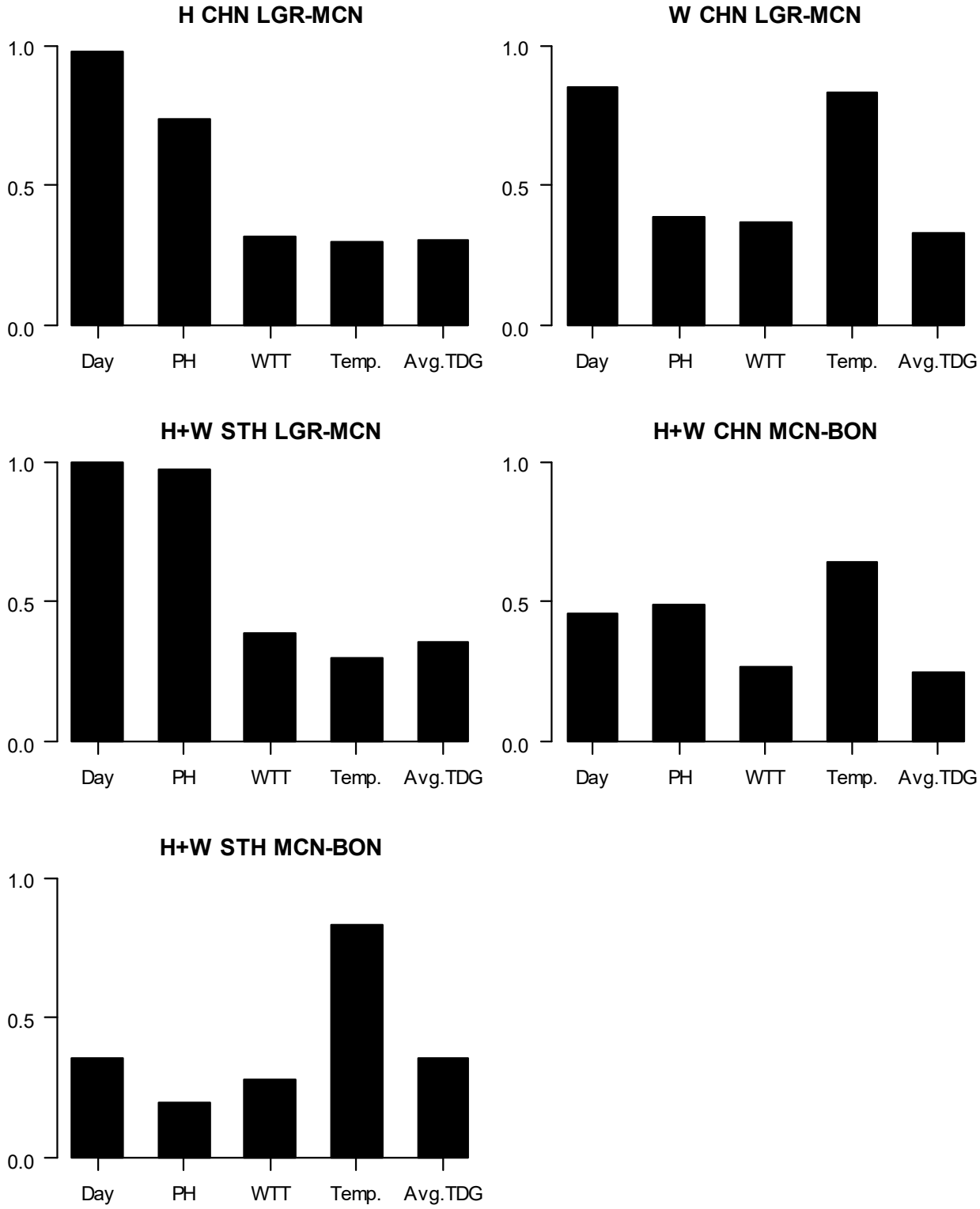

Figure 3.11 Relative variable importance values (y-axis) for instantaneous mortality rate (Z) models of release cohorts of hatchery (H) and wild (W) steelhead (STH) and yearling Chinook salmon (CHN) in the LGR–MCN and MCN–BON reaches, 1998–2016. Model variables included: Julian day of cohort release (Day), water transit time (WTT), powerhouse passage (PH), water temperature (Temp), and average Total Dissolved Gas (Avg.TDG).

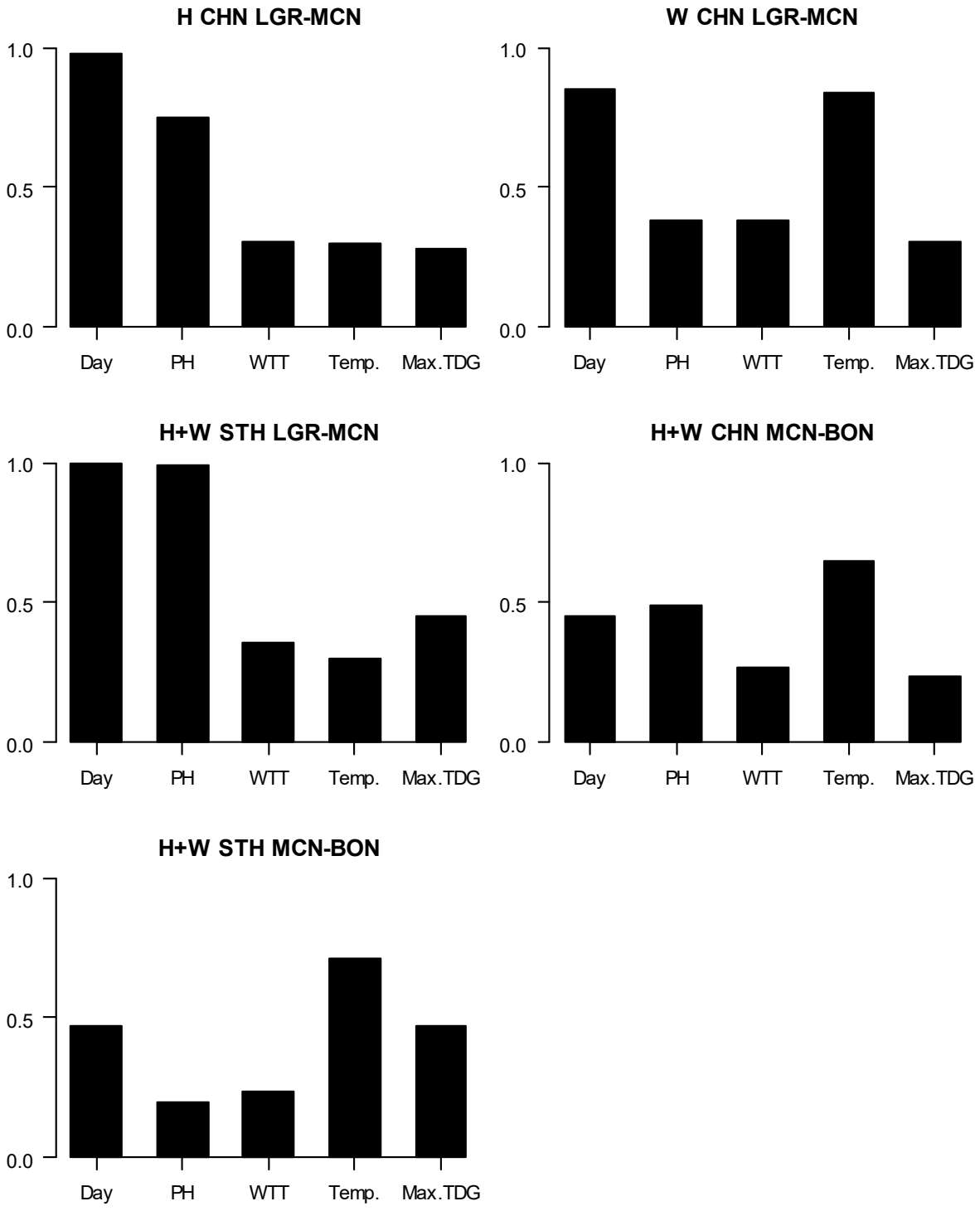

Figure 3.12 Relative variable importance values (y-axis) for instantaneous mortality rate (Z) models of release cohorts of hatchery (H) and wild (W) steelhead (STH) and yearling Chinook salmon (CHN) in the LGR–MCN and MCN–BON reaches, 1998–2016. Model variables included: Julian day of cohort release (Day), water transit time (WTT), powerhouse passage (PH), water temperature (Temp), and maximum Total Dissolved Gas (Max.TDG).

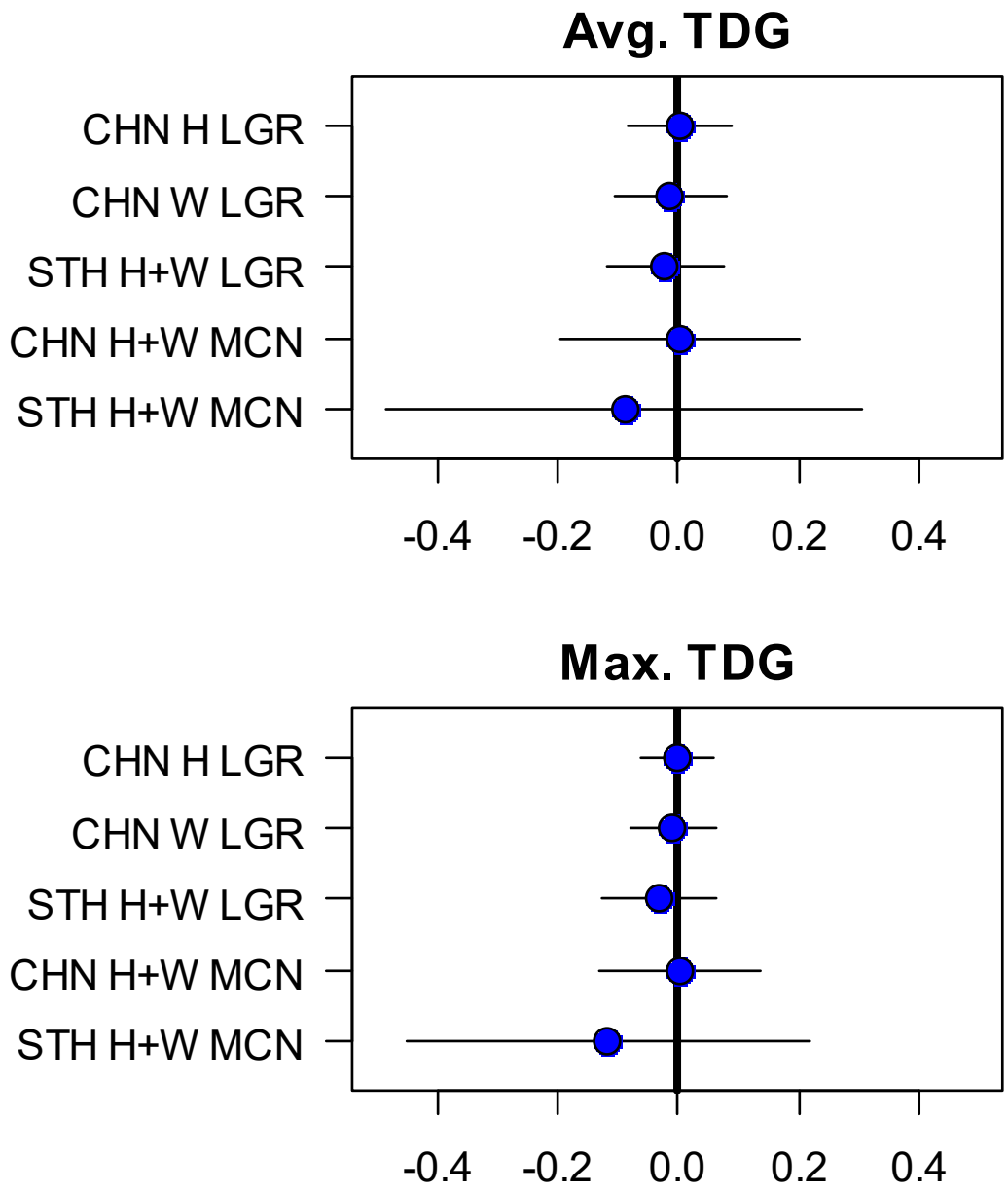

Figure 3.13 Model-averaged coefficients (blue circles) and confidence intervals (horizontal black lines) for the effect of average and maximum Total Dissolved Gas (Avg. TDG, Max. TDG) on instantaneous mortality rates (Z) for hatchery (H) and wild (W) yearling Chinook salmon (CHN) and steelhead (STH) in the LGR-MCN (LGR) and MCN-BON (BON) reaches.

Discussion

In this analysis we provided an extensive synthesis of the patterns of variation in juvenile yearling and subyearling Chinook, steelhead and sockeye fish travel time and survival within the hydrosystem. In addition to these commonly used metrics of fish travel time and survival, we

also developed and reported estimates of instantaneous mortality rates, along with estimates of precision for those rates. We observed substantial variation in mean fish travel time, survival, and instantaneous mortality rates both within- and across-years.

Across the species and reaches that were evaluated, some consistent patterns emerge. Model-averaged coefficients and relative variable importance values indicated that fish travel time is fastest when WTT is reduced (i.e., higher water velocity) and powerhouse passage rates are low. These results reflect the responses to the conditions that fish experience as they migrate through the series of reservoirs and dams in the hydropower system. The effect of WTT most likely influences the amount of time required to transit the reservoirs, with faster WTT resulting in faster fish travel time through the reservoirs. Faster WTT may also influence the amount of time required to migrate through the forebay, concrete, and tailrace areas of the dams. The effect of powerhouse passage rates most likely influences the amount of time required to migrate through the forebay, concrete and tailrace areas of the dams themselves. The powerhouse passage rates incorporate the effects of spillway weirs, flow, and spill proportions to determine the proportion of fish that are expected to pass through the powerhouse (McCann et al. 2015, Appendix J).

There are also consistent patterns in terms of the factors that tend to influence the instantaneous mortality rates. Model-averaged coefficients and relative variable importance values indicated that mortality rates tend to increase over the migration season and with water temperature. In addition, the instantaneous mortality rates tend to be lower under conditions of lower powerhouse passage rates. Potential mechanisms for the pattern of increasing mortality rates over the migration season and with water temperature could include (1) declining smolt energy reserves or physiological condition over the migration season and with water temperature, (2) increasing predation rates on smolts over the migration season and with water temperature, (3) increases in disease susceptibility or disease-related mortality over the migration season and with water temperature, or (4) some combination of these often interrelated mechanisms. Potential mechanisms for lower mortality rates with lower powerhouse passage rates include reduced forebay and tailrace predation and reduced turbine passage route proportions as powerhouse passage rates decline. The combination of factors that influence fish travel time and instantaneous mortality are the factors that influence survival, and the results indicate that individual factors may be important to one or both of these rates (FTT and *Z*, Figures 3.5 and 3.6).

Generally, models for *FTT* fit substantially better than those for *Z* or survival. Analyses suggest that there are two reasons for this. First, the *FTT* data are relatively more variable, which provides relatively more variation to explain in *FTT* than for *Z* or survival. Second, the *FTT* data have greater precision than the *Z* or survival data, which helps to separate signals from sampling noise. Among the species analyzed, steelhead survival rates are more variable than yearling Chinook salmon, possibly due to greater sensitivity to environmental conditions. Although there is little that can be done to influence the variability among cohorts in response to the environmental and management factors that they experience, increasing precision of the Z and survival estimates is expected to increase the amount of variability that is explained.

These results indicate that improvements to fish travel time, mortality rates and survival may be possible through management actions that reduce WTT and increase spill percentages. There are only two means for reducing WTT: reducing reservoir elevations and/or increasing flow rates. Currently, only the reservoirs in the lower Snake River are maintained near their

minimum operating elevations during the fish migration season. The McNary, John Day, The Dalles and Bonneville projects all operate several feet above their minimum operating elevations during the fish migration season. Even without a change in flow levels, the data indicate that there is opportunity to reduce fish travel time and increase survival through the MCN-BON reach if these four projects were to operate at their minimum operating pools. The data also indicate that there is an opportunity to reduce fish travel time and increase survival throughout the FCRPS through increases in spill levels up to the tailrace dissolved gas limits. Currently, none of the projects voluntarily operate up to the dissolved gas limit spill levels on a 24-hour basis. If all the projects were to do so, the data indicate that fish travel times are expected to be reduced, and as a consequence survival probabilities would be expected to increase.

The models developed and presented in this analysis could serve as a basis for conducting adaptive management experiments on the FCRPS. The models quantify the expected improvements that would occur through reductions in WTT and increases in spill percentages, and how those improvements may vary over the migration season. The essence of adaptive management is implementing experimental management actions and monitoring the biological responses to those management actions. The PIT-tagged fish that are released annually provide a reliable means for monitoring these types of adaptive management experiments. One recent example of an adaptive management experiment is the implementation of court-ordered summer spill at the Snake River collector projects. The PIT-tag data revealed a dramatic improvement in travel time and survival for subyearling fall Chinook salmon following the implementation of court-ordered summer spill. Similar adaptive management experiments, such as reducing WTT in the MCN–BON reach or dissolved gas limit spill operations on a 24-hour basis, could reveal similarly dramatic improvements for yearling and subyearling Chinook, steelhead and sockeye.

Regional requests and recommendations to increase spill levels to improve survival for juvenile outmigrants have been countered by concerns over potential detrimental effects of high Total Dissolved Gas levels on juvenile mortality rates or survival probabilities. Using a comprehensive data set of instantaneous mortality rates and survival probabilities collected 1998-2016, we found no evidence that high TDG levels were associated with increased mortality rates or reduced survival probabilities. If spill levels are increased in the future, similar analyses could be performed to determine whether this continues to be the case.

We see these models as powerful tools for continued development, evaluation, and refinement of alternative hypotheses on the effects of various environmental and management factors on smolt survival probabilities and migration rates. However, improvements in the precision (i.e., measurement error) of the survival estimates in the MCN–BON reach and the RIS–MCN reach could be useful for further evaluating the effects of various environmental and management factors. In these two reaches, confidence intervals are relatively wide, making it difficult to separate process variability from measurement error. There are two means for improving precision of these survival estimates: increasing the number of PIT-tagged fish or increasing the detection probabilities at the dams. Increasing the number of PIT-tagged fish that are released would help improve precision, but it likely would require a large increase to substantially improve precision. In contrast, we believe that increasing the detection efficiency through spillway detection systems has a greater potential to improve the precision in the survival estimates. In addition to helping improve survival estimate precision, spillway detection systems could also help further elucidate emerging issues of delayed mortality associated with powerhouse passage relative to spillway passage. Further work is needed to evaluate where a

spillway detection system would be most beneficial, but we see this as an important issue that should be pursued within the region.

Conclusions

- The data collected and analyzed over 1998-2016 juvenile migration years showed considerable variation both within- and across-years in fish travel time, instantaneous mortality rates, and survival rates.
- Combinations of managed factors such as water transit time and spill proportions, and unmanaged factors such as Julian Day and water temperature were found to be important for explaining the variability in juvenile migration characteristics.
- Results indicate that improvements to fish travel time, mortality rates, and survival may be possible through management actions that reduce WTT and increase spill percentages.
- Residual analyses and regression analyses found that Total Dissolved Gas was not an important factor for explaining patterns in instantaneous mortality rates or survival rates across the years analyzed.
- Concerns have been raised over the poor condition and survival of sockeye released from the Springfield Hatchery in 2015 and 2016. Snake River hatchery sockeye released in 2016 had the highest instantaneous mortality rate observed over the time series and survival was about half of average.

Additional References:

Hassemer, P. 2016. Memorandum from Pete Hassemer (IDFG) to Michele DeHart (FPC) RE: Condition of Springfield Hatchery sockeye smolts in 2015 and 2016.

Fish Passage Center. 2016. Memorandum from Michele DeHart (FPC) to Tom Rien (ODFW) RE: Review of "Factors influencing the survival of outmigrating juvenile salmonids through multiple dam passage: an individual –based approach" by Elder, Woodley, Weiland, and Strecker, June 23, 2016.

Elder, T., C.M. Woodley, M.A. Weiland, and A.L. Strecker. 2016. Factors influencing the survival of outmigrating juvenile salmonids through multiple dam passages: an individual-based approach. Ecology and Evolution 6(16):5881-5892.

CHAPTER 4
PATTERNS IN ANNUAL OVERALL SARS

Success of any hydrosystem mitigation strategy will require achievement of smolt-to-adult survival rates sufficient to meet recovery and rebuilding objectives, in combination with a program to maintain or achieve adequate survival in other life stages. An independent peer review of the transportation program in the early 1990s (Mundy et al. 1994) concluded: "[u]nless a minimum level of survival is maintained for listed species sufficient for them to at least persist, the issue of the effect of transportation is moot."

The Northwest Power and Conservation Council (NPCC 2003, 2009, 2014) adopted a goal of achieving overall SARs (including jacks) in the 2%–6% range (4% average; 2% minimum) for federal ESA-listed Snake River and upper Columbia River salmon and steelhead. For the populations in these listed groups, an overall SAR is the SAR that includes the survival of all outmigrating smolts weighted across their different in-river and transport route experiences; it is the SAR of an entire cohort of smolts, irrespective of their route of passage through the hydrosystem. The NPCC (2009) Fish and Wildlife Program objectives for unlisted populations or listed populations downstream of the Snake River and Upper Columbia River basins are to "significantly improve the smolt-to-adult return rates (SARs) for Columbia River Basin salmon and steelhead, resulting in productivity well into the range of positive population replacement."

The NPCC (2009 and 2014) also adopted a strategy to identify the effects of ocean conditions on anadromous fish survival and use this information to evaluate and adjust inland actions. The NPCC noted that while we cannot control the ocean, we can monitor ocean conditions and related salmon survival and take actions to improve the likelihood that Columbia River salmon can survive varying ocean conditions. A better understanding of the conditions salmon face in the ocean can suggest which factors will be most critical to survival, and thus provide insight as to which actions taken inland will provide the greatest restoration benefit. Analyses in this chapter address the extent to which wild spring/summer Chinook and steelhead population aggregates may be meeting the NPCC (2014) biological objectives. Parameters estimated in the CSS allow for partitioning from SARs estimates of marine survival rates from the stage smolts enter the estuary to adult return, *S.oa* (Haeseker et al. 2012), and first year ocean survival rates, *S.o1* (Wilson 2003; Zabel et al. 2006; Petrosky and Schaller 2010; Tuomikoski et al. 2012). These survival rates can then be used to evaluate ocean and smolt migration factors that may influence ocean survival as called for in the Fish and Wildlife Program (NPCC 2009).

The NPCC 2%–6% SAR objectives are consistent with analyses conducted by the Plan for Analyzing and Testing Hypotheses (PATH), in support of the 2000 Biological Opinion of the Federal Columbia River Power System (FCRPS). Marmorek et al. (1998) found that median SARs of 4% were necessary to meet the NMFS interim 48-year recovery standard for Snake River spring/summer Chinook; meeting the interim 100-year survival standard required a median SAR of at least 2%. The NPCC (2009 and 2014) SAR objectives did not specify the points in the life cycle where Chinook smolt and adult numbers should be estimated. However, the original PATH analysis for Snake River spring/summer Chinook was based on SARs calculated as adult and jack returns to the uppermost dam (Marmorek et al. 1998). PATH analyses also did not identify specific SARs necessary for steelhead survival and recovery. However, before completion of the FCRPS, steelhead SARs were somewhat greater than those of spring/summer

Chinook (Marmorek et al. 1998). The Interior Columbia River Technical Recovery Team (ICTRT 2007) developed biological recovery criteria based on the Viable Salmonid Population concepts (McElhany et al. 2000). Additional SAR objectives may be associated with the ICTRT recovery criteria for abundance and productivity when adopted or incorporated into a Recovery Plan, as well as with the objectives identified in Fish and Wildlife Program subbasin plans, and other State and Tribal fishery management plans. The Independent Scientific Advisory Board (ISAB 2012) review of the 2012 CSS draft annual report also highlighted the NPCC SAR objectives as an important regional programmatic issue. Regardless of specific future SAR objectives, the same types of data and analytical methods will be required to evaluate the overall effectiveness of hydrosystem actions in addressing recovery and mitigation goals. The time series of SARs, which the CSS is developing for various populations throughout the Columbia Basin, will be invaluable in addressing multiple long-term programmatic goals and objectives. To address these multiple objectives, we present bootstrapped SARs and confidence intervals based on CSS PIT-tagged adult returns to both Bonneville Dam (BOA) and the uppermost dam for Snake River and Yakima River fish (e.g., Lower Granite Dam, GRA; and McNary Dam, MCA). Alternative SAR objectives will likely require enumerating smolts and adults at different locations, depending on how broadly the objective is defined. That is, different adult accounting locations would be required if a SAR objective was defined narrowly for population persistence or more broadly to maintain productive natural populations with sustainable fisheries. A SAR objective for persistence may need to account for adults returning to the spawning grounds, whereas broader objectives would also need to account for adults returning to various locations to meet harvest objectives (e.g., subbasin or Columbia River mouth).

Most SAR estimates in this report are based on smolts at the uppermost FCRPS dam with juvenile detection capability (Lower Granite, McNary, John Day or Bonneville), and adults at either Bonneville Dam or the uppermost dam. PIT-tagged smolts and returning adults from the upper Columbia region pass an additional three to five Public Utility District (PUD) dams upstream of MCN (Wenatchee — three dams, Entiat — four dams, Methow — five dams) that do not have full juvenile PIT tag detection capabilities. Therefore, smolt migration mortality that occurs upstream of MCN is not accounted for in the MCN-BOA SAR estimates and the portion of the life cycle and hydrosystem migration experience represented is less than that for SAR estimates for the Snake River and Mid-Columbia salmon and steelhead populations. For upper Columbia populations we have also begun to estimate SARs from Rocky Reach Dam (RRE) where possible.

We have made preliminary comparisons of the overall SAR estimates for wild groups to the NPCC 2%–6% SAR objectives, recognizing additional accounting for harvest, straying and other upstream passage losses may be needed in the future as NPCC and other SAR objectives are clarified. We also compare SARs of hatchery groups to the 2%-6% SAR objectives, recognizing that hatchery stocks have different mitigation and management objectives than wild populations.

To compare historical population productivity in the smolt-to-adult life stage necessitates accounting for changes in mainstem harvest rates and upstream passage success (Petrosky and Schaller 2010). Mainstem Columbia River harvest rates decreased markedly in the 1970s following construction of the FCRPS and the decline in abundance and productivity of upriver Columbia and Snake River populations. Therefore, we also present a time series of SARs for Snake River wild spring/summer Chinook and steelhead based on smolts at the uppermost dam

to adult returns to the Columbia River mouth for the 1964 to 2013 (steelhead) or 2014 (Chinook) smolt migration years; this time frame spans completion of the FCRPS, decreases in Columbia River harvest rates, and a period of variable ocean conditions.

The NPCC 2%–6% SAR objective for Chinook addresses the total adult return including jacks (i.e., 1-salt male Chinook). Therefore, in this chapter we present estimates of overall Chinook SARs with jacks included and the CSS standard reporting statistic of SARs with jacks excluded. Most other Chinook analyses in this and previous reports, are based strictly on adults (age 2-salt and older). These calculations include the generation of SARs by study category, TIR, *D*, and adult upstream migration success rates. By using only 2-salt and older returning spring/summer Chinook adults in the estimation of the key CSS parameters, we are assuring that the results will be more directly reflective of the primary spawning populations (females and older males) in each Chinook ESU, region or subbasin. This is consistent with previous population viability (persistence) analyses (Marmorek et al. 1998; STUFA 2000; Karieva et al. 2000; Deriso et al. 2001; Peters and Marmorek 2001; Wilson 2003; Zabel et al. 2006; ICTRT 2007).

The primary objectives for Snake River wild and hatchery spring/summer Chinook and steelhead are to update the long-term SAR data series for CSS study fish, and to begin reporting SARs at finer geographic scales. In the 2017 annual report, we also estimate SARs of wild spring/summer Chinook groups from the Grande Ronde/Imnaha, South Fork Salmon, Middle Fork Salmon, Upper Salmon and Clearwater Major Population Groups (MPGs) for smolt migration years 2006–2015. (Note: we further subdivided SARs into subbasin for the Grande Ronde/Imnaha MPG in this report). The overall SARs are presented for all 22 years of PIT-tagged wild spring/summer Chinook data and 18 years of PIT-tagged hatchery spring/summer Chinook data. Overall SARs for Snake River aggregate wild and aggregate hatchery steelhead are presented for 18 years beginning in 1997. We also calculated SARs for Snake River wild steelhead at an MPG level (Clearwater, Grande Ronde, Imnaha, Salmon) and for A-run and B-run wild steelhead, smolt migration years 2006–2014. SARs are calculated as adult returns to either Bonneville Dam (BOA) or Lower Granite Dam (GRA).

Personnel involved with the CSS, Lower Snake River Compensation Plan (LSRCP), and Idaho Power Company (IPC) coordinated efforts to increase the PIT tagging of Snake River hatchery spring/summer Chinook and steelhead. All Snake Basin hatchery spring/summer Chinook major production releases upstream of Lower Granite Dam now have representative PIT tag releases with the addition of groups from Clearwater Hatchery spring Chinook (first year representation, 2006), Sawtooth Hatchery spring Chinook (2007), Pahsimeroi Hatchery summer Chinook (2008) and Clearwater Hatchery summer Chinook (2011). Increased hatchery steelhead tagging began in migration year 2008 so key parameters could be estimated at a finer resolution of run-type and subbasin for Grande Ronde River A-run (GRN-A), Imnaha River A-run (IMN-A), Salmon River A-run (SAL-A), Hells Canyon Dam A-run (HCD-A), Salmon River B-run (SAL-B), and Clearwater River B-run (CLW-B) steelhead groups.

The objective for Snake River sockeye is to continue the data series of SARs. PIT tagging of Snake River hatchery sockeye began in migration year 2009 as a Corps of Engineers study and is continuing under the CSS; we report the overall SARs from Sawtooth and Oxbow hatcheries for migration years 2009–2015 and from Springfield Hatchery beginning in 2015.

The primary objective for mid-Columbia River (BON to PRD) wild and hatchery spring Chinook and steelhead is to update SAR data series for subbasins in this region. Overall SARs for smolt migration years 2000–2015 are presented for wild spring Chinook from the John Day River and Yakima River. For hatchery spring Chinook, overall SARs from 2000 to 2015 are presented for Carson and Cle Elum hatcheries and for Warm Springs Hatchery spring Chinook during 2007–2015. Overall SARs are also presented for wild steelhead from the John Day River (2004–2014), Deschutes River (2007–2014) and Yakima River (2002–2014). SARs are calculated as adult returns to Bonneville Dam (BOA), and for Yakima stocks as adult returns to both McNary Dam (MCA) and BOA.

The primary objectives for upper Columbia River (above PRD) wild and hatchery spring Chinook and steelhead and sockeye are to develop and update SAR data series for subbasins in this region, and to begin SAR data series for additional populations. We estimated MCN–BOA SARs for wild spring Chinook from the Entiat/Methow River (2006–2015) and Wenatchee River (2007–2015); Leavenworth hatchery spring Chinook (2000–2015); wild steelhead (Wenatchee, Entiat and Methow rivers from 2006 to 2014); and hatchery steelhead released into the Wenatchee River (2003–2014). Because of the limited ability to detect PIT-tagged juvenile out-migrants in the Columbia River upstream of MCN, the CSS has begun to estimate SARs of Upper Columbia Chinook, steelhead and sockeye populations upstream from Rocky Reach Dam (RRE) using smolt abundance estimates at RRE for smolt migration years 2008–2014 (through 2015 for spring Chinook and sockeye). In the 2017 report, we also added three new groups in the upper Columbia region: Entiat hatchery summer Chinook (2011-2015); Winthrop hatchery spring Chinook (2009-2015); and Wenatchee wild sockeye (2014-2015) In addition, we have included time series of SARs using Fish Passage Center Smolt Monitoring Program (SMP) tagging of combined hatchery/wild groups of yearling Chinook, subyearling Chinook, steelhead and sockeye at Rock Island Dam (RIS) in an attempt to develop SARs that include a fuller portion of the migration experience through the hydrosystem. In this report, SARs are calculated as adult returns to Bonneville Dam (BOA) and in future reports CSS will also report SARs as adult returns to McNary (MCA), Priest Rapids and other PUD dams as adult detection capability allows.

Methods

Overall SARs are based on PIT-tagged fish that experienced the same conditions as untagged smolts under a given year's fish passage management scenario. Beginning in migration year 2006, this "run at large" group in the Snake River was represented by the Group T (Chapter 1 and Figure A.1). Prior to 2006 in the Snake River, we estimated the proportion of run at large represented by each study group T_0, C_0 and C_1. The CSS 2009 Annual Report (Tuomikoski et al. 2009) found good agreement between overall SARs computed with the pre-2006 and 2006 methods.

Estimation of 90% confidence intervals for annual SARs applicable to all mark populations

Nonparametric 90% confidence intervals are computed around the estimated annual overall SARs for both Snake and Columbia River basin PIT-tagged salmonid populations. The nonparametric bootstrapping approach of Efron and Tibshirani (1993) is used where first, the point estimates are calculated from the sample for each population, and then the data are re-

sampled with replacement to create 1,000 simulated samples (Berggren et al.2002, Chapter 4). These 1,000 iterations are used to produce a distribution of annual SARs from which the value in the 50th ranking is the lower limit and value in the 951st ranking is the upper limit of the resulting 90% nonparametric confidence interval.

Snake River basin populations originating above Lower Granite Dam

Estimation of overall annual SARs for pre-2006 smolt migration years

Annual estimates of LGR-to-GRA SAR reflective of the run-at-large for wild steelhead, hatchery steelhead, wild spring/summer Chinook, and hatchery spring/summer Chinook that out-migrated in 1997 (1994 for wild Chinook) to 2005 are made by weighting the SARs computed with PIT-tagged fish for each respective study category by the proportion of the run-at-large transported and remaining in-river. The proportions of the run-at-large reflected by each of the CSS study categories C_0, C_1 and T_0 were estimated as follows. First, the number of PIT-tagged smolts t_j that would have been transported at each of the three Snake River collector dams (j = 2 for LGR, j = 3 for LGS, and j = 4 for LMN) if these fish had been routed to transportation in the same proportion as the run-at-large is estimated. This estimation uses run-at-large collection and transportation data for these dams from the SMP in the weighting. The total estimated number transported across the three Snake River collector dams in LGR equivalents equals $T_0^* = t_2+t_3/S_2+t_4/(S_2S_3)$, where S_2 is the LGR-to-LGS reach survival rate and the product S_2*S_3 is the LGR-to-LMN reach survival rate. When a portion of the collected run-at-large fish is being bypassed as occurred in 1997, then there will be a component of the PIT-tagged fish also in that bypass category (termed C_1^* in this discussion). In most years, the C_1^* is at or near zero. When run-at-large bypassing occurs, $C_1^* = (T_0 + C_1) - T_0^*$. The sum of estimated smolts in categories C_0 (calculated using Equation A.2 from Appendix A), T_0^*, and C_1^* is divided into each respective category's estimated smolt number to provide the proportions to be used in the weighted SAR computation.

The proportion of the run-at-large that each category of PIT-tagged fish represents is then multiplied by its respective study category-specific SAR estimate, i.e., $SAR(C_0)$, $SAR(C_1)$, and $SAR(T_0)$, and summed to produce an annual overall weighted $SAR_{LGR\text{-}to\text{-}LGR}$ for each migration year except 2001 as follows:

$$\begin{aligned} SAR_{Annual} &= w\left(T_0^*\right) * SAR\left(T_0\right) \\ &+ w\left(C_0^*\right) * SAR\left(C_0\right) \\ &+ w\left(C_1^*\right) * SAR\left(C_1\right) \end{aligned}$$

where,

$$T_0^* = \left(t_2\right) + \left(\frac{t_3}{S_2}\right) + \left(\frac{t_4}{S_2 * S_3}\right)$$

and,

$$C_1^* = \left(T_0 + C_1\right) - T_0^*$$

reflect the number of PIT-tag smolts in transport and bypass categories, respectively, if collected PIT-tag smolts were routed to transportation in the same proportion as run-at-large; and

$$w\left(T_0^*\right) = \frac{T_0^*}{\left(T_0^* + C_0 + C_1^*\right)}$$

is the transported smolt proportion,

$$w\left(C_0\right) = \frac{C_0}{\left(T_0^* + C_0 + C_1^*\right)}$$

is the non-detected (LGR, LGS, LMN) smolt proportion, and

$$w\left(C_1^*\right) = 1 - w\left(T_0^*\right) - w\left(C_0\right)$$

is the bypass (LGR, LGS, LMN) smolt proportion.

Estimation of overall annual SARs in smolt migration year beginning 2006

With the approach of pre-assigning part of the PIT-tagged release group into a monitor-mode group (called Group T) that follows the routing of the untagged population through collector dams, fewer parameters (than was the case before 2006) need to be estimated during intermediate steps before arriving at the final overall SAR estimate. The estimation of the annual overall SAR is simply the number of returning adults in Group T divided by the estimated number of smolts arriving LGR (both detected and undetected). The estimated number of PIT-tagged smolts arriving LGR is obtained by multiplying the release number in Group T by the estimated S_1 (survival rate from release to LGR tailrace) obtained from running the CJS model on the total release. Group T reflects the untagged fish passage experience under a given year's fish passage management actions. SARs for this report represent adult returns through September 15, 2017.

Characterizing the relationship between ln(TIR) and in-river survival (S_R) – Snake River wild Chinook and steelhead

The parameter TIR is a comparison of smolt to adult survival rates for two disparate out-migration types: one where fish are collected from the river and transported via barge around the series of dams and reservoirs and one where fish are allowed to migrate in-river. Survival during the smolt stage aboard the transportation barges is assumed to be high (see Appendix A, equation A.16), whereas in-river survival through the hydrosystem (S_R) for smolts is quite variable across years (Appendix A). Therefore, the effectiveness of transportation as measured using the TIR should be partly dependent on the magnitude of juvenile in-river survival. Higher survival in-river should result in lower TIR.

We evaluated the hypothesis that TIRs were related to the in-river survival of wild Chinook and wild steelhead cohorts. Estimates of smolt survival (S_R) from Lower Granite Dam to Bonneville Dam were available as part of the estimation of SARs. Data from migration years 1994 to 2013 were included in the analysis. These data (S_R) were presented in Appendix A. Methods of estimation can also be found in Appendix A. We then used the ratio of transport SAR (Tx) to in-river SAR (C0) expressed as Tx/C0 or TIR.

Various transformation options for the TIR response variable were evaluated. Based on evaluation of quantile plots of transformed data the natural log transformation appeared most useful for normalizing the data. Information theoretic regression analysis was used to evaluate both transformations of the explanatory variable (S_R) and whether to evaluate each species together or by using separate coefficients for species. We evaluated all models using multi-model comparisons based on AICc.

Middle and Upper Columbia River basin populations

Estimation of overall annual SARs in all smolt migration years

Estimation of overall SARs for mid-Columbia and upper Columbia spring Chinook and steelhead and for upper Columbia summer Chinook and sockeye uses an estimate of the respective PIT-tagged smolt population arriving at the first monitored Columbia River dam below its release location and the corresponding Bonneville Dam (and McNary Dam for Yakima populations) detections of returning adults. PIT-tagged smolt numbers of Leavenworth and Cle Elum Hatchery spring Chinook, for example, are estimated at MCN and exclude PIT-tagged smolts transported from MCN during the NOAA transportation studies of 2002 to 2005. PIT-tagged smolt numbers of John Day River wild spring Chinook and steelhead are estimated at JDA, and those of Deschutes River (Trout Creek) wild steelhead are estimated at BON. Numbers of PIT-tagged spring Chinook smolts from Carson Hatchery are estimated at BON in years when the release-to-BON survival rate is estimated <1. An overall SAR from hatchery release as smolt to BON as adult is also estimated for Carson Hatchery and Warm Springs Hatchery spring Chinook in all available years. Nonparametric 90% confidence intervals are estimated with the same bootstrapping protocol as used for the Snake River stocks. SARs represent adult returns through September 15. 2017.

Survival rate time series: SAR, S.oa and S.o1

The CSS has compiled a historical time series of SARs for Snake River wild spring/summer Chinook and steelhead beginning in 1964 prior to completion of the FCRPS. For years prior to the CSS PIT-tag based estimates, SARs were based on run reconstruction (RR) of smolt numbers at the uppermost Snake River dam and adults returning to the Columbia River from literature sources (Raymond 1988; Marmorek et al. 1998; Petrosky et al. 2001; Petrosky and Schaller 2010).

As requested in the ISAB/ISRP (2007) review of the CSS Ten-Year Retrospective Report (Schaller et al. 2007), we continued the comparison of Snake River wild spring/summer Chinook SARs based on PIT-tags and RR for 1996–2014, with an objective of evaluating hypotheses for possible sources of bias in both the PIT-tag and RR SARs.

Ocean survival rates (*S.oa*) from smolts entering the estuary (at BON) to adults returning to GRA or the Columbia River mouth and first year ocean survival (*S.o1*) estimates were back-calculated from the overall SAR estimates for Snake River wild spring/summer Chinook and steelhead while taking into account year-to-year variability in hydrosystem survival and age composition of returning adults to the Columbia River mouth. In this Chapter the term survival rate refers to survival through a fixed life stage. The method of deconstructing SARs into first year ocean survival rates used here is described in Petrosky and Schaller (2010), and is consistent with approaches used in STUFA (2000; Appendix D), Wilson (2003), and Zabel et al. (2006). Both *S.oa* and *S.o1* represent marine survival of in-river migrants. Transported smolts are expressed as in-river equivalents by adjusting their Bonneville arrival numbers by the estimate of *D* (Petrosky and Schaller 2010). Although this differential delayed mortality is likely expressed primarily during the early marine stage, we apply it to the downstream migration stage (system survival), because it simplifies calculation of the early ocean survival rate and is consistent with earlier analyses (cited above). *S.oa* is calculated as the survival rate of in-river migrants below Bonneville Dam to adult return (including jacks) to both Lower Granite Dam and the Columbia River mouth. *S.o1* is back-calculated from the age-structured recruits to the Columbia River mouth, assuming 80% annual survival of sub-adults. This is consistent with other cohort-based Chinook modeling studies (e.g., Pacific Salmon Commission 1988), and assigns all ocean survival rate variability to the *S.o1* life stage. Estimates of *S.oa* and/or *S.o1* can then be used to evaluate ocean and smolt migration factors that may influence ocean survival as called for in the Fish and Wildlife Program (NPCC 2009).

In this report, we present estimates of SAR, *S.oa* and *S.o1* based on CSS PIT-tag data for Snake River wild Chinook and steelhead (smolt migration years 1994–2014 and 1997–2014, respectively). Estimates of SAR, *S.oa* and *S.o1* based on run reconstruction for years prior to 1994 (Chinook) or 1997 (steelhead) were presented in the 2012 CSS annual report (Tuomikoski et al. 2012, Tables 4.40 and 4.41).

Results

Snake River Overall SARs

Historical Snake River wild spring/summer Chinook SARs (upper dam smolts-to-Columbia River returns, jacks included) decreased by three-quarters from pre-FCRPS

completion in the 1960s to post-FCRPS during the 1990s and 2000s (Figure 4.1). No estimates of wild spring/summer Chinook smolt numbers or SARs were available for 1985–1992 due to insufficient marking those years (Petrosky et al. 2001). The geometric mean SAR during 1964–1969 was 4.3% compared to 1.0% during 1994–1999 and 1.1% since 2000.

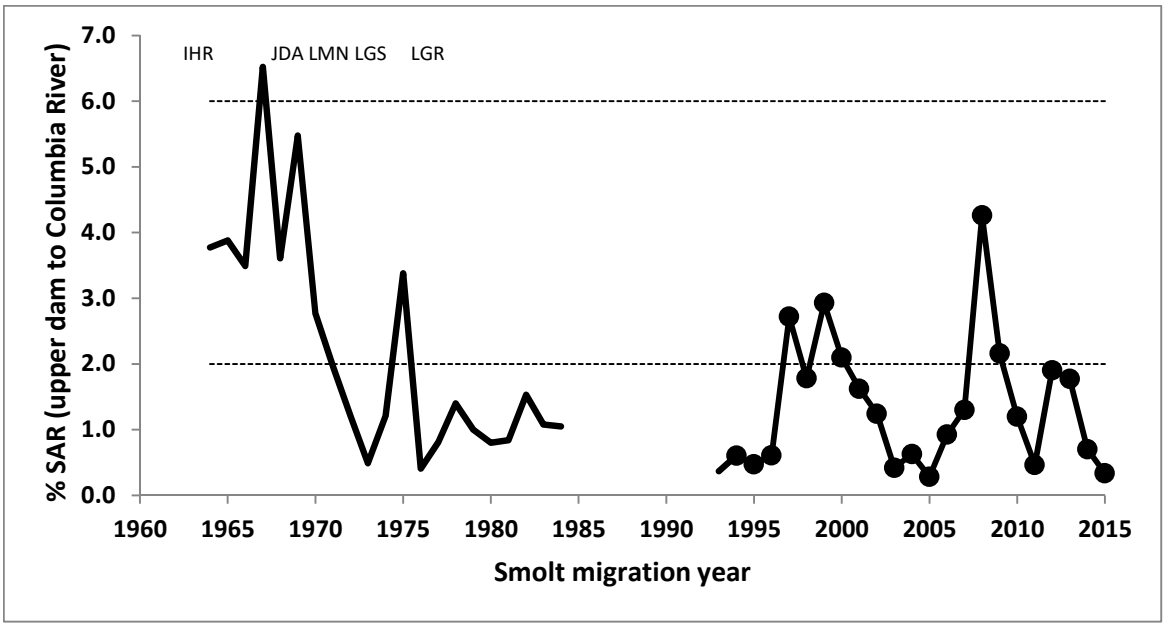

Figure 4.1 SARs from smolts at uppermost Snake River dam to Columbia River returns (including jacks) for Snake River wild spring/summer Chinook, 1964-2014. Dam construction sequence was: 1961-IHR, 1968-JDA, 1969-LMN, 1970-LGS, 1975-LGR. SARs based on run reconstruction (1964-1984 and 1993, solid line) and CSS PIT tags (1994-2015, dots and solid line). The NPCC (2014) 2%-6% SAR objective for listed wild populations is shown for reference; SAR for 2015 is complete through 2-salt returns only.

SARs (LGR-to-GRA, jacks included) of PIT-tagged Snake River wild spring/summer Chinook had a geometric mean of 0.84% and exceeded the NPCC's minimum SAR objective of 2% in only two migration years (1999 and 2008) during the period 1994–2015 (Table B.1; Figure 4.2 top left plot). LGR-GRA SARs with jacks included were about 11% higher (geometric mean of SAR ratios) than SARs with jacks excluded (Table B.1). SARs based on jack and adult returns to BOA were about 26% greater (geometric mean of SAR ratios) than SARs based on returns to GRA (Table B.2) because of the combined effect of dam passage loss, straying and Zone 6 harvest. The CSS also estimated Snake River wild spring/summer Chinook SARs at an MPG scale for the 2006–2015 smolt migration years. SARs were correlated (average r = 0.88) and appeared generally similar among the Snake River spring/summer Chinook MPGs, except that the SARs (LGR-GRA, jacks included) of the unlisted, reintroduced Clearwater River Chinook were somewhat lower (geometric mean 0.53%) than the range of SARs for the other MPGs (0.80% to 1.19%%; Tables B.3–B.14; Figure 4.3). SARs were highest in 2008 and very low in 2006, 2011, 2014 and 2015 for all MPGs.

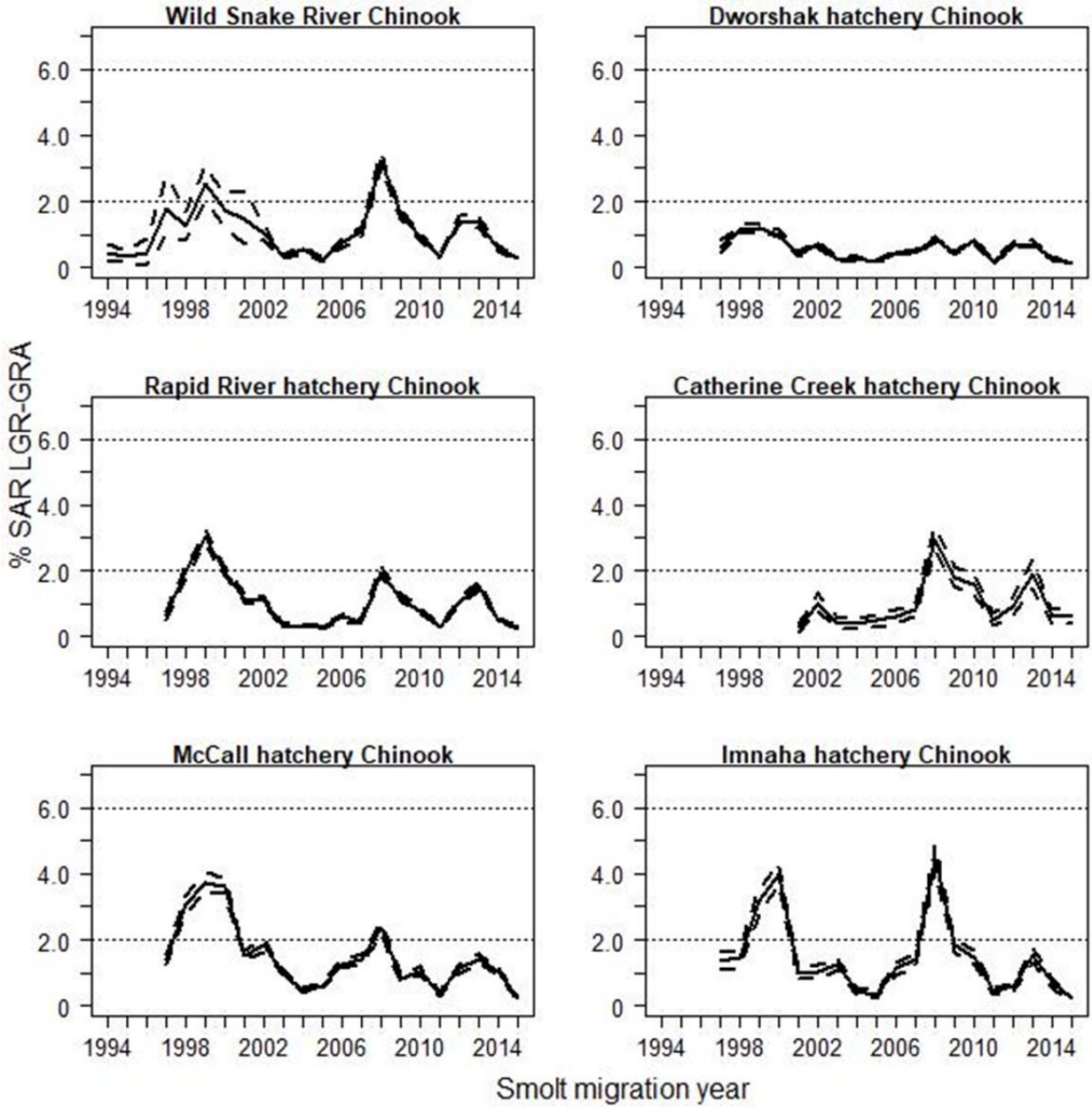

Figure 4.2. Bootstrapped LGR-to-GRA SAR (with jacks included) and upper and lower CI for Snake River wild spring/summer Chinook and five Snake River hatchery groups for migration years 1994–2015. Migration year 2015 is complete through 2-salt returns only. The NPCC (2014) 2%–6% SAR objective for listed wild populations is shown for reference.

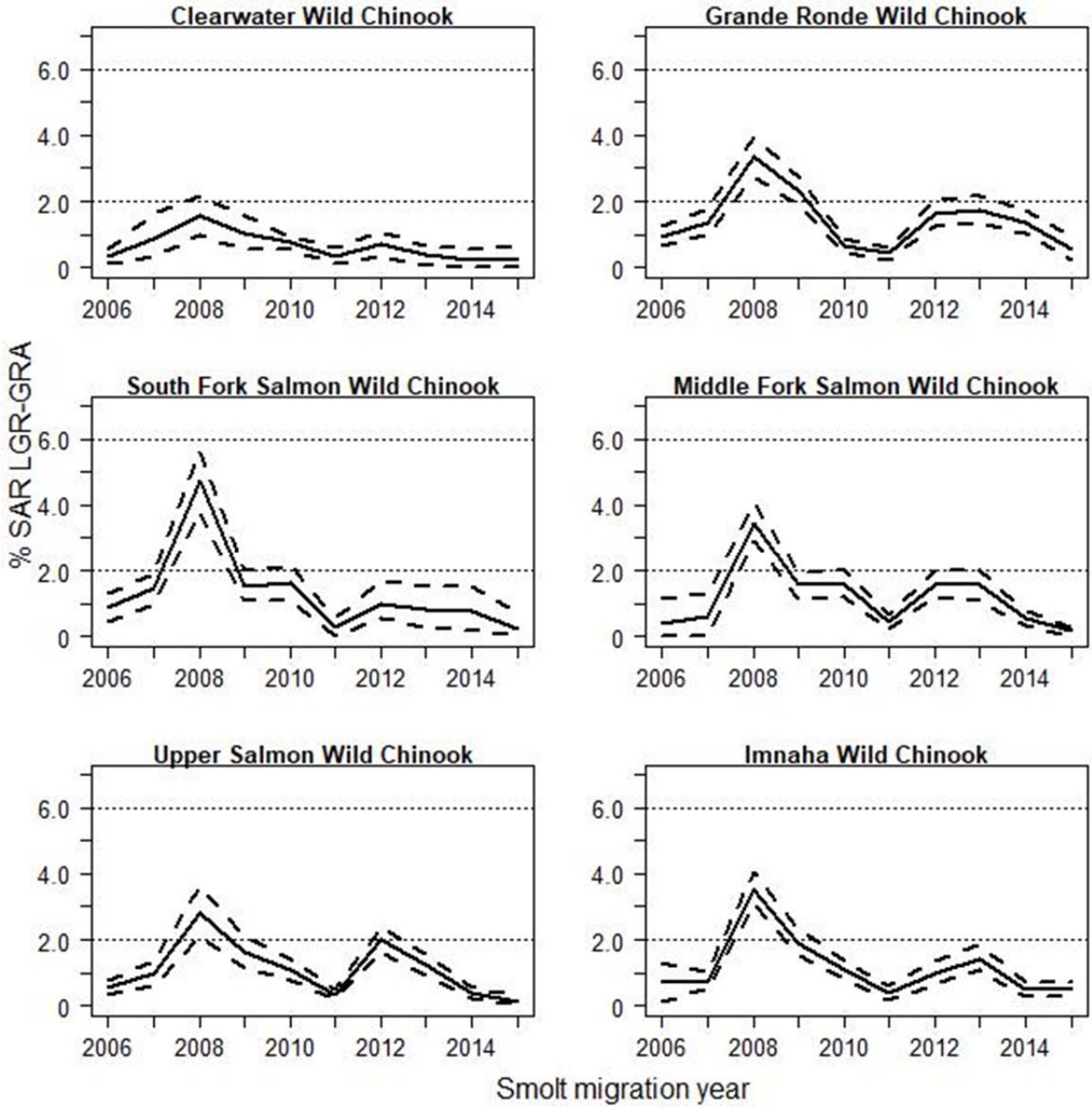

Figure 4.3. Bootstrapped LGR-to-GRA SAR (with jacks included) Snake River wild spring/summer Chinook Major Population Groups for smolt migration years 2006–2015. Migration year 2015 is complete through 2-salt returns only. The NPCC (2014) 2%–6% SAR objective for listed wild populations is shown for reference.

The estimated overall SARs for Snake River hatchery spring and summer Chinook varied by hatchery and year (Figure 4.2; Tables B.15-B.24). LGR-GRA SARs (jacks included) for Dworshak hatchery spring Chinook averaged (geometric mean) 0.47% and did not exceed 2% in any year during 1997–2015 (Table B.15). LGR-GRA SARs for Rapid River hatchery spring Chinook averaged 0.79% and exceeded 2% in a single year (1999; Table B.17). Catherine Creek hatchery Chinook SARs from 2001 through 2015 averaged 0.79% and exceeded 2% only in 2008 (Table B.19). In general, the two hatchery summer Chinook populations had higher SARs than the hatchery spring Chinook populations. LGR-GRA SARs for McCall hatchery summer

Chinook averaged (geometric mean) 1.18% and exceeded 2% in four years (1998–2000 and 2008; Table B.21). LGR-GRA SARs for Imnaha hatchery summer Chinook averaged 1.09% and exceeded 2% in three years (1999, 2000 and 2008; Table B.23). Although some difference in magnitude of SARs between groups was noted, the trends in the overall SARs (LGR-GRA) of Snake River wild and hatchery Chinook groups were similar and highly correlated (average r = 0.80) during 1997–2015.

The estimated overall SARs for additional Snake River hatchery spring and summer Chinook groups for migration years 2006–2015 are presented in Figure 4.4 and Tables B.25–B.34. LGR-to–GRA SARs (jacks included) for Clearwater Hatchery spring Chinook, Sawtooth Hatchery spring Chinook, Pahsimeroi Hatchery summer Chinook and Clearwater Hatchery summer Chinook varied by year within a range generally similar to other CSS hatchery Chinook groups. However, the estimated LGR-to-GRA SARs for Pahsimeroi Hatchery summer Chinook were very low in 2014-2015.

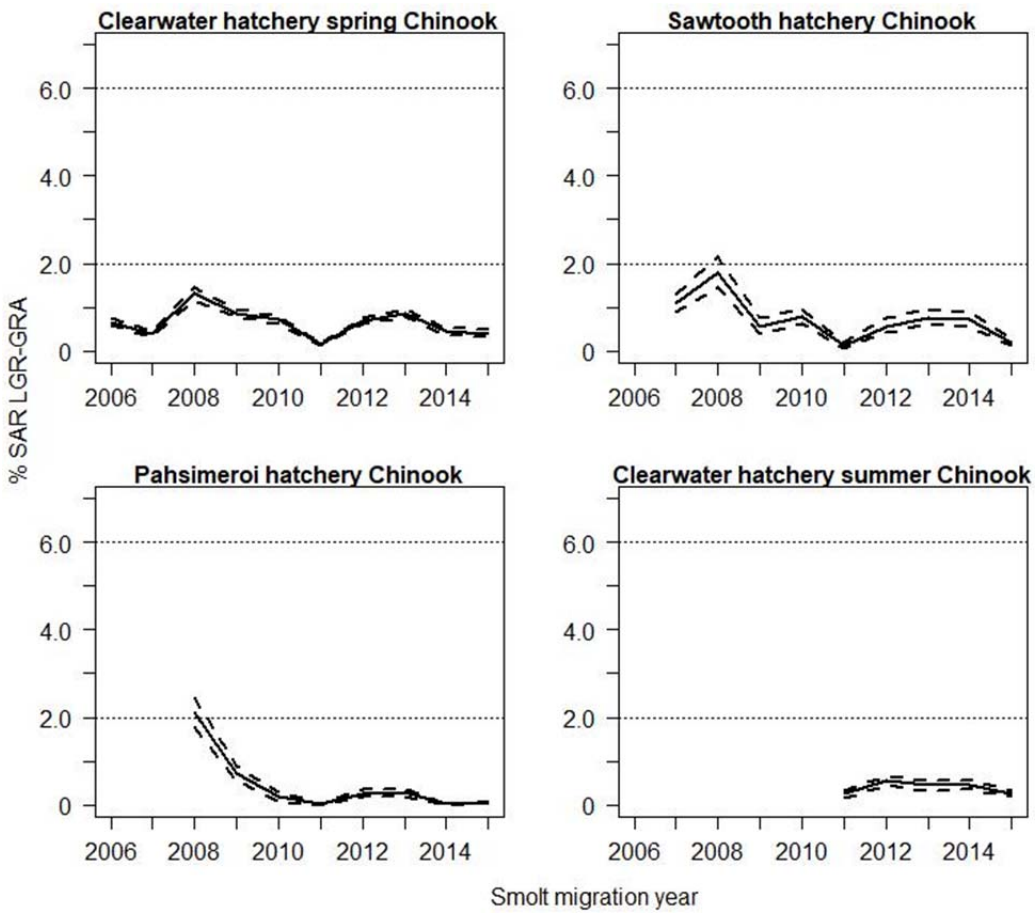

Figure 4.4. Bootstrapped LGR-to-GRA SAR (with jacks included) and upper and lower CI for four additional Snake River hatchery groups for migration years 2006-2015. Migration year 2015 is complete through 2-salt returns only. The NPCC (2014) 2%–6% SAR objective for listed wild populations is shown for reference.

Snake River wild steelhead SARs (upper dam smolts-to-Columbia River returns) decreased by two-thirds from the 1960s (pre-FCRPS completion) to the 1990s and 2000s (Figure

4.5). The geometric mean SAR during 1964–1969 was 7.2% compared to 1.9% during 1990–1999 and 2.5% during 2000–2014. Snake River wild steelhead and wild spring/summer Chinook SARs were highly correlated (r = 0.65) during the 1964–2014 period when aligned by smolt migration year.

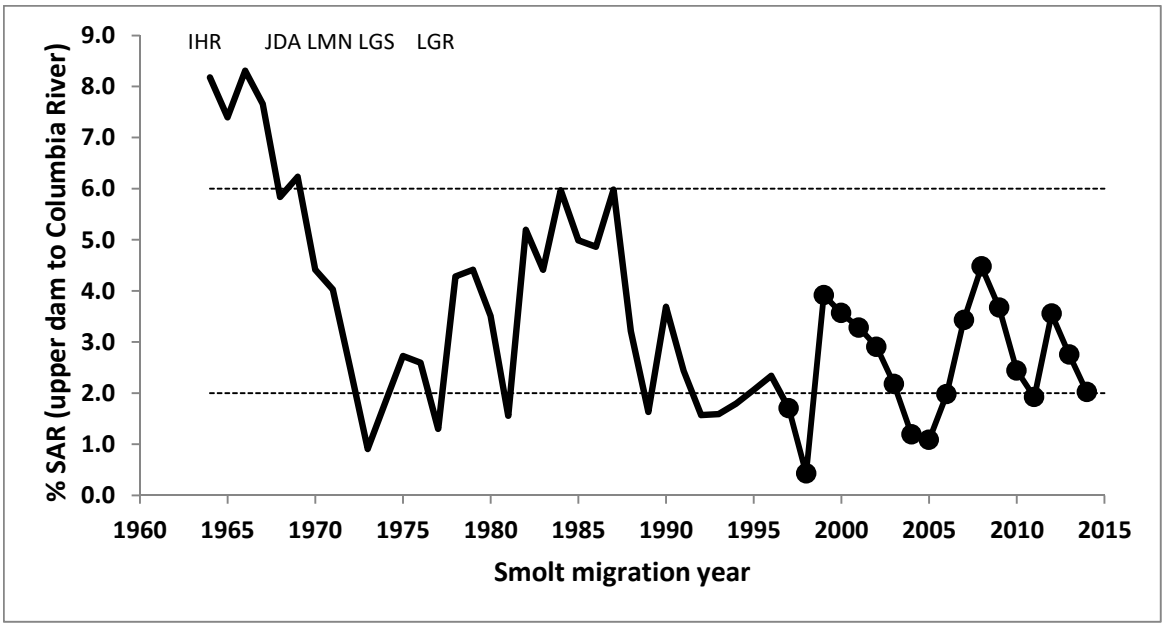

Figure 4.5. SARs from smolts at uppermost Snake River dam to Columbia River returns for Snake River wild steelhead, 1964–2014. Dam construction sequence was: 1961-IHR, 1968-JDA, 1969-LMN, 1970-LGS, 1975-LGR. SARs based on run reconstruction (1964-1996, solid line) and CSS PIT tags (1997–2014, dots and solid line). The NPCC (2014) 2%–6% SAR objective for listed wild populations is shown for reference.

The geometric mean SAR (LGR-to-GRA) of PIT-tagged Snake River wild steelhead was 1.60% during the period 1997–2014 (Table B.35; Figure 4.6 top plot); SAR point estimates exceeded the NPCC's minimum SAR objective of 2% in eight of 18 migration years (statistically significant in four years). SARs based on adult returns to BOA were about 38% greater (when comparing geometric mean of SAR ratios) than SARs based on returns to GRA (Table B.35) because of the combined effect of adult dam passage loss, straying and Zone 6 harvest. We also estimated Snake River wild steelhead SARs at an MPG level and for Snake River wild A-run and wild B-run aggregates (Tables B.36–B.42; Figure 4.7) for juvenile migration years 2006–2014. SARs were correlated (average r = 0.61) among the wild steelhead MPGs. Precision of the SAR estimate was poor for Grande Ronde wild steelhead and reasonable for other wild steelhead MPGs except 2008 for Imnaha River wild steelhead. In this report we also began to include SAR estimates for Asotin Creek wild A-run steelhead (Tucannon MPG); the LGR-GRA SAR estimate for 2014 was 0.66% (Table B.40), somewhat lower than for other Snake River wild steelhead groups. The geometric mean LGR–GRA SAR for the wild A-run group (2.12%) was about 32% higher than for the B-run group (1.60%) during 2006–2014.

The estimated overall SARs (LGR-to-GRA) for Snake River hatchery steelhead averaged 1.27% (geometric mean for 1997–2014) and significantly exceeded 2% only in 2008 (Table B.43; Figure 4.6, bottom plot). Overall SARs (LGR-to-GRA) of Snake River wild and

hatchery steelhead aggregate groups were not strongly correlated (r = 0.32) during 1997–2014, although wild and hatchery SARs are tracking more closely (r = 0.80) in the seven years since we improved hatchery group representation in 2008.

The first juvenile migration year with sufficient numbers of PIT-tagged smolts to estimate SARs for subbasin- or run-specific (e.g. Imnaha Basin A-run) Snake River hatchery steelhead stocks was 2008. Estimated overall SARs (LGR–GRA) were higher for A-run hatchery steelhead than for B-run hatchery steelhead in 2008–2014; SARs of Clearwater River B-run hatchery steelhead exceeded those from the Salmon River (Table B.44–B.49; Figure 4.8).

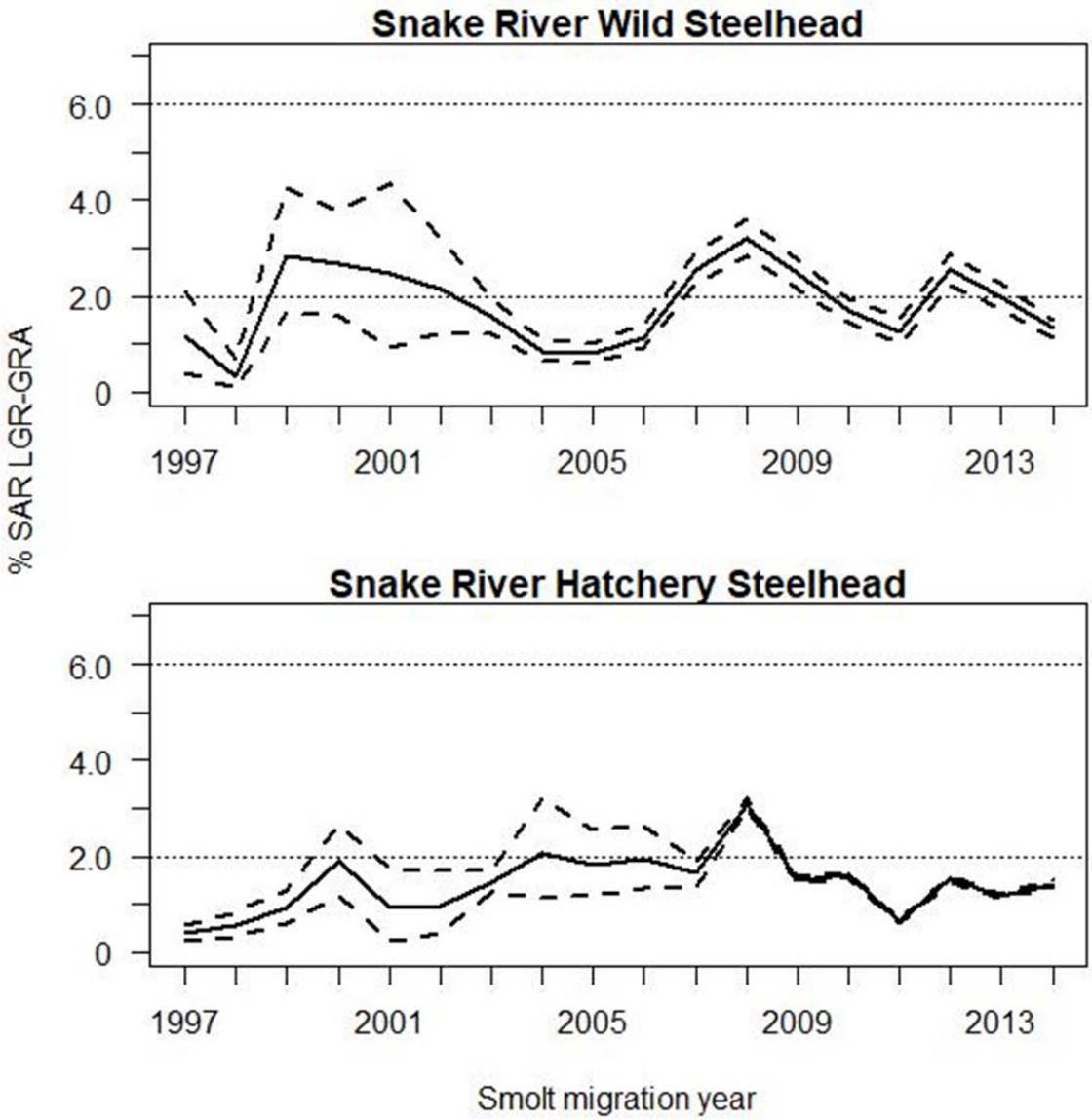

Figure 4.6. Bootstrapped LGR-to-GRA SAR and upper and lower CI for Snake River wild and hatchery steelhead for migration years 1997–2014. The 2008-2014 hatchery steelhead estimates represent the weighted mean for the 5 groups. The NPCC (2014) 2%–6% SAR objective for listed wild populations is shown for reference.

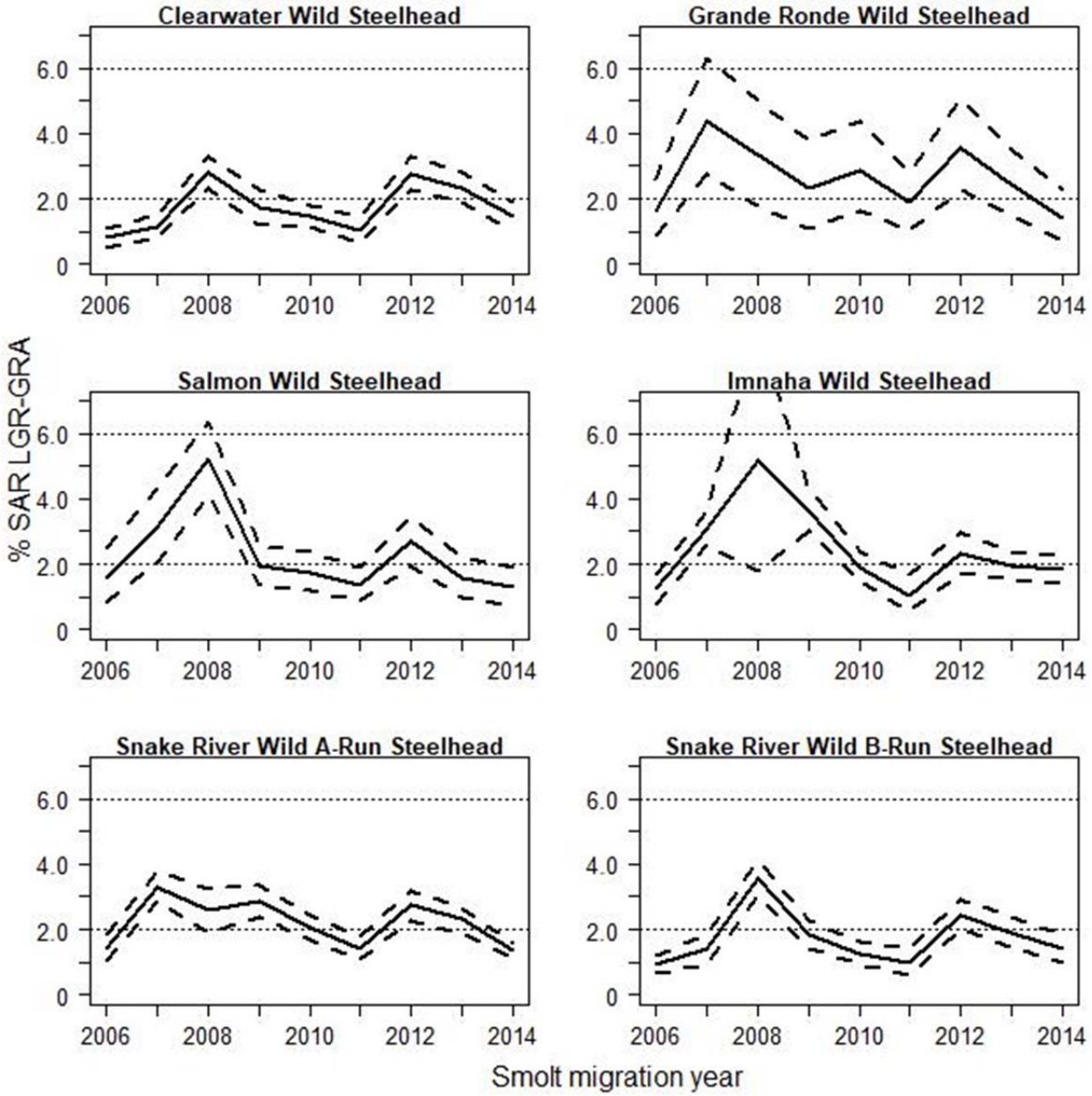

Figure 4.7. Bootstrapped LGR-to-GRA SAR and upper and lower CI for Snake River wild steelhead MPGs and aggregate wild A-run and wild B-run steelhead for migration years 2006–2014. The NPCC (2014) 2%-6% SAR objective for listed wild populations is shown for reference.

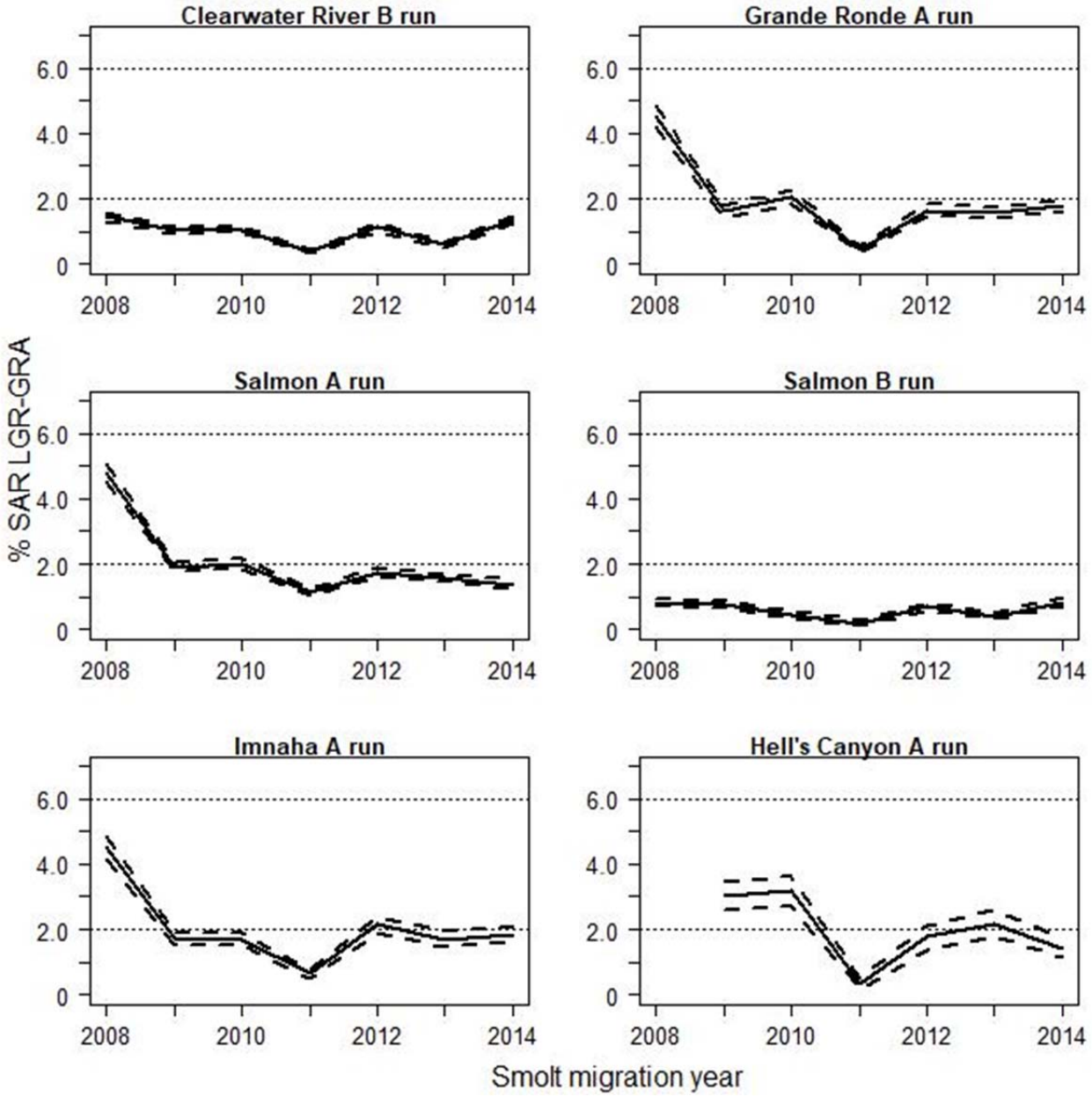

Figure 4.8. Bootstrapped LGR-to-GRA SAR and upper and lower CI for Snake River hatchery steelhead groups for migration years 2006–2014. The NPCC (2014) 2%–6% SAR objective for listed wild populations is shown for reference.

SARs of Snake River hatchery sockeye varied by year and hatchery group during smolt migration years 2009–2015 (Table B.50; Figure 4.9). The estimated SAR LGR-to-GRA for Sawtooth sockeye ranged from 0.10% to 1.15% (2009-2015), whereas Oxbow sockeye SARs ranged from 0.39% to 2.26% (2009–2012); the 2015 SAR LGR-GRA for Springfield Hatchery was 0.0%. Differences in size at release between Oxbow and Sawtooth may explain some of the between-hatchery difference in SARs, particularly in 2011 and 2012. Typically, Oxbow hatchery smolts averaged about 45 g, while Sawtooth hatchery sockeye smolts averaged about 15 g, similar in size to natural origin smolts (M. Peterson, IDFG, pers. comm.). In 2011 and 2012,

Sawtooth Hatchery smolts were smaller than normal, averaging only 8 to 9 g. In 2010 all PIT-tagged sockeye were routed in-river. There were very few incidentally transported PIT-tagged fish in 2010, whereas 33% of run-at-large juvenile sockeye were transported in 2010 (FPC 2014). Therefore, an estimate of overall SAR LGR-to-GRA was not possible in 2010 for the Sawtooth hatchery group. Sample size was limited for the Oxbow hatchery sockeye group; estimation of SAR to either GRA or BOA was not possible for the Oxbow group in 2010 and 2013. Sawtooth and Oxbow groups were coded wire tagged (CWT), in addition to PIT tagged, through the 2013 release to assist with brood stock management of returning adults. The double tagging may have influenced SARs in these years (see Chapter 6 in 2014 CSS annual report). Beginning with the 2014 release, CWT marking has been discontinued because parental based tagging methods have now been developed for brood stock management. Sockeye production was phased out at Sawtooth Hatchery after migration year 2015, with production (and the CSS mark group) being shifted to Springfield Hatchery. Both the Sawtooth and Springfield groups were PIT tagged for the 2015 transition year. The 2015 Springfield hatchery release experienced several fish health problems that affected juvenile survival and SARs. Observations by IDFG personnel during release (and at LGR) indicated fish displayed external symptoms of gas bubble disease (fin occlusion, distended bodies and exophthalmia), presumably during transit from the hatchery over Galena Summit to the release site in the Stanley Basin (Johnson et al. 2016). IDFG hatchery and research staff are working on operational remedies.

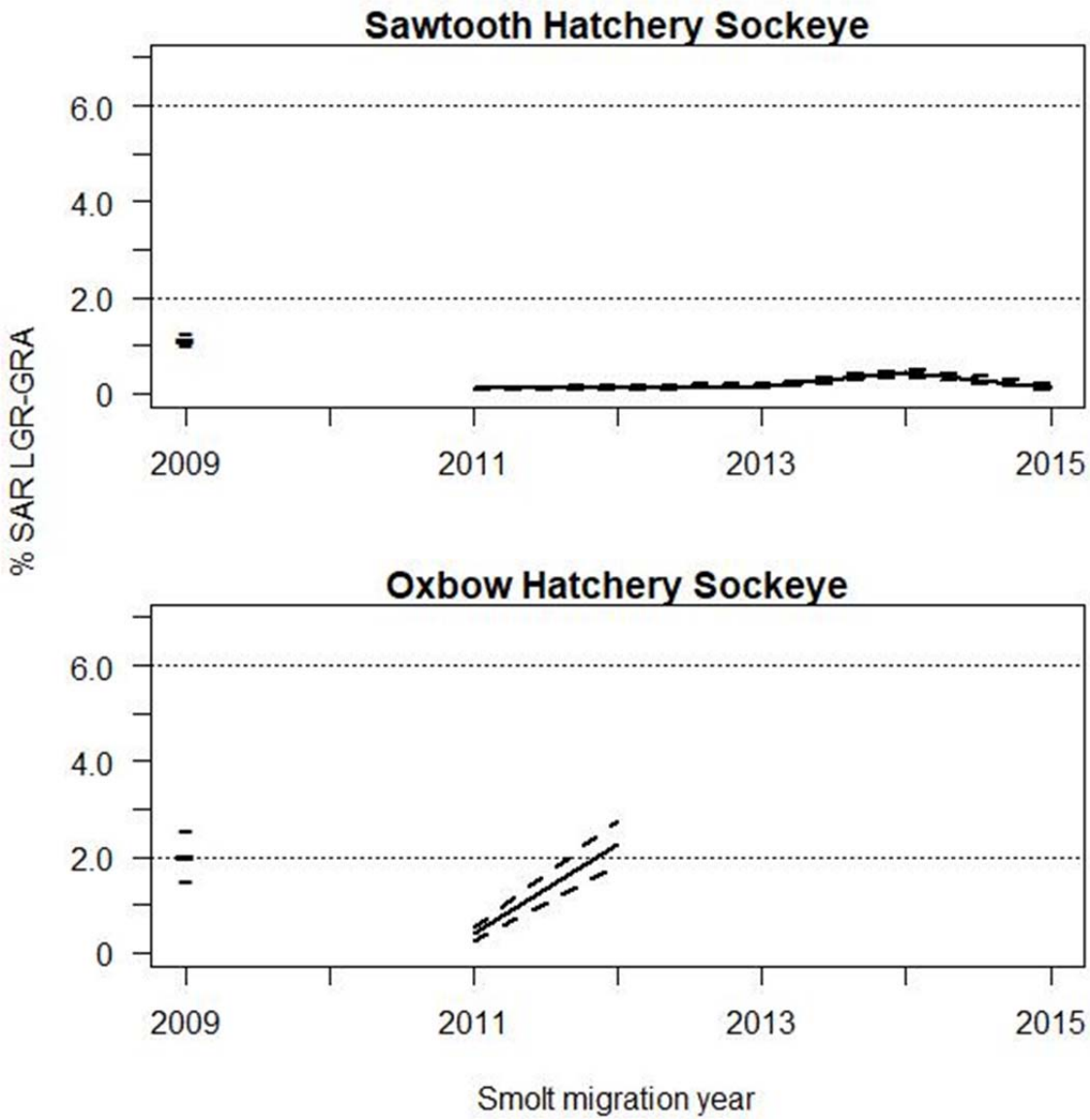

Figure 4.9. Bootstrapped LGR-to-GRA SAR and upper and lower CI for Snake River hatchery sockeye groups for migration years 2009–2015. The NPCC (2014) 2%–6% SAR objective for listed wild populations is shown for reference.

Characterizing the relationship between ln(TIR) and in-river survival (S_R) – Snake River wild Chinook and steelhead

The best fitting models based on AICc weights (Burnham and Anderson 2002) all had natural log transformed Sr (Table 1). We dropped models that included untransformed reach survival because their relative weights combined were less than 0.02. In addition, the top two models had components that were species specific. The top ranked model had a species specific intercept while the second ranked model included a species specific slope. We chose the top fitting model of the form *ln(TIR) = ln(sr) + species,* which included a species specific intercept and a common slope for survival.

Table 4.1. Information theoretic ranking of models predicting Ln(TIR). The table summarizes attributes of the top models considered. The best fitting models included species specific model components, either specific intercept or slope and log transformed Sr (in-river survival).

Model	AIC_C	ΔAIC_C	w_i
ln(sr) + species	80.1	0.00	0.33
ln (sr) + ln (sr):species	80.3	0.2	0.30
ln (sr)	80.5	1.41	0.27
ln (sr) * species	82.6	2.62	0.09

We used the top model based on AICc to illustrate the relationship between ln(TIR) and reach survival (Figure 1).

Table 4.2. Parameter estimates and std. error from the top model.

Parameter	Estimate	Std. error
Intercept	-0.6866	0.1897
ln (S_R)	-1.2905	0.1939
Species(ST)	0.3288	0.1975

Reach survival had a negative effect on Log TIR. As survival increased log TIR decreased. The model predictions were used to estimate the reach survival at which log (TIR) would decrease below 0 indicating a negative effect of transportation on SAR. Based on the model predicted steelhead TIR would drop below zero when juvenile reach survival increased above 0.75, indicating that transport would no longer mitigate for hydro-system effects when in-river survival was above that point. For yearling Chinook the model predicted that at reach survivals above 0.58 the log TIR would drop below zero.

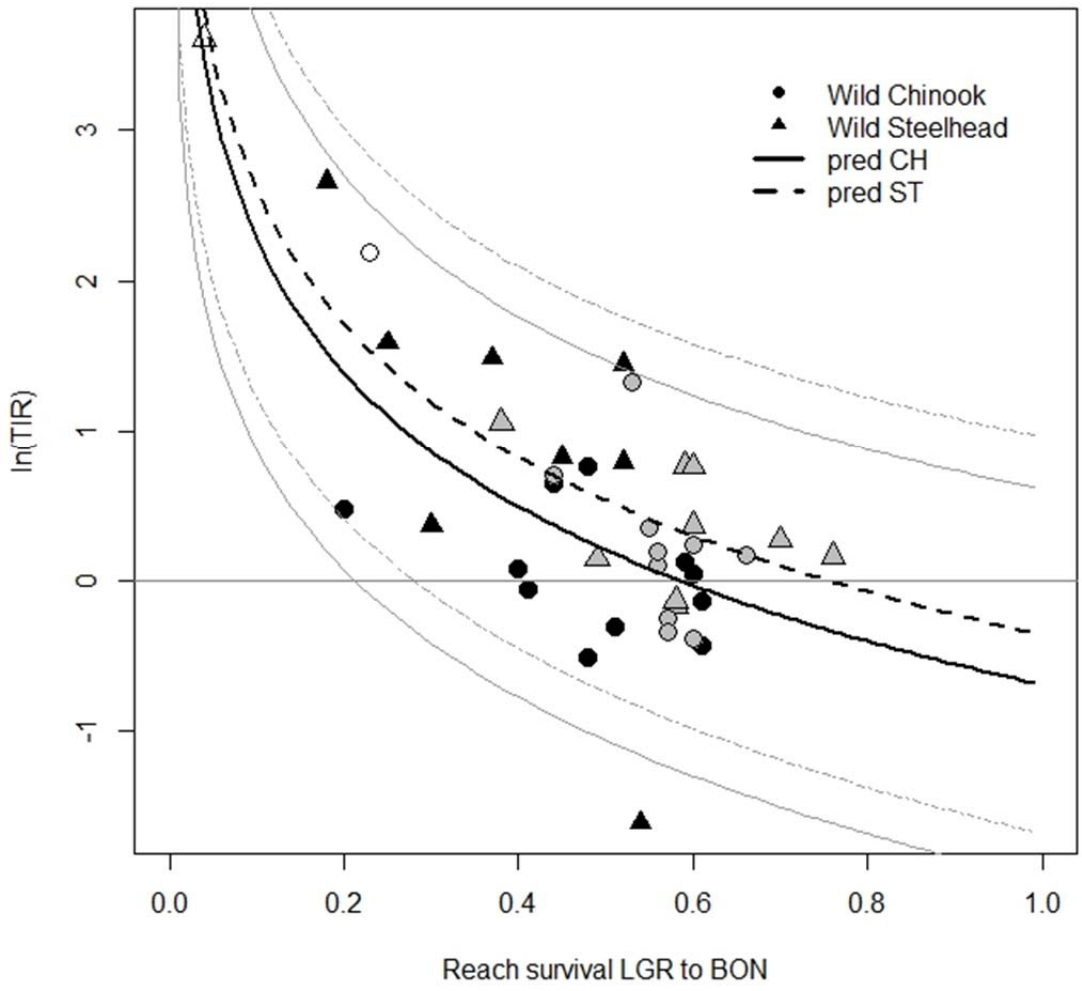

Figure 4.10. Plot of ln(TIR) versus reach survival (SR) for wild yearling Chinook for the juvenile migration years 1994 to 2015 and wild steelhead from the Snake River for the juvenile migration years 1997 to 2014. The two open symbols are migration year 2001 which had low flow and zero spill. The gray data points are migration years with court-ordered spill and delayed start to transportation (2006–2015). Curves shown are predictions from the common slope and species-specific intercept model using ln(SR) shown in Table 4.2. Thinner lines represent the 95% prediction intervals for the model. The model predicts that TIR will be less than one when juvenile Chinook survival is 0.58 or higher and juvenile steelhead survival is 0.75 or higher.

Mid-Columbia River Overall SARs

In contrast to Snake River spring/summer Chinook and steelhead, no historical SAR data sets exist for the mid-Columbia Region extending back to pre-FCRPS completion. The Yakama Nation fisheries staff estimated SARs of Yakima River natural origin spring Chinook based on run reconstruction of smolts at Chandler Dam to adults to the Yakima River mouth, beginning in smolt migration year 1983. Subbasin-to-subbasin SARs for Yakima River wild spring Chinook had a geometric mean of 2.4%, ranging from 0.6% to 13.4% during 1983–2001 (Yakima

Subbasin Summary; YIN and WDFW 2004). In addition, the Confederated Tribes of the Warm Springs Reservation of Oregon (CTWSRO) have operated a smolt trap on the Warm Springs River since the late 1970s, from which it may be possible to calculate wild spring Chinook SARs using run reconstruction methods. These longer-time series run reconstruction SAR estimates for mid-Columbia spring Chinook would be useful in future analyses.

The geometric mean SAR (JDA-to-BOA, including jacks) of PIT-tagged John Day River wild spring Chinook was 3.98% during the 16-year period 2000–2015 (Table B.73; Figure 4.11). John Day wild spring Chinook SAR point estimates exceeded the NPCC's minimum SAR objective of 2% in all migration years except 2011, and were significantly greater than 2% in all but three years (2005, 2006 and 2011). The PIT-tagged John Day River spring Chinook group represents an aggregate of three wild populations: the North Fork, Middle Fork, and upper mainstem John Day rivers. The geometric mean SAR (MCN-to-MCA) of Yakima River wild spring Chinook was 2.36% during 2002–2015 (no PIT-tagged smolts were released in 2010 or 2014). Yakima wild spring Chinook SAR point estimates exceeded the minimum 2% in seven of 12 migration years, and were significantly greater than 2% in five years (Table B.75). Yakima River wild Chinook SARs based on BOA returns were 8% greater than those based on MCA returns (Tables B.74 and B.75). SARs of John Day and Yakima River wild spring Chinook averaged (geometric mean of ratio; based on BOA returns) 3.8 times and 2.5 times, respectively, those of Snake River wild spring/summer Chinook (Table B.2), and the wild SARs were correlated (average r = 0.67) between regions during the period 2000–2015.

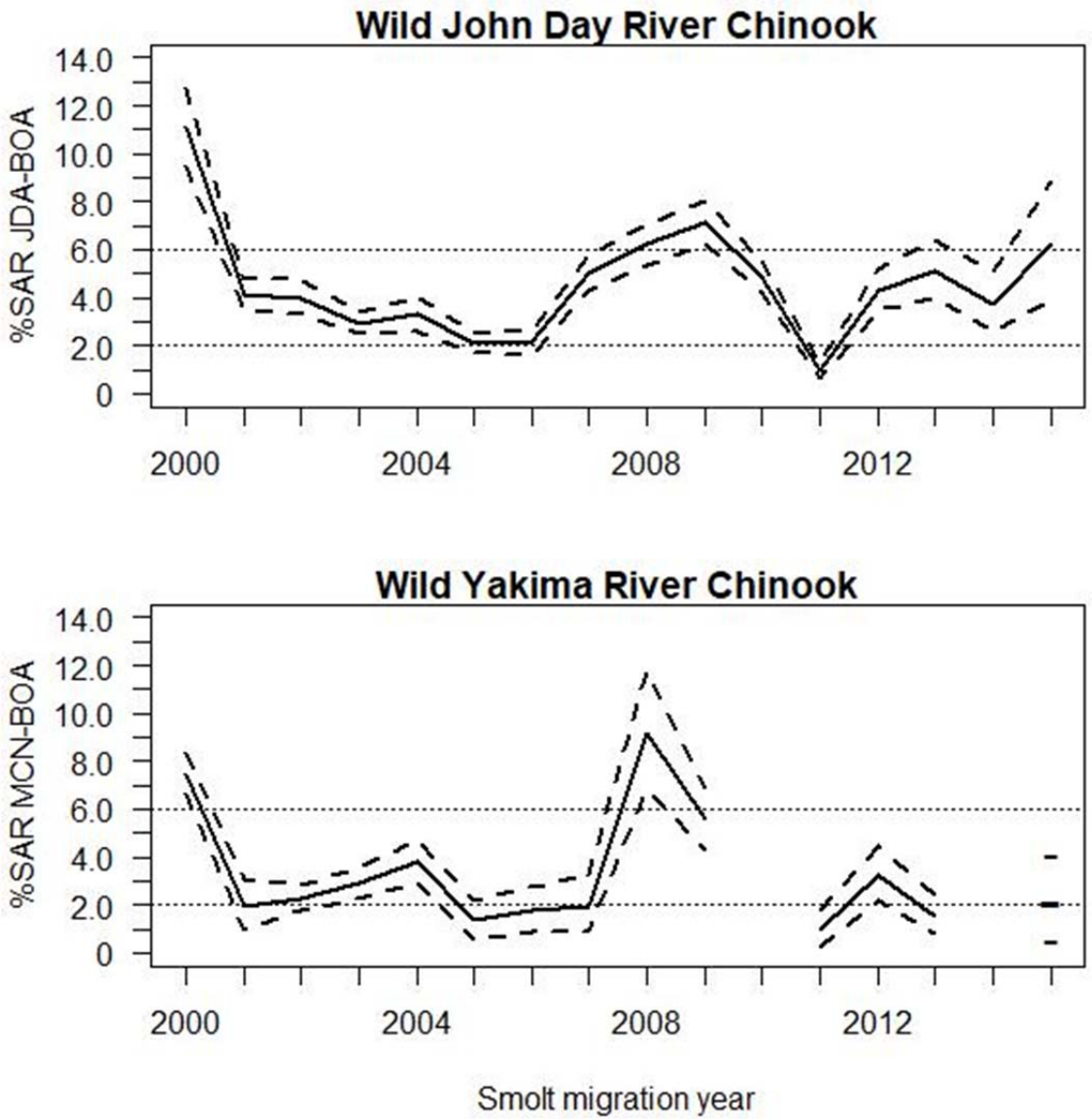

Figure 4.11. Bootstrapped SAR (including jacks) and upper and lower CI for wild spring Chinook from the John Day and Yakima rivers in the mid-Columbia region for migration years 2000–2015. Smolts are estimated at upper dam; adults are enumerated at BOA. Migration year 2015 is complete through 2-salt returns only; no PIT tagged smolts were released in the Yakima River in 2010 and 2014. The NPCC (2014) 2%–6% SAR objective for listed wild populations is shown for reference.

The estimated overall SARs (including jacks) for mid-Columbia River hatchery spring Chinook varied by hatchery and year (Tables B.76-B.79; Figure 4.12). BON-to-BOA SARs for Carson Hatchery spring Chinook averaged (geometric mean) 0.92% during 2000–2015 (Table B.76). Estimated BON-BOA SARs for Warm Springs National Fish Hatchery spring Chinook 2010–2015 averaged 1.05% (Table B.77). MCN-BOA SARs for Cle Elum Hatchery spring Chinook averaged 1.55% and were 8% higher than MCN-MCA SARs (Tables B.78 and B.79). The hatchery populations in the mid-Columbia region had much lower SARs than the John Day and Yakima wild spring Chinook populations. Although a difference in magnitude of SARs between groups was noted, the overall SARs of mid-Columbia wild and hatchery spring

Chinook groups were highly correlated (average r = 0.78) between populations during 2000–2015.

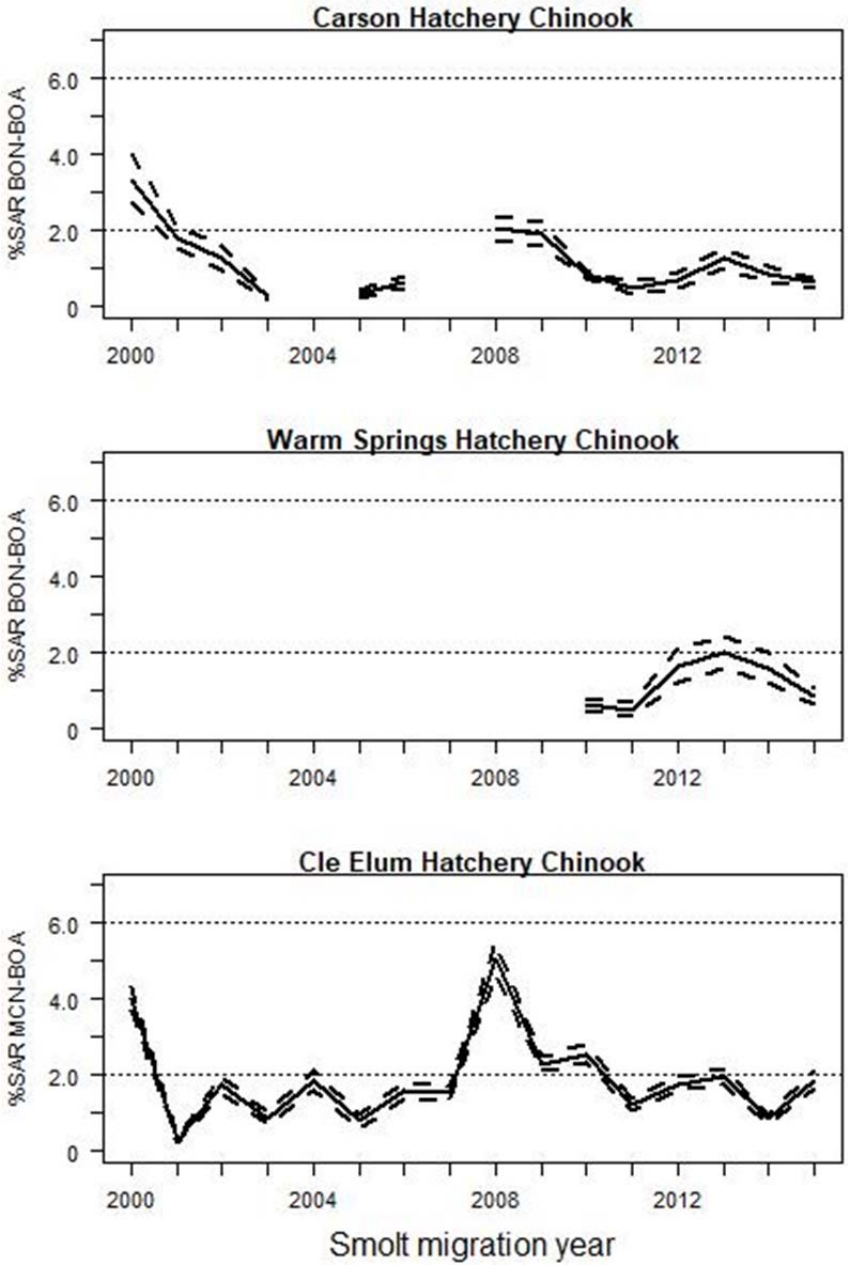

Figure 4.12. Bootstrapped SAR (including jacks) and upper and lower CI for hatchery spring Chinook in the mid-Columbia region for migration years 2000–2015. Smolts are estimated at upper dam; adults are enumerated at BOA. Migration year 2015 is complete through 2-salt returns only. SAR for Carson Hatchery not calculated for 2004 and 2007 because release to BON survival estimate > 1.0. The NPCC (2014) 2%–6% SAR objective for listed wild populations is shown for reference.

The CSS estimated SARs and confidence intervals for mid-Columbia wild steelhead from the John Day River beginning with migration year 2004, from Trout Creek in the Deschutes

River beginning with migration year 2006, and from the Yakima River beginning with migration year 2002 (Tables B.80–B.82; Figure 4.13). We have the 2004-2014 PIT-tagged wild steelhead from John Day River summarized in Table B.80. JDA-BOA SAR estimates significantly exceeded the NPCC's minimum SAR objective of 2% in ten out of 11 years (Figure 4.13); the 2011 SAR was the single exception. The PIT-tagged John Day River steelhead group represents the five wild populations of the John Day MPG: the North Fork, Middle Fork, South Fork, upper mainstem, and lower mainstem John Day rivers. However, fish in the lower mainstem John Day population from tributaries downstream of the ODFW juvenile seining site are not trapped and PIT tagged and that population is not fully represented. Deschutes River (Trout Creek) wild steelhead SARs (BON-to-BOA) significantly exceeded the NPCC's minimum SAR objective of 2% in the eight years of study, 2006-2014 (Table B.81; Figure 4.13). Yakima River wild steelhead SARs (MCN-to-MCA) significantly exceeded the NPCC's minimum SAR objective of 2% in nine out of 13 years (Table B.82; Figure 4.13); MCN-to-BOA SARs were 21% higher than MCN-to-MCA SARs. SAR confidence intervals for the Yakima wild steelhead population, in particular, were relatively wide due to limited sample size. Wild steelhead SARs from the mid-Columbia River populations exceeded by 2.5 fold, and correlated (average r = 0.53) with, wild steelhead SARs from the Snake River. Common among these populations (as well as Chinook PIT tag groups in other regions), SARs were high in 2008 and low in 2011.

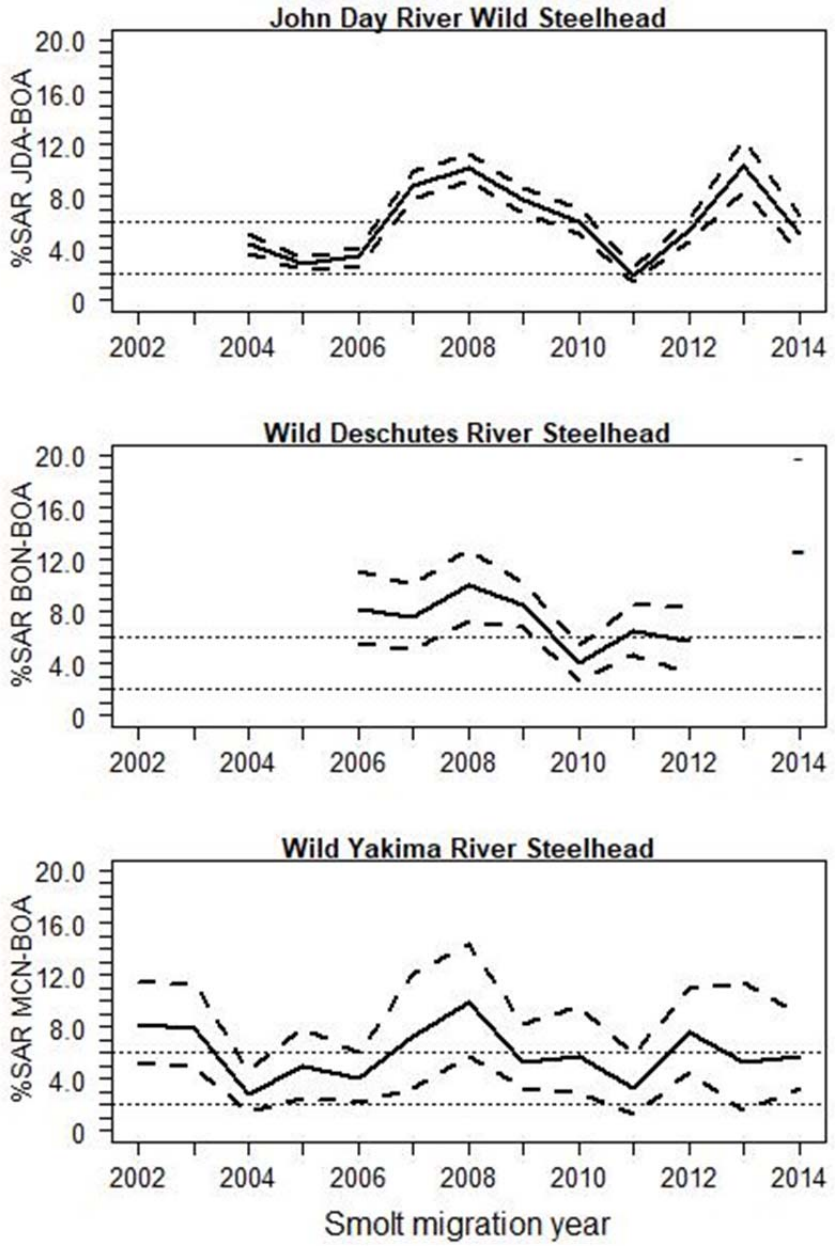

Figure 4.13. Bootstrapped SAR and upper and lower CI for wild steelhead from mid-Columbia region for migration years 2002–2014. Smolts are estimated at upper dam; adults are enumerated at BOA. Too few PIT-tagged smolts were released in the Deschutes River in 2013 for SAR estimate.The NPCC (2014) 2%–6% SAR objective for listed wild populations is shown for reference.

No PIT-tag SARs have been compiled for hatchery steelhead populations in the mid-Columbia region. There may be some potential for run reconstruction SARs for hatchery steelhead in the Deschutes and Umatilla subbasins.

Upper Columbia River Overall SARs

Raymond (1988) estimated pre-harvest SARs for upper Columbia River (above PRD) spring Chinook and steelhead, 1962–1984 smolt migration years, which may be useful for future analyses. These estimated SARs were somewhat lower than those for the Snake River during the 1960s for both species. Raymond's smolt indices for the upper Columbia were subject to several assumptions, however, creating greater uncertainty in the SAR estimates here than for the Snake River. Raymond explained that smolt indices were less available than for the Snake River because indexing of smolts at upper Columbia River dams was not ongoing except at Priest Rapids Dam between 1965 and 1967.

The estimated overall SARs (MCN to BOA, including jacks) for Wenatchee River wild spring Chinook averaged (geometric mean) 1.18% during 2007–2015 Table B.87; Figure 4.14). MCN-BOA SARs significantly exceeded 2% in one of nine years; note however, that the MCN-BOA SAR estimate does not include the juvenile mortality impacts from the three PUD dams (PRD, WAN and RIS) upstream of MCN.

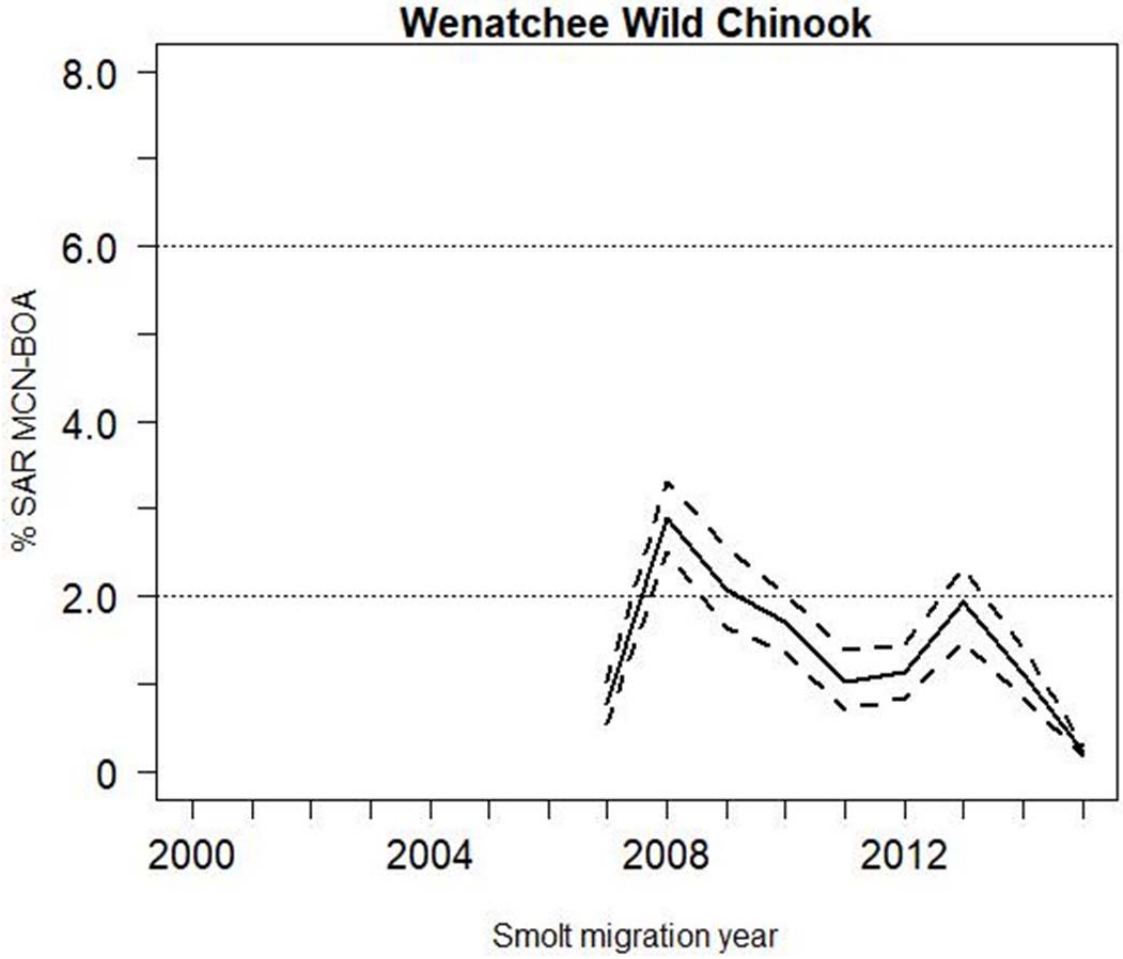

Figure 4.14. Bootstrapped SAR (MCN-to-BOA, including jacks) and upper and lower CI for Wenatchee River wild spring Chinook from Upper Columbia region for migration years 2007–2015. Migration year 2015 is complete through 2-salt returns only. The NPCC (2014) 2%–6% SAR objective for listed wild populations is shown for reference.

We have estimated SARs for wild spring Chinook from the Entiat and Methow rivers for the MCN-BOA reach for 2006-2015 and the RIS-BOA reach for 2008-2015 (Tables B.88 and B.89; Figure 4.15). SAR estimates for the RRE-BOA reach averaged 0.95% and were less than 2% in all eight years. Wild spring Chinook SARs based on smolts at RRE were 54% (geometric mean of ratio) those based on smolts at MCN, illustrating the need to monitor SARs for the complete smolt migration path through the hydrosystem.

We have also estimated SARs for wild summer Chinook from the Okanogan River for the MCN-BOA and RIS-BOA reaches for 2011-2014 (Tables B.90 and B.91, Figure 4.15). SAR estimates for the RRE-BOA reach averaged 0.58% and were significantly less than 2% in two of four years. Wild summer Chinook SARs based on smolts at RRE were 67% (geometric mean of ratio) those based on smolts at MCN. Note that Okanogan summer Chinook originate above Wells Dam (WEL) and that the RIS-BOA SAR estimate does not include mortality in the WEL-RRE reach.

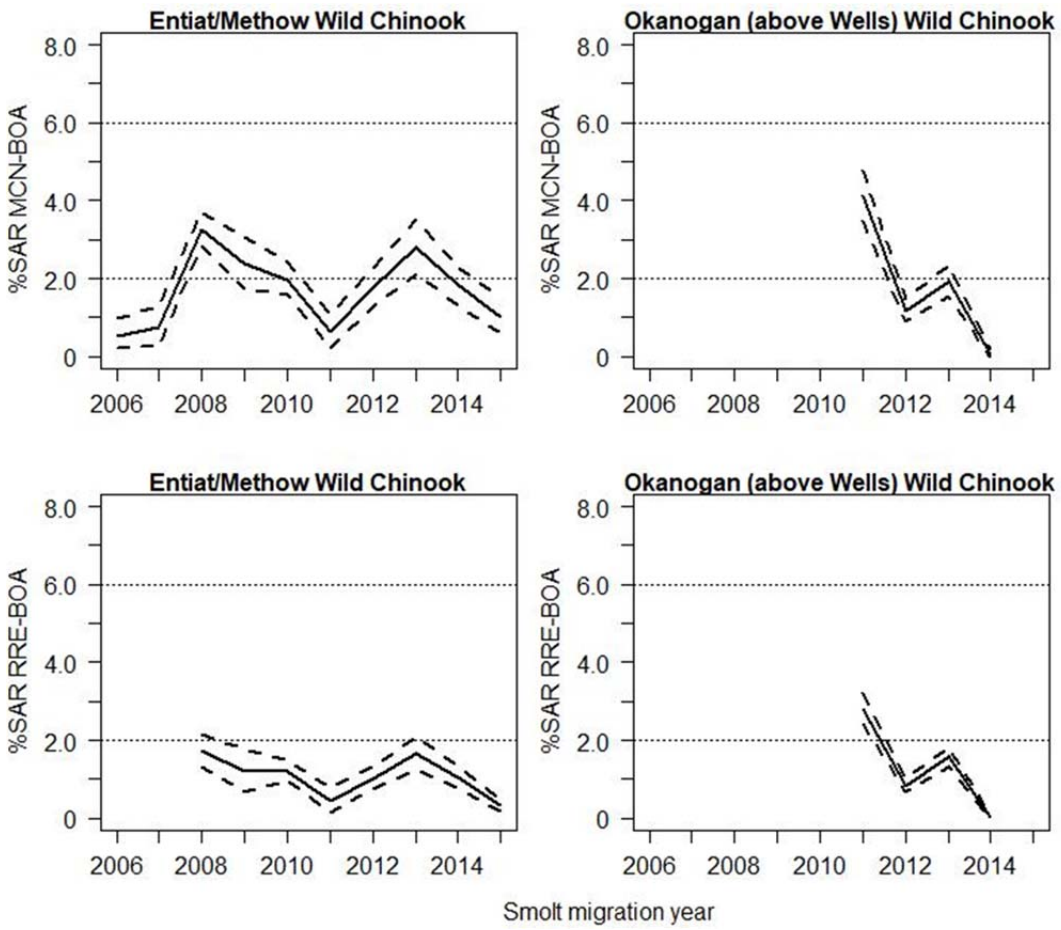

Figure 4.15. Bootstrapped SAR (MCN-to-BOA and RRE-to-BOA, including jacks) and upper and lower CI for Methow/Entiat wild spring Chinook for migration years 2007–2015 and Okanogan wild summer Chinook for migration years 2011-2014, upper Columbia River region. Migration year 2015 is complete through 2-salt returns only for wild spring Chinook. The NPCC (2014) 2%–6% SAR objective for listed wild populations is shown for reference.

The geometric mean SAR for Leavenworth hatchery spring Chinook (Wenatchee River) was 0.60% during 2000-2015 (Table B.92; Figure 4.16). The overall MCN-BOA SARs of Upper Columbia wild and hatchery spring Chinook were highly correlated with wild and hatchery spring Chinook SARs from the mid-Columbia (average r = 0.72) and with wild and hatchery spring/summer Chinook SARs from the Snake River (average r = 0.79) during 2000–2015.

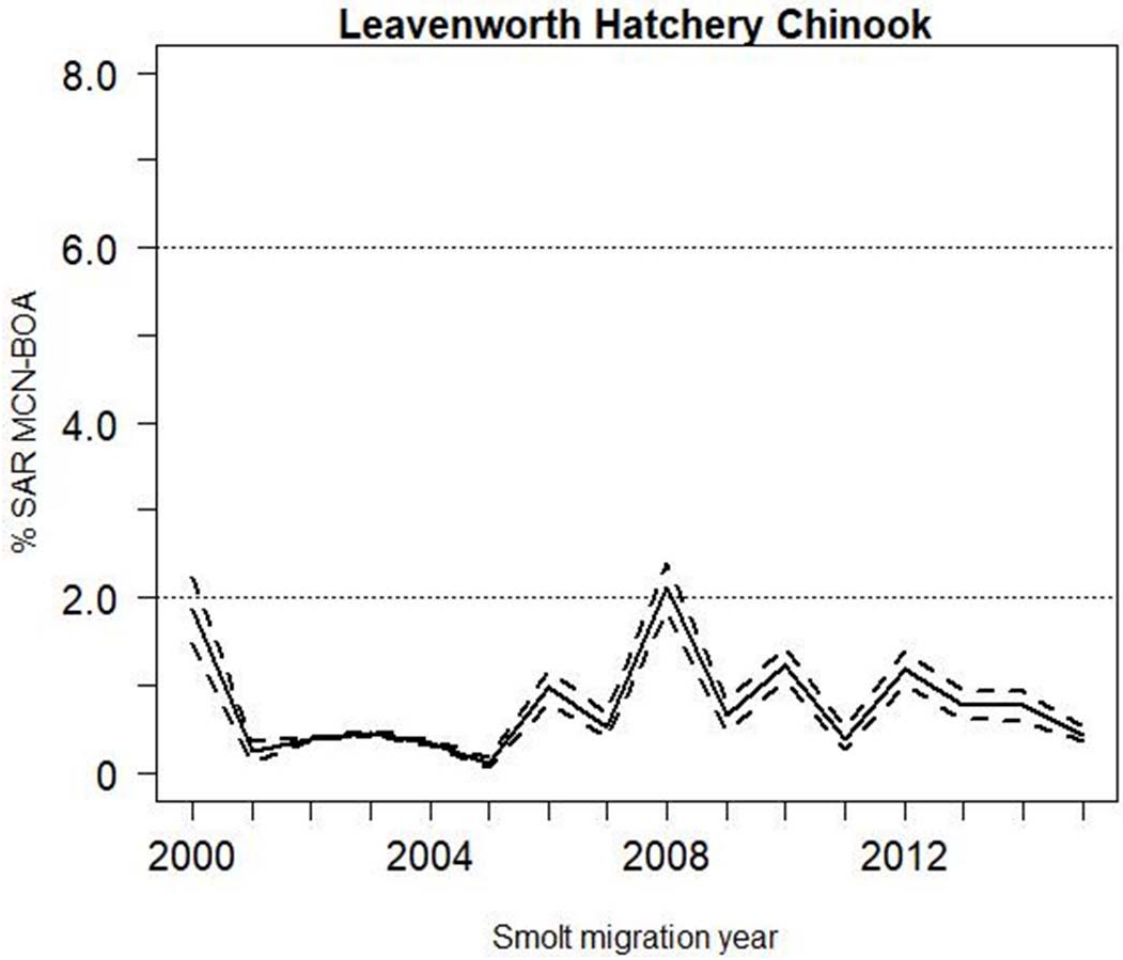

Figure4.16. Bootstrapped SAR (MCN-to-BOA, including jacks) and upper and lower CI for Leavenworth hatchery spring Chinook from Upper Columbia region for migration years 2000–2015. Migration year 2015 is complete through 2-salt returns only. The NPCC (2014) 2%–6% SAR objective for listed wild populations is shown for reference.

We have also estimated SARs for the MCN-BOA and RIS-BOA reaches for hatchery spring Chinook from Winthrop hatchery for 2009-2015 (Tables B.93 and B.94; Figure 4.17) and for hatchery summer Chinook from the Entiat River for 2011-2015 (Tables B.95 and B.96; Figure 4.17). SAR estimates for the RRE-BOA reach averaged 0.76% and 0.62% for the Winthrop and Entiat hatchery groups, respectively.

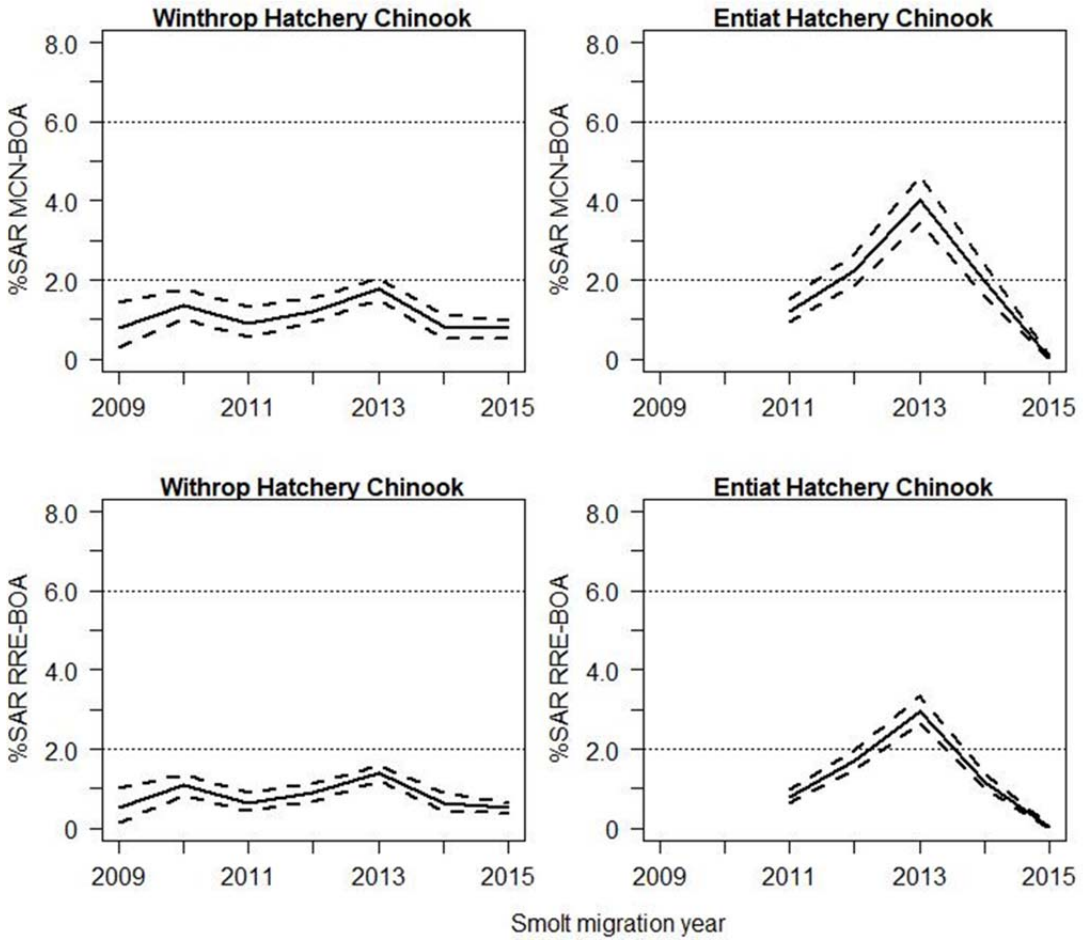

Figure 4.17. Bootstrapped SAR (MCN-to-BOA and RRE-to-BOA, including jacks) and upper and lower CI for Winthrop hatchery spring Chinook for migration years 2009-2015 and Entiat hatchery summer Chinook for migration years 2011-2015, upper Columbia River region. Migration year 2015 is complete through 2-salt returns only. The NPCC (2014) 2%–6% SAR objective for listed wild populations is shown for reference.

Overall SARs (MCN–BOA) for Upper Columbia River wild steelhead from the Wenatchee, Entiat and Methow rivers averaged 3.65% during 2006–2014 (Table B.97; Figure 4.18). Overall SARs from RRE to BOA were also estimated in 2008–2014 for Upper Columbia River wild steelhead from the Entiat and Methow rivers (Table B.98; Figure 4.18). This represents a subgroup of the wild steelhead aggregate reported in Table B.97 (i.e., excludes Wenatchee River steelhead). Wild steelhead SARs based on smolts at RRE averaged 2.36% and exceeded 2% in three out of seven years. Wild steelhead SARs based on smolts at RRE were 61% (geometric mean of ratio) those based on smolts at MCN in 2008–2014, again demonstrating the need to monitor SARs for the complete smolt migration path through the hydrosystem.

SARs (MCN–BOA) for Upper Columbia River hatchery steelhead released into the Wenatchee River (Eastbank and Chelan hatcheries) ranged from 0.90% to 5.78% during 2003–2014 (Table B.99; Figure 4.19).

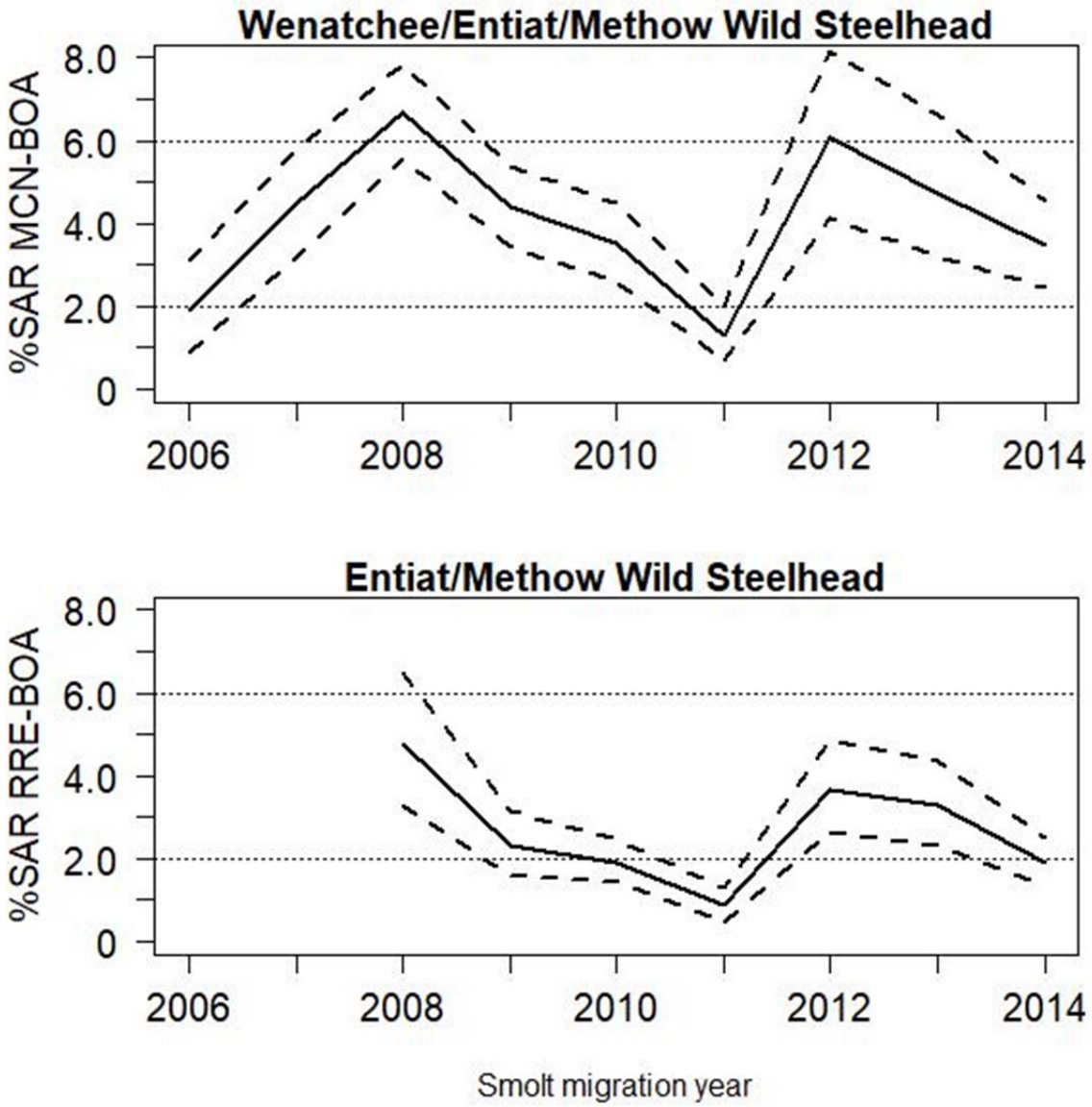

Figure 4.18. Bootstrapped SAR and upper and lower CI for wild steelhead from the Upper Columbia region through the 2014 migration year. MCN-BOA SARs are estimated for the Wenatchee/Entiat/Methow group; RRE-BOA SARs are estimated for the Entiat/Methow subgroup. The NPCC (2014) 2%–6% SAR objective for listed wild populations is shown for reference.

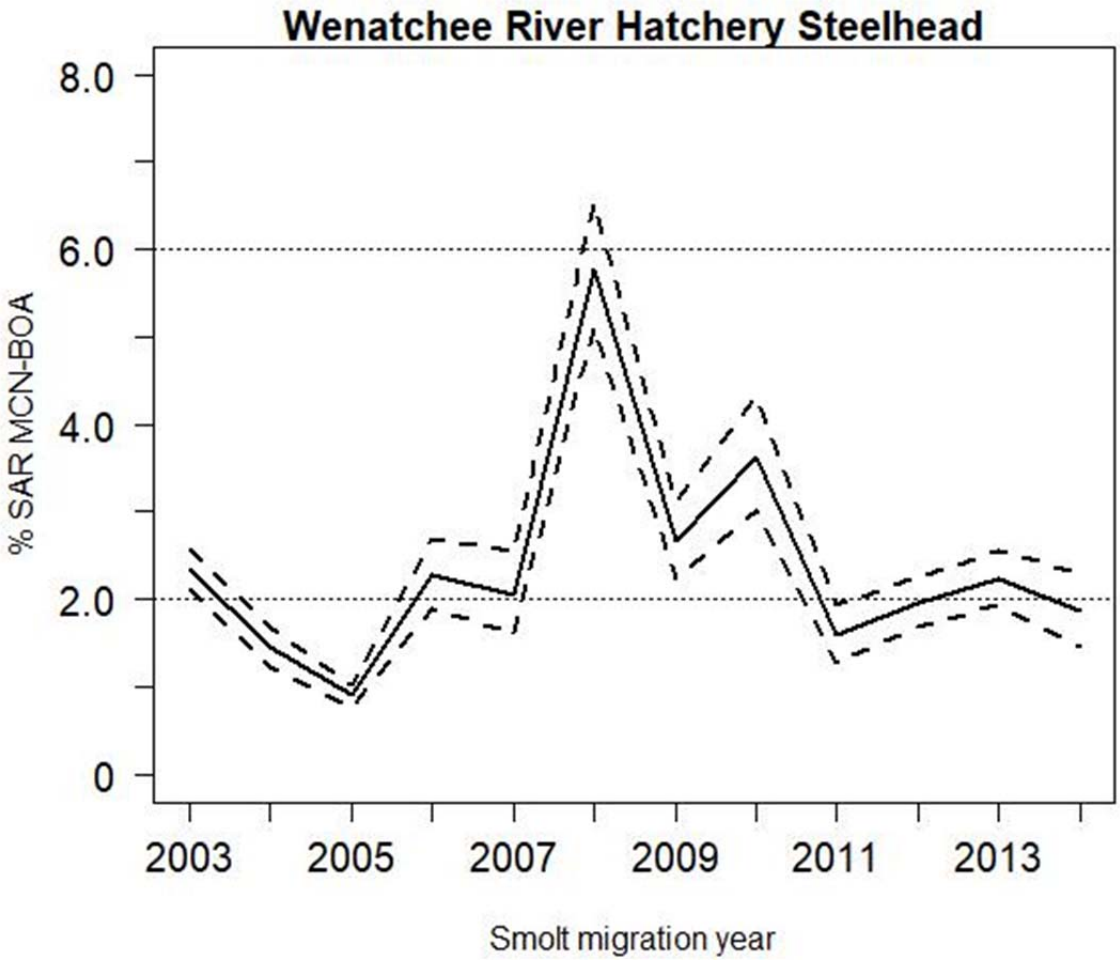

Figure 4.19. Bootstrapped SAR (MCN-to-BOA) and upper and lower CI for Wenatchee River hatchery steelhead from Upper Columbia region through the 2014 migration year. The hatchery steelhead group is a wild x wild cross released in the Wenatchee basin (reared at Chelan, East Bank, or Turtle Rock hatcheries depending on year). The NPCC (2014) 2%–6% SAR objective for listed wild populations is shown for reference.

The estimated overall SAR (MCN–BOA) for Wenatchee River wild sockeye ranged from 1.3% to 2.7% in 2014-2015 (Table B.100; Figure 4.20). The estimated overall SAR (MCN–BOA) for Okanagon River wild sockeye ranged from 1.5% to 3.0% in 2014-2015; an estimate was not made for 2013 because the RRE-MCN juvenile survival estimate was unreliable that year (Table B.101; Figure 4.20). The estimated overall SAR (RRE–BOA) ranged from 1.2% in 2015 to 8.1% in 2013 (Table B.101; Figure 4.20).

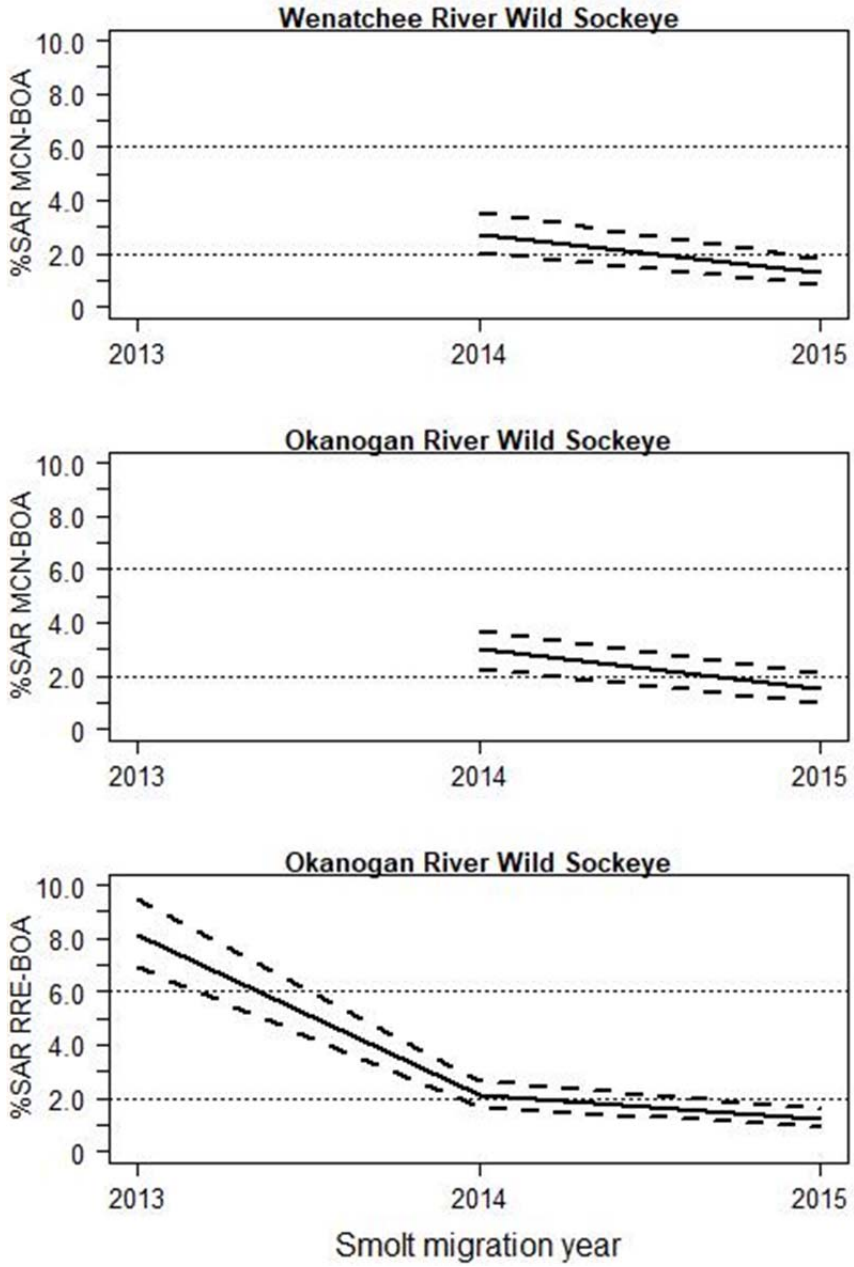

Figure 4.20. Bootstrapped SAR (MCN-to-BOA and RRE-BOA) and upper and lower CI for Okanogan River and Wenatchee River wild sockeye from Upper Columbia region, 2013-2015 migration years. The NPCC (2014) 2%–6% SAR objective for listed wild populations is shown for reference.

Because the component of Upper Columbia SARs upstream of McNary Dam is missing for most populations and migration years due to insufficient smolt PIT tag detection capability, the CSS used smolts PIT-tagged at Rock Island Dam (RIS) by the SMP to estimate SARs further upriver closer to their entry into the mainstem migration corridor in the hydrosystem. The SMP estimates survival from RIS, downstream of the Wenatchee basin, to McNary Dam for run-at-large hatchery and wild steelhead and Chinook smolts captured, PIT-tagged, and released at RIS (FPC annual report 2015). Survival estimates through this 360-kilometer reach are estimated in 2-week periods across several migration years when sample size is available (Figure 4.21). The

2-week estimates are highly variable but consistently indicate that a large mortality occurs from RIS to MCN for the run-at-large juvenile spring Chinook and steelhead (geometric mean survival ~ 0.60). For the Wenatchee stocks, this implies that if estimating SARs similarly to other CSS groups were possible, they would average about 60% of that indicated by the MCN to BOA SAR. For example, the geometric mean MCN to BOA SAR for Wenatchee hatchery steelhead (Table B.99) would change from 2.16% to 1.30%.

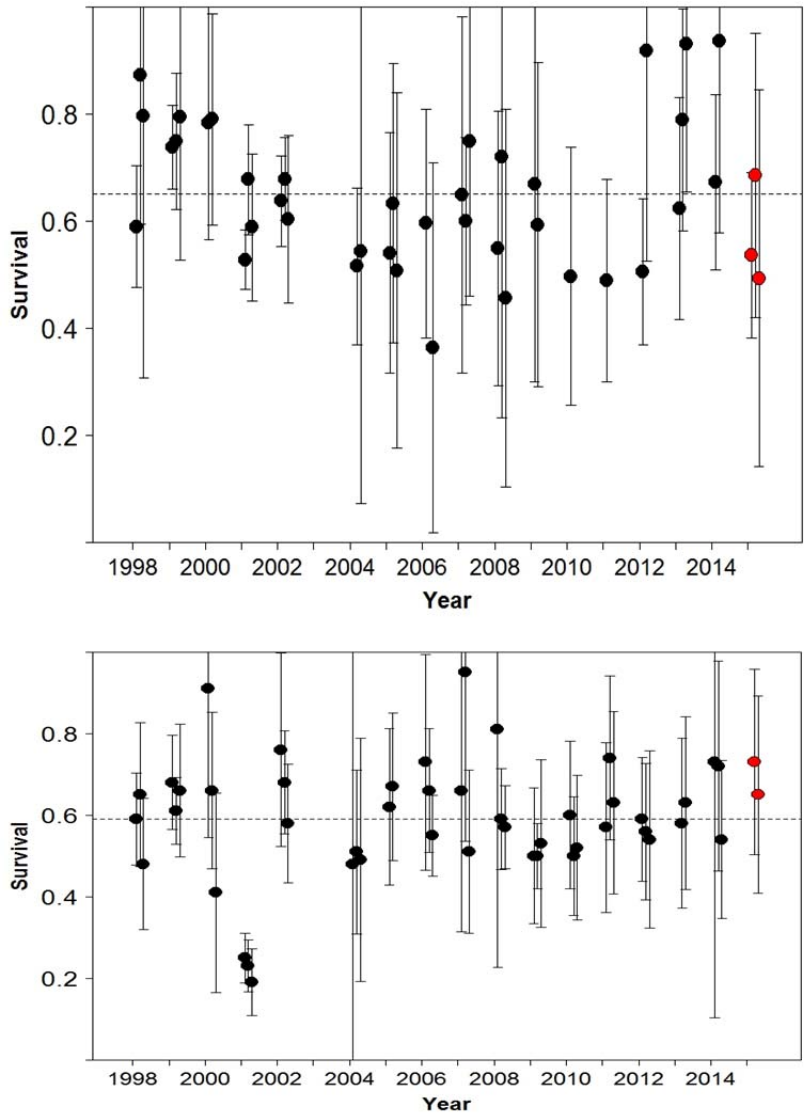

Figure 4.21. Spring out-migrants' juvenile survival from RIS to MCN. The top panel is hatchery + wild yearling spring Chinook and the bottom panel is hatchery + wild steelhead. These are 2-week CJS estimates for smolts captured, PIT-tagged, and released at RIS as part of the SMP project (FPC 2015 annual report). The confidence interval plotted is 95%. The geometric means (through 2014) noted by the horizontal dashed line were 0.61 and 0.59 for Chinook and steelhead respectively.

SARs from smolts tagged at RIS to adults at BOA are summarized in Tables B.102 to B.105 and Figure 4.22 for the SMP PIT tag groups of Upper Columbia wild and hatchery spring

(yearling) Chinook, summer (subyearling) Chinook, steelhead and sockeye. The RIS to BOA SARs of the four Upper Columbia population groups were inter-correlated (average r = 0.50). The SARs of SMP spring Chinook and steelhead groups are 56% and 49% of those for tributary-tagged wild groups (Tables B.88, B.98, B.102 and B.104), likely because of the mixed hatchery/wild composition of the sample and because collection, handling, and tagging at the dam may introduce a negative SAR bias. However, the SMP groups provide a consistent, 16-year time series of survival rates that, except for Leavenworth hatchery spring Chinook, is otherwise lacking in this region.

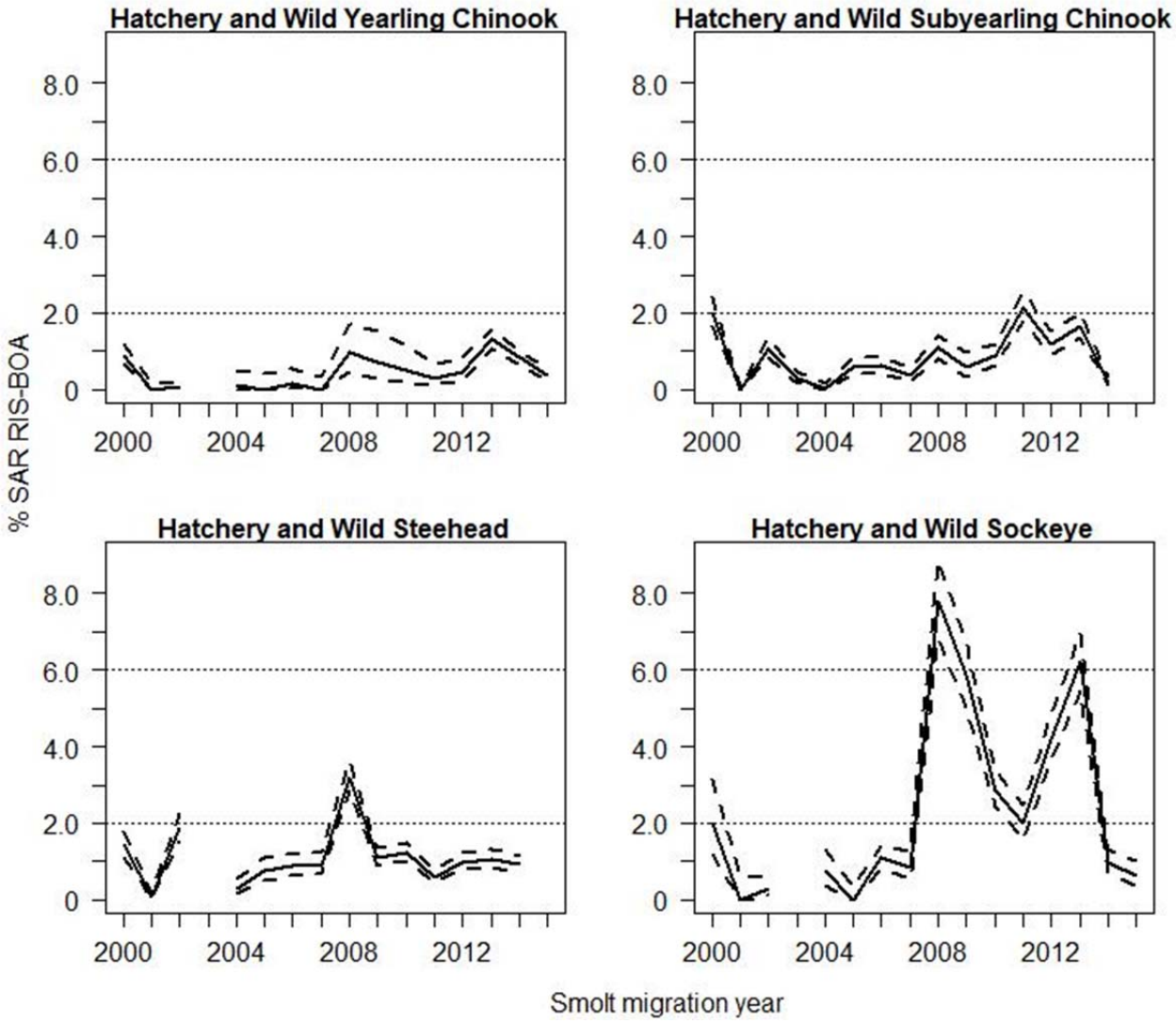

Figure 4.22. SAR (RIS-to-BOA) and upper and lower CI for Upper Columbia wild and hatchery Yearling Chinook , Subyearling Chinook, steelhead and sockeye tagged at Rock Island Dam for the Smolt Monitoring Program, 2000–2015. Smolts were tagged at upper dam; adults are enumerated at BOA. The NPCC (2014) 2%–6% SAR objective for listed wild populations is shown for reference.

Comparison of PIT-tag and Run Reconstruction SARs

The ISAB/ISRP (2007) review of the CSS Ten-Year Retrospective Report (Schaller et al. 2007), encouraged the CSS to investigate differences, and reasons for any differences, between SARs based on PIT-tags and those based on run reconstruction (RR) methods. Schaller et al. (2007) found that the NOAA RR SAR point estimates (Williams et al. 2005) were about 19% higher (geometric mean) than those produced by CSS using PIT-tags. It was unclear whether a bias existed in the RR SARs, PIT-tag SARs, or both, due, in part, to uncertainties and assumptions in both methods. Knudsen et al. (2009) reported that hatchery spring Chinook from the Yakima River that were coded-wire-tagged, elastomer marked, and ad-clipped returned at a 33% higher rate than fish that were PIT-tagged, coded-wire-tagged, elastomer marked, and ad-clipped. The Knudsen study illustrated the potential for PIT-tag effects, however, its applicability to other river reaches or populations of fish is unknown (Tuomikoski et al. 2009; DeHart 2009).

Snake River wild spring/summer Chinook SARs based on IDFG run reconstruction (Camacho et al. 2017) were 46% greater (geometric mean of ratio) than those based on PIT tags, during migration years 1996–2014 (Figure 4.22). The RR and PIT-tag SARs were highly correlated (0.93), and both time series indicated SARs were well short of the NPCC (2014) 2%–6% SAR objectives across the majority of years.

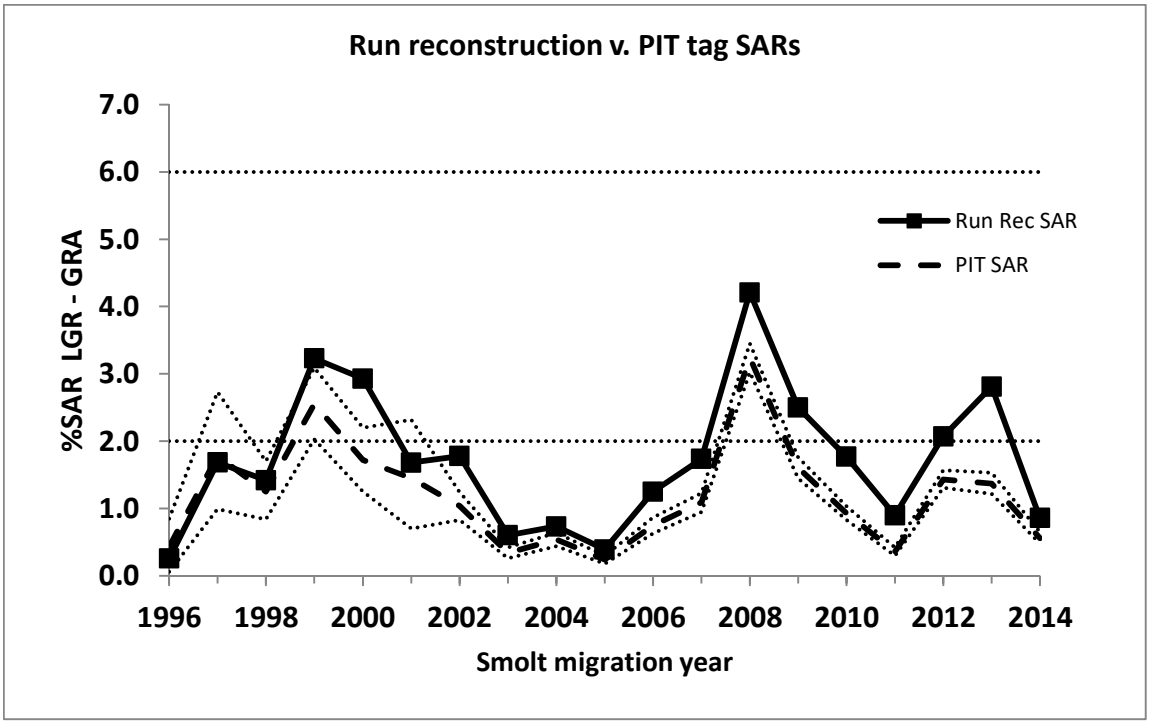

Figure 4.22. IDFG run reconstruction SARs (including jacks) compared to CSS PIT-tag SARs and 90% CI, Snake River wild spring/summer Chinook, migration years 1996–2014. NPCC (2014) 2%–6% SAR objectives for listed wild populations are shown for reference.

In the CSS 2009 annual report (Tuomikoski et al. 2009), we compared SARs and estimates of juveniles and associated variance used in the IDFG run reconstruction of Snake

River wild spring/summer Chinook at Lower Granite Dam (Copeland et al. 2008) with CSS PIT-tag estimates. The difference between RR and PIT tag SARs did not appear to be predominantly due to differences in juvenile abundance estimation methods. Tuomikoski et al. (2009) concluded that estimates of juvenile population abundance derived in CSS, when using the SMP collection index, were similar to those reported by Copeland et al. (2008). Tuomikoski et al. (2009) also developed a bootstrap variance estimator to account for variation in daily detection probability estimates and collection samples for use with the RR methods.

In the CSS 2010 annual report (Tuomikoski et al. 2010), we examined SAR methodologies, and developed hypotheses for possible sources of bias in both RR and PIT tag SARs for Snake River wild spring/summer Chinook. We also identified ongoing and future studies and comparisons to examine this question further.

The following factors could potentially bias PIT-tag SARs: (1) non-representative tagging; (2) post-tagging mortality; (3) tag loss (shedding or damaged tags); (4) weighting schemes from different passage routes (before 2006); and (5) adult detection efficiency. Tuomikoski et al. (2010) concluded that factors 2 and 3 appeared most plausible (but un-quantified) for Snake River wild spring/summer Chinook PIT tag SARs.

For RR SARs, bias could result because: (1) wild smolt indices and wild adult indices may incorporate different proportions of adipose-intact hatchery fish; (2) window counts used in the RR are not corrected for fallback or counting period; (3) window counts use length criteria to separate jacks and adults; and (4) age composition estimation errors tend to inflate SARs. All factors appeared plausible for at least some past RR estimates; Tuomikoski et al. (2010) suggested a focus on RR adult data based on LGR adult trap sampling may be useful for future PIT tag and RR SAR comparisons.

There is potential for bias in both the CSS PIT tag and IDFG RR SAR estimates, although both provide useful, highly correlated estimates. To date, a definitive control group has been lacking to quantify the potential post-marking mortality or tag shedding bias in PIT tag SARs. Similarly, it is not yet possible to evaluate the extent of bias in RR SARs. CSS has identified several hypotheses that might help explain the observed differences in SARs between PIT tag and RR methods. Determining the extent and causes of bias ultimately will be important in the synthesis and interpretation of the different survival rate data sets (see CSS 2014 report, Chapter 6).

Ocean Survival Rates (*S.oa* and *S.o1*)

Estimated ocean survival rates (with recruits calculated at the Columbia River mouth), *S.oa*, for Snake River wild spring/summer Chinook during 1994–2014 ranged from 0.003 to 0.061 and the 21-year geometric mean was 0.019 (Table B.106). These recent *S.oa* rates for spring/summer Chinook were more than five-fold lower than the geometric mean of 0.099 for the 1964–1969 period (Figure 4.20). Similarly, *S.oa* for wild steelhead declined more than 6-fold from a geometric mean of 0.175 during 1964–1969 to 0.028 during 1997–2014 (Table B.107; Figure 4.23).

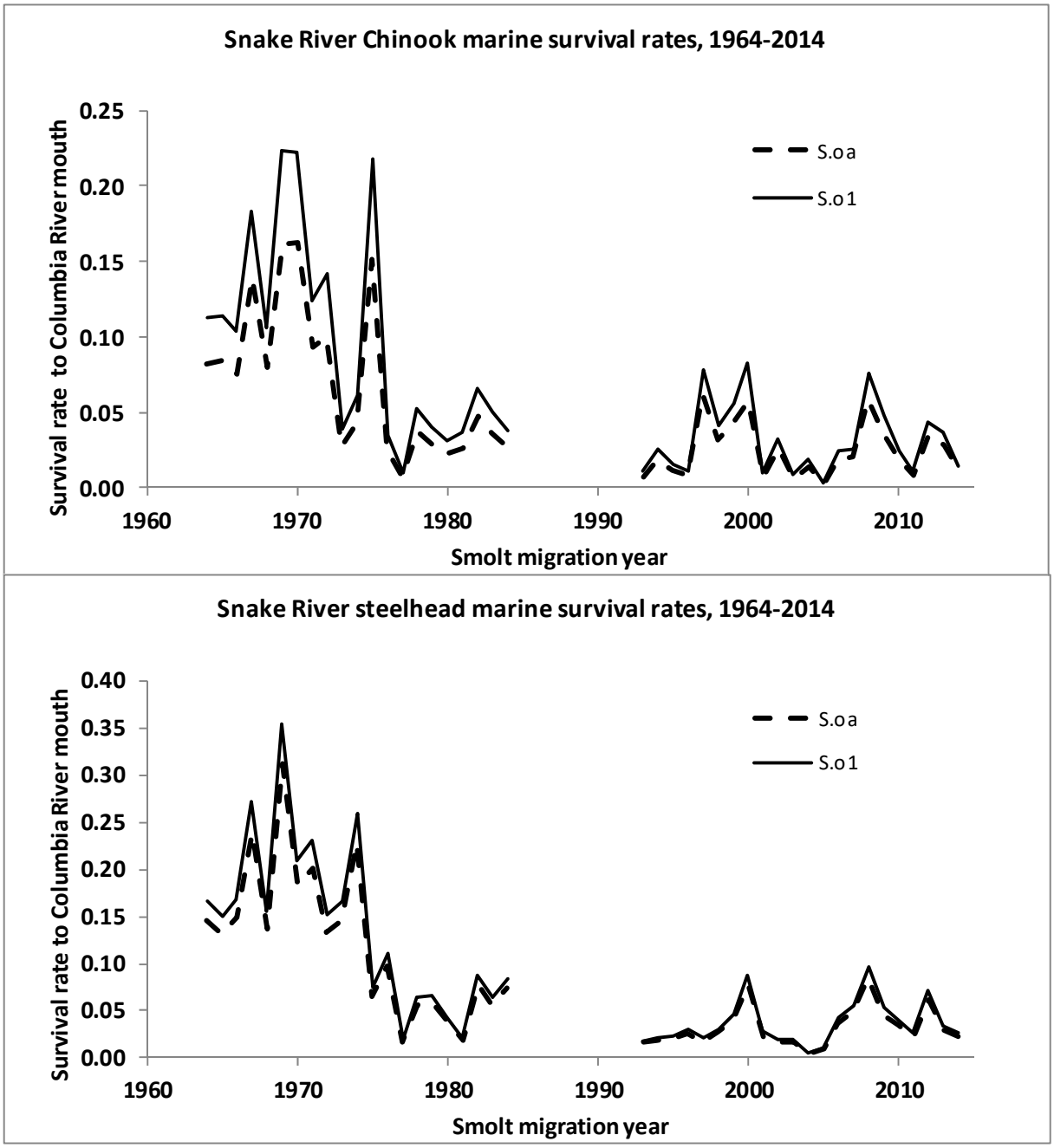

Figure 4.23 Marine survival rates for Snake River wild spring/summer Chinook and steelhead, 1964–2014.

Estimated first year ocean survival rates, *S.o1*, for Snake River wild spring/summer Chinook during 1994-2014 ranged from 0.004 in 2005 to 0.082 in 2000 and the 21-year geometric mean was 0.025 (Table B.106). Estimated *S.o1* for wild steelhead during 1997–2014 ranged from 0.005 in 2004 to 0.097 in 2008 and the 18-year geometric mean was 0.032 (Table B.107). Over the same 18-year period as shown for wild steelhead, the geometric mean of *S.o1* was 0.027 for Snake River wild spring/summer Chinook. In contrast, the geometric mean of first year ocean survival during 1964–1969 was estimated to be 0.134 and 0.199 for

Snake River spring/summer Chinook and steelhead, respectively (Petrosky and Schaller 2010; Tuomikoski et al. 2012).

To date, CSS has estimated *S.oa* and *S.o1* only for Snake River wild spring/summer Chinook and steelhead, but will explore estimating *S.oa* and *S.o1* for mid-Columbia and upper Columbia wild spring Chinook and steelhead in future reports as we develop the relevant time series of SARs and in-river survival rates. The *S.oa* and *S.o1* calculations are simplified for these regions without the impacts of juvenile collection and transportation from the FCRPS dams, although detection capability for juvenile outmigrants is more limited.

Discussion

In summary, it appears that neither Snake River wild spring/summer Chinook nor wild steelhead populations are consistently meeting the NPCC 2%–6% SAR objective. Geometric mean SARs (LGR-to-GRA) were 0.84% and 1.60% for PIT-tagged wild spring/summer Chinook and steelhead, respectively. In the 19 years since 1997, SARs have significantly exceeded the 2% minimum in only two years for Snake River wild Chinook and four years for wild steelhead. SARs of both species have been well short of the NPCC objective of an average 4% SAR.

Although Snake River hatchery spring/summer Chinook exhibited a generally more positive response to transportation and relatively lower levels of differential delayed mortality (higher *D*) than wild populations (Appendix A), annual SARs of Snake River wild and hatchery spring/summer Chinook were highly correlated across years. In view of this high correlation, continuing the CSS time series of hatchery SARs will be important to augment wild spring/summer Chinook SAR information in future years of low tag return numbers of wild adults and in the investigation of survival rate variation of wild populations. In addition, the time series provides valuable management information for the specific hatcheries and for management of FCRPS river operations.

Similar factors during the smolt migration and estuary and ocean life stages appear to influence survival rates of Snake River wild and hatchery spring/summer Chinook populations, based on our evaluation of trends in SARs for the wild and hatchery groupings. We also observed a high degree of synchrony in SARs of wild spring/summer Chinook at the MPG level. A high degree of synchrony among populations may pose additional risk to metapopulation persistence when abundance is low (McElhany et al. 2000; Isaak et al. 2003). There were survival rate differences among spring/summer Chinook hatcheries such as Dworshak NFH, which showed generally poorer SARs within years than Rapid River, McCall and Imnaha hatcheries; conversely, the McCall and Imnaha hatcheries typically had among the highest SARs within a year.

Reasons for the relative lack of correlation between Snake River wild and hatchery steelhead SARs during 1997–2014 are unknown, but appear to be related to the opportunistic nature of assembling aggregate hatchery steelhead groups from various monitoring programs prior to 2008. More representative tagging for Snake River steelhead hatcheries began in coordination with LSRCP and IPC in migration year 2008. Wild and hatchery steelhead SARs have tracked more closely (r =0.80) in the seven years since we improved hatchery group representation. Future implementation of the CSS design and analysis for hatchery steelhead

should allow for evaluation of any disparity among groups (e.g., among facilities or A-run vs. B-run) to help craft appropriate retrospective weightings for aggregate hatchery steelhead SARs. A moderate correlation between wild spring/summer Chinook and wild steelhead SARs is apparent.

Overall SARs of Snake River wild spring/summer Chinook and steelhead are the net effect of SARs for the different routes of in-river passage and juvenile transportation. None of the passage routes have resulted in SARs that met the NPCC SAR objectives for either species (Appendix A). The relative effectiveness of transportation has been observed to decline as in-river conditions and survival rates improve.

The CSS began a time series of SARs for Snake River hatchery sockeye in 2009. Sockeye SARs have varied by year and hatchery group (Sawtooth and Oxbow hatcheries). Sockeye production was phased out at Sawtooth Hatchery after migration year 2015, with production (and the CSS mark group) being shifted to Springfield Hatchery. The 2015 Springfield Hatchery release experienced severe fish health problems, which were reflected in poor juvenile survival and a low SAR (no adult PIT tag returns).

Mid-Columbia River wild spring Chinook populations, as represented by the John Day River and Yakima River aggregate groups, have experienced SARs generally within or close to the range of the NPCC 2%–6% SAR objective. The geometric mean SARs for John Day River and Yakima River wild spring Chinook were 4.0% and 2.4%, respectively, during 2000–2015. CSS has begun time series of wild steelhead SARs for the John Day, Deschutes and Yakima rivers, with most SARs meeting (or exceeding) the NPCC 2%–6% SAR objective.

Mid-Columbia River hatchery spring Chinook (Carson, Warm Springs and Cle Elum) SARs have varied by year and hatchery during 2000–2015. SARs for Carson Hatchery were less than those for Cle Elum Hatchery; SARs for the three hatcheries were consistently less than those for John Day and Yakima wild spring Chinook. Although differing in magnitude, SARs were highly correlated among wild and hatchery spring Chinook stocks within the mid-Columbia Region.

The CSS has begun to establish a time series of SARs (MCN-BOA and RRE-BOA) for Upper Columbia River wild and hatchery salmon and steelhead populations. Leavenworth Hatchery spring Chinook SARs were highly correlated with SARs of wild and hatchery spring and spring/summer Chinook stocks from both the mid-Columbia and Snake regions during 2000–2015. The MCN-BOA reach excludes much of the migration corridor for upper Columbia populations, which pass an additional three (Wenatchee River), four (Entiat River) or five (Methow River) PUD dams upstream of MCN. Consequently, SARs based on detections of PIT-tagged smolts at MCN are biased high. The CSS has begun to estimate SARs of wild spring Chinook and steelhead from populations upstream of Rocky Reach Dam beginning with the 2008 juvenile outmigration year, and with the 2013 juvenile migration year for wild summer Chinook and wild sockeye. SARs from spring Chinook and steelhead smolts at RRE were about 60% of those based on smolts at MCN for these populations and years. Increases in PIT tag detection capability in the Columbia River upstream of MCN will make regional monitoring of overall SARs more comparable to the SARs for salmon and steelhead populations in the Snake River and Mid-Columbia regions.

The high degree of inter-regional correlation in SARs of wild and hatchery spring and spring/summer Chinook populations indicates that common environmental factors are influencing survival rates from outmigration to the estuary and ocean environments. This

"common year effect" between Snake River wild spring/summer Chinook and mid-Columbia wild spring Chinook has been previously estimated from spawner-recruit patterns (e.g., Deriso et al. 2001; Schaller and Petrosky 2007; Schaller et al. 2014).

PIT tag SARs of Snake River wild spring/summer Chinook were highly correlated with IDFG RR SARs for the period 1996–2014, and SARs from both time series were well short of the NPCC 2%–6% SAR objective. The RR SARs were 46% higher than PIT-tag SARs. We developed several hypotheses in the 2010 CSS report that might help explain the observed differences in SARs between PIT-tag and RR methods. There is potential for bias in both the CSS PIT-tag and IDFG RR SAR estimates, although both provide useful, highly correlated estimates. To date, a definitive RR control group has been lacking to quantify the potential bias from post-marking mortality or tag loss in PIT-tag SARs. Determining the extent and causes of bias in both types of estimates is a priority research topic, and ultimately will be important in the synthesis and interpretation of the different survival rate data sets.

Several studies should yield additional insight into the question of PIT-tag effects on SARs in the near future. The USFWS (in collaboration with the CSS oversight committee) is working towards implementing an independent study of PIT-tag bias to evaluate and test the repeatability of Knudsen et al. (2009) results. Double tagging experiments are currently being implemented for Carson Hatchery (see Chapter 6 of 2014 CSS annual report).

CSS studies have found that the life-cycle survival, SAR and marine survival rates for Snake River spring/summer Chinook and steelhead were strongly related to both ocean conditions and seaward migration conditions through the FCRPS (Schaller et al. 2007; Petrosky and Schaller 2010; Haeseker et al. 2012; Hall and Marmorek 2013; Schaller et al. 2014). Lower survival rates for spring/summer Chinook were associated with warmer ocean conditions, reduced upwelling in the spring, and slower river velocity during the smolt migration or multiple passages through powerhouses at dams (Petrosky and Schaller 2010; Schaller et al. 2014). Similarly, lower survival rates for steelhead were associated with warmer ocean conditions, reduced upwelling in the spring, slower river velocity and warmer river temperatures (Petrosky and Schaller 2010). Parameters estimated in CSS, including in-river survival, transport proportions and *D*, allow for partitioning of the SARs to estimate ocean survival rates, *S.oa*, and first year ocean survival rates, *S.o1*. The NPCC (2009 and 2014) highlighted the need to identify the effects of ocean conditions on anadromous fish survival so that this information can be used to evaluate and adjust inland conservation and mitigation actions. The NPCC recognized that a better understanding of the conditions salmon face in the ocean could reveal factors that are most critical to survival, and thus which actions taken inland could provide the greatest benefit to improve the likelihood that Columbia River Basin salmon populations can be recovered in the face of varying ocean conditions (NPCC 2009 and 2014). The time series of SARs, *S.oa* and *S.o1* can then be used to evaluate ocean and smolt migration factors that may influence ocean survival of Snake River and upper Columbia salmon and steelhead as called for in the Fish and Wildlife Program (NPCC 2009 and 2014).

Additional comparisons of PIT-tag data within seasons suggest that shared environmental factors are influencing mortality rates of Snake River wild spring/summer Chinook and steelhead (Haeseker et al. 2012). Mortality rates in both species were positively correlated: (1) during freshwater outmigration as smolts through a series of hydropower dams and reservoirs; (2) during the period of post-hydrosystem, estuarine/marine residence through adult return; and (3) during the overall life-cycle from smolt outmigration through adult return, suggesting that

shared environmental factors are influencing mortality rates of both species. In addition, evidence of positive co-variation in mortality rates between the freshwater and subsequent marine-adult life stage for each species, suggests that factors affecting mortality in freshwater partially affect mortality during the marine-adult life stage (Haeseker et al. 2012). The percentage of river flow spilled and water transit time were important factors for characterizing variation in survival rates not only during freshwater outmigration, but also during estuarine/ marine residence (Haeseker et al. 2012); the Pacific Decadal Oscillation index was also important for characterizing variation in marine survival rates and SARs of both species. This work, along with the findings in Schaller et al. (2007), Petrosky and Schaller (2010) and Schaller et al. (2014), have illuminated a promising direction of inquiry for CSS work. We plan to continue evaluation of the correlation of SARs among the regions. In the 2013 CSS Workshop (Hall and Marmorek 2013), we used these retrospective models to evaluate which environmental and river management variables best explained the variation in survival rates for the various life stages (e.g., SAR, *S.oa*, *S.o1, and* S.r), and developed prospective models to evaluate expected responses to alternative spill management scenarios (CSSOC 2017). This study direction is consistent with NPCC direction and past recommendations from the ISAB/ISRP. These tools hold promise for evaluating river operations with respect to NPCC objectives, and in guiding design for adaptive management experiments.

Conclusions

- Overall PIT-tag SARs for Snake River wild spring/summer Chinook and wild steelhead fell well short of the Northwest Power and Conservation Council (NPCC) SAR objectives of a 4% average for recovery and 2% minimum.
- PIT-tag SARs of Snake River hatchery spring/summer Chinook varied by hatchery and year, and were highly correlated with those of wild spring/summer Chinook. There was a general lack of correlation between Snake River hatchery and wild steelhead SARs.
- Overall SARs of Snake River wild spring/summer Chinook and steelhead are the net effect of SARs for the different routes of in-river passage and juvenile transportation. None of the passage routes have resulted in SARs that met the NPCC SAR objectives for either species. The relative effectiveness of transportation has been observed to decline as in-river conditions and survival rates improve.
- PIT-tag SARs for Mid-Columbia wild spring Chinook (John Day and Yakima rivers) and wild steelhead (John Day, Deschutes and Yakima rivers) generally fell within the 2%–6% range of the NPCC SAR objectives.
- Hatchery (Carson and Cle Elum) and wild spring Chinook SARs from the Mid-Columbia region were highly correlated; hatchery SARs were consistently lower in magnitude.

- PIT-tag SARs for Upper Columbia hatchery spring Chinook (Leavenworth) were highly correlated with wild and hatchery spring/summer and spring Chinook stocks from both the Snake and Mid-Columbia regions. Due to limited juvenile detection capability in the Columbia River mainstem upstream of MCN, previous Upper Columbia SAR time series have been presented as MCN-to-BOA, which overstates life cycle survival by excluding mortality within the migration corridor upstream of MCN. The CSS has begun to estimate SARs beginning with smolts at Rocky Reach Dam to address this issue.
- SARs based on run reconstruction methods were greater than and highly correlated with, PIT-tag SARs of Snake River wild spring Chinook. Both time series indicate survival rates fell well short of the NPCC 2%–6% SAR objective. Potential for bias in SAR estimates exists in both the run reconstruction and PIT-tag methodologies. Determining the extent and cause of bias ultimately will be important in the synthesis and interpretation of the different survival rate data sets.
- Parameters estimated in CSS, including in-river survival, transport proportions and *D*, allow for partitioning of SARs to estimate ocean survival rates. The time series of SARs and ocean survival rates can be used to evaluate ocean environmental variables and smolt migration conditions within the FCRPS that may influence ocean survival of Snake River and upper Columbia salmon and steelhead as called for in the Fish and Wildlife Program (NPCC 2014

CHAPTER 5
SARs AND PRODUCTIVITY

Since its inception, the CSS has been reporting observed smolt-to-adult survival rates (SARs) for wild and hatchery salmon and steelhead relative to the Northwest Power and Conservation Council's Columbia Basin Fish and Wildlife Program implementation (NPCC 2003, 2009, 2014) 2%-6% SAR objectives (*see* Chapter 4). Recent SARs have consistently fallen short of these objectives for wild population groups in the Snake and upper Columbia rivers, whereas recent SARs for most of the mid-Columbia wild population groups have fallen within this 2%-6% range. The NPCC's (2014) Columbia River Basin Fish and Wildlife Program contains several qualitative goal statements and quantitative objectives to prioritize the restoration efforts, including supporting tribal and non-tribal harvest, and achieving smolt-to-adult return rates in the 2%-6% range (average 4%; minimum 2%) for listed Snake River and upper Columbia salmon and steelhead. The Program also supports the ISAB's recommendation to evaluate the 2%-6% SAR objective to reflect the survival of populations needed to achieve recovery and harvest goals.

The genesis of the NPCC 2%–6% SAR objectives was from analyses conducted by the Plan for Analyzing and Testing Hypotheses (PATH), in support of the NMFS 2000 Biological Opinion of the Federal Columbia River Power System (FCRPS). Marmorek et al. (1998) found that median SARs of 4% were necessary to meet the NMFS interim 48-year recovery standard for Snake River spring/summer Chinook; meeting the interim 100-year survival standard required a median SAR of at least 2%. The NPCC (2009 and 2014) SAR objectives did not specify the points in the life cycle where Chinook smolt and adult numbers should be estimated. However, the original PATH analysis for Snake River spring/summer Chinook was based on SARs calculated as adult and jack returns to the uppermost dam (Marmorek et al. 1998). PATH analyses also did not identify specific SARs necessary for steelhead survival and recovery. However, before completion of the FCRPS, steelhead SARs were somewhat greater than those of spring/summer Chinook (Marmorek et al. 1998). The Interior Columbia River Technical Recovery Team (ICTRT 2007) developed biological recovery criteria based on the Viable Salmonid Population concepts (McElhany et al. 2000). Additional SAR objectives may be associated with the ICTRT recovery criteria for abundance and productivity when adopted or incorporated into a Recovery Plan, as well as with the objectives identified in Fish and Wildlife Program subbasin plans, and other State and Tribal fishery management plans. Broad-scale recovery goals, such as these, are higher than required for U.S. federal ESA delisting and typically include a provision for restoring sustainable fisheries of wild salmon and steelhead. The Independent Scientific Advisory Board (ISAB 2012) review of the 2012 CSS draft annual report also highlighted the NPCC SAR objectives as an important regional programmatic issue.

A SAR objective for persistence may need to account for adults returning to the spawning grounds, whereas broader objectives would also need to account for adults returning to various locations to meet harvest objectives (e.g., subbasin or Columbia River mouth). In the 2017 annual report, we continue to investigate the relation between SARs and population productivity using two approaches. The first approach is related to persistence objectives and summarizes the SAR levels of Snake River wild spring/summer Chinook and steelhead associated with population replacement at recent levels of abundance. The second approach incorporates stock-recruitment functions to investigate the association between pre-harvest SARs and historical

productivity levels relative to broad-scale recovery objectives for wild Snake River spring/summer Chinook and mid-Columbia spring Chinook.

Analyses in this Chapter support objectives of the Columbia River Basin Fish and Wildlife Program (NPCC 2014), encouraging a regional review of the NPCC SAR objectives relative to the survival of populations needed to achieve salmon and steelhead recovery and harvest goals. In 2016, the CSS began a comparison of Snake River steelhead SARs to population productivity for Fish Creek (Clearwater Major Population Group (MPG)) and Rapid River (Salmon MPG) populations that complement those for Snake River spring/summer Chinook. We added comparable data for Pahsimeroi River steelhead (Salmon River MPG) in this report. In 2017 we also updated the analysis of pre-harvest SARs and historical productivity for Snake River spring/summer Chinook and John Day River spring Chinook. The CSS plans to continue to update and expand these analyses as Chinook and steelhead run reconstruction data are updated and become available. For example, sampling of smolts and adults at rotary screw traps and weirs in Joseph Creek and the Wallowa River in northeastern Oregon could inform future management objectives.

Comparisons of Chinook and steelhead population productivity and SARs are conducted at the finest geographic scales possible, consistent with the ISAB (2013) review comments of the CSS draft 2013 annual report. Analyses in this Chapter are also complimentary to the Chapter 2 analysis for the Grande Ronde/Imnaha spring/summer Chinook MPG, adding data from populations and MPGs across the entire Snake River spring/summer Chinook ESU. Notably, analyses in this chapter include population data from the Middle Fork Salmon River MPG that is primarily in wilderness and has little potential for improvement to tributary habitat or survival during the egg-to-smolt life stage.

Methods

Recent SARs and Population Replacement

In the 2017 annual report, we continue our investigation of the relation between SARs and realized population productivity of Snake River spring/summer Chinook populations for brood years 1992–2010. Spring/summer Chinook populations used in this analysis are 17 Snake River populations across four MPGs used in Schaller et al. (2014). Populations (and MPGs) include: Bear Valley, Marsh, Sulphur and Big creeks (Middle Fork Salmon); South Fork Salmon River Mainstem, East Fork South Fork Salmon River and Secesh River (South Fork Salmon); Lemhi River, East Fork Salmon River, Upper Salmon River and Valley Creek (Upper Salmon); and Wenaha River, Minam River, Lostine/Wallowa River, Catherine Creek, Upper Grande Ronde River and Imnaha River (Grande Ronde/Imnaha). The 18th population, Big Sheep Creek (Imnaha River tributary), used in Schaller et al. (2014) is functionally extinct and not included in this summary. Snake River spring/summer Chinook run reconstruction data consisting of spawner and spawning-ground recruit estimates were recently updated by ODFW, IDFG and NPT staff through 2014 or 2015 adult returns (2009 or 2010 brood year) and submitted to NOAA Fisheries for the 2016 ESA Status Review. Hatchery-origin Chinook on the spawning grounds are accounted for in the run reconstructions on the basis of identifiable marks (e.g., adipose fin clips or other marks). Those fish are not recruits of fish that spawn in nature.

We defined the realized Chinook population productivity as ln((adult recruits to spawning grounds)/(adult spawners)) for brood years 1992–2010 (or 2009). Productivity in terms of spawning ground recruits (R_{sg}) is most applicable to evaluation of population persistence (e.g., ICTRT 2007) and spawning escapement objectives. We used the CSS estimates of LGR-GRA SARs (jacks excluded) for wild spring/summer Chinook for smolt migration years 1994–2012. We used aggregate wild SARs for smolt migration years 1994–2005, and MPG-specific SARs for 2006–2012 in this analysis. We selected SARs excluding jacks for this summary because that metric aligns most closely with the ICTRT population productivity metric that also excludes jacks on the spawning grounds. We plotted population productivity against SARs for the 17 individual populations and for the four MPGs. We then summarized the population productivities by MPG and graphically compared distributions of observed productivity by SAR category: <1.0% SAR, 1.0 - 1.9% SAR, and ≥ 2.0% SAR. These graphical comparisons begin to illuminate the SARs needed for population abundance to stabilize or increase, given recent (1992–2010) wild adult abundance levels; however, it is primarily observational and does not attempt to account for density-dependent effects on recruitment at higher spawner abundances.

We continue to investigate the relation between SAR and realized population productivity of Snake River steelhead using data from Fish Creek (a major tributary of the Lochsa River Population, Clearwater River MPG), Rapid River (a major tributary of the Lower Salmon Population, Salmon River MPG) and Pahsimeroi River (Salmon River MPG). Hatchery influence is minimized in these drainages by exclusion of any hatchery production or strays at the weirs (Copeland et al. 2015). Data from Fish Creek included brood years 1996-2010 and data from Rapid River and Pahsimeroi River included brood years 2003-2010. Steelhead from Fish Creek are classified as B-run; steelhead from Rapid River and Pahsimeroi River are classified as A-run. Steelhead run reconstruction data were obtained from Copeland et al. (2015) as updated by Stark et al. (2016) to include data collected in 2015.

We defined the realized steelhead population productivity as ln((recruits to spawning grounds)/(spawner)). Steelhead cohorts produce smolts ranging in age from one to five (or more) years old, in contrast to spring/summer Chinook, which primarily produce only yearling smolts (with a few exceptions). Therefore, to calculate SARs by brood year we weighted multiple years of SARs by the juvenile outmigrant age structure. We used CSS estimates of LGR-GRA SARs for wild A-run (Rapid River and Pahsimeroi River) or B-run (Fish Creek) steelhead for smolt migration years 2006-2012 (Tables B.41, B.42). Prior to smolt migration year 2006, we used SAR estimates for the wild aggregate steelhead (Table B.35). We used the age composition of spring migrants at rotary screw traps to index average smolt age composition from Copeland et al. (2015). For Fish Creek, age composition was 12.5% one-year, 50.0% two-year, 33.3% three-year, and 4.2% four-year. Average age composition for Rapid River steelhead was 9.1% one-year, 25.8% two-year, 49.5% three-year, 14.5% four-year, and 1.1% five-year. Average age composition for Pahsimeroi River steelhead was 79.1% one-year, 19.7% two-year and 8% three-year.

We plotted population productivity against brood year SARs for the Fish Creek, Rapid River and Pahsimeroi River steelhead populations. We then graphically compared distributions of observed productivity by brood year SAR category: <1.0% SAR, 1.0 - 1.9% SAR, and ≥ 2.0% SAR.

SARs and Historical Productivity

We also continue to examine the relation of SARs to historical pre-harvest productivity, updating the (density-dependent) stock-recruitment functions from Schaller et al. (2014). Schaller et al. defined spawners (S) as adult spawners and recruits (R) as pre-harvest recruits (adults and jacks) to the Columbia River mouth.

In the 2017 report we added data from the 2005-2010 (or 2009) brood years for Snake River spring/summer Chinook and refitted stock-recruitment functions following the Schaller et al. methodology. As noted above, Snake River spring/summer estimates of spawners and spawning-ground recruits (R_{sg}, including jacks) were recently updated for the NOAA Fisheries 2016 ESA Status Review. We expanded the spawning ground recruit (R_{sg}) estimates to pre-harvest recruits to the Columbia River mouth (R) using U.S. v. OR Technical Advisory Committee harvest mortality impact estimates from tributary sport and tribal fisheries and from fisheries below Bonneville Dam, and the CSS upstream passage survival estimates between Bonneville Dam and Lower Granite Dam. The recently updated S and R_{sg} estimates, in some cases, used different redd count expansions from those used in the Schaller et al. analysis, which necessitated refitting spawner-recruit relationships.

Spawner-recruit (SR) relationships were developed for 18 populations of Snake River spring/summer Chinook from four MPGs for brood years 1950s–2010. Non-stationarity in migration and marine conditions was accounted for by using a period effect:

$$ln(R_{ij}/S_{ij}) = T_i + a - \beta(S_{ij} - \overline{S_{..}}) + \varepsilon_{ij}$$

where T_i is the class effect (period), a is the intercept, β is the slope, $\overline{S_{..}}$ is the average spawners for all observations during both time periods, ε_{ij} is the normally distributed residual, i is the class (period), and j is the observation (brood year).

Schaller et al. (2014) classified SR data into two primary periods defined by FCRPS development and operations affecting the threatened Snake River populations. The first period, pre-1970 brood years, was before completion of the final two Snake River dams. The second period, post-1974 brood years (1975–2010), was characterized by completion of the full eight-dam complex, collection and transportation of smolts around dams in barges and trucks, turbine screening programs, spill passage structures, and other management actions to improve passage at the dams (Budy et al. 2002, Haeseker et al. 2012). The 1970–1974 period was excluded from fitting of the recruitment functions because it was a period of construction and changing operations in the Snake River that caused extremely high levels of atmospheric gas supersaturation in high-flow years (Raymond 1979) before mass transportation of smolts had begun.

Schaller et al. (2014) also presented SR residuals, designated as survival rate indices (SRIs), which we have updated for the 1950s-2010 brood years. They defined SRIs as the deviation of the observed ln(R/S) from the pre-1970 expected ln(R/S). The pre-1970 period represented a baseline before full development of the FCRPS, and prior to initiation of mass juvenile transportation.

Pre-harvest SARs (Returns to the mouth of the Columbia River) for Snake River aggregate wild Chinook are available beginning in 1964 (1962 brood year; Figure 4.1; Table

B.106). Snake River average annual SRI estimates are regressed against the aggregate ln(SARs), and plotted by decade to examine temporal patterns of the association. In addition, we examined SRI and SAR patterns within the four Snake River MPGs. Average annual SRI estimates for each MPG are also regressed against the aggregate ln(SARs) and plotted to examine spatial patterns across the Snake River ESU.

Schaller et al. (2014) similarly developed SR relationships for three populations of John Day River spring Chinook in the Mid-Columbia MPG downstream of the lower Snake River and McNary dams for brood years 1950s–2004 and estimated SRIs as defined above. In the 2017 report, we added data from the 2005-2010 brood years for those populations (Bare et al. 2015 and 2016). We used the Schaller et al. stock-recruitment functions to continue the SRI monitoring metric; stock-recruitment functions will be refit and SRIs recalculated for the 2018 report. The SARs based on PIT tags for John Day River wild Chinook are available beginning in smolt migration year 2000 (1998 brood year) (Table B.73). The SRI estimates (SR residuals) are regressed against the pre-harvest ln(SARs) for the John Day River populations for the 13 years of overlap. Pre-harvest returning adults in fisheries downstream of Bonneville Dam in the SAR estimates are from U.S v Oregon TAC estimates of harvest of or impacts to wild-origin fish destined to return upstream of Bonneville Dam.

Results

Recent Chinook SARs and Population Replacement

Aggregate Snake River wild Chinook SARs (LGR-GRA, jacks excluded) during smolt migration years 1994–2012 (brood years 1992-2010) averaged 0.81% (geometric mean) and ranged from 0.22% to 2.74% (Table B.1). SARs were less than 1% during 11 years, in the 1%-2% range during six years, and greater than 2% during only two of 19 years.

A strong association is evident between Rsg/S and SAR for Snake River Chinook populations. Generational declines in abundance (ln(Rsg/S) < 0) occurred in 130 out of 184 cases (71%) where SARs were less than 1%, in 20 out of 96 (21%) cases where SARs were between 1% and 2%, and in only one out of 34 cases (3%) where SARs were greater than 2% (Figure 5.1 upper panel). The patterns of association between Rsg/S and SAR were generally similar across the four MPGs (Figure 5.1, lower panel). Average population replacement for Grande Ronde/Imnaha and South Fork Salmon MPGs at recent abundances however, appears to require somewhat higher SARs than for Middle Fork Salmon and Upper Salmon MPGs (Figure 5.1, lower panel).

SARs less than 1% consistently resulted in generational decreases in abundance (ln(Rsg/S) < 0) in all four Chinook MPGs (Figure 5.2). Conversely, SARs greater than 2% resulted in generational increases in abundance in all four MPGs. Observed productivity was generally positive (median ln(Rsg/S) > 0) when SARs were in the 1%–2% range; this result might be expected, because population abundance was typically very low and only a fraction of the Minimum Abundance Thresholds (MAT; Table 5.1) established for long-term population viability (ICTRT 2007). These graphical comparisons begin to illuminate the SARs needed for Snake River Chinook population abundance to stabilize or increase, given recent (brood years 1992–2010) abundance levels.

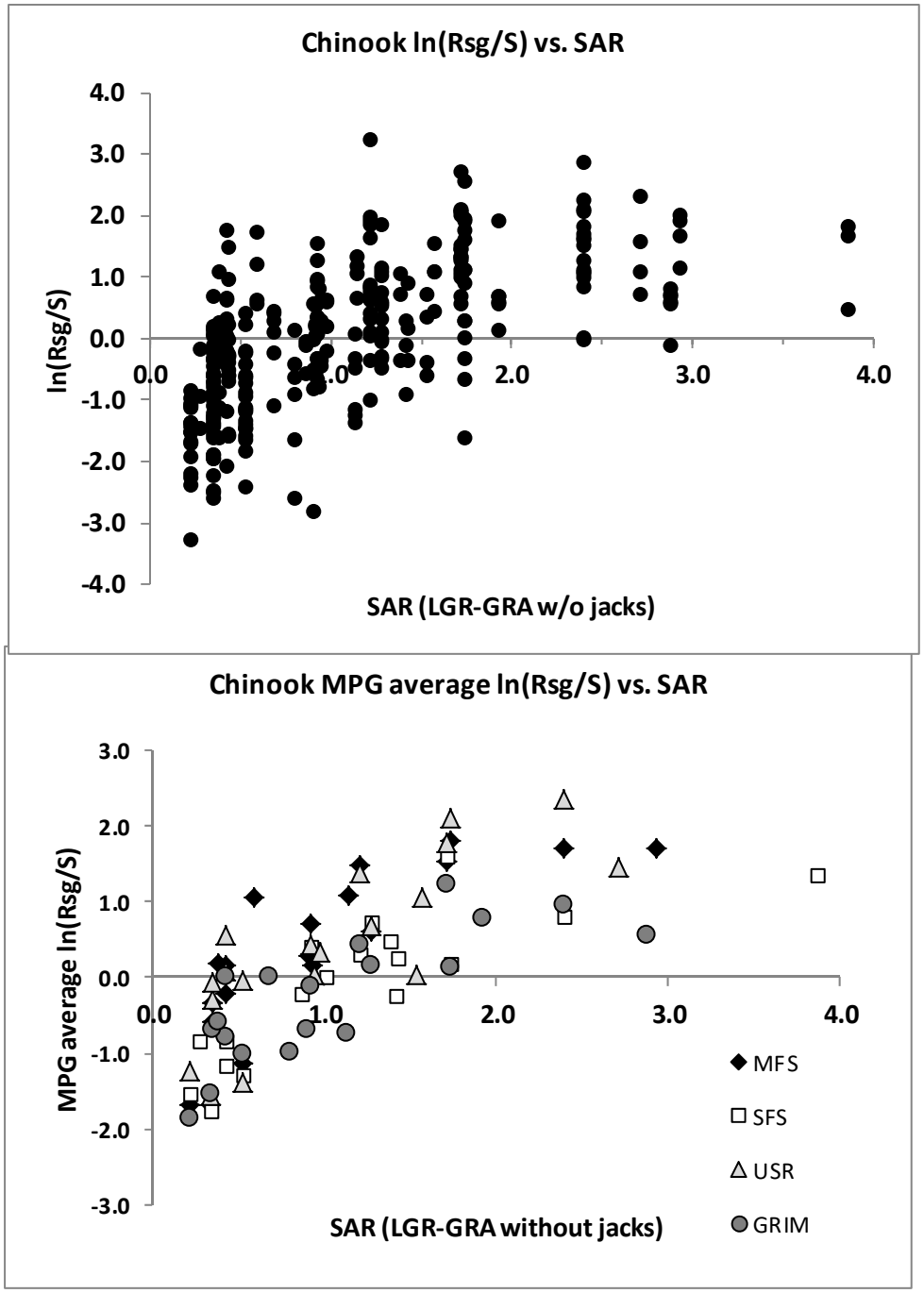

Figure 5.1. Association of spawning ground recruits/spawner, ln(Rsg/S), and SAR for 17 Snake River spring/summer Chinook populations (upper panel), and by Major Population Group (MPG) (lower panel), brood years 1992-2010. SARs represent LGR-GRA, excluding jacks (1994--2012 smolt migration years). MPGs are Middle Fork Salmon (MFS), South Fork Salmon (SFS), Upper Salmon (USR) and Grande Ronde/Imnaha (GRIM).

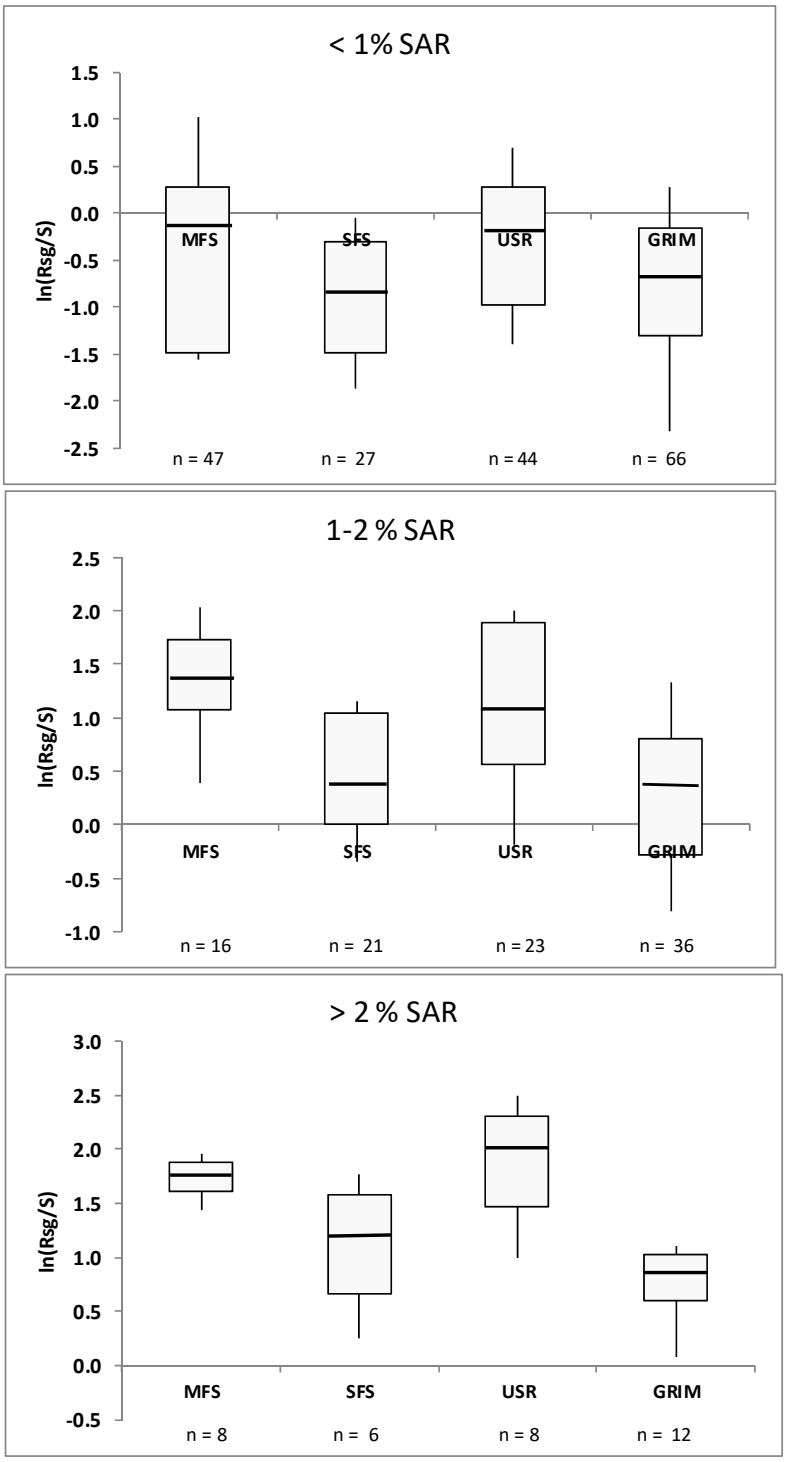

Figure 5.2. Snake River spring/summer Chinook population productivity (ln(Rsg/S)) by MPG and SAR category, brood years 1992–2010. Boxes show 25th percentile, median and 75th percentile of ln(Rsg/S); whiskers show 10th and 90th percentiles of ln(Rsg/S). SARs represent LGR-GRA, excluding jacks (1994--2012 smolt migration years). MPGs are Middle Fork Salmon (MFS), South Fork Salmon (SFS), Upper Salmon (USR) and Grande Ronde/Imnaha (GRIM).

Table 5.1. Summary population abundance statistics, Snake River spring/summer Chinook populations, 1992–2010 brood years.

MPG, Population	Average total adult spawners	Range total adult spawners	Average hatchery fraction	ICTRT (2007) Minimum Abundance Threshold (MAT)	Average natural adult spawners as %MAT
Middle Fork Salmon (MFS)					
Bear Valley Creek	421	16 - 1315	0%	750	56%
Marsh Creek	222	0 - 872	0%	500	44%
Sulphur Creek	61	0 - 201	0%	500	12%
Big Creek	191	3 - 668	0%	1000	19%
South Fork Salmon (SFS)					
South Fork Mainstem	1207	203 - 2464	40%	1000	72%
East Fork South Fork	381	47 - 1067	26%	1000	28%
Secesh River	572	142 - 1400	4%	750	73%
Upper Salmon River (USR)					
Lemhi	126	9 - 691	0%	1000	13%
East Fork Salmon River	274	11 - 866	12%	1000	24%
Upper Salmon Mainstem	558	27 - 1740	28%	1000	40%
Valley Creek	89	0 - 288	0%	500	18%
Grande Ronde/Imnaha (GRIM)					
Catherine Creek	211	27 - 914	40%	1000	13%
Grande Ronde Upper Mainstem	235	4 - 2037	37%	1000	15%
Lostine River	565	33 - 3359	36%	1000	36%
Minam River	401	54 - 888	11%	750	47%
Wenaha River	406	73 - 832	16%	750	45%
Imnaha River Mainstem	1020	158 - 2736	58%	1000	43%

Recent Steelhead SARs and Population Replacement

The Fish Creek steelhead analysis was based on Rsg/S estimates for brood years 1996-2010; age 1-4 smolts from these brood years migrated during 1997-2014. SARs (LGR-GRA) from smolt migration years 1997-2014 averaged (geometric mean) 1.47% and ranged from 0.30% to 3.54% (Tables B.35 and B.42). Weighted brood year SARs for 1996-2010 averaged 1.66% and ranged from 0.87% to 2.61% (Table 5.2). Spawning ground recruits/spawner (Rsg/S) of Fish Creek steelhead ranged from 0.37 in 2002 to 10.25 in 1997 (Table 5.2).

The Rapid River steelhead analysis was based on Rsg/S estimates for brood years 2003-2010; age 1-5 smolts from these brood years migrated during 2004-2015 (approximately 1% migrated in 2015). SARs (LGR-GRA) from smolt migration years 2004-2014 averaged (geometric mean) 1.83% and ranged from 0.80% to 3.30% (Tables B.35 and B.41). Weighted brood year SARs for 2003-2010 averaged 2.21% and ranged from 1.50% to 2.70% (Table 5.2). Spawning ground recruits/spawner (Rsg/S) of Rapid River steelhead ranged from 0.34 in 2008 to 2.13 in 2007 (Table 5.2).

The Pahsimeroi River steelhead analysis was based on Rsg/S estimates for brood years 2003-2010; age 1-3 smolts from these brood years migrated during 2004-2013. SARs (LGR-GRA) from smolt migration years 2004-2013 averaged (geometric mean) 1.78% and ranged from 0.80% to 3.30% (Tables B.35 and B.41). Weighted brood year SARs for 2003-2010 averaged 1.79% and ranged from 0.84% to 3.15% (Table 5.2). Spawning ground recruits/spawner (Rsg/S) of Rapid River steelhead ranged from 0.18 in 2003 to 9.86 in 2007 (Table 5.2).

Table 5.2. Estimates of brood year SAR and spawning ground recruits/spawner (Rsg/S) for Fish Creek, Rapid River and Pahsimeroi River steelhead populations. Brood years represented are 1996–2010 for Fish Creek and 2003-2010 for Rapid River and Pahsimeroi River. Brood year SARs represent LGR-GRA (Fish Creek 1997--2014 smolt migration years; Rapid River 2004-2014 smolt migration years; Pahsimeroi 2004-2013 smolt migration years).

	Fish Creek		Rapid River		Pahsimeroi River	
Brood year	Brood year SAR	Rsg/S	Brood year SAR	Rsg/S	Brood year SAR	Rsg/S
1996	1.35	2.95				
1997	2.45	10.25				
1998	2.60	3.45				
1999	2.35	2.65				
2000	1.94	3.45				
2001	1.37	0.89				
2002	0.93	0.37				
2003	0.87	0.78	1.50	0.84	0.84	0.18
2004	1.17	0.92	2.48	0.99	0.94	0.76
2005	2.07	3.03	2.69	1.69	1.80	0.86
2006	2.61	2.44	2.70	1.46	3.15	2.72
2007	1.82	1.41	2.23	2.13	2.63	9.86
2008	1.30	0.43	1.91	0.34	2.71	5.82
2009	1.56	0.81	2.25	0.35	1.93	6.00
2010	2.04	2.25	2.17	0.35	1.68	1.03

An association is evident between Rsg/S and brood year SAR for steelhead from Fish Creek, Rapid River and Pahsimeroi River. Generational declines in abundance (Rsg/S < 1; ln(Rsg/S < 0)) occurred in 11 out of 16 cases where brood year SARs were less than 2% (Table 5.2; Figure 5.3). Population replacement (ln(Rsg/S) = 0) for Rapid River steelhead at recent

abundance appears to require higher SARs than for Fish Creek or Pahsimeroi River steelhead, although sample sizes are limited.

SARs less than 1% resulted in generational decreases in steelhead abundance (ln(Rsg/S) < 0) (Figure 5.4). Conversely, SARs greater than 2% resulted in generational increases in steelhead abundance. Observed productivity was frequently negative (median ln(Rsg/S) < 0) when SARs were in the 1%–2% range. These graphical comparisons begin to illuminate the SARs needed for steelhead population abundance to stabilize or increase, given recent abundance levels.

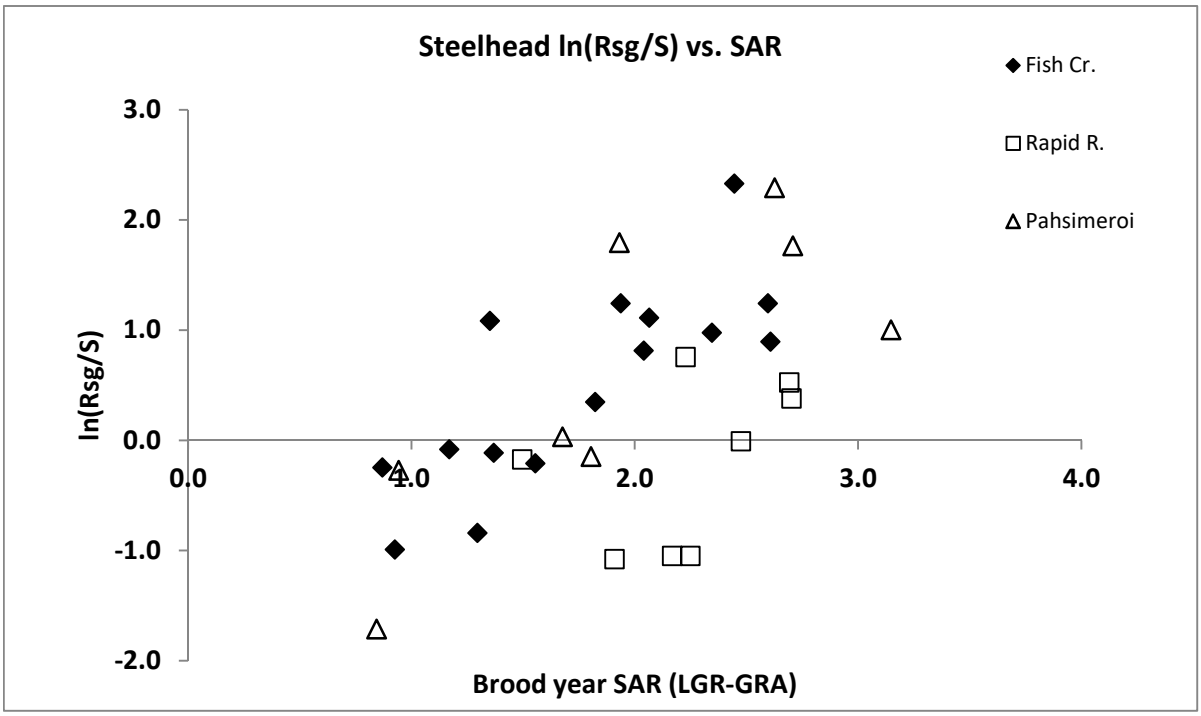

Figure 5.3. Association of spawning ground recruits/spawner, ln(Rsg/S), and brood year SAR for Fish Creek, Rapid River and Pahsimeroi River steelhead. Brood years represented are 1996–2010 for Fish Creek; 2003-2010 for Rapid River and 2003-2010 for Pahsimeroi River. Brood year SARs represent LGR-GRA (Fish Creek 1997--2014 smolt migration years; Rapid River 2004-2014 smolt migration years; Pahsimeroi River 2004-2013 smolt migration years).

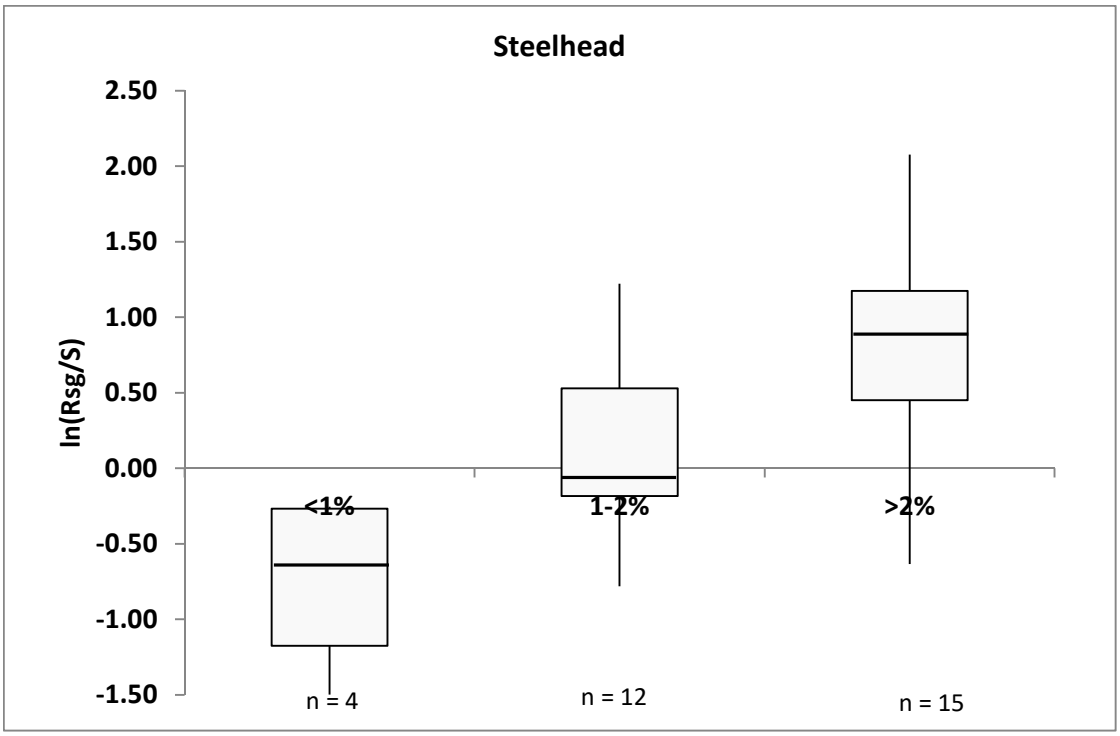

Figure 5.4 Snake River steelhead population productivity (ln(Rsg/S)) by brood year SAR category for Fish Creek, Rapid River and Pahsimeroi River. Brood years represented are 1996–2010 for Fish Creek and 2003-2010 for Rapid River and Pahsimeroi River. Boxes show 25th percentile, median and 75th percentile of ln(Rsg/S); whiskers show 10th and 90th percentiles of ln(Rsg/S). Brood year SARs represent LGR-GRA (Fish Creek 1997--2014 smolt migration years; Rapid River 2004-2014 smolt migration years; Pahsimeroi River 2004-2013 smolt migration years).

SARs and Historical Productivity

Snake River spring/summer Chinook spawner and recruitment functions from Schaller et al. (2014) were updated through brood year 2010 (2009 for SFS MPG and Lostine and upper Grande Ronde rivers) and are presented in Table 5.3. Productivity and survival rates declined more for Snake River Chinook salmon than for John Day River spring Chinook salmon after FCRPS completion (post-1974). Average productivity (T_i+a) declined from the pre-1970 baseline by 2.04 for Snake River populations and by 0.85 for John Day River populations (Table 5.3) for brood years 1975–2010. In other words, expected R/S declined to 13% of the pre-FCRPS productivity for Snake River populations and 43% for John Day populations.

Table 5.3. Analysis of covariance results for Ricker recruitment functions that used period (treatment) and spawners (covariate) for stream-type Chinook salmon Major Population Groups (MPG) and populations from the Snake River and John Day River regions, brood years 1950s-2010. Snake River recruitment functions are updated from Schaller et al. (2014 Table 2).

				Intercept			H0: T1 = T2		H0: B < 0	
Region, MPG	Population	Brood years	Fraction of hatchery spawners (post-1974)	T1+a pre-1970	T2+a post-1974	T1-T2	Intercept H0: T1=T2, p	Slope (-B)	P	R^2
Snake River										
Middle Fork Salmon (MFS)	Bear Valley	1957-2010	0.00	3.9106	1.1108	2.7998	<0.0001	-0.0016235	0.0001	0.34
	Marsh	1957-2010	0.00	3.8693	0.9261	2.9433	<0.0001	-0.0022774	0.0001	0.40
	Sulphur	1957-2010	0.00	3.6798	0.9513	2.7285	<0.0001	-0.0065454	0.0000	0.39
	Big	1957-2010	0.00	2.9854	1.1491	1.8363	0.0004	-0.0029004	0.0001	0.30
South Fork Salmon (SFS)	Mainstem	1957-2009	0.26	1.7520	0.6410	1.1110	0.0002	-0.0003868	0.0006	0.28
	East Fork South Fork	1957-2009	0.13	2.4525	1.0305	1.4220	<0.0001	-0.0015816	0.0000	0.38
	Secesh	1957-2009	0.03	1.5982	1.1717	0.4265	0.0909	-0.001203	0.0001	0.26
Upper Salmon (USR)	Lemhi	1957-2010	0.00	2.6233	0.6163	2.0069	0.0004	-0.0008325	0.0032	0.24
	Upper Salmon	1957-2010	0.19	2.9461	1.1687	1.7774	<0.0001	-0.0009877	0.0000	0.48
	East Fork	1957-2010	0.09	2.9885	0.8365	2.1520	0.0004	-0.0010258	0.0004	0.26
	Valley	1957-2010	0.00	3.0550	0.8647	2.1904	<0.0001	-0.0027451	0.0000	0.35
Grande Ronde/Imnaha (GRIM)	Imnaha	1949-2010	0.36	2.3855	0.6583	1.7271	<0.0001	-0.0005809	0.0000	0.57
	Big Sheep	1964-2004	0.26	1.7178	-0.7791	2.4968	0.0819	0.0009798	0.2972	0.23
	Wenaha	1949-2010	0.18	2.5126	0.4643	2.0483	<0.0001	-0.0007867	0.0119	0.38
	Lostine	1949-2009	0.27	3.2120	1.0739	2.1381	<0.0001	-0.0018258	0.0000	0.54
	Minam	1954-2010	0.13	2.4079	0.8035	1.6044	<0.0001	-0.0010349	0.0000	0.45
	Catherine	1953-2010	0.33	2.7378	0.2325	2.5053	<0.0001	-0.0009101	0.0012	0.40
	Upper Grande Ronde	1956-2009	0.30	3.3919	0.5843	2.8076	<0.0001	-0.0036027	0.0000	0.53
	Snake River mean		0.14			2.0401				
John Day River										
John Day (JDA)	Upper Mainstem	1959-2010	0.02	1.9346	1.2056	0.7289	0.0102	-0.00136	0.0004	0.47
	Middle Fork	1960-2010	0.02	1.8733	1.2855	0.5878	0.0964	-0.00158	0.0003	0.46
	North Fork	1959-2010	0.02	2.6916	1.4550	1.2366	<0.0001	-0.00072	0.0001	0.63
	John Day mean		0.02			0.8511				

Historical survival rate indices (SRIs) for Snake River spring/summer Chinook updated from Schaller et al. (2014) (Figure 5.5, upper panel) illustrate large declines in life cycle survival rates associated with development and completion of the FCRPS in the 1970s as well as with other environmental changes. SRIs averaged -2.02 (range, -4.3 to -0.6) for the 1975–2010 brood years, indicating that life cycle productivity declined to only about 13% ($e^{-2.02}$) of that during the pre-1970 base period.

A plot of the average SRI from 18 Snake River Chinook populations versus SARs to the Columbia River mouth is shown in Figure 5.6. SARs explained a large portion (79%) of the variability in recruitment during this time period (1964-2012 smolt migration years), after accounting for density dependence in life cycle survival rates. SARs in the 1960s (1964–1969 smolt migration years) ranged from 3.5% to 6.5%, while parental spawner levels resulted in pre-harvest recruitments within the expected range (by definition) for the base period. Both SARs and SRIs declined in the 1970s, and have remained depressed in subsequent decades into the 2000s. The relation between SAR and SRI appears very consistent across the decades. The relation between SAR and SRI also remained quite stable from that presented in the 2016 report with the incorporation of the latest SR estimates and the addition of 2005-2010 brood year data. The prediction line indicates that a pre-harvest SAR of 2% is associated with 35% of base-period

productivity; pre-harvest SARs of 4% and 6% are associated with 70% and 105% of base-period productivity, respectively (Figure 5.6). In general, the pattern of SARs and SRIs suggests that achieving pre-harvest SARs in the 4% to 6% range would be necessary to fully restore historical (pre-1970s) productivity for Snake River spring/summer Chinook.

The pattern of SRIs and SARs appears quite similar across the four MPGs of the Snake River spring/summer Chinook ESU (Figure 5.7). Historical levels of productivity (pre-1970) were associated with pre-harvest SARs in the range of 4% to 6% for all MPGs.

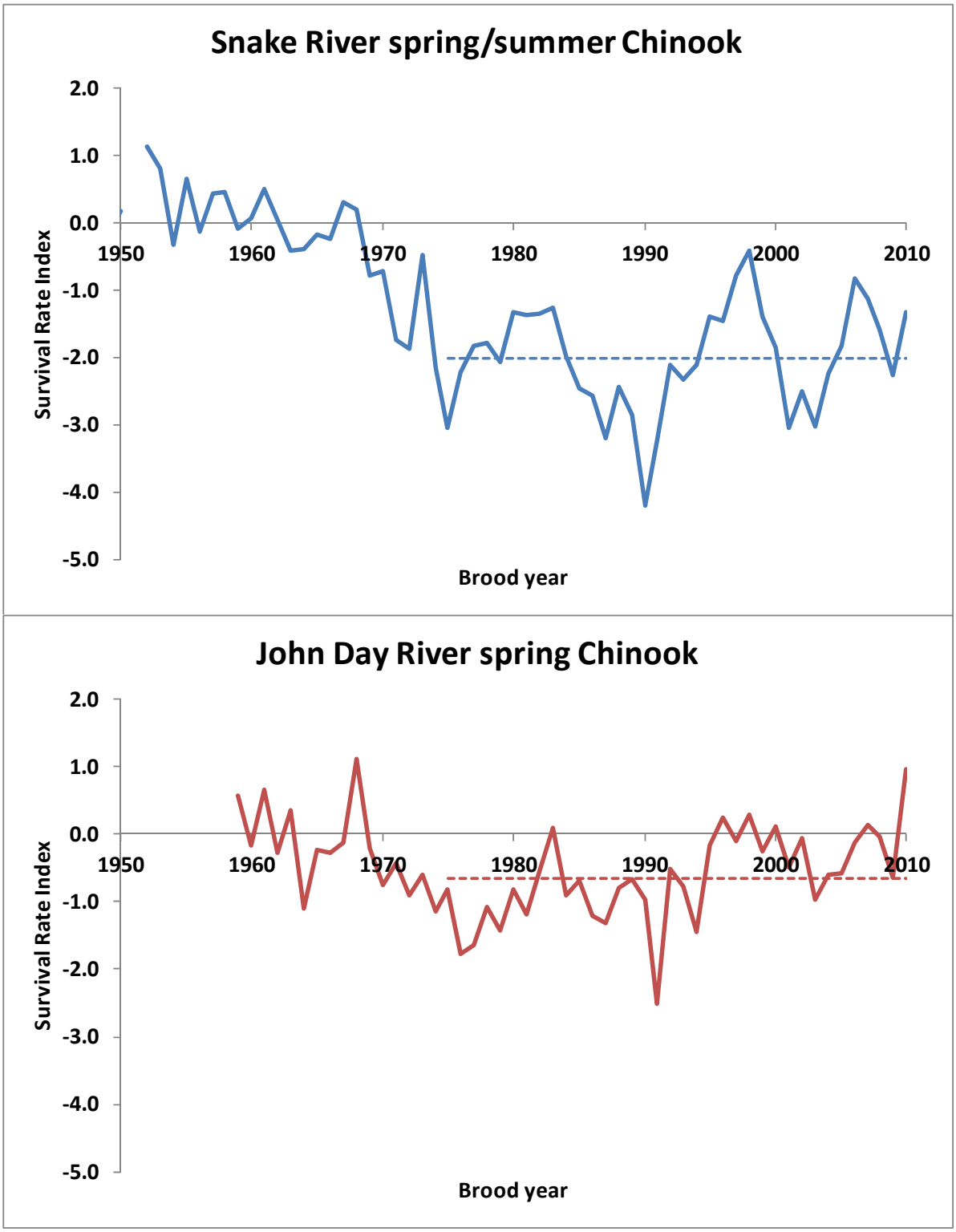

Figure 5.5 Survival rate indices for Snake River spring/summer Chinook (upper panel) and John Day River spring Chinook (lower panel), 1950s-2010 brood years (updated from Schaller et al. 2014). Dashed lines show the average SRI for 1975-2010 brood years.

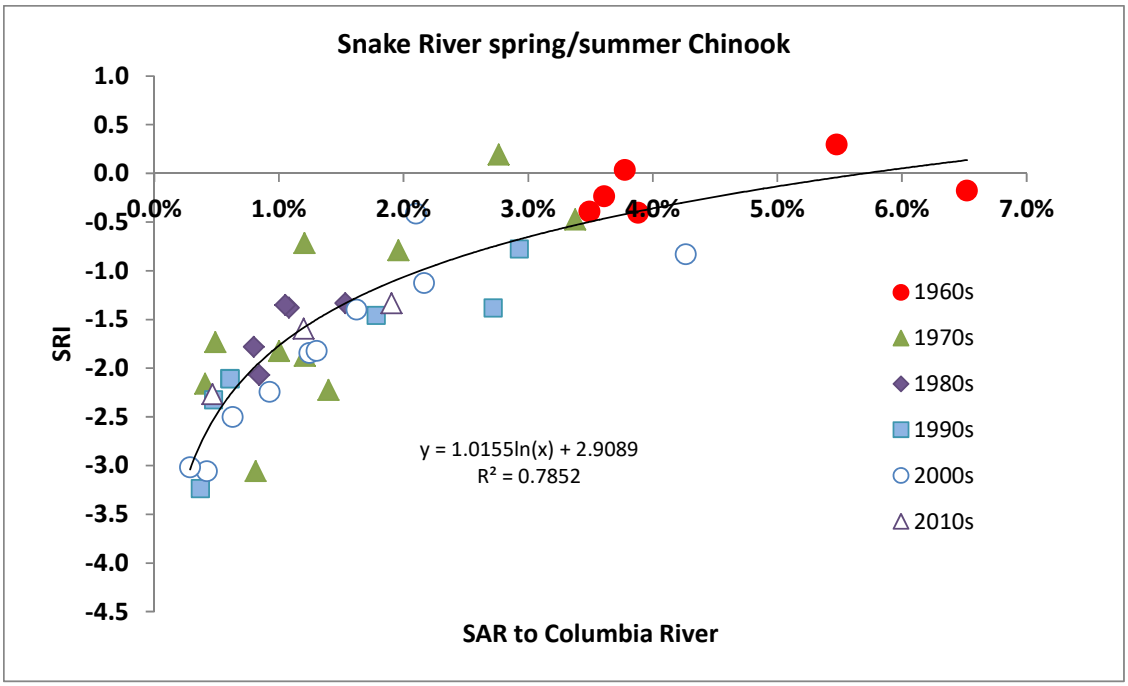

Figure 5.6 Comparison of survival rate indices (SRIs) and SARs of Snake River spring/summer Chinook, 1964-2012 smolt migration years. SRIs represent the annual average from 18 Snake River populations, where SRI = 0 is the average expected productivity for the pre-1970 brood years (Schaller et al. 2014). SARs to the Columbia River mouth are from Table B.106 and the 2012 CSS annual report (Tuomikoski et al. 2012). The prediction line is fitted through all years of data.

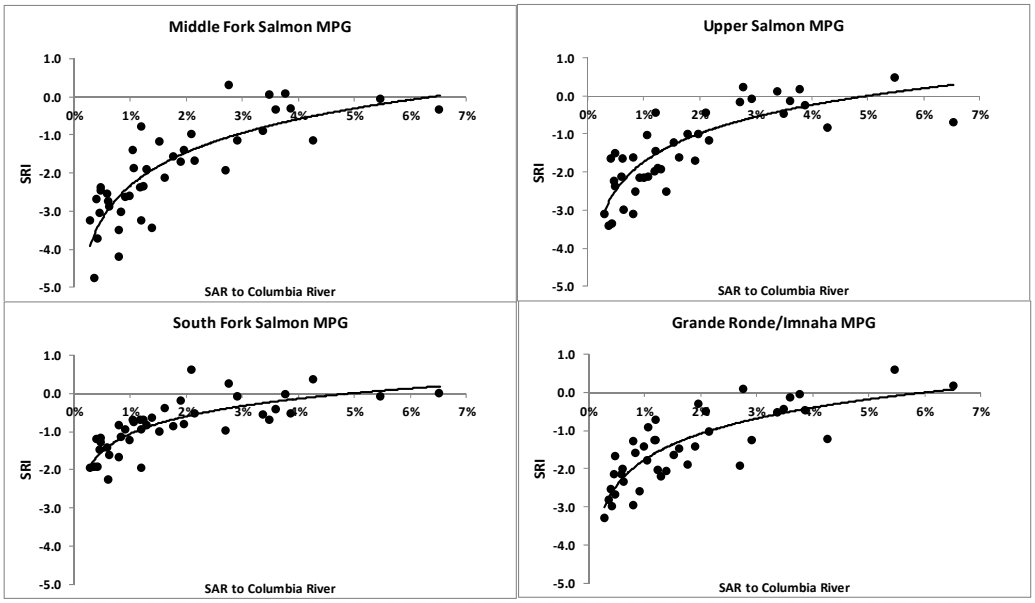

Figure 5.7 Comparison of survival rate indices (SRIs) and SARs for four MPGs of Snake River spring/summer Chinook, 1964-2012 smolt migration years. SRIs represent the annual average from populations within each MPG (Schaller et al. 2014). SARs to the Columbia River mouth are from Table B.106 and the 2012 CSS annual report (Tuomikoski et al. 2012). The prediction line is fitted through all observations.

Historical survival rate indices (SRIs) for John Day River spring Chinook updated from Schaller et al. (2014) (Figure 5.5, lower panel) illustrate declines in life cycle survival rates since the late 1960s. SRIs averaged -0.65 (range, -2.5 to 1.1) during the 1975–2010 brood years, indicating that life cycle productivity declined to about 52% of that during the pre-1970 base period.

The relation between John Day River spring Chinook SARs and SRIs appears generally similar to that in the Snake River. Historical (1950–60s) productivity for John Day spring Chinook appears to be associated with pre-harvest SARs in the 4%–6% range (Figure 5.8).

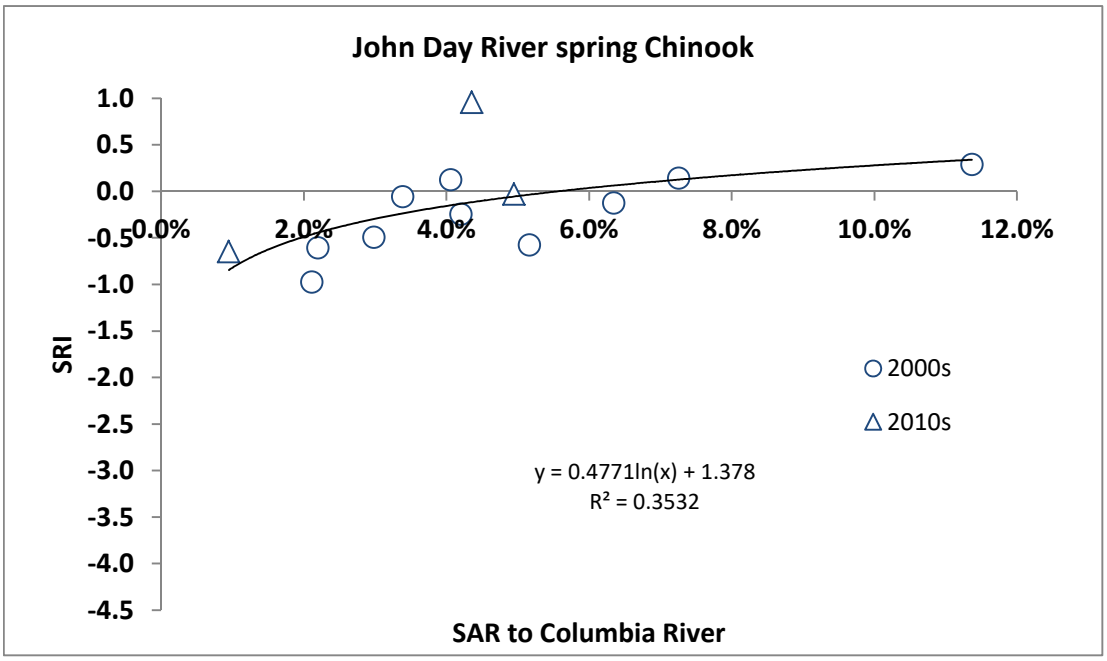

Figure 5.8. Comparison of survival rate indices (SRIs) and SARs of John Day River spring/summer Chinook, 2000-2012 smolt migration years. SRIs represent the annual average from three John Day River populations, where SRI = 0 is the average expected productivity for the pre-1970 brood years (Schaller et al. 2014).

The CSS has been working to update the SAR vs. SRI analyses, incorporating SR data (where available) for additional brood years beyond 2004. As noted previously, IDFG, ODFW and NPT submitted in 2015 updated spawner and recruit estimates for Snake River spring/summer Chinook populations for the NOAA ESA Status Review update process. In addition, ODFW has recently updated spawner and recruit estimates for the John Day River through brood year 2010 (Bare et al. 2015 and 2016). SR updates from both regions calculated recruits to spawning grounds, which then needed to be expanded to Columbia River recruits to examine historical patterns of productivity. In addition, some of the revised Snake River spawner estimates relied on different redd count expansions than used in the Schaller et al. (2014) analysis, which necessitated refitting the SR models. This report includes final updates for Snake River populations and preliminary updates for John Day River populations through brood year 2010.

Discussion

The graphical summary of SARs and realized population productivity (spawning ground recruits) presented in this chapter begins to illuminate the SARs necessary for Snake River spring/summer Chinook population abundance to stabilize or increase, given the depressed wild abundance levels in recent years. It begins to address the ISAB (2012) review comments of the CSS draft 2012 annual report, as well as to support objectives of the amended Columbia River Basin Fish and Wildlife Program (NPCC 2014), encouraging a regional review of the NPCC SAR objectives. Additionally, it continues recent years' reporting of wild spring/summer Chinook SARs at finer geographic and MPG scales as observed in the ISAB (2013) review of the CSS draft 2013 annual report. This summary is also complimentary to the Chapter 2 analysis for the Grande Ronde/Imnaha MPG, adding data from populations and MPGs across the entire Snake River spring/summer Chinook ESU. Notably, the summary in this chapter includes population data from the Middle Fork Salmon River MPG that is primarily in wilderness and has little potential for improvement to tributary habitat or survival during the egg-to-smolt life stage.

The observations to date are relevant to and generally support the NPCC (2014) 2%–6% SAR objectives. We have observed major Chinook population declines associated with SARs (LGR-GRA) less than 1%, and increased life-cycle productivity for Snake River populations in the few years that SARs exceeded 2%. These observations of SARs and population increases or declines at recent abundances do not account for the density-dependent nature of recruitment at higher abundance.

Unlike most Columbia River stream-type Chinook populations, steelhead smolts from the same brood year emigrate over several years. We began to explore the relationship of SARs to population productivity for three Snake River spawning tributaries: Fish Creek (Clearwater River MPG), Rapid River (Salmon River MPG) and Pahsimeroi River (Salmon MPG). To align population productivity (spawning ground recruits/spawner) with SARs, we calculated a weighted brood year SAR, based on smolt age composition. Similar to our observations for Snake River Chinook, we have observed steelhead population declines associated with brood year SARs (LGR-GRA) less than 1%, and increased life-cycle productivity for Snake River steelhead populations in the years that brood year SARs exceeded 2%.

We might expect more variation for steelhead populations in response to SARs due to their more complex life history. The response likely varies according to smolt age composition, with populations producing older smolts requiring relatively higher SARs to achieve population replacement, which is consistent with these results. In the limited data set presented here, Rapid River age composition is older than Fish Creek and Pahsimeroi River age composition. Currently we have data for three populations but potential exists to expand this analysis in the future.

In the 2017 report we examine the relation of SAR to historical pre-harvest productivity using the (density-dependent) stock-recruitment functions from Schaller et al. (2014). Results indicate that pre-harvest SARs in the range of 4%-6% are associated with historical (pre-1970) levels of productivity for Snake River spring/summer Chinook. The relation between pre-harvest SARs and life-cycle productivity (spawner-recruit residuals) appears similar across Snake River spring/summer Chinook MPGs. These observations, which account for density dependence, are also generally consistent with the NPCC (2014) 2%–6% SAR objectives.

Historical levels of productivity also appear to be achieved with pre-harvest SARs in the range of 4%–6% for John Day River Chinook. The Mid-Columbia spring Chinook ESU is not listed under the ESA, and SARs for MPGs in this ESU have generally been within the 2%-6% range. SARs (JDA-to-BOA) for John Day River spring Chinook adults and jacks averaged (geometric mean) 4.0%, and ranged from 0.9% to 11.1% during the 2000-2015 smolt migration years (Table B.73). Yakima River spring Chinook adult and jack SARs (MCN-to-BOA) averaged 2.7%, and ranged from 1.0% to 9.2% for the same years (Table B.74). These observations for an unlisted ESU also lend support to the NPCC (2014) 2%-6% SAR objectives for stream-type Chinook in the Columbia River Basin.

Conclusions

- Major population declines of Snake River wild spring/summer Chinook were associated with SARs less than 1% and increased life-cycle productivity occurred when SARs exceeded 2%.
- Snake River wild steelhead population declines were associated with brood year SARs less than 1%, and increased life-cycle productivity occurred in the years that brood year SARs exceeded 2%.
- Pre-harvest SARs in the range of 4% to 6% are associated with historical levels of productivity for Snake River wild spring/summer Chinook. In addition, historical levels of productivity appear to be achieved with pre-harvest SARs in the range of 4%-6% for John Day River wild spring Chinook.

CHAPTER 6
ESTIMATION OF SARS, TIRS AND *D* FOR SNAKE RIVER SUBYEARLING FALL CHINOOK

Introduction

During the review of the 2010 Comparative Survival Study (CSS) Annual Report, the CSS Oversight Committee received a request to include fall Chinook migration and smolt-to-adult return (SAR) data in future CSS reports. The addition of fall Chinook to the CSS monitoring analyses and data time series serves two purposes: to meet the objectives of the CSS study and to provide data and analyses to the Fall Chinook Planning Team. In 2007, the *U.S. v. Oregon* parties approved a consensus proposal entitled *Evaluating the Responses of Snake River and Columbia River basin fall Chinook Salmon to Dam Passage Strategies and Experiences*. The intent of the parties agreeing to the consensus proposal is for the salmon managers to work together with the U.S. Army Corps of Engineers (USACE) on collaborative analyses that include methods consistent with the CSS. The 2015 report was the fifth CSS report to include analyses of fall Chinook adult returns to the Snake River, both overall for the entire run and by study category, as is reported for spring/summer Chinook, steelhead, and sockeye. As such, the inclusion of fall Chinook in the CSS is a work in progress. The CSS Oversight Committee expects to refine tools and analyses for fall Chinook in future reports. Further, as information is available the CSS develops SAR estimates for other wild and hatchery fall Chinook groups in the Mid-Columbia River (e.g., Columbia River Hanford Reach, Deschutes River, Spring Creek and Little White Salmon National Fish hatcheries).

The CSS, working with Nez Perce Tribe (NPT), helped fund PIT-tag marking of 40,400 subyearling fall Chinook in 2015, over 50,000 tags in 2016 and over 60,000 fall Chinook tagged in 2017. This effort was considered a pilot program to re-instate annual marking that had been discontinued after migration year 2012 due to the end of a USACE-funded transportation study. The joint effort by CSS and NPT will make available a limited number of PIT-tag marks on two release groups in the Snake River. As a pilot effort, its scope is limited, but will provide some level of information for an entire ESU that currently has no comprehensive marking program to evaluate the effects of transportation on adult return rates. Prior to providing PIT tags for the marking effort, the CSS developed a power analysis to determine an adequate mark group as well as proportions of fish to be pre-assigned to transport and in-river categories (McCann et al. 2015). Reach survivals (S_R) for these groups will be reported in each year's CSS annual report.

The inclusion of fall Chinook in the CSS follows the foundational objective of the CSS to establish a long-term dataset that measures the survival rate of annual generations of salmon and steelhead from the outmigration as smolts to their return to freshwater as adults to spawn (i.e., SAR or smolt-to-adult return rate). The primary objective for fall Chinook SAR estimation was to use the CSS methodology to estimate overall SARs and SARs by study category that have been used successfully with other salmonid species (see Chapter 4 and Appendix A for methods descriptions). These SAR estimates could then be used to evaluate the efficacy of transportation, particularly for cohorts of actively migrating subyearling Chinook. These cohorts would not include either a large portion of late season migrants or a high proportion of holdover detections.

In addition to including fall Chinook from the Snake River, the CSS was also asked to include fall Chinook groups from the Mid-Columbia River as well. These groups include wild fall Chinook marked in the Hanford Reach and the Lower Deschutes River was well as hatchery releases from Little White Salmon, and Spring Creek National Fish Hatcheries.

Methods

Methods to estimate SARs have been described previously (McCann et al. 2015). Methods to calculate TIR and *D* have also been presented (see Chapter 4 and Appendix A).

Results

SAR Estimation

Data for the adults that escaped marine fisheries used in SAR estimation were updated through the end of 2016, so that returns through 5-salt were complete for 2011 and earlier migration years while 4-salt adults were complete for 2012. Based on our analysis no new PIT-tag adults were observed for the Snake River hatchery fall Chinook groups that out-migrated as juveniles in 2011 so that those SARs were complete last year. Only SARs for 2012 Snake River Chinook will be presented in this report. The estimated SARs for both overall LGR to GRA and by study category are reported as well as transport/in-river ratios where adequate data were available for the Snake River groups. No update is available for wild Snake River fall Chinook.

In response to requests from fisheries managers as well as the ISAB, we included new groups of fish released in locations outside the Snake River to compare to those released above Lower Granite Dam. Included in this report are SAR estimates for wild subyearling fall Chinook marked at Hanford Reach in the Columbia River above McNary Dam. We also estimated SARs for wild fall Chinook PIT tagged and released in the Deschutes River. PIT-tag subyearling fall Chinook smolts released from Spring Creek National Fish Hatchery and Little White Salmon National Fish Hatchery were also included. For the Hanford releases, SARs were estimated from McNary Dam as juveniles to Bonneville Dam as adults, while for Deschutes River wild and Hatchery fish from Spring Creek and Little White Salmon releases SAR estimates are from Bonneville Dam as juveniles back to Bonneville Dam as adults.

Patterns in Annual Overall SARs

Overall LGR-to-GRA SARs for Snake River subyearling fall Chinook have been low in the years we have analyzed (McCann et al. 2015). For hatchery fall Chinook releases, overall SARs excluding 1-salt (or jacks) ranged from 0.12% to 0.56% for releases in 2006, 0.0% to 0.3% in 2007 (McCann et al. 2015). SARs for migration years 2008 and 2011 tended to be highest, while SARs for migration year 2009 appeared similar to 2006. There were only additions of 4-salt adults for the 2012 juvenile migration groups. Increases in SARs were small as expected (Table 6.1). These estimates are likely complete. The highest SAR LGR to GRA was for Cedar

Flats at 0.83%, while the lowest was for Lyons Ferry Hatchery releases in the Snake River at 0.41%.

Table 6.1. Overall LGR-to-GRA SARs for Snake River Basin (above LGR) Hatchery origin PIT-tagged subyearling fall Chinook, 2012 (with 90% confidence intervals).

Release Site, Tag Site, (PIT-tag coord-id)	Smolts arriving LGR	SAR without Jacks (Non-parametric CI 90% LL - 90% UL)	SAR with Jacks (Non-parametric CI 90% LL - 90% UL)
Big Canyon Creek, Lyons Ferry Hatchery, (BDA)	14,898	0.71 (0.60 - 0.83)	1.00 (0.86 - 1.14)
Cedar Flats, Cedar Flats, (BDA)	5,163	0.83 (0.62 - 1.04)	0.91 (0.68 - 1.13)
Captain John Rapids, Lyons Ferry Hatchery, (BDA)	15,919	0.70 (0.59 - 0.81)	0.86 (0.74 - 0.98)
Grande Ronde River, Irrigon Hatchery, (BDA)	8,059	0.52 (0.39 - 0.66)	0.69 (0.54 - 0.85)
Luke's Gulch, Luke's Gulch, (BDA)	6,328	0.44 (0.31 - 0.60)	0.52 (0.38 - 0.68)
Pittsburgh Landing, Lyons Ferry Hatchery, (BDA)	12,788	0.73 (0.60 - 0.86)	0.99 (0.84 - 1.14)
Snake River, Lyons Ferry Hatchery, (BDA)	5,547	0.41 (0.28 - 0.56)	0.49 (0.34 - 0.65)
Snake River, Irrigon Hatchery, (BDA)	12,770	0.67 (0.55 - 0.80)	0.86 (0.73 - 1.00)
Snake River, Oxbow Hatchery, (IPC)	5,046	0.42 (0.27 - 0. 58)	0.61 (0.43 - 0.80)

Note: SARs are calculated with and without jacks.

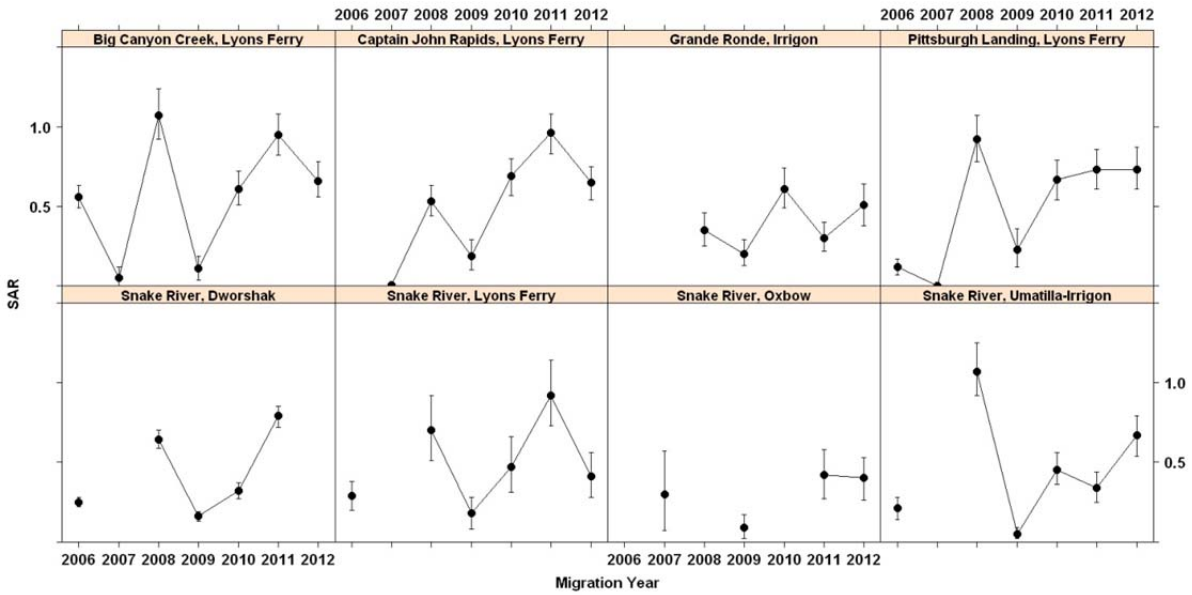

Figure 6.1 Patterns in overall SARs (LGR to GRA), excluding jacks, for subyearling Chinook PIT-tag release groups shown by release site and mark site for migration years 2006 to 2012. Only groups with 3 or more migration years of returns are included. Vertical bars represent 90% non-parametric CIs.

As requested by ISAB and consistent with other species reported in the CSS, SARs are reported for adults at Bonneville Dam in contrast to returns to Lower Granite Dam. Not surprisingly, SARs for nearly every group were higher when using Bonneville Dam adult observations compared to Lower Granite adults. When jacks were included, SARs in a few cases approached or exceeded 1% (McCann et al. 2015).

The highest 2012 LGR-to-BOA SAR was for the Cedar Flats release at 1.14, while the lowest LGR-to-BOA SAR (without jacks) the lowest was for Lyons Ferry Hatchery releases in the Snake River at 0.56%. (Table 6.3). Overall SARS LGR-to-BOA for migration year 2012 were higher than 2009 but lower than those for 2010 and 2011 (McCann et al. 2015; Table 6.4). As stated previously the SARs for migration year 2012 include up to 4-salt adults.

Table 6.2. Overall LGR-to-BOA SARs for Snake River Basin (above LGR) Hatchery origin PIT-tagged subyearling fall Chinook, 2012 (with 90% confidence intervals).

Release Site, Tag Site, (PIT-tag coord-id)	Smolts arriving LGR	SAR without Jacks (Non-parametric CI 90% LL - 90% UL)	SAR with Jacks (Non-parametric CI 90% LL - 90% UL)
Big Canyon Creek, Lyons Ferry Hatchery, (BDA)	14,898	1.06 (0.92 - 1.20)	1.45 (1.28 - 1.63)
Cedar Flats, Cedar Flats, (BDA)	5,163	1.20 (0. 95 - 1.48)	1.34 (1.08 - 1.63)
Captain John Rapids, Lyons Ferry Hatchery, (BDA)	15,919	1.14 (1.00 - 1.28)	1.39 (1.23 - 1.54)
Grande Ronde River, Irrigon Hatchery, (BDA)	8,059	0.86 (0.69 - 1.02)	1.10 (0.92 - 1.30)
Luke's Gulch, Luke's Gulch, (BDA)	6,328	0.66 (0.48 - 0.85)	0.79 (0.59 - 0.99)
Pittsburgh Landing, Lyons Ferry Hatchery, (BDA)	12,788	1.09 (0.94 - 1.24)	1.48 (1.31 - 1.65)
Snake River, Lyons Ferry Hatchery, (BDA)	5,547	0.56 (0.40 - 0.73)	0.67 (0.49 - 0.86)
Snake River, Irrigon Hatchery, (BDA)	12,770	1.07 (0.92 - 1.23)	1.35 (1.17 - 1.53)
Snake River, Oxbow Hatchery, (IPC)	5,046	0.71 (0.51 - 0.92)	1.13 (0.87 - 1.38)

Note: SARs are calculated with and without jacks.

Updating the 2012 SAR with additional returning adults did not appreciably change the pattern of SARs across migration years or release groups (Figure 6.2).

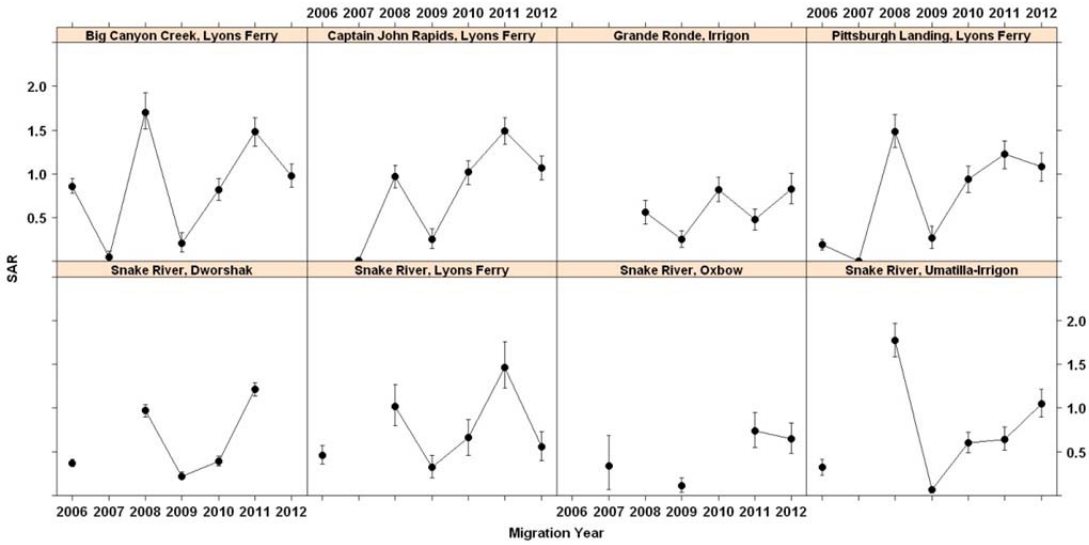

Figure 6.2. Patterns in overall SARs (LGR to BOA), excluding jacks, for subyearling Chinook PIT-tag release groups shown by release site and mark site for migration years 2006 to 2012. Only groups with 3 or more migration years of returns are included.

McNary Dam to Bonneville Dam SARs for Hanford Reach PIT-tag release groups were included for the first time in 2013 (Table 6.3). By comparison to Snake River releases, SARs for these cohorts ranged between 0.12% and 3.21% (excluding jacks).

Table 6.3. Overall MCN-to-BOA SARs for Columbia River (Hanford Reach) PIT-tagged wild subyearling fall Chinook, 2000 to 2013 (with 90% confidence intervals).

Juvenile migration year	Smolts arriving MCN	MCN-to-BOA without Jacks (Non-parametric CI 90% LL - 90% UL)	MCN-to-BOA with Jacks (Non-parametric CI 90% LL - 90% UL)	Smolts released	REL-to-BOA without Jacks (Non-parametric CI 90% LL - 90% UL)
2000	4,521	2.68 (2.27 - 3.11)	2.88 (2.45 - 3.32)	10,967	1.10 (0.93 - 1.28)
2001	3,642	0.68 (0.47 - 0.91)	0.71 (0.50 - 0.94)	9,973	0.25 (0.17 - 0.33)
2003	930	0.43 (0.11 - 0.82)	0.43 (0.11 - 0.82)	2,975	0.13 (0.03 - 0.27)
2004	1,000	0.20 (0.00 - 0.44)	0.20 (0.00 - 0.44)	2,989	0.07 (0.00 - 0.17)
2005	6,602	0.26 (0.15 - 0.37)	0.29 (0.18 - 0.40)	22,634	0.08 (0.04 - 0.11)
2007	7,790	0.35 (0.24 - 0.46)	0.45 (0.33 - 0.58)	21,007	0.13 (0.09 - 0.17)
2008	5,543	2.00 (1.62 - 2.39)	2.27 (1.88 - 2.71)	16,651	0.67 (0.56 - 0.77)
2009	4,614	0.72 (0.51 - 0.96)	0.89 (0.65 - 1.17)	13,728	0.24 (0.17 - 0.31)
2010	1,418	2.61 (1.88 - 3.40)	2.96 (2.15 - 3.88)	4,850	0.76 (0.56 - 0.97)
2011	4,050	3.21 (2.65 - 3.84)	3.46 (2.88 - 4.12)	10,337	1.26 (1.08 - 1.43)
2012	1,335	1.80 (1.17 - 2.47)	1.87 (1.22 - 2.57)	4,885	0.49 (0.33 - 0.66)
2013	1,440	1.53 (0.98 - 2.15)	1.87 (1.23 - 2.60)	4,184	0.53 (0.36 - 0.72)
2014	3,400	0.12 (0.03 - 0.22)	0.29 (0.15 - 0.46)	9,940	0.04 (0.01 - 0.07)

SAR estimates for Spring Creek National Fish Hatchery are presented in Table 6.4. For those PIT-tag groups there were multiple releases in some years resulting in two to three SAR estimates depending upon the year. SARs are presented from Bonneville Dam as smolts to Bonneville Dam as adult returns as well as from release at the hatchery as smolts back to Bonneville Dam as adults. Marked releases were available for SAR estimation beginning in 2008. In many cases, the initial survival estimate from release to Bonneville Dam was greater than one causing the estimated smolt population arriving at Bonneville Dam to be higher than one. This in turn made SAR estimates lower than estimated SARs from release to Bonneville. Where those occurred, the SAR estimates were not included since they were considered biased. The overestimation of survival, particularly for these Spring Creek NFH release groups, may be caused by relatively high bypass mortality that has been observed in the Smolt Monitoring Program over the past several years (see the Fish Passage Center memo from 2012 that addressed powerhouse operation effects on subyearling Chinook survival at http://www.fpc.org/documents/memos/153-12.pdf). If bypass mortality is high, and since many of the detected fish pass through the bypass (as opposed to the corner collector) this would represent a violation of the mark-recapture survival model assumption of equal survival probability for detected and undetected fish.

Table 6.4. Overall BON-to-BOA SARs for Columbia River Spring Creek National Fish Hatchery PIT-tagged subyearling fall Chinook, 2008 to 2014 (with 90% confidence intervals).

Juvenile migration year	Month of release	Smolts arriving BON	BON-to-BOA without Jacks (Non-parametric CI 90% LL - 90% UL)	BON-to-BOA with Jacks (Non-parametric CI 90% LL - 90% UL)	Smolts released	REL-to-BOA without Jacks (Non-parametric CI 90% LL - 90% UL)
2008	March	5,877	0.34 (0.19 - 0.52)	0.43 (0.25 - 0.64)	7,477	0.27 (0.17 - 0.36)
2008	April	NA[A]	--	--	3,953	0.63 (0.43 - 0.83)
2008	May	NA[A]	--	--	2,677	0.52 (0.30 - 0.75)
2009	April	NA[A]	--	--	8,686	0.06 (0.02 - 0.10)
2009	May	NA[A]	--	--	5,950	0.22 (0.13 - 0.32)
2010	April	NA[A]	--	--	8,962	0.25 (0.16 - 0.33)
2010	May	5,908	0.20 (0.11 - 0.31)	0.24 (0.14 - 0.36)	5,971	0.20 (0.12 - 0.30)
2011	April	8,163	0.16 (0.09 - 0.25)	0.16 (0.09 - 0.25)	8,956	0.15 (0.08 - 0.21)
2011	May	NA[A]	--	--	5,983	0.23 (0.13 - 0.33)
2012	April	NA[A]	--	--	14,750	0.26 (0.20 - 0.34)
2013	April	8,041	0.62 (0.46 - 0.80)	0.75 (0.56 - 0.96)	8,964	0.56 (0.44 - 0.68)
2013	May	5,527	0.58 (0.39 - 0.79)	0.67 (0.46 - 0.90)	5,976	0.54 (0.38 - 0.69)
2014	April	NA[A]			8,873	0.08 (0.03 - 0.14)
2014	May	NA[A]			5,993	0.02 (0.00 - 0.05)

[A] Not calculated; release to BON survival estimate > 1.0.

Such a violation, lower survival for detected fish, could cause an underestimate of detection probability and an over-estimate of the population arriving at the dam—which is what has been observed for many of the release groups.

SAR estimates for Little White Salmon National Fish Hatchery were included for the first time in 2014 (Table 6.5). SARs are presented from Bonneville Dam as smolts to Bonneville Dam as adult returns. Marked releases were available for SAR estimation beginning in 2008. In contrast to Spring Creek releases, these groups had initial survival estimates below one in all years SARs were estimated. The Little White Salmon releases were done in late June or early July each year and fish were much larger at release.

Table 6.5. Overall BON-to-BOA SARs and REL-to-BOA SARs for Columbia River Little White Salmon National Fish Hatchery PIT-tagged subyearling fall Chinook, 2008 to 2014 (with 90% confidence intervals).

Juvenile migration year	Smolts arriving BON	BON-to-BOA without Jacks (Non-parametric CI	BON-to-BOA with Jacks (Non-parametric CI	Smolts released	REL-to-BOA without Jacks (Non-parametric CI

		90% LL - 90% UL)	90% LL - 90% UL)		90% LL - 90% UL)
2008	14,393	1.74 (1.52 - 1.99)	1.85 (1.62 - 2.10)	24,886	1.01 (0.90 - 1.11)
2009	14,805	0.84 (0.70 - 1.00)	0.95 (0.80 - 1.12)	24,947	0.50 (0.43 - 0.57)
2010	15,140	2.69 (2.35 - 3.06)	2.75 (2.41 - 3.13)	24,951	1.63 (1.50 - 1.77)
2011	17, 680	3.33 (2.77 - 3.95)	3.40 (2.83 - 4.04)	24,638	2.39 (2.23 - 2.54)
2012	16, 381	0.74 (0.57 - 0.93)	0.79 (0.60 - 0.98)	24,947	0.49 (0.41 - 0.57)
2013	10,505	1.22 (1.02 - 1.44)	1.33 (1.12 - 1.57)	14,959	0.86 (0.73 - 0.99)
2014	8,191	0.09 (0.04 - 0.14)	0.09 (0.04 - 0.14)	14,925	0.05 (0.02 - 0.07)

Note: BON-to-BOA SARs are calculated with and without jacks.

SAR estimates for Deschutes River wild fall Chinook were included for the first time in 2014 (Table 6.6). SARs are presented from Bonneville Dam as smolts to Bonneville Dam as adult returns as well as from release to Bonneville Dam as adults. Marked releases were available for SAR estimation beginning in 2011.

Table 6.6. Overall BON-to-BOA SARs and REL-to-BOA SARs for Deschutes River PIT-tagged wild subyearling fall Chinook from 2011 and 2014 (with 90% confidence intervals).

Juvenile migration year	Smolts arriving BON	BON-to-BOA without Jacks (Non-parametric CI 90% LL - 90% UL)	BON-to-BOA with Jacks (Non-parametric CI 90% LL - 90% UL)	Smolts released	REL-to-BOA without Jacks (Non-parametric CI 90% LL - 90% UL)
2011	5,670	2.40 (1.65 - 3.33)	3.07 (2.12 - 4.20)	19,897	0.68 (0.59 - 0.78)
2012	6,998	0.73 (0.43 - 1.08)	0.93 (0.56 - 1.37)	20,798	0.25 (0.19 - 0.30)
2013	8,466	0.52 (0.31 - 0.75)	0.85 (0.54 - 1.21)	26,322	0.17 (0.13 - 0.21)
2014	3,822	0.81 (0.46 - 1.19)	0.84 (0.49 - 1.23)	19,899	0.16 (0.12 - 0.20)

Note: BON-to-BOA SARs are calculated with and without jacks.

Estimates of SAR by Study Category

Presented here are the LGR-to-GRA SAR estimates by route of juvenile passage or study category for Snake River subyearling fall Chinook for the migration year 2012. These SARs represent portions of the run as a whole and the C_0 and transport SARs are components that

make up TIR and *D*. Explanations of methods for calculating these component SARs can be found in Chapter 4 and Appendix A. While the C_1 SARs are reported, those SARs do not represent a significant portion of the non-PIT-tagged population, since transportation occurs throughout the migration of subyearling Chinook. This contrasts with yearling Chinook and steelhead from the Snake River, where transportation has been delayed in recent years, beginning in May at the collector sites.

Similar to the overall SARs, the SARs by juvenile passage route did not increase appreciably after with the inclusion of the additional returning adults. The C_0 SAR of 0.94% for Cedar Flats release was highest SAR from either the T_x or C_0 groups (Table 6.7). All nine of the estimates for C_0 in-river SARs were higher than the transport SARs for 2012. There were three cases when the in-river C_0 SAR was significantly higher than transport SARs.

Table 6.7. Estimated LGR-to-GRA SAR (%) by study category without jacks for PIT-tagged hatchery subyearling Chinook by release site, tag site and coordinator ID from 2012 (with 90% confidence intervals).

Release Site, Tag Site, (PIT-tag coord_id)	SAR(T_x) %		SAR(C_0) %		SAR(C_1) %	
Big Canyon Creek, Lyons Ferry Hatchery, (BDA)	0.60	(0.43 - 0.77)	0.81	(0.69 - 0.93)	1.38	(0.00 - 6.67)
Cedar Flats, Cedar Flats, (BDA)	0.71	(0.39 - 1.07)	0.94	(0.75 - 1.14)	1.69	(0.00 - 5.88)
Captain John Rapids, Lyons Ferry Hatchery, (BDA)	0.53	(0.40 - 0.68)	0.81	(0.70 - 0.93)	0.00	(0.00 - 0.00)
Grande Ronde River, Irrigon Hatchery, (BDA)	0.41	(0.22 - 0.61)	0.61	(0.51 - 0.72)	0.00	(0.00 - 0.00)
Luke's Gulch, Luke's Gulch, (BDA)	0.28	(0.10 - 0.48)	0.56	(0.43 - 0.71)	0.00	(0.00 - 0.00)
Pittsburgh Landing, Lyons Ferry Hatchery, (BDA)	0.59	(0.44 - 0.75)	0.83	(0.70 - 0.96)	1.14	(0.00 - 4.08)
Snake River, Lyons Ferry Hatchery, (BDA)	0.34	(0.15 - 0.59)	0.36	(0.25 - 0.48)	0.00	(0.00 - 0.00)
Snake River, Irrigon Hatchery, (BDA)	0.44	(0.28 - 0.59)	0.75	(0.63 - 0.86)	0.00	(0.00 - 0.00)
Snake River, Oxbow Hatchery, (IPC)	0.25	(0.11 - 0.43)	0.66	(0.46 - 0.84)	0.00	(0.00 - 0.00)

Figure 6.3 shows the patterns in SARs by study category for release groups with three or more return years available. In most cases SARs for transport and in-river groups followed similar patterns with the highest returns in 2008 and lowest returns in 2006 or 2007 (where available).

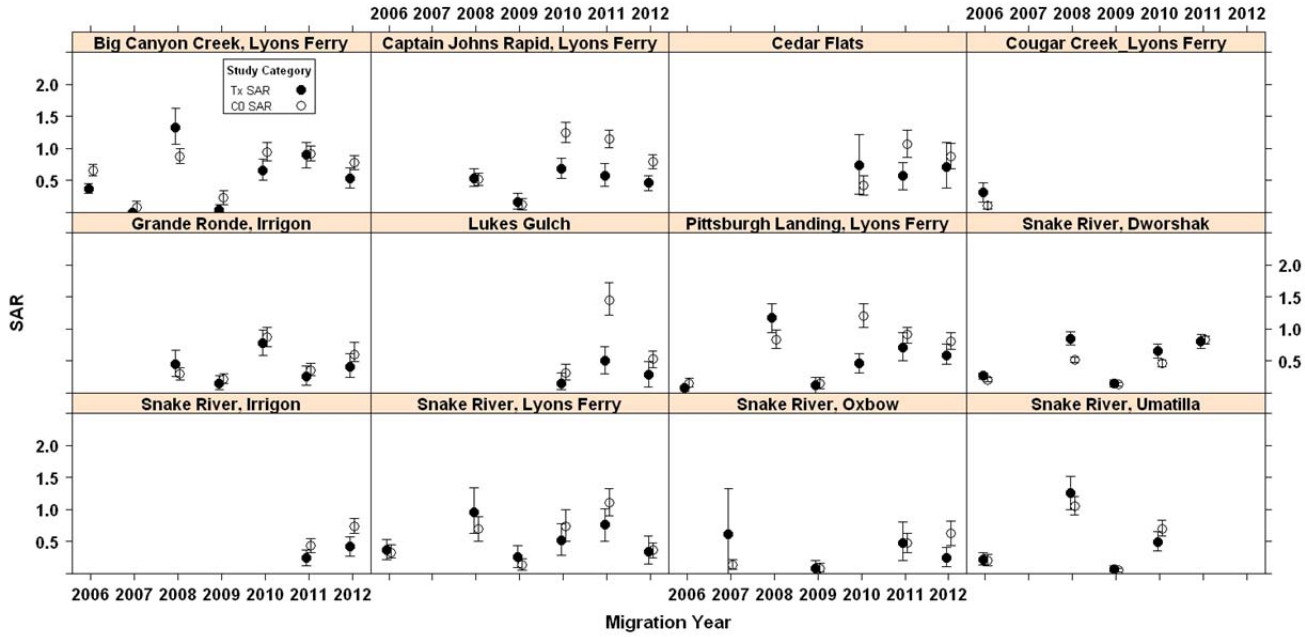

Figure 6.3. Patterns in SARs LGR-to-GRA by study category (excluding jacks), for transported and in-river PIT-tag groups of subyearling fall Chinook salmon released above Lower Granite Dam for the years 2006 to 2012. Error bars represent 90% non-parametric confidence intervals. Only groups with three or more migration years of returns are included.

Estimates of TIR and *D*

The estimates of transport/in-river SAR LGR to LGR ratios or TIR, and ratios of transport/in-river SARs post Bonneville Dam or *D*, are reported below using methods described in Chapter 4.

Estimates of TIR and *D* for migration year 2012 are reported in Table 6.8. All TIR estimates in 2012 were less than one. Six release groups had TIR estimates that were significantly below one, indicating that the in-river SAR for the C_0 groups were significantly higher than that of the transport group. None of the TIRs for 2012 release groups were greater than one. The data for migration year 2012 are nearly complete with very few adult returns expected from return year 2017. Estimates of *D* were all less than one for 2012, similar to what was seen in 2010 (McCann et al. 2015) and 2011, and *D* was significantly less than one for eight of the nine groups.

Table 6.8. Estimated TIR and *D* in LGR-to-GRA SAR (%) without jacks for PIT-tagged hatchery subyearling Chinook by release site, tag site and coordinator ID from 2012 (with 90% confidence intervals).

Release Site, Tag Site, (PIT-tag coord-id)	TIR		*D*	
Big Canyon Creek, Lyons Ferry Hatchery, (BDA)	**0.74**	(0.52 - **0.99**)	**0.56**	(0.39 - **0.78**)
Cedar Flats, Cedar Flats, (BDA)	0.75	(0.39 - 1.24)	**0.55**	(0.29 - **0.93**)
Captain John Rapids, Lyons Ferry Hatchery, (BDA)	**0.66**	(0.48 - **0.87**)	**0.49**	(0.35 - **0.66**)
Grande Ronde River, Irrigon Hatchery, (BDA)	0.67	(0.38 - 1.01)	**0.43**	(0.23 - **0.69**)
Luke's Gulch, Luke's Gulch, (BDA)	**0.50**	(0.19 – **0.88**)	**0.32**	(0.13 - **0.59**)
Pittsburgh Landing, Lyons Ferry Hatchery, (BDA)	**0.72**	(0.52 – **0.96**)	**0.52**	(0.36 – **0.72**)
Snake River, Lyons Ferry Hatchery, (BDA)	0.96	(0.43 – 1.84)	0.91	(0.40 - 1.88)
Snake River, Irrigon Hatchery, (BDA)	**0.59**	(0.38 - **0.82**)	**0.51**	(0.31 - **0.74**)
Snake River, Oxbow Hatchery, (BDA)	**0.38**	(0.16 - **0.69**)	**0.34**	(0.13 - **0.66**)

Note: TIRs and *D* significantly different than one are bolded.

Figure 6.4 shows the patterns in natural log TIRs for all cohorts where sufficient information was available to estimate TIRs. Overall, there were 48 TIRs that were estimated for the years 2006 to 2012 PIT-tag cohorts. Of the 48 estimated cohorts, 31 TIRs were above zero (on the natural log scale) and 17 below. However, only five TIRs were significantly above zero (90% confidence intervals did not overlap zero), indicating a significant benefit to transport, while 18 TIRs were significantly below zero indicating a significant benefit to in-river passage. The Big Canyon Creek release of production subyearling Chinook had significant TIRs for four years (confidence intervals not overlapping 0). For 25 cohorts TIRs were not significant.

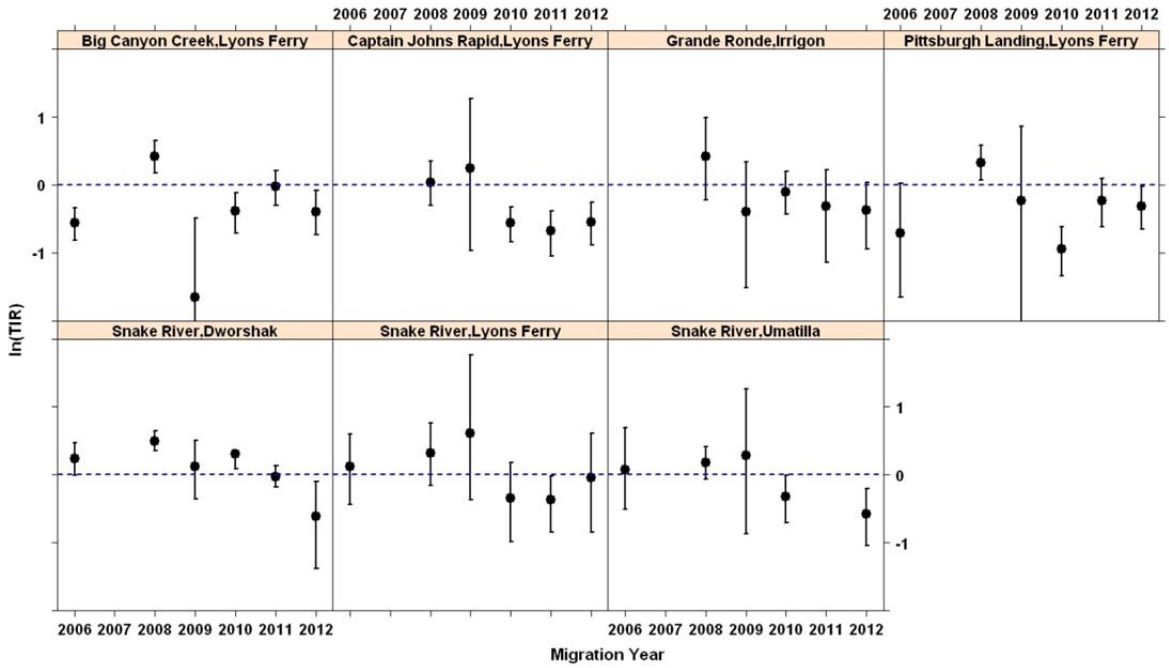

Figure 6.4. Patterns in TIRs LGR-to-GRA (excluding jacks), for transported and in-river PIT-tag groups of subyearling fall Chinook salmon released above Lower Granite Dam for the years 2006 to 2012. Confidence intervals overlapping one indicate non-significant TIRs. Dashed line at zero indicates equal SARs for transport and in-river study categories. TIRs were plotted on a natural log scale.

Figure 6.5 shows patterns in ln TIRs versus in-river survival for subyearling fall Chinook cohorts that had sufficient data available to estimate SARs by study category. Similar to the patterns seen in yearling Chinook and steelhead (presented in Figure A.19 in Appendix A), a trend of decreasing transport benefit with increasing reach survival is apparent. Wild Chinook and wild steelhead annual estimates of ln(TIR) versus juvenile reach survival were plotted in for comparison purposes. The prediction line in Figure 6.5 has a negative slope and was estimated to intersect the ln(TIR) line at 0 with 90% CI (-0.71,0.71) at about 0.42 reach survival. For fall Chinook the point at which the ln(TIR) crosses zero is at a lower reach survival than predicted for steelhead and Chinook. This illustrates that transportation benefited only the fall Chinook cohorts in our analysis when in-river survival was relatively low. TIRs were similar in range for yearling Chinook and steelhead to that of subyearling fall Chinook, when comparing only the years 2006 to 2012 (See Figure A.19 in Appendix A). In years prior to 2006, for yearling Chinook and steelhead, there were years when TIRs were quite high, especially when reach survivals were lower than 0.4 (for steelhead especially). It should be pointed out that the hatchery subyearling Chinook TIR data presented in Figure 6.5 had multiple data points per year, and included only the years 2006 through 2012, in contrast to the wild steelhead and wild yearling Chinook data points that show only 1 annual TIR and begin with migration year 1994 for wild yearling Chinook and 1997 for wild steelhead.

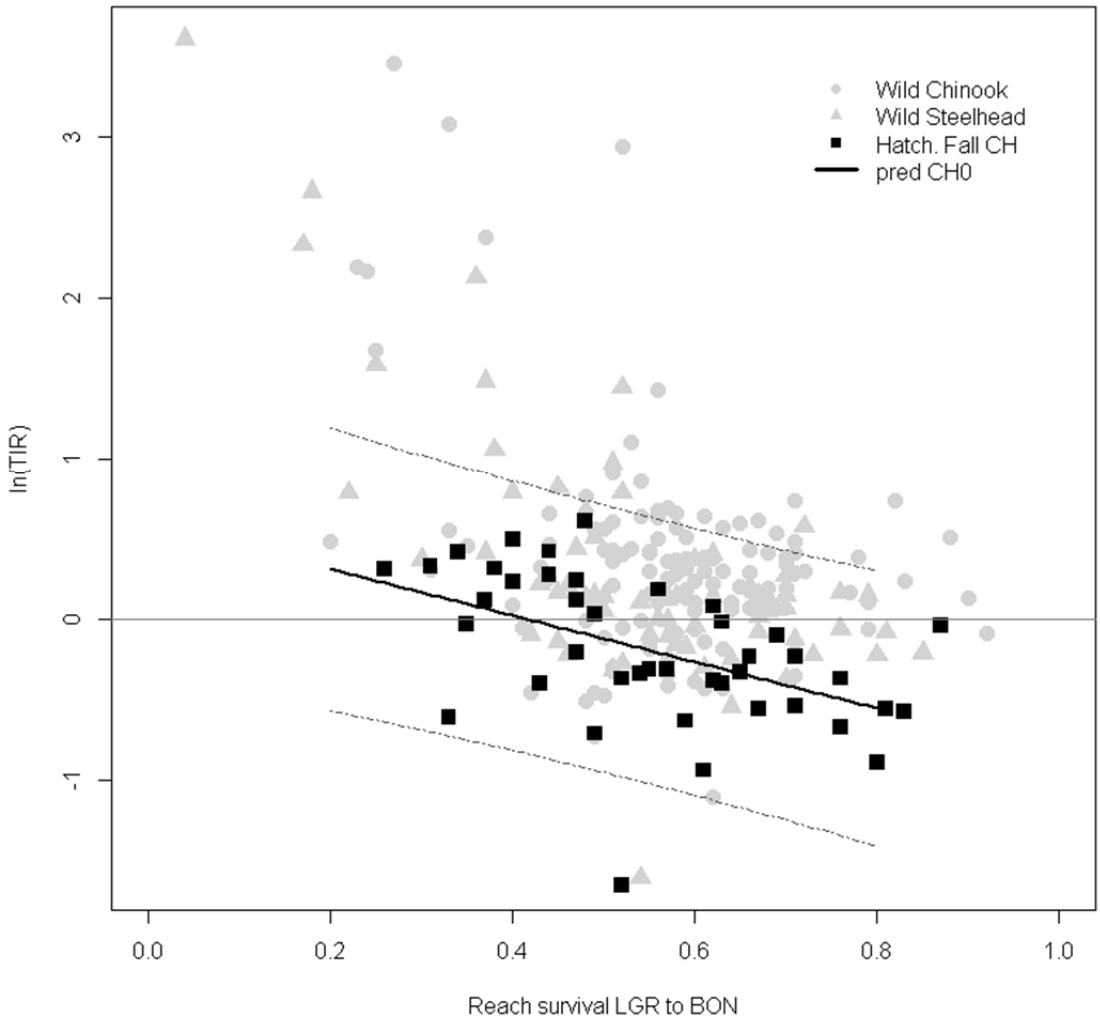

Figure 6.5. Log of Transport/in-river ratio of adult returns versus juvenile survival from LGR to BON for production releases of subyearling fall Chinook with regression line and 95% prediction intervals. All release groups from migration years 2006 to 2012, were included. Wild yearling Chinook and wild Steelhead annual TIR estimates were also plotted for comparison.

Conclusions

Updating the overall SARs with additional returning adults for the juvenile migration years 2011 and 2012 did not change observations reported by McCann et al. (2015).

Overall smolt-to-adult return rates to Lower Granite Dam (excluding jacks) for Snake River hatchery subyearling fall Chinook were low in three of the seven years we have analyzed. Fall Chinook overall SARs ranged from 0.12% to 0.56% for hatchery releases in 2006 and 0.0% to 0.3% in 2007. The highest SARs were observed for migration years 2008, and 2011, with SARs ranging between 0.30% and 1.07%. SARs for 2009 were relatively low as well, with SARs ranging between 0.05% and 0.23%. For the 2010 migration year, SARs were between the

low returns from 2009 and the highest returns from 2008. SARs for 2010 ranged between 0.20% and 0.97%. For migration year 2012 SARs ranged between 0.40 and 0.79. Return data for migration year 2012 now includes 4-salt adults.

Eighteen of 48 study cohorts showed significant benefit to adult returns from migrating in-river as juveniles while five cohorts showed a significant transport benefit. Overall, 25 TIRs were not significantly different than one. In all, 31 of 48 adult return cohorts showed a benefit to in-river migration (ln TIRs less than 0) while 17 showed a transport benefit.

Estimated *D* values for subyearling Snake River fall Chinook were below 1, for nearly all groups in the years 2006 to 2012. That was similar to patterns seen in yearling Chinook and steelhead (hatchery and wild groups) in the same years. A longer time series for subyearling Chinook would be helpful to determine if *D* estimates would have been higher prior to 2005 (the beginning of court-ordered summer spill) similar to the pattern seen for hatchery and wild steelhead groups that had *D* values that were well above 1 for several years prior to 2006.

Based on TIRs of adult returns to LGR it appears that the juvenile smolt transportation program does not mitigate for the adverse impacts of the operation of the FCRPS on fall Chinook groups that we analyzed.

Transport benefit appears to be related to in-river survival from LGR to BON, similar to what has been demonstrated for yearling Chinook and steelhead, with transport benefit decreasing as in-river survival increases.

SAR estimates for wild subysearling Chinook marked in the Deschutes River were included for the first time in 2014. Marking of Deschutes River fall Chinook began in migration year 2011. Similarly, SAR estimates for Little White Salmon National Fish Hatchery were also provided for the first time in 2014.

CHAPTER 7
PATTERNS OF VARIATION IN AGE-AT-MATURITY FOR PIT-TAGGED SPRING/SUMMER CHINOOK SALMON IN THE COLUMBIA RIVER BASIN

The spring/summer Chinook salmon in the Columbia River basin that have been PIT-tagged through the CSS and other tagging projects provide important information on survival, migration timing, and other demographic parameters. In this chapter we examine information on the age-at-maturity for returning adults that have been PIT-tagged. Analyzing age-at-maturity data is important for several reasons. First, age-at-maturity data are commonly used as the basis for sibling models (Peterman 1982) to generate pre-season forecasts of adult salmon returns (Haeseker et al. 2008). Improving the understanding of the patterns of variation in age-at-maturity could therefore help improve the accuracy of pre-season forecasts that are used in managing fisheries. Second, age-at-maturity data provide a useful monitoring tool for identifying changes in age composition over time. For example, research has shown that age-at-maturity in salmon can be influenced by hatchery mating practices (Hankin et al. 1993, Heath et al. 1994) as well as hatchery rearing and growth conditions (Thorpe 1991, Heath et al. 1994, Shearer et al. 2006). If particular hatchery stocks are showing undesirable changes in age composition (e.g., high proportions of Age-3 "jacks" or declining trends in age-at-maturity), then there may be cause for examining the mating, rearing, or growth conditions for that stock. Alternatively, if patterns in age-at-maturity are similar between hatchery and wild stocks then other, non-hatchery factors may be driving changes in age composition. Temporal changes in age-at-maturity have also been associated with environmental factors that appear to operate during ocean residence, which could influence both hatchery and wild stocks (Pyper et al. 1999, Holt and Peterman 2004). Through analyses age-at-maturity data, it may be possible to separate the effects of hatchery practices versus ocean environmental conditions and thus improve biological understanding and management of these populations.

In terms of analyzing age-at-maturity, data derived from PIT-tags have several advantages. First, the detection systems in adult dam ladders provide both a high sampling rate (effectively 100%) and a consistent sampling environment for collecting age-at-maturity data. PIT-tags also allow for individual identification and for determining stock origin, which can be useful partitioning sources of variation among the mixed-stock populations that comprise the overall returns to the Columbia River Basin. Finally, PIT-tags allow for estimation of survival at several life stages, which may be important for answering questions about whether age-at-maturity is associated with life-stage-specific survival.

Previous CSS analyses (Tuomikoski et al. 2011) found that there were no differences in mean age-at-maturity based on juvenile outmigration history (i.e., transported versus in-river migration), suggesting that other factors outside the juvenile migration corridor were responsible

for variation in mean age-at-maturity. Further, there were no associations between estimates of smolt to adult return rates (SARs) and mean age-at-maturity, suggesting that the factors that influenced SARs were different from the factors that influenced mean age-at-maturity. Tuomikoski et al. (2011) found that there were stock effects, as well as year effects that were common across stocks, which accounted for variability in the mean age-at-maturity and the proportion returning at Age-3 across juvenile outmigration years 1997-2008. In this chapter, we continue to examine questions about the observed variation in age-at-maturity. Using data from juvenile outmigration years 1997-2011, we examine whether there continue to be stock and year effects that account for variability in mean age-at-maturity and the proportion of adults that return at Age-3, Age-4, and Age-5. Based on review comments provided by the Independent Scientific Advisory Board, we also conducted an analysis that examined whether there were any spatial patterns of correlation in age-at-maturity metrics among stocks. If local environmental conditions (e.g., water temperature during rearing) are an important factor that influenced age-at-maturity, then stocks that are proximate to each other may be more correlated than stocks that are distant.

Methods

We summarized data on age-at-maturity for eleven stocks of spring/summer Chinook salmon that were PIT-tagged across the Columbia River Basin over juvenile migration years 1997-2011 (Table 7.1). The eleven stocks included of three wild stocks (Snake River wild aggregate, John Day River wild aggregate, and Yakima River wild aggregate) and eight hatchery stocks (Carson, Dworshak, Rapid River, Catherine Creek acclimation pond, Imnaha River acclimation pond, McCall, Cle Elum, and Leavenworth). Adult returns consisted of Age-3, Age-4 and Age-5 fish. Age-3 fish are predominantly male and are termed "jacks." For Snake River stocks, adults were enumerated at Lower Granite Dam, while all other stocks were enumerated at Bonneville Dam. Bonneville Dam began adult PIT detection in 1998, but full coverage of the adult ladders did not occur until 2002. Adult detection capability has been in place at Lower Granite Dam since 1988. We did not make any adjustments to account for the harvest occurs downstream of Bonneville Dam or the harvest occurs between Bonneville Dam and Lower Granite Dam. We calculated mean age-at-maturity and the proportion of the adults that were Age-3, Age-4, and Age-5 for each stock and by juvenile outmigration year. In addition to the data on PIT-tagged adult returns, we obtained data from the *U.S. v. Oregon* Technical Advisory Committee on age-specific returns of spring Chinook salmon to the Columbia River for juvenile outmigration years 1980-2011. These mixed-stock data were used to compare longer-term trends in age-at-maturity with the more recent, stock-specific data derived from PIT tags.

We fit linear and generalized linear models to examine patterns in the age-at-maturity data. The full model for examining patterns in mean age at maturity was of the form

$$mean\ age_{i,j} = Stock_i + Year_j + \epsilon_{i,j},$$

where $mean\ age_{i,j}$ is the mean age of stock i from juvenile outmigration year j, $Stock_i$ is the effect of stock i, $Year_j$ is the effect of juvenile outmigration year j, and $\epsilon_{i,j}$ is a normally-

distributed error term with a mean of zero and a variance of σ^2. In addition to the full model, we also fit a null model with constant mean age across stocks and juvenile migration years and models with only stock and only year effects. For each model, we calculated the Akaike's Information Criterion corrected for small sample size (AICc), AICc differences (ΔAICc), and the coefficient of determination (R^2) between the observed mean ages-at-maturity and the model predictions.

We fit binomial logit models for characterizing the proportion returning at Age-3, Age-4, and Age-5. Although logistic regression models could have been applied, binomial logit models provide a test of the fit of the model based on residual deviance and provide better-behaved diagnostics (Fox 2008). Regression models using the empirical logit also could have been applied (Wharton and Hui 2011), but would have required ad hoc adjustments to account for the zero returns that occurred in some age classes and years. For each stock and age class, the binomial probability of success ($\pi_{i,j}$) was calculated as the number of individuals that returned at each age class ($a_{i,j}$) divided by the total number of adults that returned ($n_{i,j}$), where *i* is the index for stock and *j* is the index for juvenile outmigration year. Separate models were developed for each of the three age classes. The full binomial logit model was of the form

$$log_e\left(\frac{\pi_{i,j}}{1-\pi_{i,j}}\right) = Stock_i + Year_j,$$

where $\pi_{i,j}$ is the binomial probability of success for stock *i* from juvenile outmigration year *j*, $Stock_i$ is the effect of stock *i*, and $Year_j$ is the effect of juvenile outmigration year *j*. In addition to the full model, we also fit a null model with constant probability of success across stocks and juvenile migration years and models with only stock and only year effects. All of the binomial logit models displayed evidence of overdispersion, where the residual deviance was substantially larger than the degrees of freedom. To account for and estimate this overdispersion, we fit binomial models with overdispersion (Kery and Schaub 2012) using OpenBUGS software (Lunn et al. 2009). These overdispersed binomial models included a normally-distributed random effect for each stock-year combination. For each model, we calculated the Deviance Information Criterion (DIC) and the coefficient of determination (R^2) between the observed proportions by age and the model predictions.

Based on review comments by the Independent Scientific Advisory Board, we conducted an analysis of the degree of spatial correlation in the maturity metrics to examine whether local environmental conditions may be influential on maturity rates. We began this analysis by first assigning a geographic rearing location for each stock (Figure 8.1). For hatcheries, this was the geographic location of the hatchery. For the three wild stocks, we assigned a geographic rearing location as the river location upstream of which the majority of fish were tagged and released. For each stock, we calculated the linear distance between that stock and all other stocks. Pearson's correlation coefficient was calculated for each time series pair of mean age-at-maturity, proportion Age-3, proportion Age-4, and proportion Age-5 values. With eleven stocks, there were 55 unique pairs. Pairwise correlations were plotted against distance to examine whether local environmental conditions may be influential on maturity rates. If local environmental conditions were influential, stocks that were proximate to each other would be expected to be more highly correlated with each other than stocks that were distant from each other.

Table 7.1. Summary of the rear type, juvenile outmigration years, and number of PIT-tagged adult returns (Adults) for each of the eleven stocks used in the age-at-maturity analyses.

Stock	Rear type	Outmigration years	Adults
Snake R. aggregate	Wild	1997-2011	4,880
John Day R. aggregate	Wild	2000-2011	1,432
Yakima R. aggregate	Wild	2000-2011	493
Carson	Hatchery	2000-2011	1,804
Catherine Creek	Hatchery	2001-2011	800
Cle Elum	Hatchery	2000-2011	2,858
Dworshak	Hatchery	1997-2011	3,241
Imnaha	Hatchery	1997-2011	2,916
Leavenworth	Hatchery	2000-2011	2,339
McCall	Hatchery	1997-2011	6,355
Rapid River	Hatchery	1997-2011	4,861

Results

Model results showed that stock and year effects were important factors that accounted for variation in mean age-at-maturity and the proportions Age-3, Age-4, and Age-5 (Tables 7.2-7.5). Compared to the null model, models of mean age that included stock effects reduced the AICc by 68 to 193 points, clearly indicating the importance of stock effects (Table 7.2). Similarly, models of mean age that included year effects reduced the AICc by 36 to 193 points compared to the null model (Table 7.2). The best fitting models based on AICc included both stock and year effects, and this model explained 83% of the variability in mean age-at-maturity. Similar results were found for the proportions returning at Age-3, Age-4, and Age-5 (Tables 7.3-7.5), with reductions in DIC for models that included stock and year effects compared to the null model. The best fitting models explained 83%, 64%, and 82% of the variability in the proportion returning at Age-3, Age-4, and Age-5, respectively.

Plots of the observations versus model predictions for mean age-at-maturity and the proportions Age-3, Age-4, and Age-5 illustrate the importance of these stock and year effects (Figures 7.2-7.5). Stocks with the oldest age-at-maturity included the Snake and John Day river wild stocks and the Leavenworth and Carson hatchery stocks (Figure 7.2). Stocks with the youngest age-at-maturity included the Imnaha and Catherine Creek hatchery stocks. There was considerable year-to-year variability in age-at-maturity that was shared across stocks, with the oldest age-at-maturity occurring in the 2000, 2004, and 2005 juvenile outmigration years. The

youngest age-at-maturity occurred in the 2007, 2008, and 2010 juvenile outmigration years. Across stocks, the mean age-at-maturity maturity generally declined over the 1997-2011 juvenile migration years analyzed.

Stocks with the lowest proportions returning at Age-3 included wild stocks from the Snake, John Day, and Yakima rivers and hatchery stocks from Carson and Leavenworth hatcheries (Figure 7.3). Stocks with the highest proportions returning at Age-3 included the Imnaha and McCall hatchery stocks. There was considerable year-to-year variability in the proportions returning at Age-3 that was shared across stocks, with the greatest proportions returning at Age-3 in the 2007, 2008, and 2010 juvenile outmigration years. The lowest proportions returning at Age-3 occurred in the 1997, 1999, 2000, 2004, and 2005 juvenile migration years. Across stocks, the proportions returning at Age-3 generally increased over the 1997-2011 juvenile outmigration years analyzed.

The highest proportions returned at Age-4 and differences among stocks were less apparent (Figure 7.4). Stocks with the highest proportions returning at Age-4 included the Yakima River wild and the Carson hatchery stocks, while stocks with the lowest proportions returning at Age-4 included the Imnaha and McCall hatchery stocks. There was less year-to-year variability in the proportions returning at Age-4, but the lowest proportions returning at Age-4 occurred in 2000, 2008, and 2010 while the highest proportions occurred in 1997 and 1999. The proportion returning at Age-4 decreased slightly over the 1997-2011 juvenile outmigration years analyzed.

Stocks with the highest proportions returning at Age-5 included the wild stocks from the Snake and John Day rivers and hatchery stocks from Leavenworth and Dworshak hatcheries (Figure 7.5). Stocks with the lowest proportions returning at Age-5 included the Cle Elum, Imnaha, and Catherine Creek hatchery stocks. There was considerable year-to-year variability in the proportions returning at Age-5 that was shared across stocks, with the greatest proportions returning at Age-5 in 2000, followed by the 2004 and 2005 juvenile migration years. The lowest proportions returning at Age-5 occurred in the 2002 and 2007 juvenile migration years. Across stocks, the proportions returning at Age-5 decreased over the 1997-2011 juvenile outmigration years analyzed.

Review comments provided by the Independent Scientific Advisory Board raised the question of whether there were any patterns of correlation in the age-at-maturity metrics among stocks from different regions of the basin. To examine this question, we plotted the correlations between stock pairs for the four maturity metrics against the geographic distance between those stock pairs (Figure 7.6). Plots showed that the correlations between stocks were similar across the range of distances between stocks. These results indicate that the temporal patterns of variation in mean age-at-maturity and the proportions returning at Age-3, Age-4, and Age-5 are shared across stocks within the basin and do not appear to be associated with local environmental conditions. These results are consistent with the linear and binomial logit model results, which indicated that common year effects were important factors that explained the variability in the age-at-maturity metrics.

Age-specific returns of spring Chinook salmon to the Columbia River over juvenile migration years 1980-2011 provide context to the patterns observed using the PIT tag data (Figure 7.7). These data show a declining pattern in mean age-at-maturity over 1980-2011, a pattern that was also evident in the more recent and stock-specific PIT tag data during 1997-2011

(Figure 7.2). The declining trend in mean age-at-maturity was largely due to increases in the Age-4 proportions and decreases in the Age-5 proportions during 1980 through the mid-1990's (Figure 7.7), and increases in the proportions returning at Age-3 from 2000-2011. Although trends are evident, there is substantial year-to-year variability in the proportions returning at Age-3, Age-4, and Age-5.

Discussion

The analyses presented in this chapter provide another example of the numerous ways that data from PIT-tags can be used to help improve understanding and management of salmon populations in the Columbia River Basin. Age-at-maturity is an important component of salmon population dynamics and demography, and is an important element for management of salmon populations. For example, sibling relationships (Peterman 1982) are commonly used to generate pre-season forecasts of salmon abundance (Haeseker et al. 2008). The results presented in this chapter have some important implications for development of sibling forecasting models. First, the identification of significant differences between stocks in their age at maturity suggests that using a common sibling model across all stocks may not perform well. Some stocks have high proportions of jacks (Age-3) while other stocks have very few jacks (Figure 7.3). Variation in stock-specific adult returns, combined with variation in stock-specific age composition will tend to confound sibling relationships and the pre-season forecasts that are based on those relationships. One alternative would be to develop stock-specific sibling relationships that account for these differences in age-composition between stocks. The stock-specific PIT-tag data provide a source of data to develop stock-specific models, and stock-specific run-reconstruction data could similarly provide a source of data for developing stock-specific models. In addition to stock-specific sibling models, the presence of temporal trends in the proportions returning at each age class suggests that sibling relationships may not be stationary. Because of this, models that allow for non-stationarity, such as Kalman-filter sibling models (Holt and Peterman 2004), could be considered when developing and evaluating pre-season forecasts. Over the 1980-2011 timeframe, there has been a large increase in the hatchery proportion of the overall returns. Because hatchery populations generally showed lower age-at-maturity, this increase in hatchery proportions may be one of the factors that could explain the declining trends in mean age-at-maturity. Although Kalman-filter models may be better suited to account-for low-frequency, temporal trends in the age-at-maturity data, dealing with the high-frequency variation will likely remain a challenge.

The identification of large, high-frequency, year-to-year variation in mean age-at-maturity and the proportion returning at each age class by outmigration year indicates that there are factors that are similarly influencing age-at-maturity across Columbia River Basin stocks. Pyper et al. (1999) and Holt and Peterman (2004) found regional covariation in age-at-maturity for sockeye salmon, but this study appears to be one of the first to identify regional covariation in age-at-maturity for Chinook salmon. It is interesting to note that the between-stock correlations for mean age observed in this study of Chinook salmon are considerably stronger than those observed for sockeye salmon in Pyper et al. (1999). A logical next step for future work on this topic would be to evaluate candidate factors that may be associated with the estimated year

effects. If the factors that are influencing age-at-maturity can be identified, then there is additional opportunity to improve forecasting by accounting for this high-frequency variation in sibling relationships. For example, if it were known that a higher or lower proportion of jacks were expected from a particular outmigration year, then the predicted return of Age-4 adults could be modeled and adjusted accordingly. Biological monitoring data, such as size of returning Age-3 fish, scale ageing studies that examine growth patterns, age composition of the spawning population that produced the broods, or the abundance of conspecific salmonids that may compete with Chinook salmon for food resources, may provide useful indices of these factors. Environmental monitoring data such as the North Pacific Gyre Index or the Pacific Decadal Oscillation Index could also be examined to assess whether these indices can be used to account for the patterns of variation in the age-at-maturity metrics.

Conclusions

- Both stock effects and common year effects were important factors for explaining patterns in mean age-at-maturity and the proportions returning at Age-3, Age-4, and Age-5.
- Stocks with the oldest mean age-at-maturity included the Snake and John Day river wild stocks and the Leavenworth and Carson hatchery stocks, and stocks with the youngest mean age-at-maturity included the Imnaha and Catherine Creek hatchery stocks.
- There was considerable year-to-year variability in age-at-maturity that was shared across stocks, with the oldest age-at-maturity occurring in the 2000, 2004, and 2005 juvenile outmigration years and the youngest age-at-maturity occurring in the 2007, 2008, and 2010 juvenile outmigration years.
- Across stocks, the mean age-at-maturity maturity generally declined over the 1997-2011 juvenile migration years analyzed.
- Correlation plots showed that the temporal patterns of variation in mean age-at-maturity and the proportions returning at Age-3, Age-4, and Age-5 were shared across stocks within the basin and therefore do not appear to be associated with local environmental conditions.

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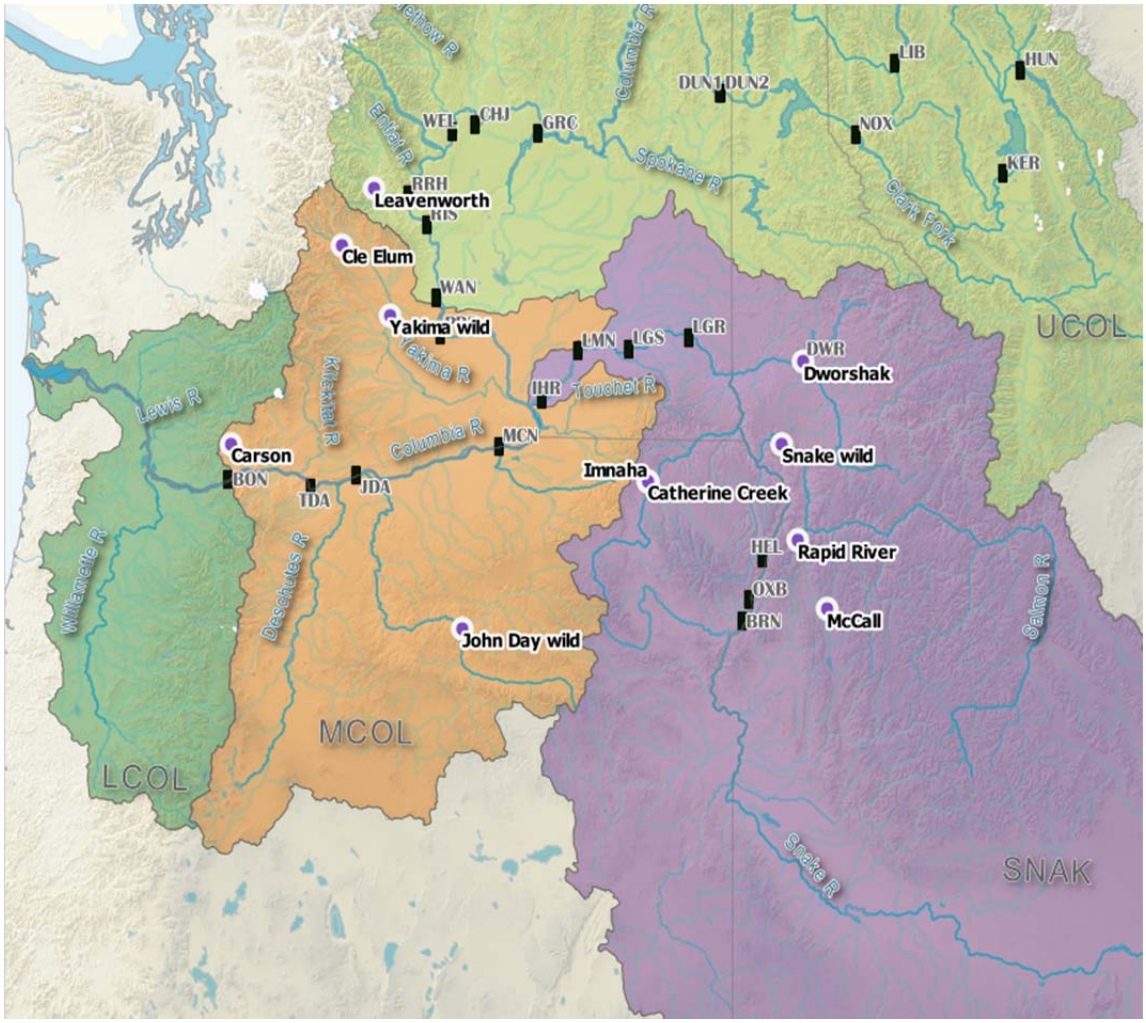

Figure 7.1 Geographic rearing locations (blue circles) that were assigned to each of the eleven spring-summer Chinook salmon stocks that were analyzed.

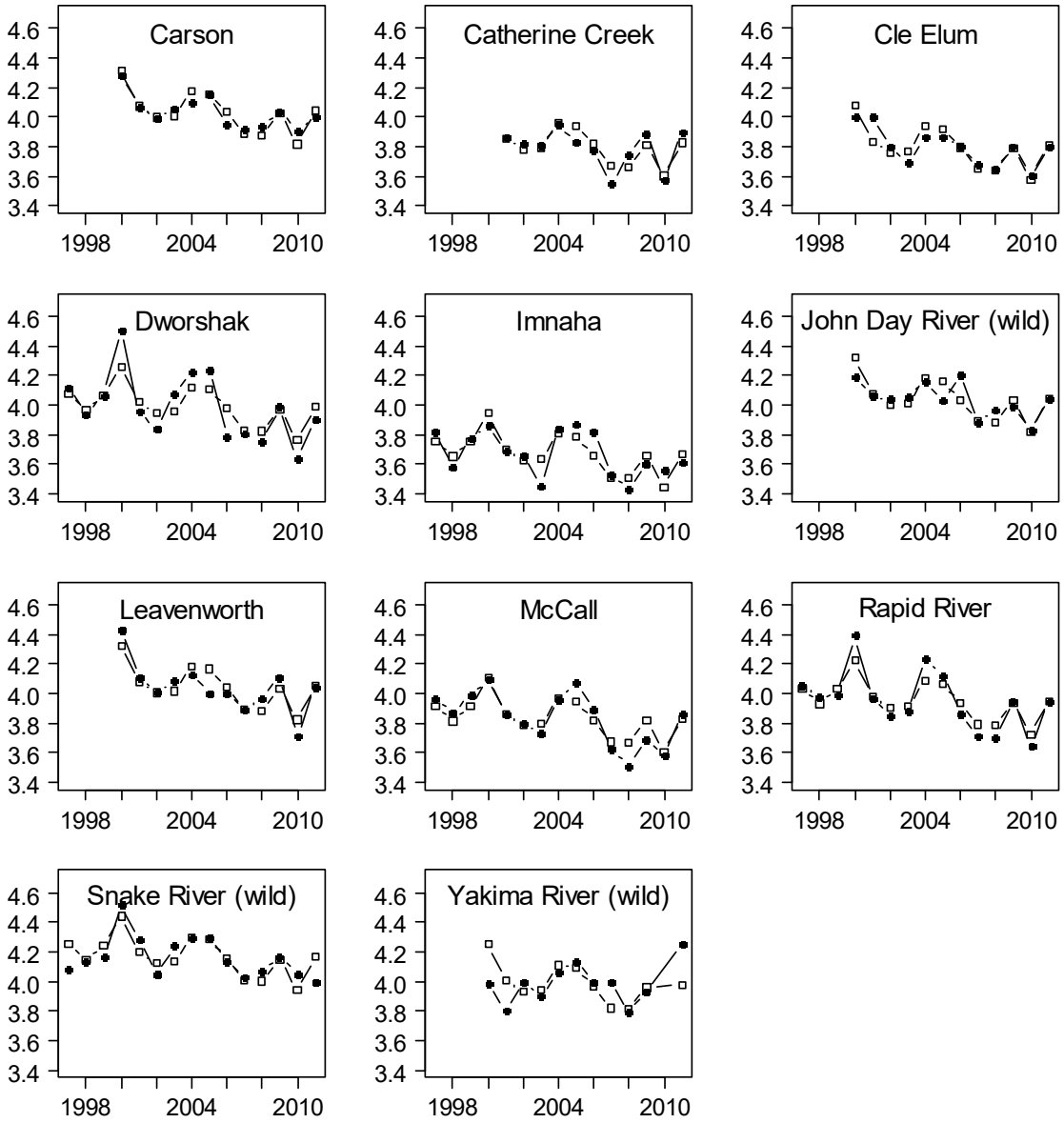

Figure 7.2 Observations (filled circles) and model predictions (open squares) of mean age-at-maturity (y-axis) of hatchery and wild stocks of spring/summer Chinook salmon over juvenile migration years 1997 through 2011.

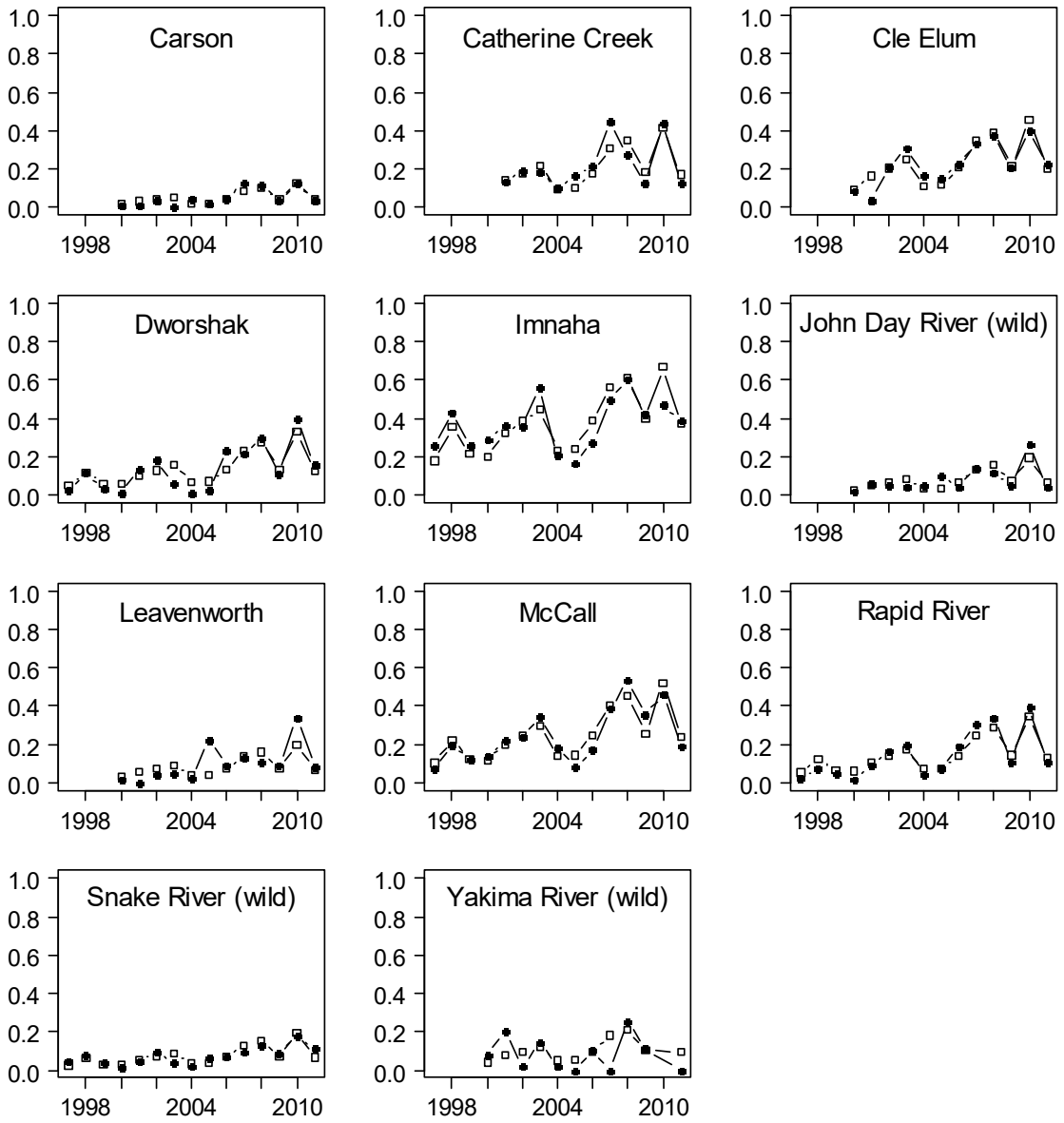

Figure 7.3 Observations (filled circles) and model predictions (open squares) of the proportion returning at Age-3 (y-axis) of hatchery and wild stocks of spring/summer Chinook salmon over juvenile migration years 1997 through 2011.

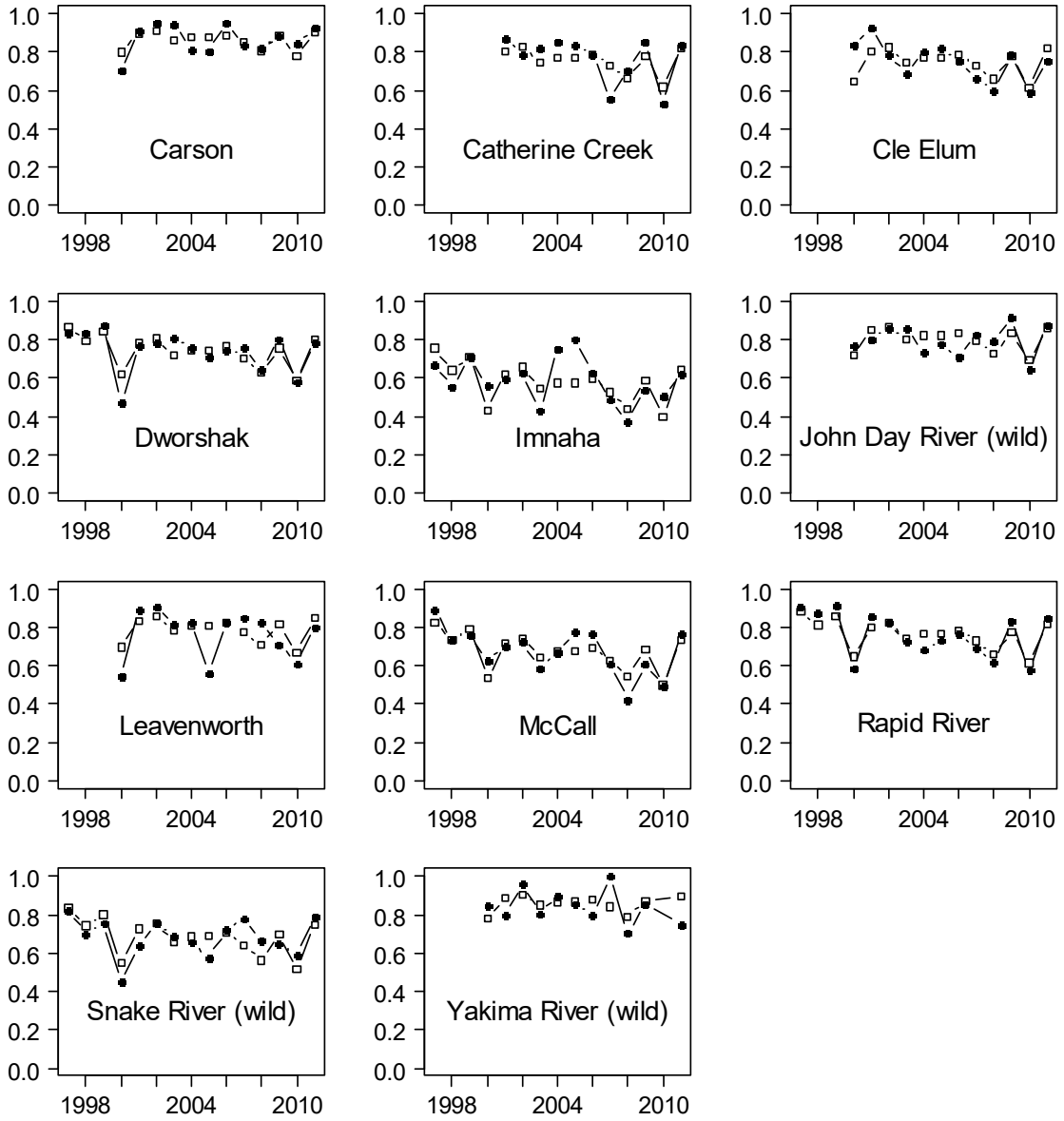

Figure 7.4 Observations (filled circles) and model predictions (open squares) of the proportion returning at Age-4 (y-axis) of hatchery and wild stocks of spring/summer Chinook salmon over juvenile migration years 1997 through 2011.

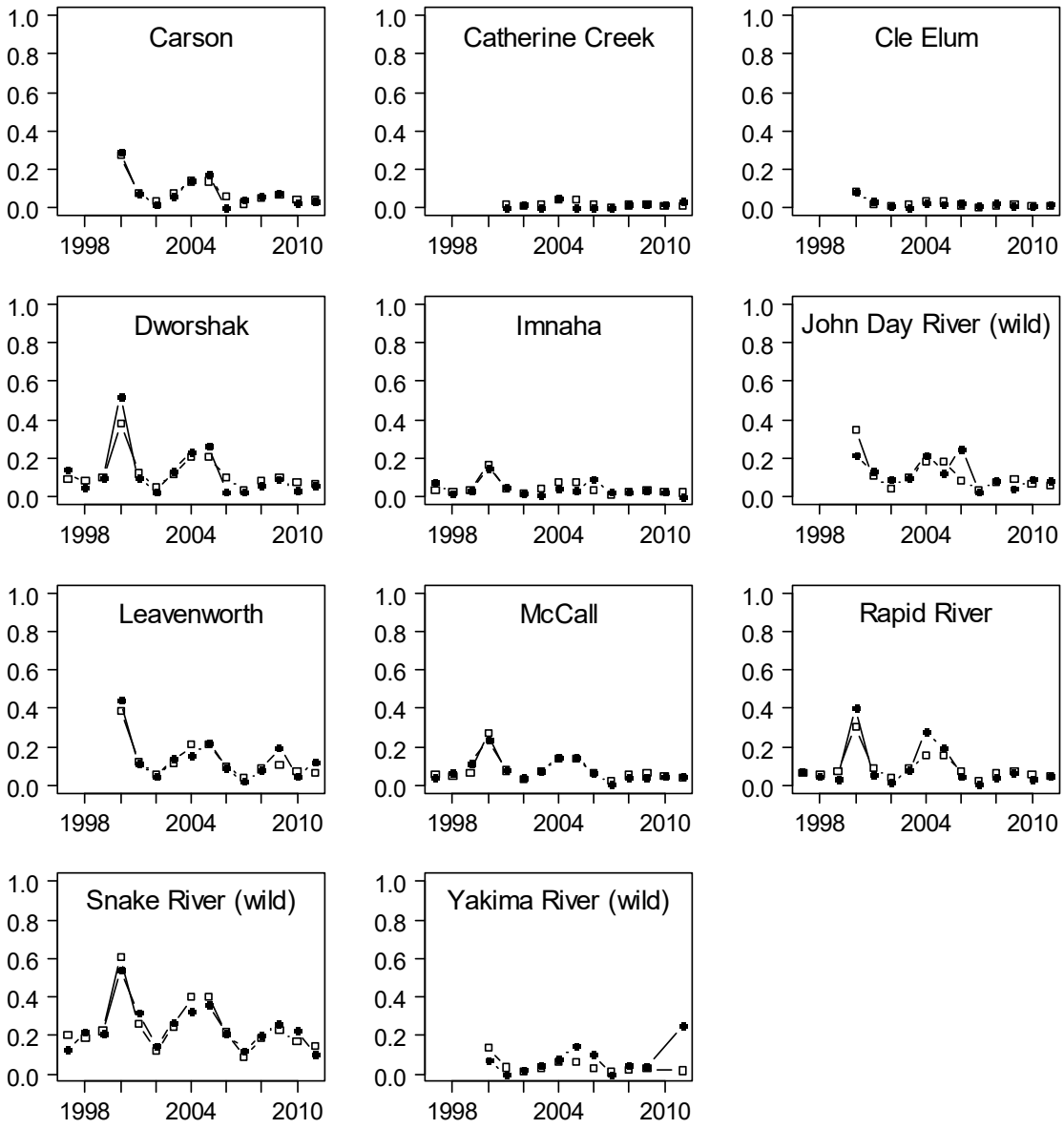

Figure 7.5 Observations (filled circles) and model predictions (open squares) of the proportion returning at Age-5 (y-axis) of hatchery and wild stocks of spring/summer Chinook salmon over juvenile migration years 1997 through 2011.

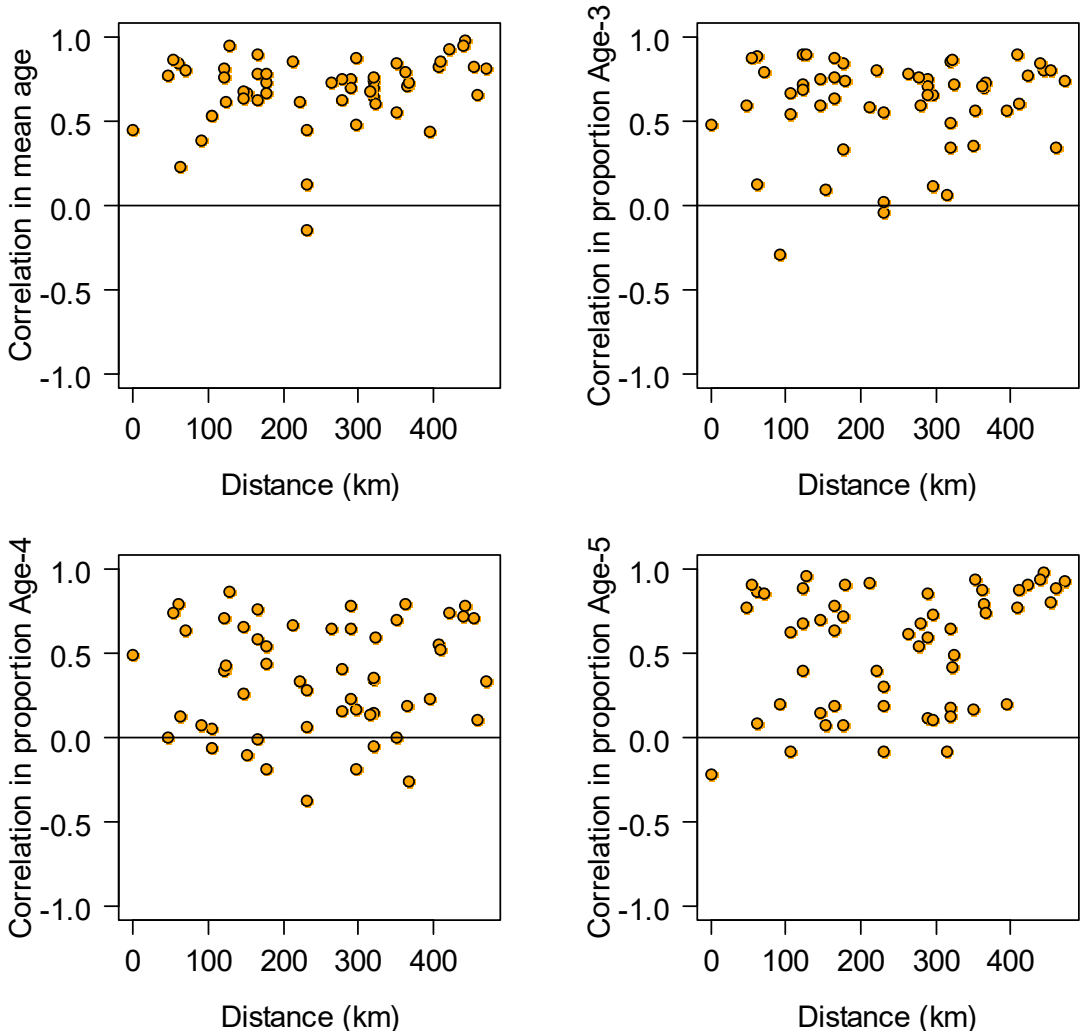

Figure 7.6 Pairwise correlations in mean age-at-maturity, proportion Age-3, proportion Age-4, and proportion Age-5 versus distance (km) between stock pairs for each of the 55 stock pairs.

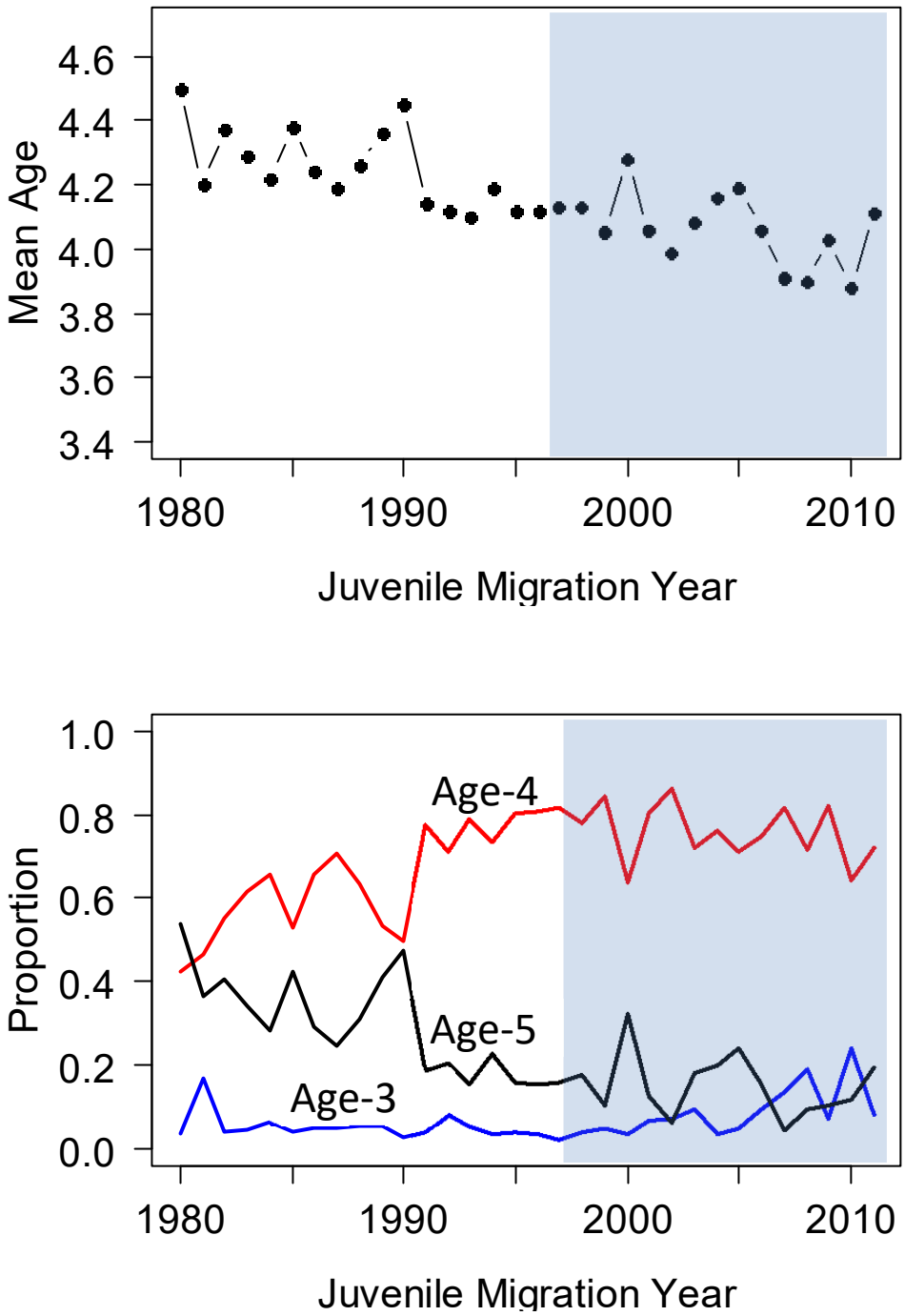

Figure 7.7 ***U.S. v. Oregon*** **Technical Advisory Committee estimates of mean age-at-maturity (upper panel) and proportions returning at Age-3, Age-4, and Age-5 (lower panel) for spring Chinook salmon returns to the Columbia River for juvenile outmigration years 1980 to 2011. The shaded region in both panels represents the time period with PIT tag data that were analyzed in this chapter (1997-2011).**

Table 7.2 Summary of model variables, number of estimated parameters (k), adjusted R^2 values, Akaike's Information Criterion corrected for small sample sizes (AICc), and AICc differences (ΔAICc) for models of mean age.

Model	Variables	k	R^2	AICc	Δ AICc
1	Constant	2	0.00	-40	193
2	Stock	12	0.46	-107	125
3	Year	16	0.37	-75	157
4	Stock + Year	26	0.83	-232	0

Table 7.3 Summary of model variables, R^2 values, and Deviance Information Criterion (DIC) values for models of the proportion Age-3.

Model	Variables	R^2	DIC
1	Constant	0.00	893
2	Stock effects	0.46	886
3	Year effects	0.31	889
4	Stock + Year effects	0.83	867

Table 7.4 Summary of model variables, R^2 values, and Deviance Information Criterion (DIC) values for models of the proportion Age-4.

Model	Variables	R^2	DIC
1	Constant	0.00	983
2	Stock effects	0.32	974
3	Year effects	0.25	981
4	Stock + Year effects	0.64	965

Table 7.5 Summary of model variables, R^2 values, and Deviance Information Criterion (DIC) values for models of the proportion Age-5.

Model	Variables	R^2	DIC
1	Constant	0.00	813
2	Stock effects	0.34	796
3	Year effects	0.38	809
4	Stock + Year effects	0.82	775

CHAPTER 8
CSS ADULT SUCCESS-SUMMER CHINOOK, SNAKE RIVER SOCKEYE AND STEELHEAD

Introduction

The Comparative Survival Study (CSS) has been assessing adult salmon and steelhead upstream migration success through the Federal Columbia River Power System (FCRPS) beginning with the 2010 Annual Report. These analyses were included in response to regional concerns regarding high stray rates of Snake River steelhead (*Oncorhynchus mykiss*) and salmon that were transported as juveniles. Early analyses indicated that salmon and steelhead that were transported downstream in the smolt transportation program had lower upstream migration success and higher stray rates. This was considered problematic for some middle Columbia River listed steelhead stocks which were affected by Snake River steelhead straying.

National Oceanic and Atmospheric Administration (NOAA) has established performance standards for adult salmon migration success in the Biological Opinions for the FCRPS. In the earlier Biological Opinions, NOAA included Reasonable and Prudent Alternatives that addressed water temperature thresholds for salmon migration corridors. In addition, the Environmental Protection Agency began a basin wide evaluation to establish Total Maximum Daily Load (TMDL) for water temperature. Higher water temperatures occurred earlier and for longer periods in recent years, and the worst occurrence was observed in 2015 resulting in extraordinary fish kills. In response to regional concerns regarding upstream adult migration success, the CSS analysis of upstream migration success was expanded to evaluate upstream migration success of steelhead, summer Chinook (*O. tshawytscha*) and sockeye (*O. nerka*) to assess the effects of water temperature and smolt transportation on adult upstream migration success. We anticipate that the CSS monitoring and analyses of adult upstream migration success will continue to evolve and refine the definition of the water temperature variables, including understanding of temperature exposure, the effect of fishway ladder temperatures and fishway ladder temperature differentials.

In this chapter, we develop models in generalized regression, mixed effects, and Cormack-Jolly-Seber frameworks to estimate the relationship between temperature, juvenile transport, and salmon survival. We focus our analysis on three salmonid species in the Snake River: the summer run portion of the Snake River spring/summer Chinook salmon ESU, sockeye salmon, and A-run populations of steelhead, using temperature encountered at Bonneville Dam and PIT-tag detection at Bonneville and upstream dams from 2003 to 2016.

Methods

Data Selection

Summer Chinook

We included PIT-tagged adult summer Chinook that were detected at Bonneville dam during return years 2003 to 2016. For each fish in the data set, we included its detection history at Bonneville, McNary, Ice Harbor, and Lower Granite dam. We also matched each fish with Bonneville forebay temperature at the time of its detection/arrival, along with juvenile migration history (transported or not). We only included later returning summer Chinook (i.e. PTAGIS

species codes of 12H and 12W) and adults that spent at least two years at sea. In other words, we did not include jacks, spring and fall adult Chinook, nor Chinook with unknown origins. We did not distinguish between hatchery and wild fish, nor did we attempt to quantify the seasonal or annual changes in harvest in the fisheries between Bonneville and McNary dams, because it was not the focus of this analysis.

Snake River Sockeye

We included both hatchery and wild sockeye adults from the Snake River that were PIT-tagged as juveniles and detected as adults at Bonneville Dam during return years 2003 to 2016. For this data set, we incorporated the same criteria as the summer Chinook analysis to include detection histories, water temperature and juvenile migration history.

Snake River Steelhead

We included PIT-tagged wild and hatchery steelhead that were detected as adults at Bonneville Dam during return years 2003 to 2015 (June to September). For this data set, we only selected steelhead originating upstream of Lower Monumental Dam and excluded both wild and hatchery B-run fish due to their later migration timing. We did not include steelhead that returned in 2016 because that, for steelhead, returning cohort would not be complete until the winter of 2017. We used the same criteria to include detection histories, water temperature and juvenile migration history as for the summer Chinook and Snake River sockeye.

Data Analysis

Summer Chinook

We examined the relationships between water temperature and 1) travel time, 2) arrival timing, and 3) survival. For the travel time-temperature relationship, we calculated the travel time in days between Bonneville and McNary dams for all fish that were detected at McNary (i.e. fish that successfully made it from Bonneville to McNary dams). We assigned the fish in our data set into different groups based on the temperature they encountered at Bonneville dam, ranging from 7 to 23°C. We then summarized the portions of fish with travel time more than 10 days across all temperature ranges. Because the majority (more than 85%) of adult summer Chinook that completed travel from Bonneville to McNary did it within 10 days, we considered travel time more than 10 days as being delayed. To test if there was a difference in travel time between fish with different migration histories, we fitted a logistic regression model (**`glm()`** in R) with travel time greater than 10 days (1 if yes, 0, no) as the response variable and juvenile migration history and the temperature range each fish encountered at the Bonneville Dam as the explanatory variable. We also fitted a generalized additive model (GAM) using log-transformed travel time as the response, and water temperature with the default smoothing function provided by R package **`mgcv`** (Wood 2011) and arrival date as the explanatory variables.

For the arrival timing-temperature relationship, we graphically summarized each year the arrival time of all fish in our data set along with the water temperature they encountered at Bonneville dam.

To estimate the survival-temperature relationship, we used a Cormack-Jolly-Seber (CJS) model with individual covariates. We employed a Bayesian framework to run our CJS models because it allowed immense flexibility to fit complex models. However, with large number of records in our data set, each CJS model took us several hours to run using computationally intensive Markov chain Monte Carlo (MCMC) algorithms. In order to explore the data and identify

suitable models, we first ran analyses using GAM and mixed effects logistic regression (a form of generalized linear mixed model, or GLMM). We know from previous analyses that detection rate at the adult fish way were generally quite high (close to 100%). As a result, the estimates using logistic regression and CJS models were similar. Therefore, we used GLMM's as surrogates for selecting suitable CJS models. All GLMM were fitted in R (R Core Team, 2016) using package `lme4` (Bates et al. 2015).

We first fitted a GAM to assess the overall pattern. We set up the GAM using detection at McNary as the response and temperature with smoothing function and arrival date as the explanatory variables (McNary detection~ s(Temp)+ Arrival). After getting a general idea, we fitted multiple models in mixed effects logistic regression. The models had McNary detection as the response and temperature as the main explanatory variable. To account for juvenile transport and seasonal effects, we included transport history and arrival date as well. In addition, we considered interaction terms between temperature, arrival date, and transport history. Continuous variables such as temperature and arrival date were standardized in order to improve model fit. Also, to account for variations between years and between individuals, we included random year effects and random individual effects in the model. We set up the linear predictors of regression models in three different forms: a) a piece-wise linear form with a change point, b) a quadratic form, and c) a linear form without any change points. We decided on a model that was the most biologically plausible to us and/or the lowest AIC value (Akaike 1973). Then we selected explanatory variables using a backward elimination stepwise process. During which, we started with all candidate variables in the model, and deleted them one by one until no more could be eliminated without losing significant model fit. We evaluated the model fit using a sequence of comparisons of AIC values.

Our final analysis on the survival-temperature relationship was repeated with a CJS model using the explanatory variables selected through the above process. The response variable of the CJS model included detection at Bonneville, McNary, and above McNary (i.e. detection at Ice Harbor and Lower Granite combined into a single event), which gave us a three-digit capture history. By doing so, we were able to estimate the detection and survival rates of adult summer Chinook to McNary. Details of the CJS model for summer Chinook can be found in Supplemental Materials A.

Snake River Sockeye

We applied the same analytic process to Snake River sockeye as for the summer Chinook. We examined the relationships between water temperature and fish 1) travel time, 2) arrival timing, and 3) survival. For travel time-temperature relationship, the procedures were unchanged, except the temperature in the Snake River sockeye data set ranged from 13 to 23°C. We fitted a logistic regression model with travel time greater than 10 days (1 if yes, 0, no) as the response and juvenile migration histories and the temperature range each fish encountered at the Bonneville Dam as the explanatory variable to test for a difference in travel time between in-river and transported fish. We also fitted a GAM using log transformed travel time as the response, and water temperature (with smoothing function), arrival date, and transportation history as the explanatory variables.

For survival-temperature relationships, the procedures were slightly modified. First, we fitted a GAM to assess the overall pattern (McNary detection~ s(Temp)+ Arrival+ Transport history). Second, we fitted multiple models in mixed effects logistic regression using McNary detection as the response, temperature, transport history, arrival date as the fixed effects explanatory

variables, and individual fish and migration year as the random effects. We set up linear predictors of the models in three different forms: a) third-degree polynomial, b) quadratic, and c) linear. We decided on a final model and selected explanatory variables following the same backward stepwise procedures as in the summer Chinook analysis. Finally, with the decided variables, we estimated the survival-temperature relationship using a CJS model. Details of the Snake River sockeye CJS model can be found in Supplemental Materials A. We did not modify the procedures for assessing arrival timing-temperature relationship.

Snake River Steelhead

We applied the same analytic process to the Snake River steelhead as for the summer Chinook. We examined the relationships between water temperature and 1) travel time, 2) arrival timing, and 3) survival. For the travel time-temperature relationship, the procedures were mostly unchanged, except the temperature in the Snake River sockeye data set ranged from 4 to 24°C. In addition, steelhead had the tendency to stray more than Chinook and sockeye and it was common (around 60%) in our data set for steelhead to spend more than 10 days traveling between Bonneville and McNary. This behavior is typical of summer run steelhead where they enter freshwater during spring and summer, but do not return to their natal origins to spawn until as late as winter during the subsequent calendar year. This longer travel time could be explained by the propensity of Snake River steelhead to stray and/or suspend their migration until the following year (Keefer et al. 2015). Therefore, we decided to use 30 days or more as the cut-off for delayed travel time for steelhead. We fitted a logistic regression model with travel time greater than 30 days (1 if yes, 0, no) as the response and juvenile migration histories and the temperature range each fish encountered at the Bonneville Dam as the explanatory variable to test for a difference in travel time between in-river and transported fish. We also fitted a GAM using log-transformed travel time as the response, and water temperature (with smoothing function) and arrival date as the explanatory variables.

For survival-temperature relationships, the procedures were slightly modified. First, we fitted a GAM to assess the overall pattern (McNary detection~ s(Temp)+ Arrival+ Transport history). Second, we fitted multiple models in mixed effects logistic regression using McNary detection as the response, temperature, transport history, arrival date, and random individual and random year effects as the explanatory variables. We set up linear predictors of the models in three different forms: a) a linear form, b) a piece-wise linear form with a change point, and c) a quadratic form. We decided on a final model and selected explanatory variables using a backward stepwise procedure. Finally, with the selected variables, we estimated the survival-temperature relationship using a CJS model. Details of the Snake River steelhead CJS model can be found in Supplemental Materials A. We did not modify the procedures for assessing the arrival timing-temperature relationship.

Results

Summer Chinook

Transported summer Chinook were more likely to have a long travel time (> 10 days) at most temperature ranges, compared to in-river fish ($p < 0.001$; Figure 8.1). The relationship between travel time and water temperature was mostly linear if we took arrival date into account. Results from our GAM showed a negative and mostly linear relationship between travel time and water temperature for in-river summer Chinook. For transported fish, travel time also decreased with increasing temperature, but with a higher rate after 13°C (Figure 8.2).

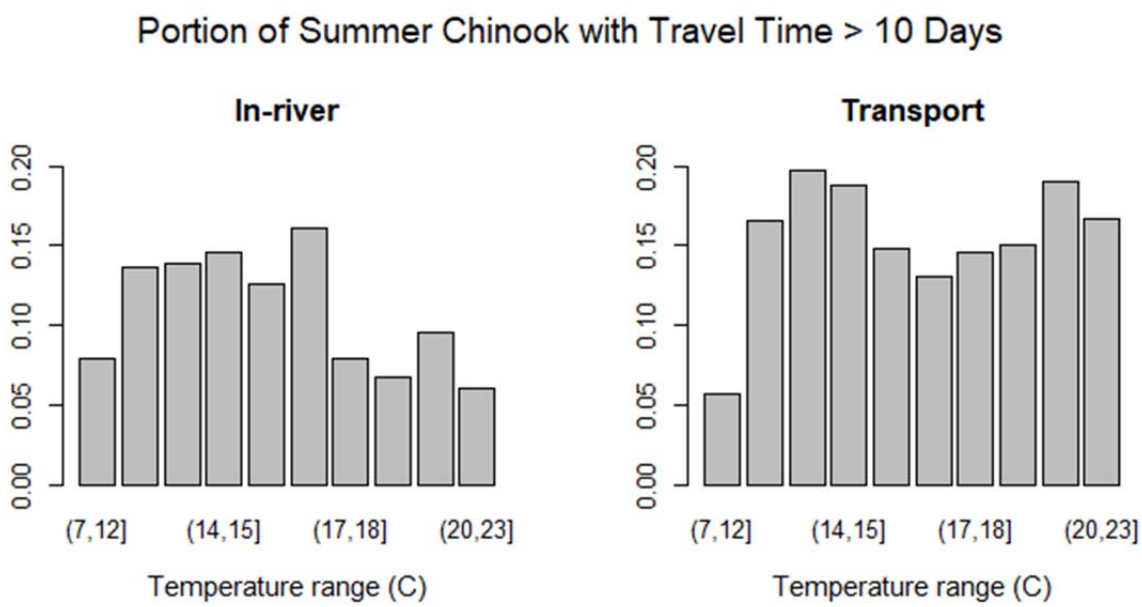

Figure 8.1. Bar chart shows the portion of fish with travel time more than ten days in water temperature ranging from 7 to 23°

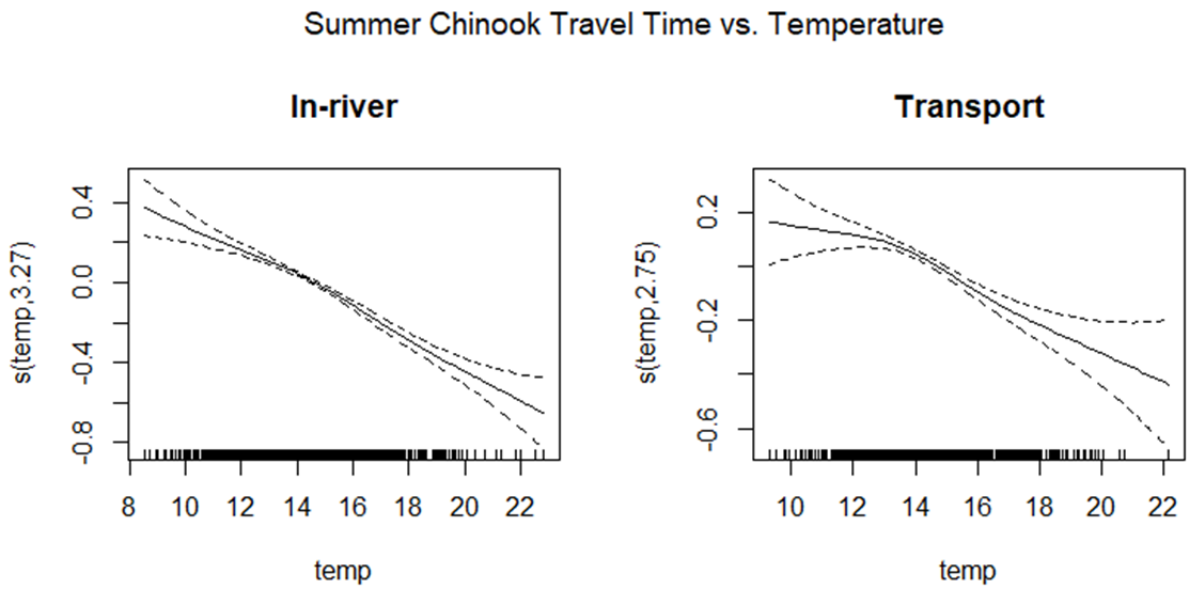

Figure 8.2. GAM shows a negative relationship between travel time and temperature for summer Chinook. The model is log(travel time)~ s(temperature)+ arrival date.

We began the assessment of survival and temperature with a GAM. After fitting the model and plotting the results, we saw a non-linear relationship between detection and temperature with a possible change point at approximately 15°C (Figure 8.3).

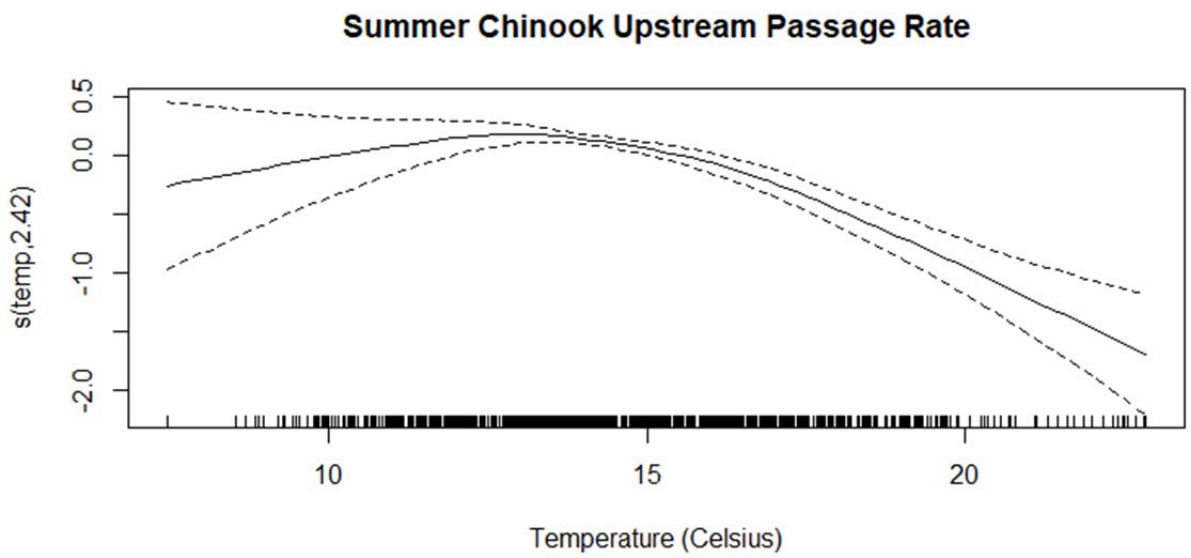

Figure 8.3. GAM shows a convex curve relationship between survival and temperature. The model is McNary detection~ s(temp)+ arrival. We used thin plate regression splines as the smooth function with smoothing parameter = 5.

Next, we set up multiple models in mixed effects logistic regression. Based on the results from GAM, we decided that, in addition to a model in linear form, we would fit models in quadratic form and piecewise linear form (with a change point at mean temperature of 14.64°C) in order to capture the non-linear survival-temperature relationship. We compared models with and without the random effects, and the results showed that random year effects improved model fit by nearly 200 AIC values, but no improvement was brought by including random individual effects (Table 8.1).

Table 8.1. Description of quadratic model with and without random effects and their corresponding AIC value, deviance, and residual degrees of freedom (Residual DF).

Model	Variables	AIC	Deviance	Residual DF
Random individuals and years	Polynomial form, Random individuals, Random years	7129	7105	7196
Random years	Polynomial form, Random years	7127	7105	7197
No Random effects	Polynomial form	7326	7306	7198

After deciding to keep the random year effects in all models, evaluation showed that piecewise and quadratic models were equally parsimonious based on similar AIC values (Table 8.2). However, we decided on a quadratic model because it required no predetermined change point. The final quadratic model included McNary detection as the response, and temperature^2, temperature, transport history, arrival date^2, arrival date, temp^2:transport interaction, temp:transport interaction, and random year effects as the explanatory variables (Table 8.3).

The variables water temperature and arrival date were highly correlated in our summer Chinook data set (Pearson's correlation= 0.73). Constructing a model without addressing collinearity between the variables could result inflated variance estimates, which then lead to an overly large p-value and a wrong inference (Zuur et al. 2010). However, after examining issues related to collinearity, we saw no strong evidence impacting our analysis (Supplemental Materials B). Therefore, we kept both temperature and arrival date in our model. We included the arrival date variable in our model to account for seasonal shifts in phenology that might be important overlapping with predators, prey, competition, and/or harvest in the seasonal fisheries that could vary across the years used in our analyses; these sorts of change could be missed or overlooked if we excluded arrival date, especially since model selection indicated it is an important variable to our model.

Table 8.2. Description of piecewise, quadratic, and linear models and their corresponding AIC value, deviance, and residual degrees of freedom (Residual DF).

Model	Variables	AIC	Deviance	Residual DF
Piecewise	Temp< 14.64, Temp≥ 14.64, Arrival date, Arrival^2, Temp< 14.64:Transport, Temp≥ 14.64:Transport, Arrival date^2:Transport, Arrival date:Transport, Transport, Random year effects	7126	7104	7197
Quadratic (full)	Temperature, Temp^2, Arrival date, Arrival^2, Temperature:Transport, Temp^2:Transport, Arrival date:Transport, Arrival^2:Transport, Transport, Random year effects	7127	7105	7197
Linear form	Temperature, Arrival date, Transport, Temp:Transport Arrival:Transport, Random year effects	7153	7139	7201

Table 8.3. Description of three quadratic models in the backward stepwise selection process, and their corresponding AIC value, deviance, and residual degrees of freedom (Residual DF). We started with a full model and proceeded to delete variables one by one until AIC stopped decreasing.

Model	Variables	AIC	Deviance	Residual DF
Quadratic (full)	Temperature, Temp^2, Arrival date, Arrival^2, Temperature:Transport, Temp^2:Transport, Arrival date:Transport, Arrival^2:Transport, Transport, Random year effects	7127	7105	7197
Quadratic 1	Temperature, Temp^2, Arrival date, Arrival^2, Temperature:Transport, Temp^2:Transport, Transport, Random year effects	7124	7106	7199
Quadratic 2	Temperature, Temp^2, Arrival date, Arrival^2, Transport, Random year effects	7126	7112	7201

Finally, we estimated the survival-temperature relationship using a CJS model with the same fixed and random effects as the final logistic regression model, "Quadratic 1." The results showed a survival of 0.84 (95% CRI= 0.79 to 0.88) from Bonneville to McNary Dam at mean water temperature (14.64°C) and mean arrival date (06/02), and a detection rate at McNary of nearly 100% (0.997, 95% CRI= 0.995 to 0.999). Summer Chinook adults exhibited a survival pattern that was mostly constant at lower water temperature; however, transported fish showed a steepening decrease in survival after approximately 16 or 17 °C, but evidence was not strong enough to support a negative survival-temperature relationship. For the in-river fish, there was little evidence suggesting a negative survival-temperature relationship (Table 8.4; Figure 8.4). It was important to point out that we fitted the model using all available data, but we only drew conclusions from where the majority of data existed (non-shaded areas in Figure 8.4). We caution against making conclusions regarding survival at extreme temperatures because observations were scarce at the extreme ends of the temperature spectra.

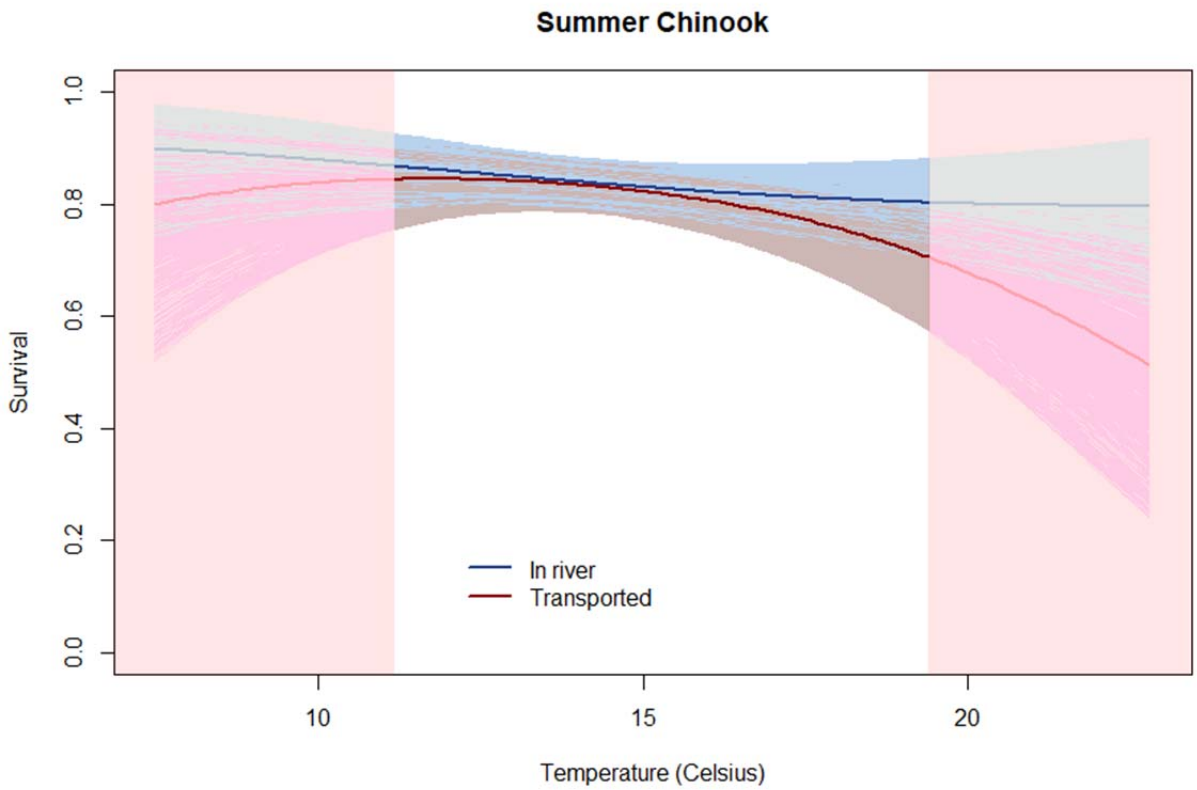

Figure 8.4. Plot shows the estimated relationship between summer Chinook adult survival and water temperature using a CJS model with individual covariates (temperature, temperature^2, transport history, arrival date, arrival^2, temp:transport, and temp^2:transport interaction and random year effects). The light lines represent uncertainties (ie. 95% credible interval) in the CJS model. Between the shaded areas represented the 2.5th to 97.5th percentiles of the data.

Table 8.4. Estimates from the CJS model for summer Chinook show no strong evidence for a curved relationship between survival and water temperature for in-river fish (interval for Temperature^2 coefficient overlapping 0). But for the transport group, estimates show a convex-curved survival-temperature relationship (negative Temp^2 + Temp^2:Trans coefficients).

	Mean	SD	95% CRI	$\hat{R}$	Eff size
(Intercept)	1.622	0.166	(1.307, 1.966)	1.012	229
Temp^2	0.021	0.029	(-0.034, 0.077)	1	13626
Temperature	-0.133	0.116	(-0.36, 0.095)	1.006	460
Transported	-0.046	0.076	(-0.197, 0.103)	1	5760
Arrival^2	-0.114	0.026	(-0.167, -0.063)	1	20000
Arrival date	-0.218	0.091	(-0.396, -0.042)	1.006	462
Temp^2:Trans	-0.072	0.04	(-0.15, 0.005)	1	20000
Temp:Trans	-0.039	0.07	(-0.177, 0.098)	1	15424
P (McN)	0.997	0.001	(0.995, 0.999)	1	12895
P (Upp)	1	0	(0.999, 1)	1.001	5910
ϕ (Upp)	0.999	0.001	(0.996, 1)	1.002	6185
σ_{year}	0.558	0.13	(0.364, 0.868)	1.001	6644
Year2003	0.088	0.184	(-0.284, 0.442)	1.008	338
Year2004	-0.174	0.193	(-0.568, 0.193)	1.009	277
Year2005	0.849	0.239	(0.39, 1.335)	1.005	516
Year2006	0.14	0.223	(-0.305, 0.574)	1.005	548
Year2007	0.369	0.223	(-0.067, 0.818)	1.006	414
Year2008	0.401	0.222	(-0.042, 0.828)	1.003	883
Year2009	0.226	0.203	(-0.174, 0.627)	1.006	455
Year2010	-0.016	0.188	(-0.405, 0.34)	1.006	452
Year2011	-0.827	0.206	(-1.255, -0.442)	1.004	697
Year2012	0.256	0.212	(-0.168, 0.671)	1.004	638
Year2013	0.283	0.221	(-0.154, 0.721)	1.006	472
Year2014	-0.717	0.185	(-1.098, -0.365)	1.01	264
Year2015	-0.787	0.214	(-1.224, -0.364)	1.014	182
Year2016	-0.001	0.207	(-0.414, 0.406)	1.011	236
Deviance	6017	73.11	(5875.84, 6161.968)	1	20000

Twenty-three percent of summer Chinook encountered a water temperature higher than 16°C at Bonneville Dam (Figure 8.5). 2008 had the lowest portion (1%) of summer Chinook that were exposed to temperature higher than 16°C, and 2015 had the highest (74%). Transported and in-river fish showed similar arrival timing.

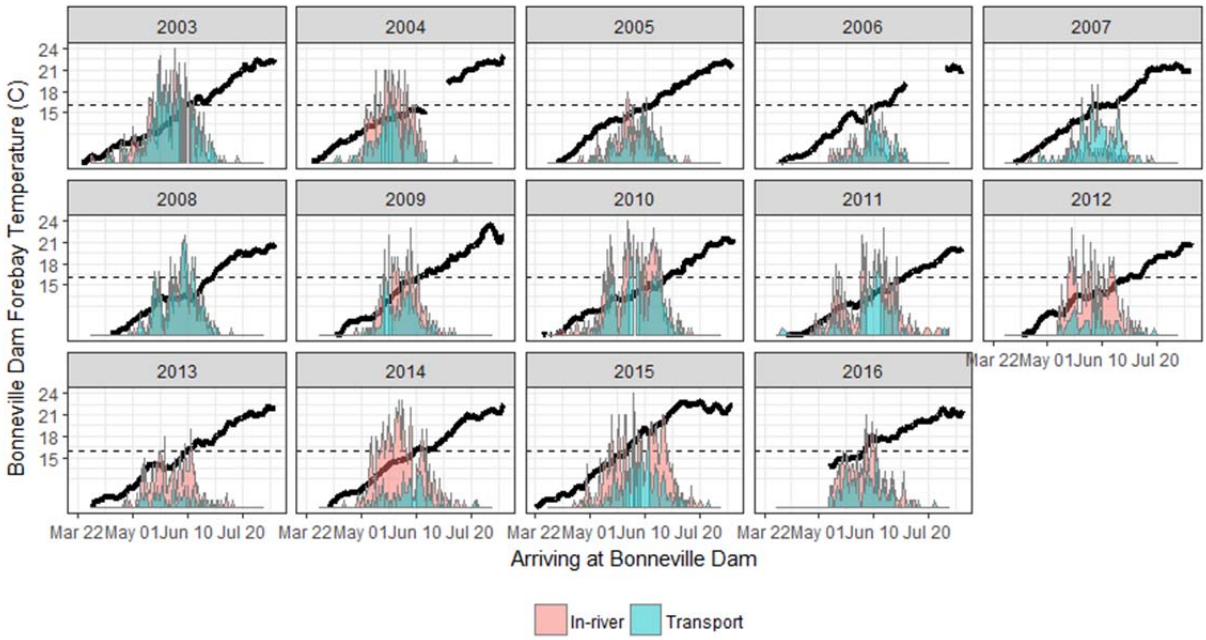

Figure 8.5. Black lines indicate the forebay temperature corresponding to the adult summer Chinook arrival dates at Bonneville Dam. Below the temperature lines are the distributions of arrival dates for in-river and transported fish. Dash lines indicate 16 °C.

Snake River Sockeye

Travel time for the Snake River sockeye that were transported as juveniles tends to be longer compared to the in-river fish ($p < 0.001$; Figure 8.6). The in-river fish exhibited no obvious signs for travel time increase until temperature reached the 22 and 23°C range. GAM also showed a similar pattern (Figure 8.7).

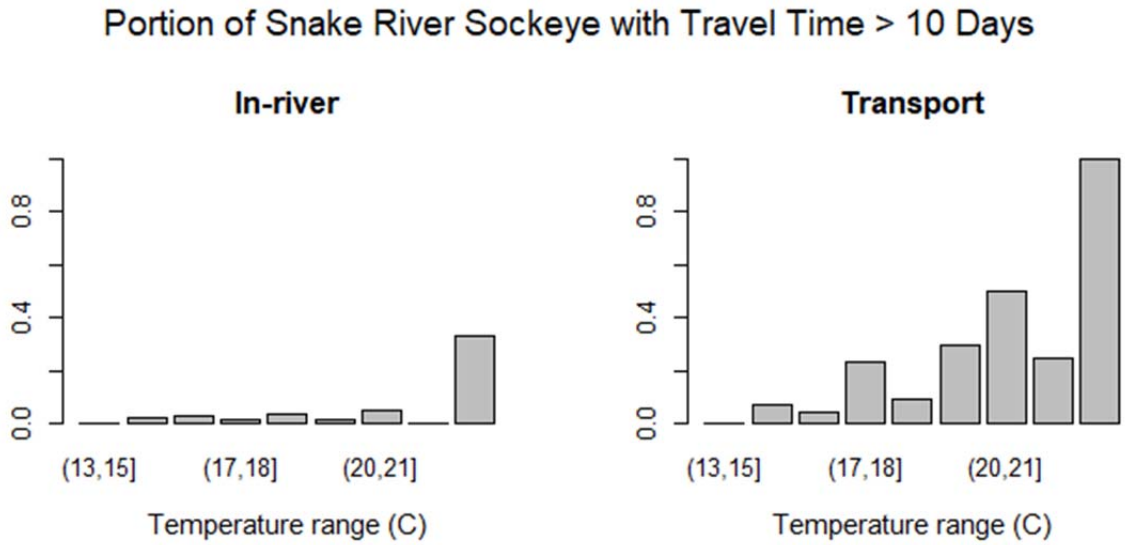

Figure 8.6. Bar chart shows the portion of fish with travel time more than ten days in water temperature ranging from 13 to 23°C.

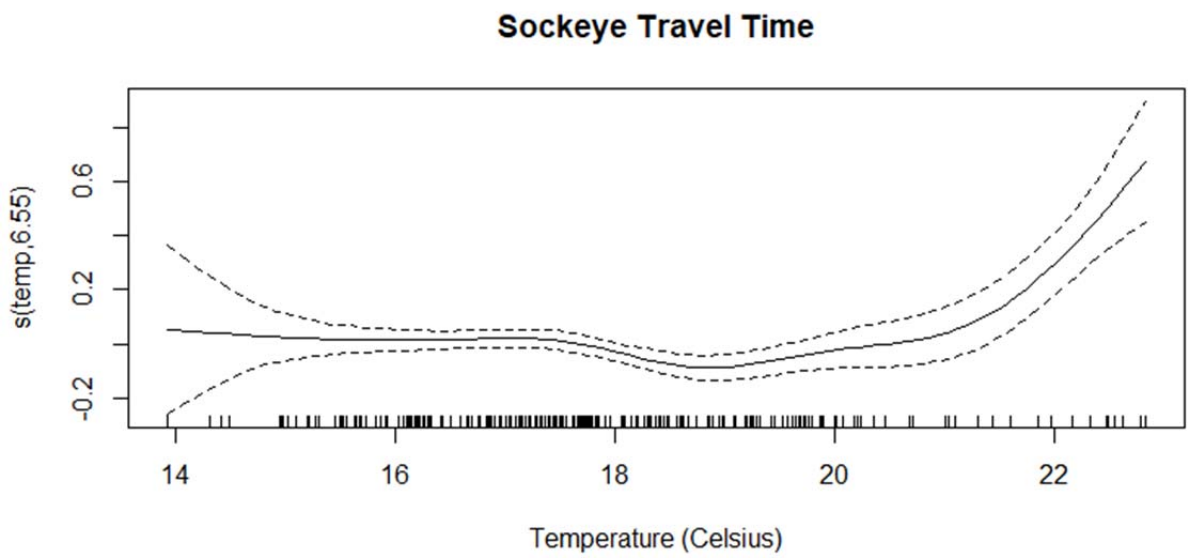

Figure 8.7. GAM shows a nonlinear relationship between travel time and temperature. The model is log(travel time)~ s(temp) + arrival time + transportation.

We began the assessment of survival and temperature by fitting a GAM. The model suggested a non-linear relationship between detection and temperature with a possible change point (Figure 8.8).

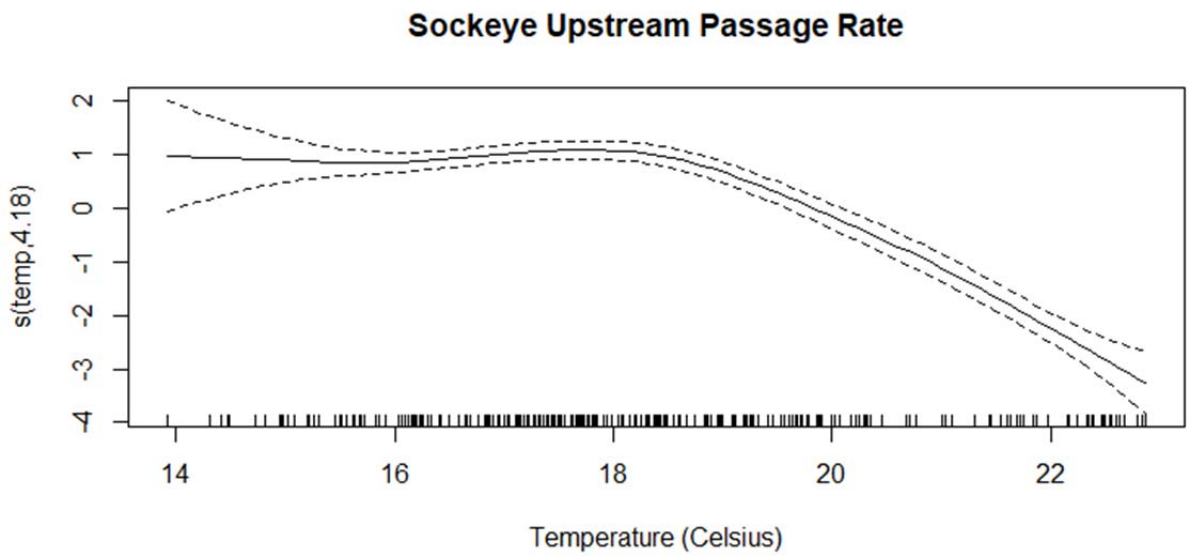

Figure 8.8. GAM shows a nonlinear relationship between survival and temperature, with a change point around 18°C. The model is McNary detection~ s(Temp)+ Arrival+ Transport history.

Following the results from GAM, we constructed mixed effects logistic regression models using detection at McNary as the response variable, and temperature, arrival date at Bonneville, transport history, random individual effects, and random year effects as the explanatory

variables. We first compared models in polynomial forms with and without random effects and found that models with random effects did not do better than the model without (Table 8.5).

Table 8.5. Description of third order polynomial with and without random effects and their corresponding AIC value, deviance, and residual degrees of freedom (Residual DF).

Model	Variables	AIC	Deviance	Residual DF
Random individuals and years	Polynomial form, Random individuals, Random years	2233	2211	2116
Random years	Polynomial form, Random years	2231	2211	2117
No Random effects	Polynomial form	2232	2214	2118

After excluding the random effects, we compared models in linear, quadratic, and third order polynomial forms and found that the model in third order polynomial form had the lowest AIC and deviance values (Table 8.6). In this case, both third order polynomial and quadratic models produced similar results. We chose the quadratic model because its outputs were more plausible based on our understanding of salmon biology.

Table 8.6. Description of third order polynomial, quadratic, and linear models and their corresponding AIC value, deviance, and residual degrees of freedom (Residual DF).

Model	Variables	AIC	Deviance	Residual DF
Third order Polynomial	Temperature, $Temp^2$, $Temp^3$, Transport, Arrival date, Temp:Transport, $Temp^2$:Transport, $Temp^3$:Transport	2232	2214	2118
Quadratic (full)	Temperature, $Temp^2$, Transport, Arrival date, Temp:Transport, $Temp^2$:Transport	2238	2224	2120
Linear form	Temperature, Transport, Arrival date, Temp:Transport	2368	2358	2122

Next, we followed a stepwise procedure to select variables to be included in the final model. We decided on a final model that included temperature, $temperature^2$, transportation, and their interaction terms as the explanatory variables (Quadratic 1, Table 8.7).

Table 8.7. Description of three quadratic models in the backward stepwise selection process, and their corresponding AIC value, deviance, and residual degrees of freedom (Residual DF). We started with a full model and proceeded to delete variables one by one until AIC stopped decreasing.

Model	Variables	AIC	Deviance	Residual DF
Quadratic (full)	Temperature, $Temp^2$, Transport, Arrival date, Temp:Transport, $Temp^2$:Transport	2238	2224	2120
Quadratic 1	Temperature, $Temp^2$, Transport, Temp:Transport, $Temp^2$:Transport	2238	2226	2121
Quadratic 2	Temperature, $Temp^2$, Arrival date	2332	2324	2123

After deciding on the final logistic regression model, we estimated the survival-temperature relationship using a CJS model with varying detection and survivals, and individual covariates for survival from Bonneville to McNary Dam. We followed the same procedures to construct a three-digit detection history for each individual fish, which included detection at Bonneville, McNary, and above McNary. We constructed the individual covariates in the CJS model following the previous model "quadratic 1". The results showed a survival of 0.74 (95% CRI= 0.70 to 0.77) from Bonneville to McNary Dam at mean temperature (18.68°C), and a detection at McNary of 0.98 (95% CRI= 0.96 to 0.99). Estimates from the CJS model showed that in-river Snake River sockeye had a decreasing survival once water temperature passed approximately 18°C, and transported sockeye showed a decreasing survival before water temperature reached 18°C. Overall, transported fish had a lower survival compared to the in-river fish (Table 8.8, Figure 8.9).

Table 8.8. Estimates from the CJS model for Snake River sockeye show a convex-curved relationship between survival and water temperature (negative coefficient for $Temperature^2$), regardless of transport history. On average, fish that were transported as juveniles have a lower survival compared to the fish that migrated in the river.

	Mean	SD	95% CRI	$\hat{R}$	Eff size
(Intercept)	1.025	0.094	(0.844, 1.212)	1.004	614
Temperature	-0.739	0.076	(-0.89, -0.594)	1.001	5710
$Temp^2$	-0.837	0.081	(-0.997, -0.678)	1.004	695
Transport	-1.225	0.152	(-1.523, -0.932)	1.002	1502
Temp:Trans	-0.883	0.157	(-1.2, -0.588)	1.002	1571
$Temp^2$:Trans	0.145	0.165	(-0.181, 0.463)	1.002	1265
P (Mcn)	0.975	0.006	(0.963, 0.985)	1	20000
P (Upp)	0.99	0.009	(0.968, 1)	1.002	2422
ϕ (Upp)	0.962	0.032	(0.882, 0.999)	1	5797
Deviance	1840	72.63	(1713.809, 1997.365)	1.002	2211

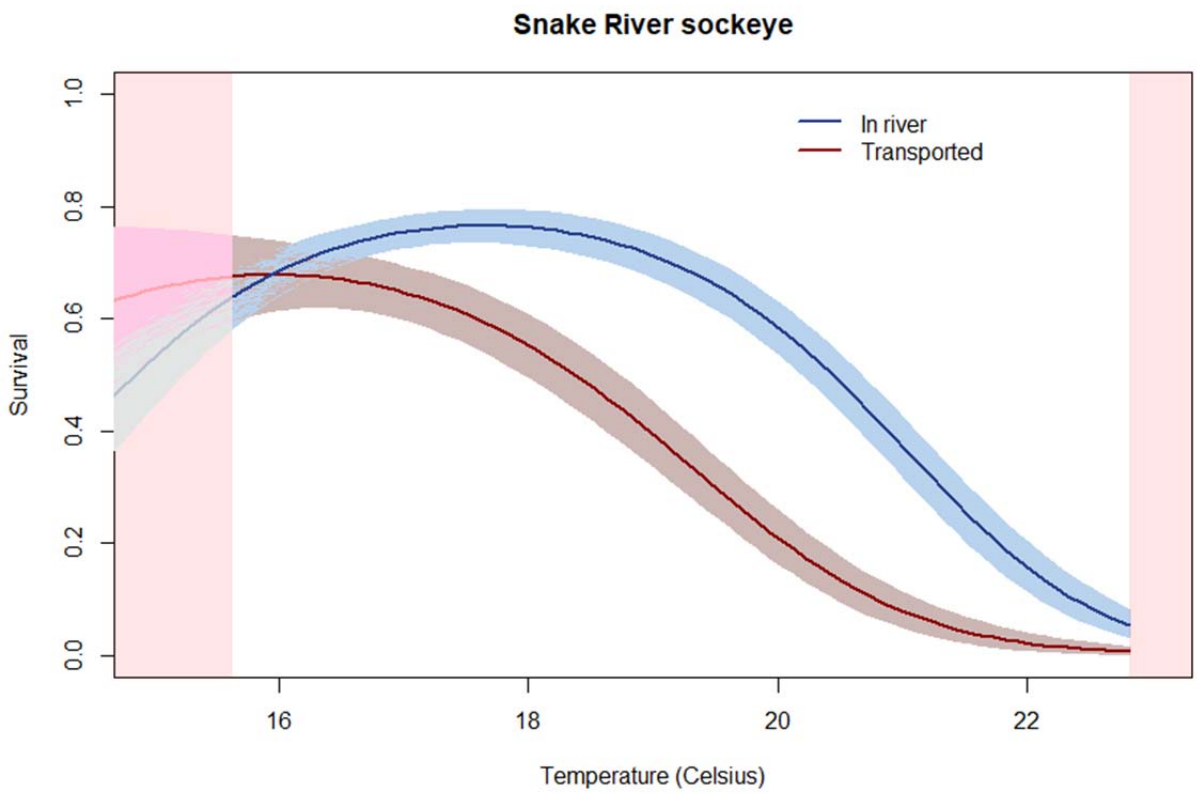

Figure 8.9. We estimate the relationship between survival and temperature using a CJS model with individual covariates in a quadratic form. All available data are used for the fitted relationship, but due to scarce sample sizes at the lower ends of observed temperatures (below 16°C, shaded area), our discussion focuses on observations above the 5th percentile.

Fifty-three percent of Snake River sockeye encountered a water temperature higher than 18°C at Bonneville Dam (Figure 8.10). Excluding earlier years with low counts (2003 to 2010), 2015 had the highest portion (100%) of sockeye arriving at a temperature higher than 18°C, with 2014 the second highest (62%). In-river and transported fish appeared to have arrived at similar times at Bonneville Dam.

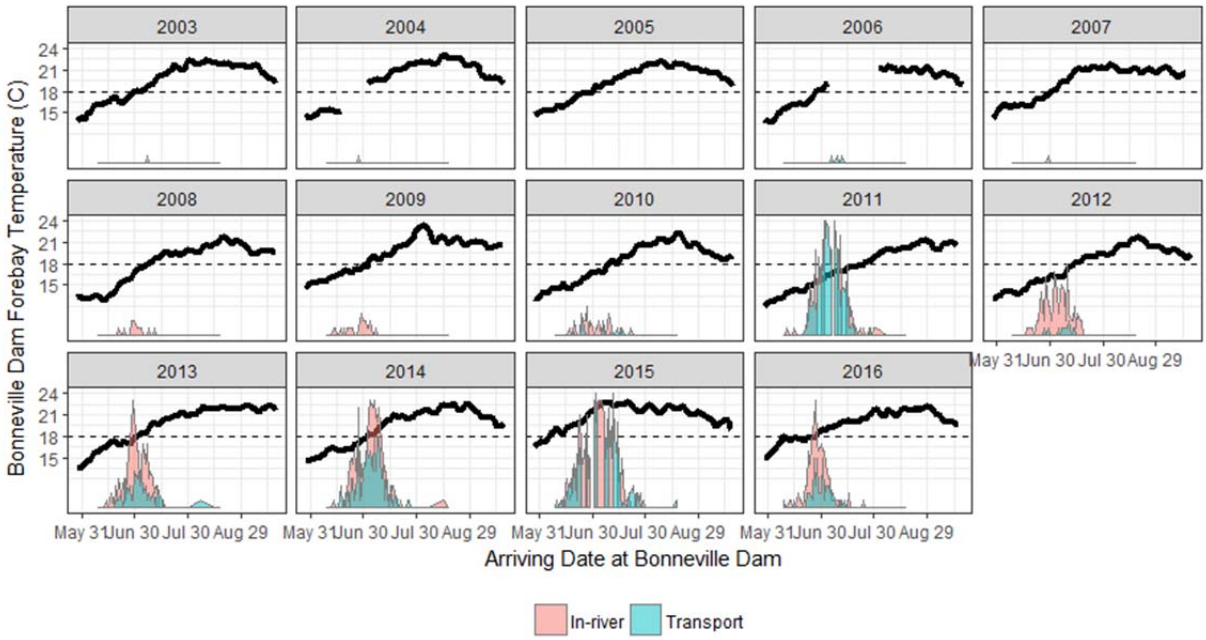

Figure 8.10. Black lines indicate the forebay temperature corresponding to the adult sockeye arrival dates at Bonneville Dam. Below the temperature lines are the distributions of arrival dates for in-river and transported fish.

Snake River Steelhead

Snake River steelhead adults experienced water temperature at Bonneville ranging from 12.8 to 23.5°C. Travel time for the steelhead that were transported as juveniles tends to be longer compared to the in-river fish ($p < 0.01$; Figure 8.11). The pattern showed the travel time increased with water temperature. GAM also showed a similar pattern (Figure 8.12).

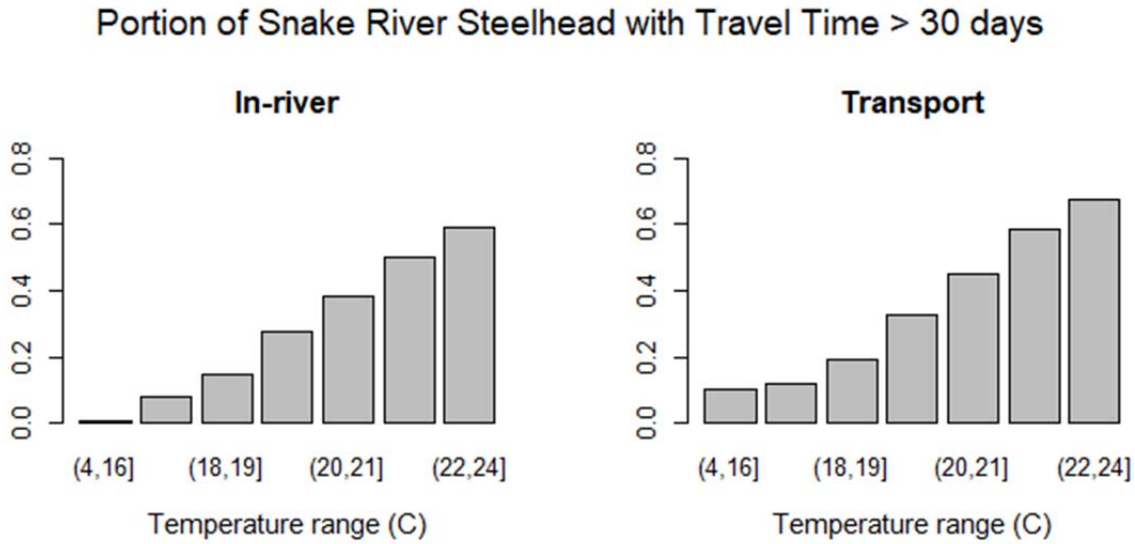

Figure 8.11. Bar chart shows the portion of steelhead with travel time more than 30 days in water temperature ranging from 4 to 24°C.

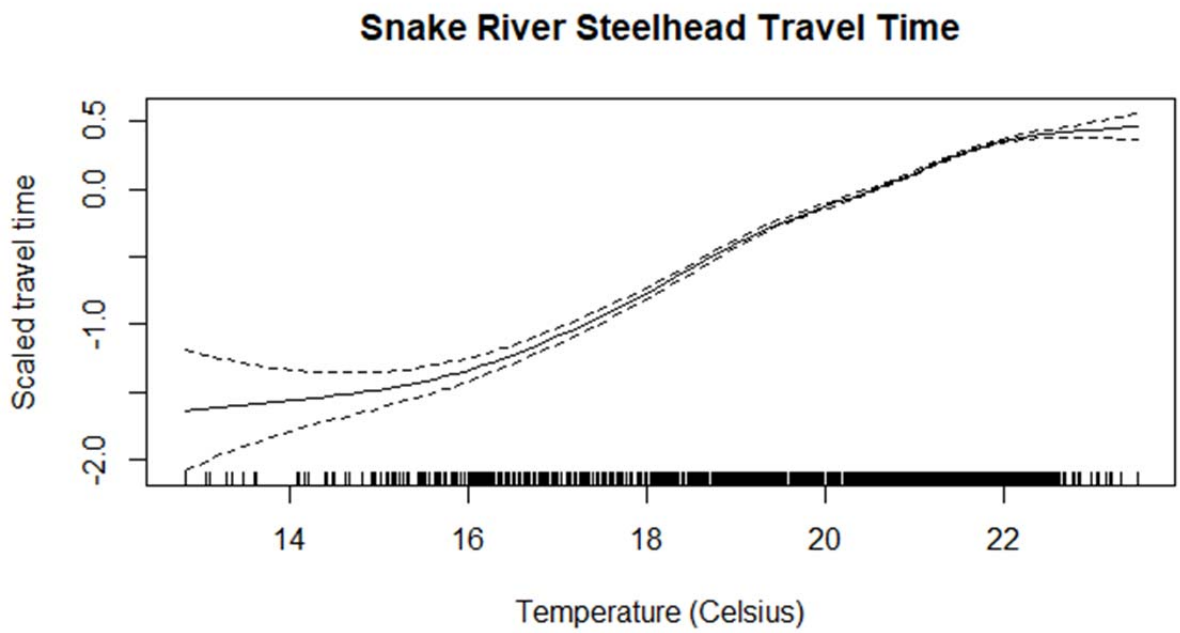

Figure 8.12. GAM shows a nonlinear relationship between travel time and temperature. The model is log(travel time)~ s(temp) + arrival time.

We assessed steelhead survival and water temperature first by fitting a GAM. The model suggested a mostly linear relationship between McNary detection and arrival date (Figure 8.13A). The relationship between detection and temperature was not completely linear. We observed some "bumps" around 18 and 20°C that suggested possible change points (Figure 8.13B).

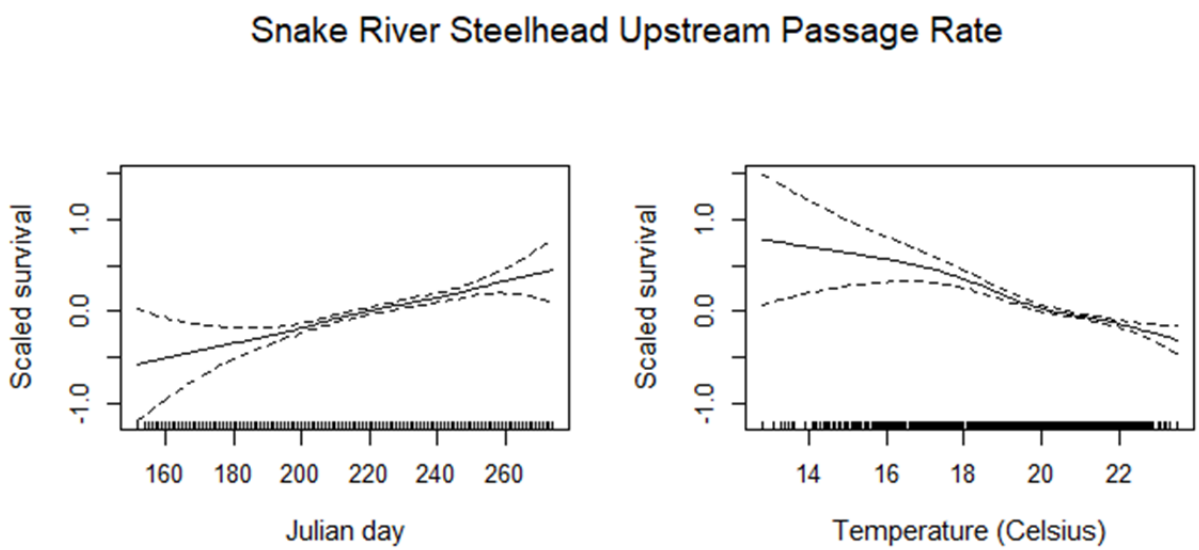

Figure 8.13. A: Left plot shows a positive relationship between survival and arrival date. B: Right plot shows a nonlinear relationship between survival and temperature for steelhead, with a change point around 16°C. The generalized additive model is specified as MCA detection~ s(Temp)+ s(Arrival).

Following the results from GAM, we constructed mixed effects logistic regression models and conducted a selection process. First, to assess the form of temperature-survival relationship, we compared models in linear, piecewise linear, and quadratic forms and found that all models had similar AIC values (Table 8.9). Based on the earlier GAM, and results from a previous analysis (FPC 2016), we used a change point of 18°C for the piecewise linear model. We chose a quadratic model because GAM suggested a possibility of a non-linear survival-temperature relationship.

Table 8.9. Description of models in the selection process and their corresponding AIC value, deviance, and residual degrees of freedom (Residual DF). In the backward stepwise selection process, we started with a full model and proceeded to delete variables one by one until AIC stopped decreasing.

Model	Variables	AIC	Deviance	Residual DF
Piecewise linear	Temp< 18°C, Temp≥ 18°C, Arrival date, Arrival^2, Transport, Temp< 18:Transport, Temp≥ 18:Transport, Arrival:Transport, Arrival^2:Transport, Random individual effects, Random year effects	31772	31752	29622
Linear form	Temperature, Arrival date, Transport, Temp:Transport, Arrival:Transport, Random individual effects, Random year effects	31769	31753	29624
Quadratic (Random individual & year effects)	Temperature, Temp^2, Arrival date, Arrival^2, Transport, Temp:Transport, Temp^2:Transport, Arrival:Transport, Arrival^2:Transport, Random individual effects, Random year effects	31768	31748	29622
Quadratic (Random year effects)	Temperature, Temp^2, Arrival date, Arrival^2, Transport, Temp:Transport, Temp^2:Transport, Arrival:Transport, Arrival^2:Transport, Random year effects	31766	31748	29623
Quadratic (fixed effects only)	Temperature, Temp^2, Arrival date, Arrival^2, Transport, Temp:Transport, Temp^2:Transport, Arrival:Transport, Arrival^2:Transport	31776	31760	29624
Quadratic 1	Temperature, Temp^2, Arrival date, Arrival^2, Transport, Temp:Transport, Temp^2:Transport, Random year effects	31764	31748	29624
Quadratic 2	Temperature, Temp^2, Arrival date, Transport, Temp:Transport, Temp^2:Transport, Random year effects	31856	31842	29625
Quadratic 3	Temperature, Temp^2, Arrival date, Transport, Random year effects	31782	31770	29626

Next, we compared logistic regression models with and without random effects. The model with random year effects had a better model fit according to both AIC values and drop in deviance (Table 8.9). After deciding the random effects were needed, we followed a stepwise procedure to

select variables to be included in the final model. We decided on a final model that included temperature^2, temperature, arrival date, transport history, temperature^2:transport, temperature:transport interactions, and random year effects as the explanatory variables (Quadratic 1, Table 8.9).

After deciding on the final logistic regression model, we estimated the survival-temperature relationship using a CJS model. We followed the same procedures (as for Chinook and sockeye) to construct the detection history for each individual steelhead, that included detection at Bonneville, McNary, and above McNary dams (Ice Harbor and/or Lower Granite). We constructed the individual covariates in the CJS model following the model "Quadratic 1." The results showed a survival of 0.80 (96% CRI= 0.78 to 0.82) from Bonneville to McNary Dam at the mean temperature (20.63°C) and mean arrival date (08/10), and a detection rate at McNary of 0.99 (95% CRI= 0.992 to 0.994). Estimates from the CJS model for Snake River steelhead showed a negative trend in survival for adult steelhead, regardless of transport history. On average, fish that were transported as juveniles have a lower survival compared to in-river fish (Table 8.10, Figure 8.14).

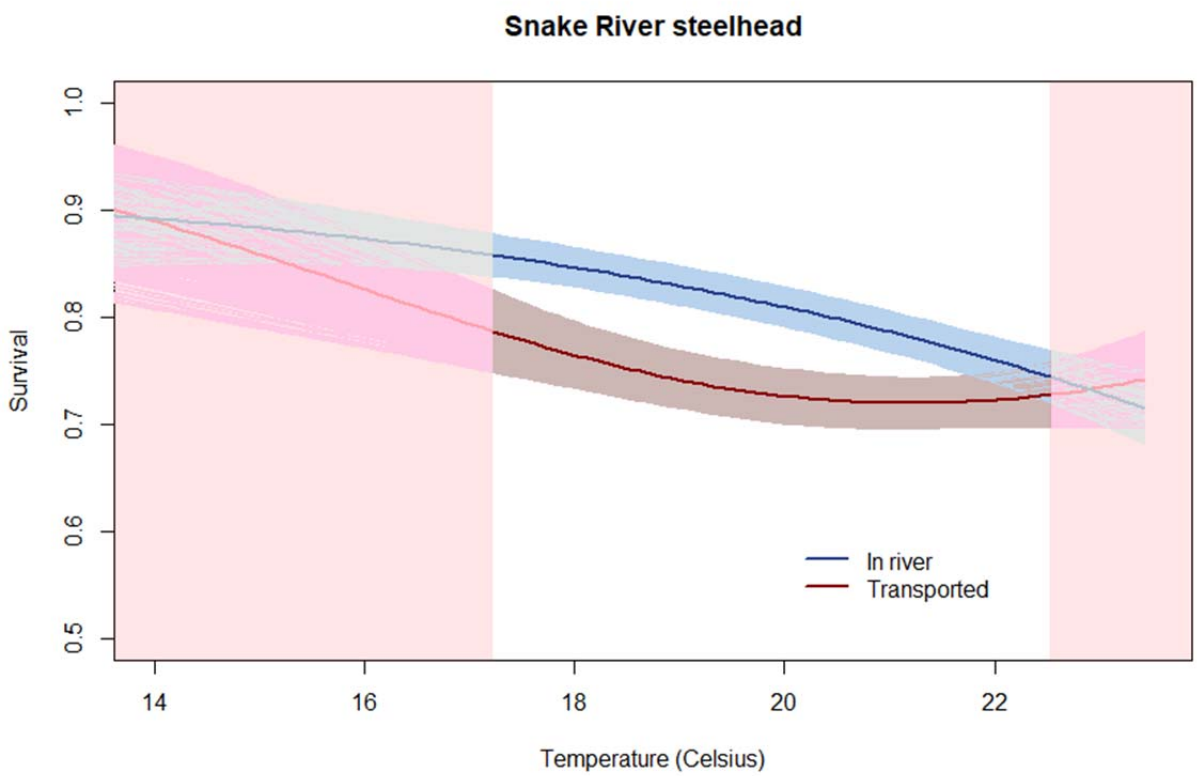

Figure 8.14. We estimate the relationship between survival and temperature using a CJS model with individual covariates in a quadratic form and random year effects. All available data are used for the fitted relationship, but our discussion focuses on the 2.5th to 97.5th percentiles (non-shaded area). Notice the scale of survival is from 0.5 to 1, as opposed to 0 to 1 in previous analyses.

Table 8.10. Estimates from the CJS model for Snake River steelhead show a convex-curved relationship between survival and water temperature (negative coefficient for Temperature^2). On average, fish that were transported as juveniles have a lower survival compared to in-river fish.

	Mean	SD	95% CRI	R-hat	Effective Size
(Intercept)	1.359	0.062	(1.235, 1.481)	1.011	258
Temperature^2	-0.008	0.011	(-0.029, 0.014)	1.002	4926
Temperature	-0.199	0.024	(-0.245, -0.153)	1.002	1892
Transported	-0.408	0.036	(-0.48, -0.337)	1.001	4086
Arrival date	0.17	0.017	(0.137, 0.204)	1	6022
Temp^2:Trans	0.053	0.022	(0.011, 0.095)	1.001	3006
Temp:Trans	0.163	0.037	(0.092, 0.237)	1.002	1226
P (McN)	0.993	0.001	(0.992, 0.994)	1	10000
P (Upp)	1	0	(0.999, 1)	1.006	952
ϕ (Upp)	0.999	0.001	(0.998, 1)	1.003	2841
σ^2	6.907	7.442	(0.007, 23.493)	1	5487
Year2003	0.157	0.083	(-0.018, 0.289)	1.003	970
Year2004	0.188	0.077	(0.012, 0.295)	1.002	1196
Year2005	0.088	0.107	(-0.131, 0.276)	1.002	1195
Year2006	-0.156	0.101	(-0.293, 0.076)	1.001	3063
Year2007	0.121	0.084	(-0.047, 0.274)	1.005	572
Year2008	-0.11	0.082	(-0.266, 0.055)	1.005	677
Year2009	0.032	0.067	(-0.096, 0.164)	1.008	331
Year2010	-0.006	0.071	(-0.146, 0.134)	1.008	349
Year2011	-0.018	0.074	(-0.164, 0.128)	1.008	348
Year2012	-0.018	0.079	(-0.173, 0.136)	1.009	322
Year2013	-0.168	0.069	(-0.287, -0.026)	1.008	328
Year2014	-0.065	0.071	(-0.205, 0.073)	1.01	265
Year2015	0.073	0.076	(-0.072, 0.225)	1.006	451
Deviance	25183	158.9	(24877.856, 25496.565)	1.001	3495

Our data showed that 95% of Snake River steelhead encountered water temperatures higher than 18°C at Bonneville Dam (Figure 8.15). At nearly 100%, return years 2006 and 2015 had the highest portion of PIT-tagged adult steelhead experiencing water temperatures higher than 18°C.

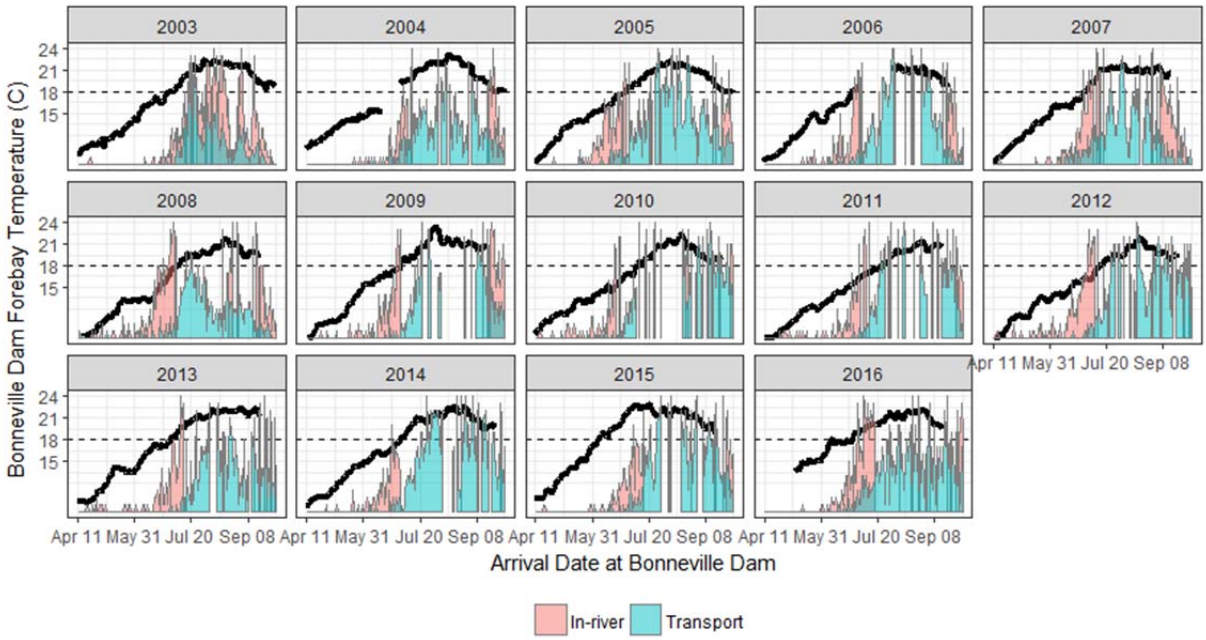

Figure 8.15. Black lines indicate the forebay temperature corresponding to the adult steelhead arrival dates at Bonneville Dam. Below the temperature lines are the distributions of arrival dates for in river and transported fish.

Discussion

Summer Chinook

Our model suggested that both in-river and transport groups showed mostly constant survival at cooler temperature (< 16°C). While the survival of in-river summer Chinook seemed not to response to warming water temperature, the survival for transported summer Chinook showed a steepening decrease after approximately 16 °C (although the evidence was not strong enough to support a nagative relationship).

Our analysis indicated that summer Chinook adults traveled faster when water temperatures increased (Figure 8.2). However, this analysis did not account for fish that did not survive to McNary dam. If slower fish were less likely to survive to McNary (possibly due to longer temperature exposures), they would not have been included in this analysis. Because travel time could only be estimated on survivors in our data, we could not objectively estimate the effects of temperature on travel time in this analysis[1]. Nonetheless, comparison using only successful

[1] In earlier assessments of juvenile salmon and steelhead travel time, the ISAB raised concerns over the known, negative bias in "observed" travel times that occurred because travel times were based only on survivors rather than the full release group, that consisted of observed and unobserved individuals (Tuomikoski et al. 2013, pages G-25 and 26). This issue had been recognized for many years (FPC 1989, page 74). In response to the ISAB concerns, the CSS conducted a simulation analysis that assessed the degree of bias in mean fish travel time for juvenile migrants (Tuomikoski et al. 2013, Appendix J). Those simulations showed that the degree of bias was relatively small for travel times and the survival rates that were typically observed for juveniles. However, when survival was low and/or the travel times were long, the degree of bias could be substantial (e.g., greater than 20%). The CSS had not conducted simulations to examine the degree of bias for adults, but the low adult survival rates in 2015 were in the range where a substantial travel time bias was expected. In the case of sockeye, the travel times were so long in 2015

migrants could still reveal useful information regarding travel time. In our case, we suspected that the travel time might be underestimated, but at least both in-river and transport groups were subjected to the same bias. Therefore, when the objective was to compare the difference, it was still reasonable to only use the survivors.

For the in-river group, summer Chinook survival in our analysis showed no evidence of negative relationship with water temperature compared to the transport group. It was worth noting that the majority of summer Chinook arrived at Bonneville early in the season encountering water temperatures between 11 to 19°C (Figure 8.4). Overall, less than a quarter of the fish experienced temperature greater than 16°C (Figure 8.5). In other words, our data suggested that majority of PIT-tagged adult summer Chinook were not exposed to warm water at Bonneville Dam. Therefore, the lack of a negative survival-temperature relationship did not necessarily mean resilience to warm water temperature for summer Chinook.

Snake River Sockeye

Substantial evidence suggests survival decreases for Snake River sockeye subjected to warm water temperature, regardless of transport history. The majority of PIT-tagged adult sockeye returned when water temperatures exceeded 18°C, and of the three species included in our analyses, sockeye appeared to be the most sensitive to increases in water temperature.

For the in-river sockeye, survival started to drop once water temperature reached approximately 18°C. However, for the transport group, a decreasing survival before water temperature reached 18°C (Figure 8.9) was observed. Similar to summer Chinook, sockeye adults that were transported as juveniles tended to have longer travel times during their adult upstream migration (Figure 8.6). These delays could lead to longer exposure to warm water, diseases, loss of fat reserves, higher vulnerability to harvest, and difficulty negotiating project-specific temperature gradient passage barriers at fishways. The negative effects of increased travel time could manifest themselves through lower survival.

We observed a little over half of the sockeye ascending Bonneville Dam experienced water temperatures over 18°C. In contrast, less than one quarter of later returning summer Chinook Salmon were exposed to these temperatures. We witnessed an extreme example in 2015 where 100% of returning PIT-tagged sockeye experienced water temperature over 18°C at Bonneville dam. The survival for the same year was the lowest on record (FPC, 2015).

Snake River Steelhead

Our analyses of Snake River steelhead suggested that survivals of in-river and transported fish decreased when water temperatures increased, and the survival of transported fish was lower compared to in-river fish (Figure 8.14).

Steelhead adults tended to have longer travel times compared to summer Chinook and Snake River sockeye population. The majority (95%) of steelhead adults ascending Bonneville Dam encountered water temperatures above 18°C. Yet it was unclear from our analysis to what extent of warm temperature exposure for Snake River steelhead. In terms of survival, Snake River steelhead responded less drastically to warm water temperature compared to species such as Snake River sockeye.

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that even the negative bias did not overwhelm the long travel times that were observed. However, the negative bias were likely reflected in the summer Chinook data of 2015.

Conclusions

- All three species in our analyses showed that the survivals for transported fish started to decrease at a lower temperature compared to fish that migrated in-river.
- Summer Chinook that were transported as juveniles had a decreasing upstream migration survival after water temperatures reached around 16°C. However, the evidence was not strong enough to suggest a negative relationship.
- The survival for in-river sockeye started to decrease after water temperatures reached 18°C, while the survival for transported sockeye started to decrease before 18°C. Of the three species included in our analyses, sockeye appear to be the most sensitive to increase in water temperature.
- The survival for in-river steelhead showed a steady decrease as the water temperature increased, and the survival of transported fish was lower at most temperature range compared to in-river fish.
- This analysis reflected the exposure of each marked group to higher water temperatures. Less than 25% of the summer Chinook in this analysis were exposed to water temperatures above 16°C. Fifty-three percent of sockeye were exposed to water temperatures above 18°C in our data. And in 2015, 100% of sockeye were exposed to water temperatures above 18°C. Ninety-five percent of steelhead included in this analysis were exposed to water temperatures above 18°C.
- Transported summer Chinook, Snake River sockeye, and steelhead had longer upstream migration travel time which could result in more exposure to warm water temperatures.

Supplemental Materials A

Summer Chinook CJS model details

We estimated the survival of adult summer Chinook using a CJS model with individual covariates (temperature, temperature^2, transport history, arrival date, arrival^2, temp:transport, and temp^2:transport interaction) and random year effects. We followed a state-space formulation of the CJS model that was introduced by Gimmenz et al. (2007) and Royle (2008). The state-space likelihood approach allows a flexible set up, especially for fitting models with individual covariates and random effects (Kéry & Schaub 2012).

In a state-space model, the adult salmon migration was broken down into two processes: the state process (z) and the observation process (y). The observation process was what we observed in the migration process (i.e. detection history), which was conditioned on the true state (dead or alive) of individual fish. In other words, we would only detect a fish if it was alive, and no fish would be detected if it was dead. Therefore, by incorporating the state process into survival modeling, we could account for fish that were alive but missed by the PIT-tag detectors. We used the following equations to define the state process:

$z_{i,1} = 1$ defined that all fish were to be alive when first detected at Bonneville.

And $z_{i,t}|z_{i,t-1} \sim Bernoulli(z_{i,t-1} \cdot \phi_{i,t-1})$, where t = 2, 3, defined the true state of individual i at occasion t, conditioned on the previous state at occasion $t-1$. If an individual fish was alive between Bonneville and McNary, it could be detected at McNary at occasion t= 2. If an individual was alive above McNary, it could be detected at the upper dams (Ice Harbor and/or Lower Granite) during occasion t= 3. The observation process was what manifested in the detection histories, and it was modeled as:

$y_{i,t}|z_{i,t} \sim Bernoulli(z_{i,t} \cdot p_t)$, where $p_t \overset{iid}{\sim} Unif(0,1)$. p_t were the detection probabilities at McNary (t= 2) and the upper dams (t= 3). The inclusion of the state variable ($z_{i,t}$) ensured that dead individuals would not be detected, and accounted for individuals that were alive but missed by the detectors.

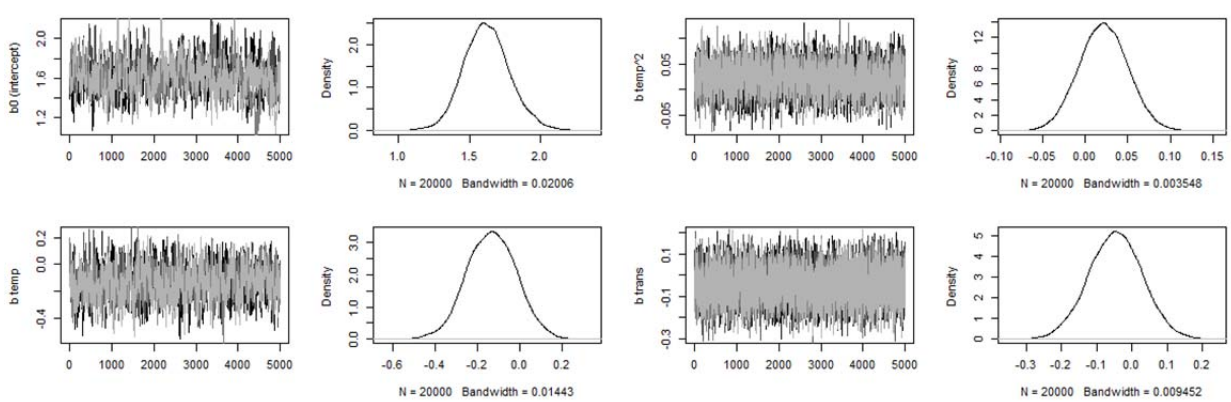
To incorporate the individual covariates and random year effects, we modeled the survival from Bonneville to McNary Dam ($\phi_{i,1}$) using a logit link function:

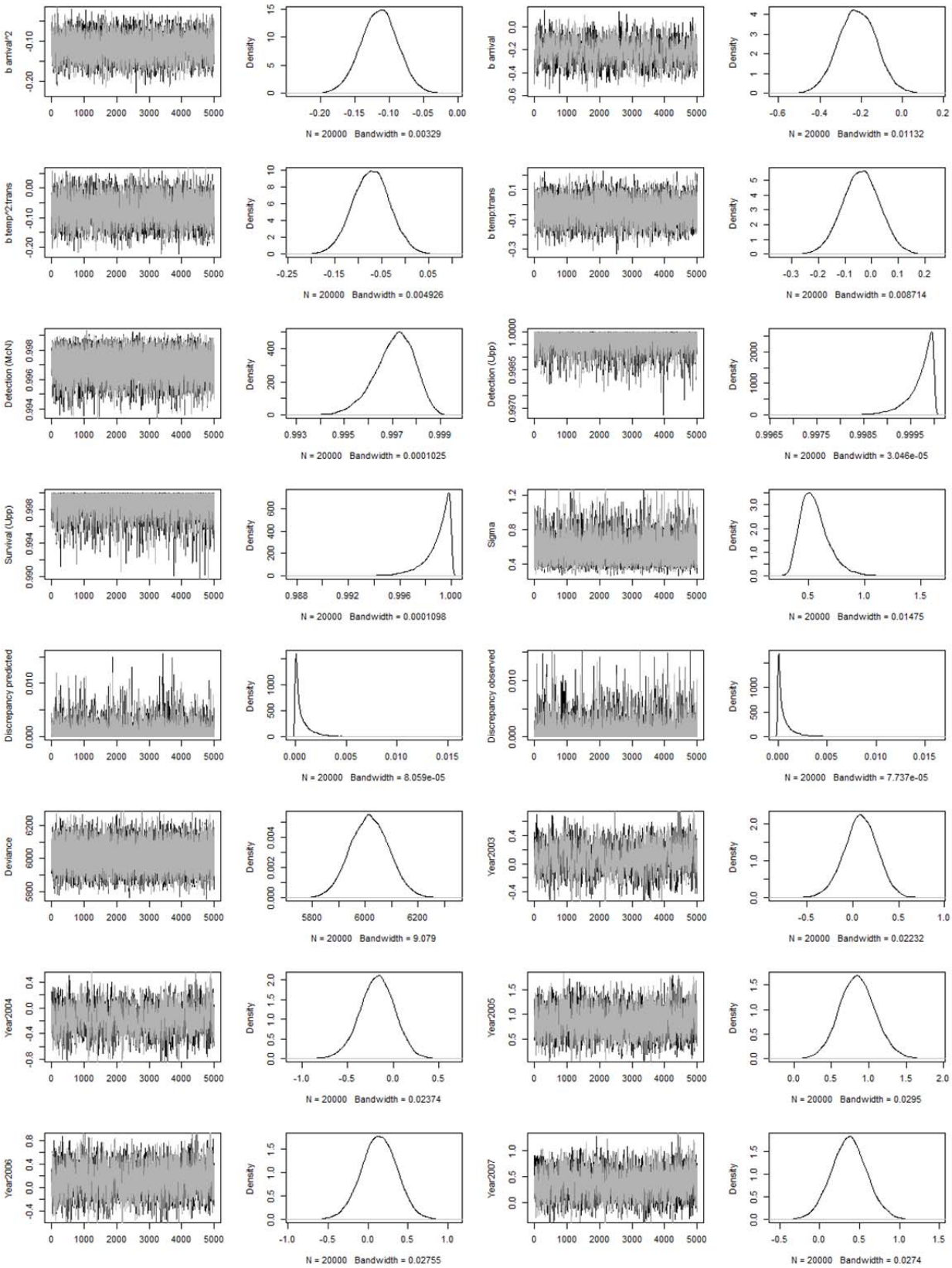
$$logit(\phi_{i,1}) = \beta_0 + \beta_{temp^2} \cdot temp_i^2 + \beta_{temp} \cdot temp_i + \beta_{trans} \cdot trans_i + \beta_{arrival^2} \cdot arrival_i^2 + \beta_{arrival} \cdot arrival_i + \beta_{temp^2:trans} \cdot temp_i^2 \cdot trans_i + \beta_{temp:trans} \cdot temp_i \cdot trans_i + \alpha_{year[i]}.$$

Survival upstream of McNary Dam was not the focus of this analysis (and was confounded with detection upstream of McNary), and we assigned a vague prior distribution: $\phi_{i,2} \sim Unif(0,1)$. We followed the recommendations by Gelman et al. (2008) and Broms et al. (2016) for choosing the prior distributions:

where $\beta_0 \sim Cauchy(0,10)$,
$\beta_{temp^2}, \beta_{temp}, \beta_{trans}, \beta_{arrival^2}, \beta_{arrival}, \beta_{temp^2:trans}$, and $\beta_{temp:trans}, \overset{iid}{\sim} Cauchy(0,2.5)$,
$\alpha_{year[i]} \sim N(0, \sigma_{year}^2)$, year= 2003 to 2016,
and $\sigma_{year} \sim half - Cauchy(0,2.25)$.

To facilitate better model convergence, we standardized all continuous variables. All CJS models in this analysis were fitted in JAGS through an R environment (**`jagsUI`**; Kellner, 2016). The sampling included 4 chains of 20,000 iterations, with burn-in of 10,000 each. To reduce file size, we only kept every other draw of our MCMC sampling (thinning of 2), which yielded a total of 20,000 sample draws from the joint posterior. Gelman's diagnostics showed that all parameters had $\hat{R}$'s close to 1 and adequate effect sizes. Traceplots showed well mixing for all parameters (Figure 8.16). Diagnostics indicated no major concerns overall for model convergence.




b arrival^2
Density
N = 20000 Bandwidth = 0.00329
b arrival
N = 20000 Bandwidth = 0.01132
b temp^2:trans
N = 20000 Bandwidth = 0.004926
b temp:trans
N = 20000 Bandwidth = 0.008714
Detection (McN)
N = 20000 Bandwidth = 0.0001025
Detection (Upp)
N = 20000 Bandwidth = 3.046e-05
Survival (Upp)
N = 20000 Bandwidth = 0.0001098
Sigma
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Discrepancy predicted
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Discrepancy observed
N = 20000 Bandwidth = 7.737e-05
Deviance
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Year2003
N = 20000 Bandwidth = 0.02232
Year2004
N = 20000 Bandwidth = 0.02374
Year2005
N = 20000 Bandwidth = 0.0295
Year2006
N = 20000 Bandwidth = 0.02755
Year2007
N = 20000 Bandwidth = 0.0274

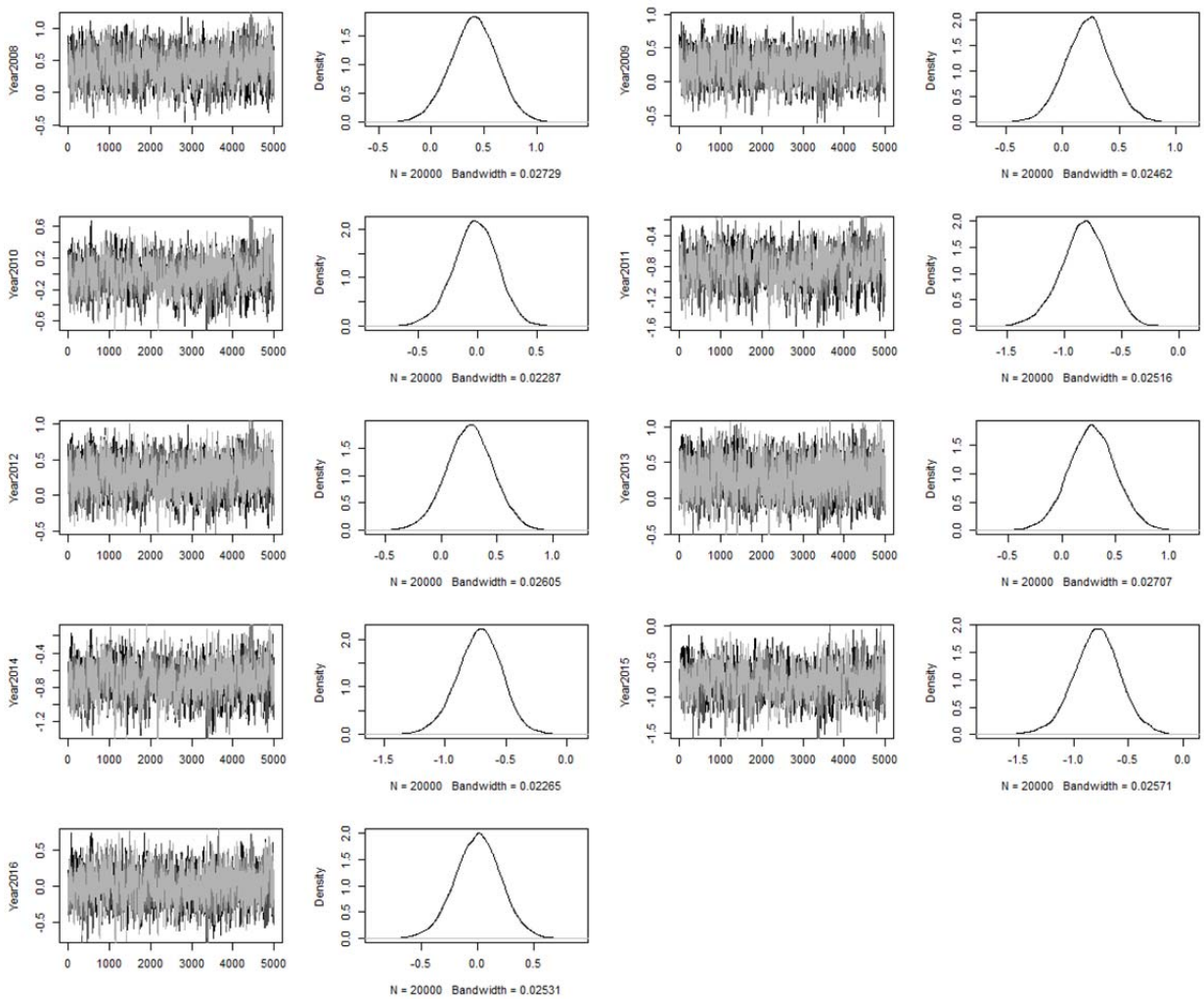


Figure 8.16. Traceplots show well mixing and indicated no major concerns for model convergence.

We modified a procedure described in Kéry & Schaub (2012, p.224) to test the goodness-of-fit (GOF) of our CJS model by comparing predicted and observed values. Mainly, for each MCMC iteration $s = 1, \ldots, S$, we calculated the Freeman-Tukey statistics from ϕ and p associated with each sample i the second detection occasion, $t = 2$ (where the focus of our analysis):

$$D^{(s)} = \{(\mathbf{y}|\boldsymbol{\phi}^{(s)}, \mathbf{P}^{(s)})^{1/2} - (E\mathbf{y}|\boldsymbol{\phi}^{(s)}, \mathbf{P}^{(s)})^{1/2}\}_{t=2}^{2}$$

$$= \{(\sum_{i=1}^{N} \mathbf{y}_{i,2})^{1/2} - (\sum_{i=1}^{N} E\,\mathbf{y}_{i,2})^{1/2}\}^2,$$

and compared it to the statistics for predicted values ($\tilde{\mathbf{y}}$):

$$\widetilde{D}^{(s)} = \{(\sum_{i=1}^{N} \tilde{\mathbf{y}}_{i,2})^{1/2} - (\sum_{i=1}^{N} E\,\tilde{\mathbf{y}}_{i,2})^{1/2}\}^2,$$

where predicted true state and and detection of each individual were sampled every iteration:

$$\tilde{z}_{i,t}^{(s)} \mid \tilde{z}_{i,t-1}^{(s)} \sim Bernoulli(\tilde{z}_{i,t-1}^{(s)} \cdot \phi_{i,t-1}^{(s)})$$

$$\tilde{y}_{i,t}^{(s)} \mid \tilde{z}_{i,t}^{(s)} \sim Bernoulli(\tilde{z}_{i,t}^{(s)} \cdot p_{i,t}^{(s)}).$$

We then obtained an index that was also known as Bayesian *p*-value, by calculating the portion of $\tilde{\mathbf{D}} > \mathbf{D}$. A model that fitted well to the data should have a portion close to 0.5. Our posterior predictive check showed an adequate model fit with a Bayesian *p*-value of 0.504. Figure 8.17 compared replicate and actual discrepancy measures of CJS model for summer Chinook. The Bayesian *p*-value is the portion of points above 1:1 (red) line.

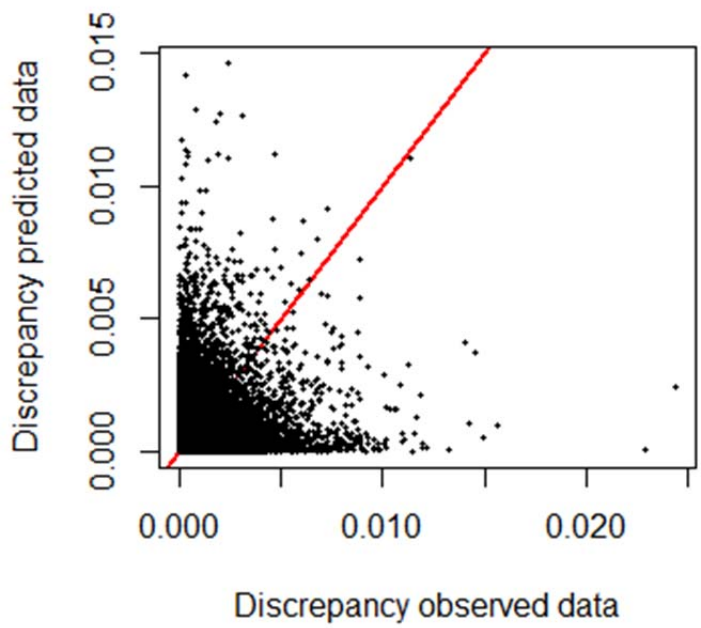


Figure 8.17. Posterior predictive check of CJS model fit by a scatterplot of the discrepancy measure for replicated vs. observed data. Portions of points on either side of the 1:1 (red) line give indications on the fit of the model. An ideal model fit would produce 50-50 portion on either side of the 1:1 line.

Snake River sockeye CJS model details

We estimated the survival of adult sockeye using a CJS model with individual covariates (temperature, temperature^2, transportation history, and their interaction terms). We followed a state-space formulation of the sockeye CJS model, in which the adult salmon migration was broken down into two processes: the state process (*z*) and the observation process (*y*). We used the following equations to define the state process:

$z_{i,1} = 1$ defined that all fish were to be alive when first detected at Bonneville.

And $z_{i,t}|z_{i,t-1} \sim Bernoulli(z_{i,t-1} \cdot \phi_{i,t-1})$, where t = 2, 3, defined the true state of individual i at occasion t, conditioned on the previous state at occasion $t-1$. Detection at McNary occurred at occasion t= 2, and detection above McNary at the upper dams (Ice Harbor and/or Lower

Granite) occurred during occasion t= 3. The observation process was what manifested in the detection histories, and it was modeled as:

$y_{i,t}|z_{i,t} \sim Bernoulli(z_{i,t} \cdot p_t)$, where $p_t \overset{iid}{\sim} Unif(0,1)$. p_t were the detection probabilities at McNary (t= 2) and above McNary (t= 3).

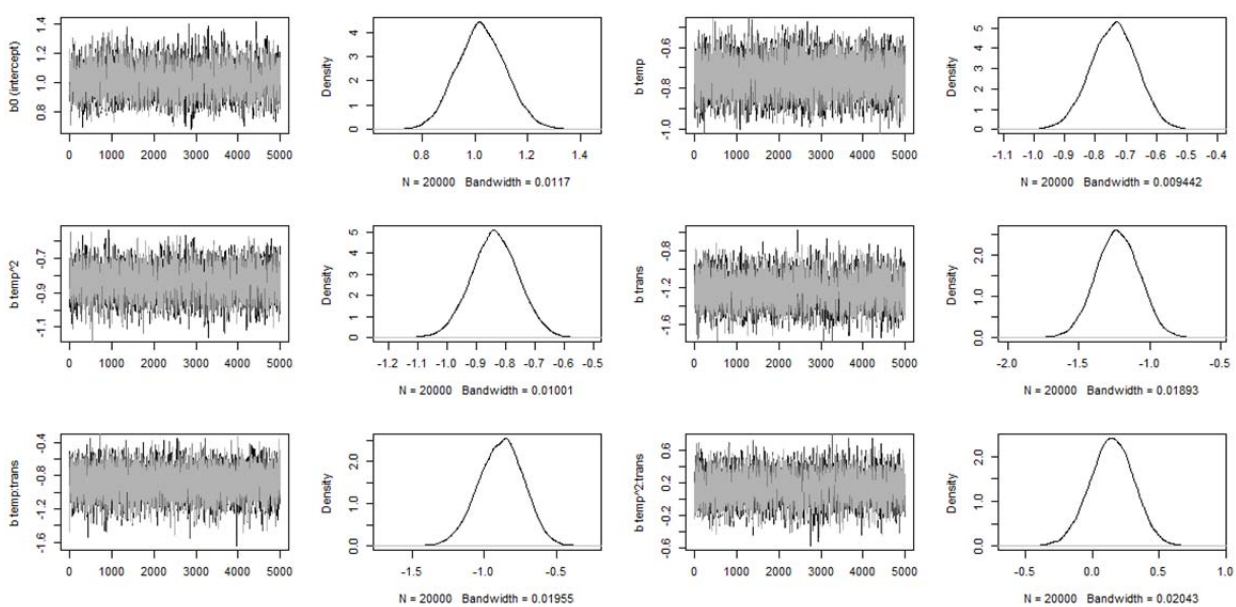
To incorporate the individual covariates, we modeled the survival from Bonneville to McNary Dam ($\phi_{i,1}$) using a logit link function:

$logit(\phi_{i,1}) = \beta_0 + \beta_{temp} \cdot temp_i + \beta_{temp^2} \cdot temp_i^2 + \beta_{trans} \cdot trans_i + \beta_{temp:trans} \cdot temp_i \cdot trans_i + \beta_{temp^2:trans} \cdot temp_i^2 \cdot trans_i$.

And we assigned a vague prior distribution for survival upstream of McNary Dam: $\phi_{i,2} \sim Unif(0,1)$. We followed the recommendations by Gelman et al. (2008) and Broms et al. (2016) for choosing the prior distributions:

where $\beta_0 \sim Cauchy(0,10)$,
and $\beta_{temp}, \beta_{temp^2}, \beta_{trans}, \beta_{temp:trans}$, and $\beta_{temp^2:trans} \overset{iid}{\sim} Cauchy(0,2.5)$,

To facilitate better model convergence, we standardized all continuous variables. The MCMC simulation included 4 chains of 10,000 iterations, with burn-in of 5,000 each and no thinning. The sampling yielded 20,000 total samples from the joint posterior. Gelman's diagnostics showed that $\hat{R}$'s were close to 1, and all parameters had reasonable effect sizes. Traceplots also showed well mixing (Figure 8.18). Overall diagnostics indicated that the sampling were adequately converged. Posterior predictive check showed a decent model fit with a Bayesian *p*-value of 0.506 (closer to 0.5 the better). Figure 8.19 compared replicate and observed discrepancy measures of CJS model for adult sockeye. The Bayesian *p*-value is the portion of points above 1:1 (red) line. We described in details of our posterior predictive check in the summer Chinook section.



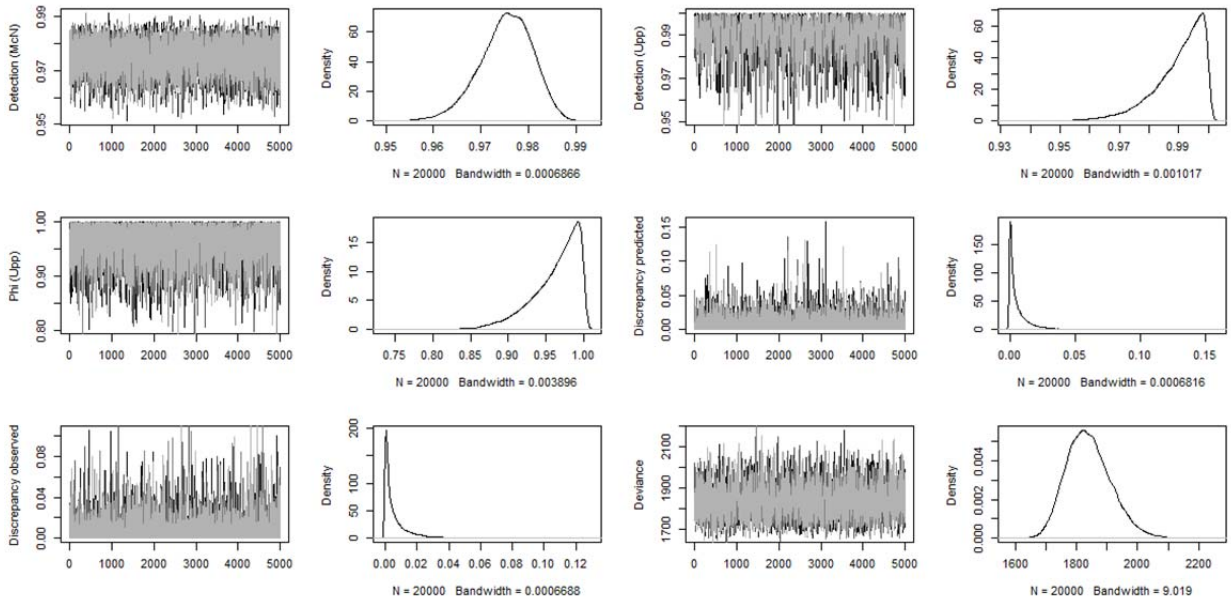


Figure 8.18. Traceplots show well mixing except for σ^2 (variance for individual random effects), which barely reach stationarity. Despite some less than ideal conditions, overall diagnostics indicated that the sampling were adequately converged.

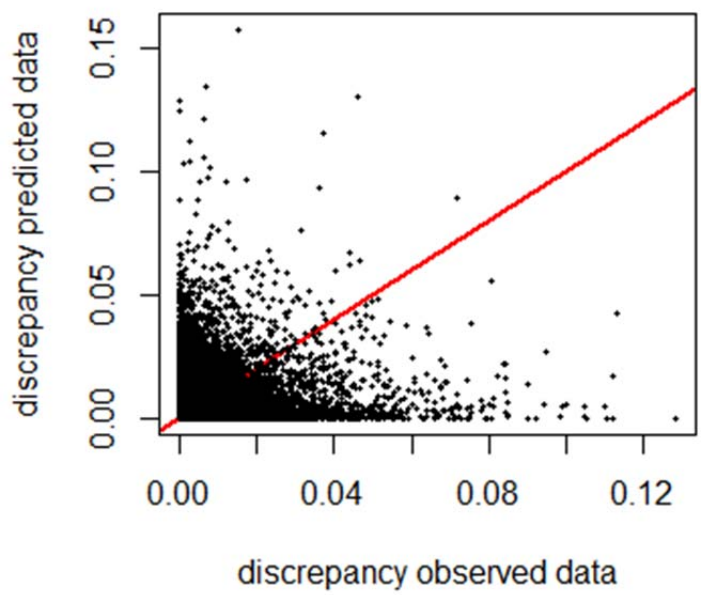


Figure 8.19. Posterior predictive check of CJS model fit by a scatterplot of the discrepancy measure for replicated vs. observed data. Portions of points on either side of the 1:1 (red) line give indications on the fit of the model. An ideal model fit would produce 50-50 portion on either side of the 1:1 line.

Snake River steelhead CJS model details

We estimated the survival of adult steelhead using a CJS model with individual covariates (temperature, temperature^2, transport history, arrival date, arrival^2, temp:transport, and temp^2:transport interaction) and random year effects. We followed a state-space formulation of the CJS model, in which the adult salmon migration was broken down into two processes: the state process (z) and the observation process (y). We used the following equations to define the state process:

$z_{i,1} = 1$ defined that all fish were to be alive when first detected at Bonneville.

And $z_{i,t}|z_{i,t-1} \sim Bernoulli(z_{i,t-1} \cdot \phi_{i,t-1})$, where t = 2, 3, defined the true state of individual i at occasion t, conditioned on the previous state at occasion $t-1$. Detection at McNary occurred at occasion t= 2, and detection above McNary at the upper dams (Ice Harbor and/or Lower Granite) occurred during occasion t= 3. The observation process was what manifested in the detection histories, and it was modeled as:

$y_{i,t}|z_{i,t} \sim Bernoulli(z_{i,t} \cdot p_t)$, where $p_t \overset{iid}{\sim} Unif(0,1)$. p_t were the detection probabilities at McNary (t= 2) and the upper dams (t= 3).

To incorporate the individual covariates and random year effects, we modeled the survival ($\phi_{i,1}$) using a logit link function:

$$logit(\phi_{i,1}) = \beta_0 + \beta_{temp^2} \cdot temp_i^2 + \beta_{temp} \cdot temp_i + \beta_{trans} \cdot trans_i + \beta_{arrival^2} \cdot arrival_i^2 + \beta_{arrival} \cdot arrival_i + \beta_{temp^2:trans} \cdot temp_i^2 \cdot trans_i + \beta_{temp:trans} \cdot temp_i \cdot trans_i + \alpha_{year[i]},$$

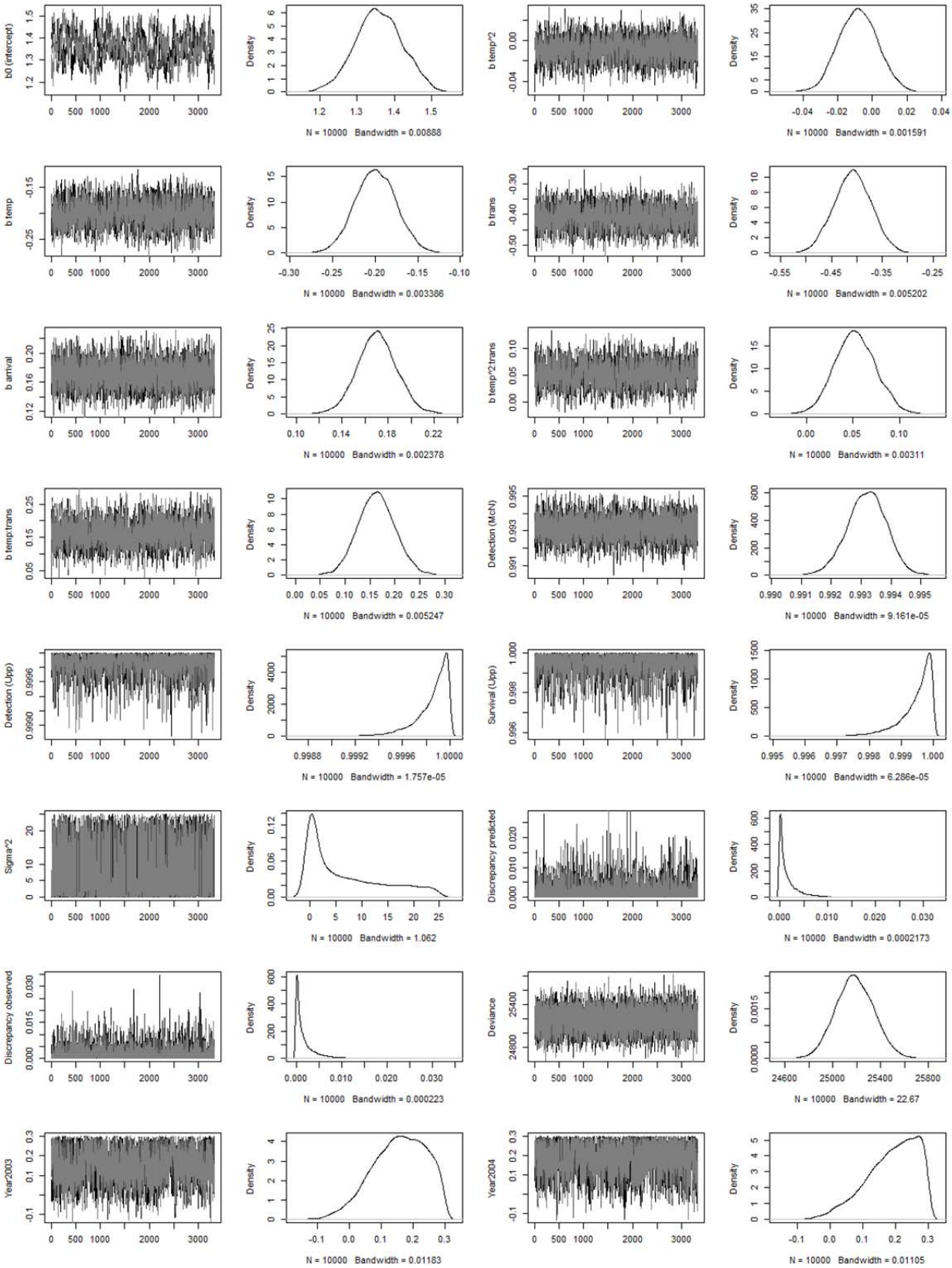
where $\beta_0, \beta_{temp^2}, \beta_{temp}, \beta_{trans}, \beta_{arrival^2}, \beta_{arrival}, \beta_{temp^2:trans}$, and $\beta_{temp:trans}, \overset{iid}{\sim} N(0,1000)$,

$\alpha_{year[i]} \sim N(0, \sigma_{year}^2)$, year= 2003 to 2015,

and $\sigma_{year} \sim Unif(0,5)$.

And we assigned a vague prior distribution for survival upstream of McNary Dam: $\phi_{i,2} \sim Unif(0,1)$.

To facilitate better model convergence, we standardized all continuous variables. The MCMC simulation included 4 chains of 4,000 iterations, with burn-in of 1,500 each and no thinning. The sampling yielded 10,000 total samples from the joint posterior. Gelman's diagnostics showed that $\hat{R}$'s were all close to 1, and all parameters had adequate effect sizes. Traceplots showed well mixing (Figure 8.20), and overall diagnostics indicated no major concerns for model convergence. Posterior predictive check showed an adequate model fit with a Bayesian p-value of 0.499 (closer to 0.5 the better). Figure 8.21 compared replicate and actual discrepancy measures of CJS model for Snake River steelhead. The Bayesian p-value is the portion of points above 1:1 (red) line. We described in details of our posterior predictive check in the summer Chinook section.


b0 (intercept)
Density
N = 10000 Bandwidth = 0.00888
b temp^2
N = 10000 Bandwidth = 0.001591
b temp
N = 10000 Bandwidth = 0.003386
b trans
N = 10000 Bandwidth = 0.005202
b arrival
N = 10000 Bandwidth = 0.002378
b temp^2:trans
N = 10000 Bandwidth = 0.00311
b temp:trans
N = 10000 Bandwidth = 0.005247
Detection (McH)
N = 10000 Bandwidth = 9.161e-05
Detection (Upp)
N = 10000 Bandwidth = 1.757e-05
Survival (Upp)
N = 10000 Bandwidth = 6.286e-05
Sigma^2
N = 10000 Bandwidth = 1.062
Discrepancy predicted
N = 10000 Bandwidth = 0.0002173
Discrepancy observed
N = 10000 Bandwidth = 0.000223
Deviance
N = 10000 Bandwidth = 22.67
Year2003
N = 10000 Bandwidth = 0.01183
Year2004
N = 10000 Bandwidth = 0.01105

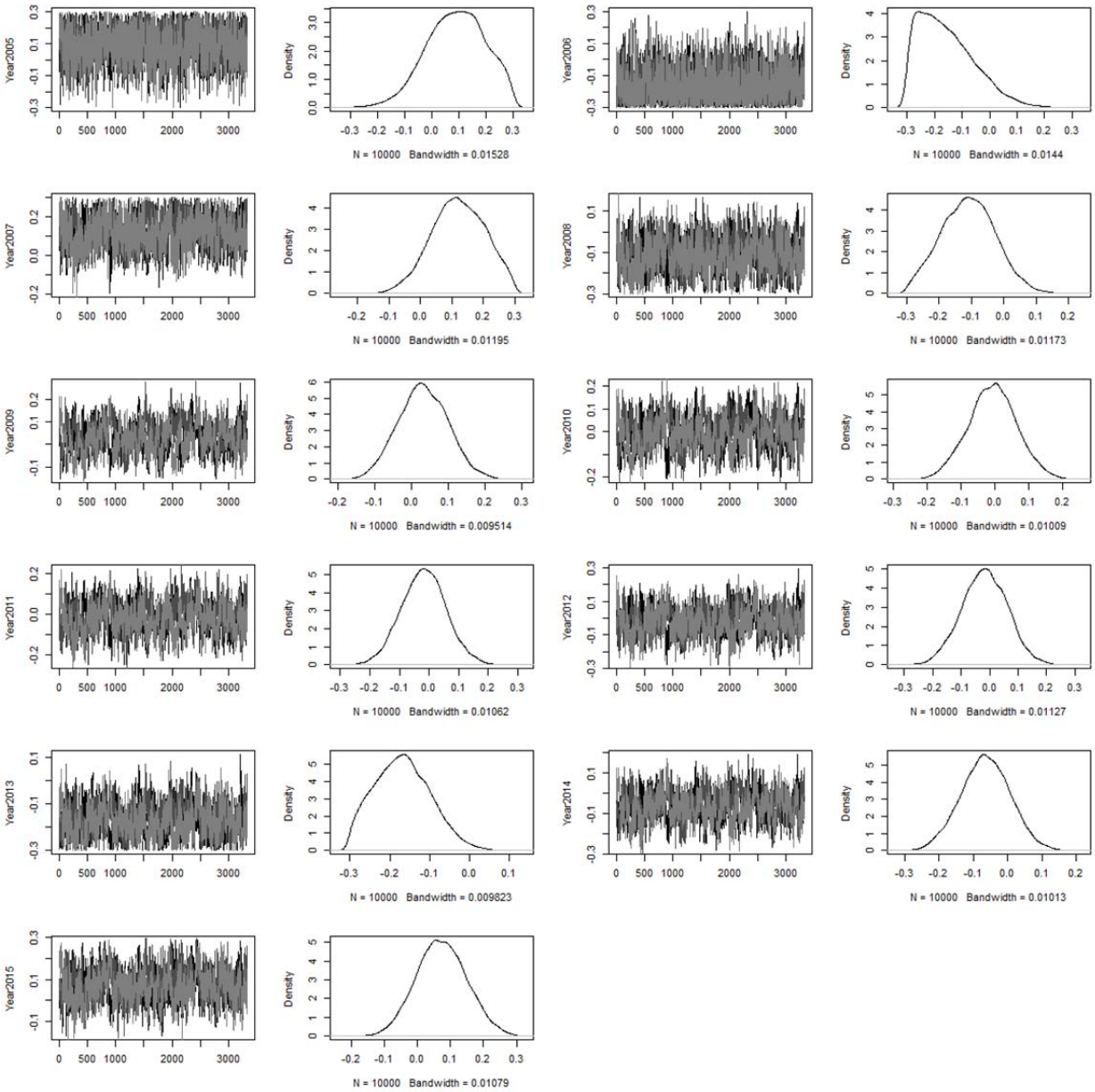


Figure 8.20. Traceplots show well mixing, and overall diagnostics indicated that the sampling were adequately converged.

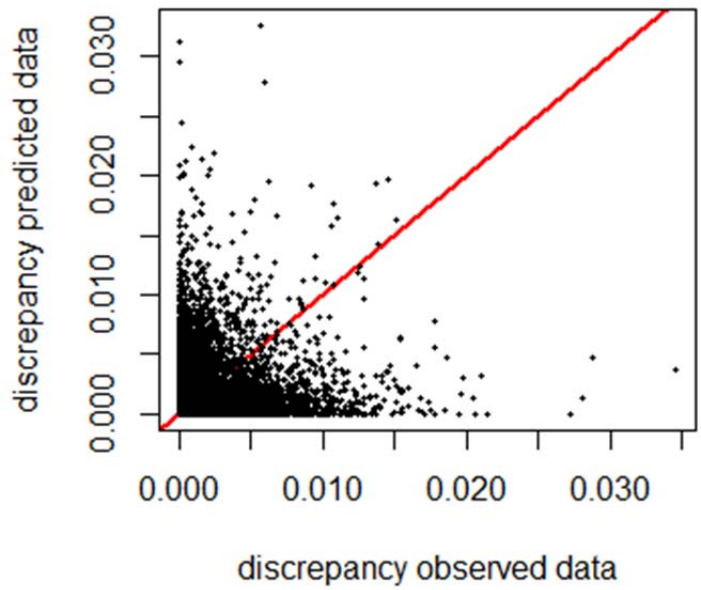


Figure 8.21. Posterior predictive check of CJS model fit by a scatterplot of the discrepancy measure for replicated vs. observed data. Portions of points on either side of the 1:1 (red) line give indications on the fit of the model. An ideal model fit would produce 50-50 portion on either side of the 1:1 line.

Supplemental Materials B

Collinearity between water temperature and arrival date

Summer Chinook

We examined collinearity between variables in our final GLMM model using correlation and variance inflation factor (VIF). The Pearson's correlation = 0.73, and VIF's for temperature and arrival date were 10.02 and 8.65, respectively. Zuur et al. (2010) suggested a cut-off VIF value of 5 to indicate collinear variables, which our VIF's certainly exceeded.

One of the major problems associated with collinearity was that variance estimates could be inflated. The consequence was getting an overly large *p*-value that make an effect difficult to detect, and it might potentially lead to a wrong inference (Zuur et al. 2010). To examine the potential impacts of collinearity in our model, we compared GLMM's with and without arrival date. The results showed some changes in the estimates for temperature^2 and temperature (Table 8.11); however, even with the changes in estimates, our overall conclusions for summer Chinook was the same. Because, the initial purpose of our analysis was not to predict survival rate using water temperature, collinearity did not seem to affect our conclusions for survival-temperature relationship. Also, excluding arrive date might overlook seasonal shifts that overlap with predators, prey, competition, and/or fishery harvest, especially model selection indicated it as an important variable. Therefore, we decided that keeping arrival date in the model outweighed the problems caused by collinearity.

Table 8.11. Estimates output from models with arrival date (top) and without arrival date (bottom).

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	1.614	0.1368	11.8	0.00001
Temperature^2	0.01465	0.02848	0.5143	0.607
Temperature	-0.1185	0.1148	-1.031	0.3023
Transport History	-0.1126	0.02647	-4.256	0.00002081
Arrival Date^2	-0.2203	0.09007	-2.446	0.01444
Arrival Date	-0.05548	0.0758	-0.732	0.4642
Temperature^2:Transport	-0.06561	0.03932	-1.668	0.09525
Temperature:Transport	-0.04423	0.06928	-0.6384	0.5232

	Estimate	Std. Error	z value	Pr(>|z|)
(Intercept)	1.544	0.1345	11.47	0.00001
Temperature^2	-0.03277	0.02296	-1.428	0.1534
Temperature	-0.3418	0.04679	-7.305	0.00001
Transport History	-0.05375	0.07572	-0.7099	0.4777
Temperature^2:Transport	-0.06952	0.04032	-1.724	0.08467
Temperature:Transport	-0.0577	0.07037	-0.8199	0.4122

Snake River Sockeye

Model selection process indicated that arrival date did not contribute significantly to the model fit, so it was excluded from the final model.

Snake River Steelhead

We examined collinearity between variables in our final GLMM model using correlation and VIF. The Pearson's correlation = 0.39, and VIF for temperature and arrival date were high at 1.97 and 1.33, respectively. Our results showed our steelhead model was not severely impacted by collinearity.

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APPENDIX A

SURVIVALS (SR), SAR, TIR, AND D FOR SNAKE RIVER HATCHERY AND WILD SPRING/SUMMER CHINOOK SALMON, STEELHEAD, AND SOCKEYE

APPENDIX A

SURVIVALS (S_R), SAR BY STUDY CATEGORY, TIR, AND *D* FOR SNAKE RIVER HATCHERY AND WILD SPRING/SUMMER CHINOOK, STEELHEAD, SOCKEYE, AND FALL CHINOOK

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APPENDIX A

SURVIVALS (S_R), SAR BY STUDY CATEGORY, TIR, AND *D* FOR SNAKE RIVER HATCHERY AND WILD SPRING/SUMMER CHINOOK, STEELHEAD, SOCKEYE, AND FALL CHINOOK

Introduction

This appendix presents juvenile in-river survival (termed S_R) from LGR tailrace to BON tailrace for PIT-tagged Snake River wild and hatchery spring/summer Chinook, hatchery and wild subyearling fall Chinook, steelhead, and sockeye smolts analyzed in the CSS. Prior to the 2012 report, these juvenile survival data were presented in Chapter 2. In addition, this appendix presents smolt-to-adult survival (SAR) probability estimates (by study category) for Snake River PIT-tagged spring/summer Chinook, fall Chinook, summer steelhead, and sockeye smolts analyzed in the CSS. Prior to the 2012 report, the SARs, TIR, and *D* data were presented in Chapter 4. Parameters estimated in this appendix include (i) S_R (annual in-river survival from LGR tailrace to BON tailrace), (ii) annual SAR from LGR to GRA (LGR's adult ladder) by study category (transported smolts [T_0 or T_X beginning 2006], in-river migrants not detected at a Snake River transportation site [C_0], and in-river migrants with at least one detection at a Snake River transportation site [C_1]), (iii) TIR (ratio of SAR of transported and SAR of C_0 migrants), and (iv) *D* (ratio of post-Bonneville transported SAR and SAR of C_0 migrants). In-river survival (S_R) estimates are provided for PIT-tagged Snake River wild spring/summer Chinook (1994–2016), hatchery spring/summer Chinook (1997–2016), wild steelhead (1997-2016), hatchery steelhead (1997–2016), hatchery sockeye (2009–2016), and wild and hatchery subyearling fall Chinook (2006-2012 and 2015-2016). Annual SARs, TIR, and *D* values are estimated for PIT-tagged wild spring/summer Chinook (1994–2015), hatchery spring/summer Chinook (1997–2015), wild and hatchery steelhead (1997–2014), hatchery sockeye (2009–2015), and wild and hatchery subyearling fall Chinook (2006-2012). A primary focus of comparisons (SARs, TIR, and *D*) is between the transported and in-river smolt migrants.

The S_R, SAR, TIR, and *D* parameter estimates are presented in tables and figures within this appendix and are available from the FPC Web site (www.fpc.org). Data on the PIT-tag numbers by release site and PIT-tag returning adult age composition are also available from the FPC Web site and in Appendices C and F of this report, respectively. The data on the juvenile migrant reach survival probabilities (used to expand PIT-tag smolt counts in the three study categories to LGR equivalents for each migration year) and estimated numbers of smolts (and associated returning adults) in the CSS study categories are available only from the FPC Web site. These two series of data have become voluminous and difficult to present in report appendices, but are easily accessible from the FPC Web site in downloadable formats amenable to analyses by interested users. The FPC Web site is updated with these data after the final report is issued. These data are accessed from the FPC Web site homepage as follows:

(i) Click on "SURVIVAL & TRAVEL TIMES," then "JUVENILES" to access:

a. "CSS Number of Fish by Site" – provides PIT-tag numbers by release site for juvenile data above and smolt-to-adult data below.

b. "CSS Reach Survival Data" – provides survival rate estimates for individual reaches.

c. "CSS S_R, TIR, and D" – provides estimate S_R for LGR-to-BON reach survival rate.

(ii) Click on "SURVIVAL & TRAVEL TIMES," then "SMOLT-TO-ADULT" to access:

a. "CSS SARs by study category" – provides data for T_0 (or T_X), C_0, and C_1 by juvenile year and release.

b. "CSS Annual SARs for Zones in the Snake and Columbia Rivers" – provides annual overall SARs for all groups of Snake, Middle Columbia, and Upper Columbia Chinook, steelhead, and sockeye.

c. "CSS SR, TIR, and D" – provides estimated TIR and *D* by juvenile year and release.

d. "CSS Ten Year Report Results and Expectations" – allows user to query the results and expectations data presented in Appendix E of the CSS Ten Year Report.

e. "CSS Returning Adults Age Composition" – provides number of returning adults for PIT-tagged fish by juvenile year, release, and age.

f. "Number of Smolts and Returning Adults by Study Category" – provides data for T_0 (or T_X), C_0, and C_1 by juvenile year and release.

Methods

Estimation of juvenile in-river survival (S_R)

In this appendix, we define the hydrosystem as the overall reach between Lower Granite (LGR) and Bonneville (BON) dams. There are six dams between LGR and BON: Little Goose (LGS), Lower Monumental (LMN), Ice Harbor (IHR), McNary (MCN), John Day (JDA), and The Dalles (TDA). We used Cormack-Jolly-Seber (CJS) methods to estimate survival probabilities through the two reaches based on detections at the dams and in a PIT-tag trawl (TWX) operating below BON (Cormack 1964, Jolly 1965, Seber 1965, Burnham et al. 1987).

The array of detection sites in the Snake and Columbia rivers is analogous to multiple recaptures of tagged individuals, allowing for standard multiple mark-recapture survival estimates over several reaches of the hydrosystem using the CJS method. This method was used to obtain estimates of survival and corresponding standard errors for up to six reaches between release site and tailrace of BON (survival estimates S_1 through S_6). An overall survival probability from LGR-to-BON, referred to as S_R is the product of the reach survival estimates. Estimates of individual reach survival (e.g., LGR-to-LGS) can exceed 100%; however, this is often associated with an underestimate of survival in preceding or subsequent reaches. Therefore, when computing a multi-reach survival estimate, we allow individual reach survival

estimates to exceed 100%. An estimate of S_R was considered unreliable when its point estimate exceeded 100% or its coefficient of variation exceeded 25%.

The number of inter-dam reaches for which an annual survival could be estimated was a function of the number of smolts in each release and the recovery effort available. When fewer than six individual reach survival estimates could be made, the product of the useable estimates was extrapolated to estimate S_R. Prior to 1998, PIT-tag detection capability at JDA and TWX was limited. Reliable survival estimates in those years were possible only to the tailrace of LMN or MCN. After 1998, reliable survival estimates to the tailrace of JDA were possible in most cases. Estimation of S_R with fewer than six individual independent estimates was calculated as follows: first, the product of the survival estimates over the longest reach possible was converted to survival per mile, and then this was expanded to the number of miles between LGR and BON. However, because survival per mile rates thus generated were generally lower for the Snake River (LGR to MCN) than for the Columbia River (MCN to BON), direct estimates of in-river survival over the longest reach possible were preferable. For all groups, we provide nonparametric bootstrap confidence intervals for the closed form CJS estimators of juvenile reach survival.

Estimation of smolt numbers in study categories

Comparisons between SARs for groups of smolts with different hydrosystem experiences are made from a common start and end point. Thus, LGR-to-GRA SARs were estimated for all groups of smolts including those not detected at LGR as juveniles. The population of PIT-tagged study fish arriving at LGR was partitioned into three pathways related to the route of subsequent passage through the hydrosystem. Fish were "destined" to (1) pass in-river through the Snake River collector dams in a non-bypass channel route (spillways or turbines), (2) pass in-river through the dam's bypass channel, or (3) pass in a truck or barge to below BON. These three routes of hydrosystem passage defined the study categories C_0, C_1 and T_0 (or T_X beginning 2006), respectively.

The Snake River basin fish used in SAR estimation were PIT-tagged and released in tributaries and mainstem locations upstream from LGR reservoir. Other investigators (Sanford and Smith 2002; Paulsen and Fisher 2005; Budy and Schaller 2007) have used detection information from smolts released both above LGR and at LGR for their estimates of SARs. Because all Snake River spring/summer Chinook, steelhead, and sockeye juveniles must pass through the LGR reservoir, we believe that smolts released upstream from LGR most closely reflect the impacts of the Lower Snake and Columbia River hydrosystem on the untagged run at large in-river migrating fish. The C_0 group may include only smolts released above LGR, since it is defined as those fish that remained in-river while migrating past the three Snake River collector dams undetected. Fish collected and marked at LGR do not have a similar experience.

Symbol Definitions

<u>Symbols for Primary Statistics</u>

R_1 = number of PIT-tagged fish released
X_{12} = number of smolts transported at LGR
X_{102} = number of first-detected smolts transported at LGS
X_{112} = number of LGR bypassed smolts transported at LGS

X_{1002} = number of first-detected smolts transported at LMN
X_{1102} = number of LGR bypassed smolts transported at LMN
X_{1012} = number of LGS bypassed smolts transported at LMN
X_{1112} = number of both LGR and LGS bypassed smolts transported at LMN
X_{1a2} = number of smolts transported at LGS where "a" codes to 1 if detected and 0 if undetected
X_{1aa2} = number of smolts transported at LMN where "a" codes to 1 if detected and 0 if undetected

m_{12} = number of fish first detected at LGR
m_{13} = number of fish first detected at LGS
m_{14} = number of fish first detected at LMN

d_2 = number of fish removed at LGR (includes all transported fish, site-specific mortalities, unknown disposition fish, and fish removed for use by other research studies)
d_3 = number of fish removed at LGS (includes all transported fish, site-specific mortalities, unknown disposition fish, and fish removed for use by other research studies)
d_4 = number of fish removed at LMN (includes all transported fish, site-specific mortalities, unknown disposition fish, and fish removed for use by other research studies)

$d_{5.0}$ = number of removals for C_0 type fish at MCN
$d_{6.0}$ = number of removals for C_0 type fish at JDA
$d_{7.0}$ = number of removals for C_0 type fish at BON

$d_{5.1}$ = number of removals for C_1 type fish at MCN
$d_{6.1}$ = number of removals for C_1 type fish at JDA
$d_{7.1}$ = number of removals for C_1 type fish at BON

Symbols for Primary Parameters

d_{C0} = Sum of site-specific removals at dams below LMN of fish not detected previously at a Snake River Dam estimated in LGR-equivalents.

Note: Pre-2003 uses fixed expansion rate of 50% survival probability for all removals below LMN. Beginning with migration year 2003, d_{C0} contains site-specific removals below that have been expanded by their corresponding estimated survival probability from LGR.

d_{C1} = Sum of site-specific removals at dams below LMN of fish previously detected at a Snake River Dam estimated in LGR-equivalents.

Note: Pre-2003 uses fixed expansion rate of 50% survival probability for all removals below LMN. Beginning with migration year 2003, d_{C1} contains site-specific removals below that have been expanded by their corresponding estimated survival probability from LGR.

S_1 = survival from hatchery release site to LGR tailrace
S_2 = survival from LGR tailrace to LGS tailrace

S_3 = survival from LGS tailrace to LMN tailrace
S_4 = survival from LMN tailrace to MCN tailrace
S_5 = survival from MCN tailrace to JDA tailrace
S_6 = survival from JDA tailrace to BON tailrace

P_2 = detection probability at LGR
P_3 = detection probability at LGS
P_4 = detection probability at LMN
P_5 = detection probability at MCN
P_6 = detection probability at JDA
P_7 = detection probability at BON

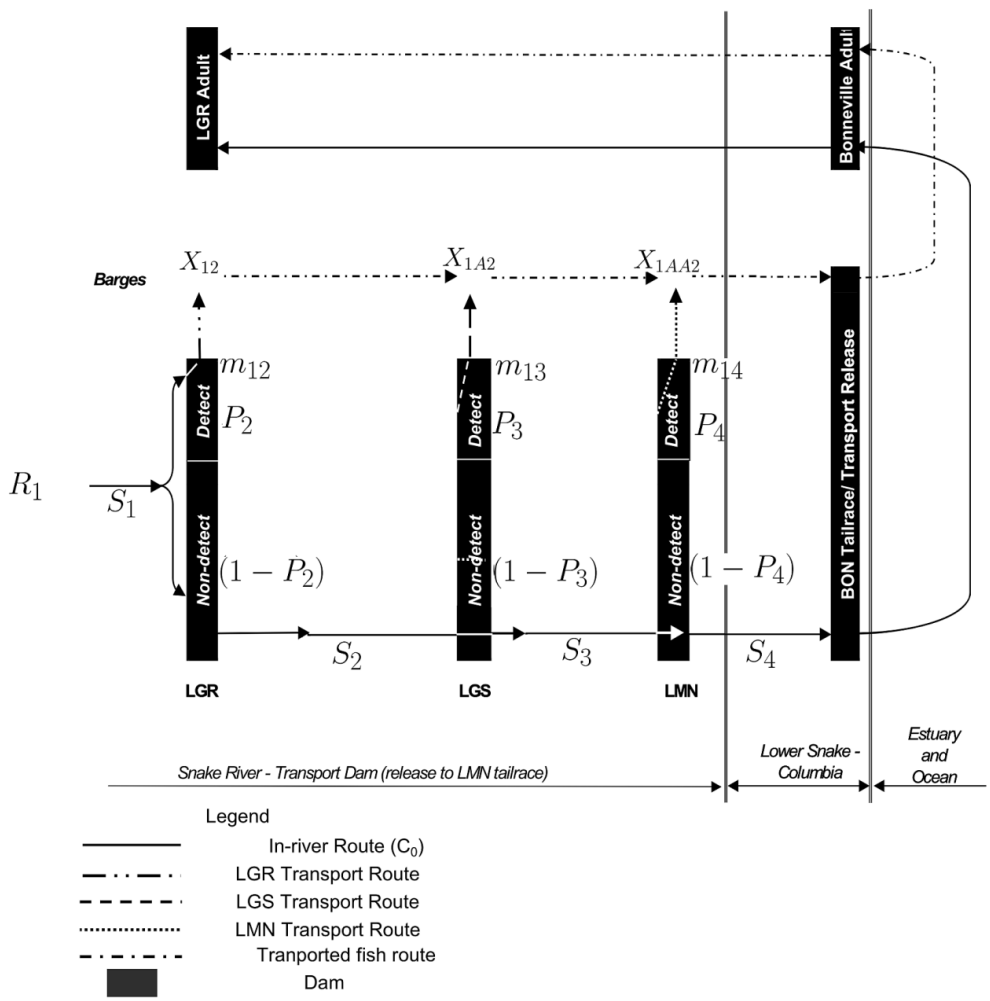

Figure A.1. Schematic of the Lower Snake and Columbia River system with focus on the three transport sites and estimation methods after migration year 2006. Locations for some primary statistics and parameters are shown.

Pre-2006 migration years

The PIT-tagged study groups should mimic the experience of the non-tagged fish that they represent. For migration years prior to 2006, only first-time detected tagged smolts at a dam are considered for inclusion in the transportation (T_0) group since non-tagged smolts were nearly always transported when they entered a bypass/collector facility (where PIT-tag detectors are in operation) at a Snake River dam. Prior to 2006, smolts that were returned to river at LGR, LGS, and LMN were primarily PIT-tagged study fish. Typically during these years, most of the transported smolts were from LGR with the remainders being transported from LGS and LMN. Because some smolts died while migrating in-river from LGR to either LGS or LMN, the actual numbers transported at LGS and LMN were divided by the survival estimates from LGR to each respective transportation site to produce LGR equivalents starting numbers. The combination of PIT-tagged fish first-time detected and transported from LGR, LGS, and LMN forms Category T_0. Using the definitions presented in the previous section, the formula for estimating the number of juvenile fish in Category T_0 is:

$$T_0 = X_{12} + \frac{X_{102}}{S_2} + \frac{X_{1002}}{S_2 * S_3} \qquad [A.1]$$

The PIT-tagged smolts that passed all Snake River dams undetected (C_0) were the group most representative of the non-tagged smolts that migrated in-river during the years prior to 2006, since the C_0 group never entered collection facilities at collector dams. Detected PIT-tagged smolts were not representative because they do enter these facilities, and because non-tagged fish that entered a detection/collection facility were normally removed for transportation. The starting number of C_0 fish was also computed in LGR equivalents, and therefore required estimates of survival. To estimate the number of smolts that were not detected at any of the collector projects (C_0), the number of smolts first detected (transported and non-transported) at LGR, LGS, and LMN (in LGR equivalents) was subtracted from the total number of smolts estimated to arrive at LGR. The number of smolts arriving at LGR was estimated by multiplying the release to LGR survival probability (S_1) and release number (R_1) (or equivalently, dividing the number of smolts detected at LGR [m_{12}] by the CJS estimate of seasonal LGR detection probability p_2) specific for the smolt group of interest.

Smolts detected at MCN, JDA, and BON were not excluded from the C_0 group since fish entering the bypass facilities at these projects, both tagged and untagged, were generally returned to the river. However, any removal of fish at sites below LMN had to be taken into account. Using symbols defined in the previous section, the formula for estimating the number of juvenile fish in Category C_0 is:

$$C_0 = R * S_1 - \left(m_{12} + \frac{m_{13}}{S_2} + \frac{m_{14}}{S_2 * S_3}\right) - d_{C0} \qquad [A.2]$$

where, for migration years 1994–2002,

$$d_{C0} = \left(\frac{d_{5.0} + d_{6.0} + d_{7.0}}{0.5}\right)$$

and beginning in 2003,

$$d_{C0} = \left(\frac{d_{5.0}}{S_2 * S_3 * S_4} + \frac{d_{6.0}}{S_2 * S_3 * S_4 * S_5} + \frac{d_{7.0}}{S_2 * S_3 * S_4 * S_5 * S_6}\right)$$

The last group of interest was comprised of fish that were detected at one or more Snake River dams and remained in-river below LMN. These PIT-tagged fish formed Category C_1. Prior to 2006, the C_1 category existed primarily because a portion of the PIT-tagged smolts entering the detection/collection facility are returned to the river so reach survival estimates are possible. Although these fish do not mimic the general untagged population, they are of interest with regard to possible effects on subsequent survival of passing through Snake River dam bypass/collection systems, and in investigating non-transport operations. Using symbols defined in the previous section, the formula for estimating the number of juvenile fish in Category C_1 is:

$$C_1 = (m_{12} - d_2) + \left(\frac{(m_{13} - d_3)}{S_2}\right) + \left(\frac{(m_{14} - d_4)}{S_2 * S_3}\right) - d_{C1} \qquad \text{[A.3]}$$

where, for migration years 1994–2002,

$$d_{C1} = \left(\frac{(d_{5.1} + d_{6.1} + d_{7.1})}{0.5}\right)$$

and, beginning in 2003,

$$d_{C1} = \left(\frac{d_{5.1}}{S_2 * S_3 * S_4} + \frac{d_{6.1}}{S_2 * S_3 * S_4 * S_5} + \frac{d_{7.1}}{S_2 * S_3 * S_4 * S_5 * S_6}\right)$$

A combination of exceptionally low in-river survival and no-spill hydrosystem operations maximized the transportation of smolts in 2001 and resulted in very few estimated Category C_0 migrants. Furthermore, the C_0 smolts that did exist passed mostly through turbines without the opportunity to pass via spill as in prior years. Obtaining a valid estimate of the number of PIT-tagged wild and hatchery steelhead in Category C_0 in 2001 was also problematic due to the apparently large amount of residualism that year (Berggren et al. 2005a). Most in-river steelhead migrants that returned as adults were actually detected as smolts in the lower river in 2002 (details are in the CSS 10-year Retrospective Analysis Report, Schaller et al. 2007). Returning adults of steelhead and Chinook that had no detections as juveniles were more likely to have either completed their smolt migration in 2002 or passed undetected into the raceways during a computer outage in mid-May at LGR than to have traversed the entire hydrosystem undetected in

2001. Because of the uncertainty in passage route and the timing of the undetected PIT-tagged migrants in 2001, the C_1 group was the only viable in-river group for estimation purposes. Due to these conditions in 2001, C_1 data were used instead of C_0 data in the computation of SAR, TIR, and *D* parameters (described below) and therefore are presented separately for comparison to other years in the multi-year geometric averages computed for S_R, TIR, and *D*.

The C_0 and C_1 groups were combined in two additional migration years. Spills were lower in migration years 2004 and 2005 than previous years at both LGR and LGS (excluding 2001), resulting in high collection efficiency at those two dams and a lower than usual percentage of PIT-tagged smolts estimated to pass the three collector dams on the Snake River undetected (C_0 migrants). In 2004, <6% of the LGR population of wild and hatchery Chinook PIT-tagged smolts were in Category C_0. Only 2.3% of the hatchery steelhead and 2.6% of the wild steelhead were in Category C_0. In 2005, 4.0% of the wild Chinook LGR population, 4.9%-7.9% of the five CSS hatchery Chinook groups, 1.8% of the hatchery steelhead, and 1.4% of the wild steelhead were in the C_0 category. When the estimated number of C_0 PIT-tagged smolts is extremely low, attempting to estimate SAR(C_0) is problematic since few or no adult returns will result in unreliable SAR estimates with large confidence intervals. Therefore, we combined the estimated C_0 and C_1 smolt numbers for PIT-tagged steelhead in 2004 and both Chinook and steelhead in 2005 in order to create a larger in-river group for estimating SARs, TIR, and *D*. This combined in-river group should adequately approximate the SAR of the smolts passing the three collector dams undetected for the following reason. Since smolts that pass the three collector dams undetected may do so through either spill or turbines, when the provision of spill is limited, as occurred in 2004 and 2005, there will be a higher proportion of undetected smolts utilizing the turbine route. With project passage survival ranked highest through spill and lowest through turbines, and intermediate through the bypass, the SARs of C_0 and C_1 smolts will likely be more similar in magnitude in low spill years such as 2004 and 2005, and therefore, using a combined in-river group for SAR, TIR and *D* estimation is justified.

Migration years 2006 and later

In 2006, the protocol for transportation operations was altered by delaying the start date of transportation at LGR, LGS, and LMN (dates shown in Appendix D). The goal of this change in protocol was to improve the overall SARs by allowing more early run-at-large migrants to out-migrate entirely in-river when, historically, transport SARs tended to be low (NOAA 2008). Additionally, spill percentages at the Snake River transportation projects during 2006–2015 were consistently higher than many previous years (see Figure 1.6).

Also in 2006, the CSS began randomly pre-assigning PIT-tagged wild and hatchery Chinook and wild steelhead smolts into monitor-mode (Group T) and return-to-river mode (Group R) operations. In this appendix, the total release, which is the combination of T and R groups, is designated as Group CRT. Group T follows the same fate as the run at large throughout the hydrosystem, while Group R followed a default return to river action at the transportation dams. With a delayed transportation initiation during these years, two new smolt experiences are developed. First, for the transportation study group, the combination of both first-time detected (T_0) and prior-detected transported smolts obtained from Group T represent the transported fish from the run at large (referred to as T_X). Additionally, the transported fish (T_X) exist only over a particular temporal window of the smolt out-migration. The portion of the run that this window includes depends on the intersection of the start date of transportation

and timing for the run at large from a particular study group (e.g., Dworshak hatchery Chinook, or wild Snake River steelhead). Second, the C_1 group (detected and returned to river) now represents the portion of the run at large that out-migrates before transportation started whereas in years before 2006, this group represented a very small portion of the actual run at large (see discussion of C_1 group in previous section). One advantage of the pre-assignment approach, when calculating an overall SAR, is that these relationships are automatically encapsulated and properly weighted within Group T since they "follow the fate" of the run at large. Pre-assignment of the PIT-tagged hatchery steelhead and hatchery sockeye did not begin until 2008 and 2009, respectively. Parameters may have suffixes of "t", "r", or "crt" for groups T, R, and CRT attached whenever necessary to avoid confusion about which group is being used to create the parameter estimate. Figure A.2 shows the relation between the transport (T_0 and T_X) and in-river (C_0 and C_1) study categories and the T, R, and CRT groups from which these categories originate.

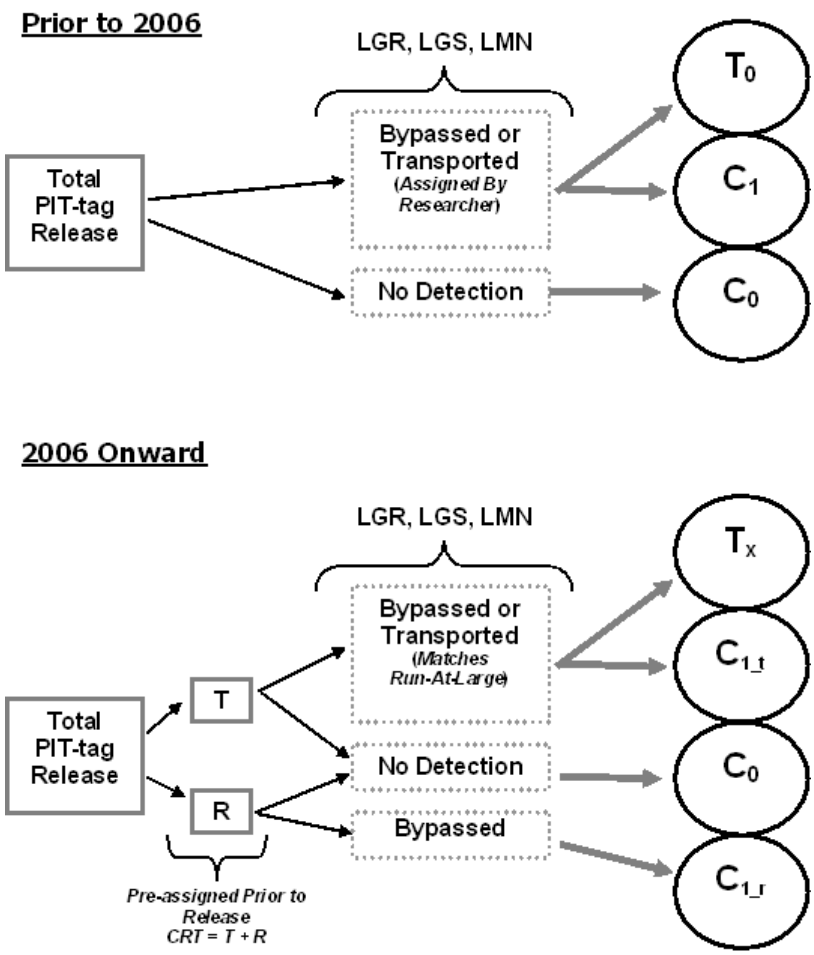

Figure A.2. Schematic depicting how the differently marked cohorts are used to translate into SARs for all years of the CSS relative to the passage of PIT-tagged smolts at the three Snake River collection/ transportation dams (LGR, LGS, and LMN). The upper flow chart covers years prior to pre-assignments and the lower flow chart covers years with pre-assignment of tags to Group T (monitor-mode) and Group R (bypass-mode). All CSS Snake River releases incorporate the pre-assignment approach starting in 2006 for hatchery and wild Chinook, 2008 for hatchery steelhead, and 2009 for hatchery sockeye.

The formula for estimating the number of juvenile smolts in Group T in Category T_X is:

$$T_{X_t} = X_{12} + \frac{X_{1a2}}{S_2} + \frac{X_{1aa2}}{S_2 * S_3} \qquad [A.4]$$

where

$$a = 0 \; if \; undetected \; and \; 1 \; if \; detected \; at \; a \; dam \; prior \; to \; the \; transportation \; site$$

It is not necessary to limit our use to Group T fish when estimating C_0, since the pre-assignment affects only the passage routes of detected smolts. By using Group CRT, we have access to more PIT-tagged C_0 smolts and returning adults for computing the SAR(C_0) estimate. Since the reach survival probabilities and collection probabilities are computed using Group CRT, Equation A.2 may still be used for estimating number of juvenile smolts in Category C_0:

$$C_{0_crt} = \text{"}see \; Equation \; A.2\text{"}$$

However, when estimating C_0 or C_1 smolt numbers in either Group T or Group R, expectation equations should be used. This is because the computation of C_0 and C_1 smolt numbers with the m-matrix statistics m_{12}, m_{13}, and m_{14} is sensitive to the estimated reach survival probabilities being used. Reach survival probabilities are estimated using Group CRT. Groups T and R are subsets of Group CRT. The magnitudes of m_{12}, m_{13}, and m_{14} relative to the release number R_1 may vary slightly across groups T and R due to sampling variability, resulting in shifts in the proportion of C_0 and C_1 smolts estimated for each of the two groups. This is not the case when E[C_0] and E[C_1] equations (shown below) are used, since the same set of reach survival probabilities and collection probabilities generated with Group CRT are passed to groups T and R for use in estimating key study parameters. Since the random pre-assignment action (bypass or transport) occurs after collection, the same collection probability should apply to both groups, and survival estimates should be applicable to either group while it is in-river. The reach survival probabilities Sj's and collection probabilities Pj's computed with Group CRT are passed to Groups T and R, while the parameters R_1, X_{12}, X_{1A2}, X_{1AA2}, and C_1 removals (d_1, d_2, d_3, d_4) and C_0 removals (d_0) are specific to the respective group.

Therefore, when estimating the proportion of Group T smolts by passage experience as in Appendix E or comparing SARs of C_1 smolts bypassed over the entire season (Group R) with C_0 smolts (Group CRT) as in the meta analysis of Chapter 7 in the 2010 CSS annual report (Tuomikoski et al., 2010), we use the following expectation formulas. We used the equation below to estimate the expected C_0 smolt numbers given the known removal of d_{C0} or E[C_0 | d_{C0}]. Because d_{C0} is often zero and for simplicity we refer to this value as E[C_0] hereafter. The equation is used similarly for both the T and CRT groups.

$$E[C_0] = R_1 * S_1 * (1 - P_2) * (1 - P_3) * (1 - P_4) - d_{C0} \qquad [A.5]$$

where

$$d_{C0} = \frac{d_{5.0}}{S_2 * S_3 * S_4} + \frac{d_{6.0}}{S_2 * S_3 * S_4 * S_5} + \frac{d_{7.0}}{S_2 * S_3 * S_4 * S_5 * S_6}$$

Similarly the expected C_1 smolt numbers were estimated for either T or R group where known removals d_{C1}, d_2, d_3, and d_4 are constants. The expected value given known removals is $E[C_1 \mid d_{C1}]$ and is referred to as $E[C_1]$ hereafter. This estimate is obtained by first re-arranging terms in Equation A.3,

$$C_1 = m_{12} + \frac{m_{13}}{S_2} + \frac{m_{14}}{S_2 * S_3} - \left[d_2 + \frac{d_3}{S_2} + \frac{d_4}{S_2 * S_3} + d_{C1}\right]$$

where

$$d_{C1} = \frac{d_{5.1}}{S_2 * S_3 * S_4} + \frac{d_{6.1}}{S_2 * S_3 * S_4 * S_5} + \frac{d_{7.1}}{S_2 * S_3 * S_4 * S_5 * S_6}$$

and substituting the following expectations for m_{12}, m_{13}, and m_{14}

$$E[m_{12}] = R_1 * S_1 * P_2$$

$$E[m_{13}] = R_1 * S_1 * (1 - P_2) * S_2 * P_3$$

$$E[m_{14}] = R_1 * S_1 * (1 - P_2) * S_2 * (1 - P_3) * S_3 * P_4$$

to yield:

$$E[C_1] = R_1 * S_1 * [P_2 + (1 - P_2) * P_3 + (1 - P_2) * (1 - P_3) * P_4] - \left[d_2 + \frac{d_3}{S_2} + \frac{d_4}{S_2 * S_3} + d_{C1}\right] \quad [A.6]$$

Special considerations for migration year 2010

In some cases, the closed form estimators of the CJS model performed poorly during out-migration 2010. For example, survival estimates for the LGS to LMN reach were above 1.0 and detection probabilities were remarkably low. This was potentially due to increased bird predation at the bypass outfall of Lower Monumental Dam in 2010 (FPC 2011). CJS methodology assumes that detected and undetected fish survive to downstream projects at the same rate. For example, if fish detected at LMN had lower survival to downstream projects than undetected fish (e.g., high predation at the bypass outfall), then this CJS assumption has been

violated. This violation could result in an overestimate of the population at LMN and an under-estimate of the detection probability at LMN. Therefore, reach survival from LGS to LMN could be overestimated.

To correct for any subsequent potential biases associated in SARs, all survival estimates used in equations A.2, A.3 (using Group T fish), and A.4 were 'adjusted' to 100% whenever the point estimate or bootstrap estimate exceeded 100%. This adjustment is more logical than using survival estimates that exceeded 100% and the resulting estimates of SAR, TIR and *D* changed very little implying that these estimators are relatively insensitive to variation in the short reach smolt survival estimates. The estimate for C_1 SAR used equation A.3 instead of A.6 because of remarkably low detection probabilities at LMN that were probably a result of the above noted bias. To reflect the experience of the run at large, Group T fish were used in the C_1 SAR calculation. When survival estimates were limited to 100%, the resulting SARs had an absolute increase of no more than 0.02 for 2010 Snake River Chinook groups. This increase of 0.02 occurred for only one of the 2010 Snake River Chinook groups.

Estimation of SARs and Ratios of SARs for Study Categories

LGR is the primary upriver evaluation site for most objectives of the CSS. Adults detected at GRA (LGR's adult ladder) were assigned to a particular study category based on the study category they belonged to as a smolt (fish with no previous detections at any dam were automatically assigned to Category C_0). In the SAR estimation, the adult steelhead and sockeye count is the sum of the 1- to 3-ocean returns (mini-jacks returning in the same year as their smolt out-migration are excluded). The adult Chinook count is the sum of the 2- to 4-ocean returns. Chinook jacks and mini-jacks (1-ocean or less, precocious males) are excluded in the estimation of SARs by study category. In Chapter 4, wild and hatchery Chinook annual overall SAR estimates are presented both with and without jacks. However, mini-jacks are excluded in the estimates of annual overall SARs for wild and hatchery Chinook that are presented in Chapter 4.

SARs are calculated by study category with the adult tally in the numerator and estimated smolt numbers in the denominator. Prior to 2006 (2008 for hatchery steelhead) when there was no pre-assignment of CSS study fish to Groups T and R, the formulas are:

$$SAR(T_0) = \frac{\{AT_{LGR} + AT_{LGS} + AT_{LMN}\}}{T_0} \qquad [A.7]$$

where

$$AT_{LGR} = adults\ at\ LGR\ that\ were\ transported\ as\ juveniles\ from\ LGR$$

$$AT_{LGS} = adults\ at\ LGR\ that\ were\ transported\ as\ juveniles\ from\ LGS$$

$$AT_{LMN} = adults\ at\ LGR\ that\ were\ transported\ as\ juveniles\ from\ LMN$$

$$SAR(C_0) = \frac{\{AC_0\}}{C_0} \qquad [A.8]$$

where

$$AC_0 = adults\ at\ LGR\ with\ C_0\ smolt\ outmigration\ history$$

$$SAR(C_1) = \frac{\{AC_1\}}{C_1} \qquad [A.9]$$

where

$$AC_1 = adults\ at\ LGR\ with\ C_1\ smolt\ outmigration\ history$$

As stated previously, due to change in operations, transported smolts had different potential detection histories depending on if the migration year was before 2006 or not. The adult counts included in the transport SARs reflect these changes. Counts of returning adults (i.e., AT_{LGR}, AT_{LGS}, AT_{LMN}) from smolt migration years before 2006 include capture histories of X_{12}, X_{102}, or X_{1002} (sometimes referred to as "first-time detects"). Counts of adults with smolt migration years of 2006 and later include both first-time detected and previously detected fish. The abbreviated capture histories for the smolt out-migration experience of adults from the T_X group (using a '1' for a single release followed by a 1,0, or 2 to denote bypass, undetected, or transported at LGR, LGS, or LMN) would be 12, 102, 1002, 112, 1012, 1102, or 1112. Using the pre-assigned fish in Group T, the equation for SAR(T_X_t) is:

$$SAR(T_{X_t}) = \frac{\{AT_{LGR_t} + AT_{LGS_t} + AT_{LMN_t}\}}{T_{X_t}} \qquad [A.10]$$

Using the total release, the formula for SAR(C_0_crt) is:

$$SAR(C_{0_crt}) = \frac{\{AC_{0_crt}\}}{C_{0_crt}} \qquad [A.11]$$

Using the pre-assigned fish in Group T, the equations for SAR[EC_1_t] is:

$$SAR[EC_{1_t}] = \frac{\{AC_{1_t}\}}{E[C_{1_t}]} \qquad [A.12]$$

The difference between SAR(T_0) (or SAR(T_X_t) beginning 2006) and SAR(C_0) is characterized as the ratio of these SARs and denoted as the TIR (transport: in-river ratio):

$$TIR = \frac{SAR(T_0)}{SAR(C_0)} \qquad [A.13]$$

The statistical test of whether SAR(T_0) (or SAR(T_X_t) beginning 2006) is significantly different than SAR(C_0) is conducted by evaluating whether TIR differs from one. We use the criteria that the non-parametric 90% confidence interval's lower limit of TIR (rounded to hundredths) must exceed 1.00 or its upper limit must be less than 1.00. This provides a statistical two-tailed ($\alpha = 0.10$) test of H_0 TIR = 1 versus H_A TIR $\neq 1$. The upper and lower limit values of the 90% confidence interval for TIR (and any other parameter of interest) are obtained at the 50th and 951st rank order position from the 1,000 bootstrapped resampling of the PIT-tagged population of interest.

Estimation of *D*

The parameter used to evaluate the differential delayed effects of transportation in relation to in-river out-migrants is *D*. *D* is the ratio of SARs of transported smolts (SAR(T_0)) to in-river out-migrants (SAR(C_0)), but unlike TIR, the SAR is estimated from BON instead of from LGR. If the value of *D* is around 1, there is little or no differential mortality occurring between transported and in-river migrating smolts once they are both below BON. The estimate of *D* (substituting T_X for T_0 for migration years 2006 and later) is:

$$D = \frac{SAR_{BON-LGR}(T_0)}{SAR_{BON-LGR}(C_0)} \qquad \text{[A.14]}$$

The total number of smolts passing BON is not observed directly. However, *D* can be estimated by removing the portion of the LGR-to-GRA SAR that contains the LGR to BON juvenile hydrosystem survival. So, the parameters S_T and S_R were divided out of their respective LGR-to-GRA SAR values to estimate the $SAR_{BON\text{-}LGR}$ for each study group shown in Equation A.14. The resulting estimate of *D* (substituting T_X for T_0 for migration years 2006 and later) was calculated as:

$$D = \frac{\left(\frac{SAR(T_0)}{S_T}\right)}{\left(\frac{SAR(C_0)}{S_R}\right)} \qquad \text{[A.15]}$$

where S_R is the estimated in-river survival from LGR tailrace to BON tailrace and S_T is the assumed direct transportation survival probability (0.98) adjusted for in-river survival to the respective transportation sites for those fish transported from LGS or LMN.

In the denominator of *D* (in-river portion), the quotient is simply SAR(C_0)/S_R, where S_R is estimated using CJS estimates (expanded to the entire hydrosystem if necessary). Errors in estimates of S_R influenced the accuracy of *D* estimates: recall that when it was not possible to estimate S_R directly, an expansion based on a "per mile" survival probability obtained from an upstream reach (where survival could be directly estimated) was instead applied to the remaining downstream reach (see *Estimation of juvenile in-river survival (S_R)* above).

In the numerator of *D* (transportation portion), the quotient is SAR(T_0)/S_T, where S_T is a weighted harmonic mean estimate of the in-river survival probability between LGR tailrace and downstream Snake River transportation sites for the estimated project-specific proportion of the

transported run at large at these two downstream transportation sites. Calculation of S_T includes an estimate of survival to each transportation site, effectively putting S_T into LGR equivalents similar to SAR(T_0), with a fixed 98% survival probability for the fish once they were placed into the transportation vehicle (truck or barge). The S_T estimate for years prior to 2006 is:

$$S_T = (0.98) * \frac{(t_2 * t_3 * t_4)}{\left(t_2 + \frac{t_3}{S_2} + \frac{t_4}{S_2 * S_3}\right)} \qquad [A.16]$$

where t_j is the estimate of the fraction of PIT-tagged fish that would have been transported at each dam (e.g., t_2 = LGR, t_3 = LGS, and t_4 = LMN) if all PIT-tagged fish had been routed to transport at the same rate as the run at large (i.e., untagged fish).

Beginning in 2006 with pre-assignment to Group T for all PIT-tagged fish groups except hatchery steelhead, the values for t_j were obtained directly using Group T for the number of PIT-tagged smolts (X) with the following capture histories (shown in subscript): $t_2 = X_{12}$, $t_3 = X_{1A2}$, and $t_4 = X_{1AA2}$. Since the routing of the PIT-tagged hatchery steelhead was in the same proportion at each collector dam, the values for t_j were obtained directly with the total release for the above capture histories. Using this approach for all PIT-tagged groups properly accounted for the effect of the later start of transportation in years beginning in 2006. The S_T estimate for years 2006 and later is:

$$S_T = (0.98)\left[\frac{X_{12} + X_{1a2} + X_{1aa2}}{X_{12} + \frac{X_{1a2}}{S_2} + \frac{X_{1aa2}}{S_2 * S_3}}\right] \qquad [A.17]$$

The estimates of S_T have ranged between 0.88 and 0.98 for Chinook and steelhead across all the years evaluated.

A statistical test of whether D is significantly greater or less than 1 was conducted in the same manner as was done with TIR. We use the criteria that the non-parametric 90% confidence interval's lower limit of D (rounded to hundredths) must exceed 1.00 or its upper limit must be less than 1.00. This provides a statistical two-tailed ($\alpha = 0.10$) test of H_0 $D = 1$ versus H_A $D \neq 1$.

Results

Estimates of Annual Survival (S_R)

Presented here are the juvenile in-river survival estimates (S_R) for the Lower Granite Dam to Bonneville Dam reach for Snake River wild and hatchery spring/summer Chinook, wild and hatchery steelhead, hatchery sockeye, and wild and hatchery subyearling fall Chinook.

Wild and Hatchery Spring/Summer Chinook

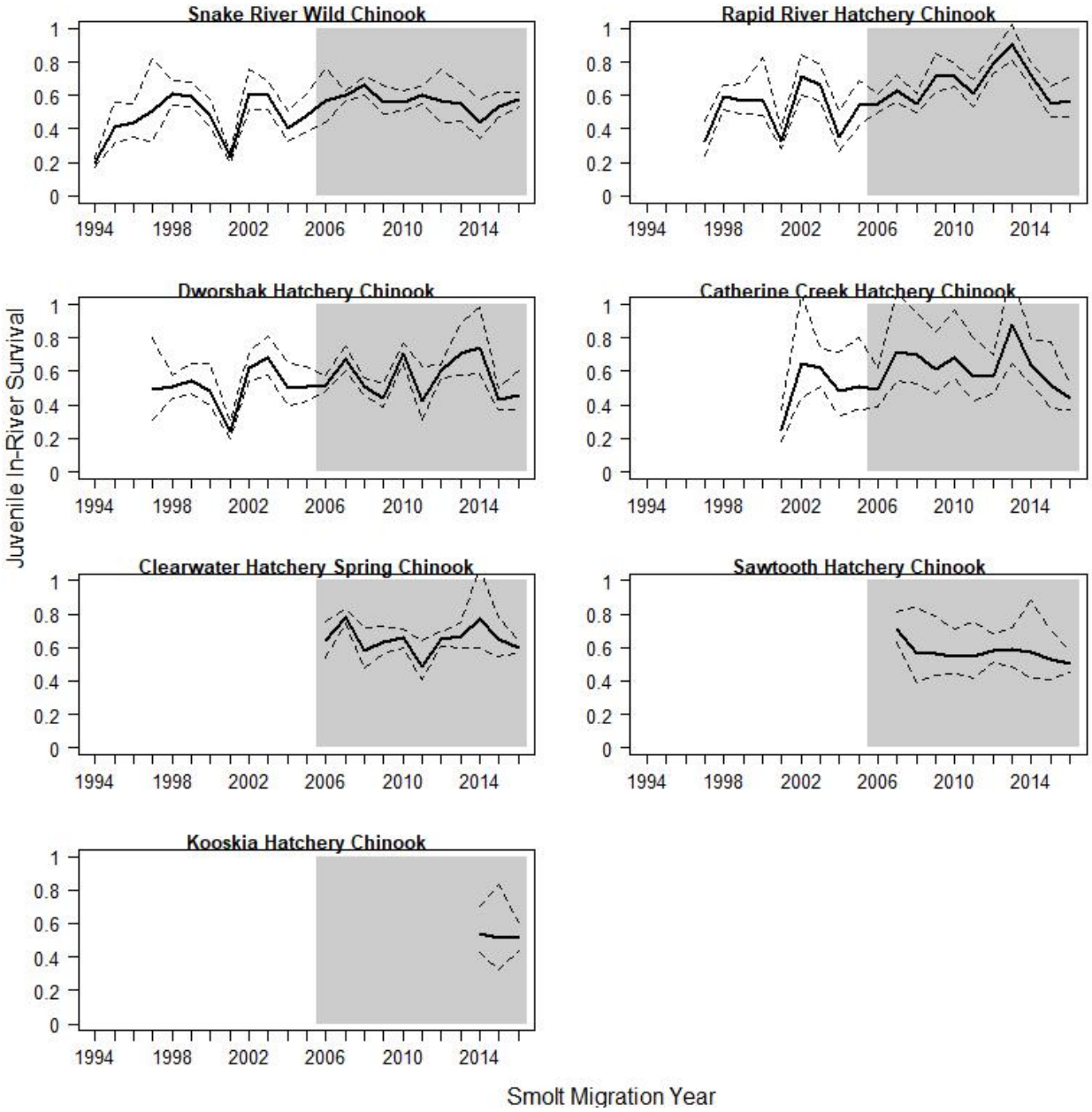

Figure A.3. Trend in juvenile in-river survival LGR to BON (S_R) for PIT-tagged Snake River wild spring/summer Chinook (1994-2015) and hatchery spring Chinook (1994-2016) (with 90% confidence intervals). Shaded area highlights the period of Court Order spill and later start of transportation. Data are from Tables A.1 and A.2.

Table A.1. Estimated in-river survival LGR to BON (S_R) of PIT-tagged Snake River wild spring/summer Chinook (1994-2016) and hatchery spring Chinook from Rapid River Hatchery, Dworshak NFH, and Catherine Creek AP (1994-2016) (with 90% confidence intervals). Migration years 2006 and later use reach survival probability estimates of combined T and R groups.

Migration Year	Aggregate Wild Chinook	Rapid River Hatchery	Dworshak NFH	Catherine Creek AP
1994	0.20[3] (0.17 - 0.22)			
1995	0.41[2] (0.32 - 0.56)			
1996	0.44[3] (0.35 - 0.55)			
1997	0.51[3] (0.33 - 0.82)	0.33[3] (0.24 - 0.45)	0.49[3] (0.31 - 0.80)	
1998	0.61[1] (0.54 - 0.69)	0.59[1] (0.52 - 0.66)	0.51[1] (0.44 - 0.58)	
1999	0.59 (0.53 - 0.68)	0.57 (0.49 - 0.67)	0.54 (0.47 - 0.65)	
2000	0.48 (0.41 - 0.58)	0.58 (0.48 - 0.83)	0.48 (0.40 - 0.65)	
2002	0.61 (0.52 - 0.76)	0.71 (0.60 - 0.84)	0.62 (0.54 - 0.72)	0.65 (0.44 - 1.06)
2003	0.60 (0.52 - 0.69)	0.66 (0.57 - 0.78)	0.68 (0.58 - 0.81)	0.62[1] (0.51 - 0.74)
2004	0.40 (0.33 - 0.51)	0.35 (0.27 - 0.51)	0.50 (0.40 - 0.66)	0.48[1] (0.34 - 0.72)
2005	0.48 (0.39 - 0.61)	0.54 (0.42 - 0.69)	0.51 (0.42 - 0.63)	0.51[1] (0.37 - 0.80)
2006	0.57 (0.44 - 0.77)	0.55[1] (0.50 - 0.61)	0.52[1] (0.48 - 0.58)	0.49[1] (0.39 - 0.62)
2007	0.60[1] (0.57 - 0.63)	0.63 (0.56 - 0.72)	0.67 (0.60 - 0.75)	0.72 (0.54 - 1.07)
2008	0.66[2] (0.60 - 0.71)	0.55[2] (0.50 - 0.61)	0.51[2] (0.46 - 0.56)	0.70[2] (0.53 - 0.95)
2009	0.56 (0.49 - 0.66)	0.71 (0.62 - 0.85)	0.44 (0.39 - 0.53)	0.61[1] (0.47 - 0.84)
2010	0.56 (0.51 - 0.63)	0.71 (0.65 - 0.79)	0.71 (0.65 - 0.77)	0.68 (0.56 - 0.88)
2011	0.60[1] (0.55 - 0.65)	0.61[1] (0.53 - 0.70)	0.42 (0.31 - 0.60)	0.57[2] (0.43 - 0.77)
2012	0.57 (0.44 - 0.78)	0.79[2] (0.73 - 0.86)	0.60[1] (0.56 - 0.64)	0.57[1] (0.47 - 0.70)
2013	0.55 (0.45 - 0.67)	0.90[2] (0.81 - 1.02)	0.71 (0.58 - 0.89)	0.88[2] (0.65 - 1.20)
2014	0.44 (0.34 - 0.58)	0.72[2] (0.65 - 0.80)	0.74 (0.59 – 0.98)	0.64[2] (0.53 - 0.79)
2015	0.53[2] (0.47 - 0.62)	0.55[1] (0.47 - 0.65)	0.43 (0.37 – 0.50)	0.52 (0.38 - 0.78)
2016[A]	0.58[1] (0.53 - 0.62)	0.57 (0.47 - 0.71)	0.46 (0.37 – 0.60)	0.44 (0.37 – 0.53)
Geomean	**0.51**	**0.60**	**0.55**	**0.60**
2001	0.23 (0.20 - 0.27)	0.33 (0.28 - 0.40)	0.24 (0.20 - 0.30)	0.25 (0.18 - 0.37)

[1 to 3] Number of reaches with a constant "per mile" survival probability expansion applied (1 = 25% expansion JDA to BON; 2 = 51% expansion MCN to BON; 3 = 77% expansion LMN to BON).
[A] Estimate of S_R for wild Chinook may change as group is finalized for estimation of SARs.

Table A.2. Estimated in-river survival LGR to BON (S_R) of PIT-tagged Snake River wild spring/summer Chinook (1994-2016) and hatchery spring Chinook from Clearwater, Sawtooth Hatchery, and Kooskia hatcheries (1994-2016) (with 90% confidence intervals). Migration years 2006 and later use reach survival probability estimates of combined T and R groups.

Migration Year	Aggregate Wild Chinook	Clearwater Hatchery (Spring)	Sawtooth Hatchery	Kooskia Hatchery
1994	0.20[3] (0.17 - 0.22)			
1995	0.41[2] (0.32 - 0.56)			
1996	0.44[3] (0.35 - 0.55)			
1997	0.51[3] (0.33 - 0.82)			
1998	0.61[1] (0.54 - 0.69)			
1999	0.59 (0.53 - 0.68)			
2000	0.48 (0.41 - 0.58)			
2002	0.61 (0.52 - 0.76)			
2003	0.60 (0.52 - 0.69)			
2004	0.40 (0.33 - 0.51)			
2005	0.48 (0.39 - 0.61)			
2006	0.57 (0.44 - 0.77)	0.64[1] (0.54 - 0.75)		
2007	0.60[1] (0.57 - 0.63)	0.78[1] (0.74 - 0.83)	0.71[1] (0.63 - 0.81)	
2008	0.66[2] (0.60 - 0.71)	0.58[2] (0.48 - 0.72)	0.56[2] (0.39 - 0.84)	
2009	0.56 (0.49 - 0.66)	0.63 (0.56 - 0.73)	0.56[1] (0.43 - 0.79)	
2010	0.56 (0.51 - 0.62)	0.66 (0.60 - 0.71)	0.55 (0.44 - 0.71)	
2011	0.60[1] (0.55 - 0.65)	0.49 (0.41 - 0.63)	0.55[1] (0.41 - 0.76)	
2012	0.57 (0.44 - 0.78)	0.65[1] (0.62 - 0.70)	0.58[1] (0.51 - 0.68)	
2013	0.55 (0.45 - 0.67)	0.67[1] (0.60 - 0.75)	0.59[1] (0.49 - 0.72)	
2014	0.44 (0.34 - 0.58)	0.77 (0.60 – 1.07)	0.57 (0.42 - 0.88)	0.54[1] (0.43 – 0.70)
2015	0.53[2] (0.47- 0.62)	0.65 (0.55 - 0.78)	0.53 (0.41 - 0.70)	0.51[2] (0.32 – 0.83)
2016[A]	0.58[1] (0.53 - 0.62)	0.60[1] (0.57 – 0.64)	0.50[1] (0.45 – 0.58)	0.52[2] (0.44 – 0.61)
Geomean	**0.51**	**0.64**	**0.57**	**0.52**
2001	0.23 (0.20 - 0.27)			

[1 to 3] Number of reaches with a constant "per mile" survival probability expansion applied (1 = 25% expansion JDA to BON; 2 = 51% expansion MCN to BON; 3 = 77% expansion LMN to BON).
[A] Estimate of S_R for wild Chinook may change as group is finalized for estimation of SARs.

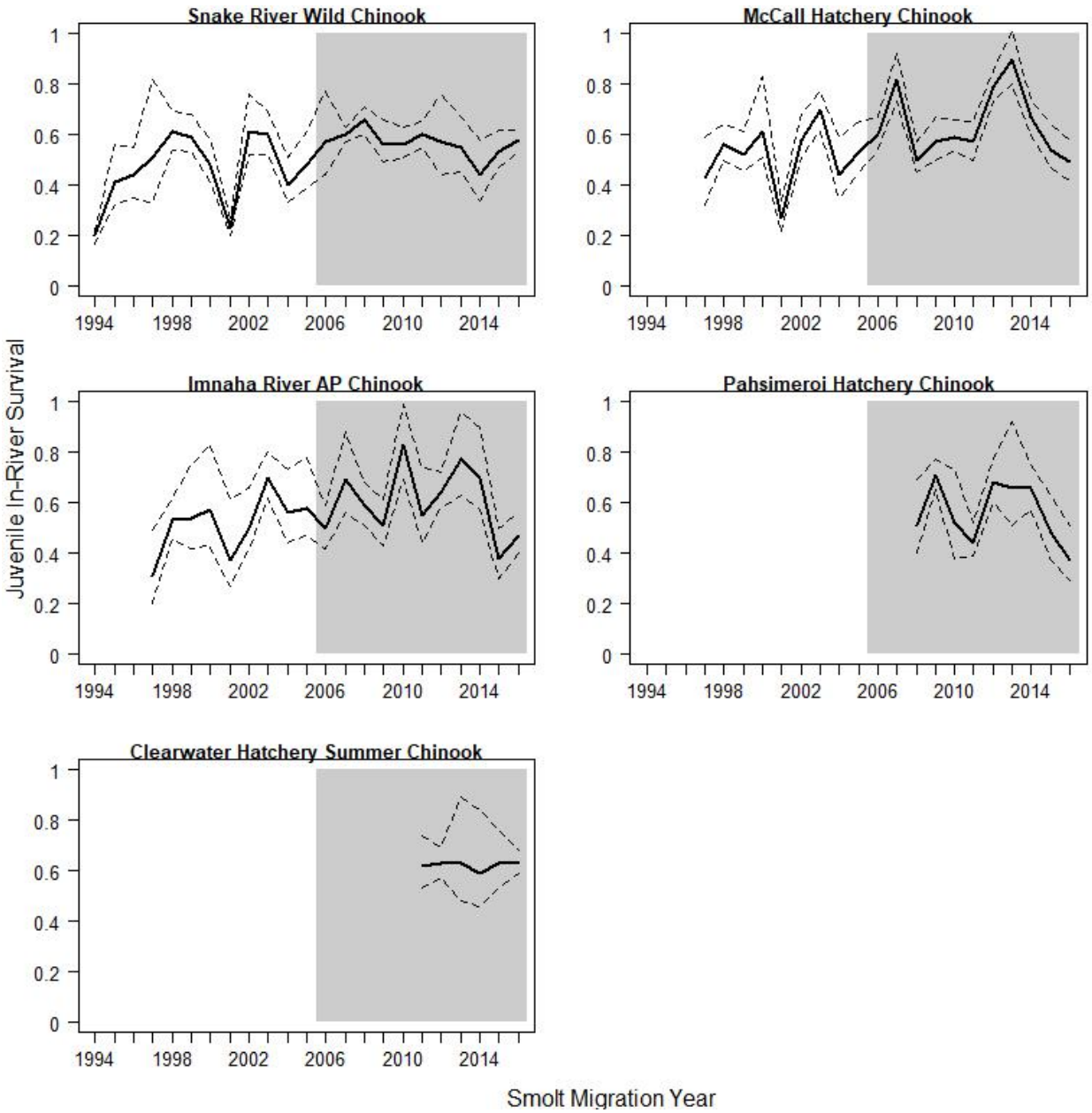

Figure A.4. Trend in juvenile in-river survival LGR to BON (S_R) for PIT-tagged Snake River wild spring/summer Chinook (1994-2015) and hatchery summer Chinook (1994 to 2016) (with 90% confidence intervals). Shaded area highlights the period of Court Order spill and later start of transportation. Data for wild Chinook are from Table A.1 and hatchery summer Chinook are from Table A.3.

Table A.3. Estimated in-river survival LGR to BON (S_R) of PIT-tagged hatchery summer Chinook from McCall Hatchery, Imnaha AP, Pahsimeroi Hatchery, and Clearwater hatcheries (1997-2016) (with 90% confidence intervals). Migration years 2006 and later use reach survival probability estimates of combined T and R groups.

Migration Year	McCall Hatchery	Imnaha AP	Pahsimeroi Hatchery	Clearwater Hatchery (Summer)
1997	0.43[3] (0.32 - 0.59)	0.31[3] (0.20 - 0.49)		
1998	0.56[1] (0.50 - 0.64)	0.53[1] (0.46 - 0.62)		
1999	0.52 (0.46 - 0.61)	0.54 (0.42 - 0.75)		
2000	0.61 (0.51 - 0.83)	0.57 (0.43 - 0.83)		
2002	0.58 (0.51 - 0.68)	0.50 (0.41 - 0.66)		
2003	0.70 (0.62 - 0.77)	0.70[1] (0.62 - 0.80)		
2004	0.44 (0.35 - 0.59)	0.56[1] (0.44 - 0.73)		
2005	0.53 (0.45 - 0.65)	0.58[1] (0.47 - 0.78)		
2006	0.60[1] (0.54 - 0.67)	0.50[1] (0.42 - 0.59)		
2007	0.82 (0.73 - 0.92)	0.69 (0.56 - 0.88)		
2008	0.50[2] (0.45 - 0.57)	0.59[2] (0.51 - 0.68)	0.51[2] (0.40 - 0.69)	
2009	0.57 (0.50 - 0.67)	0.51[1] (0.43 - 0.61)	0.71[2] (0.65 - 0.77)	
2010	0.59 (0.53 - 0.66)	0.83 (0.69 - 0.99)	0.52 (0.38 - 0.73)	
2011	0.57[2] (0.50 - 0.65)	0.55[1] (0.44 - 0.74)	0.44[1] (0.39 - 0.52)	0.62[1] (0.53 - 0.73)
2012	0.79[1] (0.73 - 0.85)	0.64[1] (0.58 - 0.72)	0.68[1] (0.60 - 0.77)	0.63[1] (0.57 - 0.69)
2013	0.90[2] (0.80 - 1.01)	0.77[1] (0.63 - 0.96)	0.66 (0.51 - 0.92)	0.63 (0.48 - 0.89)
2014	0.67[2] (0.60 - 0.74)	0.70[1] (0.57 - 0.90)	0.66[1] (0.57 - 0.75)	0.59 (0.46 - 0.84)
2015	0.54 (0.47 - 0.64)	0.38 (0.30 - 0.50)	0.48[2] (0.37 - 0.63)	0.63 (0.53 - 0.76)
2016	0.49 (0.42 - 0.58)	0.47[1] (0.40 - 0.56)	0.37 (0.29 - 0.51)	0.63[1] (0.59 - 0.68)
Geomean	**0.59**	**0.56**	**0.55**	**0.62**
2001	0.27 (0.22 - 0.34)	0.37 (0.27 - 0.61)		

[1 to 3] Number of reaches with a constant "per mile" survival probability expansion applied (1 = 25% expansion JDA to BON; 2 = 51% expansion MCN to BON; 3 = 77% expansion LMN to BON).

Wild and Hatchery Steelhead

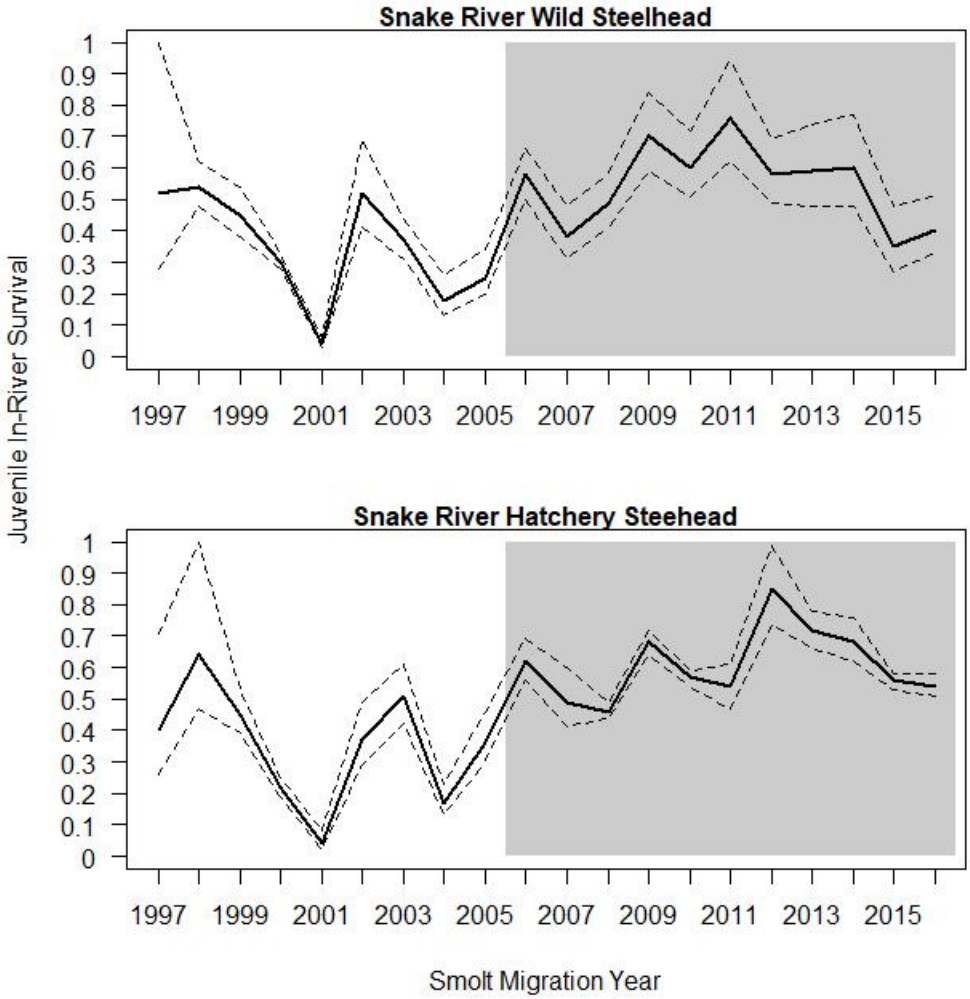

Figure A.5. Trend in juvenile in-river survival LGR to BON (S_R) for PIT-tagged Snake River aggregate wild (1997-2016) and aggregate hatchery (1997-2016) steelhead (with 90% confidence intervals). Shaded area highlights the period of Court Order spill and later start of transportation. Data displayed in figure are from Table A.4.

Table A.4. Estimated in-river survival LGR to BON (S_R) of PIT-tagged aggregate wild (1997-2016) and hatchery steelhead (1997-2016) (with 90% confidence intervals). Migration years 2006 and later use reach survival probability estimates of combined T and R groups.

Migration Year	Aggregate Wild Steelhead	Aggregate Hatchery Steelhead
1997	0.52[1] (0.28 - 1.00)	0.40[1] (0.26 - 0.71)
1998	0.54[1] (0.48 - 0.62)	0.64 (0.47 - 1.00)
1999	0.45 (0.38 - 0.54)	0.45 (0.39 - 0.53)
2000	0.30[1] (0.28 - 0.33)	0.22[1] (0.19 - 0.25)
2002	0.52 (0.41 - 0.69)	0.37 (0.29 - 0.49)
2003	0.37 (0.31 - 0.44)	0.51 (0.42 - 0.61)
2004	0.18[2] (0.13 - 0.26)	0.17[2] (0.13 - 0.23)
2005	0.25[1] (0.20 - 0.34)	0.36[1] (0.30 - 0.46)
2006	0.58[1] (0.50 - 0.66)	0.62[1] (0.56 - 0.69)
2007	0.38 (0.31 - 0.48)	0.49 (0.41 - 0.60)
2008	0.49[2] (0.41 - 0.58)	0.46[2] (0.44 - 0.49)
2009	0.70[1] (0.59 - 0.85)	0.68 (0.63 - 0.72)
2010	0.60 (0.51 - 0.72)	0.57 (0.54 - 0.59)
2011	0.76[2] (0.62 - 0.94)	0.54 (0.47 - 0.61)
2012	0.58[2] (0.49 - 0.69)	0.85 (0.74 - 0.99)
2013	0.59[1] (0.48 - 0.74)	0.72 (0.66 - 0.78)
2014	0.60[1] (0.48 - 0.77)	0.68 (0.62 - 0.76)
2015[A]	0.35 (0.27 - 0.48)	0.56 (0.53 - 0.58)
2016[A]	0.40 (0.33 - 0.51)	0.54 (0.51 - 0.58)
Geomean	**0.46**	**0.49**
2001	0.04 (0.03 - 0.06)	0.04 (0.02 - 0.08)

[1 to 3] Number of reaches with a constant "per mile" survival probability expansion applied (1 = 25% expansion JDA to BON; 2 = 51% expansion MCN to BON; 3 = 77% expansion LMN to BON).

[A] Estimate of S_R for wild steelhead may change as group is finalized for estimation of SARs.

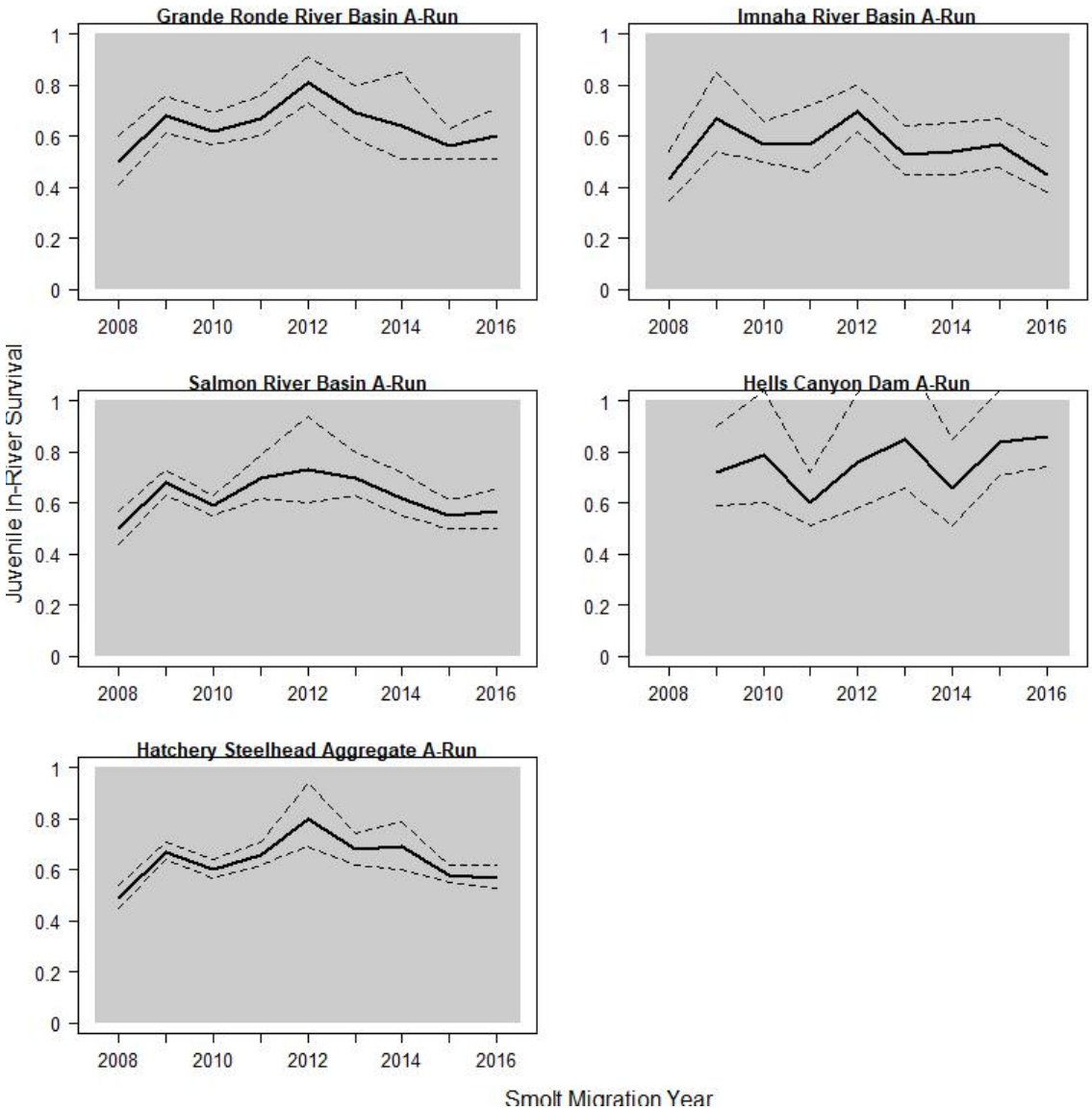

Figure A.6 Trend in juvenile in-river survival LGR to BON (S_R) for various groups of PIT-tagged Snake River A-Run hatchery steelhead (2008-2016) (with 90% confidence intervals). Shaded area highlights the period of Court Order spill and later start of transportation. Data displayed in figure are from Table A.5.

Table A.5. Estimated in-river survival LGR to BON (S_R) of PIT-tagged hatchery A-Run steelhead for migration years 2008 through 2016 (with 90% confidence intervals). All reach survival estimates are of combined T and R groups.

Migration Year	Grande Ronde R. A-run (Wallowa)	Imnaha R. A-run	Salmon R. A-run	Mainstem below HCD A-run	Combined A-run
2008	0.50[2] (0.41 - 0.60)	0.43[2] (0.35 - 0.54)	0.50[2] (0.44 - 0.57)		0.49[2] (0.45 - 0.54)
2009	0.68[2] (0.61 - 0.76)	0.67[2] (0.54 - 0.85)	0.68[2] (0.63 - 0.73)	0.72[2] (0.59 - 0.90)	0.67[2] (0.64 - 0.71)
2010	0.62 (0.56 - 0.69)	0.57 (0.50 - 0.66)	0.59 (0.55 - 0.63)	0.79[2] (0.60 - 1.04)	0.60 (0.57 - 0.64)
2011	0.67[2] (0.60 - 0.76)	0.57[2] (0.46 - 0.72)	0.70[2] (0.62 - 0.79)	0.60[2] (0.51 - 0.72)	0.66 (0.62 - 0.71)
2012	0.81[1] (0.73 - 0.91)	0.70[1] (0.62 - 0.80)	0.73 (0.60 - 0.94)	0.76[2] (0.58 - 1.03)	0.80 (0.69 - 0.94)
2013	0.69[1] (0.59 - 0.80)	0.53[1] (0.45 - 0.64)	0.70[1] (0.63 - 0.80)	0.85[1] (0.66 - 1.18)	0.68[1] (0.62 - 0.74)
2014	0.64 (0.51 - 0.85)	0.54[1] (0.45 - 0.65)	0.62[1] (0.55 - 0.72)	0.66[2] (0.51 - 0.85)	0.69 (0.60 - 0.79)
2015	0.56 (0.51 - 0.63)	0.57 (0.48 - 0.67)	0.55 (0.50 - 0.61)	0.84 (0.71 - 1.04)	0.58 (0.55 - 0.62)
2016	0.60 (0.51 - 0.71)	0.45 (0.38 - 0.56)	0.57 (0.50 - 0.65)	0.86[1] (0.74 - 1.04)	0.57 (0.53 - 0.62)
Geomean	**0.64**	**0.55**	**0.62**	**0.75**	**0.63**

[1 to 3] Number of reaches with a constant "per mile" survival probability expansion applied (1 = 25% expansion JDA to BON; 2 = 51% expansion MCN to BON; 3 = 77% expansion LMN to BON).

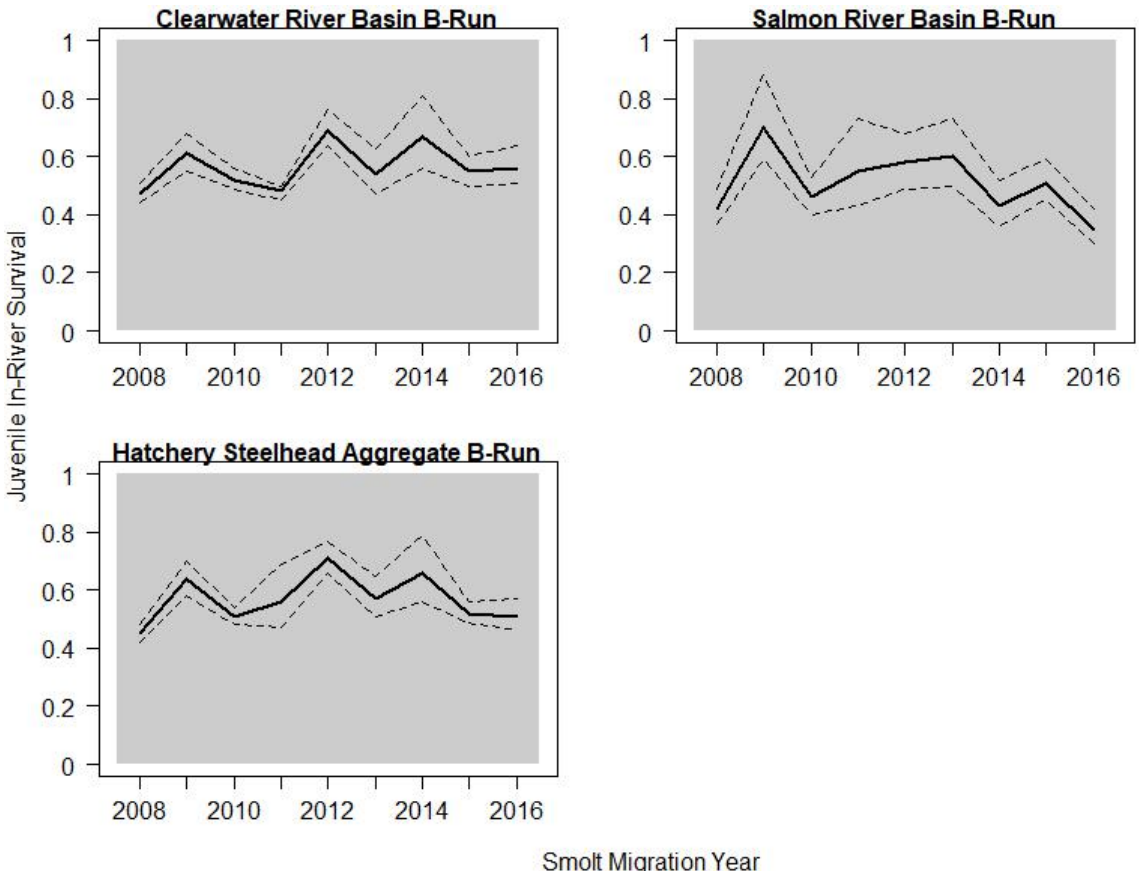

Figure A.7 Trend in juvenile in-river survival LGR to BON (S_R) for various groups of PIT-tagged Snake River B-Run hatchery steelhead (2008-2016) (with 90% confidence intervals). Shaded area highlights the period of Court Order spill and later start of transportation. Data displayed in figure are from Table A.6.

Table A.6. Estimated in-river survival LGR to BON (S_R) of PIT-tagged hatchery B-Run steelhead for migration years 2008 through 2016 (with 90% confidence intervals). All reach survival estimates are of combined T and R groups.

Migration Year	Clearwater R. B-run	Salmon R. B-run	Combined B-run
2008	0.47[2] (0.44 - 0.51)	0.42[2] (0.37 - 0.49)	0.45[2] (0.42 - 0.48)
2009	0.61 (0.55 - 0.68)	0.70 (0.59 - 0.88)	0.64 (0.58 - 0.70)
2010	0.52 (0.49 - 0.56)	0.46 (0.40 - 0.53)	0.51 (0.47 - 0.70)
2011	0.48[2] (0.46 - 0.50)	0.55[2] (0.43 - 0.73)	0.56 (0.47 - 0.69)
2012	0.69[1] (0.64 - 0.76)	0.58[1] (0.49 - 0.68)	0.71[1] (0.66 - 0.77)
2013	0.54 (0.47 - 0.63)	0.60[1] (0.50 - 0.73)	0.57 (0.51 - 0.65)
2014	0.67 (0.56 - 0.81)	0.43[1] (0.36 - 0.52)	0.66 (0.56 - 0.79)
2015	0.55 (0.50 - 0.60)	0.51 (0.45 - 0.59)	0.52 (0.49 - 0.56)
2016	0.56 (0.51 - 0.64)	0.35 (0.30 - 0.42)	0.51 (0.46 - 0.57)
Geomean	**0.56**	**0.50**	**0.56**

[1 to 3] Number of reaches with a constant "per mile" survival probability expansion applied (1 = 25% expansion JDA to BON; 2 = 51% expansion MCN to BON; 3 = 77% expansion LMN to BON).

Hatchery Sockeye

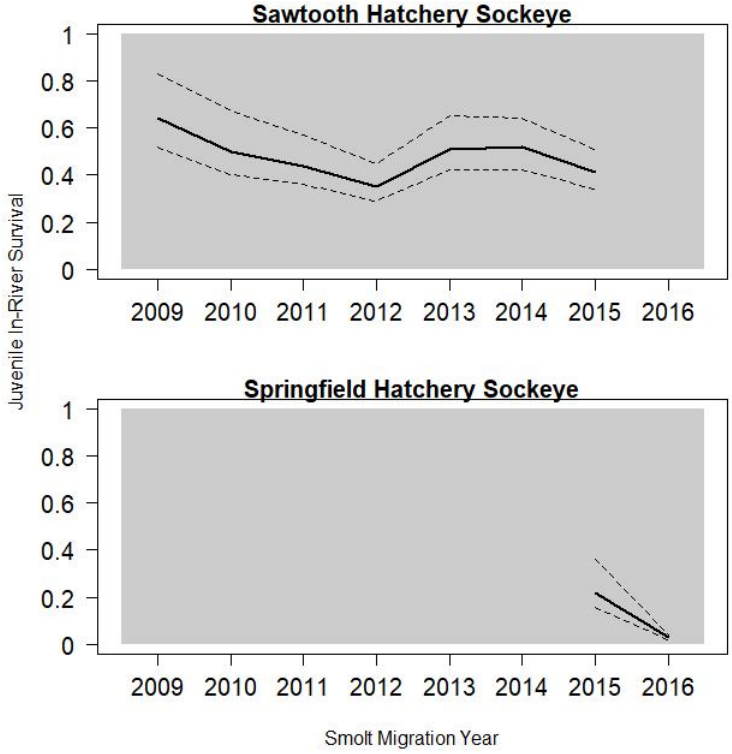

Figure A.8. Trend in in-river survival LGR to BON (S_R) of PIT-tagged Snake River hatchery sockeye from Sawtooth (2009-2015) and Springfield (2015-2016) hatcheries (with 90% confidence intervals). Shaded area highlights the period of Court Order spill and later start of transportation. Data displayed in figure are from Table A.7. Due to small sample sizes, S_R for Oxbow Hatchery sockeye could not be estimated.

Table A.7. Estimated in-river survival LGR to BON (S_R) of PIT-tagged Snake River hatchery sockeye from Sawtooth (2009-2015) and Springfield (2015-2016) hatcheries (with 90% confidence intervals). All reach survival estimates are of combined T and R groups. Due to small sample sizes, S_R for the Oxbow Hatchery sockeye could not be estimated.

Migration Year	Sawtooth Hatchery	Springfield Hatchery
2009	0.64 (0.52 - 0.83)	
2010	0.50 (0.40 - 0.67)	
2011	0.44[1] (0.35 - 0.57)	
2012	0.35 (0.29 - 0.45)	
2013	0.51 (0.42 - 0.65)	
2014	0.52[1] (0.42 - 0.64)	
2015	0.41 (0.34 - 0.51)	0.22 (0.16 - 0.36)
2016	---	0.03[1] (0.02 - 0.04)
Geomean	**0.47**	**0.08**

[1 to 3] Number of reaches with a constant "per mile" survival probability expansion applied (1 = 25% expansion JDA to BON; 2 = 51% expansion MCN to BON; 3 = 77% expansion LMN to BON).

Wild and Hatchery Subyearling Fall Chinook

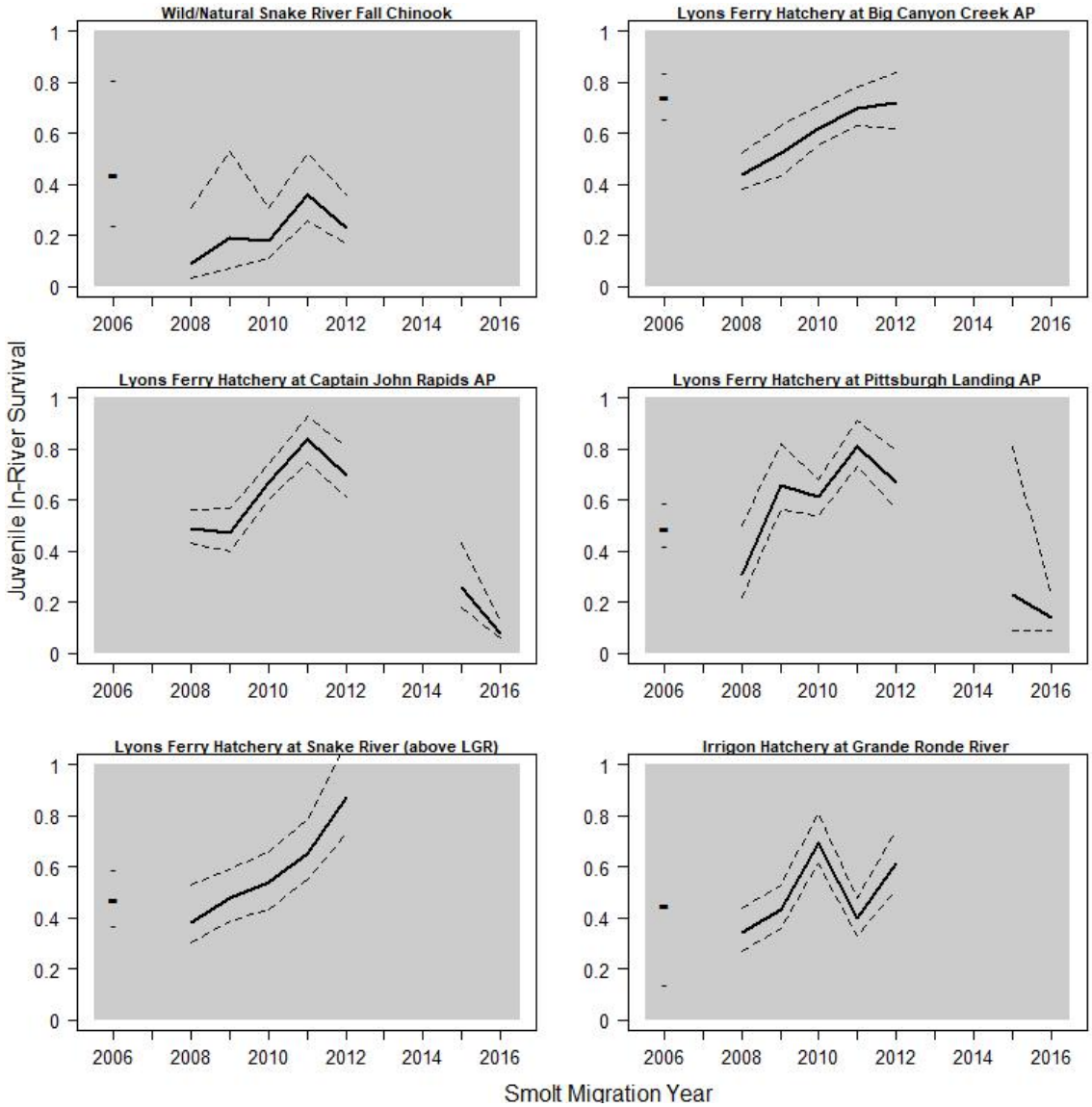

Figure A.9. Trend in in-river survival LGR to BON (S_R) for PIT-tagged Snake River wild/natural subyearling fall Chinook, Lyons Ferry Hatchery subyearling fall Chinook, and Irrigon Hatchery subyearling fall Chinook (released into the Grande Ronde River) (2006-2016) (with 90% confidence intervals). Shaded area highlights the period of Court Order spill and later start of transportation. Data for wild/natural and Lyons Ferry Hatchery fall Chinook are from Table A.8. Data for Irrigon Hatchery fall Chinook (released into the Grande Ronde River) are from Table A.9.

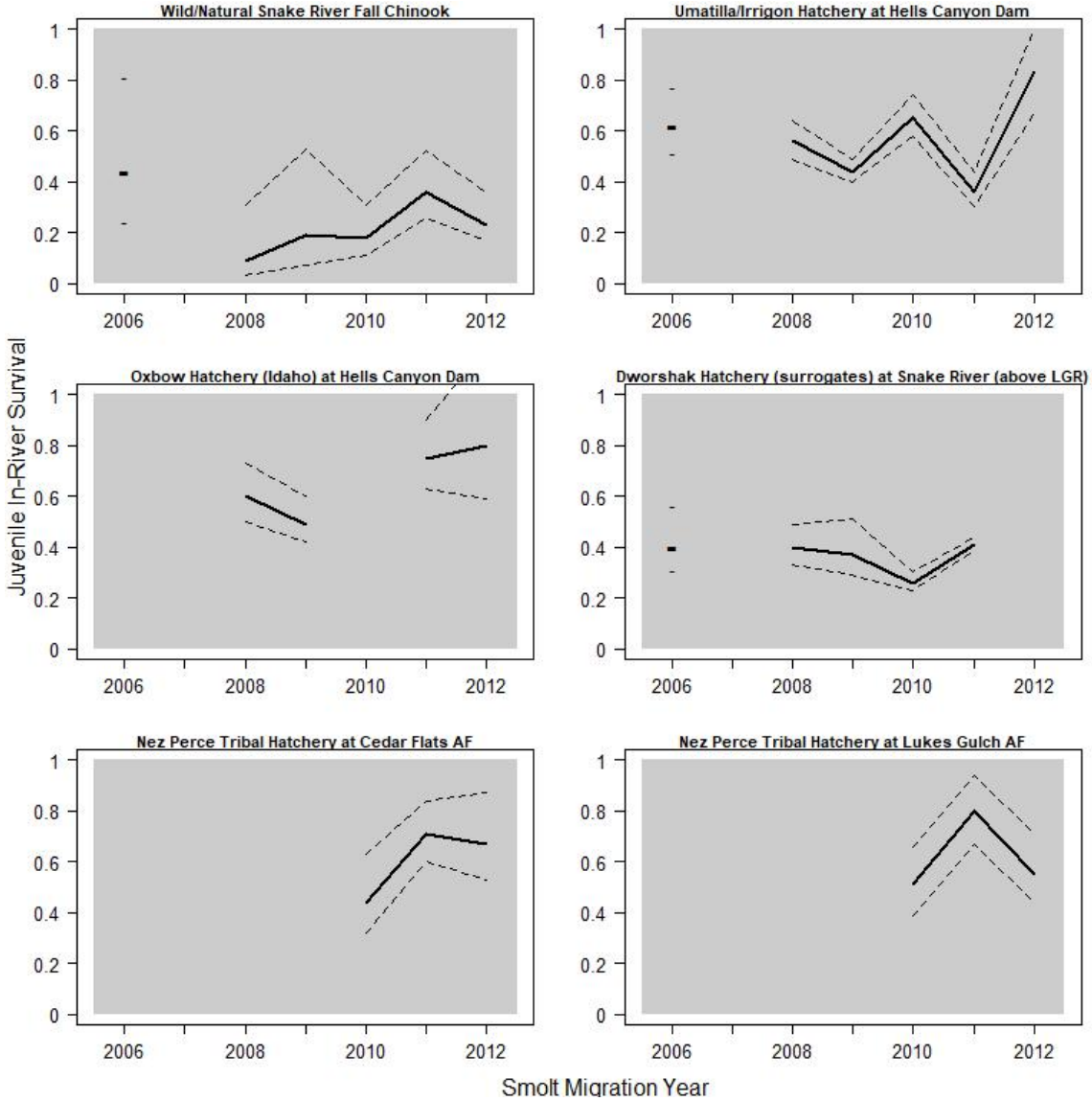

Figure A.10. Trend in in-river survival LGR to BON (S_R) for PIT-tagged Snake River wild/natural subyearling fall Chinook and Hatchery subyearling fall Chinook (various hatcheries and release sites) in migration years 2006 to 2012 (with 90% confidence intervals). Shaded area highlights the period of Court Order spill and later start of transportation. Data for wild/natural fall Chinook are from Table A.8. Data for hatchery fall Chinook (various hatcheries and release sites) are from Tables A.9 and A.10.

Table A.8. Estimated in-river survival LGR to BON (S_R) of PIT-tagged wild/natural subyearling fall Chinook and hatchery subyearling fall Chinook reared at Lyons Ferry Hatchery (LYFE) and released at Big Canyon Creek Acclimation Pond, Captain John Rapids Acclimation Pond, Pittsburg Landing Acclimation Pond or into the mainstem Snake River (above Lower Granite Dam) for migration years 2006 through 2012, and 2015-2016 (with 90% confidence intervals). All reach survival estimates are of combined T and R groups.

Migration Year	Wild/Natural fall Chinook	LYFE released at Big Canyon Creek AP	LYFE released at Captain John Rapids AP	LYFE released at Pittsburg Landing AP	LYFE released at Mainstem Snake River (above LGR)
2006	0.44[3] (0.24 – 0.81)	0.74 (0.66 – 0.84)		0.49[1] (0.42 – 0.59)	0.47[3] (0.37 – 0.59)
2007[A]	---	---	---	---	---
2008	0.09[2] (0.03 – 0.31)-	0.44[1] (0.38 – 0.52)	0.49[1] (0.43 – 0.56)	0.31[2] (0.22 – 0.50)	0.38[1] (0.30 – 0.53)
2009	0.19[2] (0.07 – 0.53)	0.52[1] (0.43 – 0.63)	0.47[1] (0.40 – 0.57)	0.66[1] (0.56 – 0.82)	0.48[1] (0.39 – 0.59)
2010	0.18[3] (0.11 – 0.31)	0.62[1] (0.55 – 0.71)	0.67[1] (0.60 – 0.74)	0.61[1] (0.54 – 0.68)	0.54[1] (0.43 – 0.66)
2011	0.36[3] (0.26 – 0.52)	0.70[3] (0.63 – 0.78)	0.84[3] (0.75 – 0.90)	0.81[3] (0.73 – 0.91)	0.65[3] (0.55 – 0.79)
2012	0.23[3] (0.17 – 0.36)	0.72[1] (0.62 – 0.84)	0.70[1] (0.61 – 0.81)	0.67[1] (0.57 – 0.80)	0.87[1] (0.73 – 1.08)
2015	---	---	0.26[1] (0.18 – 0.43)	0.23[3] (0.09 – 0.81)	---
2016	---	---	0.08[1] (0.06 – 0.12)	0.14[1] (0.09 – 0.23)	---
Geomean	**0.22**	**0.61**	**0.41**	**0.43**	**0.54**

[1 to 3] Number of reaches with a constant "per mile" survival probability expansion applied (1 = 25% expansion JDA to BON; 2 = 51% expansion MCN to BON; 3 = 77% expansion LMN to BON).

[A] S_R not reported for 2007 due to small sample sizes and lack of pre-assignments in that year.

Table A.9. Estimated in-river survival LGR to BON (S_R) of PIT-tagged hatchery subyearling fall Chinook released in various locations throughout the Snake River (above Lower Granite Dam) including: the Grande Ronde River (reared at Irrigon Hatchery), below Hells Canyon Dam (reared at Umatilla or Irrigon Hatchery), below Hells Canyon Dam (reared at Oxbow Hatchery in Idaho), and the mainstem Snake River (reared at Dworshak National Fish Hatchery) (surrogates) for migration years 2006 through 2012 (with 90% confidence intervals). All reach survival estimates are of combined T and R groups.

Migration Year	Irrigon Hatchery released into Grande Ronde River	Umatilla/Irrigon Hatchery released below Hells Canyon Dam	Oxbow Hatchery (Idaho) released below Hells Canyon Dam	Dworshak Hatchery (surrogates) released into Snake River
2006	0.45[2] (0.14 – 1.35)[A]	0.62[1] (0.51 – 0.77)	---	0.40[2] (0.31 – 0.56)
2007[B]	---	---	---	---
2008	0.34[1] (0.27 – 0.44)	0.56[1] (0.49 – 0.64)	0.60[1] (0.50 – 0.73)	0.40[2] (0.33 – 0.49)
2009	0.43[1] (0.36 – 0.53)	0.44[1] (0.40 – 0.49)	0.49[1] (0.42 – 0.60)	0.37[2] (0.29 – 0.51)
2010	0.69[1] (0.61 – 0.81)	0.65[1] (0.58 – 0.74)	---[C]	0.26[1] (0.23 – 0.30)
2011	0.40[3] (0.33 – 0.48)	0.36[3] (0.30 – 0.44)	0.75[3] (0.63 – 0.90)	0.41[3] (0.39 – 0.44)
2012	0.61[1] (0.51 – 0.74)	0.83[1] (0.67 – 1.00)	0.80[1] (0.59 – 1.19)	---[D]
Geomean	**0.47**	**0.56**	**0.65**	**0.36**

[1 to 3] Number of reaches with a constant "per mile" survival probability expansion applied (1 = 25% expansion JDA to BON; 2 = 51% expansion MCN to BON; 3 = 77% expansion LMN to BON).

[A] 2006 release into Grande Ronde River were reared at Lyons Ferry Hatchery

[B] S_R not reported for 2007 due to small sample sizes and lack of pre-assignments in that year.

[C] No PIT-tags were released for this group in 2010.

[D] S_R not reported due to high estimates of holdover rates.

Table A.10. Estimated in-river survival LGR to BON (S_R) of PIT-tagged hatchery subyearling fall Chinook reared at the Nez Perce Tribal Hatchery and released from Cedar Flats Acclimation Facility or Lukes Gulch Acclimation Facility for migration years 2010 through 2012 (with 90% confidence intervals). All reach survival estimates are of combined T and R groups.

Migration Year	Cedar Flats Acclimation Facility	Lukes Gulch Acclimation Facility
2010	0.44[1] (0.32 – 0.63)	0.51[1] (0.39 – 0.66)
2011	0.71[3] (0.60 – 0.84)	0.80[3] (0.67 – 0.94)
2012	0.67[1] (0.53 – 0.87)	0.55[1] (0.44 – 0.71)
Geomean	**0.59**	**0.61**

[1 to 3] Number of reaches with a constant "per mile" survival probability expansion applied (1 = 25% expansion JDA to BON; 2 = 51% expansion MCN to BON; 3 = 77% expansion LMN to BON).

Estimates of SAR by Study Category

Presented here are the LGR-to-GRA SAR estimates (without jacks for Chinook) by route of juvenile passage or study category. These SARs represent portions of the run as a whole, and the C_0 and transport SARs are components that make up TIR and *D*.

Wild and Hatchery Spring/Summer Chinook

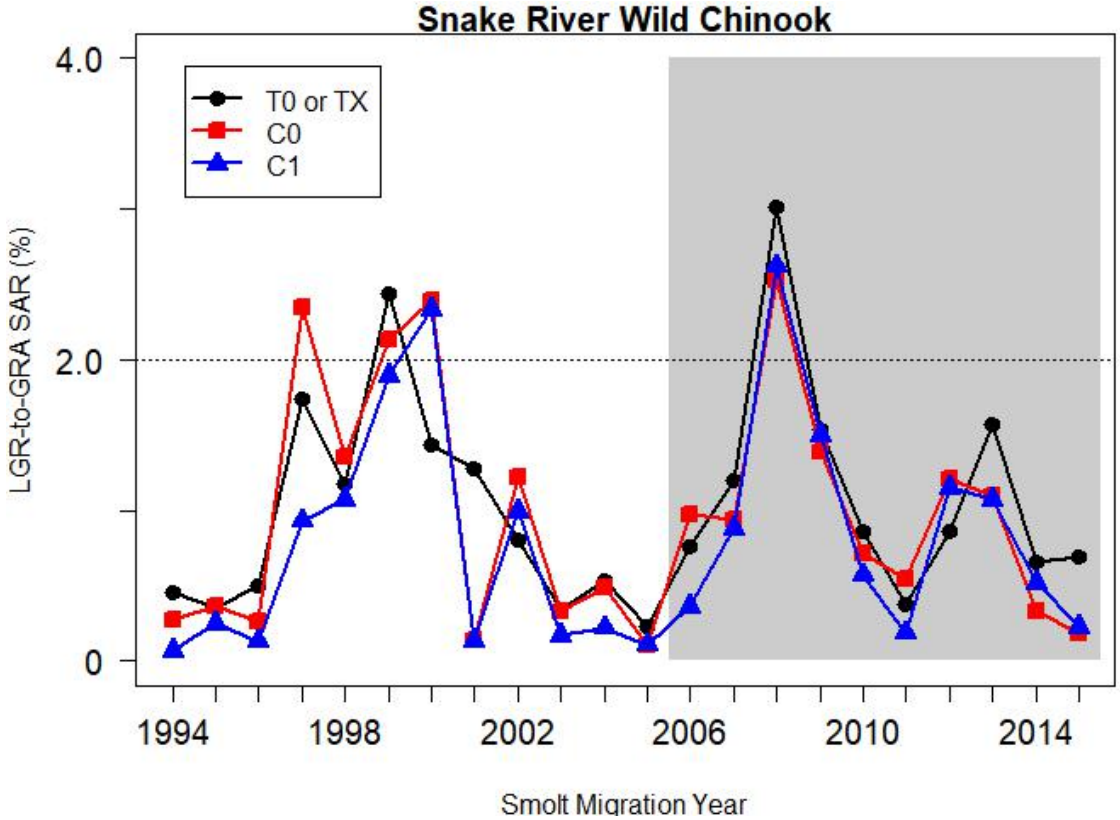

Figure A.11. Estimated LGR-to-GRA SAR (without jacks) for PIT-tagged wild spring/summer Chinook aggregate in transport (T_0 or T_X beginning 2006) and in-river (C_0 and C_1) study categories for migration years 1994 to 2015 (incomplete adult returns for 2015). Shaded area highlights the period of Court Order spill and later start of transportation. The NPCC (2014) 2% SAR objective for listed wild populations is shown for reference. For 2001 and 2005, only 1 in-river SAR was calculated (see methods). Wild Chinook data from Table A.11.

Table A.11. Estimated LGR-to-GRA SAR (%) (without jacks) for PIT-tagged wild Chinook in annual aggregate for each study category from 1994 to 2015 (with 90% confidence intervals).

Migration Year	SAR(T_0) %		SAR(C_0) %		SAR(C_1) %	
1994	0.45	(0.20 – 0.72)	0.28	(0.11 – 0.51)	0.07	(0.02 – 0.14)
1995	0.35	(0.17 – 0.57)	0.37	(0.18 – 0.57)	0.25	(0.18 – 0.32)
1996	0.50	(0.00 – 1.07)	0.26	(0.10 – 0.48)	0.13	(0.06 – 0.23)
1997	1.74	(0.44 – 3.27)	2.35	(1.45 – 3.36)	0.93	(0.60 – 1.32)
1998	1.18	(0.71 – 1.70)	1.36	(1.05 – 1.70)	1.07	(0.91 – 1.22)
1999	2.43	(1.85 – 3.07)	2.13	(1.78 – 2.50)	1.89	(1.76 – 2.04)
2000	1.43	(0.74 – 2.14)	2.39	(2.08 – 2.72)	2.33	(2.12 – 2.52)
2001	1.28	(0.54 – 2.14)	Assume = SAR(C1)		0.14	(0.10 – 0.18)
2002	0.80	(0.57 – 1.04)	1.22	(0.99 – 1.45)	0.99	(0.84 – 1.14)
2003	0.34	(0.24 – 0.45)	0.33	(0.23 – 0.43)	0.17	(0.12 – 0.23)
2004	0.53	(0.42 – 0.63)	0.49	(0.26 – 0.74)	0.22	(0.16 – 0.29)
2005	0.23	(0.17 – 0.29)	0.11 [A]	(0.07 – 0.15)		
Monitor Mode Years[B]	**SAR(T_X)_t %**		**SAR(C_0)_crt %**		**SAR(EC_1)_t %**	
2006	0.76	(0.60 – 0.90)	0.97	(0.71 – 1.26)	0.36	(0.18 – 0.56)
2007	1.20	(0.88 – 1.51)	0.94	(0.79 – 1.10)	0.88	(0.67 – 1.14)
2008	3.01	(2.70 – 3.30)	2.53	(2.23 – 2.87)	2.62	(2.22 – 3.04)
2009	1.54	(1.32 – 1.77)	1.39	(1.14 – 1.63)	1.50	(1.26 – 1.76)
2010	0.86	(0.71 – 1.00)	0.71	(0.62 – 0.81)	0.57	(0.26 – 0.91)
2011	0.38	(0.27 – 0.49)	0.55	(0.41 – 0.72)	0.19	(0.12 – 0.27)
2012	0.86	(0.64 – 1.11)	1.21	(1.00 – 1.42)	1.15	(1.00 – 1.32)
2013	1.57	(1.31 – 1.82)	1.10	(0.94 – 1.25)	1.07	(0.76 – 1.39)
2014	0.66	(0.52 – 0.82)	0.33	(0.22 – 0.44)	0.52	(0.41 – 0.65)
2015[C]	0.69	(0.39 – 0.99)	0.18	(0.12 – 0.25)	0.23	(0.09 – 0.40)
22-yr avg.	**1.04**	**(0.77 – 1.31)**	**0.97**	**(0.68 – 1.26)**	**0.79**	**(0.51 – 1.07)**

[A] In-river SAR is combination of groups C_0 and C_1.
[B] Estimated SARs for T_X and C_1 with Group T (reflects later start of transportation), and C_0 with combined Group CRT.
[C] Incomplete, 2-salt returns through Sept. 15, 2017.

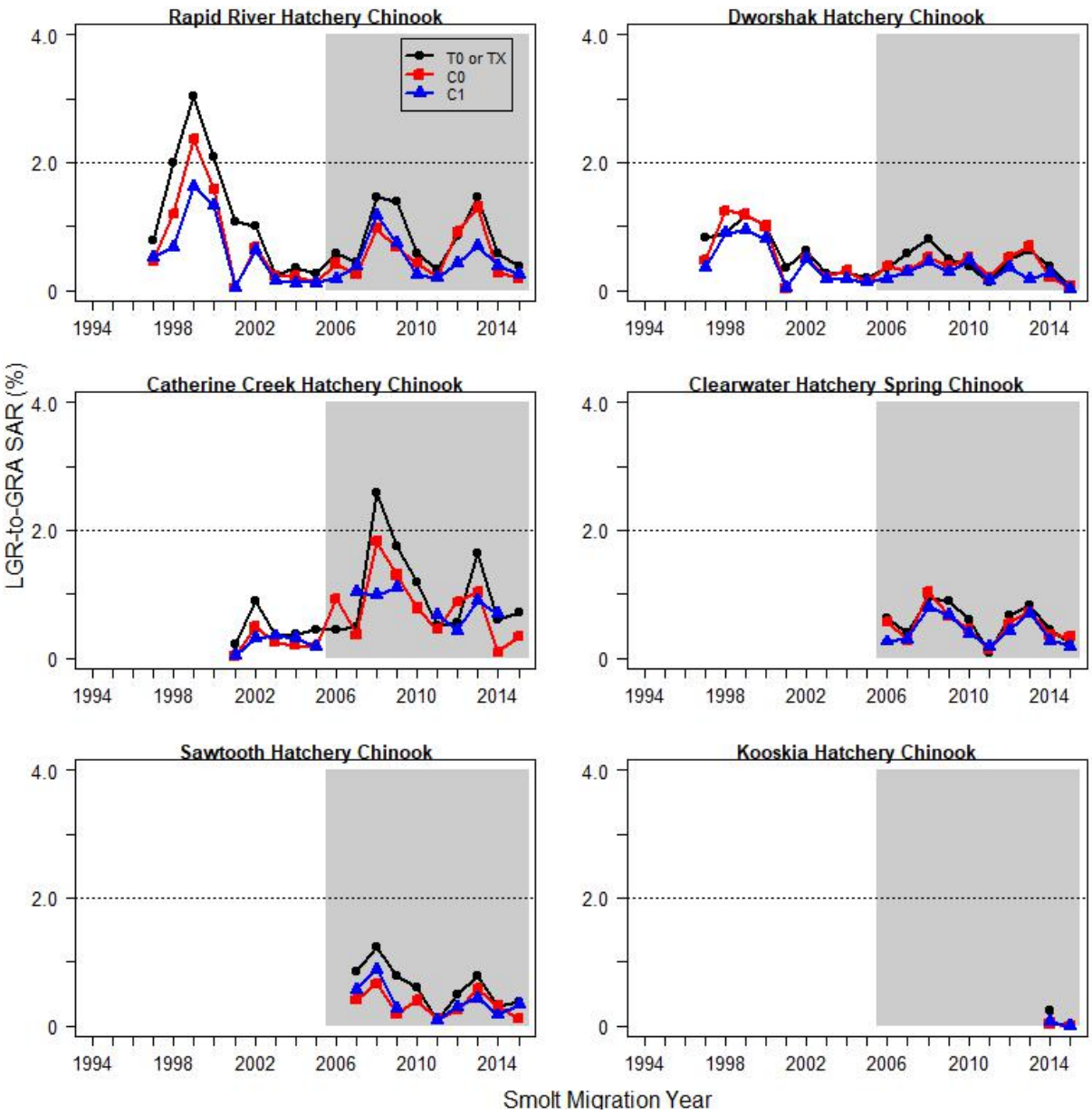

Figure A.12. Estimated LGR-to-GRA SAR (without jacks) for PIT-tagged spring Chinook from Rapid River, Dworshak, Catherine Creek (Lookingglass Hatchery), Clearwater, Sawtooth, and Kooskia hatcheries in transport (T_0 or T_X beginning 2006) and in-river (C_0 and C_1) study categories for migration years 1997 to 2015 (incomplete adult returns for 2015). Shaded area highlights the period of Court Order spill and later start of transportation. The NPCC (2014) 2% SAR objective for listed wild populations is shown for reference. For 2001 and 2005, only 1 in-river SAR was calculated (see methods). Data for individual hatchery groups are from tables A.12-A.17.

Table A.12. Estimated LGR-to-GRA SAR (%) (without jacks) for PIT-tagged spring Chinook from Rapid River Hatchery for each study category from 1997 to 2015 (with 90% confidence intervals).

Migration Year	SAR(T_0) %		SAR(C_0) %		SAR(C_1) %	
1997	0.79	(0.57 – 1.01)	0.45	(0.31 – 0.63)	0.53	(0.39 – 0.68)
1998	2.00	(1.80 – 2.21)	1.20	(0.95 – 1.48)	0.67	(0.56 – 0.79)
1999	3.04	(2.78 – 3.31)	2.37	(2.07 – 2.68)	1.63	(1.46 – 1.79)
2000	2.10	(1.91 – 2.28)	1.59	(1.40 – 1.81)	1.33	(1.07 – 1.58)
2001	1.08	(0.96 – 1.21)	{Assume =SAR(C_1)}		0.05	(0.02 – 0.08)
2002	1.01	(0.86 – 1.16)	0.67	(0.55 – 0.79)	0.63	(0.53 – 0.74)
2003	0.25	(0.18 – 0.32)	0.23	(0.17 – 0.29)	0.15	(0.08 – 0.24)
2004	0.36	(0.29 – 0.43)	0.23	(0.11 – 0.39)	0.12	(0.07 – 0.16)
2005	0.27	(0.21 – 0.34)	0.12[A]	(0.07 – 0.16)		
Monitor Mode Years[B]	**SAR(T_X)_t %**		**SAR(C_0)_crt %**		**SAR(EC_1)_t %**	
2006	0.57	(0.48– 0.66)	0.42	(0.30 – 0.54)	0.19	(0.05 – 0.35)
2007	0.45	(0.34 – 0.57)	0.25	(0.19 – 0.31)	0.38	(0.22 – 0.56)
2008	1.47	(1.32 – 1.62)	0.97	(0.82 – 1.13)	1.18	(0.90 – 1.48)
2009	1.40	(1.21 – 1.60)	0.68	(0.57 – 0.79)	0.74	(0.53 – 0.98)
2010	0.57	(0.43 – 0.74)	0.43	(0.37 – 0.50)	0.24	(0.00 – 0.74)
2011	0.33	(0.26 – 0.41)	0.23	(0.15 – 0.29)	0.20	(0.09 – 0.32)
2012	0.86	(0.73 – 1.01)	0.92	(0.79 – 1.06)	0.43	(0.28 – 0.58)
2013	1.45	(1.25 – 1.67)	1.30	(1.17 – 1.43)	0.70	(0.29 – 1.22)
2014	0.58	(0.48 – 0.69)	0.28	(0.21 – 0.34)	0.39	(0.16 – 0.66)
2015[C]	0.38	(0.24 – 0.52)	0.19	(0.15 – 0.23)	0.24	(0.00 – 0.55)
19-yr avg.	**1.00**	**(0.69 – 1.31)**	**0.66**	**(0.41 – 0.91)**	**0.52**	**(0.34 – 0.70)**

[A] In-river SAR is combination of groups C_0 and C_1.
[B] Estimated SARs for T_X and C_1 with Group T (reflects later start of transportation), and C_0 with combined Group CRT.
[C] Incomplete, 2-salt returns through Sept. 15, 2017.

Table A.13. Estimated LGR-to-GRA SAR (%) (without jacks) for PIT-tagged spring Chinook from Dworshak Hatchery for each study category from 1997 to 2015 (with 90% confidence intervals).

Migration Year	SAR(T_0) %		SAR(C_0) %		SAR(C_1) %	
1997	0.83	(0.52 – 1.19)	0.47	(0.26 – 0.72)	0.36	(0.21 – 0.54)
1998	0.90	(0.77 – 1.02)	1.25	(1.08 – 1.42)	0.90	(0.77 – 1.04)
1999	1.18	(1.01 – 1.35)	1.19	(1.01 – 1.37)	0.95	(0.82 – 1.07)
2000	1.00	(0.88 – 1.12)	1.01	(0.87 – 1.16)	0.81	(0.62 – 1.02)
2001	0.36	(0.29 – 0.43)	{Assume =SAR(C_1)}		0.04	(0.02 – 0.07)
2002	0.62	(0.49 – 0.75)	0.50	(0.42 – 0.58)	0.50	(0.40 – 0.58)
2003	0.26	(0.19 – 0.33)	0.21	(0.16 – 0.27)	0.18	(0.10 – 0.27)
2004	0.28	(0.23 – 0.35)	0.32	(0.21 – 0.44)	0.18	(0.13 – 0.25)
2005	0.20	(0.16 – 0.26)	0.14[A]	(0.10 – 0.19)		
Monitor Mode Years[B]	**SAR(T_X)_t %**		**SAR(C_0)_crt %**		**SAR(EC_1)_t %**	
2006	0.36	(0.29 – 0.44)	0.38	(0.30 – 0.47)	0.19	(0.09 – 0.31)
2007	0.59	(0.35 – 0.86)	0.32	(0.27 – 0.38)	0.29	(0.19 – 0.40)
2008	0.80	(0.64 – 0.95)	0.52	(0.43 – 0.61)	0.45	(0.30 – 0.61)
2009	0.49	(0.37 – 0.61)	0.38	(0.30 – 0.46)	0.29	(0.17 – 0.43)
2010	0.37	(0.24 – 0.52)	0.52	(0.46 – 0.59)	0.47	(0.25 – 0.69)
2011	0.13	(0.07 – 0.20)	0.21	(0.15 – 0.28)	0.15	(0.09 – 0.23)
2012	0.50	(0.35 – 0.66)	0.53	(0.44 – 0.63)	0.36	(0.25 – 0.46)
2013	0.62	(0.46 – 0.80)	0.69	(0.61 – 0.78)	0.18	(0.07 – 0.32)
2014	0.37	(0.29 – 0.47)	0.20	(0.15 – 0.26)	0.28	(0.13 – 0.44)
2015[C]	0.06	(0.00 – 0.19)	0.07	(0.04 – 0.10)	0.03	(0.00 – 0.09)
19-yr avg.	**0.52**	**(0.39 – 0.65)**	**0.47**	**(0.33 – 0.61)**	**0.36**	**(0.25 – 0.47)**

[A] In-river SAR is combination of groups C_0 and C_1.
[B] Estimated SARs for T_X and C_1 with Group T (reflects later start of transportation), and C_0 with combined Group CRT.
[C] Incomplete, 2-salt returns through Sept. 15, 2017.

Table A.14. Estimated LGR-to-GRA SAR (%) (without jacks) for PIT-tagged spring Chinook from Catherine Creek AP for each study category from 2001 to 2015 (with 90% confidence intervals).

Migration Year	SAR(T_0) %		SAR(C_0) %		SAR(C_1) %	
2001	0.23	(0.12 – 0.35)	{Assume =SAR(C1)}		0.04	(0.00 – 0.09)
2002	0.89	(0.59 – 1.20)	0.49	(0.28 – 0.74)	0.32	(0.18 – 0.50)
2003	0.36	(0.20 – 0.56)	0.25	(0.10 – 0.41)	0.35	(0.14 – 0.61)
2004	0.38	(0.21 – 0.57)	0.20	(0.00 – 0.60)	0.32	(0.11 – 0.54)
2005	0.44	(0.24 – 0.65)	0.18[A]	(0.04 – 0.35)		
Monitor Mode Years[B]	**SAR(T_X)_t %**		**SAR(C_0)_crt %**		**SAR(EC_1)_t %**	
2006[C]	0.45	(0.24 – 0.67)	0.93	(0.55 – 1.33)	---	
2007	0.50	(0.27 – 0.76)	0.37	(0.20 – 0.55)	1.04	(0.25 – 2.40)
2008	2.58	(2.15 – 3.02)	1.83	(1.39 – 2.27)	0.99	(0.44 – 1.71)
2009	1.76	(1.37 – 2.17)	1.30	(0.96 – 1.67)	1.10	(0.40 – 2.08)
2010[C,D]	1.18	(0.77 – 1.63)	0.78	(0.58 – 0.98)	---	
2011	0.52	(0.30 – 0.78)	0.45	(0.21 – 0.71)	0.67	(0.16 – 1.32)
2012	0.55	(0.27 – 0.90)	0.89	(0.55 – 1.29)	0.44	(0.11 – 0.81)
2013	1.63	(1.11 – 2.16)	1.03	(0.66 – 1.43)	0.90	(0.00 – 2.33)
2014	0.60	(0.34 – 0.86)	0.10	(0.00 – 0.26)	0.70	(0.19 – 1.51)
2015[C E]	0.71	(0.27 – 1.27)	0.34	(0.20 – 0.50)	---	
15-yr avg.	**0.85**	**(0.54 – 1.16)**	**0.61**	**(0.37 – 0.85)**	**0.59**	**(0.39 – 0.79)**

[A] In-river SAR is combination of groups C_0 and C_1.
[B] Estimated SARs for T_X and C_1 with Group T (reflects later start of transportation), and C_0 with combined Group CRT.
[C] C_1 SAR not estimable - small estimated juvenile population with zero returning adults.
[D] See Section: *Special Considerations for Migration Year 2010* on page A-11.
[E] Incomplete, 2-salt returns through Sept. 15, 2017.

Table A.15. Estimated LGR-to-GRA SAR (%) (without jacks) for PIT-tagged spring Chinook from Clearwater Hatchery for each study category from 2006 to 2015 (with 90% confidence intervals).

Migration Year[A]	SAR(T_X)_t %		SAR(C_0)_crt %		SAR(EC_1)_t %	
2006	0.63	(0.53 – 0.74)	0.57	(0.43 – 0.70)	0.26	(0.09 – 0.47)
2007	0.41	(0.24 – 0.58)	0.28	(0.22 – 0.33)	0.30	(0.18 – 0.43)
2008	0.93	(0.76 – 1.11)	1.03	(0.85 – 1.22)	0.80	(0.53 – 1.08)
2009	0.89	(0.71 – 1.08)	0.66	(0.56 – 0.76)	0.67	(0.52 – 0.85)
2010[B]	0.60	(0.42 – 0.76)	0.45	(0.39 – 0.50)	0.39	(0.19 – 0.63)
2011	0.09	(0.04 – 0.15)	0.14	(0.09 – 0.19)	0.18	(0.12 – 0.24)
2012	0.67	(0.48 – 0.85)	0.55	(0.46 – 0.64)	0.44	(0.36 – 0.53)
2013	0.82	(0.61 – 1.03)	0.73	(0.66 – 0.82)	0.71	(0.51 – 0.92)
2014	0.45	(0.32 – 0.59)	0.37	(0.30 – 0.45)	0.28	(0.18 – 0.38)
2015[C]	0.25	(0.00 – 0.75)	0.34	(0.26 – 0.42)	0.19	(0.10 – 0.31)
10-yr avg.	**0.57**	**(0.40 – 0.74)**	**0.51**	**(0.35 – 0.67)**	**0.42**	**(0.28 – 0.56)**

[A] All monitor mode years, estimated SARs for T_X and C_1 with Group T (reflects later start of transportation), and C_0 with combined Group CRT.
[B] See Section: *Special Considerations for Migration Year 2010* on page A-11.
[C] Incomplete, 2-salt returns through Sept. 15, 2017.

Table A.16. Estimated LGR-to-GRA SAR (%) (without jacks) for PIT-tagged spring Chinook from Sawtooth Hatchery for each study category from 2007 to 2015 (with 90% confidence intervals).

Migration Year[A]	SAR(T_X)_t %		SAR(C_0)_crt %		SAR(EC_1)_t %	
2007	0.85	(0.61 – 1.12)	0.41	(0.26 – 0.59)	0.57	(0.14 – 1.11)
2008	1.23	(0.89 – 1.61)	0.66	(0.32 – 1.03)	0.89	(0.22 – 1.79)
2009	0.79	(0.48 – 1.13)	0.19	(0.09 – 0.32)	0.28	(0.00 – 0.64)
2010[B,C]	0.60	(0.35 – 0.89)	0.40	(0.27 – 0.54)	---	
2011	0.09	(0.02 – 0.18)	0.11	(0.03 – 0.22)	0.09	(0.00 – 0.26)
2012	0.49	(0.29 – 0.72)	0.25	(0.11 – 0.42)	0.30	(0.07 – 0.58)
2013	0.79	(0.58 – 1.02)	0.58	(0.41 – 0.76)	0.44	(0.00 – 1.68)
2014	0.31	(0.17 – 0.47)	0.31	(0.18 – 0.44)	0.17	(0.00 – 0.37)
2015[D]	0.37	(0.15 – 0.61)	0.11	(0.06 – 0.16)	0.33	(0.00 – 0.98)
9-yr avg.	**0.61**	**(0.38 – 0.84)**	**0.34**	**(0.21 – 0.47)**	**0.38**	**(0.20 – 0.56)**

[A] All monitor mode years, estimated SARs for T_X and C_1 with Group T (reflects later start of transportation), and C_0 with combined Group CRT.
[B] See Section: *Special Considerations for Migration Year 2010* on page A-11.
[C] C_1 SAR not estimable - small estimated juvenile population with zero returning adults.
[D] Incomplete, 2-salt returns through Sept. 15, 2017.

Table A.17. Estimated LGR-to-GRA SAR (%) (without jacks) for PIT-tagged spring Chinook from Kooskia Hatchery for each study category from 2014 to 2015 (with 90% confidence intervals).

Migration Year[A]	SAR(T_X)_t %	SAR(C_0)_crt %	SAR(EC_1)_t %
2014	0.24 (0.06 – 0.43)	0.04 (0.00 – 0.11)	0.07 (0.00 – 0.20)
2015[B,C]	---	0.00 (0.00 – 0.00)	0.00 (0.00 – 0.00)

[A] All monitor mode years, estimated SARs for T_X and C_1 with Group T (reflects later start of transportation), and C_0 with combined Group CRT.
[B] Transport SAR not estimable – small estimated juvenile population and zero returning adults.
[C] Incomplete, 2-salt returns through Sept. 15, 2017.

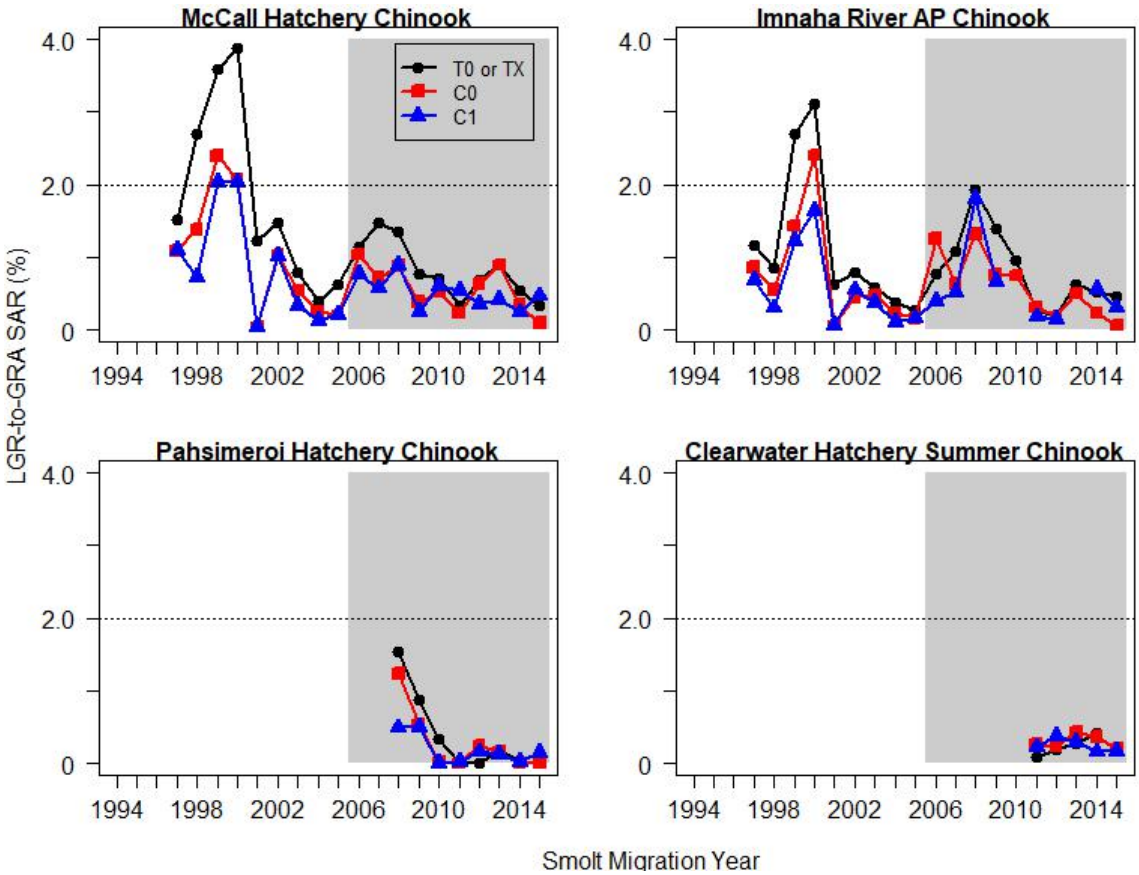

Figure A.13. Estimated LGR-to-GRA SAR (without jacks) for PIT-tagged summer Chinook from McCall, Imnaha (Lookingglass Hatchery), Pahsimeroi, and Clearwater hatcheries in transport (T_0 or T_X beginning 2006) and in-river (C_0 and C_1) study categories for migration years 1994 to 2015 (incomplete adult returns for 2015). Shaded area highlights the period of Court Order spill and later start of transportation. The NPCC (2014) 2% SAR objective for listed wild populations is shown for reference. For 2001 and 2005, only 1 in-river SAR was calculated (see methods). Data for individual hatchery groups are from tables A.18-A.21.

Table A.18. Estimated LGR-to-GRA SAR (%)(without jacks) for PIT-tagged summer Chinook from McCall Hatchery for each study category from 1997 to 2015 (with 90% confidence intervals).

Migration Year	SAR(T_0) %		SAR(C_0) %		SAR(C_1) %	
1997	1.51	(1.26 – 1.77)	1.09	(0.88 – 1.34)	1.10	(0.92 – 1.29)
1998	2.69	(2.44 – 2.96)	1.38	(1.05 – 1.69)	0.73	(0.62 – 0.87)
1999	3.59	(3.29 – 3.87)	2.40	(2.12 – 2.69)	2.03	(1.82 – 2.26)
2000	3.88	(3.60 – 4.18)	2.06	(1.84 – 2.29)	2.03	(1.68 – 2.38)
2001	1.24	(1.10 – 1.38)	{Assume =SAR(C1)}		0.04	(0.01 – 0.07)
2002	1.48	(1.27 – 1.70)	1.03	(0.87 – 1.20)	1.02	(0.89 – 1.18)
2003	0.79	(0.68 – 0.92)	0.54	(0.45 – 0.62)	0.34	(0.24 – 0.46)
2004	0.40	(0.34 – 0.48)	0.25	(0.09 – 0.44)	0.12	(0.07 – 0.16)
2005	0.62	(0.54 – 0.71)	0.20[A]	(0.16 – 0.26)		
Monitor Mode Years[B]	**SAR(T_X)_t %**		**SAR(C_0)_crt %**		**SAR(EC_1)_t %**	
2006	1.15	(1.01 – 1.30)	1.04	(0.85 – 1.22)	0.77	(0.42 – 1.20)
2007	1.48	(1.20 – 1.75)	0.71	(0.60 – 0.82)	0.57	(0.32 – 0.86)
2008	1.35	(1.17 – 1.54)	0.88	(0.73 – 1.03)	0.89	(0.59 – 1.24)
2009	0.76	(0.60 – 0.94)	0.38	(0.30 – 0.47)	0.25	(0.09 – 0.43)
2010[C]	0.71	(0.54 – 0.91)	0.52	(0.44 – 0.61)	0.61	(0.00 – 1.43)
2011	0.33	(0.24 – 0.43)	0.23	(0.17 – 0.31)	0.54	(0.35 – 0.76)
2012	0.69	(0.52 – 0.86)	0.63	(0.51 – 0.76)	0.36	(0.24 – 0.50)
2013	0.89	(0.73 – 1.07)	0.89	(0.78 – 0.99)	0.42	(0.10 – 0.94)
2014	0.55	(0.43 – 0.66)	0.34	(0.27 – 0.42)	0.24	(0.06 – 0.44)
2015[D]	0.33	(0.20 – 0.47)	0.09	(0.07 – 0.12)	0.47	(0.00 – 1.77)
19-yr avg.	**1.29**	**(0.87 – 1.71)**	**0.77**	**(0.51 – 1.03)**	**0.67**	**(0.44 – 0.90)**

[A] In-river SAR is combination of groups C_0 and C_1.
[B] Estimated SARs for T_X and C_1 with Group T (reflects later start of transportation), and C_0 with combined Group CRT.
[C] See Section: *Special Considerations for Migration Year 2010* on page A-11.
[D] Incomplete, 2-salt returns through Sept. 15, 2017.

Table A.19. Estimated LGR-to-GRA SAR (%) (without jacks) for PIT-tagged summer Chinook from Imnaha River AP for each study category from 1997 to 2015 (with 90% confidence intervals).

Migration Year	SAR(T_0) %		SAR(C_0) %		SAR(C_1) %	
1997	1.16	(0.77 – 1.60)	0.86	(0.53 – 1.22)	0.69	(0.48 – 0.93)
1998	0.85	(0.65 – 1.09)	0.55	(0.28 – 0.83)	0.30	(0.20 – 0.42)
1999	2.69	(2.28 – 3.08)	1.43	(1.08 – 1.82)	1.22	(0.98 – 1.49)
2000	3.11	(2.77 – 3.44)	2.41	(2.01 – 2.83)	1.64	(1.22 – 2.08)
2001	0.62	(0.49 – 0.78)	{Assume =SAR(C_1)}		0.06	(0.01 – 0.11)
2002	0.79	(0.56 – 1.04)	0.45	(0.29 – 0.63)	0.55	(0.38 – 0.72)
2003	0.58	(0.40 – 0.75)	0.48	(0.34 – 0.62)	0.38	(0.20 – 0.59)
2004	0.38	(0.26 – 0.49)	0.23	(0.07 – 0.48)	0.11	(0.04 – 0.20)
2005	0.28	(0.18 – 0.40)	0.16[A]	(0.08 – 0.26)		
Monitor Mode Years[B]	**SAR(T_X)_t %**		**SAR(C_0)_crt %**		**SAR(EC_1)_t %**	
2006	0.77	(0.58 – 0.97)	1.25	(0.93 – 1.61)	0.40	(0.10 – 0.77)
2007	1.07	(0.73 – 1.43)	0.63	(0.48 – 0.79)	0.52	(0.28 – 0.80)
2008	1.92	(1.61 – 2.23)	1.32	(1.02 – 1.65)	1.80	(1.30 – 2.35)
2009	1.39	(1.10 – 1.67)	0.76	(0.57 – 0.97)	0.67	(0.33 – 1.07)
2010[C,D]	0.95	(0.65 – 1.27)	0.75	(0.61 – 0.91)	---	
2011	0.26	(0.13 – 0.38)	0.31	(0.16 – 0.47)	0.18	(0.00 – 0.44)
2012	0.20	(0.07 – 0.33)	0.18	(0.10 – 0.30)	0.14	(0.05 – 0.25)
2013[D]	0.63	(0.40 – 0.86)	0.50	(0.38 – 0.63)	---	
2014	0.52	(0.36 – 0.69)	0.23	(0.13 – 0.35)	0.56	(0.13 – 1.11)
2015[E]	0.45	(0.24 – 0.67)	0.06	(0.02 – 0.10)	0.30	(0.00 – 0.87)
19-yr avg.	**0.98**	**(0.65 – 1.31)**	**0.66**	**(0.42 – 0.90)**	**0.57**	**(0.34 – 0.80)**

[A] In-river SAR is combination of groups C_0 and C_1.
[B] Estimated SARs for T_X and C_1 with Group T (reflects later start of transportation), and C_0 with combined Group CRT.
[C] See Section: *Special Considerations for Migration Year 2010* on page A-11.
[D] C_1 SAR not estimable - small estimated juvenile population with zero returning adults.
[E] Incomplete, 2-salt returns through Sept. 15, 2017.

Table A.20. Estimated LGR-to-GRA SAR (%) (without jacks) for PIT-tagged summer Chinook from Pahsimeroi Hatchery for each study category from 2008 to 2015 (with 90% confidence intervals).

Migration Year[A]	SAR(T_X)_t %		SAR(C_0)_crt %		SAR(EC_1)_t %	
2008	1.53	(1.18 – 1.88)	1.24	(0.85 – 1.63)	0.49	(0.12 – 0.95)
2009	0.87	(0.19 – 1.58)	0.54	(0.36 – 0.73)	0.50	(0.31 – 0.71)
2010[B]	0.33	(0.08 – 0.64)	0.02	(0.00 – 0.05)	---	
2011	0.00	(0.00 – 0.00)	0.00	(0.00 – 0.00)	0.02	(0.00 – 0.07)
2012[C]	---		0.24	(0.11 – 0.38)	0.16	(0.08 – 0.25)
2013	0.17	(0.00 – 0.36)	0.15	(0.08 – 0.22)	0.12	(0.00 – 0.28)
2014	0.04	(0.00 – 0.11)	0.00	(0.00 – 0.00)	0.02	(0.00 – 0.07)
2015[C,D]	---		0.01	(0.00 – 0.02)	0.14	(0.00 – 0.36)
8-yr avg.	**0.49**	**(0.00[E] – 1.03)**	**0.28**	**(0.00[E] – 0.59)**	**0.21**	**(0.05 – 0.37)**

[A] All monitor mode years, estimated SARs for T_X and C_1 with Group T (reflects later start of transportation), and C_0 with combined Group CRT.
[B] C_1 SAR not estimable – small estimated juvenile population and zero returning adults.
[C] Transport SAR not estimable – small estimated juvenile population and zero returning adults.
[D] Incomplete, 2-salt returns through Sept. 15, 2017.
[E] The lower limit of the 90% confidence interval is shown as 0.00 rather than the negative value resulting from the limited degree of freedom and lack of precision.

Table A.21. Estimated LGR-to-GRA SAR (%) (without jacks) for PIT-tagged summer Chinook from Clearwater Hatchery for each study category from 2011 to 2015 (with 90% confidence intervals).

Migration Year[A]	SAR(T_X)_t %		SAR(C_0)_crt %		SAR(EC_1)_t %	
2011	0.08	(0.00 – 0.17)	0.26	(0.14 – 0.38)	0.22	(0.10 – 0.37)
2012	0.19	(0.06 – 0.39)	0.23	(0.12 – 0.35)	0.38	(0.25 – 0.52)
2013	0.27	(0.09 – 0.45)	0.43	(0.31 – 0.55)	0.29	(0.07 – 0.56)
2014	0.42	(0.26 – 0.60)	0.36	(0.25 – 0.47)	0.16	(0.06 – 0.29)
2015[B,C]	---		0.21	(0.15 – 0.28)	0.17	(0.04 – 0.31)
5-yr avg.	**0.24**	**(0.05 – 0.43)**	**0.30**	**(0.20 – 0.40)**	**0.24**	**(0.14 – 0.34)**

[A] All monitor mode years, estimated SARs for T_X and C_1 with Group T (reflects later start of transportation), and C_0 with combined Group CRT.
[B] Transport SAR not estimable – small estimated juvenile population and zero returning adults.
[C] Incomplete, 2-salt returns through Sept. 15, 2017.

Wild and Hatchery Steelhead

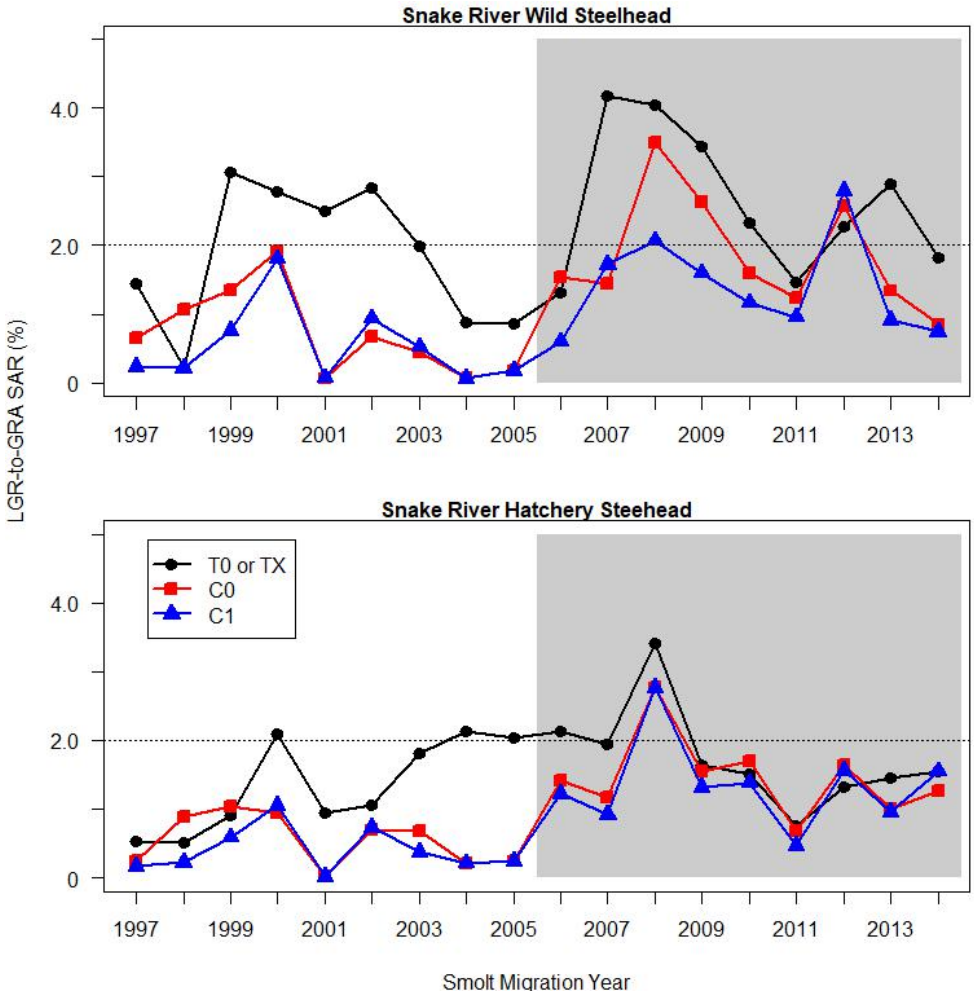

Figure A.14. Estimated LGR-to-GRA SAR for PIT-tagged wild and hatchery steelhead aggregate in transport (T_0 or T_X beginning 2008) and in-river (C_0 and C_1) study categories for migration years 1997 to 2014. Shaded area highlights the period of Court Order spill and later start of transportation. The NPCC (2014) 2% SAR objective for listed wild populations is shown for reference. For 2001, 2004, and 2005, only 1 in-river SAR was calculated (see methods). Data for wild steelhead from Table A.22 and hatchery steelhead aggregate from Table A.23. SARs for wild steelhead (2006-2014) and hatchery steelhead aggregate (2008-2014) include all groups with pre-assignment in those years (see Tables A.22-A.31 for details).

Table A.22. Estimated LGR-to-GRA SAR (%) for PIT-tagged wild steelhead in annual aggregate for each study category from 1997 to 2014 (with 90% confidence intervals).

Migration Year	SAR(T_0) %		SAR(C_0) %		SAR(C_1) %	
1997	1.45	(0.36 – 2.80)	0.66	(0.00 – 1.34)	0.23	(0.10 – 0.39)
1998	0.21	(0.00 – 0.63)	1.07	(0.51 – 1.73)	0.21	(0.12 – 0.33)
1999	3.07	(1.74 – 4.66)	1.35	(0.80 – 1.96)	0.76	(0.60 – 0.94)
2000	2.79	(1.55 – 4.11)	1.92	(1.40 – 2.49)	1.81	(1.59 – 2.03)
2001	2.49	(0.93 – 4.37)	{Assume =SAR(C_1)}		0.07	(0.03 – 0.10)
2002	2.84	(1.52 – 4.43)	0.67	(0.46 – 0.90)	0.94	(0.77 – 1.11)
2003	1.99	(1.52 – 2.51)	0.45	(0.27 – 0.66)	0.52	(0.37 – 0.66)
2004	0.87	(0.65 – 1.11)	0.06[A]	(0.02 – 0.11)		
2005	0.84	(0.63 – 1.07)	0.17[A]	(0.11 – 0.25)		
Monitor Mode Years[B]	**SAR(T_X)_t %**		**SAR(C_0)_crt %**		**SAR(EC_1)_t %**	
2006	1.31	(1.02 – 1.66)	1.54	(0.72 – 2.44)	0.60	(0.27 – 0.92)
2007	4.18	(3.60 – 4.83)	1.44	(1.12 – 1.79)	1.72	(1.17 – 2.33)
2008	4.05	(3.43 – 4.76)	3.49	(2.89 – 4.09)	2.07	(1.50 – 2.70)
2009	3.45	(2.88 – 4.01)	2.64	(2.07 – 3.31)	1.60	(1.15 – 2.08)
2010	2.33	(1.87 – 2.80)	1.60	(1.35 – 1.87)	1.17	(0.53 – 1.92)
2011	1.46	(1.07 – 1.87)	1.24	(0.84 – 1.70)	0.96	(0.55 – 1.43)
2012	2.27	(1.64 – 2.89)	2.57	(2.07 – 3.09)	2.80	(2.35 – 3.30)
2013	2.89	(2.45 – 3.34)	1.34	(1.09 – 1.63)	0.91	(0.47 – 1.40)
2014[C]	1.82	(1.51 – 2.17)	0.85	(0.64 – 1.07)	0.74	(0.44 – 1.11)
18-yr avg.	**2.24**	**(1.78 – 2.70)**	**1.29**	**(0.90 – 1.68)**	**0.96**	**(0.63 – 1.29)**

[A] In-river SAR is combination of groups C_0 and C_1.
[B] Estimated SARs for T_X and C_1 with Group T (reflects later start of transportation), and C_0 with combined Group CRT.
[C] Incomplete steelhead adult returns until 3-salt returns (if any) occur after Sept. 15, 2017 at GRA.

Table A.23. Estimated LGR-to-GRA SAR (%) for PIT-tagged hatchery steelhead in annual aggregate for each study category from 1997 to 2014 (with 90% confidence intervals).

MigrationYear	SAR(T_0) %		SAR(C_0) %		SAR(C_1) %	
1997	0.52	(0.24 – 0.81)	0.24	(0.09 – 0.39)	0.17	(0.12 – 0.22)
1998	0.51	(0.22 – 0.84)	0.89	(0.61 – 1.19)	0.22	(0.17 – 0.28)
1999	0.90	(0.51 – 1.33)	1.04	(0.79 – 1.31)	0.59	(0.51 – 0.69)
2000	2.10	(1.22 – 3.07)	0.95	(0.71 – 1.19)	1.05	(0.92 – 1.18)
2001	0.94	(0.24 – 1.78)	{Assume =SAR(C_1)}		0.016	(0.005 – 0.03)
2002	1.06	(0.32 – 2.11)	0.70	(0.54 – 0.88)	0.73	(0.61 – 0.85)
2003	1.81	(1.50 – 2.13)	0.68	(0.52 – 0.86)	0.37	(0.26 – 0.47)
2004	2.13	(1.17 – 3.27)	0.21[A]	(0.15 – 0.26)		
2005	2.03	(1.28 – 2.83)	0.24[A]	(0.18 – 0.30)		
2006[B]	2.14	(1.49 – 2.84)	1.42	(0.94 – 1.93)	1.23	(1.06 – 1.41)
2007[B]	1.94	(1.51 – 2.38)	1.17	(0.96 – 1.38)	0.92	(0.78 – 1.07)
Monitor Mode Years[C]	**SAR(T_X)_t %**		**SAR(C_0)_crt %**		**SAR(EC_1)_t %**	
2008[D]	3.41	(3.25 – 3.56)	2.78	(2.63 – 2.92)	2.77	(2.57 – 2.97)
2009	1.65	(1.55 – 1.75)	1.55	(1.44 – 1.66)	1.32	(1.22 – 1.42)
2010	1.51	(1.41 – 1.63)	1.69	(1.61 – 1.76)	1.38	(1.16 – 1.62)
2011	0.75	(0.68 – 0.82)	0.68	(0.61 – 0.75)	0.47	(0.41 – 0.53)
2012	1.32	(1.21 – 1.43)	1.64	(1.53 – 1.75)	1.56	(1.46 – 1.67)
2013	1.45	(1.35 – 1.56)	1.01	(0.95 – 1.07)	0.96	(0.82 – 1.10)
2014[E]	1.55	(1.45 – 1.66)	1.27	(1.20 – 1.35)	1.55	(1.40 – 1.71)
18-yr avg.	**1.54**	**(1.25 – 1.83)**	**1.01**	**(0.73 – 1.29)**	**0.88**	**(0.59 – 1.17)**

[A] In-river SAR is combination of groups C_0 and C_1.
[B] No pre-assignment for hatchery steelhead, so one group; transport SARs estimated with T_X smolts.
[C] Estimated SARs for T_X and C_1 with Group T (reflects later start of transportation), and C_0 with combined Group CRT.
[D] SARs for 2008 hatchery steelhead aggregate includes all groups with pre-assignment (see Tables A.20–A.27 for details).
[E] Incomplete steelhead adult returns until 3-salt returns (if any) occur after Sept. 15, 2017 at GRA.

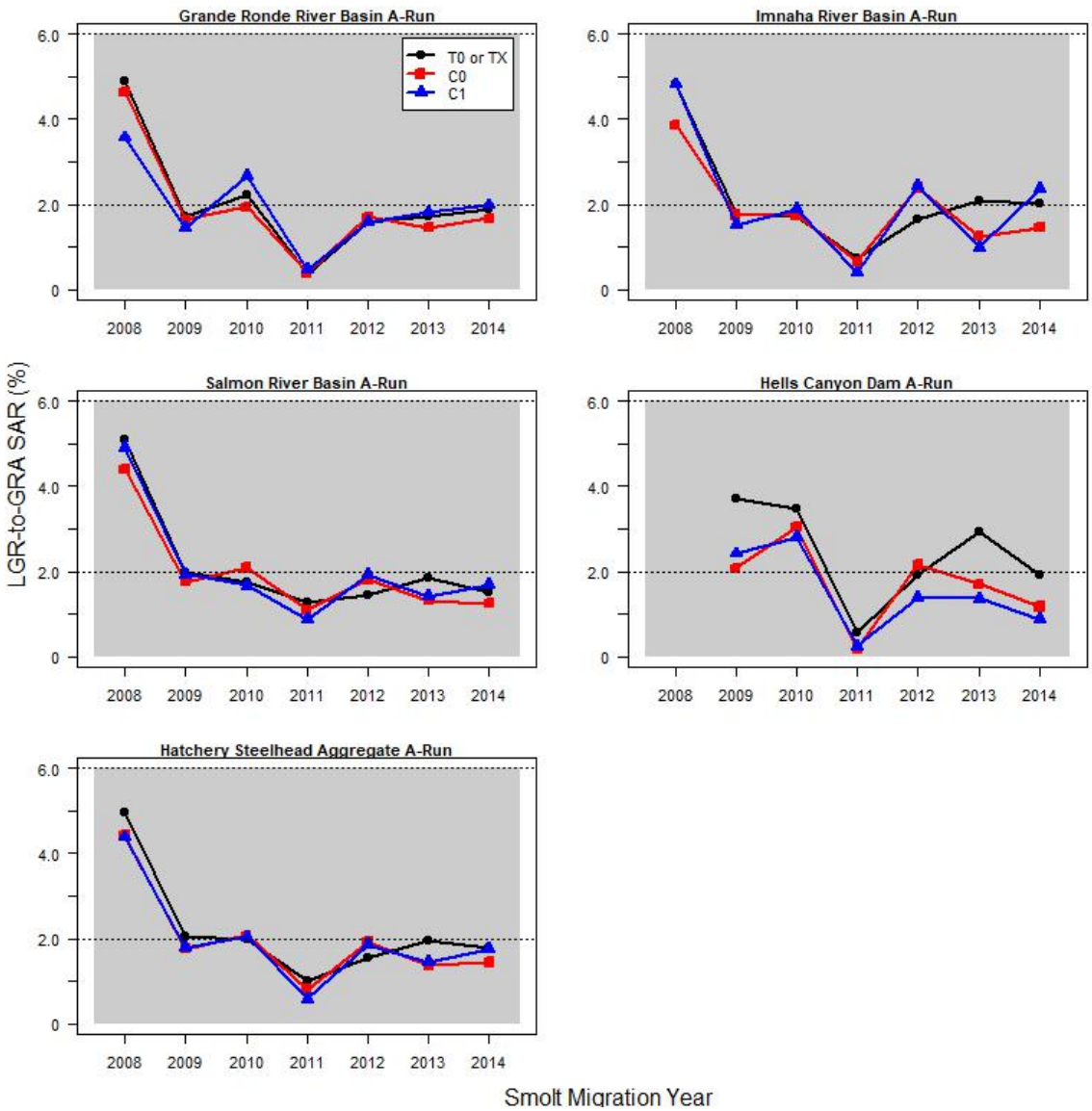

Figure A.15. Estimated LGR-to-GRA SAR (%) for individual groups of PIT-tagged A-run hatchery steelhead in transport (T_0 or T_X beginning 2008) and in-river (C_0 and C_1) study categories for migration years 2008 to 2014. Shaded area highlights the period of Court Order spill and later start of transportation. The NPCC (2014) 2%-6% SAR objective for listed wild populations is shown for reference. Data for individual A-run hatchery steelhead groups are from Tables A.24–A.28.

Table A.24. Estimated LGR-to-GRA SAR (%) for PIT-tagged Grande Ronde Basin (A-Run) hatchery steelhead for each study category from 2008 to 2014 (with 90% confidence intervals).

Migration Year[A]	SAR(T_X)_t %		SAR(C_0)_crt %		SAR(EC_1)_t %	
2008[B]	4.89	(4.46 – 5.33)	4.65	(4.18 – 5.15)	3.57	(3.04 – 4.10)
2009	1.72	(1.47 – 2.00)	1.64	(1.37 – 1.91)	1.46	(1.15 – 1.80)
2010	2.22	(1.86 – 2.57)	1.94	(1.74 – 2.15)	2.67	(1.82 – 3.66)
2011	0.37	(0.23 – 0.53)	0.40	(0.29 – 0.52)	0.46	(0.32 – 0.61)
2012	1.58	(1.24 – 1.96)	1.71	(1.44 – 1.98)	1.58	(1.34 – 1.83)
2013	1.71	(1.41 – 2.02)	1.45	(1.27 – 1.66)	1.81	(1.30 – 2.41)
2014[C]	1.88	(1.56 – 2.21)	1.67	(1.47 – 1.88)	1.98	(1.54 – 2.41)
7-yr avg.	**2.05**	**(0.96 – 3.14)**	**1.92**	**(0.89 – 2.96)**	**1.93**	**(1.15 – 2.71)**

[A] All monitor mode years, estimated SARs for T_X and C_1 with Group T (reflects later start of transportation), and C_0 with combined Group CRT.
[B] Not pre-assigned to T and R groups. Pre-2006 methods applied for this year (see *Pre-2006 Migration Years* in above Methods section for details).
[C] Incomplete steelhead adult returns until 3-salt returns (if any) occur after Sept. 15, 2017, at GRA.

Table A.25. Estimated LGR-to-GRA SAR (%) for PIT-tagged Imnaha Basin (A-Run) hatchery steelhead for each study category from 2008 to 2014 (with 90% confidence intervals).

Migration Year[A]	SAR(T_X)_t %		SAR(C_0)_crt %		SAR(EC_1)_t %	
2008[B]	4.84	(4.35 – 5.31)	3.87	(3.35 – 4.42)	4.82	(4.07 – 5.61)
2009	1.78	(1.48 – 2.06)	1.75	(1.44 – 2.08)	1.51	(1.13 – 1.86)
2010	1.72	(1.41 – 2.04)	1.75	(1.52 – 1.98)	1.90	(1.10 – 2.94)
2011	0.75	(0.55 – 0.95)	0.66	(0.48 – 0.86)	0.39	(0.19 – 0.63)
2012	1.65	(1.32 – 1.99)	2.39	(1.97 – 2.81)	2.43	(2.01 – 2.86)
2013	2.10	(1.77 – 2.44)	1.25	(1.03 – 1.50)	0.99	(0.49 – 1.57)
2014[C]	2.03	(1.75 – 2.34)	1.45	(1.17 – 1.71)	2.36	(1.62 – 3.25)
7-yr avg.	**2.12**	**(1.11 – 3.13)**	**1.87**	**(1.06 – 2.68)**	**2.06**	**(0.93 – 3.19)**

[A] All monitor mode years, estimated SARs for T_X and C_1 with Group T (reflects later start of transportation), and C_0 with combined Group CRT.
[B] Not pre-assigned to T and R groups. Pre-2006 methods applied for this year (see *Pre-2006 Migration Years* in above Methods section for details).
[C] Incomplete steelhead adult returns until 3-salt returns (if any) occur after Sept. 15, 2017, at GRA.

Table A.26. Estimated LGR-to-GRA SAR (%) for PIT-tagged Salmon River Basin (A-Run) hatchery steelhead for each study category from 2008 to 2014 (with 90% confidence intervals).

Migration Year[A]	SAR(T_X)_t %		SAR(C_0)_crt %		SAR(EC_1)_t %	
2008	5.09	(4.73 – 5.49)	4.41	(4.01 – 4.78)	4.91	(4.25 – 5.60)
2009	2.00	(1.81 – 2.20)	1.76	(1.53 – 2.00)	1.94	(1.71 – 2.19)
2010	1.76	(1.56 – 1.97)	2.09	(1.93 – 2.25)	1.67	(1.14 – 2.25)
2011	1.28	(1.14 – 1.43)	1.10	(0.95 – 1.26)	0.87	(0.69 – 1.08)
2012	1.45	(1.26 – 1.64)	1.82	(1.62 – 2.02)	1.93	(1.72 – 2.14)
2013	1.85	(1.65 – 2.06)	1.32	(1.18 – 1.44)	1.41	(1.01 – 1.82)
2014[B]	1.51	(1.29 – 1.74)	1.25	(1.09 – 1.41)	1.69	(1.32 – 2.06)
7-yr avg.	**2.13**	**(1.08 – 3.18)**	**1.96**	**(1.06 – 2.86)**	**2.06**	**(1.02 – 3.10)**

[A] All monitor mode years, estimated SARs for T_X and C_1 with Group T (reflects later start of transportation), and C_0 with combined Group CRT.

[B] Incomplete steelhead adult returns until 3-salt returns (if any) occur after Sept. 15, 2017, at GRA.

Table A.27. Estimated LGR-to-GRA SAR (%) for PIT-tagged Hells Canyon Dam (A-Run) hatchery steelhead for each study category from 2009 to 2014 (with 90% confidence intervals).

Migration Year[A]	SAR(T_X)_t %		SAR(C_0)_crt %		SAR(EC_1)_t %	
2009	3.71	(3.04 – 4.27)	2.08	(1.46 – 2.71)	2.42	(1.64 – 3.30)
2010[B]	3.49	(2.77 – 4.22)	3.04	(2.54 – 3.60)	2.81	(0.50 – 8.04)
2011	0.56	(0.24 – 0.91)	0.19	(0.00 – 0.46)	0.25	(0.10 – 0.45)
2012	1.93	(1.15 – 2.77)	2.15	(1.49 – 2.90)	1.38	(0.92 – 1.80)
2013	2.92	(2.16 – 3.79)	1.70	(1.30 – 2.11)	1.37	(0.49 – 2.61)
2014[C]	1.91	(1.39 – 2.51)	1.17	(0.82 – 1.57)	0.88	(0.46 – 1.39)
6-yr avg.	**2.42**	**(1.35 – 3.49)**	**1.72**	**(0.85 – 2.59)**	**1.52**	**(0.66 – 2.38)**

[A] All monitor mode years, estimated SARs for T_X and C_1 with Group T (reflects later start of transportation), and C_0 with combined Group CRT.

[B] See Section: *Special Considerations for Migration Year 2010*.

[C] Incomplete steelhead adult returns until 3-salt returns (if any) occur after Sept. 15, 2017, at GRA.

Table A.28. Estimated LGR-to-GRA SAR (%) for PIT-tagged hatchery steelhead (Aggregate A-Run) for each study category from 2008 to 2014 (with 90% confidence intervals).

Migration Year[A]	SAR(T_X)_t %		SAR(C_0)_crt %		SAR(EC_1)_t %	
2008	4.96	(4.71 – 5.22)	4.42	(4.14 – 4.70)	4.38	(3.98 – 4.79)
2009	2.04	(1.91 – 2.19)	1.76	(1.61 – 1.91)	1.79	(1.62 – 1.95)
2010	2.00	(1.84 – 2.14)	2.07	(1.96 – 2.19)	2.04	(1.67 – 2.49)
2011	0.99	(0.89 – 1.09)	0.81	(0.71 – 0.90)	0.59	(0.50 – 0.69)
2012	1.54	(1.40 – 1.70)	1.92	(1.78 – 2.06)	1.85	(1.71 – 2.00)
2013	1.94	(1.80 – 2.10)	1.38	(1.29 – 1.48)	1.45	(1.20 – 1.74)
2014[B]	1.79	(1.65 – 1.94)	1.44	(1.32 – 1.55)	1.76	(1.50 – 2.00)
7-yr avg.	**2.18**	**(1.17 – 3.19)**	**1.97**	**(1.05 – 2.89)**	**1.98**	**(1.06 – 2.90)**

[A] All monitor mode years, estimated SARs for T_X and C_1 with Group T (reflects later start of transportation), and C_0 with combined Group CRT.

[B] Incomplete steelhead adult returns until 3-salt returns (if any) occur after Sept. 15, 2017, at GRA.

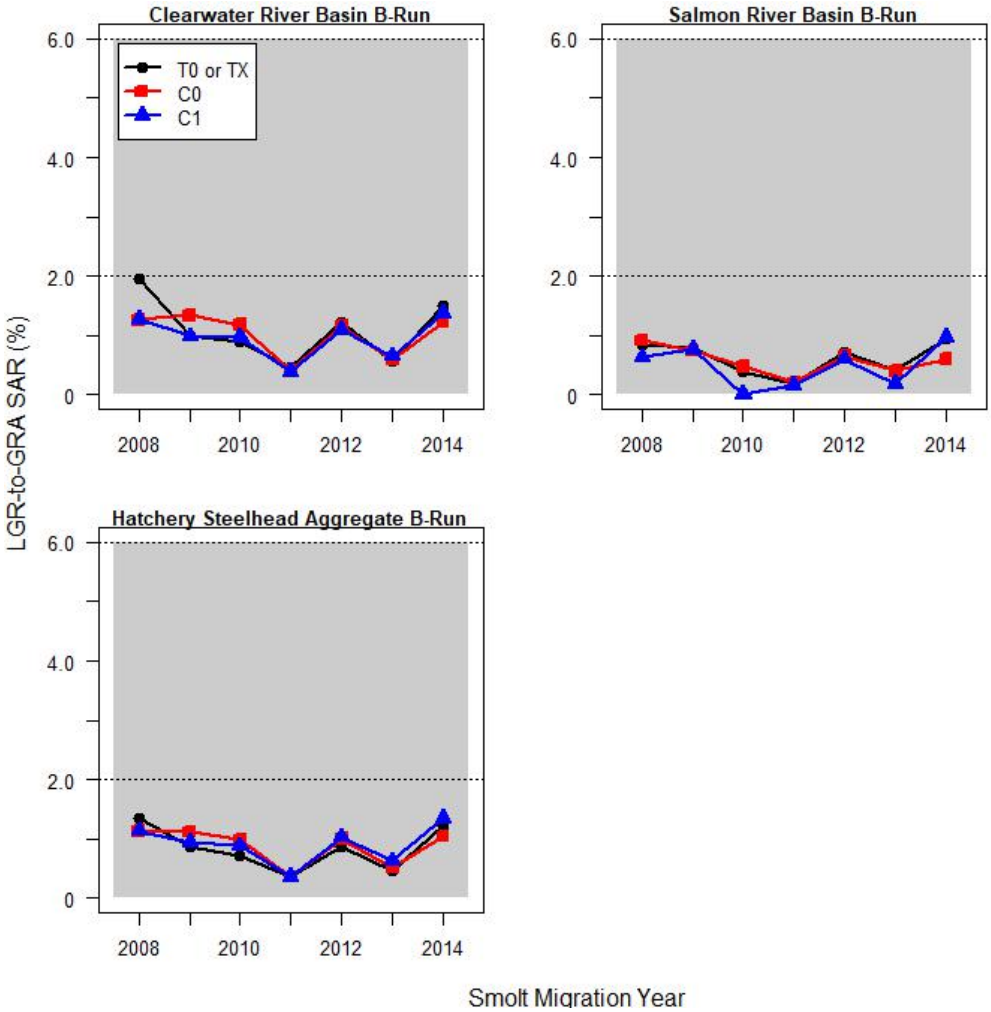

Figure A.16. Estimated LGR-to-GRA SAR (%) for individual groups of PIT-tagged B-run hatchery steelhead in transport (T_0 or T_X beginning 2008) and in-river (C_0 and C_1) study categories for migration years 2008 to 2014. Shaded area highlights the period of Court Order spill and later start of transportation. The NPCC (2014) 2%-6% SAR objective for listed wild populations is shown for reference. Data for individual B-run hatchery steelhead groups are from Tables A.29–A.31.

Table A.29. Estimated LGR-to-GRA SAR (%) for PIT-tagged Clearwater River Basin (B-Run) hatchery steelhead for each study category from 2008 to 2014 (with 90% confidence intervals).

Migration Year[A]	SAR(T_X)_t %		SAR(C_0)_crt %		SAR(EC_1)_t %	
2008	1.96	(1.68 – 2.23)	1.26	(1.10 – 1.43)	1.28	(1.05 – 1.49)
2009	0.99	(0.79 – 1.20)	1.34	(1.12 – 1.57)	0.98	(0.86 – 1.11)
2010	0.90	(0.73 – 1.06)	1.18	(1.07 – 1.31)	0.97	(0.71 – 1.25)
2011	0.47	(0.36 – 0.60)	0.41	(0.31 – 0.53)	0.39	(0.32 – 0.47)
2012	1.21	(0.87 – 1.57)	1.15	(0.94 – 1.37)	1.09	(0.93 – 1.25)
2013	0.56	(0.36 – 0.74)	0.59	(0.51 – 0.68)	0.65	(0.51 – 0.80)
2014[B]	1.50	(1.28 – 1.75)	1.22	(1.08 – 1.36)	1.38	(1.15 – 1.59)
7-yr avg.	**1.08**	**(0.66 – 1.50)**	**1.02**	**(0.73 – 1.31)**	**0.96**	**(0.69 – 1.23)**

[A] All monitor mode years, estimated SARs for T_X and C_1 with Group T (reflects later start of transportation), and C_0 with combined Group CRT.

[B] Incomplete steelhead adult returns until 3-salt returns (if any) occur after Sept. 15, 2017, at GRA.

Table A.30. Estimated LGR-to-GRA SAR (%) for PIT-tagged Salmon River Basin (B-Run) hatchery steelhead for each study category from 2008 to 2014 (with 90% confidence intervals).

Migration Year[A]	SAR(T_X)_t %		SAR(C_0)_crt %		SAR(EC_1)_t %	
2008	0.84	(0.68 – 1.01)	0.92	(0.74 – 1.11)	0.63	(0.37 – 0.92)
2009	0.79	(0.64 – 0.95)	0.74	(0.54 – 0.94)	0.77	(0.55 – 1.02)
2010[B]	0.38	(0.25 – 0.54)	0.48	(0.36 – 0.60)	---	
2011	0.18	(0.10 – 0.28)	0.20	(0.09 – 0.32)	0.16	(0.00 – 0.34)
2012	0.72	(0.56 – 0.91)	0.65	(0.45 – 0.86)	0.60	(0.30 – 0.97)
2013	0.40	(0.29 – 0.53)	0.40	(0.28 – 0.52)	0.19	(0.00 – 0.59)
2014[C]	0.95	(0.79 – 1.14)	0.60	(0.45 – 0.76)	0.96	(0.37 – 1.82)
7-yr avg.	**0.61**	**(0.38 – 0.84)**	**0.57**	**(0.38 – 0.76)**	**0.55**	**(0.26 – 0.84)**

[A] All monitor mode years, estimated SARs for T_X and C_1 with Group T (reflects later start of transportation), and C_0 with combined Group CRT.

[B] C_1 SAR not estimable – small estimated juvenile population and zero returning adults.

[C] Incomplete steelhead adult returns until 3-salt returns (if any) occur after Sept. 15, 2017, at GRA.

Table A.31. Estimated LGR-to-GRA SAR (%) for PIT-tagged hatchery steelhead (Aggregate B-Run) for each study category from 2008 to 2014 (with 90% confidence intervals).

Migration Year[A]	SAR(T_X)_t %		SAR(C_0)_crt %		SAR(EC_1)_t %	
2008	1.34	(1.20 – 1.49)	1.13	(1.02 – 1.26)	1.13	(0.95 – 1.32)
2009	0.87	(0.74 – 1.01)	1.12	(0.96 – 1.29)	0.94	(0.83 – 1.06)
2010	0.72	(0.60 – 0.84)	0.99	(0.90 – 1.09)	0.88	(0.67 – 1.10)
2011	0.36	(0.28 – 0.44)	0.36	(0.28 – 0.44)	0.37	(0.31 – 0.44)
2012	0.87	(0.72 – 1.03)	1.00	(0.84 – 1.16)	1.03	(0.89 – 1.17)
2013	0.45	(0.34 – 0.56)	0.52	(0.45 – 0.59)	0.63	(0.50 – 0.78)
2014[B]	1.21	(1.06 – 1.36)	1.04	(0.93 – 1.14)	1.35	(1.15 – 1.55)
7-yr avg.	**0.83**	**(0.54 – 1.12)**	**0.88**	**(0.64 – 1.12)**	**0.90**	**(0.64 – 1.16)**

[A] All monitor mode years, estimated SARs for T_X and C_1 with Group T (reflects later start of transportation), and C_0 with combined Group CRT.

[B] Incomplete steelhead adult returns until 3-salt returns (if any) occur after Sept. 15, 2017, at GRA.

Hatchery Sockeye

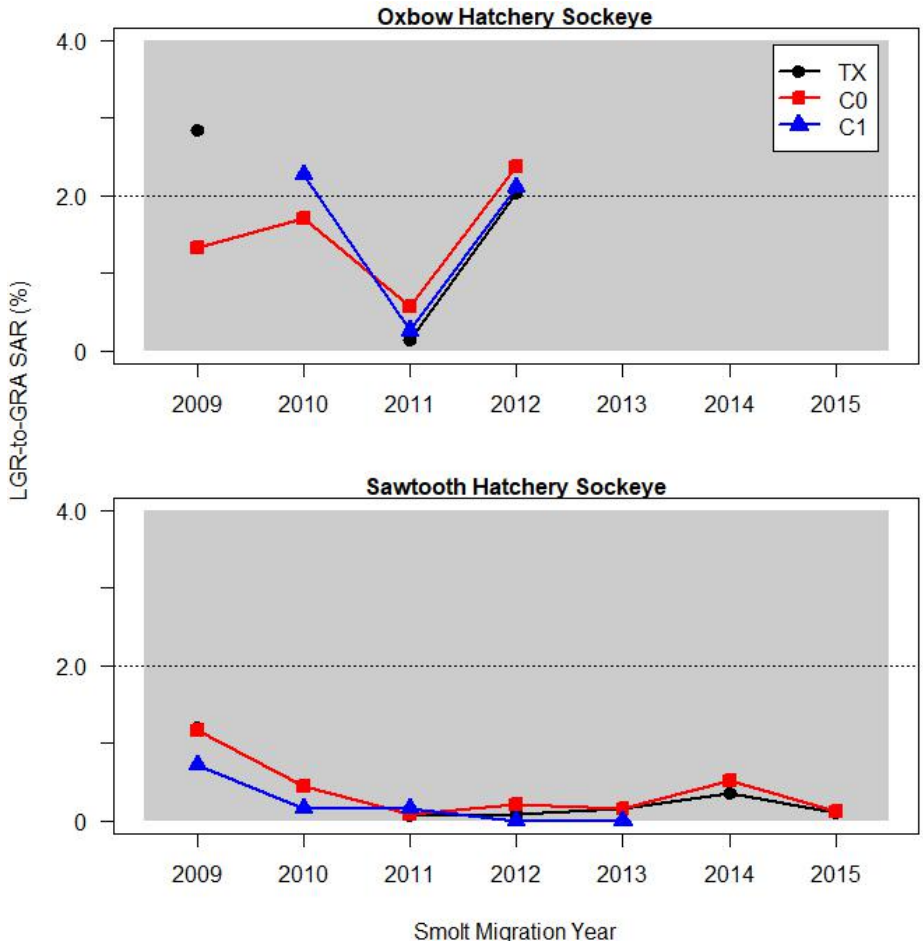

Figure A.17. Estimated LGR-to-GRA SAR for PIT-tagged sockeye from Oxbow and Satwooth hatcheries in transport (T_X) and in-river (C_0 and C_1) study categories for migration years 2009 to 2015 (incomplete adult returns for 2015). Shaded area highlights the period of Court Order spill and later start of transportation. The NPCC (2014) 2% SAR objective for listed wild populations is shown for reference. Data for individual hatchery sockeye groups are from Tables A.32 and A.33. Springfield hatchery sockeye not displayed due to only one year of SAR data (Table A.34).

Table A.32. Estimated LGR-to-GRA SAR (%) for PIT-tagged sockeye reared from Oxbow Hatchery for each study category from 2009 to 2012 (with 90% confidence intervals). Estimates beyond 2012 are not possible, due to decreased in PIT-tag release numbers.

Migration Year[A]	SAR(T_X)_t %	SAR(C_0)_crt %	SAR(EC_1)_t %
2009[B,C]	2.84 (1.89 – 3.64)	1.33 (0.89 – 1.86)	---
2010[D,E]	---	1.71 (1.18 – 2.29)	2.27 (1.03 – 3.71)
2011	0.14 (0.00 – 0.29)	0.58 (0.36 – 0.82)	0.26 (0.06 – 0.52)
2012	2.03 (1.41 – 2.70)	2.37 (1.88 – 2.92)	2.11 (0.00 – 11.11)
4-yr avg.	**1.67 (0.00 – 4.53)[F]**	**1.50 (0.48 – 2.52)**	**1.55 (0.00 – 3.86)[F]**

[A] All monitor mode years, estimated SARs for T_X and C_1 with Group T (reflects later start of transportation), and C_0 with combined Group CRT.
[B] Used same methodology outlined in *Special Considerations for Migration Year 2010* (see page A-11) for 2009 Oxbow.
[C] C_1 SAR not estimable – small estimated juvenile population and zero returning adults.
[D] See Section: *Special Considerations for Migration Year 2010* on page A-11.
[E] Transport SAR not estimable – small estimated juvenile population and zero returning adults.
[F] Lower limit of 90% confidence interval shows as 0.00 rather than negative value resulting from limited degrees of freedom and lack of precision.

Table A.33. Estimated LGR-to-GRA SAR (%) for PIT-tagged sockeye reared from Sawtooth Hatchery for each study category from 2009 to 2015 (with 90% confidence intervals).

Migration Year[A]	SAR(T_X)_t %	SAR(C_0)_crt %	SAR(EC_1)_t %
2009	1.21 (1.03 – 1.40)	1.16 (0.98 – 1.35)	0.72 (0.35 – 1.15)
2010[B]	---	0.45 (0.29 – 0.60)	0.16 (0.00 – 0.34)
2011	0.07 (0.03 – 0.13)	0.08 (0.04 – 0.12)	0.16 (0.09 – 0.24)
2012	0.08 (0.04 – 0.12)	0.21 (0.13 – 0.30)	0.00 (0.00 – 0.00)
2013	0.16 (0.10 – 0.23)	0.16 (0.10 – 0.22)	0.00 (0.00 – 0.00)
2014[C]	0.36 (0.24 – 0.50)	0.52 (0.43 – 0.62)	---
2015[C,D]	0.10 (0.00 – 0.21)	0.13 (0.09 – 0.18)	---
6-yr avg.	**0.33 (0.00[E] – 0.73)**	**0.39 (0.09 – 0.69)**	**0.21 (0.00[E] – 0.53)**

[A] All monitor mode years, estimated SARs for T_X and C_1 with Group T (reflects later start of transportation), and C_0 with combined Group CRT.
[B] Transport SAR not estimable – small estimated juvenile population and zero returning adults.
[C] C_1 SAR not estimable – small estimated juvenile population and zero returning adults.
[D] Incomplete, 2-salt returns through Sept. 15, 2017.
[E] The lower limit of 90% confidence limit is shown as 0.00 rather than the negative value resulting from limited degrees of freedom and lack of precision.

Table A.34. Estimated LGR-to-GRA SAR (%) for PIT-tagged sockeye reared from Springfield Hatchery for each study category from 2015 (with 90% confidence intervals).

Migration Year[A]	SAR(T_X)_t %	SAR(C_0)_crt %	SAR(EC_1)_t %
2015[B,C]	0.00 (0.00 – 0.00)	0.00 (0.00 – 0.00)	---

[A] All monitor mode years, estimated SARs for T_X and C_1 with Group T (reflects later start of transportation), and C_0 with combined Group CRT.
[B] C_1 SAR not estimable – small estimated juvenile population and zero returning adults.
[C] Incomplete, 2-salt returns through Sept. 15, 2017.

Wild and Hatchery Subyearling Fall Chinook

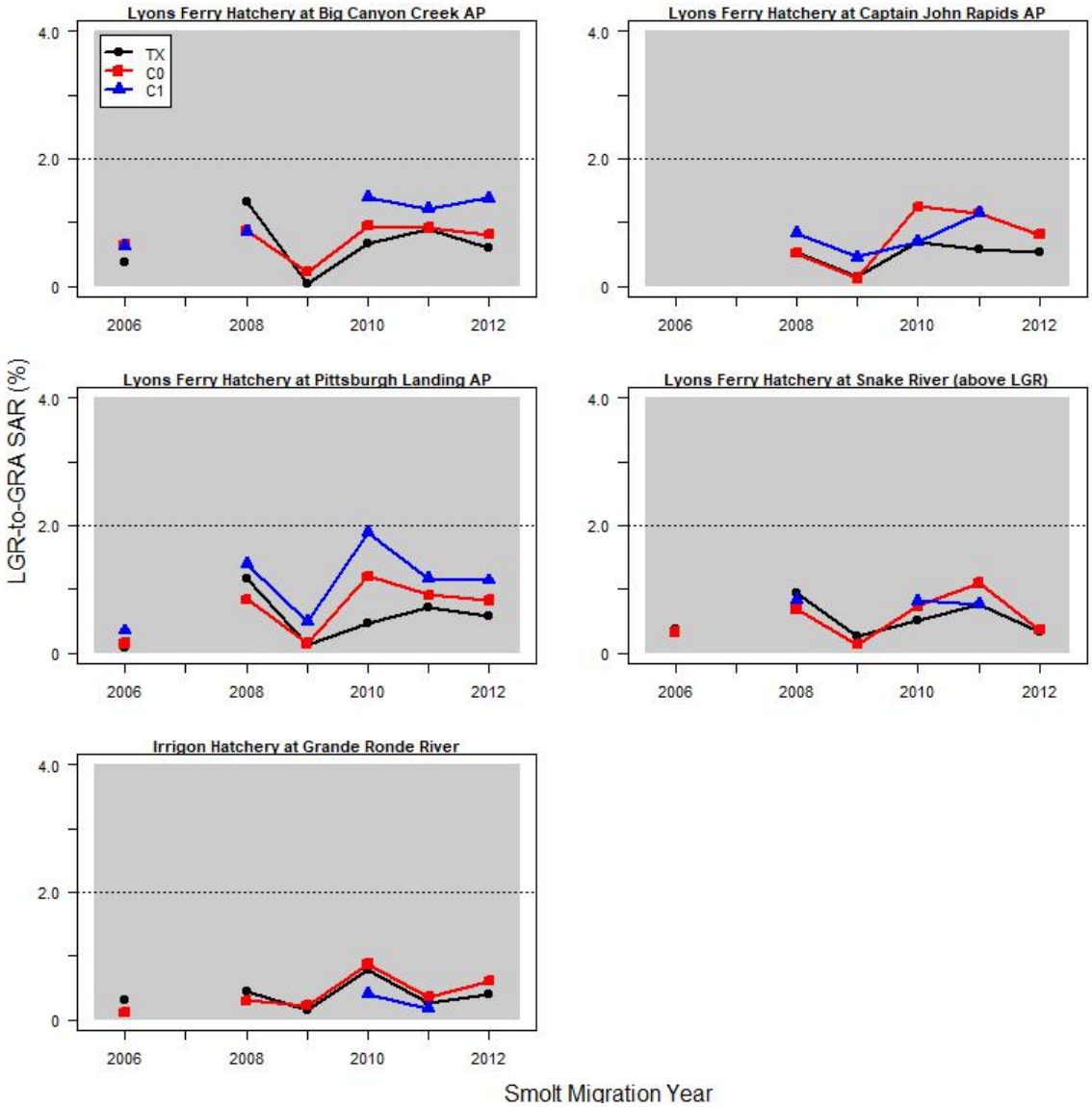

Figure A.18. Estimated LGR-to-GRA SAR for PIT-tagged Lyons Ferry and Irrigon hatchery subyearling fall Chinook in transport (T_X) and in-river (C_0 and C_1) study categories for migration years 2006 to 2012. Shaded area highlights the period of Court Order spill and later start of transportation. The NPCC (2014) 2% SAR objective for listed wild populations is shown for reference. Data for above figures are from Tables A.36 through A.40. Data for Snake River wild/natural subyearling fall Chinook not displayed due to only one year of SAR data (Table A.35).

Table A.35. Estimated LGR-to-GRA SAR (%) (without jacks) for PIT-tagged wild/natural subyearling fall Chinook tagged and released into the mainstem Snake River (above Lower Granite Dam) for each study category from 2006 to 2009 (with 90% confidence intervals). Due to small sample sizes and no adult returns for some categories, estimates of SARs by study categories were not possible for migration years 2007-2012.

Migration Year[A]	SAR(T_X)_t %	SAR(C_0)_crt %	SAR(EC_1)_t %
2006[B]	0.56 (0.00 – 1.73)	0.96 (0.34 – 1.69)	---

[A] All monitor mode years, estimated SARs for T_X and C_1 with Group T (reflects later start of transportation), and C_0 with combined Group CRT.
[B] C_1 SAR not estimable – small estimated juvenile population and zero returning adults.

Table A.36. Estimated LGR-to-GRA SAR (%) (without jacks) for PIT-tagged Lyons Ferry Hatchery subyearling fall Chinook released from Big Canyon Creek Acclimation Pond (Clearwater River) for each study category from 2006 to 2012 (with 90% confidence intervals).

Migration Year[A]	SAR(T_X)_t %	SAR(C_0)_crt %	SAR(EC_1)_t %
2006	0.37 (0.30 – 0.45)	0.66 (0.57 – 0.75)	0.64 (0.21 – 1.20)
2007[B]	---	---	---
2008	1.33 (1.07 – 1.63)	0.88 (0.76 - 1.00)	0.86 (0.00 – 1.98)
2009[C]	0.04 (0.00 – 0.13)	0.23 (0.13 – 0.34)	---
2010	0.66 (0.51 – 0.83)	0.95 (0.81 – 1.10)	1.40 (0.78 – 2.15)
2011	0.90 (0.70 – 1.09)	0.92 (0.81 – 1.04)	1.21 (0.66 – 1.91)
2012	0.60 (0.43 – 0.77)	0.81 (0.69 – 0.93)	1.38 (0.00 – 6.67)
6-yr avg.	**0.65 (0.25 – 1.05)**	**0.74 (0.50 – 0.98)**	**1.10 (0.74 – 1.46)**

[A] All monitor mode years, estimated SARs for T_X and C_1 with Group T (reflects later start of transportation), and C_0 with combined Group CRT.
[B] All PIT-tagged fish were routed in-river. Therefore, estimates of SARs by study category were not possible.
[C] C_1 SAR not estimable – small estimated juvenile population and zero returning adults.

Table A.37. Estimated LGR-to-GRA SAR (%) (without jacks) for PIT-tagged Lyons Ferry Hatchery subyearling fall Chinook released from Captain John Landing Acclimation Pond for each study category from 2007 to 2012 (with 90% confidence intervals).

Migration Year[A]	SAR(T_X)_t %	SAR(C_0)_crt %	SAR(EC_1)_t %
2007[B]	---	---	---
2008	0.50 (0.41 – 0.69)	0.52 (0.43 – 0.62)	0.83 (0.17 – 2.00)
2009	0.16 (0.06 – 0.30)	0.13 (0.05 – 0.22)	0.46 (0.00 – 1.50)
2010	0.69 (0.54 – 0.85)	1.25 (1.09 – 1.41)	0.70 (0.26 – 1.27)
2011	0.58 (0.41 – 0.76)	1.15 (1.01 – 1.28)	1.15 (0.67 – 1.66)
2012[C]	0.53 (0.40 – 0.68)	0.81 (0.70 – 0.93)	---
5-yr avg.	**0.50 (0.29 – 0.71)**	**0.77 (0.28 – 1.26)**	**0.79 (0.40 – 1.18)**

[A] All monitor mode years, estimated SARs for T_X and C_1 with Group T (reflects later start of transportation), and C_0 with combined Group CRT.
[B] All PIT-tagged fish were routed in-river. Therefore, estimates of SARs by study category were not possible.
[C] C_1 SAR not estimable – small estimated juvenile population and zero returning adults.

Table A.38. Estimated LGR-to-GRA SAR (%) (without jacks) for PIT-tagged Lyons Ferry Hatchery subyearling fall Chinook released from Pittsburg Landing Acclimation Pond for each study category from 2006 to 2012 (with 90% confidence intervals).

Migration Year[A]	SAR(T_X)_t %	SAR(C_0)_crt %	SAR(EC_1)_t %
2006	0.08 (0.03 – 0.12)	0.15 (0.09 – 0.23)	0.35 (0.00 – 0.81)
2007[B]	---	---	---
2008	1.17 (0.94 – 1.40)	0.84 (0.70 – 0.99)	1.40 (0.34 – 3.30)
2009	0.12 (0.00 – 0.25)	0.15 (0.07 – 0.25)	0.49 (0.00 – 1.62)
2010	0.46 (0.32 – 0.61)	1.20 (1.02 – 1.39)	1.89 (0.96 – 3.09)
2011	0.71 (0.50 – 0.94)	0.91 (0.78 – 1.03)	1.17 (0.61 – 1.79)
2012	0.59 (0.44 – 0.75)	0.83 (0.70 – 0.96)	1.14 (0.00 – 4.08)
6-yr avg.	**0.52 (0.15 – 0.89)**	**0.68 (0.29 – 1.07)**	**1.07 (0.55 – 1.59)**

[A] All monitor mode years, estimated SARs for T_X and C_1 with Group T (reflects later start of transportation), and C_0 with combined Group CRT.

[B] All PIT-tagged fish were routed in-river. Therefore, estimates of SARs by study category were not possible.

Table A.39. Estimated LGR-to-GRA SAR (%) (without jacks) for PIT-tagged Lyons Ferry Hatchery subyearling fall Chinook released into the mainstem Snake River (above Lower Granite Dam) for each study category from 2006 to 2012 (with 90% confidence intervals).

Migration Year[A]	SAR(T_X)_t %	SAR(C_0)_crt %	SAR(EC_1)_t %
2006[B]	0.37 (0.22 – 0.53)	0.33 (0.24 – 0.45)	---
2007[C]	---	---	---
2008	0.95 (0.62 – 1.34)	0.69 (0.50 – 0.88)	0.83 (0.00 – 3.53)
2009[B]	0.26 (0.09 – 0.44)	0.14 (0.05 – 0.23)	---
2010	0.52 (0.29 – 0.78)	0.73 (0.51 – 1.00)	0.82 (0.00 – 2.06)
2011	0.76 (0.50 – 1.01)	1.10 (0.90 – 1.33)	0.76 (0.00 – 1.80)
2012[B]	0.34 (0.15 – 0.59)	0.36 (0.25 – 0.48)	---
6-yr avg.	**0.53 (0.29 – 0.77)**	**0.56 (0.25 – 0.87)**	**0.80 (0.72 – 0.88)**

[A] All monitor mode years, estimated SARs for T_X and C_1 with Group T (reflects later start of transportation), and C_0 with combined Group CRT.

[B] C_1 SAR not estimable – small estimated juvenile population and zero returning adult.

[C] All PIT-tagged fish were routed in-river. Therefore, estimates of SARs by study category were not possible.

Table A.40. Estimated LGR-to-GRA SAR (%) (without jacks) for PIT-tagged Irrigon Hatchery subyearling fall Chinook released into the Grande Ronde River for each study category from 2006 to 2012 (with 90% confidence intervals).

Migration Year[A]	SAR(T_X)_t %	SAR(C_0)_crt %	SAR(EC_1)_t %
2006[B,C]	0.31 (0.17 – 0.46)	0.11 (0.00 – 0.17)	---
2007[D]	---	---	---
2008[C]	0.45 (0.26 – 0.67)	0.30 (0.20 – 0.39)	---
2009[C]	0.15 (0.06 – 0.27)	0.23 (0.15 – 0.31)	---
2010	0.78 (0.59 – 0.98)	0.87 (0.72 – 1.03)	0.40 (0.00 – 0.98)
2011	0.26 (0.12 – 0.43)	0.36 (0.27 – 0.47)	0.18 (0.00 – 0.58)
2012[C]	0.41 (0.22 – 0.61)	0.61 (0.51 – 0.72)	---
6-yr avg.	**0.39 (0.19 – 0.59)**	**0.41 (0.16 – 0.66)**	**0.29 (0.00 – 1.27)**[E]

[A] All monitor mode years, estimated SARs for T_X and C_1 with Group T (reflects later start of transportation), and C_0 with combined Group CRT.
[B] 2006 release was reared at Lyons Ferry Hatchery
[C] C_1 SAR not estimable – small estimated juvenile population and zero returning adults.
[D] All PIT-tagged fish were routed in-river. Therefore, estimates of SARs by study category were not possible.
[E] Lower limit of 90% confidence interval shown as 0.00 rather than negative value resulting from limited degrees of freedom and lack of precision.

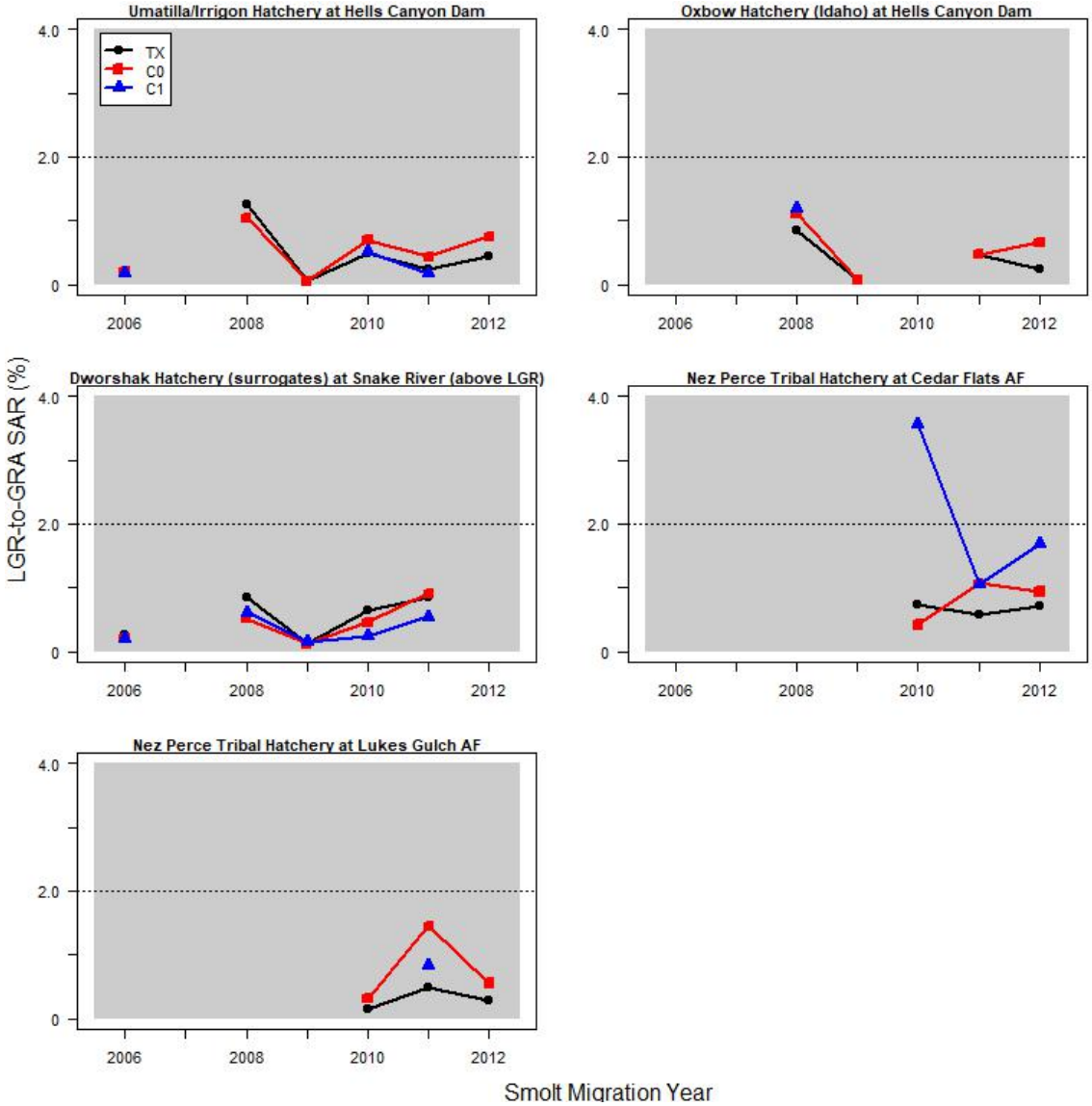

Figure A.19. Estimated LGR-to-GRA SAR for PIT-tagged subyearling fall Chinook (various hatcheries and release locations) in transport (T_X) and in-river (C_0 and C_1) study categories for migration years 2006 to 2012. Shaded area highlights the period of Court Order spill and later start of transportation. The NPCC (2014) 2% SAR objective for listed wild populations is shown for reference. Data for above figures are from Tables A.41 through A.45.

Table A.41. Estimated LGR-to-GRA SAR (%) (without jacks) for PIT-tagged Umatilla/Irrigon Hatchery subyearling fall Chinook released into the Snake River below Hells Canyon Dam for each study category from 2006 to 2012 (with 90% confidence intervals).

Migration Year[A]	SAR(T_X)_t %	SAR(C_0)_crt %	SAR(EC_1)_t %
2006	0.22 (0.13 – 0.32)	0.20 (0.12 – 0.29)	0.18 (0.00 – 0.56)
2007[B]	---	---	---
2008[C]	1.25 (1.00 – 1.52)	1.05 (0.91 – 1.20)	---
2009[C]	0.07 (0.03 – 0.12)	0.05 (0.03 – 0.08)	---
2010	0.49 (0.35 – 0.65)	0.70 (0.58 – 0.83)	0.52 (0.25 – 0.87)
2011	0.24 (0.12 – 0.37)	0.44 (0.33 – 0.55)	0.17 (0.00 – 0.53)
2012[C]	0.44 (0.28 – 0.59)	0.75 (0.63 – 0.86)	---
6-yr avg.	**0.45 (0.07 – 0.59)**	**0.53 (0.19 – 0.87)**	**0.29 (0.00 – 0.70)[D]**

[A] All monitor mode years, estimated SARs for T_X and C_1 with Group T (reflects later start of transportation), and C_0 with combined Group CRT.
[B] All PIT-tagged fish were routed in-river. Therefore, estimates of SARs by study category were not possible.
[C] C_1 SAR not estimable – small estimated juvenile population and zero returning adults.
[D] Lower limit of 90% confidence interval shown as 0.00 rather than negative value resulting from limited degrees of freedom and lack of precision.

Table A.42. Estimated LGR-to-GRA SAR (%) (without jacks) for PIT-tagged Oxbow Hatchery (Idaho) subyearling fall Chinook released into the Snake River below Hells Canyon Dam for each study category from 2006 to 2012 (with 90% confidence intervals).

Migration Year[A]	SAR(T_X)_t %	SAR(C_0)_crt %	SAR(EC_1)_t %
2007[B]	---	---	---
2008	0.86 (0.58 – 1.16)	1.11 (0.86 – 1.36)	1.19 (0.29 – 2.42)
2009[C]	0.08 (0.00 – 0.20)	0.08 (0.02 – 0.16)	---
2010[D]	---	---	---
2011[C]	0.47 (0.20 – 0.81)	0.47 (0.33 – 0.62)	---
2012[C]	0.25 (0.11 – 0.43)	0.66 (0.46 – 0.84)	---
4-yr avg.	**0.42 (0.00 – 0.88)[E]**	**0.58 (0.00 – 1.16)**	**---**

[A] All monitor mode years, estimated SARs for T_X and C_1 with Group T (reflects later start of transportation), and C_0 with combined Group CRT.
[B] All PIT-tagged fish were routed in-river. Therefore, estimates of SARs by study category were not possible.
[C] C_1 SAR not estimable – small estimated juvenile population and zero returning adults.
[D] No PIT-tags were released for this group in 2010.
[E] Lower limit of 90% confidence interval shown as 0.00 rather than negative value resulting from limited degrees of freedom and lack of precision.

Table A.43. Estimated LGR-to-GRA SAR (%) (without jacks) for PIT-tagged Dworshak Hatchery subyearling fall Chinook (surrogates) released into the mainstem Snake River (above Lower Granite Dam) for each study category from 2006 to 2011 (with 90% confidence intervals).

Migration Year[A]	SAR(T_X)_t %	SAR(C_0)_crt %	SAR(EC_1)_t %
2006	0.27 (0.22 – 0.32)	0.21 (0.18 – 0.24)	0.20 (0.05 – 0.44)
2007[B]	---	---	---
2008	0.85 (0.75 – 0.95)	0.52 (0.47 – 0.56)	0.62 (0.29 – 1.07)
2009	0.14 (0.09 – 0.19)	0.13 (0.11 – 0.16)	0.16 (0.11 – 0.21)
2010	0.65 (0.54 – 0.77)	0.46 (0.41 – 0.52)	0.24 (0.06 – 0.46)
2011	0.85 (0.75 – 0.96)	0.91 (0.84 – 0.97)	0.55 (0.32 – 0.81)
2012[C]	---	---	---
5-yr avg.	**0.55 (0.20 – 0.90)**	**0.45 (0.12 – 0.78)**	**0.35 (0.12 – 0.58)**

[A] All monitor mode years, estimated SARs for T_X and C_1 with Group T (reflects later start of transportation), and C_0 with combined Group CRT.
[B] Due to low broodstock, no PIT-tags were released in this group in 2007.
[C] SARs not estimable due to high estimated holdover rates.

Table A.44. Estimated LGR-to-GRA SAR (%) (without jacks) for PIT-tagged Nez Perce Tribal Hatchery subyearling fall Chinook released from the Cedar Flats Acclimation Facility (Clearwater River) for each study category from 2010 to 2012 (with 90% confidence intervals).

Migration Year[A]	SAR(T_X)_t %	SAR(C_0)_crt %	SAR(EC_1)_t %
2010	0.74 (0.29 – 1.22)	0.42 (0.27 – 0.58)	3.57 (0.00 – 25.00)
2011	0.57 (0.35 – 0.78)	1.07 (0.86 – 1.29)	1.05 (0.25 – 2.42)
2012	0.71 (0.39 – 1.07)	0.94 (0.75 – 1.14)	1.69 (0.00 – 5.88)
3-yr avg.	**0.67 (0.48 – 0.86)**	**0.81 (0.10 – 1.52)**	**2.10 (0.00 – 4.80)[B]**

[A] All monitor mode years, estimated SARs for T_X and C_1 with Group T (reflects later start of transportation), and C_0 with combined Group CRT.
[B] Lower limit of 90% confidence interval shown as 0.00 rather than negative value resulting from limited degrees of freedom and lack of precision.

Table A.45. Estimated LGR-to-GRA SAR (%) (without jacks) for PIT-tagged Nez Perce Tribal Hatchery subyearling fall Chinook released from the Lukes Gulch Acclimation Facility (Clearwater River) for each study category from 2010 to 2012 (with 90% confidence intervals).

Migration Year[A]	SAR(T_X)_t %	SAR(C_0)_crt %	SAR(EC_1)_t %
2010[B]	0.15 (0.05– 0.31)	0.32 (0.20 – 0.45)	---
2011	0.50 (0.30 – 0.72)	1.45 (1.21 – 1.72)	0.83 (0.00 – 2.16)
2012[B]	0.28 (0.10 – 0.48)	0.56 (0.43 – 0.71)	---
3-yr avg.	**0.31 (0.00 – 0.68)[C]**	**0.78 (0.00 – 2.01)[C]**	**---**

[A] All monitor mode years, estimated SARs for T_X and C_1 with Group T (reflects later start of transportation), and C_0 with combined Group CRT.
[B] C_1 SAR not estimable – small estimated juvenile population and zero returning adults.
[C] Lower limit of 90% confidence interval shows as 0.00 rather than negative value resulting from limited degrees of freedom and lack of precision.

Estimates of TIR and *D*

Presented here are the estimates of Transport:In-River SAR Ratios (TIR) and differential delayed effects of transportation (*D*) for Snake River spring/summer Chinook, steelhead, sockeye, and subyearling fall Chinook.

Wild and Hatchery Spring/Summer Chinook

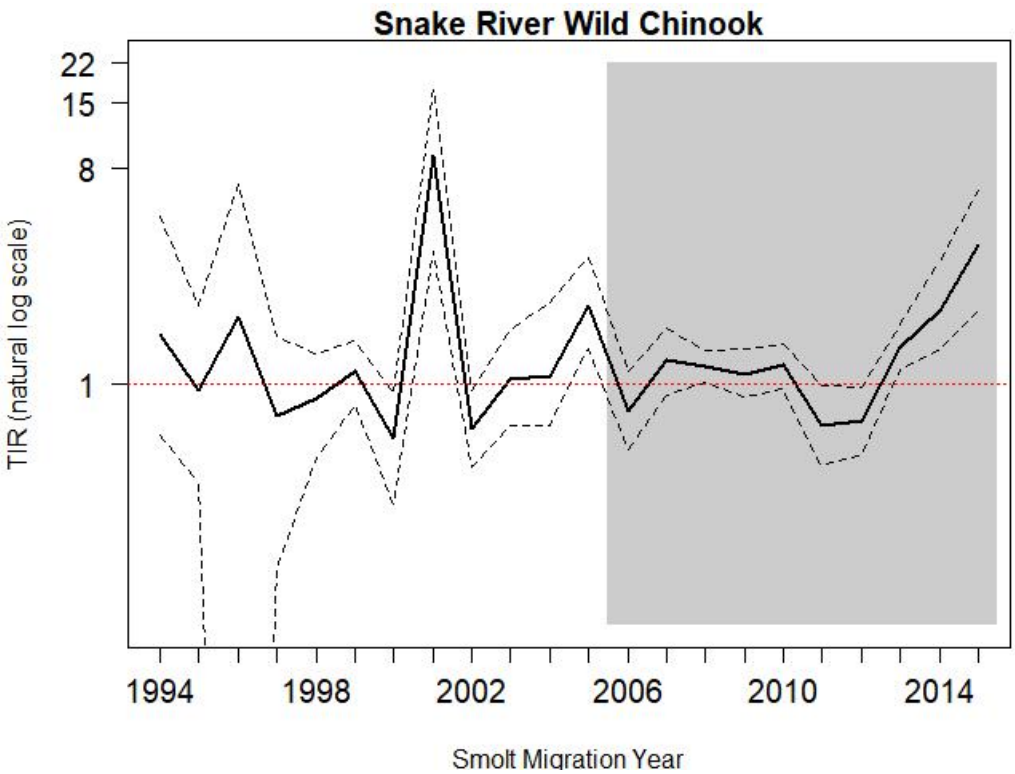

Figure A.20. Trend in TIR on the natural log scale for PIT-tagged Snake River wild Chinook for migration years 1994 to 2015 (with 90% confidence intervals). The red horizontal dotted line denotes a TIR value of 1 (in-river and transport SARs equal). Shaded area highlights the period of Court Order spill and later start of transportation. TIR calculation for 2001 and 2005 differs from other years as in-river SAR component of ratio includes C_1 fish (see methods). Wild Chinook data are from Table A.46.

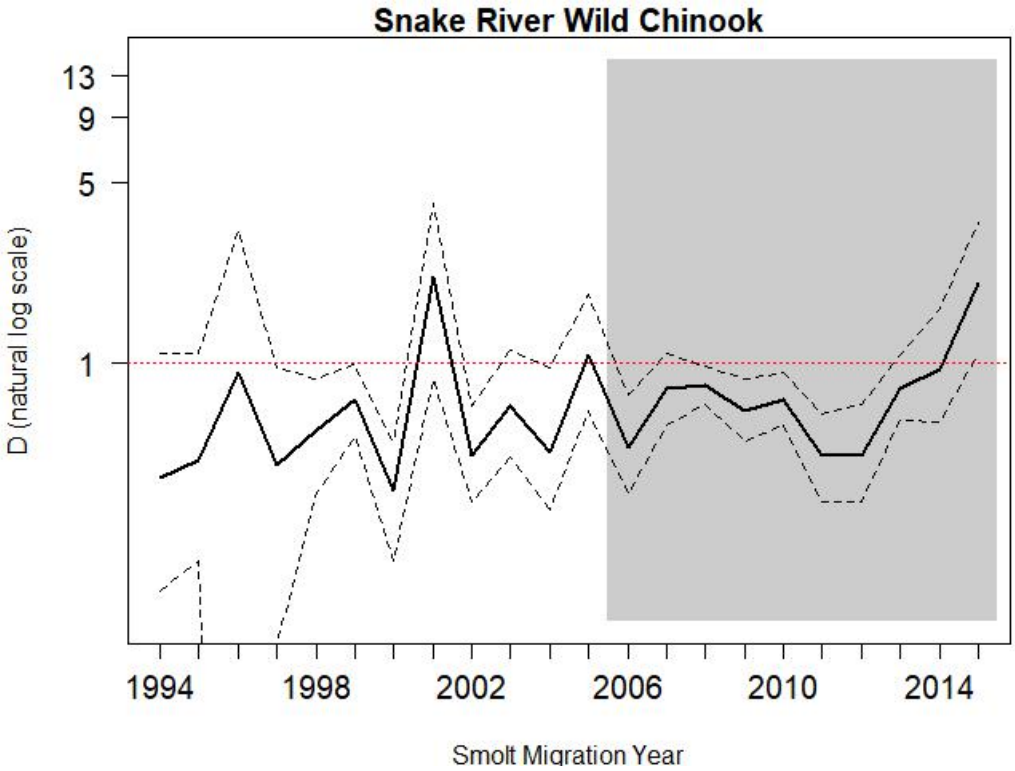

Figure A.21. Trend in *D* on the natural log scale for PIT-tagged Snake River wild Chinook in migration years 1994–2015 (with 90% confidence intervals). The red horizontal dotted line denotes a *D* value of 1 (in-river and transport post-BON survivals are equal). Shaded area highlights the period of Court Order spill and later start of transportation. *D* calculation for 2001 and 2005 differs from other years as in-river SAR component of ratio includes C_1 fish (see methods). Wild Chinook data are from Table A.46.

Table A.46. Estimated TIR and *D* of PIT-tagged wild Chinook for migration years 1994 to 2015 (with 90% confidence intervals). Lower limit values >1.00 are in bold and upper limit values <1.00 are in bold-italics. After 2005, transport operations initiated on a delayed start date compared to previous years.

Migration Year	TIR		*D*	
1994	1.62	(0.62 – 5.05)	0.36	(0.13 – 1.09)
1995	0.95	(0.39 – 2.14)	0.42	(0.17 – 1.09)
1996	1.92	(0.00 – 6.80)	0.92	(0.00 – 3.24)
1997	0.74	(0.17 – 1.58)	0.40	(0.08 – ***0.95***)
1998	0.87	(0.50 – 1.35)	0.55	(0.31 – ***0.87***)
1999	1.14	(0.82 – 1.51)	0.72	(0.52 – ***0.98***)
2000	0.60	(0.32 – ***0.92***)	0.32	(0.17 – ***0.50***)
2001[A]	8.96	(**3.61** – 16.8)	2.16	(0.87 – 4.16)
2002	0.65	(0.45 – ***0.94***)	0.44	(0.29 – ***0.68***)
2003	1.05	(0.68 – 1.68)	0.68	(0.43 – 1.12)
2004	1.09	(0.68 – 2.19)	0.45	(0.27 – ***0.95***)
2005[B]	2.14	(**1.40** – 3.45)	1.07	(0.65 – 1.85)
Monitor Mode Years[C]				
2006	0.78	(0.54 – 1.14)	0.47	(0.31 – ***0.75***)
2007	1.27	(0.91 – 1.71)	0.80	(0.57 – 1.09)
2008	1.19	(**1.02** – 1.39)	0.82	(0.69 – ***0.97***)
2009	1.11	(0.89 – 1.41)	0.65	(0.50 – ***0.87***)
2010	1.21	(0.96 – 1.48)	0.72	(0.57 – ***0.92***)
2011	0.68	(0.46 – ***0.99***)	0.44	(0.29 – ***0.63***)
2012	0.71	(0.51 – ***0.98***)	0.44	(0.29 – ***0.69***)
2013	1.42	(**1.15** – 1.78)	0.79	(0.60 – 1.07)
2014	2.03	(**1.40** – 3.25)	0.94	(0.59 – 1.62)
2015[D]	3.79	(**2.03** – 6.43)	2.03	(**1.08** – 3.81)
Geomean	1.26	(1.00 – 1.58)	0.66	(0.54 – ***0.79***)

[A] For migration year 2001, the SAR(C_1) value is used in the derivation of TIR and *D*.
[B] In-river SAR is combination of groups C_0 and C_1 in derivation of TIR and *D*.
[C] TIR and *D* use SAR for T_X estimated with Group T and C_0 with combined Group CRT.
[D] Incomplete, 2-salt returns through Sept. 15, 2017.

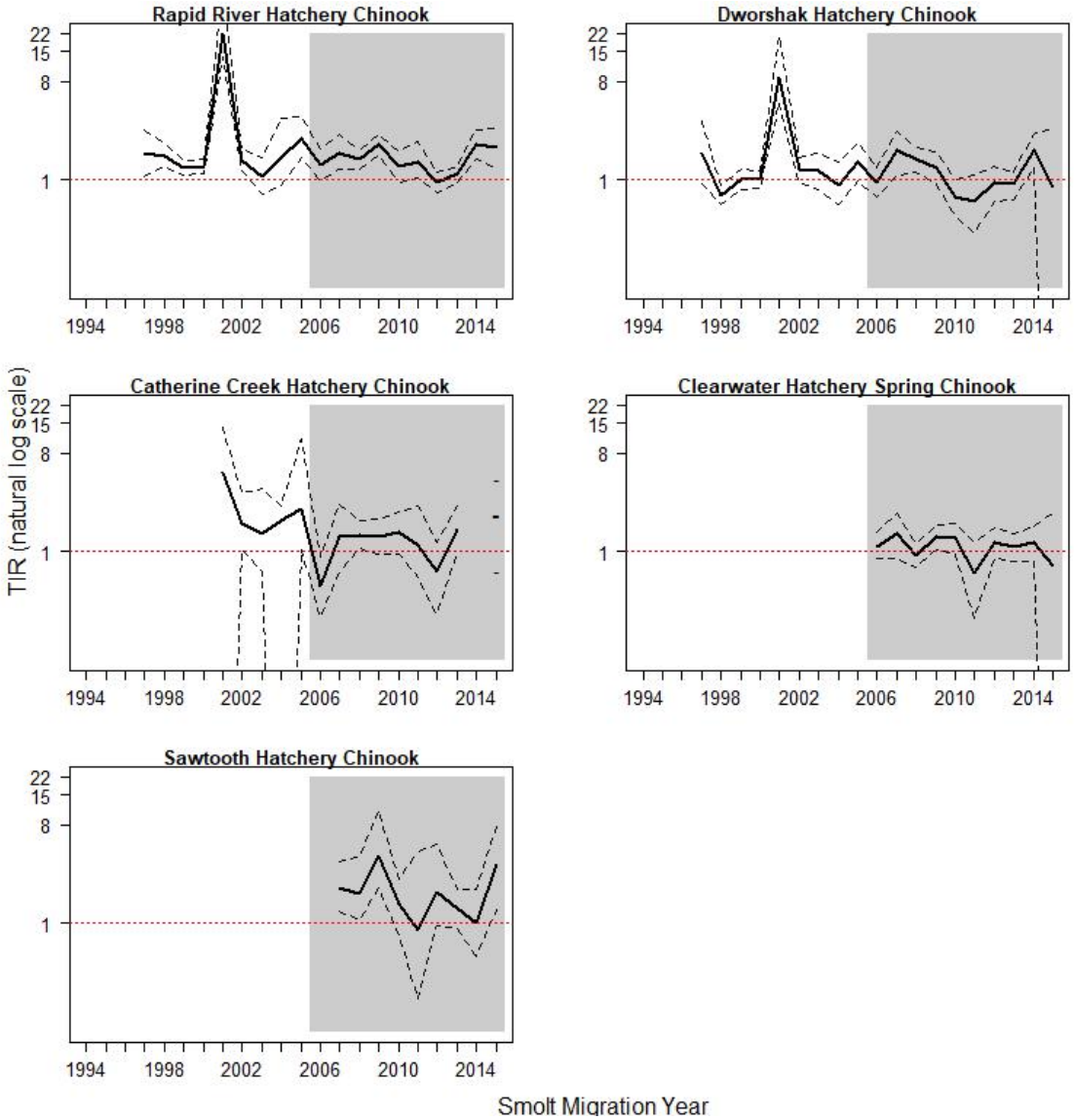

Figure A.22. Trend in TIR on the natural log scale for PIT-tagged Snake River spring Chinook from Rapid River, Dworshak, Catherine Creek (Lookingglass), Clearwater, and Sawtooth hatcheries for migration years 1994 to 2015 (with 90% confidence intervals). The red horizontal dotted line denotes a TIR value of 1 (in-river and transport SARs equal). Shaded area highlights the period of Court Order spill and later start of transportation. TIR calculation for 2001 and 2005 differs from other years as in-river SAR component of ratio includes C_1 fish (see methods). Data for individual hatcheries are from Tables A.47–A.51. Spring Chinook from Kooskia Hatchery are not displayed due to inability to estimate TIR (Table A.52).

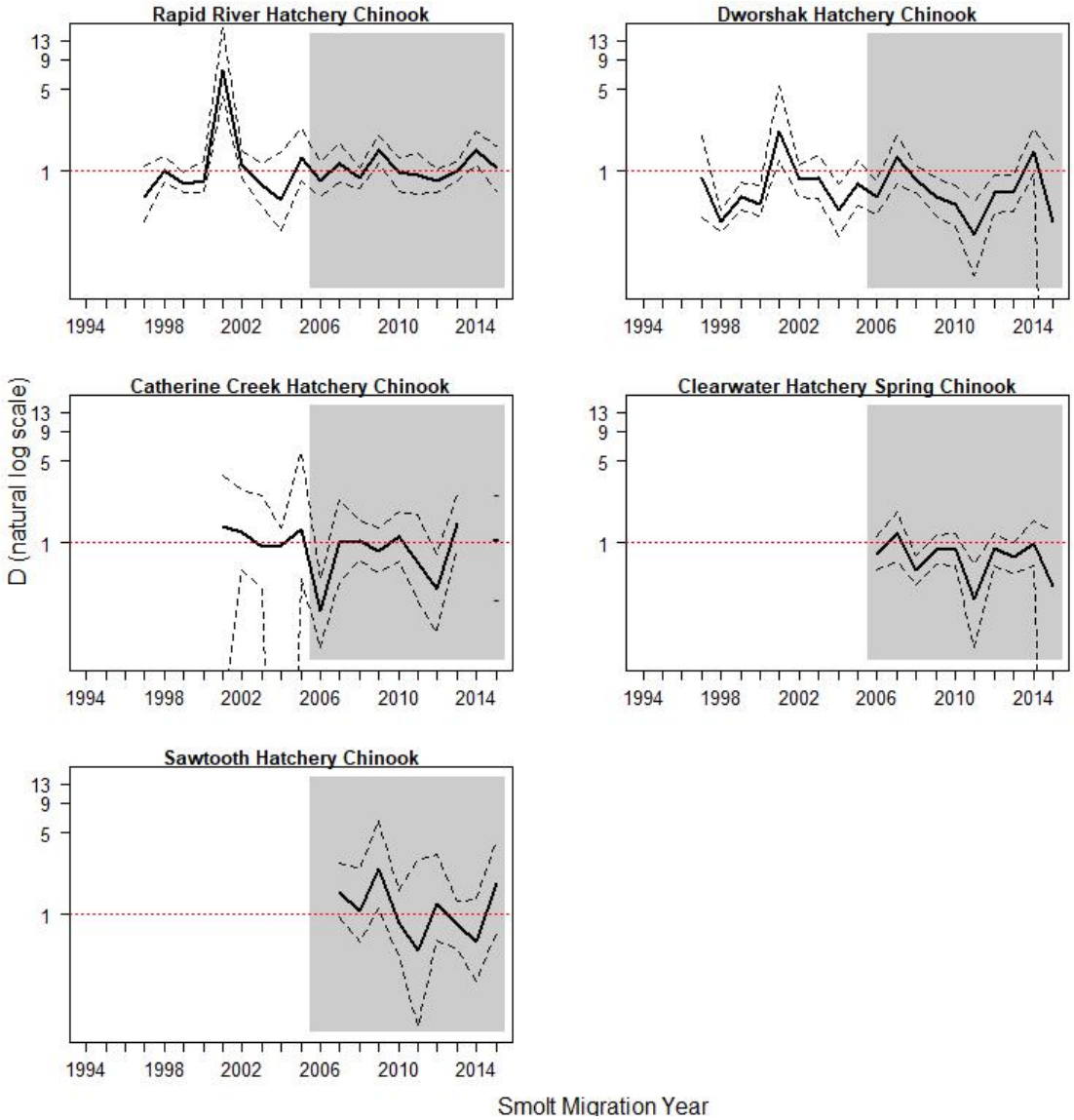

Figure A.23. Trend in *D* on the natural log scale for PIT-tagged Snake River spring Chinook from Rapid River, Dworshak, Catherine Creek (Lookingglass), Clearwater, and Sawtooth hatcheries in migration years 1994–2015 (with 90% confidence intervals). The red horizontal dotted line denotes a *D* value of 1 (in-river and transport post-BON survivals are equal). Shaded area highlights the period of Court Order spill and later start of transportation. *D* calculation for 2001 and 2005 differs from other years as in-river SAR component of ratio includes C_1 fish (see methods). Data for individual hatcheries from Tables A.47–A.51. Spring Chinook from Kooskia Hatchery are not displayed due to inability to estimate *D* (Table A.52).

Table A.47. Estimated TIR and *D* of PIT-tagged Rapid River Hatchery spring Chinook for 1997 to 2015 (with 90% confidence intervals). Lower limit values >1.00 are in bold and upper limit values <1.00 are in bold-italics. After 2005, transport operations initiated on a delayed start date compared to previous years.

Migration Year	TIR		*D*	
1997	1.73	(**1.08** – 2.85)	0.61	(0.37 – 1.09)
1998	1.66	(**1.32** – 2.16)	1.01	(0.80 – 1.36)
1999	1.28	(**1.11** – 1.51)	0.79	(0.65 – ***0.99***)
2000	1.32	(**1.13** – 1.55)	0.82	(0.66 – 1.25)
2001[A]	21.70	(**13.3** – 54.1)	7.33	(**4.40** – 16.9)
2002	1.51	(**1.20** – 1.91)	1.14	(0.87 – 1.52)
2003	1.07	(0.73 – 1.58)	0.75	(0.50 – 1.15)
2004	1.57	(0.88 – 3.67)	0.57	(0.31 – 1.46)
2005[B]	2.36	(**1.59** – 3.79)	1.31	(0.83 – 2.30)
Monitor Mode Years[C]				
2006	1.35	(0.98 – 1.91)	0.83	(0.60 – 1.19)
2007	1.77	(**1.25** – 2.57)	1.18	(0.81 – 1.74)
2008	1.52	(**1.26** – 1.85)	0.87	(0.71 – 1.08)
2009	2.08	(**1.69** – 2.57)	1.51	(**1.17** – 2.00)
2010	1.33	(0.95 – 1.78)	0.97	(0.68 – 1.31)
2011	1.47	(**1.02** – 2.25)	0.93	(0.63 – 1.44)
2012	0.94	(0.75 – 1.17)	0.82	(0.65 – 1.04)
2013	1.12	(0.94 – 1.33)	1.00	(0.83 – 1.21)
2014	2.07	(**1.52** – 2.88)	1.52	(**1.12** – 2.21)
2015[D]	1.98	(**1.25** – 2.96)	1.08	(0.67 – 1.65)
Geomean	1.75	(**1.35** – 2.27)	1.06	(0.85 – 1.31)

[A] For migration year 2001, the SAR(C_1) value is used in the derivation of TIR and *D*.
[B] In-river SAR is combination of groups C_0 and C_1 in derivation of TIR and *D*.
[C] TIR and *D* use SAR for T_X estimated with Group T and C_0 with combined Group CRT.
[D] Incomplete, 2-salt returns through Sept. 15, 2017.

Table A.48. Estimated TIR and *D* of PIT-tagged Dworshak Hatchery spring Chinook for 1997 to 2015 (with 90% confidence intervals). Lower limit values >1.00 are in bold and upper limit values <1.00 are in bold-italics. After 2005, transport operations initiated on a delayed start date compared to previous years.

Migration Year	TIR		*D*	
1997	1.75	(0.92 – 3.46)	0.88	(0.40 – 2.01)
1998	0.72	(0.59 – ***0.88***)	0.37	(0.30 – ***0.47***)
1999	0.99	(0.81 – 1.24)	0.60	(0.47 – ***0.81***)
2000	0.99	(0.82 – 1.19)	0.53	(0.42 – ***0.75***)
2001[A]	8.76	(**5.04** – 20.4)	2.21	(**1.23** – 5.30)
2002	1.24	(0.93 – 1.61)	0.84	(0.61 – 1.12)
2003	1.21	(0.81 – 1.75)	0.88	(0.58 – 1.37)
2004	0.89	(0.59 – 1.43)	0.46	(0.28 – ***0.77***)
2005[B]	1.43	(0.97 – 2.17)	0.77	(0.51 – 1.22)
Monitor Mode Years[C]				
2006	0.95	(0.69 – 1.30)	0.60	(0.43 – ***0.83***)
2007	1.84	(**1.11** – 2.81)	1.31	(0.78 – 2.02)
2008	1.53	(**1.17** – 1.99)	0.86	(0.66 – 1.13)
2009	1.29	(0.92 – 1.80)	0.60	(0.42 – ***0.88***)
2010	0.70	(0.46 – 1.01)	0.52	(0.34 – ***0.75***)
2011	0.63	(0.32 – 1.09)	0.29	(0.13 – ***0.56***)
2012	0.94	(0.63 – 1.31)	0.65	(0.44 – ***0.93***)
2013	0.90	(0.65 – 1.17)	0.67	(0.45 – ***0.94***)
2014	1.85	(**1.29** – 2.64)	1.46	(0.96 – 2.23)
2015[D]	0.85	(0.00 – 2.92)	0.37	(0.00 – 1.28)
Geomean	1.22	(0.97 – 1.53)	0.69	(0.57 – ***0.84***)

[A] For migration year 2001, the SAR(C_1) value is used in the derivation of TIR and *D*.
[B] In-river SAR is combination of groups C_0 and C_1 in derivation of TIR and *D*.
[C] TIR and *D* use SAR for T_X estimated with Group T and C_0 with combined Group CRT.
[D] Incomplete, 2-salt returns through Sept. 15, 2017.

Table A.49. Estimated TIR and *D* of PIT-tagged Catherine Creek AP spring Chinook for 2001 to 2015 (with 90% confidence intervals). Lower limit values >1.00 are in bold and upper limit values <1.00 are in bold-italics. After 2005, transport operations initiated on a delayed start date compared to previous years.

Migration Year	TIR		*D*	
2001[A]	5.33	(0.00 – 13.6)	1.38	(0.03 – 3.79)
2002	1.81	(**1.02** – 3.43)	1.23	(0.59 – 2.79)
2003	1.45	(0.65 – 3.79)	0.94	(0.41 – 2.53)
2004	1.94	(0.00 – 2.57)	0.95	(0.00 – 1.33)
2005[B]	2.48	(**1.02** – 10.6)	1.32	(0.50 – 5.90)
Monitor Mode Years[C]				
2006	0.48	(0.25 – ***0.88***)	0.26	(0.13 – ***0.50***)
2007	1.35	(0.65 – 2.71)	1.02	(0.46 – 2.29)
2008	1.41	(**1.06** – 1.92)	1.05	(0.72 – 1.53)
2009	1.35	(0.94 – 1.95)	0.85	(0.55 – 1.35)
2010[D]	1.51	(0.94 – 2.32)	1.13	(0.70 – 1.86)
2011	1.15	(0.57 – 2.58)	0.68	(0.32 – 1.72)
2012	0.66	(0.27 – 1.21)	0.41	(0.17 – ***0.80***)
2013	1.58	(0.97 – 2.63)	1.48	(0.86 – 2.62)
2014[E]		---		---
2015[F]	2.11	(0.66 – 4.54)	1.09	(0.33 – 2.57)
Geomean	1.51	(**1.16** – 1.97)	0.90	(0.72 – 1.14)

[A] For migration year 2001, the SAR(C_1) value is used in the derivation of TIR and *D*.
[B] In-river SAR is combination of groups C_0 and C_1 in derivation of TIR and *D*.
[C] TIR and *D* use SAR for T_X estimated with Group T and C_0 with combined Group CRT.
[D] See Section: *Special Considerations for Migration Year 2010* on page A-11.
[E] Too few adults in Transport and/or C_0 group to estimate TIR and D.
[F] Incomplete, 2-salt returns through Sept. 15, 2017.

Table A.50. Estimated TIR and *D* of PIT-tagged Clearwater Hatchery spring Chinook for 2006 to 2015 (with 90% confidence intervals). Lower limit values >1.00 are in bold and upper limit values <1.00 are in bold-italics. After 2005, transport operations initiated on a delayed start date compared to previous years.

Migration Year[A]	TIR		*D*	
2006	1.11	(0.85 – 1.50)	0.80	(0.59 – 1.13)
2007	1.47	(0.86 – 1.24)	1.21	(0.70 – 1.85)
2008	0.91	(0.71 – 1.18)	0.59	(0.44 – ***0.78***)
2009	1.35	(**1.04** – 1.76)	0.88	(0.66 – 1.18)
2010[B]	1.33	(0.94 – 1.78)	0.90	(0.64 – 1.21)
2011	0.63	(0.24 – 1.22)	0.33	(0.13 – ***0.66***)
2012	1.22	(0.86 – 1.66)	0.90	(0.63 – 1.21)
2013	1.11	(0.80 – 1.44)	0.76	(0.55 – 1.01)
2014	1.21	(0.81 – 1.69)	0.99	(0.63 – 1.57)
2015[C]	0.74	(0.00 – 2.20)	0.43	(0.00 – 1.27)
Geomean	1.07	(0.92 – 1.26)	0.73	(0.58 – ***0.92***)

[A] TIR and *D* use SAR for T_X estimated with Group T and C_0 with combined Group CRT.
[B] See Section: *Special Considerations for Migration Year 2010* on page A-11.
[C] Incomplete, 2-salt returns through Sept. 15, 2017.

Table A.51. Estimated TIR and *D* of PIT-tagged Sawtooth Hatchery spring Chinook for 2007 to 2015 (with 90% confidence intervals). Lower limit values >1.00 are in bold and upper limit values <1.00 are in bold-italics. After 2005, transport operations initiated on a delayed start date compared to previous years.

Migration Year[A]	TIR		*D*	
2007	2.08	(**1.27** – 3.66)	1.56	(0.96 – 2.73)
2008	1.88	(**1.08** – 4.11)	1.08	(0.58 – 2.46)
2009	4.19	(**2.08** – 10.67)	2.42	(**1.13** – 6.33)
2010[B]	1.51	(0.78 – 2.56)	0.85	(0.44 – 1.58)
2011	0.85	(0.20 – 4.47)	0.49	(0.11 – 2.89)
2012	1.93	(0.94 – 5.22)	1.24	(0.60 – 3.31)
2013	1.36	(0.88 – 2.02)	0.82	(0.51 – 1.31)
2014	1.01	(0.49 – 2.02)	0.58	(0.27 – 1.33)
2015[C]	3.39	(**1.31** – 7.67)	1.82	(0.69 – 4.30)
Geomean	1.79	(**1.30** – 2.47)	1.07	(0.77 – 1.48)

[A] TIR and *D* use SAR for T_X estimated with Group T and C_0 with combined Group CRT.
[B] See Section: *Special Considerations for Migration Year 2010* on page A-11.
[C] Incomplete, 2-salt returns through Sept. 15, 2017.

Table A.52. Estimated TIR and *D* of PIT-tagged Kooskia Hatchery spring Chinook for 2014 to 2015 (with 90% confidence intervals). Lower limit values >1.00 are in bold and upper limit values <1.00 are in bold-italics.

Migration Year[A]	TIR	*D*
2014[B]	---	---
2015[B C]	---	---

[A] TIR and *D* use SAR for T_X estimated with Group T and C_0 with combined Group CRT.
[B] Too few adults in Transport and/or C_0 group to estimate TIR and D.
[C] Incomplete, 2-salt returns through Sept. 15, 2017.

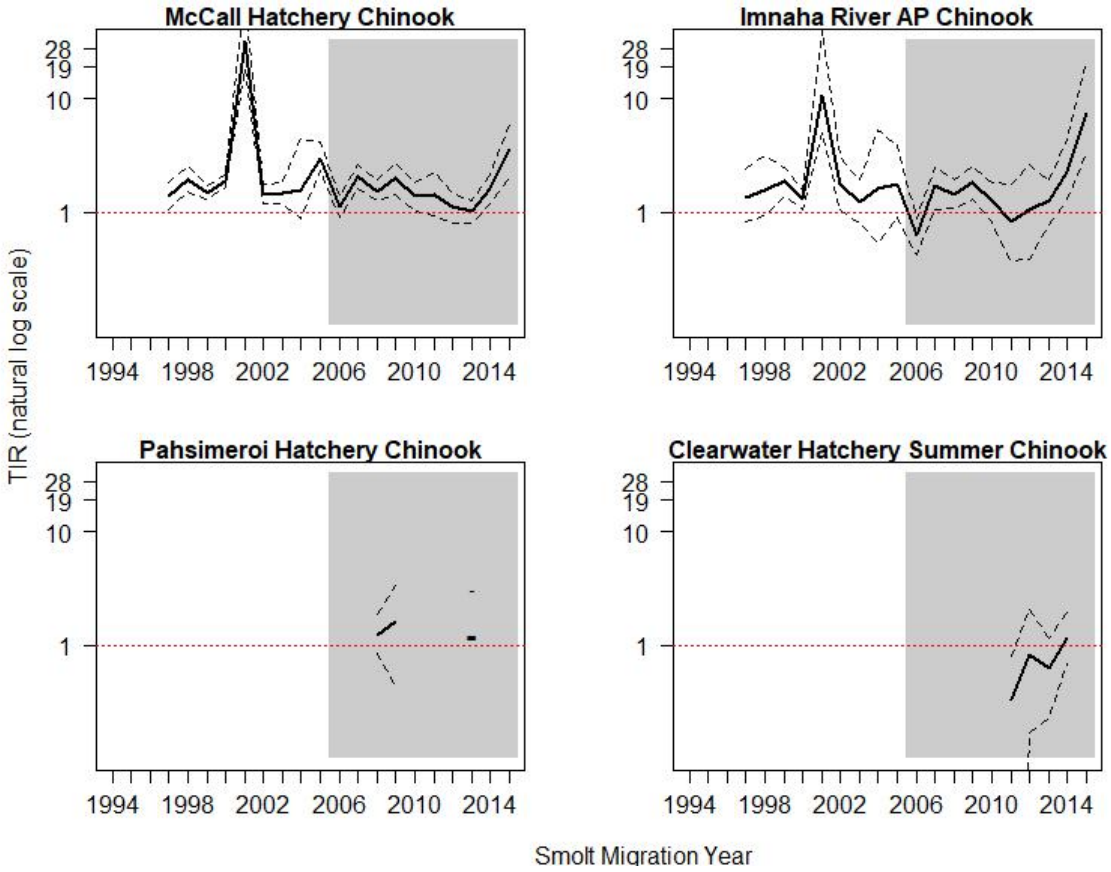

Figure A.24. Trend in TIR on the natural log scale for PIT-tagged Snake River summer Chinook from McCall, Imnaha (Lookingglass), Pahsimeroi, and Clearwater hatcheries for migration years 1994 to 2015 (with 90% confidence intervals). The red horizontal dotted line denotes a TIR value of 1 (in-river and transport SARs equal). Shaded area highlights the period of Court Order spill and later start of transportation. TIR calculation for 2001 and 2005 differs from other years as in-river SAR component of ratio includes C_1 fish (see methods). Data for individual hatcheries are from Tables A.53–A.56. TIR estimates were not always possible for Pahsimeroi and Clearwater hatcheries. See footnotes in Tables A.55 and A.56 for details.

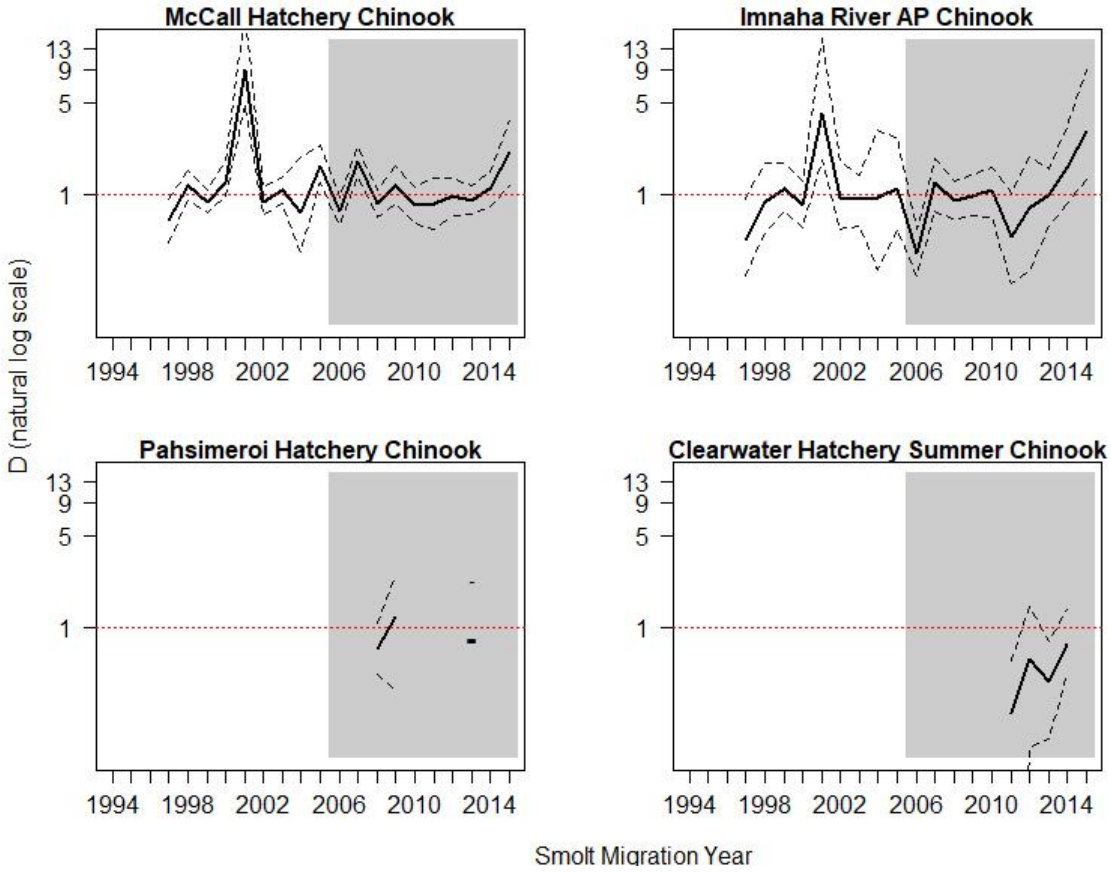

Figure A.25. Trend in *D* on the natural log scale for PIT-tagged Snake River summer Chinook from McCall, Imnaha (Lookingglass Hatchery), Pahsimeroi, and Clearwater hatcheries in migration years 1994–2015 (with 90% confidence intervals). The red horizontal dotted line denotes a *D* value of 1 (in-river and transport post-BON survivals are equal). Shaded area highlights the period of Court Order spill and later start of transportation. *D* calculation for 2001 and 2005 differs from other years as in-river SAR component of ratio includes C_1 fish (see methods). Data for individual hatcheries are from Tables A.53–A.56. *D* estimates were not always possible for Pahsimeroi and Clearwater hatcheries. See footnotes in Tables A.55 and A.56 for details.

Table A.53. Estimated TIR, and *D* of PIT-tagged McCall Hatchery summer Chinook for 1997 to 2015 (with 90% confidence intervals). Lower limit values >1.00 are in bold and upper limit values <1.00 are in bold-italics. After 2005, transport operations initiated on a delayed start date compared to previous years.

Migration Year	TIR		*D*	
1997	1.38	(**1.06** – 1.80)	0.64	(0.43 – ***0.93***)
1998	1.96	(**1.54** – 2.56)	1.16	(0.89 – 1.54)
1999	1.49	(**1.29** – 1.73)	0.87	(0.72 – 1.07)
2000	1.89	(**1.67** – 2.15)	1.24	(0.98 – 1.81)
2001[A]	31.9	(**17.9** – 88.4)	8.95	(**4.87** – 24.1)
2002	1.44	(**1.18** – 1.79)	0.87	(0.68 – 1.14)
2003	1.47	(**1.18** – 1.83)	1.09	(0.85 – 1.37)
2004	1.59	(0.87 – 4.37)	0.72	(0.37 – 1.95)
2005[B]	3.02	(**2.32** – 4.12)	1.66	(**1.23** – 2.36)
Monitor Mode Years[C]				
2006	1.11	(0.90 – 1.38)	0.74	(0.59 – ***0.95***)
2007	2.09	(**1.63** – 2.65)	1.78	(**1.35** – 2.31)
2008	1.54	(**1.26** – 1.94)	0.84	(0.67 – 1.08)
2009	2.00	(**1.45** – 2.71)	1.17	(0.84 – 1.64)
2010[D]	1.37	(**1.01** – 1.84)	0.82	(0.60 – 1.13)
2011	1.43	(0.94 – 2.25)	0.84	(0.55 – 1.34)
2012	1.11	(0.79 – 1.48)	0.97	(0.69 – 1.32)
2013	1.01	(0.81 – 1.28)	0.90	(0.71 – 1.16)
2014	1.60	(**1.19** – 2.12)	1.10	(0.81 – 1.48)
2015[E]	3.57	(**2.04** – 5.94)	2.07	(**1.17** – 3.59)
Geomean	1.91	(**1.41** – 2.58)	1.15	(0.91 – 1.45)

[A] For migration year 2001, the SAR(C_1) value is used in the derivation of TIR and *D*.
[B] In-river SAR is combination of groups C_0 and C_1 in derivation of TIR and *D*.
[C] TIR and *D* use SAR for T_X estimated with Group T and C_0 with combined Group CRT.
[D] See Section: *Special Considerations for Migration Year 2010* on page A-11.
[E] Incomplete, 2-salt returns through Sept. 15, 2017.

Table A.54. Estimated TIR and *D* of PIT-tagged Imnaha AP summer Chinook for 1997 to 2015 (with 90% confidence intervals). Lower limit values >1.00 are in bold and upper limit values <1.00 are in bold-italics. After 2005, transport operations initiated on a delayed start date compared to previous years.

Migration Year	TIR		*D*	
1997	1.36	(0.83 – 2.37)	0.45	(0.24 – ***0.92***)
1998	1.55	(0.93 – 3.15)	0.87	(0.51 – 1.72)
1999	1.89	(**1.40** – 2.51)	1.11	(0.75 – 1.72)
2000	1.29	(**1.06** – 1.58)	0.82	(0.56 – 1.25)
2001[A]	10.80	(**4.94** – 39.8)	4.15	(**1.83** – 15.3)
2002	1.75	(**1.07** – 3.03)	0.95	(0.54 – 1.78)
2003	1.21	(0.80 – 1.86)	0.91	(0.57 – 1.41)
2004	1.64	(0.54 – 5.32)	0.94	(0.27 – 3.14)
2005[B]	1.77	(0.91 – 3.93)	1.11	(0.54 – 2.69)
Monitor Mode Years[C]				
2006	0.62	(0.42 – ***0.89***)	0.36	(0.24 – ***0.54***)
2007	1.70	(**1.05** – 2.50)	1.22	(0.74 – 1.90)
2008	1.45	(**1.10** – 1.92)	0.89	(0.66 – 1.25)
2009	1.83	(**1.31** – 2.53)	0.97	(0.68 – 1.39)
2010[D]	1.27	(0.82 – 1.80)	1.07	(0.67 – 1.61)
2011	0.83	(0.37 – 1.76)	0.48	(0.21 – 1.03)
2012	1.06	(0.38 – 2.61)	0.78	(0.26 – 1.94)
2013	1.27	(0.77 – 1.90)	1.00	(0.58 – 1.56)
2014	2.28	(**1.27** – 4.49)	1.60	(0.84 – 3.28)
2015[E]	7.47	(**3.34** – 21.85)	3.04	(**1.29** – 8.99)
Geomean	1.70	(**1.30** – 2.21)	1.00	(0.80 – 1.26)

[A] For migration year 2001, the SAR(C_1) value is used in the derivation of TIR and *D*.
[B] In-river SAR is combination of groups C_0 and C_1 in derivation of TIR and *D*.
[C] TIR and *D* use SAR for T_X estimated with Group T and C_0 with combined Group CRT.
[D] See Section: *Special Considerations for Migration Year 2010* on page A-11.
[E] Incomplete, 2-salt returns through Sept. 15, 2017.

Table A.55. Estimated TIR and *D* of PIT-tagged Pahsimeroi Hatchery summer Chinook for 2008 to 2015 (with 90% confidence intervals). Lower limit values >1.00 are in bold and upper limit values <1.00 are in bold-italics. After 2005, transport operations initiated on a delayed start date compared to previous years.

Migration Year[A]	TIR		*D*	
2008	1.23	(0.85 – 1.90)	0.68	(0.44 – 1.09)
2009	1.62	(0.44 – 3.34)	1.20	(0.33 – 2.44)
2010[B]		---		---
2011[B]		---		---
2012[B]		---		---
2013	1.18	(0.00 – 3.09)	0.80	(0.00 – 2.26)
2014[B]		---		---
2015[B,C]		---		---
Geomean	1.33	(0.93 – 1.90)	0.87	(0.47 – 1.59)

[A] TIR and *D* use SAR for T_X estimated with Group T and C_0 with combined Group CRT.
[B] Too few adults in Transport and/or C_0 study category to estimate TIR and *D*.
[C] Incomplete, 2-salt returns through Sept. 15, 2017.

Table A.56. Estimated TIR and *D* of PIT-tagged Clearwater Hatchery summer Chinook for 2011 and 2015 (with 90% confidence intervals). Lower limit values >1.00 are in bold and upper limit values <1.00 are in bold-italics. After 2005, transport operations initiated on a delayed start date compared to previous years.

Migration Year[A]	TIR		*D*	
2011	0.33	(0.07 – ***0.80***)	0.22	(0.05 – ***0.56***)
2012	0.83	(0.17 – 2.08)	0.58	(0.12 – 1.44)
2013	0.62	(0.23 – 1.15)	0.39	(0.14 – ***0.79***)
2014	1.17	(0.68 – 1.95)	0.75	(0.43 – 1.37)
2015 [B,C]		---		---
Geomean	0.65	(0.36 – 1.17)	0.43	(0.24 – ***0.78***)

[A] TIR and *D* use SAR for T_X estimated with Group T and C_0 with combined Group CRT.
[B] Too few adults in Transport and/or C_0 study category to estimate TIR and *D*.
[C] Incomplete, 2-salt returns through Sept. 15, 2017.

Wild and Hatchery Steelhead

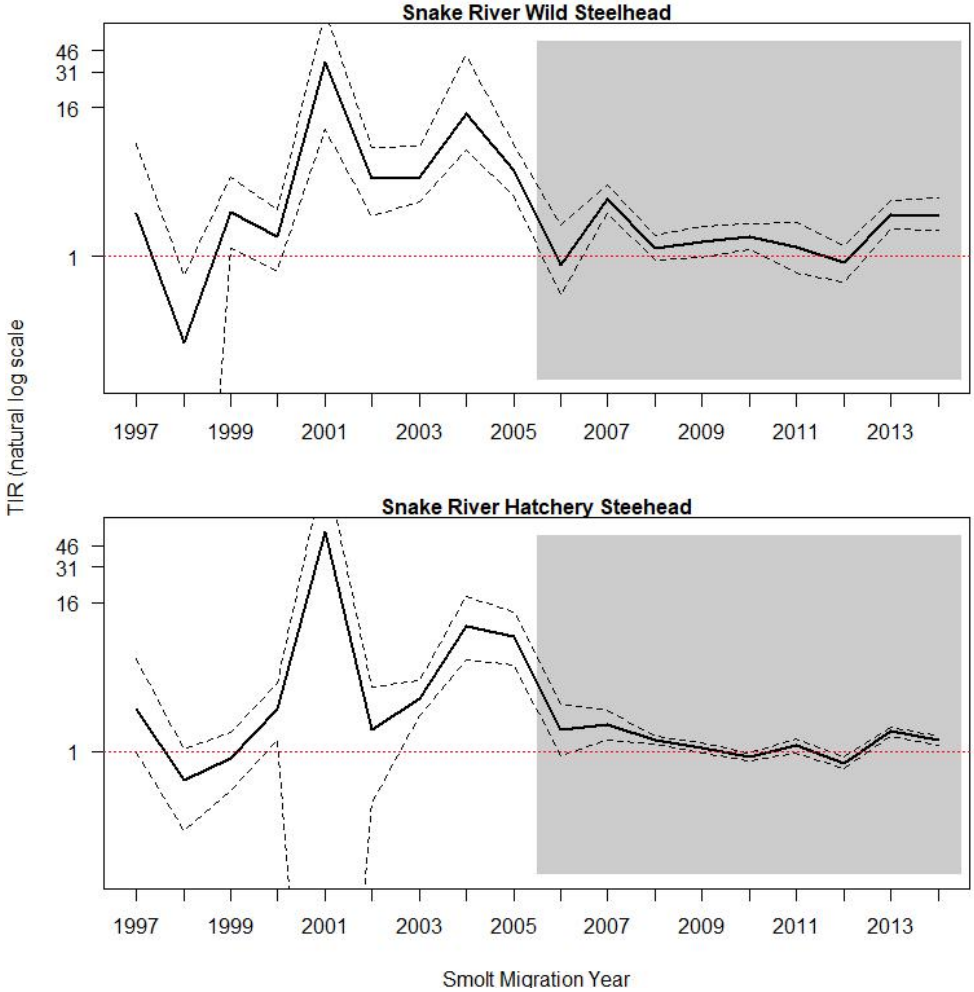

Figure A.26. Trend in TIR on the natural log scale for PIT-tagged Snake River wild (aggregate) and hatchery (aggregate) in migration years 1997 to 2014 (with 90% confidence intervals). The red horizontal dotted line denotes a TIR value of 1 (in-river and transport SARs equal). Shaded area highlights the period of Court Order spill and later start of transportation. TIR calculation for 2001, 2004, and 2005 differs from other years as in-river SAR component of ratio includes C_1 fish (see methods). Data for wild steelhead (aggregate) are from Table A.57; hatchery (aggregate) steelhead data are from Table A.58.

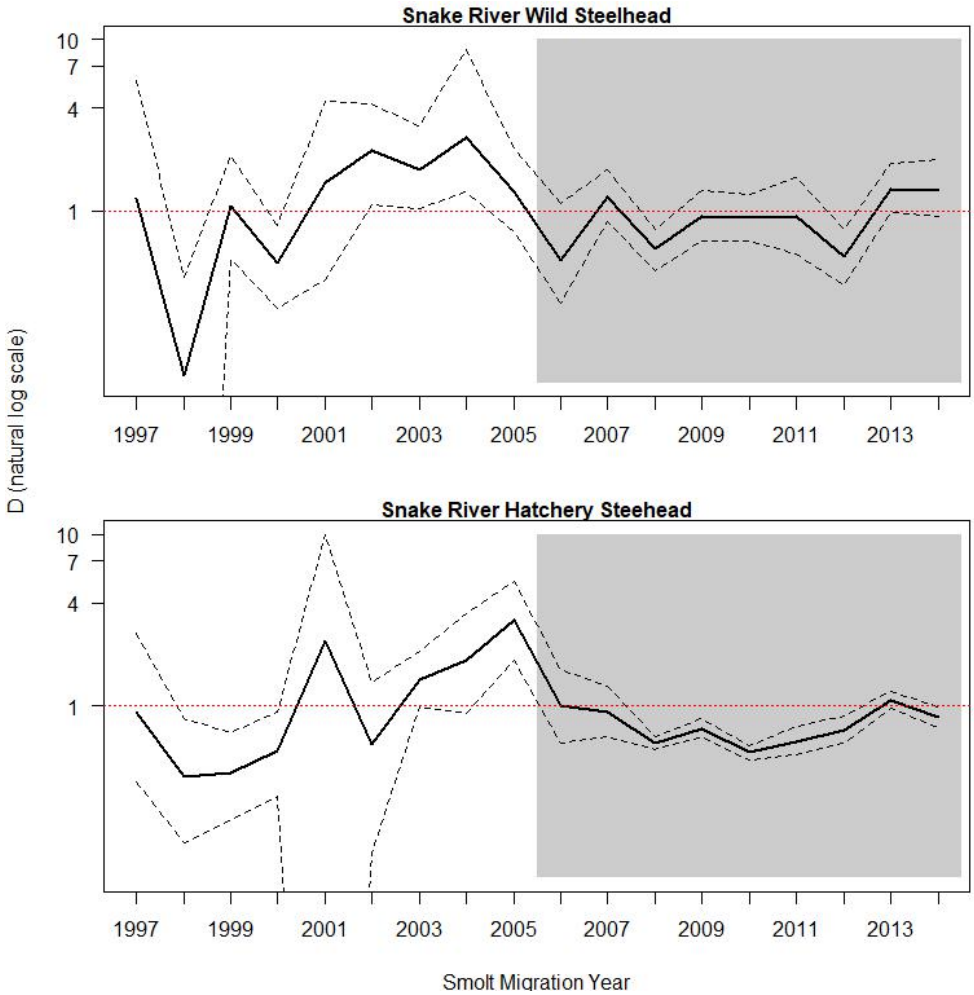

Figure A.27. Trend in *D* on the natural log scale for PIT-tagged Snake River wild (aggregate) and hatchery (aggregate) steelhead in migration years 1997–2014 (with 90% confidence intervals). The red horizontal dotted line corresponds to a *D* value of 1 (in-river and transport post-BON survivals are equal). Shaded area highlights the period of Court Order spill and later start of transportation. *D* calculation for 2001, 2004, and 2005 differs from other years as in-river SAR component of ratio includes C_1 fish (see methods). Data for wild steelhead (aggregate) are from Table A.57; hatchery (aggregate) steelhead data are from Table A.58.

Table A.57. Estimated TIR and *D* of PIT-tagged wild steelhead for migration years 1997 to 2014 (with 90% confidence intervals). Lower limit values >1.00 are in bold and upper limit values <1.00 are in bold-italics. After 2005, transport operations initiated on a delayed start date compared to previous years.

Migration Year	TIR		*D*	
1997	2.20	(0.00 – 8.16)	1.18	(0.00 – 5.74)
1998	0.20	(0.00 – ***0.70***)	0.11	(0.00 – ***0.41***)
1999	2.28	(**1.15** – 4.38)	1.07	(0.53 – 2.09)
2000	1.45	(0.77 – 2.40)	0.50	(0.27 – ***0.82***)
2001[A]	37.00	(**10.6** – 94.6)	1.46	(0.40 – 4.40)
2002	4.25	(**2.12** – 7.67)	2.24	(**1.09** – 4.25)
2003	4.41	(**2.74** – 7.73)	1.75	(**1.04** – 3.16)
2004[B]	14.30	(**7.19** – 42.10)	2.69	(**1.29** – 8.78)
2005[B]	4.88	(**3.01** – 7.98)	1.30	(0.76 – 2.30)
Monitor Mode Years[C]				
2006	0.85	(0.49 – 1.80)	0.52	(0.29 – 1.11)
2007	2.89	(**2.21** – 3.80)	1.20	(0.87 – 1.74)
2008	1.16	(0.93 – 1.49)	0.60	(0.45 – ***0.79***)
2009	1.31	(0.99 – 1.75)	0.94	(0.67 – 1.32)
2010	1.45	(**1.12** – 1.85)	0.92	(0.67 – 1.26)
2011	1.18	(0.74 – 1.86)	0.93	(0.56 – 1.56)
2012	0.88	(0.62 – 1.22)	0.54	(0.37 – ***0.78***)
2013	2.15	(**1.65** – 2.80)	1.35	(0.98 – 1.90)
2014[D]	2.14	(**1.61** – 3.00)	1.33	(0.93 – 1.99)
Geomean	2.23	(**1.40** – 3.55)	0.95	(0.71 – 1.28)

[A] For migration year 2001, the SAR(C_1) value is used in the derivation of TIR and *D*.
[B] In-river SAR is combination of groups C_0 and C_1 in derivation of TIR and *D*.
[C] TIR and *D* use SAR for T_X estimated with Group T and C_0 with combined Group CRT.
[D] Incomplete steelhead adult returns until 3-salt returns (if any) occur after Sept. 15, 2017, at GRA.

Table A.58. Estimated TIR, and *D* of PIT-tagged hatchery (aggregate) steelhead for migration years 1997 to 2014 (with 90% confidence intervals). Lower limit values >1.00 are in bold and upper limit values <1.00 are in bold-italics. After 2005, transport operations initiated on a delayed start date compared to previous years.

Migration Year	TIR		*D*	
1997	2.21	(0.99 – 5.66)	0.92	(0.36 – 2.67)
1998	0.58	(0.23 – 1.05)	0.39	(0.16 – ***0.85***)
1999	0.87	(0.48 – 1.41)	0.41	(0.22 – ***0.70***)
2000	2.20	(**1.22** – 3.58)	0.55	(0.30 – ***0.93***)
2001[A]	59.70	(0.00 – 215.6)	2.40	(0.00 – 10.0)
2002	1.51	(0.38 – 3.33)	0.60	(0.14 – 1.38)
2003	2.65	(**1.93** – 3.71)	1.43	(0.99 – 2.10)
2004[B]	10.30	(**5.43** – 17.9)	1.85	(0.91 – 3.46)
2005[B]	8.44	(**5.04** – 13.4)	3.19	(**1.86** – 5.37)
2006[C]	1.50	(0.93 – 2.42)	1.01	(0.61 – 1.63)
2007[C]	1.66	(**1.22** – 2.16)	0.92	(0.66 – 1.30)
Monitor Mode Years[D]				
2008[E]	1.23	(**1.15** – 1.31)	0.61	(0.56 – ***0.66***)
2009	1.06	(0.97 – 1.17)	0.74	(0.66 – ***0.84***)
2010	0.90	(0.83 – ***0.97***)	0.54	(0.49 – ***0.59***)
2011	1.11	(0.97 – 1.27)	0.62	(0.52 – ***0.76***)
2012	0.80	(0.73 – ***0.90***)	0.72	(0.61 – ***0.88***)
2013	1.44	(**1.31** – 1.58)	1.08	(0.97 – 1.23)
2014[F]	1.22	(**1.11** – 1.33)	0.86	(0.75 – ***0.99***)
Geomean	1.99	(**1.25** – 3.15)	0.88	(0.69 – 1.11)

[A] For migration year 2001, the SAR(C_1) value is used in the derivation of TIR and *D*.
[B] In-river SAR is combination of groups C_0 and C_1 in derivation of TIR and *D*.
[C] No pre-assignment for hatchery steelhead, so one group; transport SARs estimated with T_X smolts.
[D] Estimated SARs for T_X and C_1 with Group T (reflects later start of transportation), and C_0 with combined Group CRT.
[E] TIR and D estimates for 2008 hatchery steelhead aggregate includes all groups with pre-assignment (see Tables A.23–A.26 and A.28-A.29 for details).
[F] Incomplete steelhead adult returns until 3-salt returns (if any) occur after Sept. 15, 2017, at GRA.

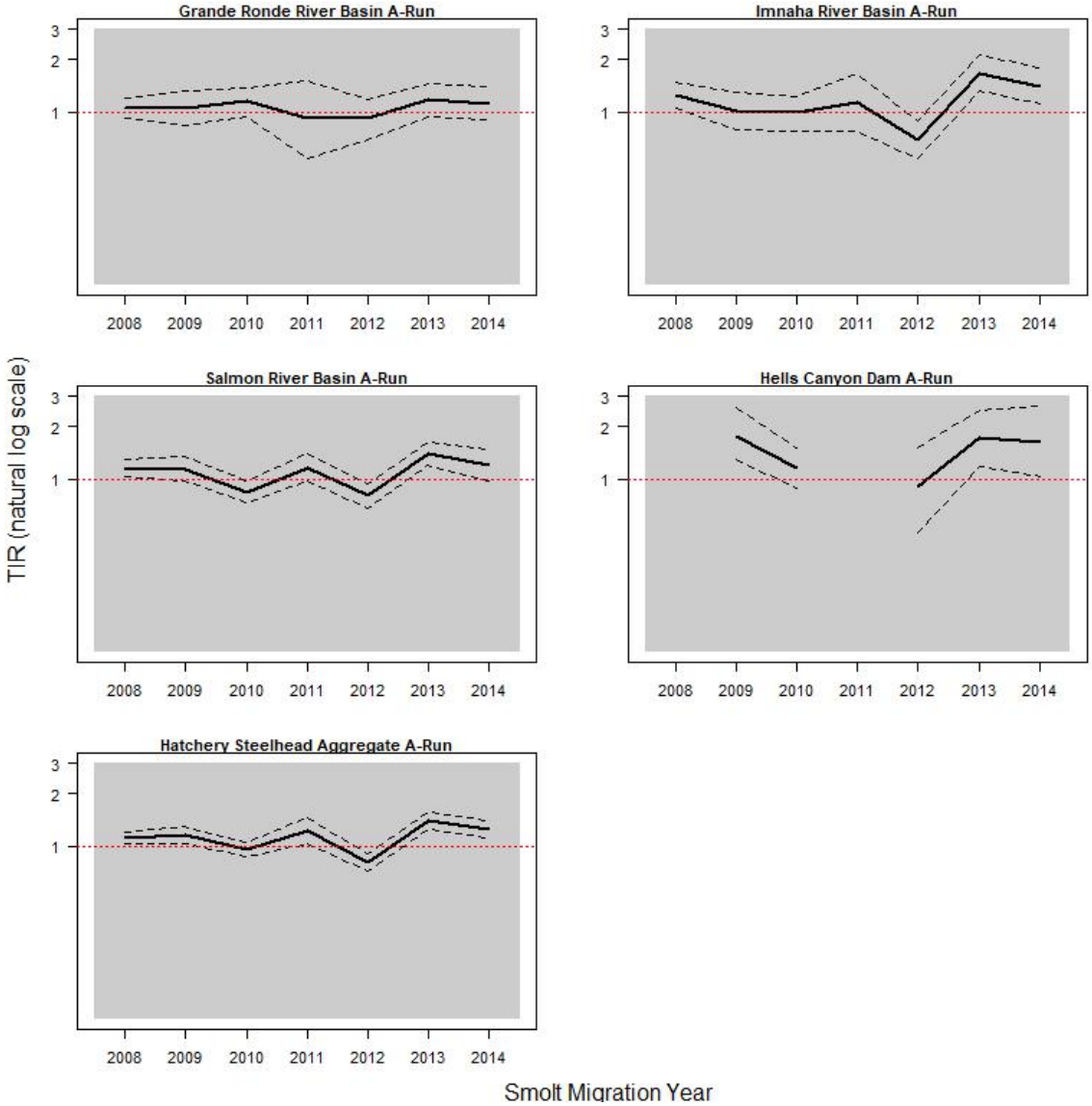

Figure A.28. Trend in TIR on the natural log scale for PIT-tagged Snake River A-run hatchery steelhead in migration years 2008 to 2014 (with 90% confidence intervals). The red horizontal dotted line denotes a TIR value of 1 (in-river and transport SARs equal). Shaded area highlights the period of Court Order spill and later start of transportation. Data for hatchery A-run steelhead are from Tables A.59–A.63.

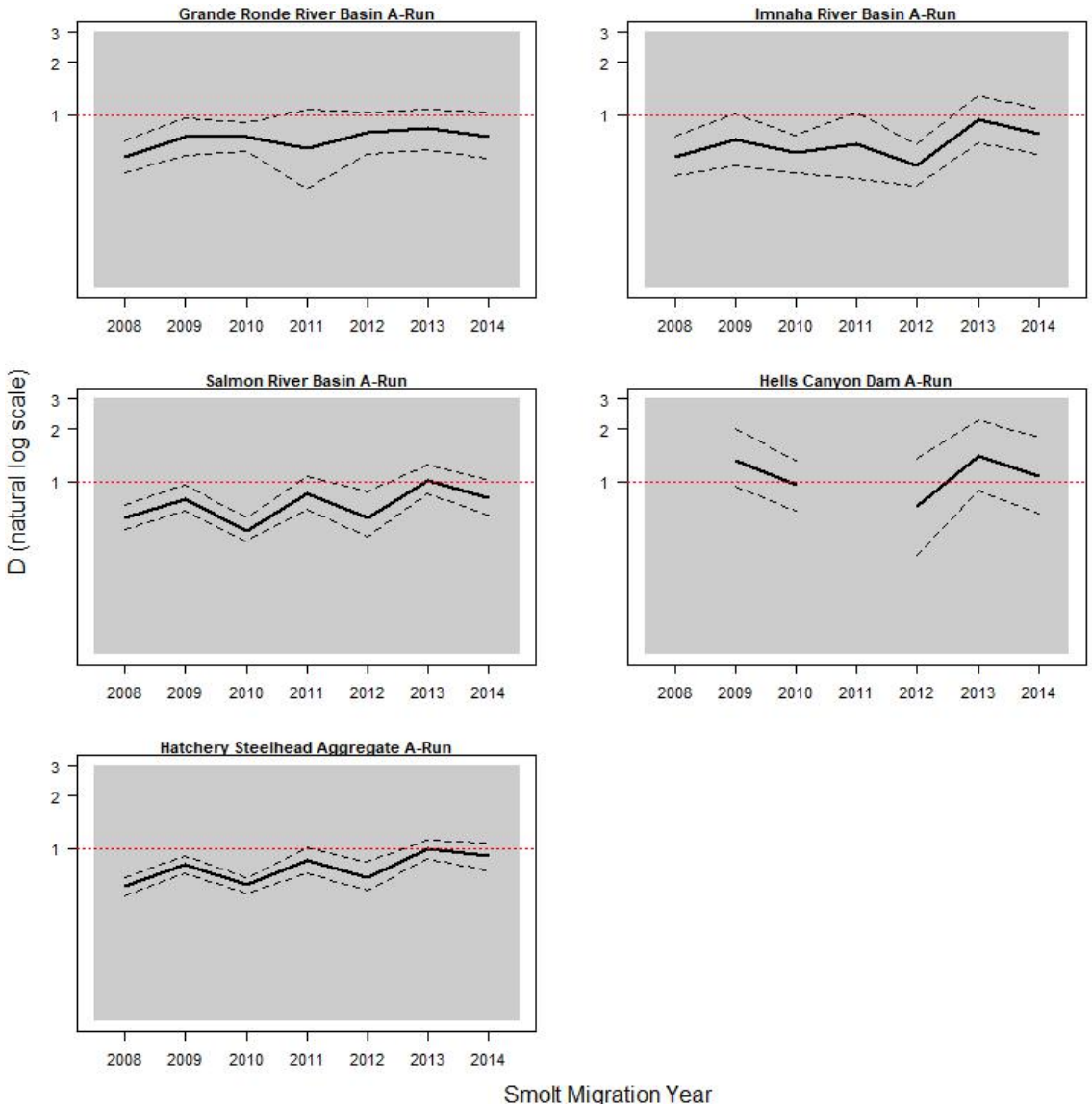

Figure A.29. Trend in *D* on the natural log scale for PIT-tagged Snake River A-run hatchery steelhead in migration years 2008 to 2014 (with 90% confidence intervals). The red horizontal dotted line denotes a *D* value of 1 (in-river and transport post-BON survivals are equal). Shaded area highlights the period of Court Order spill and later start of transportation. Data for hatchery A-run steelhead are from Tables A.59–A.63.

Table A.59. Estimated TIR, and *D* of PIT-tagged Grande Ronde Basin (A-Run) hatchery steelhead for migration years 2008 to 2014 (with 90% confidence intervals). Lower limit values >1.00 are in bold and upper limit values <1.00 are in bold-italics.

Migration Year[A]	TIR		*D*	
2008[B]	1.05	(0.92 – 1.20)	0.57	(0.46 – ***0.70***)
2009	1.05	(0.83 – 1.33)	0.74	(0.58 – ***0.95***)
2010	1.15	(0.94 – 1.37)	0.75	(0.61 – ***0.91***)
2011	0.92	(0.54 – 1.50)	0.64	(0.37 – 1.08)
2012	0.92	(0.69 – 1.19)	0.79	(0.59 – 1.03)
2013	1.18	(0.93 – 1.45)	0.83	(0.63 – 1.08)
2014[C]	1.12	(0.91 – 1.39)	0.74	(0.56 – 1.04)
Geomean	1.05	(0.98 – 1.13)	0.72	(0.65 – ***0.79***)

[A] TIR and *D* use SAR for T_X estimated with Group T and C_0 with combined Group CRT.
[B] Not pre-assigned to T and R groups. Pre-2006 methods applied for these groups (see *Pre-2006 Migration Years* in the Methods section above for details).
[C] Incomplete steelhead adult returns until 3-salt returns (if any) occur after Sept. 15, 2017, at GRA.

Table A.60. Estimated TIR, and *D* of PIT-tagged Imnaha River Basin (A-Run) hatchery steelhead for migration years 2008 to 2014 (with 90% confidence intervals). Lower limit values >1.00 are in bold and upper limit values <1.00 are in bold-italics.

Migration Year[A]	TIR		*D*	
2008[B]	1.25	(**1.06** – 1.47)	0.57	(0.44 – ***0.75***)
2009	1.02	(0.79 – 1.29)	0.71	(0.51 – 1.01)
2010	0.99	(0.78 – 1.23)	0.60	(0.46 – ***0.76***)
2011	1.13	(0.77 – 1.66)	0.67	(0.43 – 1.03)
2012	0.69	(0.54 – ***0.88***)	0.51	(0.39 – ***0.67***)
2013	1.68	(**1.31** – 2.15)	0.94	(0.69 – 1.29)
2014[C]	1.40	(**1.12** – 1.79)	0.78	(0.59 – 1.07)
Geomean	1.13	(0.91 – 1.39)	0.67	(0.58 – ***0.78***)

[A] TIR and *D* use SAR for T_X estimated with Group T and C_0 with combined Group CRT.
[B] Not pre-assigned to T and R groups. Pre-2006 methods applied for these groups (see *Pre-2006 Migration Years* in the Methods section above for details).
[C] Incomplete steelhead adult returns until 3-salt returns (if any) occur after Sept. 15, 2017, at GRA.

Table A.61. Estimated TIR, and *D* of PIT-tagged Salmon River Basin (A-Run) hatchery steelhead for migration years 2008 to 2014 (with 90% confidence intervals). Lower limit values >1.00 are in bold and upper limit values <1.00 are in bold-italics.

Migration Year[A]	TIR		*D*	
2008	1.15	(**1.04** – 1.29)	0.62	(0.53 – ***0.73***)
2009	1.14	(0.97 – 1.35)	0.79	(0.67 – ***0.95***)
2010	0.84	(0.73 – ***0.97***)	0.52	(0.45 – ***0.61***)
2011	1.16	(0.98 – 1.40)	0.85	(0.69 – 1.08)
2012	0.80	(0.67 – ***0.94***)	0.62	(0.48 – ***0.86***)
2013	1.40	(**1.21** – 1.62)	1.02	(0.85 – 1.24)
2014[B]	1.21	(0.98 – 1.48)	0.81	(0.64 – 1.02)
Geomean	1.08	(0.93 – 1.25)	0.73	(0.62 – ***0.87***)

[A] TIR and *D* use SAR for T_X estimated with Group T and C_0 with combined Group CRT.
[B] Incomplete steelhead adult returns until 3-salt returns (if any) occur after Sept. 15, 2017, at GRA.

Table A.62. Estimated TIR, and *D* of PIT-tagged Hells Canyon Dam (A-Run) hatchery steelhead for migration years 2009 to 2014 (with 90% confidence intervals). Lower limit values >1.00 are in bold and upper limit values <1.00 are in bold-italics.

Migration Year[A]	TIR		*D*	
2009	1.78	(**1.29** – 2.58)	1.33	(0.93 – 2.03)
2010[B]	1.16	(0.88 – 1.51)	0.96	(0.68 – 1.33)
2011[C]	---		---	
2012	0.90	(0.49 – 1.52)	0.71	(0.37 – 1.34)
2013	1.72	(**1.19** – 2.49)	1.39	(0.88 – 2.25)
2014[D]	1.63	(**1.04** – 2.64)	1.07	(0.65 – 1.80)
Geomean	1.39	(**1.05** – 1.85)	1.06	(0.82 – 1.37)

[A] TIR and *D* use SAR for T_X estimated with Group T and C_0 with combined Group CRT.
[B] See section: *Special Considerations for Migration Year 2010*.
[C] Too few adults in C_0 group to estimate TIR and *D*.
[D] Incomplete steelhead adult returns until 3-salt returns (if any) occur after Sept. 15, 2017, at GRA.

Table A.63. Estimated TIR, and *D* of PIT-tagged hatchery steelhead (Aggregate A-Run) for migration years 2008 to 2014 (with 90% confidence intervals). Lower limit values >1.00 are in bold and upper limit values <1.00 are in bold-italics.

Migration Year[A]	TIR		*D*	
2008	1.12	(**1.04** – 1.21)	0.60	(0.53 – ***0.68***)
2009	1.16	(**1.04** – 1.29)	0.81	(0.72 – ***0.90***)
2010	0.96	(0.87 – 1.05)	0.61	(0.55 – ***0.67***)
2011	1.23	(**1.04** – 1.45)	0.85	(0.71 – 1.01)
2012	0.80	(0.71 – ***0.91***)	0.68	(0.57 – ***0.83***)
2013	1.41	(**1.26** – 1.56)	0.99	(0.87 – 1.12)
2014[B]	1.24	(**1.12** – 1.40)	0.90	(0.75 – 1.07)
Geomean	1.12	(0.97 – 1.28)	0.76	(0.66 – ***0.88***)

[A] TIR and *D* use SAR for T_X estimated with Group T and C_0 with combined Group CRT.
[B] Incomplete steelhead adult returns until 3-salt returns (if any) occur after Sept. 15, 2017, at GRA.

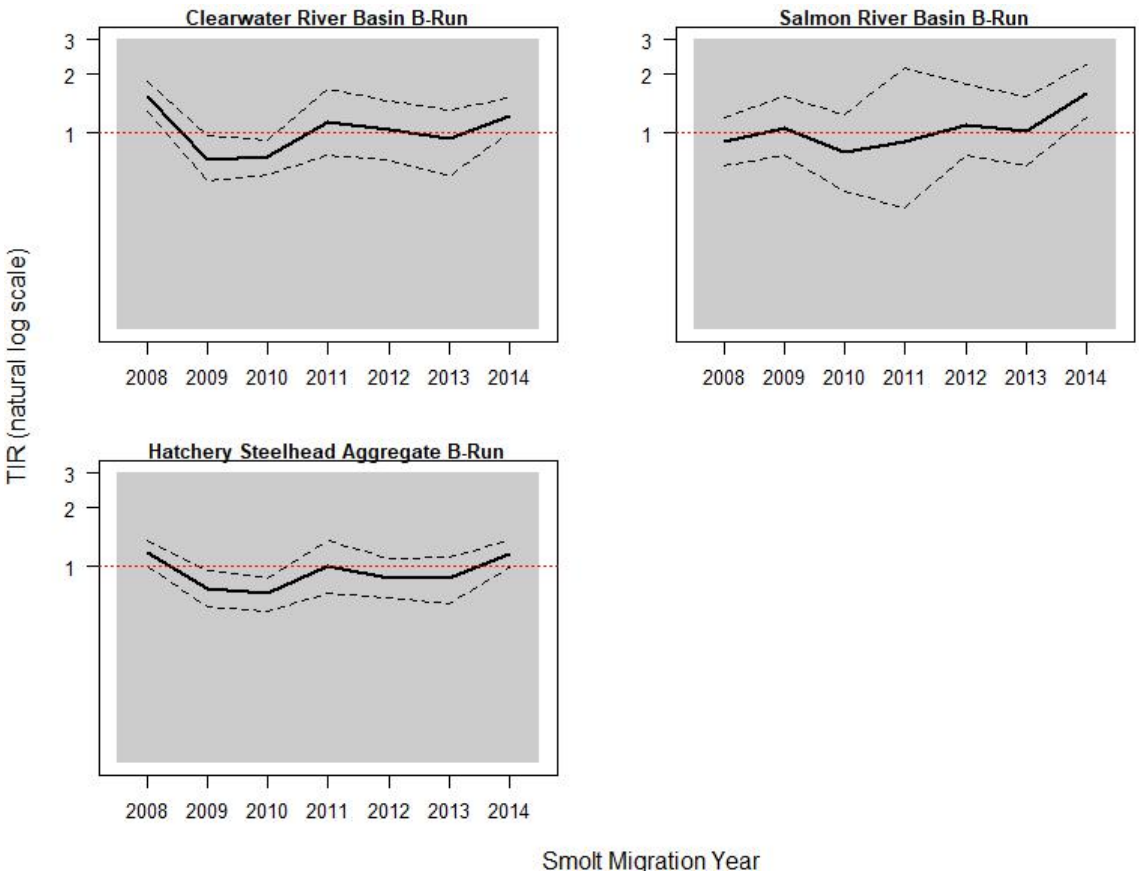

Figure A.30. Trend in TIR on the natural log scale for PIT-tagged Snake River B-run hatchery steelhead in migration years 2008 to 2014 (with 90% confidence intervals). The red horizontal dotted line denotes a TIR value of 1 (in-river and transport SARs equal). Shaded area highlights the period of Court Order spill and later start of transportation. Data for hatchery B-run steelhead are from Tables A.64–A.66.

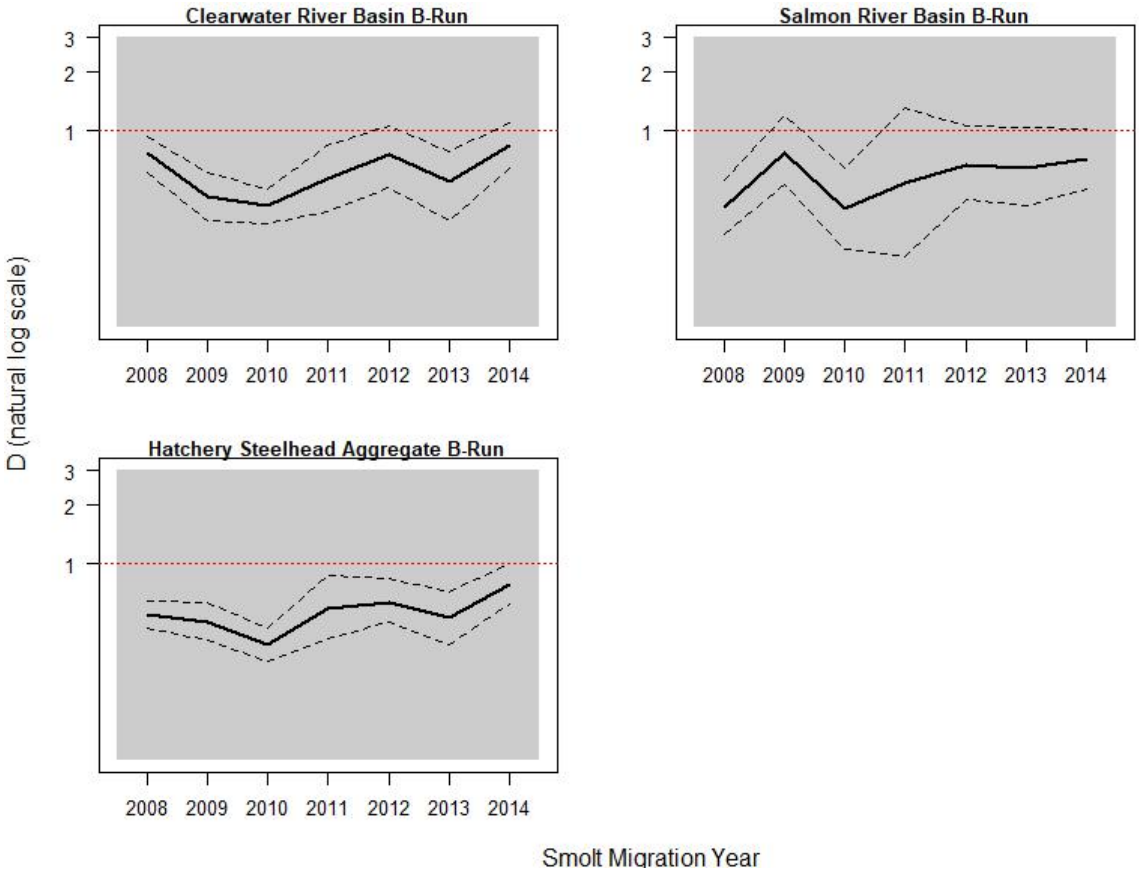

Figure A.31. Trend in *D* on the natural log scale for PIT-tagged Snake River B-run hatchery steelhead in migration years 2008 to 2014 (with 90% confidence intervals). The red horizontal dotted line denotes a *D* value of 1 (in-river and transport post-BON survivals are equal). Shaded area highlights the period of Court Order spill and later start of transportation. Data for hatchery B-run steelhead are from Tables A.64–A.66.

Table A.64. Estimated TIR, and *D* of PIT-tagged Clearwater River Basin (B-Run) hatchery steelhead for migration years 2008 to 2014 (with 90% confidence intervals). Lower limit values >1.00 are in bold and upper limit values <1.00 are in bold-italics.

Migration Year[A]	TIR		*D*	
2008	1.55	(**1.28** – 1.85)	0.77	(0.61 – ***0.94***)
2009	0.74	(0.57 – ***0.97***)	0.46	(0.35 – ***0.62***)
2010	0.76	(0.61 – ***0.92***)	0.42	(0.34 – ***0.51***)
2011	1.14	(0.78 – 1.69)	0.57	(0.39 – ***0.84***)
2012	1.05	(0.73 – 1.46)	0.76	(0.52 – 1.07)
2013	0.94	(0.60 – 1.31)	0.55	(0.35 – ***0.79***)
2014[B]	1.23	(**1.01** – 1.50)	0.85	(0.65 – 1.11)
Geomean	1.03	(0.85 – 1.25)	0.61	(0.50 – ***0.74***)

[A] TIR and *D* use SAR for T_X estimated with Group T and C_0 with combined Group CRT.
[B] Incomplete steelhead adult returns until 3-salt returns (if any) occur after Sept. 15, 2017, at GRA.

Table A.65. Estimated TIR, and *D* of PIT-tagged Salmon River Basin (B-Run) hatchery steelhead for migration years 2008 to 2014 (with 90% confidence intervals). Lower limit values >1.00 are in bold and upper limit values <1.00 are in bold-italics.

Migration Year[A]	TIR		*D*	
2008	0.91	(0.68 – 1.20)	0.41	(0.30 – ***0.56***)
2009	1.07	(0.78 – 1.54)	0.78	(0.53 – 1.20)
2010	0.80	(0.51 – 1.25)	0.40	(0.25 – ***0.65***)
2011	0.91	(0.42 – 2.17)	0.54	(0.23 – 1.31)
2012	1.11	(0.77 – 1.76)	0.67	(0.45 – 1.07)
2013	1.02	(0.68 – 1.54)	0.65	(0.42 – 1.04)
2014[B]	1.60	(**1.21** – 2.22)	0.72	(0.51 – 1.03)
Geomean	1.04	(0.88 – 1.22)	0.58	(0.47 – ***0.70***)

[A] TIR and *D* use SAR for T_X estimated with Group T and C_0 with combined Group CRT.
[B] Incomplete steelhead adult returns until 3-salt returns (if any) occur after Sept. 15, 2017, at GRA.

Table A.66. Estimated TIR, and *D* of PIT-tagged hatchery steelhead (Aggregate B-Run) for migration years 2008 to 2014 (with 90% confidence intervals). Lower limit values >1.00 are in bold and upper limit values <1.00 are in bold-italics.

Migration Year[A]	TIR		*D*	
2008	1.18	(**1.01** – 1.37)	0.55	(0.47 – ***0.65***)
2009	0.78	(0.63 – ***0.95***)	0.51	(0.41 – ***0.64***)
2010	0.73	(0.59 – ***0.87***)	0.39	(0.32 – ***0.47***)
2011	1.00	(0.73 – 1.36)	0.59	(0.42 – ***0.88***)
2012	0.87	(0.69 – 1.11)	0.64	(0.51 – ***0.84***)
2013	0.87	(0.65 – 1.13)	0.53	(0.39 – ***0.72***)
2014[B]	1.17	(0.99 – 1.37)	0.79	(0.63 – 1.00)
Geomean	0.93	(0.81 – 1.07)	0.56	(0.48 – ***0.66***)

[A] TIR and *D* use SAR for T_X estimated with Group T and C_0 with combined Group CRT.
[B] Incomplete steelhead adult returns until 3-salt returns (if any) occur after Sept. 15, 2017, at GRA.

Hatchery Sockeye

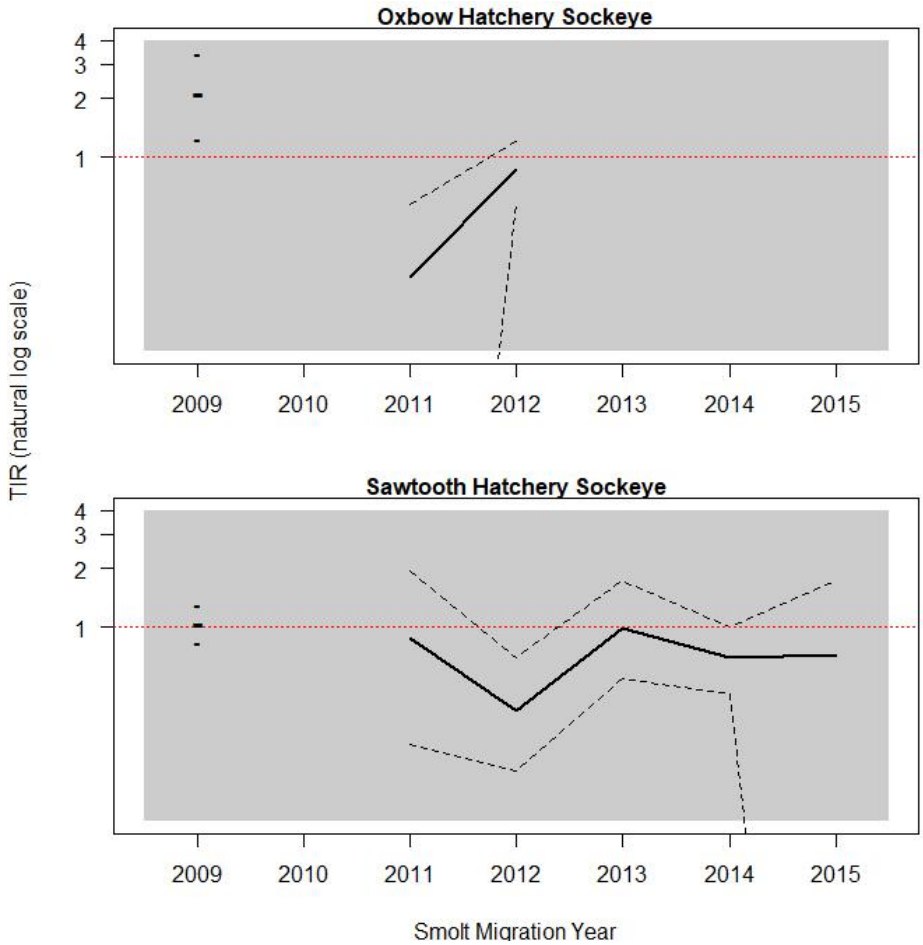

Figure A.32. Trend in TIR on the natural log scale for PIT-tagged Snake River hatchery sockeye in migration years 2009 to 2015 (with 90% confidence intervals). The red horizontal dotted line denotes a TIR value of 1 (in-river and transport SARs equal). Shaded area highlights the period of Court Order spill and later start of transportation. Data for hatchery sockeye are from Tables A.67-A.69. Springfield hatchery sockeye not displayed due to inability to estimate TIR for 2015 (Table A.69).

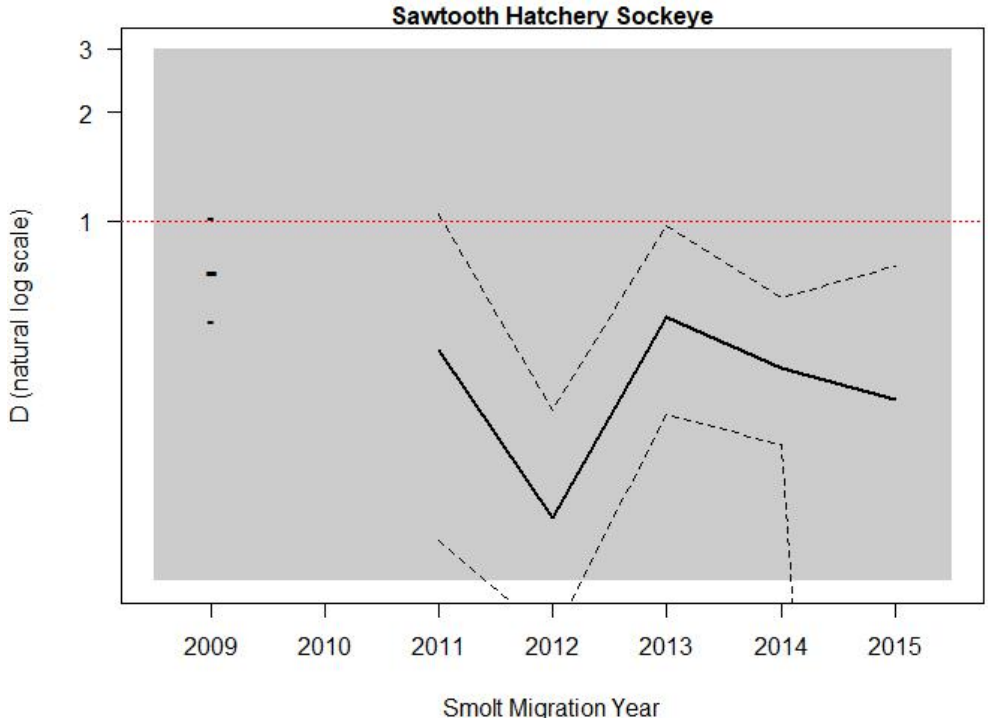

Figure A.33. Trend in *D* on the natural log scale for PIT-tagged Sawtooth Hatchery sockeye in migration years 2009-2015 (with 90% confidence intervals). The red horizontal dotted line corresponds to a *D* value of 1 (in-river and transport post-BON survivals are equal). Shaded area highlights the period of Court Order spill and later start of transportation. Data for hatchery sockeye are from Table A.65. Oxbow and Springfield hatchery sockeye are not displayed because of inability to estimate *D* for these groups (Tables A.67 and A.69).

Table A.67. Estimated TIR and *D* of PIT-tagged hatchery sockeye reared at Oxbow Hatchery for migration years 2009 to 2012 (with 90% confidence intervals). Lower limit values >1.00 are in bold and upper limit values <1.00 are in bold-italics.

Migration Year[A]	TIR	*D*[B]
2009[C]	2.13 (**1.23** – 3.37)	---
2010[D]	---	---
2011	0.24 (0.00 – ***0.57***)	---
2012	0.86 (0.57 – 1.21)	---
Geomean	0.76 (0.12 – 4.83)	---

[A] TIR and *D* use SAR T_X estimated with Group T and C_0 with combined Group CRT.
[B] Due to small sample sizes, could not estimate *D* for this group.
[C] Used same methodology outlined in *Special Considerations for Migration Year 2010* on Page A-11 for 2009 out-migrants.
[D] Too few adults in Transport group to estimate TIR.

Table A.68. Estimated TIR and *D* of PIT-tagged hatchery sockeye reared at Sawtooth Hatchery for migration years 2009 to 2015 (with 90% confidence intervals). Lower limit values >1.00 are in bold and upper limit values <1.00 are in bold-italics.

Migration Year[A]	TIR	*D*
2009	1.04 (0.83 – 1.30)	0.72 (0.53 – 1.02)
2010[B]	---	---
2011	0.88 (0.25 – 1.94)	0.44 (0.13 – 1.05)
2012	0.37 (0.18 – ***0.69***)	0.15 (0.07 – ***0.30***)
2013	0.99 (0.54 – 1.73)	0.54 (0.29 – ***0.97***)
2014	0.70 (0.45 – 1.01)	0.39 (0.24 – ***0.61***)
2015[C]	0.72 (0.00 – 1.72)	0.32 (0.00 – ***0.75***)
Geomean	0.74 (0.54 – 1.01)	0.38 (0.25 – ***0.60***)

[A] TIR and *D* use SAR T_X estimated with Group T and C_0 with combined Group CRT.
[B] Too few adults in Transport category to estimate TIR and *D*.
[C] Incomplete. 2-salt returns through Sept. 15, 2017

Table A.69. Estimated TIR and *D* of PIT-tagged hatchery sockeye reared at Springfield Hatchery for migration year 2015 (with 90% confidence intervals). Lower limit values >1.00 are in bold and upper limit values <1.00 are in bold-italics.

Migration Year[A]	TIR	*D*
2015[B,C]	---	---

[A] TIR and *D* use SAR T_X estimated with Group T and C_0 with combined Group CRT.
[B] As of July 22, 2017, no returning adults detected for this group. Therefore, cannot estimate TIR or *D*.
[C] Incomplete. 2-salt returns through Sept. 15, 2017.

Wild and Hatchery Subyearling Fall Chinook

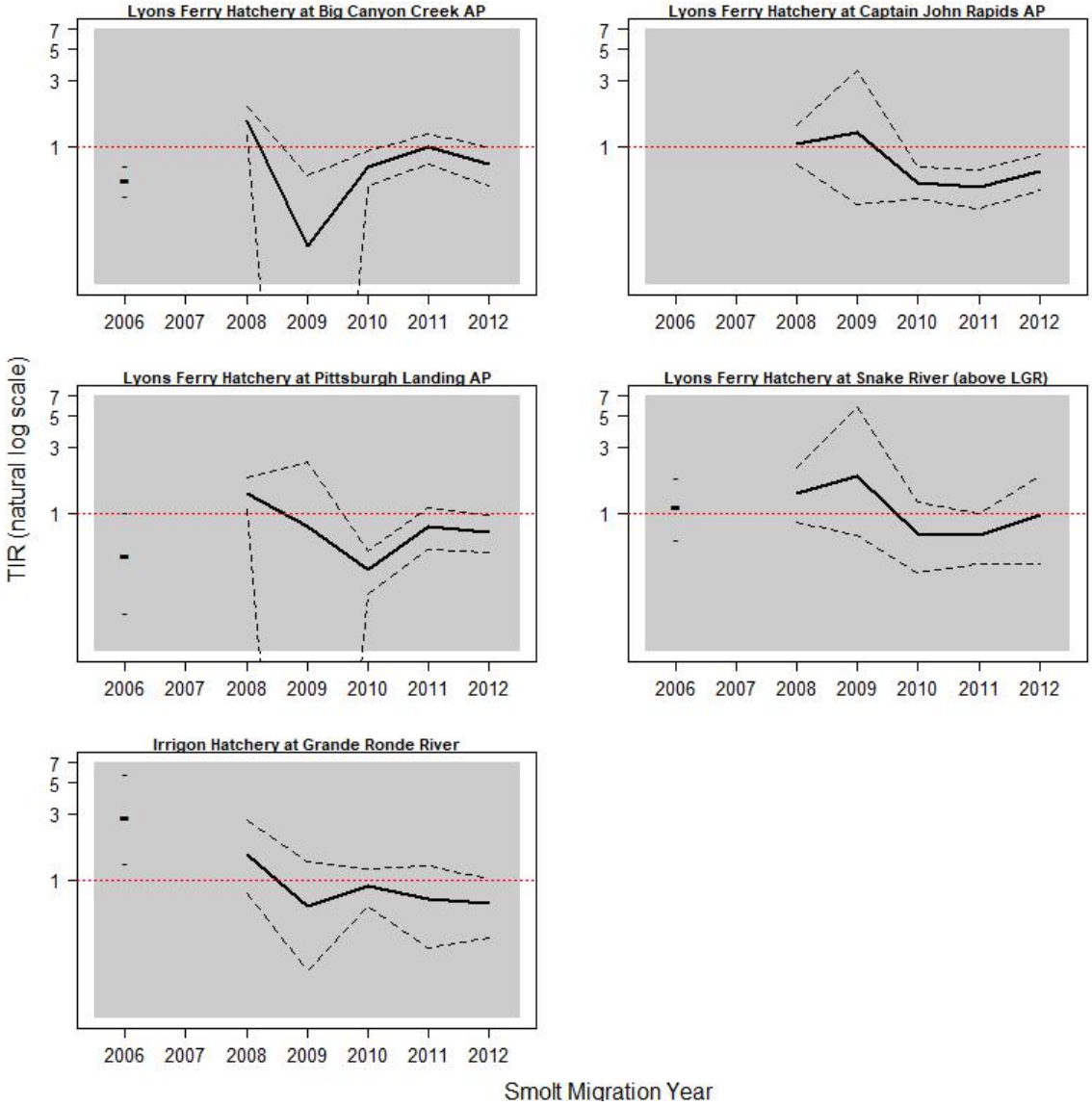

Figure A.34. Trend in TIR on the natural log scale for PIT-tagged Lyons Ferry and Irrigon hatchery subyearling fall Chinook in migration years 2006-2012 (with 90% confidence intervals). The red horizontal dotted line denotes a TIR value of 1 (in-river and transport SARs equal). Shaded area highlights the period of Court Order spill and later start of transportation. Data for Lyons Ferry and Irrigon hatchery subyearling fall Chinook are from Tables A.71-A.75. Data for Snake River wild/natural subyearling fall Chinook not displayed due to only one year of TIR data (Table A.70).

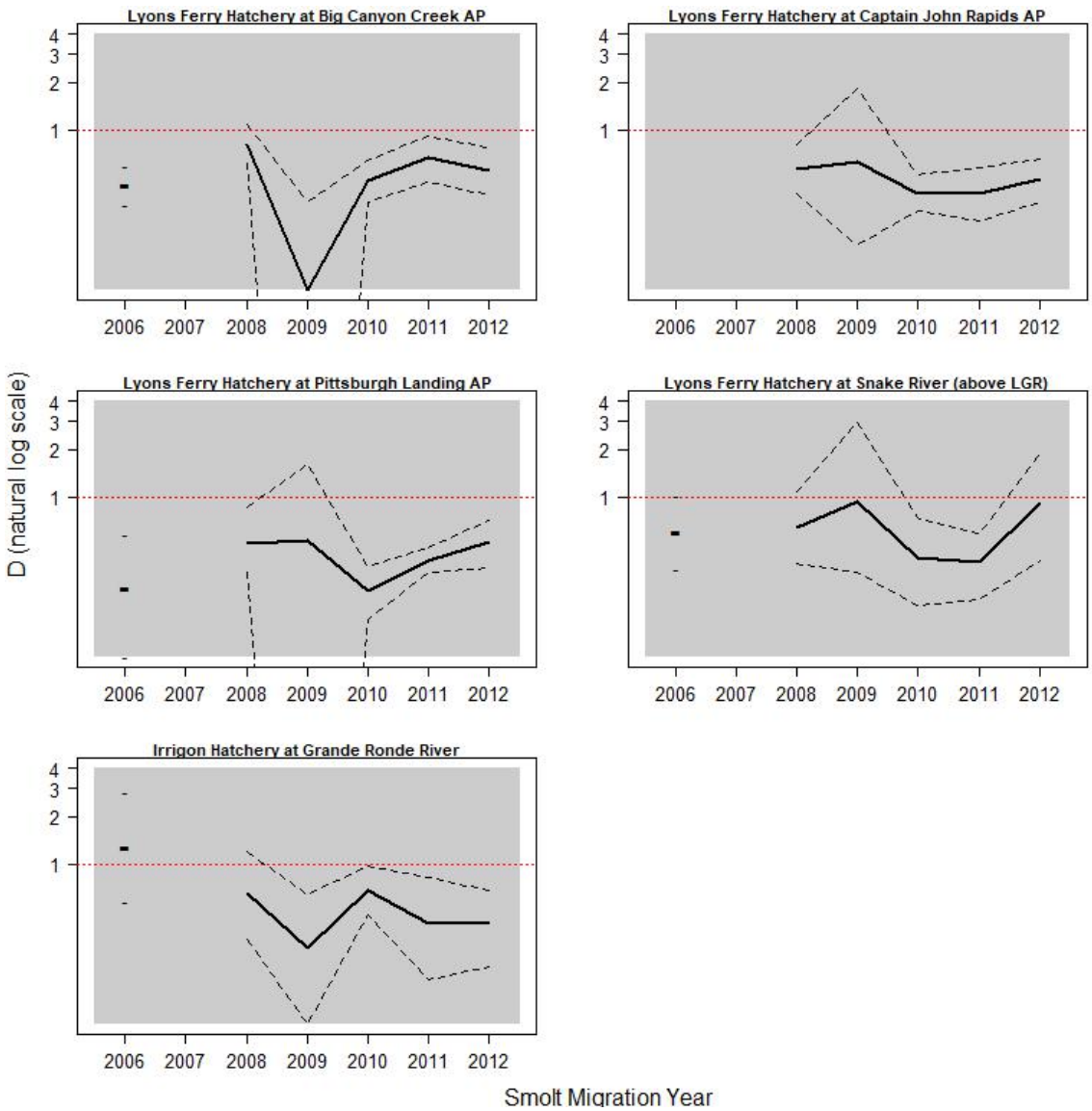

Figure A.35. Trend in *D* on the natural log scale for PIT-tagged Lyons Ferry and Irrigon hatchery subyearling fall Chinook in migration years 2006-2012 (with 90% confidence intervals). The red horizontal dotted line corresponds to a *D* value of 1 (in-river and transport post-BON survivals are equal). Shaded area highlights the period of Court Order spill and later start of transportation. Data for Lyons Ferry and Irrigon hatchery subyearling fall Chinook are from Tables A.71-A.75.

Table A.70. Estimated TIR and *D* of PIT-tagged wild/natural subyearling fall Chinook tagged and released in the mainstem Snake River (above Lower Granite Dam) in 2006 (with 90% confidence intervals). Lower limit values >1.00 are in bold and upper limit values <1.00 are in bold-italics. Due to small sample sizes, estimates of TIR and *D* were not possible for migration years 2007-2012.

Migration Year[A]	TIR	*D*
2006	0.59 (0.00 – 2.52)	0.31 (0.00 – 1.36)

[A] TIR and *D* use SAR T_X estimated with Group T and C_0 with combined Group CRT.

Table A.71. Estimated TIR and *D* of PIT-tagged Lyons Ferry Hatchery subyearling fall Chinook released from Big Canyon Creek Acclimation Pond (Clearwater River) from migration year 2006 to 2012 (with 90% confidence intervals). Lower limit values >1.00 are in bold and upper limit values <1.00 are in bold-italics.

Migration Year[A]	TIR	*D*
2006	0.57 (0.44 – ***0.72***)	0.45 (0.34 – ***0.60***)
2007[B]	---	---
2008	1.52 (**1.19** – 1.92)	0.81 (0.62 – 1.08)
2009	0.19 (0.00 – ***0.61***)	0.10 (0.00 – ***0.35***)
2010	0.70 (0.52 – ***0.92***)	0.48 (0.35 – ***0.65***)
2011	0.98 (0.74 – 1.23)	0.67 (0.47 – ***0.92***)
2012	0.74 (0.52 – ***0.99***)	0.56 (0.39 – ***0.78***)
Geomean	0.66 (0.37 – 1.17)	0.43 (0.23 – ***0.80***)

[A] TIR and *D* use SAR T_X estimated with Group T and C_0 with combined Group CRT.
[B] All PIT-tagged fish were routed in-river. Therefore, estimates of TIR and *D* were not possible.

Table A.72. Estimated TIR and *D* of PIT-tagged Lyons Ferry Hatchery subyearling fall Chinook released from Captain John Rapids Acclimation Pond from migration year 2007 to 2012 (with 90% confidence intervals). Lower limit values >1.00 are in bold and upper limit values <1.00 are in bold-italics.

Migration Year[A]	TIR	*D*
2007[B]	---	---
2008	1.03 (0.74 – 1.42)	0.57 (0.40 – 0.***81***)
2009	1.27 (0.38 – 3.56)	0.63 (0.19 – 1.82)
2010	0.55 (0.42 – ***0.70***)	0.40 (0.31 – ***0.52***)
2011	0.51 (0.35 – ***0.68***)	0.40 (0.27 – ***0.58***)
2012	0.66 (0.48 – ***0.87***)	0.49 (0.35 – ***0.66***)
Geomean	0.75 (0.51 – 1.10)	0.49 (0.40 – ***0.60***)

[A] TIR and *D* use SAR T_X estimated with Group T and C_0 with combined Group CRT.
[B] All PIT-tagged fish were routed in-river. Therefore, estimates of TIR and *D* were not possible.

Table A.73. Estimated TIR and *D* of PIT-tagged Lyons Ferry Hatchery subyearling fall Chinook released from Pittsburg Landing Acclimation Pond from migration year 2006 to 2012 (with 90% confidence intervals). Lower limit values >1.00 are in bold and upper limit values <1.00 are in bold-italics.

Migration Year[A]	TIR	*D*
2006	0.49 (0.19 – 1.02)	0.27 (0.10 – ***0.58***)
2007[B]	---	---
2008	1.39 (**1.07** – 1.79)	0.51 (0.34 – ***0.86***)
2009	0.79 (0.00 – 2.36)	0.53 (0.00 – 1.60)
2010	0.39 (0.26 – ***0.53***)	0.26 (0.17 – ***0.37***)
2011	0.79 (0.54 – 1.09)	0.40 (0.34 – ***0.48***)
2012	0.72 (0.52 – ***0.96***)	0.52 (0.36 – ***0.72***)
Geomean	0.70 (0.49 – 1.01)	0.40 (0.30 – ***0.52***)

[A] TIR and *D* use SAR T_X estimated with Group T and C_0 with combined Group CRT.
[B] All PIT-tagged fish were routed in-river. Therefore, estimates of TIR and *D* were not possible.

Table A.74. Estimated TIR and *D* of PIT-tagged Lyons Ferry Hatchery subyearling fall Chinook released into the mainstem Snake River (above Lower Granite Dam) from migration year 2006 to 2012 (with 90% confidence intervals). Lower limit values >1.00 are in bold and upper limit values <1.00 are in bold-italics.

Migration Year[A]	TIR	*D*
2006	1.12 (0.64 – 1.82)	0.61 (0.35 – 1.01)
2007[B]	---	---
2008	1.37 (0.85 – 2.13)	0.65 (0.38 – 1.08)
2009	1.84 (0.69 – 5.82)	0.94 (0.34 – 2.93)
2010	0.71 (0.37 – 1.19)	0.42 (0.21 – ***0.74***)
2011	0.69 (0.43 – ***0.98***)	0.39 (0.23 – ***0.59***)
2012	0.96 (0.43 – 1.84)	0.91 (0.40 – 1.88)
Geomean	1.05 (0.77 – 1.43)	0.62 (0.46 – ***0.84***)

[A] TIR and *D* use SAR T_X estimated with Group T and C_0 with combined Group CRT.
[B] All PIT-tagged fish were routed in-river. Therefore, estimates of TIR and *D* were not possible.
[C] Incomplete, 3-salt returns through Dec. 31, 2015.

Table A.75. Estimated TIR and *D* of PIT-tagged Irrigon Hatchery subyearling fall Chinook released into the Grande Ronde River from migration year 2006 to 2012 (with 90% confidence intervals). Lower limit values >1.00 are in bold and upper limit values <1.00 are in bold-italics.

Migration Year[A]	TIR	*D*
2006[B]	2.81 (**1.33** – 5.79)	1.28 (0.58 – 2.80)
2007[C]	---	---
2008	1.51 (0.80 – 2.69)	0.66 (0.34 – 1.21)
2009	0.64 (0.22 – 1.34)	0.30 (0.10 – ***0.65***)
2010	0.89 (0.65 – 1.20)	0.69 (0.48 – ***0.98***)
2011	0.73 (0.32 – 1.25)	0.43 (0.19 – ***0.83***)
2012	0.67 (0.38 – 1.01)	0.43 (0.23 – ***0.69***)
Geomean	1.03 (0.64 – 1.66)	0.56 (0.37 – ***0.86***)

[A] TIR and *D* use SAR T_X estimated with Group T and C_0 with combined Group CRT.
[B] 2006 release was reared at Lyons Ferry Hatchery
[C] All PIT-tagged fish were routed in-river. Therefore, estimates of TIR and *D* were not possible.

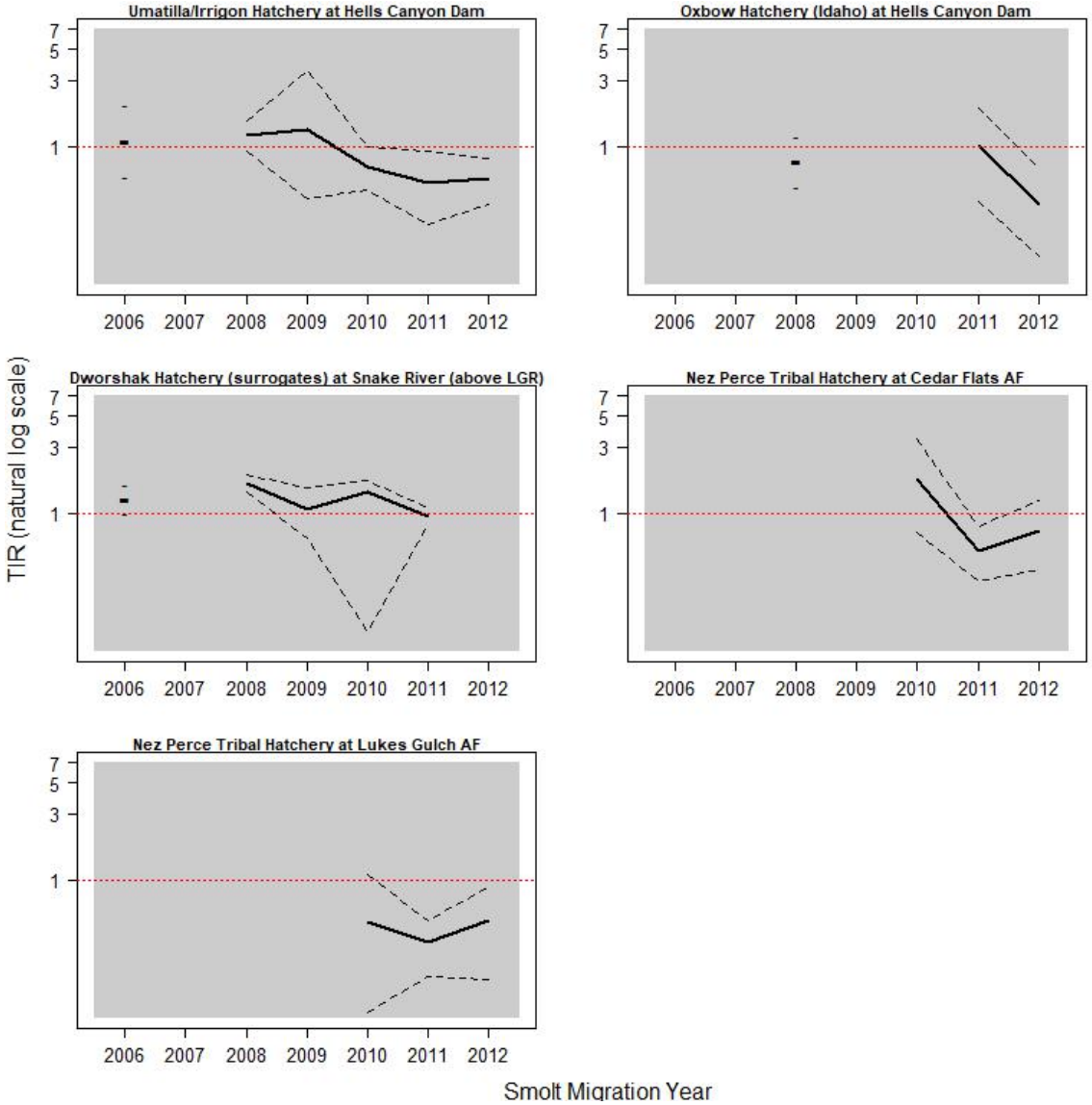

Figure A.36. Trend in TIR on the natural log scale for PIT-tagged subyearling fall Chinook (various hatcheries and release locations) in migration years 2006-2012 (with 90% confidence intervals). The red horizontal dotted line denotes a TIR value of 1 (in-river and transport SARs equal). Shaded area highlights the period of Court Order spill and later start of transportation. Data for above figure are from Tables A.76-A.80.

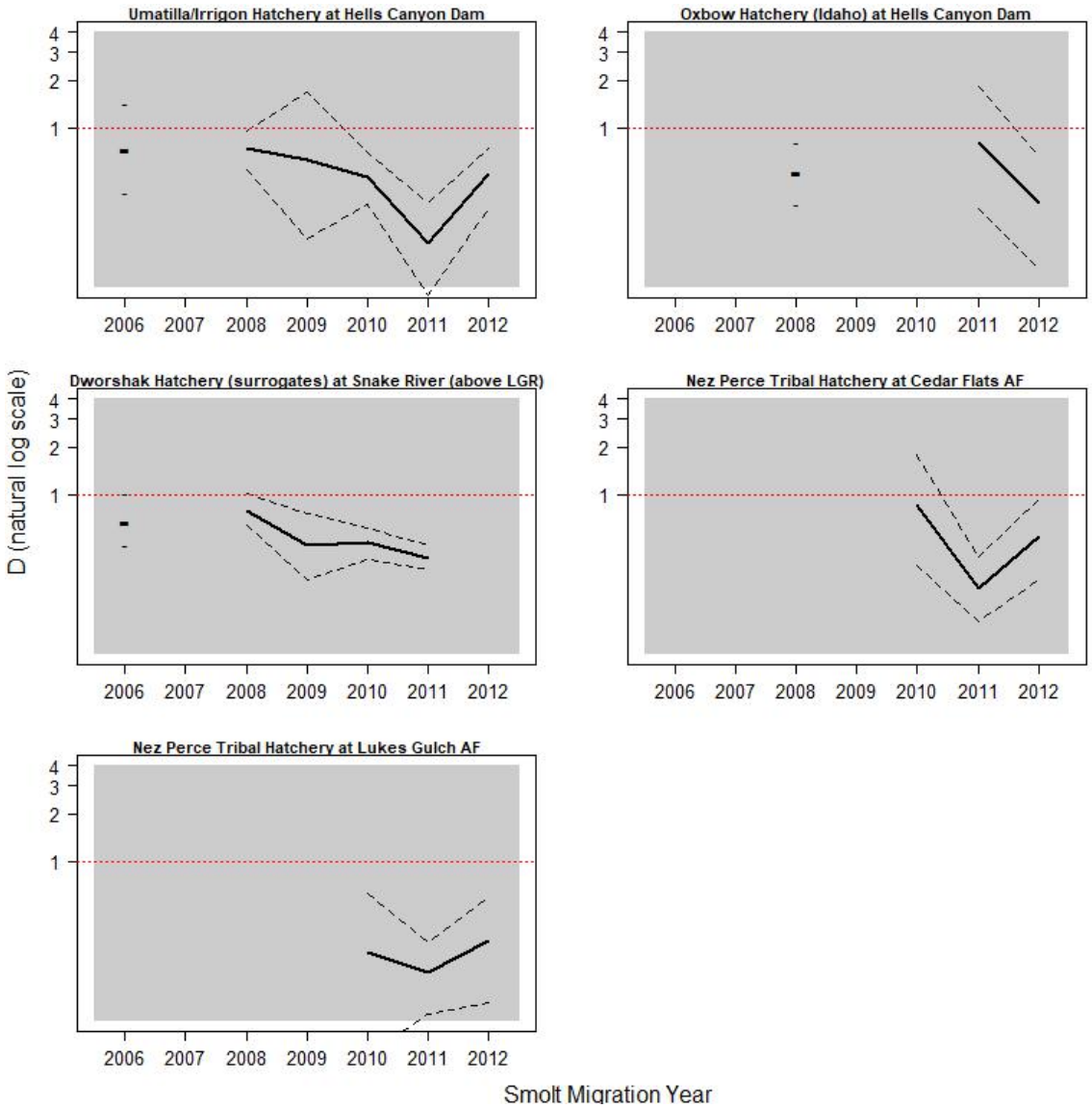

Figure A.37. Trend in *D* on the natural log scale for PIT-tagged subyearling fall Chinook (various hatcheries and release locations) in migration years 2006-2012 (with 90% confidence intervals). The red horizontal dotted line corresponds to a *D* value of 1 (in-river and transport post-BON survivals are equal). Shaded area highlights the period of Court Order spill and later start of transportation. Data for above figure are from Tables A.76-A.80.

Table A.76. Estimated TIR and *D* of PIT-tagged Umatilla/Irrigon Hatchery subyearling fall Chinook released into the Snake River below Hells Canyon Dam from migration year 2006 to 2012 (with 90% confidence intervals). Lower limit values >1.00 are in bold and upper limit values <1.00 are in bold-italics.

Migration Year[A]	TIR	*D*
2006	1.08 (0.60 – 2.00)	0.73 (0.39 – 1.43)
2007[B]	---	---
2008	1.20 (0.93 – 1.51)	0.74 (0.55 – ***0.96***)
2009	1.32 (0.42 – 3.53)	0.63 (0.20 – 1.69)
2010	0.70 (0.48 – ***0.98***)	0.49 (0.33 – ***0.70***)
2011	0.55 (0.27 – ***0.93***)	0.19 (0.09 – ***0.34***)
2012	0.59 (0.38 – ***0.82***)	0.51 (0.31 – ***0.74***)
Geomean	0.85 (0.61 – 1.17)	0.50 (0.33 – ***0.76***)

[A] TIR and *D* use SAR T_X estimated with Group T and C_0 with combined Group CRT.
[B] All PIT-tagged fish were routed in-river. Therefore, estimates of TIR and *D* were not possible.

Table A.77. Estimated TIR and *D* of PIT-tagged Oxbow Hatchery (Idaho) subyearling fall Chinook released into the Snake River below Hells Canyon Dam from migration year 2007 to 2012 (with 90% confidence intervals). Lower limit values >1.00 are in bold and upper limit values <1.00 are in bold-italics.

Migration Year[A]	TIR	*D*
2007[B]	---	---
2008	0.78 (0.50 – 1.16)	0.52 (0.33 – ***0.81***)
2009[C]	---	---
2010[D]	---	---
2011	1.01 (0.40 – 1.88)	0.82 (0.31 – 1.82)
2012	0.38 (0.16 – ***0.69***)	0.34 (0.13 – ***0.66***)
Geomean	0.69 (0.31 – 1.50)	0.54 (0.27 – 1.07)

[A] TIR and *D* use SAR T_X estimated with Group T and C_0 with combined Group CRT.
[B] All PIT-tagged fish were routed in-river. Therefore, estimates of TIR and *D* were not possible.
[C] Too few adults in Transport and/or C_0 category to estimate TIR and D.
[D] No PIT-tags were released in 2010.

Table A.78. Estimated TIR and *D* of PIT-tagged Dworshak Hatchery subyearling fall Chinook (surrogates) released into the mainstem Snake River (above Lower Granite Dam) from migration year 2006 to 2011 (with 90% confidence intervals). Lower limit values >1.00 are in bold and upper limit values <1.00 are in bold-italics.

Migration Year[A]	TIR	*D*
2006	1.26 (0.99 – 1.59)	0.67 (0.48 – 1.02)
2007[B]	---	---
2008	1.64 (**1.42** – 1.90)	0.80 (0.64 – 1.03)
2009	1.06 (0.66 – 1.54)	0.48 (0.29 – ***0.77***)
2010	1.41 (0.14 – 1.70)	0.50 (0.39 – ***0.62***)
2011	0.94 (0.81 – 1.09)	0.40 (0.34 – ***0.48***)
2012[C]	---	---
Geomean	1.24 (1.00 – 1.53)	0.55 (0.42 – ***0.72***)

[A] TIR and *D* use SAR T_X estimated with Group T and C_0 with combined Group CRT.
[B] Due to low broodstock, no PIT-tags were released for this group in 2007.
[C] TIR and D not estimable due to high estimated holdover rates.

Table A.79. Estimated TIR and *D* of PIT-tagged Nez Perce Tribal Hatchery subyearling fall Chinook released from Cedar Flats Acclimation Facility (Clearwater River) from migration year 2010 to 2012 (with 90% confidence intervals). Lower limit values >1.00 are in bold and upper limit values <1.00 are in bold-italics.

Migration Year[A]	TIR	*D*
2010	1.76 (0.73 – 3.43)	0.87 (0.36 – 1.78)
2011	0.53 (0.32 – ***0.79***)	0.26 (0.16 – ***0.41***)
2012	0.75 (0.39 – 1.24)	0.55 (0.29 – ***0.93***)
Geomean	0.89 (0.31 – 2.51)	0.50 (0.18 – 1.40)

[A] TIR and *D* use SAR T_X estimated with Group T and C_0 with combined Group CRT.

Table A.80. Estimated TIR and *D* of PIT-tagged Nez Perce Tribal Hatchery subyearling fall Chinook released from Lukes Gulch Acclimation Facility (Clearwater River) from migration year 2010 to 2012 (with 90% confidence intervals). Lower limit values >1.00 are in bold and upper limit values <1.00 are in bold-italics.

Migration Year[A]	TIR	*D*
2010	0.49 (0.11 – 1.08)	0.27 (0.06 – ***0.63***)
2011	0.35 (0.20 – ***0.51***)	0.20 (0.11 – ***0.31***)
2012	0.50 (0.19 – ***0.88***)	0.32 (0.13 – ***0.59***)
Geomean	0.44 (0.31 – ***0.62***)	0.26 (0.17 – ***0.39***)

[A] TIR and *D* use SAR T_X estimated with Group T and C_0 with combined Group CRT.

APPENDIX B

SUPPORTING TABLES TO CHAPTER 4 — OVERALL SARS

APPENDIX B

ANNUAL OVERALL SARS
(SUPPORTING TABLES TO CHAPTERS 4 AND 6)

Snake River wild spring/summer Chinook

Table B.1. Overall LGR-to-GRA SARs for Snake River Basin (above LGR) Wild Chinook, 1994 to 2015. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-GRA without Jacks			LGR-to-GRA with Jacks		
		%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL	%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL
1994	15,260	0.43	0.22	0.66	0.47	0.24	0.70
1995	20,206	0.35	0.20	0.52	0.35	0.19	0.52
1996	7,868	0.42	0.06	0.84	0.43	0.06	0.85
1997	2,898	1.73	0.97	2.68	1.78	0.99	2.73
1998	17,363	1.21	0.82	1.64	1.25	0.84	1.70
1999	33,662	2.39	1.89	2.94	2.55	2.03	3.09
2000	25,053	1.71	1.22	2.24	1.72	1.25	2.20
2001	22,415	1.27	0.54	2.11	1.45	0.70	2.32
2002	23,356	0.92	0.75	1.10	1.04	0.83	1.24
2003	31,093	0.34	0.26	0.41	0.34	0.26	0.42
2004	32,546	0.52	0.43	0.63	0.54	0.44	0.64
2005	35,216	0.22	0.17	0.28	0.24	0.18	0.30
2006	15,274	0.70	0.58	0.81	0.75	0.63	0.87
2007	14,919	0.98	0.85	1.11	1.09	0.95	1.23
2008	18,599	2.74	2.53	2.95	3.24	3.02	3.45
2009	18,781	1.45	1.31	1.60	1.61	1.45	1.76
2010	26,624	0.74	0.66	0.83	0.93	0.83	1.04
2011	23,304	0.33	0.27	0.39	0.36	0.30	0.42
2012	21,576	1.10	0.99	1.22	1.43	1.31	1.57
2013	18,867	1.21	1.08	1.36	1.37	1.22	1.53
2014	21,417	0.52	0.44	0.60	0.57	0.49	0.65
2015[B]	12,262	0.22	0.15	0.29	0.28	0.20	0.35
Geometric mean		0.76			0.84		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using total tag release in years through 2005 and Group T tags beginning in 2006.
[B] Incomplete, 2-salt returns through Sept. 15, 2017.

Table B.2. Overall LGR-to-BOA SARs for Snake River Basin (above LGR) Wild Chinook, 2000 to 2015. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-BOA without Jacks			LGR-to-BOA with Jacks		
		%SAR Estimate	Non-parametric CI		%SAR Estimate	Non-parametric CI	
			90% LL	90% UL		90% LL	90% UL
2000	25,053	2.60	1.95	3.28	2.69	2.01	3.39
2001	22,415	1.81	0.90	2.89	1.99	1.10	2.99
2002	23,356	1.14	0.94	1.35	1.29	1.07	1.52
2003	31,093	0.34	0.26	0.42	0.34	0.27	0.42
2004	32,546	0.68	0.56	0.80	0.69	0.58	0.80
2005	35,216	0.29	0.23	0.36	0.30	0.24	0.37
2006	15,274	0.84	0.73	0.98	0.90	0.77	1.03
2007	14,919	1.16	1.01	1.31	1.27	1.12	1.43
2008	18,599	3.56	3.33	3.79	4.13	3.90	4.37
2009	18,781	1.93	1.76	2.09	2.09	1.90	2.26
2010	26,624	0.92	0.82	1.02	1.16	1.05	1.28
2011	23,304	0.42	0.35	0.49	0.45	0.38	0.52
2012	21,576	1.48	1.35	1.62	1.84	1.69	2.00
2013	18,867	1.56	1.41	1.72	1.71	1.55	1.88
2014	21,417	0.61	0.52	0.70	0.69	0.59	0.77
2015[B]	12,262	0.27	0.20	0.35	0.33	0.25	0.42
Geometric mean		0.94			1.04		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using total tag release in years through 2005 and Group T tags beginning in 2006.
[B] Incomplete, 2-salt returns through Sept. 15, 2017.

Table B.3. Overall LGR-to-GRA SARs for Clearwater River Wild Chinook, 2006–2015. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-GRA without Jacks			LGR-to-GRA with Jacks		
		%SAR Estimate	Non-parametric CI		SAR Estimate	Non-parametric CI	
			90% LL	90% UL		90% LL	90% UL
2006	1,778	0.28	0.11	0.52	0.34	0.11	0.57
2007	574	0.87	0.19	1.54	0.87	0.33	1.64
2008	1,152	1.39	0.84	2.08	1.56	1.00	2.19
2009	1,076	1.02	0.49	1.59	1.02	0.54	1.59
2010	5,694	0.76	0.57	0.96	0.76	0.57	0.95
2011	1,432	0.35	0.14	0.63	0.35	0.14	0.63
2012	1,301	0.69	0.32	1.07	0.69	0.32	1.07
2013	1,075	0.37	0.09	0.67	0.37	0.09	0.67
2014	819	0.24	0.00	0.58	0.24	0.00	0.58
2015[B]	465	0.22	0.00	0.64	0.22	0.00	0.64
Geometric mean		0.51			0.53		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using Group T tags.
[B] Incomplete, 2-salt returns through Sept. 15, 2017.

Table B.4. Overall LGR-to-BOA SARs for Clearwater River Wild Chinook, 2006–2015. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-BOA without Jacks			LGR-to-BOA with Jacks		
		%SAR Estimate	Non-parametric CI		SAR Estimate	Non-parametric CI	
			90% LL	90% UL		90% LL	90% UL
2006	1,778	0.39	0.17	0.66	0.45	0.18	0.73
2007	574	1.04	0.38	1.77	1.04	0.36	1.81
2008	1,152	1.74	1.09	2.48	1.91	1.25	2.60
2009	1,076	1.39	0.84	1.97	1.39	0.81	2.07
2010	5,694	1.05	0.85	1.30	1.07	0.86	1.34
2011	1,432	0.49	0.21	0.83	0.49	0.21	0.83
2012	1,301	0.69	0.31	1.11	0.69	0.31	1.11
2013	1,075	0.74	0.36	1.21	0.74	0.36	1.21
2014	819	0.37	0.00	0.74	0.37	0.00	0.74
2015[B]	465	0.22	0.00	0.64	0.22	0.00	0.64
Geometric mean		0.68			0.70		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using Group T tags.
[B] Incomplete, 2-salt returns through Sept. 15, 2017.

Table B.5. Overall LGR-to-GRA SARs for Grande Ronde Basin Wild Chinook, 2006–2015. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-GRA without Jacks			LGR-to-GRA with Jacks		
		%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL	SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL
2006	3,469	0.89	0.65	1.18	0.95	0.68	1.24
2007	2,672	1.16	0.80	1.51	1.38	0.99	1.77
2008	2,382	2.94	2.41	3.56	3.32	2.74	3.94
2009	2,781	2.16	1.69	2.65	2.30	1.87	2.77
2010	3,743	0.53	0.35	0.75	0.64	0.44	0.86
2011	3,262	0.43	0.24	0.62	0.43	0.24	0.62
2012	3,094	1.45	1.09	1.84	1.65	1.26	2.05
2013	3,238	1.51	1.16	1.90	1.76	1.37	2.19
2014	3,384	1.30	0.97	1.65	1.36	1.02	1.71
2015[B]	1,311	0.46	0.17	0.79	0.53	0.22	0.92
Geometric mean		1.07			1.19		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using Group T tags.
[B] Incomplete, 2-salt returns through Sept. 15, 2017.

Table B.6. Overall LGR-to-BOA SARs for Grande Ronde Basin Wild Chinook, 2006–2015. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-BOA without Jacks			LGR-to-BOA with Jacks		
		%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL	SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL
2006	3,469	1.07	0.80	1.36	1.12	0.82	1.42
2007	2,672	1.50	1.11	1.89	1.72	1.31	2.16
2008	2,382	3.82	3.16	4.51	4.20	3.52	4.88
2009	2,781	2.77	2.25	3.32	2.84	2.30	3.40
2010	3,743	0.80	0.56	1.04	0.94	0.68	1.20
2011	3,262	0.49	0.30	0.70	0.49	0.30	0.70
2012	3,094	2.00	1.58	2.45	2.20	1.74	2.64
2013	3,238	1.91	1.50	2.35	2.16	1.73	2.63
2014	3,384	1.51	1.15	1.89	1.60	1.23	1.99
2015[B]	1,311	0.61	0.28	1.00	0.76	0.39	1.20
Geometric mean		1.37			1.51		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using Group T tags.
[B] Incomplete, 2-salt returns through Sept. 15, 2017.

Table B.7. Overall LGR-to-GRA SARs for Imnaha River Basin Wild Chinook, 2006–2015. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-GRA without Jacks			LGR-to-GRA with Jacks		
		%SAR Estimate	Non-parametric CI		SAR Estimate	Non-parametric CI	
			90% LL	90% UL		90% LL	90% UL
2006	714	0.70	0.27	1.27	0.70	0.14	1.28
2007	4,111	0.63	0.42	0.84	0.78	0.58	1.02
2008	4,050	2.81	2.36	3.28	3.53	3.07	4.05
2009	3,160	1.68	1.33	2.08	1.90	1.50	2.30
2010	4,094	0.83	0.60	1.07	1.10	0.81	1.38
2011	2,413	0.33	0.16	0.64	0.37	0.20	0.59
2012	2,389	0.80	0.51	1.10	1.00	0.68	1.36
2013	2,980	1.21	0.89	1.55	1.44	1.08	1.82
2014	3,397	0.44	0.26	0.62	0.50	0.30	0.70
2015[B]	3,025	0.43	0.24	0.65	0.50	0.29	0.73
Geometric mean		0.80			0.94		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using Group T tags.
[B] Incomplete, 2-salt returns through Sept. 15, 2017.

Table B.8. Overall LGR-to-BOA SARs for Imnaha River Basin Wild Chinook, 2006–2015. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-BOA without Jacks			LGR-to-BOA with Jacks		
		%SAR Estimate	Non-parametric CI		SAR Estimate	Non-parametric CI	
			90% LL	90% UL		90% LL	90% UL
2006	714	0.70	0.26	1.24	0.84	0.29	1.43
2007	4,111	0.71	0.49	0.93	0.88	0.64	1.12
2008	4,050	3.88	3.38	4.38	4.72	4.15	5.32
2009	3,160	2.44	2.00	2.89	2.66	2.17	3.14
2010	4,094	0.93	0.68	1.18	1.27	0.98	1.57
2011	2,413	0.41	0.21	0.63	0.50	0.29	0.75
2012	2,389	1.13	0.78	1.48	1.51	1.11	1.92
2013	2,980	1.48	1.15	1.86	1.71	1.34	2.14
2014	3,397	0.50	0.30	0.70	0.62	0.41	0.83
2015[B]	3,025	0.50	0.30	0.74	0.56	0.35	0.82
Geometric mean		0.97			1.18		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using Group T tags.
[B] Incomplete, 2-salt returns through Sept. 15, 2017.

Table B.9. Overall LGR-to-GRA SARs for South Fork Salmon River Basin Wild Chinook, 2006–2015. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-GRA without Jacks			LGR-to-GRA with Jacks		
		%SAR Estimate	Non-parametric CI		SAR Estimate	Non-parametric CI	
			90% LL	90% UL		90% LL	90% UL
2006	1,276	0.86	0.47	1.32	0.86	0.44	1.32
2007	2,113	1.42	0.99	1.90	1.47	1.01	1.92
2008	1,632	3.86	3.07	4.69	4.72	3.80	5.62
2009	1,891	1.38	0.95	1.83	1.53	1.09	2.02
2010	1,488	1.41	0.92	1.98	1.61	1.09	2.18
2011	1,100	0.27	0.00	0.54	0.27	0.00	0.54
2012	887	1.01	0.53	1.68	1.01	0.53	1.68
2013	611	0.82	0.30	1.50	0.82	0.30	1.50
2014	515	0.78	0.19	1.50	0.78	0.19	1.50
2015[B]	412	0.24	0.00	0.73	0.24	0.00	0.73
Geometric mean		0.91			0.95		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using Group T tags.
[B] Incomplete, 2-salt returns through Sept. 15, 2017.

Table B.10. Overall LGR-to-BOA SARs for South Fork Salmon River Basin Wild Chinook, 2006–2015. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-BOA without Jacks			LGR-to-BOA with Jacks		
		%SAR Estimate	Non-parametric CI		SAR Estimate	Non-parametric CI	
			90% LL	90% UL		90% LL	90% UL
2006	1,276	0.94	0.54	1.41	0.94	0.52	1.38
2007	2,113	1.61	1.16	2.10	1.66	1.24	2.13
2008	1,632	4.78	3.90	5.65	5.76	4.78	6.82
2009	1,891	1.85	1.35	2.36	2.01	1.48	2.58
2010	1,488	1.55	1.03	2.10	1.88	1.33	2.51
2011	1,100	0.27	0.00	0.54	0.27	0.00	0.54
2012	887	1.24	0.66	1.97	1.24	0.66	1.97
2013	611	1.31	0.58	2.19	1.31	0.58	2.19
2014	515	0.78	0.19	1.50	0.78	0.19	1.50
2015[B]	412	0.49	0.00	1.15	0.49	0.00	1.15
Geometric mean		1.13			1.19		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using Group T tags.
[B] Incomplete, 2-salt returns through Sept. 15, 2017.

Table B.11. Overall LGR-to-GRA SARs for Middle Fork Salmon River Basin Wild Chinook, 2006–2015. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-GRA without Jacks			LGR-to-GRA with Jacks		
		%SAR Estimate	Non-parametric CI		SAR Estimate	Non-parametric CI	
			90% LL	90% UL		90% LL	90% UL
2006	260	0.38	0.00	1.16	0.38	0.00	1.14
2007	341	0.59	0.00	1.35	0.59	0.00	1.32
2008	3,035	2.93	2.41	3.47	3.46	2.90	4.06
2009	2,636	1.14	0.81	1.48	1.56	1.17	1.96
2010	2,889	0.93	0.66	1.24	1.59	1.22	2.03
2011	3,176	0.35	0.19	0.53	0.44	0.25	0.64
2012	2,515	0.91	0.61	1.25	1.59	1.21	2.02
2013	2,265	1.46	1.03	1.87	1.55	1.09	1.98
2014	3,045	0.49	0.29	0.72	0.56	0.34	0.79
2015[B]	2,472	0.04	0.00	0.12	0.16	0.04	0.30
Geometric mean		0.60			0.85		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using Group T tags.
[B] Incomplete, 2-salt returns through Sept. 15, 2017.

Table B.12. Overall LGR-to-BOA SARs for Middle Fork Salmon River Basin Wild Chinook, 2006–2015. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-BOA without Jacks			LGR-to-BOA with Jacks		
		%SAR Estimate	Non-parametric CI		SAR Estimate	Non-parametric CI	
			90% LL	90% UL		90% LL	90% UL
2006	260	0.38	0.00	1.15	0.38	0.00	1.15
2007	341	1.17	0.29	2.23	1.17	0.29	2.15
2008	3,035	3.49	2.93	4.12	4.09	3.50	4.72
2009	2,636	1.56	1.17	1.97	1.97	1.56	2.45
2010	2,889	1.11	0.82	1.46	1.83	1.44	2.30
2011	3,176	0.41	0.25	0.59	0.50	0.31	0.72
2012	2,515	1.35	0.99	1.74	2.03	1.58	2.52
2013	2,265	1.81	1.37	2.27	1.90	1.44	2.36
2014	3,045	0.56	0.36	0.79	0.66	0.43	0.91
2015[B]	2,472	0.04	0.00	0.12	0.16	0.04	0.30
Geometric mean		0.76			1.03		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using Group T tags.
[B] Incomplete, 2-salt returns through Sept. 15, 2017.

Table B.13. Overall LGR-to-GRA SARs for Upper Salmon River Basin Wild Chinook, 2006–2015. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-GRA without Jacks			LGR-to-GRA with Jacks		
		%SAR Estimate	Non-parametric CI		SAR Estimate	Non-parametric CI	
			90% LL	90% UL		90% LL	90% UL
2006	2,885	0.52	0.31	0.75	0.55	0.34	0.78
2007	1,968	0.97	0.61	1.36	0.97	0.63	1.37
2008	1,623	2.71	2.01	3.41	2.83	2.12	3.60
2009	2,102	1.57	1.15	2.05	1.62	1.17	2.10
2010	3,604	0.94	0.66	1.23	1.08	0.79	1.39
2011	4,801	0.35	0.21	0.52	0.35	0.21	0.52
2012	3,792	1.53	1.22	1.89	1.98	1.62	2.36
2013	3,436	1.19	0.89	1.50	1.25	0.94	1.57
2014	3,484	0.34	0.19	0.51	0.37	0.22	0.55
2015[B]	2,312	0.09	0.00	0.19	0.13	0.00	0.27
Geometric mean		0.72			0.80		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using Group T tags.
[B] Incomplete, 2-salt returns through Sept. 15, 2017.

Table B.14. Overall LGR-to-BOA SARs for Upper Salmon River Basin Wild Chinook, 2006–2015. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-BOA without Jacks			LGR-to-BOA with Jacks		
		%SAR Estimate	Non-parametric CI		SAR Estimate	Non-parametric CI	
			90% LL	90% UL		90% LL	90% UL
2006	2,885	0.66	0.42	0.93	0.69	0.45	0.96
2007	1,968	1.02	0.65	1.43	1.02	0.67	1.43
2008	1,623	3.88	3.06	4.74	4.07	3.26	4.92
2009	2,102	1.95	1.46	2.48	2.00	1.48	2.53
2010	3,604	1.11	0.80	1.43	1.28	0.96	1.60
2011	4,801	0.46	0.31	0.62	0.46	0.31	0.62
2012	3,792	1.87	1.52	2.27	2.32	1.92	2.75
2013	3,436	1.63	1.27	1.99	1.69	1.33	2.03
2014	3,484	0.40	0.23	0.58	0.43	0.26	0.61
2015[B]	2,312	0.13	0.04	0.25	0.17	0.04	0.32
Geometric mean		0.91			1.00		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using Group T tags.
[B] Incomplete, 2-salt returns through Sept. 15, 2017.

Snake River hatchery spring and summer Chinook

Table B.15. Overall LGR-to-GRA SARs for Dworshak hatchery spring Chinook, 1997–2015. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-GRA without Jacks			LGR-to-GRA with Jacks		
		%SAR Estimate	Non-parametric CI		%SAR Estimate	Non-parametric CI	
			90% LL	90% UL		90% LL	90% UL
1997	8,175	0.62	0.44	0.81	0.63	0.46	0.84
1998	40,218	1.00	0.89	1.11	1.14	1.04	1.25
1999	40,804	1.18	1.05	1.32	1.22	1.08	1.36
2000	39,412	1.00	0.92	1.10	1.01	0.92	1.12
2001	41,251	0.36	0.29	0.43	0.42	0.35	0.49
2002	45,233	0.57	0.48	0.65	0.72	0.63	0.81
2003	38,612	0.24	0.19	0.29	0.25	0.20	0.30
2004	45,505	0.29	0.23	0.34	0.29	0.23	0.34
2005	43,042	0.19	0.15	0.24	0.20	0.16	0.25
2006	29,511	0.35	0.29	0.42	0.46	0.40	0.52
2007	28,511	0.36	0.31	0.42	0.46	0.40	0.53
2008	25,643	0.57	0.50	0.65	0.85	0.75	0.95
2009	24,778	0.38	0.32	0.45	0.43	0.37	0.50
2010	32,204	0.47	0.41	0.53	0.80	0.72	0.89
2011	26,267	0.17	0.13	0.22	0.19	0.15	0.24
2012	26,750	0.47	0.41	0.55	0.67	0.59	0.76
2013	29,108	0.59	0.52	0.67	0.72	0.63	0.81
2014	29,739	0.26	0.22	0.31	0.29	0.24	0.34
2015[B]	22,583	0.08	0.05	0.11	0.11	0.08	0.15
Geometric mean		0.40			0.47		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using total tag release in years through 2005 and Group T tags beginning in 2006.
[B] Incomplete, 2-salt returns through Sept. 15, 2017.

Table B.16. Overall LGR-to-BOA SARs for Dworshak hatchery spring Chinook, 2000–2015. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-BOA without Jacks			LGR-to-BOA with Jacks		
		%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL	%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL
2000	39,412	1.51	1.40	1.63	1.52	1.40	1.64
2001	41,251	0.43	0.36	0.50	0.50	0.42	0.58
2002	45,233	0.73	0.64	0.82	0.85	0.75	0.96
2003	38,612	0.30	0.24	0.35	0.31	0.26	0.36
2004	45,505	0.53	0.46	0.61	0.53	0.46	0.60
2005	43,042	0.29	0.23	0.34	0.29	0.24	0.35
2006	29,511	0.56	0.49	0.64	0.68	0.61	0.76
2007	28,511	0.49	0.42	0.56	0.62	0.54	0.70
2008	25,643	1.01	0.90	1.11	1.33	1.21	1.45
2009	24,778	0.53	0.45	0.61	0.59	0.51	0.66
2010	32,204	0.70	0.62	0.77	1.15	1.04	1.25
2011	26,267	0.24	0.19	0.29	0.26	0.20	0.31
2012	26,750	0.66	0.58	0.75	0.89	0.80	0.99
2013	29,108	0.85	0.75	0.94	1.01	0.91	1.11
2014	29,739	0.37	0.31	0.42	0.40	0.34	0.46
2015[B]	22,583	0.13	0.09	0.18	0.17	0.12	0.21
Geometric mean		0.50			0.58		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using total tag release in years through 2005 and Group T tags beginning in 2006.
[B] Incomplete, 2-salt returns through Sept. 15, 2017.

Table B.17. Overall LGR-to-GRA SARs for Rapid River hatchery spring Chinook, 1997–2015. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-GRA without Jacks			LGR-to-GRA with Jacks		
		%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL	%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL
1997	15,765	0.65	0.52	0.79	0.65	0.52	0.78
1998	32,148	1.88	1.71	2.07	1.98	1.80	2.18
1999	35,895	2.91	2.69	3.13	3.04	2.82	3.25
2000	35,194	1.94	1.79	2.08	1.96	1.82	2.10
2001	38,026	1.06	0.94	1.18	1.16	1.04	1.29
2002	41,471	0.90	0.79	1.01	1.07	0.95	1.19
2003	37,911	0.24	0.19	0.29	0.31	0.26	0.37
2004	36,178	0.34	0.28	0.41	0.36	0.29	0.42
2005	38,231	0.25	0.20	0.31	0.27	0.22	0.33
2006	26,349	0.50	0.43	0.58	0.60	0.52	0.68
2007	25,798	0.34	0.28	0.40	0.47	0.40	0.53
2008	29,071	1.30	1.19	1.41	1.96	1.82	2.10
2009	26,304	1.03	0.92	1.14	1.17	1.07	1.28
2010	28,623	0.48	0.41	0.55	0.78	0.69	0.87
2011	27,821	0.28	0.23	0.33	0.31	0.26	0.36
2012	26,887	0.83	0.74	0.92	1.02	0.92	1.12
2013[B]	26,839	1.30	1.18	1.42	1.54	1.41	1.67
2014	27,415	0.43	0.37	0.50	0.50	0.43	0.57
2015[B]	29,508	0.22	0.18	0.37	0.30	0.25	0.36
Geometric mean		0.66			0.79		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using total tag release in years through 2005 and Group T tags beginning in 2006.
[B] Incomplete, 2-salt returns through Sept. 15, 2017.

Table B.18. Overall LGR-to-BOA SARs for Rapid River hatchery spring Chinook, 2000–2015. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-BOA without Jacks			LGR-to-BOA with Jacks		
		%SAR Estimate	Non-parametric CI		%SAR Estimate	Non-parametric CI	
			90% LL	90% UL		90% LL	90% UL
2000	35,194	2.60	2.43	2.75	2.62	2.45	2.78
2001	38,026	1.35	1.22	1.49	1.45	1.30	1.59
2002	41,471	1.02	0.91	1.14	1.21	1.09	1.34
2003	37,911	0.32	0.27	0.38	0.40	0.34	0.46
2004	36,178	0.43	0.36	0.50	0.44	0.38	0.52
2005	38,231	0.31	0.26	0.37	0.33	0.27	0.40
2006	26,349	0.74	0.66	0.83	0.85	0.76	0.95
2007	25,798	0.48	0.41	0.56	0.62	0.54	0.70
2008	29,071	1.82	1.69	1.95	2.55	2.39	2.69
2009	26,304	1.44	1.32	1.57	1.57	1.44	1.69
2010	28,623	0.74	0.65	0.84	1.12	1.01	1.23
2011	27,821	0.35	0.29	0.41	0.38	0.33	0.44
2012	26,887	1.13	1.02	1.24	1.33	1.22	1.44
2013	26,839	1.52	1.39	1.65	1.78	1.65	1.93
2014	27,415	0.55	0.48	0.63	0.63	0.55	0.71
2015[B]	29,508	0.28	0.23	0.34	0.37	0.31	0.43
Geometric mean		0.75			0.88		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using total tag release in years through 2005 and Group T tags beginning in 2006.
[B] Incomplete, 2-salt returns through Sept. 15, 2017.

Table B.19. Overall LGR-to-GRA SARs for Catherine Creek hatchery spring Chinook, 2001–2015. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-GRA without Jacks			LGR-to-GRA with Jacks		
		%SAR Estimate	Non-parametric CI		%SAR Estimate	Non-parametric CI	
			90% LL	90% UL		90% LL	90% UL
2001	10,885	0.22	0.12	0.34	0.26	0.15	0.40
2002	8,435	0.77	0.56	1.00	1.00	0.76	1.28
2003	7,202	0.31	0.20	0.43	0.40	0.25	0.54
2004	5,348	0.36	0.20	0.54	0.40	0.22	0.58
2005	4,848	0.40	0.22	0.60	0.48	0.27	0.68
2006	4,289	0.49	0.32	0.69	0.61	0.41	0.81
2007	4,695	0.43	0.27	0.59	0.83	0.61	1.06
2008	6,605	2.13	1.83	2.44	2.95	2.60	3.32
2009	5,381	1.54	1.26	1.83	1.80	1.50	2.10
2010	6,329	0.88	0.68	1.10	1.55	1.24	1.85
2011	4,366	0.48	0.32	0.65	0.50	0.33	0.69
2012	3,615	0.69	0.46	0.91	0.94	0.67	1.22
2013	3,209	1.37	1.01	1.76	1.87	1.47	2.30
2014	3,834	0.44	0.26	0.62	0.63	0.41	0.82
2015[B]	3,890	0.41	0.25	0.60	0.59	0.39	0.82
Geometric mean		0.59			0.79		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using total tag release in years through 2005 and Group T tags beginning in 2006.
[B] Incomplete, 2-salt returns through Sept. 15, 2017.

Table B.20. Overall LGR-to-BOA SARs for Catherine Creek hatchery spring Chinook, 2001–2015. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-BOA without Jacks			LGR-to-BOA with Jacks		
		%SAR Estimate	Non-parametric CI		%SAR Estimate	Non-parametric CI	
			90% LL	90% UL		90% LL	90% UL
2001	10,885	0.36	0.23	0.51	0.42	0.27	0.59
2002	8,435	1.00	0.76	1.25	1.23	0.97	1.51
2003	7,202	0.33	0.21	0.48	0.42	0.27	0.57
2004	5,348	0.44	0.25	0.64	0.48	0.30	0.69
2005	4,848	0.51	0.31	0.73	0.58	0.37	0.82
2006	4,289	0.79	0.58	1.03	0.91	0.66	1.15
2007	4,695	0.60	0.41	0.79	1.04	0.80	1.29
2008	6,605	2.72	2.38	3.07	3.69	3.28	4.10
2009	5,381	2.10	1.77	2.41	2.40	2.03	2.75
2010	6,329	1.20	0.97	1.43	1.96	1.65	2.33
2011	4,366	0.64	0.44	0.84	0.66	0.46	0.87
2012	3,615	0.94	0.69	1.21	1.22	0.93	1.54
2013	3,209	1.65	1.27	2.06	2.18	1.76	2.64
2014	3,834	0.60	0.40	0.80	0.83	0.58	1.06
2015[B]	3,890	0.51	0.33	0.72	0.72	0.50	0.96
Geometric mean		0.78			1.00		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using total tag release in years through 2005 and Group T tags beginning in 2006.
[B] Incomplete, 2-salt returns through Sept. 15, 2017.

Table B.21. Overall LGR-to-GRA SARs for McCall[A] hatchery summer Chinook, 1997–2015. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving LGR[B]	LGR-to-GRA without Jacks			LGR-to-GRA with Jacks		
		%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL	%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL
1997	22,381	1.31	1.15	1.46	1.41	1.25	1.58
1998	27,812	2.50	2.28	2.73	3.07	2.80	3.32
1999	31,571	3.26	3.02	3.49	3.73	3.48	4.02
2000	31,825	3.12	2.92	3.33	3.63	3.41	3.84
2001	36,784	1.20	1.07	1.34	1.54	1.39	1.70
2002	32,599	1.34	1.18	1.49	1.82	1.64	2.00
2003	43,144	0.68	0.60	0.76	1.00	0.91	1.09
2004	40,150	0.39	0.33	0.46	0.47	0.40	0.55
2005	43,229	0.57	0.50	0.64	0.61	0.54	0.69
2006	21,794	1.06	0.95	1.18	1.27	1.15	1.41
2007	19,082	0.90	0.78	1.01	1.43	1.28	1.59
2008	21,044	1.14	1.02	1.26	2.37	2.19	2.56
2009	18,495	0.52	0.44	0.61	0.83	0.72	0.94
2010	20,552	0.58	0.49	0.67	1.06	0.93	1.18
2011	22,876	0.31	0.25	0.38	0.37	0.31	0.44
2012	20,541	0.59	0.51	0.68	1.13	1.01	1.26
2013	23,998	0.89	0.79	0.99	1.43	1.30	1.55
2014	25,957	0.42	0.35	0.49	1.05	0.94	1.16
2015[C]	26,495	0.14	0.11	0.18	0.22	0.17	0.27
Geometric mean		0.82			1.18		

[A] SAR estimates are based on unweighted methodology, as outlined in Chapter 4.
[B] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using total tag release in years through 2005 and Group T tags beginning in 2006.
[C] Incomplete, 2-salt returns through Sept. 15, 2017.

Table B.22. Overall LGR-to-BOA SARs for McCall[A] hatchery summer Chinook, 2000–2015. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving LGR[B]	LGR-to-BOA without Jacks			LGR-to-BOA with Jacks		
		%SAR Estimate	Non-parametric CI		%SAR Estimate	Non-parametric CI	
			90% LL	90% UL		90% LL	90% UL
2000	31,825	3.61	3.39	3.83	4.00	3.78	4.23
2001	36,784	1.43	1.28	1.59	1.72	1.56	1.87
2002	32,599	1.66	1.48	1.85	2.05	1.84	2.24
2003	43,144	0.76	0.68	0.85	1.06	0.97	1.15
2004	40,150	0.52	0.44	0.61	0.62	0.54	0.71
2005	43,229	0.67	0.59	0.76	0.73	0.65	0.82
2006	21,794	1.29	1.15	1.42	1.52	1.39	1.67
2007	19,082	1.10	0.97	1.23	1.67	1.53	1.82
2008	21,044	1.55	1.40	1.70	3.07	2.87	3.27
2009	18,495	0.94	0.82	1.05	1.25	1.11	1.38
2010	20,552	0.73	0.63	0.84	1.32	1.19	1.47
2011	22,876	0.41	0.34	0.48	0.48	0.40	0.56
2012	20,541	0.99	0.87	1.11	1.64	1.50	1.79
2013	23,998	1.69	1.55	1.82	2.34	2.17	2.50
2014	25,957	0.59	0.51	0.66	1.05	0.94	1.16
2015[C]	26,495	0.22	0.17	0.27	0.29	0.24	0.35
Geometric mean		0.93			1.28		

[A] SAR estimates are based on unweighted methodology, as outlined in Chapter 4.
[B] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using total tag release in years through 2005 and Group T tags beginning in 2006.
[C] Incomplete, 2-salt returns through Sept. 15, 2017.

Table B.23. Overall LGR-to-GRA SARs for Imnaha hatchery summer Chinook, 1997–2015. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-GRA without Jacks			LGR-to-GRA with Jacks		
		%SAR Estimate	Non-parametric CI		%SAR Estimate	Non-parametric CI	
			90% LL	90% UL		90% LL	90% UL
1997	8,254	0.98	0.76	1.23	1.35	1.10	1.64
1998	13,577	0.80	0.63	1.00	1.46	1.20	1.73
1999	13,244	2.41	2.09	2.74	3.20	2.82	3.57
2000	14,267	2.89	2.63	3.16	3.99	3.66	4.31
2001	15,650	0.61	0.48	0.77	0.97	0.80	1.17
2002	13,962	0.68	0.52	0.85	1.02	0.83	1.23
2003	14,948	0.53	0.42	0.65	1.26	1.08	1.43
2004	12,867	0.36	0.25	0.46	0.45	0.33	0.58
2005	11,172	0.27	0.17	0.37	0.32	0.23	0.43
2006	8,753	0.80	0.64	0.96	1.12	0.95	1.30
2007	9,596	0.67	0.53	0.80	1.39	1.18	1.57
2008	10,148	1.76	1.55	1.97	4.47	4.13	4.83
2009	9,734	1.04	0.85	1.21	1.84	1.63	2.07
2010	9,907	0.78	0.62	0.94	1.45	1.24	1.67
2011	8,351	0.24	0.15	0.33	0.43	0.32	0.56
2012	10,021	0.18	0.11	0.25	0.59	0.46	0.72
2013	10,360	0.52	0.40	0.64	1.54	1.33	1.76
2014	9,761	0.42	0.31	0.54	0.70	0.55	0.84
2015[B]	9,948	0.15	0.09	0.21	0.22	0.14	0.30
Geometric mean		0.62			1.09		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using total tag release in years through 2005 and Group T tags beginning in 2006.
[B] Incomplete, 2-salt returns through Sept. 15, 2017.

Table B.24. Overall LGR-to-BOA SARs for Imnaha hatchery summer Chinook, 2000–2015. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-BOA without Jacks			LGR-to-BOA with Jacks		
		%SAR Estimate	Non-parametric CI		%SAR Estimate	Non-parametric CI	
			90% LL	90% UL		90% LL	90% UL
2000	14,267	3.46	3.16	3.78	4.48	4.14	4.84
2001	15,650	0.77	0.62	0.94	1.12	0.95	1.31
2002	13,962	0.89	0.70	1.09	1.19	0.98	1.41
2003	14,948	0.67	0.54	0.80	1.25	1.08	1.43
2004	12,867	0.57	0.44	0.72	0.68	0.54	0.83
2005	11,172	0.35	0.24	0.46	0.43	0.31	0.55
2006	8,753	0.99	0.83	1.18	1.41	1.21	1.62
2007	9,596	0.85	0.72	1.02	1.64	1.43	1.87
2008	10,148	2.48	2.22	2.76	5.55	5.16	5.94
2009	9,734	1.66	1.44	1.88	2.58	2.30	2.84
2010	9,907	0.94	0.78	1.12	1.82	1.59	2.06
2011	8,351	0.38	0.28	0.50	0.62	0.48	0.77
2012	10,021	0.39	0.29	0.49	0.92	0.76	1.09
2013	10,360	1.20	1.00	1.38	2.43	2.14	2.72
2014	9,761	0.52	0.40	0.65	0.97	0.81	1.14
2015[B]	9,948	0.23	0.16	0.31	0.32	0.23	0.43
Geometric mean		0.79			1.29		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using total tag release in years through 2005 and Group T tags beginning in 2006.
[B] Incomplete, 2-salt returns through Sept. 15, 2017.

Table B.25. Overall LGR-to-GRA SARs for Clearwater Hatchery spring Chinook, 2006–2015. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-GRA without Jacks			LGR-to-GRA with Jacks		
		%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL	%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL
2006	25,964	0.57	0.49	0.65	0.67	0.58	0.75
2007	29,961	0.30	0.25	0.35	0.40	0.34	0.46
2008	19,336	0.97	0.85	1.10	1.31	1.17	1.45
2009	28,743	0.71	0.63	0.80	0.87	0.78	0.96
2010	37,579	0.48	0.42	0.54	0.71	0.63	0.79
2011	31,107	0.15	0.12	0.18	0.16	0.13	0.20
2012	33,279	0.51	0.44	0.57	0.69	0.61	0.77
2013	30,442	0.73	0.65	0.81	0.86	0.78	0.95
2014	24,949	0.36	0.29	0.42	0.44	0.37	0.51
2015[B]	16,502	0.29	0.23	0.36	0.40	0.33	0.48
Geometric mean		0.45			0.57		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using Group T tags.
[B] Incomplete, 2-salt returns through Sept. 15, 2017.

Table B.26. Overall LGR-to-BOA SARs for Clearwater Hatchery spring Chinook, 2006–2015. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-BOA without Jacks			LGR-to-BOA with Jacks		
		%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL	%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL
2006	25,964	0.88	0.79	0.98	1.00	0.90	1.11
2007	29,961	0.43	0.36	0.49	0.54	0.47	0.61
2008	19,336	1.36	1.22	1.51	1.76	1.60	1.94
2009	28,743	1.03	0.93	1.13	1.20	1.09	1.31
2010	37,579	0.65	0.58	0.73	0.93	0.84	1.03
2011	31,107	0.22	0.17	0.26	0.23	0.19	0.28
2012	33,279	0.69	0.61	0.76	0.90	0.81	0.98
2013	30,442	0.88	0.79	0.97	1.04	0.95	1.14
2014	29,949	0.50	0.43	0.57	0.60	0.52	0.68
2015[B]	16,502	0.46	0.38	0.55	0.57	0.48	0.67
Geometric mean		0.63			0.77		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using Group T tags.
[B] Incomplete, 2-salt returns through Sept. 15, 2017.

Table B.27. Overall LGR-to-GRA SARs for Sawtooth Hatchery spring Chinook, 2007–2015. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-GRA without Jacks			LGR-to-GRA with Jacks		
		%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL	%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL
2007	7,761	0.63	0.50	0.79	1.08	0.88	1.28
2008	4,514	1.00	0.75	1.25	1.77	1.45	2.14
2009	4,916	0.39	0.25	0.54	0.57	0.39	0.76
2010	6,631	0.45	0.32	0.60	0.78	0.61	0.97
2011	7,446	0.08	0.03	0.13	0.13	0.07	0.20
2012	6,300	0.40	0.27	0.54	0.57	0.43	0.74
2013	8,520	0.69	0.54	0.85	0.77	0.61	0.95
2014	8,618	0.34	0.24	0.45	0.73	0.57	0.89
2015[B]	10,027	0.17	0.11	0.24	0.20	0.13	0.28
Geometric mean		0.37			0.58		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using Group T tags.
[B] Incomplete, 2-salt returns through Sept. 15, 2017.

Table B.28. Overall LGR-to-BOA SARs for Sawtooth Hatchery spring Chinook, 2007–2015. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-BOA without Jacks			LGR-to-BOA with Jacks		
		%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL	%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL
2007	7,761	0.72	0.55	0.89	1.20	0.99	1.42
2008	4,514	1.20	0.93	1.49	2.15	1.78	2.53
2009	4,916	0.43	0.27	0.58	0.61	0.44	0.82
2010	6,631	0.54	0.40	0.71	1.01	0.80	1.22
2011	7,446	0.12	0.05	0.19	0.17	0.09	0.26
2012	6,300	0.54	0.40	0.70	0.76	0.59	0.95
2013	8,520	1.01	0.83	1.19	1.12	0.93	1.31
2014	8,618	0.43	0.32	0.55	0.95	0.77	1.13
2015[B]	10,027	0.24	0.16	0.32	0.28	0.20	0.38
Geometric mean		0.48			0.74		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using Group T tags.
[B] Incomplete, 2-salt returns through Sept. 15, 2017.

Table B.29. Overall LGR-to-GRA SARs for Kooskia Hatchery spring Chinook, 2014–2015. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-GRA without Jacks			LGR-to-GRA with Jacks		
		%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL	%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL
2014	5,108	0.12	0.04	0.20	0.16	0.08	0.25
2015[B]	2,182	0.00	0.00	0.00	0.00	0.00	0.00
Geometric mean		N/A			N/A		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using Group T tags.
[B] Incomplete, 2-salt returns through Sept. 15, 2017.

Table B.30. Overall LGR-to-BOA SARs for Kooskia Hatchery spring Chinook, 2014–2015. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-BOA without Jacks			LGR-to-BOA with Jacks		
		%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL	%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL
2014	5,108	0.20	0.10	0.30	0.27	0.16	0.41
2015[B]	2,182	0.05	0.00	0.14	0.05	0.00	0.14
Geometric mean		0.10			0.12		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using Group T tags.
[B] Incomplete, 2-salt returns through Sept. 15, 2017.

Table B.31. Overall LGR-to-GRA SARs for Pahsimeroi Hatchery summer Chinook, 2008–2015. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-GRA without Jacks			LGR-to-GRA with Jacks		
		%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL	%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL
2008	5,963	1.26	1.02	1.49	2.11	1.80	2.44
2009	6,892	0.55	0.40	0.70	0.73	0.57	0.89
2010	5,729	0.09	0.03	0.16	0.19	0.10	0.30
2011	7,375	0.01	0.00	0.04	0.01	0.00	0.04
2012	8,692	0.16	0.09	0.23	0.26	0.18	0.36
2013	9,056	0.15	0.09	0.22	0.28	0.18	0.37
2014	11,933	0.02	0.00	0.03	0.02	0.00	0.03
2015[B]	11,689	0.03	0.01	0.05	0.03	0.01	0.06
Geometric mean		0.10			0.14		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using Group T tags.
[B] Incomplete, 2-salt returns through Sept. 15, 2017.

Table B.32. Overall LGR-to-BOA SARs for Pahsimeroi Hatchery summer Chinook, 2008–2015. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-BOA without Jacks			LGR-to-BOA with Jacks		
		%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL	%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL
2008	5,963	1.66	1.39	1.98	2.70	2.33	3.07
2009	6,892	0.91	0.73	1.11	1.07	0.87	1.28
2010	5,729	0.10	0.04	0.18	0.23	0.13	0.34
2011	7,375	0.01	0.00	0.04	0.01	0.00	0.04
2012	8,692	0.22	0.14	0.31	0.37	0.27	0.48
2013	9,056	0.28	0.19	0.37	0.43	0.31	0.56
2014	11,933	0.03	0.00	0.05	0.03	0.00	0.05
2015[B]	11,689	0.03	0.01	0.06	0.05	0.02	0.09
Geometric mean		0.14			0.20		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using Group T tags.
[B] Incomplete, 2-salt returns through Sept. 15, 2017.

Table B.33. Overall LGR-to-GRA SARs for Clearwater Hatchery summer Chinook, 2011–2015. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-GRA without Jacks			LGR-to-GRA with Jacks		
		%SAR Estimate	Non-parametric CI		%SAR Estimate	Non-parametric CI	
			90% LL	90% UL		90% LL	90% UL
2011	9,359	0.18	0.12	0.26	0.25	0.17	0.33
2012	10,191	0.30	0.22	0.40	0.55	0.44	0.67
2013	9,918	0.32	0.22	0.41	0.45	0.34	0.56
2014	13,119	0.32	0.24	0.41	0.45	0.36	0.55
2015[B]	13,707	0.20	0.14	0.27	0.26	0.18	0.33
Geometric mean		0.26			0.37		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using Group T tags.
[B] Incomplete, 2-salt returns through Sept. 15, 2017.

Table B.34. Overall LGR-to-BOA SARs for Clearwater Hatchery summer Chinook, 2011–2015. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-BOA without Jacks			LGR-to-BOA with Jacks		
		%SAR Estimate	Non-parametric CI		%SAR Estimate	Non-parametric CI	
			90% LL	90% UL		90% LL	90% UL
2011	9,359	0.24	0.16	0.32	0.30	0.22	0.40
2012	10,191	0.48	0.37	0.60	0.78	0.63	0.92
2013	9,918	0.83	0.68	0.98	1.03	0.85	1.20
2014	13,119	0.53	0.42	0.63	0.77	0.64	0.90
2014[B]	13,707	0.29	0.22	0.37	0.34	0.26	0.43
Geometric mean		0.43			0.58		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using Group T tags.
[B] Incomplete, 2-salt returns through Sept. 15, 2017.

Snake River wild Steelhead

Table B.35. Overall LGR-to-GRA and LGR-to-BOA SARs for Snake River Basin (above LGR) Wild Steelhead, 1997–2014.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-GRA			LGR-to-BOA		
		%SAR Estimate	Non-parametric CI		%SAR Estimate	Non-parametric CI	
			90% LL	90% UL		90% LL	90% UL
1997	3,830	1.16	0.39	2.11	--	--	--
1998	7,109	0.30	0.07	0.68	--	--	--
1999	8,820	2.84	1.67	4.24	--	--	--
2000	13,609	2.66	1.59	3.79	2.99	1.88	4.17
2001	12,929	2.47	0.93	4.33	3.95	1.87	6.17
2002	13,378	2.14	1.24	3.21	2.60	1.47	3.82
2003	12,926	1.57	1.22	1.94	1.86	1.47	2.25
2004	13,263	0.85	0.63	1.08	1.31	1.03	1.58
2005	15,124	0.80	0.59	1.00	1.01	0.79	1.23
2006	5,431	1.14	0.91	1.40	1.92	1.59	2.21
2007	7,083	2.57	2.26	2.90	3.30	2.92	3.67
2008	5,730	3.21	2.82	3.62	4.38	3.91	4.84
2009	5,976	2.46	2.13	2.77	3.56	3.17	3.98
2010	8,313	1.71	1.46	1.95	2.37	2.08	2.68
2011	4,932	1.26	1.01	1.53	1.85	1.53	2.17
2012	6,890	2.54	2.23	2.88	3.40	3.04	3.76
2013	8,422	1.99	1.73	2.25	2.70	2.39	2.99
2014	9,691	1.32	1.12	1.51	1.98	1.76	2.22
Geometric mean (97-14)		1.60	Geometric mean (00-14)		2.43		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using total tag release through 2005 and Group T tags beginning in 2006.

Table B.36. Overall LGR-to-GRA and LGR-to-BOA SARs for Clearwater Basin Wild Steelhead, 2006–2014.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-GRA			LGR-to-BOA		
		%SAR Estimate	Non-parametric CI		%SAR Estimate	Non-parametric CI	
			90% LL	90% UL		90% LL	90% UL
2006	2,747	0.80	0.52	1.09	1.24	0.89	1.61
2007	2,249	1.16	0.80	1.53	1.51	1.06	1.95
2008	3,546	2.79	2.35	3.29	3.95	3.41	4.53
2009	1,747	1.72	1.20	2.25	2.29	1.68	2.90
2010	3,566	1.46	1.13	1.81	1.91	1.51	2.30
2011	1,838	1.03	0.64	1.45	1.14	0.72	1.59
2012	2,937	2.76	2.25	3.31	3.40	2.82	3.99
2013	3,042	2.33	1.87	2.81	2.70	2.19	3.21
2014	1,858	1.45	1.02	1.92	1.88	1.38	2.41
Geometric mean		1.58			2.05		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using Group T tags.

Table B.37. Overall LGR-to-GRA and LGR-to-BOA SARs for Grande Ronde Basin Wild Steelhead, 2006–2014.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-GRA			LGR-to-BOA		
		%SAR Estimate	Non-parametric CI		%SAR Estimate	Non-parametric CI	
			90% LL	90% UL		90% LL	90% UL
2006	553	1.63	0.86	2.59	3.61	2.39	5.05
2007	432	4.39	2.76	6.28	4.86	3.11	7.00
2008	357	3.36	1.78	5.00	5.60	3.61	7.94
2009	342	2.34	1.08	3.80	4.39	2.61	6.40
2010	489	2.87	1.65	4.34	4.09	2.55	5.87
2011	640	1.87	1.05	2.81	3.28	2.13	4.46
2012	533	3.57	2.27	5.06	4.13	2.71	5.79
2013	654	2.45	1.50	3.49	3.82	2.65	5.19
2014	644	1.40	0.71	2.25	2.64	1.67	3.72
Geometric mean		2.49			3.96		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using Group T tags.

Table B.38. Overall LGR-to-GRA and LGR-to-BOA SARs for Imnaha Basin Wild Steelhead, 2006–2014.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-GRA			LGR-to-BOA		
		%SAR Estimate	Non-parametric CI		%SAR Estimate	Non-parametric CI	
			90% LL	90% UL		90% LL	90% UL
2006	1,701	1.23	0.78	1.69	2.23	1.69	2.84
2007	3,581	3.10	2.62	3.62	4.13	3.60	4.71
2008	2,064	5.17	1.79	9.16	5.57	2.14	9.59
2009	2,228	3.64	3.00	4.32	5.07	4.30	5.89
2010	2,209	1.90	1.45	2.39	2.67	2.12	3.24
2011	945	1.06	0.53	1.70	1.69	1.04	2.45
2012	1,588	2.33	1.71	2.95	3.78	3.00	4.53
2013	2,758	1.96	1.54	2.40	2.97	2.43	3.48
2014	3,185	1.82	1.44	2.26	2.76	2.29	3.29
Geometric mean		2.20			3.21		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using Group T tags.

Table B.39. Overall LGR-to-GRA and LGR-to-BOA SARs for Salmon Basin Wild Steelhead, 2006–2014.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-GRA			LGR-to-BOA		
		%SAR Estimate	Non-parametric CI		%SAR Estimate	Non-parametric CI	
			90% LL	90% UL		90% LL	90% UL
2006	630	1.59	0.80	2.47	1.91	1.08	2.88
2007	828	3.14	2.07	4.29	3.74	2.66	4.99
2008	1,385	5.20	4.12	6.33	6.50	5.22	7.70
2009	1,450	1.93	1.38	2.56	3.10	2.33	3.91
2010	1,927	1.76	1.22	2.40	2.59	1.90	3.39
2011	1,471	1.36	0.88	1.89	2.18	1.58	2.90
2012	1,374	2.69	1.97	3.44	3.57	2.78	4.43
2013	1,226	1.55	0.98	2.20	2.37	1.63	3.20
2014	1,087	1.29	0.71	1.90	1.75	1.09	2.45
Geometric mean		2.05			2.84		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using Group T tags.

Table B.40. Overall LGR-to-GRA and LGR-to-BOA SARs for Asotin Creek Wild Steelhead, 2014.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-GRA			LGR-to-BOA		
		%SAR Estimate	Non-parametric CI		%SAR Estimate	Non-parametric CI	
			90% LL	90% UL		90% LL	90% UL
2014	1,974	0.66	0.36	0.98	1.27	0.83	1.71

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using Group T tags.

Table B.41. Overall LGR-to-GRA and LGR-to-BOA SARs for Snake River Basin (above LGR) Wild A-run Steelhead, 2006–2014.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-GRA			LGR-to-BOA		
		%SAR Estimate	Non-parametric CI		%SAR Estimate	Non-parametric CI	
			90% LL	90% UL		90% LL	90% UL
2006	2,382	1.43	1.02	1.83	2.65	2.10	3.16
2007	4,491	3.30	2.87	3.76	4.27	3.76	4.81
2008	1,635	2.57	1.90	3.22	3.79	3.07	4.61
2009	3,572	2.88	2.40	3.35	4.23	3.66	4.83
2010	4,675	2.05	1.69	2.43	2.91	2.48	3.36
2011	2,989	1.41	1.07	1.78	2.17	1.74	2.60
2012	3,226	2.73	2.28	3.21	3.78	3.24	4.33
2013	4,695	2.30	1.92	2.65	3.19	2.73	3.62
2014	6,633	1.36	1.12	1.60	2.16	1.86	2.45
Geometric mean		2.12			3.14		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using Group T tags.

Table B.42. Overall LGR-to-GRA and LGR-to-BOA SARs for Snake River Basin (above LGR) Wild B-run Steelhead, 2006–2014.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-GRA			LGR-to-BOA		
		%SAR Estimate	Non-parametric CI		%SAR Estimate	Non-parametric CI	
			90% LL	90% UL		90% LL	90% UL
2006	3,049	0.92	0.65	1.22	1.34	1.02	1.72
2007	1,872	1.39	0.93	1.85	1.76	1.24	2.32
2008	3,559	3.54	3.03	4.10	4.69	4.08	5.32
2009	2,393	1.84	1.39	2.28	2.59	2.08	3.16
2010	2,788	1.26	0.91	1.65	1.69	1.28	2.14
2011	1,905	1.00	0.62	1.40	1.31	0.92	1.76
2012	3,293	2.46	2.02	2.91	3.16	2.68	3.67
2013	2,496	1.88	1.46	2.38	2.40	1.89	2.98
2014	2,105	1.43	1.01	1.86	1.90	1.41	2.43
Geometric mean		1.60			2.13		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using Group T tags.

Snake River hatchery Steelhead

Table B.43. Overall LGR-to-GRA and LGR-to-BOA SARs for Snake River Basin (above LGR) Hatchery Steelhead (all groups combined), 1997–2014.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-GRA			LGR-to-BOA		
		%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL	%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL
1997	24,710	0.39	0.23	0.57	--	--	--
1998	23,507	0.56	0.31	0.85	--	--	--
1999	27,193	0.92	0.59	1.28	--	--	--
2000	24,565	1.89	1.16	2.68	2.28	1.46	3.08
2001	20,877	0.92	0.24	1.74	1.38	0.52	2.31
2002	20,681	0.95	0.40	1.72	0.98	0.29	1.71
2003	21,400	1.46	1.24	1.68	1.82	1.57	2.08
2004	17,082	2.08	1.14	3.19	2.28	1.24	3.45
2005	19,640	1.83	1.17	2.55	2.95	2.07	3.87
2006	13,473	1.96	1.32	2.62	2.71	1.98	3.52
2007	21,828	1.64	1.37	1.92	2.34	2.00	2.66
2008	89,884	3.09	3.00	3.19	4.46	4.34	4.59
2009	103,947	1.49	1.43	1.56	2.14	2.07	2.21
2010	109,158	1.60	1.53	1.67	2.30	2.22	2.38
2011	105,914	0.64	0.60	0.68	0.96	0.91	1.01
2012	91,741	1.52	1.46	1.59	2.21	2.13	2.30
2013	102,604	1.17	1.12	1.23	1.58	1.52	1.65
2014	95,952	1.43	1.36	1.49	1.97	1.90	2.04
Geometric mean (97-14)		1.27	Geometric mean (00-14)		2.01		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using total tag release in years through 2007 and Group T tags beginning in 2008.

Table B.44. Overall LGR-to-GRA and LGR-to-BOA SARs for Grande Ronde River Basin (A-Run) Hatchery Steelhead, 2008–2014.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-GRA			LGR-to-BOA		
		%SAR Estimate	Non-parametric CI		%SAR Estimate	Non-parametric CI	
			90% LL	90% UL		90% LL	90% UL
2008	16,858	4.54	4.23	4.85	6.75	6.37	7.15
2009	15,279	1.62	1.44	1.79	2.45	2.23	2.68
2010	16,205	2.05	1.86	2.25	3.17	2.92	3.43
2011	15,236	0.43	0.35	0.53	0.71	0.61	0.83
2012	15,408	1.65	1.47	1.82	2.57	2.35	2.78
2013	15,031	1.56	1.39	1.73	2.32	2.10	2.54
2014	15,718	1.78	1.61	1.96	2.63	2.42	2.83
Geometric mean		1.62			2.48		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using Group T tags.

Table B.45. Overall LGR-to-GRA and LGR-to-BOA SARs for Imnaha River Basin (A-Run) Hatchery Steelhead, 2008–2014.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-GRA			LGR-to-BOA		
		%SAR Estimate	Non-parametric CI		%SAR Estimate	Non-parametric CI	
			90% LL	90% UL		90% LL	90% UL
2008	12,468	4.50	4.15	4.83	6.70	6.26	7.12
2009	11,286	1.72	1.50	1.91	2.63	2.38	2.89
2010	11,873	1.69	1.50	1.91	2.43	2.19	2.68
2011	10,532	0.64	0.50	0.76	0.94	0.78	1.10
2012	10,440	2.16	1.92	2.39	3.16	2.87	3.45
2013	11,106	1.70	1.49	1.94	2.51	2.25	2.79
2014	11,797	1.83	1.64	2.04	2.70	2.46	2.95
Geometric mean		1.78			2.63		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using Group T tags.

Table B.46. Overall LGR-to-GRA and LGR-to-BOA SARs for Hells Canyon Dam (A-Run) Hatchery Steelhead, 2009–2014.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-GRA			LGR-to-BOA		
		%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL	%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL
2009	4,536	3.04	2.60	3.46	4.76	4.23	5.28
2010	5,289	3.16	2.69	3.60	4.63	4.04	5.17
2011	4,015	0.35	0.20	0.52	0.55	0.36	0.75
2012	3,605	1.78	1.38	2.13	2.69	2.25	3.12
2013	3,769	2.15	1.78	2.58	2.71	2.28	3.21
2014	4,404	1.43	1.14	1.76	2.61	2.25	3.04
Geometric mean		1.62			2.48		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using Group T tags.

Table B.47. Overall LGR-to-GRA and LGR-to-BOA SARs for Salmon River Basin (A-Run) Hatchery Steelhead, 2008–2014.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-GRA			LGR-to-BOA		
		%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL	%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL
2008[B]	19,133	4.78	4.51	5.07	6.45	6.13	6.78
2009	29,321	1.91	1.78	2.04	2.52	2.37	2.67
2010	34,240	1.99	1.85	2.14	2.75	2.60	2.92
2011	31,923	1.13	1.04	1.23	1.68	1.56	1.80
2012	31,756	1.74	1.62	1.87	2.55	2.40	2.70
2013	30,124	1.58	1.47	1.70	2.10	1.97	2.26
2014	22,929	1.37	1.24	1.50	1.90	1.74	2.05
Geometric mean		1.86			2.58		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using Group T tags.
[B] Excludes 1,200 released from Niagara Springs due to low number and exclusive return to river at transportation sites.

Table B.48. Overall LGR-to-GRA and LGR-to-BOA SARs for Salmon River Basin (B-Run) Hatchery Steelhead, 2008–2014.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-GRA			LGR-to-BOA		
		%SAR Estimate	Non-parametric CI		%SAR Estimate	Non-parametric CI	
			90% LL	90% UL		90% LL	90% UL
2008	16,673	0.83	0.71	0.95	1.28	1.14	1.43
2009	15,706	0.75	0.64	0.86	1.12	0.98	1.26
2010	11,808	0.43	0.34	0.54	0.59	0.48	0.71
2011	11,152	0.19	0.12	0.26	0.39	0.30	0.49
2012	11,194	0.69	0.57	0.82	0.96	0.82	1.11
2013	14,021	0.41	0.32	0.50	0.49	0.40	0.59
2014	14,378	0.83	0.72	0.97	1.04	0.91	1.18
Geometric mean		0.53			0.77		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using Group T tags.

Table B.49. Overall LGR-to-GRA and LGR-to-BOA SARs for Clearwater River Basin (B-Run) Hatchery Steelhead, 2008–2014.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-GRA			LGR-to-BOA		
		%SAR Estimate	Non-parametric CI		%SAR Estimate	Non-parametric CI	
			90% LL	90% UL		90% LL	90% UL
2008	24,718	1.46	1.33	1.58	2.17	2.01	2.33
2009	28,455	1.04	0.93	1.14	1.48	1.37	1.60
2010	29,993	1.05	0.96	1.15	1.51	1.39	1.63
2011	34,771	0.41	0.35	0.46	0.59	0.52	0.66
2012	19,900	1.12	1.01	1.24	1.45	1.31	1.59
2013	27,692	0.59	0.51	0.66	0.70	0.62	0.78
2014	27,493	1.35	1.23	1.47	1.64	1.52	1.78
Geometric mean		0.93			1.25		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using Group T tags.

Snake River hatchery Sockeye

Table B.50. Overall LGR-to-GRA and LGR-to-BOA SARs for Snake River Hatchery Sockeye, 2009–2015 (SAWT = Sawtooth Hatchery, OXBH = Oxbow Hatchery, Oregon, SPRF = Springfield Hatchery).

Hatchery-Juvenile migration year	Smolts arriving LGR[A]	LGR-to-GRA			LGR-to-BOA		
		%SAR Estimate	Non-parametric CI		%SAR Estimate	Non-parametric CI	
			90% LL	90% UL		90% LL	90% UL
SAWT-2009	17,224	1.15	1.02	1.29	1.81	1.65	1.98
SAWT-2010[B]	----	---	---	---	---	---	---
SAWT-2011	26,238	0.10	0.06	0.13	0.19	0.14	0.23
SAWT-2012	21,420	0.12	0.08	0.15	0.29	0.23	0.35
SAWT-2013	19,224	0.15	0.11	0.20	2.72	2.51	2.93
SAWT-2014	18,444	0.46	0.38	0.54	0.73	0.62	0.84
SAWT-2015[C]	16,841	0.13	0.09	0.18	0.25	0.18	0.33
Geometric mean		0.22			0.61		
OXBH-2009	2,214	2.03	1.52	2.56	2.98	2.30	3.72
OXBH-2010[B]	---	---	---	---	---	---	---
OXBH-2011	5,442	0.39	0.25	0.54	1.21	0.97	1.47
OXBH-2012	4,857	2.26	1.81	2.75	4.10	3.41	4.85
Geometric mean			1.21		2.46		
SPRF-2015[C]	10,572	0.00	0.00	0.00	0.00	0.00	0.00

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using Group T tags.
[B] All PIT tagged sockeye were routed in-river. There were very few incidentally transported PIT-tagged fish for both groups, therefore, estimate of overall SAR (LGR-to-GRA and LGR-to-BOA) was not possible.
[C] Incomplete, 2-salt returns through Sept. 15, 2017.

Snake River wild/natural subyearling fall Chinook

Table B.51. Overall LGR-to-GRA SARs for Snake River Basin (above LGR) wild/natural subyearling fall Chinook, 2006 to 2011. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-GRA without Jacks			LGR-to-GRA with Jacks		
		%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL	%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL
2006	363	0.28	0.00	0.85	0.28	0.00	0.84
2007[B]	---	---	---	---	---	---	---
2008	302	0.99	0.29	2.14	1.66	0.63	2.90
2009	499	0.60	0.17	1.27	0.80	0.20	1.54
2010[C]	---	---	---	---	---	---	---
2011	1,467	0.68	0.36	1.06	0.95	0.55	1.39
Geometric mean		0.80			0.87		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using total tag release in years through 2005 and Group T tags beginning in 2006.
[B] SAR not possible due to low sample size.
[C] SAR not reported due to high estimated holdover rates.

Table B.52. Overall LGR-to-BOA SARs for Snake River Basin (above LGR) wild/natural subyearling fall Chinook, 2006 to 2011. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-BOA without Jacks			LGR-to-BOA with Jacks		
		%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL	%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL
2006	363	0.83	0.24	1.75	0.83	0.00	1.70
2007[B]	---	---	---	---	---	---	---
2008	302	1.99	0.70	3.40	2.98	1.40	4.72
2009	499	1.20	0.40	2.15	1.40	0.62	2.46
2010[C]	---	---	---	---	---	---	---
2011	1,467	0.89	0.52	1.33	1.16	0.74	1.66
Geometric mean		1.15			1.42		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using total tag release in years through 2005 and Group T tags beginning in 2006.
[B] SAR not possible due to low sample size.
[C] SAR not reported due to high estimated holdover rates.

Snake River hatchery subyearling fall Chinook

Table B.53. Overall LGR-to-GRA SARs for Lyons Ferry Hatchery subyearling fall Chinook released at Big Canyon Creek Acclimation Pond (Clearwater River), 2006 to 2012. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-GRA without Jacks			LGR-to-GRA with Jacks		
		%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL	%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL
2006	32,030	0.54	0.47	0.61	0.89	0.80	0.98
2007[B]	---	---	---	---	---	---	---
2008	12,280	1.07	0.92	1.24	1.86	1.64	2.08
2009	5,239	0.11	0.04	0.19	0.19	0.10	0.29
2010	14,021	0.80	0.68	0.92	1.03	0.89	1.16
2011	16,275	0.95	0.82	1.08	1.24	1.09	1.38
2012	14,898	0.71	0.60	0.83	1.00	0.86	1.14
Geometric mean		0.57			0.86		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using total tag release in years through 2005 and Group T tags beginning in 2006.
[B] All PIT-tagged fish were routed in-river. There were very few incidentally transported PIT-tagged fish for both groups, therefore, estimate of overall SAR (LGR-to-GRA and LGR-to-BOA) was not possible.

Table B.54. Overall LGR-to-BOA SARs for Lyons Ferry Hatchery subyearling fall Chinook released at Big Canyon Creek Acclimation Pond (Clearwater River), 2006 to 2012. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-BOA without Jacks			LGR-to-BOA with Jacks		
		%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL	%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL
2006	32,030	0.85	0.76	0.94	1.25	1.15	1.36
2007[B]	---	---	---	---	---	---	---
2008	12,280	1.70	1.51	1.93	2.70	2.41	2.99
2009	5,239	0.21	0.11	0.33	0.29	0.17	0.42
2010	14,021	1.17	1.02	1.32	1.45	1.29	1.63
2011	16,275	1.48	1.32	1.64	1.81	1.63	1.99
2012	14,898	1.06	0.92	1.20	1.45	1.28	1.63
Geometric mean		0.91			1.25		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using total tag release in years through 2005 and Group T tags beginning in 2006.
[B] All PIT-tagged fish were routed in-river. There were very few incidentally transported PIT-tagged fish for both groups, therefore, estimate of overall SAR (LGR-to-GRA and LGR-to-BOA) was not possible.

Table B.55. Overall LGR-to-GRA SARs for Lyons Ferry Hatchery subyearling fall Chinook released at Captain John Rapids Acclimation Pond, 2007 to 2012. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-GRA without Jacks			LGR-to-GRA with Jacks		
		%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL	%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL
2007[B]	---	---	---	---	---	---	---
2008	15,205	0.53	0.44	0.63	1.05	0.90	1.19
2009	5,889	0.19	0.10	0.29	0.37	0.25	0.51
2010	14,865	0.97	0.84	1.10	1.51	1.34	1.68
2011	16,949	0.96	0.83	1.08	1.35	1.20	1.50
2012	15,919	0.70	0.59	0.81	0.86	0.74	0.98
Geometric mean		0.58			0.93		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using total tag release in years through 2005 and Group T tags beginning in 2006.
[B] All PIT-tagged fish were routed in-river. There were very few incidentally transported PIT-tagged fish for both groups, therefore, estimate of overall SAR (LGR-to-GRA and LGR-to-BOA) was not possible.

Table B.56. Overall LGR-to-BOA SARs for Lyons Ferry Hatchery subyearling fall Chinook released at Captain John Rapids Acclimation Pond, 2007 to 2012. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-BOA without Jacks			LGR-to-BOA with Jacks		
		%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL	%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL
2007[B]	---	---	---	---	---	---	---
2008	15,205	0.97	0.84	1.10	0.61	1.46	1.79
2009	5,889	0.25	0.15	0.37	0.46	0.32	0.60
2010	14,865	1.67	1.49	1.85	2.30	2.09	2.51
2011	16,949	1.49	1.34	1.64	1.96	1.79	2.15
2012	15,919	1.14	1.00	1.28	1.39	1.23	1.54
Geometric mean		0.93			1.36		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using total tag release in years through 2005 and Group T tags beginning in 2006.
[B] All PIT-tagged fish were routed in-river. There were very few incidentally transported PIT-tagged fish for both groups, therefore, estimate of overall SAR (LGR-to-GRA and LGR-to-BOA) was not possible.

Table B.57. Overall LGR-to-GRA SARs for Lyons Ferry Hatchery subyearling fall Chinook released at Pittsburg Landing Acclimation Pond, 2006 to 2012. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-GRA without Jacks			LGR-to-GRA with Jacks		
		%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL	%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL
2006	14,894	0.12	0.07	0.17	0.24	0.17	0.31
2007[B]	---	---	---	---	---	---	---
2008	11,464	0.92	0.78	1.07	1.79	1.58	2.00
2009	4,786	0.23	0.12	0.36	0.36	0.23	0.51
2010	10,772	0.83	0.69	0.98	1.23	1.06	1.42
2011	13,624	0.73	0.61	0.86	0.95	0.81	1.09
2012	12,788	0.73	0.60	0.86	0.99	0.85	1.14
Geometric mean		0.47			0.75		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using total tag release in years through 2005 and Group T tags beginning in 2006.
[B] All PIT-tagged fish were routed in-river. There were very few incidentally transported PIT-tagged fish for both groups, therefore, estimate of overall SAR (LGR-to-GRA and LGR-to-BOA) was not possible.

Table B.58. Overall LGR-to-BOA SARs for Lyons Ferry Hatchery subyearling fall Chinook released at Pittsburg Landing Acclimation Pond, 2006 to 2012. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-BOA without Jacks			LGR-to-BOA with Jacks		
		%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL	%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL
2006	14,894	0.19	0.13	0.25	0.34	0.25	0.42
2007[B]	---	---	---	---	---	---	---
2008	11,464	1.48	0.13	1.68	2.52	2.26	2.78
2009	4,786	0.27	0.15	0.40	0.42	0.27	0.58
2010	10,772	1.42	1.24	1.61	1.91	1.69	2.14
2011	13,624	1.23	1.06	1.38	1.48	1.30	1.65
2012	12,788	1.09	0.94	1.24	1.48	1.31	1.65
Geometric mean		0.72			1.07		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using total tag release in years through 2005 and Group T tags beginning in 2006.
[B] All PIT-tagged fish were routed in-river. There were very few incidentally transported PIT-tagged fish for both groups, therefore, estimate of overall SAR (LGR-to-GRA and LGR-to-BOA) was not possible.

Table B.59. Overall LGR-to-GRA SARs for Lyons Ferry Hatchery subyearling fall Chinook released into the mainstem Snake River (above LGR), 2006 to 2012. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-GRA without Jacks			LGR-to-GRA with Jacks		
		%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL	%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL
2006	11,083	0.29	0.20	0.38	0.42	0.32	0.53
2007[B]	---	---	---	---	---	---	---
2008	5,693	0.70	0.51	0.92	1.18	0.91	1.45
2009	5,078	0.18	0.08	0.28	0.35	0.23	0.50
2010	4,248	0.64	0.44	0.88	0.94	0.71	1.11
2011	6,491	0.92	0.73	1.14	1.26	1.03	1.51
2012	5,547	0.41	0.28	0.56	0.49	0.34	0.65
Geometric mean		0.45			0.68		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using total tag release in years through 2005 and Group T tags beginning in 2006.
[B] Due to low broodstock, no PIT-tags were released in this group in 2007.

Table B.60. Overall LGR-to-BOA SARs for Lyons Ferry Hatchery subyearling fall Chinook released into the mainstem Snake River (above LGR), 2006 to 2012. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-BOA without Jacks			LGR-to-BOA with Jacks		
		%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL	%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL
2006	11,083	0.46	0.36	0.57	0.63	0.51	0.77
2007[B]	---	---	---	---	---	---	---
2008	5,693	1.02	0.80	1.27	1.67	1.37	1.98
2009	5,078	0.32	0.20	0.46	0.49	0.33	0.66
2010	4,248	1.13	0.88	1.42	1.48	1.20	1.82
2011	6,491	1.46	1.23	1.76	1.82	1.55	2.12
2012	5,547	0.56	0.40	0.73	0.67	0.49	0.86
Geometric mean		0.72			0.99		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using total tag release in years through 2005 and Group T tags beginning in 2006.
[B] Due to low broodstock, no PIT-tags were released in this group in 2007.

Table B.61. Overall LGR-to-GRA SARs for Irrigon Hatchery subyearling fall Chinook released into the Grande Ronde River, 2006 to 2012. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-GRA without Jacks			LGR-to-GRA with Jacks		
		%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL	%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL
2006[B]	11,143	0.21	0.14	0.29	0.31	0.22	0.40
2007[C]	---	---	---	---	---	---	---
2008	7,987	0.35	0.25	0.46	0.68	0.53	0.84
2009	8,795	0.20	0.13	0.29	0.28	0.20	0.39
2010	11,009	0.79	0.66	0.94	0.95	0.81	1.11
2011	9,233	0.30	0.22	0.40	0.44	0.33	0.57
2012	8,059	0.52	0.39	0.66	0.69	0.54	0.85
Geometric mean		0.35			0.51		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using total tag release in years through 2005 and Group T tags beginning in 2006.
[B] 2006 release was reared at Lyons Ferry Hatchery
[C] Due to low broodstock, no PIT-tags were released in this group in 2007.

Table B.62. Overall LGR-to-BOA SARs for Irrigon Hatchery subyearling fall Chinook released into the Grande Ronde River, 2006 to 2012. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-BOA without Jacks			LGR-to-BOA with Jacks		
		%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL	%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL
2006[B]	11,143	0.28	0.19	0.36	0.43	0.32	0.56
2007[C]	---						
2008	7,987	0.56	0.43	0.70	0.94	0.75	1.13
2009	8,795	0.25	0.17	0.34	0.34	0.24	0.45
2010	11,009	1.32	1.15	1.50	1.54	1.34	1.73
2011	9,233	0.48	0.36	0.60	0.62	0.49	0.76
2012	8,059	0.86	0.69	1.02	1.10	0.92	1.30
Geometric mean		0.53			0.72		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using total tag release in years through 2005 and Group T tags beginning in 2006.
[B] 2006 release was reared at Lyons Ferry Hatchery
[C] Due to low broodstock, no PIT-tags were released in this group in 2007.

Table B.63. Overall LGR-to-GRA SARs for Umatilla/Irrigon Hatchery subyearling fall Chinook released into the Snake River below Hells Canyon Dam, 2006 to 2012. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-GRA without Jacks			LGR-to-GRA with Jacks		
		%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL	%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL
2006	11,930	0.21	0.14	0.28	0.31	0.23	0.39
2007[B]	---	---	---	---	---	---	---
2008	12,201	1.07	0.92	1.25	2.29	2.06	2.51
2009	15,156	0.05	0.02	0.09	0.15	0.09	0.20
2010	13,428	0.62	0.50	0.73	0.84	0.71	0.97
2011	10,509	0.34	0.25	0.44	0.44	0.34	0.55
2012	12,770	0.67	0.55	0.80	0.86	0.73	1.00
Geometric mean		0.34			0.57		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using total tag release in years through 2005 and Group T tags beginning in 2006.
[B] Due to low broodstock, no PIT-tags were released in this group in 2007.

Table B.64. Overall LGR-to-BOA SARs for Umatilla/Irrigon Hatchery subyearling fall Chinook released into the Snake River below Hells Canyon Dam, 2006 to 2012. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-BOA without Jacks			LGR-to-BOA with Jacks		
		%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL	%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL
2006	11,930	0.32	0.23	0.41	0.45	0.36	0.56
2007[B]	---	---	---	---	---	---	---
2008	12,201	1.17	1.58	1.97	3.32	3.02	3.60
2009	15,156	0.07	0.03	0.10	0.16	0.11	0.22
2010	13,428	0.94	0.80	1.08	1.21	1.06	1.37
2011	10,509	0.64	0.52	0.78	0.76	0.63	0.92
2012	12,770	1.07	0.92	1.23	1.35	1.17	1.53
Geometric mean		0.54			0.82		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using total tag release in years through 2005 and Group T tags beginning in 2006.
[B] Due to low broodstock, no PIT-tags were released in this group in 2007.

Table B.65. Overall LGR-to-GRA SARs for Oxbow Hatchery (Idaho) subyearling fall Chinook released into the Snake River below Hells Canyon Dam, 2007 to 2012. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-GRA without Jacks			LGR-to-GRA with Jacks		
		%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL	%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL
2007[B]	---	---	---	---	---	---	---
2008	5,577	0.90	0.70	1.12	2.22	1.91	2.56
2009	4,569	0.09	0.02	0.17	0.31	0.17	0.45
2010	---	---	---	---	---	---	---
2011	5,251	0.42	0.27	0.58	0.61	0.44	0.80
2012	5,046	0.42	0.27	0.58	0.61	0.43	0.80
Geometric mean		0.35			0.71		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using total tag release in years through 2005 and Group T tags beginning in 2006.
[B] All PIT-tagged fish were routed in-river. There were very few incidentally transported PIT-tagged fish for both groups, therefore, estimate of overall SAR (LGR-to-GRA and LGR-to-BOA) was not possible.

Table B.66. Overall LGR-to-BOA SARs for Oxbow Hatchery (Idaho) subyearling fall Chinook released into the Snake River below Hells Canyon Dam, 2007 to 2012. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-BOA without Jacks			LGR-to-BOA with Jacks		
		%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL	%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL
2007[B]	---	---	---	---	---	---	---
2008	5,577	1.51	1.24	1.79	3.03	2.67	3.43
2009	4,569	0.11	0.04	0.20	0.33	0.20	0.47
2010	---	---	---	---	---	---	---
2011	5,251	0.74	0.55	0.95	1.07	0.84	1.32
2012	5,046	0.71	0.51	0.92	1.13	0.87	1.38
Geometric mean		0.54			1.05		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using total tag release in years through 2005 and Group T tags beginning in 2006.
[B] All PIT-tagged fish were routed in-river. There were very few incidentally transported PIT-tagged fish for both groups, therefore, estimate of overall SAR (LGR-to-GRA and LGR-to-BOA) was not possible.

Table B.67. Overall LGR-to-GRA SARs for Dworshak Hatchery subyearling fall Chinook (surrogates) released into the mainstem Snake River (above Lower Granite Dam), 2006 to 2012. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-GRA without Jacks			LGR-to-GRA with Jacks		
		%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL	%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL
2006	63,844	0.25	0.22	0.28	0.36	0.32	0.40
2007[B]	---	---	---	---	---	---	---
2008	62,103	0.64	0.59	0.70	1.09	1.02	1.16
2009	85,076	0.15	0.13	0.17	0.22	0.19	0.25
2010	44,215	0.52	0.46	0.58	0.83	0.74	0.90
2011	56,234	0.86	0.80	0.93	1.06	0.98	1.13
2012[C]	---	---	---	---	---	---	---
Geometric mean		0.40			0.60		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using total tag release in years through 2005 and Group T tags beginning in 2006.
[B] Due to low broodstock, no PIT-tags were released in this group in 2007.
[C] SAR not reported due to high estimated holdover rates.

Table B.68. Overall LGR-to-BOA SARs for Dworshak Hatchery subyearling fall Chinook (surrogates) released into the mainstem Snake River (above Lower Granite Dam), 2006 to 2012. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-BOA without Jacks			LGR-to-BOA with Jacks		
		%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL	%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL
2006	63,844	0.37	0.33	0.41	0.49	0.44	0.54
2007[B]	---	---	---	---	---	---	---
2008	62,103	0.97	0.90	1.04	1.51	1.42	1.60
2009	85,076	0.21	0.18	0.23	0.29	0.26	0.32
2010	44,215	0.74	0.66	0.81	1.07	0.98	1.17
2011	56,234	1.33	1.25	1.41	1.57	1.48	1.66
2012[C]	---	---	---	---	---	---	---
Geometric mean		0.59			0.82		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using total tag release in years through 2005 and Group T tags beginning in 2006.
[B] Due to low broodstock, no PIT-tags were released in this group in 2007.
[C] SAR not reported due to high estimated holdover rates.

Table B.69. Overall LGR-to-GRA SARs for Nez Perce Tribal Hatchery subyearling fall Chinook released from Cedar Flats Acclimation Facility (Clearwater River), 2010 to 2012. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-GRA without Jacks			LGR-to-GRA with Jacks		
		%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL	%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL
2010	2,850	0.56	0.34	0.78	0.63	0.40	0.87
2011	6,680	0.91	0.73	1.11	1.36	1.14	1.60
2012	5,163	0.83	0.62	1.04	0.91	0.68	1.13
Geometric mean		0.75			0.92		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using total tag release in years through 2005 and Group T tags beginning in 2006.

Table B.70. Overall LGR-to-BOA SARs for Nez Perce Tribal Hatchery subyearling fall Chinook released from Cedar Flats Acclimation Facility (Clearwater River), 2010 to 2012. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-BOA without Jacks			LGR-to-BOA with Jacks		
		%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL	%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL
2010	2,850	0.95	0.66	1.25	1.05	0.75	1.36
2011	6,680	1.66	1.39	1.94	2.40	2.07	2.73
2012	5,163	1.20	0.95	1.48	1.34	1.08	1.63
Geometric mean		1.24			1.50		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using total tag release in years through 2005 and Group T tags beginning in 2006.

Table B.71. Overall LGR-to-GRA SARs for Nez Perce Tribal Hatchery subyearling fall Chinook released from Lukes Gulch Acclimation Facility (Clearwater River), 2010 to 2012. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-GRA without Jacks			LGR-to-GRA with Jacks		
		%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL	%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL
2010	4,436	0.20	0.11	0.32	0.54	0.39	0.71
2011	6,595	0.80	0.62	0.98	1.08	0.87	1.30
2012	6,328	0.44	0.31	0.60	0.52	0.38	0.68
Geometric mean		0.41			0.67		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using total tag release in years through 2005 and Group T tags beginning in 2006.

Table B.72. Overall LGR-to-BOA SARs for Nez Perce Tribal Hatchery subyearling fall Chinook released from Lukes Gulch Acclimation Facility (Clearwater River), 2010 to 2012. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving LGR[A]	LGR-to-BOA without Jacks			LGR-to-BOA with Jacks		
		%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL	%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL
2010	4,436	0.47	0.31	0.64	0.88	0.65	1.11
2011	6,595	2.00	1.71	2.28	2.47	2.15	2.78
2012	6,328	0.66	0.48	0.85	0.79	0.59	0.99
Geometric mean		0.85			1.20		

[A] Estimated population of tagged study fish alive to LGR tailrace (includes fish detected at the dam and those estimated to pass undetected) using total tag release in years through 2005 and Group T tags beginning in 2006.

Middle Columbia wild spring Chinook

Table B.73. Overall JDA-to-BOA SARs for John Day River Basin Wild Chinook, 2000 to 2015. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving JDA[A]	JDA-to-BOA without Jacks			JDA-to-BOA with Jacks		
		%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL	%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL
2000	1,310	10.91	9.32	12.55	11.14	9.51	12.77
2001	2,743	3.86	3.25	4.50	4.12	3.48	4.76
2002	2,513	3.78	3.13	4.52	3.98	3.29	4.75
2003	4,388	2.80	2.38	3.26	2.92	2.49	3.39
2004	2,805	3.14	2.46	3.88	3.32	2.60	4.07
2005	3,817	1.86	1.51	2.22	2.07	1.71	2.47
2006	2,237	2.06	1.55	2.59	2.15	1.63	2.70
2007	2,726	4.33	3.65	5.00	5.06	4.33	5.76
2008	2,973	5.48	4.69	6.27	6.22	5.36	7.08
2009	3,219	6.77	5.95	7.63	7.11	6.25	8.03
2010	3,095	3.55	2.99	4.14	4.85	4.18	5.49
2011	2,569	0.90	0.59	1.24	0.93	0.63	1.28
2012	2,528	3.40	2.70	4.20	4.27	3.49	5.15
2013	1,151	4.08	3.06	5.18	5.12	3.93	6.39
2014	997	3.41	2.31	4.70	3.71	2.56	5.07
2015[B]	483	4.14	2.39	6.22	6.21	3.92	8.86
Geometric mean		3.51			3.98		

[A] Estimated population of tagged study fish alive to JDA tailrace (included fish detected at the dam and those estimated to pass undetected). CJS estimation of S1 uses PIT-tags detected on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON.
[B] Incomplete, 2-salt returns through Sept. 15, 2017.

Table B.74. Overall MCN-to-BOA SARs for Yakima River Basin Wild Chinook, 2000 to 2015. SARs are calculated with and without jacks. No PIT-tagged smolts released in 2010 or 2014.

Juvenile migration year	Smolts arriving MCN[A]	MCN-to-BOA without Jacks			MCN-to-BOA with Jacks		
		%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL	%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL
2000	2,581	6.90	6.10	7.73	7.48	6.67	8.38
2001	521	1.54	0.73	2.52	1.92	0.98	3.04
2002	2,130	2.25	1.73	2.82	2.30	1.77	2.86
2003	2,143	2.47	1.91	3.04	2.89	2.27	3.55
2004	1,297	3.70	2.87	4.62	3.78	2.95	4.70
2005	519	1.35	0.57	2.20	1.35	0.57	2.20
2006	565	1.59	0.76	2.65	1.77	0.85	2.78
2007	362	1.93	0.86	3.26	1.93	0.86	3.26
2008	512	6.84	4.93	8.96	9.19	6.85	11.73
2009	990	4.95	3.78	6.21	5.56	4.33	6.88
2010	0	--	--	--	--	--	--
2011	411	0.97	0.24	1.79	0.97	0.24	1.79
2012	826	2.79	1.85	3.85	3.27	2.19	4.45
2013	704	1.42	0.75	2.25	1.56	0.83	2.44
2014	0	--	--	--	--	--	--
2015[B]	238	2.10	0.50	4.09	2.52	0.65	4.52
Geometric mean		2.43			2.69		

[A] Estimated population of tagged study fish alive to MCN tailrace (included fish detected at the dam and those estimated to pass undetected). CJS estimation of S1 uses PIT-tags detected on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON.

[B] Incomplete, 2-salt returns through Sept. 15, 2017.

Table B.75. Overall MCN-to-MCA SARs for Yakima River Basin Wild Chinook, 2002 to 2015. SARs are calculated with and without jacks. No PIT-tagged smolts released in 2010 or 2014.

Juvenile migration year	Smolts arriving MCN[A]	MCN-to-MCA without Jacks			MCN-to-MCA with Jacks		
		%SAR Estimate	Non-parametric CI		%SAR Estimate	Non-parametric CI	
			90% LL	90% UL		90% LL	90% UL
2002	2,130	2.16	1.67	2.71	2.21	1.70	2.76
2003	2,143	2.52	1.94	3.09	2.89	2.28	3.52
2004	1,297	3.47	2.67	4.38	3.62	2.83	4.54
2005	519	1.35	0.57	2.20	1.35	0.57	2.20
2006	565	1.42	0.57	2.32	1.59	0.72	2.51
2007	362	1.93	0.85	3.25	1.93	0.85	3.25
2008	512	5.67	3.98	7.61	8.01	5.91	10.38
2009	990	4.14	3.15	5.29	4.65	3.59	5.82
2010	0	--	--	--	--	--	--
2011	411	0.73	0.00	1.47	0.73	0.00	1.47
2012	826	2.79	1.84	3.82	3.27	2.23	4.43
2013	704	1.56	0.86	2.41	1.71	0.94	2.61
2014	0	--	--	--	--	--	--
2015[B]	238	1.68	0.33	3.33	2.10	0.48	4.09
Geometric mean		2.13			2.36		

[A] Estimated population of tagged study fish alive to MCN tailrace (included fish detected at the dam and those estimated to pass undetected). CJS estimation of S1 uses PIT-tags detected on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON.
[B] Incomplete, 2-salt returns through Sept. 15, 2017.

Middle Columbia hatchery spring Chinook

Table B.76. Overall BON-to-BOA SARs for Carson Hatchery Chinook, 2000–2015. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving BON [A]	BON-to-BOA without Jacks			BON-to-BOA with Jacks			Smolts released	REL-to-BOA without Jacks		
		%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL	%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL		%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL
2000	12,945	3.30	2.71	3.91	3.34	2.75	4.00	14,992	2.85	2.62	3.07
2001	12,506	1.78	1.50	2.05	1.81	1.51	2.09	14,978	1.49	1.32	1.65
2002	12,349	1.22	0.94	1.54	1.26	0.95	1.57	14,983	1.01	0.88	1.14
2003	12,709	0.27	0.19	0.36	0.27	0.19	0.36	14,983	0.23	0.17	0.29
2004	NA [B]	--	--	--	--	--	--	14,973	0.62	0.51	0.73
2005	14,053	0.32	0.23	0.42	0.33	0.23	0.43	14,958	0.30	0.23	0.37
2006	10,509	0.60	0.45	0.77	0.63	0.48	0.79	14,971	0.42	0.33	0.51
2007	NA [B]	--	--	--	--	--	--	14,943	0.54	0.43	0.63
2008	12,250	1.80	1.51	2.11	2.05	1.72	2.37	14,884	1.48	1.32	1.65
2009	11,595	1.84	1.54	2.17	1.91	1.60	2.23	14,975	1.42	1.32	1.63
2010	11,056	0.75	0.64	0.86	0.86	0.73	0.98	14,947	0.75	0.64	0.86
2011	10,873	0.46	0.33	0.63	0.48	0.35	0.66	14,953	0.33	0.26	0.42
2012	13,070	0.61	0.44	0.82	0.67	0.48	0.89	14,941	0.54	0.44	0.64
2013	13,006	1.21	0.96	1.47	1.28	1.02	1.55	14,907	1.05	0.92	1.19
2014	10,964	0.76	0.59	0.95	0.84	0.66	1.04	14,906	0.56	0.46	0.66
2015 [C]	10,217	0.53	0.41	0.66	0.62	0.51	0.73	14,734	0.39	0.31	0.48
geometric mean		0.86			0.92				0.69		

[A] Estimated population of tagged study fish alive to BON tailrace (included fish detected at the dam and those estimated to pass undetected). CJS estimation of S1 uses PIT-tags detected on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON.
[B] Not calculated; release to BON survival estimate > 1.0
[C] Incomplete, 2-salt returns through June 24, 2017.

Table B.77. Overall BON-to-BOA SARs for Warm Springs Hatchery Chinook (Deschutes River), 2007–2015. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving BON [A]	BON-to-BOA without Jacks			BON-to-BOA with Jacks			Smolts released	REL-to-BOA without Jacks		
		%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL	%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL		%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL
2007 [B]	--	--	--	--	--	--	--	19,698	0.30	0.24	0.38
2008 [B]	--	--	--	--	--	--	--	19,936	0.84	0.73	0.94
2009 [B]	--	--	--	--	--	--	--	19,924	0.65	0.56	0.74
2010	8,361	0.37	0.26	0.48	0.63	0.47	0.79	14,907	0.21	0.15	0.27
2011	6,164	0.45	0.29	0.65	0.49	0.31	0.69	14,924	0.19	0.13	0.25
2012	7,802	1.26	0.92	1.63	1.64	1.23	2.10	14,806	0.66	0.56	0.77
2013	10,595	1.65	1.30	2.03	2.00	1.61	2.45	14,877	1.18	1.04	1.32
2014	9,549	1.38	1.07	1.75	1.60	1.23	2.00	14,818	0.89	0.76	1.01
2015 [C]	7,470	0.72	0.54	0.92	0.84	0.63	1.08	14,915	0.36	0.28	0.45
geometric mean		0.84			1.05				0.49		

[A] Estimated population of tagged study fish alive to BON tailrace (included fish detected at the dam and those estimated to pass undetected). CJS estimation of S1 uses PIT-tags detected on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON.
[B] Chinook smolts are released in fall and spring and form two different cohorts. Cannot distinguish between fall and spring PIT tag releases. Estimated juvenile population at BON not possible.
[C] Incomplete, 2-salt returns through Sept. 15, 2017.

Table B.78. Overall MCN-to-BOA SARs for Cle Elum Hatchery Chinook, 2000-2015. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving MCN[A]	MCN-to-BOA without Jacks			MCN-to-BOA with Jacks		
		%SAR Estimate	Non-parametric CI		%SAR Estimate	Non-parametric CI	
			90% LL	90% UL		90% LL	90% UL
2000	14,416	3.65	3.35	3.96	3.99	3.67	4.31
2001	9,269	0.28	0.19	0.38	0.29	0.20	0.39
2002	11,753	1.37	1.20	1.55	1.73	1.54	1.93
2003	11,978	0.59	0.48	0.71	0.86	0.72	1.01
2004	7,982	1.54	1.30	1.78	1.85	1.59	2.10
2005	5,792	0.66	0.49	0.83	0.78	0.59	0.98
2006	10,283	1.24	1.06	1.41	1.59	1.40	1.80
2007	12,661	1.01	0.86	1.16	1.51	1.33	1.68
2008	11,686	3.17	2.86	3.46	5.06	4.64	5.47
2009	15,382	1.82	1.65	1.99	2.29	2.10	2.49
2010	12,473	1.52	1.33	1.71	2.53	2.30	2.79
2011	11,866	0.94	0.79	1.09	1.21	1.04	1.38
2012	15,719	1.22	1.07	1.37	1.76	1.57	1.96
2013	13,269	1.38	1.20	1.56	1.95	1.74	2.16
2014	12,855	0.58	0.48	0.69	0.84	0.72	0.98
2015[B]	10,659	1.01	0.86	1.19	1.86	1.63	2.09
Geometric mean		1.14			1.55		

[A] Estimated population of tagged study fish alive to MCN tailrace (included fish detected at the dam and those estimated to pass undetected). CJS estimation of S1 uses PIT-tags detected on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON.

[B] Incomplete, 2-salt returns through Sept. 15, 2017.

Table B.79. Overall MCN-to-MCA SARs for Cle Elum Hatchery Chinook, 2002–2015. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving MCN[A]	MCN-to-MCA without Jacks			MCN-to-MCA with Jacks		
		%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL	%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL
2002	11,753	1.39	1.21	1.57	1.77	1.58	1.98
2003	11,978	0.63	0.52	0.76	0.94	0.80	1.09
2004	7,983	1.34	1.13	1.57	1.64	1.41	1.88
2005	5,792	0.59	0.43	0.76	0.73	0.54	0.92
2006	12,661	1.10	0.93	1.27	1.47	1.27	1.67
2007	12,661	0.86	0.72	1.00	1.32	1.16	1.49
2008	11,686	2.79	2.51	3.06	4.64	4.27	5.01
2009	15,382	1.57	1.40	1.73	2.03	1.84	2.22
2010	12,473	1.40	1.22	1.58	2.31	2.07	2.55
2011	11,866	0.87	0.73	1.00	1.12	0.96	1.28
2012	15,719	1.07	0.93	1.22	1.57	1.40	1.76
2013	13,269	1.33	1.15	1.50	1.87	1.66	2.07
2014	12,855	0.49	0.39	0.59	0.73	0.61	0.86
2015[B]	10,659	0.84	0.70	1.00	1.60	1.41	1.83
Geometric mean		1.05			1.51		

[A] Estimated population of tagged study fish alive to MCN tailrace (included fish detected at the dam and those estimated to pass undetected). CJS estimation of S1 uses PIT-tags detected on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON.

[B] Incomplete, 2-salt returns through Sept. 15, 2017.

Middle Columbia wild Steelhead

Table B.80. Overall JDA-to-BOA SARs for John Day River Basin Wild Steelhead, 2004–2014.

Juvenile migration year	Smolts arriving JDA[A]	JDA-to-BOA		
		%SAR Estimate	Non-parametric CI	
			90% LL	90% UL
2004	2,530	4.35	3.60	5.18
2005	3,571	2.77	2.31	3.28
2006	1,910	3.35	2.65	4.07
2007	2,874	8.80	7.73	9.89
2008	3,069	10.23	9.19	11.31
2009	2,556	7.67	6.63	8.65
2010	2,190	6.08	5.18	7.04
2011	2,252	1.95	1.46	2.51
2012	3,202	5.43	4.56	6.34
2013	1,502	10.25	8.36	12.30
2014	1,309	5.04	3.75	6.52
Geometric mean		5.30		

[A] Estimated population of tagged study fish alive to JDA tailrace (included fish detected at the dam and those estimated to pass undetected). CJS estimation of S1 uses PIT-tags detected on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON.

Table B.81. Overall BON-to-BOA SARs for Deschutes River Basin (Trout Creek) Wild Steelhead, 2006–2014.

Juvenile migration year	Smolts arriving BON[A]	BON-to-BOA %SAR Estimate	BON-to-BOA Non-parametric CI 90% LL	BON-to-BOA Non-parametric CI 90% UL
2006	815	8.22	5.57	11.06
2007	942	7.54	5.07	9.98
2008	1,277	9.95	7.20	12.79
2009	1,830	8.47	6.84	10.21
2010	806	3.97	2.59	5.46
2011	1,704	6.45	4.68	8.49
2012	1,940	5.67	3.31	8.31
2013[B]	---	---	---	---
2014	212	12.73	6.20	19.84
Geometric mean		7.47		

[A] Estimated population of tagged study fish alive to BON tailrace (included fish detected at the dam and those estimated to pass undetected). CJS estimation of S1 uses PIT-tags detected on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON.

[B] Too few PIT-tags released to obtain reliable estimate of smolts arriving at BON. Therefore, estimate of BON-to-BOA SAR was not possible.

Table B.82. Overall MCN-to-BOA and MCN-to-MCA SARs for Yakima River Basin Wild Steelhead, 2002–2014.

Juvenile migration year	Smolts arriving MCN[A]	MCN-to-BOA %SAR Estimate	MCN-to-BOA Non-parametric CI 90% LL	MCN-to-BOA Non-parametric CI 90% UL	MCN-to-MCA %SAR Estimate	MCN-to-MCA Non-parametric CI 90% LL	MCN-to-MCA Non-parametric CI 90% UL
2002	357	8.12	5.24	11.37	6.16	3.72	8.83
2003	293	7.85	4.93	11.19	6.49	4.05	9.29
2004	387	2.84	1.46	4.67	2.58	1.26	4.29
2005	263	4.94	2.56	7.90	4.56	2.29	7.36
2006	397	4.03	2.20	5.98	3.27	1.70	4.97
2007	219	7.30	3.29	12.06	6.39	2.87	10.55
2008	215	9.79	5.67	14.26	8.85	4.93	13.24
2009	360	5.27	3.26	8.20	4.72	2.79	7.28
2010	331	5.74	2.91	9.56	4.53	2.13	7.71
2011	213	3.28	1.32	5.82	2.34	0.88	4.57
2012	381	7.60	4.52	10.87	5.24	2.99	7.91
2013	250	5.20	1.60	11.33	4.00	1.18	9.10
2014	329	5.78	3.23	8.87	5.17	2.85	8.14
Geometric mean		5.64			4.65		

[A] Estimated population of tagged study fish alive to MCN tailrace (included fish detected at the dam and those estimated to pass undetected). CJS estimation of S1 uses PIT-tags detected on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON.

Middle Columbia wild subyearling fall Chinook

Table B.83. Overall MCN-to-BOA and Rel-to-BOA SARs for Hanford Reach subyearling wild fall Chinook, 2000-2014. SARs are calculates with and without jacks.

Juvenile migration year	Smolts arriving MCN [A]	MCN-to-BOA without Jacks			MCN-to-BOA with Jacks			Smolts released	REL-to-BOA without Jacks		
		%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL	%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL		%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL
2000	4,521	2.68	2.27	3.11	2.88	2.45	3.32	10,967	1.10	0.93	1.28
2001	3,642	0.68	0.47	0.91	0.71	0.50	0.94	9,973	0.25	0.17	0.33
2002	--	--	--	--	--	--	--	--	--	--	--
2003	820	0.43	0.11	0.82	0.43	0.11	0.82	2,975	0.13	0.03	0.27
2004	1,000	0.20	0.00	0.44	0.20	0.00	0.44	2,989	0.07	0.00	0.17
2005	6,602	0.26	0.15	0.37	0.29	0.18	0.40	22,634	0.08	0.04	0.11
2006	--	--	--	--	--	--	--	--	--	--	--
2007	7,790	0.35	0.24	0.46	0.45	0.33	0.58	21,007	0.13	0.09	0.17
2008	5,543	2.00	1.62	2.39	2.27	1.88	2.71	16,651	0.67	0.56	0.77
2009	4,614	0.72	0.51	0.96	0.89	0.65	1.17	13,728	0.24	0.17	0.31
2010	1,418	2.61	1.88	3.40	2.96	2.15	3.88	4,850	0.76	0.56	0.97
2011	4,050	3.21	2.65	3.84	3.46	2.88	4.12	10,337	1.26	1.08	1.43
2012	1,335	1.80	1.17	2.47	1.87	1.22	2.57	4,885	0.49	0.33	0.66
2013[B]	1,440	1.53	0.98	2.15	1.87	1.23	2.60	4,184	0.53	0.36	0.72
2014[C]	3,400	0.12	0.03	0.22	0.29	0.15	0.46	9,940	0.04	0.01	0.07
geometric mean		0.80			0.95				0.27		

[A] Estimated population of tagged study fish alive to MCN tailrace (included fish detected at the dam and those estimated to pass undetected). CJS estimation of S1 uses PIT-tags detected on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON.
[B] Incomplete, 3-salt returns through December 31, 2016.
[C] Incomplete, 2-salt returns through December 31, 2016.

Table B.84. Overall BON-to-BOA and Rel-to-BOA SARs for Deschutes River subyearling wild fall Chinook, 2011-2014. SARs are calculates with and without jacks.

Juvenile migration year	Smolts arriving BON [A]	BON-to-BOA without Jacks			BON-to-BOA with Jacks			Smolts released	REL-to-BOA without Jacks		
		%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL	%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL		%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL
2011	5,670	2.40	1.65	3.33	3.07	2.12	4.20	19,897	0.68	0.59	0.78
2012	6,998	0.73	0.43	1.08	0.93	0.56	1.37	20,798	0.25	0.19	0.30
2013[B]	8,466	0.52	0.31	0.75	0.85	0.54	1.21	26,322	0.17	0.13	0.21
2014[C]	3,822	0.81	0.46	1.19	0.84	0.49	1.23	19,899	0.16	0.12	0.20
geometric mean		0.93			1.19				0.26		

[A] Estimated population of tagged study fish alive to BON tailrace (included fish detected at the dam and those estimated to pass undetected). CJS estimation of S1 uses PIT-tags detected on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON.
[B] Incomplete, 3-salt returns through December 31, 2016.
[C] Incomplete, 2-salt returns through December 31, 2016.

Middle Columbia hatchery subyearling fall Chinook

Table B.85. Overall BON-to-BOA and Rel-to-BOA SARs for Spring Creek Hatchery subyearling fall Chinook, 2008-2014. SARs are calculates with and without jacks.

Juvenile migration year	Month of Release	Smolts arriving BON [A]	BON-to-BOA without Jacks			BON-to-BOA with Jacks			Smolts released	REL-to-BOA without Jacks		
			%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL	%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL		%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL
2008	March	5,877	0.34	0.19	0.52	0.43	0.25	0.64	7,477	0.27	0.17	0.36
2008[B]	April	---	---	---	---	---	---	---	3,853	0.63	0.43	0.83
2009[B]	April	---	---	---	---	---	---	---	8,686	0.06	0.02	0.10
2010[B]	April	---	---	---	---	---	---	---	8,962	0.25	0.16	0.33
2011	April	8,163	0.16	0.09	0.25	0.16	0.09	0.25	8,956	0.15	0.08	0.21
2012[B]	April	---	---	---	---	---	---	---	8,772	0.28	0.19	0.39
2013[C]	April	8,041	0.62	0.46	0.80	0.75	0.56	0.96	8,964	0.56	0.44	0.68
2014[B,D]	April	---	---	---	---	---	---	---	8,873	0.08	0.03	0.14
geometric mean (Apr)			0.31			0.35				0.21		
2008[B]	May	---	---	---	---	---	---	---	2,677	0.52	0.30	0.75
2009[B]	May	---	---	---	---	---	---	---	5,950	0.22	0.13	0.32
2010	May	5,908	0.20	0.11	0.31	0.24	0.14	0.36	5,971	0.20	0.12	0.30
2011[B]	May	---	---	---	---	---	---	---	5,983	0.23	0.13	0.33
2012[B]	May	---	---	---	---	---	---	---	5,978	0.23	0.13	0.35
2013[C]	May	5,527	0.58	0.39	0.79	0.67	0.46	0.90	5,976	0.54	0.38	0.69
2014[B,D,E]	May	---	---	---	---	---	---	---	5,993	0.02	0.00	0.05
geometric mean (May)			0.34			0.40				0.20		

[A] Estimated population of tagged study fish alive to BON tailrace (included fish detected at the dam and those estimated to pass undetected). CJS estimation of S1 uses PIT-tags detected on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON.
[B] BON-to-BOA SAR not calculated, release to BON survival > 1.0.
[C] Incomplete, 3-salt returns through December 31, 2016.
[D] Incomplete, 2-salt returns through December 31, 2016.
[E] May release was rescheduled for April 30th due to high flows in the Columbia River

Table B.86. Overall BON-to-BOA and Rel-to-BOA SARs for Little White Salmon Hatchery subyearling fall Chinook, 2008-2014. SARs are calculates with and without jacks.

Juvenile migration year	Smolts arriving BON [A]	BON-to-BOA without Jacks			BON-to-BOA with Jacks			Smolts released	REL-to-BOA without Jacks		
		%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL	%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL		%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL
2008	14,393	1.74	1.52	1.99	1.85	1.62	2.10	24,886	1.01	0.90	1.11
2009	14,805	0.84	0.70	1.00	0.95	0.80	1.12	24,947	0.50	0.43	0.57
2010	15,140	2.69	2.35	3.06	2.75	2.41	3.13	24,951	1.63	1.50	1.77
2011	17,680	3.33	2.77	3.95	3.40	2.83	4.04	24,638	2.39	2.23	2.54
2012	16,381	0.74	0.57	0.93	0.79	0.60	0.98	24,947	0.49	0.41	0.57
2013[B]	10,505	1.22	1.02	1.44	1.33	1.12	1.57	14,959	0.86	0.73	0.99
2014[C]	8,191	0.09	0.04	0.14	0.09	0.04	0.14	14,925	0.05	0.02	0.07
geometric mean		1.01			1.06				0.63		

[A] Estimated population of tagged study fish alive to BON tailrace (included fish detected at the dam and those estimated to pass undetected). CJS estimation of S1 uses PIT-tags detected on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON.
[B] Incomplete, 3-salt returns through December 31, 2016.
[C] Incomplete, 2-salt returns through December 31, 2016.

Upper Columbia wild Chinook

Table B.87. Overall MCN-to-BOA SARs for Upper Columbia Wild Chinook (Wenatchee River), 2007 to 2015. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving MCN[A]	MCN-to-BOA (without jacks)			MCN-to-BOA (with jacks)		
		%SAR Estimate	Non-parametric CI		%SAR Estimate	Non-parametric CI	
			90% LL	90% UL		90% LL	90% UL
2007	3,019	0.76	0.54	1.02	0.76	0.54	1.02
2008	5,747	2.75	2.40	3.14	2.89	2.51	3.30
2009	3,329	1.98	1.57	2.44	2.07	1.63	2.55
2010	4,833	1.37	1.08	1.66	1.70	1.37	2.03
2011	2,854	0.95	0.64	1.30	1.02	0.70	1.39
2012	3,779	0.95	0.68	1.24	1.14	0.84	1.46
2013	3,004	1.86	1.39	2.25	1.93	1.48	2.32
2014	3,955	0.91	0.67	1.18	1.11	0.84	1.41
2015[B]	3,229	0.19	0.14	0.24	0.23	0.18	0.29
Geometric mean		1.06			1.18		

[A] Estimated population of tagged study fish alive to MCN tailrace (included fish detected at the dam and those estimated to pass undetected). CJS estimation of S1 uses PIT-tags detected on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON.
[B] Incomplete, 2-salt returns through Sept. 15, 2017.

Table B.88. Overall MCN-to-BOA SARs for Upper Columbia Wild Chinook (Entiat and Methow Rivers), 2006 to 2015. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving MCN[A]	MCN-to-BOA (without jacks)			MCN-to-BOA (with jacks)		
		%SAR Estimate	Non-parametric CI		%SAR Estimate	Non-parametric CI	
			90% LL	90% UL		90% LL	90% UL
2006[B]	927	0.43	0.11	0.81	0.54	0.20	0.98
2007	804	0.75	0.26	1.27	0.75	0.26	1.27
2008	4,901	2.94	2.51	3.38	3.26	2.82	3.73
2009	1,625	2.22	1.58	2.87	2.40	1.72	3.06
2010	3,244	1.85	1.45	2.28	1.97	1.57	2.42
2011	972	0.41	0.10	0.79	0.62	0.22	1.09
2012	2,035	1.23	0.83	1.64	1.77	1.27	2.28
2013	1,857	2.21	1.61	2.85	2.80	2.11	3.53
2014	2,397	1.71	1.23	2.19	1.84	1.33	2.32
2015[C]	1,458	0.69	0.34	1.09	1.03	0.59	1.51
Geometric mean		1.18			1.43		

[A] Estimated population of tagged study fish alive to MCN tailrace (included fish detected at the dam and those estimated to pass undetected). CJS estimation of S1 uses PIT-tags detected on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON.
[B] 2006 is Entiat River only.
[C] Incomplete, 2-salt returns through Sept. 15, 2017.

Table B.89. Overall RRE-to-BOA SARs for Upper Columbia Wild Chinook (Entiat and Methow Rivers)[A], 2008 to 2015. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving RRE[B]	RRE-to-BOA (without jacks)			RRE-to-BOA (with jacks)		
		%SAR Estimate	Non-parametric CI		%SAR Estimate	Non-parametric CI	
			90% LL	90% UL		90% LL	90% UL
2008[C]	9,309	1.55	1.17	1.94	1.72	1.30	2.15
2009[C]	3,253	1.11	0.64	1.65	1.20	0.69	1.76
2010_	5,292	1.13	0.89	1.39	1.21	0.97	1.47
2011	1,361	0.29	0.07	0.55	0.44	0.15	0.79
2012	3,494	0.72	0.47	0.97	1.03	0.75	1.33
2013	3,123	1.31	0.94	1.68	1.66	1.25	2.08
2014	4,189	0.98	0.74	1.27	1.05	0.79	1.35
2015[D]	4,671	0.21	0.11	0.35	0.32	0.19	0.48
Geometric mean		0.76			0.94		

[A] The Entiat/Methow wild Chinook aggregate is the same group as used for the MCN-to-BOA reach. SARs are calculated as number of adults at BOA divided by estimated number of smolts at Rocky Reach Dam.
[B] Estimated population of tagged study fish alive to MCN tailrace (included fish detected at the dam and those estimated to pass undetected). CJS estimation of S1 uses PIT tags detected on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON.
[C] Uses recaptures at Rocky Reach Dam. After 2009, both the new juvenile detector and recaptures at Rocky Reach Dam are used.
[D] Incomplete, 2-salt returns through Sept. 15, 2017.

Table B.90. Overall MCN-to-BOA SARs for Upper Columbia Wild Summer Chinook (Okanogan River or Columbia Mainstem above Wells Dam), 2011 to 2014. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving MCN[A]	MCN-to-BOA (without jacks)			MCN-to-BOA (with jacks)		
		%SAR Estimate	Non-parametric CI		%SAR Estimate	Non-parametric CI	
			90% LL	90% UL		90% LL	90% UL
2011	4,062	4.01	3.38	4.67	4.14	3.47	4.77
2012	5,913	1.03	0.79	1.30	1.17	0.91	1.46
2013	6,794	1.81	1.44	2.22	1.91	1.53	2.34
2014[B]	1,540	0.06	0.00	0.18	0.06	0.00	0.18
Geometric mean		0.82			0.86		

[A] Estimated population of tagged study fish alive to MCN tailrace (included fish detected at the dam and those estimated to pass undetected). CJS estimation of S1 uses PIT-tags detected on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON.
[B] Incomplete, 3-salt returns through Sept. 15, 2017.

Table B.91. Overall RRE-to-BOA SARs for Upper Columbia Wild Summer Chinook (Okanogan River or Columbia Mainstem above Wells Dam)[A], 2011 to 2014. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving RRE[B]	RRE-to-BOA (without jacks)			RRE-to-BOA (with jacks)		
		%SAR Estimate	Non-parametric CI		%SAR Estimate	Non-parametric CI	
			90% LL	90% UL		90% LL	90% UL
2011	5,978	2.73	2.34	3.14	2.81	2.43	3.21
2012	8,246	0.74	0.57	0.92	0.84	0.66	1.02
2013	8,280	1.49	1.25	1.72	1.57	1.33	1.80
2014[C]	3,147	0.03	0.00	0.09	0.03	0.00	0.09
Geometric mean		0.55			0.58		

[A] This is the same group as used for the MCN-to-BOA reach. SARs are calculated as number of adults at BOA divided by estimated number of smolts at Rocky Reach Dam.
[B] CJS estimation of S1 uses both the juvenile detector and recaptures at Rocky Reach Dam, as well as PIT-tags on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON.
[C] Incomplete, 3-salt returns through Sept. 15, 2017.

Upper Columbia hatchery Chinook

Table B.92. Overall MCN-to-BOA SARs for Leavenworth Hatchery spring Chinook, 2000 to 2015. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving MCN[A]	MCN-to-BOA without Jacks			MCN-to-BOA with Jacks		
		%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL	%SAR Estimate	Non-parametric CI 90% LL	Non-parametric CI 90% UL
2000	4,337	1.84	1.48	2.22	1.87	1.49	2.24
2001	3,823	0.24	0.11	0.37	0.24	0.11	0.37
2002	179,051	0.36	0.34	0.38	0.38	0.35	0.40
2003	153,755	0.42	0.40	0.45	0.45	0.42	0.48
2004	105,788	0.34	0.31	0.37	0.34	0.31	0.38
2005	7,888	0.09	0.04	0.15	0.11	0.06	0.18
2006	8,214	0.89	0.72	1.06	0.97	0.80	1.16
2007	8,820	0.46	0.34	0.58	0.53	0.40	0.67
2008	9,186	1.89	1.64	2.17	2.11	1.84	2.40
2009	6,964	0.59	0.44	0.75	0.65	0.48	0.81
2010	9,810	0.82	0.67	0.98	1.23	1.05	1.43
2011	6,563	0.35	0.24	0.48	0.38	0.26	0.52
2012	9,006	1.05	0.87	1.24	1.19	0.99	1.39
2013	9,267	0.69	0.55	0.85	0.77	0.62	0.94
2014	8,691	0.60	0.46	0.73	0.76	0.60	0.92
2015[B]	7,932	0.35	0.27	0.43	0.44	0.35	0.53
Geometric mean		0.53			0.60		

[A] Estimated population of tagged study fish alive to MCN tailrace (included fish detected at the dam and those estimated to pass undetected). CJS estimation of S1 uses PIT-tags detected on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON.

[B] Incomplete, 2-salt returns through Sept. 15, 2017.

Table B.93. Overall MCN-to-BOA SARs for Winthrop Hatchery spring Chinook, 2009 to 2015. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving MCN[A]	MCN-to-BOA without Jacks			MCN-to-BOA with Jacks		
		%SAR Estimate	Non-parametric CI		%SAR Estimate	Non-parametric CI	
			90% LL	90% UL		90% LL	90% UL
2009	761	0.66	0.24	1.25	0.79	0.29	1.43
2010	3,354	0.51	0.30	0.74	1.37	1.01	1.79
2011	2,214	0.72	0.42	1.04	0.90	0.57	1.30
2012	4,259	1.06	0.79	1.34	1.22	0.94	1.53
2013	8,934	1.19	0.98	1.40	1.77	1.50	2.05
2014	2,968	0.57	0.34	0.85	0.81	0.52	1.14
2015[B]	5,096	0.63	0.44	0.84	0.77	0.54	0.98
Geometric mean		0.73			1.04		

[A] Estimated population of tagged study fish alive to MCN tailrace (included fish detected at the dam and those estimated to pass undetected). CJS estimation of S1 uses PIT-tags detected on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON.
[B] Incomplete, 2-salt returns through Sept. 15, 2017.

Table B.94. Overall RRE-to-BOA SARs for Winthrop Hatchery spring Chinook[A], 2009 to 2015. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving RRE[B]	RRE-to-BOA without Jacks			RRE-to-BOA with Jacks		
		%SAR Estimate	Non-parametric CI		%SAR Estimate	Non-parametric CI	
			90% LL	90% UL		90% LL	90% UL
2009	1,166	0.43	0.10	0.88	0.51	0.15	1.03
2010	4,266	0.40	0.25	0.57	1.08	0.83	1.36
2011	3,147	0.51	0.32	0.73	0.64	0.43	0.89
2012	5,734	0.78	0.58	0.98	0.91	0.69	1.12
2013	11,266	0.94	0.80	1.10	1.40	1.22	1.59
2014	3,715	0.46	0.29	0.67	0.65	0.44	0.89
2015[B]	7,484	0.43	0.30	0.55	0.52	0.38	0.65
Geometric mean		0.54			0.76		

[A] This is the same group as used for the MCN-to-BOA reach. SARs are calculated as number of adults at BOA divided by estimated number of smolts at Rocky Reach Dam.
[B] CJS estimation of S1 uses both the juvenile detector and recaptures at Rocky Reach Dam, as well as PIT-tags on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON.
[C] Incomplete, 2-salt returns through Sept. 15, 2017.

Table B.95. Overall MCN-to-BOA SARs for Entiat Hatchery summer Chinook, 2011 to 2015. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving MCN[A]	MCN-to-BOA without Jacks			MCN-to-BOA with Jacks		
		%SAR Estimate	Non-parametric CI		%SAR Estimate	Non-parametric CI	
			90% LL	90% UL		90% LL	90% UL
2011	5,847	0.99	0.76	1.25	1.21	0.94	1.50
2012	6,758	2.16	1.79	2.54	2.23	1.83	2.63
2013	6,117	3.76	3.24	4.34	4.01	3.46	4.61
2014	5,140	1.73	1.39	2.10	1.98	1.60	2.38
2015[C]	5,089	0.04	0.00	0.09	0.04	0.00	0.09
Geometric mean		0.89			0.97		

[A] Estimated population of tagged study fish alive to MCN tailrace (included fish detected at the dam and those estimated to pass undetected). CJS estimation of S1 uses PIT-tags detected on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON.
[B] Incomplete, 2-salt returns through Sept. 15, 2017.

Table B.96. Overall RRE-to-BOA SARs for Entiat Hatchery summer Chinook[A], 2011 to 2015. SARs are calculated with and without jacks.

Juvenile migration year	Smolts arriving RRE[B]	RRE-to-BOA without Jacks			RRE-to-BOA with Jacks		
		%SAR Estimate	Non-parametric CI		%SAR Estimate	Non-parametric CI	
			90% LL	90% UL		90% LL	90% UL
2011	8,954	0.65	0.57	0.81	0.79	0.64	0.97
2012	8,829	1.65	1.42	1.90	1.71	1.47	1.96
2013	8,271	2.78	2.46	3.11	2.96	2.63	3.32
2014	8,614	1.03	0.86	1.23	1.18	1.00	1.39
2015[C]	8,452	0.02	0.00	0.06	0.02	0.00	0.06
Geometric mean		0.57			0.62		

[A] This is the same group as used for the MCN-to-BOA reach. SARs are calculated as number of adults at BOA divided by estimated number of smolts at Rocky Reach Dam.
[B] CJS estimation of S1 uses both the juvenile detector and recaptures at Rocky Reach Dam, as well as PIT-tags on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON.
[C] Incomplete, 2-salt returns through Sept. 15, 2017.

Upper Columbia wild Steelhead

Table B.97. Overall MCN-to-BOA SARs for Upper Columbia Wild Steelhead (Wenatchee, Entiat, and Methow Rivers), 2006 to 2014.

Juvenile migration year	Smolts arriving MCN[A]	MCN-to-BOA %SAR Estimate	MCN-to-BOA Non-parametric CI 90% LL	MCN-to-BOA Non-parametric CI 90% UL
2006[B]	472	1.91	0.86	3.09
2007	891	4.49	3.19	5.81
2008	2,268	6.66	5.55	7.82
2009	1,636	4.40	3.45	5.39
2010	1,481	3.51	2.61	4.50
2011	993	1.31	0.70	2.01
2012	740	6.08	4.13	8.15
2013	928	4.74	3.18	6.61
2014	1,182	3.47	2.47	4.56
Geometric mean		3.65		

[A] Estimated population of tagged study fish alive to MCN tailrace (included fish detected at the dam and those estimated to pass undetected). CJS estimation of S1 uses PIT-tags detected on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON.
[B] 2006 is Entiat River only, all other years are Entiat, Methow, and Wenatchee combined.

Table B.98. Overall RRE-to-BOA SARs for Upper Columbia Wild Steelhead (Entiat and Methow Rivers)[A], 2008–2014.

Juvenile migration year	Smolts arriving RRE[B]	RRE-to-BOA %SAR Estimate	RRE-to-BOA Non-parametric CI 90% LL	RRE-to-BOA Non-parametric CI 90% UL
2008[C]	2,664	4.77	3.31	6.47
2009[C]	2,695	2.30	1.57	3.17
2010	2,143	1.91	1.44	2.44
2011	1,382	0.87	0.45	1.29
2012	986	3.65	2.62	4.85
2013	1,177	3.31	2.31	4.36
2014	1,755	1.88	1.34	2.52
Geometric mean		2.37		

[A] The Entiat/Methow wild steelhead aggregate is a subgroup of that used for the MCN-to-BOA reach (excludes Wenatchee). SARs are calculated as number of adults at BOA divided by estimated number of smolts at Rocky Reach Dam.
[B] CJS estimation of S1 uses PIT-tags detected on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON.
[C] Uses recaptures at Rocky Reach Dam. After 2009, both the new juvenile detector and recaptures at Rocky Reach Dam are used.

Upper Columbia hatchery Steelhead

Table B.99. Overall MCN-to-BOA SARs for Upper Columbia Hatchery Steelhead released into the Wenatchee River Basin (Eastbank and Chelan Hatcheries), 2003–2014.

Juvenile migration year	Smolts arriving MCN[A]	MCN-to-BOA %SAR Estimate	MCN-to-BOA Non-parametric CI 90% LL	MCN-to-BOA Non-parametric CI 90% UL
2003	13,366	2.35	2.12	2.58
2004	9,183	1.46	1.22	1.69
2005	14,720	0.90	0.77	1.03
2006	4,058	2.29	1.90	2.70
2007	3,514	2.05	1.61	2.56
2008	4,673	5.78	5.11	6.52
2009	4,589	2.66	2.23	3.12
2010	4,383	3.63	3.02	4.31
2011	5,520	1.59	1.27	1.94
2012	8,463	1.97	1.68	2.26
2013	8,520	2.23	1.93	2.55
2014	3,809	1.86	1.45	2.30
Geometric mean		2.16		

[A] Estimated population of tagged study fish alive to MCN tailrace (included fish detected at the dam and those estimated to pass undetected). CJS estimation of S1 uses PIT-tags detected on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON.

Upper Columbia wild Sockeye

Table B.100. Overall MCN-to-BOA SARs for Wenatchee River Wild Sockeye, 2014–2015.

Juvenile migration year	Smolts arriving MCN[A]	MCN-to-BOA %SAR Estimate	MCN-to-BOA Non-parametric CI 90% LL	MCN-to-BOA Non-parametric CI 90% UL
2014	1,851	2.73	2.07	3.54
2015[B]	1,821	1.32	0.86	1.84
Geometric mean		1.90		

[A] Estimated population of tagged study fish alive to MCN tailrace (included fish detected at the dam and those estimated to pass undetected). CJS estimation of S1 uses PIT-tags detected on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON.
[B] Incomplete, 2-salt returns through Sept. 15, 2017.

Table B.101. Overall MCN-to-BOA and RRE-to-BOA SARs for Okanogan River Wild Sockeye, 2013–2015.

Juvenile migration year	Smolts arriving MCN[A]	MCN-to-BOA %SAR Estimate	MCN-to-BOA Non-parametric CI 90% LL	MCN-to-BOA Non-parametric CI 90% UL	Smolts arriving RRE[B]	RRE-to-BOA %SAR Estimate	RRE-to-BOA Non-parametric CI 90% LL	RRE-to-BOA Non-parametric CI 90% UL
2013[C D]	--	--	--	--	1,993	8.13	6.96	9.45
2014[C]	2,110	2.99	2.25	3.71	2,937	2.15	1.70	2.66
2015[E]	2,524	1.51	0.99	2.09	3,060	1.24	0.94	1.59
Geometric mean		2.12				2.79		

[A] Estimated population of tagged study fish alive to MCN tailrace (included fish detected at the dam and those estimated to pass undetected). CJS estimation of S1 uses PIT-tags detected on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON.
[B] CJS estimation of S1 uses both the detector and recaptures at Rocky Reach Dam, as well as PIT-tags detected on bird colonies in the Columbia River estuary and adult detections to augment the NOAA Trawl detections below BON.
[C] PIT-tagged sockeye were coded as "unknown" rearing type. Some PIT-tagged smolts may have been hatchery sockeye released into Skaha Lake as fry.
[D] Juvenile survival estimate for RRE-MCN reach was greater than 100%, resulting in an overestimate of the juvenile population at MCN. Therefore, $SAR_{MCN\text{-}to\text{-}BOA}$ was not estimated for this year.
[E] Incomplete, 2-salt returns through Sept. 15, 2017.

Upper Columbia wild and hatchery Chinook, Steelhead, and Sockeye Tagged at Rock Island Dam

Table B.102. Overall RIS-to-BOA SARs for Upper Columbia Wild and Hatchery Yearling Chinook tagged at Rock Island Dam, 2000 to 2015. SARs are calculated with and without jacks.

Juvenile migration year	Smolts tagged at RIS[A]	RIS-to-BOA (without jacks)			RIS-to-BOA (with jacks)		
		%SAR Estimate	Exact Binomial CI		%SAR Estimate	Exact Binomial CI	
			90% LL	90% UL		90% LL	90% UL
2000	3,989	0.90	0.67	1.19	0.90	0.67	1.19
2001	1,837	0.00	0.00	0.16	0.00	0.00	0.16
2002	3,987	0.05	0.01	0.16	0.08	0.02	0.19
2003[B]	--	--	--	--	--	--	--
2004	910	0.11	0.01	0.52	0.11	0.01	0.52
2005	723	0.00	0.00	0.41	0.00	0.00	0.41
2006	1,127	0.18	0.03	0.56	0.18	0.03	0.56
2007	859	0.00	0.00	0.35	0.00	0.00	0.35
2008	843	0.47	0.16	1.08	0.95	0.47	1.71
2009	688	0.73	0.29	1.52	0.73	0.29	1.52
2010	799	0.50	0.17	1.14	0.50	0.17	1.14
2011	1,338	0.15	0.03	0.47	0.30	0.10	0.68
2012	1,702	0.24	0.08	0.54	0.47	0.23	0.85
2013	5,220	1.15	0.92	1.40	1.32	1.07	1.59
2014	4,834	0.64	0.46	0.83	0.86	0.64	1.03
2015[C]	5,188	0.37	0.25	0.52	0.39	0.25	0.54
Geometric mean		--			--		
Arithmetic mean		0.37			0.45		

[A] Tagged as part of Smolt Monitoring Program. SARs are calculated as number of adults at BOA divided by number of smolts marked and released at Rock Island Dam. Confidence intervals are Clopper-Pearson binomial confidence intervals (Clopper and Pearson 1934).
[B] No data in 2003 due to bypass inoperable during spring outmigration
[C] Incomplete, 2-salt returns through Sept. 15, 2017.

Table B.103. Overall RIS-to-BOA SARs for Upper Columbia Wild and Hatchery subyearling Chinook tagged at Rock Island Dam, 2000 to 2014. SARs are calculated with and without jacks.

Juvenile migration year	Smolts tagged at RIS[A]	RIS-to-BOA (without jacks)			RIS-to-BOA (with jacks)		
		%SAR Estimate	Exact Binomial CI		%SAR Estimate	Exact Binomial CI	
			90% LL	90% UL		90% LL	90% UL
2000	4,073	1.94	1.60	2.33	2.01	1.66	2.41
2001	4,484	0.00	0.00	0.07	0.00	0.00	0.07
2002	4,800	1.00	0.78	1.27	1.06	0.83	1.34
2003	4,338	0.28	0.16	0.45	0.28	0.16	0.45
2004	3,183	0.03	0.00	0.15	0.03	0.00	0.15
2005	3,547	0.54	0.35	0.79	0.59	0.40	0.85
2006	4,208	0.57	0.39	0.80	0.62	0.43	0.86
2007	3,596	0.31	0.17	0.51	0.36	0.21	0.57
2008	3,678	1.06	0.80	1.38	1.09	0.82	1.41
2009	1,889	0.58	0.33	0.96	0.58	0.33	0.96
2010	3,625	0.85	0.62	1.15	0.88	0.64	1.18
2011	4,387	2.10	1.75	2.49	2.14	1.80	2.54
2012	3,656	1.12	0.85	1.45	1.18	0.90	1.51
2013	4,021	1.44	1.17	1.79	1.64	1.34	1.99
2014[B]	4,690	0.19	0.11	0.30	0.21	0.11	0.34
Geometric mean		--			--		
Arithmetic mean		0.80			0.85		

[A] Tagged as part of Smolt Monitoring Program. SARs are calculated as number of adults at BOA divided by number of smolts marked and released at Rock Island Dam. Confidence intervals are Clopper-Pearson binomial confidence intervals (Clopper and Pearson 1934).

[B] Incomplete, 3-salt returns through Sept. 15, 2017.

Table B.104. Overall RIS-to-BOA SARs for Upper Columbia Wild and Hatchery Steelhead tagged at Rock Island Dam, 2000 to 2014.

Juvenile migration year	Smolts tagged at RIS[A]	RIS-to-BOA		
		%SAR Estimate	Exact Binomial CI	
			90% LL	90% UL
2000	3,946	1.42	1.12	1.77
2001	4,027	0.07	0.02	0.19
2002	3,996	1.88	1.54	2.27
2003[B]	--	--	--	--
2004	2,627	0.30	0.15	0.55
2005	2,850	0.77	0.52	1.10
2006	3,181	0.88	0.63	1.20
2007	3,551	0.90	0.66	1.21
2008	6,052	3.21	2.84	3.60
2009	5,304	1.09	0.87	1.36
2010	6,630	1.22	1.01	1.47
2011	7,226	0.58	0.44	0.75
2012	5,943	0.99	0.79	1.23
2013	5,255	1.07	0.84	1.33
2014	6,276	0.92	0.73	1.13
Geometric mean		0.84		
Arithmetic mean		1.09		

[A] Tagged as part of Smolt Monitoring Program. SARs are calculated as number of adults at BOA divided by number of smolts marked and released at Rock Island Dam. Confidence intervals are Clopper-Pearson binomial confidence intervals (Clopper and Pearson 1934).

[B] No data in 2003 due to bypass inoperable during spring outmigration.

Table B.105. Overall RIS-to-BOA SARs for Upper Columbia Wild and Hatchery Sockeye tagged at Rock Island Dam, 2000 to 2015.

Juvenile migration year	Smolts tagged at RIS[A]	RIS-to-BOA		
		%SAR Estimate	Exact Binomial CI	
			90% LL	90% UL
2000	656	1.98	1.18	3.13
2001	491	0.00	0.00	0.61
2002	2,091	0.29	0.13	0.57
2003[B]	--	--	--	--
2004	1,083	0.74	0.37	1.33
2005	888	0.00	0.00	0.34
2006	3,600	1.08	0.82	1.41
2007	2,097	0.86	0.56	1.27
2008	1,910	7.80	6.81	8.89
2009	2,059	5.88	5.05	6.80
2010	3,527	2.86	2.42	3.37
2011	2,977	1.98	1.58	2.46
2012	3,231	4.18	3.61	4.80
2013	2,674	6.21	5.46	6.96
2014	3,059	0.98	0.72	1.31
2015[C]	1,689	0.65	0.36	1.01
Geometric mean		---		
Arithmetic mean		2.37		

[A] Tagged as part of Smolt Monitoring Program. SARs are calculated as number of adults at BOA divided by number of smolts marked and released at Rock Island Dam. Confidence intervals are Clopper-Pearson binomial confidence intervals (Clopper and Pearson 1934).
[B] No data in 2003 due to bypass inoperable during spring outmigration.
[C] Incomplete, 2-salt returns through Sept. 15, 2017.

First Year Estuary and Ocean Survival Rates

Table B.106. Estimation of first year estuary and ocean survival rates, So1, for Snake River wild spring/summer Chinook 1994–2014 based on CSS parameter estimates for SAR, in-river survival, proportion transported and *D*.

Migration year	In-river survival (S_R)	Proportion transported (pT)	D	System survival	CSS SAR (LGR-LGR)	SAR (LGR - Col. R. mouth)	S.oa (LGR)	S.oa (Col. R.)	S.o1
1994	0.20	0.86	0.36	0.33	0.45%	0.61%	0.014	0.018	0.025
1995	0.41	0.81	0.42	0.41	0.36%	0.47%	0.009	0.012	0.016
1996	0.44	0.71	0.92	0.77	0.42%	0.61%	0.005	0.008	0.011
1997	0.51	0.57	0.40	0.44	1.82%	2.72%	0.041	0.061	0.078
1998	0.61	0.82	0.55	0.55	1.32%	1.78%	0.024	0.032	0.042
1999	0.59	0.86	0.72	0.69	2.48%	2.93%	0.036	0.042	0.055
2000	0.48	0.71	0.32	0.36	1.74%	2.10%	0.048	0.058	0.082
2001	0.23	0.99	2.16	2.10	1.33%	1.62%	0.006	0.008	0.010
2002	0.61	0.71	0.44	0.48	1.02%	1.24%	0.021	0.026	0.033
2003	0.60	0.69	0.68	0.65	0.35%	0.42%	0.005	0.007	0.009
2004	0.40	0.93	0.45	0.44	0.53%	0.63%	0.012	0.014	0.019
2005	0.48	0.93	1.07	1.01	0.23%	0.29%	0.002	0.003	0.004
2006	0.57	0.66	0.47	0.50	0.75%	0.92%	0.015	0.019	0.024
2007	0.60	0.21	0.80	0.64	1.09%	1.30%	0.017	0.020	0.026
2008	0.66	0.46	0.82	0.73	3.24%	4.26%	0.045	0.059	0.076
2009	0.56	0.42	0.65	0.59	1.61%	2.16%	0.027	0.036	0.048
2010	0.56	0.40	0.72	0.62	0.93%	1.20%	0.015	0.019	0.024
2011	0.60	0.35	0.42	0.53	0.36%	0.47%	0.007	0.009	0.011
2012	0.57	0.21	0.44	0.54	1.43%	1.90%	0.026	0.035	0.043
2013	0.55	0.35	0.79	0.63	1.37%	1.77%	0.022	0.028	0.037
2014	0.44	0.34	0.94	0.60	0.57%	0.71%	0.009	0.012	0.015
geometric mean	0.489	0.562	0.620	0.593	0.88%	1.12%	0.015	0.019	0.025

Table B.107. Estimation of first year estuary and ocean survival rates, So1, for Snake River wild steelhead 1997–2014 based on CSS parameter estimates for SAR, in-river survival, proportion transported and *D*.

Migration year	In-river survival (S_R)	Proportion transported (pT)	D	System survival	CSS SAR (LGR-LGR)	SAR (LGR - Col. R. mouth)	S.oa (LGR)	S.oa (Col. R.)	S.o1
1997	0.52	0.72	1.18	0.98	1.16%	1.70%	0.013	0.017	0.020
1998	0.54	0.89	0.11	0.15	0.30%	0.43%	0.021	0.028	0.030
1999	0.45	0.87	1.07	0.97	2.84%	3.92%	0.031	0.040	0.047
2000	0.30	0.85	0.50	0.46	2.66%	3.56%	0.061	0.077	0.087
2001	0.04	0.99	1.46	1.42	2.47%	3.28%	0.018	0.023	0.028
2002	0.52	0.68	2.24	1.65	2.14%	2.90%	0.014	0.018	0.020
2003	0.37	0.72	1.75	1.34	1.57%	2.18%	0.013	0.016	0.019
2004	0.18	0.97	2.69	2.57	0.85%	1.19%	0.004	0.005	0.005
2005	0.27	0.93	1.30	1.20	0.78%	1.08%	0.007	0.009	0.011
2006	0.58	0.65	0.52	0.53	1.14%	1.98%	0.021	0.037	0.042
2007	0.38	0.40	1.20	0.70	2.57%	3.43%	0.037	0.049	0.055
2008	0.49	0.41	0.60	0.53	3.21%	4.48%	0.061	0.085	0.097
2009	0.70	0.45	0.94	0.80	2.44%	3.67%	0.031	0.046	0.054
2010	0.60	0.35	0.93	0.71	1.70%	2.44%	0.024	0.034	0.039
2011	0.76	0.48	0.93	0.83	1.26%	1.92%	0.015	0.023	0.026
2012	0.58	0.23	0.53	0.57	2.54%	3.55%	0.045	0.062	0.071
2013	0.59	0.47	1.35	0.93	1.99%	2.81%	0.021	0.030	0.035
2014	0.58	0.47	1.33	0.92	1.32%	2.15%	0.014	0.023	0.026
geometric mean	0.406	0.593	0.951	0.822	1.60%	2.29%	0.020	0.028	0.032

APPENDIX C

SOURCE OF PIT-TAGGED FISH

APPENDIX C

SOURCE OF PIT-TAGGED FISH

Snake River Wild Spring/Summer Chinook

Table C.1. Number of PIT-tagged wild Snake River spring/summer Chinook parr/smolts from tributaries above Lower Granite Dam (plus Snake River trap) used in the CSS analyses for migration years 1994 to 2015.

Migr Year	Total PIT tags	Clearwater River (Rkm 224)	Snake River Trap[A] (Rkm 225)	Grande Ronde River (Rkm 271)	Salmon River (Rkm 303)	Imnaha River (Rkm 308)
1994	49,660	8,292	1,423	8,829	27,725	3,391
1995	74,642	17,606	1,948	12,330	40,610	2,148
1996	21,524	2,246	913	7,079	7,017	4,269
1997	9,781	671	None	3,870	3,543	1,697
1998	33,836	4,681	921	8,644	11,179	8,411
1999	81,493	13,695	3,051	11,240	43,323	10,184
2000	67,841	9,921	1,526	7,706	39,609	9,079
2001	47,775	3,745	29	6,354	23,107	14,540
2002	67,286	14,060	1,077	9,715	36,051	6,428
2003	102,978	15,108	383	14,065	60,251	13,171
2004	99,710	17,204	541	12,103	56,131	13,731
2005	111,152	23,897	318	9,243	67,829	9,865
2006	52,978	8,663	2,639	10,457	30,094	1,125
2007	52,496	3,041	373	9,267	28,561	11,254
2008	55,839	5,049	1,576	8,316	30,058	10,840
2009	55,565	5,305	3,807	7,848	29,824	8,781
2010	87,304	17,299	849	11,724	40,367	17,065
2011	77,438	6,384	4,965	9,776	47,662	8,651
2012	82,382	7,360	3,943	12,282	49,174	9,623
2013	78,929	6,312	285	11,221	50,240	10,871
2014	75,248	4,633	1,963	10,690	47,377	10,585
2015	58,513	6,380	102	7,832	34,134	10,065
2016[B]	68,004	5,004	1,541	11,172	45,984	4,303
Average percent of total		**12.8%**	**2.4%**	**16.7%**	**53.9%**	**14.2%**

[A] Snake River trap at Lewiston, ID, collects fish originating in Salmon, Imnaha, and Grande Ronde rivers.
[B] PIT-tag numbers for wild spring/summer Chinook may change as group is finalized for estimation of SARs in future report.

Snake River Hatchery Spring/Summer Chinook

Table C.2. Rapid River Hatchery spring Chinook PIT-tagged and released in Salmon River basin specifically for CSS, 1997 to 2016.

Migration Year	Hatchery Release	Fish# / lb	Median Length at Tagging (mm)	PIT Tags Released	PIT-Tag Proportion
1997	85,838	20.5	100[A]	40,451	0.4712
1998	896,170	20.3	117	48,336	0.0539
1999	2,847,283	17.9	120	47,812	0.0168
2000	2,462,354	19.2	119	47,747	0.0194
2001	736,601	18.8	118	55,085	0.0748
2002	2,669,476	19.8	122	54,908	0.0206
2003	2,330,557	18.8	119	54,763	0.0235
2004	2,762,058	24.5	(none taken)	51,969	0.0188
2005	2,761,430	19.1	124	51,975	0.0188
2006	2,530,528	19.3	129	51,874	0.0205
2007	2,498,246	20.0	117	51,759	0.0207
2008	2,493,719	16.7	125	51,689	0.0207
2009	2,503,711	20.0	(none taken)	51,725	0.0207
2010	2,492,454	17.9	(none taken)	51,909	0.0208
2011	2,483,181	18.4	(none taken)	51,730	0.0208
2012	2,498,197	16.4	(none taken)	51,938	0.0208
2013	2,497,668	15.8	(none taken)	51,898	0.0208
2014	2,498,847	19.4	(none taken)	51,670	0.0207
2015	2,498,974	15.6	(none taken)	51,931	0.0208
2016	2,505,250	14.6	(none taken)	51,900	0.0207

[A] Tagged in fall 5 months before release; otherwise tagged in winter/spring 1–3 months before release.

Table C.3. Dworshak Hatchery spring Chinook PIT-tagged and released in Clearwater River basin specifically for CSS, 1997 to 2016.

Migration Year	Hatchery Release	Fish# / lb	Median Length at Tagging[A] (mm)	PIT Tags Released	PIT-Tag Proportion
1997	53,078	12.7	118	14,080	0.2653
1998	973,400	20.9	121	47,703	0.0490
1999	1,044,511	21.0	116	47,845	0.0458
2000	1,017,873	24.0	112	47,743	0.0469
2001	333,120	19.7	121	55,139	0.1655
2002	1,000,561	20.1	119	54,725	0.0547
2003	1,033,982	21.4	120	54,708	0.0529
2004	1,078,923	20.2	113	51,616	0.0478
2005	1,072,359	19.2	112	51,819	0.0483
2006	1,007,738	20.0	108	51,900	0.0515
2007	963,211	17.7	114	51,649	0.0536
2008	939,000	23.5	105	49,384	0.0526
2009	1,014,748	21.2	113	50,829	0.0501
2010	1,109,195	16.8	125	51,415	0.0464
2011	1,078,250	21.1	115	51,753	0.0480
2012	1,044,080	19.9	113	51,885	0.0497
2013	1,377,508	22.6	110	51,800	0.0376
2014	2,040,460	25.0	103	51,761	0.0254
2015	1,549,263	21.6	111	41,774	0.0270
2016	1,454,208	22.1	104	40,878	0.0281

[A] Tagged in winter/spring 1–3 months before release.

Table C.4. McCall Hatchery summer Chinook PIT-tagged and released in Salmon River basin specifically for CSS, 1997 to 2016.

Migration Year	Hatchery Release	Fish# / lb	Median Length at Tagging[A] (mm)	PIT Tags Released	PIT-Tag Proportion
1997	238,647	17.1	128	52,652	0.2206
1998	393,872	17.5	126	47,340	0.1202
1999	1,143,083	23.9	117	47,985	0.0420
2000	1,039,930	23.3	117	47,705	0.0459
2001	1,076,846	19.4	129	55,124	0.0512
2002	1,022,550	23.0	122	54,734	0.0535
2003	1,053,660	21.1	121	74,317	0.0705
2004	1,088,810	20.9	(none taken)	71,363	0.0655
2005	1,047,530	20.9	121	71,725	0.0685
2006	1,096,130	18.1	126	51,894	0.0473
2007	1,087,170	19.1	122	51,726	0.0476
2008	1,060,540	19.5	129	51,678	0.0487
2009	1,106,700	21.3	(none taken)	51,495	0.0465
2010	1,037,600	20.9	(none taken)	51,786	0.0499
2011	1,069,028	18.5	(none taken)	51,878	0.0485
2012	1,121,809	19.0	(none taken)	51,917	0.0463
2013	1,074,850	17.1	(none taken)	51,901	0.0483
2014	1,047,886	18.6	(none taken)	51,896	0.0495
2015	1,122,286	17.6	(none taken)	51,906	0.0463
2016	1,028,382	18.2	(none taken)	51,888	0.0505

[A] Tagged in winter/spring 1–3 months before release.

Table C.5. Imnaha Hatchery summer Chinook PIT-tagged and released in Imnaha River basin specifically for CSS, 1997 to 2016.

Migration Year	Hatchery Release	Fish# / lb	Median Length at Tagging (mm)	PIT Tags Released	PIT-Tag Proportion
1997	50,911	17.0	122[A]	13,378	0.2628
1998	93,108	21.1	122[A]	19,825	0.2129
1999	184,725	18.5	117	19,939	0.1079
2000	179,797	19.1	113	20,819	0.1158
2001	123,014	16.0	121	20,922	0.1701
2002	303,737	14.1	121	20,920	0.0689
2003	268,426	16.3	123	20,904	0.0779
2004	398,469	26.1	98	20,910	0.0525
2005	435,186	24.5	105	20,917	0.0481
2006	320,752	27.1	105	20,623	0.0643
2007	432,530	21.6	107	20,885	0.0483
2008	348,910	20.3	116	20,760	0.0595
2009	293,802	20.0	110	20,863	0.0888
2010	390,064	20.0	112	20,603	0.0528
2011	252,588	19.1	104	20,757	0.0822
2012	469,810	22.2	112	20,819	0.0443
2013	390,604	20.0	110	20,896	0.0535
2014	346,702	22.1	108	20,779	0.0599
2015	331,703	21.8	104	20,871	0.0629
2016	516,802	24.6	101	20,718	0.0401

[A] Tagged in winter/spring 1–3 months before release; otherwise tagged in fall 5–7 months before release.

Table C.6. Catherine Creek Hatchery spring Chinook PIT-tagged and released in Grande Ronde River basin specifically for CSS, 2001 to 2016.

Migration Year	Hatchery Release	Fish# / lb	Median Length at Tagging[A] (mm)	PIT Tags Released	PIT-Tag Proportion
2001	136,833	19.7	117	20,915	0.1529
2002	180,343	18.6	115	20,796	0.1153
2003	105,292	12.8	123	20,628	0.1959
2004	162,614	23.2	109	20,994	0.1291
2005	189,580	25.1	106	20,839	0.1099
2006	68,820	22.7	102	20,958	0.3045
2007	71,268	26.9	102	20,817	0.2921
2008	116,882	17.9	112	20,717	0.1772
2009	138,843	22.7	107	20,840	0.1501
2010	144,353	19.7	102	20,310	0.1407
2011	155,475	24.9	99	20,838	0.1340
2012	161,374	19.4	113	20,641	0.1279
2013	134,519	22.3	106	20,816	0.1547
2014	138,370	22.8	110	20,772	0.1501
2015	146,310	23.2	102	20,854	0.1425
2016	165,739	22.7	97	20,816	0.1256

[A] Tagged in fall 5–7 months before release.

Table C.7. Clearwater Hatchery spring Chinook PIT-tagged and released in Clearwater River basin in participation with the CSS, 2006 to 2016.

Migration Year	Hatchery Release	Fish# / lb	Median Length at Tagging (mm)[A]	PIT Tags Released	PIT-Tag Proportion
2006	1,596,697	16.5	126	44,914	0.0281
2007	1,670,006	15.6	133	44,900	0.0269
2008	1,666,315	16.8	(none taken)	37,595	0.0226
2009	2,145,480	16.8	(none taken)	68,649	0.0320
2010	2,251,033	15.3	(none taken)	72,707	0.0323
2011	2,234,031	16.2	(none taken)	68,327	0.0306
2012	2,180,789	16.6	(none taken)	65,393	0.0300
2013	2,203,720	19.0	(none taken)	68,048	0.0309
2014	2,401,813	18.2	(none taken)	68,290	0.0284
2015	2,153,215	15.6	(none taken)	43,916	0.0204

[A] Tagged in winter 3 weeks to 2 months before release.

Table C.8. Clearwater Hatchery summer Chinook PIT-tagged and released in Clearwater River basin in participation with the CSS, 2011 to 2016.

Migration Year	Hatchery Release	Fish# / lb	Median Length at Tagging (mm)[A]	PIT Tags Released	PIT-Tag Proportion
2011	204,061	15.4	(none taken)	25,488	0.1249
2012	206,317	17.8	(none taken)	25,482	0.1235
2013	208,447	20.0	(none taken)	25,450	0.1221
2014	492,243	16.0	(none taken)	25,469	0.0517
2015	528,410	15.6	(none taken)	25,477	0.0482
2016	244,485	15.9	(none taken)	25,468	0.1042

[A] Tagged in winter 3 weeks to 2 months before release.

Table C.9. Sawtooth Hatchery spring Chinook PIT-tagged and released in Salmon River basin in participation with the CSS, 2007 to 2016.

Migration Year	Hatchery Release	Fish# / lb	Median Length at Tagging[A] (mm)	PIT Tags Released	PIT-Tag Proportion
2007	995,262	17.2	111	14,934	0.0150
2008	174,132	19.1	(none taken)	14,925	0.0857
2009	274,644	14.0	(none taken)	18,671	0.0680
2010	1,455,933	22.0	(none taken)	21,283	0.0146
2011	1,735,179	23.7	(none taken)	21,333	0.0123
2012	1,456,221	27.6	(none taken)	19,041	0.0131
2013	786,864	23.3	(none taken)	21,282	0.0270
2014	1,739,906	18.0	(none taken)	18,969	0.0109
2015	1,729,449	18.2	(none taken)	21,357	0.0123
2016	1,802,907	19.5	(none taken(	21,339	0.0118

[A] Tagged in winter 1–2 months before release.

Table C.10. Pahsimeroi Hatchery summer Chinook PIT-tagged and released in Salmon River basin in participation with the CSS, 2008 to 2016.

Migration Year	Hatchery Release	Fish# / lb	Median Length at Tagging[A] (mm)	PIT Tags Released	PIT-Tag Proportion
2008	1,037,772	14.9	(none taken)	14,814	0.0143
2009	870,842	11.3	(none taken)	18,750	0.0215
2010	1,169,701	22.0	(none taken)	21,375	0.0183
2011	1,030,028	14.0	(none taken)	21,131	0.0205
2012	1,027,580	14.4	(none taken)	21,374	0.0208
2013	1,005,873	14.0	(none taken)	21,390	0.0213
2014	969,829	12.8	(none taken)	21,367	0.0220
2015	828,209	11.2	(none taken)	21,369	0.0258
2016	1,106,867	13.7	(none taken)	21,331	0.0193

[A] Tagged in winter 1–2 months before release.

Table C.11. Kooskia Hatchery spring Chinook PIT-tagged and released in Clearwater River basin in participation with the CSS, 2014 to 2016.

Migration Year	Hatchery Release	Fish# / lb	Median Length at Tagging[A] (mm)	PIT Tags Released	PIT-Tag Proportion
2014	628,007	32.0	100	12,252	0.0195
2015	661,441	24.4	(none taken)	7,967	0.0120
2016	660,034	25.1	(none taken)	7,941	0.0120

[A] Tagged in winter 1–2 months before release.

Snake River Wild Steelhead

Table C.12. Number of PIT-tagged wild steelhead smolts from tributaries above Lower Granite Dam (plus Snake River trap) used in the CSS analyses for migration years 1997 to 2015.

Migr Year	Total PIT Tags	Clearwater River (Rkm 224)	Snake River Trap[A,B] (Rkm 225)	Asotin Creek Trap (Rkm 234)	Grande Ronde River (Rkm 271)	Salmon River (Rkm 303)	Imnaha River (Rkm 308)
1997	7,703	5,518	68	0	248	1,158	711
1998	10,512	4,131	1,032	0	887	1,683	2,779
1999	15,763	5,095	886	0	1,628	5,569	2,585
2000	24,254	8,688	1,211	0	3,618	6,245	4,492
2001	24,487	8,845	867	0	3,370	7,844	3,561
2002	25,183	10,206	2,368	0	3,353	6,136	3,120
2003	24,005	5,764	1,197	0	4,257	6,818	5,969
2004	25,154	7,642	1,922	0	2,977	7,100	5,513
2005	25,000	8,391	1,349	1,400	3,771	5,652	4,437
2006	16,579	8,301	4	0	1,950	4,090	2,234
2007	17,857	5,001	1	0	2,170	4,112	6,573
2008	16,228	7,249	11	0	1,048	5,648	2,272
2009	16,625	4,066	4	0	1,494	5,951	5,110
2010	18,529	6,259	0	0	1,826	5,617	4,827
2011	12,706	3,753	14	0	2,434	4,205	2,300
2012	18,809	6,985	427	0	2,224	4,498	4,675
2013	19,499	6,606	1,002	0	2,303	3,437	6,151
2014	22,921	4,840	1,155	3,229	2,376	4,276	7,045
2015[C]	23,226	6,357	992	1,279	4,159	4,310	6,129
2016[C]	38,282	11,423	740	3,489	5,019	12,832	4,779
Average percent of total		**35.1%**	**3.6%**	**1.7%**	**12.1%**	**26.1%**	**21.4%**

[A] Snake River trap at Lewiston, ID, collects fish originating in Grande Ronde, Salmon, and Imnaha rivers; wild steelhead at this trap are not part of pre-assigned smolts in 2006 to 2011 — the few tags shown on wild steelhead were originally planned for use on wild Chinook tagging.
[B] Pre-assignments of wild steelhead from Snake River Trap at Lewiston, ID, began in 2012.
[C] PIT-tag numbers for wild steelhead may change as groups are finalized for estimation of SARs in future report.

Snake River Hatchery Steelhead

Table C.13. Number of PIT-tagged hatchery steelhead smolts from tributaries above Lower Granite Dam (plus Snake River trap) used in the CSS analyses for migration years 1997 to 2007.

Migr Year	Total PIT-Tags[A]	Clearwater River (Rkm 224)	Snake River Trap[B] (Rkm 225)	Grande Ronde River (Rkm 271)	Salmon River (Rkm 303)	Imnaha River (Rkm 308)
1997	35,409	12,872	725	6,039	9,394	6,379
1998	30,625	8,451	4,209	4,904	8,457	4,604
1999	36,667	11,486	3,925	5,316	9,132	6,808
2000	31,735	8,488	3,290	5,348	8,173	6,436
2001	28,812	9,155	3,126	4,677	7,859	3,995
2002	26,279	7,819	4,722	3,888	7,011	2,839
2003	26,083	4,912	4,171	3,113	7,764	6,123
2004	19,674	3,400	4,841	2,263	4,072	5,098
2005	23,463	7,228	3,354	2,395	3,684	6,802
2006	15,963	4,545	2,146	4,397	3,208	1,667
2007	26,323	3,893	2,545	8,979	8,820	2,086
Average percent of total		**26.7%**	**13.1%**	**17.3%**	**25.3%**	**17.6%**

[A] Total includes PIT-tagged hatchery steelhead released below Hells Canyon Dam ranging between 57 and 301 tags per year, and averaging 0.9% of total across the 11 years.
[B] Snake River trap at Lewiston, ID, collects fish released in Grande Ronde, Salmon, and Imnaha rivers, and below Hells Canyon Dam.

Table C.14. Number of PIT-tagged hatchery B-run steelhead smolts released into the Clearwater River and subsequently used in the CSS analyses for migration years 2008–2016.

Migration Year	Tag Site[A]	Hatchery Release	Fish# / lb	Median Length at Tagging (mm)	PIT Tags Released	PIT-Tag Proportion
2008	CLWH	819,264	4.6	(none taken)	20,018	0.0244
	DWOR	2,254,407	5.8	175	27,276	0.0121
2009	CLWH	835,636	4.7	(none taken)	21,191	0.0254
	DWOR	1,798,874	6.5	185	28,306	0.0157
2010	CLWH	854,960	4.5	(none taken)	23,589	0.0276
	DWOR	1,234,563	6.0	165	28,394	0.0230
2011	CLWH	1,117,487	5.1	(none taken)	33,787	0.0302
	DWOR	2,265,405	7.1	168	30,187	0.0133
2012	CLWH	730,036	4.5	(none taken)	9,498	0.0130
	DWOR	2,595,828	6.2	161.5	30,082	0.0116
2013	CLWH	957,801	7.4	(none taken)	26,531	0.0277
	DWOR	2,160,790	6.5	154	30,200	0.0140
2014	CLWH	848,715	4.6	(none taken)	18,078	0.0213
	DWOR	2,228,021	7.1	175	30,698	0.0138
2015	CLWH	927,613	5.2	(none taken)	18,078	0.0195
	DWOR	2,480,746	5.9	165	31,297	0.0126
2016	CLWH	909,237	4.8	(none taken)	21,436	0.0236
	DWOR	2,300,876	6.0	(none taken)	32,213	0.0140

[A] Hatchery at which steelhead were PIT-tagged: CLWH – Clearwater H; DWOR – Dworshak NFH.

Table C.15. Number of PIT-tagged hatchery A-run steelhead smolts released into the Grande Ronde River and subsequently used in the CSS analyses for migration years 2008–2016.

Migration Year	Tag Site[A]	Hatchery Release	Fish# / lb	Median Length at Tagging (mm)	PIT Tags Released	PIT-Tag Proportion
2008	IRRI	803,847	4.4	134	16,465	0.0205
	LYFE	175,961	4.6	(none taken)	4,000	0.0227
2009	IRRI	652,424	3.8	187	22,233	0.0341
	LYFE	170,232	4.7	(none taken)	5,974	0.0351
2010	IRRI	617,514	3.9	157	23,083	0.0374
	LYFE	163,197	4.2	(none taken)	5,985	0.0367
2011	IRRI	826,879	4.1	148	22,182	0.0268
	LYFE	197,839	4.8	(none taken)	5,967	0.0302
2012	IRRI	842,753	4.2	156	22,379	0.0266
	LYFE	176,902	4.8	(none taken)	5,978	0.0338
2013	IRRI	822,601	4.6	140	21,875	0.0266
	LYFE	205,913	4.7	(none taken)	5,991	0.0291
2014	IRRI	831,978	4.3	137	22,224	0.0267
	LYFE	209,000	5.1	(none taken)	6,000	0.0287
2015	IRRI	684,104	4.3	137	21,925	0.0320
	LYFE	206,735	5.0	(none taken)	5,981	0.0289
2016	IRRI	826,953	4.5	134	15,953	0.0193
	LYFE	200,608	4.9	(none taken)	5,997	0.0299

[A] Hatchery at which steelhead were PIT-tagged: Irrigon H – IRRI; Lyons Ferry H – LYFE.

Table C.16. Number of PIT-tagged hatchery A-run steelhead smolts released into the Imnaha River and subsequently used in the CSS analyses for migration years 2008–2017.

Migration Year	Tag Site[A]	Hatchery Release	Fish# / lb	Median Length at Tagging (mm)	PIT Tags Released	PIT-Tag Proportion
2008	IRRI	274,865	4.8	136	14,877	0.0541
2009	IRRI	187,401	4.5	179	20,838	0.1112
2010	IRRI	215,467	4.5	147	21,680	0.1006
2011	IRRI	158,027	4.3	155	21,887	0.1385
2012	IRRI	212,220	5.0	150	21,943	0.1034
2013	IRRI	235,446	4.9	136	21,882	0.0929
2014	IRRI	239,614	4.7	137	21,897	0.0914
2015	IRRI	247,642	4.6	138	14,877	0.0601
2016	IRRI	208,536	4.6	129	14,878	0.0713

[A] Hatchery at which steelhead were PIT-tagged: Irrigon H – IRRI.

Table C.17. Number of PIT-tagged hatchery A-run steelhead smolts released into the Salmon River and subsequently used in the CSS analyses for migration years 2008–2016.

Migration Year	Tag Site[A]	Hatchery Release	Fish# / lb	Median Length at Tagging (mm)	PIT Tags Released	PIT-Tag Proportion
2008[B]	MAVA	868,273	4.6	(none taken)	13,170	0.0152
	HAGE	1,208,489	4.1	(none taken)	18,116	0.0150
2009	MAVA	880,384	4.8	(none taken)	16,781	0.0191
	HAGE	1,249,216	4.4	(none taken)	16,573	0.0133
	NISP	1,248,101	3.9	(none taken)	17,064	0.0137
2010	MAVA	640,513	4.8	(none taken)	11,142	0.0174
	HAGE	1,411,833	4.4	(none taken)	27,929	0.0198
	NISP	1,260,127	4.0	(none taken)	19,866	0.0158
2011	MAVA	656,743	5.2	(none taken)	11,545	0.0176
	HAGE	1,321,547	3.8	(none taken)	27,999	0.0212
	NISP	1,243,070	5.7	(none taken)	19,742	0.0159
2012	MAVA	593,384	4.5	(none taken)	11,676	0.0197
	HAGE	1,401,863	4.5	(none taken)	28,563	0.0204
	NISP	1,311,729	5.1	(none taken)	19,674	0.0150
2013	MAVA	500,986	4.6	(none taken)	8,180	0.0163
	HAGE	1,339,869	4.3	(none taken)	31,238	0.0233
	NISP	1,233,572	6.1	(none taken)	19,134	0.0155
2014	MAVA	480,529	4.6	(none taken)	7,886	0.0164
	HAGE	1,334,177	4.6	(none taken)	16,981	0.0127
	NISP	1,259,859	4.3	(none taken)	14,053	0.0112
2015	MAVA	881,310	4.5	(none taken)	17,089	0.0194
	HAGE	1,532,012	4.7	(none taken)	7,884	0.0051
	NISP	1,293,411	4.5	(none taken)	14,033	0.0108
2016	MAVA	457,210	4.5	(none taken)	7,886	0.0172
	HAGE	1,521,122	4.7	(none taken)	16,706	0.0110
	NISP	1,306,354	4.0	(none taken)	14,057	0.0108

[A] Hatchery at which steelhead were PIT-tagged: Magic Valley H – MAVA; Hagerman NFH – HAGE; Niagara Springs H – NISP.

[B] Niagara Springs H (NISP) is not included this year since release of 1,200 PIT-tagged smolts (none in monitor-mode) is not on scale with the magnitude of PIT-tagging at other hatcheries being analyzed.

Table C.18. Number of PIT-tagged hatchery B-run steelhead smolts released into the Salmon River and subsequently used in the CSS analyses for migration years 2008–2016.

Migration Year	Tag Site[A]	Hatchery Release	Fish# / lb	Median Length at Tagging (mm)	PIT Tags Released	PIT-Tag Proportion
2008	MAVA	752,644	4.7	(none taken)	21,302	0.0283
	HAGE	179,034	4.7	(none taken)	11,330	0.0633
2009	MAVA	771,813	4.8	(none taken)	20,615	0.0267
	HAGE	171,094	4.6	(none taken)	8,344	0.0488
2010	MAVA	959,262	5.0	(none taken)	21,596	0.0225
2011	MAVA	902,866	5.1	(none taken)	20,709	0.0229
2012	MAVA	968,221	4.7	(none taken)	21,232	0.0219
2013	MAVA	1,062,884	4.4	(none taken)	29,286	0.0276
2014	MAVA	1,069,717	4.4	(none taken)	26,838	0.0251
2015	MAVA	700,650	4.5	(none taken)	26,819	0.0383
2016	MAVA	1,069,410	4.5	(none taken)	26,757	0.0250

[A] Hatchery at which steelhead were PIT-tagged: Magic Valley H – MAVA; Hagerman NFH – HAGE.

Table C.19. Number of PIT-tagged hatchery A-run steelhead smolts released into the Snake River (just below Hells Canyon Dam) and subsequently used in the CSS analyses for migration years 2009–2016.

Migration Year	Tag Site[A]	Hatchery Release	Fish# / lb	Median Length at Tagging (mm)	PIT Tags Released	PIT-Tag Proportion
2009	NISP	526,743	4.6	(none taken)	7,381	0.0140
2010	NISP	529,667	4.7	(none taken)	8,253	0.0156
2011	NISP	538,580	8.2	(none taken)	8,227	0.0153
2012	NISP	526,966	6.9	(none taken)	8,249	0.0157
2013	NISP	571,865	7.2	(none taken)	9,074	0.0159
2014	NISP	576,080	5.1	(none taken)	8,571	0.0149
2015	NISP	572,077	4.9	(none taken)	8,553	0.0150
2016	NISP	569,357	4.1	(none taken)	8,572	0.0151

[A] Hatchery at which steelhead were PIT-tagged: Niagara Springs H – NISP.

Snake River Hatchery Sockeye

Table C.20. Hatchery sockeye from Sawtooth, Oxbow (Oregon), and Springfield hatcheries[A] PIT-tagged and released in Salmon River, 2009–2015.

Migration Year	Rearing Hatchery[A]	Hatchery Release	Fish# / lb	Median Length at Tagging[B] (mm)	PIT Tags Released	PIT-Tag Proportion
2009	SAWT	99,374	30.6	101	52,551	0.5288
	OXBH	73,681	10.2	147	10,891	0.1478
2010	SAWT	99,392	28.1	106	51,684	0.5200
	OXBH	79,886	10.7	140	11,945	0.1453
2011	SAWT	136,287	54.8	84	51,672	0.3791
	OXBH	54,766	9.6	146	9,975	0.1821
2012	SAWT	80,912	50.6	96	51,710	0.6391
	OXBH[C]	85,741	8.9	147	9,971	0.1163
2013	SAWT	175,578	18.8	(none taken)	50,062	0.2851
2014	SAWT	173,992	24.9	(none taken)	49,879	0.2867
2015	SAWT	134,660	18.9	(none taken)	49,772	0.3696
	SPRF	211,205	10.0	(none taken)	49,307	0.2335
2016	SPRF	540,665	10.1	(none taken)	50,656	0.0937

[A] Hatchery at which sockeye were reared and PIT-tagged: Sawtooth – SAWT, Oxbow (Oregon) – OXBH, Springfield – SPRF.
[B] Tagged in winter ~2-4 months before release.
[C] Oxbow Hatchery sockeye were eliminated in CSS analyses after 2012 due to low PIT-tag release numbers.

Snake River Wild Subyearling Fall Chinook

Table C.21. Number of PIT-tagged Snake River Basin (above LGR) wild/natural subyearling fall Chinook used in the CSS analyses for migration years 2006 to 2011.

Migration Year	Total PIT Tags
2006	2,153
2007	---
2008	6,739
2009	6,867
2010	---
2011	3,244

Snake River Hatchery Subyearling Fall Chinook

Table C.22. Lyons Ferry Hatchery subyearling fall Chinook (released at Big Canyon Creek Acclimation Pond) that were used in the CSS analyses for migration years 2006 to 2012.

Migration Year	Hatchery Release	Fish# / lb	Median Length at Tagging[A] (mm)	PIT Tags Released	PIT-Tag Proportion
2006	504,706	57.0	83	55,835	0.1106
2007	---	---	---	---	---
2008	520,035	55.0	74	32,307	0.0621
2009	474,868	62.5	79	13,759	0.0290
2010	511,236	52.3	72	38,160	0.0746
2011	509,146	51.0	74	40,694	0.0799
2012	511,629	47.0	78	41,040	0.0802

[A] Tagged in spring 1-2 months before release.

Table C.23. Lyons Ferry Hatchery subyearling fall Chinook (released at Captain John Rapids Acclimation Pond) that were used in the CSS analyses for migration years 2008 to 2016.

Migration Year	Hatchery Release	Fish# / lb	Median Length at Tagging[A] (mm)	PIT Tags Released	PIT-Tag Proportion
2008	512,745	65.0	69	39,512	0.0771
2009	524,910	57.0	80	11,391	0.0217
2010	528,777	47.0	74	37,822	0.0715
2011	516,480	45.3	74	40,764	0.0789
2012	505,728	47.0	75	41,038	0.0811
2013	---	---	---	---	---
2014	---	---	---	---	---
2015	538,379	49.6	(none taken)	22,058	0.0410
2016	509,235	54.8	(none taken)	25,973	0.0510

[A] Tagged in spring 1-2 months before release.

Table C.24. Lyons Ferry Hatchery subyearling fall Chinook (released at Pittsburgh Landing Acclimation Pond) that were used in the CSS analyses for migration years 2006 to 2016.

Migration Year	Hatchery Release	Fish# / lb	Median Length at Tagging[A] (mm)	PIT Tags Released	PIT-Tag Proportion
2006[B]	397,085	50.0	80	24,396	0.0614
2007	---	---	---	---	---
2008	403,432	60.0	69	31,834	0.0789
2009	415,991	59.3	75	13,761	0.0331
2010	405,041	50.5	71	30,676	0.0757
2011	413,284	49.0	73	32,643	0.0790
2012	402,400	46.5	73	32,858	0.0817
2013	---	---	---	---	---
2014	---	---	---	---	---
2015	398,010	60.6	(none taken)	22,099	0.0555
2016	398,086	58.8	(none taken(	26,052	0.0654

[A] Tagged in spring 1-2 months before release.
[B] Fish reared and tagged at Umatilla Hatchery in 2006

Table C.25. Lyons Ferry Hatchery subyearling fall Chinook (released into the mainstem Snake River above LGR) that were used in the CSS analyses for migration years 2006 to 2012.

Migration Year	Hatchery Release	Fish# / lb	Median Length at Tagging[A] (mm)	PIT Tags Released	PIT-Tag Proportion
2006	211,508	50.0	76	22,865	0.1081
2007	---	---	---	---	---
2008	230,401	59.6	72	12,577	0.0546
2009	200,744	46.5	75	10,239	0.0510
2010	203,162	58.0	70	11,861	0.0584
2011	202,300	49.0	69	16,353	0.0808
2012	199,300	54.0	71	16,312	0.0818

[A] Tagged in spring 1-2 months before release.

Table C.26. Hatchery subyearling fall Chinook (released into the Grande Ronde River) that were used in the CSS analyses for migration years 2006 to 2012.

Migration Year	Rearing Hatchery[A]	Hatchery Release	Fish# / lb	Median Length at Tagging[B] (mm)	PIT Tags Released	PIT-Tag Proportion
2006	LYFE	409,165	50.6	71	25,349	0.0620
2007	---	---	---	---	---	---
2008	IRRI	303,270	47.0	76	22,261	0.0734
2009	IRRI	441,050	67.1	72	24,262	0.0550
2010	IRRI	386,840	42.2	82	30,277	0.0783
2011	IRRI	399,500	80.9	76	32,231	0.0807
2012	IRRI	384,000	48.0	84	32,416	0.0844

[A] Hatchery at which sockeye were reared and PIT-tagged: Lyons Ferry – LYFE, Irrigon – IRRI.
[B] Tagged in spring 1-2 months before release.

Table C.27. Irrigon/Umatilla hatchery subyearling fall Chinook (released below Hells Canyon Dam) that were used in the CSS analyses for migration years 2006 to 2012.

Migration Year	Rearing Hatchery[A]	Hatchery Release	Fish# / lb	Median Length at Tagging[B] (mm)	PIT Tags Released	PIT-Tag Proportion
2006	UMAH	332,165	58.0	80	21,534	0.0648
2007	---	---	---	---	---	---
2008	UMAH	770,350	44.0	82	33,224	0.0431
2009	UMAH	803,485	60.6	77	55,488	0.0691
2010	UMAH	685,735	46.4	81	49,813	0.0726
2011	IRRI	638,900	81.0	72	36,687	0.0574
2012	IRRI	800,400	46.0	83	36,926	0.0461

[A] Hatchery at which sockeye were reared and PIT-tagged: Umatilla – UMAH, Irrigon – IRRI.
[B] Tagged in spring 1-2 months before release.

Table C.28. Oxbow Hatchery (Idaho) subyearling fall Chinook (released below Hells Canyon Dam) that were used in the CSS analyses for migration years 2008 to 2012.

Migration Year	Hatchery Release	Fish# / lb	Median Length at Tagging[A] (mm)	PIT Tags Released	PIT-Tag Proportion
2008	192,471	51.4	(none taken)	15,469	0.0804
2009	202,839	54.8	(none taken)	14,844	0.0732
2010	---	---	---	---	---
2011	194,809	48.2	(none taken)	14,831	0.0761
2012	202,281	47.9	(none taken)	14,910	0.0737

[A] Tagged in spring 1-2 months before release.

Table C.29. Dworshak Hatchery subyearling fall Chinook (surrogates) (released into the mainstem Snake River above LGR) that were used in the CSS analyses for migration years 2006 to 2011.

Migration Year	Hatchery Release	Fish# / lb	Median Length at Tagging[A] (mm)	PIT Tags Released	PIT-Tag Proportion
2006	229,097	114.5	73	229,033	0.9997
2007	---	---	---	---	---
2008	202,369	N/A	78	201,723	0.9968
2009	237,741	N/A	70	237,667	0.9997
2010	195,492	N/A	68	193,985	0.9923
2011	200,754	N/A	76	185,760	0.9253

[A] Tagged within 1 day of release.

Table C.30. Nez Perce Tribal Hatchery subyearling fall Chinook (released from Cedar Flats Acclimation Facility) that were used in the CSS analyses for migration years 2010 to 2012.

Migration Year	Hatchery Release	Fish# / lb	Median Length at Tagging[A] (mm)	PIT Tags Released	PIT-Tag Proportion
2010	188,411	48.3	87	14,143	0.0751
2011	205,556	54.5	93	16,345	0.0795
2012	199,450	51.7	92	16,519	0.0828

[A] Tagged in May, ~2 weeks to 1 month before release.

Table C.31. Nez Perce Tribal Hatchery subyearling fall Chinook (released from Lukes Gulch Acclimation Facility) that were used in the CSS analyses for migration years 2010 to 2012.

Migration Year	Hatchery Release	Fish# / lb	Median Length at Tagging[A] (mm)	PIT Tags Released	PIT-Tag Proportion
2010	198,969	44.4	86	16,317	0.0820
2011	207,482	50.2	89	16,391	0.0790
2012	198,856	49.6	89	16,377	0.0824

[A] Tagged in May, ~3 weeks to 1 month before release.

Middle Columbia Wild Spring Chinook

Table C.32. Number of PIT-tagged wild Chinook parr/smolts from tributaries in the Mid-Columbia River used in the CSS analyses for migration years 2006 to 2015.

Migration Year	Total PIT-tags	Yakima River (Rkm 539)	John Day River (Rkm 351)
2000	8,034	6,183	1,851
2001	6,060	2,179	3,881
2002	12,706	8,707	3,999
2003	13,925	7,803	6,122
2004	8,303	3,931	4,372
2005	7,070	1,733	5,337
2006	5,090	2,333	2,757
2007	4,663	1,200	3,463
2008	5,603	1,675	3,928
2009	8,749	3,795	4,954
2010	5,291	0	5,291
2011	6,291	6,183	4,501
2012	8,799	2,595	6,204
2013	7,519	2,473	5,046
2014	3,129	0	3,129
2015	3,733	524	3,209
Average percent of total		**34.9%**	**65.1%**

Middle Columbia Hatchery Spring Chinook

Table C.33. Carson NFH spring Chinook PIT-tagged and released in the Wind River, 2000 to 2015.

Migration Year	Hatchery Release	Fish# / lb	Median Length at Tagging[A] (mm)	PIT Tags Released	PIT-Tag Proportion
2000	1,430,022	15.6	116	14,992	0.0105
2001	1,608,684	14.9	108	14,978	0.0093
2002	1,449,361	15.6	116	14,983	0.0103
2003	1,673,255	17.1	111	14,983	0.0090
2004	1,417,986	17.3	111	14,973	0.0106
2005	1,470,134	14.5	120	14,958	0.0102
2006	1,209,384	17.3	112	14,971	0.0124
2007	1,158,425	17.2	109	14,943	0.0129
2008	1,336,741	16.5	103	14,884	0.0111
2009	1,216,198	16.9	108	14,975	0.0123
2010	1,278,492	16.8	108	14,947	0.0117
2011	1,058,771	33.8	104	14,953	0.0141
2012	1,126,579	18.0	102	14,941	0.0133
2013	1,125,192	17.9	103	14,907	0.0132
2014	1,127,012	18.1	105	14,906	0.0132
2015	1,158,389	17.4	108	14,734	0.0127

[A] Tagged in fall and winter, approximately 3–5 months before release.

Table C.34. Warm Springs NFH spring Chinook PIT-tagged and released in the Deschutes River basin, 2007 to 2015.

Migration Year	Hatchery Release	Fish# / lb	Median Length at Tagging (mm)	PIT-Tags Released	PIT-Tag Proportion
2007[A]	520,000	25.0	100	19,698	0.0379
2008[A]	376,000	11.0	103	19,937	0.0530
2009[A]	580,897	29.8	101	19,926	0.0343
2010[B]	705,241	22.0	107	14,907	0.0211
2011[B]	537,280	30.9	108	14,924	0.0278
2012[B]	480,945	29.1	102	14,806	0.0308
2013[B]	783,546	23.9	105	14,877	0.0190
2014[B]	726,942	24.0	108	14,818	0.0204
2015[B]	371,455	28.2	109	14,915	0.0402

[A] Tagged in fall, approximately 4–5 months before release.
[B] Tagged in winter, approximately 2 months before release.

Table C.35. Cle Elum Hatchery spring Chinook PIT-tagged and released in the Yakima River basin, 2000 to 2015.

Migration Year	Hatchery Release	Fish# / lb	Median Length at Tagging[A] (mm)	PIT Tags Released	PIT-Tag Proportion
2000	589,683	19.1	102	38,467	0.0652
2001	758,789	15.0	112	39,799	0.0525
2002	834,285	22.6	112	39,419	0.0472
2003	370,236	18.0	110	39,985	0.1080
2004	836,904	28.3	103	40,015	0.0478
2005	824,692	25.0	101	39,997	0.0485
2006	785,448	N/A	95	39,987	0.0509
2007	860,002	N/A	108	40,006	0.0465
2008	642,977	26.3	109	40,001	0.0622
2009	771,265	20.3	108	40,011	0.0519
2010	851,313	30.0	106	39,999	0.0470
2011	832,941	27.7	111	40,001	0.0480
2012	794,781	29.0	107	40,003	0.0503
2013	769,182	N/A	108	39,998	0.0520
2014	802,716	N/A	110	39,997	0.0498
2015	646,755	N/A	113	39,985	0.0618

[A] Tagged in fall, approximately 4–5 months before release.

Middle Columbia Wild Steelhead

Table C.36. Number of PIT-tagged wild steelhead smolts from tributaries in the Mid-Columbia River used in the CSS analyses for migration years 2002 to 2014.

Migration Year	Total PIT Tags	Yakima River (Rkm 539)	John Day River (Rkm 351)	Deschutes River (Rkm 328)
2002	1,337	1,337	0	0
2003	904	904	0	0
2004	5,708	1,473	4,235	0
2005	7,336	1,965	5,371	0
2006	5,501	954	3,163	1,384
2007	6,565	810	4,146	1,609
2008	7,079	1,389	3,975	1,715
2009	7,938	1,352	3,844	2,742
2010	6,561	1,341	3,931	1,289
2011	8,291	1,380	2,774	4,137
2012	10,177	2,685	4,624	2,868
2013	5,931	1,302	4,629	0
2014	6,590	2,780	3,371	439
Average percent of total		**34.3%**	**49.3%**	**16.4%**

Middle Columbia Wild Subyearling Fall Chinook

Table C.37. Number of PIT-tagged wild subyearling fall Chinook from the Hanford Reach or Deschutes River that were used in the CSS analyses for migration years 2000 to 2014.

Migration Year	Total PIT Tags	Deschutes River (Rkm 328)	Hanford Reach
2000	10,967	0	10,967
2001	9,973	0	9,973
2002	0	0	0
2003	2,975	0	2,975
2004	2,989	0	2,989
2005	22,634	0	22,634
2006	0	0	0
2007	21,007	0	21,007
2008	16,651	0	16,651
2009	13,728	0	13,728
2010	4,850	0	4,850
2011	30,234	19,897	10,337
2012	25,683	20,798	4,885
2013	30,507	26,322	4,185
2014	29,839	19,899	9,940
Average percent of total (2011-2014)		**74.9%**	**25.1%**

Middle Columbia Hatchery Subyearling Fall Chinook

Table C.38. Spring Creek NFH subyearling fall Chinook PIT-tagged and released, 2008 to 2014.

Migration Year	Release Month	Hatchery Release	Fish# / lb	Median Length at Tagging[A] (mm)	PIT Tags Released	PIT-Tag Proportion
2008	March	7,416,056	143.8	68	7,477	0.0010
2008	April	3,990,744	90.8	75	3,853	0.0010
2009	April	6,479,326	114.9	69	8,686	0.0013
2010	April	6,200,507	111.8	72	8,962	0.0014
2011	April	6,229,093	110.6	71	8,956	0.0014
2012	April	6,271,782	90.8	65	8,772	0.0014
2013	April	6,441,575	101.0	67	8,964	0.0014
2014	April	6,169,418	138.7	69	8,873	0.0014
2008	May	3,492,789	N/A	75	2,677	0.0008
2009	May	4,773,958	90.0	77	5,950	0.0012
2010	May	4,550,054	76.3	77	5,910	0.0013
2011	May	4,632,199	89.6	74	5,983	0.0013
2012	May[B]	4,806,922	99.5	71	5,978	0.0012
2013	May	4,801,111	79.2	73	5,976	0.0012
2014	May	4,585,064	102.3	77	5,993	0.0013

[A] March release was tagged within 2-3 days of release, April releases were tagged within 1-2 weeks of release, and May releases were tagged approximately 1 month before release.
[B] May release was rescheduled for April 30th due to high flows in the Columbia River.

Table C.39. Little White Salmon NFH subyearling fall Chinook PIT-tagged and released, 2008 to 2014.

Migration Year	Hatchery Release	Fish# / lb	Median Length at Tagging[A] (mm)	PIT Tags Released	PIT-Tag Proportion
2008	2,001,759	96.0	67	24,886	0.012
2009	2,616,601	80.6	72	24,947	0.010
2010	2,053,707	87.2	70	24,951	0.012
2011	2,006,949	90.2	69	24,638	0.012
2012	1,995,627	86.4	64	24,953	0.013
2013	1,924,546	64.3	72	14,960	0.008
2014	1,859,849	89.5	64	14,925	0.008

[A] Tagged in summer, approximately 1 week to 1 month before release.

Upper Columbia Wild Chinook

Table C.40. Number of PIT-tagged wild Chinook parr/smolts from tributaries above Rock Island Dam used in the CSS analyses for migration years 2006 to 2015.

Migration Year	Total PIT-tags	Wenatchee River (Rkm 754)	Entiat River (Rkm 778)	Methow River (Rkm 843)	Okanogan R. or Col. R. above Wells Dam (Rkm 858)
2006	1,895	0	1,895	0	0
2007	16,177	13,434	1,538	1,205	0
2008	29,193	16,350	9,541	3,302	0
2009	18,114	14,605	2,256	1,253	0
2010	28,229	17,962	8,326	1,941	0
2011	27,663	10,581	2,916	946	13,220
2012	37,595	14,427	5,974	1,918	15,276
2013	41,210	14,426	6,866	2,065	17,853
2014	36,027	18,797	6,693	1,939	8,598
2015	29,686	22,488	4,331	2,867	N/A[A]
Average percent of total (through 2014)		**49.7%**	**27.3%**	**5.7%**	**17.3%**

[A] Tag numbers will be provided when SARs are first estimated, three years after out-migration.

Upper Columbia Hatchery Spring Chinook

Table C.41. Leavenworth NFH spring Chinook PIT-tagged and released in Wenatchee River basin, 2000 to 2015.

Migration Year	Hatchery Release	Fish# / lb	Median Length at Tagging (mm)	PIT Tags Released	PIT-Tag Proportion
2000[A]	1,680,904	18.2	116	7,387	0.0044
2001[B]	1,630,089	16.8	114	7,600	0.0047
2002[C]	1,554,362	22.4	114	317,271	0.2041
2003[B]	1,288,893	16.2	116	240,558	0.1866
2004[B]	1,422,100	25.7	119	216,600	0.1523
2005[D]	1,476,046	18.4	120	14,825	0.0100
2006[D]	1,005,505	19.0	118	14,700	0.0146
2007[D]	1,177,568	20.0	121	14,969	0.0127
2008[B]	1,539,668	18.0	111	15,968	0.0104
2009[B]	1,685,038	18.3	105	14,919	0.0089
2010[B]	1,284,653	16.1	116	14,948	0.0116
2011[B]	1,189,442	18.0	117	14,875	0.0125
2012[B]	1,186,622	17.9	117	14,901	0.0126
2013[B]	1,289,293	17.5	111	14,951	0.0116
2014[B]	1,239,025	18.5	116	14977	0.0121
2015[B]	1,139,567	17.7	115	14,994	0.0132

[A] Tagged in winter, approximately 3 months before release.
[B] Tagged in fall, approximately 5 months before release.
[C] 16% tagged in fall (~4–5 months before release) and 84% tagged in spring (~1–2 months before release).
[D] Tagged in spring, approximately 1 month before release.

Table C.42. Winthrop NFH spring Chinook PIT-tagged and released in Methow River basin, 2009 to 2015.

Migration Year	Hatchery Release	Fish# / lb	Median Length at Tagging (mm)[A]	PIT Tags Released	PIT-Tag Proportion
2009	297,082	16.7	104	1,999	0.0067
2010	495,978	15.3	103	4,984	0.0100
2011	426,980	14.4	109	3,977	0.0093
2012	551,509	15.6	105	7,838	0.0142
2013	417,558	19.8	104	16,256	0.0389
2014	560,379	16.1	105	4,943	0.0088
2015	403,510	16.4	102	9,937	0.0246

[A] Tagged in fall, approximately 5 months before release.

Table C.43. Entiat NFH summer Chinook PIT-tagged and released in Entiat River basin, 2011 to 2015.

Migration Year	Hatchery Release	Fish# / lb	Median Length at Tagging (mm)[A]	PIT Tags Released	PIT-Tag Proportion
2011	150,181	13.3	104	9,846	0.0656
2012	174,661	13.4	107	9,880	0.0566
2013	356,098	16.0	103	9,957	0.0280
2014	386,569	19.2	113	9,807	0.0254
2015	417,995	15.1	113	9,930	0.0238

[A] Tagged in fall, approximately 5 months before release.

Upper Columbia Wild Steelhead

Table C.44. Number of PIT-tagged wild steelhead smolts from tributaries above Rock Island Dam used in the CSS analyses for migration years 2006 to 2014.

Migration Year	Total PIT Tags	Wenatchee River (Rkm 754)	Entiat River (Rkm 778)	Methow River (Rkm 843)
2006	1,032	0	1,032	0
2007	2,332	828	870	634
2008	4,535	823	2,904	808
2009	4,297	732	2,517	1,048
2010	3,655	780	2,106	769
2011	2,125	475	1,150	500
2012	2,135	663	1,227	245
2013	6,295	3,481	2,010	804
2014	5,628	2,852	2,174	602
Average percent of total		**27.9%**	**55.5%**	**16.5%**

Upper Columbia Hatchery Steelhead

Table C.45. Eastbank Hatchery Complex steelhead PIT-tagged and released in Wenatchee River basin, 2003 to 2014.

Migration Year	Hatchery Release	Fish# / lb	Median Length at Tagging (mm)	PIT Tags Released	PIT-Tag Proportion
2003[A]	156,145	7.6	95	33,145	0.2123
2004[B]	65,408	6.2	114	29,909	0.4573
2005[C]	100,519	5.8	93	34,815	0.3464
2006[D]	157,313	6.1	170	9,678	0.0615
2007[D]	100,499	6.8	72	8,022	0.0798
2008[D]	144,831	6.9	(none taken)	8,848	0.0611
2009[D]	153,783	7.4	93	9,405	0.0612
2010[E]	222,093	6.4	121	9,926	0.0447
2011[F]	172,363	6.4	125	9,894	0.0574
2012[G]	163,729	11.6	102	30,019	0.1833
2013[G]	223,480	9.6	85	25,129	0.1124
2014[G]	204,520	9.3	80	15,095	0.0738

Tag sites: CHEL = Chelan PUD Hatchery, EBNK = Eastbank Hatchery, TURO = Turtle Rock Hatchery
[A] 36% were tagged in the fall (6 months before release) and 64% were tagged in spring (1 month before release).
[B] 32% were tagged in the fall (6 months before release) and 68% were tagged in spring (1 month before release).
[C] 10% tagged in the fall (8 months before release) and 90% tagged in spring (<1 month before release).
[D] Tagged in spring (<1 month before release).
[E] 3% tagged in the fall (7 Months before release) and 97% were tagged in spring (<1 months before release).
[F] 4% tagged in the fall (7 Months before release) and 96% were tagged in spring (<1 months before release).
[G] 100% tagged in the fall (7 Months before release).

Upper Columbia Wild Sockeye

Table C.46. Number of PIT-tagged Wenatchee River and Okanogan River Basin wild sockeye smolts used in the CSS analyses for migration years 2013 to 2015.

Migration Year	Total PIT Tags	Wenatchee River	Okanogan River Basin
2013	4,018	0	4,018
2014	9,875	4,820	5,055
2015	11,194	4,018	7,176
Average percent of total		**28.2%**	**71.8%**

Upper Columbia Wild and Hatchery Yearling Chinook, Subyearling Chinook, Steelhead, and Sockeye Tagged at Rock Island Dam

Table C.47. Number of PIT-tagged wild and hatchery yearling Chinook (2000-2015), subyearling Chinook (2000-2014), sockeye (2000–2015) and steelhead (2000-2014) smolts tagged at Rock Island Dam used in the CSS analyses.

Migration Year	Yearling Chinook	Subyearling Chinook	Steelhead	Sockeye
2000	3,989	4,073	3,946	656
2001	1,837	4,484	4,027	491
2002	3,987	4,800	3,996	2,090
2003	0	4,338	0	0
2004	910	3,183	2,627	1,083
2005	723	3,547	2,850	887
2006	1,127	4,208	3,181	3,600
2007	859	3,596	3,551	2,082
2008	843	3,678	6,052	1,910
2009	688	1,889	5,304	2,059
2010	799	3,625	6,629	3,527
2011	1,338	4,387	7,224	2,977
2012	1,702	3,656	5,943	3,231
2013	5,220	4,021	5,255	2,674
2014	4,834	4,690	6,276	3,059
2015	5,188			1,689

APPENDIX D

DAM-SPECIFIC TRANSPORTATION OF SARs

Appendix D
Dam-Specific Transportation SARs
(Adult returns to Lower Granite Dam without jacks)

Table D.1 Estimated dam-specific transportation SARs (%) of the PIT-tagged wild Chinook aggregate for juvenile migration years 1994 to 2015 (with 90% confidence intervals). Transported smolts include only first-time detected fish from total PIT-tag release through 2005 and both first-time and prior detected fish from Group T beginning 2006.

Migr Year	SAR(TLGR) %	(CI%)	Adult #	SAR(TLGS) %	(CI%)	Adult #	SAR(TLMN) %	(CI%)	Adult #
1994	0.67	(0.28 – 1.12)	7	0.52	(0.00 – 1.11)	2		NA	None
1995	0.41	(0.18 – 0.68)	7	0.28	(0.00 – 0.84)	1		NA	None
1996	0.37	(0.00 – 1.10)	1	1.18	(0.00 – 3.41)	1		NA	None
1997	1.08	(0.00 – 2.37)	2	6.67	(0.00 – 14.8)	2		NA	None
1998	1.34	(0.72 – 2.01)	11	0.84	(0.00 – 1.66)	3	1.27	(0.00 – 3.53)	1
1999	2.53	(1.82 – 3.28)	28	2.82	(1.49 – 4.47)	9	2.09	(0.72 – 3.58)	6
2000	1.22	(0.31 – 2.27)	4	2.46	(0.87 – 4.29)	6	1.07	(0.00 – 2.38)	2
2001	1.33	(0.46 – 2.23)	6	1.39	(0.00 – 4.11)	1		NA	None
2002	0.61	(0.30 – 0.95)	10	1.08	(0.70 – 1.53)	20	0.60	(0.00 – 1.79)	1
2003	0.31	(0.19 – 0.45)	16	0.51	(0.28 – 0.75)	13	0.17	(0.00 – 0.50)	1
2004	0.55	(0.42 – 0.67)	49	0.46	(0.25 – 0.68)	13	0.72	(0.25 – 1.24)	6
2005	0.22	(0.16 – 0.29)	27	0.31	(0.16 – 0.48)	10		NA	None
2006	0.72	(0.49 – 0.96)	28	0.72	(0.51 – 0.93)	31	1.24	(0.78 – 1.77)	17
2007	1.23	(0.82 – 1.65)	26	1.44	(0.68 – 2.21)	9	0.89	(0.26 – 1.81)	3
2008	3.39	(2.99 – 3.80)	175	2.62	(2.11 – 3.14)	67	2.47	(1.55 – 3.45)	16
2009	1.80	(1.45 – 2.15)	69	1.34	(1.00 – 1.69)	40	1.48	(0.80 – 2.24)	11
2010	0.90	(0.70 – 1.11)	54	0.88	(0.62 – 1.18)	29	0.91	(0.44 – 1.45)	8
2011	0.35	(0.21 – 0.49)	15	0.43	(0.22 – 0.66)	10	0.48	(0.16 – 0.81)	6
2012	0.88	(0.56 – 1.23)	17	0.95	(0.58 – 1.33)	16	0.88	(0.34 – 1.60)	5
2013	1.73	(1.37 – 2.08)	60	1.44	(1.04 – 1.87)	33	1.16	(0.59 – 1.77)	10
2014	0.98	(0.72 – 1.26)	32	0.40	(0.20 – 0.62)	10	0.48	(0.16 – 0.80)	6
2015[A]	0.87	(0.30 – 1.44)	6	0.78	(0.33 – 1.26)	7		NA	None

[A] Return to GRA incomplete with 2-salts through 9/15/2017.

Table D.2 Estimated dam-specific transportation SAR percentages of PIT-tagged Rapid River hatchery spring Chinook for juvenile migration years 1997 to 2015 (with 90% confidence intervals). Transported smolts include only first-time detected fish from total PIT-tag release through 2005 and both first-time and prior detected fish from Group T beginning 2006.

Migr Year	SAR(TLGR) %	(CI%)	Adult #	SAR(TLGS) %	(CI%)	Adult #	SAR(TLMN) %	(CI%)	Adult #
1997	0.80	(0.58 – 1.02)	33	NA		None	2.63	(0.00 – 7.89)	1
1998	2.12	(1.89 – 2.35)	239	1.18	(0.75 – 1.72)	16	1.02	(0.00 – 2.29)	2
1999	3.20	(2.89 – 3.52)	236	3.22	(2.79 – 3.64)	152	1.03	(0.31 – 2.13)	3
2000	2.34	(2.10 – 2.58)	243	1.89	(1.52 – 2.30)	79	2.23	(1.43 – 3.06)	27
2001	1.18	(1.04 – 1.33)	182	0.74	(0.49 – 1.00)	21	0.69	(0.17 – 1.29)	4
2002	1.14	(0.91 – 1.39)	61	0.94	(0.72 – 1.17)	50	1.05	(0.37 – 1.74)	6
2003	0.32	(0.23 – 0.43)	27	0.13	(0.05 – 0.23)	5	0.17	(0.00 – 0.53)	1
2004	0.39	(0.31 – 0.48)	53	0.30	(0.17 – 0.42)	16	0.18	(0.00 – 0.54)	1
2005	0.26	(0.19 – 0.33)	41	0.35	(0.22 – 0.51)	14	NA		None
2006	0.67	(0.53 – 0.83)	53	0.54	(0.39 – 0.70)	34	0.63	(0.38 – 0.89)	17
2007	0.58	(0.44 – 0.76)	35	0.20	(0.00 – 0.41)	3	0.17	(0.00 – 0.41)	2
2008	1.54	(1.34 – 1.73)	167	1.44	(1.18 – 1.71)	75	1.12	(0.54 – 1.80)	8
2009	1.52	(1.29 – 1.77)	106	1.21	(0.89 – 1.52)	41	1.25	(0.71 – 1.86)	14
2010	0.56	(0.37 – 0.79)	20	0.65	(0.38 – 0.95)	14	0.42	(0.00 – 0.87)	3
2011	0.38	(0.26 – 0.49)	27	0.32	(0.18 – 0.45)	14	0.27	(0.09 – 0.45)	6
2012	0.95	(0.74 – 1.17)	48	0.94	(0.70 – 1.21)	35	0.87	(0.52 – 1.23)	15
2013	1.68	(1.40 – 1.99)	93	1.04	(0.76 – 1.35)	34	1.27	(0.85 – 1.72)	25
2014	0.69	(0.52 – 0.87)	43	0.49	(0.33 – 0.68)	21	0.44	(0.23 – 0.70)	10
2015[A]	0.38	(0.17 – 0.60)	9	0.39	(0.20 – 0.60)	10	0.26	(0.00 – 0.61)	2

[A] Return to GRA incomplete with 2-salts through 9/15/2017.

Table D.3 Estimated dam-specific transportation SAR percentages of PIT-tagged Dworshak hatchery spring Chinook for juvenile migration years 1997 to 2015 (with 90% confidence intervals). Transported smolts include only first-time detected fish from total PIT-tag release through 2005 and both first-time and prior detected fish from Group T beginning 2006.

Migr Year	SAR(TLGR) %	(CI%)	Adult #	SAR(TLGS) %	(CI%)	Adult #	SAR(TLMN) %	(CI%)	Adult #
1997	0.86	(0.54 – 1.23)	16	NA		None	NA		None
1998	0.99	(0.85 – 1.14)	110	0.62	(0.41 – 0.85)	22	NA		None
1999	1.26	(1.01 – 1.53)	62	1.29	(0.99 – 1.59)	49	0.83	(0.21 – 1.62)	4
2000	1.18	(1.01 – 1.37)	116	1.08	(0.83 – 1.32)	53	0.69	(0.40 – 1.03)	14
2001	0.36	(0.29 – 0.44)	60	0.44	(0.27 – 0.60)	18	0.16	(0.00 – 0.47)	1
2002	0.64	(0.44 – 0.83)	26	0.74	(0.54 – 0.96)	32	0.27	(0.00 – 0.60)	2
2003	0.28	(0.18 – 0.39)	20	0.28	(0.16 – 0.41)	12	0.18	(0.00 – 0.38)	2
2004	0.17	(0.12 – 0.24)	22	0.45	(0.34 – 0.58)	37	0.36	(0.00 – 0.81)	2
2005	0.21	(0.16 – 0.29)	32	0.20	(0.11 – 0.31)	11	NA		None
2006	0.39	(0.24 – 0.56)	16	0.41	(0.28 – 0.56)	25	0.52	(0.31 – 0.75)	15
2007	0.63	(0.32 – 0.99)	9	0.66	(0.21 – 1.33)	3	0.51	(0.00 – 1.20)	2
2008	0.48	(0.28 – 0.68)	17	1.04	(0.78 – 1.31)	39	1.84	(1.03 – 2.72)	13
2009	0.76	(0.55 – 0.99)	32	0.67	(0.44 – 0.94)	21	0.76	(0.32 – 1.28)	7
2010	0.30	(0.17 – 0.44)	13	0.43	(0.15 – 0.73)	6	1.80	(0.00 – 3.78)	3
2011	0.14	(0.06 – 0.26)	5	0.14	(0.06 – 0.26)	5	0.13	(0.00 – 0.32)	2
2012	0.56	(0.24 – 0.96)	7	0.58	(0.34 – 0.89)	14	0.56	(0.19 – 0.96)	6
2013	0.54	(0.34 – 0.76)	17	0.59	(0.32 – 0.87)	13	1.10	(0.56 – 1.69)	10
2014	0.39	(0.23 – 0.55)	17	0.45	(0.28 – 0.62)	19	0.29	(0.13 – 0.50)	7
2015[A]	NA		None	NA		None	0.22	(0.00 – 0.65)	1

[A] Return to GRA incomplete with 2-salts through 9/15/2017.

Table D.4 Estimated dam-specific transportation SAR percentages of PIT-tagged Catherine Creek hatchery spring Chinook for juvenile migration years 2001 to 2015 (with 90% confidence intervals). Transported smolts include only first-time detected fish from total PIT-tag release through 2005 and both first-time and prior detected fish from Group T beginning 2006.

Migr Year	SAR(TLGR) %	(CI%)	Adult #	SAR(TLGS) %	(CI%)	Adult #	SAR(TLMN) %	(CI%)	Adult #
2001	0.33	(0.18 – 0.50)	11	NA		None	NA		None
2002	1.09	(0.66 – 1.53)	16	0.72	(0.29 – 1.18)	8	NA		None
2003	0.32	(0.12 – 0.57)	5	0.57	(0.14 – 1.06)	4	NA		None
2004	0.29	(0.10 – 0.48)	6	0.57	(0.14 – 1.04)	4	1.37	(0.00 – 4.17)	1
2005	0.32	(0.11 – 0.53)	6	0.95	(0.36 – 1.72)	5	NA		None
2006	0.26	(0.08 – 0.53)	3	0.54	(0.19 – 0.95)	6	0.89	(0.22 – 1.69)	4
2007	0.51	(0.22 – 0.84)	7	0.20	(0.00 – 0.61)	1	1.08	(0.00 – 2.22)	3
2008	2.52	(1.92 – 3.11)	48	3.07	(2.33 – 3.82)	47	2.03	(0.93 – 3.35)	7
2009	1.61	(1.10 – 2.12)	26	1.99	(1.29 – 2.67)	21	1.86	(0.63 – 3.31)	6
2010	1.02	(0.52 – 1.57)	10	1.82	(1.01 – 2.79)	11	0.52	(0.00 – 1.51)	1
2011	0.25	(0.00 – 0.50)	3	0.99	(0.43 – 1.59)	7	0.57	(0.00 – 1.33)	2
2012	0.43	(0.00 – 1.01)	2	0.17	(0.00 – 0.52)	1	2.08	(0.79 – 3.73)	5
2013	2.13	(1.33 – 2.94)	19	0.83	(0.21 – 1.54)	4	1.88	(0.47 – 3.57)	4
2014	0.63	(0.22 – 1.03)	6	0.70	(0.27 – 1.24)	5	0.31	(0.00 – 0.90)	1
2015[A]	0.66	(0.00 – 1.56)	2	0.93	(0.28 – 1.97)	3	NA		None

[A] Return to GRA incomplete with 2-salts through 9/15/2017

Table D.5 Estimated dam-specific transportation SAR percentages of PIT-tagged Clearwater hatchery spring Chinook for juvenile migration years 2006 to 2015 (with 90% confidence intervals). Transported smolts include both first-time and prior detected fish from Group T.

Migr Year	SAR(TLGR) %	(CI%)	Adult #	SAR(TLGS) %	(CI%)	Adult #	SAR(TLMN) %	(CI%)	Adult #
2006	0.70	(0.53 – 0.89)	43	0.69	(0.53 – 0.86)	39	0.73	(0.47 – 1.00)	20
2007	0.47	(0.26 – 0.71)	11	0.28	(0.00 – 0.60)	2	0.37	(0.00 – 0.80)	2
2008	1.12	(0.80 – 1.42)	37	0.95	(0.67 – 1.23)	33	0.93	(0.50 – 1.47)	9
2009	0.82	(0.57 – 1.07)	31	1.10	(0.76 – 1.44)	27	0.69	(0.26 – 1.28)	5
2010	0.48	(0.30 – 0.66)	19	0.98	(0.57 – 1.44)	12	0.60	(0.00 – 1.76)	1
2011	0.03	(0.00 – 0.09)	1	0.14	(0.04 – 0.27)	4	0.15	(0.00 – 0.36)	2
2012	0.77	(0.44 – 1.16)	12	0.64	(0.38 – 0.92)	15	0.97	(0.47 – 1.56)	8
2013	0.82	(0.53 – 1.11)	22	0.81	(0.47 – 1.20)	12	0.89	(0.34 – 1.58)	5
2014	0.32	(0.11 – 0.54)	7	0.71	(0.41 – 1.03)	16	0.37	(0.16 – 0.62)	7
2015[A]	NA		None	0.49	(0.00 – 1.45)	1	NA		None

[A] Return to GRA incomplete with 2-salts through 9/15/2017.

Table D.6 Estimated dam-specific transportation SAR percentages of PIT-tagged Sawtooth hatchery spring Chinook for juvenile migration years 2007 to 2015 (with 90% confidence intervals). Transported smolts include both first-time and prior detected fish from Group T.

Migr Year	SAR(TLGR) %	(CI%)	Adult #	SAR(TLGS) %	(CI%)	Adult #	SAR(TLMN) %	(CI%)	Adult #
2007	0.91	(0.60 – 1.25)	20	0.42	(0.13 – 0.85)	3	1.46	(0.61 – 2.41)	7
2008	1.08	(0.64 – 1.55)	15	1.37	(0.82 – 1.99)	15	1.80	(0.00 – 3.59)	3
2009	0.88	(0.44 – 1.38)	10	0.63	(0.16 – 1.16)	4	0.71	(0.00 – 2.14)	1
2010	0.64	(0.31 – 1.05)	8	0.70	(0.27 – 1.23)	5		NA	None
2011	0.09	(0.00 – 0.18)	2	0.072	(0.00 – 0.22)	1	0.16	(0.00 – 0.49)	1
2012	0.37	(0.09 – 0.74)	4	0.61	(0.29 – 0.95)	8	0.68	(0.20 – 1.40)	3
2013	0.46	(0.23 – 0.72)	10	0.60	(0.27 – 0.96)	9	0.16	(0.00 – 0.48)	1
2014	0.27	(0.11 – 0.48)	5	0.30	(0.08 – 0.59)	4	0.39	(0.00 – 0.79)	3
2015[A]	0.49	(0.12 – 0.90)	4	0.24	(0.00 – 0.60)	2	0.35	(0.00 – 1.02)	1

[A] Return to GRA incomplete with 2-salts through 9/15/2017.

Table D.7 Estimated dam-specific transportation SAR percentages of PIT-tagged McCall hatchery summer Chinook for juvenile migration years 1997 to 2015 (with 90% confidence intervals). Transported smolts include only first-time detected fish from total PIT-tag release through 2005 and both first-time and prior detected fish from Group T beginning 2006.

Migr Year	SAR(TLGR) %	(CI%)	Adult #	SAR(TLGS) %	(CI%)	Adult #	SAR(TLMN) %	(CI%)	Adult #
1997	1.49	(1.21 – 1.76)	87	2.86	(0.85 – 5.83)	3	3.23	(0.00 – 9.52)	1
1998	2.93	(2.65 – 3.22)	263	1.00	(0.46 – 1.62)	9	0.64	(0.00 – 1.88)	1
1999	4.36	(3.88 – 4.83)	206	3.23	(2.82 – 3.65)	161	4.93	(2.26 – 7.58)	10
2000	4.54	(4.18 – 4.94)	386	3.26	(2.69 – 3.83)	92	2.45	(1.61 – 3.36)	19
2001	1.41	(1.23 – 1.58)	184	0.76	(0.49 – 1.05)	20	0.40	(0.00 – 0.91)	2
2002	1.63	(1.31 – 1.95)	70	1.43	(1.14 – 1.74)	59	1.00	(0.00 – 2.21)	2
2003	0.82	(0.66 – 0.98)	68	0.85	(0.62 – 1.10)	36	0.81	(0.34 – 1.31)	7
2004	0.43	(0.35 – 0.51)	70	0.36	(0.21 – 0.53)	14		NA	None
2005	0.67	(0.59 – 0.77)	116	0.53	(0.36 – 0.72)	24	0.02	(0.00 – 0.07)	1
2006	1.35	(1.12 – 1.59)	80	0.98	(0.75 – 1.23)	46	1.60	(1.14 – 2.03)	37
2007	1.58	(1.23 – 1.94)	55	1.35	(0.77 – 2.00)	12	1.30	(0.64 – 1.96)	10
2008	1.36	(1.11 – 1.62)	76	1.39	(1.11 – 1.70)	55	2.17	(1.35 – 3.06)	17
2009	0.86	(0.62 – 1.12)	34	0.64	(0.41 – 0.92)	17	0.71	(0.25 – 1.19)	6
2010	0.84	(0.60 – 1.11)	29	0.54	(0.27 – 0.84)	10	0.51	(0.00 – 1.21)	2
2011	0.30	(0.18 – 0.44)	13	0.43	(0.26 – 0.62)	15	0.27	(0.10 – 0.48)	5
2012	0.60	(0.35 – 0.89)	12	0.77	(0.50 – 1.05)	22	0.96	(0.48 – 1.45)	12
2013	0.79	(0.57 – 1.02)	33	0.95	(0.68 – 1.25)	28	0.90	(0.50 – 1.31)	13
2014	0.71	(0.53 – 0.90)	39	0.41	(0.25 – 0.59)	15	0.38	(0.18 – 0.62)	8
2015[A]	0.48	(0.25 – 0.77)	10	0.32	(0.14 – 0.53)	7		NA	None

[A] Return to GRA incomplete with 2-salts through 9/15/2017.

Table D.8 Estimated dam-specific transportation SAR percentages of PIT-tagged Imnaha hatchery summer Chinook for juvenile migration years 1997 to 2015 (with 90% confidence intervals). Transported smolts include only first-time detected fish from total PIT-tag release through 2005 and both first-time and prior detected fish from Group T beginning 2006.

Migr Year	SAR(TLGR) %	(CI%)	Adult #	SAR(TLGS) %	(CI%)	Adult #	SAR(TLMN) %	(CI%)	Adult #
1997	1.21	(0.84 – 1.66)	25	NA		None	NA		None
1998	0.92	(0.69 – 1.18)	37	0.66	(0.17 – 1.22)	4	NA		None
1999	3.43	(2.82 – 4.08)	74	2.31	(1.80 – 2.86)	53	2.63	(0.00 – 5.31)	3
2000	3.99	(3.50 – 4.48)	154	2.48	(1.91 – 3.09)	45	2.26	(1.18 – 3.36)	12
2001	0.73	(0.56 – 0.92)	42	0.37	(0.13 – 0.64)	6	NA		None
2002	0.74	(0.38 – 1.12)	12	0.82	(0.51 – 1.19)	16	1.55	(0.00 – 2.97)	3
2003	0.58	(0.36 – 0.81)	18	0.64	(0.32 – 0.99)	10	0.67	(0.00 – 1.58)	2
2004	0.34	(0.21 – 0.48)	16	0.42	(0.20 – 0.68)	8	1.23	(0.00 – 2.91)	2
2005	0.34	(0.20 – 0.48)	15	0.15	(0.00 – 0.36)	2	NA		None
2006	0.83	(0.47 – 1.22)	16	0.81	(0.54 – 1.11)	19	1.22	(0.61 – 1.90)	10
2007	1.32	(0.89 – 1.77)	22	0.39	(0.00 – 1.17)	1	NA		None
2008	1.72	(1.35 – 2.10)	57	2.55	(1.94 – 3.22)	44	1.37	(0.35 – 2.59)	4
2009	1.40	(1.05 – 1.75)	40	1.68	(1.15 – 2.25)	25	0.65	(0.20 – 1.32)	3
2010	1.46	(0.94 – 1.99)	21	0.33	(0.00 – 0.67)	3	0.36	(0.00 – 1.10)	1
2011	0.13	(0.04 – 0.27)	3	0.38	(0.18 – 0.64)	6	0.39	(0.00 – 0.79)	3
2012	0.39	(0.00 – 0.77)	3	0.15	(0.00 – 0.37)	2	0.16	(0.00 – 0.48)	1
2013	0.83	(0.48 – 1.22)	14	0.40	(0.16 – 0.74)	5	0.56	(0.00 – 1.13)	3
2014	0.55	(0.31 – 0.79)	14	0.53	(0.27 – 0.80)	10	0.35	(0.11 – 0.69)	3
2015[A]	0.34	(0.08 – 0.65)	4	0.69	(0.29 – 1.15)	7	0.28	(0.00 – 0.83)	1

[A] Return to GRA incomplete with 2-salts through 9/15/2017.

Table D.9 Estimated dam-specific transportation SAR percentages of PIT-tagged Pahsimeroi hatchery summer Chinook for juvenile migration years 2008 to 2015 (with 90% confidence intervals). Transported smolts include both first-time and prior detected fish from Group T beginning 2008.

Migr Year	SAR(TLGR) %	(CI%)	Adult #	SAR(TLGS) %	(CI%)	Adult #	SAR(TLMN) %	(CI%)	Adult #
2008	1.31	(0.89 – 1.74)	26	2.34	(1.60 – 3.18)	22	0.83	(0.00 – 2.40)	1
2009	1.47	(0.32 – 2.66)	5	0.00	(0.00 – 0.00)	0	0.00	(0.00 – 0.00)	0
2010	0.25	(0.00 – 0.54)	2	0.61	(0.00 – 1.34)	2	0.00	(0.00 – 0.00)	0
2011[A]	NA		None	NA		None	NA		None
2012[A]	NA		None	NA		None	NA		None
2013	0.30	(0.00 – 0.73)	2	NA		None	NA		None
2014	NA		None	NA		None	0.14	(0.00 – 0.41)	1
2015[B]	NA		None	NA		None	NA		None

[A] No transported smolts returned as adults for Pahsimeroi 2011 or 2012.
[B] Return to GRA incomplete with 2-salts through 9/15/2017.

Table D.10 Estimated dam-specific transportation SAR percentages of PIT-tagged Clearwater hatchery summer Chinook for juvenile migration years 2011 to 2015 (with 90% confidence intervals).

Migr Year	SAR(TLGR) %	(CI%)	Adult #	SAR(TLGS) %	(CI%)	Adult #	SAR(TLMN) %	(CI%)	Adult #
2011	0.07	(0.00 – 0.20)	1	0.16	(0.00 – 0.32)	2	NA		None
2012	0.20	(0.00 – 0.59)	1	0.29	(0.00 – 0.67)	2	NA		None
2013	NA		None	0.62	(0.24 – 1.13)	5	0.38	(0.00 – 1.12)	1
2014	0.50	(0.18 – 0.90)	6	0.58	(0.27 – 0.92)	8	0.20	(0.00 – 0.42)	2
2015[A]	NA		None	NA		None	NA		None

[A] Return to GRA incomplete with 2-salts through 9/17/2017

Table D.11 Estimated dam-specific transportation SAR percentages of PIT-tagged wild steelhead in the annual aggregate groups for 1997 to 2014 (with 90% confidence intervals). Transported smolts include only first-time detected fish from total PIT-tag release through 2005 and both first-time and prior detected fish from Group T beginning 2006.

Migr Year	SAR(TLGR) %	CI %	Adult #	SAR(TLGS) %	(CI%)	Adult #	SAR(TLMN) %	(CI%)	Adults #
1997	1.87	(0.47 – 3.59)	4	NA		None	NA		None
1998	0.34	(0.00 – 1.00)	1	NA		None	NA		None
1999	2.69	(0.98 – 4.65)	6	4.44	(1.12 – 8.43)	4	2.99	(0.00 – 7.04)	2
2000	3.50	(1.51 – 5.64)	7	3.37	(0.00 – 6.86)	3	2.73	(0.74 – 5.36)	3
2001	3.09	(1.16 – 5.59)	5	NA		None	NA		None
2002	3.91	(1.55 – 6.82)	5	1.61	(0.00 – 4.92)	1	2.22	(0.65 – 4.41)	3
2003	1.73	(1.15 – 2.40)	21	2.75	(1.71 – 3.85)	18	2.20	(0.84 – 4.07)	5
2004	0.91	(0.66 – 1.19)	31	0.87	(0.37 – 1.40)	7	0.63	(0.00 – 1.90)	1
2005	0.97	(0.71 – 1.25)	34	0.62	(0.27 – 1.01)	7	NA		None
2006	1.23	(0.82 – 1.75)	19	1.56	(1.03 – 2.13)	22	1.16	(0.45 – 2.08)	5
2007	4.25	(3.45 – 5.10)	70	4.85	(3.56 – 6.19)	35	4.66	(2.87 – 6.94)	13
2008	3.88	(3.07 – 4.74)	58	5.09	(3.76 – 6.54)	34	2.44	(0.00 – 5.26)	2
2009	3.06	(2.31 – 3.81)	44	4.93	(3.78 – 6.11)	45	1.25	(0.31 – 2.43)	4
2010	2.38	(1.76 – 3.00)	39	2.64	(1.82 – 3.55)	25	1.67	(0.00 – 3.51)	3
2011	1.61	(1.02 – 2.31)	19	1.56	(0.85 – 2.34)	11	0.96	(0.24 – 1.72)	4
2012	1.46	(0.83 – 2.17)	1	3.70	(2.42 – 5.12)	19	2.46	(0.93 – 4.35)	5
2013	2.79	(2.17 – 3.46)	48	2.98	(2.25 – 3.72)	44	3.67	(2.41 – 5.02)	22
2014[A]	2.23	(1.75 – 2.74)	54	1.56	(1.08 – 2.06)	26	1.13	(0.48 – 1.88)	7

[A] Return to GRA incomplete with 2-salts through 9/15/2017.

Table D.12 Estimated dam-specific transportation SAR percentages of PIT-tagged hatchery steelhead in the annual aggregate groups for 1997 to 2014 (with 90% confidence intervals). Transported smolts include only first-time detected fish from total PIT-tag release through 2005 and both first-time and prior detected fish from total PIT-tag release beginning 2006 (pre-assignment to Group T does not begin until 2008 for hatchery steelhead).

Migr Year	SAR(TLGR) %	CI %	Adult #	SAR(TLGS) %	(CI%)	Adult #	SAR(TLMN) %	(CI%)	Adult #
1997	0.59	(0.27 – 0.96)	9	NA		None	NA		None
1998	0.63	(0.24 – 1.13)	5	0.28	(0.00 – 0.84)	1	0.64	(0.00 – 1.91)	1
1999	1.03	(0.50 – 1.69)	8	1.37	(0.34 – 2.57)	4	NA		None
2000	3.01	(1.74 – 4.56)	14	1.37	(0.00 – 3.90)	1	1.09	(0.00 – 3.09)	1
2001	1.21	(0.30 – 2.32)	4	NA		None	NA		None
2002	2.42	(0.70 – 4.93)	3	NA		None	NA		None
2003	1.98	(1.49 – 2.49)	41	2.12	(1.51 – 2.76)	32	1.21	(0.59 – 1.86)	10
2004	1.70	(0.58 – 2.83)	6	4.60	(1.28 – 8.54)	4	NA		None
2005	2.37	(1.43 – 3.43)	15	1.03	(0.00 – 2.29)	2	2.86	(0.00 – 8.82)	1
2006	1.65	(0.63 – 3.02)	5	2.58	(1.51 – 3.82)	13	2.37	(1.02 – 4.07)	7
2007	1.88	(1.22 – 2.59)	19	2.63	(1.78 – 3.51)	25	1.97	(1.13 – 3.02)	12
2008	3.12	(2.90 – 3.33)	577	3.97	(3.73 – 4.22)	640	3.99	(3.31 – 4.66)	92
2009	1.61	(1.48 – 1.74)	377	1.74	(1.55 – 1.93)	224	1.73	(1.47 – 2.00)	113
2010	1.37	(1.24 – 1.50)	275	1.82	(1.63 – 2.01)	254	1.83	(1.39 – 2.29)	46
2011	0.79	(0.69 – 0.90)	152	0.89	(0.75 – 1.03)	108	0.57	(0.44 – 0.72)	48
2012	1.33	(1.17 – 1.49)	179	1.30	(1.10 – 1.51)	116	1.59	(1.29 – 1.86)	83
2013	1.45	(1.30 – 1.64)	200	1.52	(1.37 – 1.68)	235	1.53	(1.28 – 1.82)	93
2014[A]	1.39	(1.25 – 1.54)	229	1.66	(1.48 – 1.85)	213	1.87	(1.61 – 2016)	125

[A] Return to GRA incomplete with 2-salts through 9/15/2017.

Table D.13 Estimated dam-specific transportation SAR percentages of PIT-tagged Clearwater–B hatchery steelhead for 2008 to 2014 (with 90% confidence intervals). Pre-assignment to Group T began in 2008 for hatchery steelhead.

Hatchery Group	SAR(TLGR) %	CI %	Adult #	SAR(TLGS) %	(CI%)	Adult #	SAR(TLMN) %	(CI%)	Adult #
2008	1.82	(1.49 – 2.17)	77	2.32	(1.85 – 2.79)	63	1.96	(0.85 – 3.19)	7
2009	0.93	(0.68 – 1.17)	35	1.03	(0.63 – 1.54)	15	1.23	(0.66 – 1.91)	11
2010	0.74	(0.56 – 0.93)	45	1.22	(0.86 – 1.63)	30	2.08	(1.00 – 3.37)	8
2011	0.47	(0.31 – 0.65)	20	0.73	(0.46 – 1.02)	19	0.17	(0.05 – 0.35)	3
2012	0.77	(0.43 – 1.15)	11	1.42	(0.81 – 2.19)	12	2.27	(1.21 – 3.48)	11
2013	0.70	(0.40 – 1.06)	12	0.61	(0.31 – 0.96)	10	0.18	(0.00 – 0.54)	1
2014[A]	0.96	(0.66 – 1.29)	25	2.08	(1.64 – 2.60)	49	1.54	(1.05 – 2.06)	27

[A] Return to GRA incomplete with 2-salts through 9/15/2017.

Table D.14 Estimated dam-specific transportation SAR percentages of PIT-tagged Grande Ronde–A hatchery steelhead for 2008 to 2014 (with 90% confidence intervals). Pre-assignment to Group T began in 2008 for hatchery steelhead.

Hatchery	SAR(TLGR)		Adult	SAR(TLGS)		Adult	SAR(TLMN)		Adult
Group	%	CI %	#	%	(CI%)	#	%	(CI%)	#
2008	5.16	(4.51 – 5.88)	163	5.34	(4.70 – 6.06)	153	5.19	(3.25 – 7.14)	18
2009	1.73	(1.39 – 2.11)	61	1.78	(1.32 – 2.28)	38	1.69	(1.06 – 2.43)	19
2010	1.83	(1.42 – 2.26)	49	2.52	(1.92 – 3.10)	48	4.32	(2.73 – 6.12)	16
2011	0.38	(0.16 – 0.65)	7	0.34	(0.13 – 0.62)	5	0.40	(0.10 – 0.78)	4
2012	1.53	(1.08 – 2.05)	26	1.93	(1.30 – 2.65)	22	1.47	(0.77 – 2.22)	12
2013	1.60	(1.15 – 2.15)	30	1.67	(1.23 – 2.11)	35	2.09	(1.40 – 2.82)	20
2014[A]	1.97	(1.48 – 2.48)	41	1.56	(1.11 – 2.09)	30	2.39	(1.69 – 3.14)	27

[A] Return to GRA incomplete with 2-salts through 9/15/2017.

Table D.15 Estimated dam-specific transportation SAR percentages of PIT-tagged Imnaha–A hatchery steelhead for 2008 to 2014 (with 90% confidence intervals). Pre-assignment to Group T began in 2008 for hatchery steelhead.

Hatchery	SAR(TLGR)		Adult	SAR(TLGS)		Adult	SAR(TLMN)		Adult
Group	%	CI %	#	%	(CI%)	#	%	(CI%)	#
2008	4.18	(3.51 – 4.87)	107	5.94	(5.18 – 6.75)	150	5.06	(3.43 – 6.76)	22
2009	1.72	(1.32 – 2.13)	50	1.65	(1.65 – 2.17)	27	2.31	(1.53 – 3.14)	22
2010	1.49	(1.10 – 1.91)	36	2.19	(1.64 – 2.76)	40	1.71	(0.60 – 2.91)	6
2011	0.67	(0.40 – 0.94)	17	0.99	(0.57 – 1.45)	14	0.69	(0.29 – 1.15)	7
2012	2.04	(1.51 – 2.59)	38	1.53	(1.05 – 2.10)	21	1.31	(0.71 – 1.94)	11
2013	2.24	(1.77 – 2.80)	51	2.19	(1.68 – 2.71)	50	2.06	(1.30 – 2.88)	20
2014[A]	2.18	(1.74 – 2.61)	65	1.91	(1.46 – 2.42)	42	2.09	(1.36 – 2.83)	22

[A] Return to GRA incomplete with 2-salts through 9/15/2017.

Table D.16 Estimated dam-specific transportation SAR percentages of PIT-tagged Salmon–A hatchery steelhead for 2008 to 2014 (with 90% confidence intervals). Pre-assignment to Group T began in 2008 for hatchery steelhead.

Hatchery	SAR(TLGR)		Adult	SAR(TLGS)		Adult	SAR(TLMN)		Adult
Group	%	CI %	#	%	(CI%)	#	%	(CI%)	#
2008	4.74	(4.21 – 5.31)	193	5.91	(5.32 – 6.55)	238	6.33	(4.66 – 8.08)	40
2009	2.00	(1.75 – 2.29)	147	1.98	(1.64 – 2.36)	82	2.20	(1.67 – 2.74)	44
2010	1.80	(1.52 – 2.10)	105	1.98	(1.66 – 2.33)	96	1.22	(0.67 – 1.88)	11
2011	1.38	(1.16 – 1.63)	100	1.43	(1.16 – 1.16)	64	1.01	(0.71 – 1.28)	32
2012	1.47	(1.20 – 1.74)	70	1.30	(0.96 – 1.67)	43	2.01	(1.48 – 2.59)	37
2013	1.73	(1.42 – 2.05)	84	1.94	(1.63 – 2.26)	106	2.03	(1.53 – 2.53)	43
2014[A]	1.26	(0.97 – 1.56)	49	1.74	(1.37 – 2.17)	49	2.16	(1.49 – 2.83)	29

[A] Return to GRA incomplete with 2-salts through 9/15/2017.

Table D.17 Estimated dam-specific transportation SAR percentages of PIT-tagged Salmon–B hatchery steelhead for 2008 to 2014 (with 90% confidence intervals). Pre-assignment to Group T began in 2008 for hatchery steelhead.

Hatchery Group	SAR(TLGR) %	CI %	Adult #	SAR(TLGS) %	(CI%)	Adult #	SAR(TLMN) %	(CI%)	Adult #
2008	0.82	(0.61 – 1.06)	37	0.90	(0.64 – 1.15)	36	0.96	(0.36 – 1.71)	5
2009	0.76	(0.55 – 0.97)	34	1.04	(0.75 – 1.37)	28	0.41	(0.16 – 0.74)	5
2010	0.33	(0.14 – 0.56)	7	0.51	(0.28 – 0.78)	11	0.33	(0.00 – 0.97)	1
2011	0.29	(0.14 – 0.48)	8	0.16	(0.05 – 0.33)	3		NA	None
2012	0.74	(0.51 – 0.99)	25	0.65	(0.35 – 9.05)	13	0.93	(0.47 – 1.44)	10
2013	0.32	(0.16 – 0.50)	8	0.56	(0.36 – 0.79)	19	0.23	(0.00 – 0.47)	3
2014 [A]	0.86	(0.63 – 1.10)	34	0.99	(0.70 – 1.30)	29	1.37	(0.86 – 1.98)	16

[A] Return to GRA incomplete with 2-salts through 9/15/2017.

Table D.18 Estimated dam-specific transportation SAR percentages of PIT-tagged Hells Canyon–A hatchery steelhead for 2009 to 2014 (with 90% confidence intervals). Pre-assignment to Group T began in 2008 for hatchery steelhead.

Hatchery Group	SAR(TLGR) %	CI %	Adult #	SAR(TLGS) %	(CI%)	Adult #	SAR(TLMN) %	(CI%)	Adult #
2009	0.04	(0.03 – 0.05)	50	0.04	(0.03 – 0.05)	34	0.03	(0.02 – 0.05)	12
2010	0.05	(0.04 – 0.07)	52	0.60	(0.04 – 0.08)	45	0.03	(0.01 – 0.06)	7
2011	0.30	(0.00 – 0.74)	2	0.92	(0.00 – 1.83)	3	0.87	(0.00 – 1.90)	2
2012	2.43	(1.12 – 3.87)	9	1.79	(0.63 – 3.30)	5	1.23	(0.00 – 2.84)	2
2013	2.55	(1.58 – 3.73)	15	2.75	(1.65 – 3.98)	15	3.16	(1.16 – 5.46)	6
2014[A]	1.63	(0.95 – 2.36)	15	2.30	(1.39 – 3.39)	14	1.63	(0.41 – 3.21)	4

[A] Return to GRA incomplete with 2-salts through 9/15/2017.

Table D.19 Estimated dam-specific transportation SAR percentages of PIT-tagged Sawtooth hatchery sockeye for 2009 to 2015 (with 90% confidence intervals).

Hatchery Group	SAR(TLGR) %	CI %	Adult #	SAR(TLGS) %	(CI%)	Adult #	SAR(TLMN) %	(CI%)	Adult #
2009	1.80	(1.44 – 2.19)	69	0.62	(0.40 – 0.84)	22	1.48	(1.02 – 1.93)	30
2010[A]		NA	None		NA	None		NA	None
2011	0.13	(0.04 – 0.26)	3	0.22	(0.00 – 0.64)	1	0.03	(0.00 – 0.09)	1
2012	0.14	(0.07 – 0.22)	8	0.04	(0.00 – 0.09)	2	0.05	(0.00 – 0.15)	1
2013	0.23	(0.14 – 0.34)	8	0.04	(0.00 – 0.11)	1		NA	None
2014	0.46	(0.27 – 0.67)	13	0.17	(0.00 – 0.36)	2	0.41	(0.17 – 0.66)	7
2015[B]	0.11	(0.00 – 0.35)	1	0.13	(0.00 – 0.40)	1		NA	None

[A] Only 38 PIT-tagged Sawtooth Hatchery sockeye estimated in transport category with no adult returns.
[B] Return to GRA incomplete with 2-salts through 9/15/2017

Table D.20 Estimated dam-specific transportation SAR percentages of PIT-tagged Oxbow hatchery sockeye for 2009 to 2012 (with 90% confidence intervals).

Hatchery Group	SAR(TLGR) %	CI %	Adult #	SAR(TLGS) %	(CI%)	Adult #	SAR(TLMN) %	(CI%)	Adult #
2009	3.29	(1.83 – 4.70)	13	2.09	(0.71 – 3.47)	6	3.16	(1.14 – 5.29)	6
2010[A]	NA		None	NA		None	NA		None
2011	0.12	(0.00 – 0.35)	1	NA		None	NA		None
2012	3.49	(2.27 – 4.67)	21	1.09	(0.42 – 1.98)	5	1.38	(0.00 – 2.93)	3

[A] Due to small sample sizes and other issues with 2010 (see Appendix A, Special considerations for 2010), estimates of dam-specific transportation SAR percentages were not possible.

APPENDIX E

ESTIMATED PROPORTIONS OF SMOLTS EXPERIENCING TX, C0, and C1 PASSAGE ROUTES

Appendix E
Estimated proportion of smolts experiencing T_X, C_0, and C_1 passage routes

The random pre-assignment of part of a release of PIT-tagged fish to monitor-mode (Group T) allows direct estimation of the proportion of smolts experiencing T_X, C_0, and C_1 passage routes for the CSS PIT-tag groups in recent years. Pre-assigning of the CSS PIT-tag wild and hatchery Chinook and wild steelhead groups began with the 2006 smolt migration season. Pre-assignments did not begin until 2008 for PIT-tagged hatchery steelhead. Group T reflects the untagged fish passage experience under a given year's fish passage management scenario.

Methods

In years prior to 2006, when marks were not pre-assigned to passage groups, the estimated number of smolts in each study category was adjusted to a projection of what that number could be if the proportion of smolts in each study category was the same as the run at large. This was done by utilizing the COE transportation and bypass numbers at LGR, LGS, and LMN, which are collected at the level of species and rearing type (the latter to a lesser degree of accuracy). These seasonal proportions were applied to the PIT-tagged smolts transported for a given group of interest at each dam and summed in LGR-equivalents to provide a projection of T_0* smolts transported for that particular group. The projection of C_1* bypassed was simply the remainder of ($T_0 + C_0 – T_0$*) smolts. These projections are presented in Chapter 7 (Tables 7.7, 7.8, 7.13, and 7.14 for PIT-tagged wild Chinook, hatchery Chinook by individual hatchery, wild steelhead, and hatchery steelhead, respectively) of the CSS 2009 Annual Report (Tuomikoski et al. 2009).

In years 2006 and later, the proportion of T_X, C_0, and C_1 smolts are computed directly from Group T for each corresponding CSS PIT-tag group. The reach survival rates (S_j) and collection probabilities (P_j) are computed with the total release (combined Group T smolts and the return-to-river Group R smolts) and passed to Group T, while the parameters R_1, X_{12}, X_{1A2}, X_{1AA2}, and C_1 removals (d_1, d_2, d_3, d_4) and C_0 removals (d_0) are specific to Group T. The equations for estimating the T_X, C_0, and C_1 smolt numbers in Group T are given in Chapter 4. In order for the proportion of Group T smolts being routed to T_X, C_0, and C_1 to reflect those in-river migrants estimated alive to the tailrace of LMN expanded to LGR-equivalents, any removals below LMN need to be added back into the C_0 and C_1 estimates. The following equations are therefore used to estimate the number of PIT-tagged smolts in Group T for each of the three passage history experience categories:

$$T_X = X_{12} + X_{1A2} / S_2 + X_{1AA2} / (S_2 \bullet S_3) \qquad [E.1]$$

$$C_0^* = E(C_0) + d_0 = R_1 \bullet S_1 \bullet (1-P_2) \bullet (1-P_3) \bullet (1-P_4) \qquad [E.2]$$

$$C_1^* = E(C_1) + d_1 = R_1 \bullet S_1 \bullet [P_2 + (1-P_2) \bullet P3 + (1-P_2) \bullet (1-P_3) \bullet P4] - [(d_2 + d_3/S_2 + d_4/(S_2 \bullet S_3)] \qquad [E.3]$$

and

$$P[T_X] = T_X / (T_X + C_0^* + C_1^*) \quad [E.4]$$

$$P[C_0^*] = C_0^* / (T_X + C_0^* + C_1^*) \quad [E.5]$$

$$P[C_1^*] = C_1^* / (T_X + C_0^* + C_1^*) \quad [E.6]$$

Results

Beginning in 2006 there was a major shift in the transportation operations within the FCRPS. The start of transportation was delayed at the three Snake River collector dams due to research findings suggesting that fish transported too early in the migration season have lower survival than if they were allowed to migrate in-river. In years prior to 2006, transportation of the run as a whole commenced as soon as the Snake River collection facilities became operational each year, which was around March 25 at LGR and April 1 at LGS and LMN. For years 2006 to 2014, the start of collecting fish for transportation has been delayed to:

Year	Lower Granite Dam (LGR)	Little Goose Dam (LGS)	Lower Monumental Dam (LMN)
2006	April 20	April 24	April 28
2007	May 1	May 8	May 11
2008	May 1	May 9	May 12
2009	May 1	May 5	May 8
2010	April 25	May 2	May 5
2011	May 1	May 5	May 8
2012	May 1	May 4	May 6
2013	May 1	May 3	May 7
2014	May 1	May 1	May 1
2015	May 1	May 1	May 1
2016	May 1	May 1	May 1

In years prior to 2006, the start time of transportation encompassed most of the emigrating groups of CSS marked fish. With the change to a later start of transportation beginning in 2006, there is now a portion of the population that migrates entirely in-river through the hydrosystem before transportation begins. This reduces the proportion of the smolt population being transported in a given year as seen in Tables E.1 through E.5, particularly in 2007 through 2009 with the later start of transportation compared to 2006. Despite the slightly earlier start date for transportation in 2010, the estimates for proportion transported in 2010 were generally low. This is likely due to the later migration timing of juveniles in this year, as well as the higher spill proportions at Lower Granite and Lower Monumental dams. The outmigration of PIT-tagged Dworshak NFH and Clearwater Hatchery spring Chinook tend to commence earlier than the other four CSS PIT-tag hatchery Chinook groups and have consistently had the lowest proportion transported in all eleven years (range 7.0%–52.2% for DWOR and 12.3%–66.3% for CLWH). The other CSS hatchery Chinook groups had fairly similar proportions transported within any given year, with the highest proportions occurring in 2006 (range 65.3%–70.5%) and lowest proportions in 2010 (range 18.6%–32.5%). The PIT-tagged wild Chinook aggregate also had the highest proportion transported in 2006 (66.4%), but its lowest proportion

transported estimate came in 2015 (15.5%). The PIT-tagged wild steelhead aggregate likewise had the highest proportion transported in 2006 (64.9%), while the lowest proportion transported was in 2015 (20.2%). The estimates of proportion transported are consistent among the different groups and among the three years where pre-assignments have been carried out under the CSS. In general, the proportion transported for the hatchery steelhead groups has been in the 30% to 50% range, with a few exceptions for particular groups. Finally, estimates of proportion transported for sockeye juveniles were in the range of 43.9% - 65.9%, with the exception of 2015, when proportion transported was 12.4%. With the later start of transportation in 2007 to 2016 (the first half of May), the goal of reaching a 50% spread-the-risk transport versus in-river migration appears to be more attainable now than was possible in earlier years for both wild Chinook and wild steelhead stocks. However, as was seen in 2010, this is still affected by the migration timing of juveniles.

Table E.1 Migration year 2006 estimated proportion of PIT-tagged smolts in CSS wild and hatchery Chinook and wild steelhead groups experiencing passage through transportation, bypass, or without detection at the Snake River transportation sites (based on PIT-tagged fish in the monitor-mode (TWS) group). (Non-parametric 90% confidence intervals are shown.)

Fish	Transportation			Passage w/o detection			Bypass passage		
source[1]	$Pr(T_X)$	LL	UL	$Pr(C_0)$	LL	UL	$Pr(C_1)$	LL	UL
RAPH	0.705	0.697	0.713	0.213	0.209	0.218	0.082	0.074	0.090
DWOR	0.522	0.515	0.530	0.319	0.314	0.325	0.158	0.151	0.166
CATH	0.680	0.654	0.706	0.256	0.241	0.269	0.064	0.040	0.090
CLWH	0.625	0.614	0.636	0.299	0.290	0.308	0.076	0.066	0.085
MCCA	0.653	0.643	0.663	0.275	0.269	0.281	0.072	0.062	0.081
IMNA	0.669	0.654	0.685	0.215	0.206	0.223	0.116	0.101	0.131
WCh	0.664	0.652	0.676	0.151	0.147	0.156	0.184	0.173	0.197
WSt	0.649	0.631	0.667	0.072	0.067	0.077	0.280	0.262	0.298

[1] **Hatchery spring Chinook**: RAPH=Rapid River H; DWOR =Dworshak H; CATH=Catherine Creek AP; CLWH=Clearwater H. **Hatchery summer Chinook**: MCCA=McCall H; IMNA=Imnaha AP. **Wild Chinook** aggregate is WCh and **wild steelhead** aggregate is WSt.

Table E.2 Migration year 2007 estimated proportion of PIT-tagged smolts in CSS wild and hatchery Chinook and wild steelhead groups experiencing passage through transportation, bypass, or without detection at the Snake River transportation sites (based on PIT-tagged fish in the monitor-mode (TWS) group). (Non-parametric 90% confidence intervals are shown.)

Fish	Transportation			Passage w/o detection			Bypass passage		
source[1]	$Pr(T_X)$	LL	UL	$Pr(C_0)$	LL	UL	$Pr(C_1)$	LL	UL
RAPH	0.347	0.341	0.354	0.519	0.513	0.525	0.134	0.126	0.141
DWOR	0.083	0.081	0.086	0.687	0.682	0.692	0.230	0.225	0.235
CATH	0.473	0.452	0.494	0.465	0.451	0.479	0.062	0.042	0.081
CLWH	0.123	0.119	0.127	0.686	0.680	0.692	0.191	0.185	0.197
SAWT	0.454	0.436	0.471	0.456	0.442	0.471	0.090	0.075	0.106
MCCA	0.274	0.267	0.281	0.616	0.610	0.623	0.110	0.102	0.117
IMNA	0.225	0.216	0.234	0.552	0.543	0.561	0.223	0.212	0.234
WCh	0.213	0.207	0.220	0.490	0.483	0.496	0.297	0.289	0.306
WSt	0.401	0.385	0.416	0.385	0.373	0.399	0.214	0.198	0.229

[1] **Hatchery spring Chinook**: RAPH=Rapid River H; DWOR =Dworshak H; CATH=Catherine Creek AP; CLWH=Clearwater H; SAWT=Sawtooth H. **Hatchery summer Chinook**: MCCA=McCall H; IMNA=Imnaha AP. **Wild Chinook** aggregate is WCh and **wild steelhead** aggregate is WSt.

Table E.3 Migration year 2008 estimated proportion of PIT-tagged smolts in CSS wild and hatchery Chinook and wild steelhead groups experiencing passage through transportation, bypass, or without detection at the Snake River transportation sites (based on PIT-tagged fish in the monitor-mode (TWS) group). (Non-parametric 90% confidence intervals are shown.)

Fish source[1]	Transportation			Passage w/o detection			Bypass passage		
	$Pr(T_X)$	LL	UL	$Pr(C_0)$	LL	UL	$Pr(C_1)$	LL	UL
Chinook									
RAPH	0.585	0.578	0.593	0.281	0.275	0.286	0.134	0.127	0.141
DWOR	0.338	0.331	0.345	0.470	0.463	0.478	0.192	0.184	0.199
CATH	0.600	0.579	0.619	0.293	0.281	0.306	0.107	0.088	0.125
CLWH	0.438	0.426	0.449	0.414	0.403	0.425	0.148	0.139	0.158
SAWT	0.594	0.563	0.621	0.307	0.286	0.329	0.100	0.075	0.124
MCCA	0.521	0.511	0.531	0.361	0.353	0.368	0.118	0.109	0.127
IMNA	0.541	0.528	0.552	0.283	0.275	0.292	0.176	0.164	0.188
PAHH	0.539	0.517	0.561	0.323	0.306	0.340	0.138	0.119	0.159
WCh	0.462	0.453	0.470	0.290	0.284	0.295	0.249	0.239	0.258
Steelhead									
GRN-A[2]	0.416	0.407	0.424	0.383	0.372	0.395	0.201	0.196	0.206
IMN-A[2]	0.436	0.425	0.445	0.348	0.335	0.364	0.216	0.210	0.222
SAL-A	0.485	0.476	0.493	0.350	0.343	0.358	0.165	0.157	0.174
CLWR-B	0.304	0.299	0.311	0.385	0.378	0.390	0.311	0.304	0.318
SAL-B	0.557	0.547	0.567	0.301	0.292	0.309	0.143	0.133	0.152
WSt	0.405	0.390	0.420	0.317	0.306	0.328	0.278	0.262	0.294

[1] **Hatchery spring Chinook**: RAPH=Rapid River H; DWOR =Dworshak H; CATH=Catherine Creek AP; CLWH=Clearwater H; SAWT=Sawtooth H. **Hatchery summer Chinook**: MCCA=McCall H; IMNA=Imnaha AP; PAHH=Pahsimeroi H. **Wild Chinook** aggregate is WCh. **Hatchery steelhead**: GRN-A=Grand Ronde (Wallowa) A; IMN-A=Imnaha R. A; SAL-A=Salmon R. A; CLWR-B=Clearwater R. B; SAL-B=Salmon R. B. **Wild steelhead** aggregate is WSt.

[2] Used method of estimating $Pr(T_X)$, $Pr(C_0)$, and $Pr(C_1)$ for groups without pre-assignment (see Chapter 2 of the CSS 2009 Annual Report (Tuomikoski et al. 2009) for methods).

Table E.4 Migration year 2009 estimated proportion of PIT-tagged smolts in CSS wild and hatchery Chinook, wild and hatchery steelhead groups, and hatchery sockeye experiencing passage through transportation, bypass, or without detection at the Snake River transportation sites (based on PIT-tagged fish in the monitor-mode (TWS) group). (Non-parametric 90% confidence intervals are shown.)

Fish source[1]	Transportation			Passage w/o detection			Bypass passage		
	$Pr(T_X)$	LL	UL	$Pr(C_0)$	LL	UL	$Pr(C_1)$	LL	UL
Chinook									
RAPH	0.437	0.430	0.443	0.404	0.398	0.410	0.159	0.152	0.167
DWOR	0.341	0.334	0.348	0.478	0.472	0.485	0.181	0.174	0.188
CATH	0.562	0.542	0.581	0.353	0.340	0.366	0.085	0.067	0.103
CLWH	0.245	0.240	0.251	0.486	0.480	0.492	0.269	0.262	0.275
SAWT	0.388	0.372	0.405	0.469	0.455	0.483	0.143	0.125	0.161
MCCA	0.404	0.395	0.413	0.468	0.460	0.475	0.128	0.119	0.137
IMNA	0.504	0.491	0.517	0.373	0.364	0.384	0.123	0.110	0.135
PAHH	0.084	0.078	0.089	0.394	0.384	0.403	0.523	0.512	0.535
WCh	0.416	0.408	0.425	0.225	0.221	0.229	0.359	0.350	0.367
Steelhead									
GRN-A	0.450	0.442	0.460	0.290	0.283	0.296	0.260	0.251	0.269
HCD-A	0.571	0.556	0.588	0.219	0.209	0.230	0.209	0.194	0.225
IMN-A	0.493	0.483	0.503	0.248	0.241	0.256	0.259	0.248	0.269
SAL-A	0.466	0.460	0.472	0.223	0.219	0.227	0.311	0.305	0.317
CLWR-B	0.218	0.213	0.222	0.179	0.175	0.182	0.604	0.599	0.609
SAL-B	0.539	0.531	0.548	0.214	0.208	0.220	0.247	0.238	0.255
WSt	0.453	0.439	0.468	0.190	0.183	0.198	0.357	0.341	0.371
Sockeye[2]									
SAWT	0.582	0.568	0.595	0.346	0.337	0.355	0.073	0.062	0.083

[1] **Hatchery spring Chinook**: RAPH=Rapid River H; DWOR =Dworshak H; CATH=Catherine Creek AP; CLWH=Clearwater H; SAWT=Sawtooth H. **Hatchery summer Chinook**: MCCA=McCall H; IMNA=Imnaha AP; PAHH=Pahsimeroi H. **Wild Chinook** aggregate is WCh. **Hatchery steelhead**: GRN-A=Grand Ronde (Wallowa) A; HCD-A=Mainstem below HCD; IMN-A=Imnaha R. A; SAL-A=Salmon R. A; CLWR-B=Clearwater R. B; SAL-B=Salmon R. B. **Wild steelhead** aggregate is WSt. **Hatchery sockeye**: OXBOW=Oxbow H; SAWT=Sawtooth H.

[2] Due to smalls sample sizes, proportions of Oxbow Hatchery sockeye through different passage routes cannot be calculated for migration years 2009–2011.

Table E.5 Migration year 2010 estimated proportion of PIT-tagged smolts in CSS wild and hatchery Chinook, wild and hatchery steelhead groups, and hatchery sockeye experiencing passage through transportation, bypass, or without detection at the Snake River transportation sites (based on PIT-tagged fish in the monitor-mode (TWS) group). (Non-parametric 90% confidence intervals are shown.)

Fish source[1]	Transportation			Passage w/o detection			Bypass passage		
	$Pr(T_X)$	LL	UL	$Pr(C_0)$	LL	UL	$Pr(C_1)$	LL	UL
Chinook									
RAPH	0.226	0.218	0.234	0.760	0.753	0.767	0.015	0.009	0.020
DWOR	0.186	0.180	0.192	0.727	0.721	0.733	0.086	0.081	0.092
CATH	0.293	0.274	0.312	0.697	0.680	0.714	0.010	-0.004	0.024
CLWH	0.143	0.138	0.148	0.794	0.788	0.800	0.063	0.059	0.068
SAWT	0.325	0.308	0.345	0.659	0.642	0.676	0.015	0.001	0.031
MCCA	0.279	0.269	0.289	0.705	0.695	0.714	0.016	0.009	0.023
IMNA	0.260	0.246	0.275	0.726	0.713	0.740	0.013	0.003	0.023
PAHH	0.210	0.193	0.228	0.696	0.679	0.715	0.094	0.078	0.108
WCh	0.399	0.391	0.407	0.542	0.535	0.549	0.059	0.051	0.066
Steelhead									
GRN-A	0.314	0.305	0.324	0.618	0.609	0.628	0.068	0.059	0.075
HCD-A	0.353	0.335	0.372	0.616	0.599	0.633	0.032	0.018	0.047
IMN-A	0.401	0.389	0.413	0.537	0.525	0.550	0.062	0.051	0.073
SAL-A	0.352	0.345	0.360	0.597	0.590	0.604	0.051	0.045	0.057
CLWR-B	0.309	0.302	0.316	0.540	0.534	0.548	0.151	0.144	0.157
SAL-B	0.421	0.407	0.436	0.542	0.528	0.554	0.037	0.026	0.049
WSt	0.347	0.333	0.361	0.561	0.548	0.575	0.093	0.080	0.105
Sockeye[2]									
SAWT[3]	--	--	--	--	--	--	--	--	--

[1] **Hatchery spring Chinook**: RAPH=Rapid River H; DWOR =Dworshak H; CATH=Catherine Creek AP; CLWH=Clearwater H; SAWT=Sawtooth H. **Hatchery summer Chinook**: MCCA=McCall H; IMNA=Imnaha AP; PAHH=Pahsimeroi H. **Wild Chinook** aggregate is WCh. **Hatchery steelhead**: GRN-A=Grand Ronde (Wallowa) A; HCD-A=Mainstem below HCD; IMN-A=Imnaha R. A; SAL-A=Salmon R. A; CLWR-B=Clearwater R. B; SAL-B=Salmon R. B. **Wild steelhead** aggregate is WSt. **Hatchery sockeye**: OXBOW=Oxbow H; SAWT=Sawtooth H.

[2] Due to smalls sample sizes, proportions of Oxbow Hatchery sockeye through different passage routes cannot be calculated for migration years 2009–2011.

[3] Due to small sample sizes, proportions of Sawtooth Hatchery sockeye through different passage routes cannot be calculated for migration year 2010.

Table E.6 Migration year 2011 estimated proportion of PIT-tagged smolts in CSS wild and hatchery Chinook, wild and hatchery steelhead groups, and hatchery sockeye experiencing passage through transportation, bypass, or without detection at the Snake River transportation sites (based on PIT-tagged fish in the monitor-mode (TWS) group). (Non-parametric 90% confidence intervals are shown.)

Fish source[1]	Transportation			Passage w/o detection			Bypass passage		
	$Pr(T_X)$	LL	UL	$Pr(C_0)$	LL	UL	$Pr(C_1)$	LL	UL
Chinook									
RAPH	0.508	0.501	0.515	0.329	0.323	0.335	0.163	0.155	0.170
DWOR	0.345	0.338	0.351	0.360	0.355	0.366	0.296	0.288	0.303
CATH	0.536	0.513	0.559	0.327	0.311	0.343	0.137	0.116	0.159
CLWH (sp)	0.252	0.247	0.257	0.349	0.344	0.353	0.399	0.393	0.405
CLWH (su)	0.381	0.370	0.393	0.323	0.314	0.331	0.296	0.284	0.308
SAWT	0.581	0.566	0.598	0.263	0.252	0.274	0.156	0.140	0.172
MCCA	0.433	0.425	0.441	0.397	0.389	0.405	0.171	0.163	0.179
IMNA	0.563	0.548	0.579	0.305	0.293	0.317	0.132	0.117	0.146
PAHH	0.206	0.196	0.215	0.243	0.236	0.251	0.551	0.540	0.562
WCh	0.352	0.345	0.359	0.204	0.200	0.208	0.444	0.436	0.451
Steelhead									
GRN-A	0.288	0.281	0.295	0.327	0.321	0.334	0.385	0.376	0.393
HCD-A	0.312	0.299	0.326	0.186	0.177	0.196	0.502	0.487	0.517
IMN-A	0.491	0.480	0.502	0.312	0.302	0.321	0.197	0.185	0.209
SAL-A	0.494	0.486	0.501	0.297	0.291	0.302	0.209	0.203	0.217
CLWR-B	0.257	0.252	0.261	0.183	0.179	0.186	0.561	0.556	0.566
SAL-B	0.515	0.504	0.525	0.312	0.304	0.320	0.173	0.163	0.184
WSt	0.476	0.459	0.492	0.248	0.237	0.258	0.277	0.258	0.293
Sockeye[2]									
SAWT	0.439	0.431	0.447	0.403	0.394	0.413	0.158	0.155	0.160

[1] **Hatchery spring Chinook**: RAPH=Rapid River H; DWOR =Dworshak H; CATH=Catherine Creek AP; CLWH=Clearwater H; SAWT=Sawtooth H. **Hatchery summer Chinook**: MCCA=McCall H; IMNA=Imnaha AP; PAHH=Pahsimeroi H. **Wild Chinook** aggregate is WCh. **Hatchery steelhead**: GRN-A=Grand Ronde (Wallowa) A; HCD-A=Mainstem below HCD; IMN-A=Imnaha R. A; SAL-A=Salmon R. A; CLWR-B=Clearwater R. B; SAL-B=Salmon R. B. **Wild steelhead** aggregate is WSt. **Hatchery sockeye**: OXBOW=Oxbow H; SAWT=Sawtooth H.

[2] Due to smalls sample sizes, proportions of Oxbow Hatchery sockeye through different passage routes cannot be calculated for migration years 2009–2011.

Table E.7 Migration year 2012 estimated proportion of PIT-tagged smolts in CSS wild and hatchery Chinook, wild and hatchery steelhead groups, and hatchery sockeye experiencing passage through transportation, bypass, or without detection at the Snake River transportation sites (based on PIT-tagged fish in the monitor-mode (TWS) group). (Non-parametric 90% confidence intervals are shown.)

Fish source[1]	Transportation			Passage w/o detection			Bypass passage		
	$Pr(T_X)$	LL	UL	$Pr(C_0)$	LL	UL	$Pr(C_1)$	LL	UL
Chinook									
RAPH	0.423	0.415	0.429	0.388	0.382	0.394	0.190	0.181	0.197
DWOR	0.202	0.197	0.207	0.434	0.428	0.440	0.364	0.357	0.371
CATH	0.463	0.444	0.482	0.335	0.323	0.349	0.202	0.182	0.221
CLWH (sp)	0.158	0.154	0.162	0.380	0.375	0.385	0.462	0.456	0.468
CLWH (su)	0.155	0.148	0.161	0.327	0.319	0.335	0.519	0.509	0.528
SAWT	0.488	0.472	0.506	0.301	0.291	0.312	0.210	0.193	0.227
MCCA	0.323	0.316	0.330	0.395	0.389	0.401	0.282	0.274	0.290
IMNA	0.305	0.296	0.315	0.338	0.330	0.347	0.356	0.346	0.367
PAHH	0.023	0.021	0.026	0.273	0.266	0.280	0.703	0.670	0.711
WCh	0.205	0.200	0.210	0.220	0.216	0.224	0.575	0.269	0.581
Steelhead									
GRN-A	0.247	0.241	0.254	0.279	0.273	0.286	0.473	0.465	0.481
HCD-A	0.230	0.217	0.243	0.205	0.194	0.216	0.565	0.550	0.581
IMN-A	0.407	0.396	0.417	0.270	0.262	0.279	0.323	0.312	0.334
SAL-A	0.326	0.321	0.331	0.293	0.288	0.298	0.381	0.375	0.388
CLWR-B	0.142	0.138	0.146	0.254	0.249	0.254	0.604	0.598	0.611
SAL-B	0.595	0.582	0.608	0.257	0.248	0.266	0.148	0.136	0.160
WSt	0.230	0.221	0.238	0.258	0.251	0.259	0.512	0.500	0.523
Sockeye									
OXBOW[2]	0.294	0.266	0.324	0.686	0.657	0.714	0.020	0.003	0.035
SAWT	0.672	0.6591	0.685	0.278	0.271	0.286	0.050	0.039	0.061

[1] **Hatchery spring Chinook**: RAPH=Rapid River H; DWOR =Dworshak H; CATH=Catherine Creek AP; CLWH=Clearwater H; SAWT=Sawtooth H. **Hatchery summer Chinook**: MCCA=McCall H; IMNA=Imnaha AP; PAHH=Pahsimeroi H. **Wild Chinook** aggregate is WCh. **Hatchery steelhead**: GRN-A=Grand Ronde (Wallowa) A; HCD-A=Mainstem below HCD; IMN-A=Imnaha R. A; SAL-A=Salmon R. A; CLWR-B=Clearwater R. B; SAL-B=Salmon R. B. **Wild steelhead** aggregate is WSt. **Hatchery sockeye**: OXBOW=Oxbow H; SAWT=Sawtooth H.

[2] 2012 was the last year of sockeye releases from Oxbow Hatchery.

Table E.8 Migration year 2013 estimated proportion of PIT-tagged smolts in CSS wild and hatchery Chinook, wild and hatchery steelhead groups, and hatchery sockeye experiencing passage through transportation, bypass, or without detection at the Snake River transportation sites (based on PIT-tagged fish in the monitor-mode (TWS) group). (Non-parametric 90% confidence intervals are shown.)

Fish source[1]	Transportation			Passage w/o detection			Bypass passage		
	$Pr(T_X)$	LL	UL	$Pr(C_0)$	LL	UL	$Pr(C_1)$	LL	UL
Chinook									
RAPH	0.390	0.382	0.399	0.567	0.559	0.575	0.043	0.036	0.050
DWOR	0.220	0.214	0.226	0.682	0.675	0.689	0.098	0.092	0.104
CATH	0.518	0.488	0.546	0.413	0.391	0.435	0.070	0.044	0.098
CLWH (sp)	0.157	0.152	0.161	0.685	0.679	0.692	0.158	0.153	0.164
CLWH (su)	0.228	0.219	0.238	0.633	0.622	0.645	0.139	0.128	0.150
SAWT	0.506	0.487	0.523	0.463	0.448	0.478	0.031	0.017	0.045
MCCA	0.345	0.336	0.354	0.618	0.610	0.628	0.037	0.029	0.044
IMNA	0.337	0.322	0.351	0.614	0.600	0.627	0.048	0.038	0.059
PAHH	0.127	0.121	0.135	0.683	0.672	0.694	0.190	0.179	0.201
WCh	0.349	0.341	0.357	0.470	0.462	0.477	0.181	0.172	0.189
Steelhead									
GRN-A	0.331	0.321	0.342	0.551	0.540	0.562	0.118	0.108	0.127
HCD-A	0.328	0.308	0.348	0.565	0.544	0.586	0.108	0.090	0.124
IMN-A	0.519	0.505	0.534	0.399	0.387	0.411	0.082	0.071	0.094
SAL-A	0.418	0.410	0.426	0.499	0.491	0.507	0.082	0.076	0.089
CLWR-B	0.150	0.145	0.154	0.555	0.547	0.562	0.296	0.289	0.303
SAL-B	0.533	0.518	0.548	0.430	0.417	0.443	0.037	0.025	0.047
WSt	0.469	0.454	0.483	0.401	0.389	0.415	0.130	0.118	0.143
Sockeye									
SAWT	0.524	0.510	0.538	0.410	0.399	0.422	0.066	0.057	0.076

[1] **Hatchery spring Chinook**: RAPH=Rapid River H; DWOR =Dworshak H; CATH=Catherine Creek AP; CLWH=Clearwater H; SAWT=Sawtooth H. **Hatchery summer Chinook**: MCCA=McCall H; IMNA=Imnaha AP; PAHH=Pahsimeroi H. **Wild Chinook** aggregate is WCh. **Hatchery steelhead**: GRN-A=Grand Ronde (Wallowa) A; HCD-A=Mainstem below HCD; IMN-A=Imnaha R. A; SAL-A=Salmon R. A; CLWR-B=Clearwater R. B; SAL-B=Salmon R. B. **Wild steelhead** aggregate is WSt. **Hatchery sockeye**: SAWT=Sawtooth H.

Table E.9 Migration year 2014 estimated proportion of PIT-tagged smolts in CSS wild and hatchery Chinook, wild and hatchery steelhead groups, and hatchery sockeye experiencing passage through transportation, bypass, or without detection at the Snake River transportation sites (based on PIT-tagged fish in the monitor-mode (TWS) group). (Non-parametric 90% confidence intervals are shown.)

Fish source[1]	Transportation			Passage w/o detection			Bypass passage		
	$Pr(T_X)$	LL	UL	$Pr(C_0)$	LL	UL	$Pr(C_1)$	LL	UL
Chinook									
RAPH	0.471	0.462	0.480	0.463	0.455	0.471	0.066	0.089	0.073
DWOR	0.387	0.379	0.395	0.505	0.798	0.512	0.108	0.102	0.115
CATH	0.524	0.499	0.551	0.363	0.348	0.381	0.113	0.091	0.134
CLWH (sp)	0.267	0.261	0.273	0.442	0.436	0.448	0.291	0.285	0.298
CLWH (su)	0.291	0.282	0.300	0.476	0.467	0.485	0.233	0.223	0.243
SAWT	0.457	0.442	0.471	0.408	0.397	0.420	0.135	0.122	0.148
MCCA	0.440	0.431	0.448	0.495	0.487	0.502	0.065	0.058	0.072
IMNA	0.541	0.525	0.556	0.384	0.373	0.398	0.074	0.062	0.087
PAHH	0.219	0.211	0.227	0.434	0.425	0.442	0.348	0.338	0.357
WCh	0.341	0.333	0.378	0.202	0.198	0.206	0.457	0.450	0.465
Steelhead									
GRN-A	0.333	0.322	0.344	0.487	0.476	0.497	0.180	0.172	0.188
HCD-A	0.394	0.379	0.411	0.348	0.332	0.362	0.258	0.242	0.274
IMN-A	0.543	0.529	0.556	0.363	0.351	0.375	0.094	0.082	0.104
SAL-A	0.369	0.361	0.377	0.460	0.452	0.468	0.171	0.164	0.178
CLWR-B	0.247	0.241	0.253	0.438	0.432	0.444	0.315	0.309	0.321
SAL-B	0.581	0.569	0.595	0.375	0.363	0.386	0.044	0.034	0.054
WSt	0.550	0.534	0.565	0.313	0.302	0.325	0.137	0.122	0.152
Sockeye									
SAWT	0.659	0.647	0.673	0.013	0.005	0.022	0.327	0.314	0.340

[1] **Hatchery spring Chinook**: RAPH=Rapid River H; DWOR =Dworshak H; CATH=Catherine Creek AP; CLWH=Clearwater H; SAWT=Sawtooth H. **Hatchery summer Chinook**: MCCA=McCall H; IMNA=Imnaha AP; PAHH=Pahsimeroi H. **Wild Chinook** aggregate is WCh. **Hatchery steelhead**: GRN-A=Grand Ronde (Wallowa) A; HCD-A=Mainstem below HCD; IMN-A=Imnaha R. A; SAL-A=Salmon R. A; CLWR-B=Clearwater R. B; SAL-B=Salmon R. B. **Wild steelhead** aggregate is WSt. **Hatchery sockeye**: SAWT=Sawtooth H.

Table E.10 Migration year 2015 estimated proportion of PIT-tagged smolts in CSS wild and hatchery Chinook, wild and hatchery steelhead groups, and hatchery sockeye experiencing passage through transportation, bypass, or without detection at the Snake River transportation sites (based on PIT-tagged fish in the monitor-mode (TWS) group). (Non-parametric 90% confidence intervals are shown.)

Fish source[1]	Transportation			Passage w/o detection			Bypass passage		
	$Pr(T_X)$	LL	UL	$Pr(C_0)$	LL	UL	$Pr(C_1)$	LL	UL
Chinook									
RAPH	0.188	0.180	0.197	0.783	0.775	0.792	0.028	0.023	0.033
DWOR	0.073	0.069	0.077	0.777	0.769	0.784	0.150	0.144	0.156
CATH	0.182	0.163	0.201	0.753	0.729	0.774	0.065	0.050	0.082
CLWH (sp)	0.024	0.022	0.026	0.663	0.655	0.672	0.312	0.305	0.321
CLWH (su)	0.016	0.014	0.018	0.813	0.803	0.821	0.171	0.163	0.180
SAWT	0.191	0.177	0.206	0.778	0.764	0.794	0.030	0.021	0.039
MCCA	0.194	0.185	0.204	0.798	0.788	0.807	0.008	0.002	0.014
IMNA	0.269	0.253	0.285	0.698	0.682	0.714	0.033	0.022	0.044
PAHH	0.058	0.052	0.064	0.824	0.812	0.835	0.119	0.109	0.128
WCh	0.155	0.148	0.163	0.667	0.657	0.677	0.178	0.169	0.186
Steelhead									
GRN-A	0.146	0.138	0.154	0.786	0.776	0.796	0.068	0.061	0.075
HCD-A	0.131	0.118	0.144	0.795	0.777	0.811	0.074	0.062	0.0873
IMN-A	0.187	0.175	0.200	0.768	0.754	0.780	0.045	0.035	0.055
SAL-A	0.135	0.128	0.142	0.798	0.789	0.806	0.067	0.062	0.073
CLWR-B	0.078	0.074	0.081	0.763	0.756	0.770	0.160	0.154	0.165
SAL-B	0.214	0.201	0.228	0.769	0.756	0.781	0.017	0.009	0.025
WSt	0.202	0.177	0.228	0.718	0.690	0.746	0.080	0.061	0.099
Sockeye									
SAWT	0.124	0.111	0.137	0.874	0.862	0.886	0.002	0.00	0.008

[1] **Hatchery spring Chinook**: RAPH=Rapid River H; DWOR =Dworshak H; CATH=Catherine Creek AP; CLWH=Clearwater H; SAWT=Sawtooth H. **Hatchery summer Chinook**: MCCA=McCall H; IMNA=Imnaha AP; PAHH=Pahsimeroi H. **Wild Chinook** aggregate is WCh. **Hatchery steelhead**: GRN-A=Grand Ronde (Wallowa) A; HCD-A=Mainstem below HCD; IMN-A=Imnaha R. A; SAL-A=Salmon R. A; CLWR-B=Clearwater R. B; SAL-B=Salmon R. B. **Wild steelhead** aggregate is WSt. **Hatchery sockeye**: SAWT=Sawtooth H.

Table E.11 Migration year 2016 estimated proportion of PIT-tagged smolts in CSS wild and hatchery Chinook, wild and hatchery steelhead groups, and hatchery sockeye experiencing passage through transportation, bypass, or without detection at the Snake River transportation sites (based on PIT-tagged fish in the monitor-mode (TWS) group). (Non-parametric 90% confidence intervals are shown.)

Fish source[1]	Transportation			Passage w/o detection			Bypass passage		
	$Pr(T_X)$	LL	UL	$Pr(C_0)$	LL	UL	$Pr(C_1)$	LL	UL
Chinook									
RAPH	0.327	0.321	0.333	0.337	0.332	0.341	0.336	0.330	0.343
DWOR	0.087	0.084	0.091	0.402	0.395	0.408	0.511	0.505	0.518
CATH	0.279	0.266	0.291	0.285	0.276	0.295	0.437	0.420	0.451
CLWH (sp)	0.095	0.092	0.098	0.362	0.357	0.366	0.543	0.538	0.548
CLWH (su)	0.027	0.025	0.30	0.320	0.313	0.326	0.653	0.646	0.660
SAWT	0.299	0.289	0.309	0.291	0.284	0.299	0.410	0.399	0.420
MCCA	0.469	0.461	0.478	0.401	0.394	0.408	0.130	0.122	0.138
IMNA	0.338	0.328	0.348	0.280	0.272	0.288	0.382	0.372	0.393
PAHH	0.594	0.580	0.607	0.319	0.309	0.329	0.088	0.077	0.098
WCh	0.246	0.240	0.254	0.201	0.196	0.205	0.553	0.545	0.561
Steelhead									
GRN-A	0.200	0.192	0.207	0.360	0.352	0.367	0.440	0.431	0.449
HCD-A	0.262	0.249	0.274	0.427	0.414	0.441	0.311	0.295	0.327
IMN-A	0.363	0.350	0.375	0.318	0.309	0.327	0.319	0.306	0.332
SAL-A	0.396	0.389	0.404	0.328	0.322	0.334	0.276	0.268	0.283
CLWR-B	0.085	0.082	0.088	0.346	0.342	0.351	0.569	0.563	0.574
SAL-B	0.591	0.579	0.604	0.355	0.346	0.365	0.054	0.043	0.064
WSt	0.330	0.319	0.341	0.268	0.260	0.276	0.402	0.390	0.415
Sockeye									
SPRF	0.327	0.297	0.359	0.666	0.638	0.695	0.007	0.000	0.021

[1] **Hatchery spring Chinook**: RAPH=Rapid River H; DWOR =Dworshak H; CATH=Catherine Creek AP; CLWH=Clearwater H; SAWT=Sawtooth H. **Hatchery summer Chinook**: MCCA=McCall H; IMNA=Imnaha AP; PAHH=Pahsimeroi H. **Wild Chinook** aggregate is WCh. **Hatchery steelhead**: GRN-A=Grand Ronde (Wallowa) A; HCD-A=Mainstem below HCD; IMN-A=Imnaha R. A; SAL-A=Salmon R. A; CLWR-B=Clearwater R. B; SAL-B=Salmon R. B. **Wild steelhead** aggregate is WSt. **Hatchery sockeye**: SPRF=Springfield H.

There are several benefits of having Group T for estimating these three passage experience proportions. The previous constraint of limiting transportation to first-time detects has been eliminated in creating the T_X group, and so fish bypassed at an upstream dam are now included if transported at a downstream dam. Delaying the start of transportation does not add any complication to the estimation process. Since Group T follows the monitor-mode operations at the transportation sites, it best reflects the untagged population of transported and bypassed smolts at those sites. Therefore, there is no need to adjust the PIT-tag data using proportions of collected run-at-large smolts transported and bypassed at the dams, which is available only at the species and rearing type level, to individual PIT-tagged hatchery groups that may have different passage timing history.

APPENDIX F

RETURNING AGE COMPOSITION OF ADULTS

Appendix F
Returning Age Composition of Adults

Snake River wild and hatchery Chinook returning age composition

Table F.1 Age composition of returning PIT-tagged WILD SNAKE RIVR SP/SU CHINOOK adults and jacks detected at Lower Granite Dam that were PIT-tagged during the 10-month period from July 25 to May 20 from smolt migration years 1994 to 2015.

Smolt Migr Year	Jacks 1-salt	Adults 2-salt	Adults 3-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt
1994	1	11	11	4.3	47.8	47.8
1995	1	38	20	1.7	64.4	33.9
1996	0	11	5	0.0	68.8	31.3
1997	2	33	5	5.0	82.5	12.5
1998	17	148	46	8.1	70.1	21.8
1999	25	517	144	3.6	75.4	21.0
2000	9	259	312(1[C])	1.5	44.6	53.9[C]
2001	2	30	15	4.3	63.8	31.9
2002	26	197	38	10.0	75.5	14.6
2003	3	61	24	3.4	69.3	27.3
2004	3	83	41(1[C])	2.3	64.8	32.8[C]
2005	4	38	24	6.1	57.6	36.4
2006[A]	12	124	36	7.0	72.1	20.9
2007[A]	22	178	28	9.6	78.1	12.3
2008[A]	133	675	205	13.1	66.6	20.2
2009[A]	50	357	145	9.1	64.7	26.3
2010[A]	98	321	123	18.1	59.2	22.7
2011[A]	29	210	28	10.9	78.6	10.5
2012[A]	109	371	43	20.8	70.9	8.2
2013[A]	44	261	75	11.6	68.7	19.7
2014[A]	18	133	35	9.7	71.5	18.8
2015[A, B]	13	45	NA	22.4	77.6	--
	Average (1994–2014)			10.7	71.0	18.4

[A] Smolt migration year 2006–2015 data are from combined T and R groups.
[B] Incomplete adult returns through 9/15/2017 at GRA; not included in average.
[C] One 4-salt return is included in the 3-salt calculation.

Table F.2 Age composition of returning PIT-tagged DWORSHAK NFH SPRING CHINOOK adults and jacks detected at Lower Granite Dam from smolt migration years 1997 to 2015.

Smolt Migr Year	Jacks 1-salt	Adults 2-salt	Adults 3-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt
1997	1	36	6	2.3	83.7	14.0
1998	51	372	23	11.4	83.4	5.2
1999	14	393	44	3.1	87.1	9.8
2000	3	180	197	0.8	47.4	51.8
2001	14	79	10	13.6	76.7	9.7
2002	52	222	8	18.4	78.7	2.8
2003	5	73	12	5.6	81.1	13.3
2004	1	84	26	0.9	75.7	23.4
2005	2	53	20	2.7	70.7	26.7
2006[A]	42	133	4	23.5	74.3	2.2
2007[A]	40	139	5	21.7	75.5	2.7
2008[A]	87	189	17	29.7	64.5	5.8
2009[A]	16	122	14	10.5	80.2	9.2
2010[A]	150	220	12	39.3	57.6	3.1
2011[A]	11	55	4	15.1	78.6	5.7
2012[A]	72	174	6	28.6	69.0	2.4
2013[A]	44	248	20	14.1	79.5	6.4
2014[A]	13	107	4	10.5	86.3	3.2
2015[A, B]	10	24	NA	29.4	70.6	--
Average (1997–2014)				15.7	73.3	11.0

[A] Smolt migration year 2006–2015 data are from combined T & R groups.
[B] Incomplete adult returns through 9/15/2017 at GRA; not included in average.

Table F.3 Age composition of returning PIT-tagged RAPID RIVER HATCHERY SPRING CHINOOK adults and jacks detected at Lower Granite Dam from smolt migration years 1997 to 2015.

Smolt Migr Year	Jacks 1-salt	Adults 2-salt	Adults 3-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt
1997	2	86	7	2.1	90.5	7.4
1998	32	390	23	7.2	87.6	5.2
1999	43	787	31	5.0	91.4	3.6
2000	8	371	256	1.3	58.4	40.3
2001	21	206	13	8.8	85.8	5.4
2002	60	298	5	16.5	82.1	1.4
2003	20	75	8	19.4	72.8	7.8
2004	4	67	27	4.1	68.4	27.6
2005	6	61	16	7.2	73.5	19.3
2006[A]	41	166	11	18.8	76.1	5.0
2007[A]	48	111	1	30.0	69.4	0.6
2008[A]	252	462	31	33.8	62.0	4.2
2009[A]	44	334	25	10.9	82.9	6.2
2010[A]	118	173	9	39.3	57.7	3.0
2011[A]	12	95	5	10.7	84.8	4.5
2012[A]	75	275	14	20.6	75.5	3.8
2013[A]	86	445	32	15.2	79.0	5.7
2014[A]	23	141	6	13.5	82.9	3.5
2015[A, B]	30	88	NA	25.4	74.6	--
	Average (1997–2014)			15.0	76.3	8.7

[A] Smolt migration year 2006–2015 data are from combined T & R groups.
[B] Incomplete adult returns through 9/15/2017 at GRA; not included in average.

Table F.4 Age composition of returning PIT-tagged CATHERINE CREEK HATCHERY SPRING CHINOOK adults and jacks detected at Lower Granite Dam from smolt migration years 2001 to 2015.

Smolt Migr Year	Jacks 1-salt	Adults 2-salt	Adults 3-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt
2001	2	13	0	13.3	86.7	0.0
2002	11	45	1	19.3	78.9	1.8
2003	5	22	0	18.5	81.5	0.0
2004	2	17	1	10.0	85.0	5.0
2005	3	15	0	16.7	83.3	0.0
2006[A]	10	36	0	21.7	78.3	0.0
2007[A]	26	32	0	44.8	55.2	0.0
2008[A]	71	185	6	27.1	70.6	2.3
2009[A]	17	113	3	12.8	85.0	2.3
2010[A]	59	71	3	44.3	53.4	2.3
2011[A]	4	26	1	12.9	83.9	3.2
2012[A]	18	37	1	32.1	66.1	1.8
2013[A]	20	59	1	25.0	73.8	1.3
2014[A]	7	19	0	26.9	73.1	0.0
2015[A, B]	8	20	NA	28.6	71.4	--
	Average (2001–2014)			26.5	71.7	1.8

[A] Smolt migration year 2006–2015 data are from combined T & R groups.
[B] Incomplete adult returns through 9/15/2017 at GRA; not included in average.

Table F.5 Age composition of returning PIT-tagged MCCALL HATCHERY SUMMER CHINOOK adults and jacks detected at Lower Granite Dam from smolt migration years 1997 to 2015.

Smolt Migr Year	Jacks 1-salt	Adults 2-salt	Adults 3-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt
1997	21	263	11	7.1	89.2	3.7
1998	108	394	37	20.0	73.1	6.9
1999	119	722	113	12.5	75.7	11.8
2000	144	635	239(1[C])	14.1	62.3	23.6[C]
2001	62	200	23	21.8	70.2	8.1
2002	116	347	18	24.1	72.1	3.7
2003	129	222	27	34.1	58.7	7.1
2004	25	91	20	18.4	66.9	14.7
2005	16	155	29	8.0	77.5	14.5
2006[A]	67	301	25	17.0	76.6	6.4
2007[A]	145	228	2	38.7	60.8	0.5
2008[A]	361	285	28	53.6	42.3	4.2
2009[A]	72	124	9	35.1	60.5	4.4
2010[A]	137	145	14	46.3	49.0	4.7
2011[A]	24	96	6	19.0	76.2	4.8
2012[A]	160	158	7	49.2	48.6	2.2
2013[A]	189	265	35	38.7	54.2	7.2
2014[A]	112	138	5	43.9	54.1	2.0
2015[A, B]	28	49	NA	36.4	63.6	--
	Average (1997–2014)			27.9	66.4	5.7

[A] Smolt migration year 2006–2015 data are from combined T & R groups.
[B] Incomplete adult returns through 9/15/2017 at GRA; not included in average.

Table F.6 Age composition of returning PIT-tagged IMNAHA HATCHERY SUMMER CHINOOK adults and jacks detected at Lower Granite Dam from smolt migration years 1997 to 2015.

Smolt Migr Year	Jacks 1-salt	Adults 2-salt	Adults 3-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt
1997	24	63	7	25.5	67.0	7.4
1998	54	69	2	43.2	55.2	1.6
1999	81	226	12	25.4	70.8	3.8
2000	149	289	79	28.8	55.9	15.3
2001	30	49	4	36.1	59.0	4.8
2002	46	81	2	35.7	62.8	1.6
2003	93	71	2	56.0	42.8	1.2
2004	9	33	2	20.5	75.0	4.5
2005	5	24	1	16.7	80.0	3.3
2006[A]	39	89	13	27.7	63.1	9.2
2007[A]	91	89	4	49.5	48.4	2.2
2008[A]	359	225	15	59.9	37.6	2.5
2009[A]	97	123	8	42.5	54.0	3.5
2010[A]	96	103	6	46.8	50.2	2.9
2011[A]	20	32	0	38.5	61.5	0.0
2012[A]	54	27	1	65.9	32.9	1.2
2013[A]	87	39	2	68.0	30.5	1.6
2014[A]	19	34	1	35.2	63.0	1.9
2015[A, B]	6	15	NA	28.6	71.4	--
	Average (1997–2014)			42.5	52.4	5.1

[A] Smolt migration year 2006–2015 data are from combined T & R groups.
[B] Incomplete adult returns through 9/15/2017 at GRA; not included in average.

Table F.7 Age composition of returning PIT-tagged CLEARWATER HATCHERY SPRING CHINOOK adults and jacks detected at Lower Granite Dam from smolt migration years 2006 to 2015.

Smolt Migr Year	Jacks 1-salt	Adults 2-salt	Adults 3-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt
2006[A]	25	152	11	13.3	80.9	5.9
2007[A]	41	93	2	30.1	68.4	1.5
2008[A]	74	178	23	26.9	64.7	8.4
2009[A]	49	251	18	15.4	78.9	5.7
2010[A]	119	235	10	32.7	64.6	2.8
2011[A]	9	66	4	11.4	88.5	5.1
2012[A]	94	234	6	28.1	70.1	1.8
2013[A]	64	306	9	16.9	80.7	2.4
2014[A]	32	128	1	19.9	79.5	0.6
2015[A, B]	28	71	NA	28.3	71.7	--
	Average (2006–2014)			22.7	73.5	3.8

[A] Smolt migration year 2006–2015 data are from combined T & R groups.
[B] Incomplete adult returns through 9/15/2017 at GRA; not included in average.

Table F.8 Age composition of returning PIT-tagged CLEARWATER HATCHERY SUMMER CHINOOK adults and jacks detected at Lower Granite Dam from smolt migration years 2011 to 2015.

Smolt Migr Year	Jacks 1-salt	Adults 2-salt	Adults 3-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt
2011[A]	7	23	1	22.6	74.2	3.2
2012[A]	38	39	2	48.1	49.4	2.5
2013[A]	22	51	5	28.2	65.4	6.4
2014[A]	30	62	3	31.6	65.3	3.2
2015[A, B]	12	40	NA	23.1	76.9	--
	Average (2011–2014)			34.3	61.8	3.9

[A] Smolt migration year 2011–2015 data are from combined T & R groups.
[B] Incomplete adult returns through 9/15/2017 at GRA; not included in average.

Table F.9 Age composition of returning PIT-tagged SAWTOOTH HATCHERY SPRING CHINOOK adults and jacks detected at Lower Granite Dam from smolt migration years 2007 to 2015.

Smolt Migr Year	Jacks 1-salt	Adults 2-salt	Adults 3-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt
2007[A]	37	48	2	42.5	55.2	2.3
2008[A]	36	45	4	42.4	52.9	4.7
2009[A]	11	19	0	36.7	63.3	0.0
2010[A]	30	39	4	41.1	53.4	5.5
2011[A]	5	15	1	23.8	71.4	4.8
2012[A]	14	30	1	31.1	66.7	2.2
2013[A]	13	62	13	14.8	70.5	14.8
2014[A]	42	34	1	54.5	44.2	1.3
2015[A, B]	5	20	NA	20.0	80.0	--
	Average (2007–2014)			37.2	57.7	5.1

[A] Smolt migration year 2007–2015 data are from combined T & R groups.
[B] Incomplete adult returns through 9/15/2017 at GRA; not included in average.

Table F.10 Age composition of returning PIT-tagged PAHSIMEROI HATCHERY SUMMER CHINOOK adults and jacks detected at Lower Granite Dam from smolt migration years 2008 to 2015.

Smolt Migr Year	Jacks 1-salt	Adults 2-salt	Adults 3-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt
2008[A]	55	71	13	39.6	51.1	9.4
2009[A]	14	49	0	22.2	77.8	0.0
2010[A]	7	5	0	58.3	41.7	0.0
2011[A]	0	2	0	0.0	100.0	0.0
2012[A]	14	23	0	37.8	62.2	0.0
2013[A]	15	17	3	42.9	48.6	8.6
2014[A]	0	2	0	0.0	100.0	0.0
2015[A, B]	2	3	NA	40.0	60.0	--
	Average (2008–2014)			36.2	58.3	5.5

[A] Smolt migration year 2008–2015 data are from combined T & R groups.
[B] Incomplete adult returns through 9/15/2017 at GRA; not included in average.

Snake River wild and hatchery steelhead returning age composition

Table F.11 Age composition of returning PIT-tagged WILD SNAKE RIVER STEELHEAD adults detected at Lower Granite Dam that were PIT-tagged meeting a minimum length threshold during the 12-month period from July 1 to June 30 for smolt migration years 1997 to 2014.

Smolt Migr Year	Age 1-salt	Age 2-salt	Age 3-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt
1997	4	10	0	28.6	71.4	0.0
1998	16	8	0	66.7	33.3	0.0
1999	33	49	2	39.3	58.3	2.4
2000	132	131	3	49.6	49.2	1.1
2001	5	14	2	23.8	66.7	9.5
2002	59	60	1	49.2	50.0	0.8
2003	37	63	0	37.0	63.0	0.0
2004	26	21	0	55.3	44.7	0.0
2005	17	42	1	28.3	70.0	1.7
2006[A]	37	42	1	46.3	52.5	1.3
2007[A]	115	107	1	51.6	48.0	0.4
2008[A]	236	254	6	47.6	51.2	1.2
2009[A]	100	192	4	33.8	64.9	1.4
2010[A]	155	193	7	43.7	54.4	2.0
2011[A]	41	56	3	41.0	56.0	3.0
2012[A]	121	147	1	45.0	54.6	0.4
2013[A]	81	165	1	32.8	66.8	0.4
2014[A, B]	149	123	NA	54.8	42.2	--
	Average (1997–2013)			43.4	55.5	1.1

[A] Smolt migration year 2006–2014 data are from combined T & R groups.
[B] Incomplete adult returns until 3-salt returns (if any) after 9/15/2017 at GRA; not included in average.

Table F.12 Age composition of returning PIT-tagged HATCHERY SNAKE RIVER STEELHEAD adults detected at Lower Granite Dam from smolt migration years 1997 to 2014.

Smolt Migr Year	Age 1-salt	Age 2-salt	Age 3-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt
1997	34	15	0	69.4	30.6	0.0
1998	45	32	0	58.4	41.6	0.0
1999	85	96	1	46.7	52.7	0.5
2000	178	89	1	66.4	33.2	0.4
2001	3	8	0	27.3	72.7	0.0
2002	99	49	1	66.4	32.9	0.7
2003	90	77	0	53.9	46.1	0.0
2004	21	24	0	46.7	53.3	0.0
2005	41	26	0	61.2	38.8	0.0
2006[A]	102	77	0	57.0	43.0	0.0
2007[A]	163	87	0	65.2	34.8	0.0
2008[A]	2352	964	18	70.6	28.9	0.5
2009[A]	1217	955	10	55.8	43.8	0.5
2010[A]	1487	952	3	60.9	39.0	0.1
2011[A]	552	372	4	59.5	40.1	0.4
2012[A]	1004	914	3	52.3	47.6	0.2
2013[A]	946	662	7	58.6	41.0	0.4
2014[A, B]	826	1015	NA	44.9	55.1	--
	Average (1997–2013)			59.8	39.3	0.9

[A] Smolt migration year 2006–2014 data are from combined T & R groups.
[B] Incomplete adult returns through 9/15/2017 at GRA; not included in average.

Table F.13 Age composition of returning PIT-tagged GRANDE RONDE A HATCHERY STEELHEAD adults detected at Lower Granite Dam from smolt migration years 2008 to 2014.

Smolt Migr Year	Age 1-salt	Age 2-salt	Age 3-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt
2008[A]	615	145	2	80.7	19.0	0.3
2009[A]	240	122	0	66.3	33.7	0.0
2010[A]	275	185	0	59.8	40.2	0.0
2011[A]	58	40	0	59.2	40.8	0.0
2012[A]	197	157	0	55.7	44.4	0.0
2013[A]	213	188	0	53.1	46.9	0.0
2014[A, B]	213	188	NA	53.1	46.9	--
	Average (2008–2013)			67.7	33.1	0.2

[A] Smolt migration year 2008–2014 data are from combined T & R groups.
[B] Incomplete adult returns until 3-salt returns (if any) after 9/15/2017 at GRA; not included in average.

Table F.14 Age composition of returning PIT-tagged IMNAHA A HATCHERY STEELHEAD adults detected at Lower Granite Dam from smolt migration years 2008 to 2014.

Smolt Migr Year	Age 1-salt	Age 2-salt	Age 3-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt
2008[A]	497	64	0	88.6	11.4	0.0
2009[A]	222	50	0	81.6	18.4	0.0
2010[A]	235	55	0	81.0	19.0	0.0
2011[A]	60	30	0	66.7	33.3	0.0
2012[A]	194	119	0	62.0	38.0	0.0
2013[A]	166	84	0	66.4	33.6	0.0
2014[A, B]	210	73	NA	74.2	25.8	--
	Average (2008–2013)			77.1	22.8	0.1

[A] Smolt migration year 2008–2014 data are from combined T & R groups.
[B] Incomplete adult returns until 3-salt returns (if any) after 9/15/2017 at GRA; not included in average.

Table F.15 Age composition of returning PIT-tagged HELLS CANYON A HATCHERY STEELHEAD adults detected at Lower Granite Dam from smolt migration years 2008 to 2014.

Smolt Migr Year	Age 1-salt	Age 2-salt	Age 3-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt
2008[A]	11	3	0	78.6	21.4	0.0
2009[A]	108	70	1	60.3	39.1	0.6
2010[A]	147	87	0	62.8	37.1	0.0
2011[A]	6	8	0	42.9	57.1	0.0
2012[A]	36	46	1	43.4	55.4	1.2
2013[A]	78	29	0	72.9	27.1	0.0
2014[A, B]	25	58	NA	30.1	69.9	--
	Average (2008–2013)			61.2	38.5	0.3

[A] Smolt migration year 2008–2014 data are from combined T & R groups.
[B] Incomplete adult returns until 3-salt returns (if any) after 9/15/2017 at GRA; not included in average.

Table F.16 Age composition of returning PIT-tagged SALMON A HATCHERY STEELHEAD adults detected at Lower Granite Dam from smolt migration years 2008 to 2014.

Smolt Migr Year	Age 1-salt	Age 2-salt	Age 3-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt
2008[A]	1136	155	1	87.9	12.0	0.1
2009[A]	606	166	0	78.5	21.5	0.0
2010[A]	745	207	0	78.3	21.7	0.0
2011[A]	402	104	1	79.3	20.5	0.2
2012[A]	525	239	0	68.7	31.3	0.0
2013[A]	455	160	0	74.0	26.0	0.0
2014[A, B]	282	149	NA	65.4	34.6	--
	Average (2008–2013)			78.7	21.1	0.1

[A] Smolt migration year 2008–2014 data are from combined T & R groups.
[B] Incomplete adult returns until 3-salt returns (if any) after 9/15/2017 at GRA; not included in average.

Table F.17 Age composition of returning PIT-tagged SALMON B HATCHERY STEELHEAD adults detected at Lower Granite Dam from smolt migration years 2008 to 2014.

Smolt Migr Year	Age 1-salt	Age 2-salt	Age 3-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt
2008[A]	86	177	2	32.5	66.8	0.8
2009[A]	25	137	2	15.2	83.5	1.2
2010[A]	102	53	1	65.4	34.0	0.6
2011[A]	61	26	1	69.3	29.5	1.1
2012[A]	61	87	4	40.1	57.2	2.6
2013[A]	74	41	1	63.8	35.3	0.9
2014[A, B]	76	64	NA	54.3	45.7	--
	Average (2008–2013)			43.4	55.3	1.4

[A] Smolt migration year 2008–2014 data are from combined T & R groups.
[B] Incomplete adult returns until 3-salt returns (if any) after 9/15/2017 at GRA; not included in average.

Table F.18 Age composition of returning PIT-tagged CLEARWATER B HATCHERY STEELHEAD adults detected at Lower Granite Dam from smolt migration years 2008 to 2014.

Smolt Migr Year	Age 1-salt	Age 2-salt	Age 3-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt
2008[A]	44	441	14	8.8	88.4	2.8
2009[A]	28	391	7	6.6	91.8	1.6
2010[A]	72	361	2	16.6	83.0	0.4
2011[A]	19	170	2	9.9	89.0	1.0
2012[A]	46	262	1	14.9	84.8	0.3
2013[A]	32	189	4	14.2	84.0	1.8
2014[A, B]	68	435	NA	13.5	86.5	--
	Average (2008–2012)			11.5	85.7	2.8

[A] Smolt migration year 2008–2014 data are from combined T & R groups.
[B] Incomplete adult returns until 3-salt returns (if any) after 9/15/2017 at GRA; not included in average.

Snake River hatchery sockeye returning age composition

Table F.19 Age composition of returning PIT-tagged OXBOW HATCHERY SOCKEYE adults detected at Lower Granite Dam from smolt migration years 2009 to 2013.

Smolt Migr Year	Age 1-salt	Age 2-salt	Age 3-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt
2009[A]	11	43	0	20.4	49.6	0.0
2010[A]	19	25	0	43.2	56.8	0.0
2011[A]	4	26	0	13.3	86.7	0.0
2012[A]	30	124	0	19.5	80.5	0.0
	Average (2009–2012)			22.7	77.3	0.0

[A] Smolt migration year 2009–2012 data are from combined T & R groups.

Table F.20 Age composition of returning PIT-tagged SAWTOOTH HATCHERY SOCKEYE adults detected at Lower Granite Dam from smolt migration years 2009 to 2015.

Smolt Migr Year	Age 1-salt	Age 2-salt	Age 3-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt
2009[A]	0	265	10	0.0	96.4	3.6
2010[A]	2	24	1	7.4	88.9	3.7
2011[A]	0	32	3	0.0	91.4	8.6
2012[A]	0	33	0	0.0	100.0	0.0
2013[A]	23	22	2	48.9	46.8	4.3
2014[A]	0	114	7	0.0	94.2	5.8
2015[A, B]	1	32	NA	3.0	97.0	--
Average (2009–2014)				4.6	91.1	4.3

[A] Smolt migration year 2009–2015 data are from combined T & R groups.
[B] Incomplete adult returns until 3-salt returns (if any) after 9/15/2017 at GRA; not included in average.

Snake River wild and hatchery subyearling fall Chinook

Table F.21 Age composition of returning PIT-tagged wild/natural subyearling fall Chinook adults and jacks detected at Lower Granite Dam from smolt migration years 2006 to 2012.

Smolt Migr Year	Age 1-salt	Age 2-salt	Age 3-salt	Age 4,5-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt	Percent 4-Salt
2006	0	4	8	0	0.0	33.3	66.7	0.0
2007[A]	--	--	--	--	--	--	--	--
2008	10	21	25	5	16.4	34.4	41.0	8.2
2009	5	6	5	1	29.4	35.3	29.4	5.9
2010	2	17	8	0	7.4	63.0	29.6	0.0
2011	0	13	8	2	0.0	56.5	34.8	8.7
2012	10	10	11	0	32.3	32.3	35.5	0.0
Average (2006–2012)					15.8	41.5	38.0	4.7

[A] No smolts were tagged in 2007.

Table F.22 Age composition of returning PIT-tagged HATCHERY LYONS FERRY SUBYEARLING CHINOOK released at Big Canyon Creek Acclimation Pond adults and jacks detected at Bonneville Dam from smolt migration years 2006 to 2012.

Smolt Migr Year	Age 1-salt	Age 2-salt	Age 3-salt	Age 4,5-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt	Percent 4-Salt
2006	172	180	73	3	40.2	42.1	17.1	0.7
2007[A]	--	--	--	--	--	--	--	--
2008	280	232	69	4	47.9	39.7	11.8	0.7
2009	10	10	8	0	35.7	35.7	28.6	0.0
2010	86	192	62	1	25.2	56.3	18.2	0.3
2011	128	198	107	9	29.0	44.8	24.2	2.0
2012	108	132	95	0	32.2	39.4	28.4	0.0
Average (2006–2012)					36.3	43.7	19.2	0.8

[A] No smolts were tagged in 2007.

Table F.23 Age composition of returning PIT-tagged HATCHERY LYONS FERRY SUBYEARLING CHINOOK released at Captain John Rapids Acclimation Pond adults and jacks detected at Bonneville Dam from smolt migration years 2008 to 2012.

Smolt Migr Year	Age 1-salt	Age 2-salt	Age 3-salt	Age 4,5-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt	Percent 4-Salt
2008	166	177	42	1	43.0	45.9	10.9	0.3
2009	16	12	2	0	53.3	40.0	6.7	0.0
2010	169	247	93	7	32.8	47.9	18.0	1.4
2011	155	281	109	10	27.9	50.6	19.6	1.8
2012	65	155	93	0	20.8	49.5	29.7	0.0
Average (2008–2012)					31.7	48.4	18.8	1.0

Table F.24 Age composition of returning PIT-tagged HATCHERY LYONS FERRY SUBYEARLING CHINOOK released at Pittsburg Landing Acclimation Pond adults and jacks detected at Bonneville Dam from smolt migration years 2008 to 2012.

Smolt Migr Year	Age 1-salt	Age 2-salt	Age 3-salt	Age 4,5-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt	Percent 4-Salt
2008	189	187	40	4	45.0	44.5	9.2	1.0
2009	10	12	3	0	40.0	48.0	12.0	0.0
2010	94	164	53	3	29.9	52.2	16.9	1.0
2011	89	162	80	5	26.5	48.2	23.8	1.5
2012	69	120	77	0	25.9	45.1	28.9	0.0
Average (2008–2012)					33.1	47.4	18.6	0.9

Table F.25 Age composition of returning PIT-tagged HATCHERY LYONS FERRY SUBYEARLING CHINOOK released into the mainstem Snake River adults and jacks detected at Bonneville Dam from smolt migration years 2006 to 2012.

Smolt Migr Year	Age 1-salt	Age 2-salt	Age 3-salt	Age 4,5-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt	Percent 4-Salt
2006	27	45	12	1	31.8	52.9	14.1	1.2
2007 [A]	--	--	--	--	--	--	--	--
2008	43	56	10	0	39.4	54.4	9.2	0.0
2009	12	14	2	0	42.9	50.0	7.1	0.0
2010	34	54	16	0	32.7	51.9	15.4	0.0
2011	49	91	40	3	26.8	49.7	21.9	1.6
2012	15	31	12	0	25.9	53.4	20.7	0.0
Average (2006–2012)					31.7	51.3	16.2	0.7

[A] No smolts were tagged in 2007.

Table F.26 Age composition of returning PIT-tagged IRRIGON HATCHERY SUBYEARLING CHINOOK released into the Grande Ronde River adults and jacks detected at Bonneville Dam from smolt migration years 2008 to 2012.

Smolt Migr Year	Age 1-salt	Age 2-salt	Age 3-salt	Age 4,5-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt	Percent 4-Salt
2008	49	36	13	1	49.5	36.4	13.1	1.0
2009	19	22	11	1	35.8	41.5	20.8	1.9
2010	41	144	41	2	18.0	63.2	18.0	0.9
2011	28	48	21	3	28.0	48.0	21.0	3.0
2012	67	85	66	0	30.7	39.0	30.3	0.0
Average (2008–2012)					29.2	48.0	21.8	1.0

Table F.27 Age composition of returning PIT-tagged UMATILLA/IRRIGON HATCHERY SUBYEARLING CHINOOK released into the Snake River adults and jacks detected at Bonneville Dam from smolt migration years 2006 to 2012.

Smolt Migr Year	Age 1-salt	Age 2-salt	Age 3-salt	Age 4,5-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt	Percent 4-Salt
2006	23	28	5	0	41.1	50.0	8.9	0.0
2007 [A]	--	--	--	--	--	--	--	--
2008	296	232	44	2	51.6	40.4	7.7	0.3
2009	27	15	6	0	56.3	31.3	12.5	0.0
2010	65	115	47	3	28.3	50.0	20.4	1.3
2011	28	64	16	6	24.6	56.1	14.0	5.3
2012	75	110	71	0	29.3	43.0	27.7	0.0
Average (2006–2012)					40.2	43.9	15.1	0.9

[A] No smolts were tagged in 2007.

Table F.28 Age composition of returning PIT-tagged OXBOW HATCHERY SUBYEARLING CHINOOK released into the Snake River adults and jacks detected at Bonneville Dam from smolt migration years 2008 to 2012.

Smolt Migr Year	Age 1-salt	Age 2-salt	Age 3-salt	Age 4,5-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt	Percent 4-Salt
2008	171	122	21	0	54.5	38.9	6.7	0.0
2009	14	10	0	0	58.3	41.7	0.0	0.0
2010 [A]	--	--	--	--	--	--	--	--
2011	24	38	18	2	29.3	46.3	22.0	2.4
2012	23	33	29	0	27.1	38.8	34.1	0.0
Average (2008–2012)					45.9	40.2	13.5	0.4

[A] No smolts were tagged in 2010.

Table F.29 Age composition of returning PIT-tagged DWORSHAK HATCHERY SUBYEARLING CHINOOK released into the Snake River adults and jacks detected at Bonneville Dam from smolt migration years 2006 to 2012.

Smolt Migr Year	Age 1-salt	Age 2-salt	Age 3-salt	Age 4,5-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt	Percent 4-Salt
2006	146	184	100	9	33.3	41.9	22.8	2.1
2007 [A]	--	--	--	--	--	--	--	--
2008	539	503	203	28	42.3	39.5	15.9	2.2
2009	64	81	42	1	34.0	43.1	22.3	0.5
2010	269	281	143	16	37.9	39.6	20.2	2.3
2011	209	549	324	69	18.2	47.7	28.1	6.0
2012	88	106	0	0	45.4	54.6	0.0	0.0
Average (2006–2012)					33.3	43.2	20.3	3.2

[A] No smolts were tagged in 2007.

Table F.30 Age composition of returning PIT-tagged NEZ PERCE TRIBAL HATCHERY SUBYEARLING CHINOOK released from Cedar Flats Acclimation Facility adults and jacks detected at Bonneville Dam from smolt migration years 2008 to 2012.

Smolt Migr Year	Age 1-salt	Age 2-salt	Age 3-salt	Age 4,5-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt	Percent 4-Salt
2008	26	16	14	0	46.4	28.6	25.0	0.0
2009	13	14	5	0	40.6	43.8	15.6	0.0
2010	13	25	9	1	27.1	52.1	18.8	2.1
2011	55	86	51	6	27.8	43.4	25.8	3.0
2012	9	47	42	0	9.2	48.0	42.9	0.0
Average (2008–2012)					26.9	43.5	28.0	1.6

Table F.31 Age composition of returning PIT-tagged NEZ PERCE TRIBAL HATCHERY SUBYEARLING CHINOOK released from Lukes Gulch Acclimation Facility adults and jacks detected at Bonneville Dam from smolt migration years 2008 to 2012.

Smolt Migr Year	Age 1-salt	Age 2-salt	Age 3-salt	Age 4,5-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt	Percent 4-Salt
2008	39	30	18	2	43.8	33.7	20.2	2.2
2009	1	10	6	0	5.9	58.8	35.3	0.0
2010	25	26	4	1	44.6	46.4	7.1	1.8
2011	46	116	49	4	21.4	54.0	22.8	1.9
2012	11	30	34	0	14.7	40.0	45.3	0.0
Average (2008–2012)					27.0	46.9	24.6	1.5

Middle Columbia wild and hatchery yearling Chinook

Table F.32 Age composition of returning PIT-tagged WILD JOHN DAY RIVER SP CHINOOK adults and jacks detected at Bonneville Dam from smolt migration years 2000 to 2015.

Smolt Migr Year	Age 1-salt	Age 2-salt	Age 3-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt
2000	3	112	31	2.1	76.7	21.2
2001	7	90	15(1[A])	6.2	79.6	14.2[A]
2002	5	86	9	5.0	86.0	9.0
2003	5	110	13	3.9	85.9	10.2
2004	5	68	20	5.4	73.1	21.5
2005	8	61	10	10.1	77.2	12.7
2006	2	34	12	4.2	70.8	25.0
2007	20	114	4	14.5	82.6	2.9
2008	22	147	16	11.9	79.5	8.7
2009	11	209	9	4.8	97.3	3.9
2010	40	96	14	26.7	64.0	9.3
2011	1	21	2	4.2	87.5	8.3
2012	22	82	4	20.4	75.9	3.7
2013	12	47	0	22.3	79.7	100.0
2014	3	32	2	8.1	86.5	5.4
2015[B]	10	20	NA	33.3	66.7	--
	Average (2000–2014)			10.2	80.8	9.0

[A] One 4-salt return is included in the 3-salt calculation.
[B] Incomplete adult returns through 9/15/2017 at BOA; not included in average.

Table F.33 Age composition of returning PIT-tagged YAKIMA WILD CHINOOK adults detected at Bonneville Dam from smolt migration years 2000 to 2015.

Smolt Migr Year	Age 1-salt	Age 2-salt	Age 3-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt
2000	15	164	14	7.8	95.0	7.3
2001	2	8	0	20.0	80.0	0.0
2002	1	47	1	2.0	95.9	2.0
2003	9	50	3	14.5	80.6	4.8
2004	1	44	4	2.0	89.8	8.2
2005	0	6	1	0.0	85.7	14.3
2006	1	8	1	10.0	80.0	10.0
2007	0	7	0	0.0	100.0	0.0
2008	12	33	2	25.5	70.2	4.3
2009	6	47	2	10.9	85.5	3.6
2010[A]	--	--	--	--	--	--
2011	0	3	1	0.0	75.0	25.0
2012	4	22	1	14.8	81.5	3.7
2013	1	9	1	9.1	81.8	9.1
2014[A]	--	--	--	--	--	--
2015[B]	1	5	NA	16.7	83.3	--
	Average (2000–2013)			9.8	84.4	5.8

[A] No Wild Chinook tagged in 2010 or 2014.
[B] Incomplete adult returns through 9/15/2017 at BOA; not included in average.

Table F.34 Age composition of returning PIT-tagged CARSON NFH SPRING CHINOOK adults and jacks detected at Bonneville Dam from smolt migration years 2000 to 2015.

Smolt Migr Year	Age 1-salt	Age 2-salt	Age 3-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt
2000	5	302	124(1[A])	1.2	69.9	28.9[A]
2001	3	205	18	1.3	90.7	8.0
2002	5	148	3	3.2	94.9	1.9
2003	0	32	2	0.0	94.1	5.9
2004	4	79	14	4.1	81.4	14.4
2005	1	37	8	2.2	80.4	17.4
2006	3	63	0	4.5	95.5	0.0
2007	12	80	4	12.5	83.3	4.2
2008	30	205	16	12.0	81.7	6.4
2009	8	196	17	3.6	88.7	7.7
2010	16	108	4	12.5	84.4	3.1
2011	2	48	2	3.8	92.3	3.8
2012	7	77	3	8.0	88.5	3.4
2013	9	147	10	5.4	88.6	6.0
2014	9	83	0	9.8	90.2	0.0
2015[B]	3	54	NA	5.3	94.7	--
	Average (2000–2014)			5.6	89.4	5.0

[A] One 4-salt return is included in the 3-salt calculation.
[B] Incomplete adult returns through 9/15/2017 at BOA; not included in average.

Table F.35 Age composition of returning PIT-tagged WARM SPRINGS HATCHERY SPRING CHINOOK adults and jacks detected at Bonneville Dam from smolt migration years 2007 to 2015.

Smolt Migr Year	Age 1-salt	Age 2-salt	Age 3-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt
2007	12	58	2	16.7	80.6	2.8
2008	46	158	9	21.6	74.2	4.2
2009	11	126	3	7.9	90.0	2.1
2010	22	30	1	41.5	65.6	1.9
2011	2	27	1	6.7	90.0	3.3
2012	30	97	1	23.4	75.8	0.8
2013	37	173	2	17.5	81.6	0.9
2014	21	131	2	13.6	85.1	1.3
2015[A]	9	54	NA	14.3	85.7	--
	Average (2007–2014)			18.1	79.8	2.1

[A] Incomplete adult returns through 9/15/2017 at BOA; not included in average.

Table F.36 Age composition of returning PIT-tagged CLE ELUM HATCHERY SPRING CHINOOK adults and jacks detected at Bonneville Dam from smolt migration years 2000 to 2015.

Smolt Migr Year	Age 1-salt	Age 2-salt	Age 3-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt
2000	49	478	48	8.5	83.1	8.3
2001	1	25	1	3.7	92.6	3.7
2002	42	159	2	20.7	78.3	1.0
2003	32	71	0	31.1	68.9	0.0
2004	25	119	4	16.9	80.4	2.7
2005	7	37	1	15.6	82.2	2.2
2006	37	123	4	22.6	75.0	2.4
2007	63	126	2	33.0	66.0	1.0
2008	221	354	15	37.5	60.0	2.5
2009	73	277	3	20.9	78.5	0.9
2010	127	186	3	40.2	58.9	1.0
2011	32	108	3	22.4	75.5	2.1
2012	85	187	5	30.7	67.5	1.8
2013	76	181	2	29.3	69.9	0.8
2014	33	75	0	30.6	69.4	0.0
2015[A]	90	108	NA	45.5	54.5	--
	Average (2000–2014)			25.8	71.6	2.7

Note: Total pit-tag returns from Cle Elum Hatchery's Clark Flat (Rkm 270), Jack Creek (Rkm 284), and Easton (Rkm 325) acclimation pond releases in Yakima River.

[A] Incomplete adult returns through 9/15/2017 at BOA; not included in average.

Middle Columbia wild and hatchery steelhead

Table F.37 Age composition of returning PIT-tagged WILD JOHN DAY RIVER STEELHEAD adults detected at Bonneville Dam that were PIT-tagged meeting a minimum length threshold during the 12-month period from July 1 to June 30 for each smolt migration year between 2006 and 2014.

Smolt Migr Year	Age 1-salt	Age 2-salt	Age 3-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt
2004	66	43	1	60.0	39.1	0.9
2005	69	30	0	69.7	30.3	0.0
2006	42	22	0	65.6	34.4	0.0
2007	185	68	0	73.1	26.9	0.0
2008	215	99	0	68.5	31.5	0.0
2009	106	89	1	54.1	45.4	0.5
2010	127	66	1	65.5	34.0	0.5
2011	28	16	0	63.6	36.4	0.0
2012	113	60	1	64.9	34.5	0.6
2013	82	72	0	53.2	46.8	0.0
2014[A]	42	24	NA	63.6	36.4	--
	Average (2006–2013)			64.5	35.3	0.2

[A] Incomplete adult returns until 3-salt returns (if any) after 9/15/2017 at BOA; not included in average.

Table F.38 Age composition of returning PIT-tagged DESCHUTES WILD STEELHEAD adults detected at Bonneville Dam from smolt migration years 2006 to 2014.

Smolt Migr Year	Age 1-salt	Age 2-salt	Age 3-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt
2006	38	29	0	56.7	43.3	0.0
2007	38	33	0	53.6	46.5	0.0
2008	83	44	0	65.4	34.6	0.0
2009	69	86	0	44.5	55.5	0.0
2010	18	14	0	56.3	43.7	0.0
2011	42	68	0	38.2	61.8	0.0
2012	66	43	0	60.6	39.4	0.0
2013	3	7	0	30.0	70.0	0.0
2014[A]	17	10	NA	63.0	37.0	--
Average (2006–2013)				52.4	47.6	0.0

[A] Incomplete adult returns through 9/15/2017 at BOA; not included in average.

Table F.39 Age composition of returning PIT-tagged YAKIMA WILD STEELHEAD adults detected at Bonneville Dam from smolt migration years 2002 to 2014.

Smolt Migr Year	Age 1-salt	Age 2-salt	Age 3-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt
2002	24	5	0	82.8	17.2	0.0
2003	17	6	0	73.9	26.1	0.0
2004	9	1	0	90.0	10.0	0.0
2005	10	3	0	76.9	23.1	0.0
2006	15	1	0	93.8	6.2	0.0
2007	13	3	0	81.3	18.7	0.0
2008	17	4	0	81.0	19.3	0.0
2009	10	9	0	52.6	47.4	0.0
2010	15	4	0	78.9	21.1	0.0
2011	4	3	0	57.1	42.9	0.0
2012	16	13	0	55.2	44.8	0.0
2013	7	6	0	53.8	46.2	0.0
2014[A]	11	8	NA	57.9	42.1	--
Average (2002–2013)				73.0	27.0	0.0

[A] Incomplete adult returns through 9/15/2017 at BOA; not included in average.

Middle Columbia wild and hatchery subyearling fall Chinook

Table F.40 Age composition of returning PIT-tagged Hanford Reach wild subyearling Chinook detected at Bonneville Dam from smolt migration years 2009 to 2012.

Smolt Migr Year	Age 1-salt	Age 2-salt	Age 3-salt	Age 4,5-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt	Percent 4-Salt
2009	8	4	19	10	19.5	9.8	46.3	24.4
2010	5	10	22	6	11.6	23.3	51.2	14.0
2011	10	29	54	46	7.2	20.9	38.8	33.1
2012	1	3	14	0	5.6	16.7	77.8	0.0
Average (2009–2012)					10.0	19.1	45.2	25.7

Table F.41 Age composition of returning PIT-tagged Deschutes River wild subyearling Chinook detected at Bonneville Dam from smolt migration years 2011 to 2014.

Smolt Migr Year	Age 1-salt	Age 2-salt	Age 3-salt	Age 4,5-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt	Percent 4-Salt
2011	38	53	60	22	22.0	30.6	34.7	12.7
2012	14	21	26	4	21.5	32.3	40.0	6.2
2013	28	35	36	0	28.3	35.4	36.4	0.0
2014[A]	3	1	NA	NA	75.0	25.0	--	--
Average (2011–2013)					23.7	32.3	36.2	7.7

[A] Incomplete adult returns through 9/15/2017 at BOA; not included in average.

Table F.42 Age composition of returning PIT-tagged Spring Creek hatchery subyearling Chinook detected at Bonneville Dam from smolt migration years 2008 to 2014.

Smolt Migr Year	Age 1-salt	Age 2-salt	Age 3-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt
2008	17	58	1	22.4	76.3	1.3
2009	10	18	0	35.7	64.3	0.0
2010	8	34	4	17.4	73.9	8.7
2011	0	22	5	0.0	81.5	18.5
2012	7	39	0	15.2	84.8	0.0
2013	15	75	7	15.5	77.3	7.2
2014[A]	5	8	NA	38.5	61.5	--
Average (2008–2013)				17.8	76.9	5.3

[A] Incomplete adult returns through 9/15/2017 at BOA; not included in average.

Table F.43 Age composition of returning PIT-tagged Little White Salmon Hatchery subyearling Chinook detected at Bonneville Dam from smolt migration years 2008 to 2014.

Smolt Migr Year	Age 1-salt	Age 2-salt	Age 3-salt	Age 4,5-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt	Percent 4-Salt
2008	15	76	126	49	5.6	28.6	47.4	18.4
2009	15	34	64	28	10.6	24.1	45.4	19.9
2010	10	72	256	79	2.4	17.3	61.4	18.9
2011	13	170	262	149	2.2	28.6	44.1	25.1
2012	7	19	82	21	5.4	14.7	63.6	16.3
2013	12	70	58	NA	8.6	50.0	41.4	--
2014[A]	0	7	NA	NA	0.0	100.0	--	--
Average (2008–2013)					4.3	26.1	50.3	19.3

[A] Incomplete adult returns through 9/15/2017 at BOA; not included in average.

Upper Columbia wild and hatchery yearling Chinook

Table F.44 Age composition of returning PIT-tagged WENATCHEE WILD CHINOOK adults and jacks detected at Bonneville Dam from smolt migration years 2007 to 2015.

Smolt Migr Year	Age 1-salt	Age 2-salt	Age 3-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt
2007	0	20	2(1[A])	0.0	90.9	9.1[A]
2008	8	95	63	4.8	57.2	38.0
2009	3	55	11	4.4	79.7	15.9
2010	16	58	8	19.5	70.7	9.8
2011	2	19	8	69.0	65.5	27.6
2012	7	33	3	16.3	76.7	7.0
2013	2	45	11	3.4	77.6	19.0
2014	8	33	3	18.2	75.0	6.8
2015[B]	4	25	NA	13.8	86.2	--
Average (2007–2014)				9.0	70.1	20.9

[A] One 4-salt return is included in the 3-salt calculation.
[B] Incomplete adult returns through 9/15/2017 at BOA; not included in average.

Table F.45 Age composition of returning PIT-tagged ENTIAT and METHOW WILD CHINOOK adults and jacks detected at Bonneville Dam from smolt migration years 2006 to 2015.

Smolt Migr Year	Age 1-salt	Age 2-salt	Age 3-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt
2006	1	4	0	20.0	80.0	0.0
2007	0	6	0	0.0	100.0	0.0
2008	16	96	47	10.1	60.4	29.6
2009	3	31	5	7.7	79.5	12.8
2010	4	42	18	6.3	65.6	18.1
2011	2	3	1	33.3	50.0	16.7
2012	11	22	3	30.6	61.1	8.3
2013	11	34	7	21.2	65.4	13.5
2014	3	35	8	6.5	76.1	17.4
2015[A]	5	12	NA	29.4	70.6	--
Average (2006–2014)				12.3	66.1	21.5

[A] Incomplete adult returns through 9/15/2017 at BOA; not included in average.

Table F.46 Age composition of returning PIT-tagged Upper Columbia wild summer Chinook (Okanogan River or Columbia Mainstem above Wells Dam) adults and jacks detected at Bonneville Dam from smolt migration years 2011 to 2014.

Smolt Migr Year	Age 1-salt	Age 2-salt	Age 3-salt	Age 4,5-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt	Percent 4-Salt
2011	5	34	85	44	3.0	20.2	50.6	26.2
2012	8	3	38	20	11.6	4.3	55.1	29.0
2013	7	33	55	35	5.4	25.4	42.3	26.9
2014[A]	0	1	0	NA	0.0	100.0	0.0	--
Average (2011–2013)					5.4	19.1	27.0	28.1

[A] Incomplete adult returns through 9/15/2017 at BOA; not included in average.

Table F.47 Age composition of returning PIT-tagged LEAVENWORTH NFH SPRING CHINOOK adults and jacks detected at Bonneville Dam from smolt migration years 2000 to 2015.

Smolt Migr Year	Age 1-salt	Age 2-salt	Age 3-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt
2000	1	44	36	1.2	54.3	44.4
2001	0	8	1	0.0	88.9	11.1
2002	29	613	33(1[A])	4.3	90.7	5.0[A]
2003	36	560	93	5.2	81.3	13.5
2004	8	300	56	2.2	82.4	15.4
2005	2	5	2	22.2	55.6	22.2
2006	7	66	7	8.8	82.5	8.8
2007	6	40	1	12.8	85.1	2.1
2008	20	159	15	10.3	82.0	7.7
2009	4	32	9	8.9	71.1	20.0
2010	41	74	6	33.9	61.1	5.0
2011	2	20	3	8.0	80.0	12.0
2012	12	91	4	11.2	85.0	3.7
2013	7	56	7	10.0	80.0	10.0
2014	14	51	1	21.2	77.3	1.5
2015[B]	5	11	NA	31.3	68.8	--
	Average (2000–2014)			7.4	83.1	9.5

[A] One 4-salt return is included in the 3-salt calculation.
[B] Incomplete adult returns through 9/15/2017 at BOA; not included in average.

Upper Columbia wild and hatchery steelhead

Table F.48 Age composition of returning PIT-tagged WENATCHEE, ENTIAT, and METHOW WILD STEELHEAD adults detected at Bonneville Dam from smolt migration years 2006 to 2014.

Smolt Migr Year	Age 1-salt	Age 2-salt	Age 3-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt
2006	5	4	0	55.6	44.4	0.0
2007	11	29	0	27.5	72.5	0.0
2008	86	65	0	57.0	43.1	0.0
2009	32	40	0	44.4	56.6	0.0
2010	28	24	0	53.9	46.1	0.0
2011	8	5	0	61.5	38.5	0.0
2012	26	18	1	57.8	40.0	2.2
2013	22	21	1	50.0	47.7	2.3
2014[A]	23	18	NA	56.1	43.9	--
	Average (2006–2013)			51.2	48.4	0.5

[A] Incomplete adult returns through 9/15/2017 at BOA; not included in average.

Table F.49 Age composition of returning PIT-tagged WENATCHEE HATCHERY STEELHEAD adults detected at Bonneville Dam from smolt migration years 2003 to 2014.

Smolt Migr Year	Age 1-salt	Age 2-salt	Age 3-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt
2003	167	146	1	53.2	46.5	0.3
2004	42	91	1	31.3	67.9	0.8
2005	95	37	0	72.0	28.0	0.0
2006	45	48	0	48.4	51.6	0.0
2007	19	53	0	26.4	73.6	0.0
2008	127	143	0	47.0	53.0	0.0
2009	44	76	2	63.1	62.3	1.6
2010	91	68	0	57.2	42.8	0.0
2011	33	55	0	37.5	62.5	0.0
2012	60	105	2	35.9	62.9	1.2 [A]
2013	74	115	1	38.9	60.5	0.5
2014[B]	50	21	NA	70.4	29.6	--
Average (2003–2013)				45.8	53.8	0.4

[A] One 4-salt return is included in the 3-salt calculation.
[B] Incomplete adult returns through 9/15/2017 at BOA; not included in average.

Upper Columbia wild sockeye

Table F.50 Age composition of returning PIT-tagged Okanogan River wild sockeye adults detected at Bonneville Dam from smolt migration years 2013 to 2015.

Smolt Migr Year	Age 1-salt	Age 2-salt	Age 3-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt
2013	59	99	4	36.4	61.1	2.5
2014	3	57	3	4.8	90.5	4.8
2015[A]	5	33	NA	13.2	86.8	--
Average (2013–2014)				27.6	69.3	3.1

[A] Incomplete adult returns through 9/15/2017 at BOA; not included in average.

Upper Columbia wild and hatchery Chinook, steelhead, and sockeye tagged at Rock Island Dam

Table F.51 Age composition of returning PIT-tagged WILD AND HATCHERY YEARLING CHINOOK ROCK ISLAND adults detected at Bonneville Dam from smolt migration years 2000 to 2015.

Smolt Migr Year	Age 1-salt	Age 2-salt	Age 3-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt
2000	0	16	20	0.0	44.4	55.6
2001[A]	0	0	0	0.0	0.0	0.0
2002	1	0	2	33.3	0.0	66.7
2003[B]	--	--	--	--	--	--
2004	0	1	0	0.0	100.0	0.0
2005[A]	0	0	0	0.0	0.0	0.0
2006	0	1	1	0.0	50.0	50.0
2007[A]	0	0	0	0.0	0.0	0.0
2008	4	4	0	50.0	50.0	0.0
2009	0	2	3	0.0	40.0	60.0
2010	0	3	1	0.0	75.0	25.0
2011	2	1	1	50.0	25.0	25.0
2012	4	3	1	50.0	37.5	12.5
2013	9	37	23[C]	13.0	53.6	33.3[C]
2014	9	14	17	22.5	35.0	42.5
2015[D]	1	19	NA	5.0	95.0	--
Average (2003–2014)				16.1	45.6	38.3

[A] No adult returns in 2001, 2005, or 2007.
[B] No Chinook tagged in 2003.
[C] Two 4-salt returns are included in the 3-salt calculation.
[D] Incomplete adult returns through 9/15/2017 at BOA; not included in average.

Table F.52 Age composition of returning wild and hatchery subyearling Chinook PIT-tagged at Rock Island detected at Bonneville Dam from smolt migration years 2000 to 2014.

Smolt Migr Year	Age 1-salt	Age 2-salt	Age 3-salt	Age 4,5-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt	Percent 4-Salt
2000	3	10	26	43	3.7	12.2	31.7	52.4
2001	0	0	0	0	--	--	--	--
2002	3	3	23	22	5.9	5.9	45.1	43.1
2003	0	3	4	5	0.0	25.0	33.3	41.7
2004	0	0	1	0	0.0	0.0	100.0	0.0
2005	2	2	13	4	9.5	9.5	61.9	19.0
2006	2	2	16	6	7.7	7.7	61.5	23.1
2007	2	1	8	2	15.4	7.7	61.5	15.4
2008	1	4	26	9	2.5	10.0	65.0	22.5
2009	0	4	4	3	0.0	36.4	36.4	27.3
2010	1	7	17	7	3.1	21.9	53.1	21.9
2011	2	19	49	22	2.2	20.7	53.3	23.9
2012	2	2	30	9	4.7	4.7	69.8	20.9
2013	8	20	31	7	12.1	30.3	47.0	10.6
2014[A]	1	2	7	NA	10.0	20.0	70.0	--
Average (2000–2013)					5.3	15.7	28.4	29.6

[A] Incomplete adult returns through 9/15/2017 at BOA; not included in average.

Table F.53 Age composition of returning PIT-tagged WILD AND HATCHERY STEELHEAD ROCK ISLAND adults detected at Bonneville Dam from smolt migration years 2000 to 2014.

Smolt Migr Year	Age 1-salt	Age 2-salt	Age 3-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt
2000	25	31	0	44.6	55.4	0.0
2001	0	3	0	0.0	100.0	0.0
2002	45	30	0	60.0	40.0	0.0
2003[A]	--	--	--	--	--	--
2004	2	6	0	25.0	75.0	0.0
2005	15	7	0	68.2	31.8	0.0
2006	15	13	0	53.6	46.4	0.0
2007	16	15	1	50.0	46.9	3.1
2008	135	58	1	69.9	29.9	0.5
2009	33	25	0	56.9	43.1	0.0
2010	43	38	0	53.1	46.9	0.0
2011	23	19	0	54.8	45.2	0.0
2012	33	25	1	55.9	42.4	1.7
2013	29	27	0	51.8	48.2	0.0
2014[B]	41	17	NA	70.7	29.3	--
	Average (2000–2013)			58.0	41.6	0.4

[A] No Steelhead tagged in 2003.
[B] Incomplete adult returns through 9/15/2017 at BOA; not included in average.

Table F.54 Age composition of returning wild and hatchery Sockeye PIT-tagged at Rock Island detected at Bonneville Dam from smolt migration years 2003 to 2015.

Smolt Migr Year	Age 1-salt	Age 2-salt	Age 3-salt	Percent 1-salt	Percent 2-salt	Percent 3-salt
2000	1	11	1	7.7	84.6	7.7
2001[A]	0	0	0	0.0	0.0	0.0
2002	0	6	0	0.0	100.0	0.0
2003[B]	--	--	--	--	--	--
2004	0	8	0	0.0	100.0	0.0
2005[A]	0	0	0	0.0	0.0	0.0
2006	1	36	2	2.6	92.3	5.1
2007	2	13	3	11.1	72.2	16.7
2008	18	121	10	12.1	81.2	6.7
2009	6	104	11	5.0	86.0	9.1
2010	7	92	2	6.9	91.1	2.0
2011	4	52	3	6.8	88.1	5.1
2012	12	109	14	8.9	80.4	10.4
2013	43	113	10	25.9	68.1	6.0
2014	1	25	4	3.3	83.3	13.3
2015[C]	0	11	NA	0.0	100.0	--
	Average (2000–2014)			11.2	81.7	7.1

[A] No adult returns in 2001 or 2005.
[B] No Sockeye tagged in 2003.
[C] Incomplete adult returns through 9/15/2017 at BOA; not included in average.

APPENDIX G

SNAKE RIVER ADULT SUCCESS RATES FOR TRANSPORTED AND IN-RIVER OUTMIGRANTS FOR THE RUN AS A WHOLE

Appendix G
Snake River Adult Success Rates for Transported and In-river Out-migrants and for the Run as a Whole

Quantifying the efficacy of transportation is one of the foundational goals of the Comparative Survival Study (CSS). The estimation of smolt-to-adult survival rates (SARs) from smolts at Lower Granite Dam (LGR) to adults at LGR is an element of CSS full life-cycle monitoring and is addressed in detail in Appendix A. The CSS PIT-tag data allow for evaluation of the relative upstream passage success of adults between Bonneville Dam (BON) and LGR from transport and in-river groups to further partition the LGR-LGR SARs and assess the extent to which transportation may contribute to straying or poor upstream passage conversion. The capability of estimating the relative adult passage success between BON and LGR became possible in 2002 because adult PIT-tag detection devices were completed in all of the adult ladders at BON. This appendix presents the adult success rate for transported and in-river out-migrating smolts and additionally, because it is of interest to managers, adult success estimated for the run as a whole within one adult return year.

Given that estimates of TIR and *D* both rely on SARs based on adult detections at LGR, these values include both an ocean mortality component and one occurring during upstream migration (i.e., between BON and LGR) in the year of adult return. The adult success rates presented for two out-migration types, transport and in-river, are manifest in the last portion of the smolt-to-adult life cycle from LGR to LGR. The adult success ratio presented in this appendix is estimated for each out-migration year and is analogous to the last component of differential survival measured in both TIR and *D* with one difference. Because there are few PIT-tagged adults, the adult success rates combine the C_1 and C_0 groups whereas TIR and *D* use only the C_0 group to represent in-river out-migrants (see Appendix A for definitions of TIR, *D*, C_0, and C_1). The 2005 and 2006 CSS reports (Berggren et al. 2005b and 2006), contained an analysis/comparison of the inter-dam 'drop out' rates of hatchery and wild Chinook salmon. Annual CSS reports since 2008 have reported adult success rate estimates, the complement of dropout rates, and used these estimates to partition *D* into ocean and BON_{adult} to LGR_{adult} differential survival. This appendix updates the analyses from the 2017 report and includes migration years 2000–2016 for CSS Snake River groups.

The CSS was requested to add the adult success rate by return year to the 2010 report by IDFG and ODFW because it is of interest to managers. These estimates differ from those for each out-migration type in two key respects. They are applicable for the run as a whole and are aligned with each adult return year. Conversely, the adult success rates by out-migration type are aligned with the year of the smolt out-migration and are not applicable to the run as a whole. The estimates for Snake River wild Chinook are included in this appendix and one migration year is added to the time-series. Along the same lines of interest, Snake River wild steelhead success rate estimates for the run as a whole are presented here.

Methods

Adult passage success by migration year

Adult success rates by migration year and ocean survival were estimated for Snake River CSS groups from migration year 2000 to 2016. Data on the number of PIT-tagged adults passing various dams within the FCRPS were used to estimate a success rate for returning adults from BON to LGR. Using data collected at PIT-tag interrogation systems on adult fishways, this quantity was directly estimated and compared between the transport (T_X or T_0) and in-river (C_0 and C_1) study categories in the CSS. During years with a delayed initiation of transportation (after 2005) the transport group was expanded to include fish transported with a previous detection upstream (T_X). This is a logical fit with the delayed transport protocol in these years and follows the CSS study design.

Hatchery and wild Chinook and steelhead marked with PIT tags as juvenile fish in the Snake River basin were monitored at mainstem dams on their downstream migration; after spending one to three years in the ocean, the survivors were detected as they passed upstream as adults through the hydrosystem. PIT-tag detection systems have now been installed in the fish ladders at BON, TDA, MCN, ICH, LMN, LGS and LGR and allowed the tracking of PIT-tagged adults as they passed from lower Columbia River projects to upstream Snake River projects. The adult fish traverse about 286 river miles and encounter eight dams from BON to LGR. Once fish negotiate BON, they pass through tribal fisheries (between BON and MCN) and a sport fishery in both the Columbia and Snake rivers. The detections of adults decrease at upriver sites as a result of the combination of straying, harvest mortality, and passage mortality. Another source of losses is fallbacks since adults may pass BON, later fallback below BON, and do not subsequently re-ascend.

The adult success rate is the proportion of returning PIT-tagged adults that passed BON and were detected at LGR. This calculation requires an estimate of the number of PIT-tagged adults passing BON in the fish ladders. Jacks were excluded from the Chinook success rate so that this analysis is aligned with *D* and *TIR* that both exclude jacks. Jack Chinook typically have a higher success rate than 2-salt and 3-salt Chinook (Berggren et al. 2006; Table 46). Beginning with return year 2002 the capability to detect nearly all PIT-tagged adult fish passing the three ladders at BON was in place. Although the BON detection efficiency is very high it is less than 100%. This may be for a variety of reasons: (1) adults potentially could swim over the weir crests and not pass through the orifices where the detection equipment is installed; (2) adults pass in the navigational locks; (3) adults pass during potential PIT tag antennae outages.

Efficiency at Bonneville Dam was calculated using the Manly-Parr method (Pollock and Alpizar-Jara 2005). This approach conditions on upstream detections of adults and expresses the proportion of those detected upstream that were also detected at BON as an adult. While this estimate of BON detection efficiency is based on those fish surviving to upstream sites, it is not built on an assumption of 100% survival. Rather, estimating detection efficiency in this way only assumes that survival and detection probability are equivalent for all individuals (i.e., detected and undetected fish survive at a similar rate); the number of fish actually detected at upstream sites (i.e., 'sampled') will thus vary as a function of survival, but the estimate of detection efficiency will not. To maximize the sample and the precision for these estimates BON efficiency was calculated using the pooled transported and in-river adults. Detectability of adults

at BON has been shown to be similar regardless of previous juvenile history (Tuomikoski et al. 2011) and this approach allowed for use of the maximum number of detections. The pooled efficiency parameter was then used to expand the number of BON adult detections in the adult success rate. The adult success rate was calculated as:

$$Adult.success.rate = \frac{LGR_{count}}{\left(BON_{count} \div BON_{efficiency}\right)} \qquad [G.1]$$

which can be re-arranged as:

$$Adult.success.rate = \frac{LGR_{count}}{BON_{count}} \times BON_{efficiency} \qquad [G.2]$$

These calculations were performed for each group of interest. First efficiency was calculated at BON by aggregating adult detections from the transported and in-river study groups. Then, adult success rates were calculated for adults with in-river and transportation juvenile histories separately. Because the C_1 and C_0 in-river groups had a much smaller sample size than the T_X group, and few adults returned overall, the C_0 and C_1 were combined into group (C_X). Differences exist in the C_0 and C_1 SARs (see Appendix A of this report) and some of this may be expressed during the return adult migration through the FCRPS. However, comparing their pooled adult success with adults that were transported as juveniles, still allows for testing of how differing juvenile out-migration histories (i.e., transported and not transported) affect the adult return migration. Finally, the $BON_{efficiency}$ was used to correct the adult success rate for the T_X and the C_X subset from a particular migration year, species and release group (e.g., Dworshak Hatchery Chinook that out-migrated in 2007). The use of the efficiency parameter to expand BON detected adults only applies for group estimates of success. When comparing the two group rates in a fraction (e.g., $Success_{(Tx\ or\ T0)}/Success_{Cx}$), the efficiency parameter, existing in the numerator and denominator, cancels out.

The calculations of confidence intervals for all success, efficiency, success ratios, and efficiency comparisons (i.e., transported vs. in-river) in this appendix were performed in a similar fashion to those in Appendix A but using computer program R (R Development Core Team 2010). The non-parametric bootstrapping approach of Efron and Tibshirani (1993) was employed. First the point estimates were calculated from the population, and then the data were re-sampled with replacement to create 1,000 simulated populations. Specifically, a data set of individual fish released for each group of interest (e.g., 2001 Rapid River spring Chinook) was assembled. Each data set was composed of a study category identifier—C_0, C_1, or transported—and history of adult detections at BON, MCN, ICH, and LGR. All individuals from the group of interest were included in the data set even if there were zero adult detections at any site. Each data set was randomly resampled with replacement 1,000 times and the ordered 50th and 951st members for each iterative calculation were selected to express lower and upper 90% confidence intervals for that metric within each group of interest. This was done for each of the groups shown in Tables G.1 and G.2.

Adult passage success by adult return year

Success rates by adult return year are also of interest to managers in assessing the effects of hydrosystem actions and the results of fishing pressure for specific calendar years. The CSS study data are designed to apply to a broad scope of management questions, including hydropower operations, hatchery evaluations, and habitat evaluations. In the process of filling this need, the adult success by return year for wild Snake River Chinook in the return years 2003–2016 without confidence intervals is presented in this report (Table G3).

To calculate the success rate by return year, since several migration years may compose one return year, first age specific success rate within a calendar year was calculated for adult ages 1-salt, 2-salt and 3-salt for steelhead and ages 2-salt and 3-salt for Chinook. Age 4-salts were not included because only two returns of PIT-tagged Snake River wild Chinook occurred from 2003–2016 and these composed 0.15% and 0.67% of the return from the migration years when they occurred. To preclude the use of efficiency at BON, only those adults detected at BON were used as the denominator of the success rate. Of these, the proportion that is later seen at LGR was the numerator of the success rate. Each success rate estimate then resolves to a proportion of counts.

One advantage of the current CSS protocol of randomly pre-assigning is that study groups are properly weighted to represent the run-at-large from each annual out-migration. The pre-assigned T group fish (monitor mode) are a group of PIT tags that matches the run at large in their disposition at LGR, LGS and LMN (see Chapter 1 and Appendix A for more discussion of pre-assignment) and allows for the relatively simple calculation below (equation G.3) because the incorporated counts of adults at BON and LGR are only those adults from the T group. These PIT-tagged fish followed the run-at-large during the juvenile out-migration and are properly weighted in all three study groups: C_1, C_0, and transported. One assumption used in this approach is that tagging rates (PIT-tagged smolt per un-tagged smolt) are similar across migration years because each migration year is weighted equally. This seems a reasonable assumption given the consistent effort to tag wild fish for those groups utilized in the CSS. Future reports will include estimates for hatchery groups where the tagging rate is known (see Appendix A) but this is also consistent across years for most groups. In order to calculate estimates for years with adults that were not pre-assigned to follow the run-at-large, additional adjustments were necessary.

$$\textbf{Adult Success by ReturnYear} = \frac{\sum LGR_{2-salt} + LGR_{3-salt}}{\sum BON_{2-salt} + BON_{3-salt}} \qquad [G.3]$$

Calendar years prior to 2009 include returning adults from out-migrating smolts that were not pre-assigned to follow the run-at-large. Prior to 2006, relatively few untagged fish were returned to river during the spring out-migration. However in order to estimate in-river survivals, researchers routed more PIT-tags to return-to-river than would proportionally represent unmarked in-river smolts. In these cases, the PIT-tags across the three study categories (C_1, C_0, and transported) weighted in proportion with the run-at-large, changes in each out-migration year. We used the metrics that describe these migration year differences from the bootstrap program outputs presented in Chapter 4 and those available on the FPC website

(www.fpc.org; see Appendix A for instructions on website use) to create a weighting factor. For example, first the weighting factors used for 3-salts (2005 out-migration) for the 2008 calendar year were calculated as:

$$
\begin{aligned}
NT_{3-salt} &= Pop \times Transport\ SAR \times PROP(3-salt) \times PROP(Transport) \\
NC0_{3-salt} &= Pop \times C0\ SAR \times PROP(3-salt) \times PROP(C_0) \\
NC1_{3-salt} &= Pop \times C1\ SAR \times PROP(3-salt) \times PROP(C_1) \\
&\quad and, \\
WT_{3-salt} &= \frac{NT_{3-salt}}{\sum all\ N's}\ ,\ WC0_{3-salt} = \frac{NC0_{3-salt}}{\sum all\ N's}\ ,\ WC1_{3-salt} = \frac{NC1_{3-salt}}{\sum all\ N's} \\
&\quad where, \\
Pop &= Estimated\ smolt\ population\ at\ LGR \\
Transport\ SAR &= Transport\ SAR\ from\ LGR_{SMOLT}\ to\ BON_{ADULT} \\
C0\ SAR &= C_0\ SAR\ from\ LGR_{SMOLT}\ to\ BON_{ADULT} \\
C1\ SAR &= C_1\ SAR\ from\ LGR_{SMOLT}\ to\ BON_{ADULT} \\
PROP(3\text{-}salt) &= Overall\ proportion\ of\ \mathbf{3}\text{-}salt's \\
PROP(Transport) &= Run-at-large\ population\ proportion\ of\ transported \\
PROP(C_1) &= Run-at-large\ population\ proportion\ of\ C_0 \\
PROP(C_0) &= Run-at-large\ population\ proportion\ of\ C_1
\end{aligned}
\qquad [G.4]
$$

The above weighting factors were similarly calculated for 2-salts from the 2006 out-migration. Adult success was then calculated for each study category within each age. When incorporating the above weighting factors, the overall adult success for the 2008 adult return year was:

$$
\begin{aligned}
\textbf{Adult Success by Return Year} = &\left\{\frac{\sum LGR_{2-salt_transported}}{\sum BON_{2-salt_transported}} \times WT_{2-salt}\right\} + \left\{\frac{\sum LGR_{3-salt_transported}}{\sum BON_{3-salt_transported}} \times WT_{3-salt}\right\} + \\
&\left\{\frac{\sum LGR_{2-salt_C1}}{\sum BON_{2-salt_C1}} \times WC1_{2-salt}\right\} + \left\{\frac{\sum LGR_{3-salt_C1}}{\sum BON_{3-salt_C1}} \times WC1_{3-salt}\right\} + \\
&\left\{\frac{\sum LGR_{2-salt_C0}}{\sum BON_{2-salt_C0}} \times WC0_{2-salt}\right\} + \left\{\frac{\sum LGR_{3-salt_C0}}{\sum BON_{3-salt_C0}} \times WC0_{3-salt}\right\}
\end{aligned}
\qquad [G.5]
$$

The calculations in years both with and without pre-assignment assume that the proportion of 1-salts (for steelhead only), 2-salts and 3-salts is the same across all study categories (C_1, C_0, and transported) from a single migration year. This assumption seems reasonable from comparisons of age at return across study categories (Chapter 5; Tuomikoski 2010).

Results

Table G.1 – Counts of adults at LGR and BON for all Snake River CSS groups for the juvenile out-migration years 2000–2013. Total adults are shown for fish with two different routes of passage as emigrating juveniles (transported [T_0 before 2006, T_X thereafter] and in-river groups [C_X]). The BON efficiency used for success rates is calculated from the pooled ($T_X + C_X$) groups to make use of the most detections. The BON totals shown were adults detected and expanded by efficiency (∑(BON adult detects) ÷ [BON efficiency]).

Rear-type/Species/ Migration Year[A]	LGR-T_X	BON-T_X	LGR-C_X	BON-C_X	BON Efficiency ($T_X + C_X$)
2000					
HCH-CATH	N/A	N/A	N/A	N/A	N/A
HCH-DWOR	183	295	176	228	97.1%
HCH-IMNA	211	262	143	155	99.2%
HCH-MCCA	497	583	361	400	98.4%
HCH-RAPH	349	491	246	291	97.1%
WCH	12	21	547	640	98.1%
HST	14	17	239	220	72.0%
WST	13	15	228	224	81.8%
		Geom (ST)	76.8%	Geom (CH)	98.0%
2001					
HCH-CATH	11	18	2	3	100.0%
HCH-DWOR	79	96	7	8	100.0%
HCH-IMNA	48	61	5	8	100.0%
HCH-MCCA	206	246	9	10	96.4%
HCH-RAPH	207	265	10	14	98.7%
WCH	7	10	30	33	97.4%
HST	4	6	5	7	90.9%
WST	5	8	11	16	100.0%
		Geom (ST)	95.3%	Geom (CH)	98.7%
2002					
HCH-CATH	24	33	22	21	92.0%
HCH-DWOR	60	80	169	193	97.1%
HCH-IMNA	31	41	49	60	100.0%
HCH-MCCA	131	164	232	281	97.6%
HCH-RAPH	117	132	185	210	94.0%
WCH	31	41	201	223	96.6%
HST	3	3	145	167	96.1%
WST	9	11	109	126	98.3%
		Geom (ST)	97.2%	Geom (CH)	96.2%
2003					
HCH-CATH	9	10	13	14	90.9%
HCH-DWOR	34	44	50	57	93.3%
HCH-IMNA	30	39	43	51	97.6%
HCH-MCCA	111	124	137	154	95.4%
HCH-RAPH	33	52	50	52	91.7%
WCH	30	29	51	55	92.8%
HST	83	105	81	99	97.6%
WST	44	53	52	57	96.0%
		Geom (ST)	96.8%	Geom (CH)	93.6%
2004					
HCH-CATH	11	14	7	7	94.4%
HCH-DWOR	61	121	46	66	97.0%
HCH-IMNA	26	41	8	12	97.5%
HCH-MCCA	84	113	25	41	99.2%
HCH-RAPH	70	88	23	25	95.9%
WCH	68	88	48	59	96.1%
HST	10	9	33	39	95.6%

Rear-type/Species/ Migration Year[A]	LGR-T_X	BON-T_X	LGR-C_X	BON-C_X	BON Efficiency ($T_X + C_X$)
WST	39	60	5	7	97.9%
		Geom (ST)	96.7%	Geom (CH)	96.7%
2005					
HCH-CATH	11	14	4	4	87.5%
HCH-DWOR	43	65	30	35	96.4%
HCH-IMNA	17	23	8	8	100.0%
HCH-MCCA	141	168	41	49	99.0%
HCH-RAPH	55	69	20	23	92.5%
WCH	37	48	20	28	98.4%
HST	18	29	43	56	96.9%
WST	41	52	17	17	93.9%
		Geom (ST)	95.4%	Geom (CH)	95.5%
2006					
HCH-CATH	13	25	23	34	100.0%
HCH-CLWH	102	154	61	94	98.8%
HCH-DWOR	57	93	80	131	99.3%
HCH-IMNA	46	62	55	66	99.1%
HCH-MCCA	173	200	153	186	99.1%
HCH-RAPH	107	150	69	102	96.2%
WCH	80	92	79	101	99.4%
HST	25	35	154	192	99.5%
WST	48	82	32	46	98.9%
		Geom (ST)	99.2%	Geom (CH)	98.8%
2007					
HCH-CATH	12	15	20	22	90.9%
HCH-CLWH	15	23	80	112	98.1%
HCH-DWOR	16	27	127	172	98.0%
HCH-IMNA	23	27	70	90	100.0%
HCH-MCCA	78	93	152	187	99.2%
HCH-RAPH	41	64	71	95	94.4%
HCH-SAWT	30	35	20	22	92.6%
WCH	39	47	167	197	99.5%
HST	56	84	194	238	99.2%
WST	125	165	98	123	98.7%
		Geom (ST)	99.0%	Geom (CH)	96.5%
2008					
HCH-CATH	103	128	88	116	99.0%
HCH-CLWH	80	120	119	158	98.2%
HCH-DWOR	69	125	137	227	100.0%
HCH-IMNA	107	151	131	177	99.6%
HCH-MCCA	150	209	162	214	97.9%
HCH-PAHH	49	69	35	40	100.0%
HCH-RAPH	250	363	243	329	97.9%
HCH-SAWT	33	40	16	18	100.0%
WCH	259	349	436	542	98.5%
HST-GRN-A run	334	554	427	575	99.3%
HST-IMN-A run	279	461	281	379	99.7%
HST-SAL-A run	481	707	811	994	99.6%
HST-CLW-B run	151	240	348	473	99.3%
HST-SAL-B run	79	143	115	145	98.7%
WST	101	153	227	272	99.7%
		Geom (ST)	99.4%	Geom (CH)	99.0%
2009					
HCH-CATH	57	79	59	73	97.6%
HCH-CLWH	63	99	206	278	98.0%
HCH-DWOR	41	60	95	121	96.1%

Rear-type/Species/ Migration Year[A]	LGR-T_X	BON-T_X	LGR-C_X	BON-C_X	BON Efficiency ($T_X + C_X$)
HCH-IMNA	68	107	63	104	99.3%
HCH-MCCA	57	94	76	138	97.9%
HCH-PAHH	5	9	48	77	100.0%
HCH-RAPH	162	221	196	274	97.4%
HCH-SAWT	15	16	8	8	91.3%
WCH	123	164	295	405	98.6%
HST-GRN-A run	121	207	241	313	98.5%
HST-HCD-A run	98	162	81	110	98.6%
HST-IMN-A run	101	168	171	235	98.4%
HST-SAL-A run	275	391	496	624	99.3%
HST-CLW-B run	63	107	363	499	99.4%
HST-SAL-B run	70	112	101	129	99.0%
WST	95	143	124	164	99.6%
HSK-OXBH	21	32	22	36	100.0%
HSK-SAWT	124	188	151	245	98.6%
Geom (SK)	99.3%	Geom (ST)	99.0%	Geom (CH)	97.3%
2010					
HCH-CATH	22	28	52	76	97.5%
HCH-CLWH	32	52	213	268	95.5%
HCH-DWOR	22	46	210	275	95.7%
HCH-IMNA	25	32	84	101	98.2%
HCH-MCCA	41	51	118	155	98.8%
HCH-PAHH	4	4	1	2	100.0%
HCH-RAPH	37	57	145	215	94.5%
HCH-SAWT	13	16	30	35	97.7%
WCH	92	126	212	247	99.4%
HST-GRN-A run	113	219	346	473	98.6%
HST-HCD-A run	66	104	168	231	98.5%
HST-IMN-A run	83	129	207	260	98.4%
HST-SAL-A run	214	341	739	936	98.5%
HST-CLW-B run	83	144	351	468	98.7%
HST-SAL-B run	20	30	51	64	98.8%
WST	68	102	152	181	98.3%
HSK-OXBH[B]	0	0	25	46	100.0%
HSK-SAWT[B]	0	1	25	47	96.4%
Geom (SK)	98.2%	Geom (ST)	98.5%	Geom (CH)	97.5%
2011					
HCH-CATH	12	19	15	16	99.0%
HCH-CLWH	8	19	62	83	98.6%
HCH-DWOR	12	25	47	59	99.6%
HCH-IMNA	12	20	20	26	97.5%
HCH-MCCA	33	46	69	80	95.5%
HCH-PAHH	0	0	2	2	95.7%
HCH-RAPH	47	61	53	59	98.2%
HCH-SAWT	4	5	12	13	98.8%
WCH	32	41	94	117	100.0%
HST-GRN-A run	17	38	80	113	94.5%
HST-HCD-A run	7	11	7	13	97.7%
HST-IMN-A run	39	65	52	71	100.0%
HST-SAL-A run	199	329	304	380	96.4%
HST-CLW-B run	44	76	146	202	98.6%
HST-SAL-B run	11	29	16	21	98.5%
WST	34	53	48	67	98.4%
HSK-OXBH	44	76	146	202	98.5%
HSK-SAWT	11	29	16	21	98.7%
Geom (SK)	98.6%	Geom (ST)	97.7%	Geom (CH)	98.1%

Rear-type/Species/ Migration Year[A]	LGR-T_X	BON-T_X	LGR-C_X	BON-C_X	BON Efficiency ($T_X + C_X$)
2012					
HCH-CATH	11	15	45	55	96.5%
HCH-CLWH	43	60	291	364	99.1%
HCH-CLWH_SU	4	8	75	99	98.9%
HCH-DWOR	37	51	215	281	98.9%
HCH-IMNA	16	30	66	93	98.9%
HCH-MCCA	74	107	251	357	99.1%
HCH-PAHH	0	1	37	49	100.0%
HCH-RAPH	114	151	250	320	99.7%
HCH-SAWT	20	25	25	32	100.0%
WCH	47	56	387	505	98.9%
HST-GRN-A run	62	117	292	429	99.5%
HST-HCD-A run	16	25	67	96	100.0%
HST-IMN-A run	71	114	242	341	99.4%
HST-SAL-A run	154	255	610	839	99.5%
HST-CLW-B run	34	50	274	337	99.1%
HST-SAL-B run	48	71	51	63	96.4%
WST	48	65	220	290	99.3%
HSK-OXBH	20	25	25	32	100.0%
HSK-SAWT	29	79	125	191	98.9%
Geom (SK)	99.4%	Geom(ST)	99.0%	Geom (CH)	99.0%
2013					
HCH-CATH	32	38	48	55	97.6%
HCH-CLWH	41	65	338	376	96.5%
HCH-CLWH_SU	6	32	72	112	96.6%
HCH-DWOR	41	88	271	324	96.7%
HCH-IMNA	31	51	97	157	99.4%
HCH-MCCA	105	205	384	575	99.1%
HCH-PAHH	2	5	33	49	100.0%
HCH-RAPH	172	207	391	443	96.8%
HCH-SAWT	39	52	49	70	94.6%
WCH	114	147	266	335	96.3%
HST-GRN-A run	85	141	253	348	98.9%
HST-HCD-A run	37	51	70	87	97.4%
HST-SAL-A run	236	324	379	505	99.1%
HST-CLW-B run	24	35	201	238	99.6%
HST-SAL-B run	30	38	49	53	98.8%
WST	119	162	128	166	97.8%
HSK-SAWT	39	52	49	70	94.6%
Geom (SK)	94.6%	Geom(ST)	98.6%	Geom (CH)	97.3%
2014					
HCH_CATH	18	23	8	16	100.0%
HCH_CLWH	36	47	125	160	97.0%
HCH_CLWH_SU	18	36	67	99	99.0%
HCH_DWOR	47	62	77	112	100.0%
HCH_IMNA	28	45	26	31	98.3%
HCH_MCCA	93	158	160	212	98.3%
HCH_PAHH	1	2	1	2	100.0%
HCH_RAPH	83	95	86	131	98.3%
HCH_SAWT	24	33	53	74	100.0%
WCH	51	60	135	165	99.5%
HST-GRN-A run	98	168	301	400	99.0%
HST-HCD-A run	34	74	50	74	98.1%
HST-IMN-A run	130	195	151	213	98.7%
HST-SAL-A run	127	196	304	391	98.1%
HST-CLW-B run	104	127	400	508	96.0%

Rear-type/Species/ Migration Year[A]	LGR-T_X	BON-T_X	LGR-C_X	BON-C_X	BON Efficiency ($T_X + C_X$)
HST-SAL-B run	80	103	60	72	95.0%
WST	88	134	94	133	99.5%
HSK_SAWT	22	50	99	131	100.0%
Geom(SK)	100%	Geom(ST)	97.8%	Geom (CH)	99.0%
2015					
HCH_CATH	8	10	20	28	100.0%
HCH_CLWH	2	5	97	130	100.0%
HCH_CLWH_SU	0	0	52	68	94.3%
HCH_DWOR	1	3	33	50	94.4%
HCH_IMNA	8	12	13	21	100.0%
HCH_MCCA	22	32	55	68	100.0%
HCH_PAHH	0	0	5	7	100.0%
HCH_RAPH	28	36	90	108	96.8%
HCH_SAWT	8	14	17	19	100.0%
WCH	16	18	41	51	98.4%
HST-GRN-A run	4	8	40	51	100.0%
HST-HCD-A run	3	5	14	16	100.0%
HST-IMN-A run	6	10	21	30	100.0%
HST-SAL-A run	6	7	34	39	97.6%
HST-CLW-B run	1	3	56	77	96.8%
HST-SAL-B run	1	3	4	4	100.0%
WST	1	10	12	15	92.9%
HSK_SPR	0	0	0	0	N/A
Geom(SK)	N/A	Geom(ST)	98.1%	Geom (CH)	98.4%
2016					
HCH_CATH	1	2	9	9	100.0%
HCH_CLWH	3	3	38	45	95.2%
HCH_CLWH_SU	0	0	29	35	96.8%
HCH_DWOR	0	0	3	7	100.0%
HCH_IMNA	3	3	1	1	100.0%
HCH_MCCA	35	44	42	54	100.0%
HCH_PAHH	10	11	3	5	92.9%
HCH_RAPH	5	6	13	14	94.4%
HCH_SAWT	2	3	15	16	100.0%
WCH	3	4	6	5	88.9%
HST-GRN-A run	15	24	110	155	97.3%
HST-HCD-A run	10	17	35	43	98.0%
HST-IMN-A run	33	50	69	101	98.3%
HST-SAL-A run	48	60	83	113	95.3%
HST-CLW-B run	1	3	54	77	98.5%
HST-SAL-B run	9	13	11	10	87.5%
WST	14	22	38	51	96.8%
HSK_SPR	0	0	0	0	N/A
Geom(SK)	N/A	Geom(ST)	95.9%	Geom (CH)	96.7%

[A] Rear-type and species shown are: hatchery Chinook (HCH), wild Chinook (WCH), hatchery steelhead (HST), wild steelhead (WST), and hatchery sockeye (HSK).

Hatcheries are: Catherine Creek AP (CATH), Clearwater (CLWH), Dworshak (DWOR), Imnaha AP (IMNA), McCall (MCCA), Pahsimeroi (PAHH), Rapid River (RAPH), Sawtooth (SAWT), and Oxbow (OXBH).

Hatchery steelhead basin and run-types are: Grande Ronde A run (GRN A run), Hells Canyon Dam A run (HCD A run), Imnaha A run (IMN A run), Salmon A run (SAL A run), Clearwater B run (CLW B run), and Salmon B run (SAL B run).

[B] No transport treatment in 2010; therefore estimation was not reliable.

Table G.2. Adult success rates for all CSS groups for the juvenile out-migration years 2000-2012. Adult success rate for the transported (T_0 before 2006, T_X thereafter) and in-river groups (C_X), and the success rate differential of those rates are each shown with their 90% confidence interval. The success ratio is shown in the right column; where in bold type, the two groups were significantly different at α = 0.10.

Mig. Year	Rear-type/ Species[A]	Hatchery Group[A]	Success T_0	Success C_X	Success ratio T_0/C_X
2000	HCH	DWOR	0.60 (0.55 – 0.65)	0.75 (0.70 - 0.80)	0.80 (0.72 - 0.89)
	HCH	IMNA	0.80 (0.76 – 0.84)	0.92 (0.87 - 0.95)	0.87 (0.81 - 0.93)
	HCH	MCCA	0.84 (0.81 – 0.86)	0.89 (0.86 - 0.92)	0.94 (0.91 - 0.99)
	HCH	RAPH	0.69 (0.65 – 0.72)	0.82 (0.78 - 0.86)	0.84 (0.79 - 0.90)
	WCH		0.56 (0.37 – 0.73)	0.84 (0.81 - 0.86)	0.67 (0.45 - 0.87)
	HST		0.59 (0.39 – 0.87)	0.78 (0.74 - 0.83)	0.76 (0.49 - 1.11)
	WST		0.71 (0.49 – 1.00)	0.83 (0.79 - 0.87)	0.85 (0.58 - 1.21)
2001	HCH	CATH	0.61 (0.41 – 0.80)	0.67 (0.14 - 0.98)[B]	NSD[B]
	HCH	DWOR	0.82 (0.76 – 0.89)	0.88 (0.67 - 1.00)	0.94 (0.78 - 1.29)
	HCH	IMNA	0.79 (0.70 – 0.87)	0.63 (0.33 - 1.00)	1.26 (0.81 - 2.48)
	HCH	MCCA	0.81 (0.76 – 0.85)	0.87 (0.69 - 0.98)	0.93 (0.80 - 1.17)
	HCH	RAPH	0.77 (0.73 – 0.81)	0.70 (0.50 - 0.90)	1.09 (0.85 - 1.54)
	WCH		0.68 (0.42 – 0.93)	0.89 (0.78 - 0.97)	0.77 (0.47 - 1.07)
	HST		0.61 (0.28 – 0.93)	0.65 (0.33 - 0.92)	0.93 (0.44 - 2.00)
	WST		0.63 (0.33 – 0.91)	0.69 (0.50 - 0.88)	0.91 (0.44 - 1.54)
2002	HCH	CATH	0.67 (0.53 – 0.82)	0.96 (0.86 - 1.08)	0.69 (0.52 - 0.89)
	HCH	DWOR	0.73 (0.64 – 0.82)	0.85 (0.81 - 0.89)	0.86 (0.74 - 0.97)
	HCH	IMNA	0.76 (0.65 – 0.86)	0.82 (0.73 - 0.89)	0.93 (0.77 - 1.10)
	HCH	MCCA	0.78 (0.73 – 0.83)	0.81 (0.77 - 0.85)	0.97 (0.89 - 1.06)
	HCH	RAPH	0.83 (0.77 – 0.89)	0.83 (0.78 - 0.87)	1.01 (0.92 - 1.10)
	WCH		0.73 (0.61 – 0.85)	0.87 (0.83 - 0.91)	0.84 (0.70 - 0.98)
	HST		0.96 (0.93 – 0.99)	0.83 (0.78 - 0.88)	1.15 (1.09 - 1.28)
	WST		0.80 (0.53 – 1.10)	0.85 (0.79 - 0.90)	0.95 (0.61 - 1.31)
2003	HCH	CATH	0.82 (0.57 – 1.05)	0.84 (0.66 - 1.01)	0.97 (0.63 - 1.43)
	HCH	DWOR	0.72 (0.60 – 0.85)	0.82 (0.73 - 0.90)	0.88 (0.72 - 1.09)
	HCH	IMNA	0.75 (0.62 – 0.86)	0.82 (0.73 - 0.91)	0.91 (0.74 - 1.09)
	HCH	MCCA	0.85 (0.80 – 0.91)	0.85 (0.80 - 0.90)	1.01 (0.91 - 1.10)
	HCH	RAPH	0.58 (0.47 – 0.70)	0.88 (0.79 - 0.97)	0.66 (0.52 - 0.82)
	WCH		0.96 (0.88 – 1.05)	0.86 (0.77 - 0.94)	1.12 (0.97 - 1.29)
	HST		0.77 (0.70 – 0.84)	0.80 (0.73 - 0.86)	0.97 (0.86 - 1.09)
	WST		0.80 (0.70 – 0.89)	0.88 (0.80 - 0.95)	0.91 (0.77 - 1.05)
2004	HCH	CATH	0.74 (0.55 – 0.93)	0.94 (0.67 - 1.25)	0.79 (0.50 - 1.22)
	HCH	DWOR	0.49 (0.42 – 0.56)	0.68 (0.58 - 0.77)	0.72 (0.59 - 0.89)
	HCH	IMNA	0.62 (0.49 - 0.74)	0.65 (0.42 - 0.88)	0.95 (0.65 - 1.53)
	HCH	MCCA	0.74 (0.67 - 0.81)	0.60 (0.48 - 0.74)	1.22 (0.99 - 1.56)
	HCH	RAPH	0.76 (0.69 - 0.84)	0.88 (0.75 - 1.02)	0.86 (0.72 - 1.06)
	WCH		0.74 (0.67 - 0.82)	0.78 (0.69 - 0.87)	0.95 (0.81 - 1.12)
	HST		1.06 (0.82 - 1.42)	0.81 (0.70 - 0.90)	1.31 (0.96 - 1.86)
	WST		0.64 (0.53 - 0.74)	0.70 (0.38 - 1.00)	0.91 (0.62 - 1.77)
2005	HCH	CATH	0.69 (0.45 - 0.89)	0.88 (0.42 - 1.83)	0.79 (0.31 - 1.86)
	HCH	DWOR	0.64 (0.54 - 0.74)	0.83 (0.71 - 0.93)	0.77 (0.63 - 0.96)
	HCH	IMNA	0.74 (0.59 - 0.89)	1.00 (1.00 - 1.00)	0.74 (0.59 - 0.89)
	HCH	MCCA	0.83 (0.78 - 0.88)	0.83 (0.74 - 0.91)	1.00 (0.90 - 1.15)
	HCH	RAPH	0.74 (0.65 - 0.82)	0.80 (0.66 - 0.94)	0.92 (0.74 - 1.14)
	WCH		0.76 (0.65 - 0.86)	0.70 (0.54 - 0.84)	1.08 (0.85 - 1.44)
	HST		0.60 (0.45 - 0.75)	0.74 (0.65 - 0.84)	0.81 (0.59 - 1.05)
	WST		0.74 (0.63 - 0.84)	0.94 (0.74 - 1.18)	0.79 (0.58 - 1.05)
2006	HCH	CATH	0.52 (0.36 - 0.71)	0.68 (0.55 - 0.81)	0.77 (0.51 - 1.13)
	HCH	CLWH	0.65 (0.59 - 0.72)	0.64 (0.55 - 0.72)	1.02 (0.87 - 1.22)
	HCH	DWOR	0.61 (0.53 - 0.70)	0.61 (0.53 - 0.68)	1.00 (0.84 - 1.21)
	HCH	IMNA	0.74 (0.64 - 0.82)	0.83 (0.75 - 0.90)	0.89 (0.77 - 1.04)

Mig. Year	Rear-type/ Species[A]	Hatchery Group[A]	Success T_0	Success C_X	Success ratio T_0/C_X
	HCH	MCCA	0.86 (0.82 - 0.90)	0.82 (0.77 - 0.86)	1.05 (0.98 - 1.14)
2006	HCH	RAPH	0.69 (0.62 - 0.75)	0.65 (0.57 - 0.73)	1.05 (0.91 - 1.24)
	WCH		0.86 (0.81 - 0.92)	0.78 (0.70 - 0.84)	1.11 (1.00 - 1.25)
	HST		0.71 (0.59 - 0.84)	0.80 (0.75 - 0.84)	0.89 (0.73 - 1.06)
	WST		0.58 (0.49 - 0.67)	0.69 (0.57 - 0.80)	0.84 (0.66 - 1.07)
2007	HCH	CATH	0.73 (0.54 - 0.89)	0.83 (0.67 - 0.97)	0.88 (0.63 - 1.19)
	HCH	CLWH	0.64 (0.45 - 0.82)	0.70 (0.63 - 0.78)	0.91 (0.64 - 1.19)
	HCH	DWOR	0.58 (0.41 - 0.73)	0.72 (0.67 - 0.78)	0.80 (0.56 - 1.01)
	HCH	IMNA	0.85 (0.73 - 0.96)	0.78 (0.71 - 0.85)	1.10 (0.92 - 1.28)
	HCH	MCCA	0.83 (0.77 - 0.90)	0.81 (0.76 - 0.85)	1.03 (0.93 - 1.14)
	HCH	RAPH	0.60 (0.51 - 0.70)	0.71 (0.62 - 0.78)	0.86 (0.69 - 1.06)
	HCH	SAWT	0.79 (0.68 - 0.91)	0.84 (0.71 - 0.96)	0.94 (0.76 - 1.19)
	WCH		0.83 (0.73 - 0.91)	0.84 (0.80 - 0.89)	0.98 (0.86 - 1.10)
	HST		0.66 (0.58 - 0.74)	0.81 (0.77 - 0.85)	0.82 (0.70 - 0.94)
	WST		0.75 (0.69 - 0.80)	0.79 (0.73 - 0.84)	0.95 (0.85 - 1.07)
2008	HCH	CATH	0.80 (0.74 - 0.85)	0.75 (0.68 - 0.82)	1.06 (0.95 - 1.19)
	HCH	CLWH	0.65 (0.58 - 0.73)	0.74 (0.68 - 0.80)	0.89 (0.77 - 1.02)
	HCH	DWOR	0.55 (0.48 - 0.62)	0.60 (0.55 - 0.66)	0.91 (0.77 - 1.06)
	HCH	IMNA	0.71 (0.64 - 0.76)	0.74 (0.68 - 0.79)	0.96 (0.84 - 1.08)
	HCH	MCCA	0.70 (0.65 - 0.76)	0.74 (0.69 - 0.79)	0.95 (0.86 - 1.05)
	HCH	PAHH	0.71 (0.62 - 0.80)	0.88 (0.79 - 0.96)	0.81 (0.68 - 0.95)
	HCH	RAPH	0.67 (0.63 - 0.71)	0.72 (0.68 - 0.77)	0.93 (0.86 - 1.01)
	HCH	SAWT	0.83 (0.71 - 0.92)	0.89 (0.76 - 1.00)	0.93 (0.77 - 1.13)
	WCH		0.73 (0.69 - 0.77)	0.79 (0.77 - 0.82)	0.92 (0.86 - 0.98)
	HST	GRN A Run	0.60 (0.56 - 0.63)	0.74 (0.71 - 0.77)	0.81 (0.76 - 0.87)
	HST	IMN A Run	0.60 (0.57 - 0.64)	0.74 (0.70 - 0.78)	0.82 (0.75 - 0.88)
	HST	SAL A Run	0.68 (0.65 - 0.71)	0.81 (0.79 - 0.83)	0.83 (0.79 - 0.88)
	HST	CLW B Run	0.62 (0.57 - 0.68)	0.73 (0.69 - 0.77)	0.86 (0.78 - 0.94)
	HST	SAL B Run	0.55 (0.48 - 0.62)	0.78 (0.73 - 0.84)	0.70 (0.60 - 0.81)
	WST		0.66 (0.59 - 0.72)	0.83 (0.80 - 0.87)	0.79 (0.71 - 0.87)
2009	HCH	CATH	0.70 (0.62 - 0.79)	0.79 (0.70 - 0.87)	0.89 (0.76 - 1.05)
	HCH	CLWH	0.62 (0.54 - 0.70)	0.73 (0.68 - 0.77)	0.86 (0.74 - 0.98)
	HCH	DWOR	0.66 (0.55 - 0.76)	0.75 (0.69 - 0.82)	0.87 (0.71 - 1.03)
	HCH	IMNA	0.63 (0.56 - 0.71)	0.60 (0.52 - 0.68)	1.05 (0.88 - 1.26)
	HCH	MCCA	0.59 (0.51 - 0.68)	0.54 (0.47 - 0.61)	1.10 (0.90 - 1.33)
	HCH	PAHH	0.56 (0.25 - 0.85)	0.62 (0.53 - 0.72)	0.89 (0.43 - 1.40)
	HCH	RAPH	0.71 (0.66 - 0.77)	0.70 (0.65 - 0.74)	1.02 (0.93 - 1.13)
	HCH	SAWT	0.86 (0.71 - 1.00)	0.91 (0.68 - 1.19)	0.94 (0.65 - 1.33)
	WCH		0.74 (0.68 – 0.80)	0.72 (0.68 - 0.76)	1.03 (0.93 - 1.13)
	HST	GRN A Run	0.58 (0.52 – 0.63)	0.76 (0.72 - 0.80)	0.76 (0.68 - 0.85)
	HST	HCD A Run	0.60 (0.53 – 0.65)	0.73 (0.65 - 0.80)	0.82 (0.71 - 0.95)
	HST	IMN A Run	0.59 (0.53 – 0.65)	0.72 (0.66 - 0.76)	0.83 (0.73 - 0.94)
	HST	SAL A Run	0.70 (0.66 – 0.74)	0.79 (0.76 - 0.82)	0.88 (0.83 - 0.94)
	HST	CLW B Run	0.58 (0.51 – 0.66)	0.72 (0.69 - 0.76)	0.81 (0.70 - 0.93)
	HST	SAL B Run	0.62 (0.54 – 0.70)	0.77 (0.71 - 0.84)	0.80 (0.69 - 0.92)
	WST		0.66 (0.60 – 0.73)	0.75 (0.70 - 0.80)	0.88 (0.78 - 1.00)
	HSK	OXHB	0.66 (0.52 – 0.79)	0.61 (0.47 - 0.74)	1.07 (0.77 - 1.44)
	HSK	SAWT	0.65 (0.59 – 0.71)	0.61 (0.56 - 0.66)	1.07 (0.96 - 1.21)
2010	HCH	CATH	0.77 (0.64 – 0.89)	0.67 (0.58 - 0.76)	1.15 (0.92 - 1.43)
	HCH	CLWH	0.59 (0.47 – 0.71)	0.76 (0.72 - 0.80)	0.77 (0.62 - 0.95)
	HCH	DWOR	0.46 (0.34 – 0.58)	0.73 (0.68 - 0.78)	0.63 (0.46 - 0.80)
	HCH	IMNA	0.77 (0.64 – 0.89)	0.82 (0.75 - 0.88)	0.94 (0.76 - 1.12)
	HCH	MCCA	0.79 (0.69 – 0.89)	0.75 (0.70 - 0.81)	1.06 (0.90 - 1.21)
	HCH	PAHH	1.00 (0.47 – 1.00)[B]	0.50 (0.03 - 0.97)[B]	NSD[B]
	HCH	RAPH	0.61 (0.51 – 0.72)	0.64 (0.59 - 0.69)	0.96 (0.79 - 1.16)

Mig. Year	Rear-type/ Species[A]	Hatchery Group[A]	Success T_0	Success C_X	Success ratio T_0/C_X
	HCH	SAWT	0.79 (0.63 – 0.96)	0.84 (0.73 - 0.94)	0.95 (0.74 - 1.19)
	WCH		0.73 (0.66 – 0.79)	0.85 (0.82 - 0.89)	NSD[B]
2010	HST	GRN A Run	0.51 (0.46 – 0.57)	0.72 (0.69 - 0.76)	0.71 (0.63 - 0.79)
	HST	HCD A Run	0.62 (0.55 – 0.70)	0.72 (0.66 - 0.76)	0.87 (0.75 - 1.00)
	HST	IMN A Run	0.63 (0.56 – 0.71)	0.78 (0.74 - 0.82)	0.81 (0.71 - 0.91)
	HST	SAL A Run	0.62 (0.58 – 0.66)	0.78 (0.76 - 0.80)	0.79 (0.74 - 0.86)
	HST	CLW B Run	0.57 (0.49 – 0.64)	0.74 (0.71 - 0.77)	0.77 (0.67 - 0.87)
	HST	SAL B Run	0.66 (0.52 – 0.80)	0.79 (0.70 - 0.87)	0.84 (0.65 - 1.04)
	WST		0.66 (0.58 – 0.74)	0.83 (0.78 - 0.87)	0.79 (0.69 - 0.90)
	HSK	OXHB	N/A[C]	0.54 (0.42 - 0.67)	N/A[C]
	HSK	SAWT	N/A[C]	0.51 (0.39 - 0.63)	N/A[C]
2011	HCH	CATH	0.63 (0.44 – 0.81)	0.94 (0.83 - 1.00)	0.67 (0.46 - 0.88)
	HCH	CLWH	0.40 (0.22 – 0.62)	0.72 (0.63 - 0.80)	0.56 (0.31 - 0.90)
	HCH	DWOR	0.47 (0.31 – 0.65)	0.78 (0.69 - 0.87)	0.60 (0.39 - 0.84)
	HCH	IMNA	0.60 (0.42 – 0.78)	0.77 (0.63 - 0.92)	0.78 (0.53 - 1.10)
	HCH	MCCA	0.72 (0.61 – 0.83)	0.86 (0.79 - 0.92)	0.83 (0.69 - 0.99)
	HCH	PAHH	N/A[D]	1.00 (0.22 - 1.00)	N/A[D]
	HCH	RAPH	0.76 (0.67 – 0.85)	0.89 (0.82 - 0.95)	0.86 (0.74 - 0.98)
	HCH	SAWT	0.76 (0.46 – 1.00)	0.87 (0.67 - 1.03)	0.87 (0.50 - 1.30)
	WCH		0.77 (0.65 – 0.88)	0.79 (0.73 - 0.85)	0.97 (0.80 - 1.15)
	HST	GRN A Run	0.44 (0.32 – 0.58)	0.70 (0.63 - 0.77)	0.63 (0.45 - 0.83)
	HST	HCD A Run	0.60 (0.33 – 0.88)	0.51 (0.29 - 0.75)	1.18 (0.58 - 2.40)
	HST	IMN A Run	0.60 (0.50 – 0.70)	0.73 (0.65 - 0.81)	0.82 (0.65 - 1.00)
	HST	SAL A Run	0.60 (0.55 – 0.64)	0.79 (0.76 - 0.83)	0.76 (0.69 - 0.82)
	HST	CLW B Run	0.58 (0.47 – 0.67)	0.72 (0.67 - 0.77)	0.80 (0.66 - 0.95)
	HST	SAL B Run	0.38 (0.23 – 0.53)	0.76 (0.59 - 0.92)	0.50 (0.30 - 0.77)
	WST		0.64 (0.52 – 0.75)	0.72 (0.62 - 0.81)	0.90 (0.71 - 1.11)
	HSK	OXHB	0.08 (0.00 – 0.18)	0.50 (0.39 - 0.62)	0.15 (0.00 - 0.37)
	HSK	SAWT	0.29 (0.12 – 0.50)	0.57 (0.44 - 0.68)	0.52 (0.21 - 0.93)
2012	HCH	CATH	0.69 (0.42 – 0.98)	0.71 (0.59 - 0.83)	0.97 (0.59 - 1.47)
	HCH	CLWH	0.67 (0.56 – 0.77)	0.76 (0.72 - 0.81)	0.88 (0.73 - 1.02)
	HCH	DWOR	0.70 (0.57 – 0.83)	0.72 (0.66 - 0.76)	0.98 (0.79 - 1.17)
	HCH	IMNA	0.34 (0.16 – 0.56)	0.56 (0.43 - 0.69)	0.61 (0.28 - 1.08)
	HCH	MCCA	0.60 (0.50 – 0.70)	0.60 (0.54 - 0.66)	0.99 (0.82 - 1.19)
	HCH	PAHH	N/A[D]	N/A[D]	N/A[D]
	HCH	RAPH	0.73 (0.67 – 0.79)	0.73 (0.69 - 0.78)	1.00 (0.90 - 1.10)
	HCH	SAWT	0.83 (0.67 – 0.96)	0.73 (0.56 - 0.88)	1.15 (0.87 - 1.55)
	WCH		0.83 (0.74 – 0.92)	0.76 (0.73 - 0.79)	1.10 (0.97 - 1.23)
	HST	GRN A Run	0.53 (0.46 – 0.60)	0.68 (0.64 - 0.71)	0.78 (0.66 - 0.90)
	HST	HCD A Run	0.64 (0.46 - 0.79)	0.70 (0.62 - 0.77)	0.92 (0.66 - 1.17)
	HST	IMN A Run	0.62 (0.54 - 0.70)	0.71 (0.67 - 0.74)	0.88 (0.76 - 1.01)
	HST	SAL A Run	0.60 (0.55 - 0.65)	0.72 (0.70 - 0.75)	0.83 (0.76 - 0.91)
	HST	CLW B Run	0.67 (0.56 - 0.78)	0.81 (0.77 - 0.84)	0.84 (0.69 - 0.97)
	HST	SAL B Run	0.66 (0.56 - 0.74)	0.77 (0.67 - 0.87)	0.85 (0.69 - 1.02)
	WST		0.73 (0.63 - 0.82)	0.75 (0.71 - 0.80)	0.97 (0.83 - 1.10)
	HSK	OXHB	0.36 (0.28 - 0.44)	0.65 (0.59 - 0.70)	0.56 (0.42 - 0.70)
	HSK	SAWT	0.24 (0.14 - 0.36)	0.71 (0.59 - 0.84)	0.34 (0.20 - 0.54)
2013	HCH	CATH	0.82 (0.69 - 0.93)	0.80 (0.69 - 0.90)	1.02 (0.83 - 1.24)
	HCH	CLWH	0.64 (0.54 - 0.75)	0.86 (0.83 - 0.89)	0.75 (0.62 - 0.89)
	HCH	CLWH_SU	0.19 (0.08 - 0.31)	0.56 (0.47 - 0.65)	0.34 (0.14 - 0.56)
	HCH	DWOR	0.47 (0.38 - 0.56)	0.81 (0.77 - 0.85)	0.58 (0.47 - 0.70)
	HCH	IMNA	0.43 (0.28 - 0.59)	0.40 (0.30 - 0.50)	1.08 (0.67 - 1.59)
	HCH	MCCA	0.44 (0.38 - 0.50)	0.58 (0.54 - 0.62)	0.76 (0.64 - 0.88)
	HCH	PAHH	N/A[D]	N/A[D]	N/A[D]
	HCH	RAPH	0.79 (0.74 - 0.84)	0.85 (0.82 - 0.88)	0.93 (0.86 - 1.00)

Mig. Year	Rear-type/ Species[A]	Hatchery Group[A]	Success T_0	Success C_X	Success ratio T_0/C_X
	HCH	SAWT	0.71 (0.59 - 0.82)	0.63 (0.52 - 0.74)	1.12 (0.88 - 1.42)
	HSK	SAWT	0.04 (0.03 - 0.06)	0.10 (0.07 - 0.13)	0.43 (0.26 - 0.69)
	HST	GRN A Run	0.60 (0.53 - 0.66)	0.72 (0.68 - 0.76)	0.83 (0.73 - 0.93)
2013	HST	HCD A Run	0.71 (0.59 - 0.81)	0.78 (0.71 - 0.86)	0.90 (0.74 - 1.07)
	HST	IMN A Run	0.67 (0.61 - 0.73)	0.70 (0.65 - 0.76)	0.95 (0.85 - 1.06)
	HST	SAL A Run	0.72 (0.68 - 0.76)	0.74 (0.71 - 0.78)	0.97 (0.90 - 1.04)
	HST	CLW B Run	0.66 (0.52 - 0.80)	0.85 (0.81 - 0.89)	0.77 (0.60 - 0.94)
	HST	SAL B Run	0.77 (0.65 - 0.89)	0.93 (0.88 - 0.98)	0.83 (0.68 - 0.98)
	WCH		0.75 (0.68 - 0.81)	0.77 (0.73 - 0.81)	0.97 (0.88 - 1.08)
	WST		0.72 (0.66 - 0.78)	0.75 (0.70 - 0.80)	0.95 (0.86 - 1.07)
2014	HCH	CATH	0.78 (0.63 - 0.92)	0.50 (0.27 - 0.70)	1.57 (1.05 - 2.86)
	HCH	CLWH	0.74 (0.63 - 0.85)	0.76 (0.70 - 0.81)	0.98 (0.82 - 1.15)
	HCH	CLWH_SU	0.49 (0.36 - 0.64)	0.67 (0.59 - 0.75)	0.74 (0.52 - 0.98)
	HCH	DWOR	0.76 (0.67 - 0.84)	0.69 (0.61 - 0.76)	1.10 (0.94 - 1.29)
	HCH	IMNA	0.61 (0.49 - 0.73)	0.82 (0.71 - 0.93)	0.74 (0.57 - 0.94)
	HCH	MCCA	0.58 (0.51 - 0.64)	0.74 (0.69 - 0.79)	0.78 (0.68 - 0.89)
	HCH	PAHH	N/A[D]	N/A[D]	N/A[D]
	HCH	RAPH	0.86 (0.80 - 0.92)	0.65 (0.58 - 0.71)	1.33 (1.17 - 1.51)
	HCH	SAWT	0.73 (0.59 - 0.86)	0.72 (0.63 - 0.80)	1.02 (0.81 - 1.25)
	HSK	SAWT	0.44 (0.32 - 0.56)	0.76 (0.69 - 0.81)	0.58 (0.42 - 0.75)
	HST	GRN A Run	0.58 (0.52 - 0.64)	0.75 (0.71 - 0.78)	0.78 (0.69 - 0.87)
	HST	HCD A Run	0.45 (0.36 - 0.55)	0.66 (0.59 - 0.76)	0.68 (0.52 - 0.86)
	HST	IMN A Run	0.66 (0.60 - 0.71)	0.70 (0.65 - 0.75)	0.94 (0.84 - 1.05)
	HST	SAL A Run	0.64 (0.57 - 0.69)	0.76 (0.72 - 0.80)	0.83 (0.74 - 0.92)
	HST	CLW B Run	0.79 (0.72 - 0.86)	0.76 (0.72 - 0.79)	1.04 (0.94 - 1.15)
	HST	SAL B Run	0.74 (0.66 - 0.81)	0.79 (0.71 - 0.86)	0.93 (0.81 - 1.08)
	WCH		0.85 (0.76 - 0.92)	0.81 (0.76 - 0.86)	1.04 (0.92 - 1.16)
	WST		0.65 (0.59 - 0.72)	0.70 (0.63 - 0.77)	0.93 (0.81 - 1.07)
2015	HCH	CATH	0.80 (0.57 - 1.00)	0.71 (0.56 - 0.86)	1.12 (0.75 - 1.57)
	HCH	CLWH	0.40 (0.00 - 1.00)	0.75 (0.68 - 0.81)	0.54 (0.00 - 1.26)
	HCH	CLWH_SU	N/A[D]	0.72 (0.63 - 0.81)	N/A[D]
	HCH	DWOR	N/A[D]	0.62 (0.51 - 0.74)	N/A[D]
	HCH	IMNA	0.67 (0.43 - 0.90)	0.62 (0.44 - 0.80)	1.08 (0.66 - 1.70)
	HCH	MCCA	0.69 (0.54 - 0.82)	0.81 (0.73 - 0.89)	0.85 (0.66 - 1.04)
	HCH	PAHH	N/A[D]	N/A[D]	N/A[D]
	HCH	RAPH	0.75 (0.63 - 0.86)	0.81 (0.74 - 0.87)	0.93 (0.77 - 1.09)
	HCH	SAWT	0.57 (0.33 - 0.79)	0.89 (0.77 - 1.00)	0.64 (0.37 - 0.92)
	HSK	SAWT	0.41 (0.11 - 0.72)	0.58 (0.47 - 0.70)	0.70 (0.19 - 1.30)
	HSK	SPRF	N/A[D]	N/A[D]	N/A[D]
	HST	GRN A Run	0.50 (0.20 - 0.82)	0.78 (0.70 - 0.87)	0.64 (0.24 - 1.06)
	HST	HCD A Run	0.60 (0.20 - 1.00)	0.88 (0.71 - 1.00)	0.69 (0.20 - 1.21)
	HST	IMN A Run	0.60 (0.33 - 0.86)	0.70 (0.56 - 0.83)	0.86 (0.44 - 1.33)
	HST	SAL A Run	0.84 (0.56 - 1.00)	0.85 (0.75 - 0.95)	0.98 (0.65 - 1.24)
	HST	CLW B Run	N/A[D]	0.70 (0.62 - 0.79)	N/A[D]
	HST	SAL B Run	0.33 (0.00 - 1.00)	1.00 (1.00 - 1.00)	N/A[D]
	WCH		0.87 (0.75 - 0.99)	0.79 (0.69 - 0.88)	1.11 (0.92 - 1.33)
	WST		0.09 (0.00 - 0.26)	0.74 (0.53 - 0.93)	0.13 (0.00 - 0.37)

[A] Rear-type and species shown are: hatchery Chinook (HCH), wild Chinook (WCH), hatchery steelhead (HST), wild steelhead (WST), and hatchery sockeye (HSK).

Hatcheries are: Catherine Creek AP (CATH), Clearwater (CLWH), Dworshak (DWOR), Imnaha AP (IMNA), McCall (MCCA), Pahsimeroi (PAHH), Rapid River (RAPH), Sawtooth (SAWT), and Oxbow (OXBH).

Hatchery steelhead basin and run-types are: Grande Ronde A run (GRN A run), Hells Canyon Dam A run (HCD A run), Imnaha A run (IMN A run), Salmon A run (SAL A run), Clearwater B run (CLW B run), and Salmon B run (SAL B run).

[B] Sample size was too small to effectively bootstrap (sample sizes shown in Table G.1). Exact binomial confidence interval (90 %) shown and overlap of confidence intervals for each group was used to test for NSD (no significant difference) or SD (significant difference).

[C] No transport treatment in 2010; therefore, estimation was not possible.

[D] No adults returned from transport category; or in-river category therefore, estimation was not possible.

Table G.3. Adult success rates for Snake River run wild spring/summer Chinook and wild steelhead by adult return year. Wild Chinook estimates include 2-salt and 3-salt adults as available. Wild steelhead estimates include 1-salt, 2-salt, and 3-salt adults as available.

Adult Return Year	Snake River Wild Chinook	Snake River wild steelhead
2002	0.668	0.600
2003	0.636	0.670
2004	0.874	0.556
2005	0.846	0.659
2006	0.822	0.804
2007	0.763	0.561
2008	0.803	0.737
2009	0.827	0.739
2010	0.814	0.712
2011	0.664	0.703
2012	0.811	0.696
2013	0.807	0.707
2014	0.732	0.714
2015	0.727	0.762
2016	0.823	0.571
2017	0.787	N/A

APPENDIX H

DEVELOPMENT OF A WEIGHTED BOOTSTRAP FOR UNEQUALLY REPRESENTED HATCHERY PIT-TAG GROUPS

APPENDIX H

DEVELOPMENT OF A WEIGHTED BOOTSTRAP FOR UNEQUALLY REPRESENTED HATCHERY PIT-TAG GROUPS

Introduction

The Comparative Survival Study (CSS) relies upon bootstrap resampling to develop confidence intervals for various metrics related to PIT-tag groups of interest. The bootstrap method is a comprehensive approach, which allows confidence intervals to be computed for all of the parameters of interest without requiring assumptions about the form of distribution of the parameter (Berggren et. al. 2002, Chapter 4). Nonparametric 90% confidence intervals are computed around all estimated parameters, including annual SARs. The nonparametric bootstrapping approach of Efron and Tibshirani (1993) is used where first, the point estimate is calculated from the sample for each population, and then the data are resampled, via the naïve bootstrap resampling procedure (random resampling with replacement). This approach assumes that the PIT-tag marking is representative of the intended population being marked. Part of the CSS marking efforts are to mark hatchery and wild populations as evenly among available sub-populations as possible so that estimates of SARs and other parameters are meaningful and representative of the population.

In recent years CSS marking at a few hatcheries has caused concern because tags have been split equally between two different production groups within a single hatchery, but the total production for each of these groups is known to be unequal. This has necessitated some means to account for the unequal representation of these production groups within the CSS tagging program.

In response to the non-representative marking of PIT-tag groups, the CSS has developed an alternative bootstrap protocol that weights data sets so that bootstrap resampling reflects the proportions of the overall hatchery production. The need for a weighted resampling methodology arose when two different hatchery management practices were applied to subsets of a CSS release population. In 2012, McCall Hatchery implemented an integrated brood stock program (in addition to the existing segregated broodstock program) for summer Chinook salmon. Two different combinations of adult spawners were used for broodstock where the integrated broodstock included hatchery x wild adults (natural origin) and the segregated broodstock paired hatchery x hatchery origin adults. The hatchery wished to evaluate the efficacy of both brood stock programs. For example, a total of 51,912 juvenile Chinook salmon were PIT-tagged at the hatchery as part of the CSS study in migration year 2012. Nearly equal numbers of integrated (25,962) and segregated (25,950) progeny were marked with PIT-tags (see Table Z.1). The CSS required the full complement of tags for analyses of SARs based on previous power analyses and, thus, combined the release groups for SAR analysis. However, of the

1,028,353 juvenile Chinook released, only 23% (241,265) were integrated progeny while nearly 77% (787,088) were segregated progeny. Similar production and marking proportions occurred in migration year 2013 (Table H.1).

Thus, any analyses that combined both PIT-tag sub-groups would equally weight each one based on the numbers of PIT-tags released. Such an analysis would not represent the true proportions of the release population and hence would be biased (i.e. the integrated progeny group would be overrepresented). The CSS sought to correct for this bias by developing a bootstrap resampling method that re-weighted the sample based on the relative proportions of the PIT-tag fish in the two study groups within the release population.

Table H.1. Summary of PIT-tag marking and release numbers for integrated and segregated Chinook groups at McCall Hatchery in 2012 and 2013.

	Migration year	Release	Proportion of Release	PIT-tagged	Proportion of tags
Integrated	2012	241,265	0.23	25,962	0.50
Segregated	2012	787,088	0.77	25,950	0.50
Integrated	2013	253,849	0.24	25,950	0.50
Segregated	2013	821,001	0.76	25,951	0.50

Recently, bootstrap resampling methods have been developed by researchers to account for similar situations to that described for McCall Hatchery, where the proportions of subgroups within the sampled population do not reflect the ratios of those same subgroups in the overall population of inference. Nahorniak et al. (2015) used an inverse weighted bootstrap resampling protocol to weight bootstrap samples similar to the weight of the original sampling of the population. Bootstrap samples were weighted by the inverse of the relative frequency that the original populations were sampled in order to adjust the estimated values within the bootstrap. The average bootstrap outcomes were used to estimate the true parameter values. Goodwin and Mishra (2003) used a weighted resampling design in which resampling weights were assigned to individual farms based on the number of farms those sampled farms represented from the region of interest.

Methods

Simulation of Weighted Bootstrap Methodology

Similar to Goodwin and Mishra (2003), our approach assigned weights to individual PIT-tags based on the number of fish in the release group that were represented by those tags, essentially determining the number of fish represented by each tag. Based on the ratio of tags to fish in each group, individual tags were assigned a probability based upon which group they were from. For example, for migration year 2012, PIT-tags representing the integrated group were assigned a weight of

0.0000090368 (0.23/25,962) while PIT-tags representing the segregated population were given weights of 0.0000294947.

A cumulative weight field was used to facilitate rapid data selection using a half step algorithm that reduced the number of evaluations to find the appropriate tag. The algorithm reduced the number of evaluations from n/2 using a simple forward search, where each cumulative weight value had to be evaluated in order from 1 to n. The forward search approach resulted in, on average, half the records being evaluated to find the correct cumulative value relative to the random number chosen for each random draw. The half step algorithm reduced the number of evaluations per random draw to;

$$\frac{n}{2^x} \leq 1, \qquad \text{[H.1]}$$

where x is the minimum number that makes the above statement true. The number x in Equation H.1 then represents the maximum number of cumulative values needed to be evaluated to find the appropriate random value and thus the correct tag. For migration year 2012, x = 16, such that at maximum 16 cumulative values had to be evaluated to arrive at the correct random number.

In each weighted bootstrap sample (MY 2012), 51,912 tags were drawn from the original pool of tags, using the weighting procedure described above. Summary data were calculated from the weighted samples. The sampling procedure was repeated 1,000 times to provide 1,000 weighted bootstrap resamples. From the 1,000 bootstrap resamples, the mean summary statistics were used to estimate the weighted parameters, while the 50th and 951st records were used to determine the non-parametric 90% confidence intervals. The bootstrap average estimate was found to compare quite closely to likelihood based point estimates of SARs even when few adult returns were available (Berggren et. al. 2002).

A simulation was done to prove the concept of the weighting procedure described above. Because computing time was significant, despite the use of the half step algorithm, a simulated population of 5,000 PIT-tags was used. The weighted resampling protocol was evaluated based on the number of PIT-tags that were drawn from each study group from the simulated population. Since the underlying premise was to mimic the McCall Hatchery situation, 2,500 tags were assigned to represent each group (0.50 in each Group A and Group B) while the underlying population was simulated to be 25% Group A and 75% Group B. Thus, the target number of tags to be drawn for each weighted bootstrap, would be 1,250 from Group A (i.e., Integrated group) and 3,750 from Group B (i.e, Segrated group). For each weighted resampling iteration:

1. 5,000 tags were drawn, and this process was repeated 1,000 times to form a full bootstrap sample.
2. From the 1,000 bootstrap iteratios the average number of tags drawn from each group was calculated. That number was averaged to determine how well the weighting procedure performed.

3. The calculated average from all 1,000 bootstrap iteratios was then compared to the target number of tags (5,000*0.25 or 1,250 targeted for Group A (i.e., Integrated) and 5,000*0.75 or 3,750 tags targeted for Group B (i.e., Segregated).
4. Steps 1-3 were then repeated 100 times to complete the simulation. The distribution of this average number of tags representing each group was then examined.

Weighted Bootstrap for McCall Hatchery Data

Once the weighted bootstrap resampling procedure was evaluated and deemed to be working properly, four different bootstrap runs were evaluated to determine the performance of the weighted bootstrap results. For this evaluation, we estimated annual LGR-to-BOA SARs (with jacks) for migration years 2012 and 2013 for each of the four bootstrap runs. We did not include migration year 2014 in this evaluation because returns from this year are not yet complete. We estimated LGR-to-BOA SARs (with jacks) for comparison between bootstrap runs because these returns should show the greatest contrast between the four runs.

A naïve resampling bootstrap was carried out using the aggregated PIT-tag population (combining both integrated and segregated groups), referred to as $MCCA_{agg}$ (1). This is the bootstrap methodology currently used for most CSS PIT-tag groups. In addition, naïve bootstrap resampling was done separately for the integrated $MCCA_{int}$ (2) and segregated $MCCA_{seg}$ (3) groups. Finally, the weighted bootstrap resampling method described above was estimated for the combined tag groups $MCCA_{wgt}$ (4) with the identical tags used in the aggregated bootstrap ($MCCA_{agg}$).

Results

Results of the Weighted Bootstrap Simulation

The weighted bootstrap resampling protocol resulted in a range of the total number of tags being selected from each of the simulated groups, A and B. For Group A the goal was to sample 1,250 tags on average. The number of tags selected in each bootstrap run varied from about 1,150 to just over 1,350 Group A tags (Figure H.1). The data appear normally distributed, with a mean near the target value of 1,250 and tails symmetrical above and below that value. This outcome confirmed that the weighted random draw appeared to work as designed.

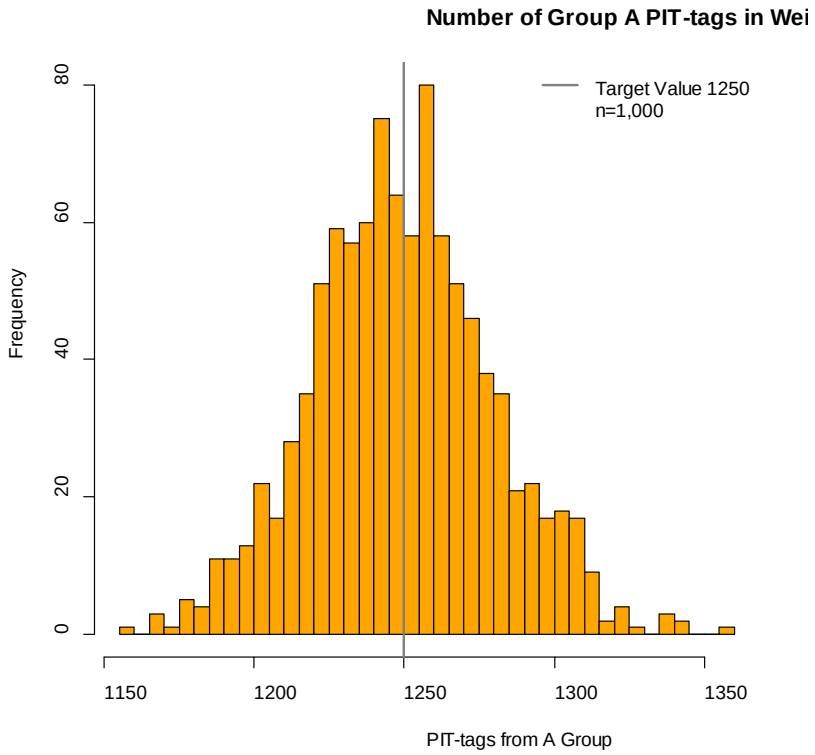

Figure H.1. Histogram of the number of Group A tags selected in a single bootstrap simulation (each simulation was 1,000 weighted resamples of the simulated population of 5,000 tags). The target value was 1,250 tags to be select from Group A (indicated in the figure by the grey vertical line).

While the results from a single boostrap run indicated that the weighted random draw appeared to work as designed (as depicted in Figure H.1), it was necessary to confirm that many bootstrap runs would also yield the same results, thus the simulation component of this exercise. Over the entire 100 bootstrap runs, the average number of tags drawn from Group A was 1,249.6, with a minimum greater than 1,248.4 and a maximum less than 1,52.5 (Figure H.2). These results show that the weighted resamples were distributed closely around the target of 1,250 for Group A, with a very small range of means around the value. Based on these results the methodology developed for resampling was considered successful.

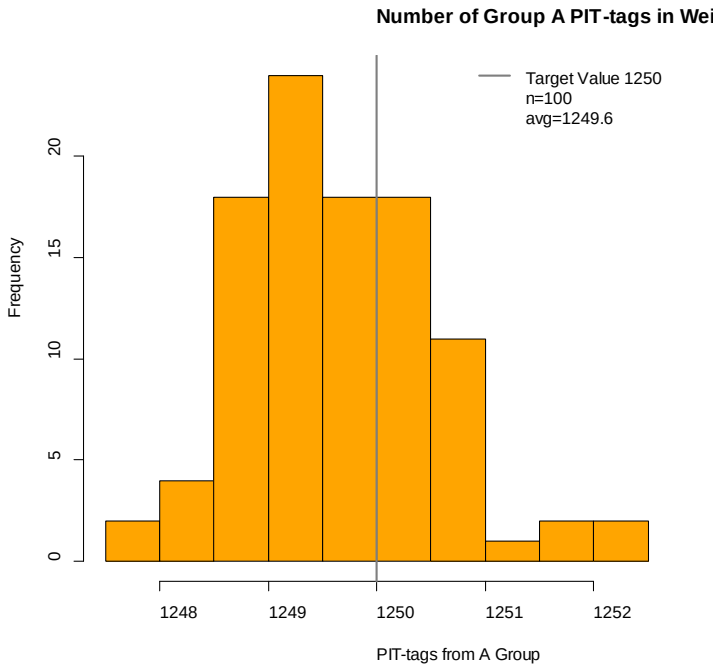

Figure H.2. Histogram of the average number of tags selected from Group A in each of 100 bootstrap simulations (each simulation was 1,000 weighted resamples of the simulated population of 5,000 tags). The target value was 1,250 tags to be select from Group A (indicated in the figure by the grey vertical line).

Results of Weighted Bootstrap of McCall Hatchery Data

The estimates of the weighted bootstrap applied to the McCall summer Chinook releases from 2012 and 2013 were compared to the naïve bootstrap approach that was reported for these groups in the CSS Annual Report (see Chapter 4 and Appendix B). When run separately, the two different hatchery release groups, the integrated ($MCCA_{int}$) and segregated ($MCCA_{seg}$) groups, had different LGR-to-BOA SARs (Table H.2). For migration year 2012, these two groups were not significantly different, based on overlapping confidence intervals. However, SAR estimates for the two groups ($MCCA_{int}$ vs. $MCCA_{seg}$) in migration year 2013 were significantly different. In both migration years, the SAR estimates for the $MCCA_{agg}$ and $MCCA_{wgt}$ groups were intermediate between the $MCCA_{int}$ and $MCCA_{seg}$ groups

Table H.2. Comparison of LGR-to-BOA SARs (with jacks) from four different bootstrap runs; see text for explanation.

Bootstrap Run	Migr_yr	SAR	np_90cill	np_90ciul	BS resampling method
Aggregate ($MCCA_{agg}$)	2012	1.64	1.50	1.79	Naïve
Integrated ($MCCA_{int}$)	2012	1.71	1.49	1.92	Naïve
Segregated ($MCCA_{seg}$)	2012	1.44	1.24	1.65	Naïve
Weighted ($MCCA_{wgt}$)	2012	1.56	1.41	1.71	Weighted
Aggregate ($MCCA_{agg}$)	2013[1]	2.21[1]	2.04	2.38	Naïve
Integrated ($MCCA_{int}$)	2013[1]	2.49[1]	2.25	2.75	Naïve
Segregated $MCCA_{seg}$)	2013[1]	1.90[1]	1.69	2.12	Naïve
Weighted ($MCCA_{wgt}$)	2013[1]	2.05[1]	1.89	2.23	Weighted

[1] The estimate presented here represent data update through 2015 and would therefore will not match SARs reported in Appendix A of the report which were updated through June of 2016.

The SAR estimate for the $MCCA_{agg}$ group could be considered a simple mean of the two subgroup SARs, since both groups are equally represented in the PIT-tag population, while the SAR for the $MCCA_{wgt}$ group could be compared to a weighted mean of two subgroup SARs (Table H.3). Weighted means in Table H.3 were based on the relative proportions of the overall hatchery release in each of the two release groups. For both migration years, the SARs for the MCCAagg group is higher than the $MCCA_{wgt}$ group, reflecting the relatively greater contribution of the integrated group to the $MCCA_{agg}$ group, while the SAR for the $MCCA_{wgt}$ group reflects that only about 25% of the release population was from integrated group so that the SAR is more heavily weighted toward the segregated group. For migration year 2013, the SAR for the $MCCA_{wgt}$ group compares closely to the weighted mean, while the SAR for the $MCCA_{agg}$ group compares more closely to the arithmetic mean.

Table H.3. Bootstrap estimated LGR-to-BOA SARs (with jacks), by method (naïve and weighted), compared to a calculated arithmetic mean and weighted mean SAR of the $MCCA_{int}$ and $MCCA_{seg}$ groups. Weighted mean was based on the proportion of the release in each group.

	SARs (by group and resampling method)					
Migr. Year	**$MCCA_{AGG}$ Naive**	**$MCCA_{WGT}$ Weighted**	**$MCCA_{SEG}$ Naive**	**$MCCA_{INT}$ Naive**	**Arithmetic Mean**	**Weighted Mean**
2012	1.64	1.56	1.44	1.71	1.58	1.50
2013	2.21[1]	2.05[1]	1.90[1]	2.49[1]	2.20	2.04

[1] The estimate presented here represent data update through 2015 and would therefore will not match SARs reported in Appendix A of the report which were updated through June of 2016.

Discussion

The use of a weighted bootstrap sampling procedure appears to have successfully accounted for the unequal representation of PIT-tags in the hatchery release population marked at McCall Hatchery. The weighted resampling methodology was successful for randomly drawing tags from the total pool in a ratio that represented the expected proportions. The weighted SARs used in this analysis were estimated average values for

the 1,000 bootstrap iteratios. Other methods of calculating this weighted value could be explored including median or 50th percentile value. However, the relatively simple approach presented here is appealing in that it is parsimonious and similar in most aspects to the existing methodology.

Similar ratios of the two groups described in the example above were evaluated, but intuitively it seems that the ratios chosen should not matter. However, we did not evaluate the performance of the methodology with other ratios or with more than two sub-populations. Those are likely areas for future exploration. While the method was developed for a single hatchery with two sub-populations, it is anticipated that the method could be applied to other situations where several sub-populations of known size are represented unequally by PIT-tags.

This analysis represents a work in progress and will continue to be developed and refined over years. The method presented here met our goal of maintaining a consistent approach to estimating confidence intervals using the bootstrap. Many of the calculations and assumptions required to develop likelihood estimates of variance remain intractable for the complex analyses used in CSS, so that a boostrap method seems the best approach available.

References

Berggren, T., H. Franzoni, L. Basham, P. Wilson, H. Schaller, C. Petrosky, E. Weber, R. Boyce and N. Bouwes. 2002. Comparative Survival Study (CSS) of PIT tagged spring/summer chinook. 2002 Annual Report, Migration Years 1997 – 2000, Mark/Recapture Activities and Bootstrap Analysis. BPA Contract #19960200. Available at http://www.fpc.org/

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Nahorniak, M., Larsen, D.P., Volk, C. and Jordan, C.E., 2015. Using Inverse Probability Bootstrap Sampling to Eliminate Sample Induced Bias in Model Based Analysis of Unequal Probability Samples. *PloS one*, *10*(6), p.e0131765.

APPENDIX I

COMPARATIVE SURVIVAL STUDY ANNUAL MEETING

This appendix contains the material presented at the Comparative Survival Study annual meeting held on April 3, 2017, at the Water Resource Center in Vancouver Washington. The presentations from that meeting are collected in this appendix in the same order as they were presented. The agenda from that meeting is shown below and is followed by a list of attendees.

This meeting has been a yearly event with summaries from the meeting presented in CSS annual reports. A question/answer session was held at the end of the presentations and a summary of this session is contained within the appendix. Below is a link to the presentations.

http://www.fpc.org/documents/CSS/Presentations_2017_CSS.pdf

It can also be found in a compact version in the following pages of this appendix.

2017 CSS Annual Meeting
List of Attendees

Names are taken from the written sign-in sheet from the event. All efforts have been made ot accurately transcribe those names and organizations

Name	Org
Adam Storch	ODFW
Alex Maule	ISAB
Alex Saint	FPC
Bill Brignon	USFWS
Bobby Hsu	FPC
Bob Heinith	CRITFC
Bob Rose	Yakima Nation
Brook Silver	USFWS
Brandon Chockley	Fish Passage Center
Brett Bowersox	IDFG
Brian McIraith	CRITFC
Carl Schwarz	Simon Fraser University
Charles Morrill	WDFW
Charlie Petrosky	IDFG
Chris Frederiksen	Yakama Nation Fisheries
Chris Piney	USACE
Christine Golightly	CRITFC
Christine Petersen	BPA
Chuck Chambertan	USACE
Curt Dotson	Grant County PUD
Dan Rauding	WDFW
David Hand	USFWS
David Heller	
David Swank	USFWS
Dawn Gilkison	CCC
Ed Bowles	ODFW
Eric Hockersmith	USACE
Erick Van Dyke	ODFW
Erin Cooper	Fish Passage Center
Fred Heutte	NWEC and Save Our Wild Salmon
Geoffrey Whisler	ODFW
Greg Kovalchuk	PSMFC
Hans Radtke	
Howard Schaller	USFWS
Jon Hess	CRITFC
John Rohrback	Colville Tribes
Julie Doumbia	BPA
Kenneth Ham	PNNL
Lance Hebdon	IDFG
Lee Blankenship	Northwest Marine Tech
Leslie Bach	NW Council
Liz Hamilton	NSIA
Makary Hutson	BPA
Margaret Filardo	Fish Passage Center
Mark Bagdovitz	USFWS
Maureen Hess	CRITFC
Megan McKibben	Office of Rep. Kurt Schrader
Michele DeHart	Fish Passage Center
Michael Garrity	WDFW
Mike Langeslay	USACE
Nancy Leonard	NW Power & Conservation Council
Natalie Richards	USACE
Nicole Czarnomski	WDFW
Paul Kline	IDFG
Pat Keniry	ODFW
Paula Calvert	ODEQ
Peggy Racht	BPA
Quinn Payton	Realtime Research
Rick Martinson	PSMFC
Rod Engle	USFWS
Ryan Koch	USFWS
Sara LaBorde	Wild Salmon Center
Susan Camp	USBR
Thomas Wadsworth	WDFW
Steve Smith	
Tim Copeland	IDFG
Tim Iverson	YN
Tom Kahler	Douglas County PUD
Tom Skiles	CRITFC
Trevor Conder	NOAA
Tucker Jones	ODFW

Comparative Survival Study Annual Meeting

Date / time: April 3, 2017 8:30 AM to 1:00 PM
Place: Water Resources Center
4600 SE Columbia Way
Vancouver, WA 98661

We ask that you please hold your questions until after the last presentation.
There is time allotted after the talks for extended discussions and questions.
Each presentation will have slide numbers for referencing back.
A 5 minute period after each presentation is provided for clarifying questions if needed.

Time	TITLE	(minutes)	presenter
8:30	**Introduction to CSS**	**20**	Jerry McCann
8:50	**Juvenile survival, travel time, and the in-river environment**	**20**	Steve Haeseker
9:10	**Effects of Juvenile Bypass Systems on Smolt to Adult Return Rates**	**20**	Steve Haeseker
9:30	**Annual SARs and TIR Snake River Spring**	**20**	Charlie Petrosky
9:50	**Upper Columbia River Chinook and Steelhead**	**20**	WDFW
10:10	**Break 15 minutes**		
10:25	**Snake River Fall Chinook**	**15**	Jerry McCann
10:40	**SARs and Productivity**	**30**	Charlie Petrosky
11:10	**Life-cycle modeling**	**40**	Bob Lessard
11:50	**Questions / Discussion**		

To end at approximately 1:00 PM however, the room is available all day for questions if needed.

Introduction to Comparative Survival Study

Jerry McCann

CSS Annual Meeting 3 Apr, 2017

Background

- **CSS was initiated in 1996 by states, tribes & USFWS to estimate salmon survival rates at various life stages**
  - **Designed to assess hydro-system operations on state, tribal, and federal fish hatcheries**
  - **Answer question posed by PATH –** "can transportation . . . compensate for the effects of the hydro-system?"
  - **NPCC had identified the need to collect annual migration characteristics including survival**
  - **NOAA biological opinions require research, monitoring and evaluation**
- **Management-oriented large scale monitoring**
  - **Observational study – over long time series**
  - **Aligned with and complementary to basin wide monitoring needs (RME)**

Background

GOALS

1. Quantify the efficacy of transportation
   - Develop a representative control group
2. Compare survival rates within and across species
3. Establish long term data set
4. Accomplish above as collaboratively and transparently as possible

Background

- CSS data is derived from PIT tags
  - Tagged specifically for CSS
  - Cooperative marking between CSS and other research studies
  - Groups marked for other studies

Background

- Collaborative scientific process was implemented for study design and to perform analyses

- CSS project independently reviewed and modified a number of times
  - Draft report typically posted – Aug 31st
  - Reviewed by ISAB, ISRP and other entities

History of ISAB/ISRP Reviews of CSS

ISAB began reviewing CSS Annual Reports in 1997; and have recommended refinements and additions

1997 – 2002

- Extend method to other species & life history types (Steelhead)
- Develop nonparametric bootstrap approach and evaluate bootstrap & compare with likelihood and MC simulations

2003 – 2006

- Evaluate the relation between reach survival and flow
- Develop finer scale analysis of survival and specific operational actions and environmental features
- Develop a ten year summary report
- Coordinate with other regional tagging/monitoring efforts

2007 – 2016

- Continued reviews of Annual Reports

The CSS is a joint project of the state & tribal fishery managers and the USFWS

DESIGN

- WDFW, CRITFC, USFWS, ODFW, IDFG (Oversight Committee)

IMPLEMENTATION & TAGGING

- FPC: Logistics, coordination
- PTAGIS: Raw Data; FPC: Reports, Estimates

DATA PREPARATION & ANALYSIS

- CSS Oversight Committee
- Fish Passage Center

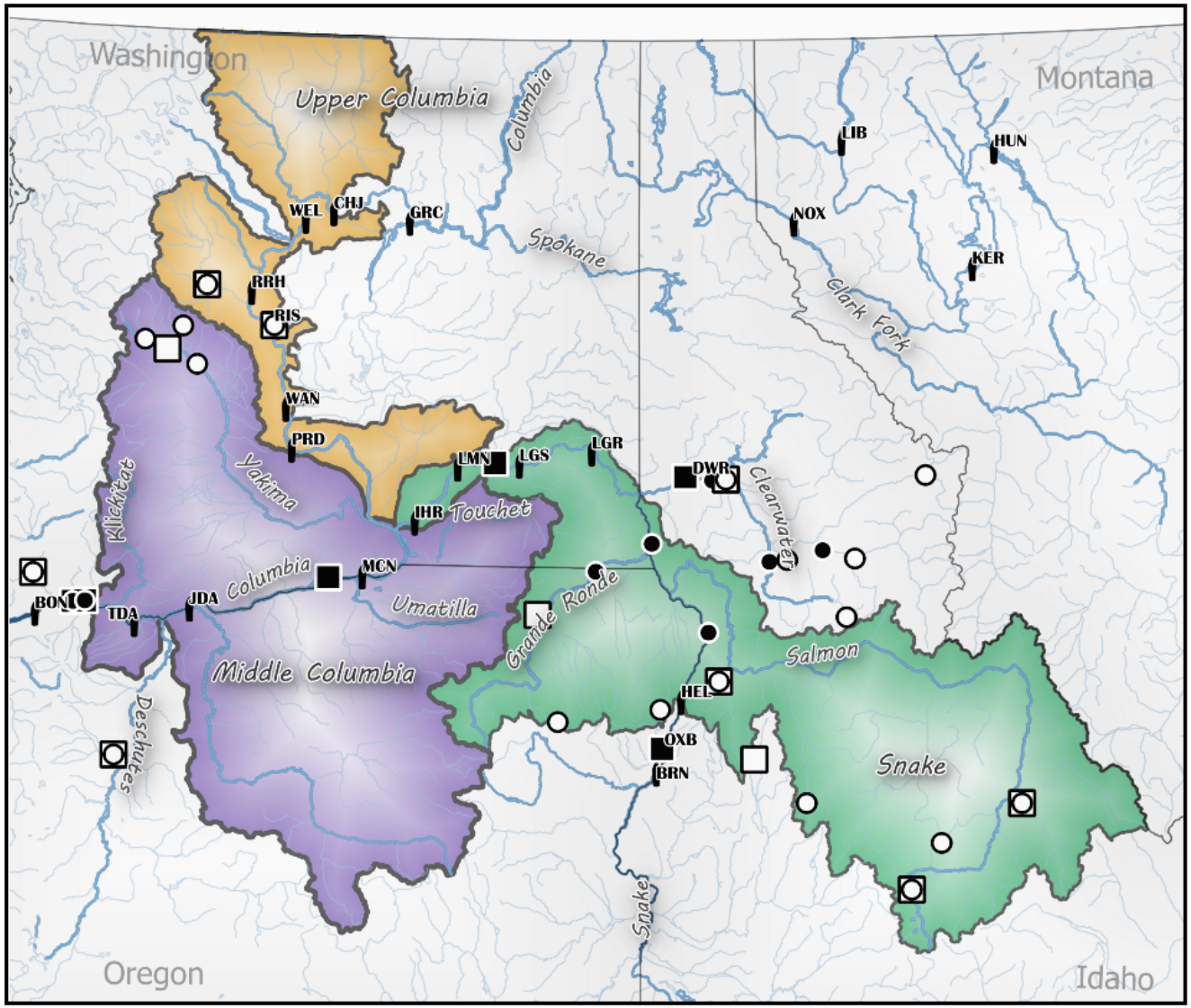
REGIONAL REVIEW

- Draft on BPA & FPC websites
- Regional Public Review; ISAB, ISRP, FPAC, NMFS, etc.

FINAL REPORT

- Posted on BPA & FPC websites

CSS PIT-Tag & Release Sites
Hatchery Chinook



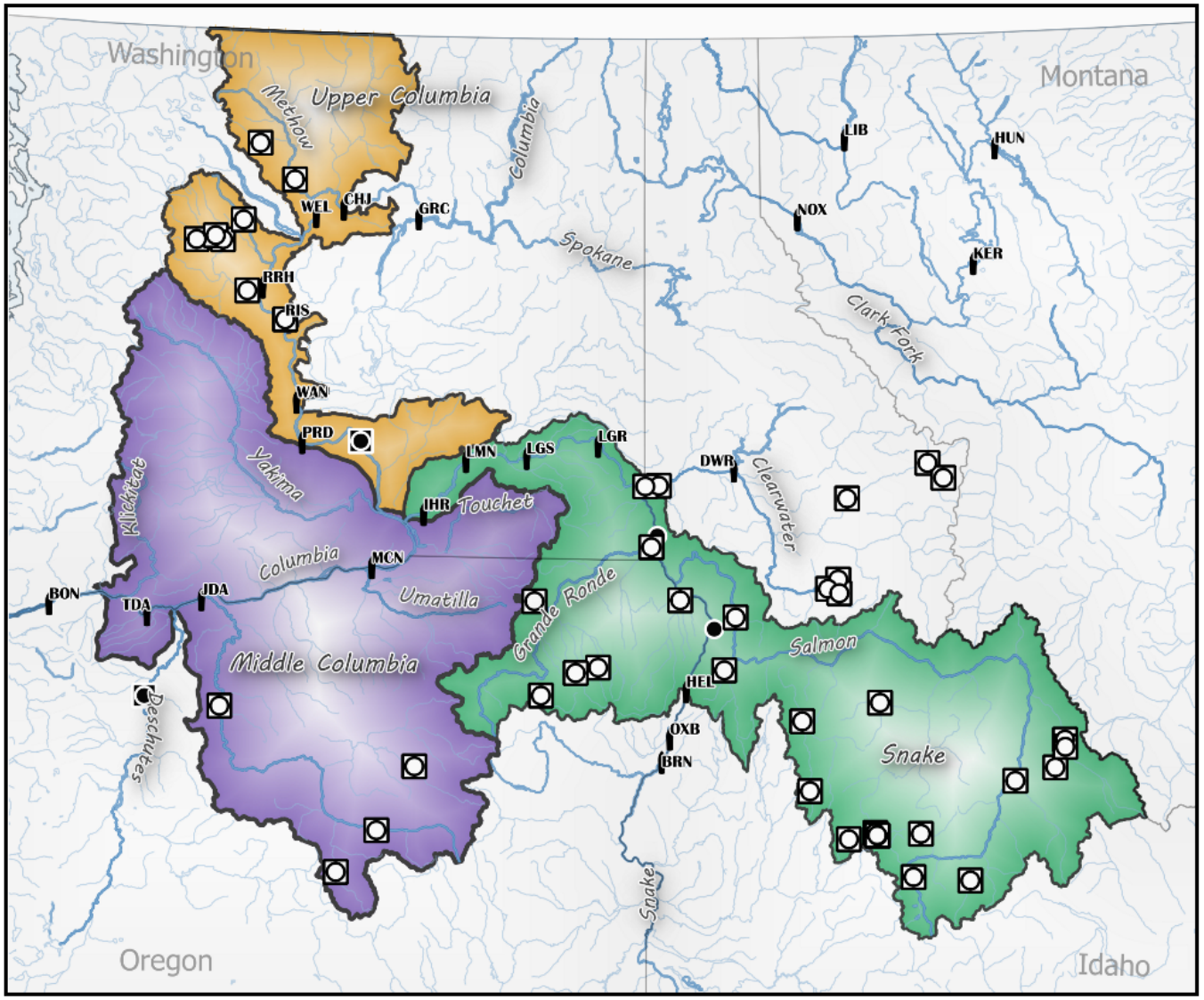
- Spring/Summer Chinook Release Sites
- Spring/Summer Chinook Tag Sites
- Fall Chinook Release Sites
- Fall Chinook Tag Sites
- Dams

Chinook ESUs
- Upper Columbia
- Middle Columbia
- Snake

N

25 0 25 50 75 100 Miles

CSS PIT-Tag & Release Sites
Wild Chinook



- Spring/Summer Chinook Release Sites
- Spring/Summer Chinook Tag Sites
- Fall Chinook Release Sites
- Fall Chinook Tag Sites

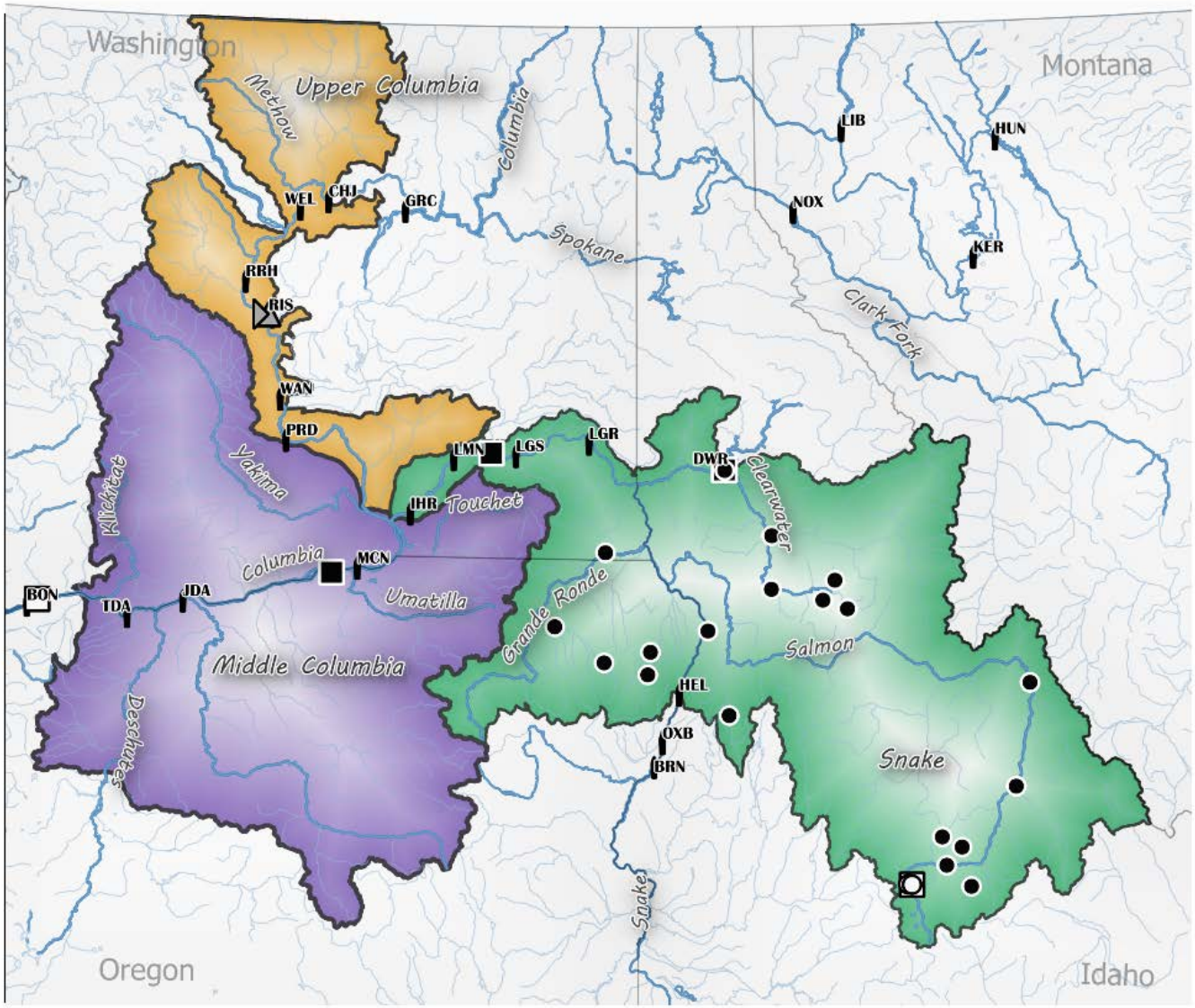
Chinook ESUs
- Upper Columbia
- Middle Columbia
- Snake

N

25 0 25 50 75 100 Miles

CSS PIT-Tag & Release Sites

Hatchery Steelhead & Hatchery Sockeye



Sockeye Release Sites
Sockeye Tag Sites
Steelhead Release Sites
Steelhead Tag Sites
Sockeye and Steelhead Release Sites

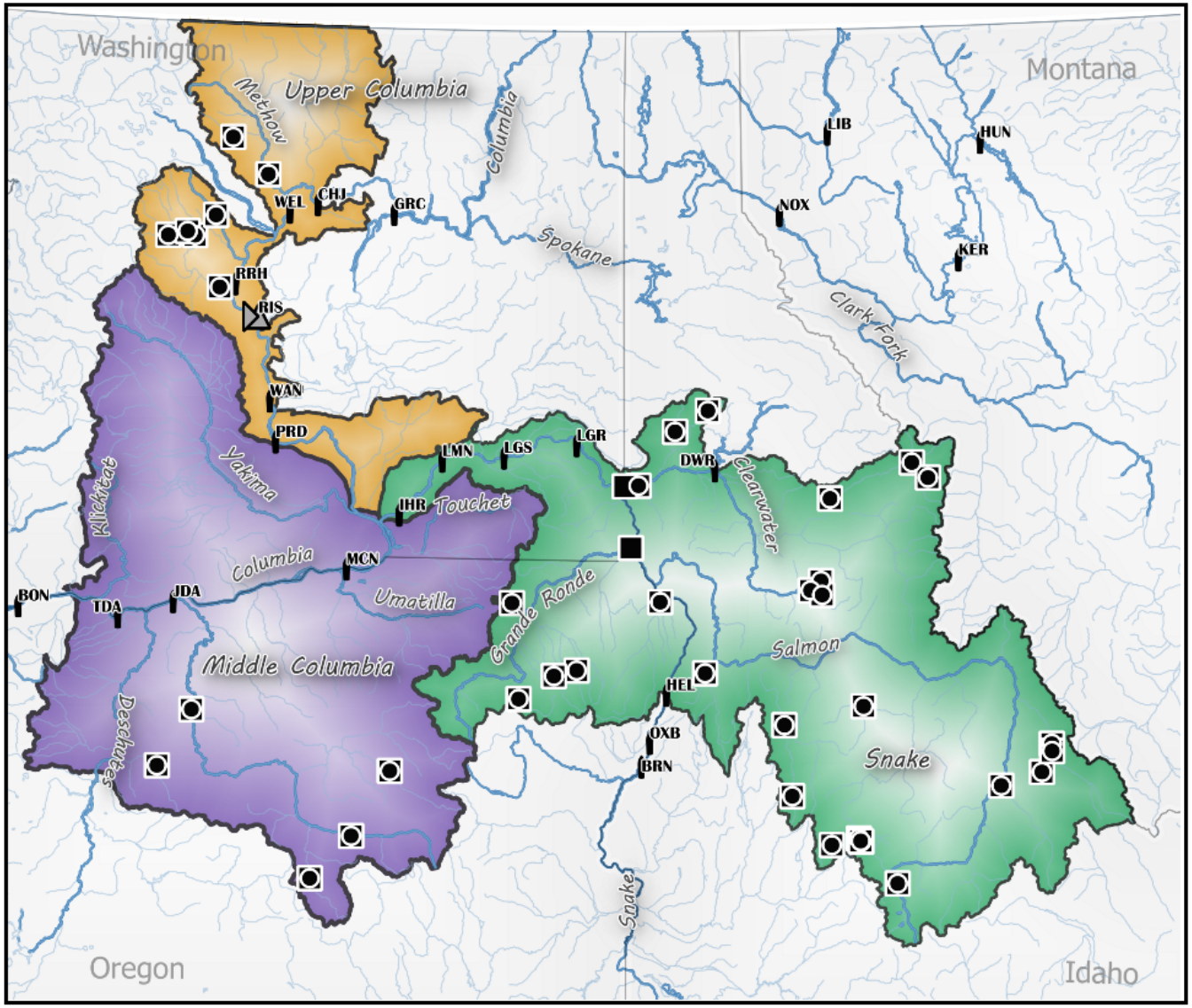
Steelhead DPSs
Upper Columbia
Middle Columbia
Snake

N

25 0 25 50 75 100 Miles

CSS PIT-Tag & Release Sites

Wild Steelhead & Wild Sockeye



Sockeye Release Sites
Sockeye Tag Sites
Steelhead Release Sites
Steelhead Tag Sites

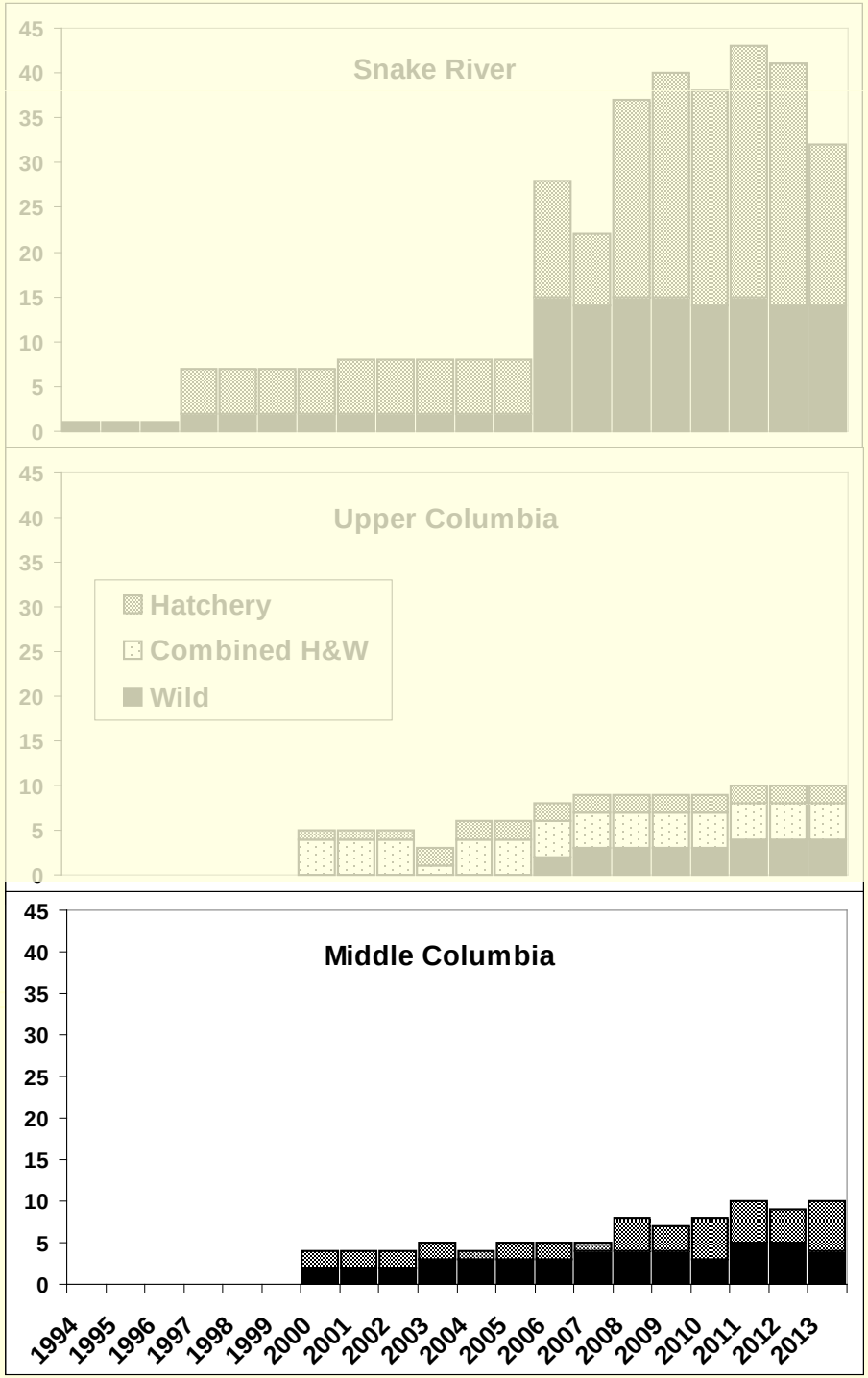
Steelhead DPSs
Upper Columbia
Middle Columbia
Snake

N

25 0 25 50 75 100 Miles

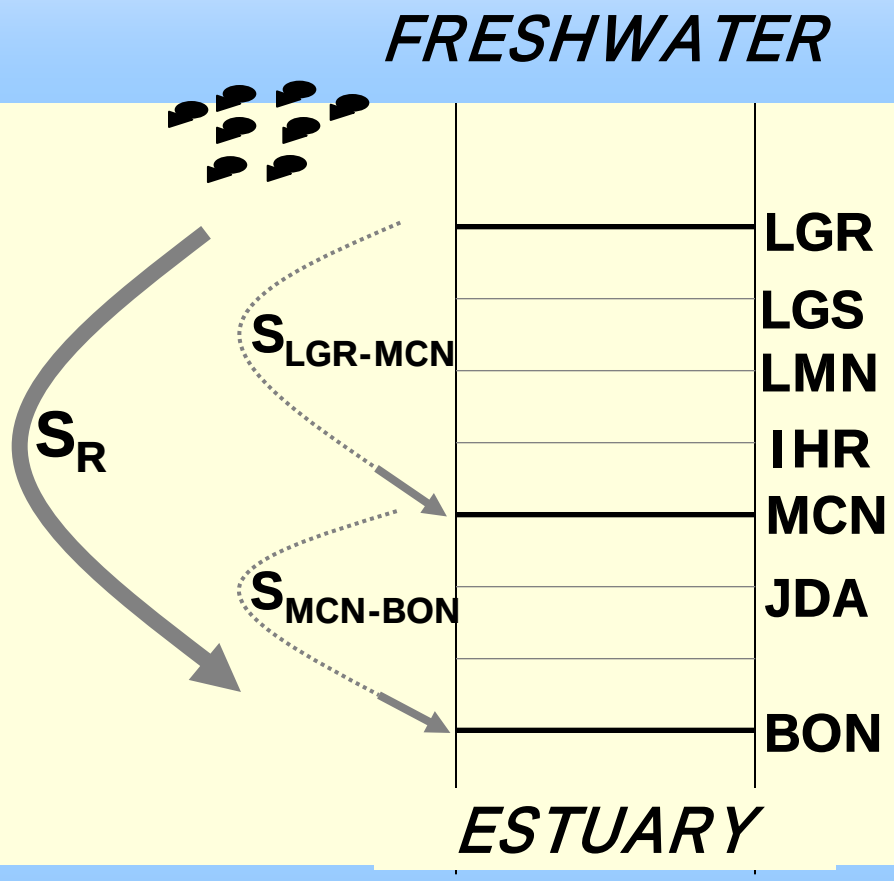
TEMPORAL COVERAGE

- Snake River
  - Longer Time Series
  - More groups developed
    - 32 different tag groups for 2013 Migr Yr
      - sp/su Chinook, ~~fall Chinook~~, steelhead, sockeye
- Upper Columbia River
  - Began in Migr Yr 2000 [BOA detect]
  - ~ 10 stocks
- **Middle Columbia River**
  - **Began in 2000 [BOA detect]**
  - **~ 10 stocks**



Smolt Survival

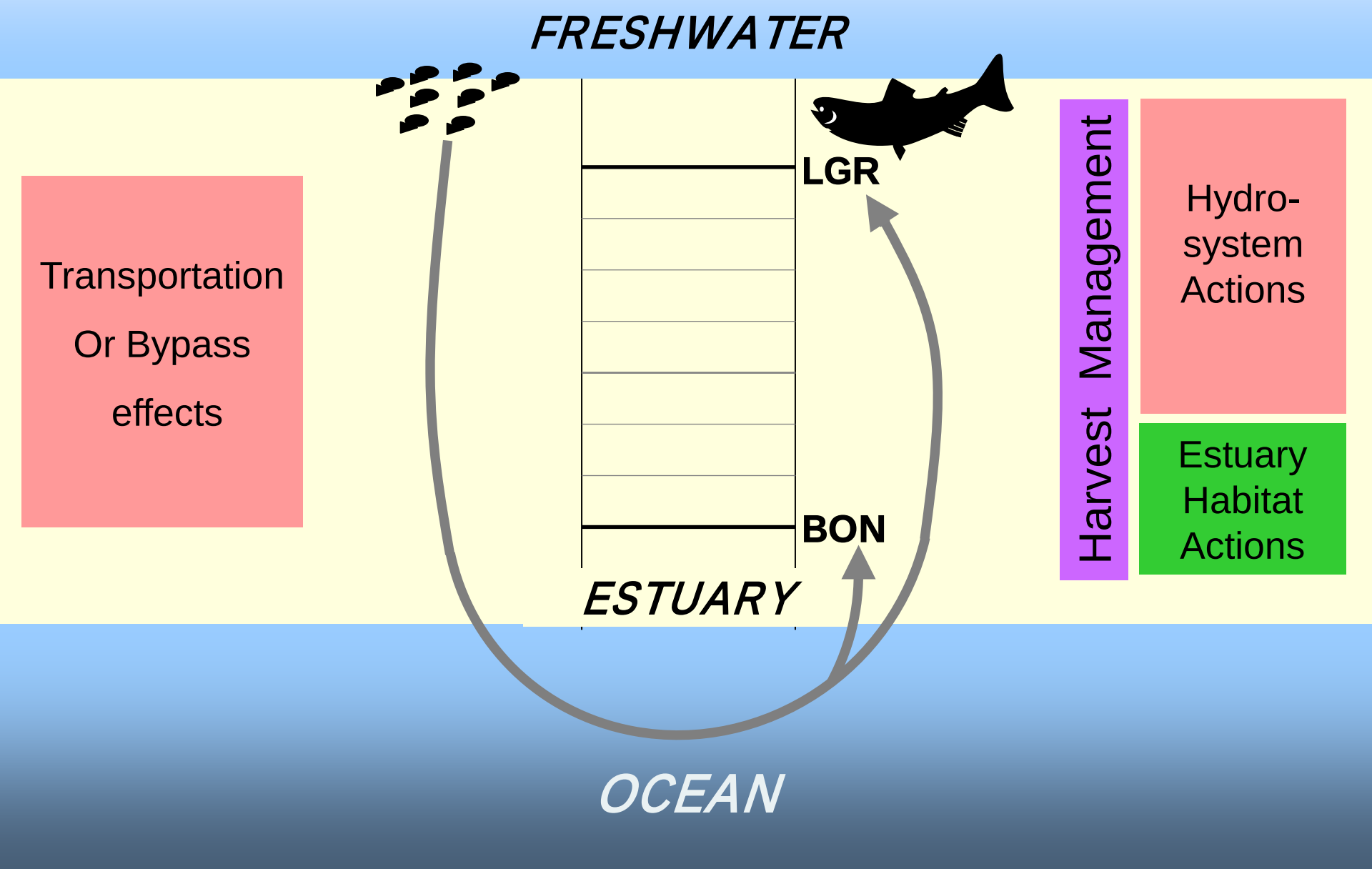
Rearing Habitat Actions



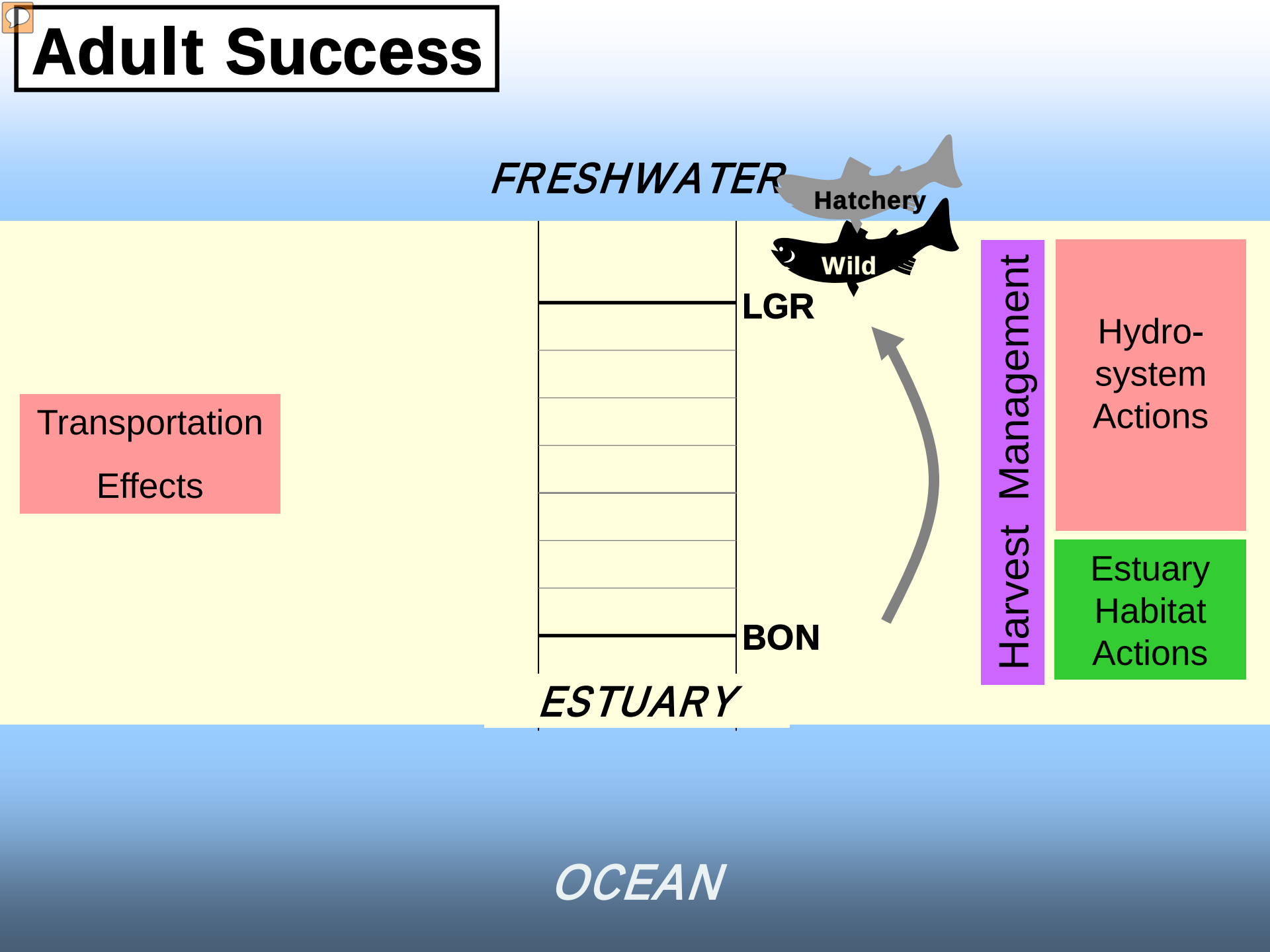
Hydro-system Actions

OCEAN

SNAKE RIVER SARS

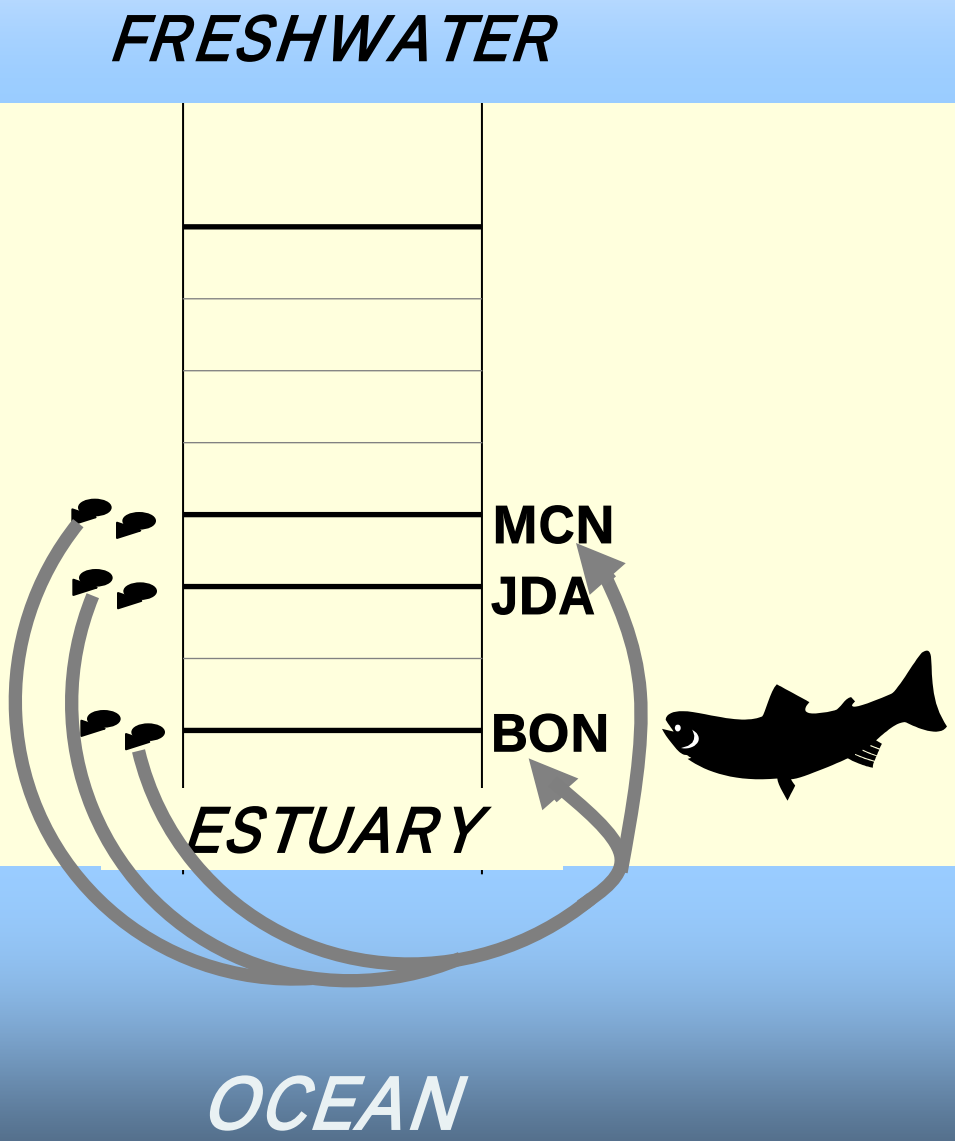


Adult Success



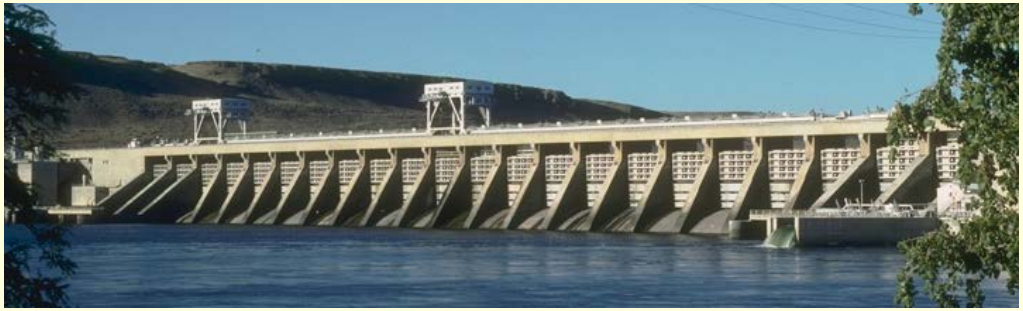
Mid and Upper Columbia R. SARS

Regional Monitoring & Evaluation



What does CSS provide for the region?

- **Long term consistent information collaboratively designed and implemented**
- **Information easily accessible and transparent**
  - **CSS PIT-tags accessed by any PTAGIS users, including fisheries managers, researchers, and academics.**
- **Long term indices (identify bottlenecks) :**
  - *Travel Times*
  - *In-river Survival Rates*
  - *In-river SARs by route of passage*
  - *Transport SARs*
  - *Adult success, conversion*
- **Comparisons of SARs**
  - *Transport to In-River*
  - *NPCC Regional SAR goal*
  - *By geographic location*
  - *By hatchery group*
  - *Hatchery to Wild*
  - *Chinook to Steelhead*



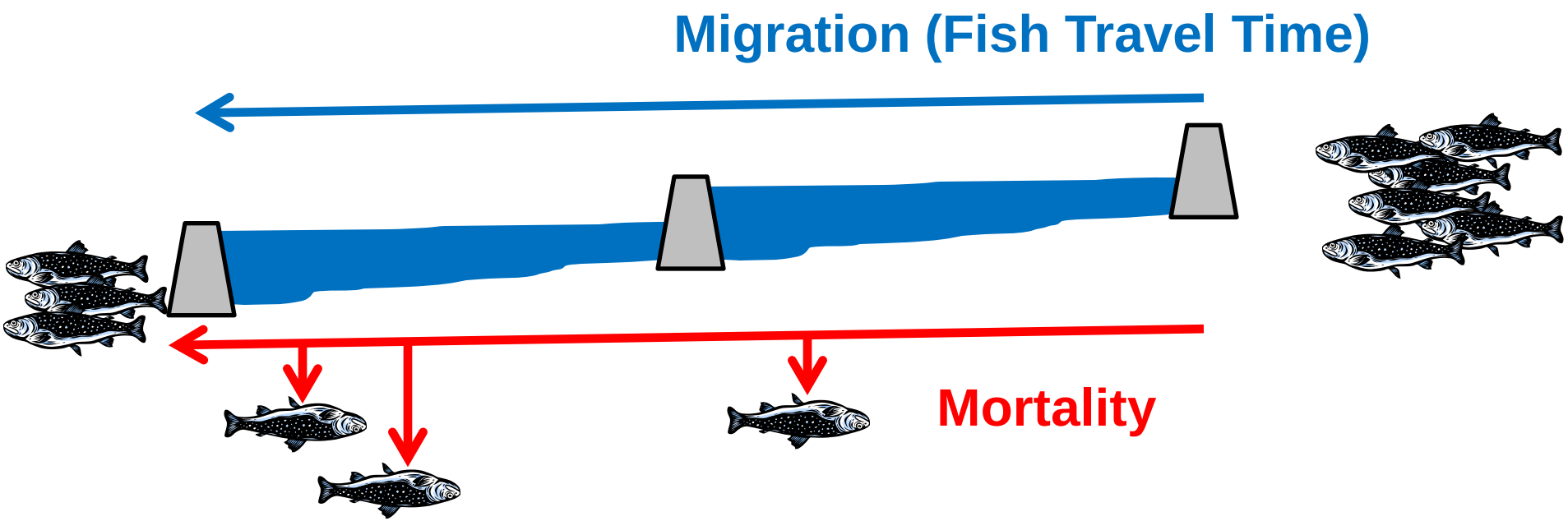
- *<u>Management questions:</u> hydropower operations, hatchery evaluations, habitat evaluations*

Juvenile survival, travel time and the in-river environment

Presenter: Steve Haeseker

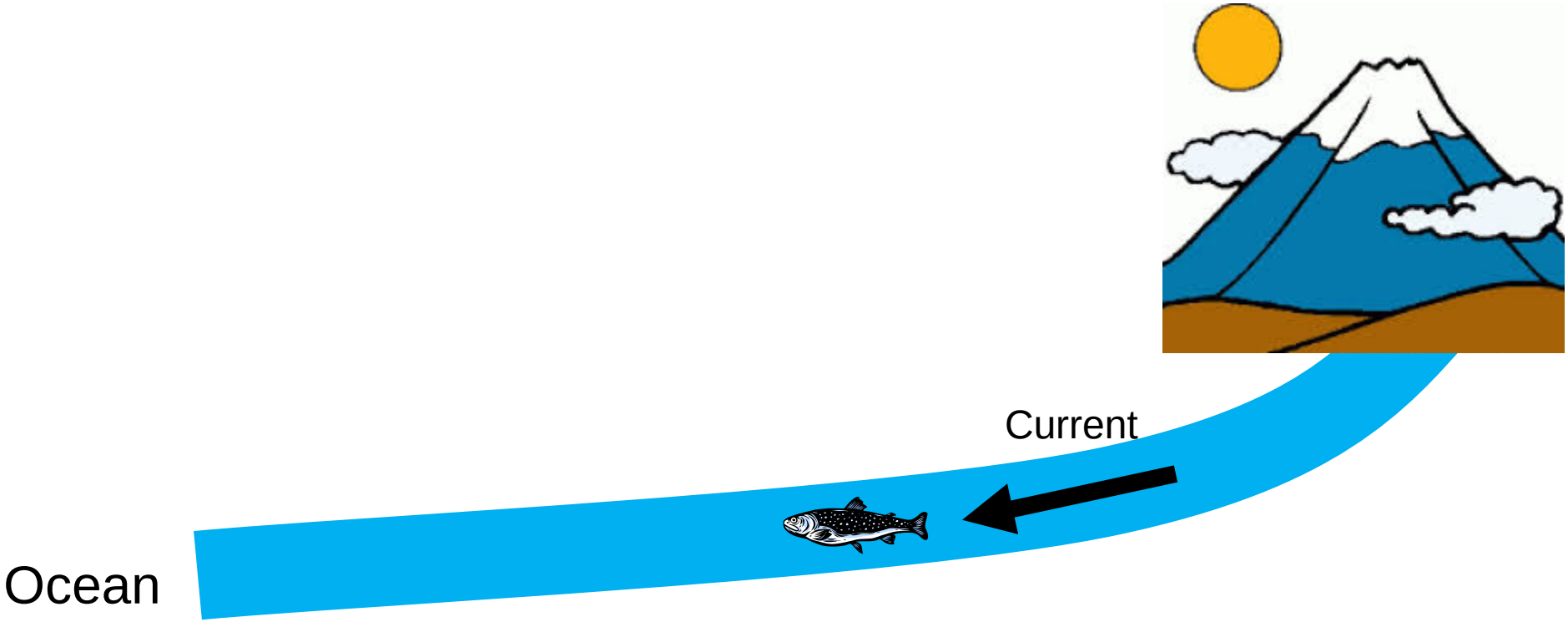
Juvenile migration

- Two simultaneous processes: migration and mortality



- Migration rates and mortality rates affect survival

Question: Do smolts generally face upstream or downstream as they migrate to sea?



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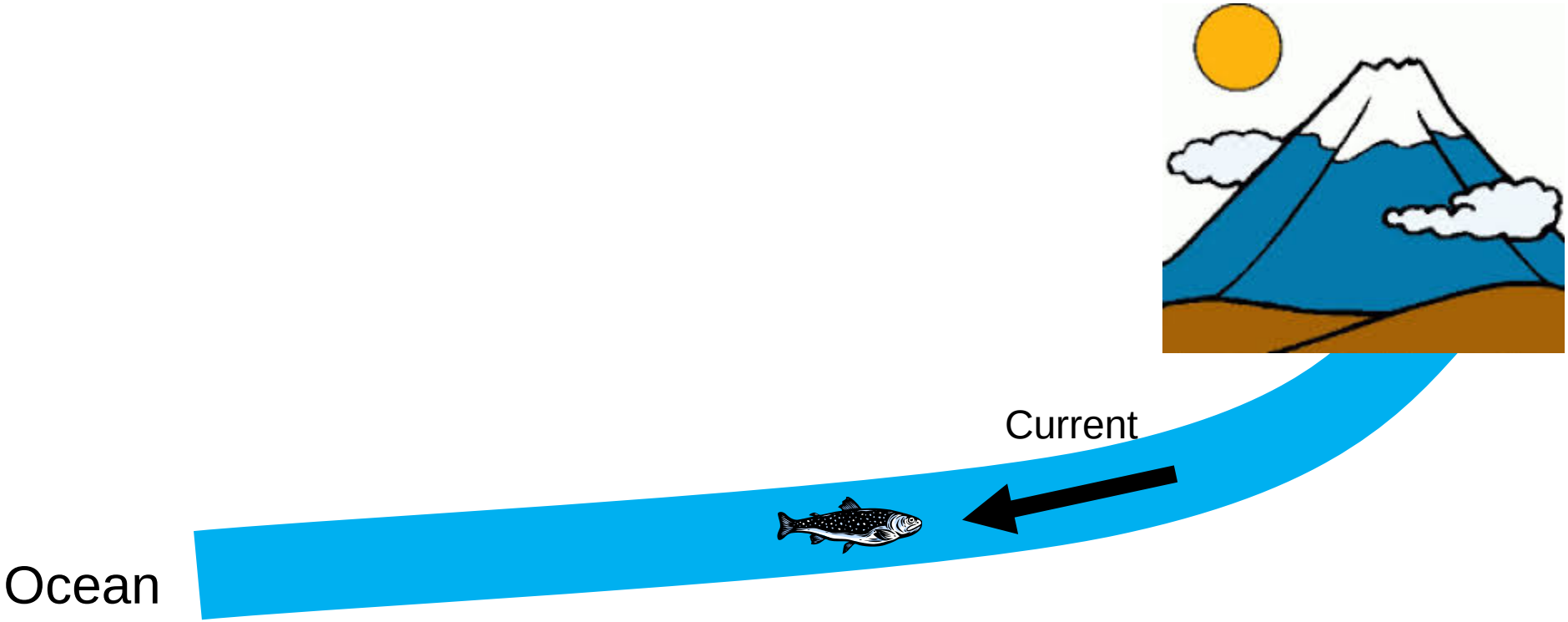
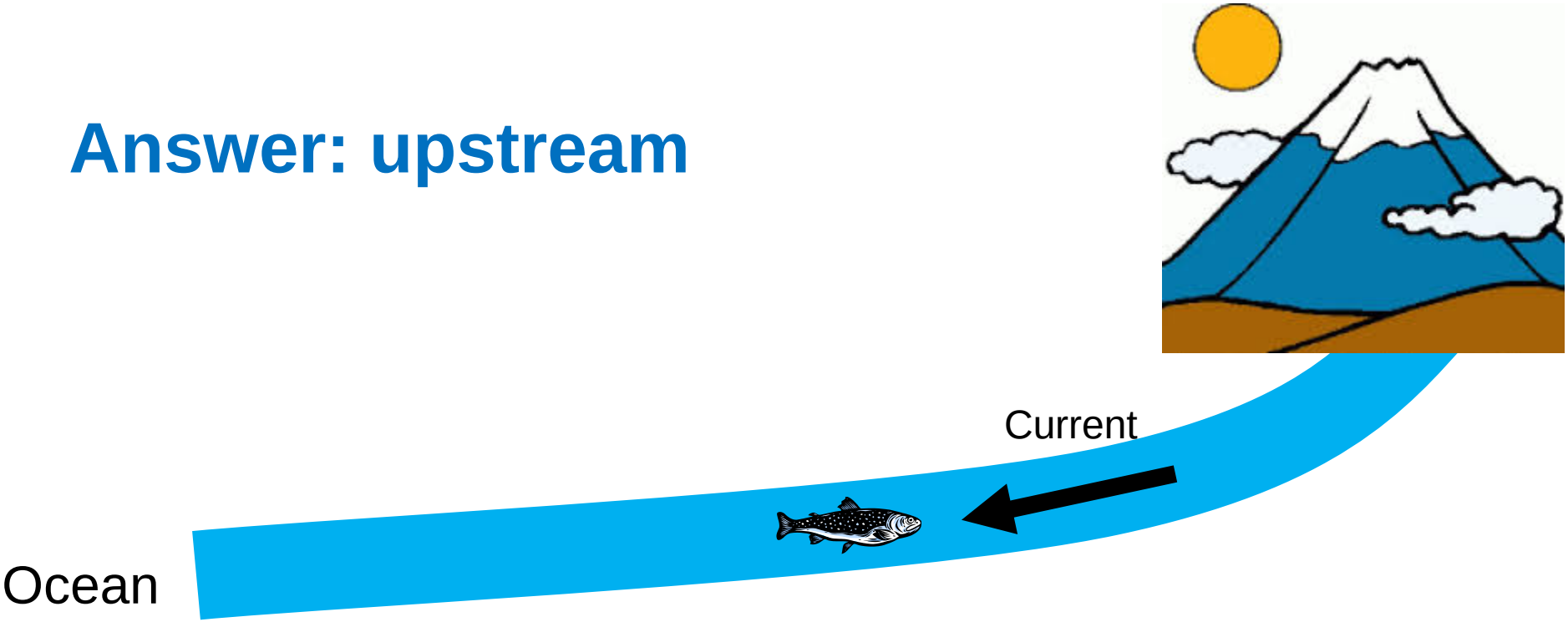
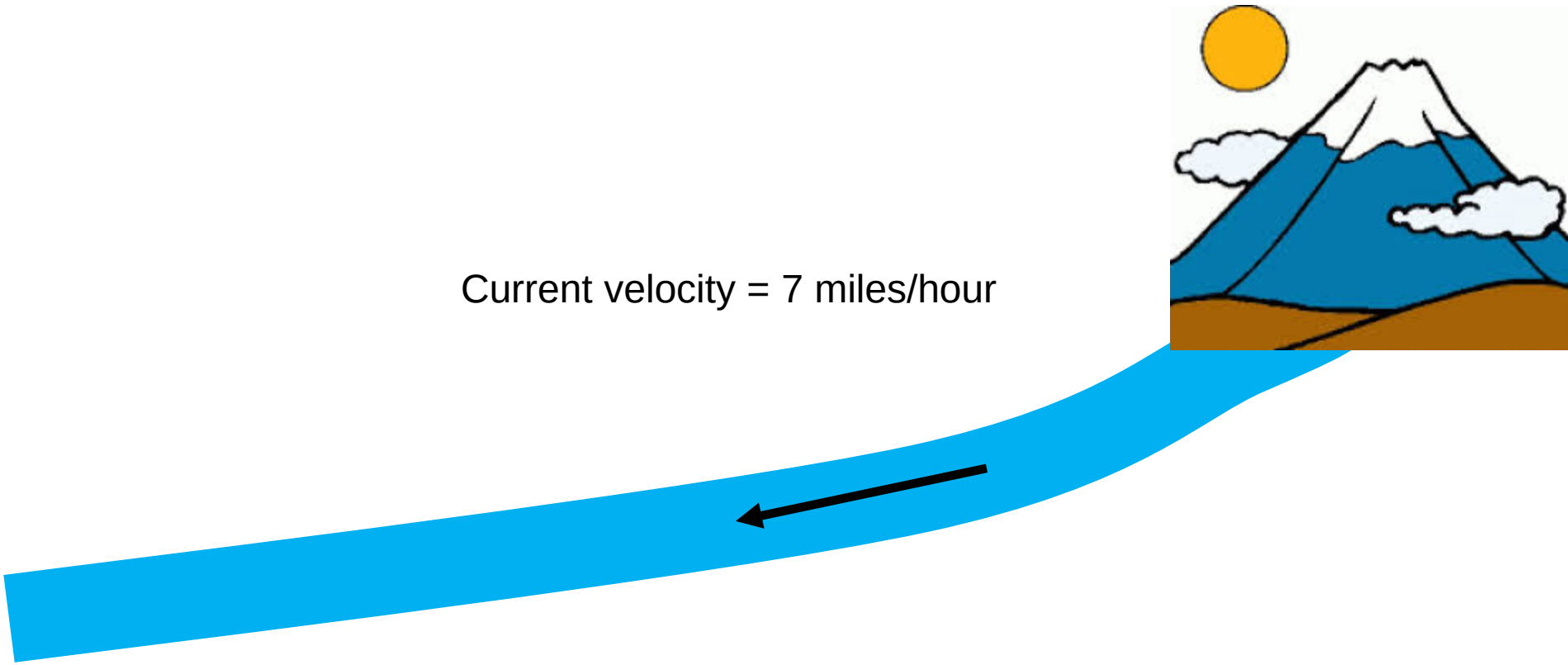


Question: Do smolts generally face upstream or downstream as they migrate to sea?

Answer: upstream



How do reservoirs affect the currents that fish rely on?



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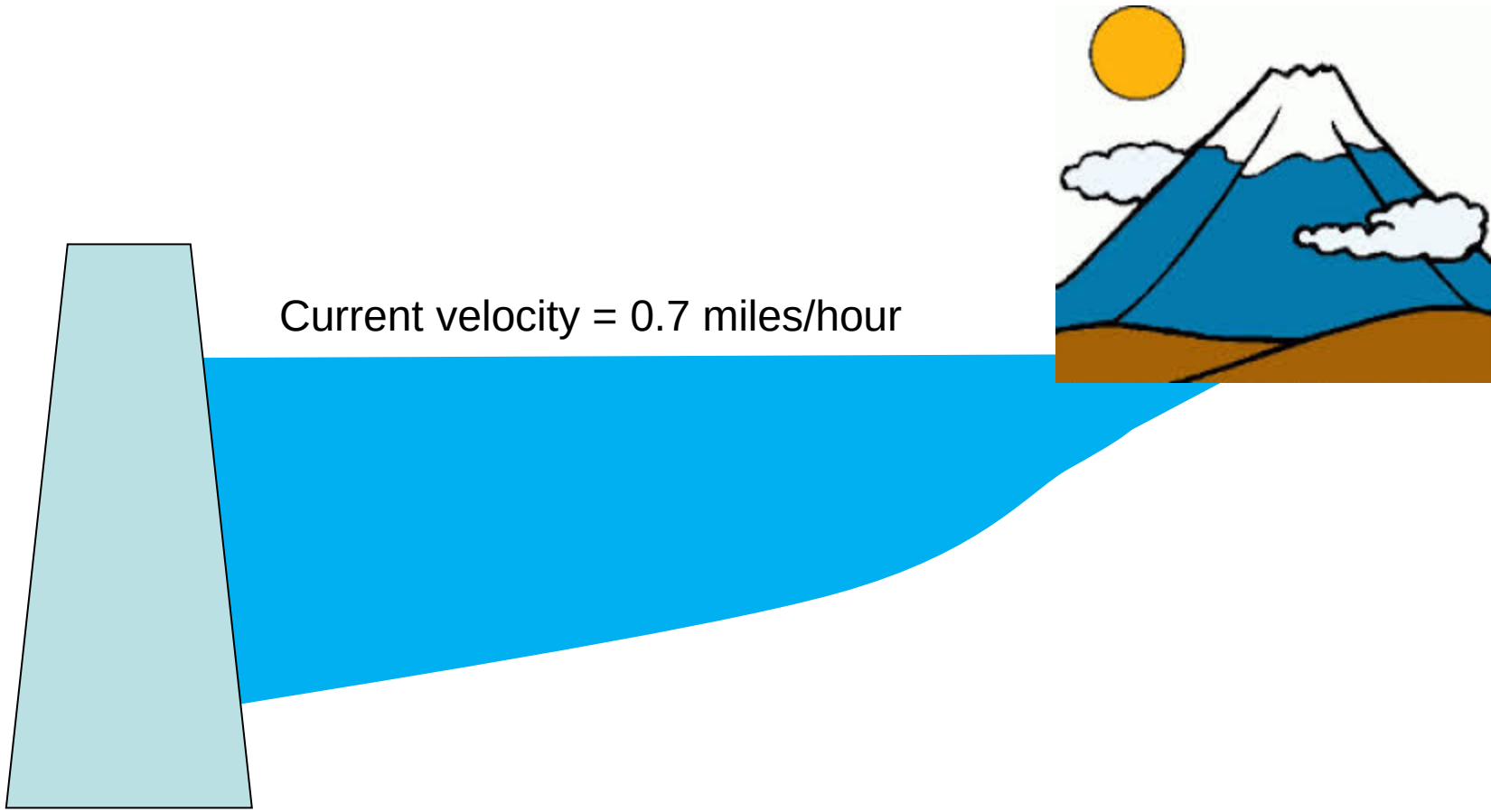

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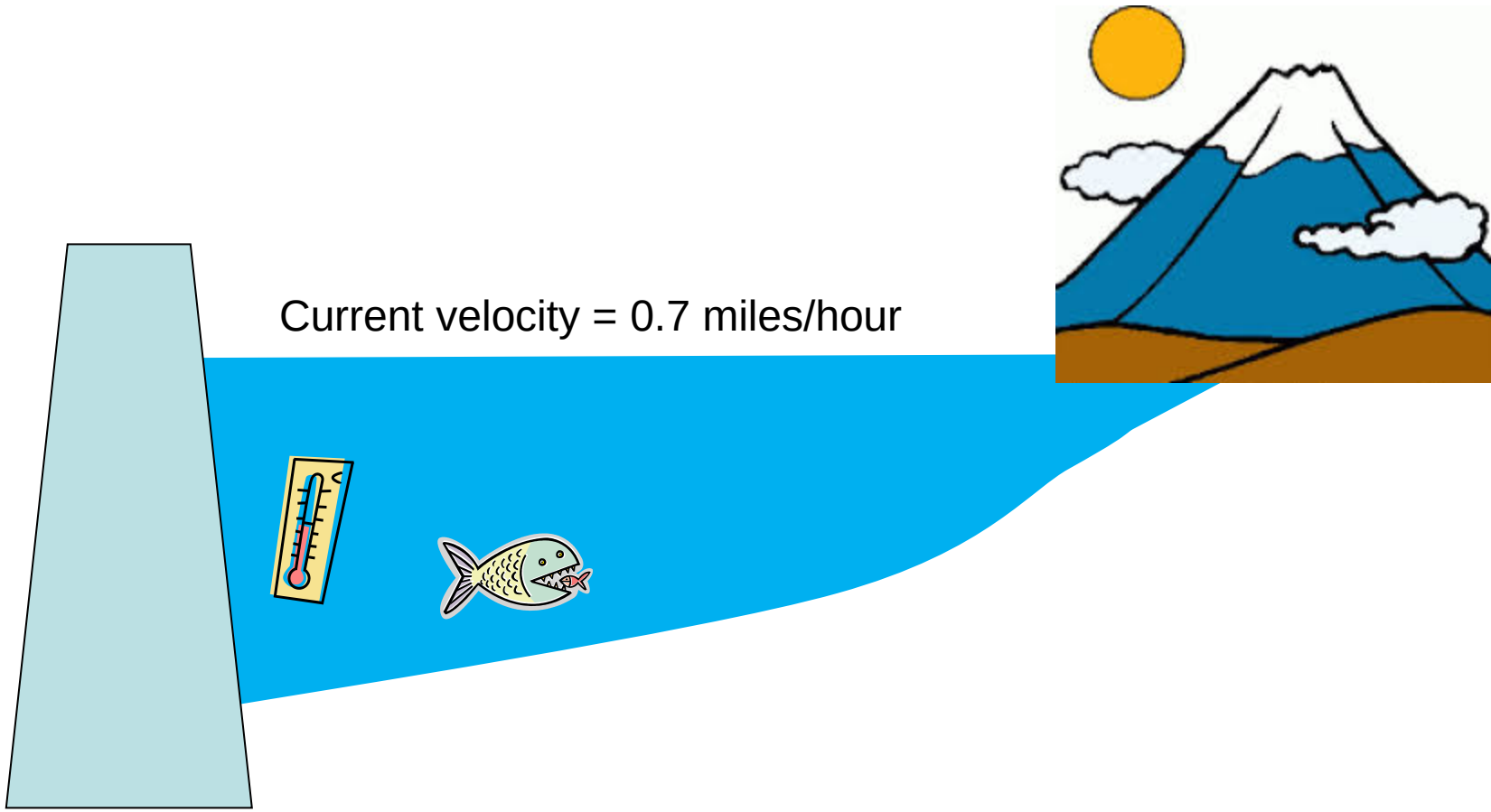
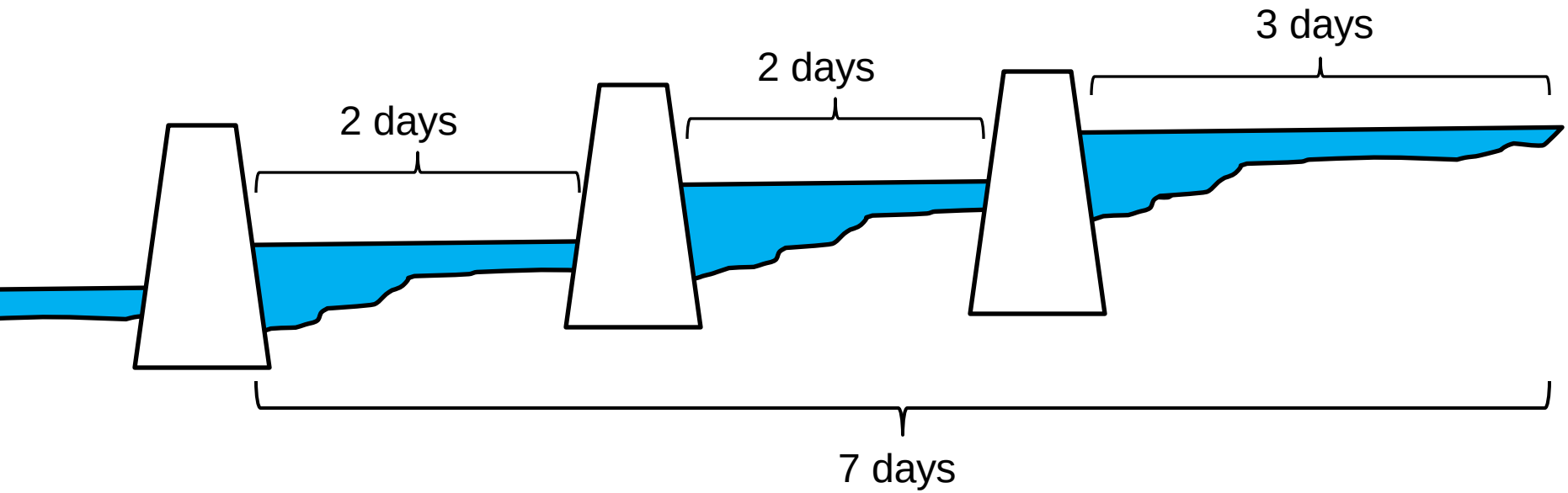
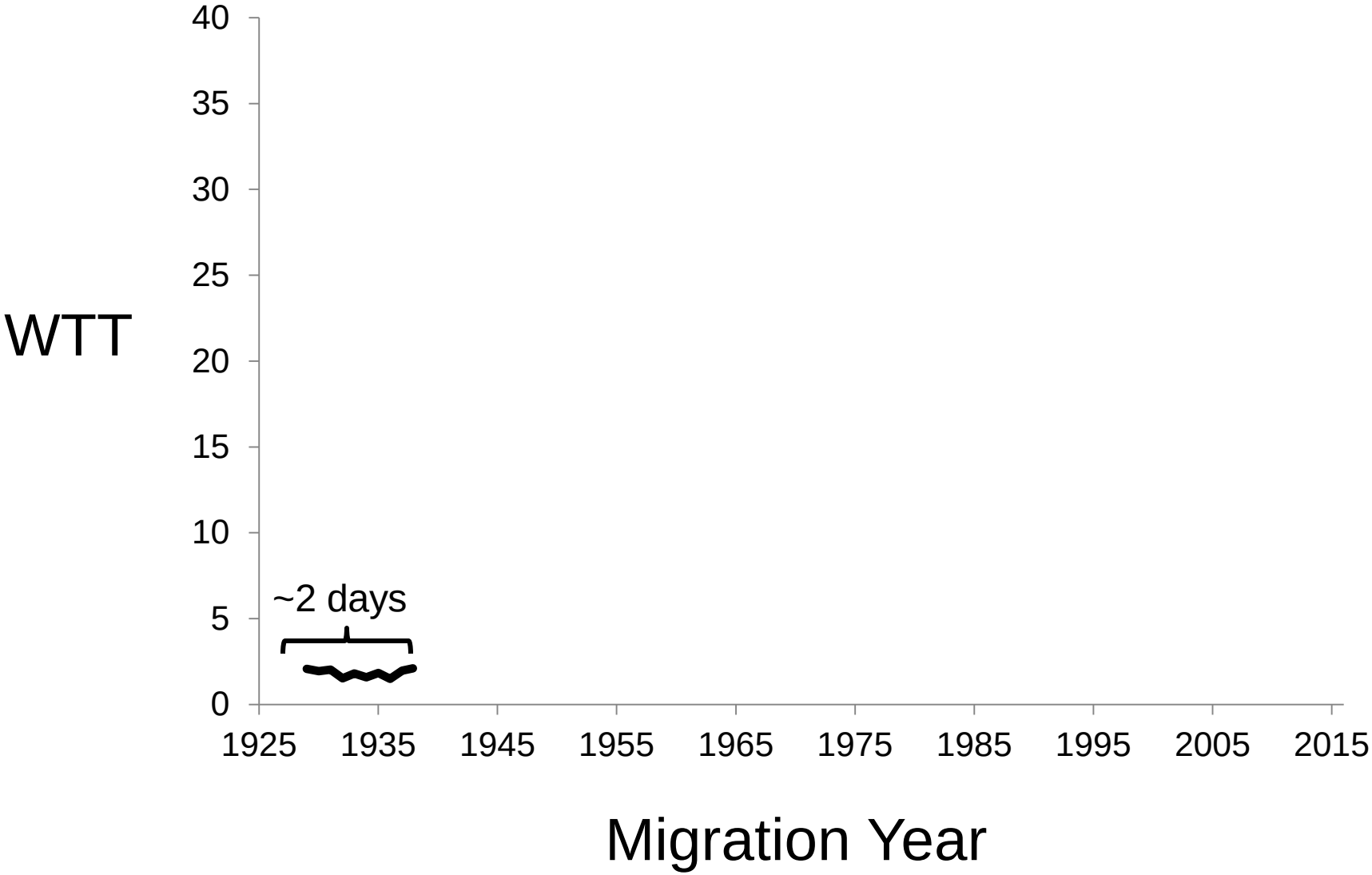


Water Transit Time (WTT)

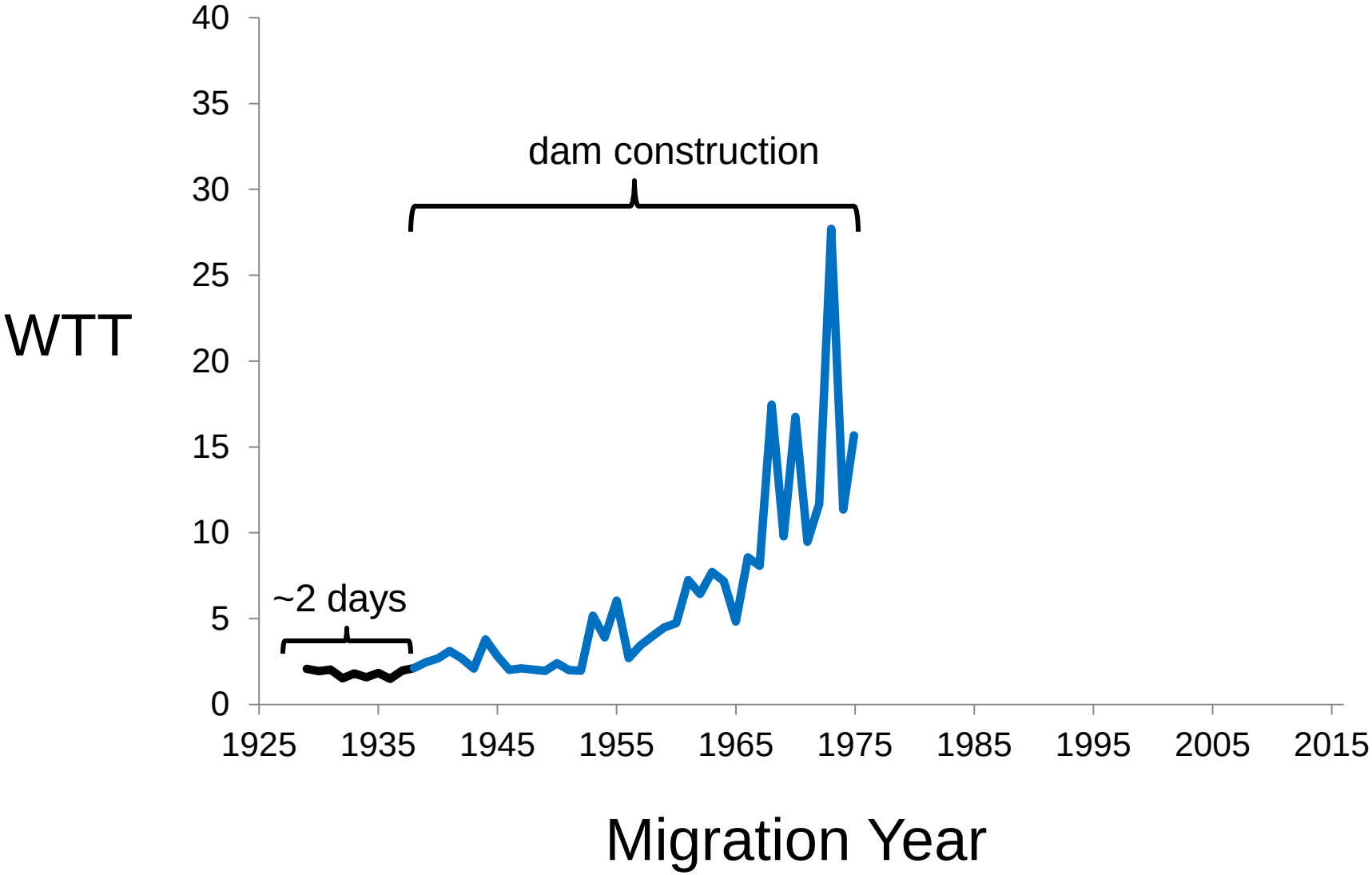
Estimate of the number of days required for average water particle to transit a reservoir (volume/flow)



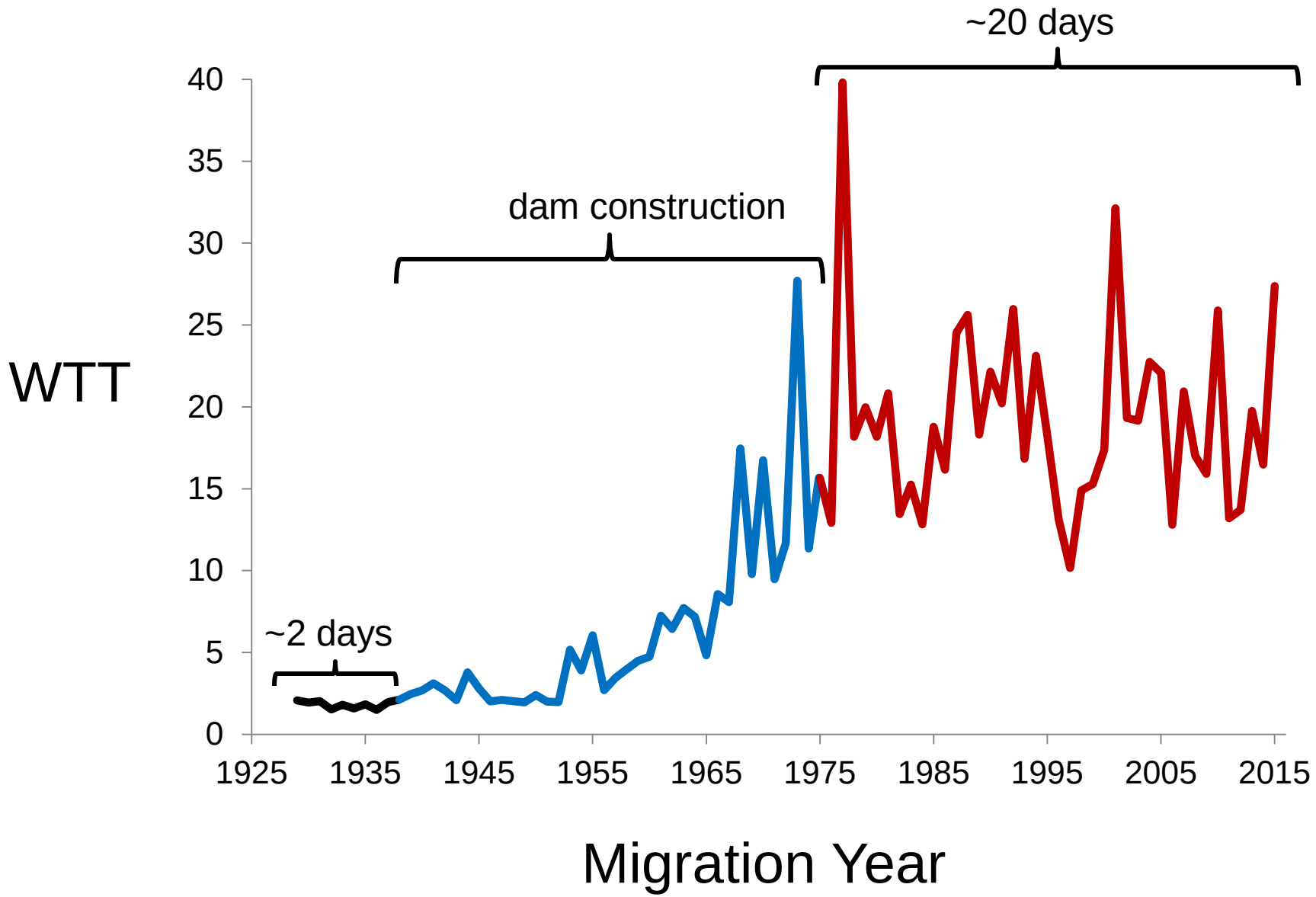
Long-term changes in Lewiston-BON WTT



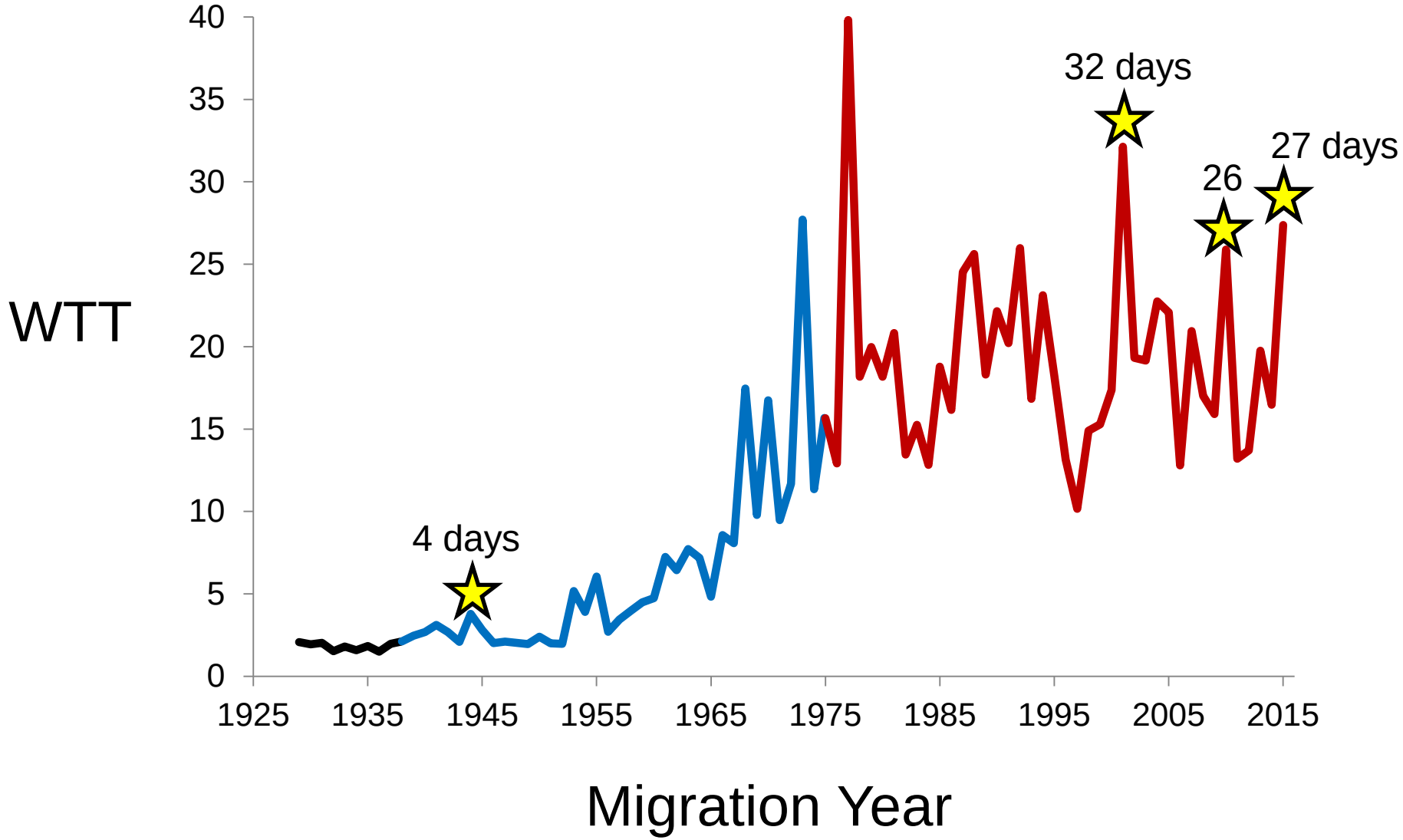
Long-term changes in Lewiston-BON WTT



Long-term changes in Lewiston-BON WTT



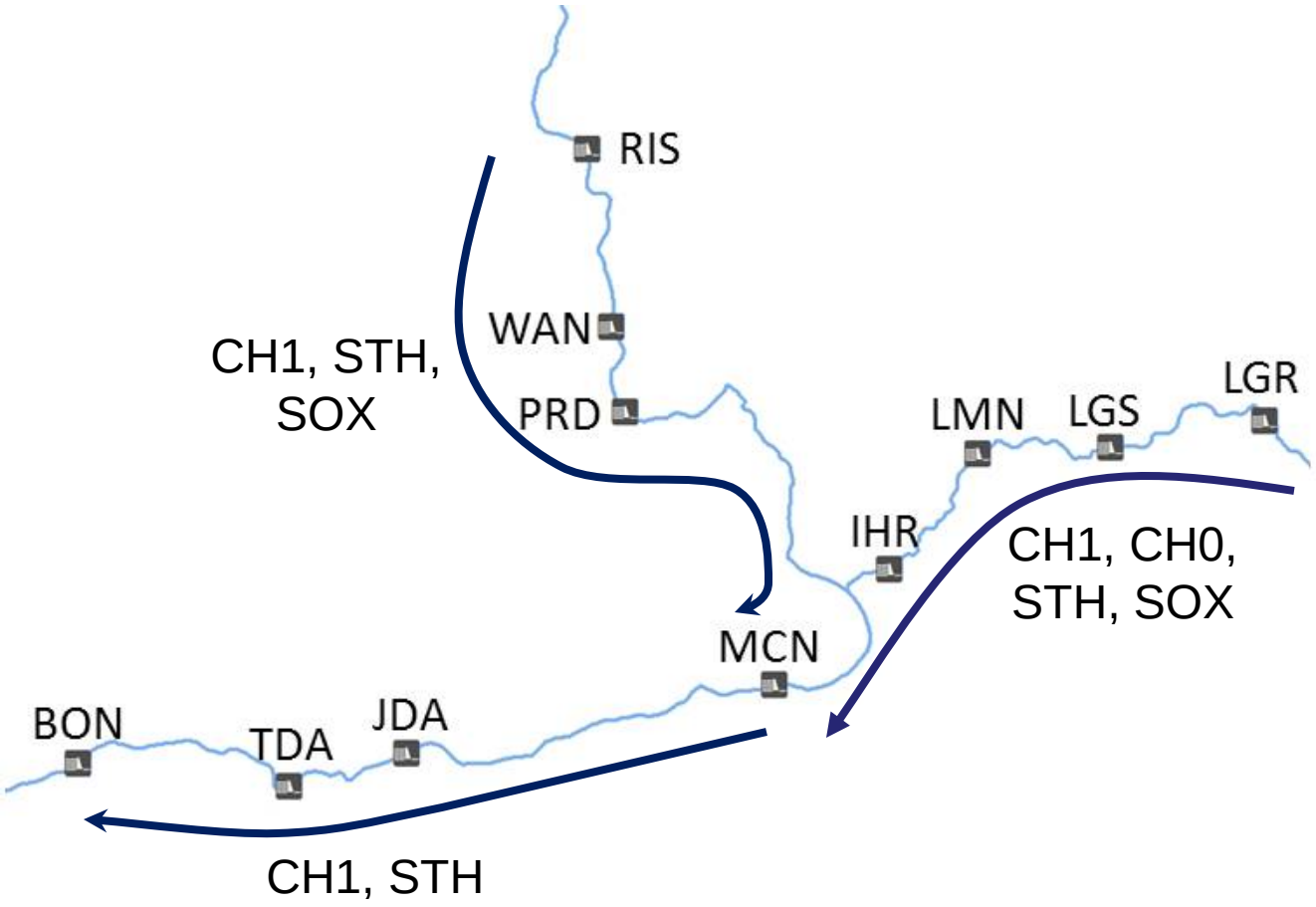
Long-term changes in Lewiston-BON WTT



Objectives:

- Measure and monitor juvenile Chinook, steelhead, and sockeye travel time and mortality rates through the hydrosystem
- Examine associations between environmental factors and travel time and mortality rates
- Develop models that explain variation in travel time and mortality rates through the hydrosystem

Monitoring methods:



Monitoring methods (1998-2014):

- Weekly/two-week release cohorts of PIT-tagged fish
- Estimated mean fish travel times (FTT), survival probabilities, and mortality rates

Environmental and Management Factors:

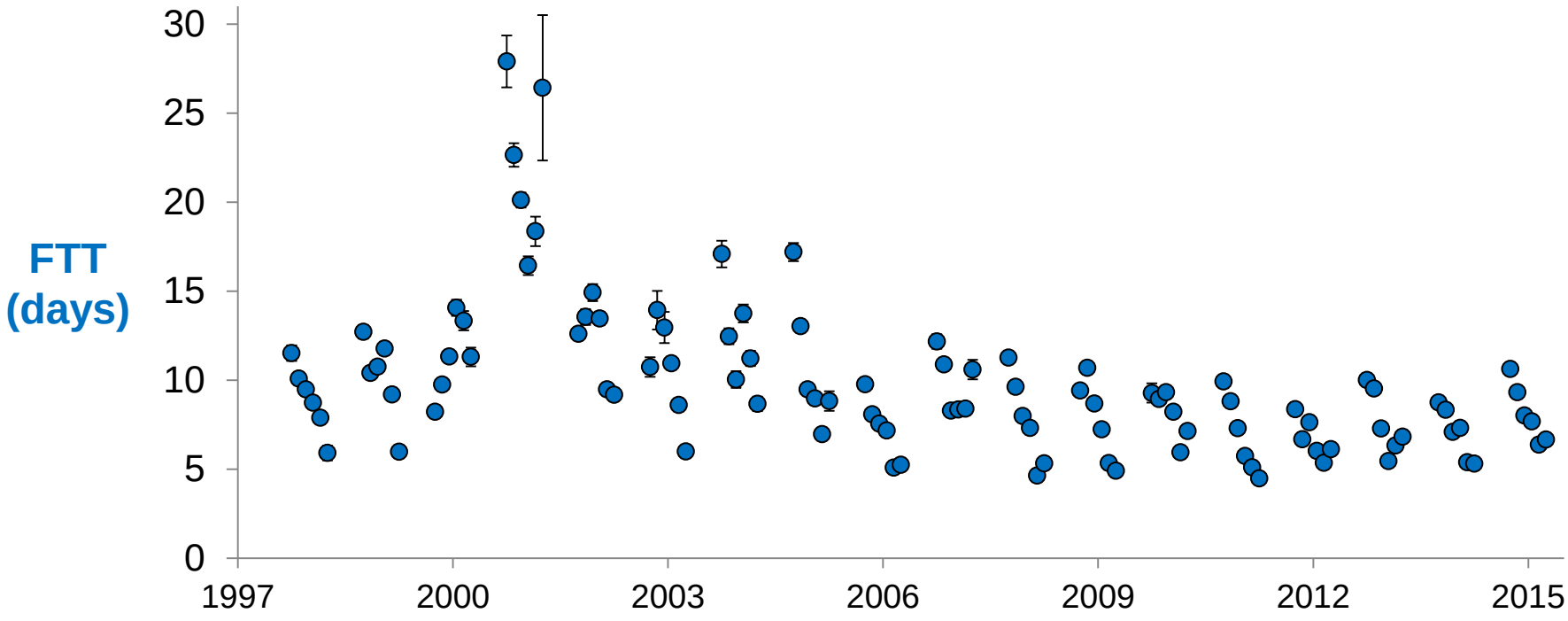
- Seasonality (Julian Day)
- Temperature
- Average percent spill
- Surface passage structures (TSW, RSW)
- Water transit time (WTT, days)

Regression with multi-model inference:

- All combinations of variables
- Relative variable importance
- Model-averaged predictions

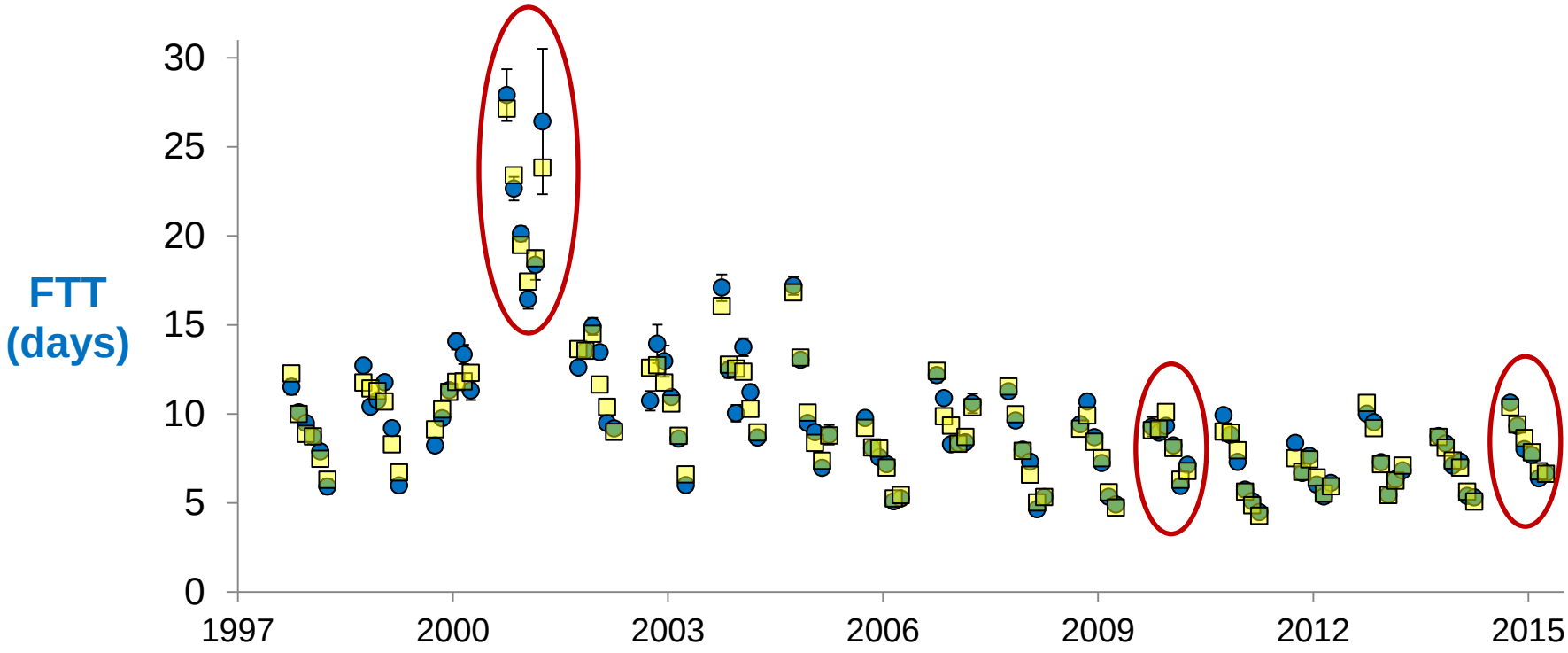
Fish Travel Times

Steelhead LGR-MCN



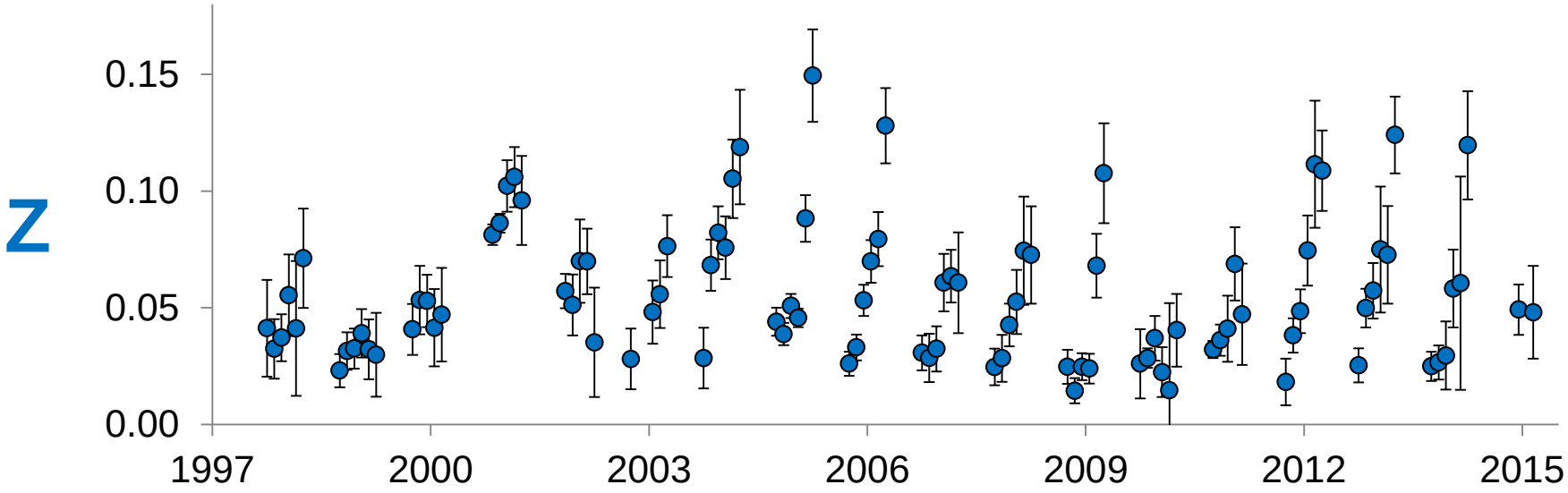
Fish Travel Times

Steelhead LGR-MCN



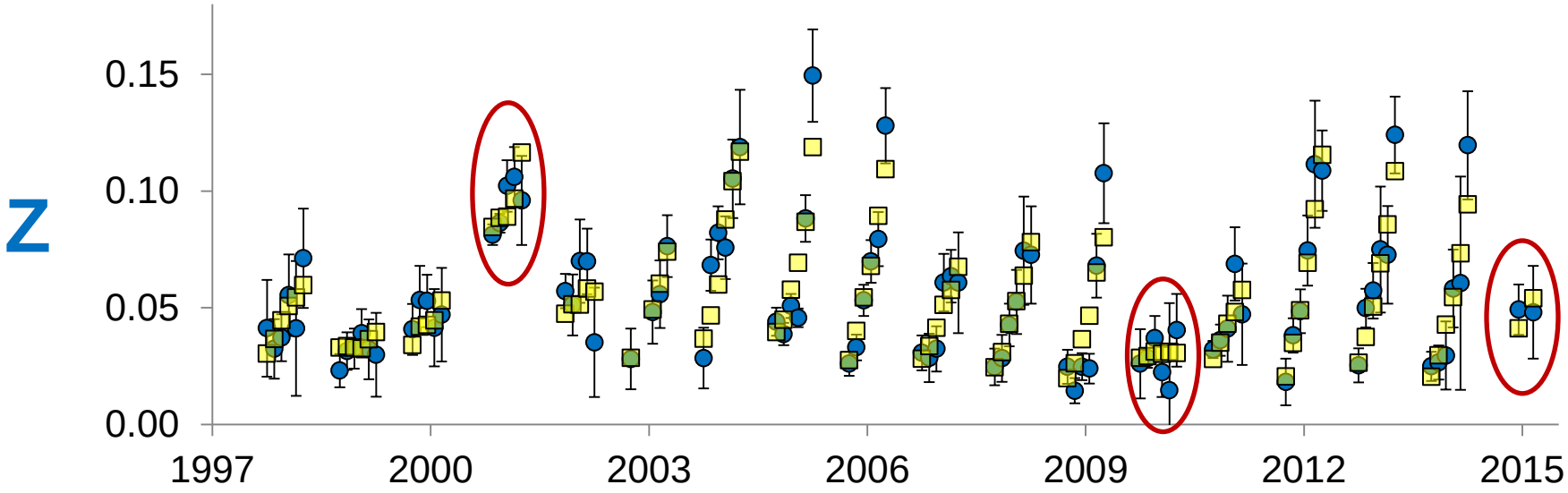
Mortality Rates

Steelhead LGR-MCN



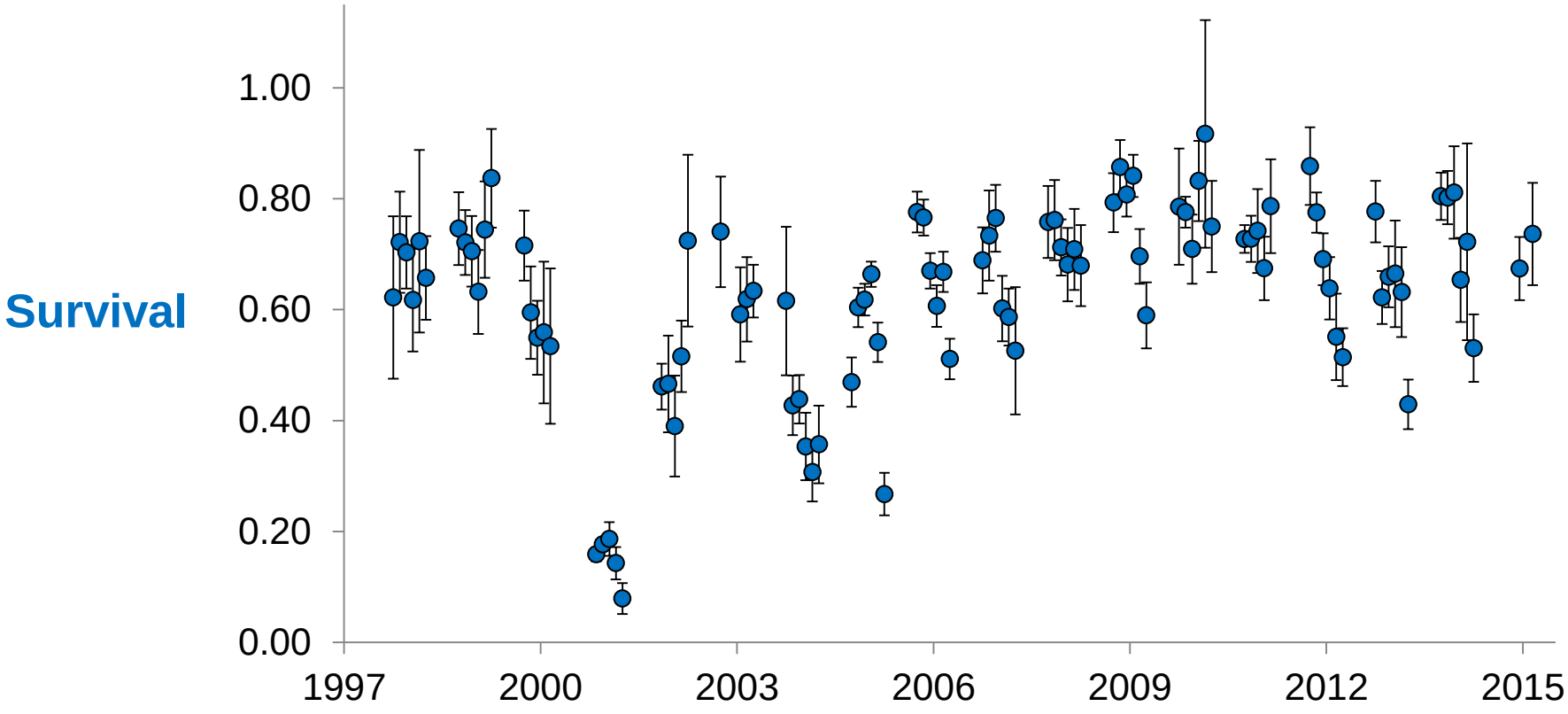
Mortality Rates

Steelhead LGR-MCN



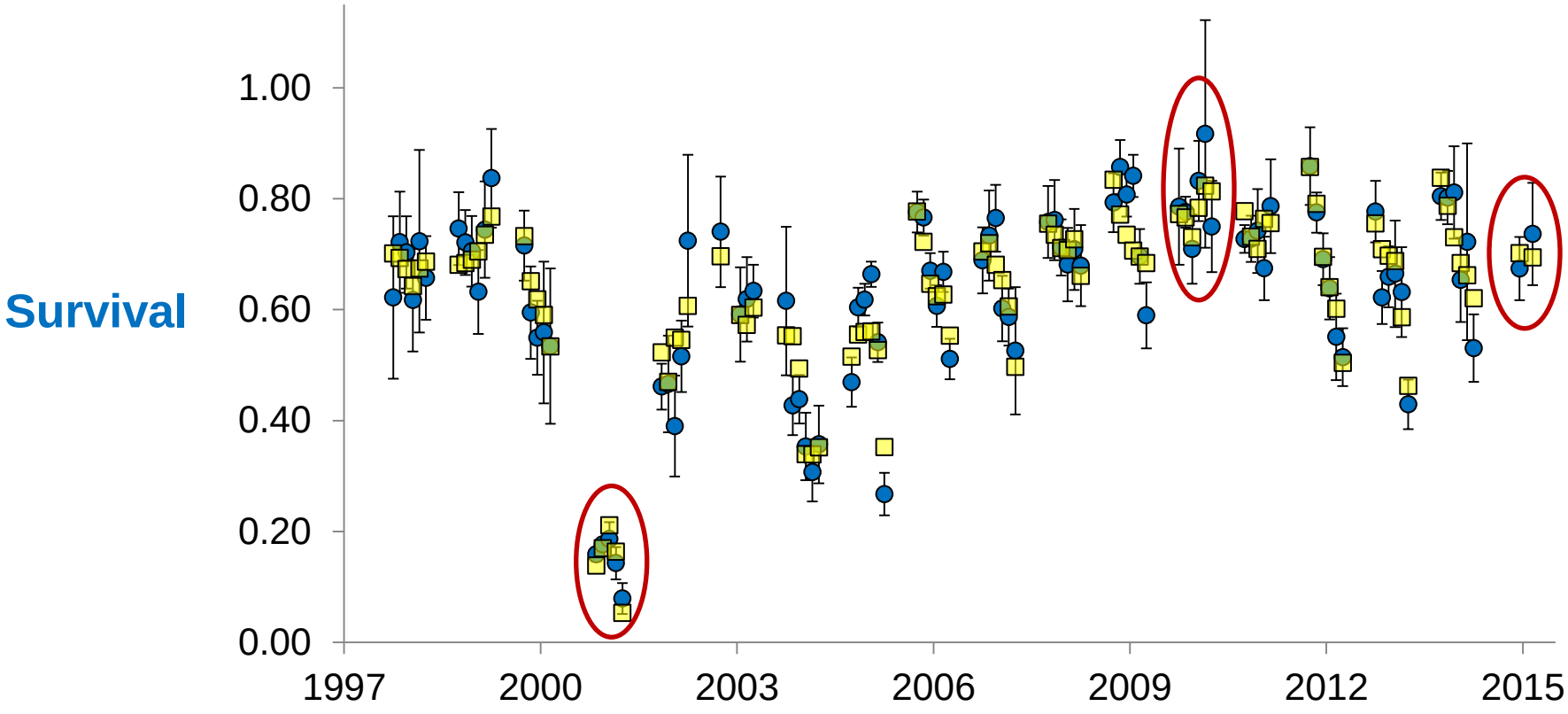
Survival

Steelhead LGR-MCN

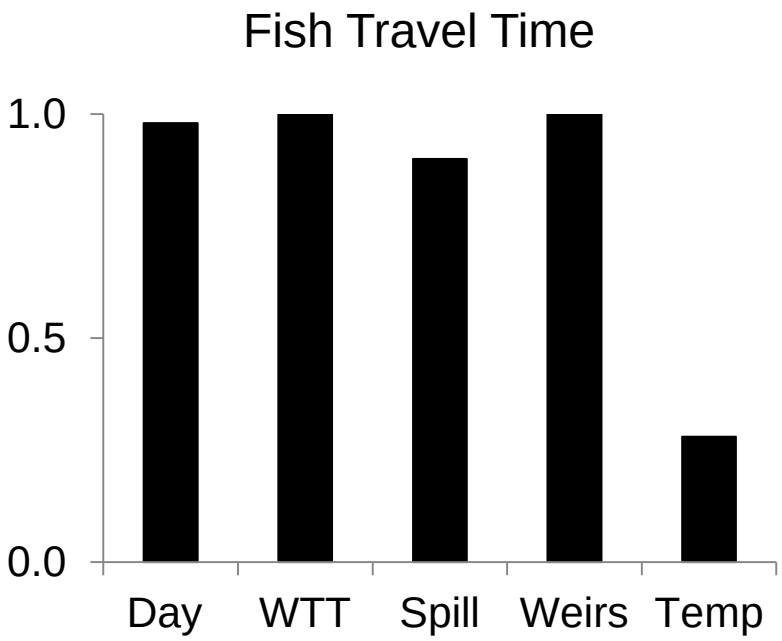


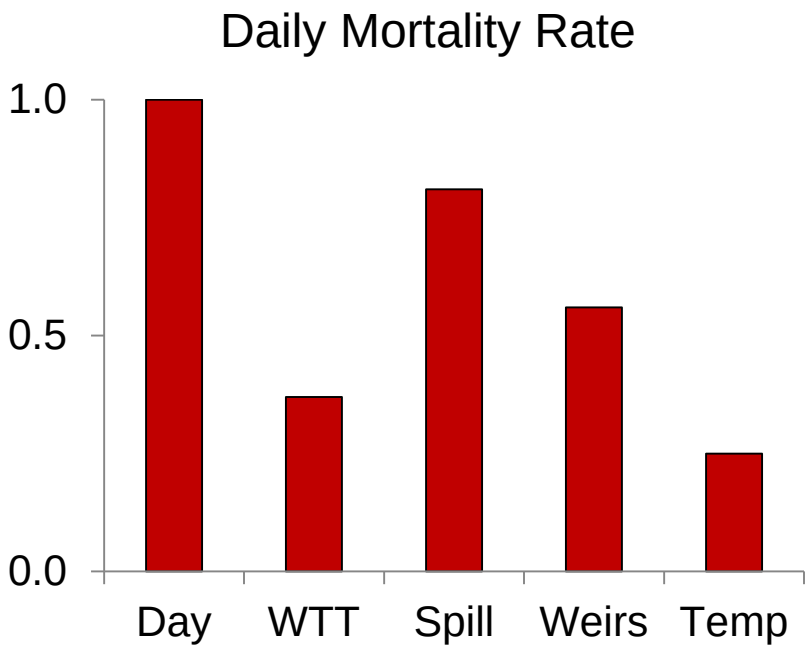
Survival

Steelhead LGR-MCN

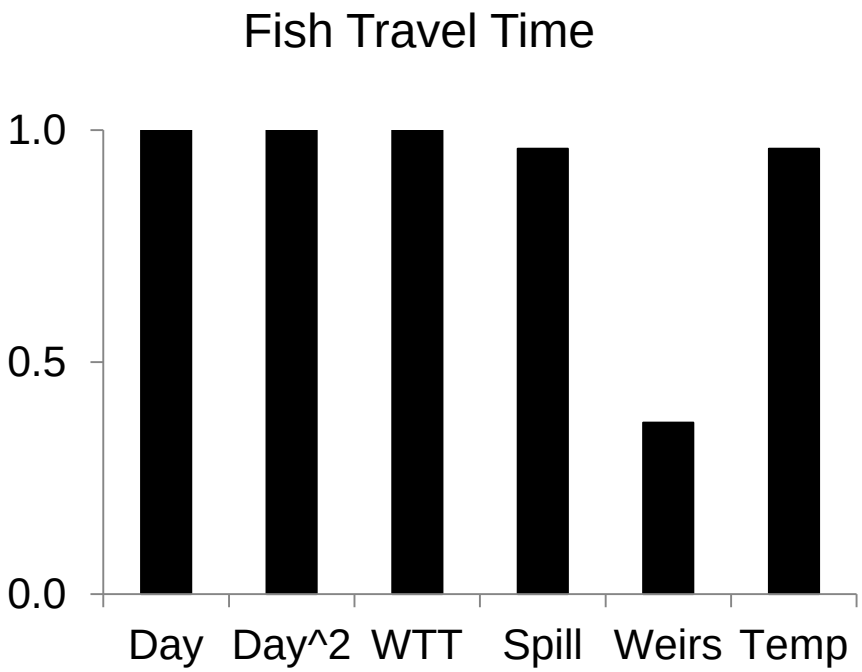


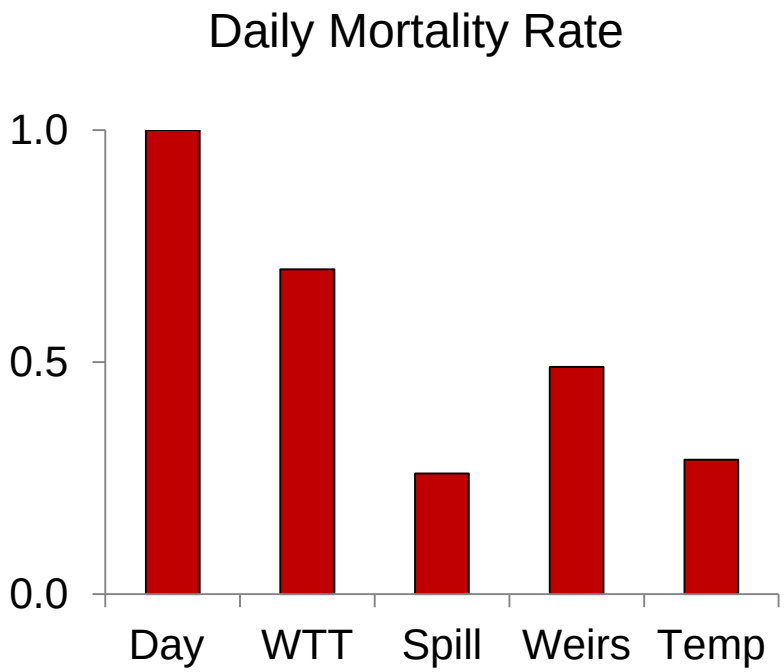
Relative Variable Importance (steelhead)



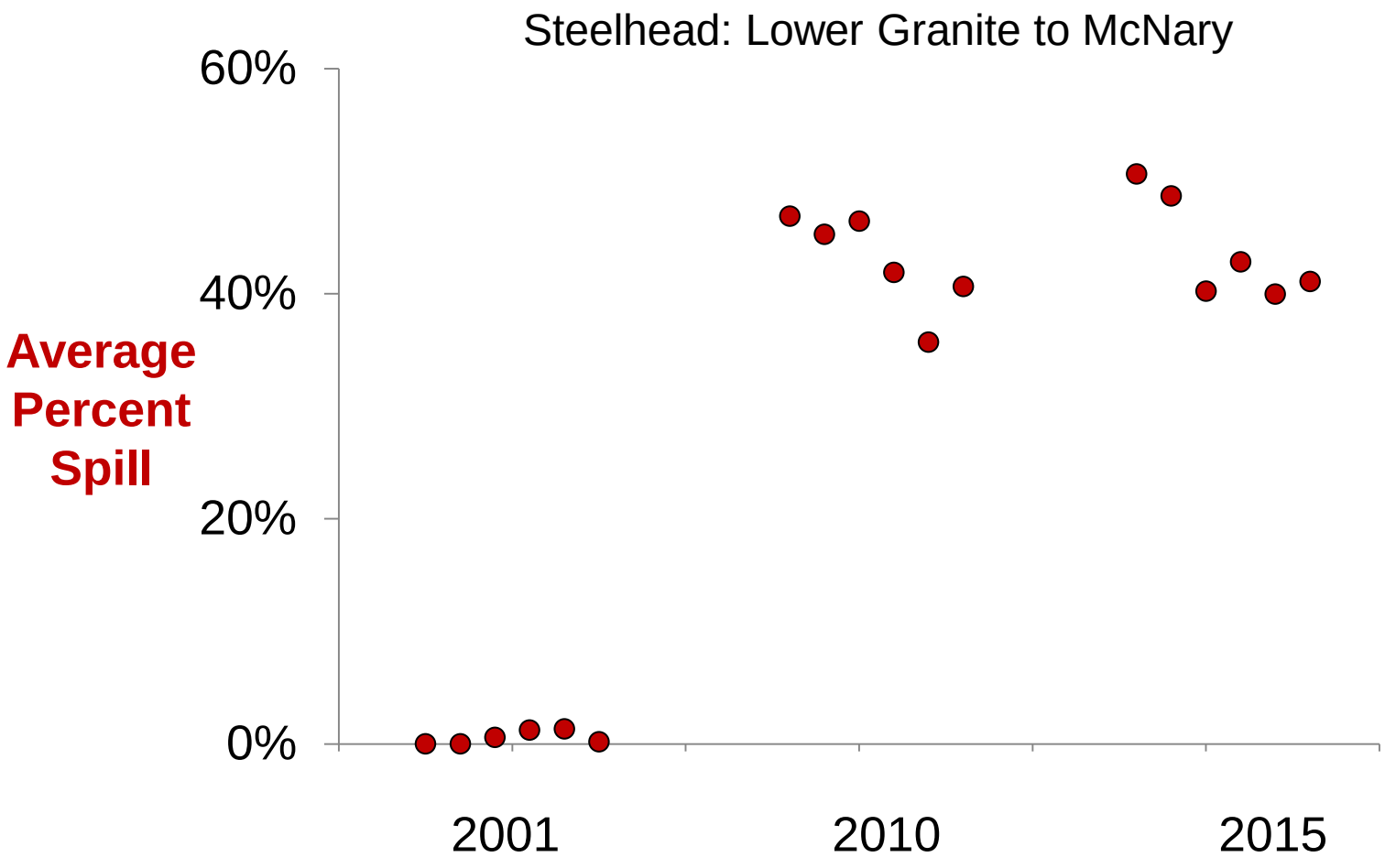


Relative Variable Importance (wild Chinook)

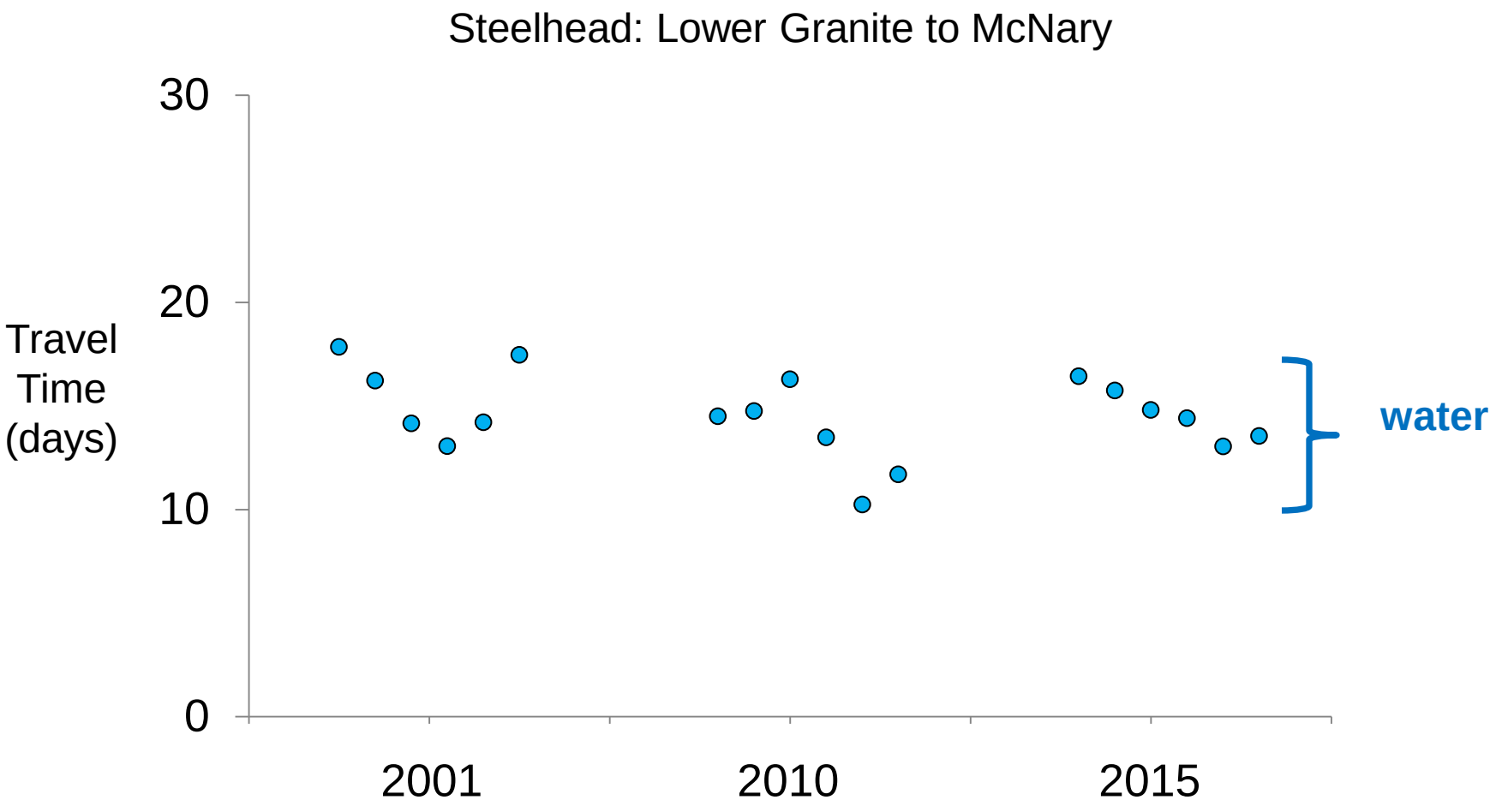




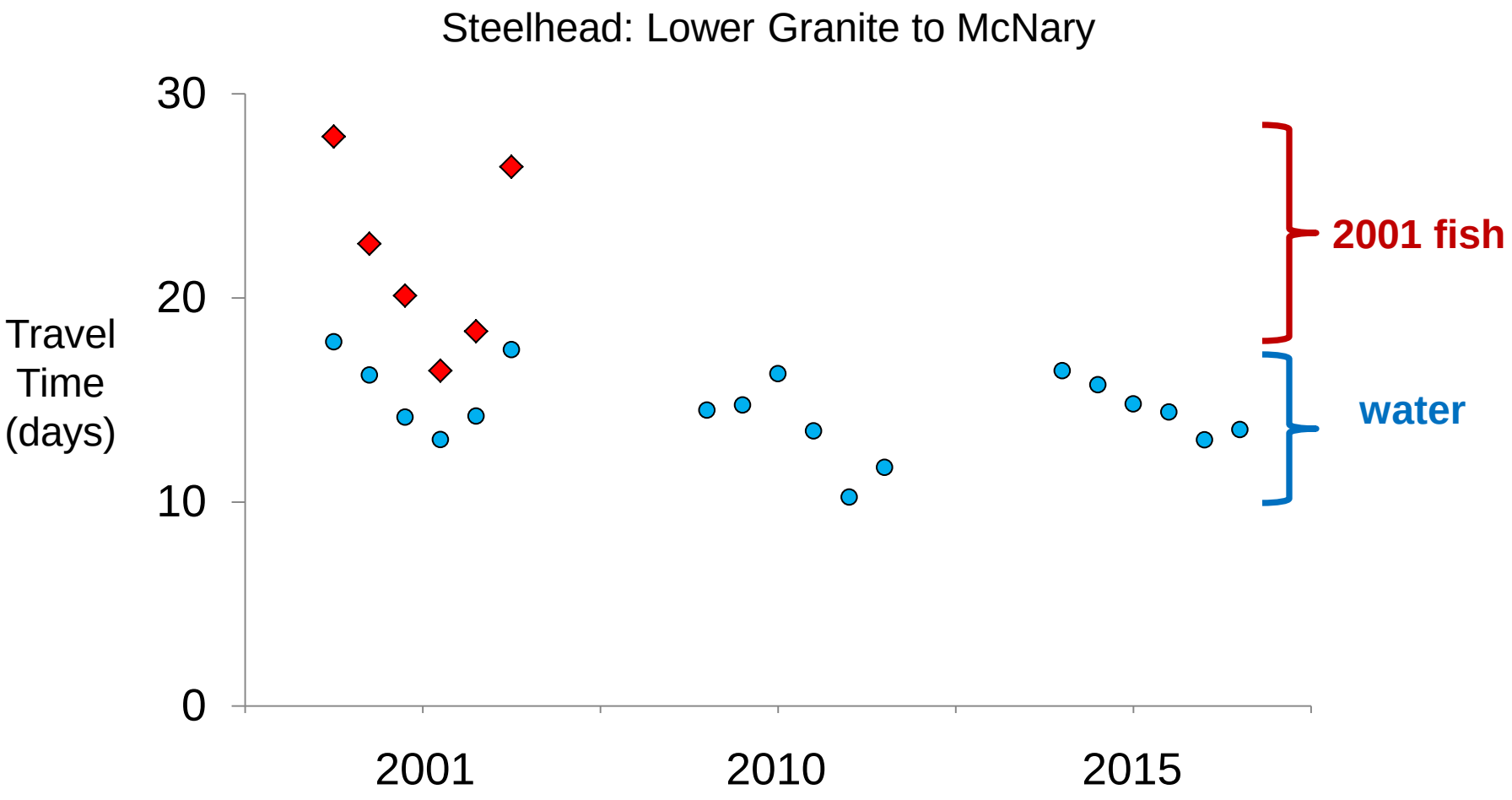
Passive Adaptive Management Experiments: Spill in low-flow years (2001, 2010, 2015)



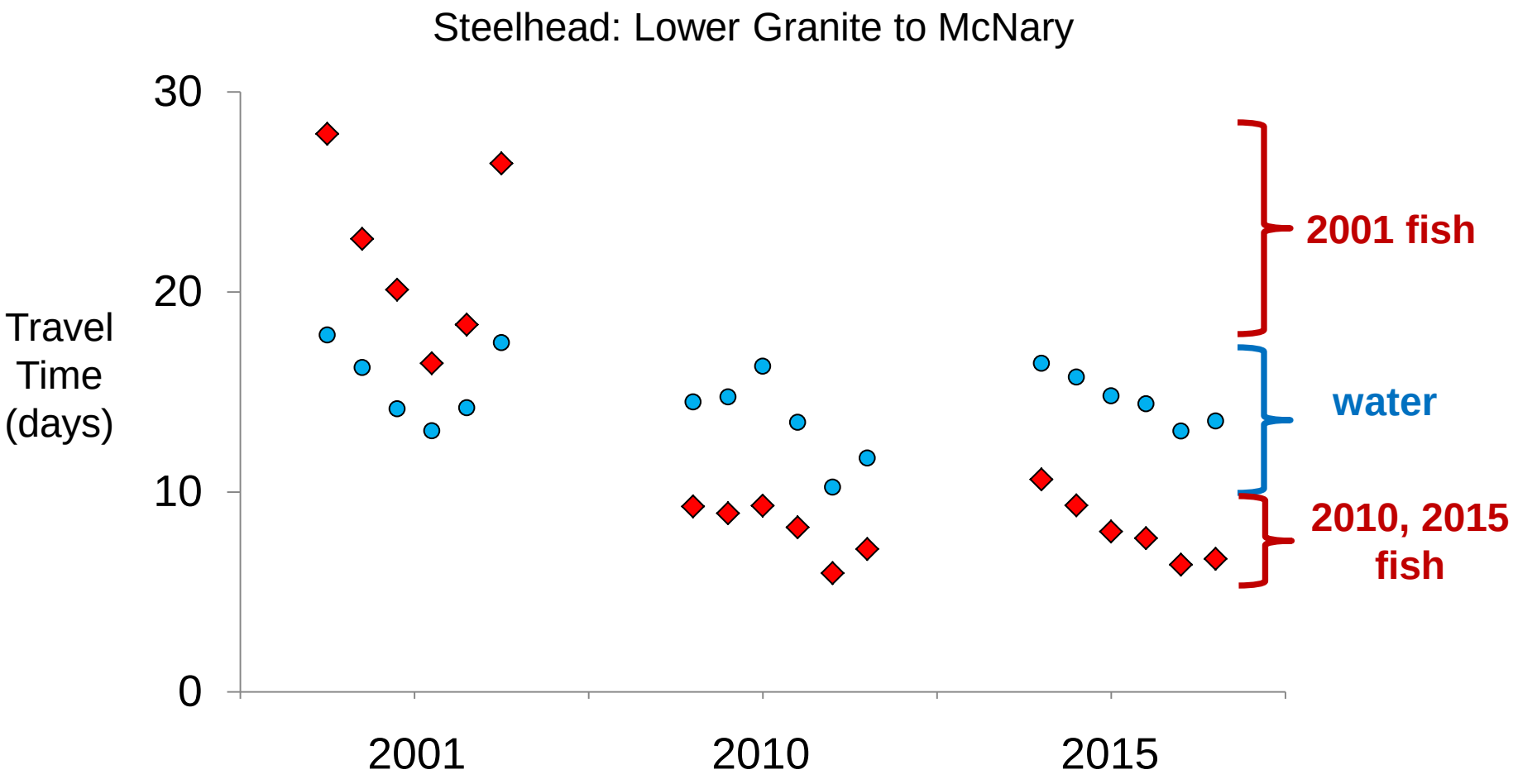
Passive Adaptive Management Experiments: Spill in low-flow years (2001, 2010, 2015)



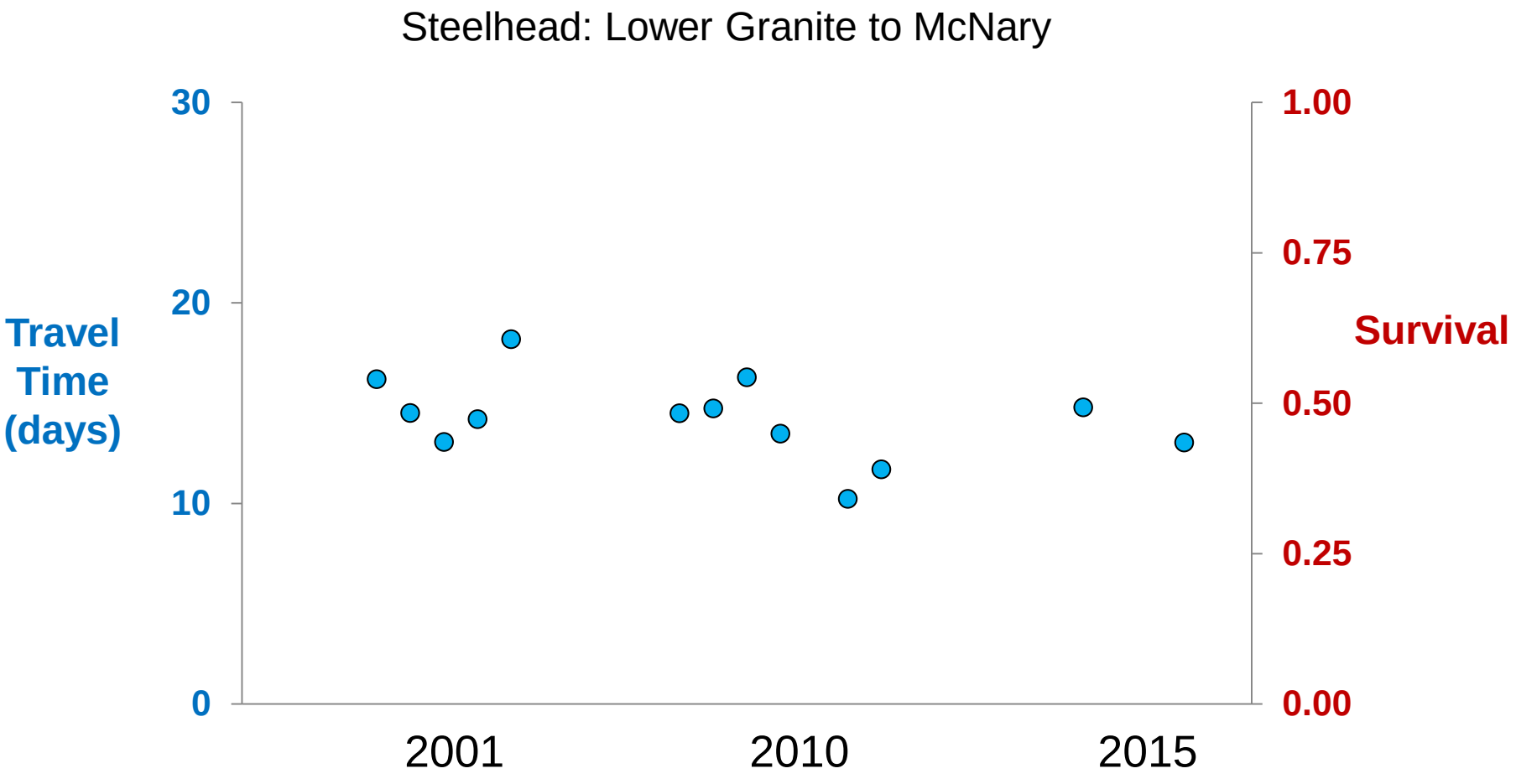
Passive Adaptive Management Experiments: Spill in low-flow years (2001, 2010, 2015)



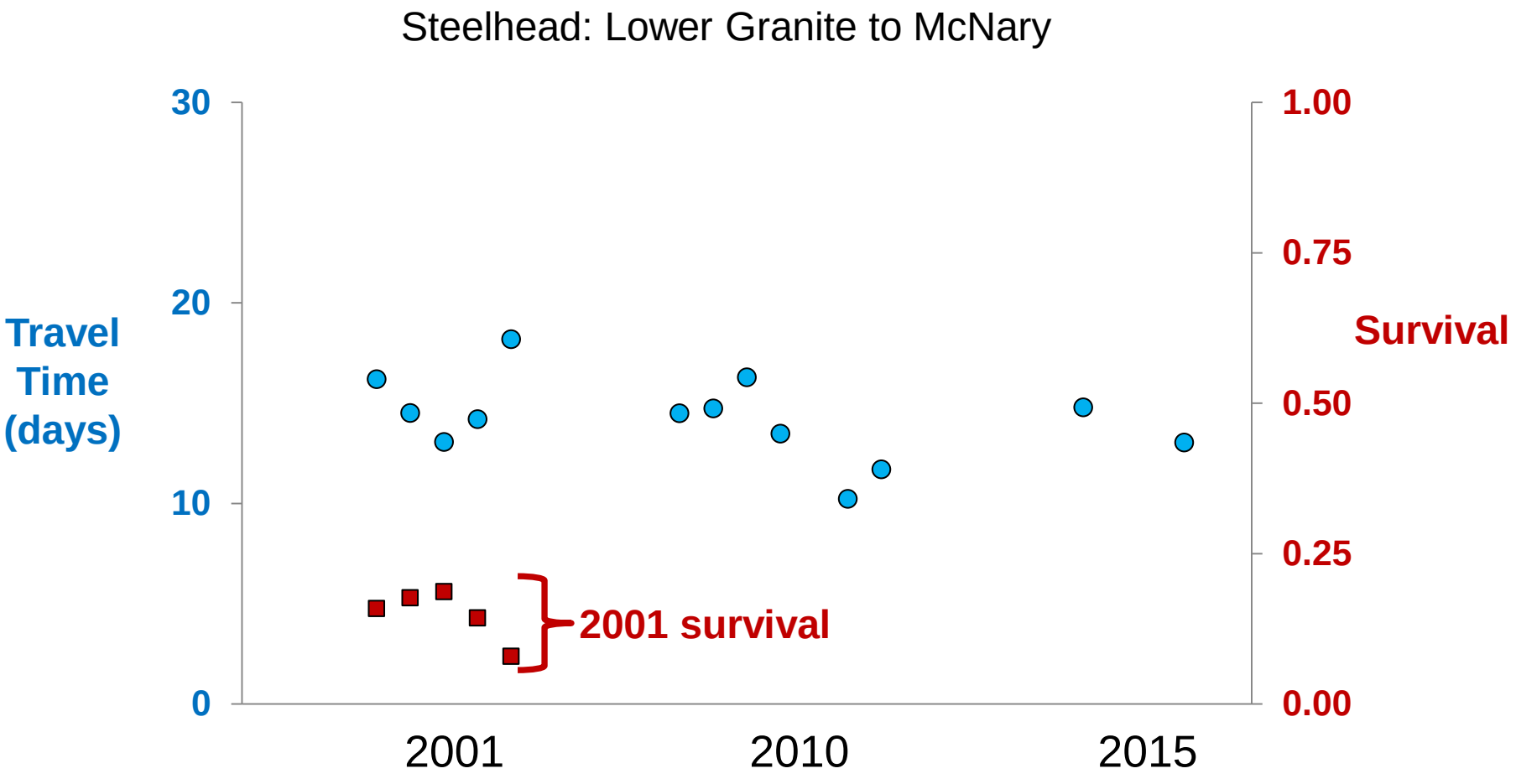
Passive Adaptive Management Experiments: Spill in low-flow years (2001, 2010, 2015)



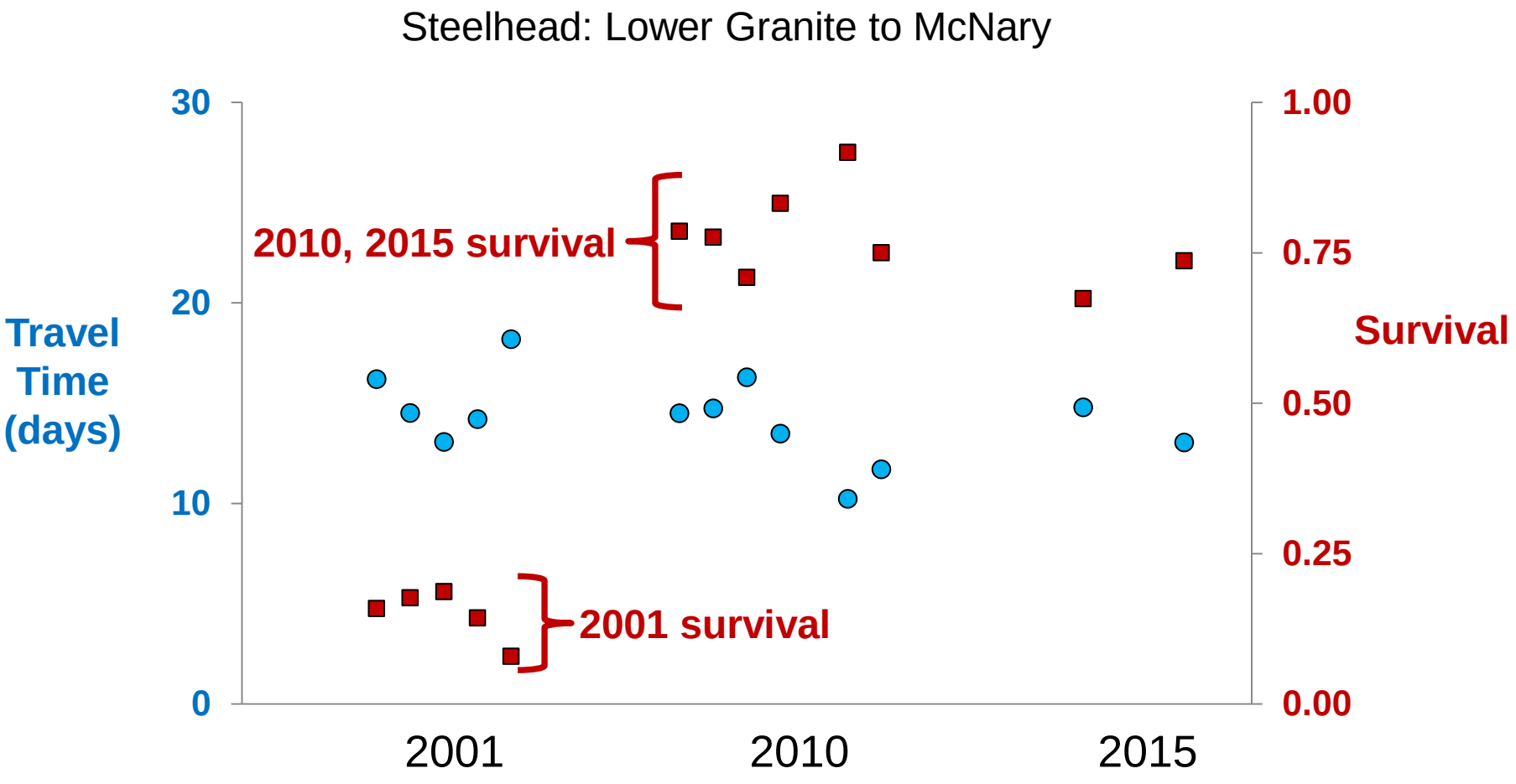
Passive Adaptive Management Experiments: Spill in low-flow years (2001, 2010, 2015)



Passive Adaptive Management Experiments: Spill in low-flow years (2001, 2010, 2015)



Passive Adaptive Management Experiments: Spill in low-flow years (2001, 2010, 2015)



Conclusions

- Assembled comprehensive data set across species and across the basin

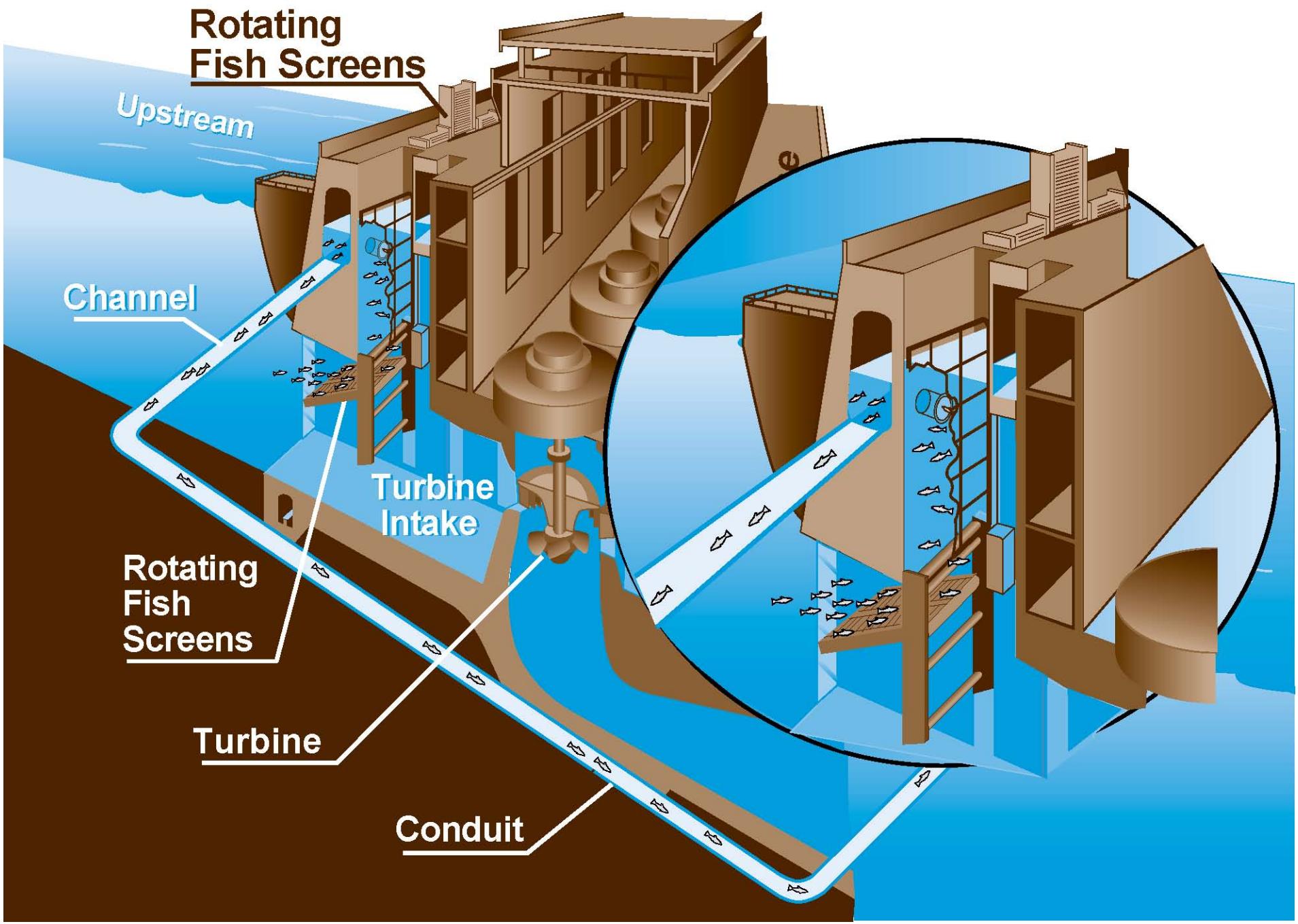
- Employed consistent analytical framework

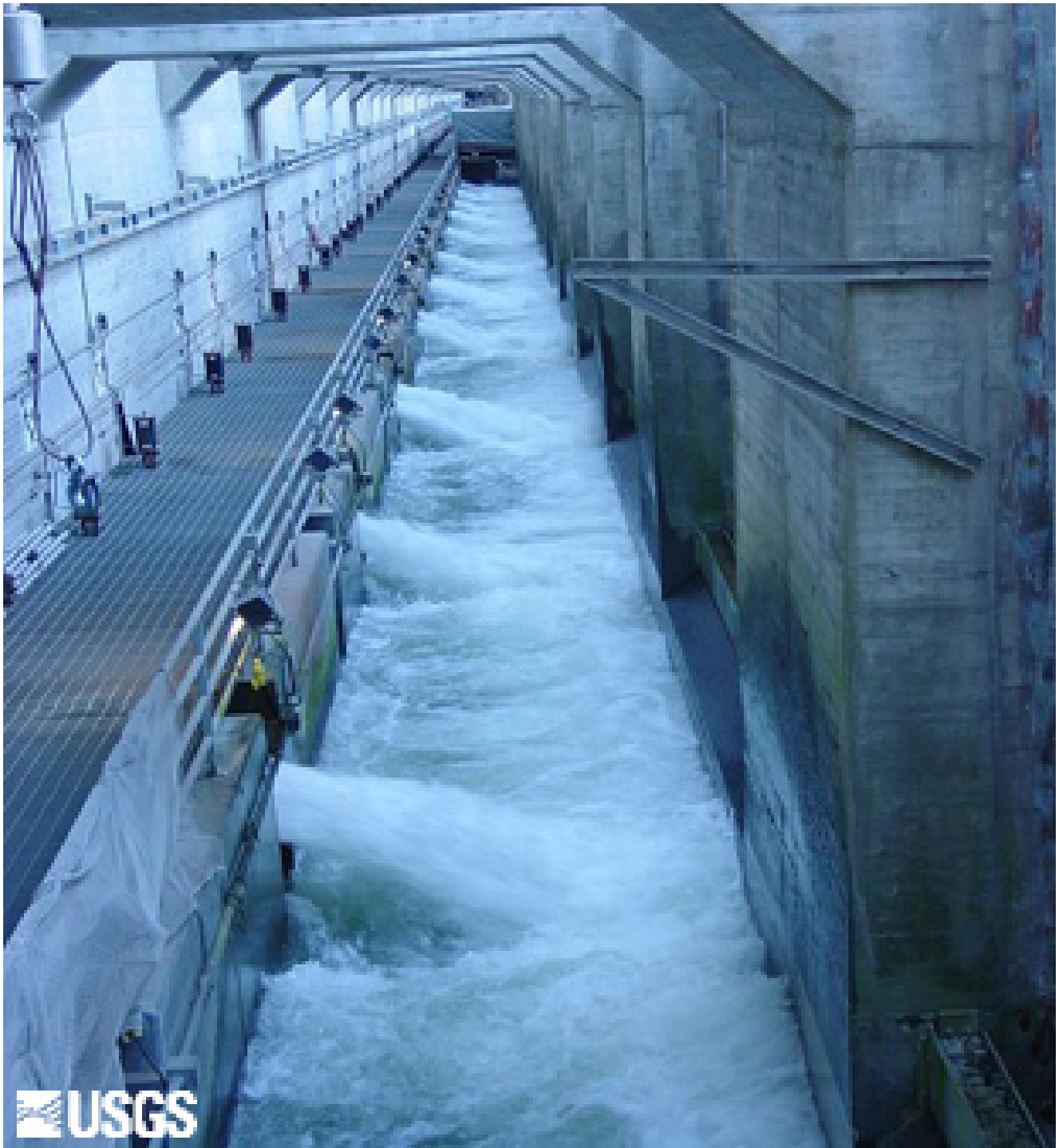
- Combinations of managed (WTT, spill) and environmental (seasonal, temperature) factors influence demographic rates

- Models provide testable hypotheses for evaluating effects of future management actions

Effects of juvenile bypass systems on Smolt-to-Adult Return (SAR)

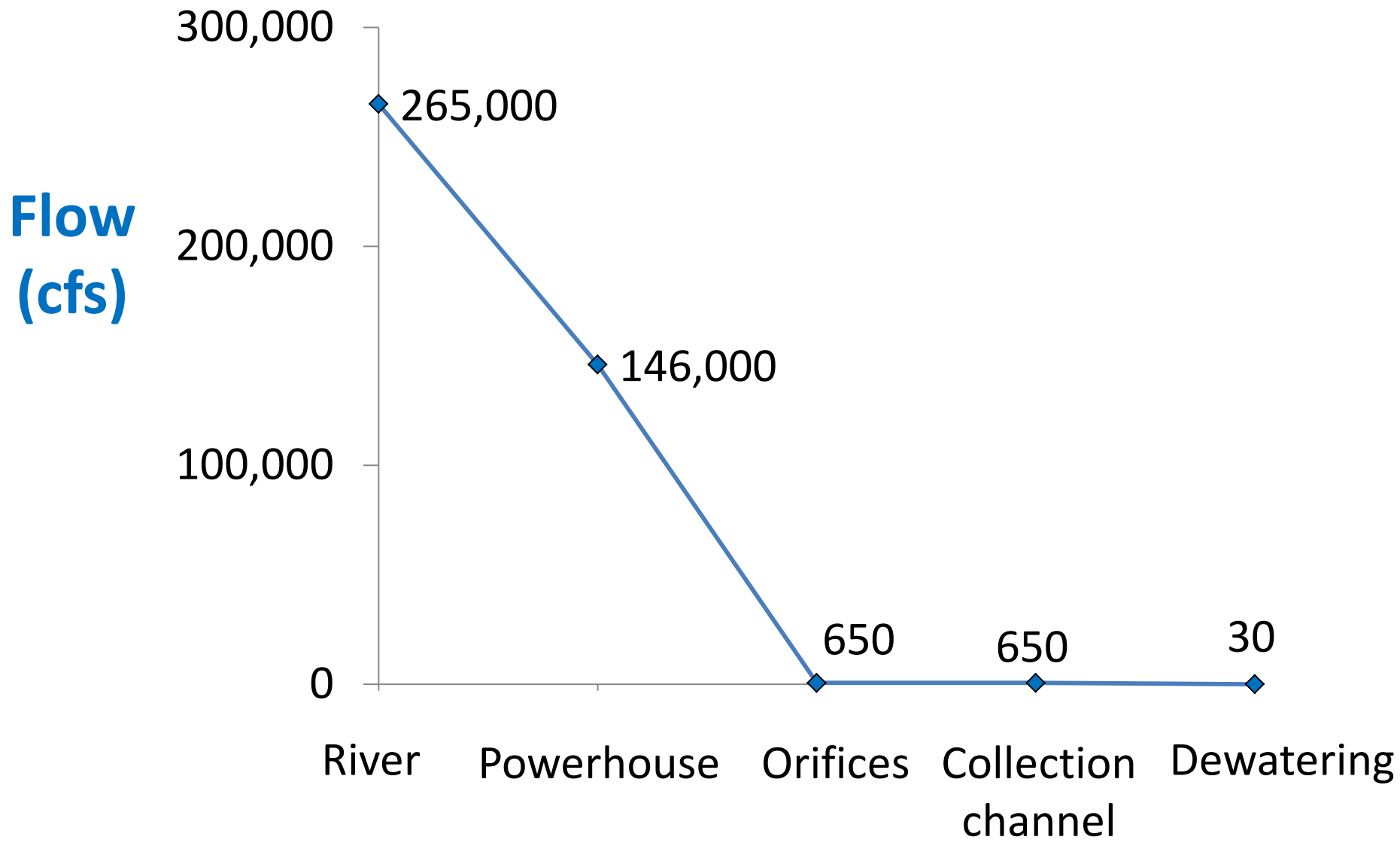
Tommy Garrison and Steve Haeseker


Rotating
Fish Screens
Upstream
Channel
Turbine
Intake
Rotating
Fish
Screens
Turbine
Conduit


USGS

WET SEPARATOR

Concentration/dewatering during collection/bypass



Does smolt bypass affect survival?

Budy et al. (2002)

- Descaling/injury
- Pressure changes
- Turbulence
- Predation

Summarized direct and indirect evidence that bypass experiences reduced survival

Collection/bypass systems

Relatively high survival through bypass route based on telemetry studies

Most survival studies do not evaluate possible delayed effects (Budy et al. 2002) resulting from passage through specific routes

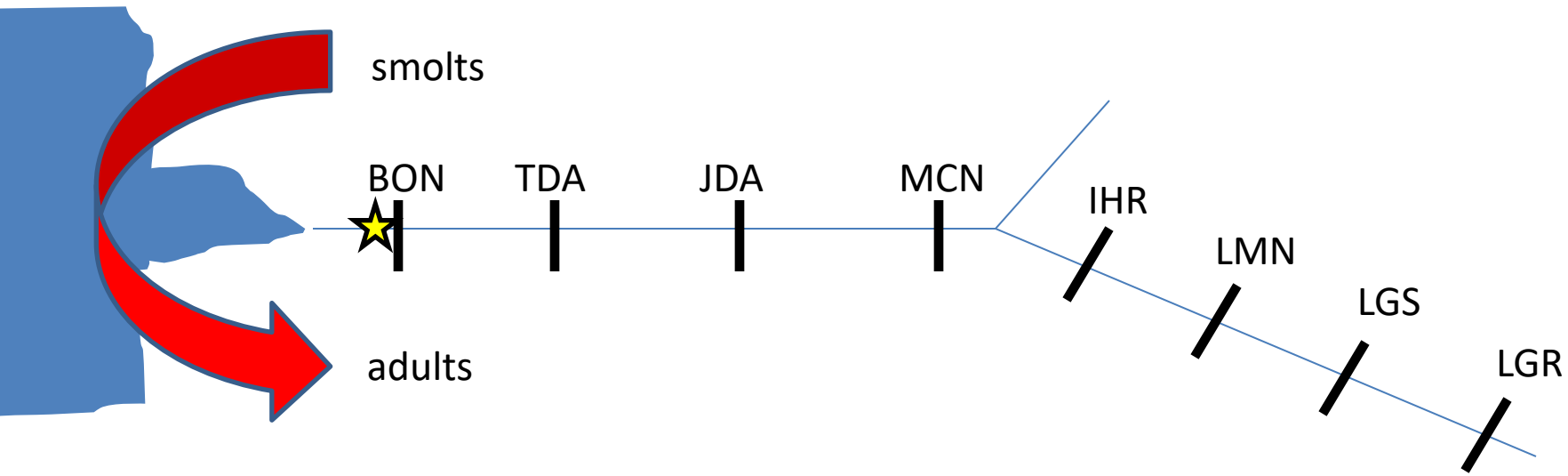
Other effects of juvenile bypass passage:

migration delay (Beeman and Maule 2001, Muir et al. 2001, Tuomikoski et al. 2010)

delayed mortality (Budy et al. 2002, Schaller and Petrosky 2007, McMichael et al. 2010)

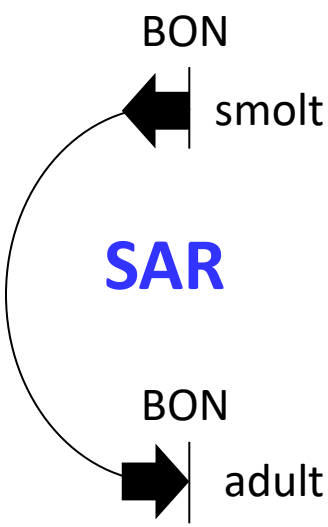
reduced smolt-to-adult survival rates (SARs) (Sandford and Smith 2002, Scheuerell and Zabel 2006, Tuomikoski et al. 2010, Buchanan et al. 2011)

Do bypass events influence ocean survival?



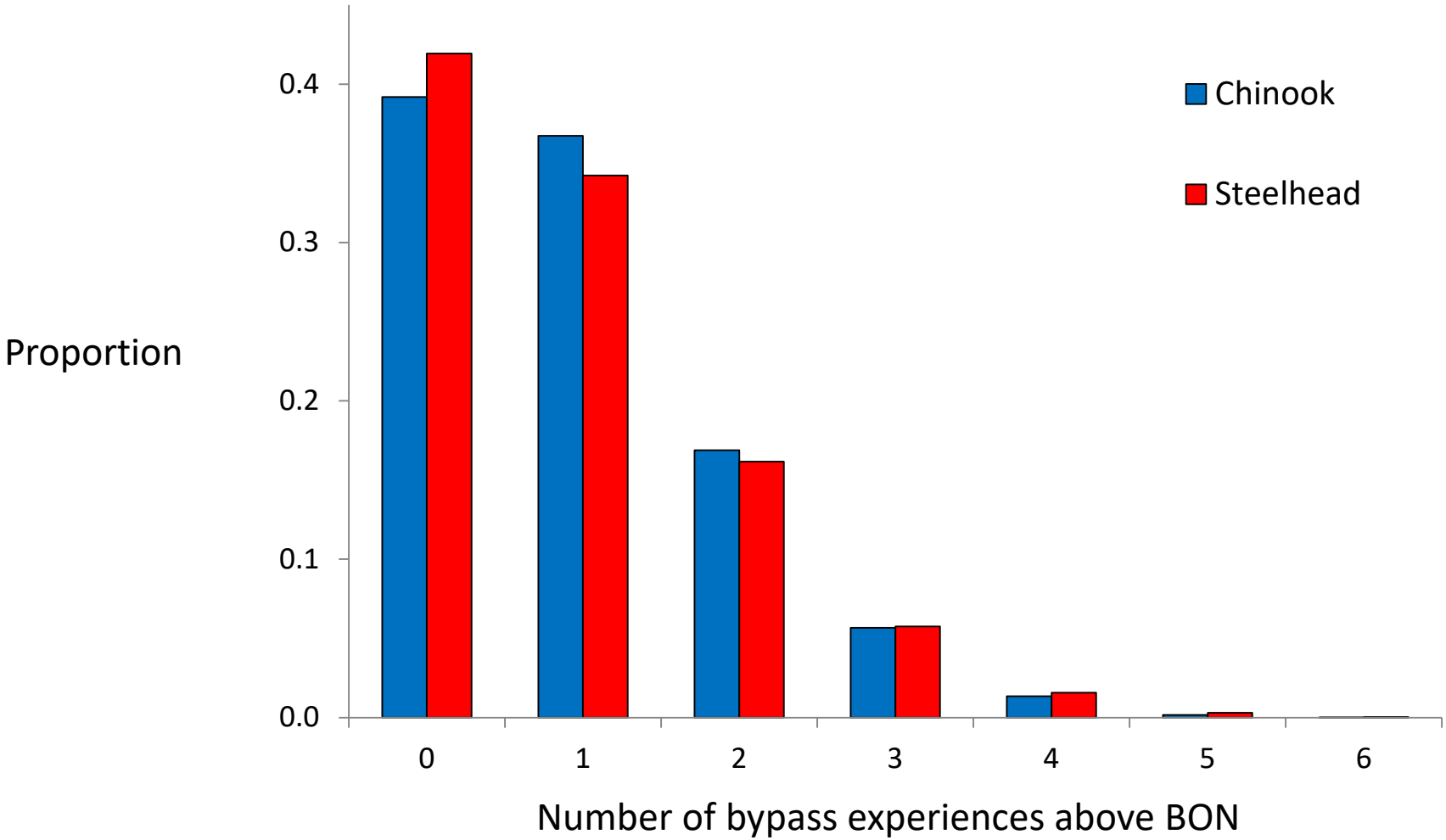
Do bypass events influence ocean survival?

- Logistic regression
- Yearling Chinook and steelhead, MYs 2006-2013



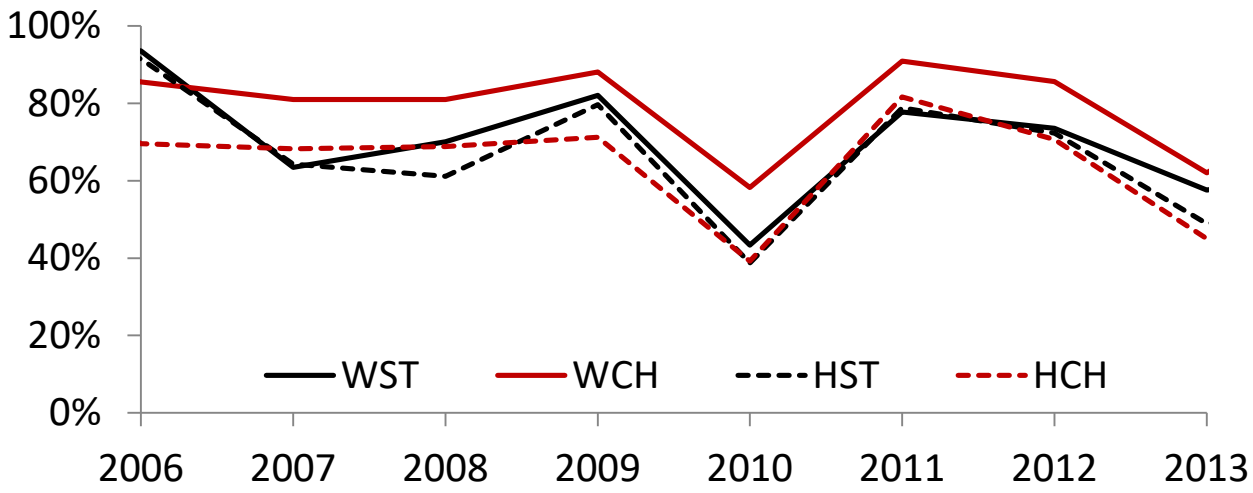
	JDA	MCN	IHR	LMN	LGS	LGR	Adult
Smolt 1	0	0	0	0	0	0	0
Smolt 2	1	0	0	0	0	0	1
Smolt 3	0	1	0	0	0	0	0

Most Chinook and steelhead are bypassed at least once

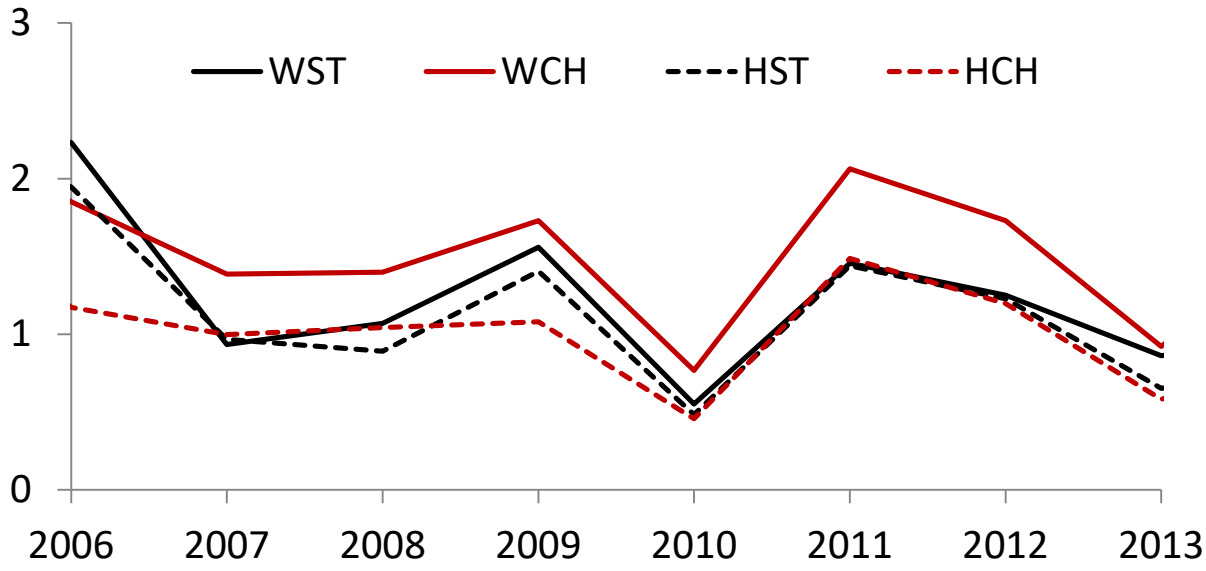


Most Chinook and steelhead are bypassed at least once

Proportion with at least one bypass



Mean number of bypass events



Methods

Logistic regression

Year effects

Bypass effects hypotheses:

1) Unique to each dam
2) Snake different from Columbia
3) Similar across dams

Hatchery/wild hypotheses:

1) Constant across years
2) Varies across years

Model-average across hypotheses

Methods

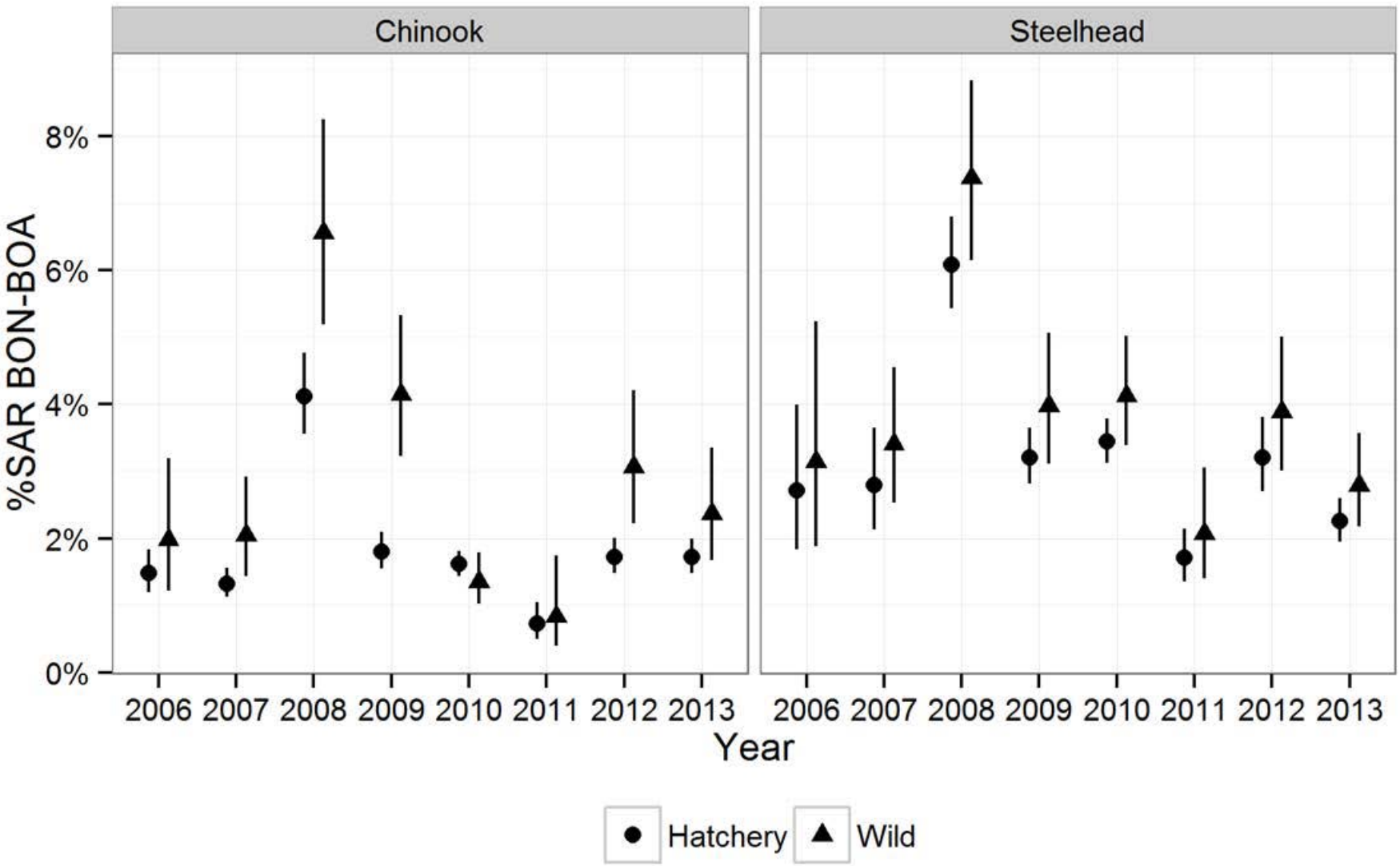
Bypass effects hypotheses:

1) Unique to each dam
2) Snake different from Columbia
3) Similar across dams **Chinook, Steelhead**

Hatchery/wild hypotheses:

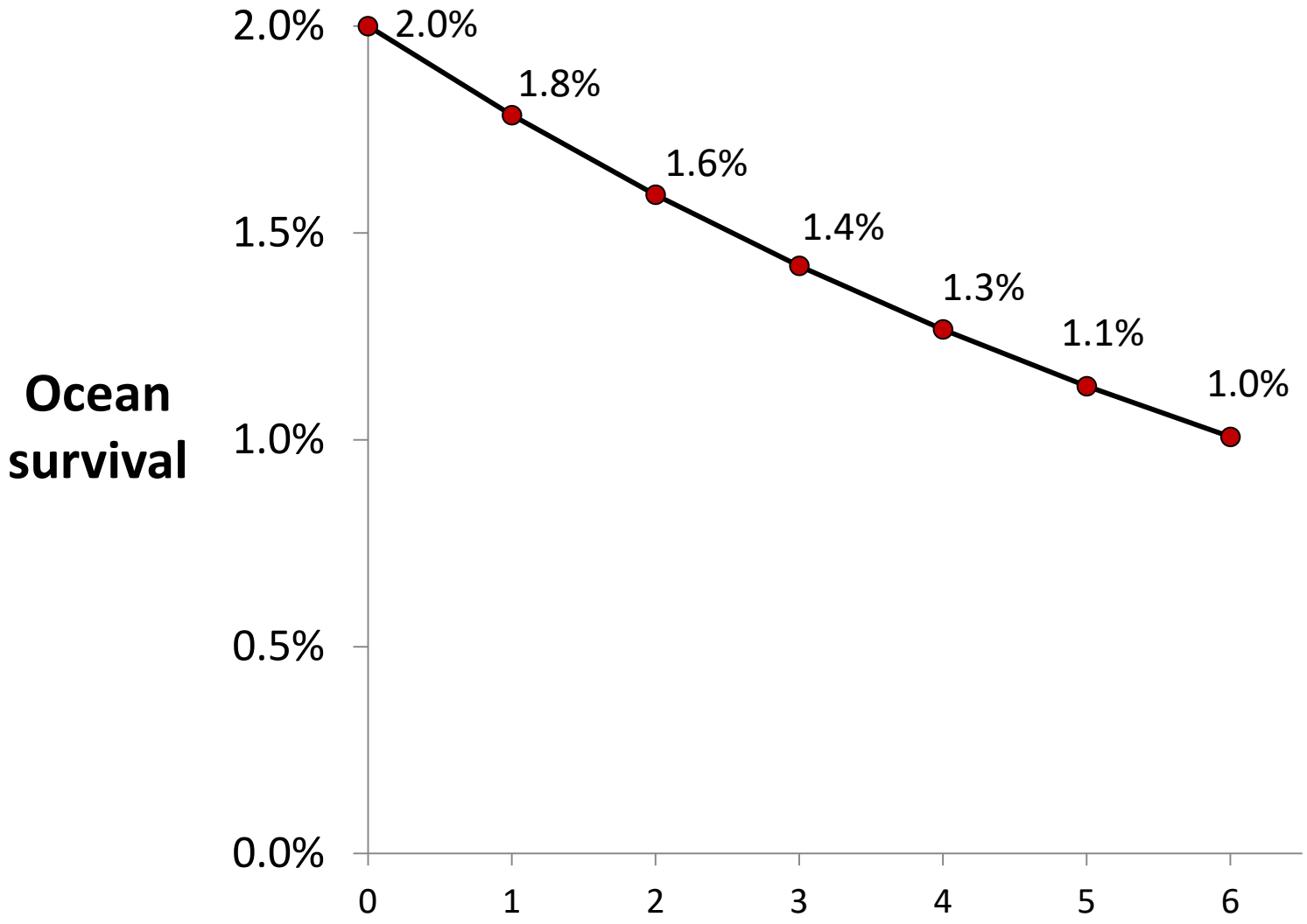
1) Constant across years **Steelhead**
2) Varies across years **Chinook**

Results

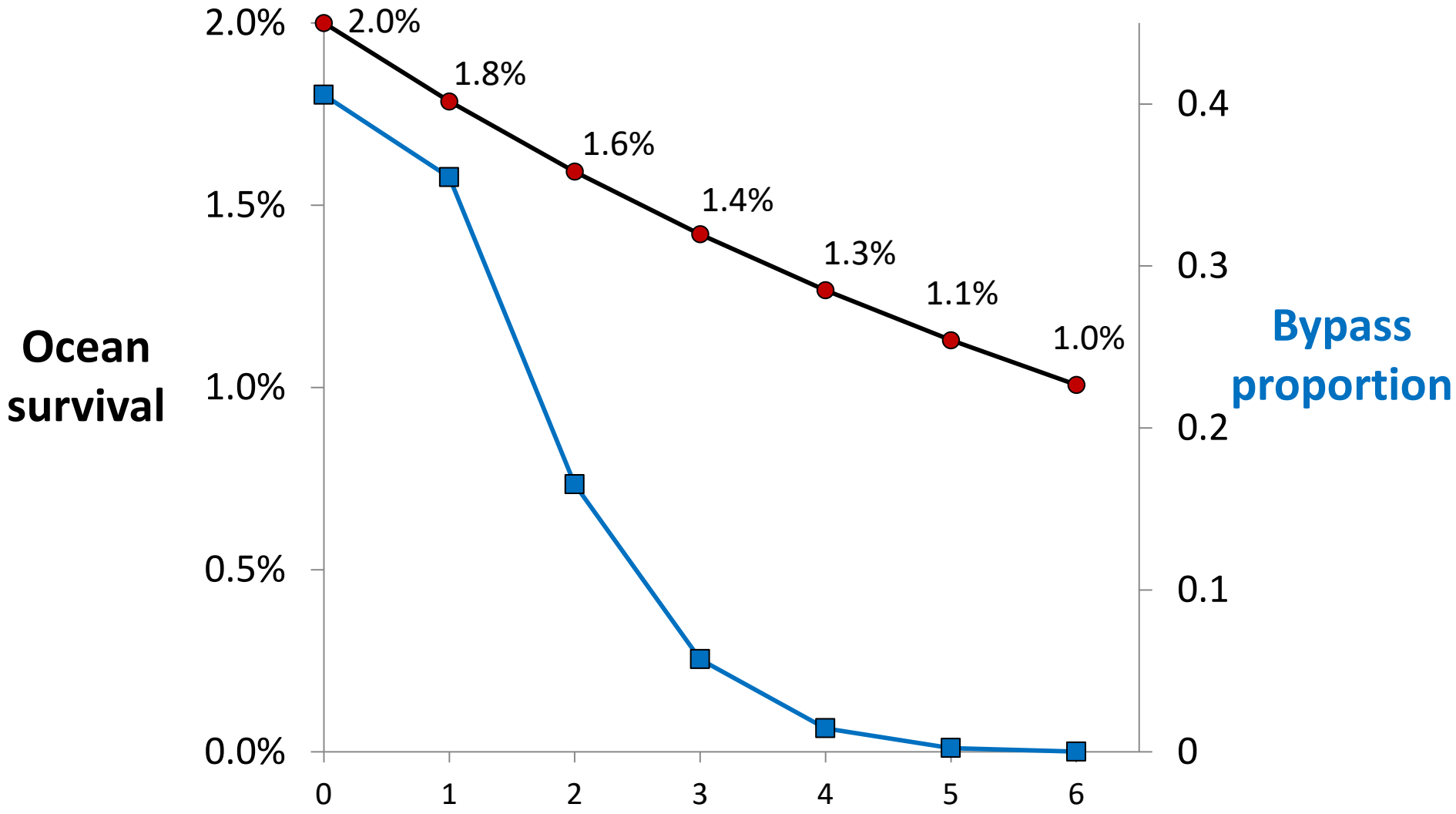

Chinook
Steelhead
%SAR BON-BOA
8%
6%
4%
2%
0%
2006 2007 2008 2009 2010 2011 2012 2013
2006 2007 2008 2009 2010 2011 2012 2013
Year
Hatchery
Wild

11% - 12% reduction in ocean survival per bypass event

11% - 12% reduction in ocean survival per bypass event



11% - 12% reduction in ocean survival per bypass event



Results likely underestimate bypass effects

1) Study only includes smolts detected alive at Bonneville Dam

Results likely underestimate bypass effects

2) Turbine passage included in “non-bypassed” group

Expected to result in a negative bias for undetected fish

Analyses and review of length selectivity

1) Similar length at tagging for detected and non-detected smolts (CSS 2006, 2010, 2016)

2) Zabel et al. (2005) – Inconsistent results, potentially non-representative smolts, did not evaluate seasonal/flow/spill effects

3) Berggren et al. (2006) – Little evidence for length selectivity among fish tagged immediately upstream

4) Hostetter et al. (2015) – Hatchery smolts collected and tagged at Lower Granite Dam, one year of study, seasonal/flow/spill effects not fully evaluated

Conclusions

Little evidence for length selectivity of bypass systems

Continued to find evidence that bypass experiences reduce ocean survival

Direct and route-specific survival estimates unlikely to reflect full impacts of passage routes

Actions that reduce powerhouse passage (bypass + turbine) expected to increase SARs

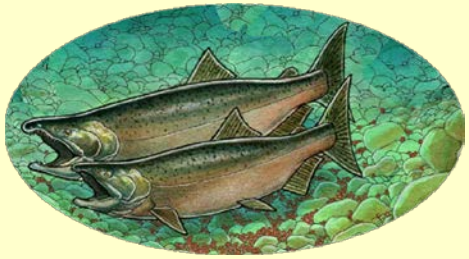
Comparative Survival Study

SAR Patterns: Snake and Mid-Columbia

Presenter: Charlie Petrosky

2017 Annual Meeting

April 3,2017



Smolt-to-Adult Survival Rate (SAR) Patterns

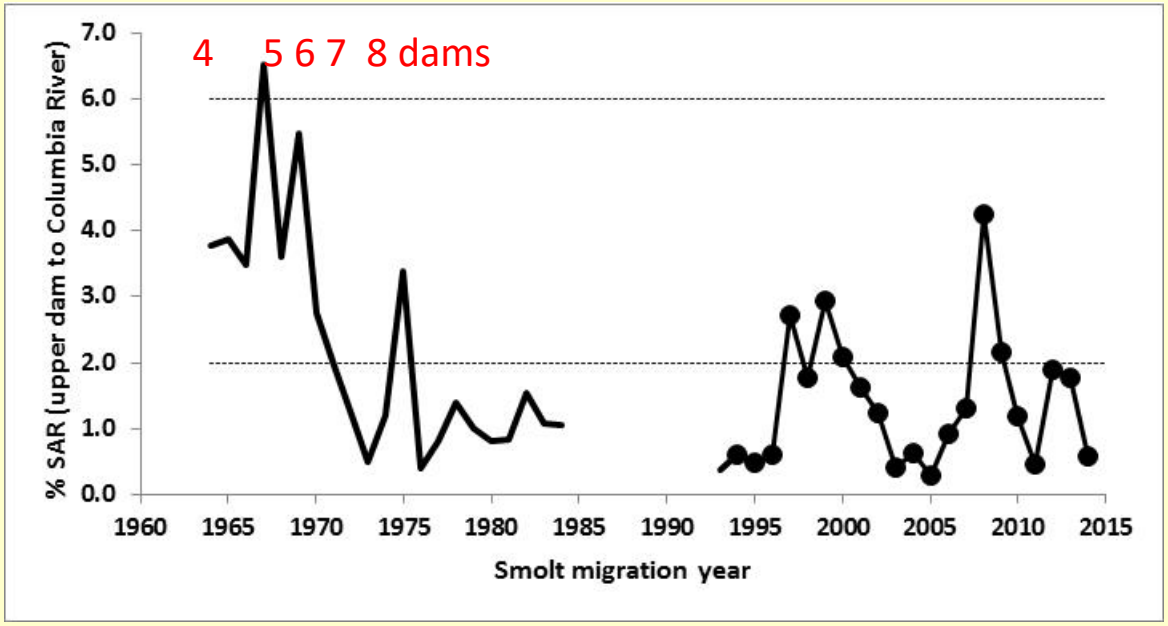
1. Snake River spring/summer Chinook, Steelhead and Sockeye:
   a. Annual SAR patterns
   b. SARs vs. NPCC 2%-6% SAR goals
   c. Transport vs. In-river SARs
2. Mid-Columbia spring Chinook and Steelhead
   a. Annual SAR patterns
   b. SARs vs. NPCC 2%-6% SAR goals

Snake River Chinook & Steelhead SARs

Historic declines associated with FCRPS development in 60s and 70s

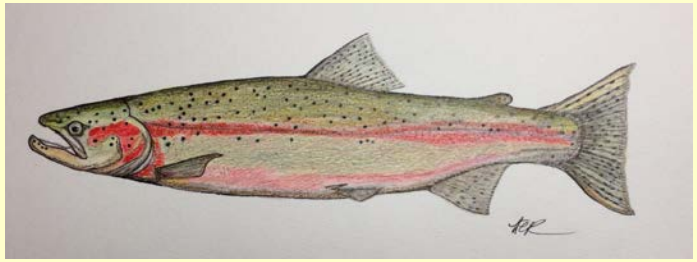
Marine conditions also varied

NPCC (2014) goal 2%-6% SAR, 4% ave.



NPCC strategy:

- identify effects of ocean conditions
- evaluate & adjust inland actions



Snake River Spring/Summer Chinook (8 dams)

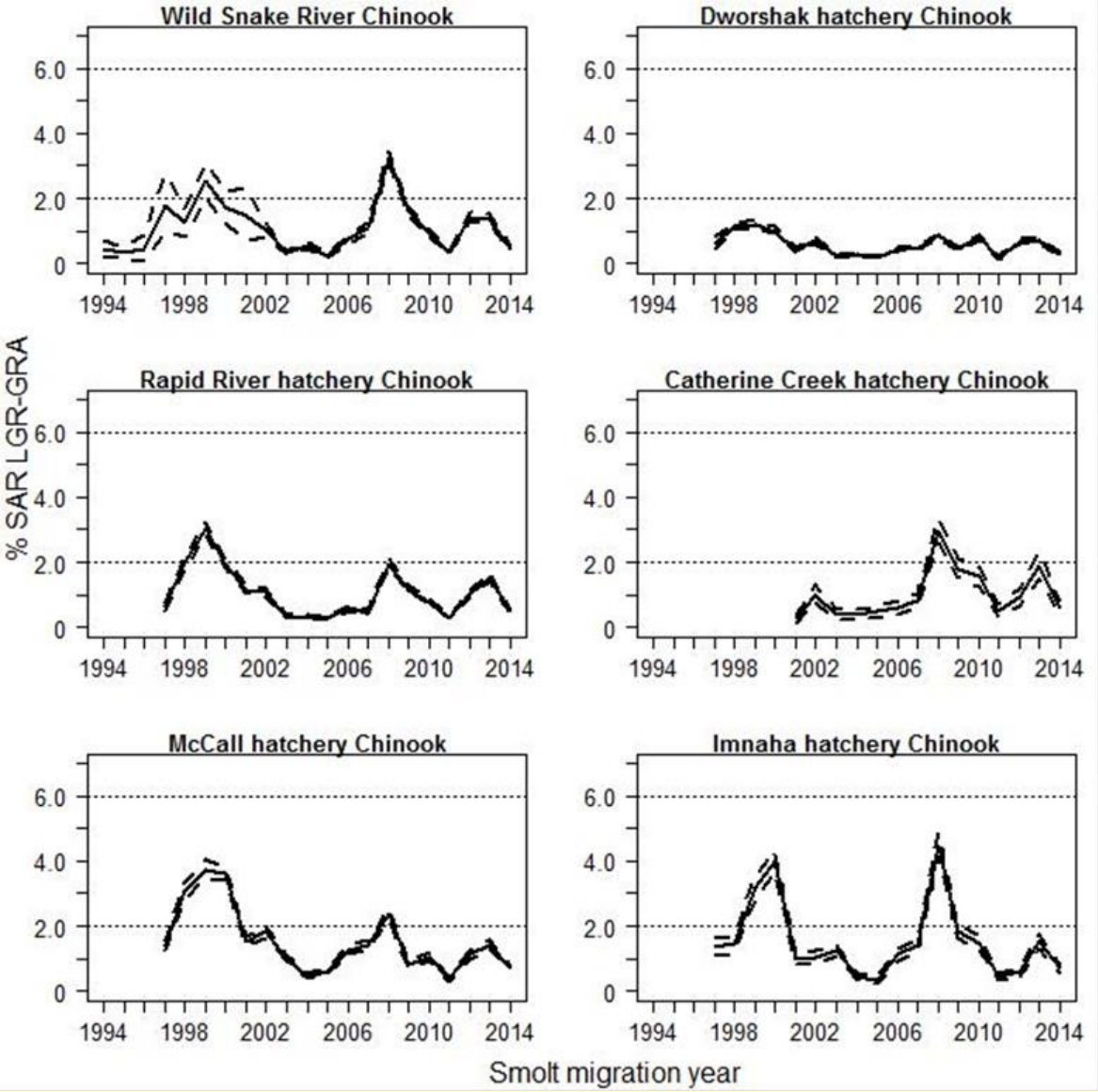
Wild & Hatchery SARs highly correlated (r ~ 0.8)

Wild SARs << NPCC goals of 2%-6% (4% average)

Wild SARs averaged 0.87% (1994-2014)

Wild SARs:

- > 2% in 2/21 years
- < 2% in 15/21 years ($p<0.05$)



Snake River Wild Chinook MPGs

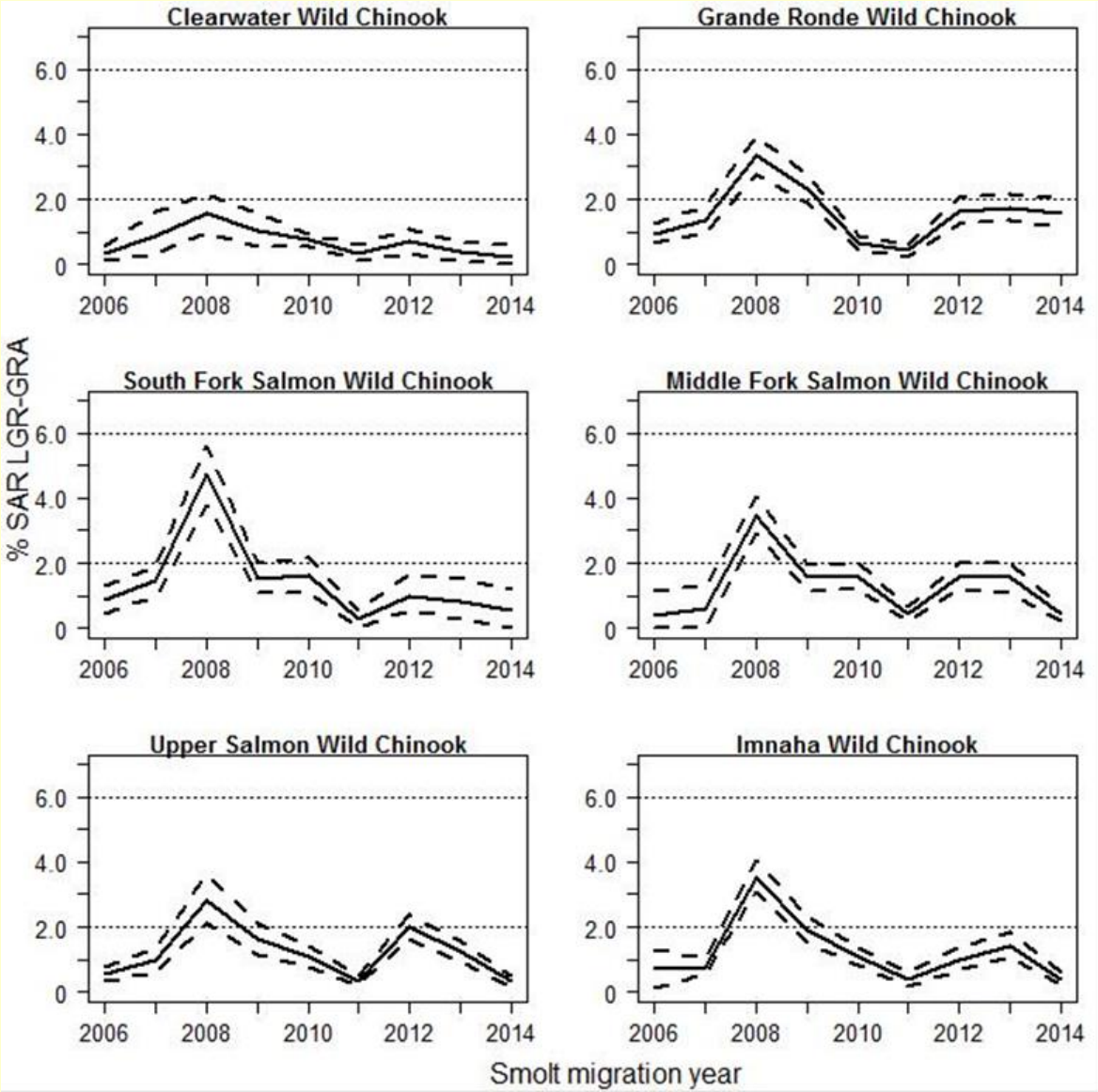
Major Population Group-specific wild SARs since 2006

Similar patterns:

- highest in 2008; low in 2010 and 2011

Generally similar magnitude:

- Clearwater MPG tended to be lower



Snake River Steelhead

Wild & Hatchery SARs correlated (r ~ 0.9) after 2008

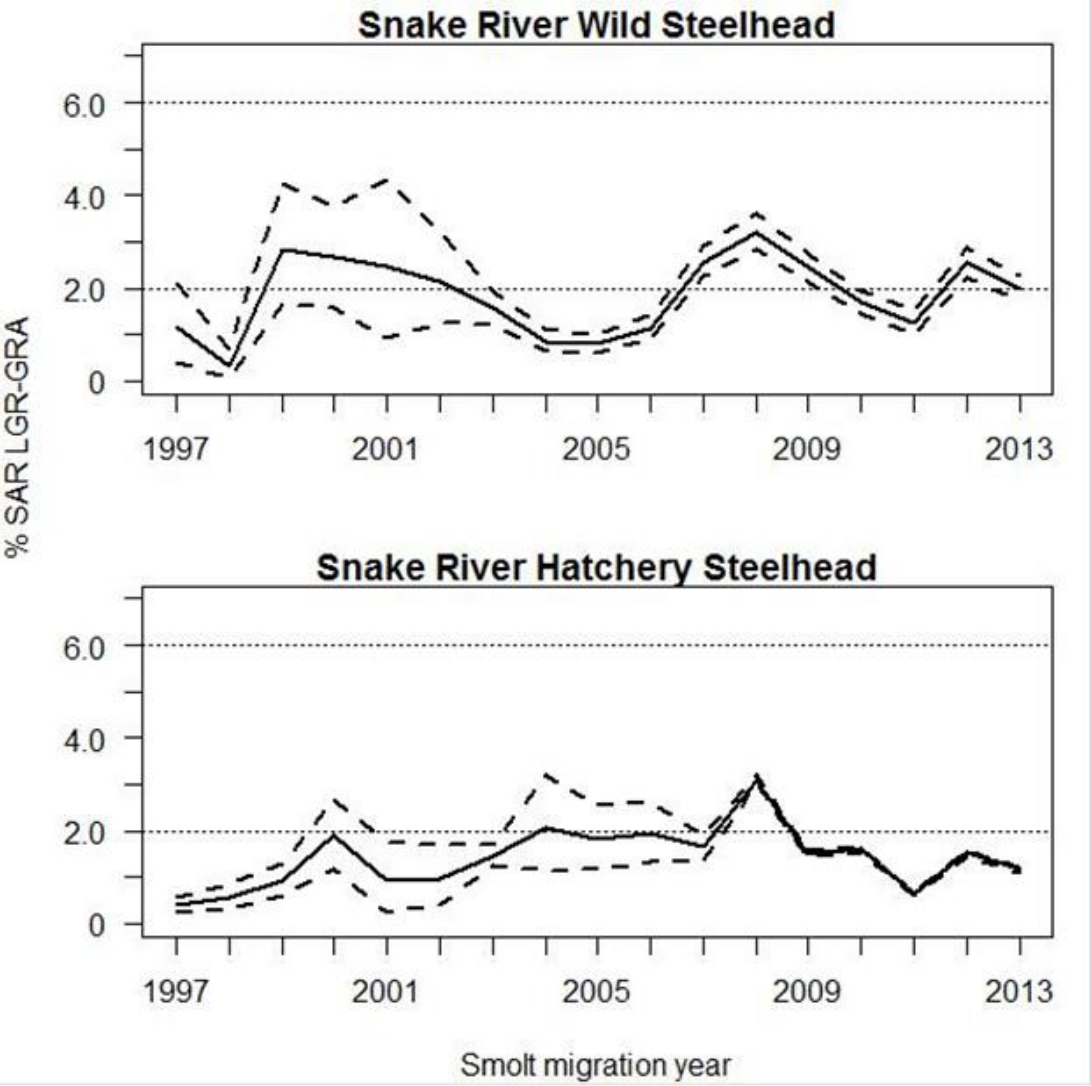
- Opportunistic hatchery group before 2008

Wild SARs << NPCC goals of 2%-6% (4% average)

Wild SARs averaged 1.6% (1997-2013)

Wild SARs:

- > 2% in 4/17 years
- < 2% in 7/17 years ($p<0.05$)

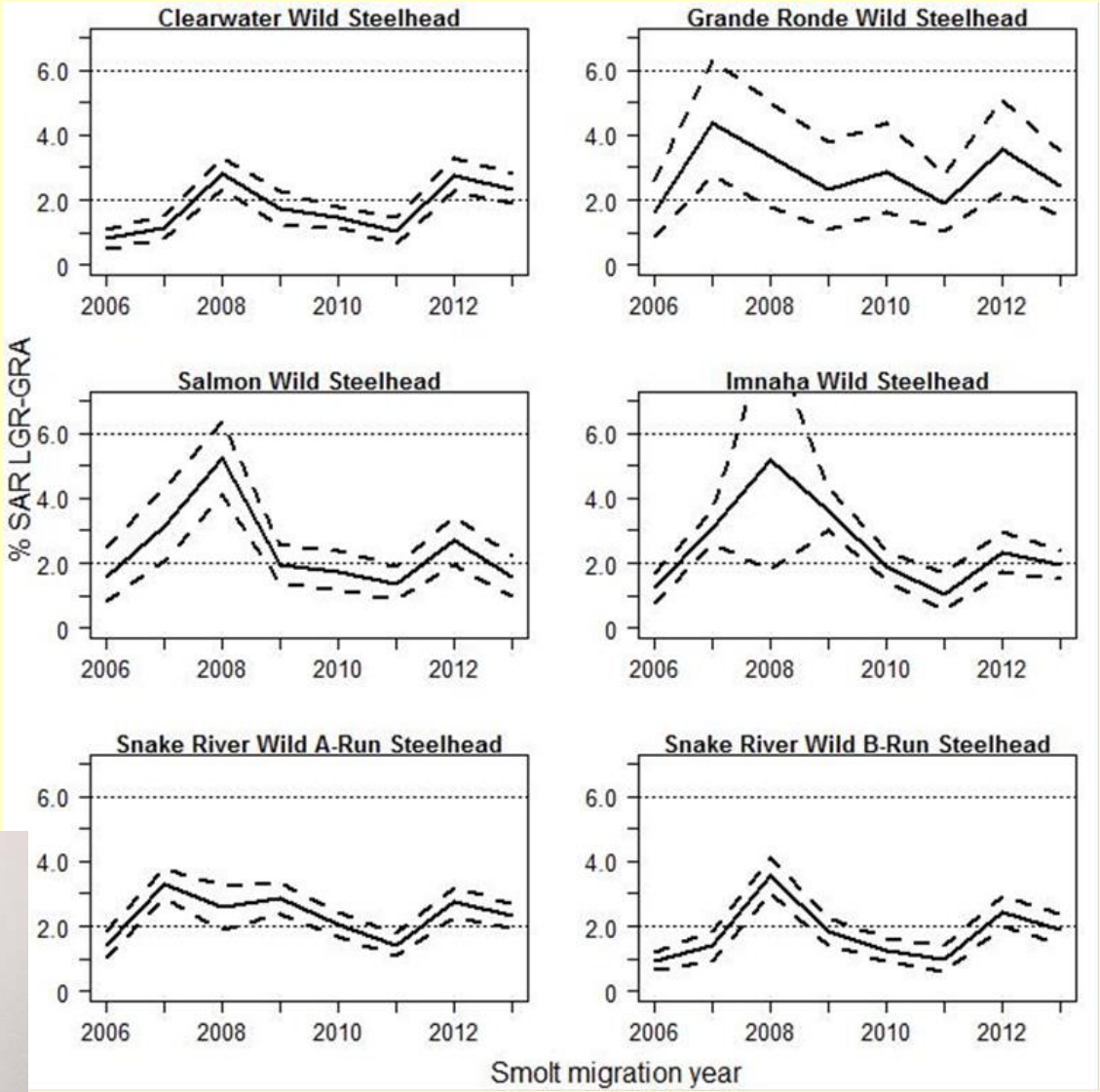


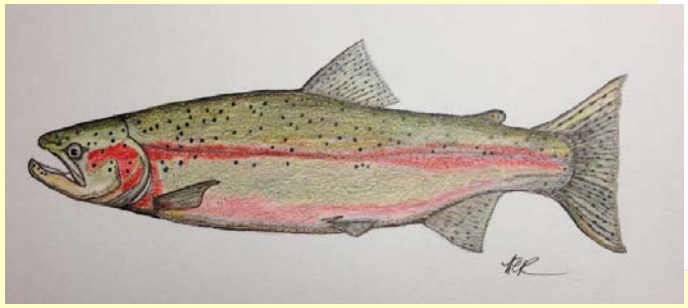
SR Wild Steelhead MPGs

MPG-specific and aggregate A-run & B-run SARs since 2006

Moderate correlation among MPGs (r ~ 0.6)

Less distinct patterns & smaller sample sizes than for Chinook





Snake River Sockeye SARs

Extremely low natural sockeye abundance

- limited SAR data

Hatchery Sockeye SARs, 2009 & 2011-2014

- Sawtooth and Oxbow hatcheries
- SARs ranged from 0.1% to 2.3%
- Oxbow SAR > Sawtooth SAR

Ongoing monitoring

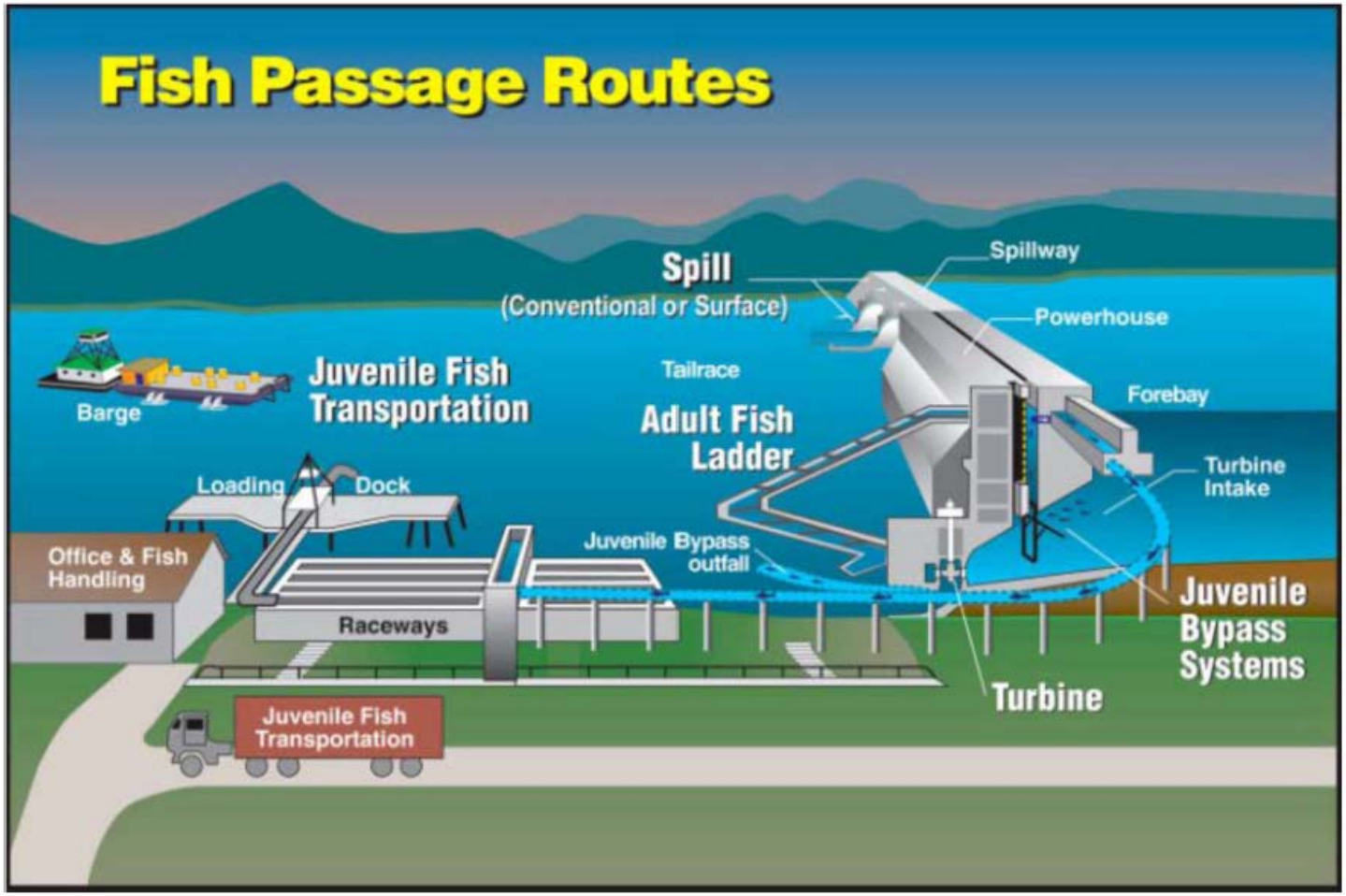
- Springfield Hatchery startup in 2015

SARs by Passage Route

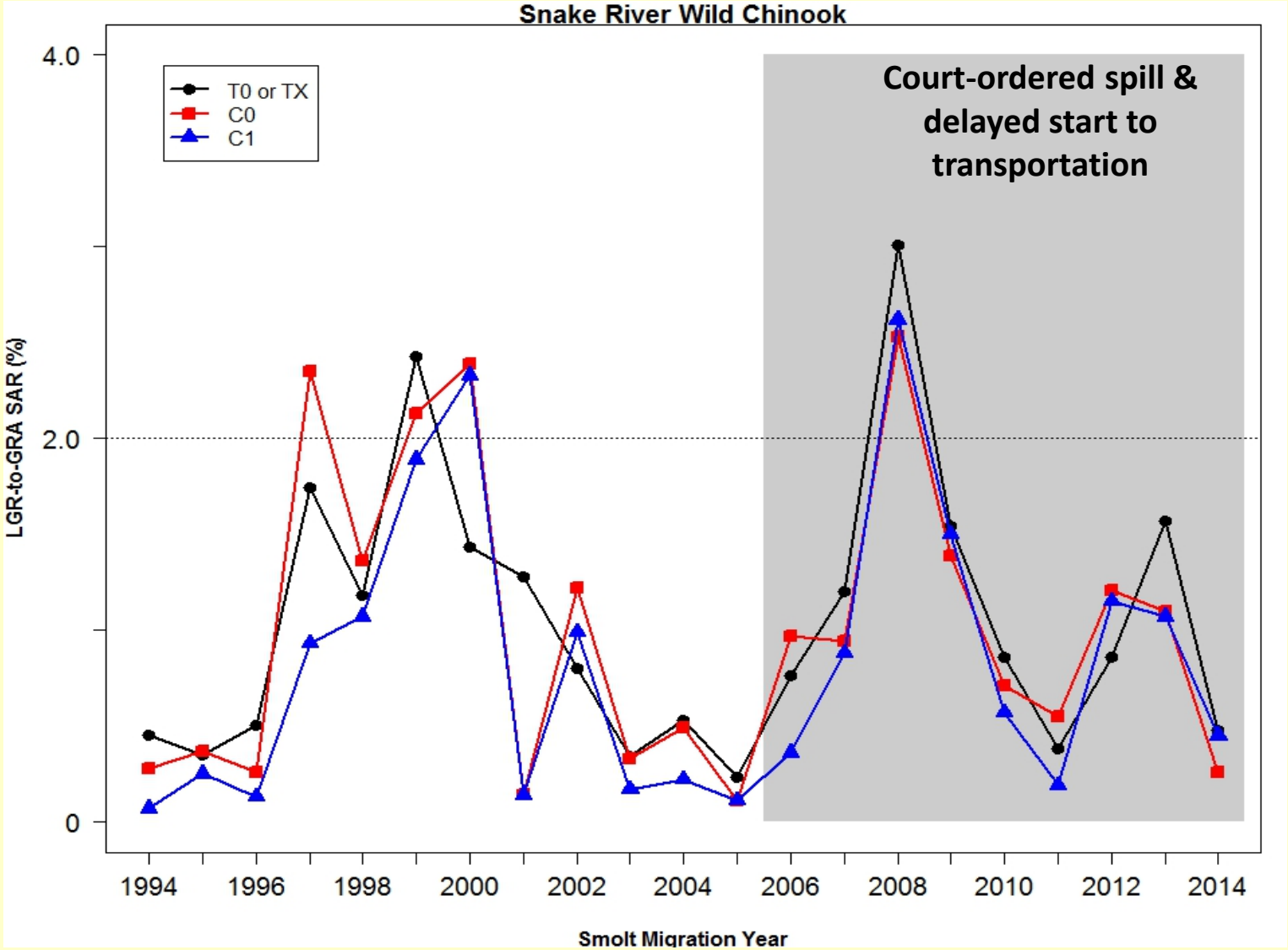
T = transported from LGR, LGS, LMN

C_0 = not collected or bypassed at LGR, LGS, LMN

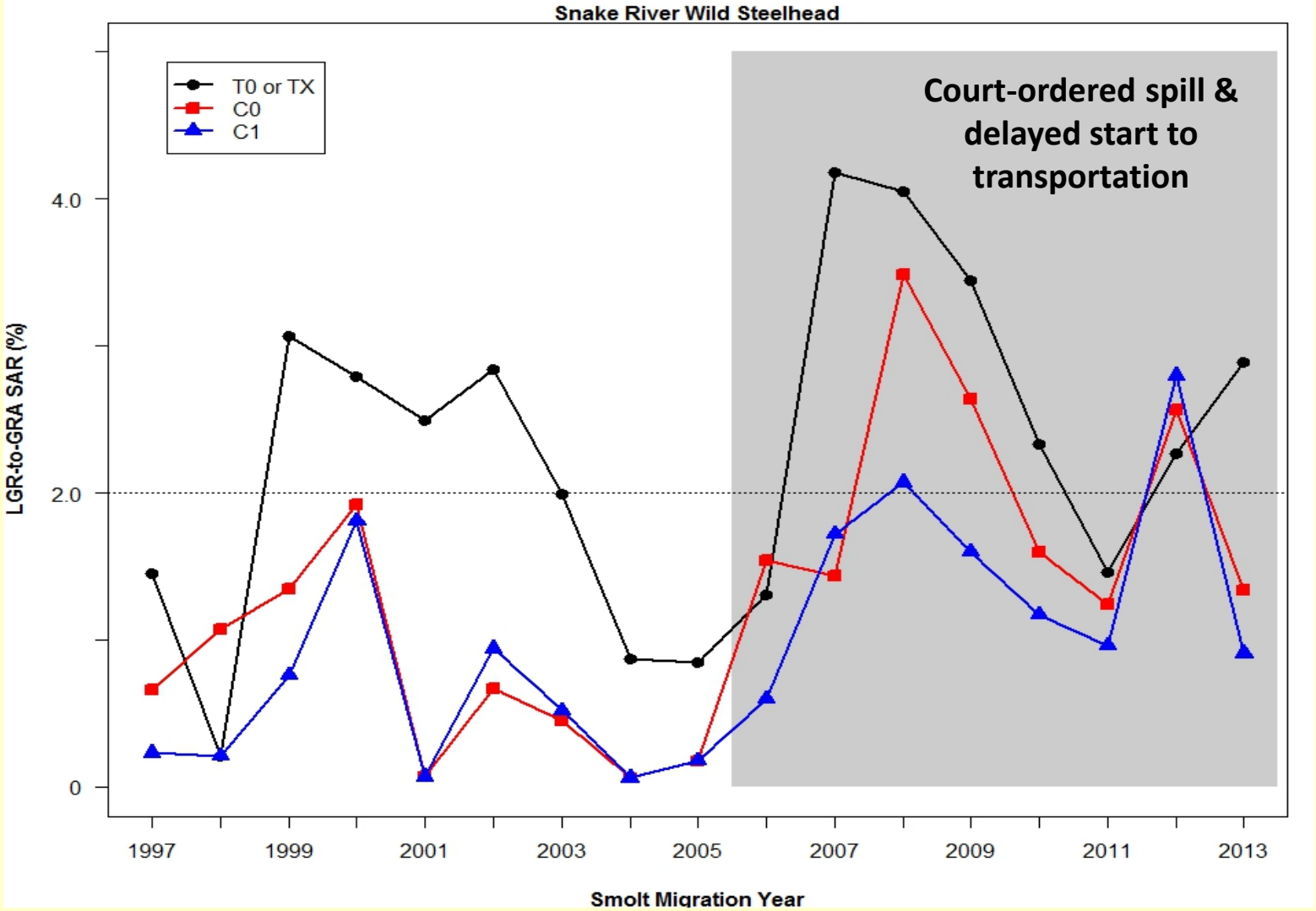
C_1 = collected and bypassed at LGR, LGS, LMN



None of passage routes have been meeting NPCC 2%-6% SAR goals



None of passage routes have been meeting NPCC 2%-6% SAR goals

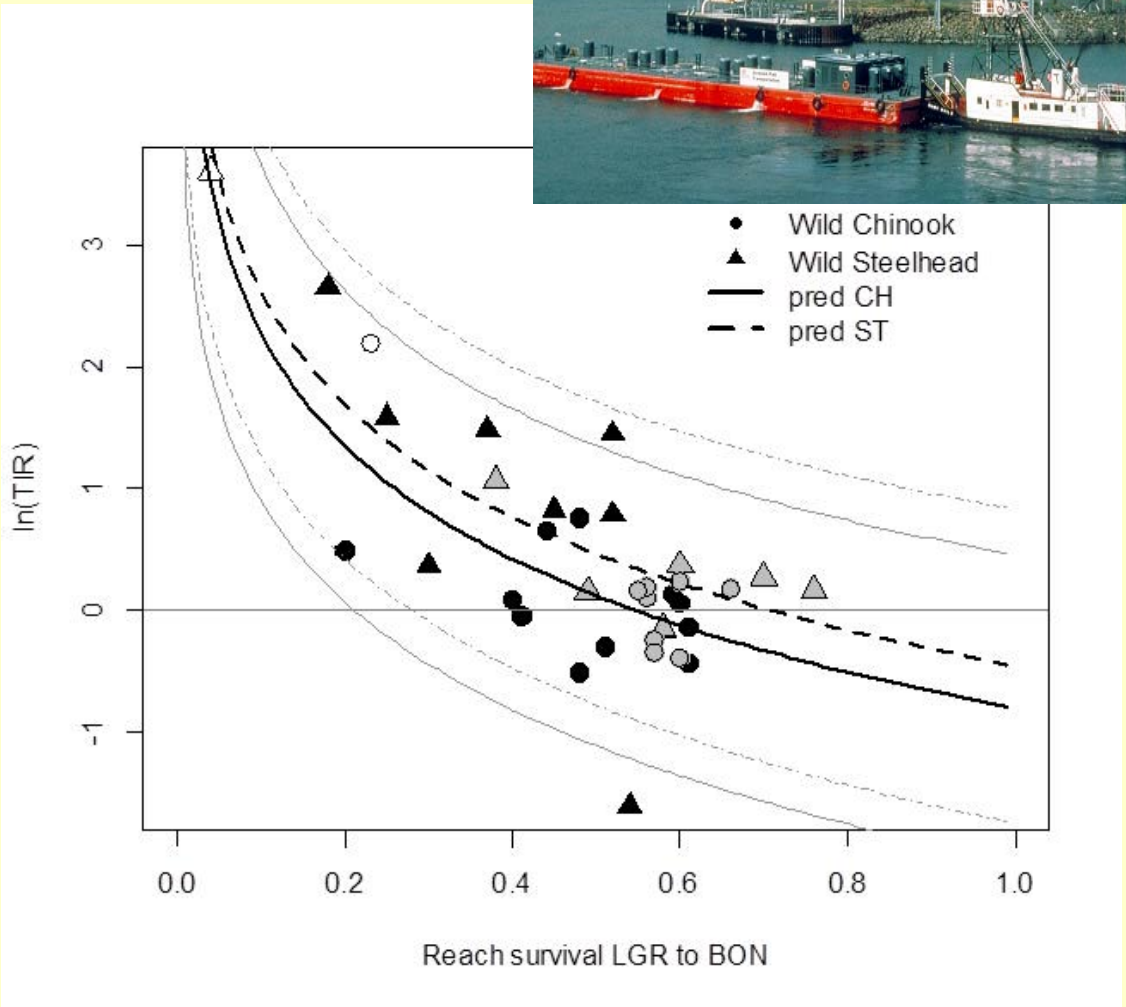


Relative Effectiveness of Transportation

Ratio of Transport SARs to In-river SAR (TIR) decreases with improved in-river conditions and juvenile survival

At S_R~0.6-0.7, relative "benefit" of transport becomes "detriment"

Potential to further improve in-river conditions and S_R



Mid-Columbia Wild Spring Chinook (3-4 dams)

Mid-C wild SARs 2.3–3.5 X Snake SARs; highly correlated with Snake (r ~ 0.7)

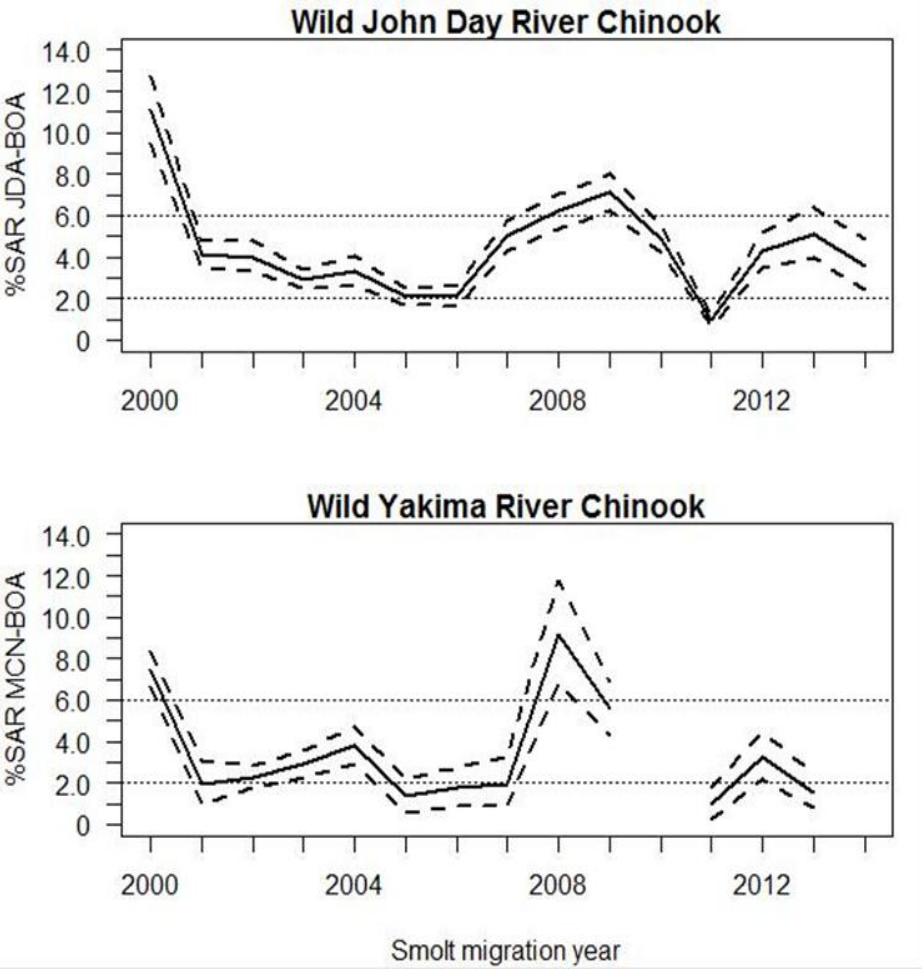
Mid-C wild SARs generally in range of NPCC goals (2000-14):

- JDA averaged 3.8% SAR
- YAK averaged 2.4% SAR

Wild SARs:

- > 2% in 17/26 year-populations
- < 2% in 2/26 year-populations

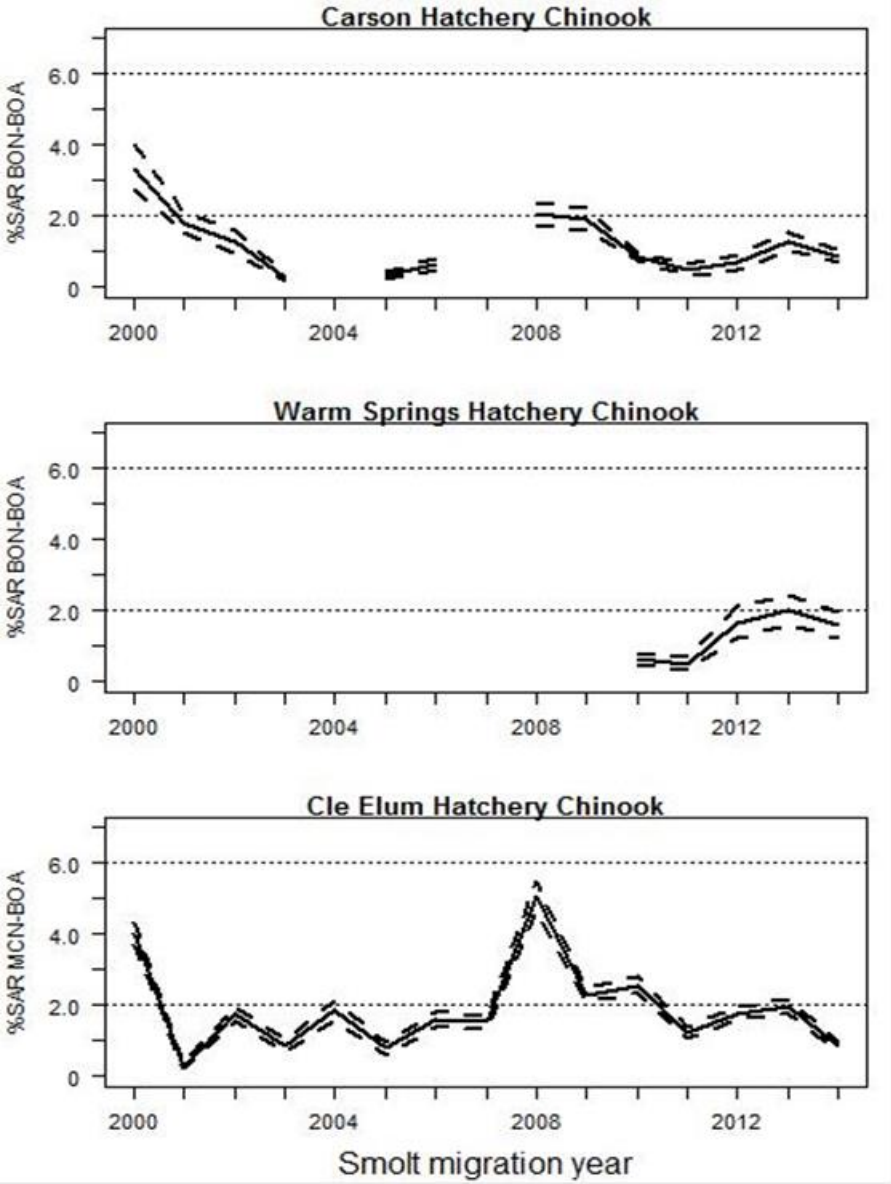
($p<0.05$)



Mid-Columbia Hatchery Spring Chinook (1-4 dams)

Mid-C hatchery Chinook SARs lower in magnitude than wild SARs

Mid-C hatchery & wild SARs highly correlated (r ~ 0.8)



Mid-Columbia Wild Steelhead

Mid-C wild SARs 2.4 X Snake SARs; highly correlated with Snake (r ~ 0.7)

No Mid-C hatchery PIT tag groups

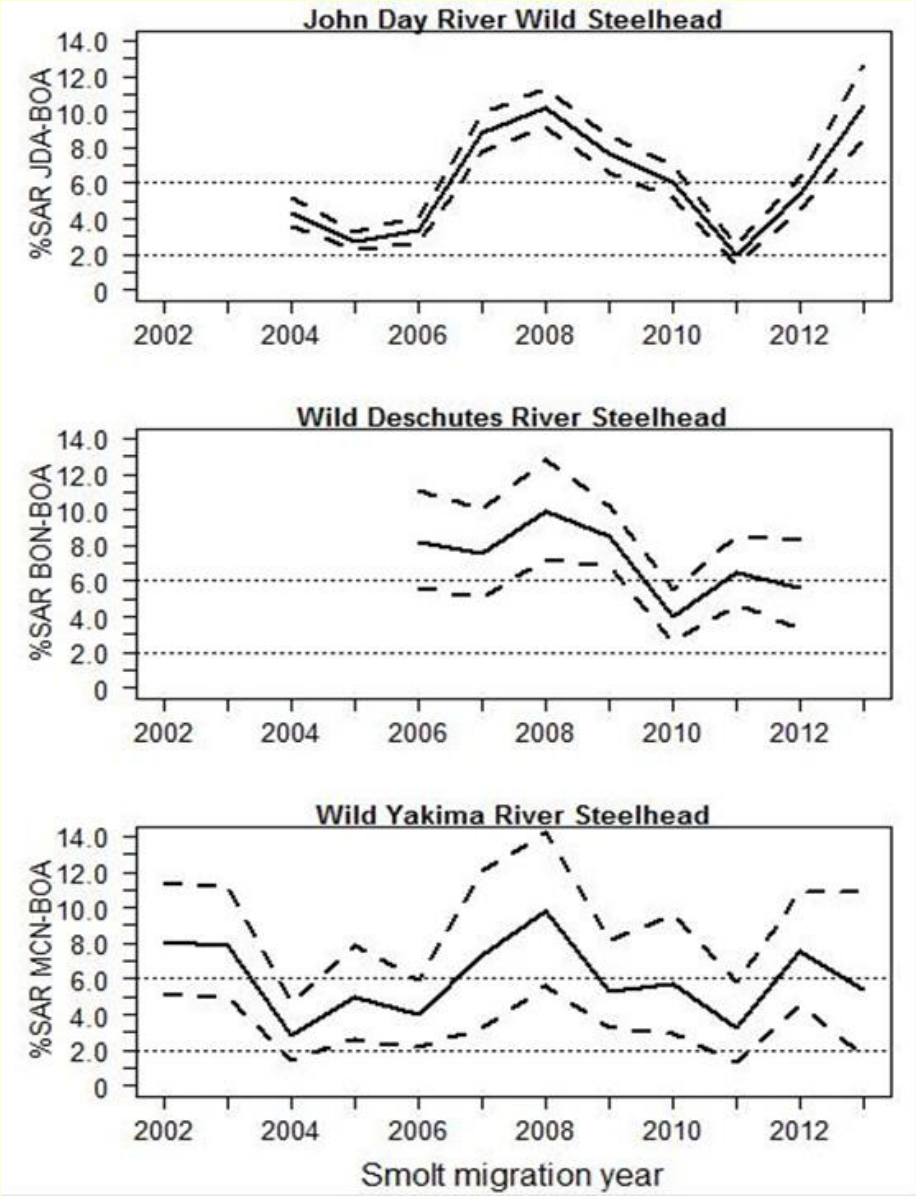
Mid-C wild SARs met or exceeded NPCC goals (2002-2013):

- JDA averaged 5.3% SAR
- DES averaged 6.9% SAR
- YAK averaged 4.6% SAR

Wild SARs:

- > 2% in 24/29 year-populations
- < 2% in 0/29 year-populations

($p<0.05$)



Summary

- Overall SARs of Snake River wild spring/summer Chinook and steelhead << NPCC 2%-6% SAR goals

- Wild and hatchery SARs are correlated for both Snake River Chinook and steelhead

- Relative efficacy of transport decreases with improved in-river conditions and juvenile survival
  - Potential to improve in-river conditions (e.g., spill, WTT)

Summary

- Mid-C wild spring Chinook and steelhead SARs generally meeting NPCC SAR goals

- Mid-C wild spring Chinook and steelhead SARs
  - 2.3X – 3.5X greater than Snake River wild SARs
  - highly correlated with Snake River wild SARs

- Upper Columbia monitoring poses special challenges:
  - Dan Rawding – next presentation…

SARs and Juvenile Metrics of Upper Columbia Stocks

Dan Rawding (WDFW)

CSS Annual Meeting April 3, 2017

CSS Objectives: Upper Columbia

- Establish long term survival estimates over the full life-cycle of upper Columbia stocks

- Develop Smolt to Adult Return rates (SARs) from the upper most dam encountered

Upper Columbia CSS Challenges:

- Low abundance of smolts makes it difficult to tag enough fish for a specific population
  - Result is often aggregate tag groups

- Mainstem juvenile detection sites are fewer
  - SARs and survival estimates may not account for full life history

Upper Columbia Mark Groups

- **Seven groups – basin and rear-type specific**
  - Wenatchee hatchery spring Chinook (Leavenworth)
  - Wenatchee wild Chinook
  - Wenatchee hatchery/wild cross Steelhead
  - Entiat-Methow aggregate wild Chinook
  - Wenatchee-Entiat-Methow aggregate wild Steelhead
  - Okanogan/Columbia River above Wells Dam wild Chinook*
  - Okanogan wild Sockeye (new in 2016)

- **Four groups - not basin or rear type specific**

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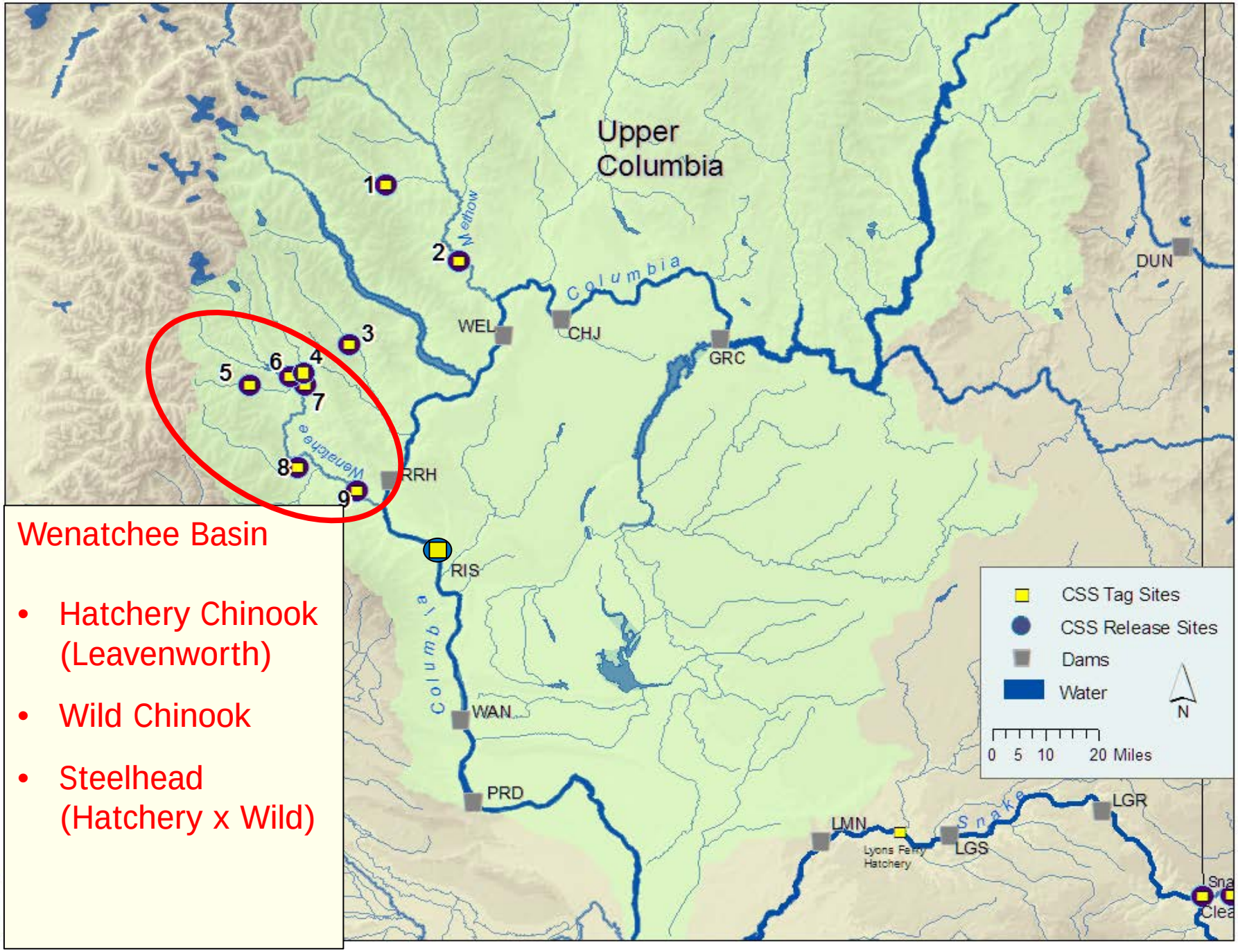
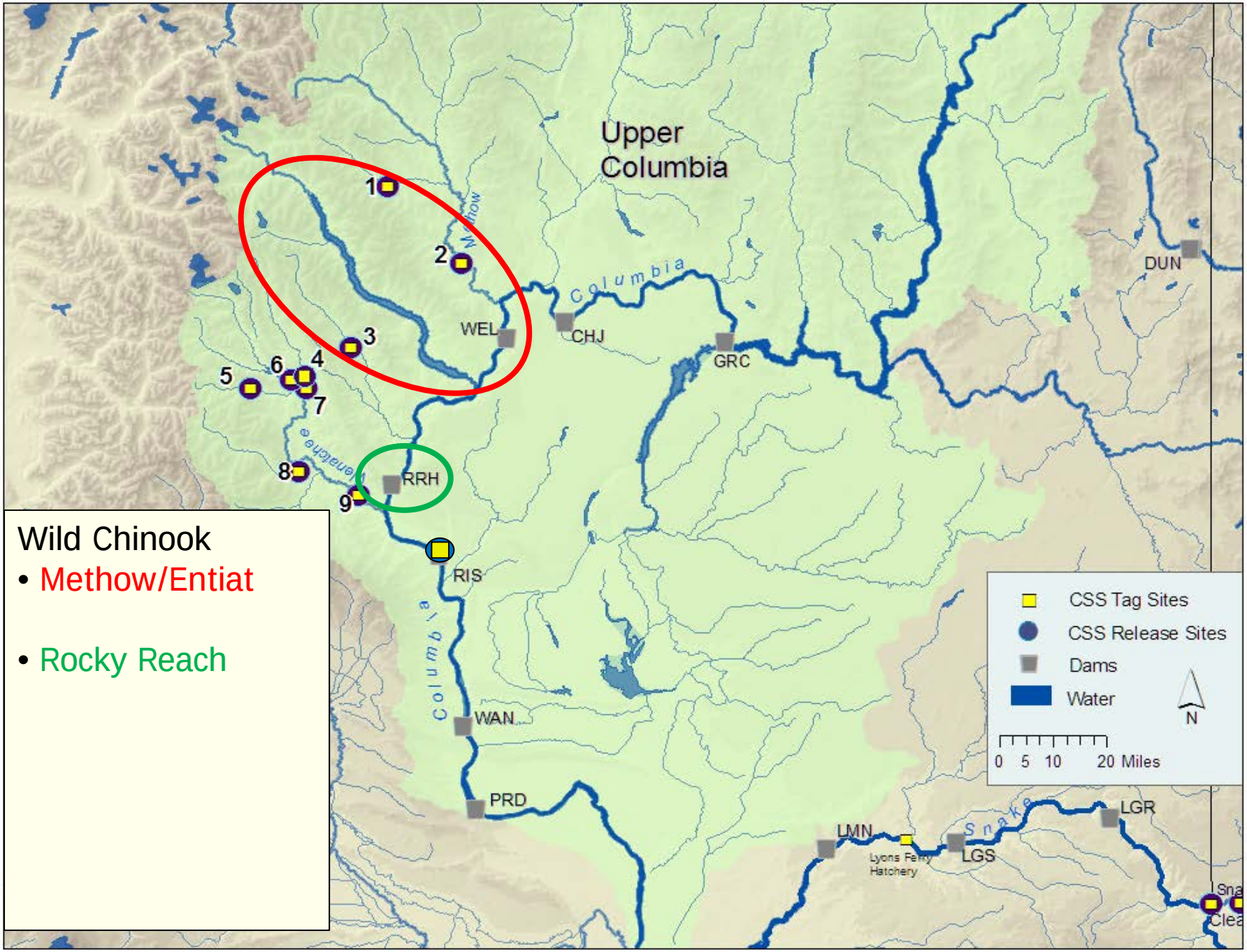


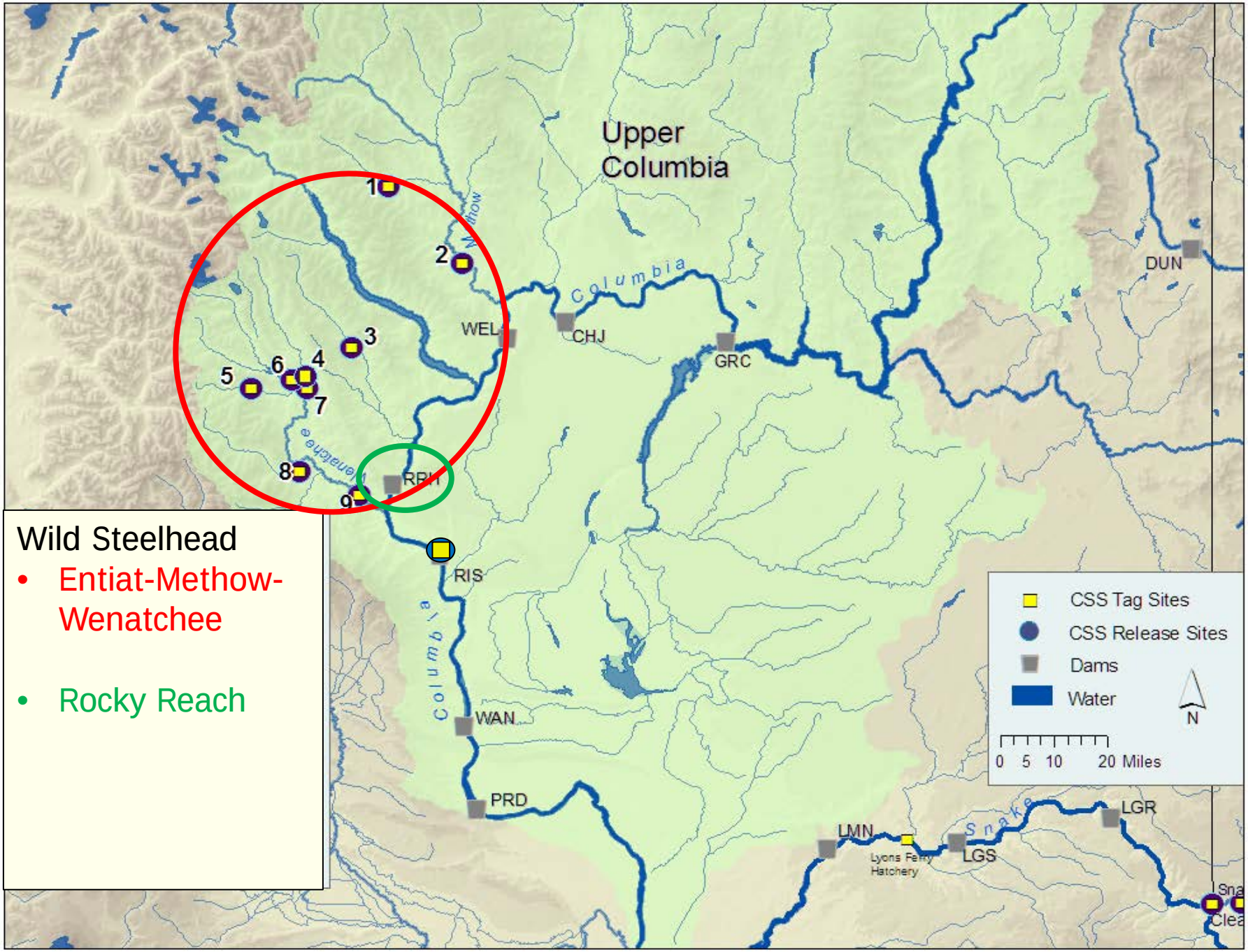
Wenatchee Basin

- Hatchery Chinook (Leavenworth)
- Wild Chinook
- Steelhead (Hatchery x Wild)



Wild Chinook

- Methow/Entiat
- Rocky Reach



Wild Steelhead

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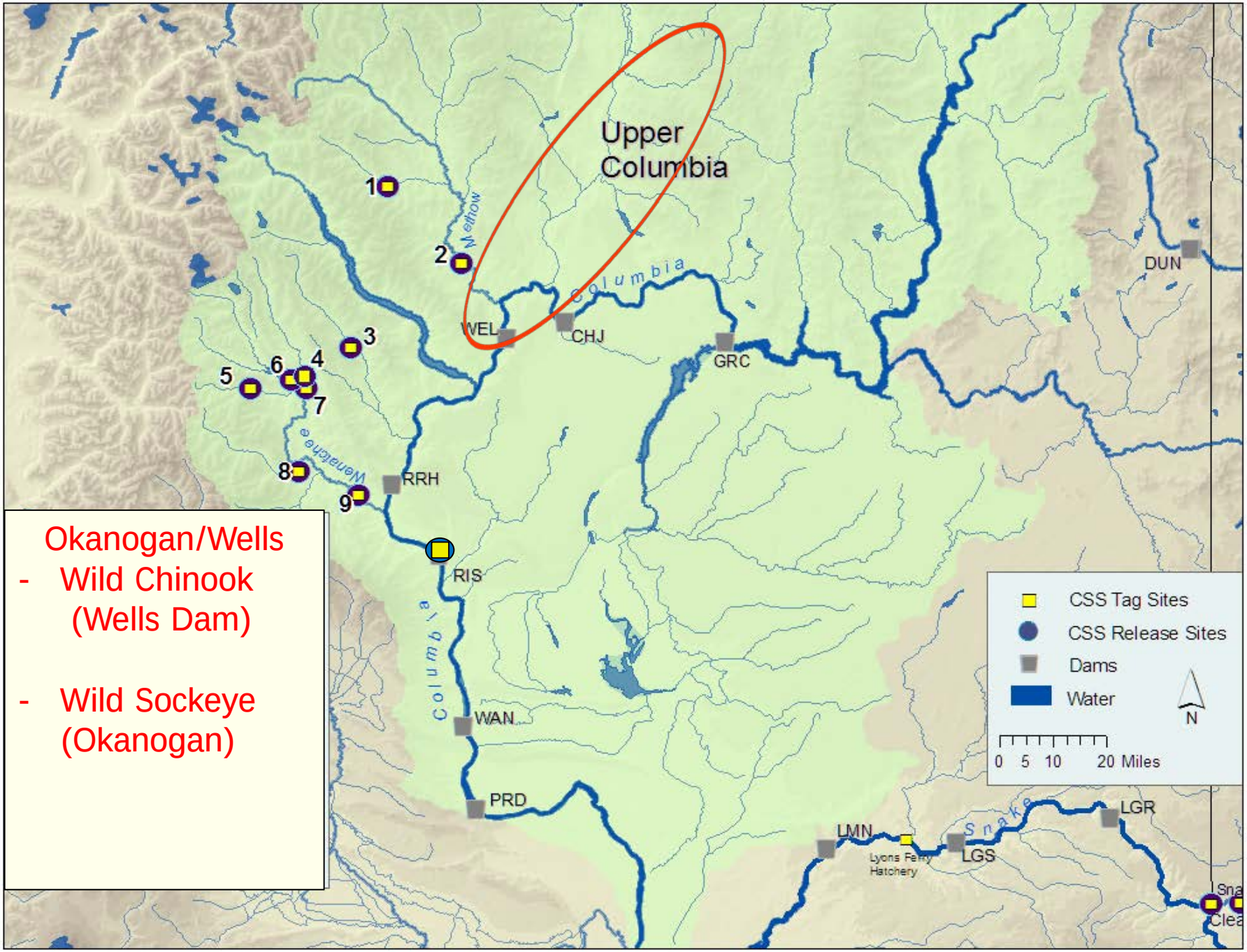
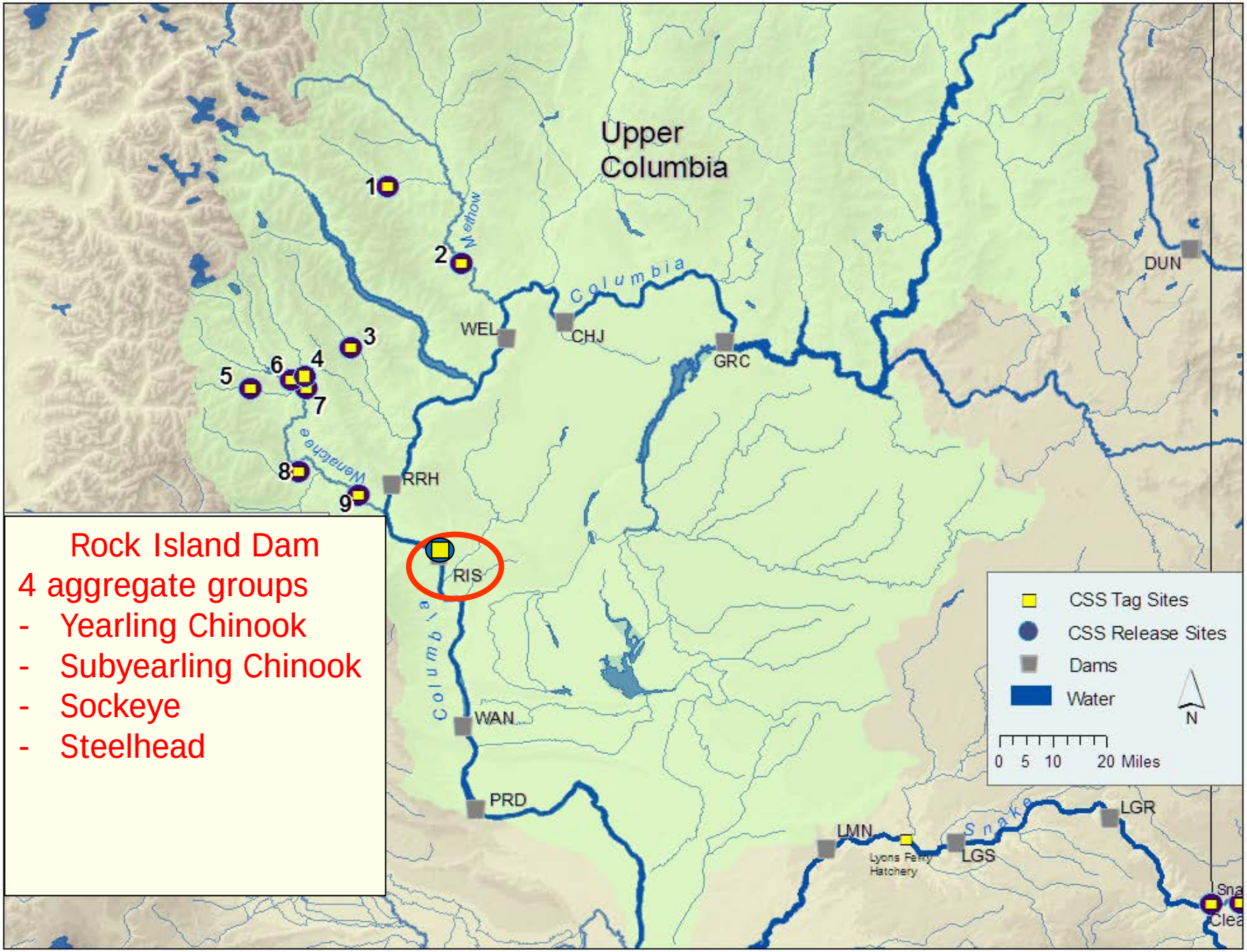

Upper Columbia
Okanogan/Wells
- Wild Chinook (Wells Dam)
- Wild Sockeye (Okanogan)
1
2
3
4
5
6
7
8
9
Methow
Columbia
Wenatchee
WEL
CHJ
GRC
DUN
RRH
RIS
WAN
PRD
LMN
Lyons Ferry Hatchery
LGS
LGR
Snake
CSS Tag Sites
CSS Release Sites
Dams
Water
N
0 5 10 20 Miles



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4 aggregate groups

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- Sockeye
- Steelhead

Rock Island-McNary Juvenile Metrics:

- RIS – MCN Reach
  - 150 miles with 2 dams in between
- Juvenile passage
  - Travel time
  - Survival
  - Instantaneous mortality
- Passage metrics relative to environmental variables

Rock Island to McNary:
Juvenile Metrics/Environmental Variables

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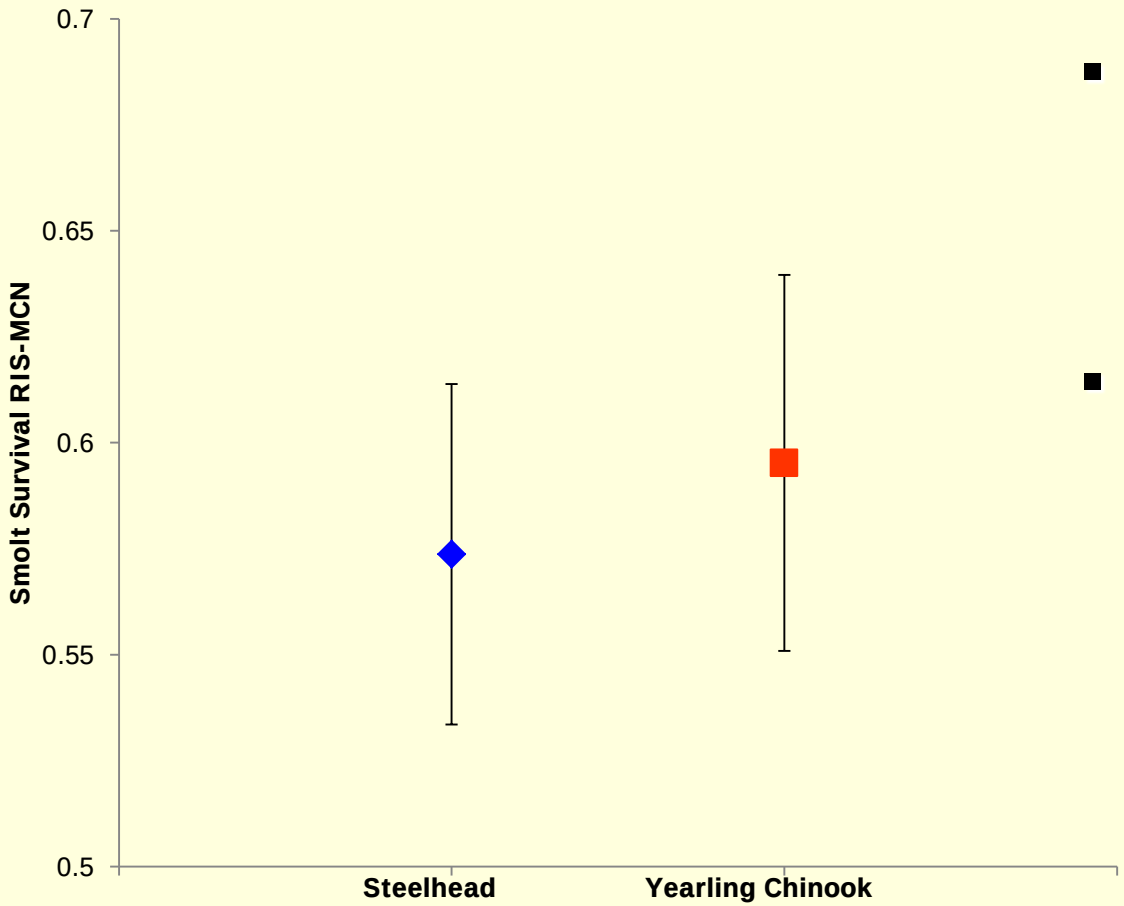
Rock Island to McNary
Juvenile Survival



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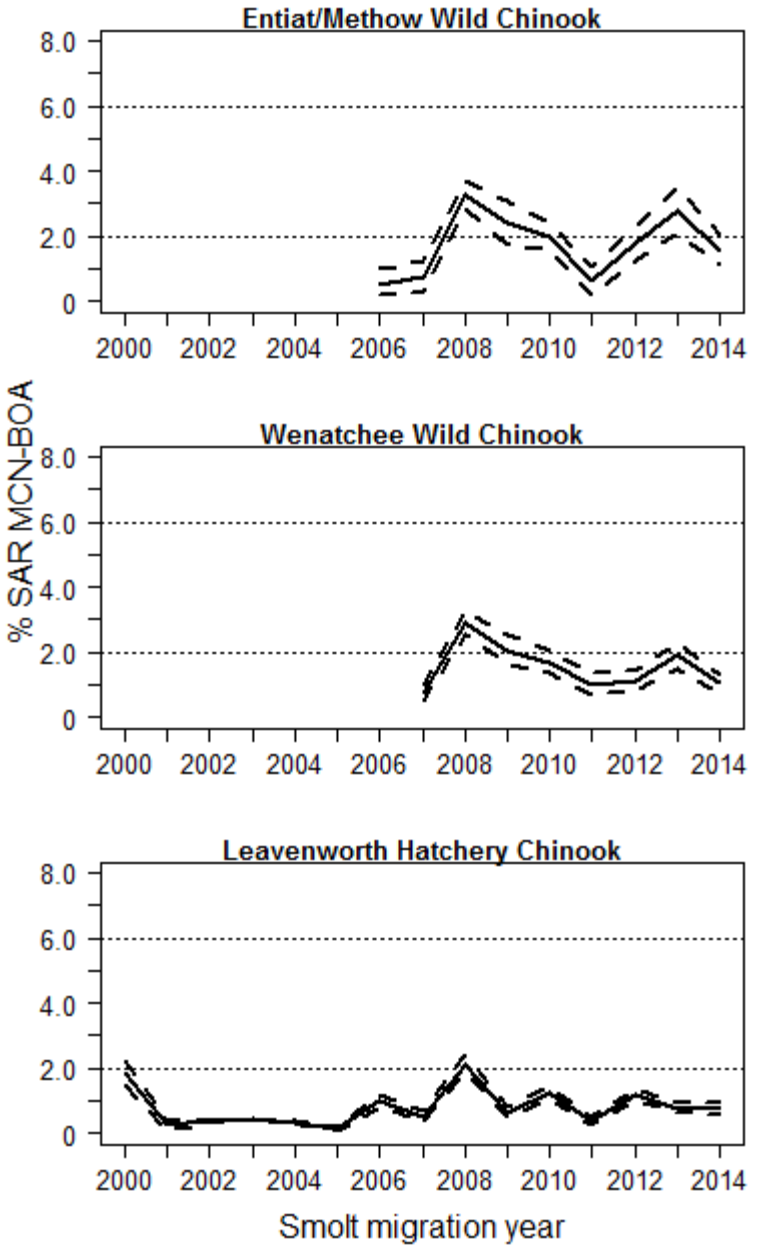

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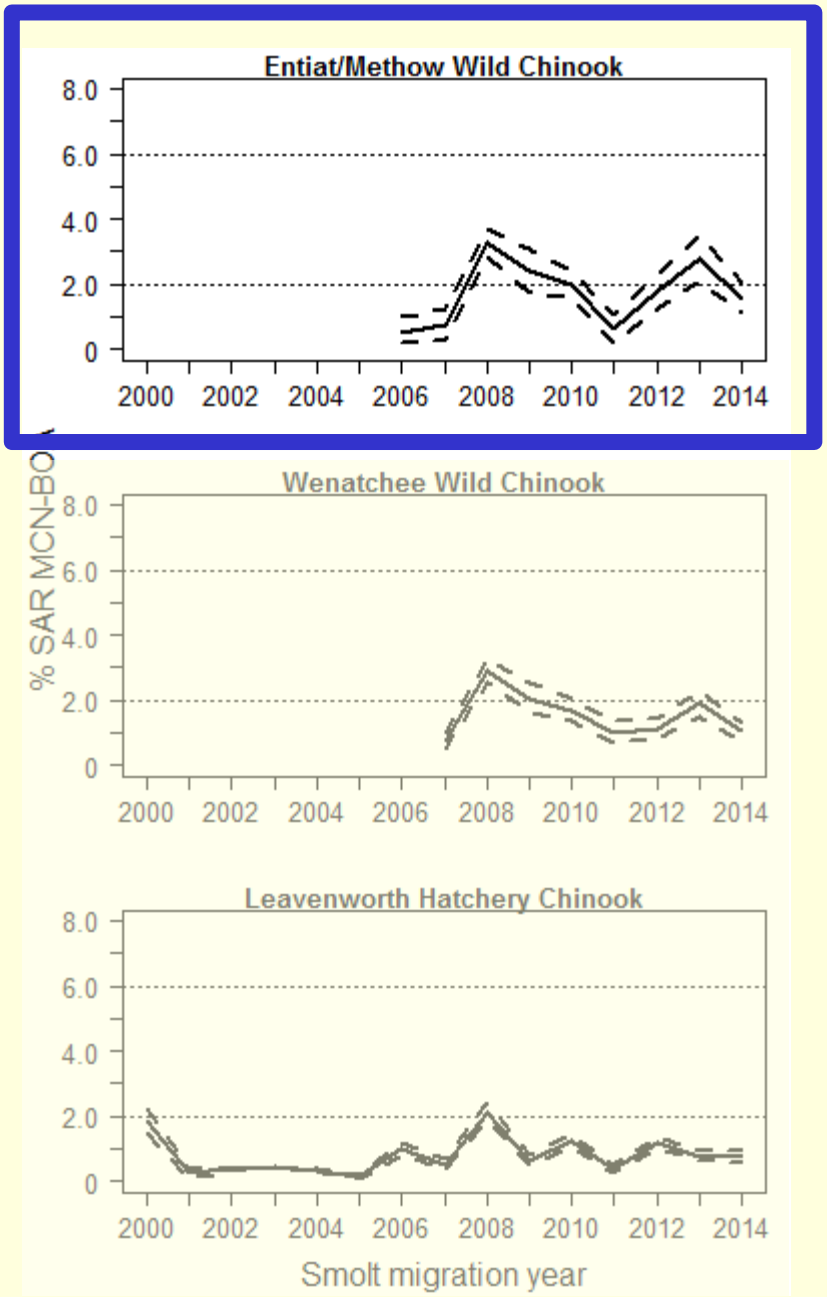

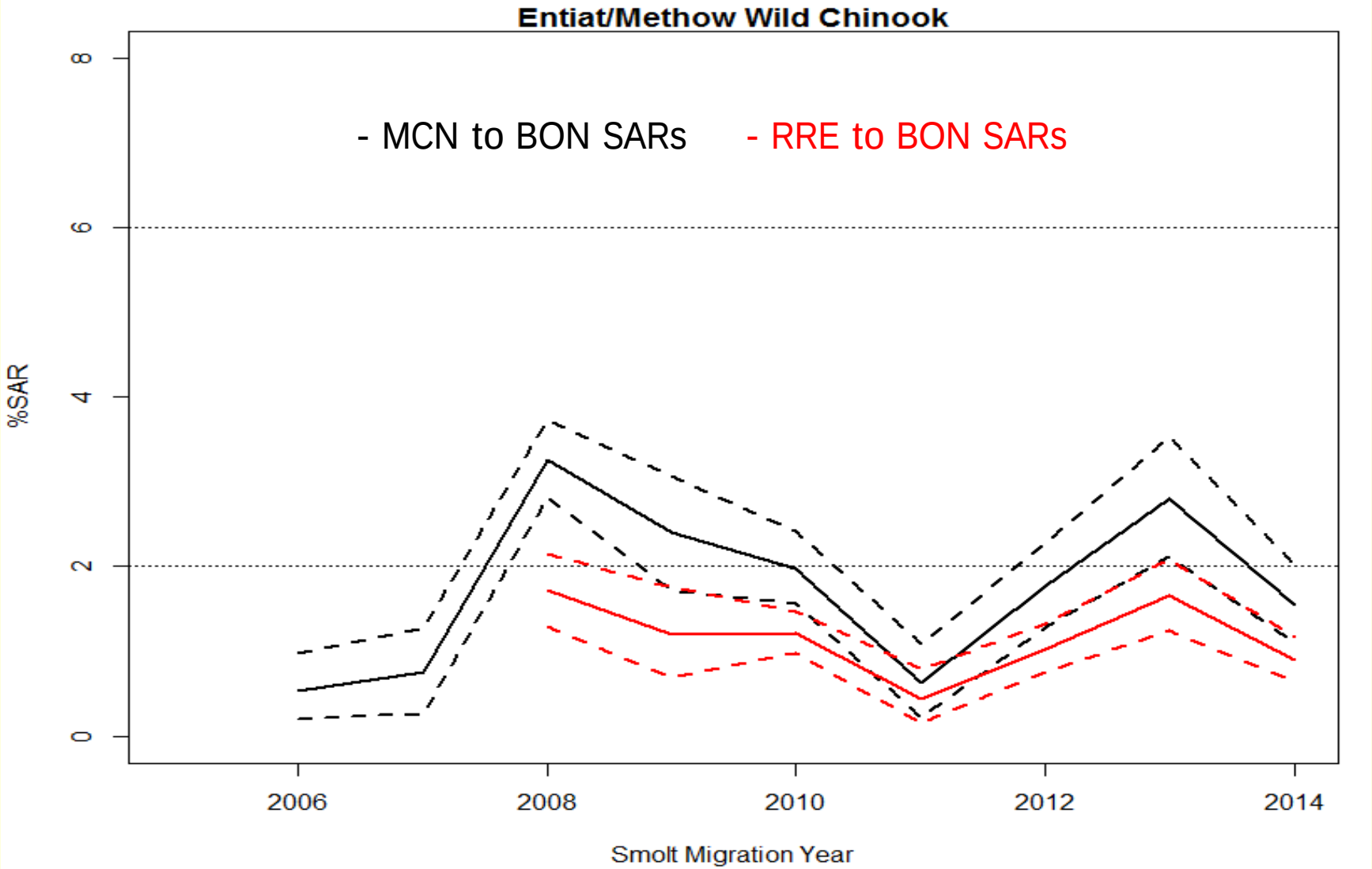

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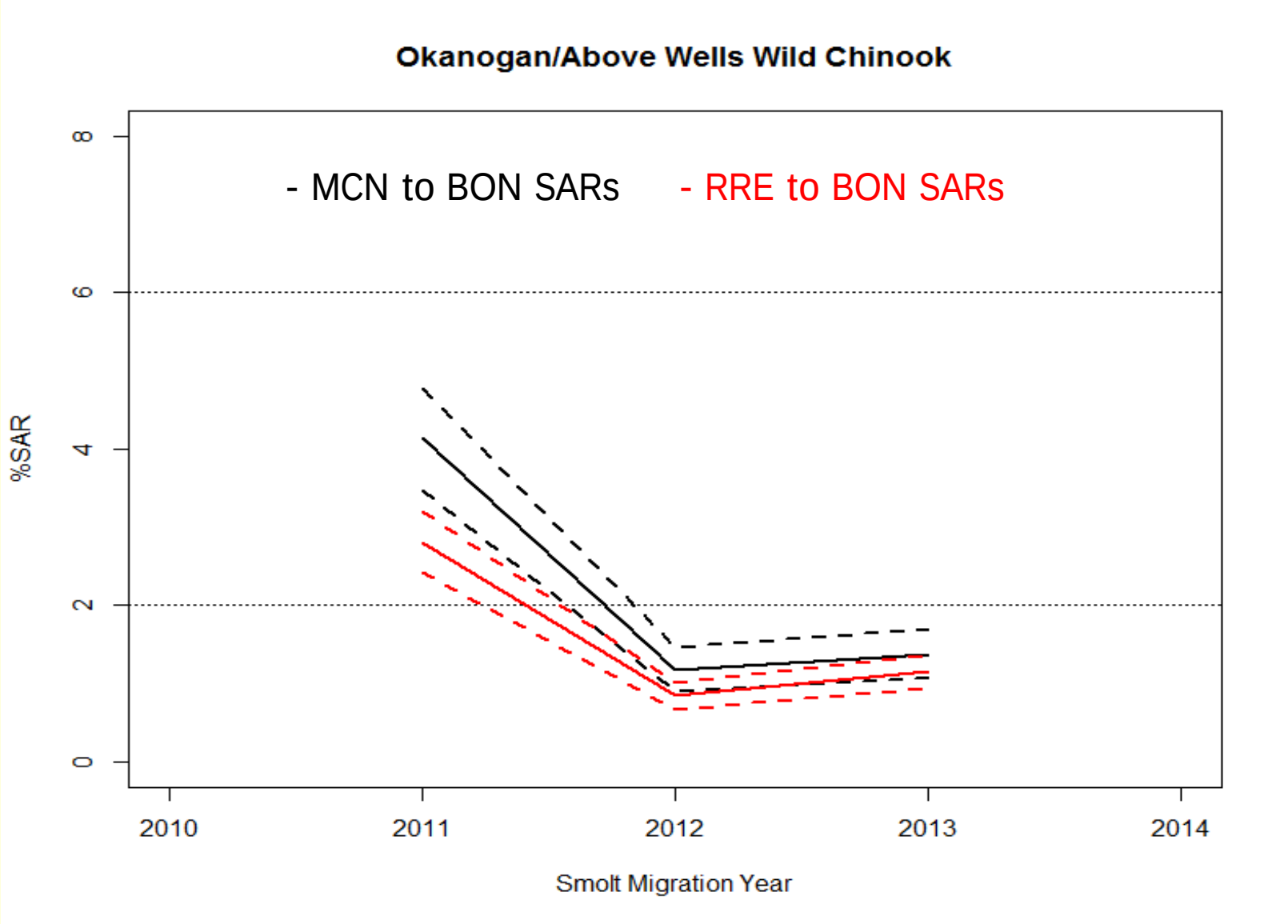

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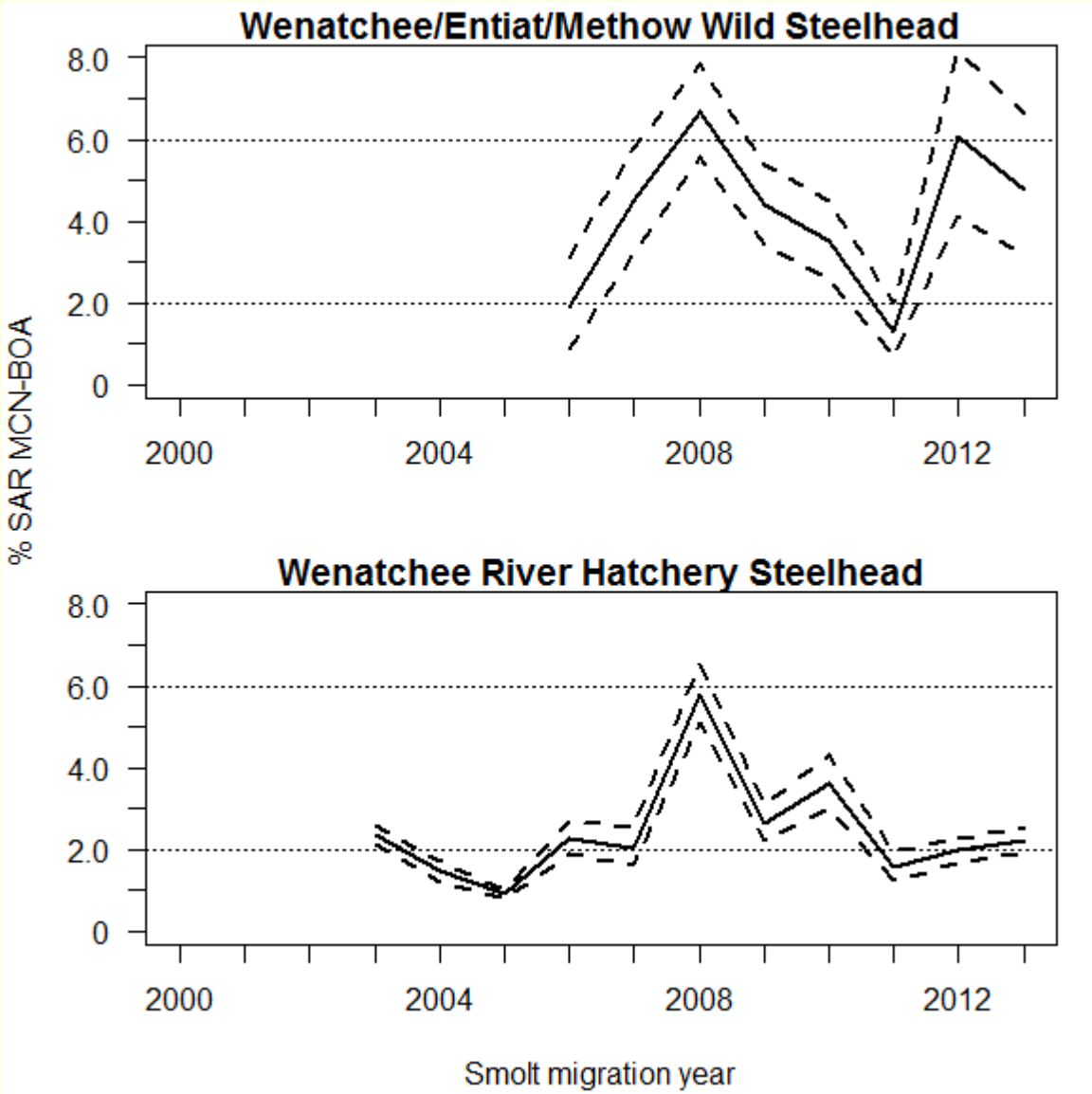
MCN to BON SARs Steelhead

Wild Steelhead

- Aggregate
- Short time series
- SARs averaged 4.1%

Hatchery Steelhead

- Wenatchee River
- Time series a little longer
- SARs averaged 2.4%



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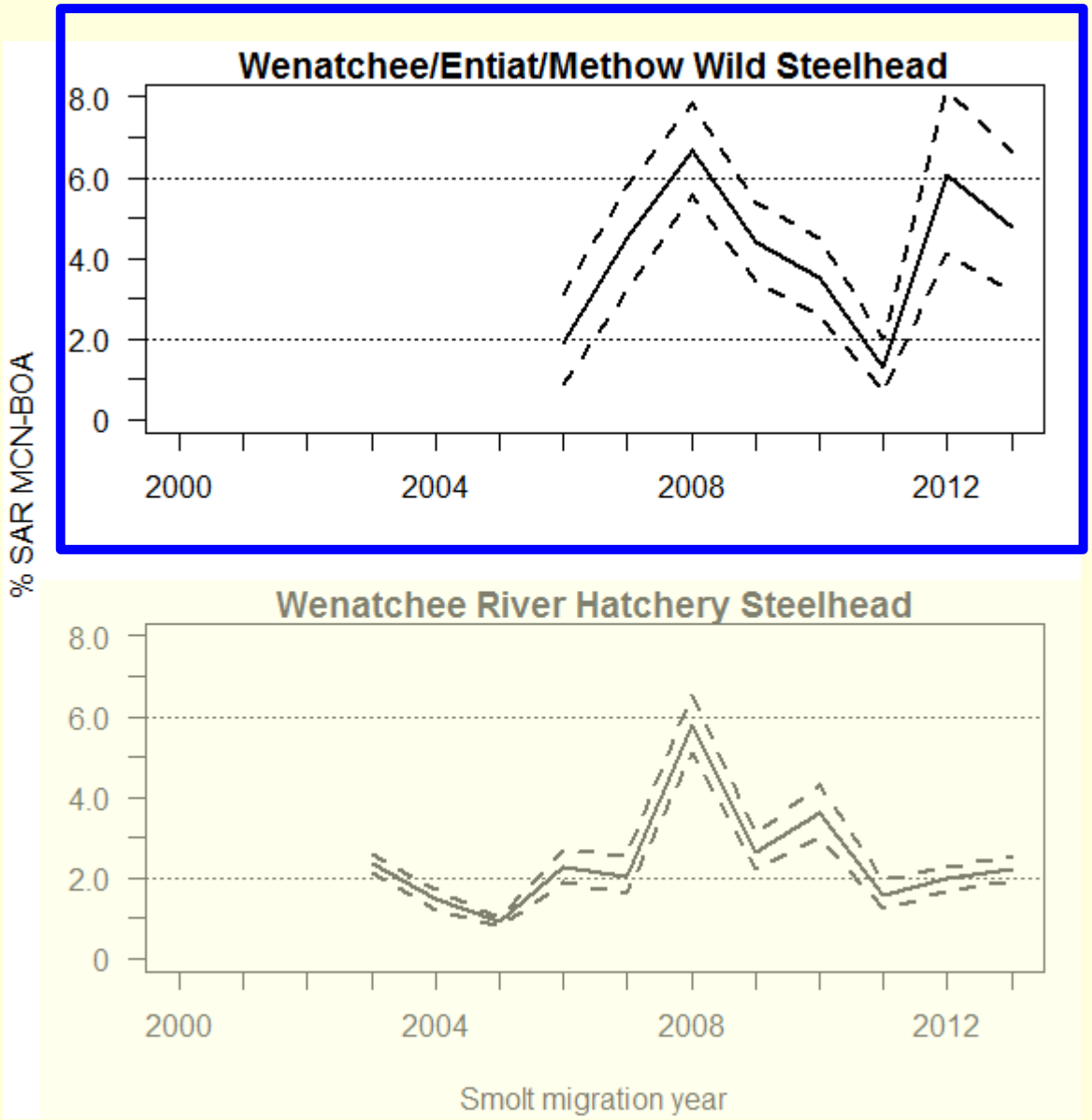

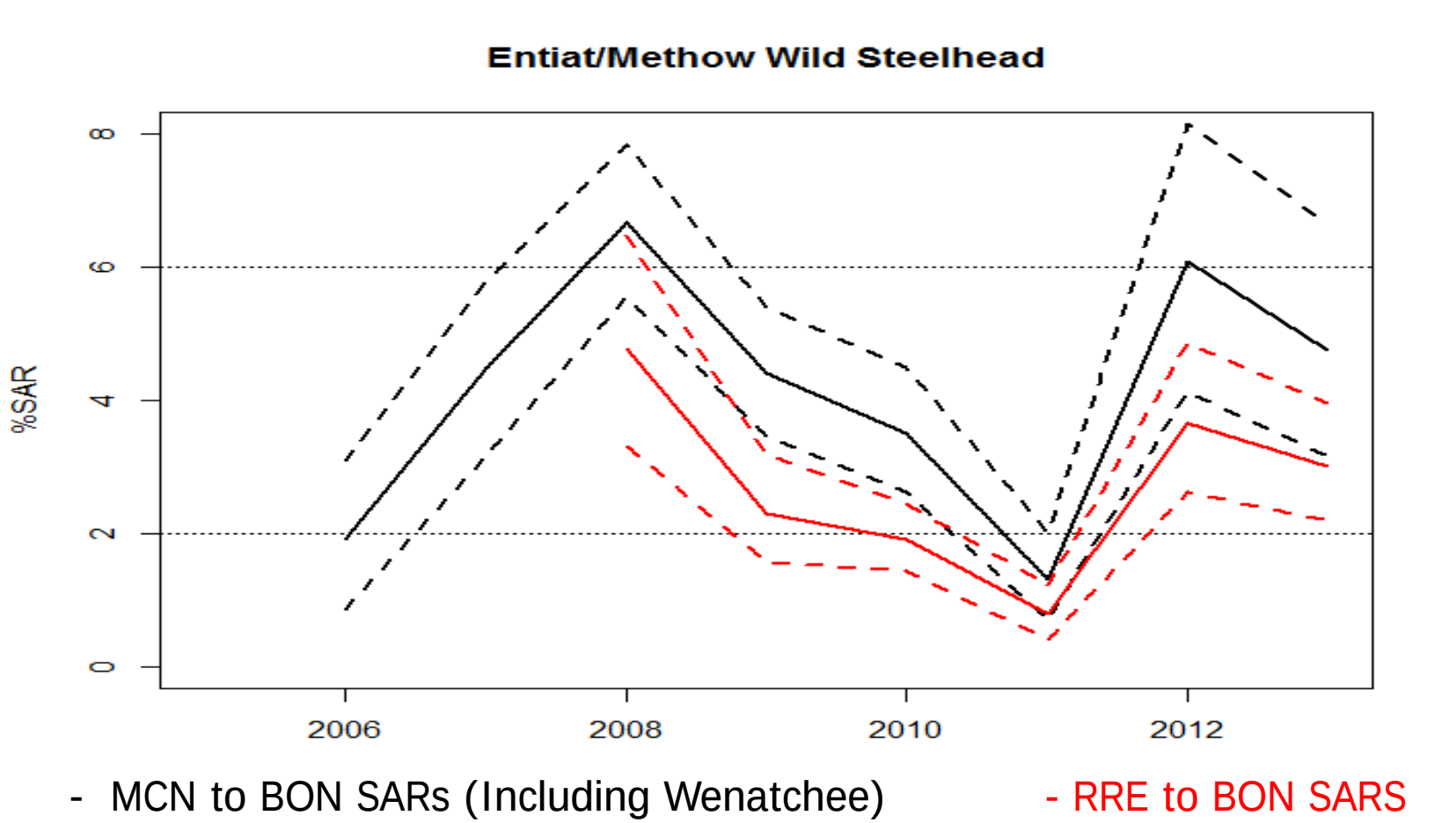

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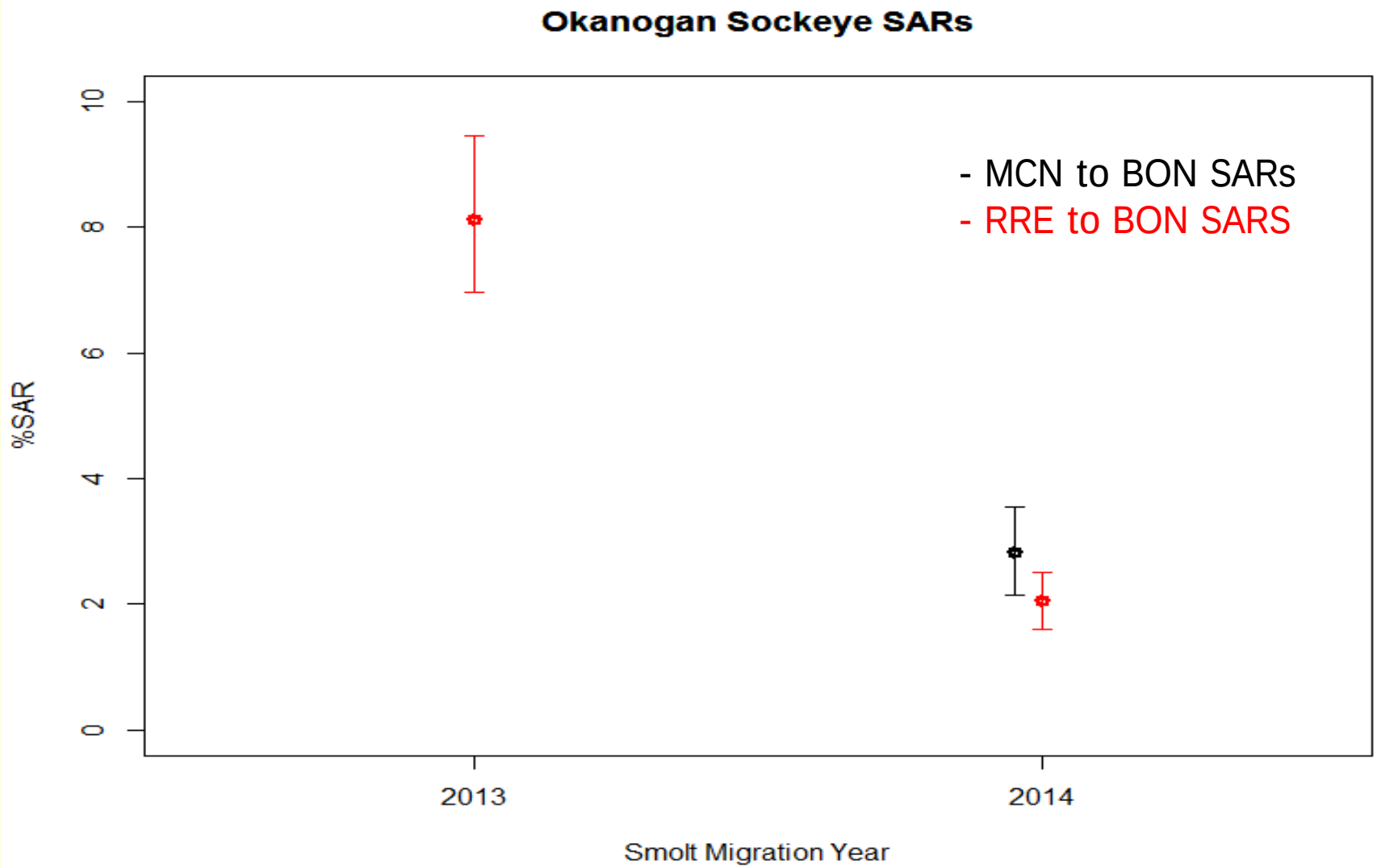


- New group in 2016 CSS Report with limited data

RIS to BON SARs
Chinook and Steelhead

Yearling Chinook

- Hatchery and wild aggregate
- SARs averaged 0.4%

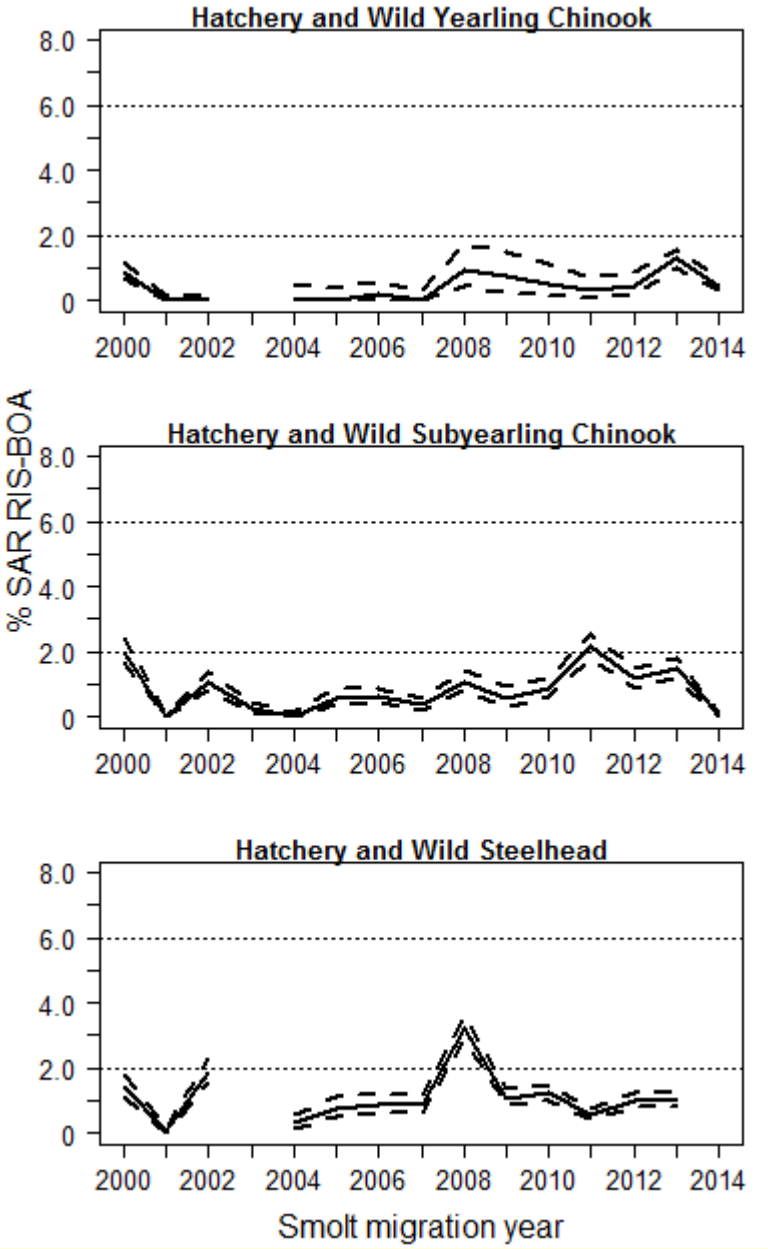
Subyearling Chinook

- Hatchery and wild aggregate
- SARs averaged 0.8%

Steelhead

- Hatchery and wild aggregate
- SARs averaged 1.1%

**Bypass inoperable during spring of 2003 – no data*



RIS to BON SARs
Sockeye

Sockeye

- Hatchery and Wild combined
- SARs averaged 2.4%
- Data part of CSS Report since 2014

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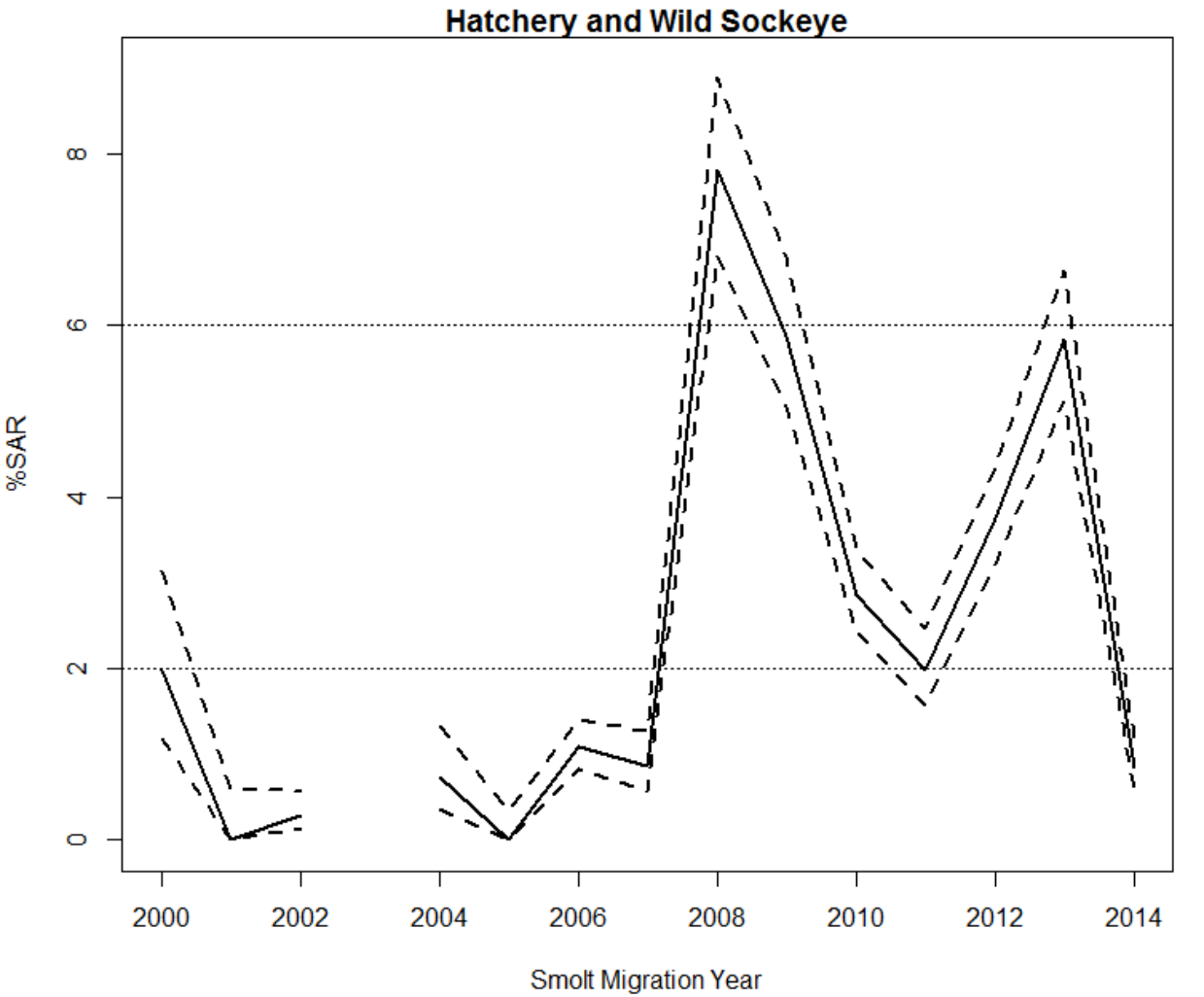
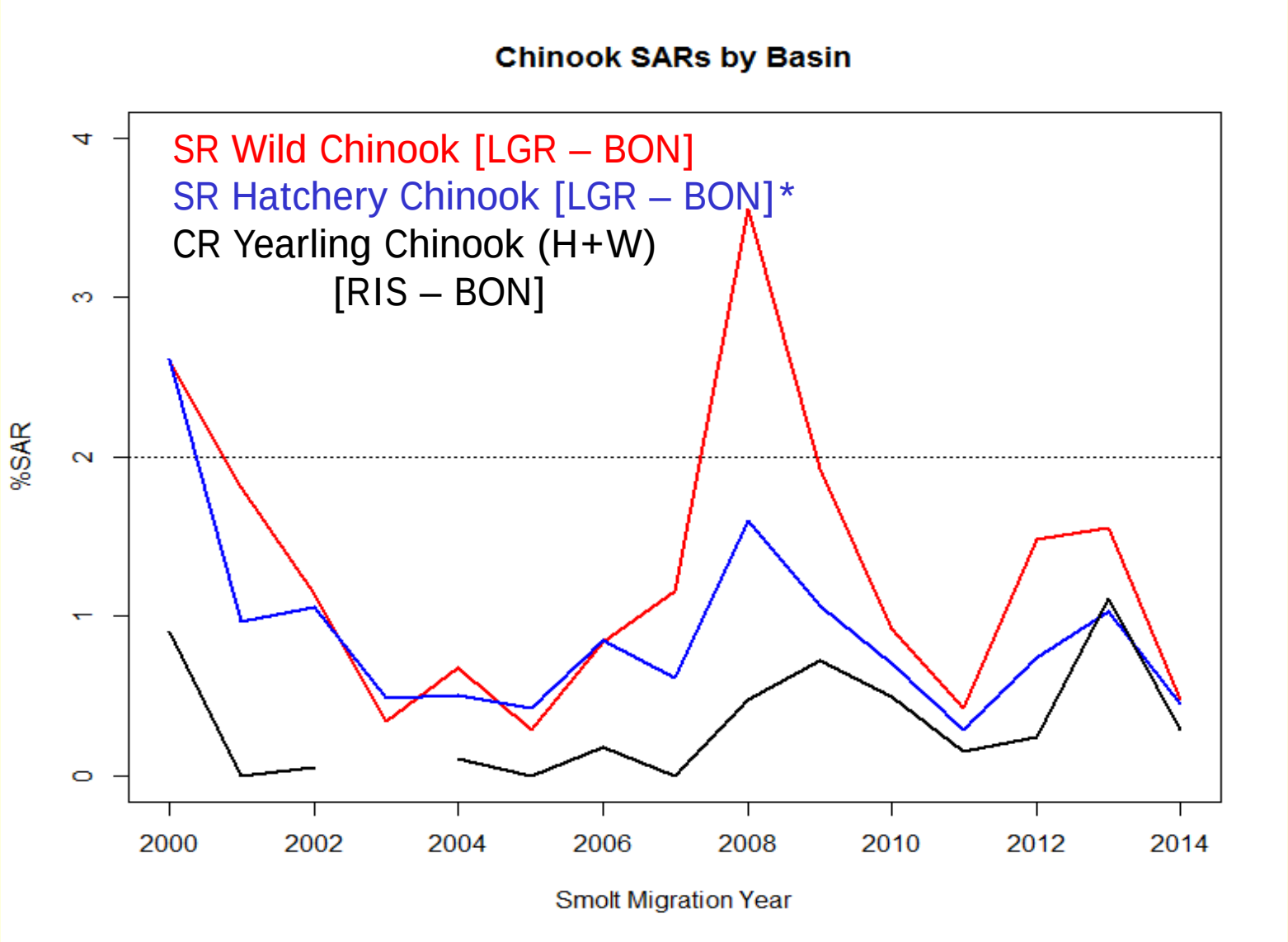
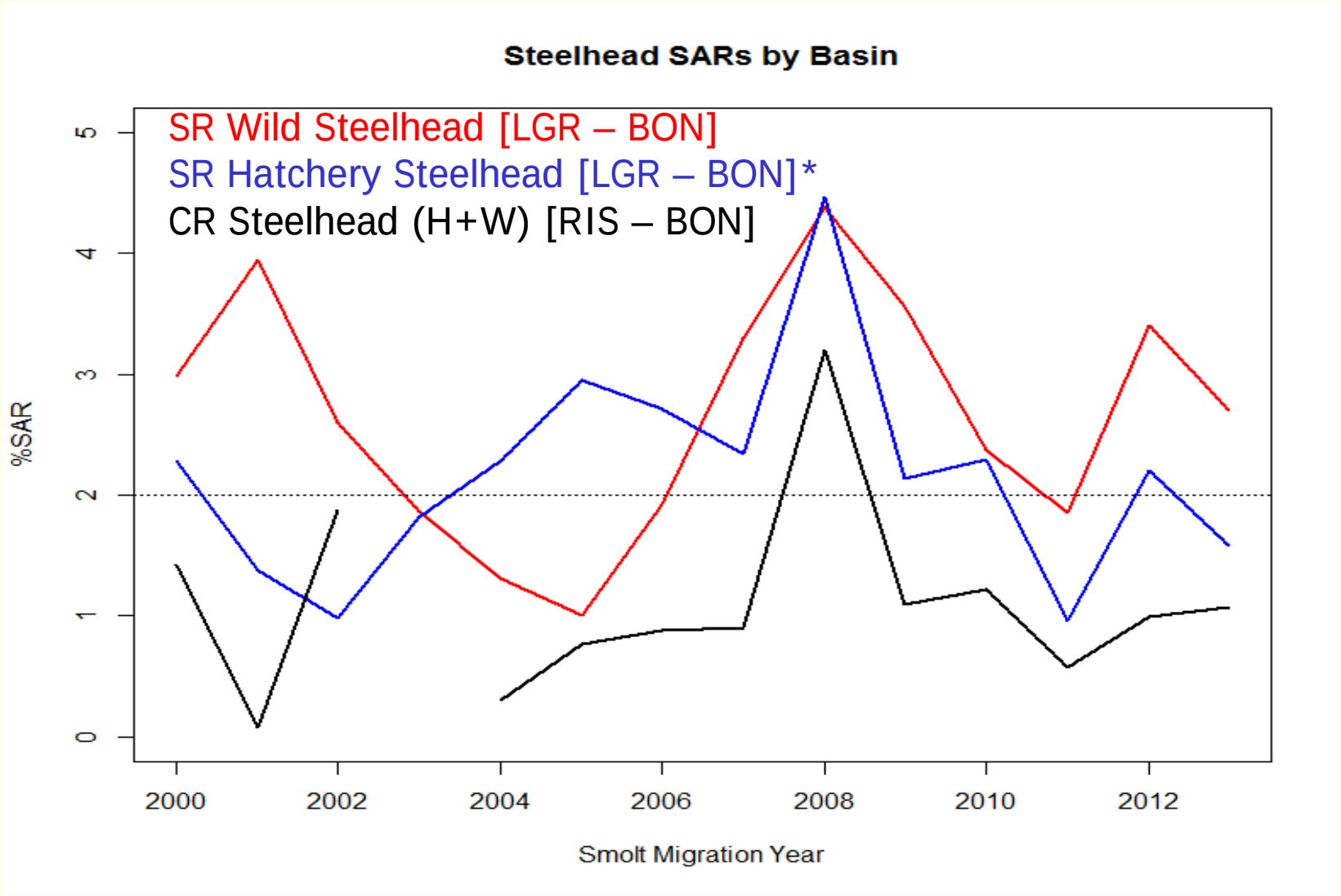




LGR to BON is approximately 286 miles [7 dams]

RIS to BON is approximately 308 miles [6 dams]

*Snake River Hatchery Chinook is a weighted average of annual hatchery specific estimates



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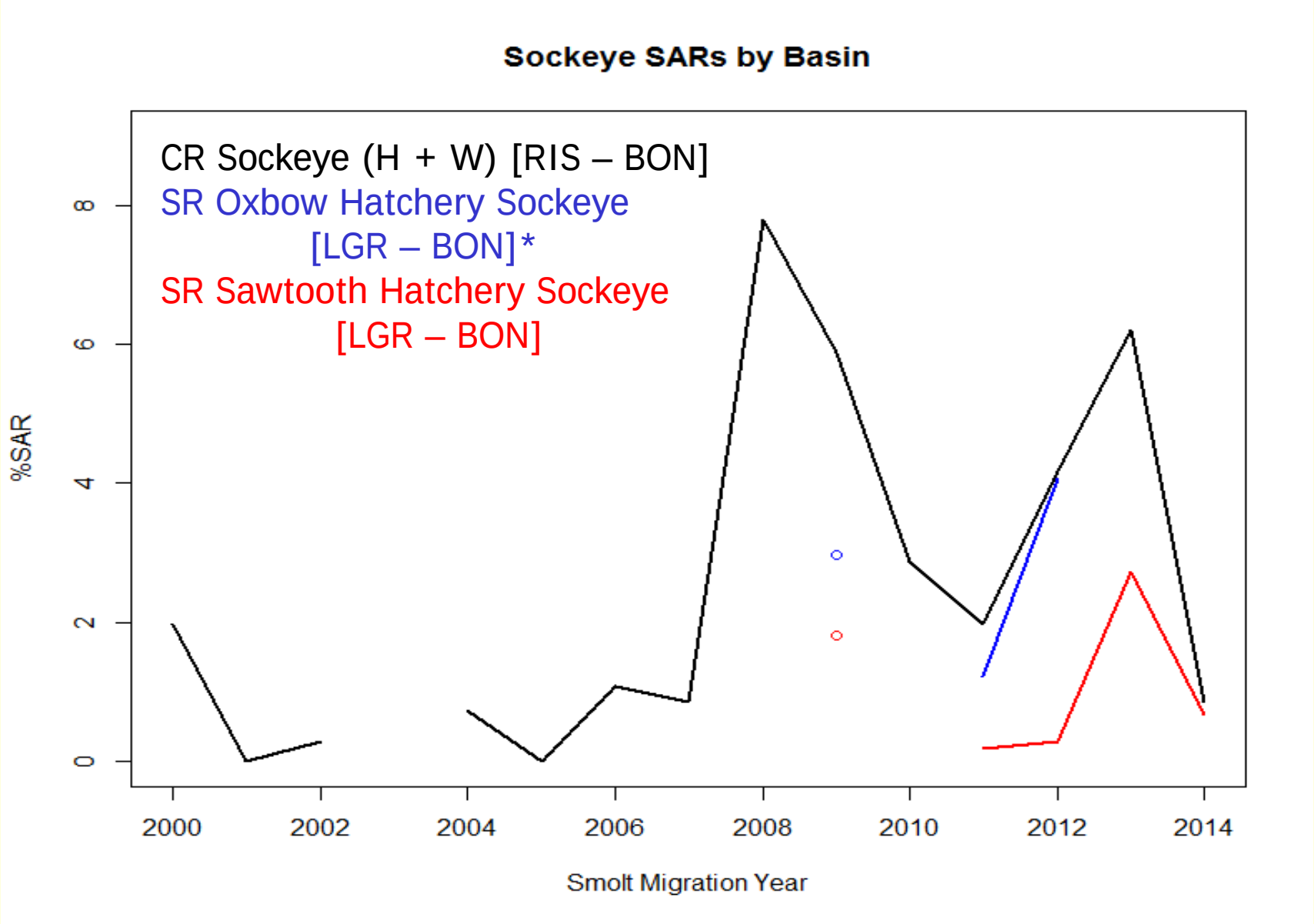

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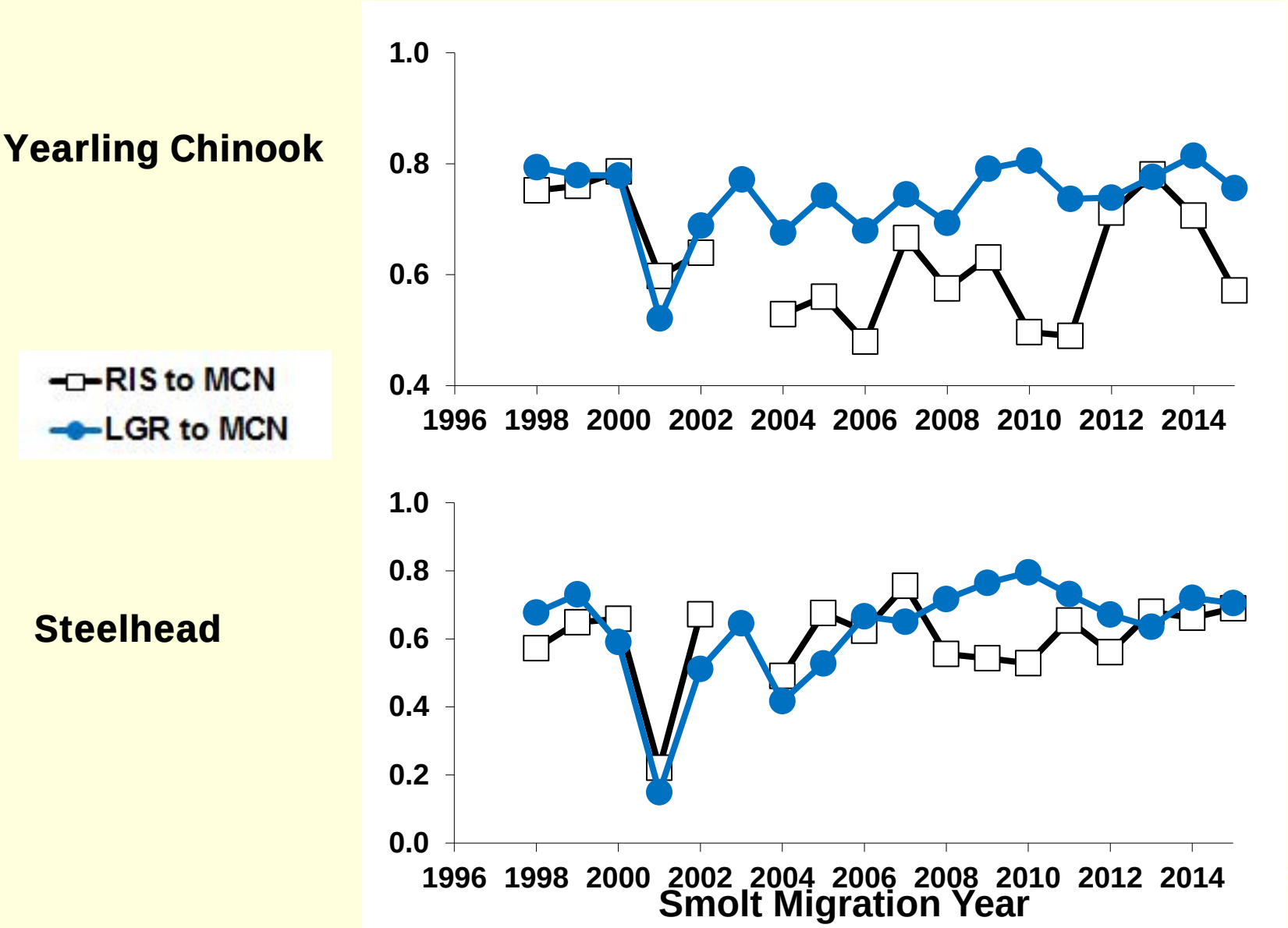
Reach Survival Comparison of Juvenile Salmon: Snake River to Upper Columbia Stocks



Conclusions

- Collaboration and coordination with marking efforts in the Upper Columbia are cost effective and provides a region-wide benefit
- Monitoring the effect of hydro system passage on Upper Columbia groups from existing marking is value added for managers
- An increase in the number of mark groups/tags and the number of detection sites will help strengthen the estimates

Conclusions

- The Upper Columbia (RIS-BON) and Snake River (LWG-BON) SAR for Chinook and steelhead trends are similar, but SAR are lower for the Upper Columbia
- Similar patterns of response to environmental variables (travel time, instantaneous mortality, & reach survivals) when compared to the Snake and Middle Columbia stocks
- Comparison of upper Columbia & Snake River sockeye survival will become more clear as the data series builds over time.

Next Up:

- Break! Reconvene at 10:25

SARs and Juvenile Metrics of Upper Columbia Stocks

Dan Rawding (WDFW)

CSS Annual Meeting April 3, 2017

CSS Objectives: Upper Columbia

- Establish long term survival estimates over the full life-cycle of upper Columbia stocks

- Develop Smolt to Adult Return rates (SARs) from the upper most dam encountered

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- Low abundance of smolts makes it difficult to tag enough fish for a specific population
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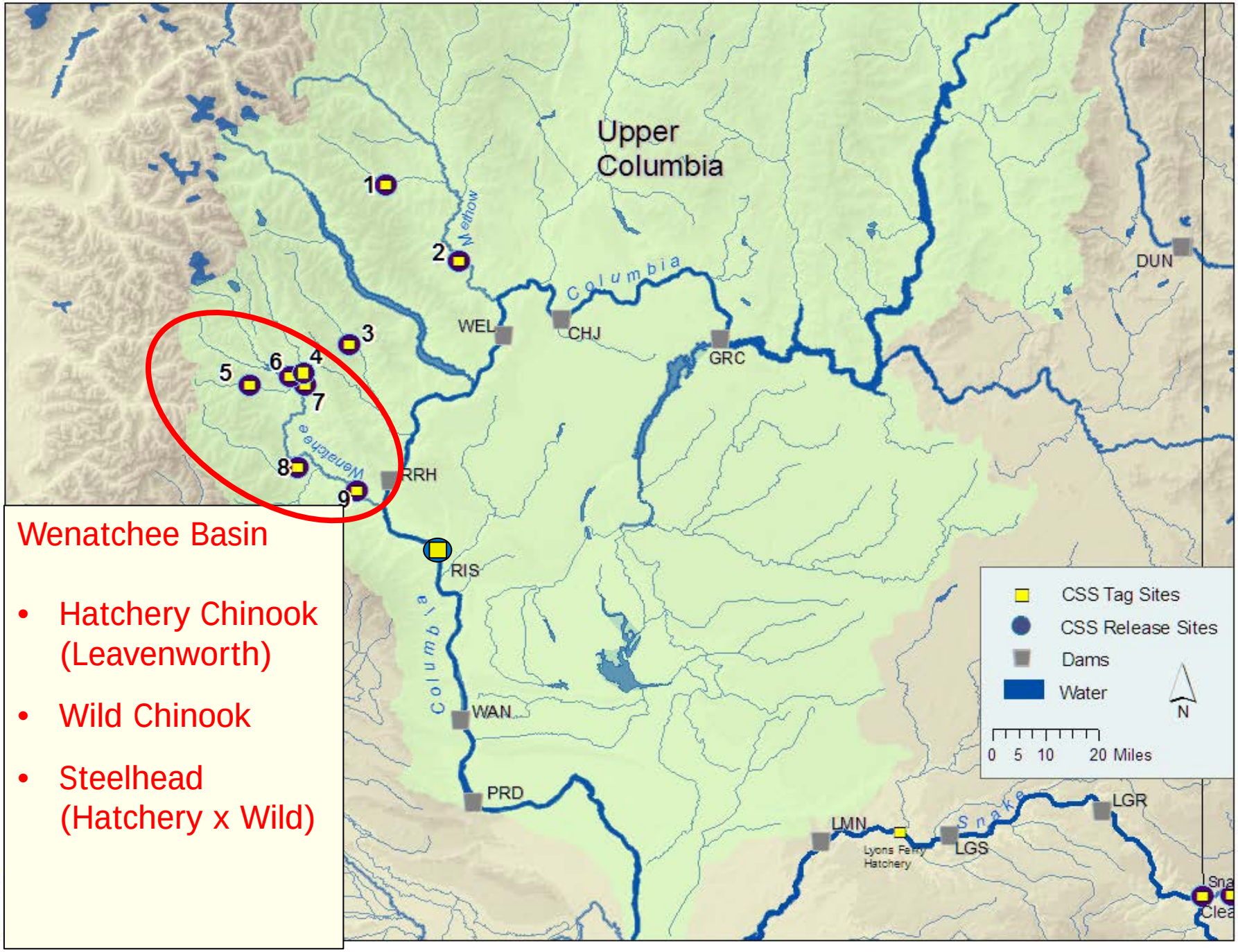

Wenatchee Basin

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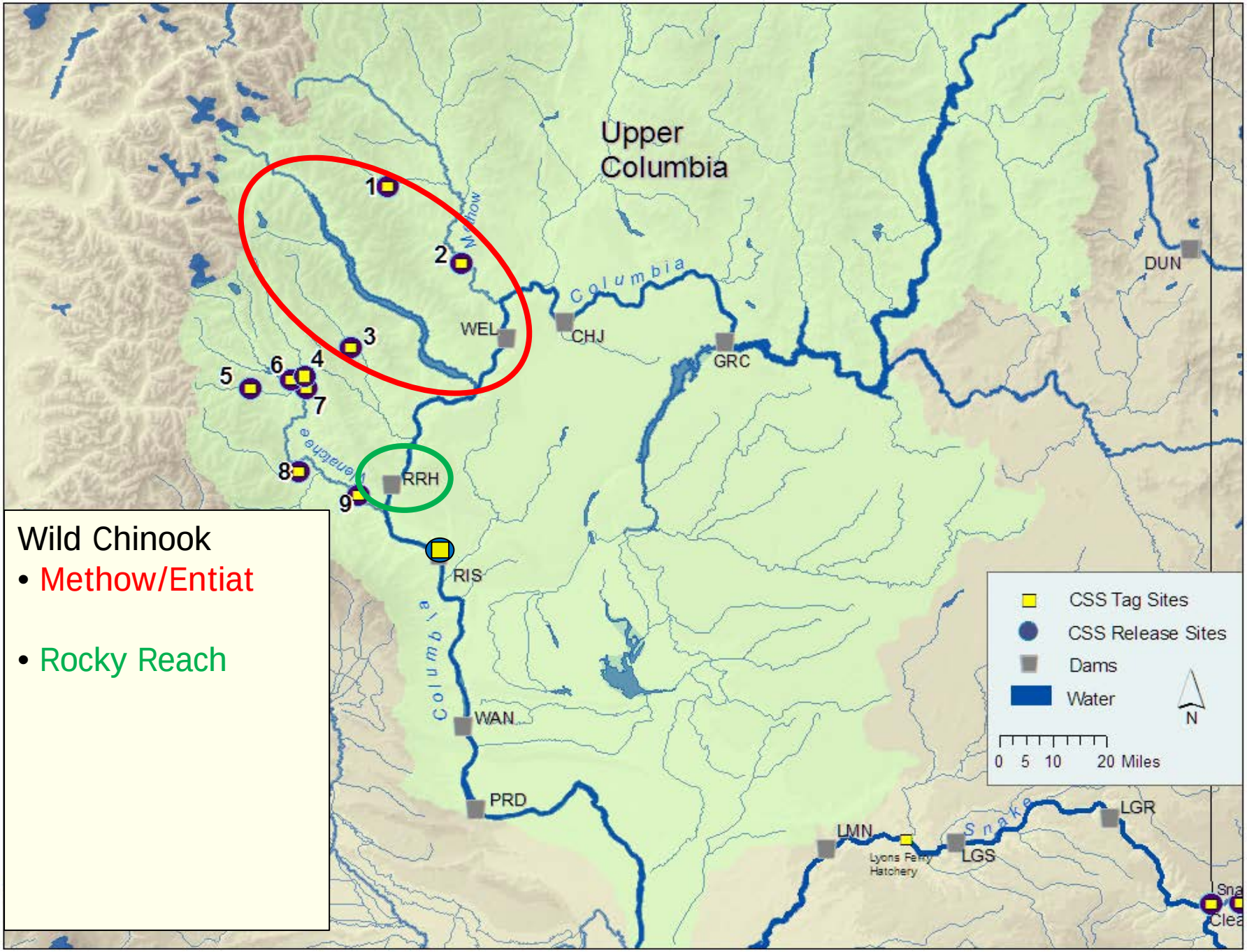
- Steelhead (Hatchery x Wild)



Wild Chinook

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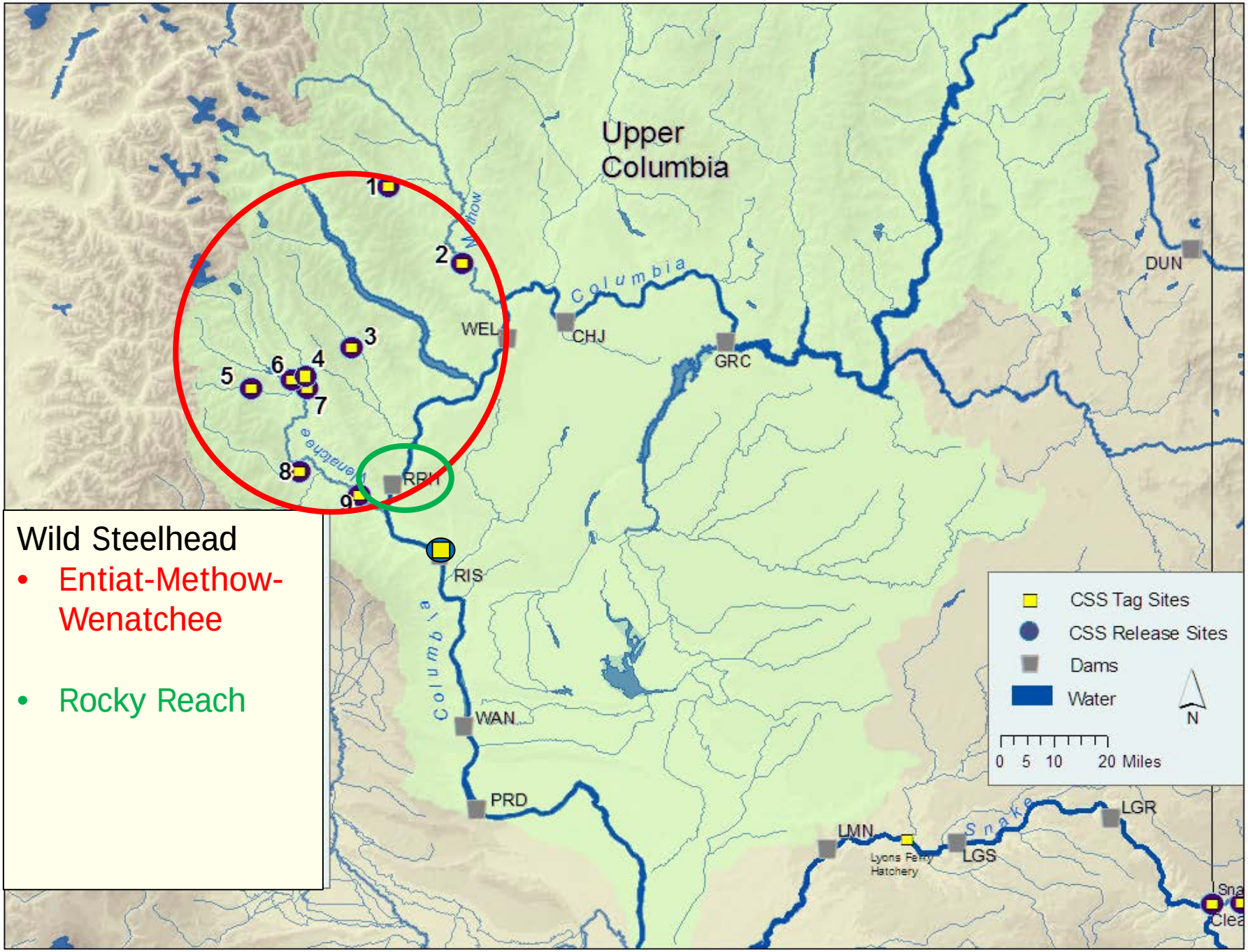

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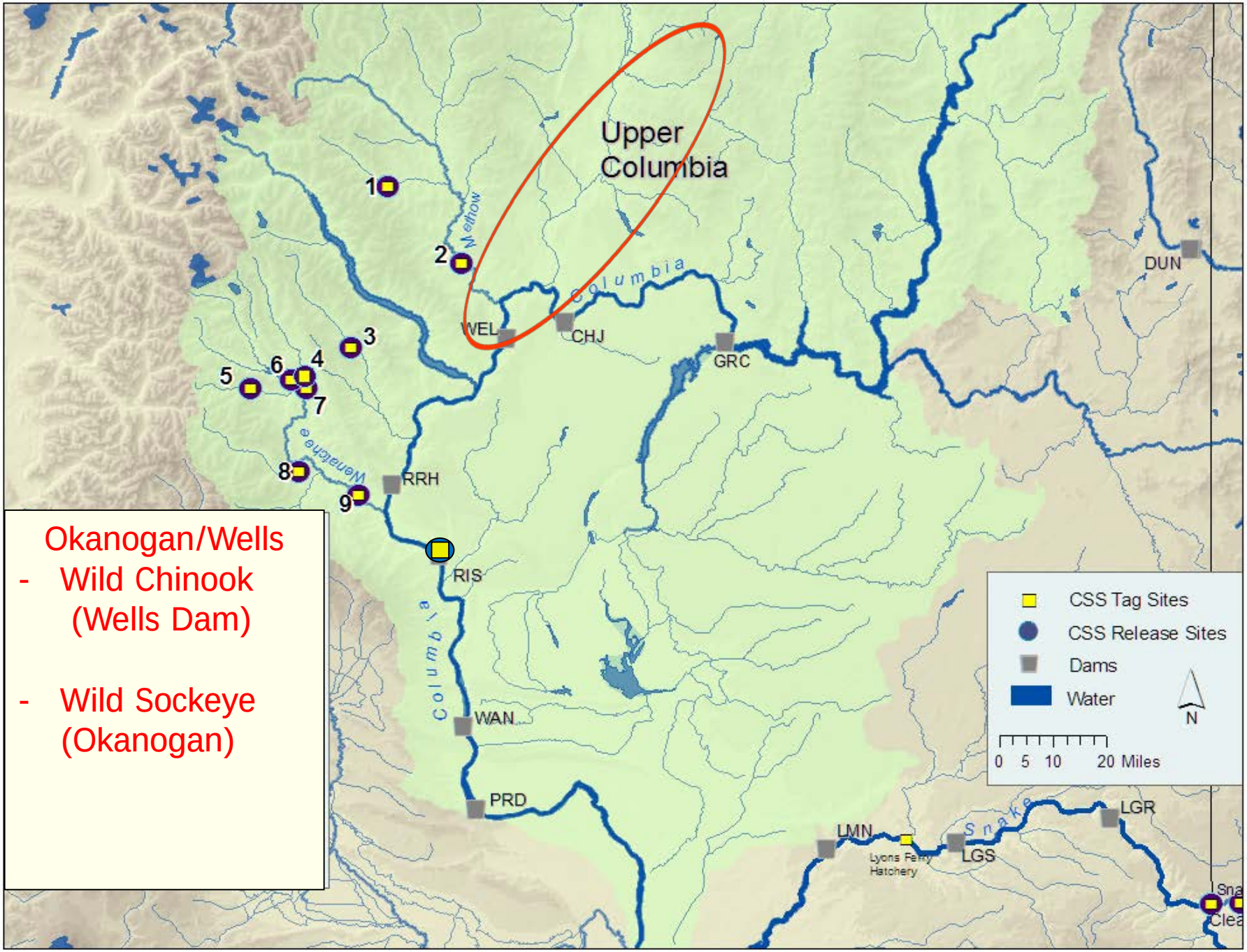
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1
2
3
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5
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7
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9
Methow
Columbia
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WEL
CHJ
GRC
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N
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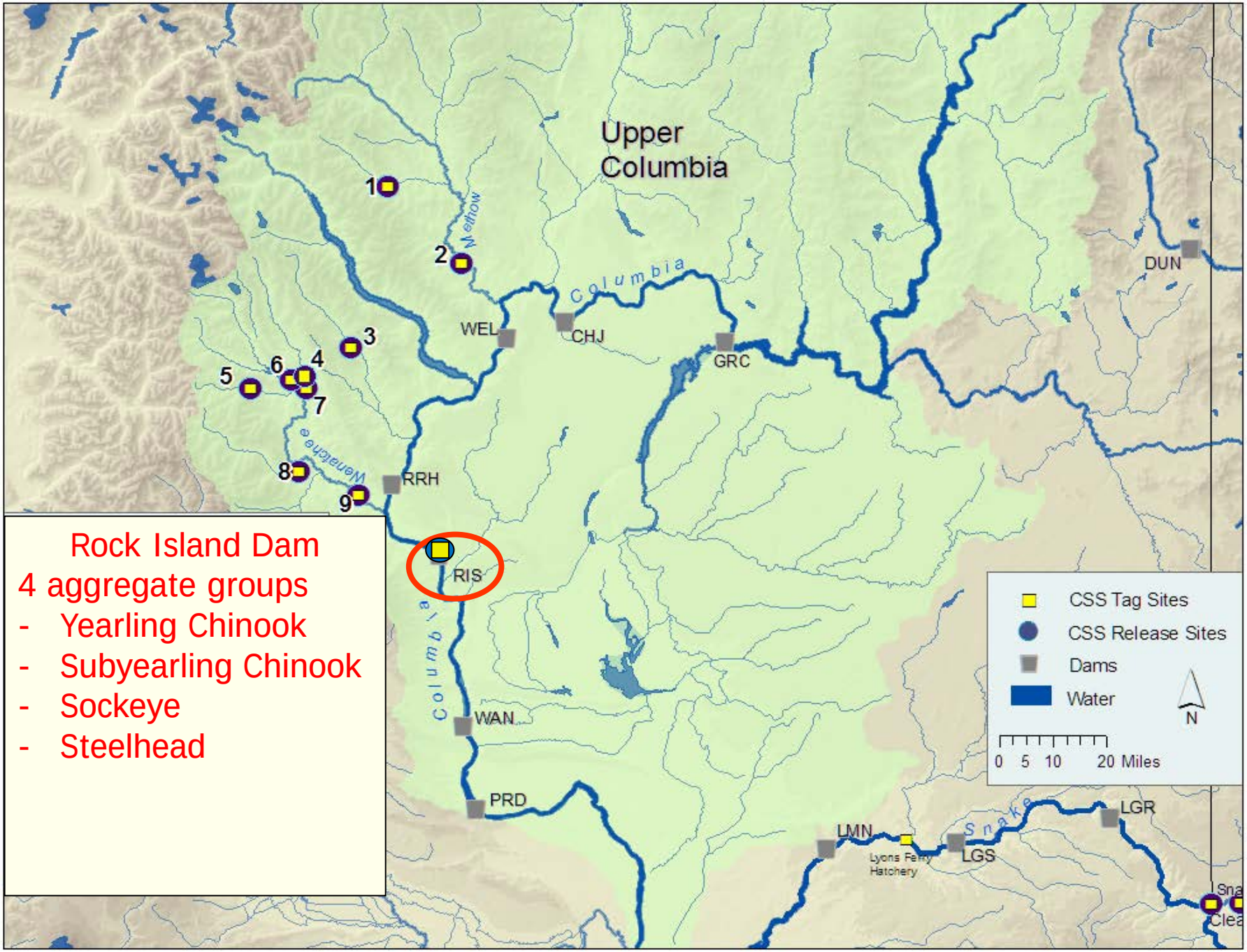

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4 aggregate groups

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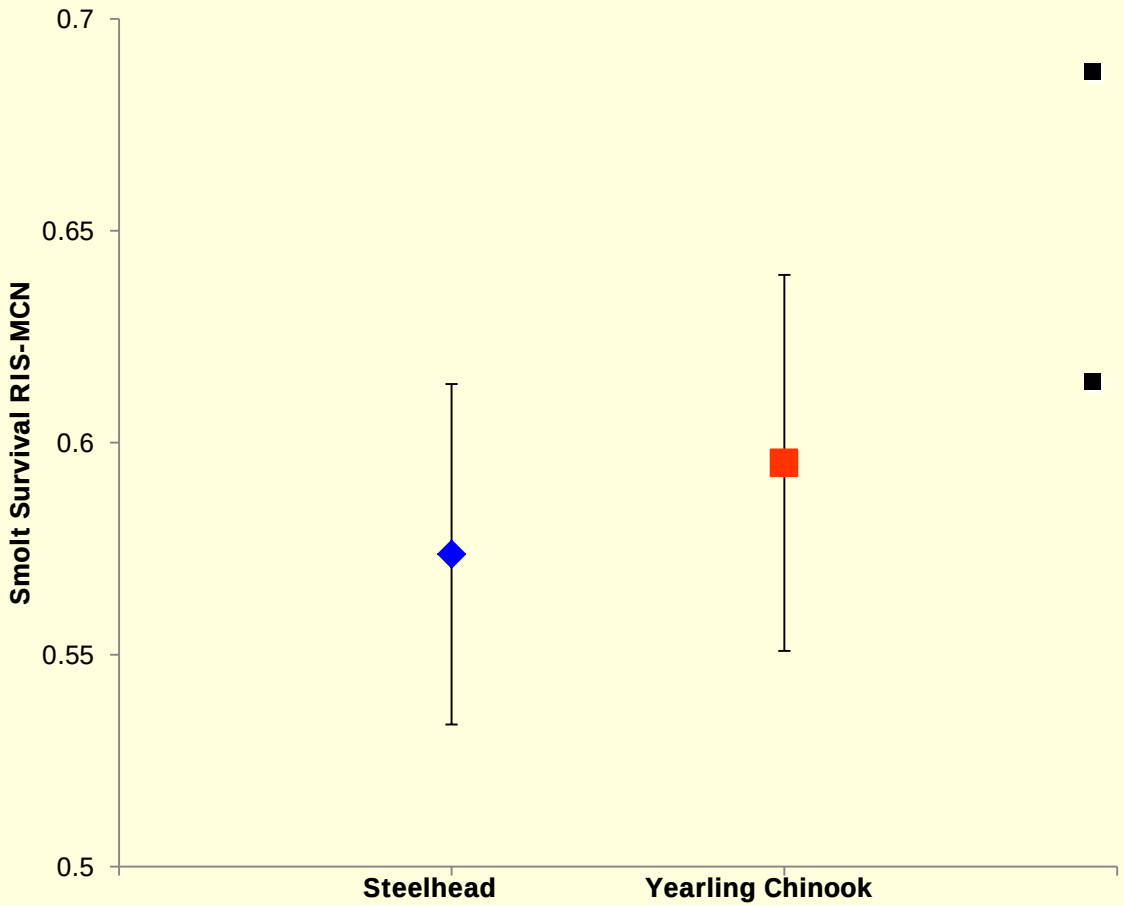

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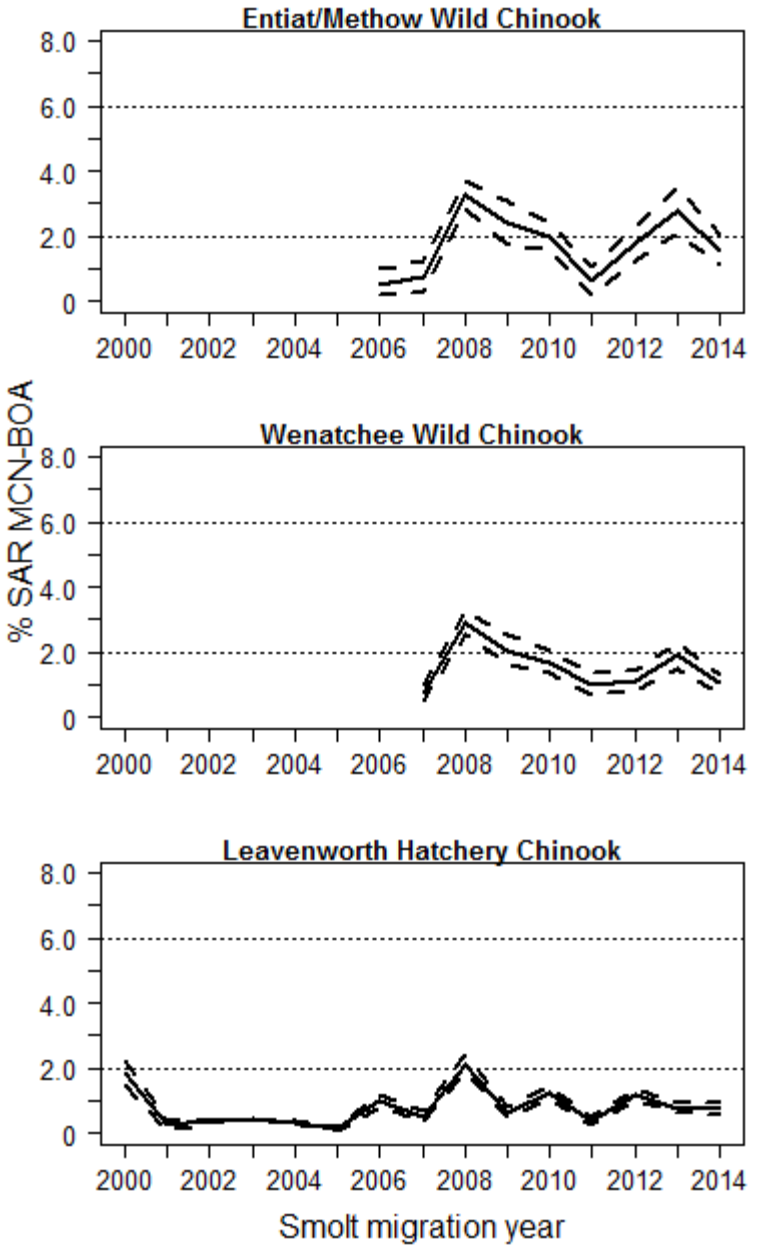

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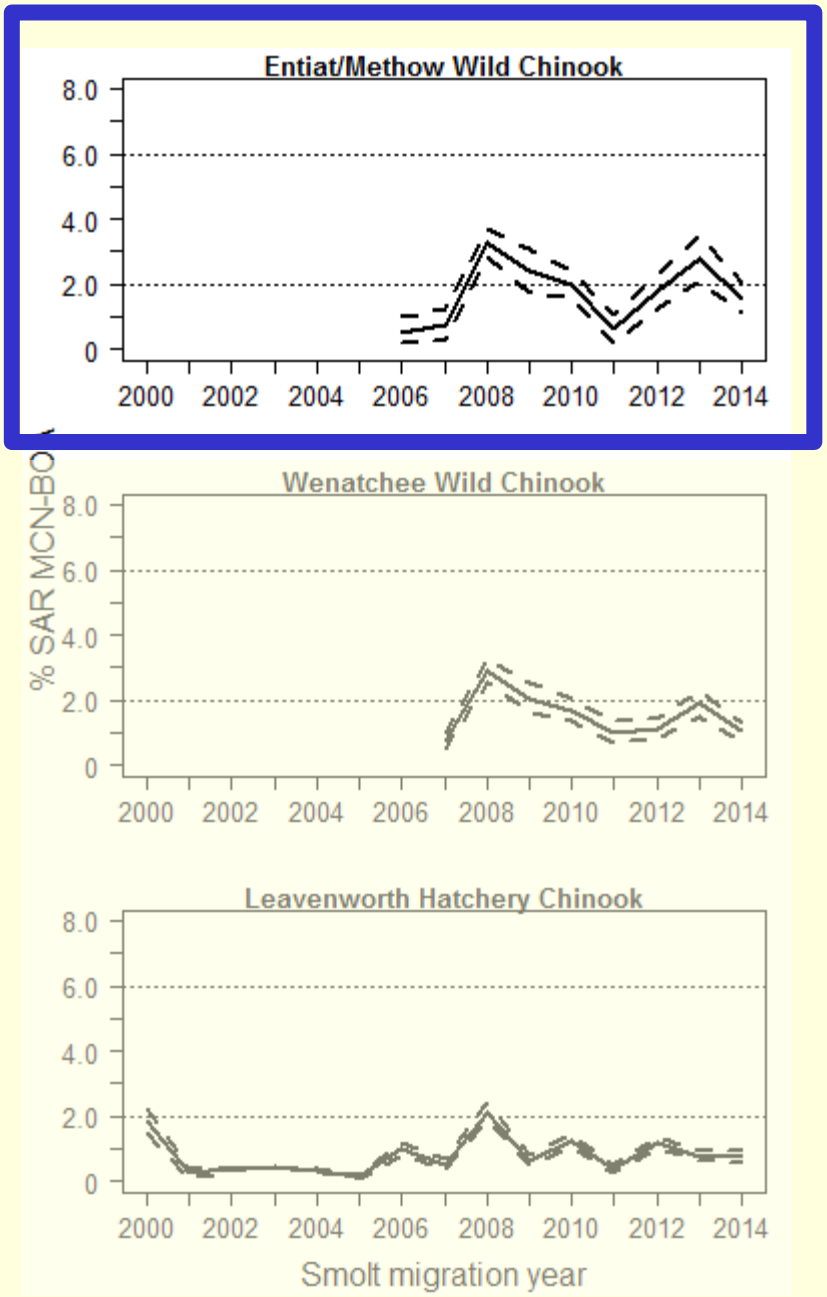

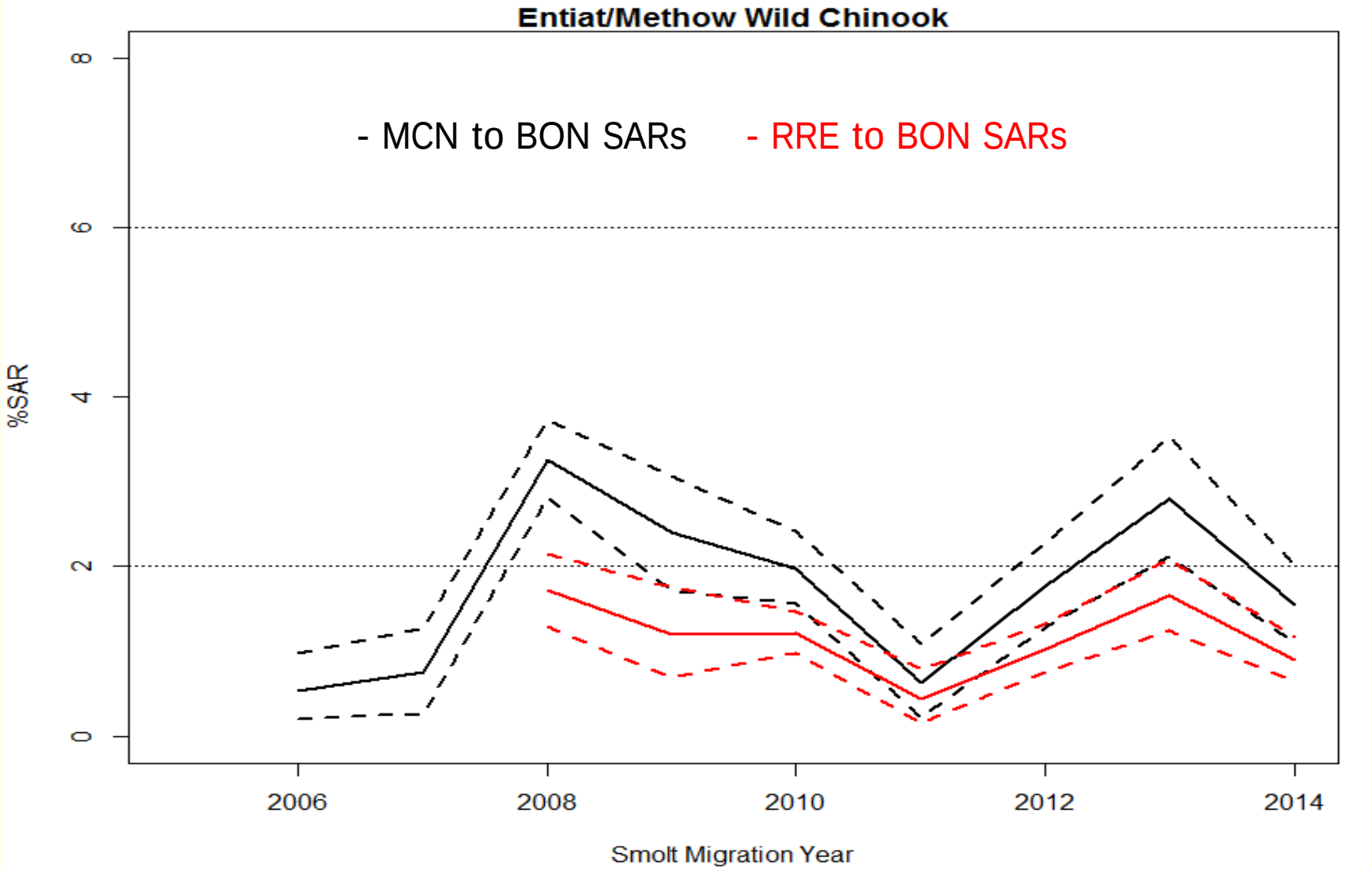

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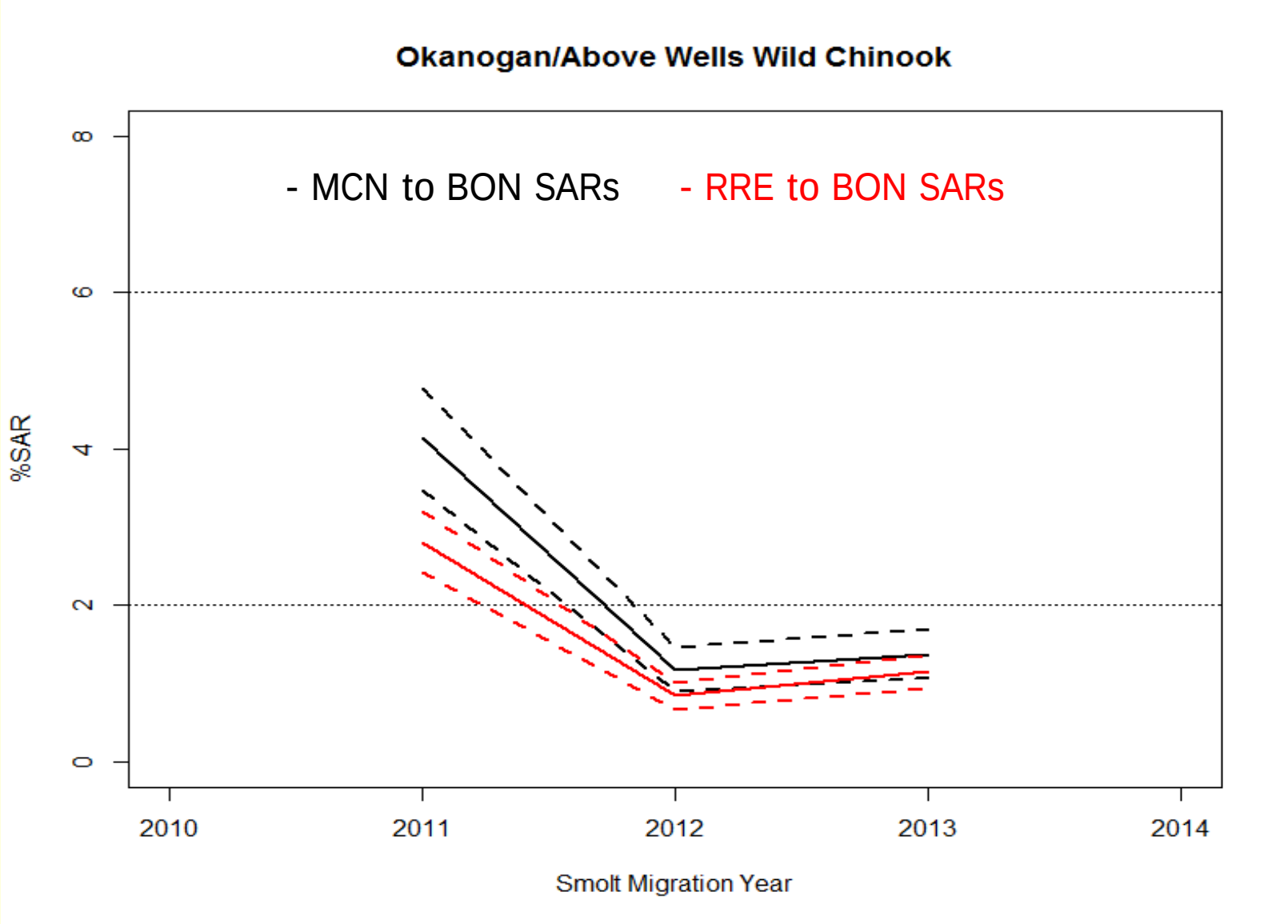

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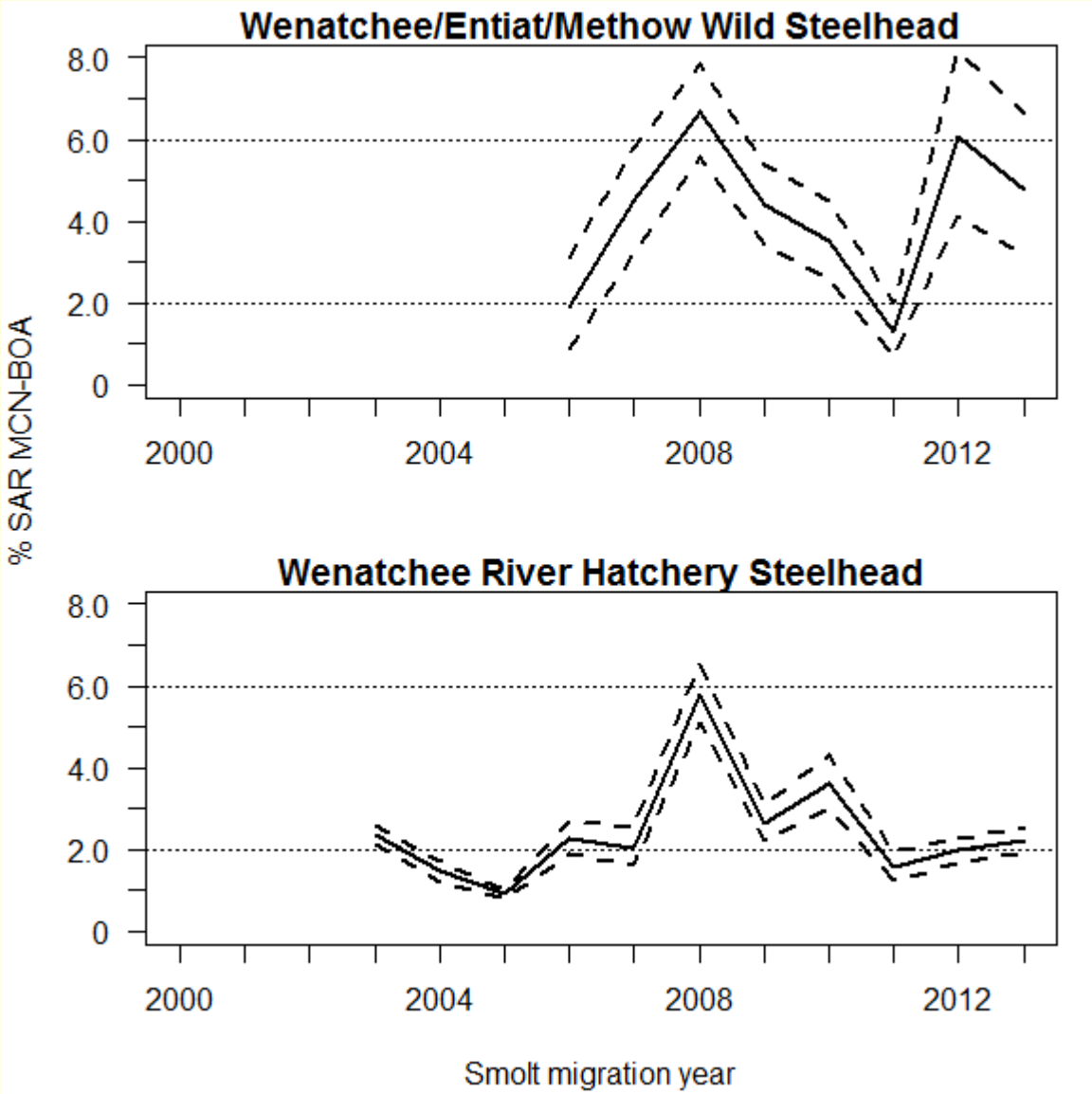

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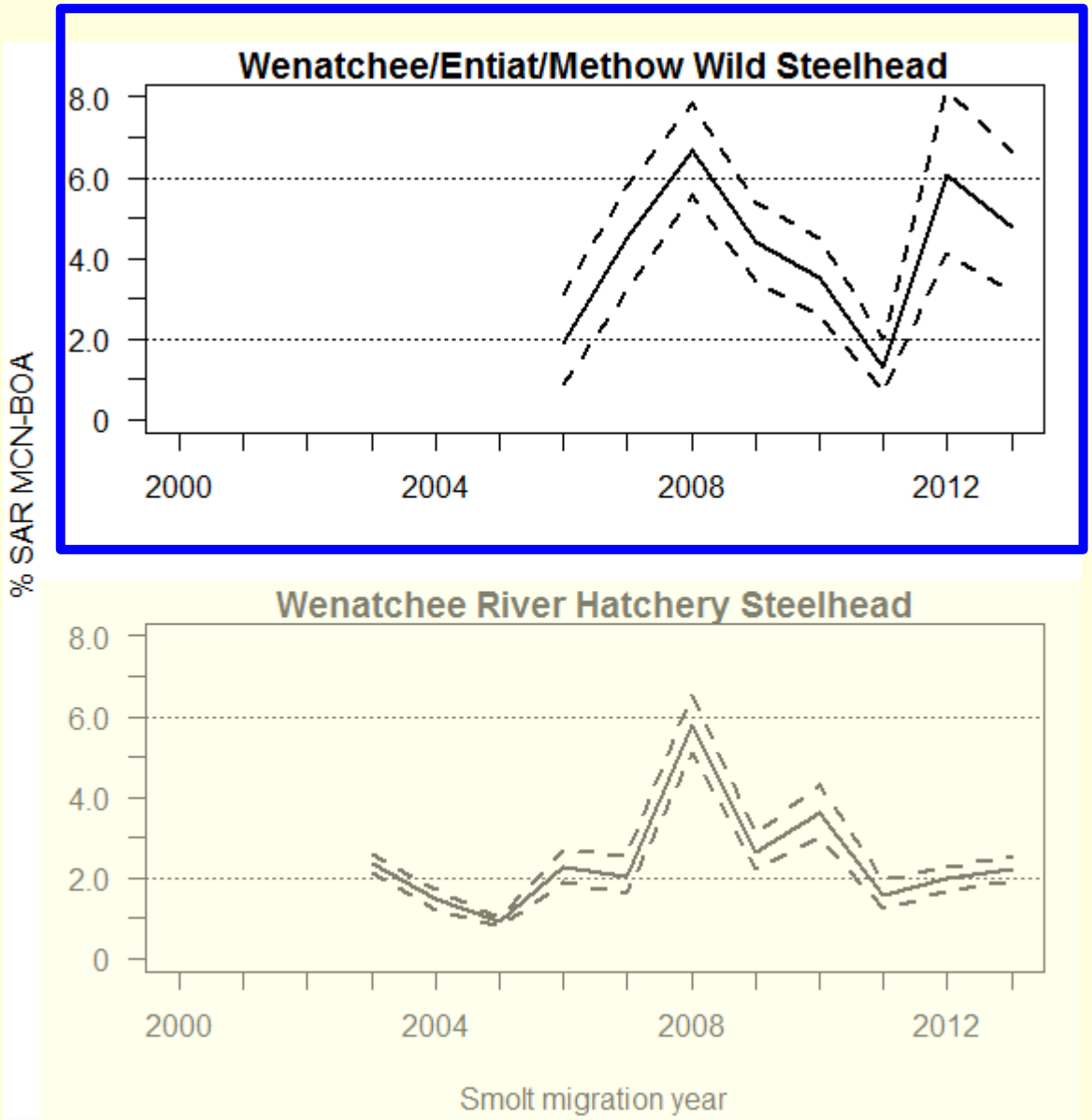

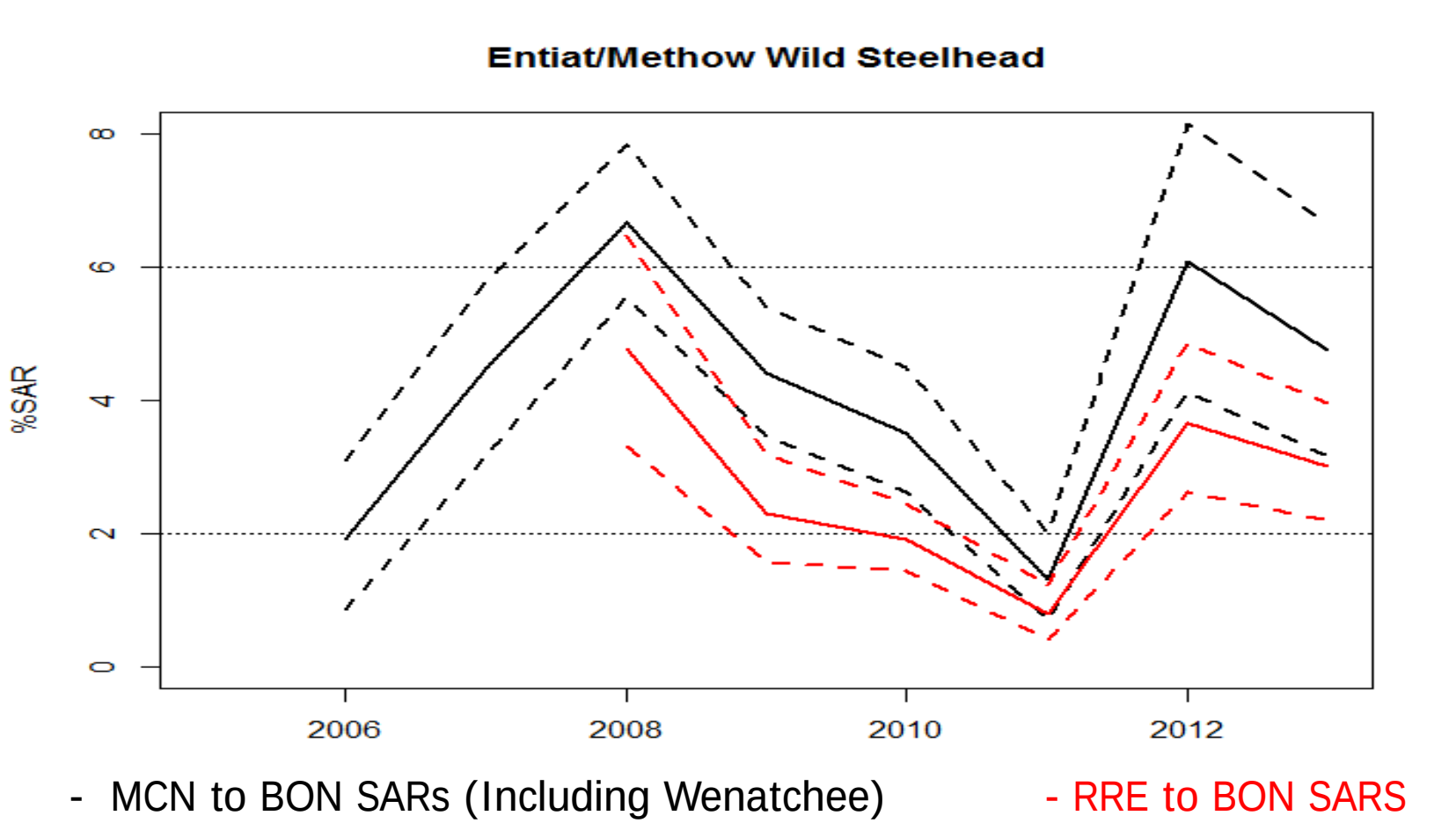

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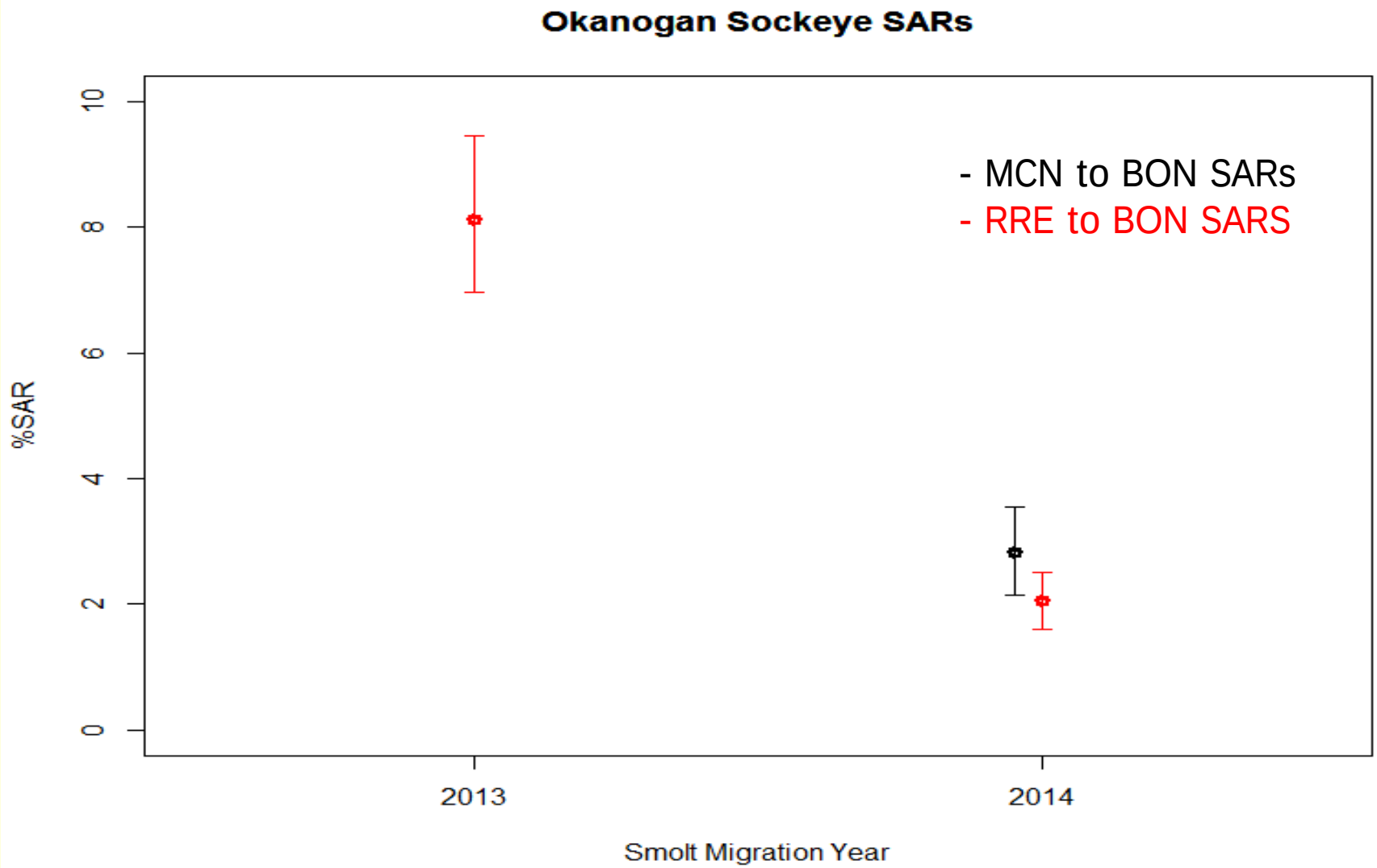


- New group in 2016 CSS Report with limited data

RIS to BON SARs
Chinook and Steelhead

Yearling Chinook

- Hatchery and wild aggregate
- SARs averaged 0.4%

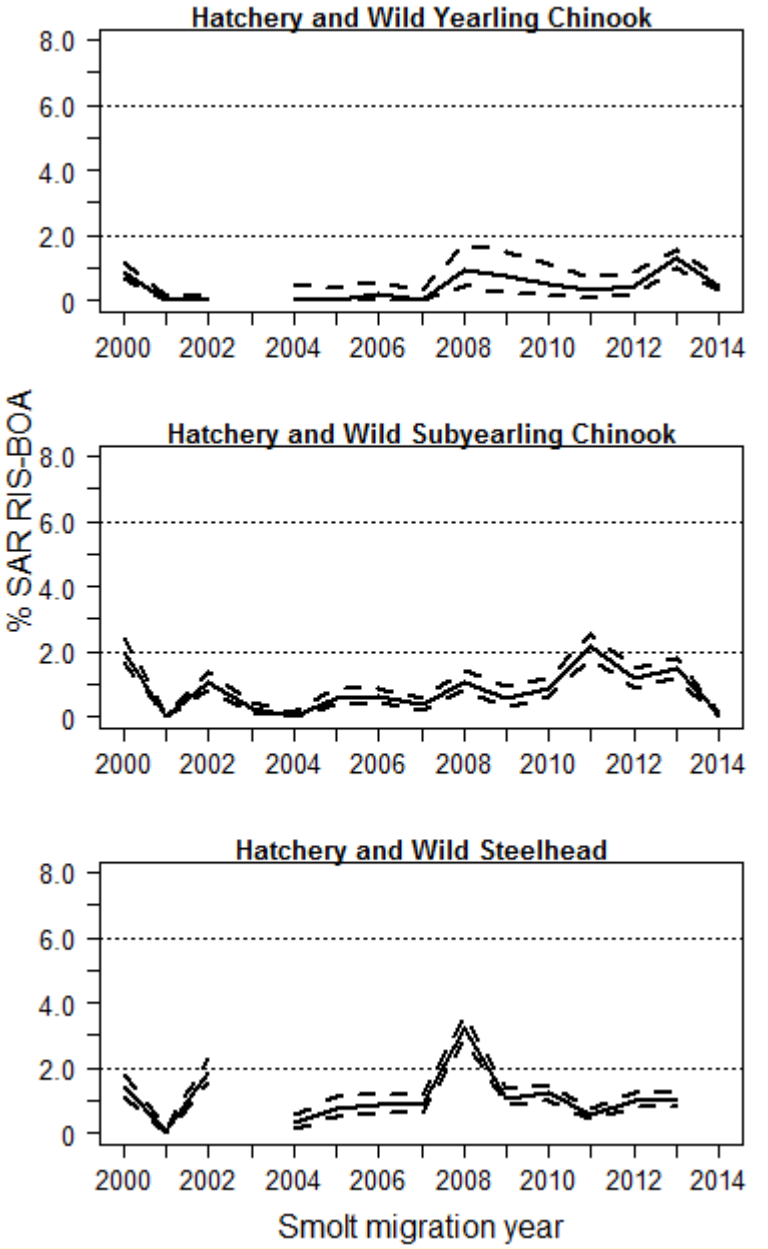
Subyearling Chinook

- Hatchery and wild aggregate
- SARs averaged 0.8%

Steelhead

- Hatchery and wild aggregate
- SARs averaged 1.1%

**Bypass inoperable during spring of 2003 – no data*

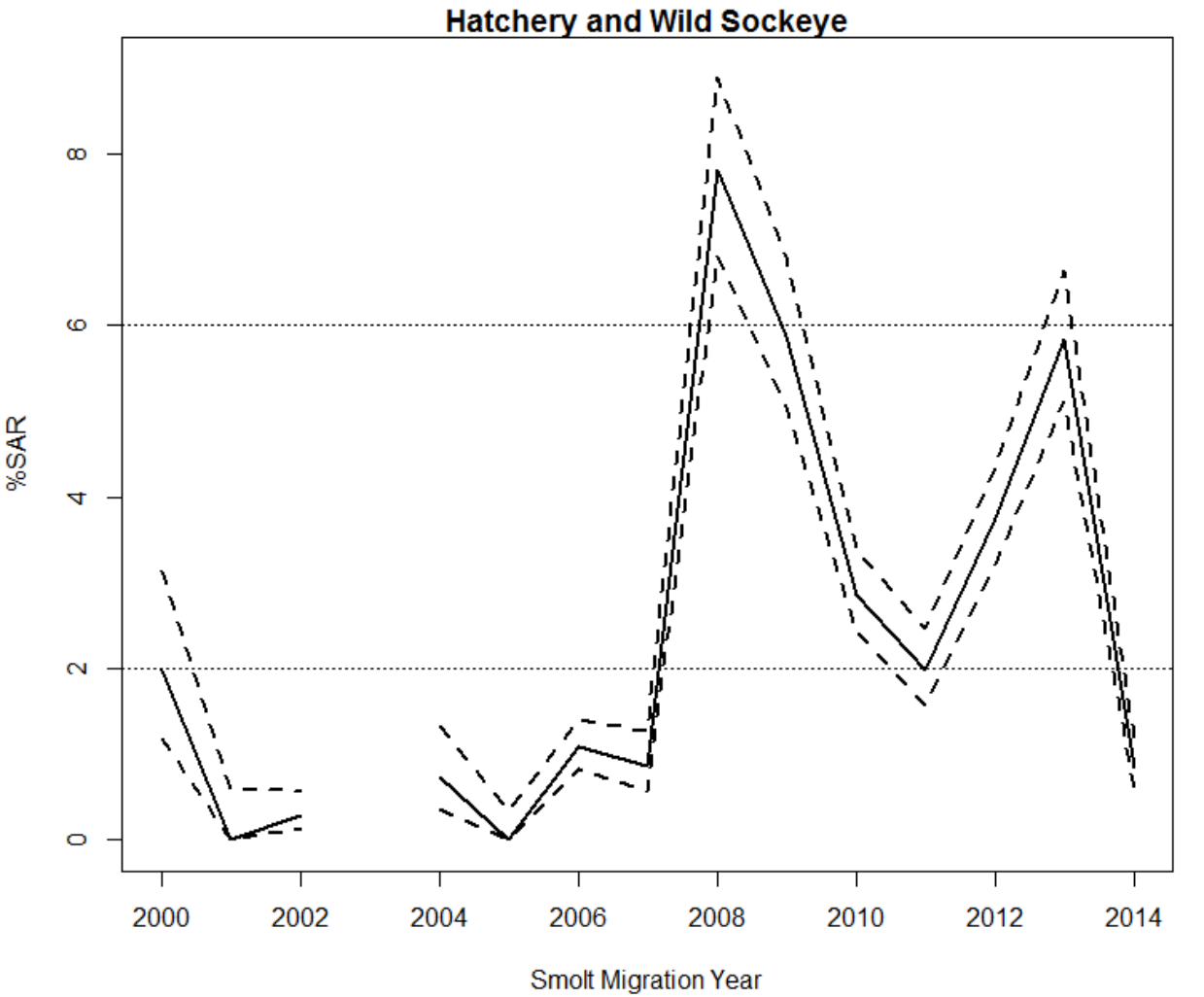


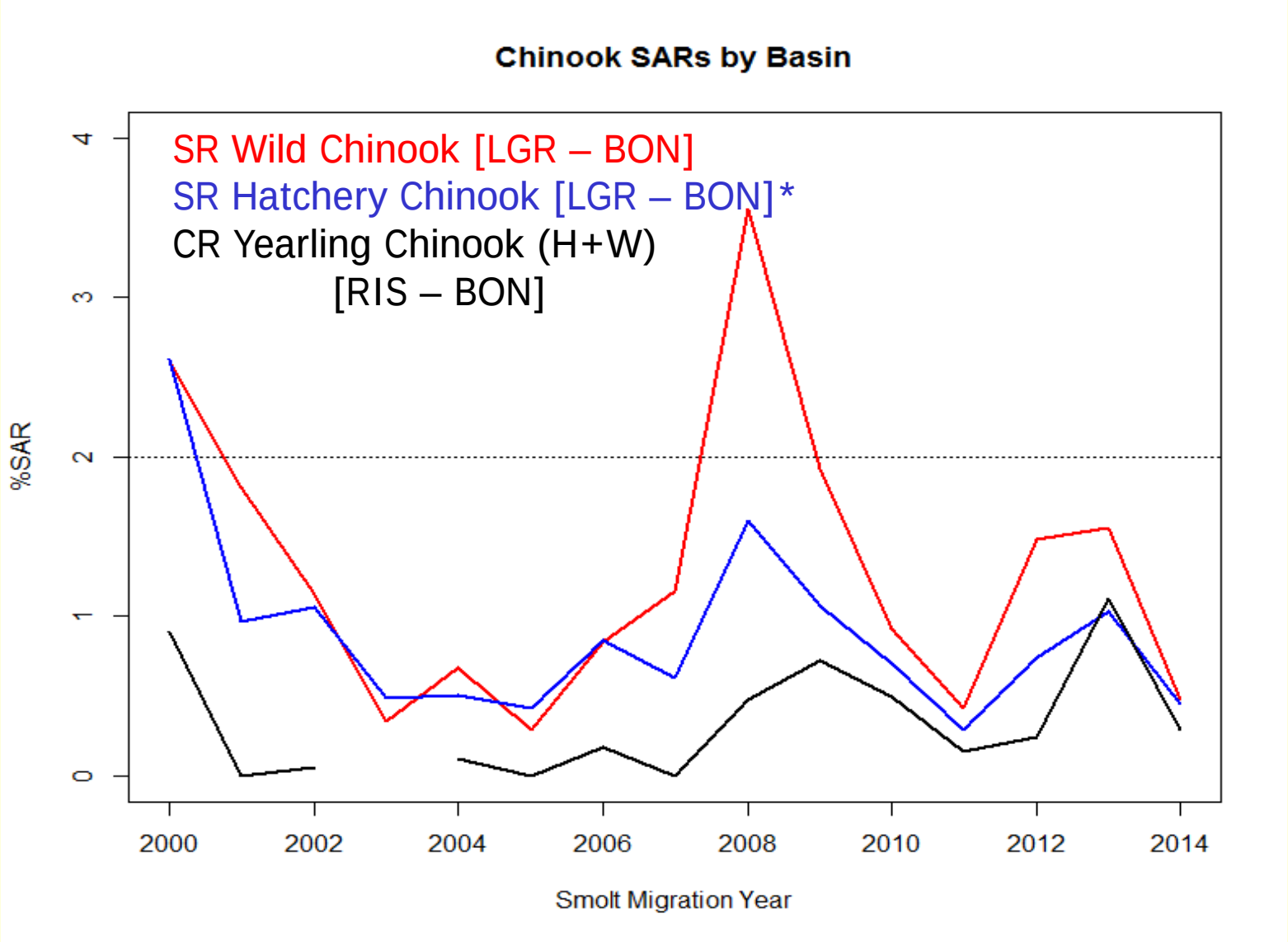
RIS to BON SARs
Sockeye

Sockeye

- Hatchery and Wild combined
- SARs averaged 2.4%
- Data part of CSS Report since 2014

**Bypass inoperable during spring of 2003 – no data*

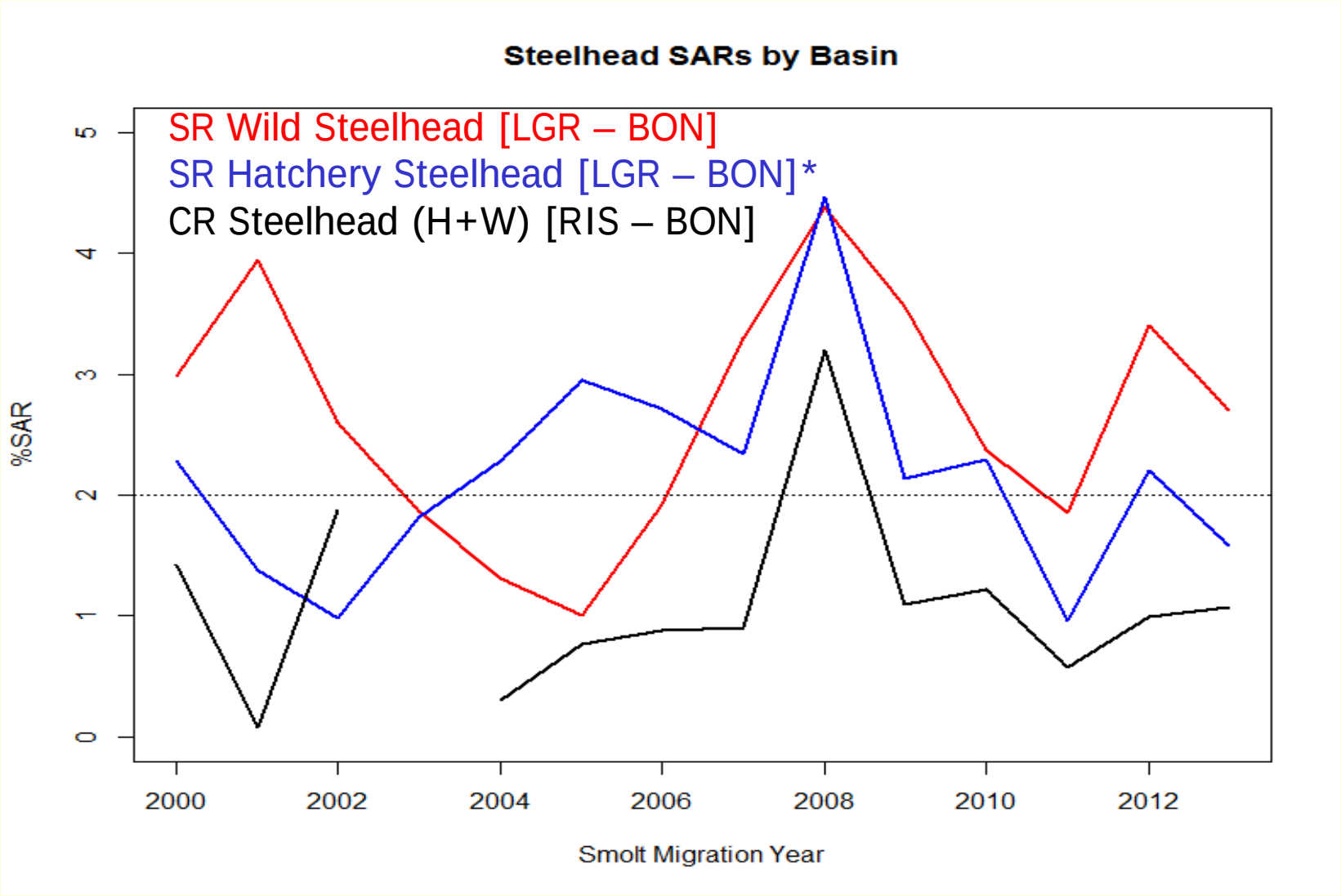




LGR to BON is approximately 286 miles [7 dams]

RIS to BON is approximately 308 miles [6 dams]

*Snake River Hatchery Chinook is a weighted average of annual hatchery specific estimates



LGR to BON is approximately 286 miles [7 dams]

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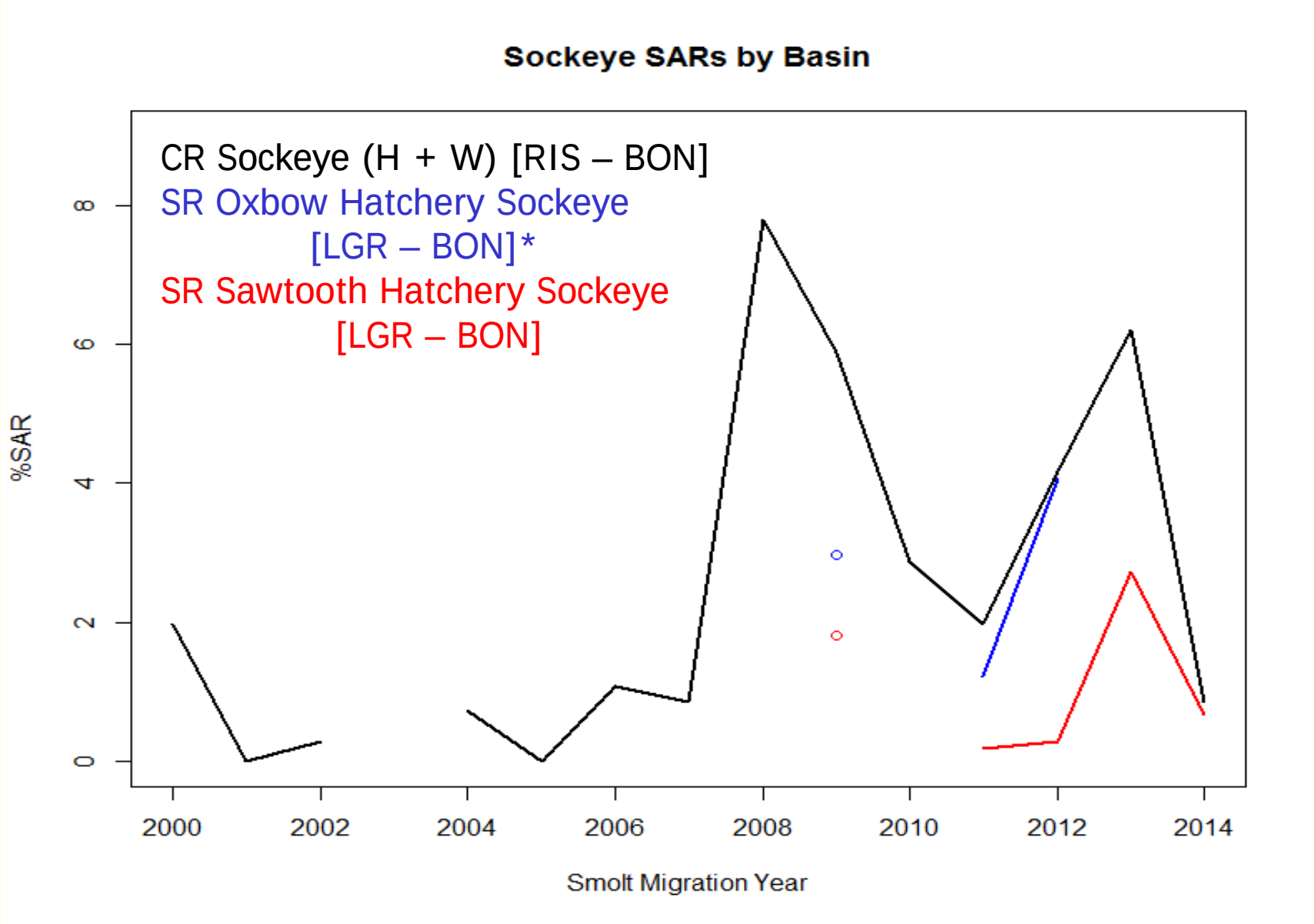
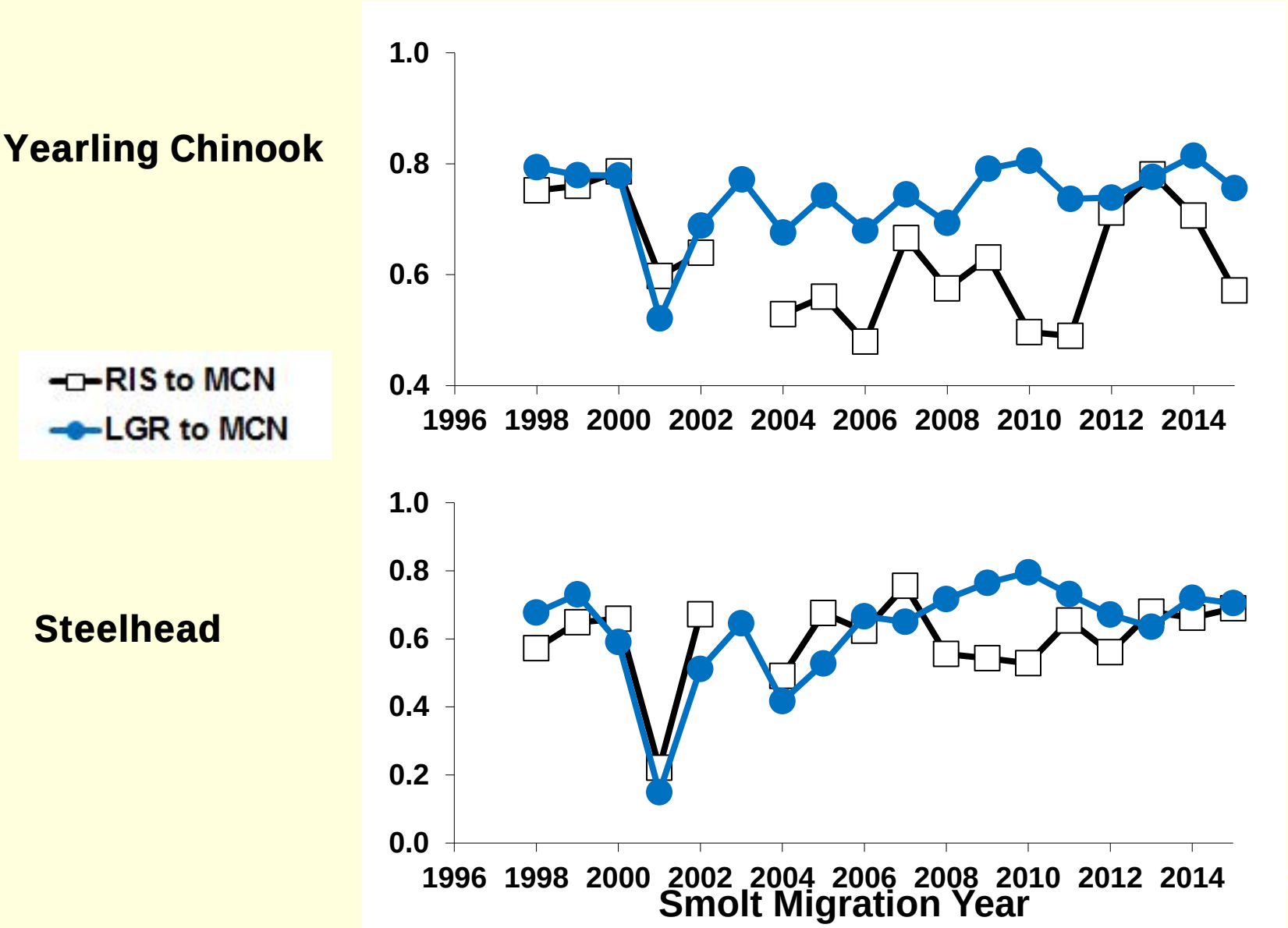
*Snake River Hatchery Steelhead 2000 – 2012 are averages of annual hatchery specific estimates



LGR to BON is approximately 286 miles [7 dams]
RIS to BON is approximately 308 miles [6 dams]
*No SARs calculated for Oxbow Hatchery for migration year 2010

Reach Survival Comparison of Juvenile Salmon: Snake River to Upper Columbia Stocks



Conclusions

- Collaboration and coordination with marking efforts in the Upper Columbia are cost effective and provides a region-wide benefit
- Monitoring the effect of hydro system passage on Upper Columbia groups from existing marking is value added for managers
- An increase in the number of mark groups/tags and the number of detection sites will help strengthen the estimates

Conclusions

- The Upper Columbia (RIS-BON) and Snake River (LWG-BON) SAR for Chinook and steelhead trends are similar, but SAR are lower for the Upper Columbia
- Similar patterns of response to environmental variables (travel time, instantaneous mortality, & reach survivals) when compared to the Snake and Middle Columbia stocks
- Comparison of upper Columbia & Snake River sockeye survival will become more clear as the data series builds over time.

Next Up:

- Break! Reconvene at 10:25

Snake River Fall Chinook

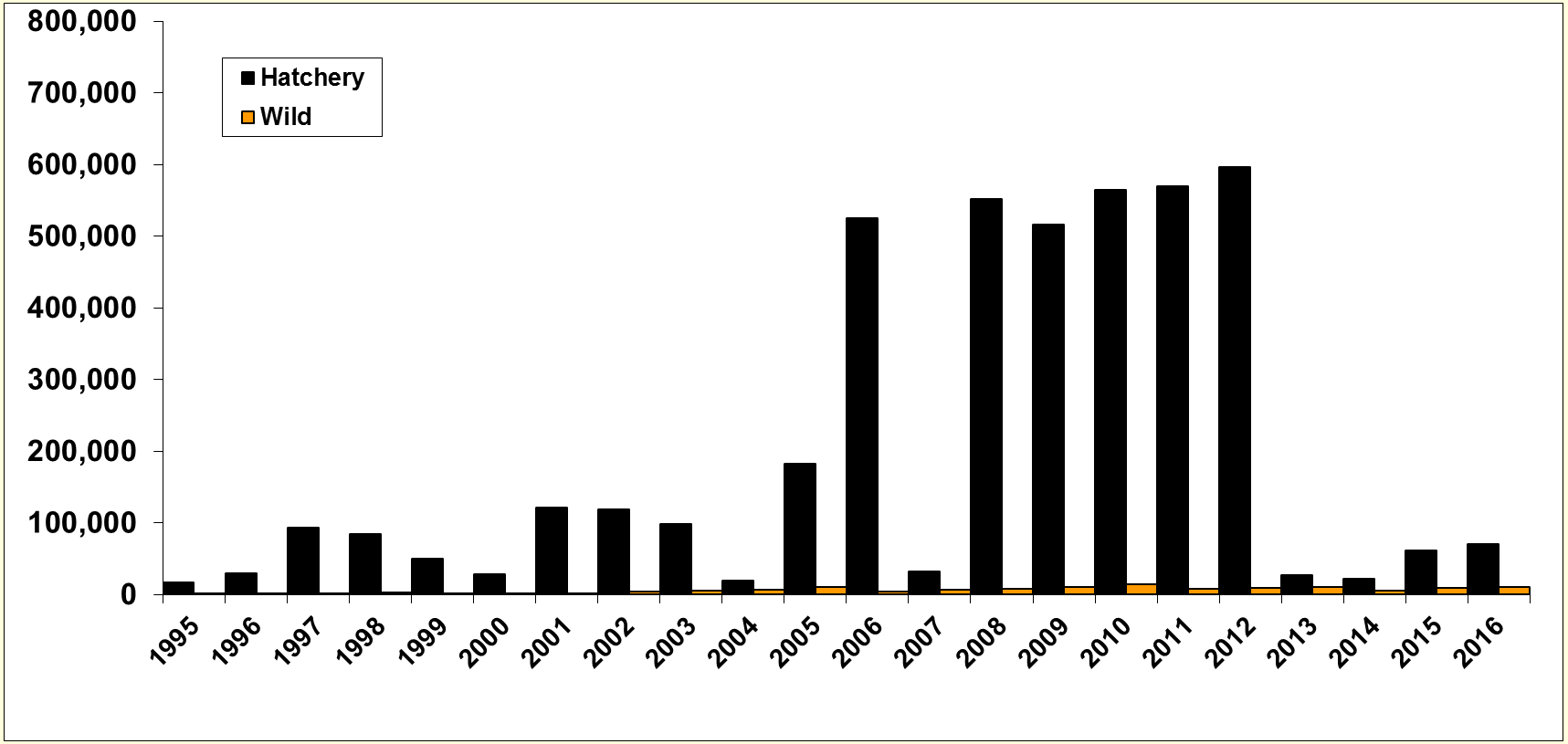
CSS Annual Meeting Apr 2017

Presenter: Jerry McCann

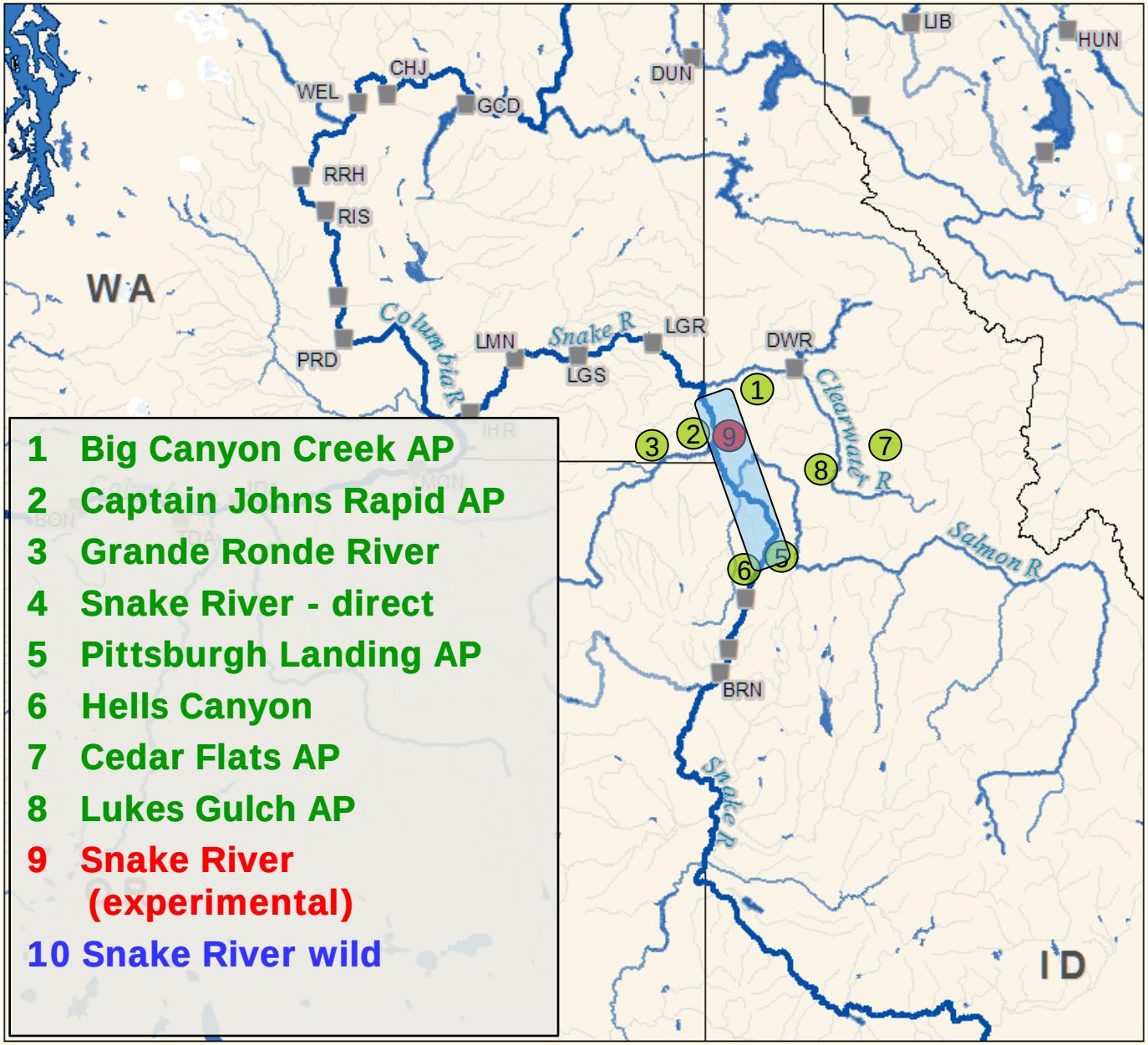
Background

- CSS was requested to develop estimates of subyearling fall Chinook SARs.
- The goal was to use CSS bootstrap methods to estimate and compare SARs for transported fish and in-river fish--applied to fall Chinook.
- Nearly all groups could be analyzed. –Nearly all subyearling production releases and in some years Snake River wild PIT tag groups could be analyzed with CSS approach.
- SARs have been developed for the years 2006 through 2012. Seven years of SARs but in 2007 marking was limited (no SARs by study category).
- Nez Perce have marked approximately 45,000 subyearlings in 2015 and 2016

Subyearling fall Chinook PIT-tag marking above Lower Granite Dam



Subyearling Fall Chinook PIT-tag Releases



Summary of Juvenile Fall Chinook Survival
Lower Granite to McNary

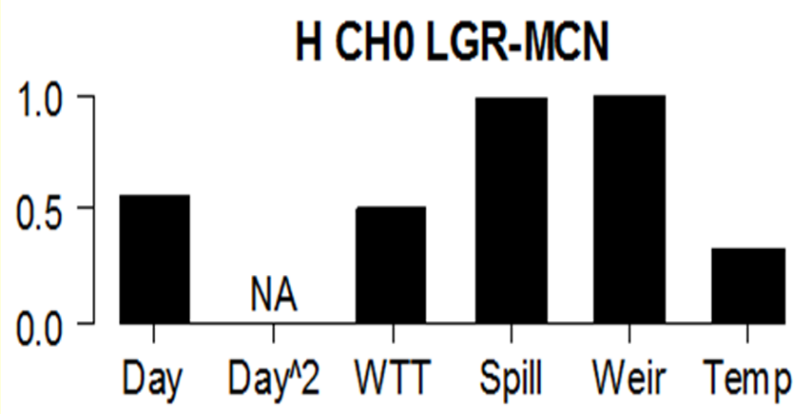
- Juvenile passage metrics (Lower Granite Dam to McNary Dam from 1998 to 2015)
  - Travel time
  - Survival
  - Instantaneous mortality

- Environmental variables were analyzed relative to passage metrics.
  - WTT, Avg. Spill, Surface Passage, Temperature, Day of year.

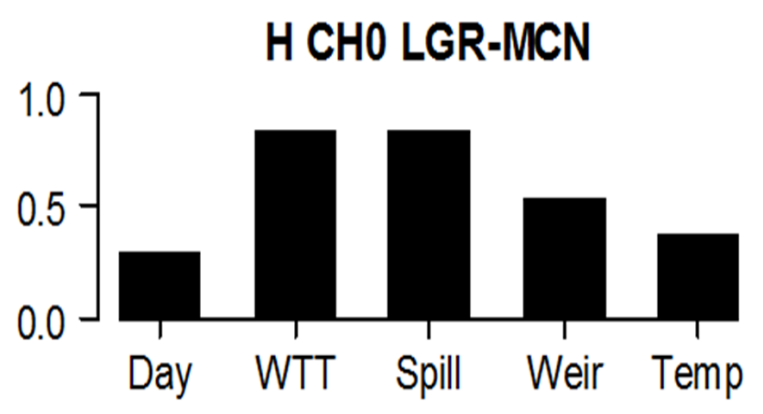
Summary of Juvenile Fall Chinook Survival
Lower Granite to McNary

- Spill, Surface Passage and WTT were the most important factors in explaining variability in fish passage metrics.

Fish Travel Time



Inst. Mortality Rate



Adaptive Management Experiments:
Hatchery Fall (subyearling) Chinook salmon

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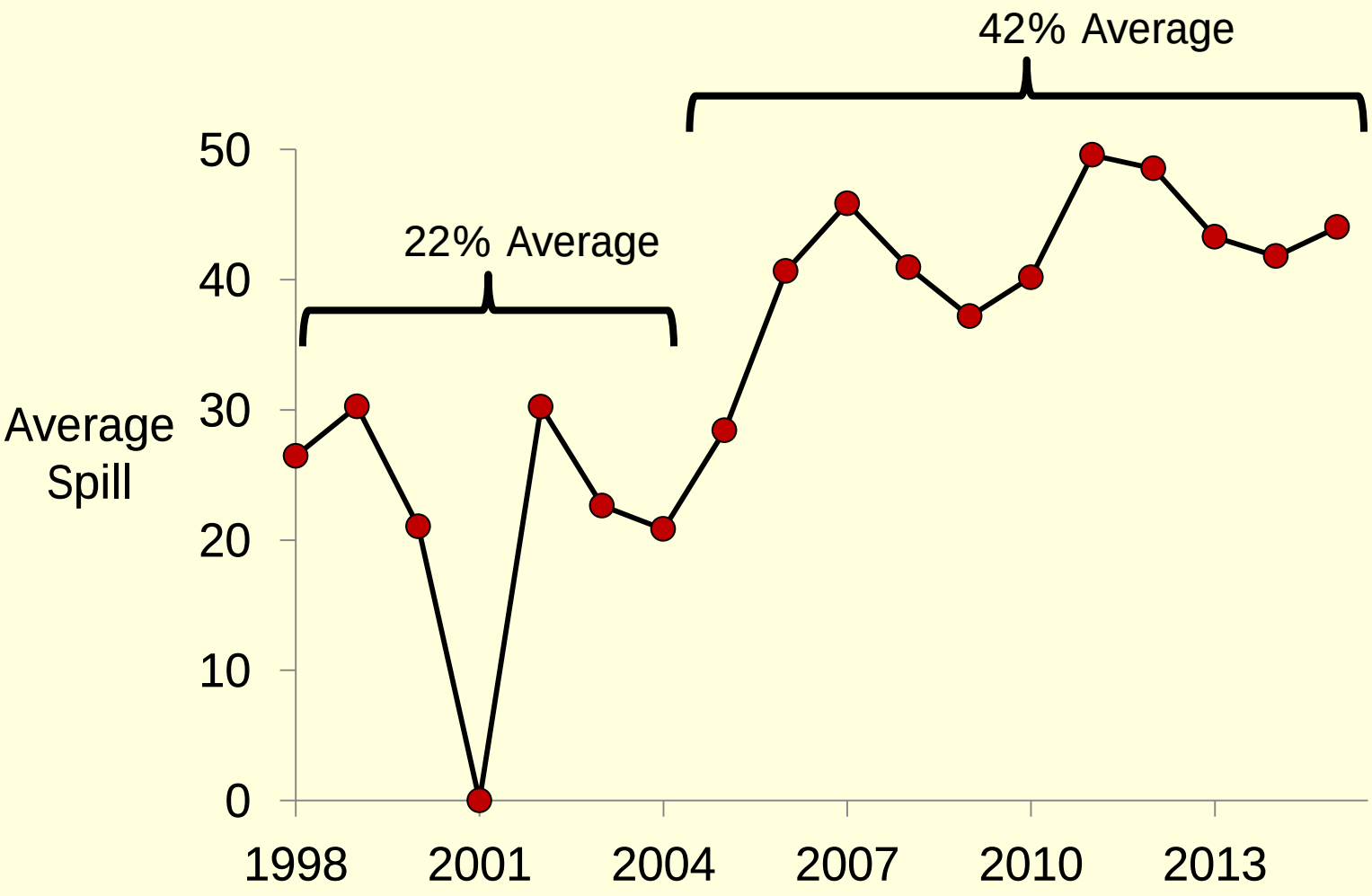
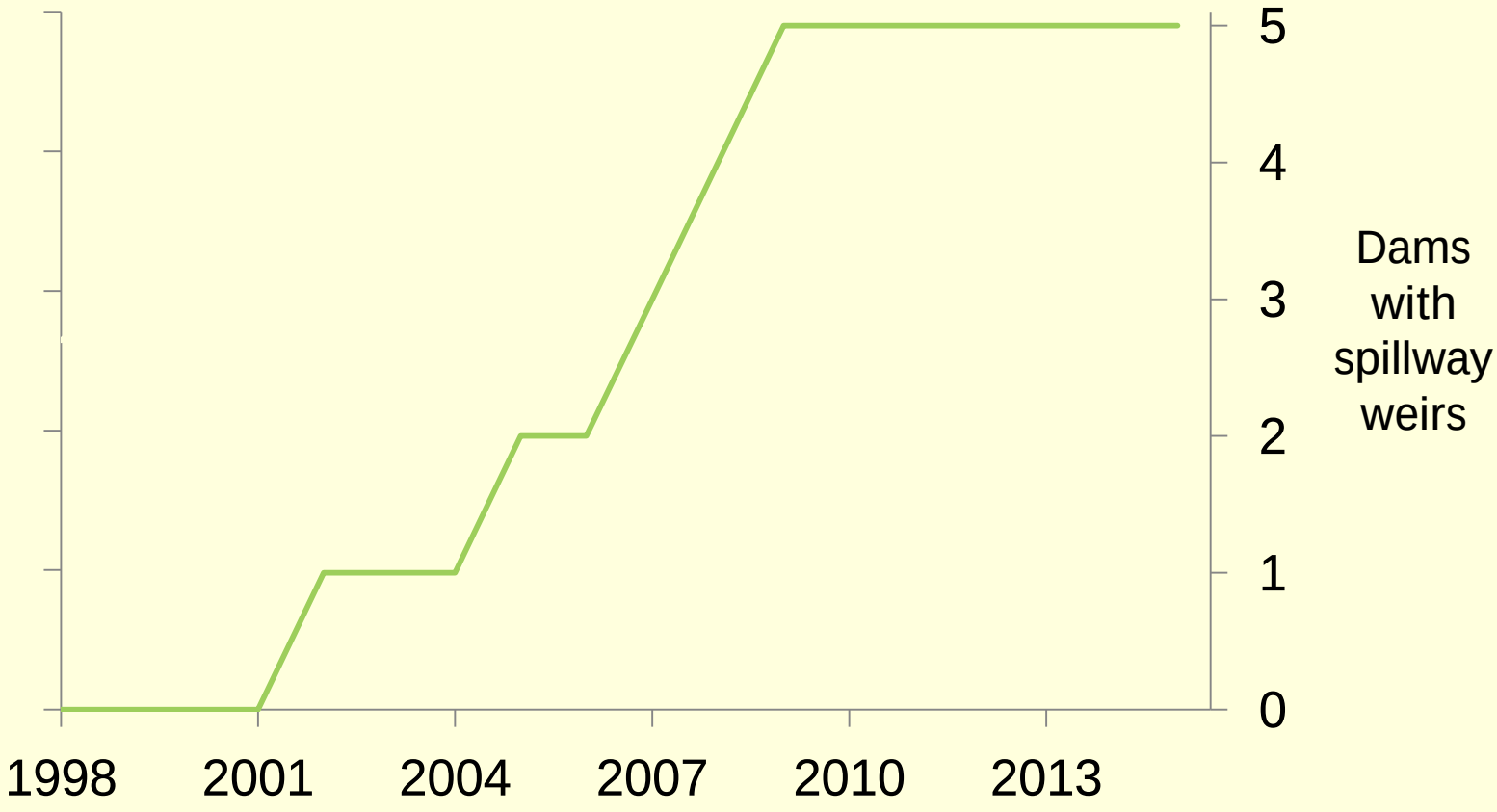
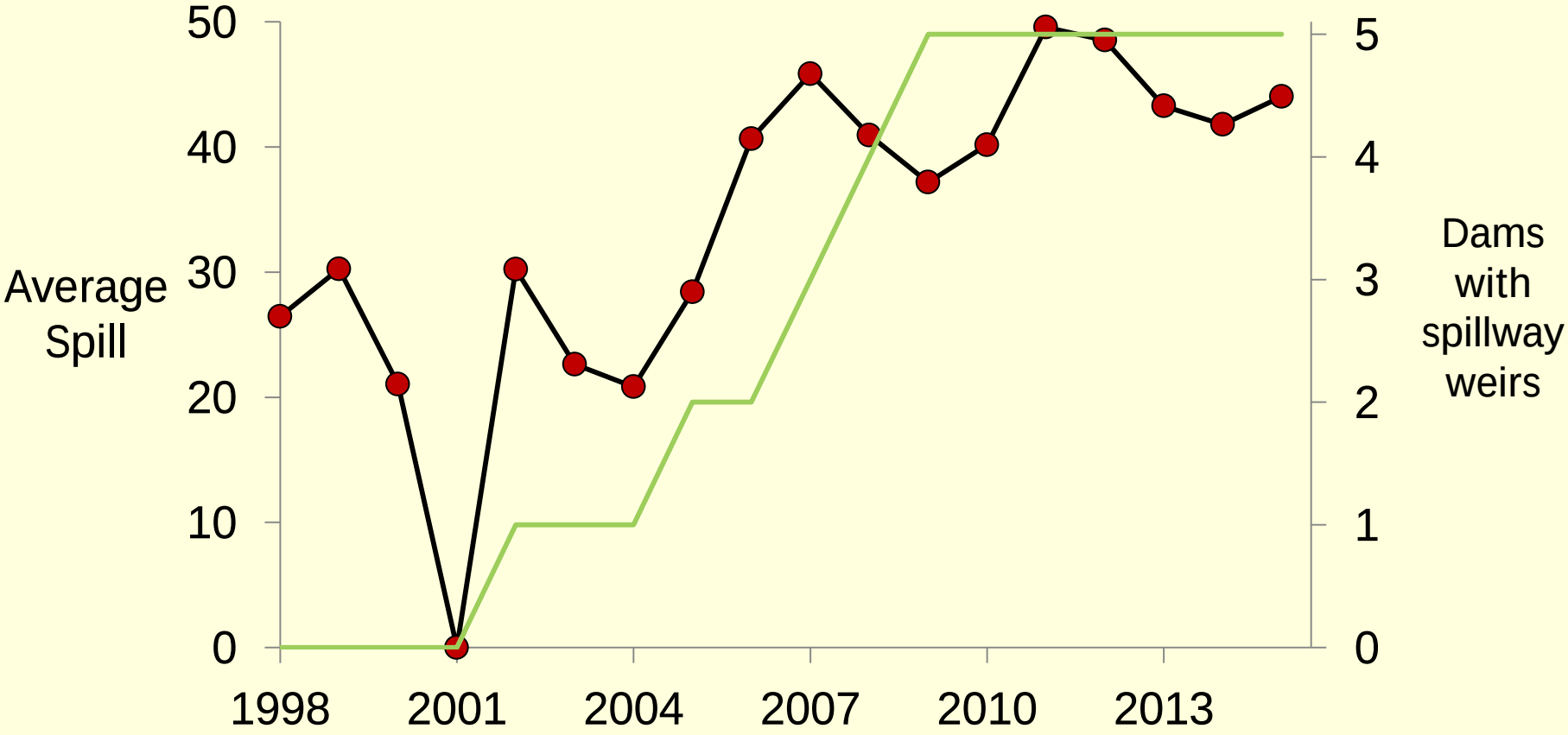
Hatchery Fall (subyearling) Chinook salmon



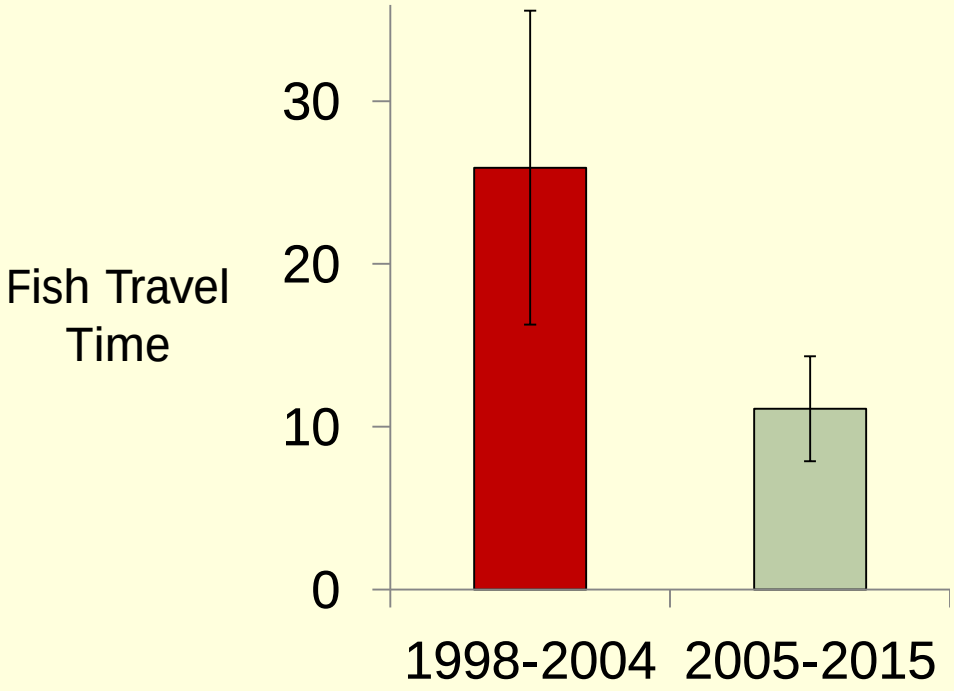
Adaptive Management Experiments:
Hatchery Fall (subyearling) Chinook salmon



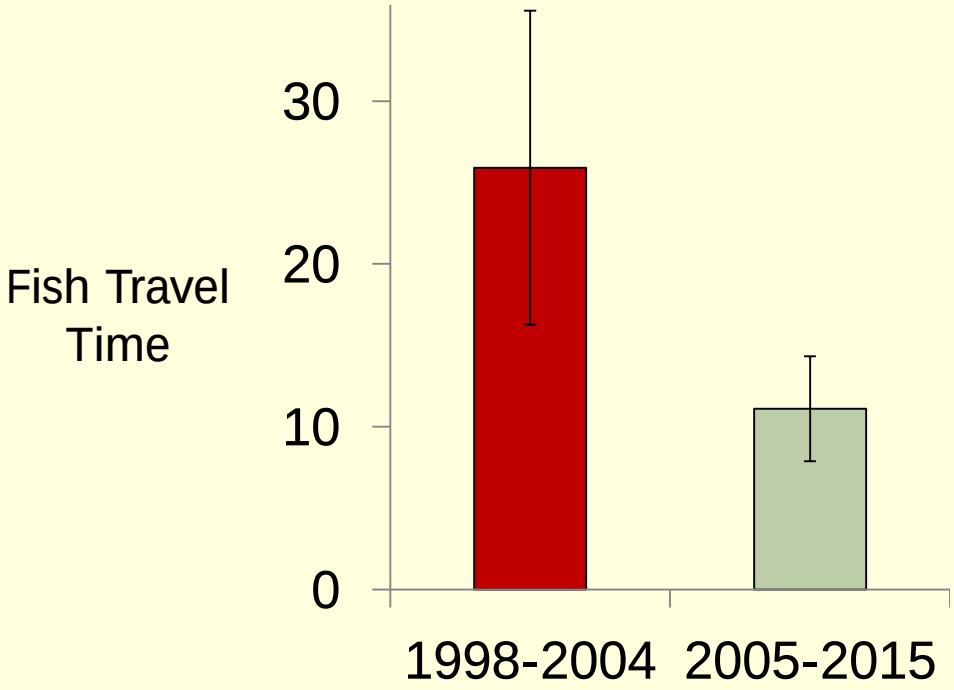
Adaptive Management Experiments:
Hatchery Fall (subyearling) Chinook salmon

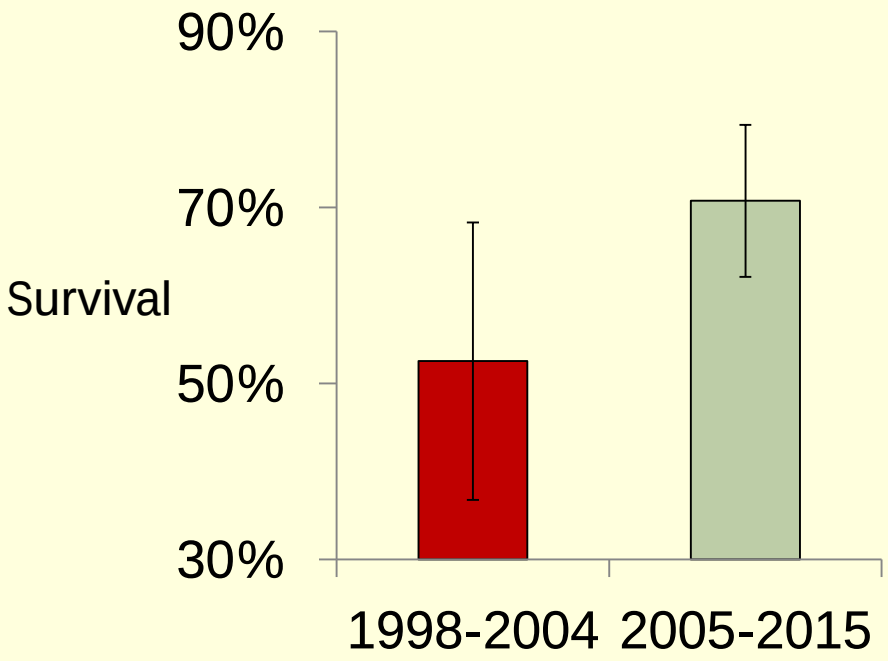


Monitoring Adaptive Management Experiments – Fall (subyearling) Chinook salmon

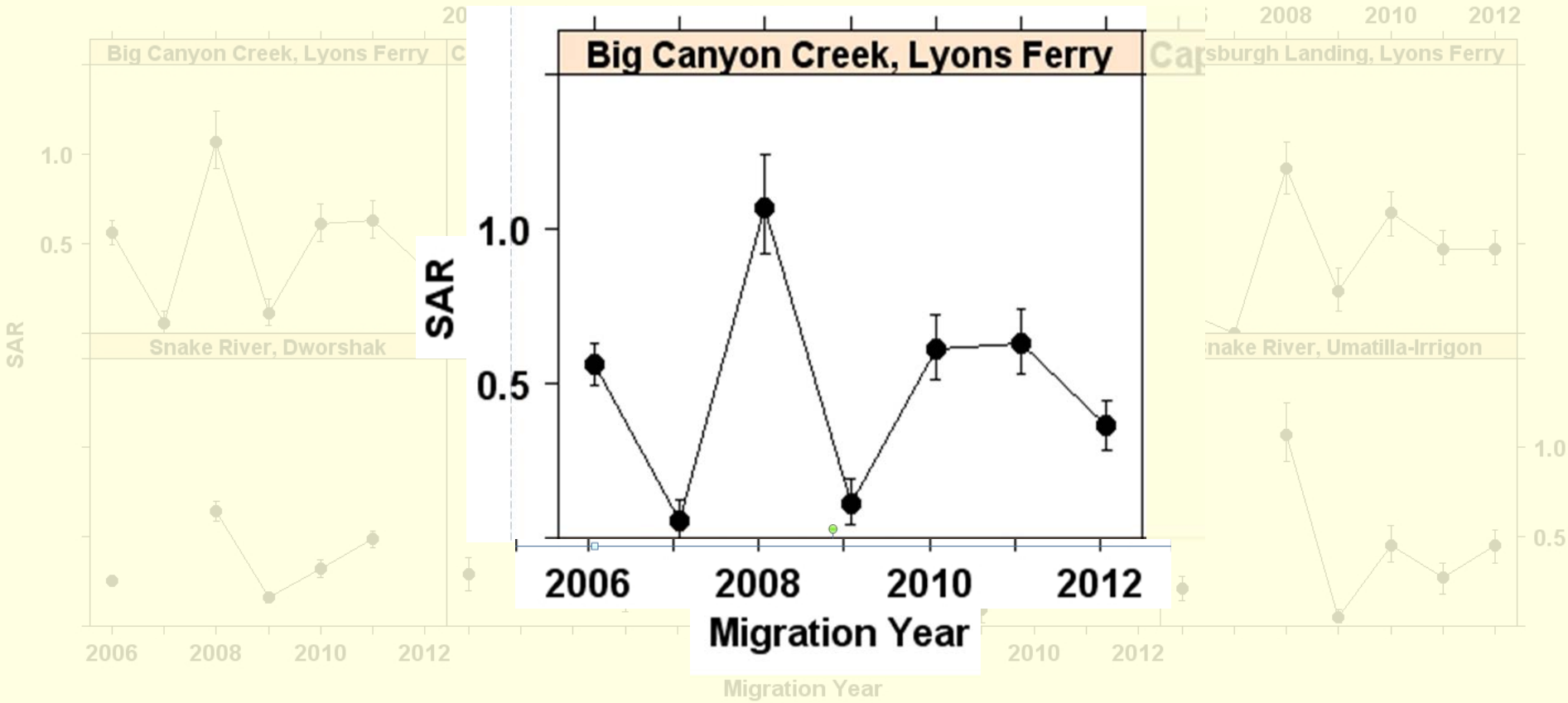


Monitoring Adaptive Management Experiments – Fall (subyearling) Chinook salmon



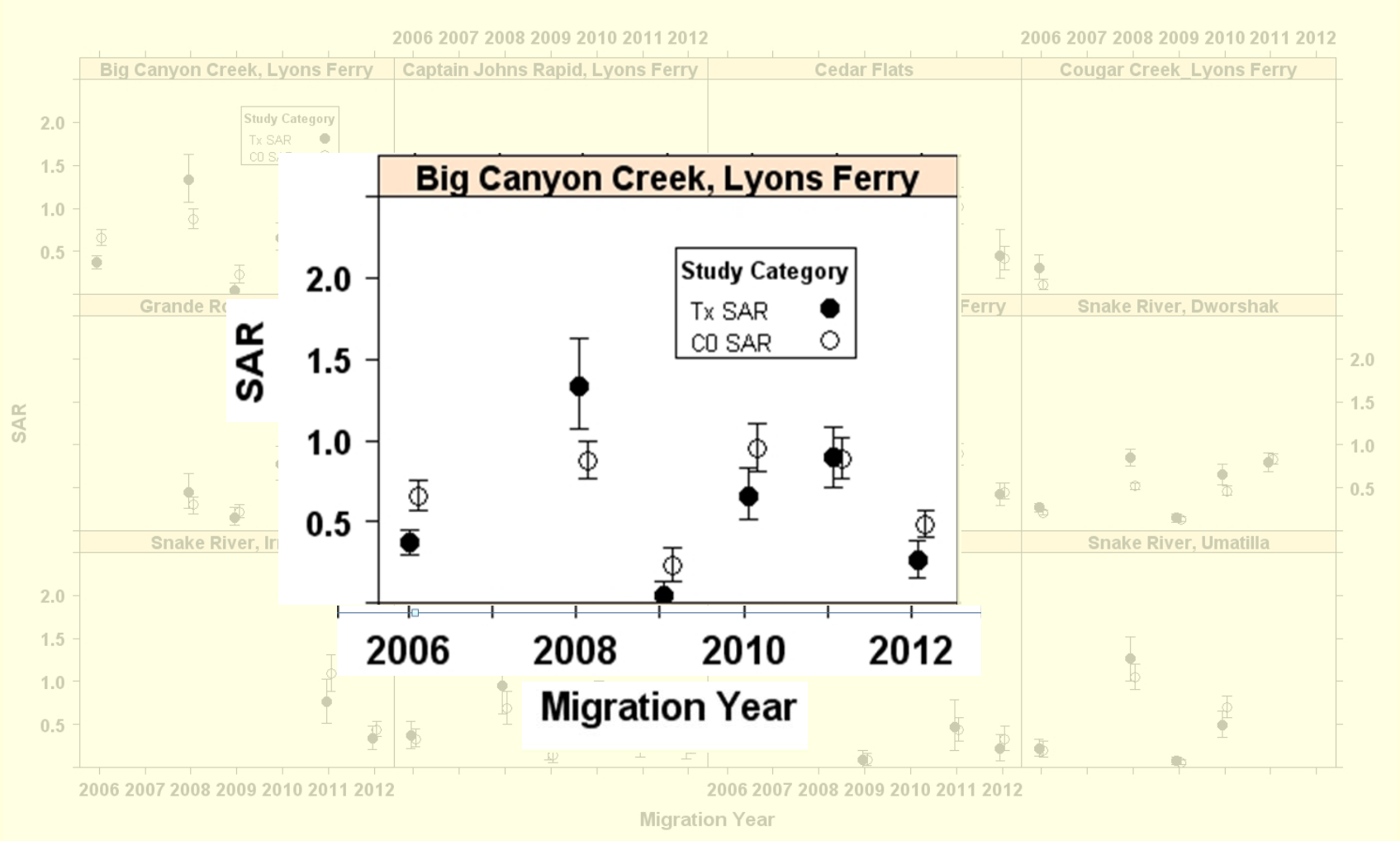


Overall SARs for Fall Chinook
LGR to GRA (jacks excluded)



- SARs ranged between 0% and 1% for the juvenile migration years 2006 to 2012
- Similar pattern as seen in spring migrants

SARs by category LGR to GRA

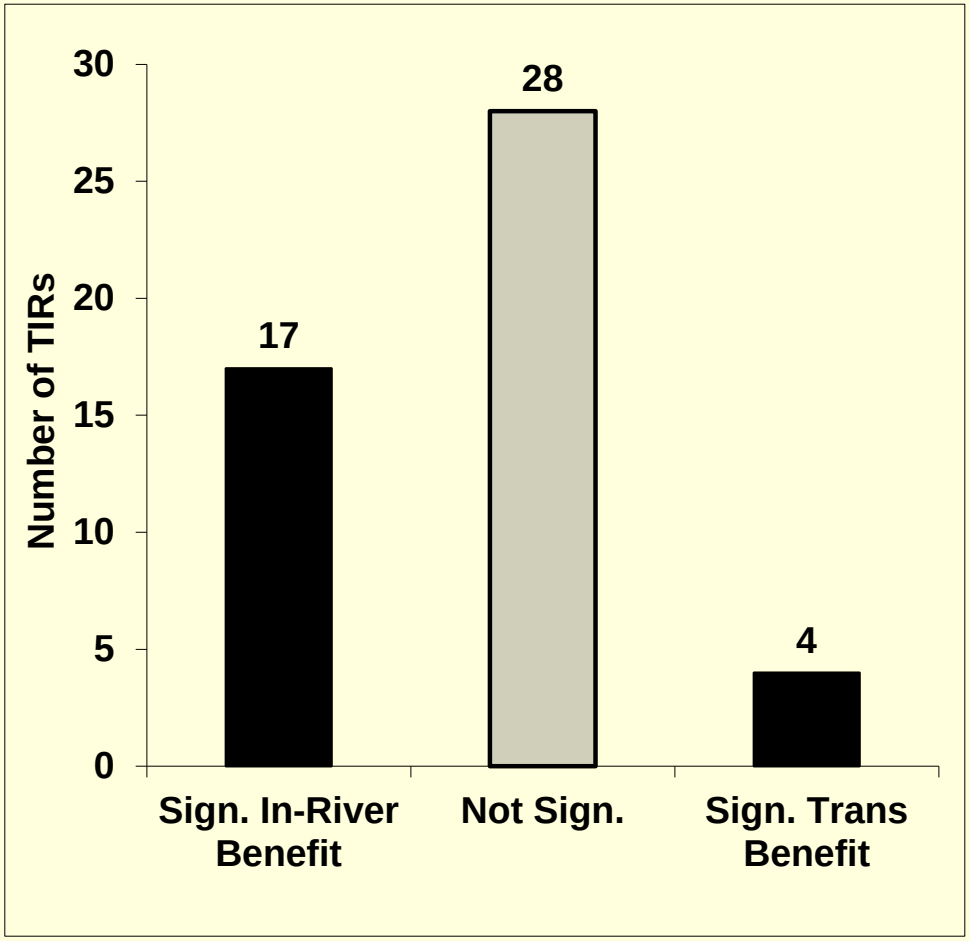


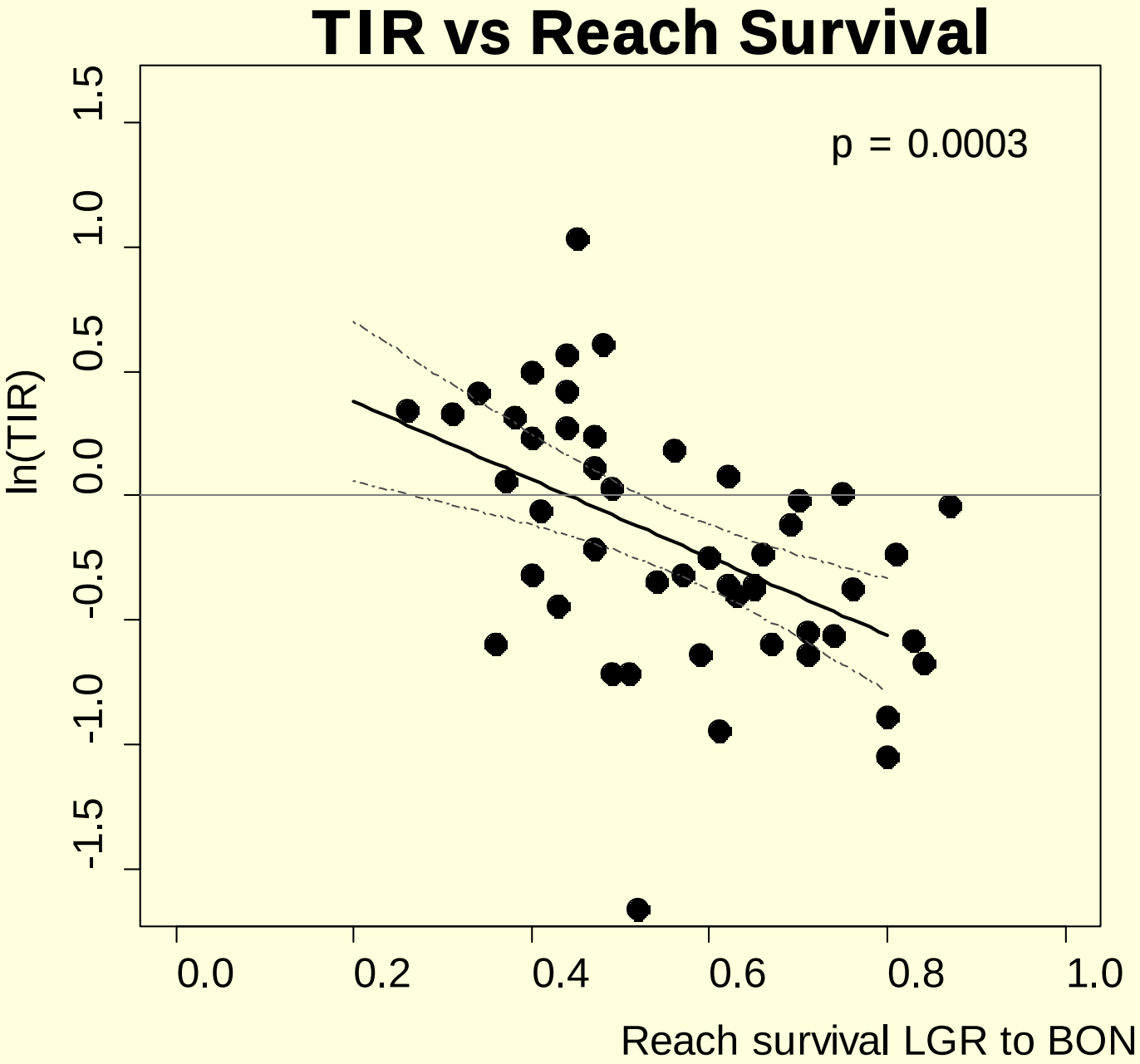
Summary of Transport in-River Ratios

$Tx/C_0 = TIR$

Ln(TIR) then values > 0 indicate transport SARs were higher, < 0 In-river SARs were higher

- 49 TIR comparisons
- 28 TIRs not significant
  - 14 higher In-river SARs
  - 14 higher Transport SAR
- 21 TIRs significant
  - 17 higher In-river SARs
  - 4 higher Transport SARs

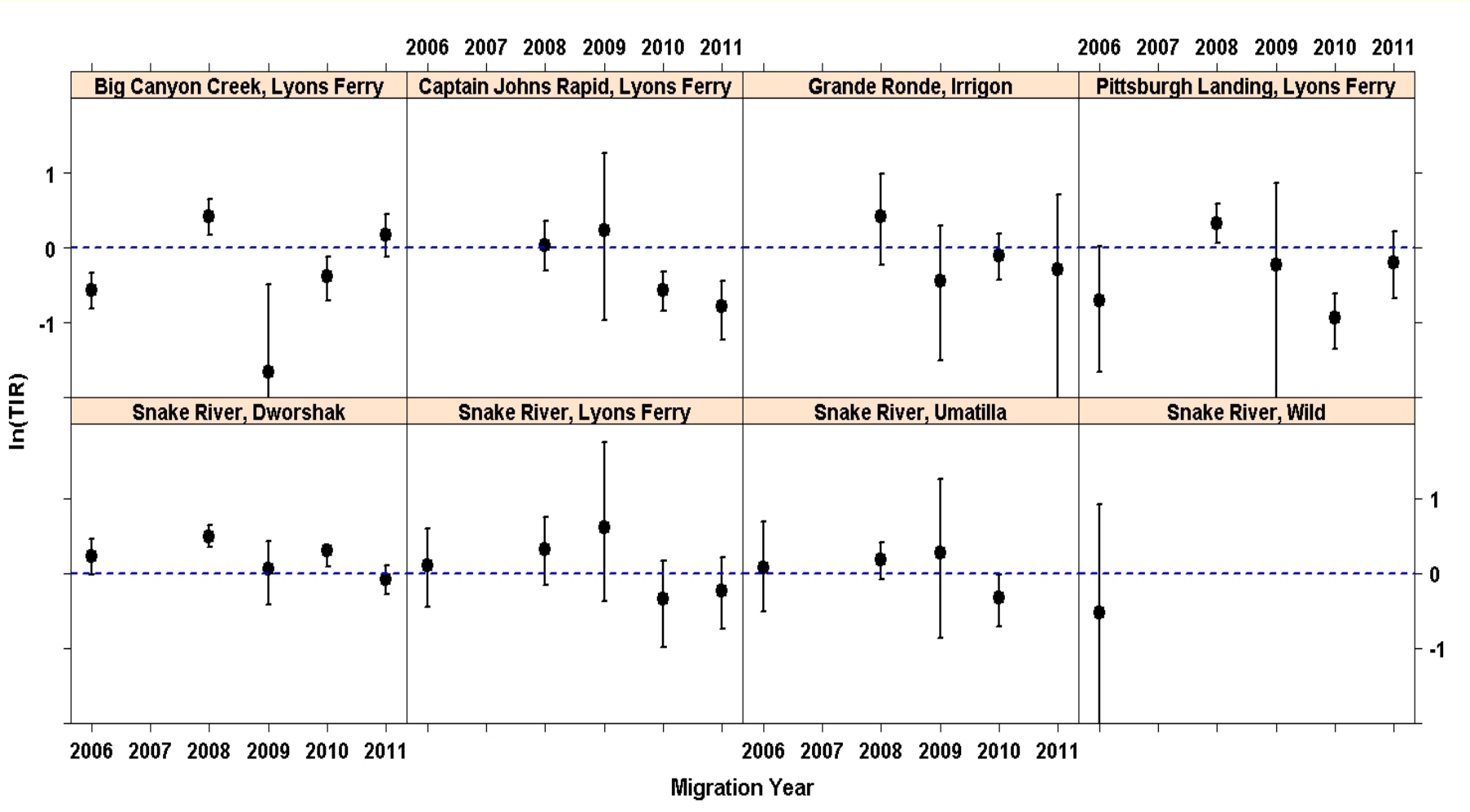



TIR vs Reach Survival
p = 0.0003
ln(TIR)
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
0.0
0.2
0.4
0.6
0.8
1.0
Reach survival LGR to BON

Conclusions

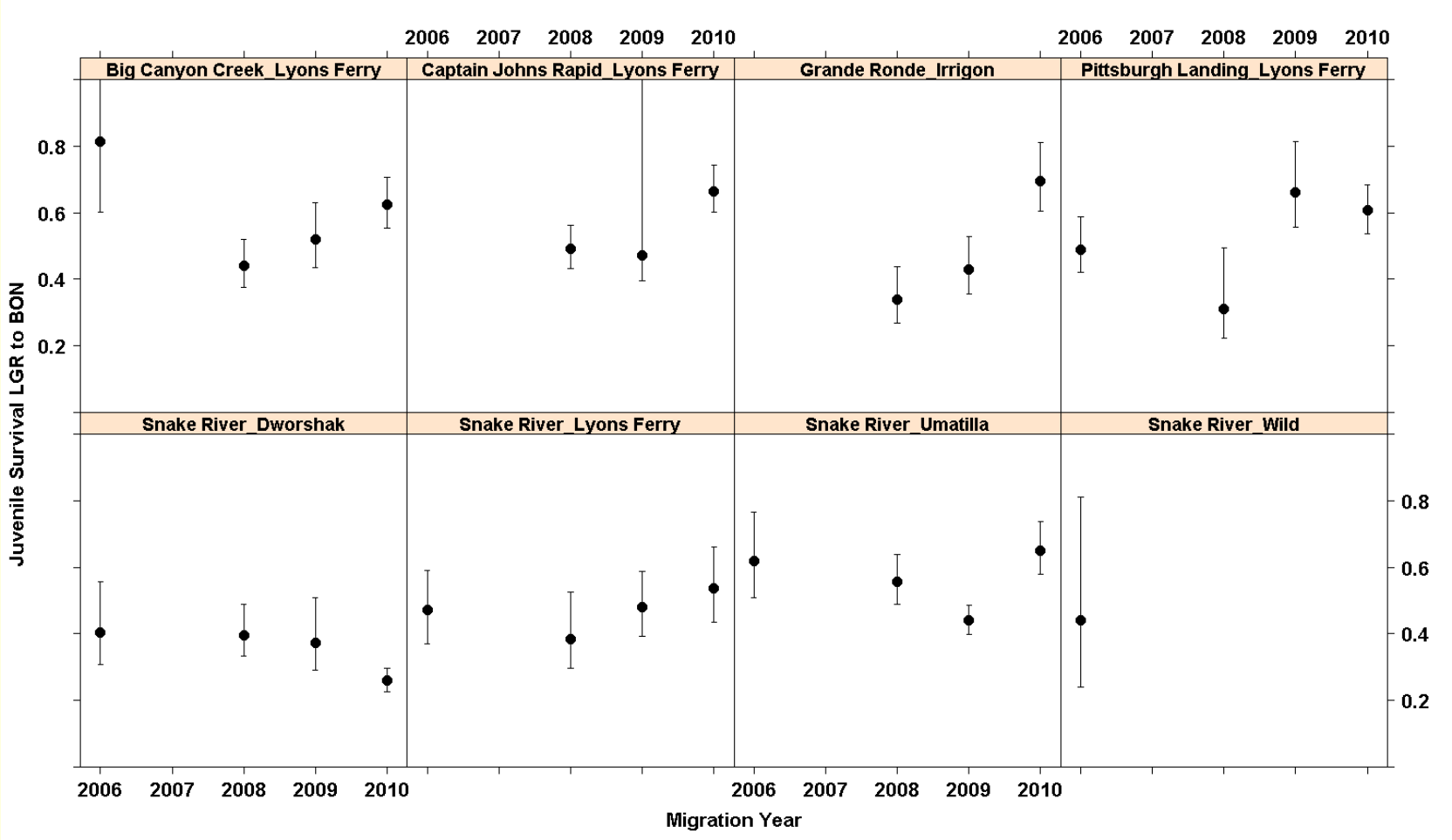
- CSS successfully produced SARs, route specific SARs, and TIRs for most subyearling production releases and some Snake River wild releases in the years 2006 to 2012.
- SARs ranged from 0% to just over 1% (LGR to LGR wo jacks).
- Only 4 groups of 49 showed significant transport benefit, while 17 groups showed significant in-river benefit.
- Transport benefit appeared to decrease with increasing in-river survival similar to pattern seen with spring migrants. Possibly lower in-river survival threshold for fall Chinook.
- Based on the results for the cohorts we analyzed (after 2005), transportation does not appear to compensate for the effects of the hydrosystem.
- Marking needed for future years—in 2015 and 2016 CSS cooperated with NPT to mark SR fall Chinook at PLAP and CJRAP totaling ~45,000 tags

Log Transport In-river ratios

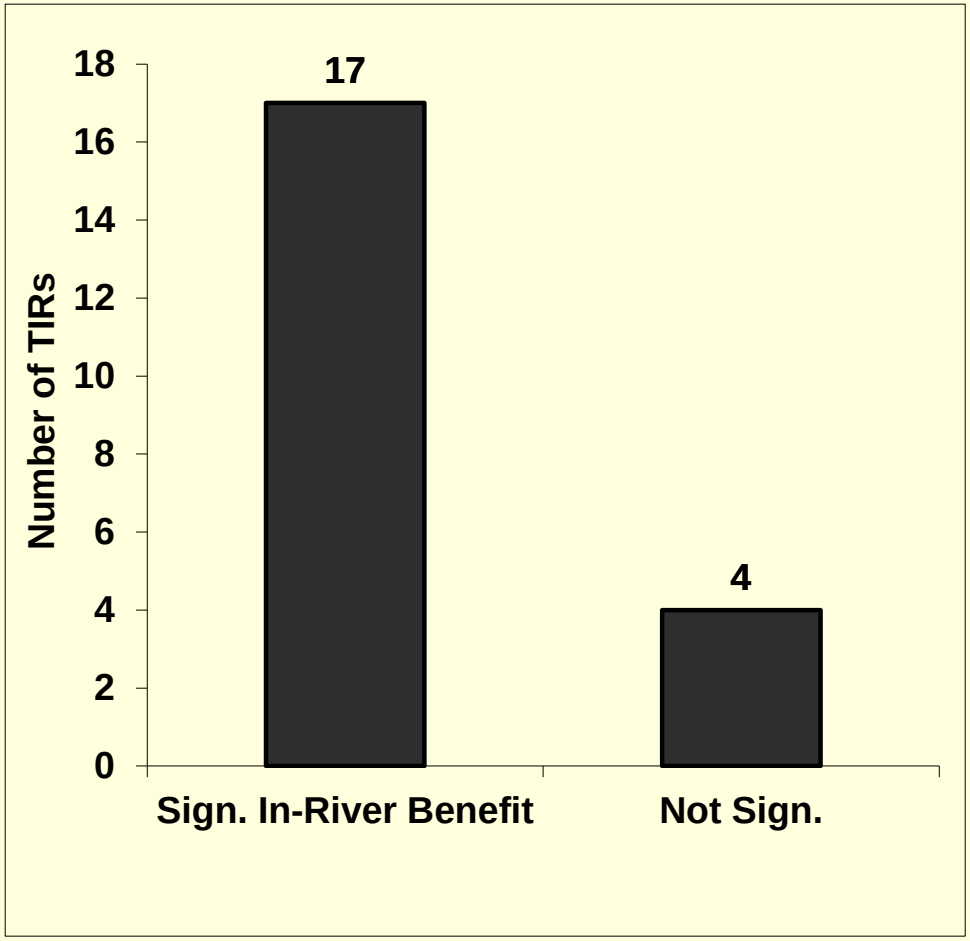


- Overall 16 TIRs above 0 and 17 below 0.
- 4 TIRs significantly above 0, and 7 significantly below 0, and 22 NS (in CSS Report 18 above zero, 22 below with 5 sign. above 0 and 9 sign below 0).

Juvenile survival LGR to BON for TIR cohorts



Summary of Transport in-River Ratios



- 23 TIRs significant
  - 18 higher In-river SARs
  - 5 higher Transport SARs

- Transportation does not mitigate for the adverse impacts of the hydro-system for the subyearling fall Chinook we analyzed

Nez Perce Marking 2015 and 2016

- Hatchery subyearling Chinook marked at Lyons Ferry and released at Captain John Rapid and Pittsburgh Landing

- Preassigned 70% Transport group and 30% in return to river groups.

- Estimated populations in each category in 2015 and 2016 at LGR were 7,500 Tx/18,700 C_0 and 11000 Tx/15000 C_0 (respectively).

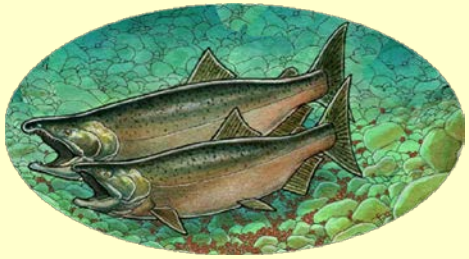
Comparative Survival Study

SARs and Productivity

Presenter: Charlie Petrosky

2017 Annual Meeting

April 3,2017



Smolt to Adult Survival Rate (SAR) Goals

PATH (1998); NMFS 2000 BiOp:

- 2% SAR met interim NMFS survival criteria
- 4% SAR met interim NMFS recovery criteria
  - Snake R. spring/summer Chinook
- Applied to Snake R. steelhead by analogy

NPCC (2004, 2009) F&W Program:

- 2%-6% SAR, average 4% SAR – ESA salmon & steelhead
- Identify effects of ocean conditions; evaluate & adjust inland management actions

2014 F&W Program & ISAB comments:

- Investigate goals, examine applicability & biological basis relative to population viability & rebuilding

SARs & Life Cycle Productivity

Snake River spring/summer Chinook and steelhead

What levels of SAR are associated with:

1) Population replacement at recent spawner abundance
2) Historical (pre-FCRPS) productivity

SR Chinook Life Cycle Productivity

1) Viability criteria to achieve low or very low risk of population extinction (ESA recovery or delisting; Interior Columbia Technical Recovery Team-ICTRT 2007):

   - Abundance must exceed <u>Minimum</u> Abundance Threshold (MAT)

   - Intrinsic productivity must be adequate to maintain population at or above MAT

     - Post-harvest recruits to spawning grounds

2) "Broad scale recovery" goals (e.g., States, Tribes, Subbasin Plans) are higher than simple ESA delisting (e.g., sustainable fisheries)

   - Pre-harvest recruits

SR Chinook Life Cycle Productivity

<u>Viability Criteria:</u>

Recent abundance

- Spring/Summer Chinook spawner abundance as % Minimum Abundance Threshold (1992-2008 brood years)

- Middle Fork Salmon MPG ~ 31% MAT
- Grande Ronde/Imnaha MPG ~ 29% MAT

ICTRT 2007 "Survival Gap"

- Life cycle survival multiplier to meet TRT viability criteria (1979-2001 brood years; 5% extinction risk)

- Middle Fork Salmon MPG ~ 1.7 - 2.7X
- Grande Ronde/Imnaha MPG ~ 1.7 - 3.8X

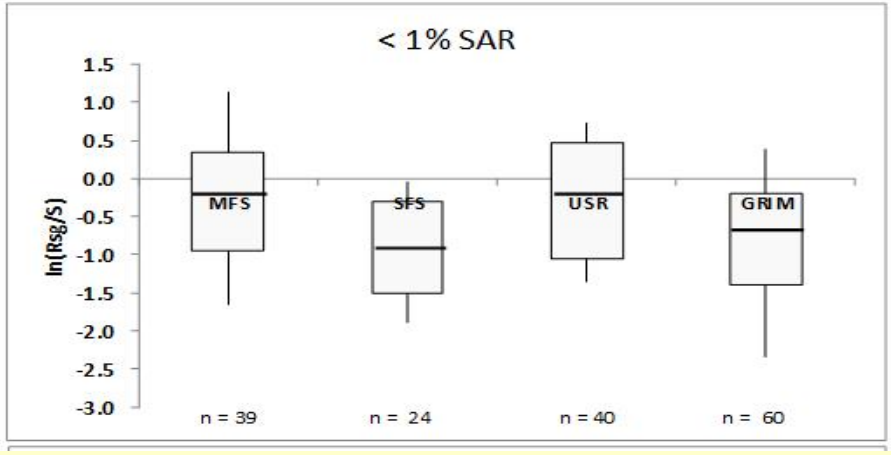
Post-harvest recruits to spawning grounds --> viability

Hypothetically, life cycle survival improvement could be in egg-smolt survival rates and/or SARs

Little room to increase egg-smolt survival in good habitats (e.g., Middle Fork Salmon MPG)

Egg-smolt survival could be increased in degraded habitats (e.g., some Grande Ronde populations) – Lessard presentation

SR spring/summer Chinook life-cycle productivity has been inadequate to maintain spawner abundance at MAT



Low SARs → low productivity

- Generally consistent pattern across MPGs
- All MPGs showed declines in abundance from one generation to the next when SARs < 1%

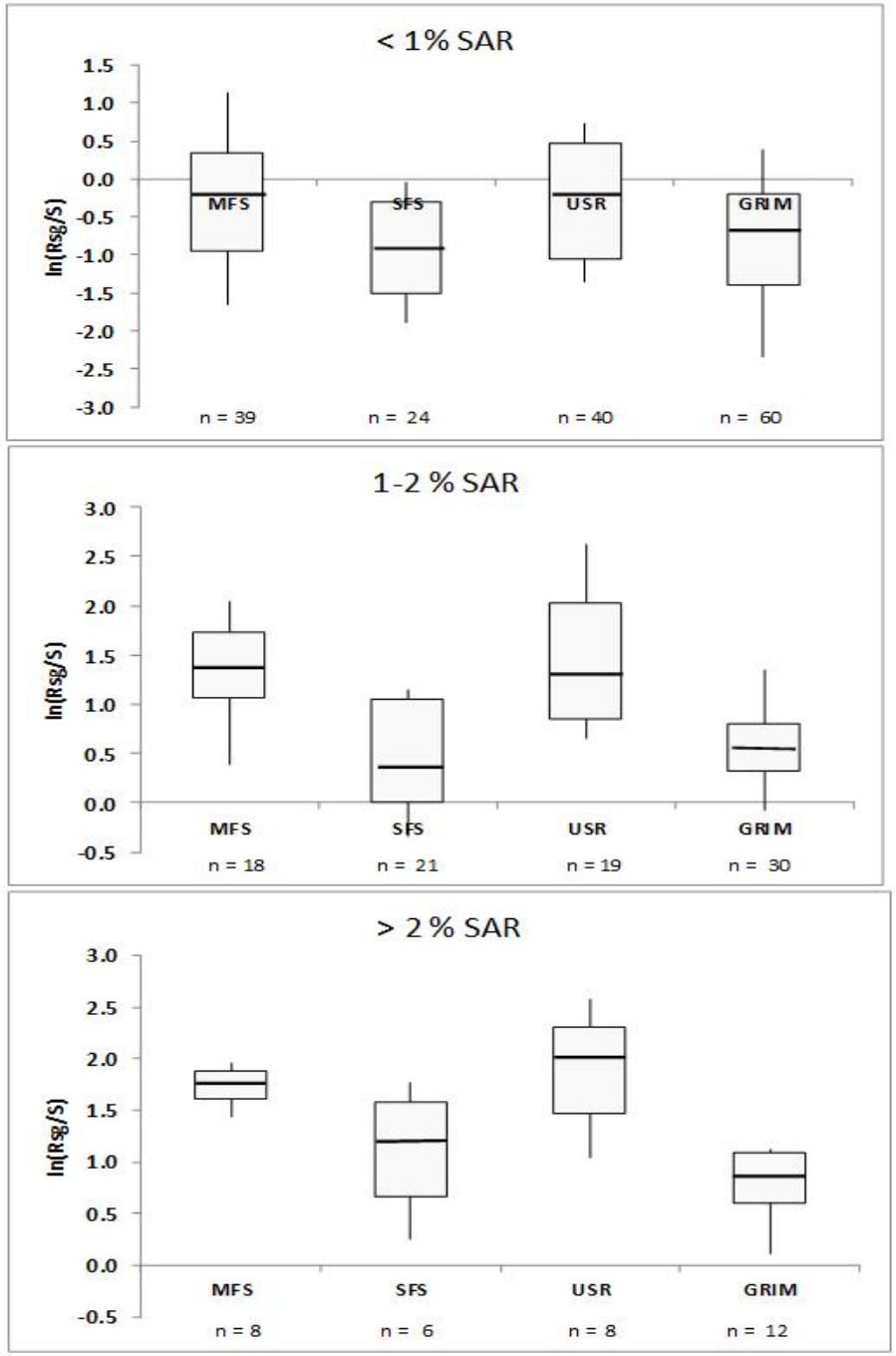
SR spring/summer Chinook life-cycle productivity has been inadequate to maintain spawner abundance at MAT

Low SARs → low productivity

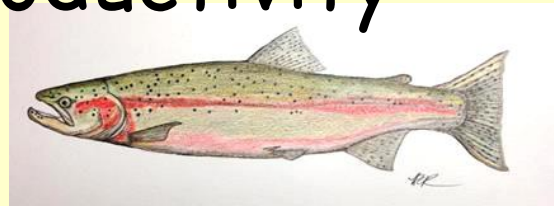
- Generally consistent pattern across MPGs

Observations to date are relevant to & support NPCC SAR objectives

- SARs < 2% → inhibit rebuilding to MAT
- SARs < 1% → major population declines



SR Steelhead Life Cycle Productivity



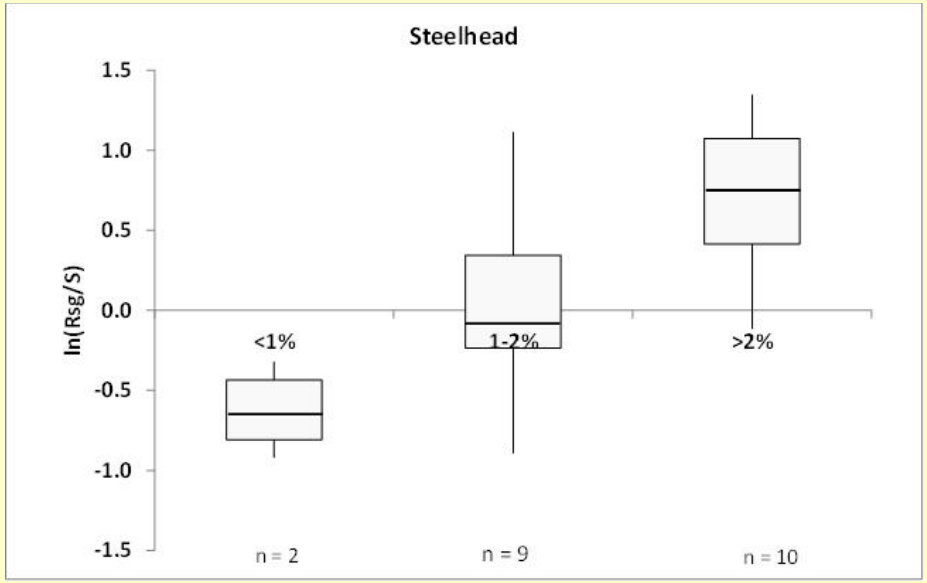
- Steelhead analytical challenges:
  - Comparatively fewer measures of life cycle productivity
    - Sampling adult spawner abundance more difficult – spring spawners during spring runoff
  - More complex life cycle – smolts emigrate over 4-5 years (e.g., brood year 2000 produced smolts in 2001-2005)
    - Calculate weighted brood year SAR to compare with life cycle productivity

- 2016 Report: Comparison of steelhead life cycle productivity and brood year SARs
  - Fish Creek, Idaho (Lochsa R. B-run), BY 1996-2009
  - Rapid River, Idaho (Lower Salmon R. A-Run), BY 2003-2009
    - Wild populations with minimal hatchery influence
  - Future CSS work – extend to other populations

SR steelhead life-cycle productivity has been inadequate to maintain spawner abundance at MAT

Low SARs → low productivity

- Fewer observations, but generally consistent results with spring/summer Chinook



Observations to date are relevant to & support NPCC SAR objectives

- SARs < 2% → inhibit rebuilding to MAT
- SARs < 1% → major population declines

SARs & Life Cycle Productivity

Snake River spring/summer Chinook

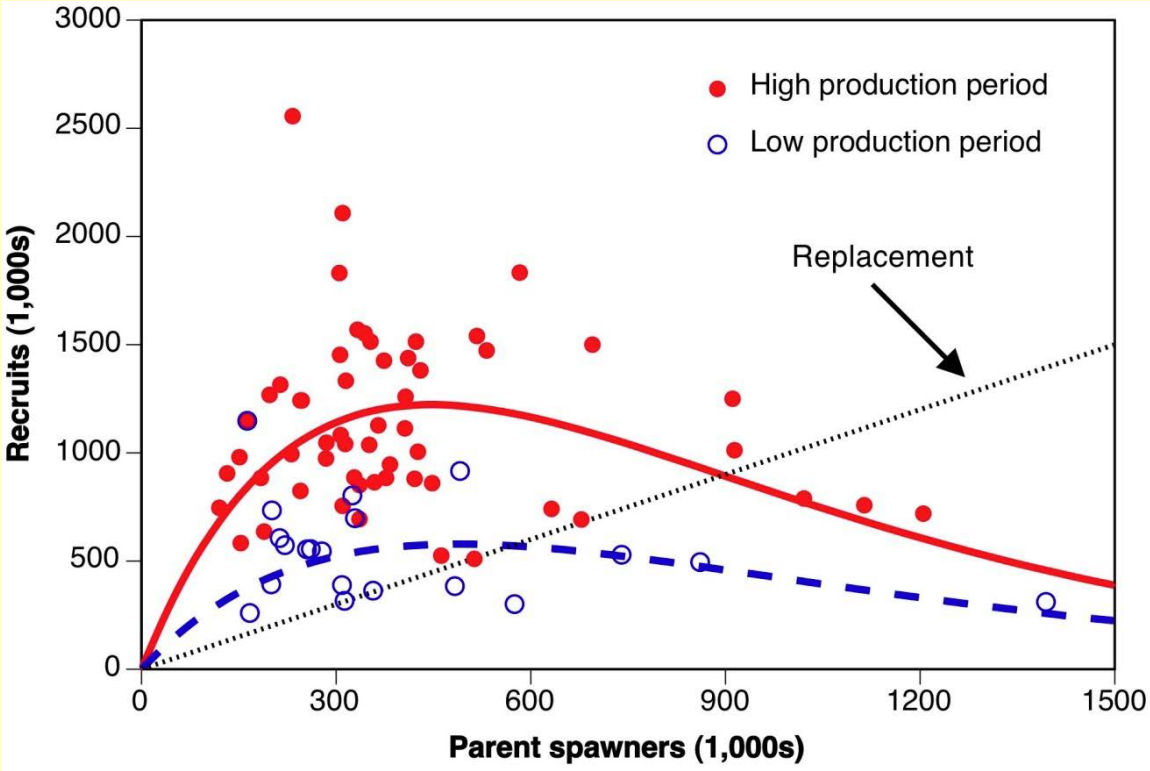
What levels of SAR are associated with:

1) Population replacement at recent spawner abundance

2) Historical (pre-FCRPS) productivity
   - Account for density dependence & changing environmental conditions
   - Pre-harvest recruits

Chinook Life Cycle Productivity

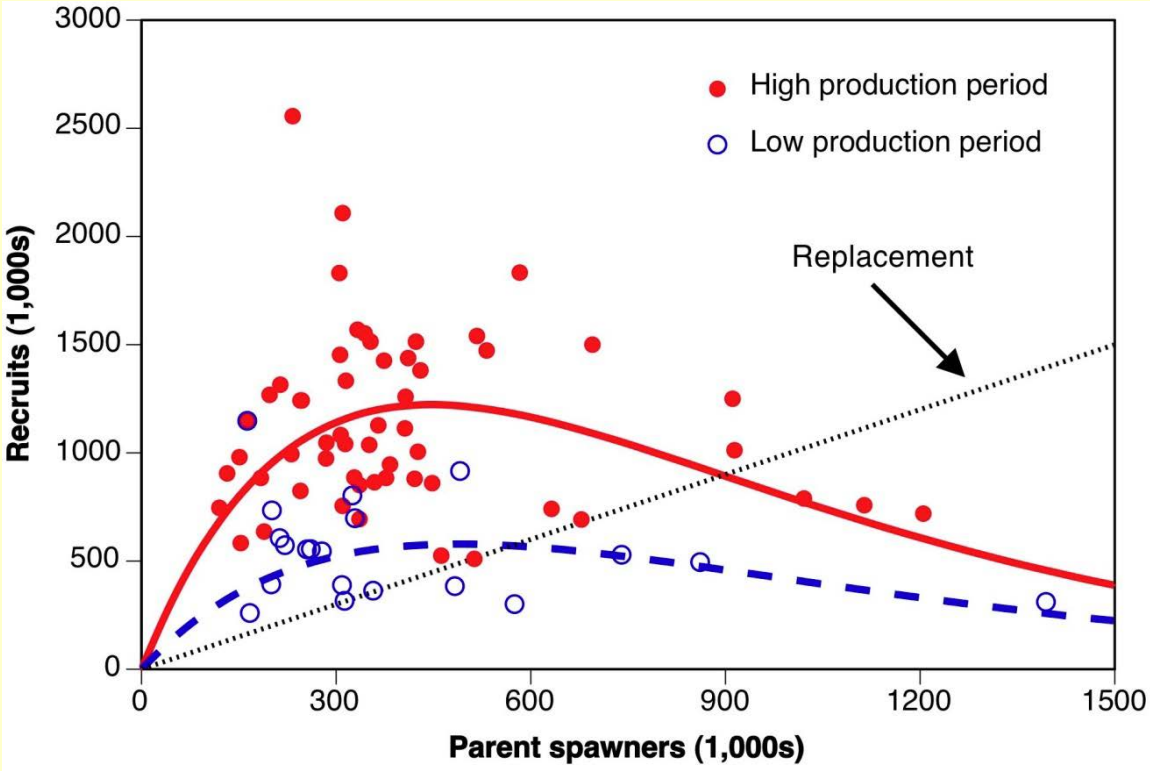
Accounting for density dependence and changing environmental conditions



e.g., Chignik Lake, Alaska sockeye recruitment functions – from ISAB 2015-1

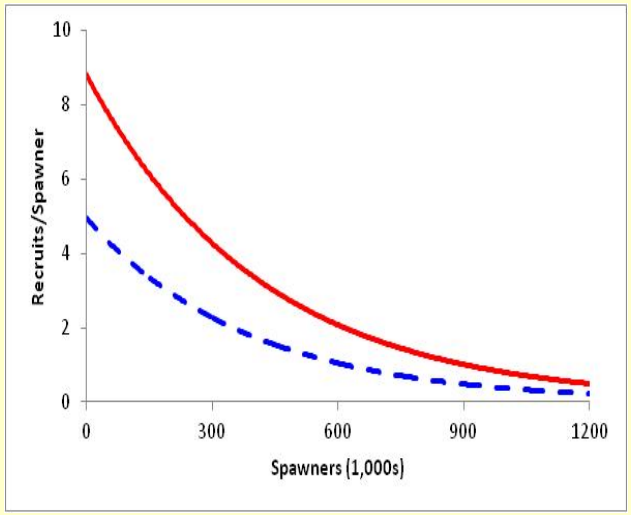
Chinook Life Cycle Productivity

Accounting for density dependence and changing environmental conditions



e.g., Chignik Lake, Alaska sockeye recruitment functions – from ISAB 2015-1

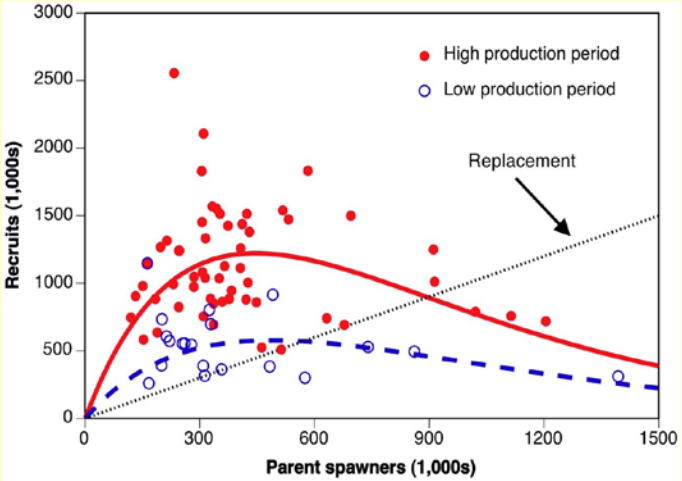
R/S decreases as S increases



Chinook Life Cycle Productivity

Accounting for density dependence and changing environmental conditions – Interior Columbia populations:

- Ricker function with period effect, pre & post FCRPS completion (Schaller et al. 1999, 2014 - CJFAS)
- 18 Snake River populations, 4 MPGs, 1950s – 2004 brood years
- 3 John Day River populations, 1 MPG, 1950s – 2004 brood years
- Tested for changes in productivity & capacity
- Pre-harvest recruits to Columbia River (to account for changing harvest patterns)



Chinook Life Cycle Productivity

Accounting for density dependence and changing environmental conditions - <u>Interior Columbia populations</u>:

SRI, Survival Rate Index

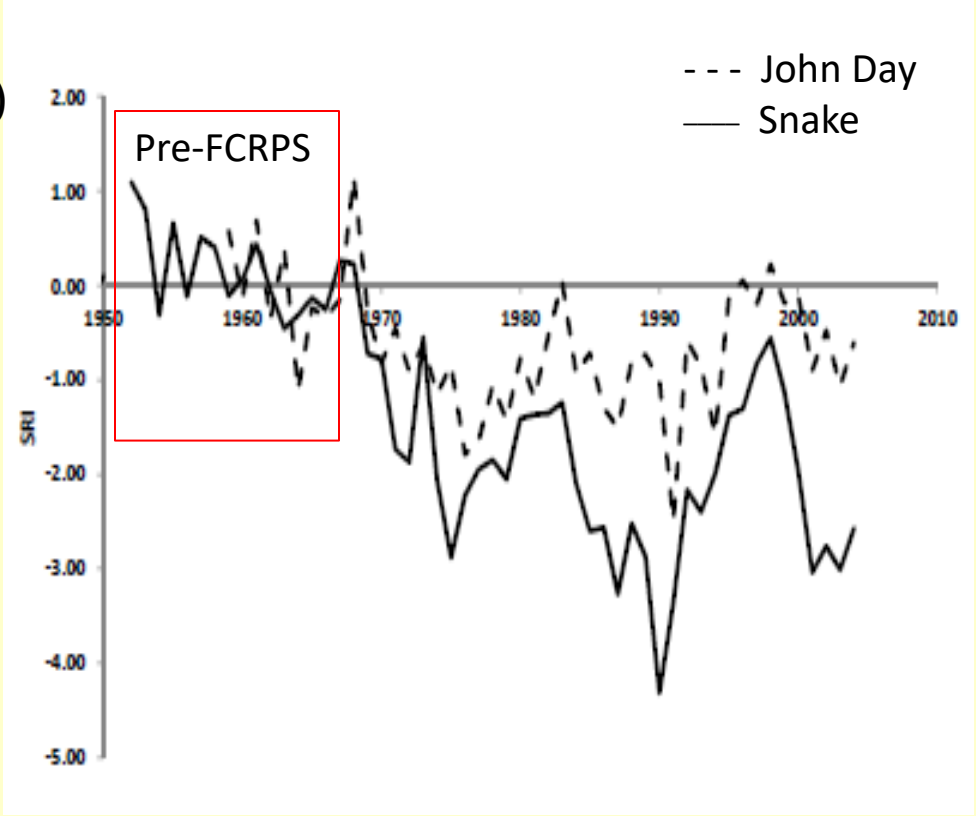
- Observed ln(R/S) – Expected ln(R/S)

where, expected productivity is defined for the period before FCRPS completion (pre-1970)

- SRI = 0, survival = 100% of expected productivity

- Strong evidence for increase in density <u>independent</u> mortality (reduced productivity); less evidence for change in capacity

- SRIs varied with ocean conditions and declined with FCRPS development

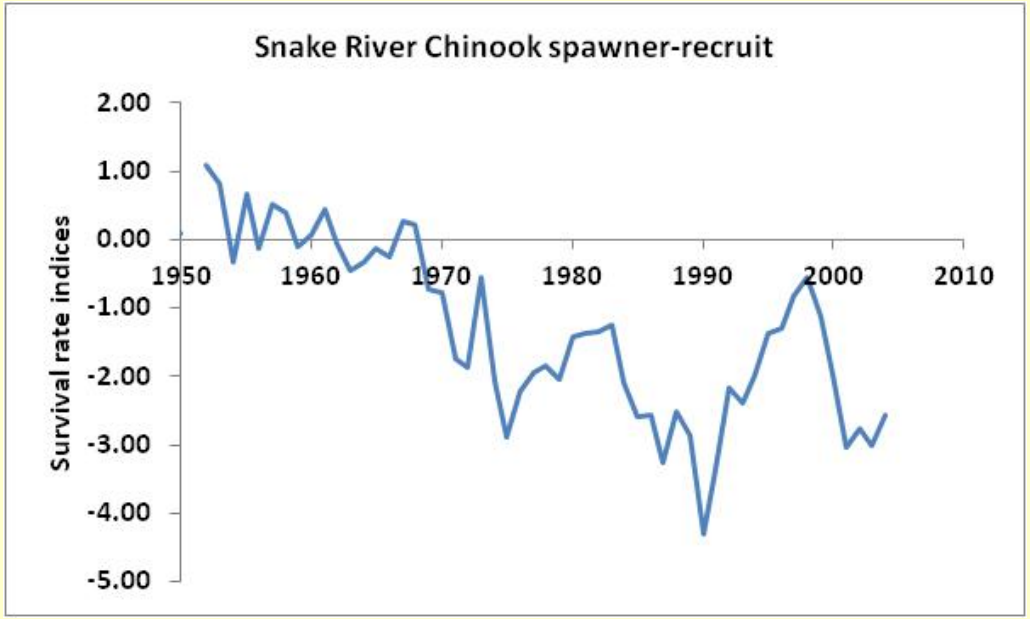


Schaller, Petrosky & Tinus 2014 CJFAS

Snake R Chinook Life Cycle Productivity & SARs

Life cycle survival rates declined to about 12% of Pre-FCRPS productivity

Post-FCRPS SRIs:
-2.1 average
(-4.3 to -0.6)

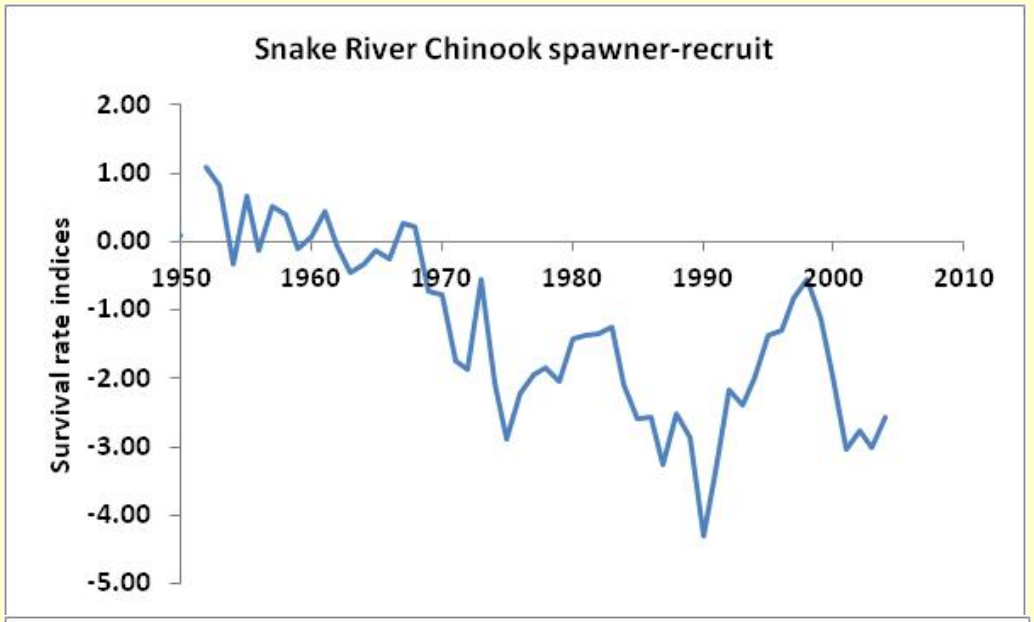


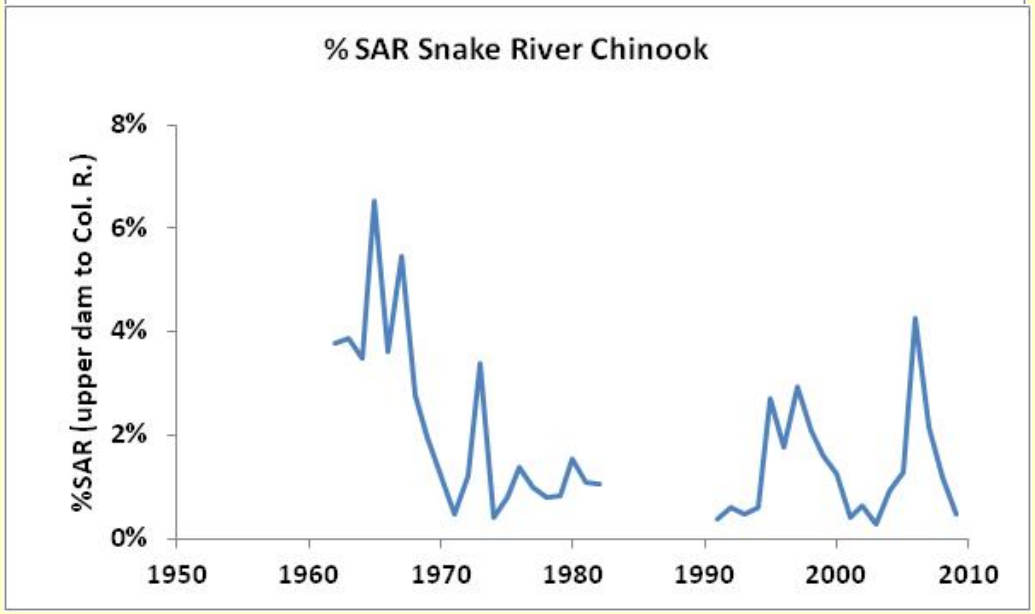
Snake R Chinook Life Cycle Productivity & SARs

Life cycle survival rates declined to about 12% of Pre-FCRPS productivity

Post-FCRPS SRIs:
-2.1 average
(-4.3 to -0.6)

SARs also varied with ocean conditions and declined with FCRPS development





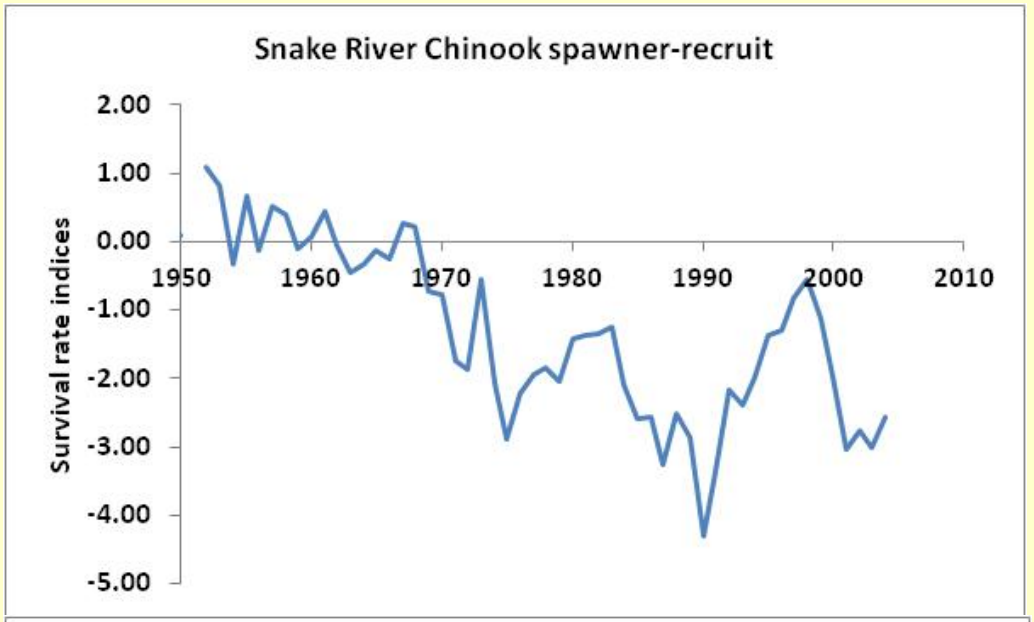
Snake R Chinook Life Cycle Productivity & SARs

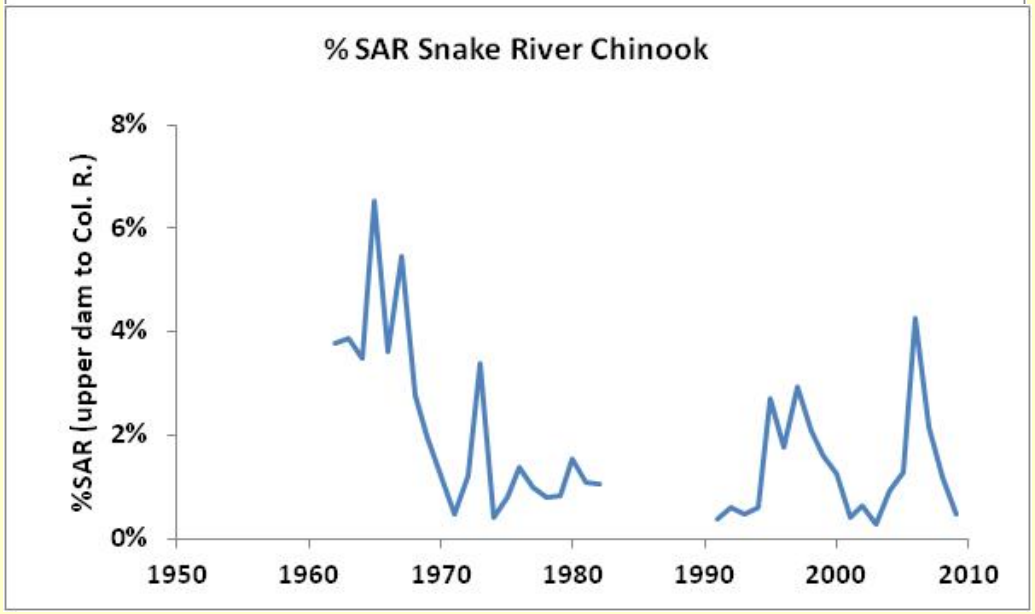
Life cycle survival rates declined to about 12% of Pre-FCRPS productivity

Post-FCRPS SRIs:
-2.1 average
(-4.3 to -0.6)

SARs also varied with ocean conditions and declined with FCRPS development

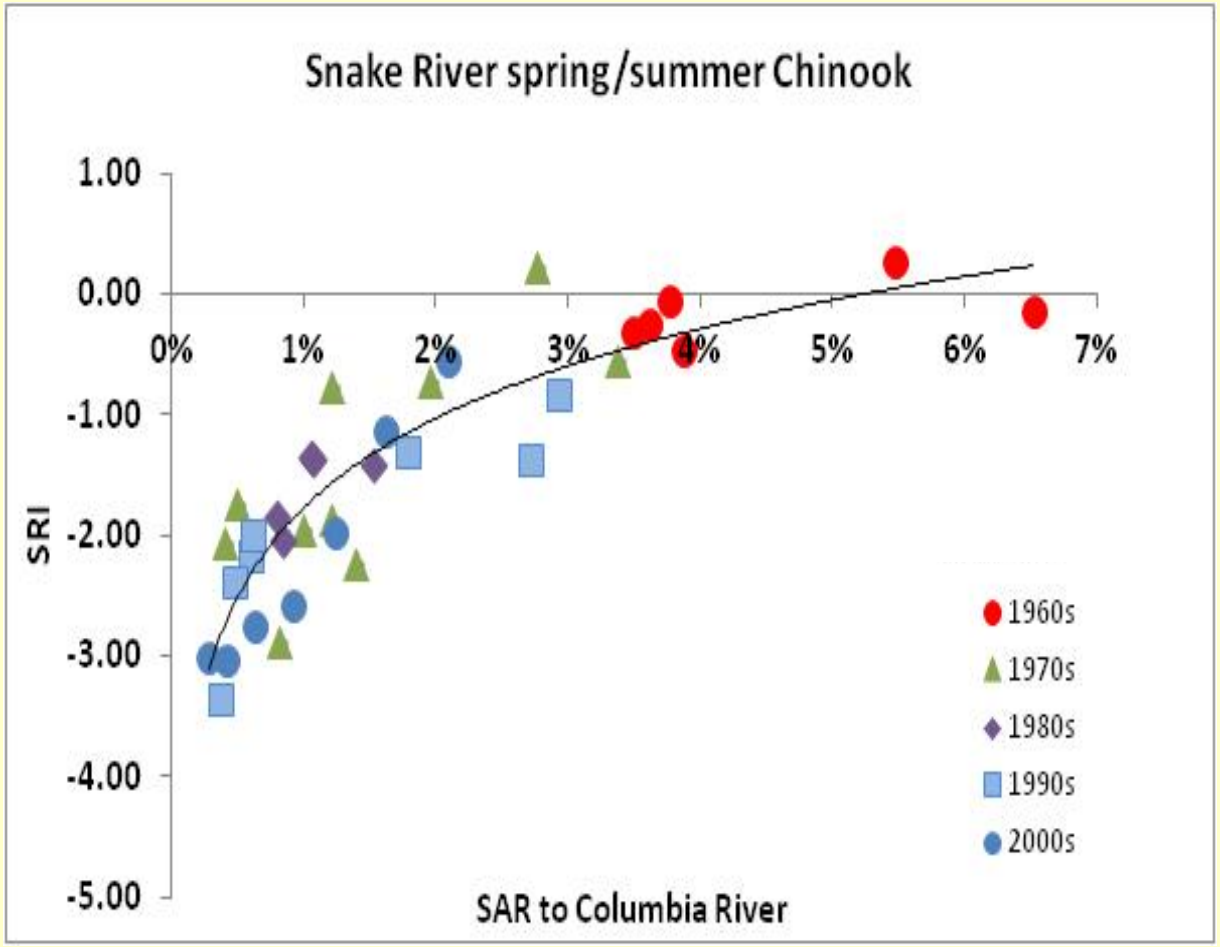
Aligning observed SARs and SRIs…





Snake R Chinook Life Cycle Productivity & SARs

SARs explain majority of variation in life-cycle productivity over this period (1964-2006)

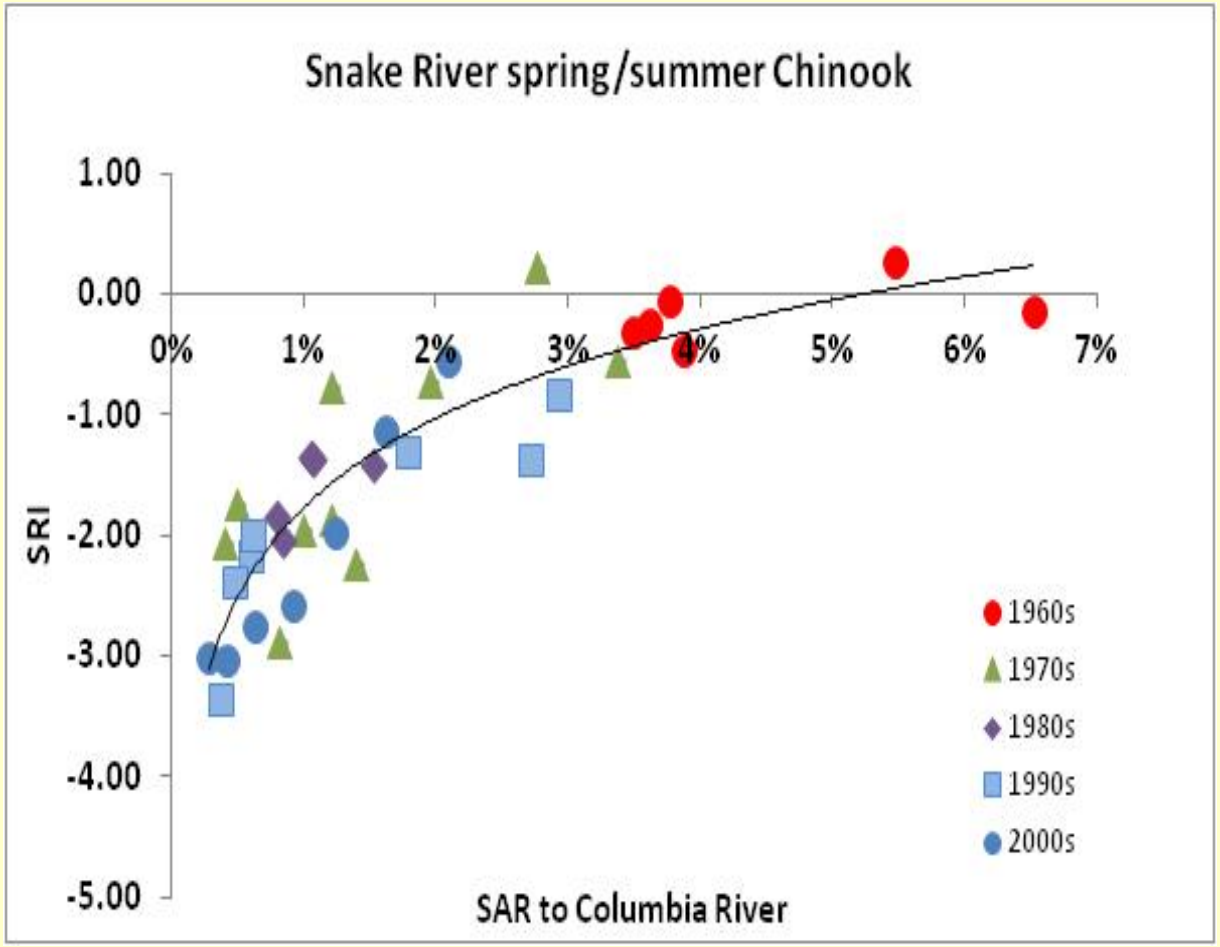


Snake R Chinook Life Cycle Productivity & SARs

SARs explain majority of variation in life-cycle productivity over this period (1964-2006)

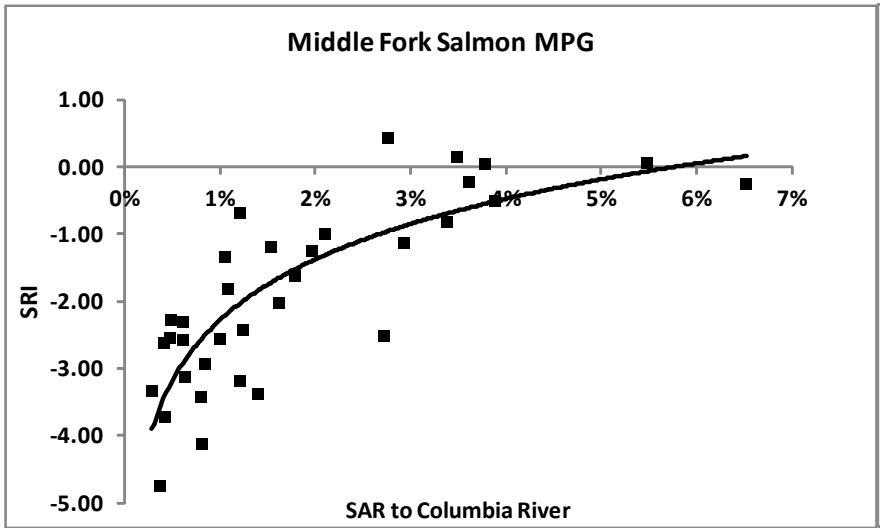
Expected productivity responses to (pre-harvest) SARs:

SAR	% pre-FCRPS
2%	36%
4%	75%
6%	116%

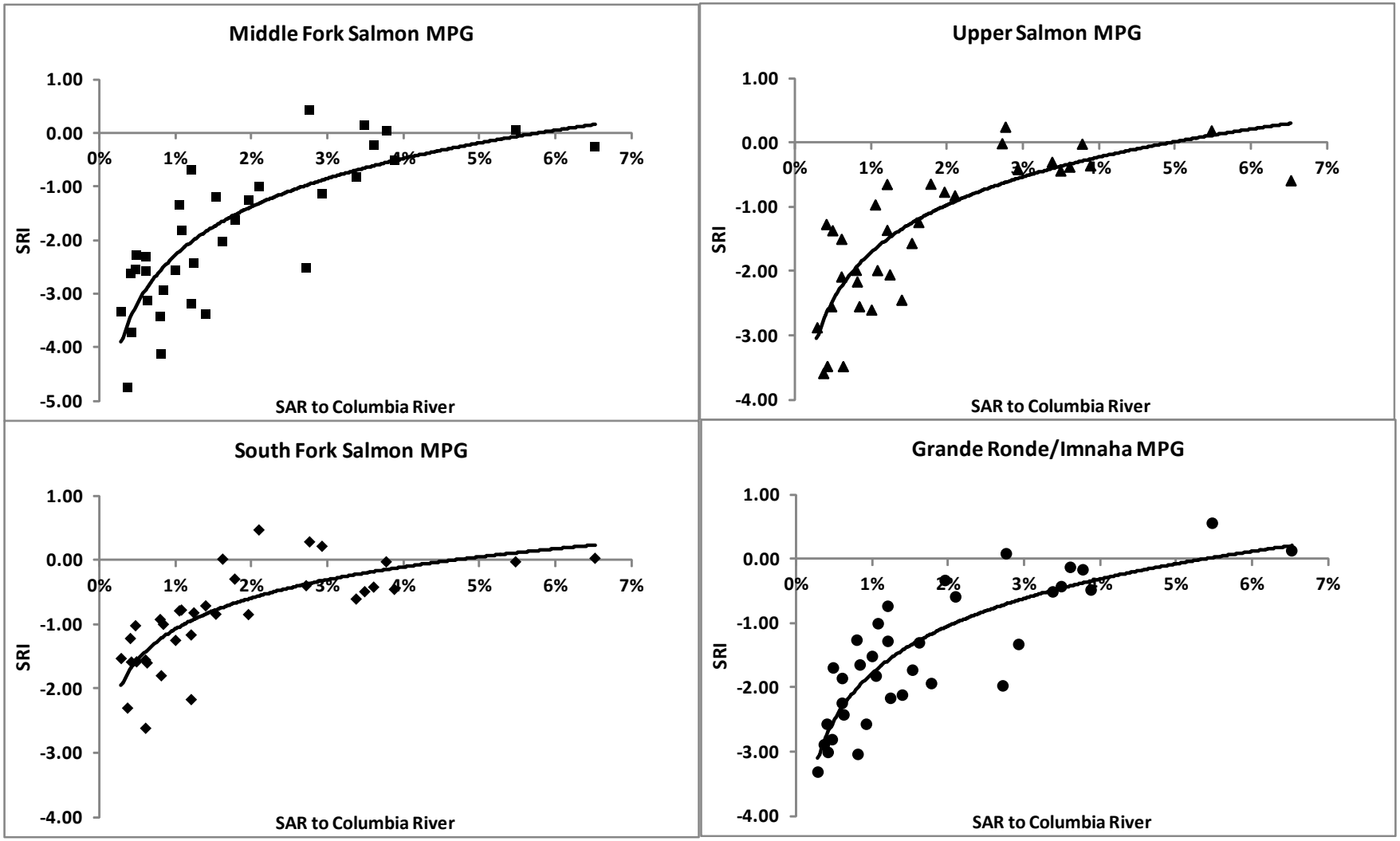


Results generally consistent with NPCC's 2-6% SAR goal

Middle Fork Salmon MPG (4 populations, 47 years)



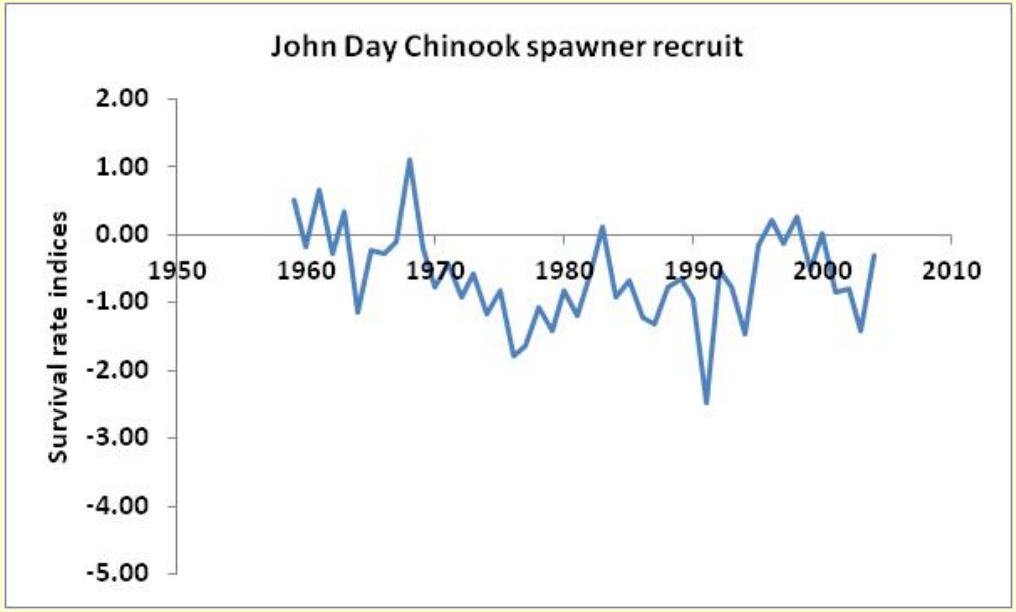
Similarity in responses across Snake River MPGs



John Day R Chinook Life Cycle Productivity & SARs

Life cycle survival rates declined to about 44% of Pre-FCRPS productivity (vs. 12% for Snake)

Post-FCRPS SRIs:
-0.8 average
(-2.5 to 0.3)



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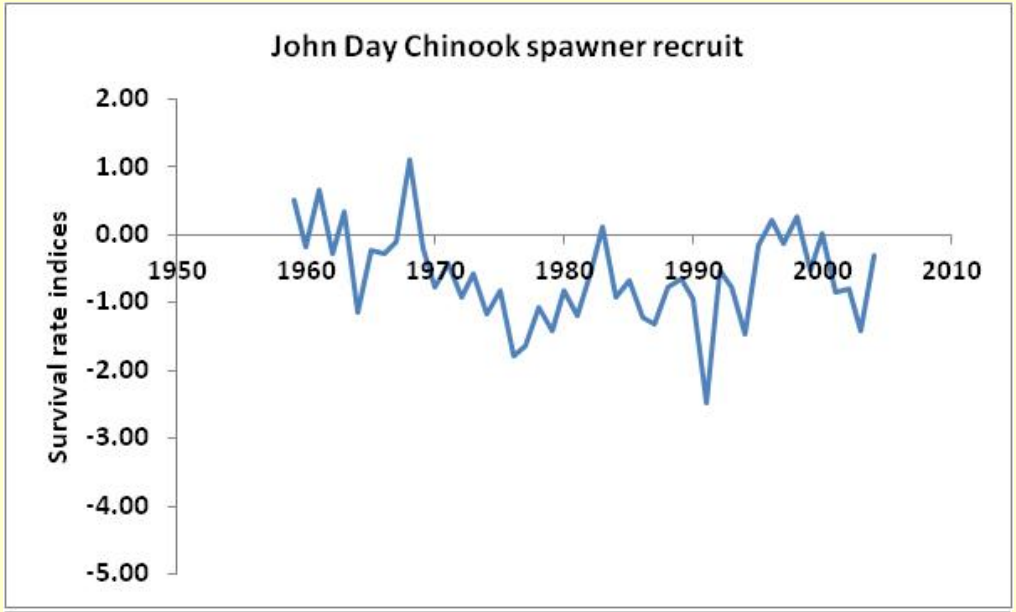
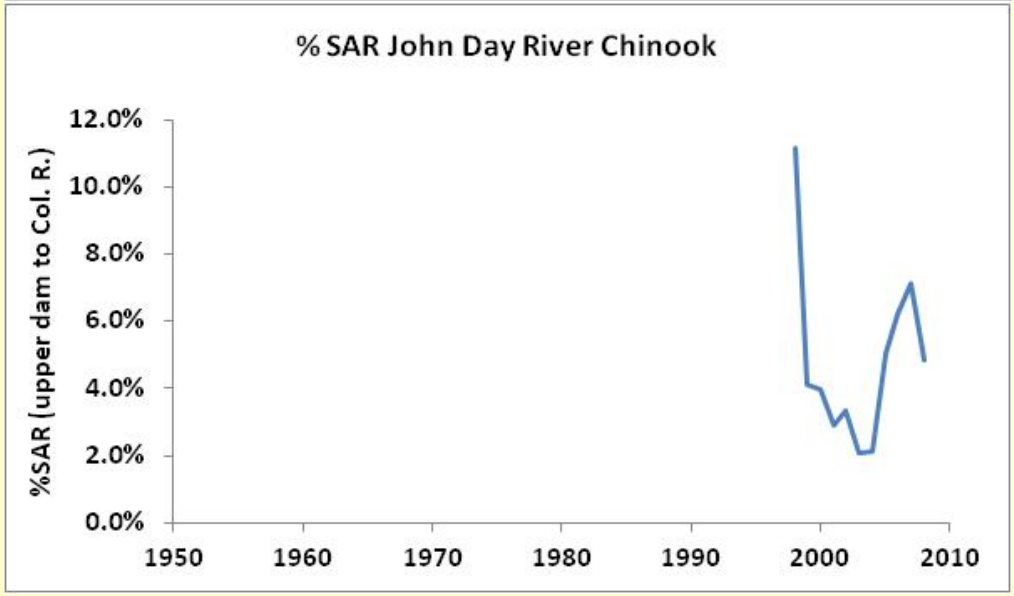
PIT tag SARs begin in 2000

Aligning observed SARs & SRIs…



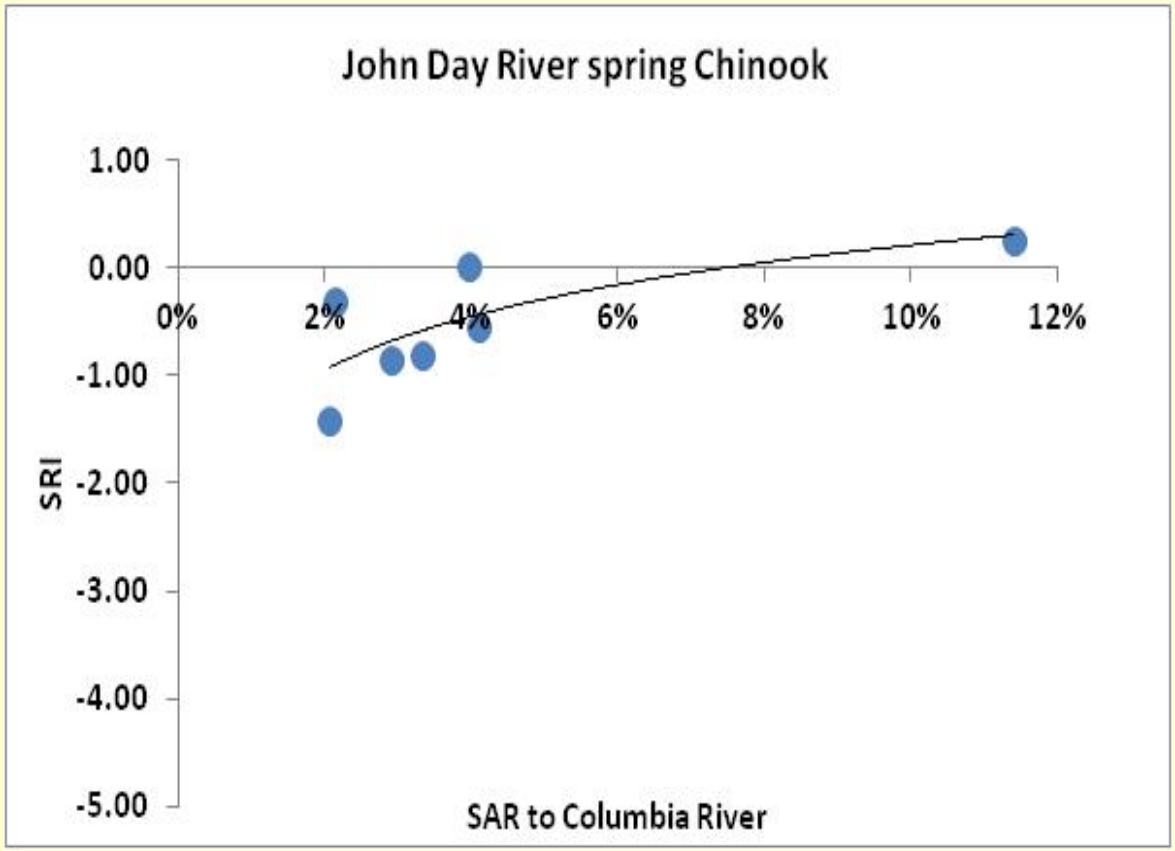


John Day R Chinook Life Cycle Productivity & SARs

Fewer SAR estimates, but…

SARs in 4-7% range associated with historical levels of productivity

Results also generally consistent with NPCC's 2-6% SAR goal



2015 ISAB review:

Comment: "The Discussion provides a good summary of key information, leading to the conclusion that pre-harvest SARs of ~4-7% are needed to improve productivity to pre-1970s levels."

"Is this sufficient to enable a self-sustaining natural population at spawning densities that exceed minimum abundance thresholds?"

2015 ISAB review:

Comment: "The Discussion provides a good summary of key information, leading to the conclusion that pre-harvest SARs of ~4-7% are needed to improve productivity to pre-1970s levels."

"Is this sufficient to enable a self-sustaining natural population at spawning densities that exceed minimum abundance thresholds?"

Response: "Pre-harvest recruits to the Columbia River [associated with 4-7% SARs] ranged from 140% to 900% of the MAT, providing considerable buffer for harvest and upstream passage survival for most populations."

"Key actions to increase SARs include reducing powerhouse passage and increasing water velocity…"

Future Work

- Update spawner-recruit analysis through recent brood years (smolt years 2007-2012)

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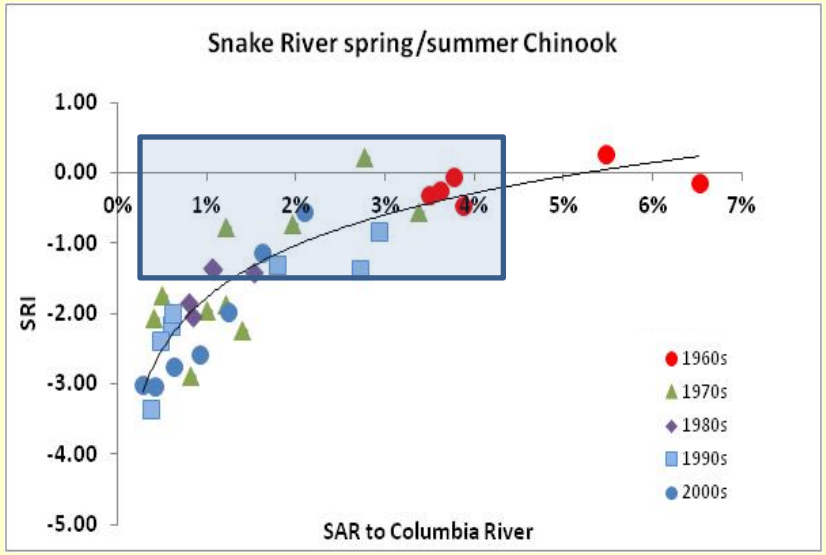
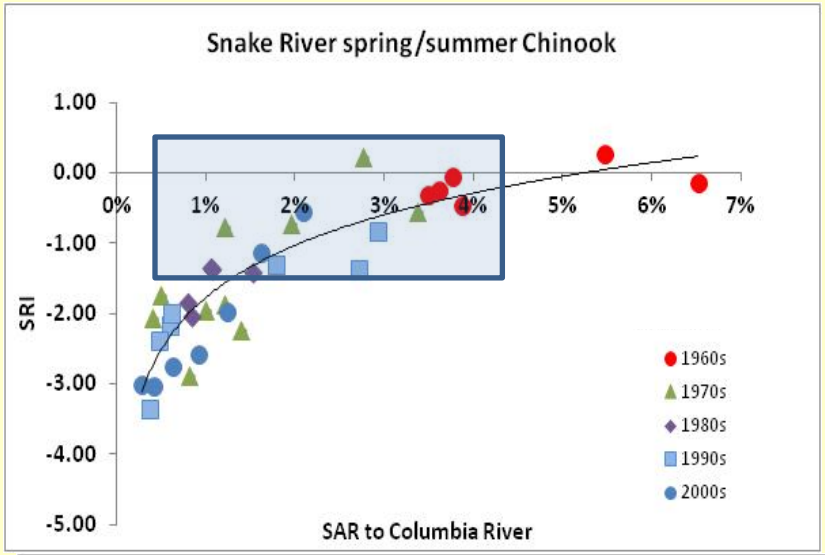
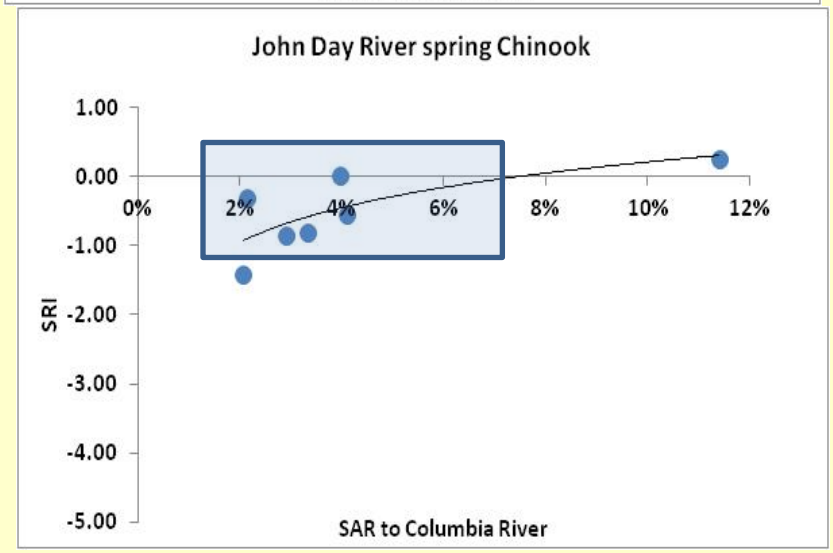
  - Snake: SAR range 0.5% to 4.3%



Future Work

- Update spawner-recruit analysis through recent brood years (smolt years 2007-2012)
  - Snake: SAR range 0.5% to 4.3%
  - John Day: SAR range 1.0% to 7.3%





Summary

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- Recent SARs (LGR to LGR) and life-cycle productivity (measured at spawning grounds):
  - Low spawner abundance (~30% Minimum Abundance Threshold)
  - SARs < 1% major population declines
  - SARs > 2% allow for population to increase (at recent low abundance)
  - Populations in good habitat: few other options to improve status

Summary

- Density dependence considerations (address ISAB 2015 comments)
  - Historical period with larger escapements and variable harvest rates (1950s to recent)
  - Fitted stock-recruitment functions available for large number of Interior Columbia spring/summer Chinook populations (pre-harvest recruits vs. spawners ~ density dependence)

Summary

- Density dependence considerations (address ISAB 2015 comments)
  - Historical period with larger escapements and variable harvest rates (1950s to recent)
  - Fitted stock-recruitment functions available for large number of Interior Columbia spring/summer Chinook populations (pre-harvest recruits vs. spawners ~ density dependence)

- SARs explain majority of variation in life-cycle productivity for Snake River spring/summer Chinook
  - SARs and life-cycle productivity declined since FCRPS completion
  - Declines associated with FCRPS development; survival varies with ocean conditions
  - SARs in 4-6% range associated with historical (pre-FCRPS) levels of productivity
  - Results generally consistent with NPCC 2-6% SAR goals
  - Unlikely to achieve "broad-scale" recovery without substantial increases in SARs

Next presentation: Life Cycle Modeling – Bob Lessard

Life cycle model evaluation of alternative spill scenarios

Presenter: Robert B Lessard

CSS annual meeting April 3, 2017

Comparing alternatives

- Use statistically validated model from 2013-2015 life cycle model evaluations
- Use a range of hydro and flow scenarios
- Simulate environment and harvest
- Predict long term abundance and SARs

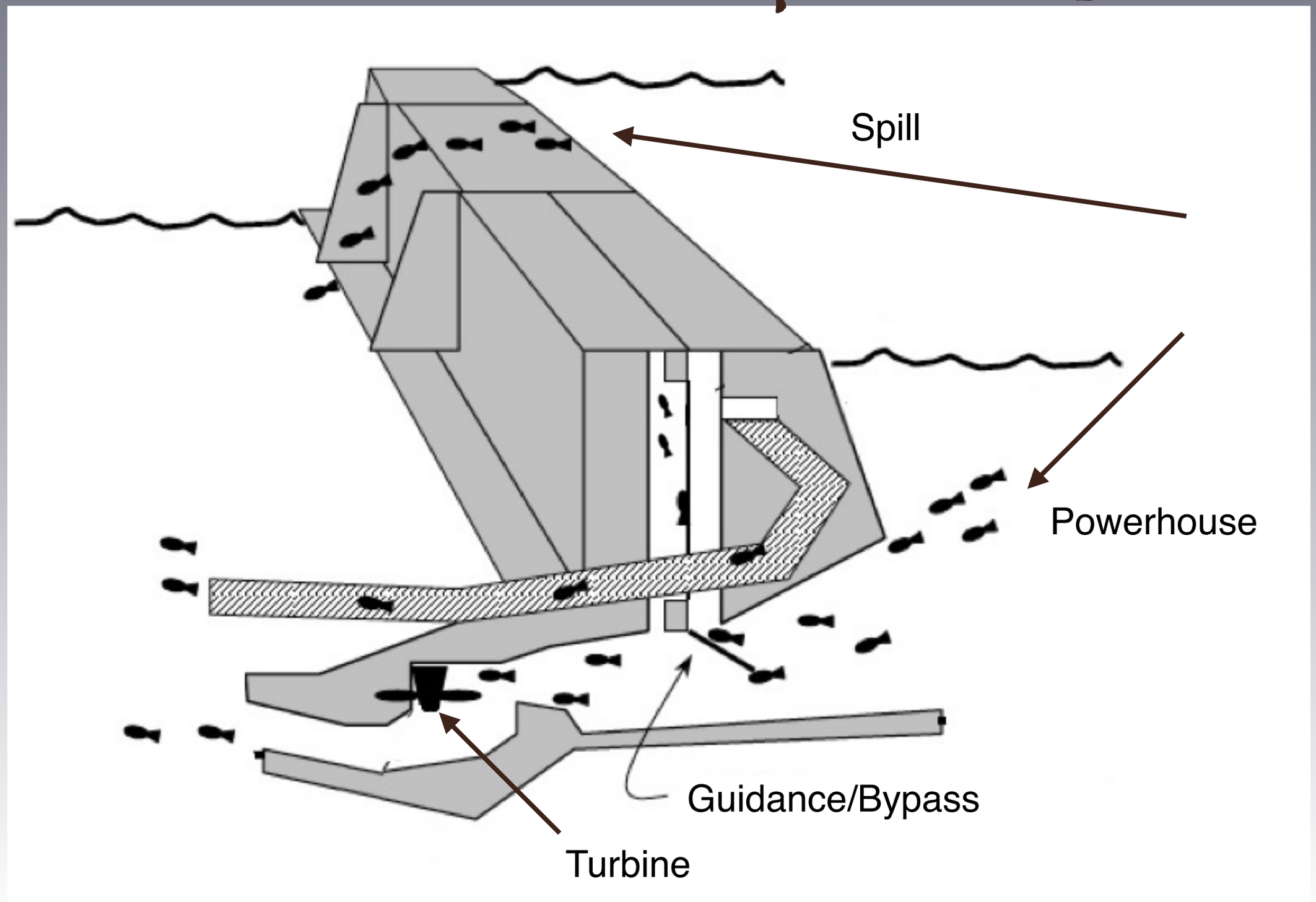
Variability and Contrast

- Uncertainty — Parameters
- Variability — Environment
- Contrast — Range of spill levels
  - BiOp, 115/120%, 120%, 125% TDG

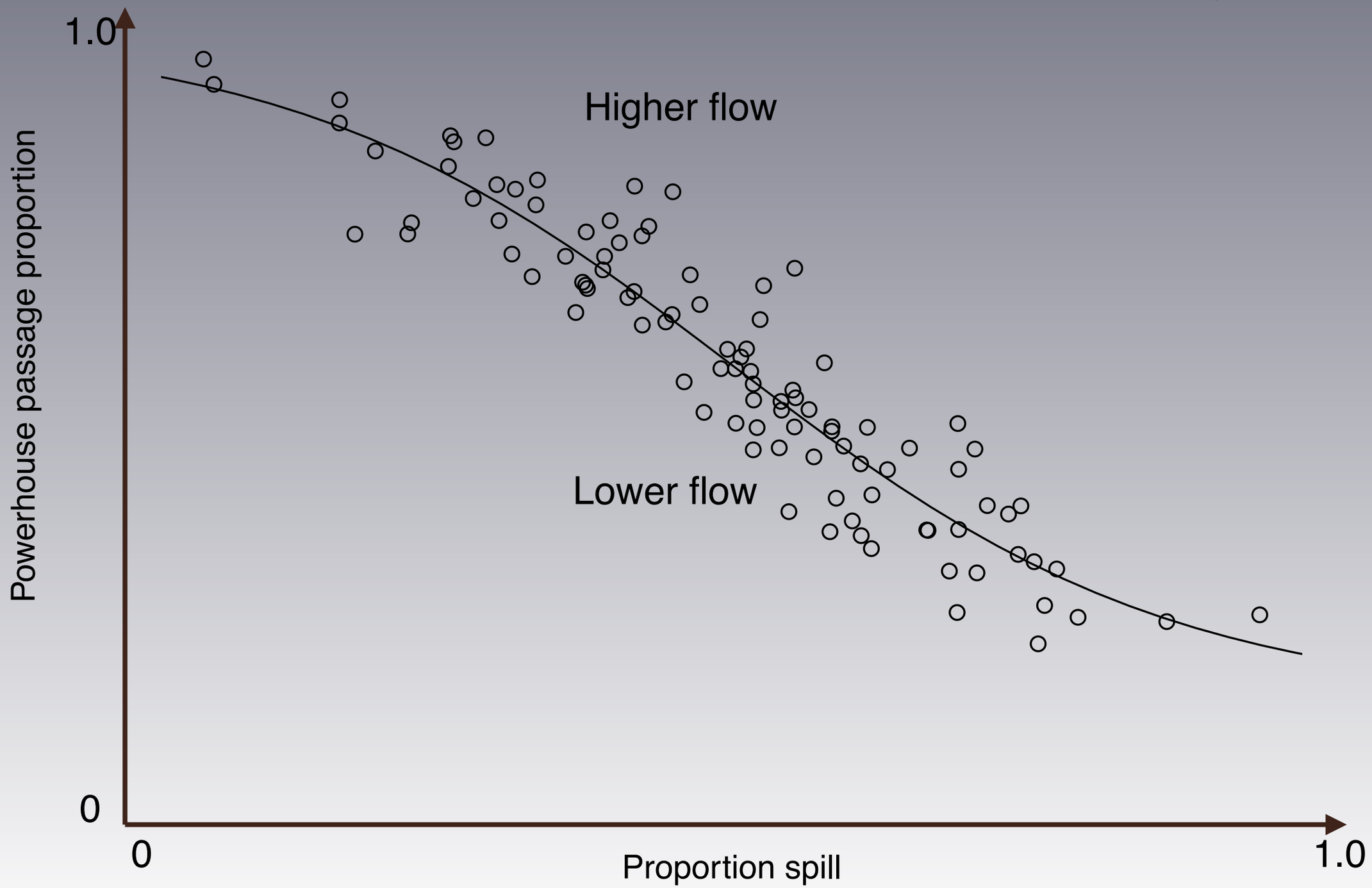
Environmental effects

- In-river juvenile migration survival
  - Water Transit Time
  - Powerhouse Passage (PITPH)
- 1st year ocean survival
  - Route of passage (PITPH)
  - Ocean conditions
    - Pacific Decadal Oscillation (PDO)
    - Ocean productivity index (Upwelling)

Powerhouse passage



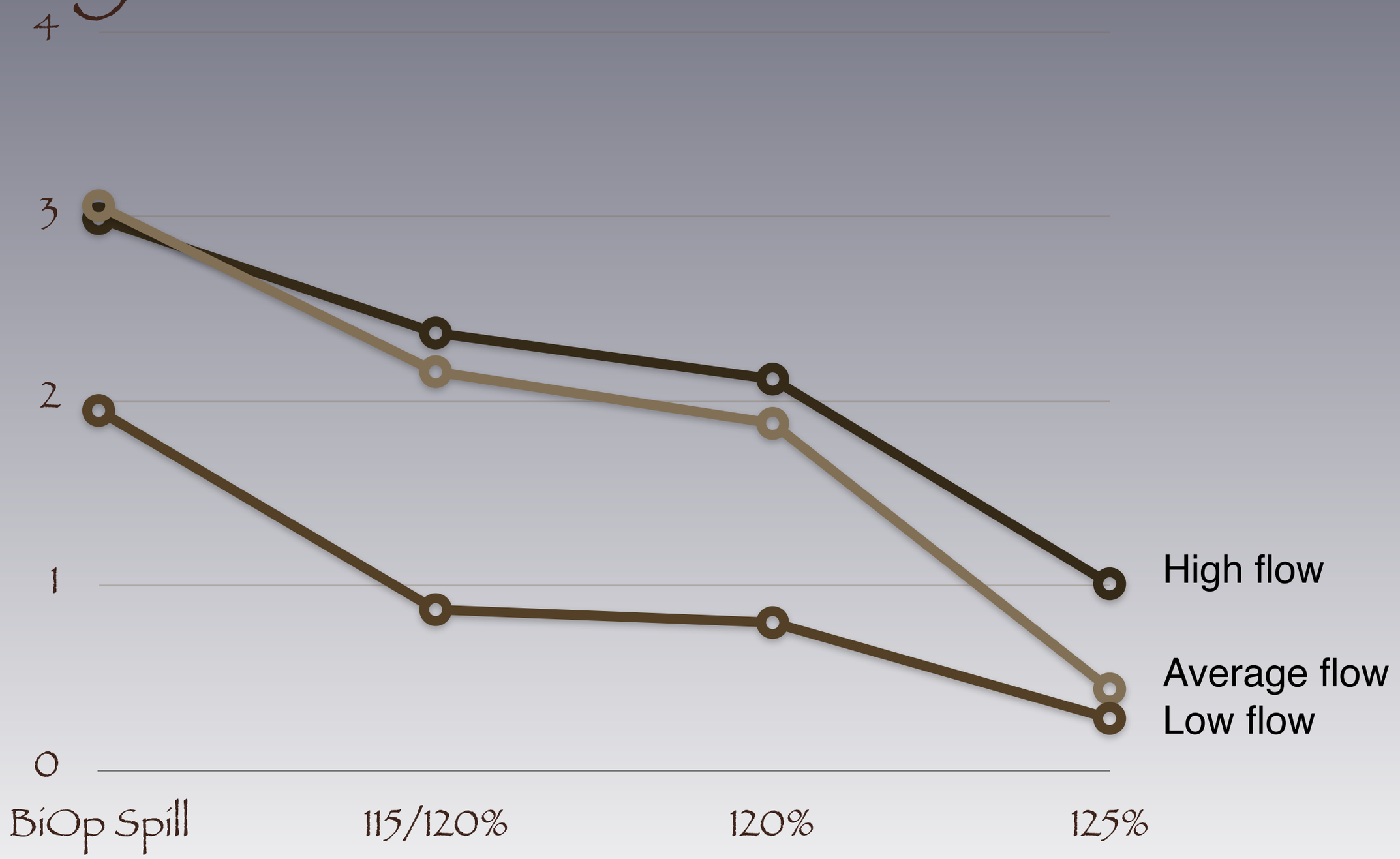
Interaction of flow and spill



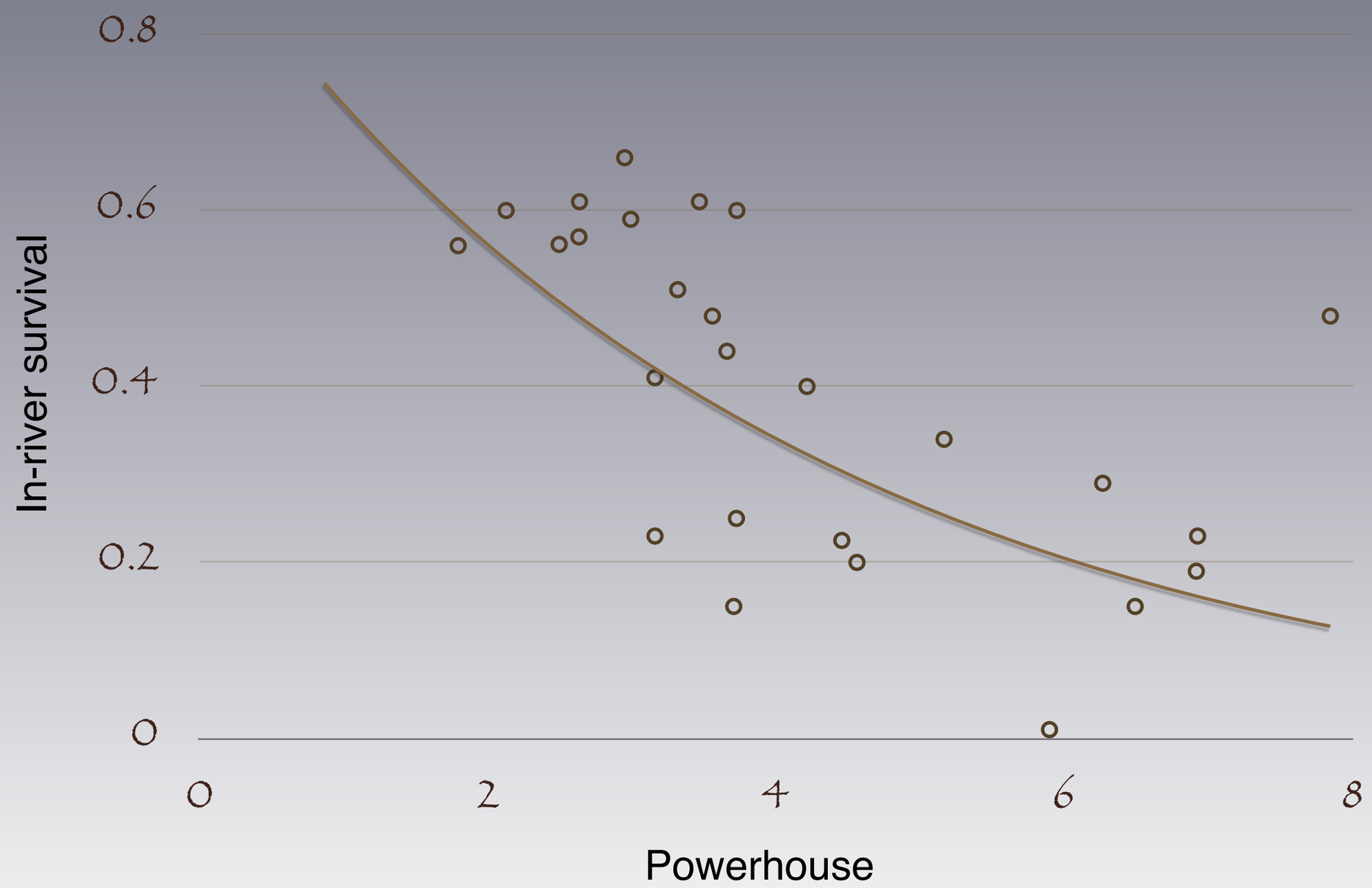
Interaction of flow and spill

- At each project PITPH is predicted by Spill % @ Flow that reaches TDG limit
- 2010 was a “typical” low flow year
- 2009 “typical” average flow
- 2011 high flow

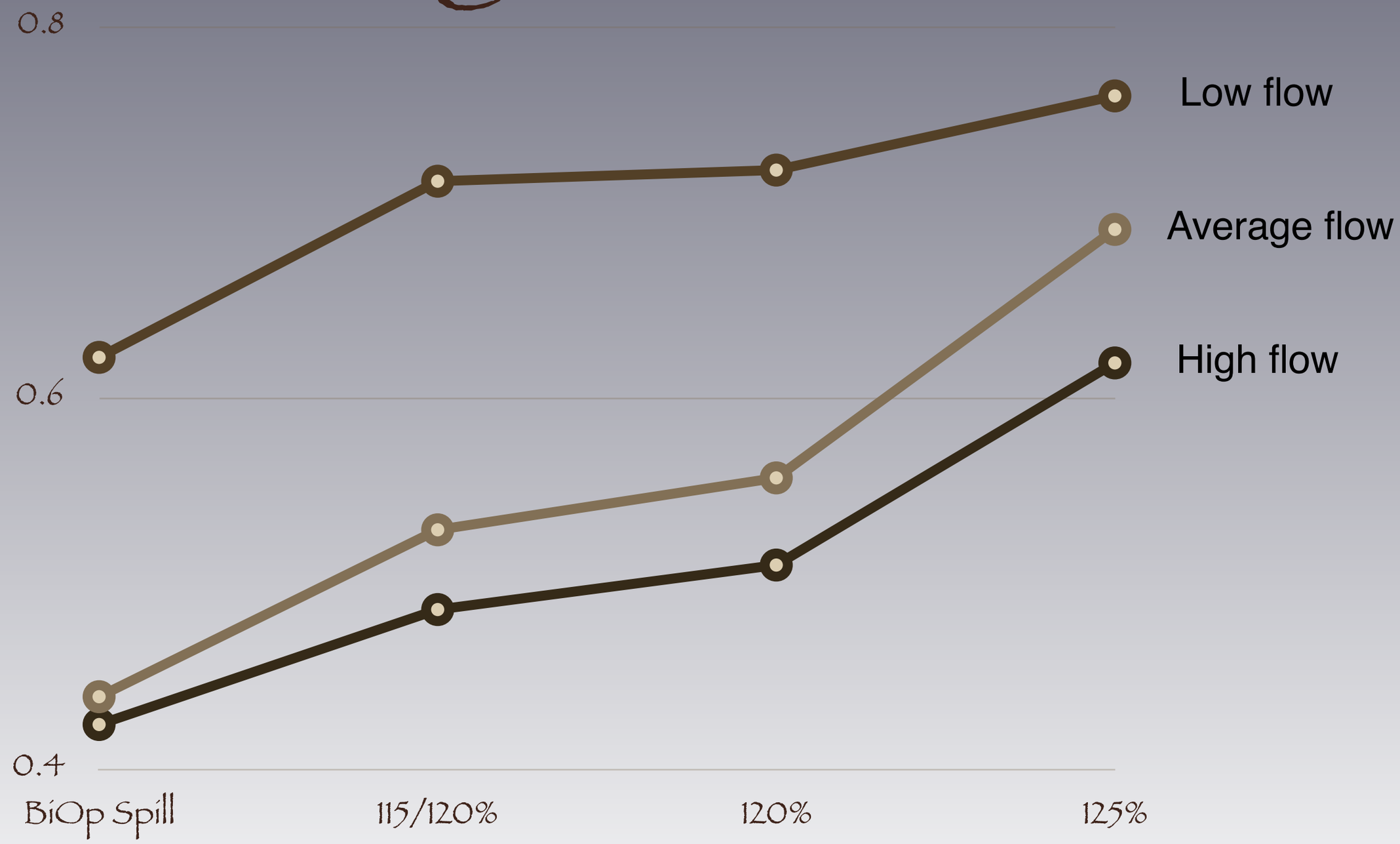
Hydro scenarios in PH



In-river migration survival

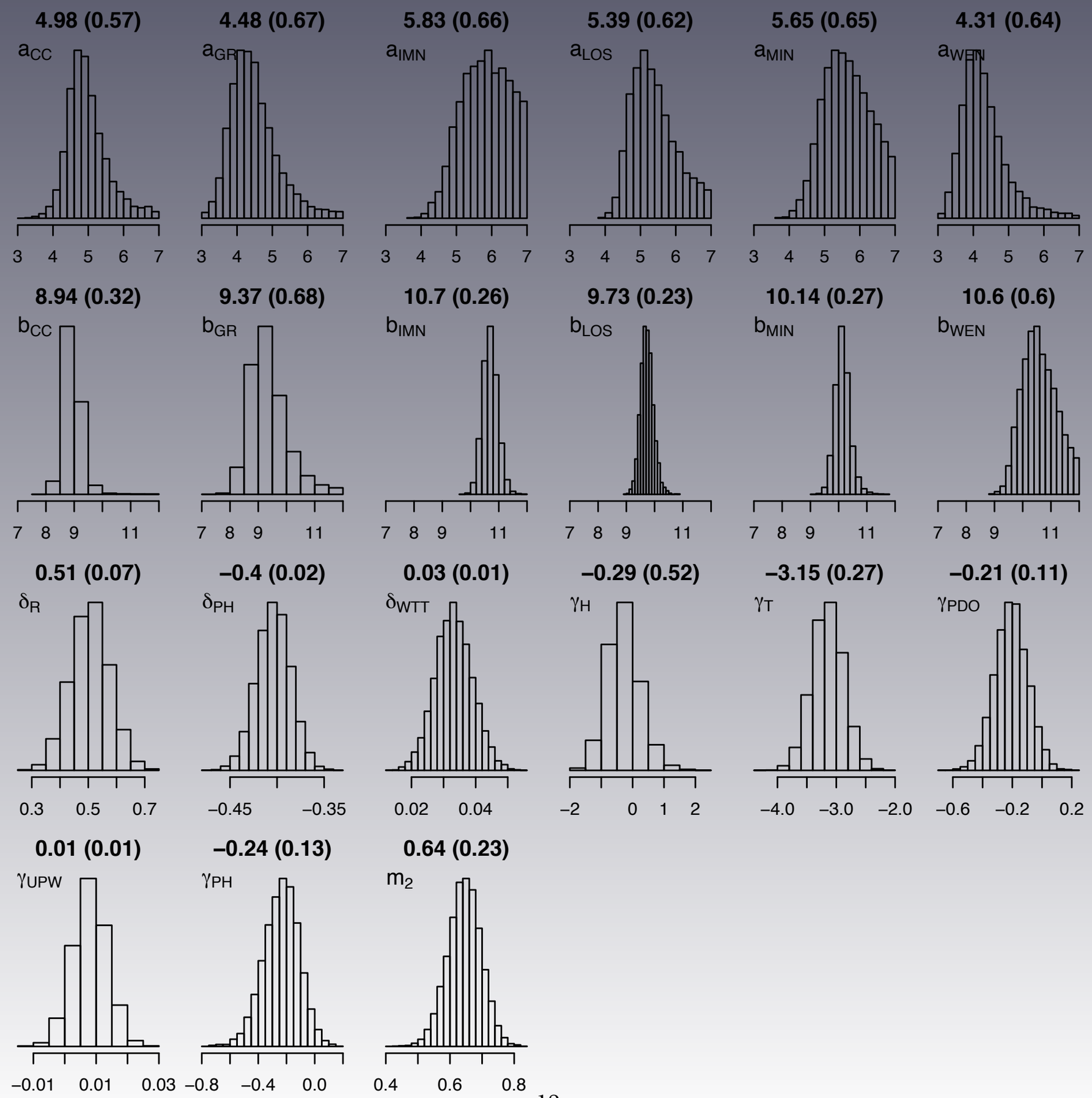


In-river migration survival

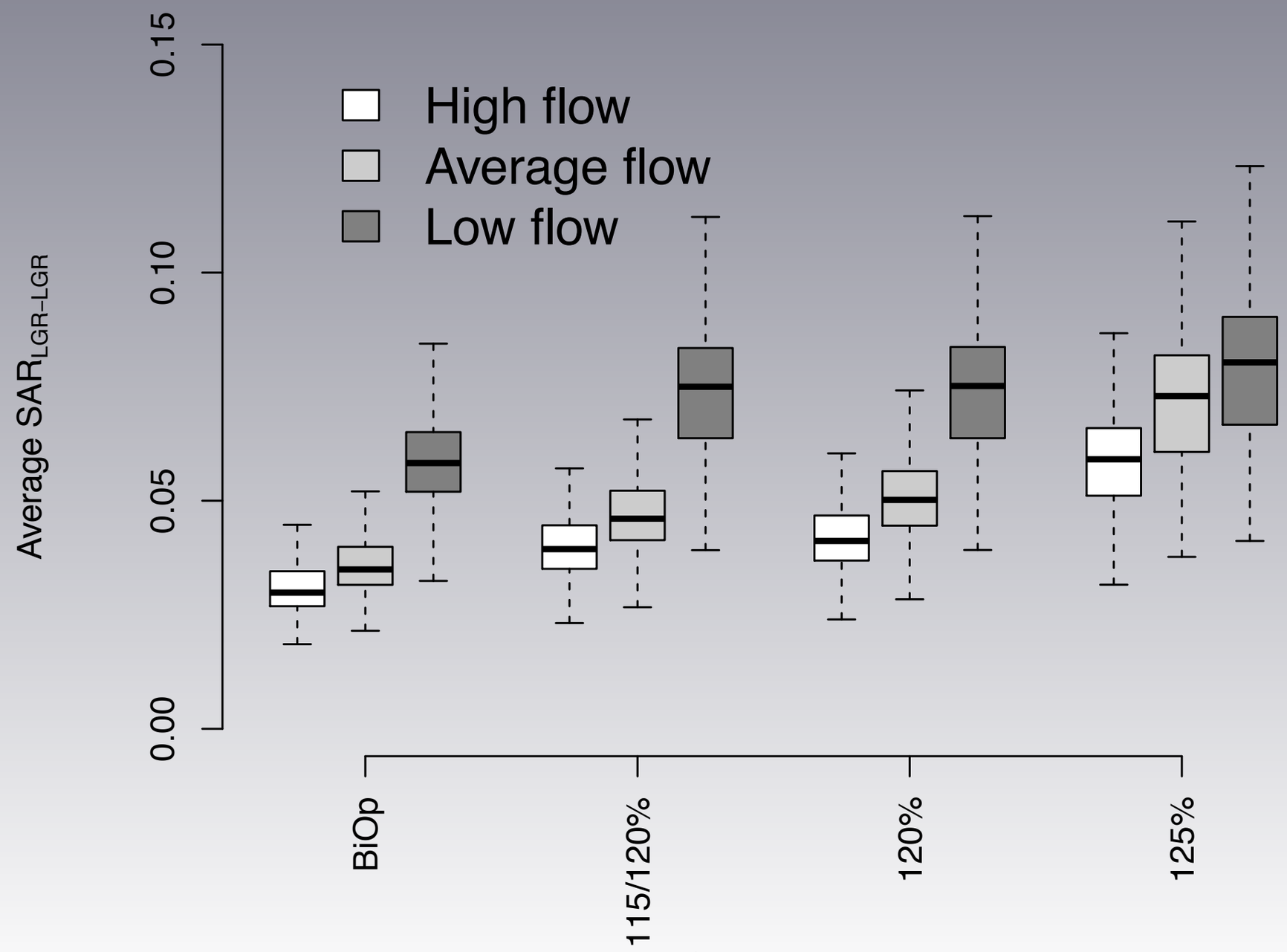


Future conditions

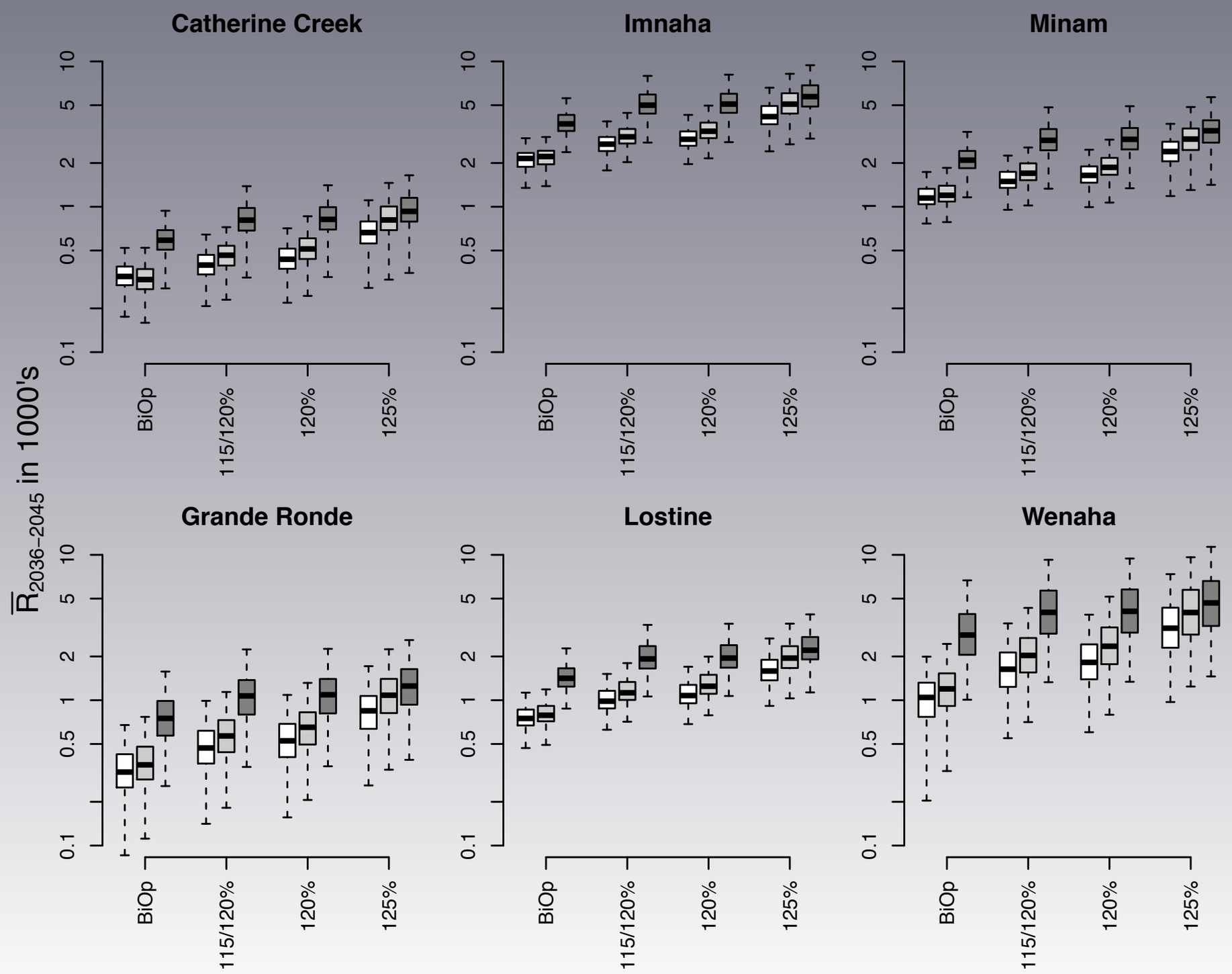
- Harvest rate increasing to 20% at 5000
  - Zone 6 < 17% currently
- Random "PDO" mimics empirical pattern
- Upwelling drawn at random from historical data
- Conversion drawn at random from 20 recent years
- Fixed 20% transportation
- Predict 2036-2045 average SAR and Abundance

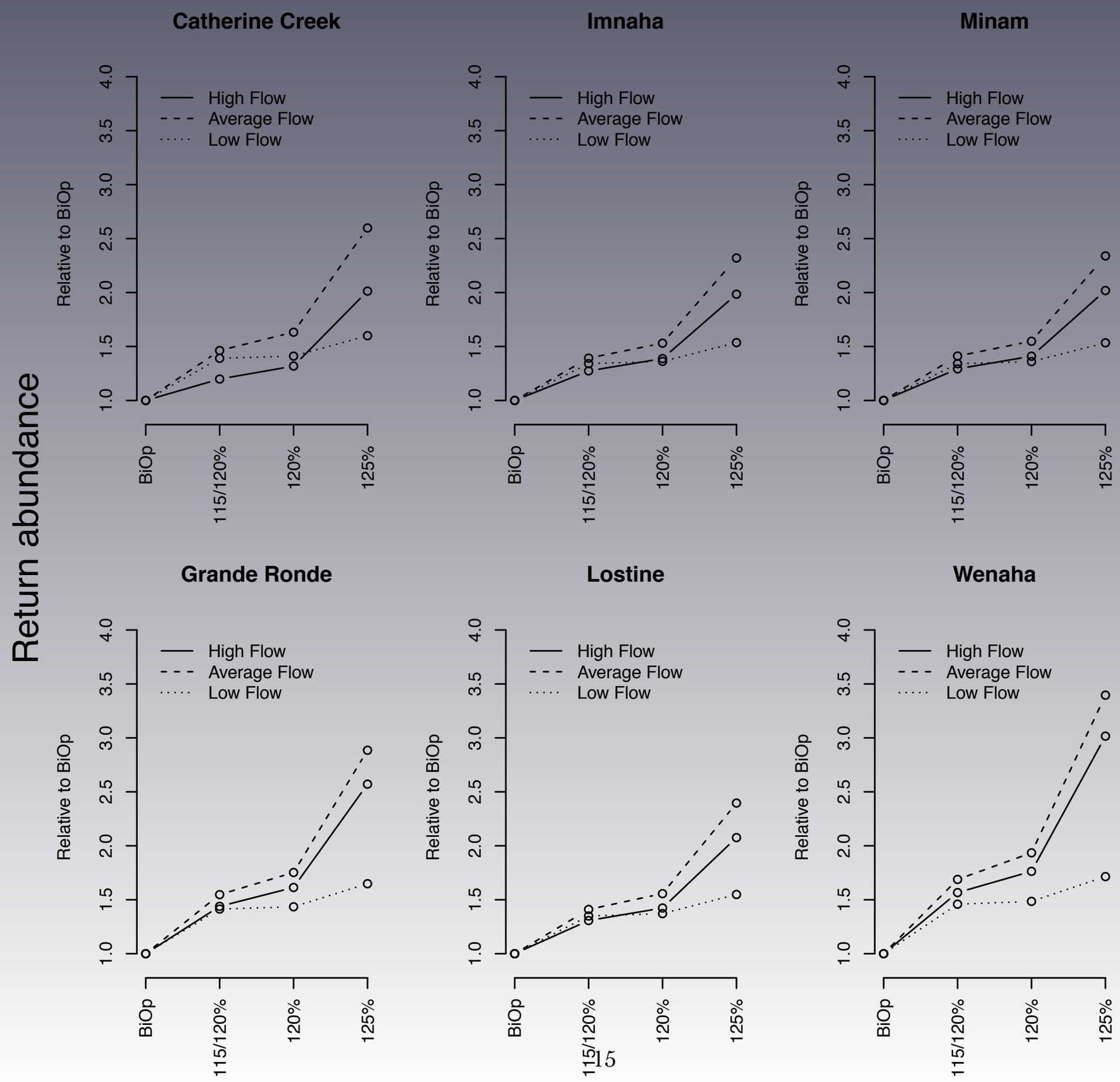

4.98 (0.57)
a_{CC}
4.48 (0.67)
a_{GR}
5.83 (0.66)
a_{IMN}
5.39 (0.62)
a_{LOS}
5.65 (0.65)
a_{MIN}
4.31 (0.64)
a_{WEN}
3 4 5 6 7
8.94 (0.32)
b_{CC}
9.37 (0.68)
b_{GR}
10.7 (0.26)
b_{IMN}
9.73 (0.23)
b_{LOS}
10.14 (0.27)
b_{MIN}
10.6 (0.6)
b_{WEN}
7 8 9 11
0.51 (0.07)
δ_R
0.3 0.5 0.7
−0.4 (0.02)
δ_{PH}
−0.45 −0.35
0.03 (0.01)
δ_{WTT}
0.02 0.04
−0.29 (0.52)
γ_H
−2 0 1 2
−3.15 (0.27)
γ_T
−4.0 −3.0 −2.0
−0.21 (0.11)
γ_{PDO}
−0.6 −0.2 0.2
0.01 (0.01)
γ_{UPW}
−0.01 0.01 0.03
−0.24 (0.13)
γ_{PH}
−0.8 −0.4 0.0
0.64 (0.23)
m_2
0.4 0.6 0.8

Predicted SARs

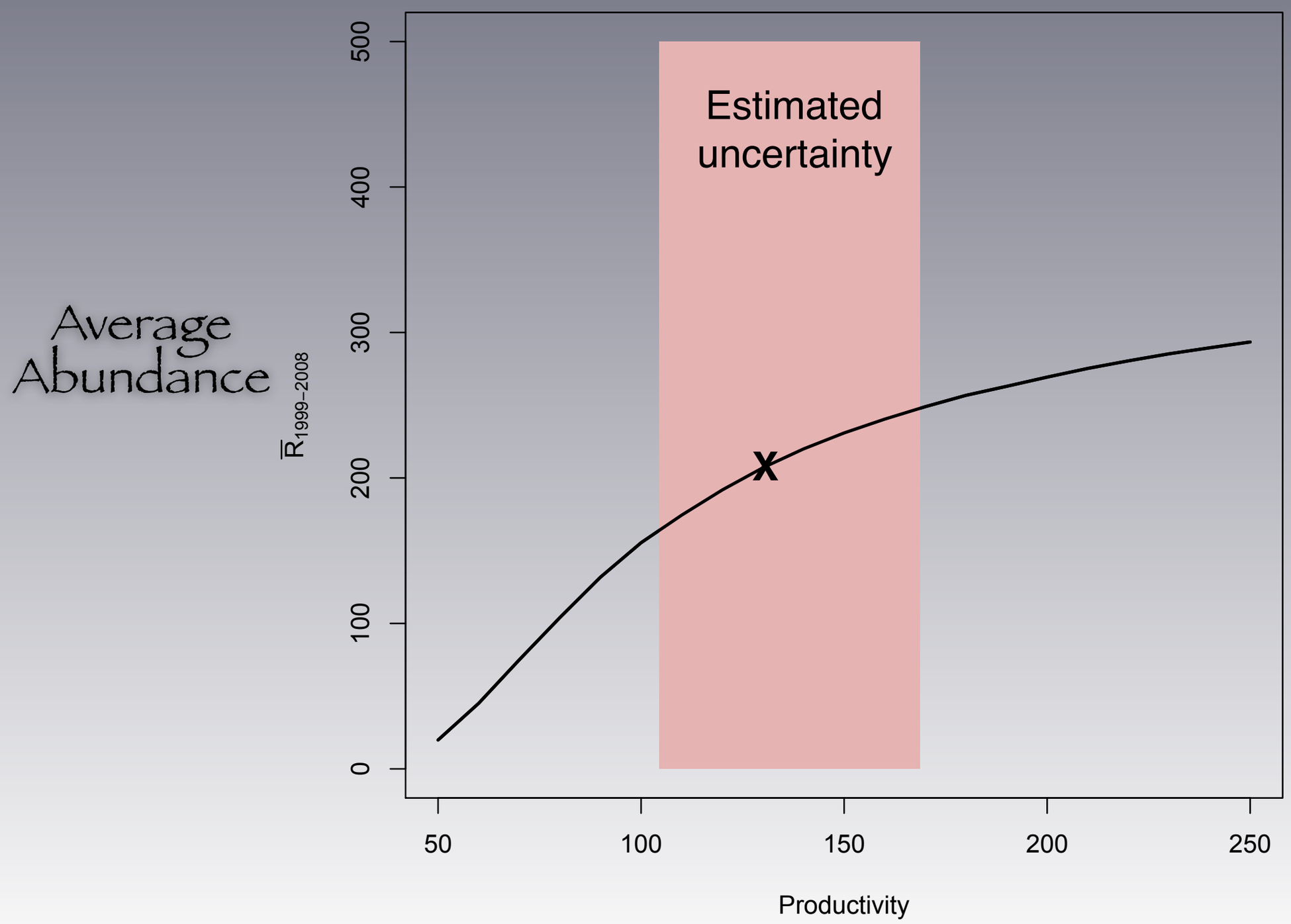


Predicted abundance

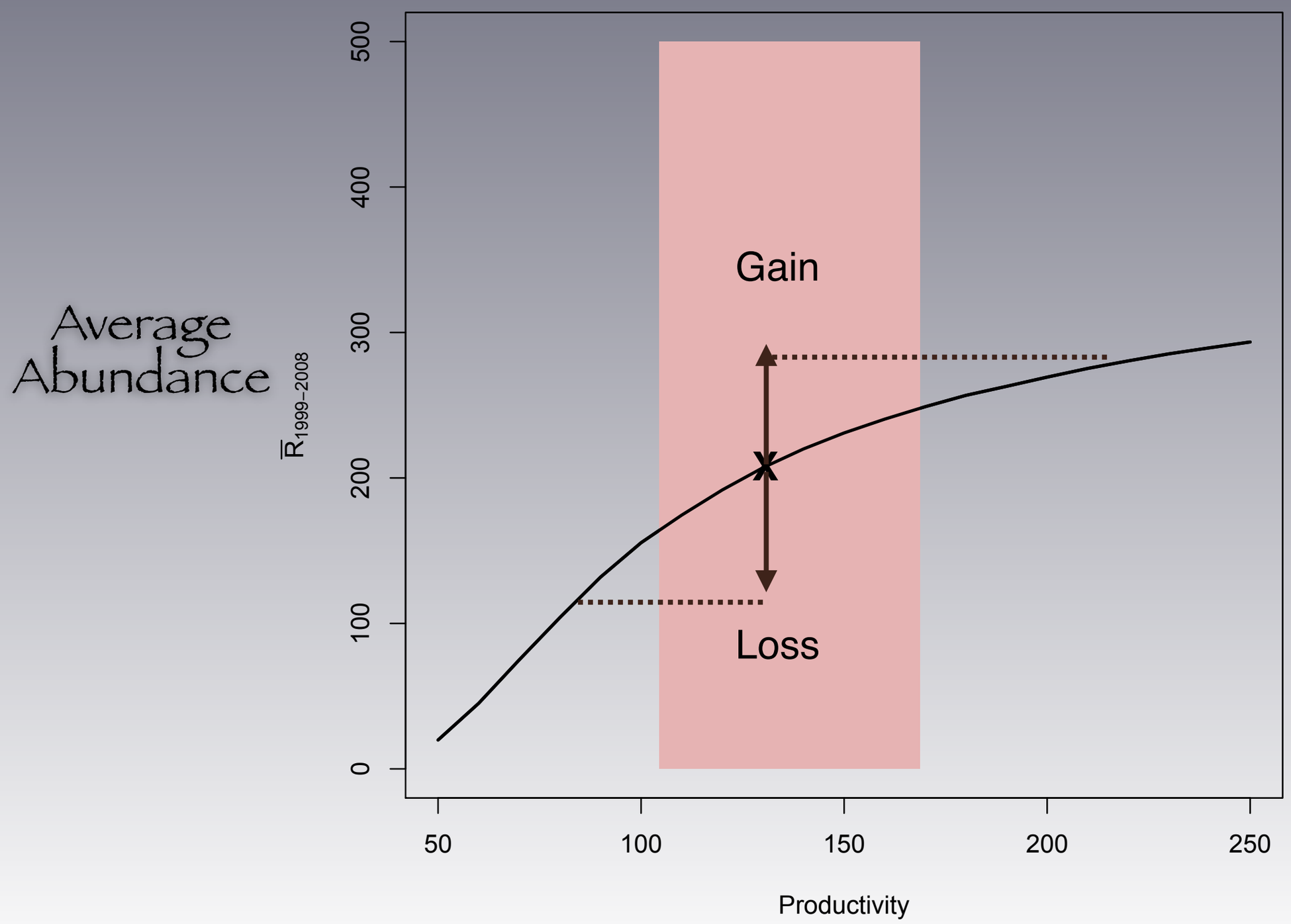


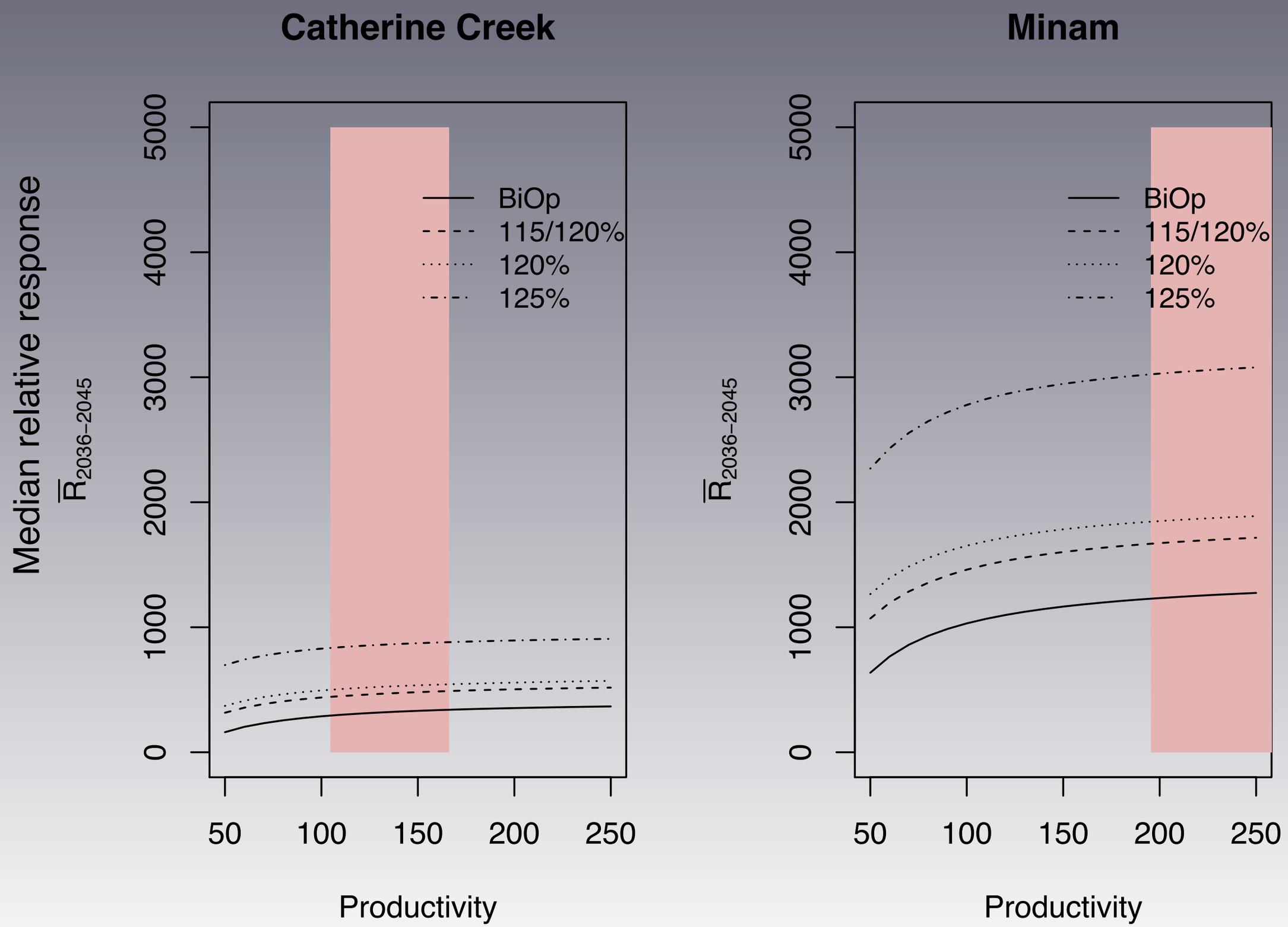

Return abundance
Catherine Creek
Imnaha
Minam
Grande Ronde
Lostine
Wenaha
High Flow
Average Flow
Low Flow
Relative to BiOp
1.0
1.5
2.0
2.5
3.0
3.5
4.0
BiOp
115/120%
120%
125%

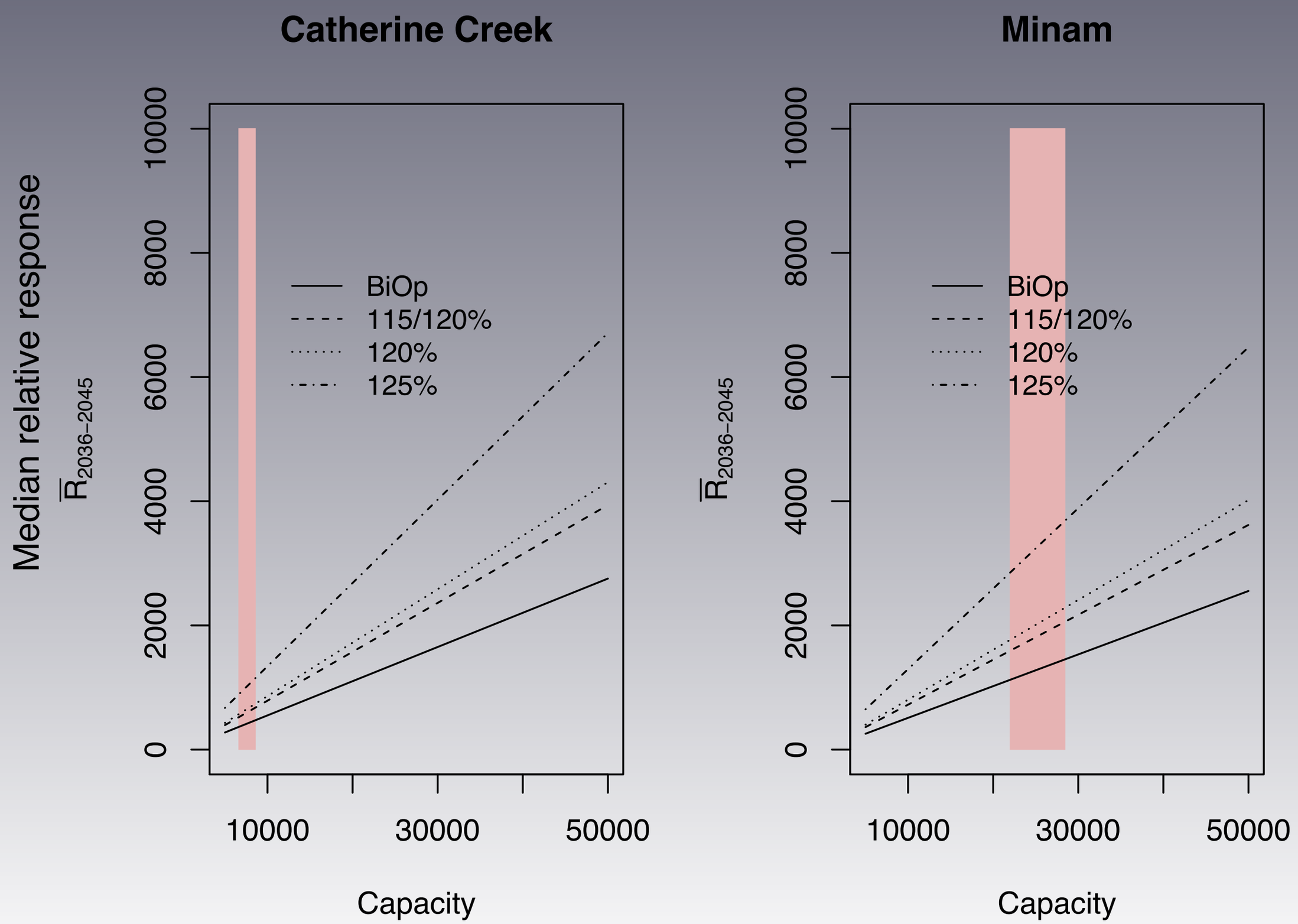
Habitat limitation



Habitat limitation




Catherine Creek
Minam
Median relative response
$\overline{R}_{2036-2045}$
0
1000
2000
3000
4000
5000
BiOp
115/120%
120%
125%
50
100
150
200
250
Productivity


Catherine Creek
Minam
Median relative response
$\overline{R}_{2036-2045}$
0
2000
4000
6000
8000
10000
BiOp
115/120%
120%
125%
10000
30000
50000
Capacity

Key findings

- More spill always produces higher survival and abundance, regardless of flow.
- Habitat-dependent abundance response
- Potential for 3X increase with higher spill

NOTE: The following transcript is provided as best heard on the recording taken on April 3, 2017 during the Annual Meeting Q&A. As such, certain names or phrases may be unheard or written incorrectly due to crosstalk, or other outside sound interference. As such, these will be marked with* ***crosstalk** and **interference** respectively.* ***Unheard words or phrases *will be marked with an unbolded -?-.* ***Time Stamps*** *represent when a new person has begun speaking. A name is provided in bold when the speaker is either introduced or known.***

00:00 **Jerry:** I should say that we are recording it so when you ask a question if you could introduce yourself and say what agency you are with so we can figure out that down the road

00:14 **Carl Schwarz:** Carl Schwarz with the ISAB for Steve with the natural ***interference*** 2015. Could you comment on how transportation differs among those two years? And something about ***interference*** predation among those two years.

00:37 **Steve:** In terms of transportation, these were all, I was presenting the results for transporting fish. In terms of the proportion transported, much much lower proportions transported in 2010 and 2015. Near 100% transported in 2009 whereas in 2010/2015 there are, maybe 15-20%, and that's, I think, mainly a function of when spill is provided at low flow a very high proportion of fish are going to lose the way when entering collection systems. In terms of predation that's a topic that we're needing to get into and planning on getting into in the future but we have not yet today.

01:42 **Jerry:** Okay, do we have another, or more questions?

01:54 **Ed Bowles:** Ed Bowles, Oregon Department of Fish and Wildlife. Just a couple questions. One following up on the earlier one, the last one that Bob fielded. I think exploring that a little bit more, and Steve this may be in your wheelhouse as well, but, the question was raised regarding that counter intuitive of higher SARs with, uh, under low flow years versus the importance of flow relative to reach and reach survival. And your answer was well it's really about spill proportion and the efficiency of that spill, and I was just wondering if you could explore that idea relative to when these fish need help - they need help every year, but when they're most vulnerable is in those conditions that are the worst under low flow conditions, drought conditions, environmental conditions that aren't as helpful. And I find that particular piece intriguing and that as managers we have the potential to partially mitigate for poor environmental conditions. I remember seeing and I don't think it was today, but just contrasting in 2001 versus 2015 relative to reach survival with something that kind of brings this home.

03:39 **Steve:** Yeah I think that my results, Bob's results we're showing that flow is important and we are also showing that spill is very important. One thing to consider is that Bob was presenting some of the results for chinook. We see a greater importance of flow especially for steelhead, we really require good flow. We don't really have a lot of control over the snow pack that is provided in any one year but we do have some control of the amount of snow that is provided and these results that both Bob and I have shown is that spill is a big factor and avoiding the powerhouse is a big factor that we have some degree of control over and it is a tool -probably the only tool- that's available to mitigate for those low flow conditions. I don't know if Bob has anything to add.

04:53 Steve, ***interference*** and in relation to that with Charlie the survival that is necessary to achieve TRT goals which ***interference*** -looking at probability of avoiding extinction, low-extinction probabilities. One of the things that drives it, is, getting of the bottom of -?- of those extremely low SARs. So the ability to avoid real ***crosstalk*** and the one thing that spill and low

flow conditions does is prevent it, and what's really interesting to me is that Bob's results really support what we're seeing relative to the necessary increased we need for survival from the -?- ***interference*** But I think that emphasizes the importance of having a tool that works in a low flow condition -?- with poor ocean conditions also -?-

06:20 Yeah, I just, just to have on, if it's not clear, because spill under low flow conditions is so effective at fish avoiding the powerhouse, that is what's really driving these results. We should go away, home from these presentations based on these results saying that flow is not important, because it is. But what happens at low flow conditions is that providing spill is such a benefit in terms of avoiding the powerhouse that you can get these big improvements in river and SARs.

07:18 **Bob Heinith:** Bob Heinith for Inter-Tribal Fish Commission. I know we don't have a lot of data on sockeye, but at this point does it look like the patterns for steelhead in terms of in-river survival and SARs and productivity for steelhead, are they are reasonable surrogate for sockeye?

07:40 I think, if anything I would say that subyearling chinook- I think steelhead are a reasonable surrogate but for some reason they have really good SARs and it's difficult at this point, you know, we have such limited data. The data that we do have suggest that the same factors that are -?- for chinook, and steelhead, and subyearling chinook are also important for sockeye. You'd think of it, that they are in the natural environment they're used to finding exit points of lakes. You can think of reservoirs as functioning as lakes and so they do appear to do a very good job of getting through the reservoirs and surviving at at a decent rate, better than some of the other species that we look at. But, what we've seen in the limited amount of data that we have, is that the same factors are important, improving the speed of the water and improving powerhouse avoidance are the things that are gonna improve sockeye as well.

08:51 What would you say, Steve, about flow, versus- flow seems to be more effective for steelhead, in terms of -?- these travel time than spring chinook

09:03 **Steve:** Yeah, if I were to rank the ability to deal with low flow conditions across the species I would say that probably sockeye and subyearling chinook are able to deal with low flow and low velocity the best and steelhead are probably the worst, they really need flow to perform well.

09:28 **Jerry:** Alright, next question?

09:42 Thank you, Northwest Energy Coalition, this may be sort of a tangent but let me ask anyway. I noticed that in chapter 3 studies include water temperature and Bob, your study does not at least that I can tell. If you did- is water temperature enough correlate with water flow and travel time that it wouldn't really tell you very much or- what's your thought about that?

10:13 **Bob:** I'm mainly not including it because I can't get a hold of it and I haven't included it in the estimation -?- so I have no way to include it now.

10:35 I think I would speak to that a little bit, the results that we presented in chapter 3, they were looking at juvenile survival and travel time, and temperature was very limited and the main drivers were typical seasonality water transit time, spill, presence of -?-. The importance of temperature for especially spring migrants where the water temperature is cool, it really wasn't a factor and even in the summer migrants the subyearling fall chinook it really wasn't showing up as being an important factor. So I think those general results of temperature not being that important for juvenile migration

and survival, I think that what kind of led Bob to kind of focus on those main drivers that we were looking at. But, whereas temperature is not so important for juveniles, I think that the place where temperature is more important is for the adults coming back and we saw results like that from 2015 where they use reservoirs, they stratify the water temperature on the surface is the hottest, that is the water that gets fed into the fish ladders and those fish ladders become hot to the downstream and they become a huge thermal barrier. Of course, made some good progress getting some cooling water in Granite and Goose as well to try to address those issues but I think that's where temperature becomes an important factor is in the adult migration, not so much in the juvenile outmigration.

12:22 **Charlie Morrill:** Jerry, and -?-. Jerry, you mentioned that one bypass event would likely mean -?- survival for juvenile that's going out, and -?- you noted that -?-. Is there a correlation between those, do they reflect some of the same dynamics that are going on? I'm not quite sure.

12:54 **Jerry:** I think he meant Steve. He did the bypass.

12:59 **Steve:** What I was reporting was the reduction in ocean survival bypass event as a smolt. That was basically a 12% reduction. That's very different than what Charlie was presenting, which what he was looking at was life cycle productivity and survival and showing that recent years of productivity was roughly 12% after full hydrosystem development compared to pre- development. The same number, but very different context.

13:39 Although I didn't actually present any of it here, when we looked at long-term SAR data sets for chinook and steelhead, we do see a fairly significant impact of powerhouse passage when we look at spawner -?- data, again we pick that up as well as water travel time in both of those

14:06 **Charlie Morrill:** Bypass would have an impact on life cycle productivity as well

14:12 Correct.

14:17 **Jerry:** Any other questions?

14:34 **Ed Bowles:** Ed Bowles again, Oregon Department of Fish and Wildlife, I guess this is maybe for Bob, but I'd be happy to hear from any of the panel. Keeping the relevancy of the CSS as each year we get a stronger and stronger -?- of information that's accumulating and we're now in a big kind of, revisit of the FCRPS relative to the -?- in development as well as in the BiOP. And I was just curious, it seems to me that the strength of this engine relative to information and analytics, I'm just curious like, Bob, your model relative to looking at scoping options under the EIS, it seems to have application there. Is the group interested or being courted taking this information and helping sort through the different scoping ideas relative to the environmental impact statement particularly it seems to me that the dynamics of a natural river option, you're still turning dials relative to powerhouse passage, you're turning dials relative to water travel time, habitat improvements, and it seems like all of these are somewhat built in and I want to make sure that this is, that the CSS is front and center in some of those analytical considerations. So I just, would appreciate some comments on that.

16:27 We went into the life cycle modeling business to basically provide the contrast and the perspective of variability in the ocean versus what can be achieved ***interference*** versus, how that contrast is across different populations and -?-. Obviously the recent court ruling speaks to a lot of exactly those things are where and where the successes might be, but there's certainly no intention to

push any agenda. We're poised to answer those questions but the whole point is to see the -?-.
Interference

17:29 I would just like to add a little bit: I think the CSS has always be interested in providing management relevant advice or guidance or predictions, and I think that we are well positioned to look at those types of questions because you are exactly right there are these knobs that can be turned, spill levels can be changed, and potentially removed, those will have effects in terms of powerhouse passage, in terms of water transit time, there are habitat alterations that could be considered and I think that we are striving to provide management relevant advice, or guidance or scenarios or things to consider in those types of discussions and if people are interested in some specific scenarios that feel we should be looking at then -?- consider trying to answer those questions. The other thing that whatever happens, I think, kind of, Bob mentioned this, That because of the consistent tagging and monitoring that is occurring and the CSS is collecting data on, that each year if something different happens we have the tools to measure the effects of those types of things. In the same way that, those comparisons in the low flow year -?- natural experiment, we are able to generate those estimates and show the effects of those management decisions that occurred and looking into the future whatever decisions are made will have some good information to show what the effects of those were and hopefully further answer the whys, why they are, they way they turned out.

19:32 We intend to continue to improve the life cycle -?- of through shoring up the statistical side of things by adding more complexity, adding more data, asking a few questions, and looking -?- that's not gonna stop. The recent court ruling had a few interesting perspectives that I don't think have been addressed yet, we haven't included anything like climate change in our numbers, one of the bigger considerations of the GIS was whether or not climate change was gonna wipe out any -?-, we haven't done that, but it could be done.

APPENDIX J

RESPONSE TO COMMENTS ON DRAFT CSS REPORT

CSS Responses to BPA comments on the 2017 CSS Annual Report.

This document provides CSS Responses to comments and questions provided by BPA on the 2017 CSS Draft Annual Report. BPA original text is itallicized and CSS responses are in standard font. Each CSS response is set apart from the BPA text. Each response begins with **CSS Response:** in bold as shown; followed by the response to the comment or question.

BPA Comments on the DRAFT CSS Annual Report (title added for clarity by CSS)

Chapter 2.

p. 27: The report notes that WTT in breach scenarios is calculated by adjusting water velocities to free flowing values for the lower four Snake River dams, and also by adjusting the lower four Columbia River dams to account for the extra volume of water from the breached Snake River (emphasis in italics added). It is unclear why the volume of flow in the lower river would be expected to increase in years after the initial breaching of any dams in the Snake River. Any increase in total river flows would seem to be a short term effect and only be applicable in the short time immediately after a dam is breached and the reservoir begins to empty.

CSS Response: Clarification and correction provided in methods.

Figure 2.5 appears to show that model may underestimate in-river survival and overestimate C0 SARs in recent years under the current hydrosystem configuration. How does this lack of predicted precision undercurrent system configurations affect the accuracy and uncertainty of the modeled predictions that follow in this chapter? How accurate is model in predicting in-river survival in recent years with low flow and high spill like 2015 or high flow and high spill like 2017?

CSS Response: This now appears as Figure 2.6. The life cycle analysis was originally implemented using the Grande Ronde/Imnaha MPG populations because there were smolt data to provide the means to examine trade-offs between tributary and mainstem/ocean dynamics, yet the populations provide relative low sample sizes of returning adult PIT tags for empirical survival comparisons. The best option has been to use Snake river spring/summer chinook aggregate SARs for empirical validation of the Grande Ronde dynamics, which means survivals of the MPG may differ from the ESU aggregate. The fact that overall the SAR and T_XSAR fit empirical trends better than the C_0SAR suggests the potential for either an

underestimate in the number of smolts outmigrating or an overestimate of the aggregate SAR. As emphasized in the discussion of the results, the accuracy is less relevant that the relative survival predicted across spill scenarios. The inter-annual variation predicted in survival is evident in all three SARs, and is manifested in the spill scenario comparisons.

Figure 2.9 updates data previously shown in figure 2.10 from the 2016 CSS report and shows projected SARs under four levels of spill and breach/ no-breach scenarios. Based on the discussion in this chapter, PITPH and WTT are the two primary freshwater variables influenced by the spill and breach scenarios (with values shown in table 2.2). As discussed at the end of this chapter, the patterns in SAR values at low, moderate and high flows shown in fig 2.9 appear different than what was reported in the 2016 CSS report. It would be helpful to add a more detailed description highlighting changes in the 2017 version of the model (i.e. expanded data sets or updated assumptions) that contributed to these changes in the 2017 results.

CSS Response: This now appears as Figure 2.10. As discussed, the introduction of new statistical terms and the use of additional years of data resulted in parameter estimates suggestive of a subtly different dynamic, that being that the faster water travel time at higher flows was predicted to be more significant in improving survivals in the current analysis. The benefit of the faster moving water is intuitive – less time exposed to predation. The fact that the water transit time emerged as a stronger positive influence on survival is a byproduct of the introduction of additional likelihood terms, and possibly the additional smolt data as well.

Also based on the results shown in figure 2.9, additional discussion of the potential contrasting effects of spill and water travel time under low and high flow scenarios would also help elucidate the modeled increase in SARs shown for the breach scenarios. There is no overlap in SARs between the non-breach and breach scenarios. For all combinations of spill and flow in the no-breach scenarios, SARs range from ~2.5-3.9%, while SARs for the breach scenario alternatives appear to range from 4.9-6.2% even though several flow/spill combinations have comparable WTT and PITPH estimates. It seems like an additional factor not represented in the PITPH/WTT table must explain this contrast in breach vs. non-breach scenarios.

As an example; modeled estimates of water travel time for all high and average flow scenarios under the non-breach alternatives range between 13-16 days. Note that the WTT estimate of 14.7 days in all low flow breaching scenarios, falls within this same range of the higher flow non-breach scenarios. Next, when looking at the associated estimates of PITPH values for the low flow/breach alternatives, the range of 1.14 to 0.66 powerhouse encounters under the BiOp-120% spill scenario range overlaps with the 1.01-.44 powerhouses for no-breach 125% TDG scenario, yet the SAR values are substantially different. Again, it is unclear what is driving the substantial modeled increase in SARs between these sets of alternatives given similar ranges of WTT and PITPH.

CSS Response: It is not surprising that predicted SARs do not overlap, because where low flow un-breached PITPH values overlap with breached values in the 115/120% and 120% spill levels, the WTT values still differ significantly (see Table 2.2). The contrast in in-river survival is already

apparent (see Figure now 2.10), and the SARs also incorporate the additional effect of PITPH effects on ocean survival.

Chapter 5

What SAR targets are predicted to yield positive population growth rate, and presumably advance Snake River steelhead and spring Chinook ESUs toward recovery?

Analytical results in Chapter 5 predict that for Snake River steelhead and spring Chinook,

- *SARs < 1% will fail to produce population growth long-term.*
- *Sustained SARs between 1-2% will produce positive population growth for both ESUs (Figures 5.1-5.2). Furthermore, the steep gradient of the fitted curves indicate the highest rate of change in productivity is evident as SARs increase from approximately 1% to approximately 2%.*
- *SARs > 2% continue to produce positive population growth, but at a slower rate than predicted for the 1-2 % SAR category.*

In the discussion and conclusions section there is little attention given to the population level benefits associated with achieving SARs exceeding 1% and approaching 2%. Instead the authors focus discussion on the > 2% category, even though the results suggest that 1-2 % SAR should foster ESU recovery, albeit over a longer timeframe. Furthermore, these results support the NPCC and ISABs calls to develop ESU specific SAR targets and a solid rationale to revisit the NPCC stated SAR goals of 2-6%.

CSS Response: As noted in the draft, Figures 5.1 and 5.2 represent realized population productivity (Rsg/S) responses at recent spawner abundances, which currently average well below the Minimum Abundance Thresholds (MAT) identified by ICTRT (2007a). These graphical comparisons begin to illuminate the SARs needed for population abundance to stabilize or increase given recent abundance. As we noted, these figures represent the empirical observations of SAR and Rsg/S without considering the influence of density dependence.

Clearly, SARs < 1% have resulted in major population declines for spring/summer Chinook at recent low abundance. We noted that generational declines in abundance occurred in 71% (130/184) of cases when SARs were less than 1% and in only one of 34 cases (3%) when SARs were greater than 2%. To address BPAs comment, we added language to identify that generational decline occurred in 21% (20/96) of cases when SARs were between 1% and 2%.

Quantitatively relating Rsg/S and SAR observations to ESA recovery potential will require use of spawner-recruit models (e.g., Chapter 2; ICTRT 2007b) within and across Major Population Groups (MPGs). Several MPG criteria are required for viability under ESA, including a mix of large and small viable populations, at least one highly viable population per MPG, and representation of all major life history strategies within viable

populations (ICTRT 2007a). Updated calculations of "survival gaps" (ICTRT 2007b), which represent the required change from the current condition to meet ICTRT viability criteria for abundance and productivity, would lend valuable insight into the degree to which SARs must be increased to meet viability.

Analyses in this Chapter support objectives of the Columbia River Basin Fish and Wildlife Program (NPCC 2014), encouraging a regional review of the NPCC SAR objectives relative the survival of populations needed to achieve salmon and steelhead recovery and harvest goals. Comparisons of Chinook and steelhead population productivity and SARs are conducted at the finest geographic scales possible, consistent with the ISAB (2013) review comments of the CSS draft 2013 annual report.

What hydro operations could yield 1-2% SARs across a range of water-years?
Chapter 2 provides guidance on this point, at least for Snake River spring Chinook. Prospective model analyses examined the expected SARs associated with several hydro operations including 2014 BiOp spill levels, 3 high-spill alternatives (up to 125% TDG), and ran the model with and without 4-dam removal in the Snake River. If we are interpreting Figure 2.9 correctly, when projected out into the future, every hydro alternative yields an average predicted SAR > 2%, regardless of water-year. If this is indeed the case, then even the BiOp alternatives are modeled to produce SAR > 2%, and yield positive population growth rate, consistent with results presented in Chapter 5.

> **CSS Response**: We would caution against over-interpretation of the Rsg/S vs. SAR observations because these represent the response at spawner levels below MAT and do not account for density dependence. Chapter 5 observations support the conclusion that SARs > 2% will produce positive population growth, <u>at recent low abundance</u>. That does not necessarily mean that 2% SAR will be sufficient for MPG and ESU viability for the reasons discussed above.

Chapter 6
Snake River fall Chinook-

What are the take home messages for SRFC?
One issue that jumps out of Chapter 6 is that transportation appears to be equivocal in providing a survival advantage for fall Chinook, and may, on balance, provide negative SAR compared to in-river migration. How do the CSS results compare with other regional analyses of the efficacy of Fall Chinook transportation? Discussion on this would be most instructive, since this ESU has exhibited a dramatic increase in abundance in recent years. An account of annual abundance of naturally produced SRFC that is presented here would be useful to provide context for these monitoring activities and analyses.

Will climate change analyses or discussions thereof, be addressed for this largely summer-migrating stock? Both juveniles and adults inhabit the mainstem during summer when water temperatures are warmest.

CSS Response: In general, the CSS has found that production subyearling Chinook salmon that migrate prior to mid-July have shown minimal benefit to transportation, and in most years have had shown either lower SARs in transport or no difference with in-river migrants. The CSS results agree with the NOAA results where there is overlap. Differences in results are due to differences in population timing, especially with regards to holdover probability, and methods used to estimate SARs. It should be noted neither study has been successful in evaluating the effects of transporting wild subyearling Chinook, due to lack of representative marking. Climate change is an important topic. And we look forward to incorporating information on climate change into our analyses as it becomes available.

Chapter 8.

The analysis interprets a negative relationship between travel time and temperature for summer Chinook including at relatively cold temperature ranges below 13-14C. This contrasts with findings in other studies of slower swimming speed at colder temps, with maximum efficiency in the 15-16C range (Salinger and Anderson 2006). This analysis uses late summer run Chinook because of the focus on survival rates at warm/hot temperatures, hence the sample size at the lower temperature range is relatively low. The Snake River spring and summer Chinook populations show a continuous range of run timing, and it might be recommended to include some spring run populations in a future analysis to increase sample size on the colder end of the range.

Also, harvest upstream of Bonneville dam may be a good addition to a future iteration of this analysis.

CSS Response: We exclude spring and fall Chinooks in our analysis, as opposed to Salinger and Anderson (2006). It is not surprising that our findings contrast with the findings by Salinger and Anderson (2006) because our scope of inference focuses on summer Chinook while Salinger and Anderson (2006) apply their findings on all spring, summer and fall run populations. We do not feel confident combining all Chinook populations in our analysis because they show different arrival timing, and possibly have different behaviors in relation to water temperature. Still, we will consider including spring run populations in the future analysis.

We agree that fishing mortality is an important factor that determines adult survival. Because fishing effort is not random over the season and may vary year by year, we have included arrival date and migration year (as random effects) in our initial models in order to account for the seasonal and annual variability that may be caused by fishing exposures. We are planning to expand our analysis in the future to consider fishing harvest in our models, if reliable harvest data is available.

Reference

Salinger, D.H. and J.J. Anderson. 2006. Effects of water temperature and flow on adult salmon migration swim speed and delay. *Transactions of the American Fisheries Society* 135:188-199.

CSS Responses to ISAB comments on the 2017 CSS Annual Report.

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Review of the Comparative Survival Study Draft 2017 Annual Report

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Review of the Comparative Survival Study (CSS) Draft 2017 Annual Report

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Review of the Comparative Survival Study (CSS) Draft 2017 Annual Report

I. Background

The Columbia River Basin Fish and Wildlife Program tasks the Fish Passage Center Oversight Board to work with the Fish Passage Center (FPC) and the ISAB to ensure independent and timely science review of FPC's analytical products. These reviews include evaluations of the Comparative Survival Study's (CSS) draft annual reports. The ISAB has reviewed these reports annually beginning seven years ago with the evaluation of the CSS's draft 2010 Annual Report and most recently the draft 2016 Annual Report (ISAB 2010-5, ISAB 2011-5, ISAB 2012-7, ISAB 2013-4, ISAB 2014-5, ISAB 2015-2, ISAB 2016-2). This review of the draft 2017 CSS Annual Report is the ISAB's eighth review of CSS annual reports.

The ISAB's review was aided by three presentations from CSS researchers at the ISAB's September 15, 2017 meeting: Treatment of total dissolved gas (TDG) in survival monitoring, SARs and Productivity, and Life cycle model evaluation of Snake River spring/summer chinook under alternative spill and breach scenarios.

II. Summary

This ISAB review begins with an overview of the latest report's key findings (this section). It then moves to suggesting topics for further CSS analysis (Section III), general comments on each chapter of the 2017 CSS Annual Report (Section IV), and ends with editorial suggestions (Section VI).

The annual CSS report is a mature product, typically including only updates with the latest year of data and expansion of analyses as more data are acquired. Many of the methods have been reviewed in previous ISAB reports, and so these methods now receive only a cursory examination. As more data are acquired, new patterns and questions arise on the interpretation of the results—this interpretation is now the primary focus of our reviews. The ISAB appreciates the CSS's detailed responses to suggestions provided in previous reviews, and we do not expect the CSS to necessarily respond immediately to new requests for further analyses by the next report—see the CSS response (Appendix J) to the ISRP's 2016 review.

Chapter 2 (Life-cycle modeling) has been updated with a revised fit of the life-cycle model using more data, and now separate smolt-to-adult ratios (SARs) are modeled for in-river and transported fish. As in the last report, the model examined 12 spill/flow scenarios. Similar to last

year's results, more spill generally leads to higher in-river survival and improved SARs. A new component to this chapter is the modeled scenario exploring the impact of breaching four Snake River dams. The model predicts an increased in-river survival by about 10 percentage points and a doubling of SARs when dams are breached. The addition of the breach scenarios was a nice complement to the spill scenarios, producing interesting results. Further consideration of assumptions used in both sets of scenarios and recommendations for experiments (short of an actual breach) that could be done to test model results would be useful.

Chapter 3 (Effect of the in-river environment on juvenile travel time and survival) is updated with new data. In addition, a preliminary investigation of the impact of total dissolved gas (TDG) on the instantaneous mortality and survival probabilities parameters was made using a graphical approach. While this approach did not show any evidence of an impact of TDG on either instantaneous mortality or survival probabilities, a more comprehensive approach of including TDG directly in the modeling process would address concerns about the interrelationship between TDG, spill, and flow that may confound results.

Chapters 4 (Patterns in SARs), Chapter 5 (SARs and productivity), and Chapter 6 (SARs for Snake River subyearling Chinook) are updated from previous years by including new population groups. As in past reports, pre-harvest SARs of 4%-6% are associated with pre-1970 levels of productivity for Snake River spring/summer Chinook. An unanswered question is that given the large amount of effort in the past to improve SARs through dam passage improvements, habitat improvements and other changes, to what extent might further improvements in hydrosystem management, predator control, and estuarine habitat lead to achieving SARs of 4%-6%?

Chapter 7 (Patterns of variation in age-at maturity for PIT tagged fish) is the same model as past years with recent data incorporated. The chapter is exploratory, and now sufficient data may be available to try to elucidate factors associated with observed changes.

Chapter 8 (CSS adult success) is a new chapter that looks at the relationship between survival of adults upstream of Bonneville and travel time, temperature, and arrival date. A complex modeling framework was used, but the ISAB is concerned that not enough assessment of the fit of the model to the data has been done to ensure that conclusions are appropriate.

III. Suggested Topics for Further Analysis

The latest CSS Report incorporates many of our past suggestions. For example, the current report has a substantial discussion of correlations among SARs from different regions or effects of transport on SARs (suggestion #1 in 2013; #1 in 2014). The life-cycle modeling now allows for variation in stream productivity and hydrosystem survival and simulates the correlative impacts

of these changes on predicted future population abundances (#2 in 2013; #2 in 2014; #2, #3 in 2015). The ISAB appreciates this effort to respond to our past queries.

Some of the past recommendations from the ISAB appear to be beyond the current scope of the CSS (see several from 2016) but will become increasing important in the future. Some of our earlier and current recommendations may seem repetitive and unachievable to be accomplished within a year to inform the next report, but they deserve some forward planning as these issues will become much more pressing in the future. In particular, if there are data gaps, these gaps should be identified for potential new data collection procedures. When life-cycle models are modified, the modification should be flexible enough to incorporate these issues. This is reflected in our recommendations for future work below.

In 2017, we recommend the following topics for future reports:

1. *Modeling flow, spill, and dam breach scenarios is very useful for policy makers. Consequently it is important that all assumptions be clearly stated and that the results are robust to these assumptions. For example, rather than using a single year to represent future flow conditions, variable flow conditions should be used to study the impact of flow/spill modifications under future climate change, and examine correlations between Pacific Decadal Oscillations (PDOs) and flows. What assumptions are being made about in-river predation under dam breach scenarios? What assumptions are being made about harvest under dam breach scenarios? Why are there discrepancies between the results of the Life-Cycle Model (Chapter 2) and the COMPASS model (refer to #4 in 2016)? The same scenarios should be run through both models and discrepancies resolved.*

The CSS life cycle model has evolved gradually to balance the desire to be realistic and precise about predictions with the need to align predictions with data and the need to make predictions that distinguish potentially beneficial operational alternatives. This needs to be done without conflating too many factors and losing the ability to identify benefits. There is always another element of population dynamics that can be modeled with more precision and finer resolution, but in doing so, we can lose the ability to distinguish between alternatives if the additional details are added on top of the alternative of interest. The CSS life cycle model forces some things to remain static, despite the potential for some dynamic response. A higher or lower fixed rate of transport or harvest or upstream conversion can be considered in a relative sense against the predictions that were made using the assumed fixed rate. The results need to be considered in a relative sense, and in light of whatever factors may be deemed to bias results positively or negatively (eg: 10% lower harvest should translate to a proportionally higher SAR).

2. *Include other important processes in the life-cycle models. In the current CSS analyses, each modeled population does not interact with other modeled populations as they migrate through the hydrosystem. Interactions among the various populations, including compensatory responses, are important and whenever possible should be folded into future modeling efforts, particularly if restoration actions increase the abundance of out-migrants.*

   Similarly, there has been a great deal of interest in the impact of predator control programs on salmon returns, especially northern pikeminnow, birds and pinnipeds. Are these programs effective? Are there compensatory responses?

   Is there evidence in the existing data about either issue? What type of data would be needed to address these issues and include them in the life-cycle models? This recommendation builds upon our previous recommendation (#1 in 2015; #3 in 2016)

   CSS Response: We do not have sufficient data to model what other populations are doing compared to the focused populations in Chapter 2. In that model we haven't detected a density dependence signal for the populations. We reiterate that there are limited data at this point to investigate compensatory responses. CSS is aware of this issue and will continue working to develop methods to account for total out-migrating smolt abundance and density dependent effects.

3. *There appear to be sufficient data to try to elucidate reasons for shifts in the age distribution of returning spring/summer Chinook (# 5 in 2016). We suggest doing so.*

   CSS Response: We are planning on investigating reasons for shifts in age distribution in future reports.

4. *The graphical analysis of the impact of TDG could be improved using direct modeling to deal with potential confounding effects of spill, flow, TDG, and temperature.*

   CSS Response: Final report uses direct modeling to evaluate effects of TDG.

5. *The (new) modeling of adult survival upstream of Bonneville should be continued and improved to identify the limiting factors to adult returns. Once these factors are*

identified, are there modifications to the hydrosystem operations that could be done to mitigate some of the factors?

CSS Response: The CSS will continue to refine analyses of adult passage success.

6. *The CSS report is a mature product and the authors are very familiar with the key assumptions made and the impact of violating the assumptions. These should be collected together in a table for each chapter to make it clearer to the readers of the report.*

   CSS Response: The CSS will attempt to more carefully identify and list assumptions in models and analyses in future reports. We appreciate the importance of this in understanding the value of the products we develop.

Below are the lists of topics we recommended in our reviews from 2013-2016. As noted above many of our recommendations were incorporated in subsequent CSS analyses and reports, and some recommendations require future planning and coordination with other entities.

In 2016, we recommended these topics (ISAB 2016-2, pages 5-6)

1. *Use variable flow conditions to study the impact of flow/spill modifications under future climate change, and examine correlations between Pacific Decadal Oscillations (PDOs) and flows.*
2. *Examine impact of restricted sizes of fish tagged and describe limitations to studies related to types/sizes of fish tagged*
3. *Modify life-cycle model to evaluate compensatory response to predation.*
4. *Comparison of CSS and NOAA in-river survival estimates.*
5. *Examine factors leading to spring/summer Chinook declines of four and five-year olds and increases in three-year olds.*

In 2015, we recommended these topics (ISAB 2015-2, pages 4-5):

1. *Use SAR data to examine both intra- and interspecific density dependence during the smolt out migration and early marine periods*
2. *Propose actions to improve SARs to pre-1970s levels*
3. *Explore additional potential relations between SARs and climate and ocean conditions*
4. *Consider ways to explore the variability of inter-cohort response*

In 2014, we recommended these topics (ISAB 2014-5, pages 2-3):

1. *Hypotheses on mechanisms regulating smolt-to-adult return rates (SARs) [update from 2013 review]*
2. *Life-cycle modeling questions and Fish and Wildlife Program SAR objectives [update from 2014 review]*
3. *New PIT/CWT study*

In 2013, we recommended these topics (ISAB 2013-4, Page 1):

1. *Hypotheses on mechanisms regulating smolt-to-adult survivals (SARs)*
2. *Life-cycle modeling questions and Fish and Wildlife Program SAR objectives*
3. *Data gaps*
4. *Rationalization of CSS's Passive Integrated Transponder (PIT)-tagging, and*
5. *Publication of a synthesis and critical review of CSS results*

IV. Comments on New or Updated Analyses in the CSS draft 2017 Annual Report by Chapter

IV.1. Chapter 1. Introduction

This chapter is similar to last year's report, and the ISAB has no major comments but has two suggestions for improving the chapter.

First, much of the text in this chapter is identical to text from the 2016 CSS report, which at times makes it difficult to determine if new data or techniques were incorporated and used in the 2017 CSS report. Some sets of data have been updated to include later years, but others have not. At times, it even appears that less data might be included. For example, Figure 1.6, lowest panel, presents less data than in 2016 CSS report. Why was the last data point in 2016 CSS removed, and why wasn't an additional year of data included in this panel?

CSS Response: The CSS agrees that some changes to Chapter 1 were not reworded to reflect current year information. Those references have been edited. However, there are multiple different data sets, representing different life stages of salmon that are reported in the CSS. In addition, the CSS reports future planning information as well. Summarizing all of this can be both difficult and confusing. And we apologize for that. As for the data point in 2016, Figure 1.6, we removed that data point for wild steelhead survival in 2015 because it was premature to present it. It takes the CSS one to two years after the initial marking to determine the proper migration year in which to assign wild steelhead. We determine it based on length and date of tagging as well as year of subsequent detection, for each trap in the Snake River basin. As you can imagine, estimating survival for these cohorts can change dramatically if sample size

changes. Usually this involves removing individuals based on recapture information a year or two after tagging. Traditionally the CSS had reported this information on wild Chinook and Steelhead with a two year delay. We made the attempt to include the 2015 survival data in 2016. After reanalyzing the mark and recapture data for steelhead we found a large change in survival cohort. We removed it because we did not want to report it until all likely changes had occurred. We will go back to a two year lag in reporting wild mark group survival estimates to reduce confusion and errors in reporting.

As another example, on p. 14, second paragraph, the text says "Two other new traps are planned to begin operation by 2016." This same wording was in the 2016 CSS report, and now that this report is being prepared in 2017, the wording makes it unclear if these traps did begin operating. A careful editing is needed in this chapter and other chapters to ensure that it is clear that year ranges are consistent (please refer to Section VI of this report for some other places where apparent discrepancies exist). The ISAB suggests that future reports include a table that shows for each chapter, which sets of data have not changed, which have received additional data, and which are waiting for additional data (and why there is a delay). For example, during the presentation to the ISAB, it was clarified that only some updated data were received (e.g., updated spawner numbers were received but updated smolt numbers were not received).

CSS Response: We will consider how to incorporate your request for future years. In reference to your specific example, we have corrected the text.

Second, more and more groups are being marked (which is good), but it may be expensive to achieve large enough sample sizes for each group as each population group becomes more and more specific. Is there a "lower limit" to the size of the population group that can be monitored? For example, Table 1.1. shows that the Lyons Ferry group has only 6,000 fish marked compared to 20,000+ elsewhere. Similarly, Table 1.2 and Table 1.3 have groups with small numbers of tagged fish (e.g., Table 1.3 shows that the Yakima steelhead group had only 250 tags applied). Is anything useful learned from a marked group this small? Do these groups provide any useful information? Based on past experience, what is the "minimum" number of tags per year needed before useful findings emerge? Can a combination of methods (e.g., genetics) be used to augment the CSS methods and therefore increase the value of tagging information?

CSS Response: The numbers listed in Table 1 and 2 represent the planned marking for the current year. These represent the number of fish to be marked that CSS has been able to coordinate with other entities. Table 3 shows what actually was marked by other researchers not associated with the CSS throughout various basins. These tags represent the groups that are available to the CSS for analysis. The CSS cannot control how many fish are marked in these

groups. In the case of the 250 steelhead in the Yakima River, that will not likely yield useful data.

The minimum number of tags needed to be useful greatly depends on the questions being answered. If the question is the relative SARs of transport versus in-river groups, then a power analysis is done, using the accepted difference in SARs that should be detected to determine a useful comparison of the two management options. Survival to Lower Granite Dam must also be considered. In that case the number could range from 15,000 to 50,000. For groups for which we seek to estimate overall SARs only, a much smaller number can be used. However, the number depends on the SAR. If it is a SAR from release to return to Bonneville Dam, very small sample sizes could work, since both numbers are counts. In some cases 500 fish might be sufficient. If the SAR is from a dam in the hydro-system below the area of marking, then a larger number of marks are needed. In the case of overall SARs the precision is determined by the sample size available and the number of adults returning.

IV.2. Chapter 2. Life cycle modeling of alternative spill and breach scenarios

The life-cycle model from previous years is changed slightly to include more years of smolt data and is now also modeling the SAR of in-river versus transported fish as well the overall SAR (the C0SAR, TXSAR, and SAR terms on page 32, respectively). Each of these SARs now contributes to the model-fitting procedure (but see the ISAB comment below regarding page 34). Additional years of spawner data are now available to add to those used in previous model fits.

Density dependence was modeled only at the smolt production stage. However, if we are restoring populations and they are co-migrating in the river, do we need to account for factor limiting in-river or estuary survival or juveniles and the returning adults? Can the pattern of PIT tag detections from each group plus reasonable estimates of production and forecasted travel time be used to forecast the "aggregate" smolt population or adult returns moving through the hydrosystem? These forecasts can be used to evaluate if the aggregate number of fish is being affected by constraints in the system.

The fitted life-cycle model was used to predict the impact of 12 spill/flow scenarios prospectively as was done in the previous year's report. Three "representative" years were used as surrogates for years with high, average, and low flows. Transport was set at 20% for future scenarios, but, as noted in previous comments by the ISAB, this may ignore that transport changes with spill.

CSS Response: It is true that the proportion of fish transported will decrease as the proportion of spill increases. A smaller fraction of the fish will go through the bypass for collection. We

note that estimated transport SARs are lower than in-river SARs. This implies that since in-river survival increases with increased spill, simulating with a high value of transportation (20%) will predict a lower overall SAR than with a lower transport fraction. SARs using a 20% transport fraction are probably biased low.

Simulating the impact of breaching the four Snake River dams was done by reducing the power house contact index and decreasing the water transit time (Table 2.2) and using these revised values in conjunction with the 12 spill/flow scenarios. However, if the dams are breached, there will be many changes to the migration environment besides faster migration times (such as water transit time (WTT)). For example, an important change might be reduced predation by smallmouth bass. Is this reduced predation implicitly assumed to be a consequence of faster migration?

CSS Response: Predation is implicitly assumed in survival estimates obtained from calibrating the model with the historical range of WTT values, so survival is sensitive to changes in WTT assuming predator ecology does not fundamentally change. If breaching causes WTT to decrease and changes the dynamics of predator ecology, the baseline predation of the new dynamic may be different from the historical baseline, but there is no way to quantify the shift in the baseline without empirical evidence.

Will future versions of the life cycle model include modeling the impacts of predation? The addition of the breach scenarios was a nice complement to the spill scenarios with interesting results. Further consideration of assumptions used in both sets of scenarios and recommendations for experiments (short of an actual breach) that could be done to test model results would be useful.

CSS Response: The model has evolved considerably since its inception in 2014, but has yet to delve into the complexities of predator/prey dynamics specifically, nor has it extended its functionality to deal with more comprehensive ecosystem based management (EBM) questions (see density dependence and multi-stock competition comments by ISAB).

Similar to last year's results, more spill generally leads to high in-river survival and improved SARs. However, slightly different parameter estimates were obtained in the revised model fitting (p. 61) and the revised model no longer predicts that in-river survival is higher for lower flows at a given spill level. Nevertheless, the overall conclusions about the scenarios are basically unchanged from last year's report.

CSS Response: Correct. The inclusion of additional smolt production data, as well as the inclusion of C_0 and transport specific SARs into the likelihood has affected parameter estimates.

Whereas previously the lower flow scenarios predicted both lower powerhouse passage rates and in-river survival, this analysis predicts that powerhouse passage rates decrease most significantly at lower flows with equivalent spills, but that the effect of slower travel times mitigates the benefit of reduced powerhouse passage. As noted though, the overall conclusions do not change.

Results show that under dam breaching scenarios, in-river survival increased by about 10 percentage points and SARs doubled. These results assume no compensatory responses or density-dependent responses later in the life cycle, and this assumption needs discussion and investigation. As noted in the discussion in the CSS draft report, the benefits from dam breaching may be overstated because other changes to the hydrosystem and the ecosystem as a result of dam breaching are not modeled.

Response: See discussion, but note that some benefits may also be understated (eg: predation).

One compensating response that is included in the model is the human response, harvest. It would be useful in future analyses of spill and dam breaching scenarios to include results when harvest is held at current levels. While there are good reasons to assume that harvest will go up with increased abundance since that is likely, there are also good arguments for holding harvest constant for purposes of interpretation of the model results (the clarity of interpreting a ceteris paribus response). Given the magnitudes of the changes in abundance due to spill and breaching scenarios, interpreting the benefits of those actions would be less ambiguous if harvest were held constant (or otherwise if the benefits to harvest were added to the benefits of return abundance, but that raises additional complications). If harvest response was limited, how would that affect the results in terms of the magnitude of increased abundance, the rate at which those increases occur, and the differences in improved abundances for different populations?

CSS Response: US v OR Technical Advisory Committee harvest rates increase as run sizes increase, with a current ceiling of 17% on Snake River Spring Chinook return abundance of 500,000. The sliding scale implemented was intended to capture that dynamic, while also providing a reference point limit on the maximum harvest rate (20% at 5000 Grande Ronde/Imnaha returns to a maximum of 40%, which predicts 15-20% harvest at return abundances predicted with BiOp level spill). Actual harvest rates would increase in relation to total upriver Columbia abundances however, which is not predicted in the model unfortunately. Spill and breach scenario impacts should be viewed in relative terms, not absolute.

A companion review of other life-cycle models (ISAB 2017-1) showed that the COMPASS model was not as optimistic about the impacts of spill/flow modifications. Has the COMPASS model

been used for the dam breaching scenario as well? How do the results compare? This chapter should include a discussion of the comparison of this life-cycle results with the results from COMPASS and why they may differ.

CSS Response: Chapter 2 is a stand-alone analysis, not a comprehensive literature review or model comparison. As the CSS life cycle modeling evolves, a comparison with COMPASS or other models may be feasible.

Specific comments

p. 27. Here and elsewhere, the treatment of the proportion transported (PTRANS) in the modeling approach could be presented more clearly. On this page referral is made to the CSS 2016 Final report, but a description of PTRANS is not provided here. While it makes the report longer, it is helpful to have a fully self-contained document.

CSS Response: We provided a description of PTRANS in the text.

p. 28. The potential effect of distinct population timing is not considered. The report needs a discussion of how this assumption could affect model results (see also comment on page 62 below).

CSS Response: The true timings of the six populations treated as a single aggregate may not be the same, but the temporal scale at which PIT tag detections are aggregated to compute survival rates requires treating them as a single timing aggregate.

p. 30. From where does the assumption of transportation survival probability of 98% come?

CSS Response: The original value was an assumption that came out of the PATH analytical process. Recently that number was evaluated by McMichael et al. (2011) "Survival of Juvenile Chinook Salmon during Barge Transport". They found that 0.98 seemed appropriate. That study is cited in revised report.

p. 34. Equation 2.19. This assumes that the in-river SAR (C0SAR), the transportation SAR (TXSAR), and overall SAR are independent in a given year. A poor ocean condition would tend to depress all three values simultaneously, so this assumption may not be tenable. Additional justifications are needed for this assumption, e.g., show bivariate plots of the three response measures. A multivariate likelihood term may be needed.

CSS Response: Independence is not assumed. Equations 2.10 and 2.11 show common PDO and UPW effects for ocean survival, but C_0SAR and T_xSAR still differ significantly by PITPH terms and

logistic survival intercept terms. The overall SAR, T_xSAR, and C_0SAR are each fit to a separate likelihood.

p. 35. It is mentioned that "Transport was set at 20% for all future years…," but this requires the reader to understand that "Transport" = PTRANS and that this means that PTRANS is equal to 20% for all scenarios (this statement only mentions the future scenarios). The rationale for setting PTRANS at 20% should be clearly explained (reference to McCann et al. 2016 is not sufficient).

CSS Response: Since 2007, the percent transported has varied from 18-46%. Spilling at higher than historical levels would likely result in fewer fish being collected for transport. We chose to fix transport at a value at the lower end of that range in order to reflect that. Although transport would be lowest at the highest spill level, implementing a sliding scale of transport would obfuscate the benefit of the spill itself.

p. 37. Regarding the use of 50% improvement in survival of adults migrating through four fewer dams when Snake dams are breached (i.e., 4/8), have the studies of adult migrants in the Columbia and Snake rivers (e.g., Keefer et al. 2008) been reviewed to see if those studies and perhaps other adult detections at dams conclude whether or not mortality at each dam (or just Snake dams versus Columbia dams) is equivalent? The models of Chapter 8 may be suitable to get a better estimate of adult survival in a breached hydrosystem.

CSS Response: The choice of a 50% assumed improvement was purely based on 4 vs. 8 dams. If the reach effect independent of the dam effect of each reach were known, a better assumption could be made. The relative predictions within spill and breach scenarios should not change as a result of this, only the relative prediction of breach vs. non breach.

p*. 38. In CSS 2016, the authors used 10,000 draws for the simulations, but in CSS 2017 they used 1,000 draws. What was the rationale for changing the number of draws? Are there any implications of the change in number of draws on the results?*

CSS Response: Drawing 1,000 samples from 2,000,000 provides the same perspective as 10,000 samples.

p. 38. In the description of the Markov Chain Monte Carlo (MCMC) simulations, the wording was changed here from CSS 2016 and was difficult to follow. The description in CSS 2016 was clearer; does the change of wording mean the approach was changed? If so, why?

CSS Response: 2016 MCMC description re-integrated into chapter.

p. 38. Why did the initialized population projections of empirical spawners change from 2010-2014 in CSS 2016 to 2010-2013 in CSS 2017? Did this change affect results?

CSS Response: 2016 report should have stated 2010-2013.

p. 44. Figure 2.4: Why was PTRANS removed from this figure compared to last year's report?

CSS Response: PTRANS does not directly affect survival, so is not relevant to Figure 2.4 (now 2.5). Removed for simplicity.

p. 45. Figure 2.5. The fits for transport SARs look better than the fit for in-river SARs. Is there an explanation for the lack of fit in the latter? Is there evidence that can be presented to support the hypothesis for this on page 41?

CSS Response: Some evidence points to the fact that T_XSAR shows a stronger correlation with PDO and UPW than C_0SAR (see Figure now 2.6). This may imply that transported fish respond more to ocean conditions.

p. 62. The added discussion is a good addition, but only one assumption is discussed. It would be helpful to provide references on some of the findings from other studies noted here. The chapter could benefit from more discussion of other assumptions such as 1) that distinct population migration timing is not considered (p. 28); 2) PTRANS is being set at 20%; 3) PITPH, WTT, and flows are being fixed for future scenarios; 4) transportation survival probability is set at 98%; 5) harvest levels also changing. How might results differ if these assumptions were varied? How certain are the authors of the values they used?

CSS Response: See revised discussion for details. We note that harvest rates and upstream migration survival rates are stated assumptions in the analysis, as is the assumption that sensitivity to migration timing is implicit in the detection rate (and therefore PITPH), and that results should be interpreted relative to alternative assumptions.

IV.3. Chapter 3. Effects of the in-river environment on juvenile travel time, instantaneous mortality rates and survival

The analysis of juvenile travel time, instantaneous mortality and survival is updated with new data and the same methods as previous years. The ISAB has no concerns about this part of the chapter.

The chapter also investigated the impact of total dissolved gas (TDG) on instantaneous mortality and survival probabilities. This was done by plotting the regression RESIDUALS from the models from past years versus TDG and looking for a pattern (Figure 3.9 and similar). This method is equivalent to investigating the impact of TDG after adjusting for the other covariates. The results are interesting. However, this method cannot account for the correlation between TDG and the other environmental variables.

A preferred method would be to include TDG directly into the regression models of previous years and again use an information theoretic framework. If TDG is a preferred covariate over the other covariates, this will be demonstrated by a high model weight on TDG. The correlation between TDG and the other environmental variables should also be explored (e.g., show plots of TDG versus the other environmental covariates) and this may help explain the lack of observed effect. The combined analysis may also indicate that the effects of variables highly correlated with TDG should have a quadratic component in the models.

CSS Response: To account for potential correlations between TDG and the other variables, we incorporated TDG into the instantaneous mortality rate models as suggested and used information-theoretic methods to evaluate TDG. The Relative Variable Importance values for the average and maximum TDG were low compared to the other variables. In addition, the model-averaged coefficients were near zero and the confidence intervals for the model-averaged coefficients overlapped zero, indicating that TDG did not affect instantaneous mortality rates in the data that were available to date. We explored the correlations between TDG and the other variables and found that the correlations were generally low. There was a moderate amount of correlation between water transit time and TDG. However, adding a quadratic component for water transit time to the models did not improve model fit based on Akaike's Information Criterion.

Specific comments

p. 70. Equation 3.6 uses a log transformed instantaneous mortality (Z) rather than a square root equation, so results are not directly comparable but will be similar. In general, a log() transformation is preferable to the sqrt() transformation on biological grounds.

CSS Response: All of the instantaneous mortality rate models used a log transformation.

p. 79. Some of the graphs show NA for the variable importance. Does this indicate that the variable was not considered at all or that models with the variable were included but had model weights that were 0?

CSS Response: The graphs that show NA indicate that those variables were not included in the model and text reflecting this was added to the figure descriptions. For example, Julian Day was not included in the Snake River sockeye models because there is only one migration group and therefore no seasonal effects can be estimated.

IV.4. Chapter 4. Patterns in annual overall SARs

This chapter was updated by the use of newly acquired data and the inclusion of new major population groups (MPG).

Tables 4.1 shows that model weights are relatively diffuse, yet the results use only the top model. Model averaging should be used for all analyses, predictions, figures, and discussion.

CSS Response: We agree that model averaging would be a valid approach to modeling nested models. However, the model set we chose, were not nested. We chose distinct models that would capture, either common slope, common intercept for both wild Chinook and Steelhead, or would indicate separate slopes and or intercepts were appropriate for these two species. We used to the top model based on AIC since we considered it still appropriate to use information theoretic approach to determine the best fitting model. Here the model chosen shared a common slope but had separate intercepts for Chinook and steelhead. This is only to illustrate the relationship. It is unclear how model averaging would be carried out in this context. Since each model has a different structure. If we model-averaged we would end up using a model with separate intercepts and separate slopes by default.

CSS reported on the relatively large absolute difference in SARs based on PIT-tags versus run reconstruction (the values are highly correlated, however). As in previous reports, this chapter listed various hypotheses. An email from Michele Dehart to the ISAB indicated that a study is underway to further evaluate PIT-tag effects on salmon survival, but results will not be ready for analysis until after summer 2017 when tagged age-5 Chinook have returned, and the report should be available in 2018. Potential bias in survival caused by tagging methodology (or in the run reconstruction methodology) is an important issue to resolve.

CSS Response: The CSS will report final results of this analysis in a Chapter in the 2018 report. We appreciate the importance of reporting this information and want to wait for final data to report it.

Specific comments

p. 91. The authors have removed "from outmigration to the estuary and ocean environments" at the end of the description of this chapter. The ISAB notes that this change was made between

the Draft 2016 CSS report we reviewed and the Final 2016 CSS report. Is the rationale for this change explained in Chapter 4, and is it relevant? Is this in response to an ISAB comment?

CSS Response: We did not find this phrase in Chapter 4 in the 2016 draft annual report, but an edit was made to the Chapter 1 description of Chapter 4 for the final 2016 report. We removed the phrase "from outmigration to the estuary and ocean environments" from Chapter 1 of the 2016 final report in response to a specific ISAB editorial comment. Our response to this specific comment in 2016 was as follows:

"Sentence was edited as follows: "SARs of wild and hatchery populations were highly correlated within and among regions, suggesting that common environmental factors were influencing survival rates." While CSS has included environmental factors in analyses of wild and hatchery population survival rates within and among regions (e.g., Chapter 3), this was not the focus of Chapter 4."

Appendix B: Supporting tables on Chapter 4 - Overall SARs

The ISAB has no concerns with this appendix, which is an update from the one presented in previous reports. Information on additional MPGs and new data has been added.

IV.5. Chapter 5. SARs and productivity

Chapter 5 continues the examination of the relationships between life cycle productivity and SARs, including the level of SARs needed to reach or exceed population replacement. This year's report is an update from previous years and includes an addition of a new major population group (Pahsimeroi). The ISAB has no major concerns with this chapter.

How were hatchery origin Chinook adults on the spawning grounds identified and excluded from the productivity estimates of the natural-origin population? There is reference to the CSS estimates of natural origin returns (p. 137), but no details are provided. A sentence or two here would be useful to describe how hatchery Chinook returns are excluded to make this chapter self-contained. For steelhead, the text indicates a weir was used to identify natural origin adult returns and was used to exclude hatchery fish.

CSS Response: Added sentence to first paragraph in methods to address request.

The findings suggest that pre-harvest SARs of 4%-6% are associated with pre-1970 levels of productivity for Snake River spring/summer Chinook. How do these SARs compare with SARs from viable wild Chinook populations in other regions? To what extent might improvements in hydrosystem management, predator control, and estuarine habitat lead to SARs of 4%-6%?

From the results in Chapter 4, it seems major improvements would be needed to reach the desired SAR range given recent poor ocean conditions which led to low SARs. This was a query by the ISAB in previous years, but it does not seem to be addressed.

CSS Response: Added language to chapter to compare to other wild Chinook populations and addressing comment.

IV.6. Chapter 6. Estimation of SARS, TIRS and *D* for Snake River Subyearling Fall Chinook

This chapter contains updates from previous years on SARs by route of passage and TIR for 2006 to 2013 with the addition of new MPGs. The ISAB has no major comments.

The 2016 CSS report included a statement regarding estimating bias in SARs due to detections of overwintering and holdover detections and late season migrants through simulations. This was removed from the 2017 CSS report. Is this issue resolved?

CSS Response: Yes the issue resolved. The CSS continues to focus on those populations that do not display a large holdover component. We will continue to use the CSS methodology as long as the populations we apply the method to show very small proportions of holdover fish.

IV.7. Chapter 7. Patterns of variation in age-at-maturity for PIT-tagged spring/summer Chinook in the Columbia River Basin

This chapter examined the mean age-at-maturity among different stocks, years, and fish type (wild or hatchery) using regression methods and is an update from last year with new data. The ISAB has no major concerns about this chapter but hopes that analyses to explain the year effects is ongoing.

A two-factor ANOVA was used to analyze the mean age-at-maturity. The analysis of the proportion of age-3, age-4, and age-5 fish was done using a binomial logit model in a Bayesian context with overdispersion.

There was evidence of both stock and year effects with 2007, 2008, and 2010 resulting in the lowest mean age of maturity and highest proportion of age-3 returns. Is there anything obvious about these years either in the river system or ocean conditions that could serve as a hypothesis for future years? As noted on page 174, one consideration for the future work is looking for factors associated with the year effects such as ocean factors associated with growth and climate change, differences in hatchery practices, or freshwater environments (tributary temps, or annual differences in migration corridor). Some preliminary investigations should be made,

e.g., using plots. The authors should continue to coordinate with the Council's Ocean and Plume Science and Management Forum.

CSS Response: Additional analyses that attempt to explain the patterns in maturity are ongoing. In future analyses we will be examining variables that characterize ocean conditions as well as indices of adult returns (e.g., length-at-age).

Specific comments

Chapter 7 in the 2016 CSS report previously examined delayed mortality, but this topic was not covered in this year's Chapter 7. Was this topic covered elsewhere in the report? If it was removed, a reference/appendix should be added to include this information, if still relevant.

CSS Response: Not all chapters are presented every year. Chapter 7 in the 2016 CSS Annual Report focused on the effects of bypass experiences on post-Bonneville Dam survival rates across juvenile migration years 2006-2013. The 2010 CSS Annual Report (Tuomikoski et al. 2010) used a similar approach to analyze juvenile migration years 2000-2008. The CSS may revisit this topic again in the future after additional years of data become available.

p. 170. The Bayesian model should be described here to make the CSS document self-contained as many readers will not be familiar with fitting overdispersed models using Bayesian methods. This could go into an appendix for this chapter.

CSS Response: We have added additional text to better describe the overdispersed binomial model that was fit. The references provided give additional information on these models.

p. 170. A simple regression model applied to the empirical logit (Wharton, 2011) would automatically account for overdispersion in the residual variance term and is an alternative to the Bayesian model. No change is necessary, but just mention this in the text.

CSS Response: We have mentioned that regression models using the empirical logit could have been applied and added this reference. However, the empirical logit approach described by Wharton and Hui (2011) does not appear to "automatically" account for overdispersion. They mention that a useful approach for modeling overdispersion is to include a random intercept term to account for the overdispersion, which we did using a Bayesian estimation approach. There is also the problem of how to handle zero counts using the empirical logit approach. Wharton and Hui (2011) discuss some ad hoc solutions to this problem, but we concluded that the binomial model, which allows for zero counts, was a better solution.

p. 176-178. The proportions of age-3, age-4 and age-5 must add to 100%. Does a ternary plot (https://en.wikipedia.org/wiki/Ternary_plot) with the points jointed over time provide any

insight?

CSS Response: We appreciate the suggestion to consider ternary plots and may examine these as a graphical tool in future analyses.

IV.8. Chapter 8. CSS adult success: summer Chinook, Snake River sockeye and steelhead

In this chapter, the authors look at the impacts of water temperature (as recorded at Bonneville) and transportation (as juveniles) on travel time and survival between Bonneville and McNary dams for summer Chinook, sockeye, and steelhead that were PIT-tagged from 2003 to 2016.

For travel time, the authors fit a Generalized Additive model (GAM) between the log(travel time) and the temperature and arrival date. A comparison of the proportion of fish that had a long travel times (e.g., more than 10 days for Chinook) was made.

A multi-step procedure was used to investigate the relationship between survival and temperature, arrival time, and transportation. Because detection probabilities are very high at McNary Dam (99%+ for Chinook and steelhead and 97%+ for sockeye), a detection/non detection at McNary is tantamount to survival/not survival between Bonneville and McNary Dam. A GAM was first fit to the detect/non-detect at McNary using a smoothed function of temperature and linear function of arrival date. Plots of the fitted relationship with temperature and arrival date were used to assess if the relationship of these covariates with survival was linear, piece-wise linear, quadratic, or cubic. These relationship forms were then used in a mixed-effects logistic regression (again using detection/non-detection at McNary as a surrogate for survival) to explore the impact of transportation, interactions between the covariates and transportation, and random effects of years and individuals. Backwards stepwise selection and AIC were used to select the most appropriate model. Finally, the most appropriate model was then fit using a Cormack-Jolly-Seber (CJS) model to the detection history at McNary and upstream of McNary using a Bayesian state-space model.

General comments

The chapter should indicate why travel time and survival between Bonneville and McNary is of primary interest, but travel time and survival upstream of McNary is not. Are data upstream of McNary lacking?

CSS Response: For CSS chapter 8, we focused on the reach between Bonneville and McNary Dams as a starting point for our analysis. We will consider expanding our assessment to upstream of McNary in the future.

This analysis does not include spring Chinook. Why not? This may have been mentioned in earlier reports, but it is not clear in this chapter. The authors should consider linking this type of analysis to estimate the change in adult survival if the Snake River dams are breached, as in Chapter 2.

CSS Response: We do not feel confident combining spring and summer Chinook populations in our analysis because they show different arrival timing, and possibly have different behaviors in relation to water temperature. We will consider including spring Chinook and dam breaching scenario in the future analysis. We began this updated analysis evaluating the role of temperature on adult success. We began by focusing on sockeye, steelhead and summer Chinook. Spring Chinook are least likely to be affected by temperature since they migrate through the hydrosystem prior to high temperatures.

This chapter needs more model assessment (absolute goodness-of-fit assessment) for all models. A Bayesian p-value check was done for the final Cormack-Jolly-Sever (CJS) model, but basic plots of observed data versus predicted values are missing. For example, when fitting models for survival to McNary Dam, no plots were shown of the empirical survival probabilities (e.g., in degree intervals) for transported/non-transported fit to assess if Figure 8.4 is realistic or not. Similarly, no plots were shown of the empirical mean travel time (again in degree intervals) versus temperature to compare to the fit shown in Figure 8.2. Without such plots it is difficult to determine if some predictions (e.g., dramatically different predicted survival or travel times in the extremes) are simple artefacts of the model fitted or are actually supported by data.

CSS Response: Most researchers accept posterior predictive check as a form of model assessment (Gelman et al. 1996), which we have included in the chapter Supplemental Materials section. The idea of a posterior predictive check is analogous to simulating data values using parameter estimates from a regression model (using OLS or maximum likelihood estimation) and comparing the simulation to the observed data. However, the assessment (such as a Bayesian *p*-value) from posterior predictive check can be subjective and is an idea still under active research.

Yet, we disagree with the idea of using empirical survival probabilities, or conversion rates, to assess model fit. First, the fitted survival curves (in Figure 8.4 for example) represent the expected outcome, not the observed survivals. Second, the survival plots in this chapter show the survival over a range of temperature while holding other variables (such as arrival date) constant in the model. It is difficult to do the same with the conversion rate and project the points on a matching dimension. Plotting the empirical survival in degree intervals can reveal relationship between temperature and survival, but can be misleading as a model assessment.

We agree that the results of an analysis can often be artifacts of model fit. Hence, for each analysis, we often conduct multiple assessments that serve as reassurance to each other. When we use Figure 8.2 to assess a positive or negative relationship between travel time and temperature, we also compare the portion of fish with long travel time at different temperature intervals. The results from both assessments lead to the same conclusion.

There is some potential bias inherent in using travel times only of fish that survive between Bonneville and McNary dams. This is recognized by the authors (page 204) and adequately discussed.

The choice of linear, piece-wise linear, quadratic, or cubic relationships using AIC or backwards selection is an attempt to fit an appropriate functional form. The method used to choose the breakpoint for the piece-wise linear function is ad hoc (depends on spotting a break in a plot), is not recommended, and further analysis does not account for the uncertainty in the choice of the breakpoint (Toms and Lesperance 2003). Because only the functional form of the relationship is of interest, the authors should investigate the use of smoothing splines rather than using ad hoc methods to select an appropriate functional form. Smoothing splines will "automatically" adjust for non-linear relationships and will not suffer from the (observed) problems of fitting a cubic, which has unrealistic predictions in the extremes because of the degree of the polynomial.

CSS Response: Piece-wise model is one of the choices for our model selection. We recognize the subjective nature of the breakpoints for our piece-wise models; therefore, piece-wise models were not selected as the final models in our analysis. We will also consider utilizing smoothing splines in the future to assess non-linear nature of survival-temperature relationship.

Fitting models in this chapter with random effects of individuals is problematic. No fish was observed more than once at a dam, and no fish was observed in more than one year. So the individual effect is completely confounded with residual error and reflects overdispersion in the logistic mixed-effect analysis or CJS analysis. Unfortunately, with individual data, it is extremely difficult to estimate overdispersion using random effects. Standard diagnostics, such as deviance/df, perform poorly. To investigate overdispersion, the authors will have to combine data into groups (e.g., release groups when juvenile) and use these groupings to estimate the degree of overdispersion. Also, fitting individual random effects is numerically problematic for both the mixed-logistic model and the CJS model because of the very large number of parameters introduced. It would not be surprising if the mixed-logistic model has convergence issues and the fit was not reliable. It would be more profitable to try to estimate the degree of overdispersion in the data and, if needed, use the standard methods to adjust for overdispersion (such as variance-inflation factors).

CSS Response: We agree with the comment that individual random effects can be problematic. In our analysis, models with individual random effects have been eliminated through model selection process. We will consider incorporating the suggestions regarding over-dispersion in the future.

Specific comments

p. 185. "… water temperature (with smoothing function)." The authors need to explain in more detail what smoothing function is used in the GAM or point to the appropriate R software reference.

CSS Response: We use R package mgcv for the GAM. And we have added the reference to that section.

p. 185. "We decided on a model that was the most biologically plausible to us and/or the lowest AIC value (Akaike 1973). Then we selected explanatory variables using a backward elimination stepwise process. During which, we started with all candidate variables in the model, and deleted them one by one until no more could be eliminated without losing significant model fit. We evaluated the model fit using a sequence of likelihood ratio tests and comparisons of AIC values." This is a mixture of AIC and hypothesis testing after a stepwise elimination procedure which is extremely ad hoc in nature. We suggest either adopting AIC for the entire process, or as noted in the general comments, switching to splines that will automatically "adjust" for non-linear relationships.

CSS Response: We rely mainly on AIC comparisons for our model selections, and only check informally using LRT as a confirmation. The results of AIC and LRT agree with each other for our assessment, and we understand that may not be the case all the time. We will exercise more caution in model selection in future analysis. We have omitted the mention of LRT in the revision in response to criticisms.

p. 185. "(b) a quadratic form." The usual practice is to fit a centered quadratic form to reduce correlation between Temp and Temp2 terms. Was this done? [It appears to have been done in the Bayesian analysis, but it is unclear if this was done for the non-Bayesian analyses.]

CSS Response: We standardized continuous variables such as temperature and arrival date in our analysis, for both Bayesian and non-Bayesian model fitting. We have included a sentence in the revision for clarification.

p. 186. "(a) a third degree polynomial." Third (and higher) polynomials are seldom appropriate given the severe restrictions placed on where the curve increases/decreases with the explanatory variable. If more than a quadratic is to be considered, a fit using splines with a small number of knots is likely more interpretable and not that much more difficult to fit.

CSS Response: We will consider incorporating this suggestion in the future.

p. 186. A paired-test appeared to be used to compare the proportion of fish with > 10 days travel time. It is not clear what the pairing variable is (year, temperature group, both?). Because proportions are being compared in a blocked design, a Manzel-Cochran-Hanzel test is the appropriate version of the chi-square test to use. Alternatively, many authors suggest a t-test on the empirical logit of the proportions (Warton 2011) rather than the raw proportions.

CSS Response: In response to the suggestion, we have followed the recommendations by Warton (2011) and utilized logistic regression models instead of paired-*t*-tests. We have made changes in the revision.

p. 190. It is not clear how the piece-wise linear function of temperature was fit using the notation given in the table. Usually, a single new variable is created which is 0 prior to the breakpoint and then (x-breakpoint) following the breakpoint.

CSS Response: In table 8.2 for example, "Temp< 14.64" means a variable that includes values less than 14.64 (and 0 following the breakpoint), "Temp≥ 14.64" means a variable that includes values greater or equal to 14.64 (and 0 prior to the breakpoint), and so on...

p. 190. "… mean survival rate." What is a "mean survival"? The authors interpret the (anti-logit) of the intercept as the "mean survival," but the intercept does not have this interpretation. These are not rates as there is no time element to the survival probabilities.

CSS Response: The "mean survival" refers to a survival estimate while setting the individual covariates at zero. We acknowledge that explanation is confusing in the CSS draft. We have made changes in the revision regarding interpretation of survival.

p. 190. Not clear exactly what model is being fit. The authors created a 3-element detection history with the first element representing the "release" at Bonneville, the second element representing detection at McNary, and the third element representing detection upstream of McNary. There are two survival probabilities in the CJS model. The first is from Bonneville to McNary and the second is upstream of McNary. The latter is confounded with detection upstream of McNary. Why doesn't Table 8.4 have this second survival parameter? The appendices appear to show that the same survival probability was assumed between Bonneville and McNary and upstream of McNary, but this was never explicitly stated. The model with equal survival "breaks" the confounding seen in the last interval of the CJS model, but there is no information to assess if this assumption is justified.

CSS Response: In the CSS draft, we have constructed CJS models that forced the survivals to be the same at Bonneville to McNary and upstream of McNary. For our analysis, the focus is the relationship between survival and temperature, and estimating individual reach survivals seems

less relevant; however, we acknowledge that the model assumptions are not clearly stated in the draft. There are enough confusions to merit revision of the models.

In the revision we allow separate estimates for survivals at Bonneville to McNary (ϕ_1) and upstream of McNary (ϕ_2), and separate estimates for detection at McNary (p_2) and upstream of McNary (p_3). ϕ_2 and p_3 are confounded, hence unidentifiable. We model the individual fixed effects only for ϕ_1, which is estimable. We have made the changes for all three species in the revision. The results from the revised models have changed slightly (Tables 8.4, 8.8, and 8.10, Figures 8.4, 8.9, and 8.14), but overall the conclusions have stayed the same.

p. 192. Figure 8.4. It is not clear how the temperature-specific credible intervals for the survival probability were computed. These appear to be based on some sort of envelope of the fitted curves, but how were the fitted curves selected to represent the credible bounds. The easiest way to compute the temperature-specific credible intervals would be to predict the response at selected temperatures and use the 2.5 and 97.5 percentiles of the predictions.

CSS Response: Yes, that is how we estimate the CRI for Figure 8.4, 8.9, and 8.14. We save the estimates as tables and plot the values as lines in 500 iterations.

p. 193. Figure 8.5. The X-axis is labeled as "Last" detection at Bonneville. What does the "last" refer to? Are these Julian dates? It is hard to infer the arrival distributions from the plots. We think you need to plot a smoothed density curve for the arrival distribution for the two groups of fish. There appear to be missing temperature data for some fish (e.g., in 2004). Were the temperature data then interpolated for these fish?

We make similar comments for the analyses of the sockeye and steelhead data.

CSS Response: The "last detection" refers to arrival at Bonneville Dam. We only count the last detection if a fish had more than one detection due to fallbacks. We have relabeled the plots using month-day format in the revision. Missing temperatures are not interpolated for the corresponding fish.

p. 195. Rather than using a cubic polynomial, we suggest using a spline with a few knots. Indeed, this would likely alleviate the problem where the authors choose the quadratic model because the results were more plausible.

CSS Response: We will consider this option in the future.

p. 196. The report indicates the individual random effects were included, but there are no variance terms for individuals in Table 8.8.

CSS Response: It is a typo and has been corrected. We did not include random individual effects in the model.

p. 206. The state space model indicates that there are two survival probabilities (as noted earlier). Only by reading the explicit equations, is it possible to deduce that the authors are forcing the two survival probabilities to be equal. Please explain explicitly in the text.

CSS Response: We have made corrections regarding to this matter. Please see comment above.

It is not clear why the observation process has the detection probabilities having a Uniform(0,1) distribution. Perhaps this is the Bayesian prior? If so, this is an odd choice for a prior because there is very good prior knowledge that the detection probabilities are 90%+. Fortunately, the choice of prior for the detection probabilities is somewhat moot given the very large sample sizes.

CSS Response: We will consider using informative or weakly informative priors for detection in future analysis.

The model for the survival probabilities indicates that the two survival probabilities are forced to be equal, which was never indicated in the text describing the model.

CSS Response: We have made corrections regarding to this matter. Please see comment above.

p. 209. Goodness of fit test should not include t=1 because the model only uses fish released alive at t=1 and there is no stochasticity.

CSS Response: We have made corrections in the revision regarding to this matter.

p. 213. Why did the authors switch to N() priors for this species compared to Cauchy priors for the previous species? Given the large sample sizes, the choice of priors is somewhat moot.
CSS Response: Gelman et al. (2008) and Broms et al. (2016) recommend using Cauchy priors in some situations such as logistic regression and hierarchical models with capture-recapture data. We have tried both Normal and Cauchy priors and found that Cauchy priors helped our MCMC sampling converge better for Chinook and sockeye models. Our prior choices seem not to affect the sampling nor results of our steelhead model, so we could have utilized either Cauchy or Normal priors in this case. Because Cauchy distribution is a special case of the *t* distribution, the underlying assumptions for Cauchy priors are not too far off from *t* or Normal priors.

IV.9. Appendix A: Survivals (SR), SAR, TIR, and *D* for Snake River Hatchery and Wild Spring/Summer Chinook Salmon, Steelhead, and Sockeye

This is an update from the previous year's report. New figures are included that now display confidence limits for many parameters and are broken out by population group.

IV.10. Appendices C through H

The draft that we reviewed did not include these appendices, but they will be included in the final CSS report and will likely contain updates for 2017. For Appendix C, the authors should refer to the ISAB's comments on Chapter 1 about the small number of tags in some groups.

V. References

Keefer, M.L., C.A. Peery, and C.C. Caudill. 2008. Migration timing of Columbia River spring Chinook salmon: effects of temperature, river discharge and ocean environment. Transactions of the American Fisheries Society 137, 1120–1133.

Toms, J.D. and M.L. Lesperance. 2003. Piecewise regression: A tool for identifying ecological thresholds. Ecology 84, 2034-2041.

Warton, D.H. 2011. The arcsine is asinine: the analysis of proportions in ecology. Ecology 92, 3-10.

VI. Editorial Suggestions

Chapter 1.

There are some places where the exact same years of data or exact same text are used as in CSS 2016 without being updated for 2017. These should be checked:

p. 14. Refer to second paragraph noted above ("Two other new traps…")
CSS Response: The sentence has been changed to "Two other new traps began operation in 2016 in these rivers (with PTAGIS release site codes LOCTRP and CLWRSF)."

p. 14. The last two sentences have the same years as CSS 2016.

CSS Response: The years have been changed.

p. 15, middle of third paragraph. "To maintain a time-series of PIT-tagged…and this is expected to continue through 2015." The next sentence seem to indicate that things changed in 2015, but the wording of "expected to continue through 2015" makes interpretation of what happened confusing.

CSS Response: The wording was changed to "…this was continued through 2015."

p. 15, first sentence of last paragraph. This uses the same years as CSS 2016.

CSS Response: The wording was changed to "…were represented in the PIT-tag aggregates for migration years beginning in 1997."

p. 17, last sentence of first paragraph. Wording is identical as CSS 2016 and states that "…2016 CSS report will include SARS for upper Columbia wild summer Chinook (RRE-BOA, MCN-BOA) for MY 2011-2013 (and possibly 2014)." Now we are reviewing 2017 CSS report, so did these things get included?

CSS Response: The wording was changed to "Upon request from Colville Tribe, beginning in 2017 CSS will include SARs for upper Columbia wild summer Chinook (RRE-BOA, MCN-BOA) beginning with MY 2011."

p. 23. Appendices I and J should refer to the 2017 CSS meeting and report.
CSS Response: The wording was changed to reflect 2016 Annual Meeting and the 2017 responses to comments.

Figure 1.1. Define C0, C1 in the caption, and perhaps use T instead of transported (once defined) to be consistent with using C0 and C1. These terms did not get defined until p. 11 and so the caption to this figure using these terms was confusing.

CSS Response: The wording was changed to define the categories instead of using the abbreviations.

Table 1.3. USFS Grand Total is "#######."

CSS Response: The Grand Total was 100,000. The table was updated.

Chapter 2

General proof reading and editing required.

p. 32. Equation 2.12. Why isn't the overall SAR normalized by the number of smolts initially produced for that brood year?

p. 32. Equation 2.13. What is the phi term in equation 2.13 and 2.14? It does not appear in Table 2.1. These SARs are normalized by the number of smolts that are transported.

p. 31 and onward. Consistency of capital S versus lower case s is needed. According to Equations 2.1 and 2.8 and Table 2.1, capital S refers to number of spawners, whereas lower case s refers to survival (e.g., Equation 2.2, Table 2.1, Equations 2.9-2.11). However, the results tend to use capital S as survival, which is very confusing (see for example, pages 32 below Equation 2.8, 40, 41, Figure 2.5, and other places). Capital S is used for spawners in Figure 2.7 (which is correct usage according to the equations).

p. 33. Equation 2.17: What is "n" in the denominator?

p. 37. Should "and breach conditions" be added to the end of the second sentence (i.e., "In the hydrosystem, those are the four spill alternatives evaluated at three flow scenarios and breach conditions.")?

p. 38, 8th sentence, "conditions can be the same as historical conditions, i.e., same environmental." Should "same" be "similar"? Historical conditions are not exactly being replicated.

p. 38, end of 8th sentence. There appears to be a typo on "to mimic a of interest"

p. 38, 10th step of first logic description. Should "breach" be added to "each spill scenario j"?

p. 41, second full sentence. Change "with the joint posterior" to "when the joint posterior"

p. 48, second full sentence. Should Figure 2.10 be Figure 2.9?

p. 48, second line. This should this read "The SAR can be viewed as more THAN a smolt to spawner ratio."

p. 49. Figure 2.8 is a common way to present three variables using a three-dimension plot, but some readers may have difficulty reading the plot. Other representations may be easier to read. For example, plot PITPH versus WTT in two-dimensions, with points for the 12 scenarios joined to show how breaching changes these two variables and a "circle" representing in-river survival with the size of the circle or the shading of the circle increasing as survival increases?

p. 51. Put Figure 2.10 and 2.11 on same graph for breach versus non-breach comparisons. Same comments for other graph pairs as well.

p. 53. Figures 2.12, 2.13 versus Figures 2.14 and 2.15: Why is it necessary to have both sets of figures? The paragraph about these on Page 48 is confusing, and it is not clear why it is necessary to show both sets of results.

p. 54. Isn't Figure 2.12 contained in Figure 2.13 with the bottom set of lines in each panel?

p. 58. Place Figure 2.16 and 2.17 on the same plot.

p. 61. The last sentence of 2nd paragraph (starts with "PITPH for John Day Chinook…") is worded awkwardly and is hard to follow. Can it be written more clearly?

p. 61, second to last sentence. What are the two competing perspectives referred to here?

p. 62, fifth sentence of conclusions. Does "empirically" mean "experimentally"? If so, suggest using "experimentally" because "empirically" has an ambiguous meaning in a chapter about modeling.

CSS Response: Revised chapter 2 reflects comments above. Note that the addition of a new Figure 2.2 in place of the original increases numbering of all figures after Figure 2.1.

Chapter 4

p. 99. Keep figure legends on same page as figure.

CSS Response: We will fix the formatting.

p. 99. The phrase "decreased four-fold" is an unclear way to say something decreased by three-quarters.

CSS Response: Edits made.

p. 109. This chapter uses log() to represent natural logarithmic transformation while other chapters use ln(). Please be consistent across chapters. Table 4.1 uses both notations.

CSS Response: Fixed the notation.

p. 110. Table 4.1 Many readers will not be familiar with the R convention that a colon (:) represents purely an interaction while an asterisk (*) represents both main effects and interactions. Use a computer language independent convention.

CSS Response: We have fixed this.

Chapter 5

p. 138. Some of the terms in the model were not displayed properly in the paragraphs under the equation.

CSS Response: We fixed formatting (the symbols T_l and ε_{ij} did not convert from Word to pdf).

p. 145. Table 5.3. The column for the slope is labeled as "-B" because the model used "–beta" in the model. This is confusing. Why not fit the model using "beta" directly and avoid the negation in the presentation? Similarly, the hypothesis of beta < 0 would be changed to beta > 0 because the model equation uses "-beta."

CSS Response: The Table 5.3 format using "-B" is consistent with that previously used in Schaller et al. (2014), and originates from Ricker's (1975) formulation of $R = \alpha S e^{-\beta S}$, where "beta" is defined as a parameter with dimensions of 1/S. It would be mathematically equivalent to directly fit "beta" as suggested, but that might result in confusion with the original Ricker definition and the previous format from the Schaller et al. table.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Fisheries Research Board of Canada Bulletin 191.

Schaller, H.A., C.E. Petrosky and E.S. Tinus. 2014. Evaluating river management during seaward migration to recover Columbia River stream-type Chinook salmon considering the variation in marine conditions. Canadian Journal of Fisheries and Aquatic Sciences. 71:259-271.

p. 148. Figure 5.5 (and others). Add the average SRI to the graphs, i.e. add a line segment at -2.02 for the top panel.

CSS Response: Figure 5.5 edited as suggested.

p. 149. Figure 5.6. Try to avoid the same symbol with different colors for different years so that black and white copies can be read properly or readers who have difficulty distinguishing color are not confused.

CSS Response: Figures 5.6 and 5.8 edited as suggested.

Chapter 6

p. 155. What are "BDA" and "IPC" used in several tables (Tables 6.1, 6.2 and others)?

CSS Response: Those are PIT-tag coordinator id's that help distinguish the tags we used from other release groups that may use the same location.

Chapter 7

p. 175. Figure 7.2 (and others). Y-axis and X-axis tick-mark values not aligned properly.

Response: We have fixed the alignment errors in these plots.

p. 179. Figure 7.6. Y-axis legend seems to be truncated and not centered on axes. X-axis legend should be centered on axis.

Response: We have fixed the legend truncations and centering errors.

Chapter 8

p. 187. Figure 1. The figure could be improved by plotting the midpoints of the temperature range on the bars.

p. 188. Figure 2. Plot the raw data along with the fitted curve to provide some assessment of the fit.

p. 189. It is usual in AIC tables to show the number of parameters and the likelihood value as well. Same comment applies to all AIC tables in this chapter.

p. 197. Figure 8.9. "… focuses on the top 95th percentile." Authors likely meant the temperatures above the 5th percentile.

p. 209. Figure 8.16. Legend uses "eta" rather than "beta" and uses "$" (similar to LaTeX).

p. 214. "… some parameters has effect sizes smaller than desired." What does this mean?

p. 217 (and elsewhere). Reporting p-values that are very small is rarely useful or sensible. Just state that p<.0001 for very small p-values.

CSS Response: Revised chapter 8 incorporates many of the comments above.

CSS Responses to NOAA comments on the 2017 CSS Annual Report.

This document provides CSS Responses to comments and questions provided by NOAA on the 2017 CSS Draft Annual Report. NOAA original text is itallicized and CSS responses are in standard font. Each CSS response is set apart from the NOAA text. Each response begins with
CSS Response: in bold as shown; followed by the response to the comment or question.

To: Michele DeHart
From: NOAA Fisheries Hydropower Branch
Subject: Comments on draft 2017 CSS report
Date: October 13, 2017

Michele,

Thank you for the opportunity to comment on the draft CSS report. Our comments follow.

1. *Page 88 states that the CSS model could be used to evaluate the effects of how changes in spill operations would affect the survival of juveniles through the FCRPS. It is anticipated that during the year 2018 spill will be increased to a level of 120%/115% TDG (forebay/tailrace). It would be informative to include the evaluation of the anticipated change in juvenile survival and SARS relative to the BiOp operation in the report. It would also be informative to report how this change in operations will affect the PITPH rate.*

   CSS Response: We have conducted extensive analyses on juvenile survival, juvenile travel time, ocean survival, SARs, and TIRs under BiOp, 115% forebay/120% tailrace, 120% tailrace, and 125% tailrace TDG levels. The methods and results of these analyses are summarized in the CSS Oversight Committee response to the ISAB (CSSOC 2017).

2. *The PIT power house (PITPH) variable is a rather recent addition to the CSS model and it would be helpful if you could provide a better explanation of what it represents i.e. are sluiceways considered power house passages or is it strictly JBS routes of passage. The basis for the question is our attempt to duplicate this number using the COMPASS model appears to provide different results, i.e. COMPASS indicates many fewer bypass occurrences are generated than what CSS appears to be calculating in this year's report. I say appears, because our results would be similar to what CSS produced in its 2016 report in figure 7.1, or in Chapter 2's figure 2.1 of this year's report. However, Chapter 2 also had figure 2.8 which has a much higher PITPH number*

and does not appear to be very sensitive to a change in spill from the current BiOp to the 120/115 level. So, an explanation of why there is such disparity in the figures cited would be helpful. We are familiar with Appendix J in the 2015 report and the procedure it provided is very similar to the NWFSC's method. So a further explanation of what other factors are included would be beneficial.

CSS Response: Figure 7.1 from the 2016 CSS Annual Report shows the mean number of PIT-tag detections that fish had prior to Bonneville Dam. This is not the same as PITPH. PITPH includes bypass and turbine encounters. It would also include passage through the powerhouse at The Dalles Dam which does not have PIT-tag detection in it's bypass. Thus the figures should not be the same. The CSS has used a powerhouse encounter rate derived from PIT tag data (referred to as PITPH) to represent the impacts of dam passage (stress and mortality) on juvenile salmon as well as delayed effects on adult return rates (Appendix J, McCann et al., 2015). The PITPH index uses the PIT tag detection rate and an estimated fish guidance efficiency to estimate the fraction of fish passing through the powerhouse (bypass and turbine routes combined) at each dam. The PITPH index is the sum of the fractions passing through the powerhouses of all projects, from LGR to BON combined. The value could range from zero (no powerhouse passages) to eight (fish encounter powerhouses at all eight dams during juvenile migration).

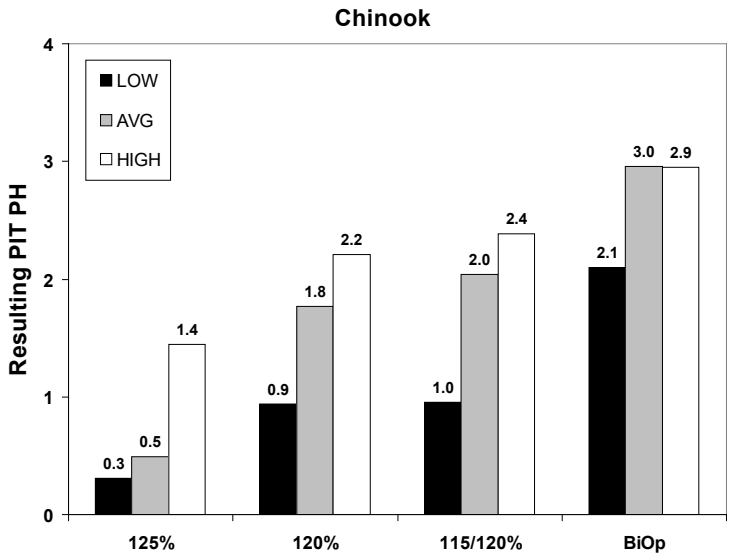
To better illustrate the effects of potential increased spill operations on juvenile passage as well as adult returns, we simulated passage of juvenile salmon through the LGR to BON dam reach and estimated PITPH values for those fish using flow data from three recent years. Powerhouse passage proportions were calculated using the methods described in Appendix J of (McCann et al., 2015). Flow and spill data were summarized for all eight dams from the years; 2009 an average flow year; 2010 a low flow year; and 2011 a high flow year. We simulated PITPH values obtained under multiple alternate operational scenarios using the flow data representing a range of flow years. The alternate scenarios involved operating dams to different TDG levels relative to the current BiOp operations. The alternate operational spill levels are defined in terms of the limits of total dissolved gas (TDG) produced at each project.

Table 1. Operational scenarios evaluated in simulations under three different flow conditions (low flow represented by 2010; average flow represented by 2009; and high flow represented by 2011).

Operational Scenario	Description of constraints to operations
BiOp	Maintain spill levels according to the regulations consistent with the current Biological Opinion.
115%/120%	Increase spill up to limits of 120% TDG in the tailraces and 115% TDG in the forebays.

120%	Increase spill up to a limit of 120% TDG in tailraces.
125%	Increase spill up to a limit of 125% TDG in tailraces.

The results of the simulations for Snake River yearling spring/summer Chinook are summarized in Figure 1. The simulated PITPH values we calculated were consistent with those reported by (McCann et. al., 2016) Chapter 2 using the same flow years and scenarios, although the dam operations they used spanned a much wider time period (April 1 to August 31) while ours used operations from April 8 to around June 15 of each year. Our simulations showed that, under the current BiOp operational constraints, the PITPH index ranged between 2.1 in a low flow year (2010) up to 3.0 in average to high flow years (2009 and 2011 respectively). The PITPH Index was



shown to decrease

Figure 1. PITPH Indices for calculated for simulated yearling Chinook salmon migrants originating above Lower Granite Dam and survivng to pass Bonneville Dam. The PIT PH values are indices of the number of powerhouses encountered based on the dam operations during juvenile salmon out-migration. Each operation scenario was simulated under low, medium and high flow conditions using the years 2010, 2009 and 2011 respectively to represent those various levels of flow years.

substantially lower under an operational scenario 115%/120% which constrained spill volumes to 115% total dissolved gas, as measured in the downstream dam forebays, and 120% in the tailraces of the dams. The PITPH values under the 115%/120% scenario ranged between 1.0 in a low flow year (2010) to 2.0-2.4 in an average (2009) to high (2011) flow year, respectively. This exercise demonstrates that increasing spill to the 115%/120% scenario, over the BiOp, in a low flow year would reduce PITPH by over 50%.

3. *The analysis of temperature effects in Chapter 8 and how transported fish often display reduced travel time under high temperature was a new addition to this year's report. The effect of transport on delay has been noted by several authors previously. As the report notes, delay makes the fish more vulnerable to decreased survival from the fishery, stress and disease. However, this section should also note that even with the effects of delay the TIR for all summer chinook hatcheries (a total of 8 of them contained in this year's report) is greater than 1 and noting this would add value to this section. Also in 2015, the year with exceptional temperatures, the TIR for McCall hatchery and the Imnaha hatchery had TIRs of 3.85 and 7.47 respectively. This indicates transport was very beneficial for these fish in that year.*

   CSS Response: This question, similar to the previous one, mixes different metrics/measurements together. Chapter 8 would have been evaluating adults that returned in 2015 and experienced high river temperatures while migrating up-river. Furthermore, Chapter 8 analyses of summer Chinook did not include jacks. Therefore, adults returning in 2015 would have been a mix of 2012 and 2013 out-migrants. The TIRs for hatchery summer Chinook in migration years 2012 and 2013 ranged from 0.62 to 1.27 and all confidence intervals around these estimates overlapped 1.0 (Tables A.53-A.56). Comparing TIRs for juveniles that out-migrated in 2015 is a very different subject, as those adults would not have returned until 2017 and 2018. Finally, it is unclear which 8 hatchery summer Chinook you are referring to in our question, as there are only 4 hatchery summer Chinook stocks in the 2017 CSS Annual Report DRAFT (McCall, Imnaha, Pahsimeroi, and Clearwater). Of these four, the CSS was only able to estimate TIRs for three in migration year 2015..

4. *The CSS describes Fish Travel Time (FTT) as a key variable in terms of both in-river survival and adult returns. The CSS also describes power house passage as a key variable that negatively affects FTT because of the delay fish encounter when they use the power house as a route of passage. How much delay does the CSS assign to this route of passage? A table of what the estimated additional delay by each power house project would be informative. The basis for this question is delay has been substantially reduced following the installation of the surface passage routes and the provision of 24 hour spill in 2006. A description of how the CSS accounts for this change in project configuration and operations would increase the understanding of how the long term data set of 1998 to 2016 relative to the changes in spill operations and the addition of surface passage in the years up to the year 2009 addresses this issue.*

   CSS Response: Because of the multivariate nature of the FTT regressions, the effect of powerhouse passage on FTT depends on the levels of PITPH and the other variables in the model. That is, the effects of powerhouse passages depend on the level of the PITPH variable along with Julian Day, water transit time, and water temperature that are also included in the models. Because of this, it is not possible to provide a table of the amount of delay associated with each powerhouse passage event.
   The calculated values of the PITPH variable incorporate the changes in project configurations over time, explicitly accounting for the installation of spillway surface passage structures and the changes in spill levels that occurred over time. These changes are reflected in the changing values for the PITPH variable over time.

To: Michele DeHart
From: NOAA Fisheries Hydropower Branch
Subject: Comments on draft 2017 CSS report
Date: October 13, 2017

Michele,

We are providing one additional comment on the 2017 drft CSS report. Thank you for the opportunity to comment on the draft CSS report.

It would helpful if your report contained the annual estimates of the population size of juveniles arriving at Lower Granite Dam that was used to make the estimates provided in Tables A11 (wild spring chinook) and A22 (wild steelhead) used to compute the TIRs presented in these tables.

CSS Response: These are estimates of LGR equivalent populations of PIT-tagged wild yearling Chinook and wild Steelhead. Providing this information for all tables in the report would require major changes in formatting. However, in response to this request, we have provided estimates for these two groups below.

Table A.11. Estimated LGR LGR-to-GRA SAR (%) (without jacks) for PIT-tagged wild Chinook in annual aggregate for each study category from 1994 to 2015 (with 90% confidence intervals).

	T_0 or Tx_t Group			C_0 or C_0_crt Group			C_1 or EC_1_t Group		
Migration Year	**Juv. PIT-Tag Pop. (LGR Equiv.)**	**SAR(T_0) %**		**Juv. PIT-Tag Pop. (LGR Equiv.)**	**SAR(C_0) %**		**Juv. PIT-Tag Pop. (LGR Equiv.)**	**SAR(C_1) %**	
1994	2,004	0.45	(0.20 – 0.72)	1,801	0.28	(0.11 – 0.51)	4,431	0.07	(0.02 – 0.14)
1995	2,283	0.35	(0.17 – 0.57)	2,709	0.37	(0.18 – 0.57)	14,206	0.25	(0.18 – 0.32)
1996	400	0.50	(0.00 – 1.07)	1,917	0.26	(0.10 – 0.48)	5,209	0.13	(0.06 – 0.23)
1997	230	1.74	(0.44 – 3.27)	680	2.35	(1.45 – 3.36)	1,936	0.93	(0.60 – 1.32)
1998	1,271	1.18	(0.71 – 1.70)	3,081	1.36	(1.05 – 1.70)	12,276	1.07	(0.91 – 1.22)
1999	1,768	2.43	(1.85 – 3.07)	4,469	2.13	(1.78 – 2.50)	26,140	1.89	(1.76 – 2.04)
2000	839	1.43	(0.74 – 2.14)	6,494	2.39	(2.08 – 2.72)	16,833	2.33	(2.12 – 2.52)
2001	547	1.28	(0.54 – 2.14)	231	Assume = SAR(C1)		20,307	0.14	(0.10 – 0.18)
2002	3,886	0.80	(0.57 – 1.04)	6,218	1.22	(0.99 – 1.45)	12,687	0.99	(0.84 – 1.14)
2003	8,713	0.34	(0.24 – 0.45)	8,919	0.33	(0.23 – 0.43)	12,744	0.17	(0.12 – 0.23)
2004	12,887	0.53	(0.42 – 0.63)	2,264	0.49	(0.26 – 0.74)	16,561	0.22	(0.16 – 0.29)
2005	15,911	0.23	(0.17 – 0.29)	1,358	0.11 [A]	(0.07 – 0.15)	17,066	0.11 [A]	(0.07 – 0.15)
Monitor Mode Years[B]		**SAR(T_X)_t %**			**SAR(C_0)_crt %**			**SAR(EC_1)_t %**	
2006	10,066	0.76	(0.60 – 0.90)	3,498	0.97	(0.71 – 1.26)	2,796	0.36	(0.18 – 0.56)
2007	3,169	1.20	(0.88 – 1.51)	11,156	0.94	(0.79 – 1.10)	4,424	0.88	(0.67 – 1.14)
2008	8,573	3.01	(2.70 – 3.30)	7,664	2.53	(2.23 – 2.87)	4,615	2.62	(2.22 – 3.04)
2009	8,711	1.54	(1.32 – 1.77)	6,426	1.39	(1.14 – 1.63)	6,732	1.50	(1.26 – 1.76)
2010	10,621	0.86	(0.71 – 1.00)	22,273	0.71	(0.62 – 0.81)	1,568	0.57	(0.26 – 0.91)
2011	8,165	0.38	(0.27 – 0.49)	6,671	0.55	(0.41 – 0.72)	10,293	0.19	(0.12 – 0.27)
2012	4,412	0.86	(0.64 – 1.11)	7,215	1.21	(1.00 – 1.42)	2,394	1.15	(1.00 – 1.32)
2013	6,580	1.57	(1.31 – 1.82)	13,472	1.10	(0.94 – 1.25)	3,414	1.07	(0.76 – 1.39)
2014	7,271	0.66	(0.52 – 0.82)	6,442	0.33	(0.22 – 0.44)	9,764	0.52	(0.41 – 0.65)
2015[C]	1,889	0.69	(0.39 – 0.99)	12,667	0.18	(0.12 – 0.25)	2,194	0.23	(0.09 – 0.40)
22-yr avg.		**1.04**	**(0.77 – 1.31)**		**0.97**	**(0.68 – 1.26)**		**0.79**	**(0.51 – 1.07)**

[A] In-river SAR is combination of groups C_0 and C_1.

[B] Estimated SARs for T_X and C_1 with Group T (reflects later start of transportation), and C_0 with combined Group CRT.

[C] Incomplete, 2-salt returns through Sept. 15, 2017.

Table A.22. Estimated LGR-to-GRA SAR (%) for PIT-tagged wild steelhead in annual aggregate for each study category from 1997 to 2014 (with 90% confidence intervals).

	T_0 or Tx_t Group			C_0 or C_0_crt Group			C_1 or EC_1_t Group		
Migration Year	**Juv. PIT-Tag Pop. (LGR Equiv.)**	**SAR(T_0) %**		**Juv. PIT-Tag Pop. (LGR Equiv.)**	**SAR(C_0) %**		**Juv. PIT-Tag Pop. (LGR Equiv.)**	**SAR(C_1) %**	
1997	275	1.45	(0.36 – 2.80)	454	0.66	(0.00 – 1.34)	2,984	0.23	(0.10 – 0.39)
1998	480	0.21	(0.00 – 0.63)	750	1.07	(0.51 – 1.73)	5,150	0.21	(0.12 – 0.33)
1999	391	3.07	(1.74 – 4.66)	1,113	1.35	(0.80 – 1.96)	6,992	0.76	(0.60 – 0.94)
2000	466	2.79	(1.55 – 4.11)	1,871	1.92	(1.40 – 2.49)	10,616	1.81	(1.59 – 2.03)
2001	201	2.49	(0.93 – 4.37)	103	{Assume =SAR(C_1)}		11,892	0.07	(0.03 – 0.10)
2002	317	2.84	(1.52 – 4.43)	4,045	0.67	(0.46 – 0.90)	8,726	0.94	(0.77 – 1.11)
2003	2,210	1.99	(1.52 – 2.51)	3,324	0.45	(0.27 – 0.66)	7,137	0.52	(0.37 – 0.66)
2004	4,474	0.87	(0.65 – 1.11)	330	0.06[A]	(0.02 – 0.11)	7,865	0.06[A]	(0.02 – 0.11)
2005	4,852	0.84	(0.63 – 1.07)	205	0.17[A]	(0.11 – 0.25)	9,177	0.17[A]	(0.11 – 0.25)
Monitor Mode Years[B]		**SAR(T_X)_t %**			**SAR(C_0)_crt %**			**SAR(EC_1)_t %**	
2006	3,502	1.31	(1.02 – 1.66)	585	1.54	(0.72 – 2.44)	1,511	0.60	(0.27 – 0.92)
2007	2,823	4.18	(3.60 – 4.83)	3,877	1.44	(1.12 – 1.79)	1,509	1.72	(1.17 – 2.33)
2008	2,319	4.05	(3.43 – 4.76)	2,924	3.49	(2.89 – 4.09)	1,591	2.07	(1.50 – 2.70)
2009	2,697	3.45	(2.88 – 4.01)	1,782	2.64	(2.07 – 3.31)	2,127	1.60	(1.15 – 2.08)
2010	2,875	2.33	(1.87 – 2.80)	7,170	1.60	(1.35 – 1.87)	769	1.17	(0.53 – 1.92)
2011	2,330	1.46	(1.07 – 1.87)	1,858	1.24	(0.84 – 1.70)	1,356	0.96	(0.55 – 1.43)
2012	1,585	2.27	(1.64 – 2.89)	2,842	2.57	(2.07 – 3.09)	3,496	2.80	(2.35 – 3.30)
2013	3,946	2.89	(2.45 – 3.34)	5,431	1.34	(1.09 – 1.63)	1,096	0.91	(0.47 – 1.40)
2014[C]	4,771	1.82	(1.51 – 2.17)	5,044	0.85	(0.64 – 1.07)	1,749	0.74	(0.44 – 1.11)
18-yr avg.		**2.24**	**(1.78 – 2.70)**		**1.29**	**(0.90 – 1.68)**		**0.96**	**(0.63 – 1.29)**

[A] In-river SAR is combination of groups C_0 and C_1.

[B] Estimated SARs for T_X and C_1 with Group T (reflects later start of transportation), and C_0 with combined Group CRT.

[C] Incomplete steelhead adult returns until 3-salt returns (if any) occur after Sept. 15, 2017 at GRA.

Appendix K

Supplemental Analysis of Spill and Breach Scenarios Using Long-Time Series Prospective Models

Supplemental Analysis of Spill and Breach Scenarios Using Long-Time Series Prospective Models

The Comparative Survival Study Oversight Committee (CSSOC 2017) evaluated the potential of management experiments to improve survival rates of ESA-listed Snake River spring/summer Chinook and steelhead by increasing voluntary spill levels at Federal Columbia River Power System (FCRPS) dams in the lower Columbia and Snake rivers. CSSOC (2017) provided documentation of modeling and rationale for alternative spill scenarios developed for the 2013 CSS workshop (Hall and Marmorek 2013) at the request of the Independent Scientific Advisory Board (ISAB). That report, "Documentation of Experimental Spill Management: Models, Hypotheses, Study Design and response to the ISAB", included retrospective and prospective analyses using long-time series data sets based on run reconstruction of Chinook and steelhead survival, and shorter time series based on PIT tag data collected through the CSS. CSSOC (2017) evaluated effects of four alternative spill management operations (BiOp, 115/120, 120, and 125%TDG gas caps) using both the longer run reconstruction and shorter PIT tag data sets, and proposed an experimental design for implementation.

The long-time series of annual survival rates based on run reconstructions of spawning adults, adult recruits returning to spawn (Rsg/S), and outmigrating juveniles, extends back to before FCRPS completion. It can be compared to annual river and ocean environmental conditions, changes to hydrosystem configuration, and river management to provide considerable contrast in those conditions (Petrosky and Schaller 2010; Schaller et al. 2014). Shorter time series of PIT tag data provide survival rate estimates that are more precise and specific to life-stage and in-season conditions (Haeseker et al. 2012). These studies demonstrate a general consistency of results across data sets and models that contribute to the weight of evidence underpinning support for potential management experiments.

Chapter 2 of CSSOC (2017) presented retrospective analyses for effects of FCRPS and ocean variables on survival rates of Snake River spring/summer Chinook and steelhead. The analyses used long-term data sets for life-cycle survival rates for Snake River spring/summer Chinook, as represented by Survival Rate Indices (SRIs; Schaller et al. 2014), and SARs (upper dam to the Columbia River mouth) of both Snake River spring/summer Chinook and steelhead (Petrosky and Schaller 2010). These retrospective models found that survival rates of Snake River spring/summer Chinook and steelhead were negatively associated with water transit time, number of powerhouse passages and, in some cases with proportion of juveniles transported (CSSOC 2017). Survival rates were also negatively associated with warmer sea surface temperatures and seasonal poor spring upwelling or fall down-welling conditions.

In a recent court Opinion (NWF v. NMFS 2016), Judge Michael Simon ruled that NMFS, in its 2014 FCRPS Biological Opinion (BiOp), had violated the National Environmental Policy Act

(NEPA) by failing to have a "hard look" at all reasonable alternatives to the recovery of listed salmon populations. NEPA requires that Federal agencies complete an Environmental Impact Statement (EIS) that for Columbia and Snake river salmon and steelhead includes additional actions to protect listed salmon and steelhead. An option to breach one or more of the four Lower Snake River dams to increase survival by removing negative impacts to juveniles migrating downstream and adult salmon and steelhead returning upstream to spawn is required by the court ruling. The CSS PIT-tag based models are currently being used in this EIS process to prospectively model effects of dam breaching, along with the life cycle model analyses in Chapter 2 of McCann et al. (2017). ODFW's review comments of the CSS draft 2017 annual report requested a presentation of the methods and results of the models fit to the long-term run reconstruction time series applied in a similar prospective manner, assuming the same spill scenarios and breaching the lower Snake River dams. This supplemental analysis has been prepared in response to that request.

Our primary objective in this supplemental analysis is to compare the projected survival increases of the four spill scenarios alone with scenarios that include dam breaching and spill. As described in CSSOC (2017), the primary use of these analyses for the historical data sets is to complement the more detailed modeling based on shorter PIT tag data sets. These analyses also complement the evolving life cycle modeling analyses from recent CSS annual reports (Chapter 2 in McCann et al., 2016 and 2017).

Methods

In this supplemental analysis, we used the retrospective models for the long time-series data sets in CSSOC (2017; Tables 2.1-2.6) to estimate the effectiveness of breaching Lower Snake River dam options compared to the spill management options evaluated in CSSOC (2017). Multi-model inference (MMI) and best model approaches (CSSOC 2017; Chapter 5) were used to prospectively model four spill scenarios (BiOp, 115/120, 120 and 125% TDG) with and without breaching Lower Snake River dams, consistent with key scenarios under consideration in the court-ordered EIS. We present results of these prospective model runs for smolt migration years 1977-2006 for the SRI data set and 1977-2009 for the SAR data sets. Prospective models for spill scenarios without breaching Snake River dams were identical to those described in Chapter 5 of CSSOC (2017).

To model the Snake River dam breach options prospectively, we estimated what the Water Transit Time (WTT) and N_Powerhouse would have been for those years in the absence of Lower Snake River dams for each of the spill scenarios (juvenile transport proportion (pT) would be zero with dam breach). Observed average flows (BON, April 16-May 31) were categorized as low, medium or high flow years to assign the calculated spill proportions to calculate N_Powerhouse for each year, 1977-2009; the low, medium and high categories corresponded to

the model scenarios in CSSOC (2017; Chapter 4) for the years 2010, 2009, and 2011, respectively .

Water Transit Time (WTT) averaged 19.4 days and ranged from 10.2 to 39.8 days during 1977-2009 with eight FCRPS dams (Figure 1). If lower Snake River dams were breached, WTT would have averaged 9.2 days, with a range of 5.2 to 18.1 days for these years. The number of powerhouse passages (as represented by the N_Powerhouse variable) averaged 6.1 (range, 4.5-7.9) during 1977-2009 (Figure 2). N_Powerhouse would decrease with increasing spill levels with the existing FCRPS dams in place (Figure 2, upper panel), and with Lower Snake River dam breach options (Figure 2, lower panel). Juvenile transport proportion (pT) averaged 0.62 and ranged from 0.21 to 0.99 during 1977-2009 (Figure 3); pT would decrease with increasing spill levels with the existing FCRPS dams in place, and become zero under the Snake River dam breach options.

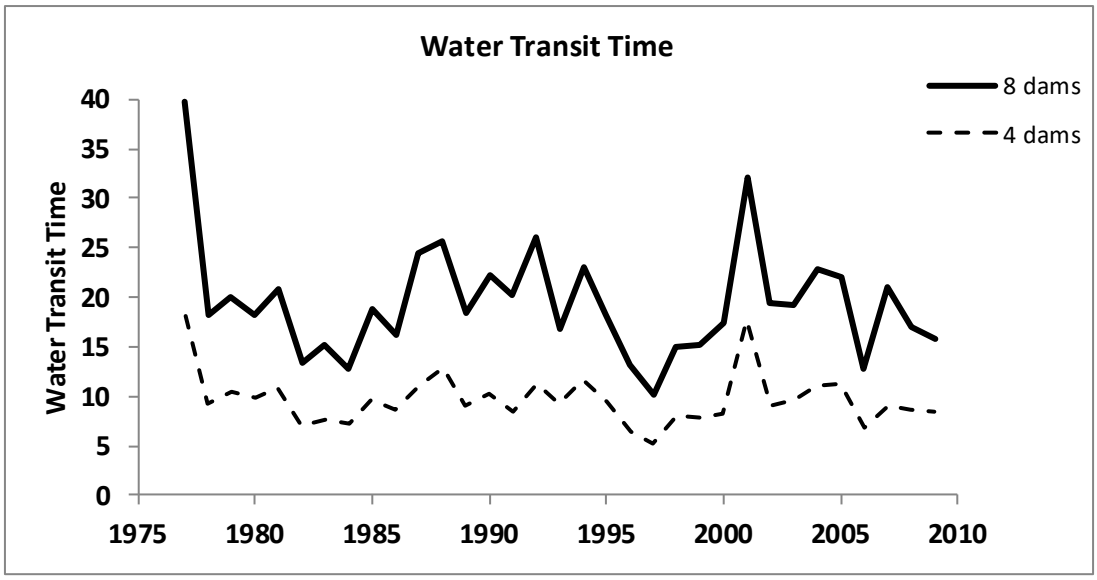


Figure 1. Observed Water Transit time (WTT, in days) for smolt migration years 1977-2009 for the 8-dam scenarios and estimated WTT for Lower Snake River dam breach options (4-dam scenarios).

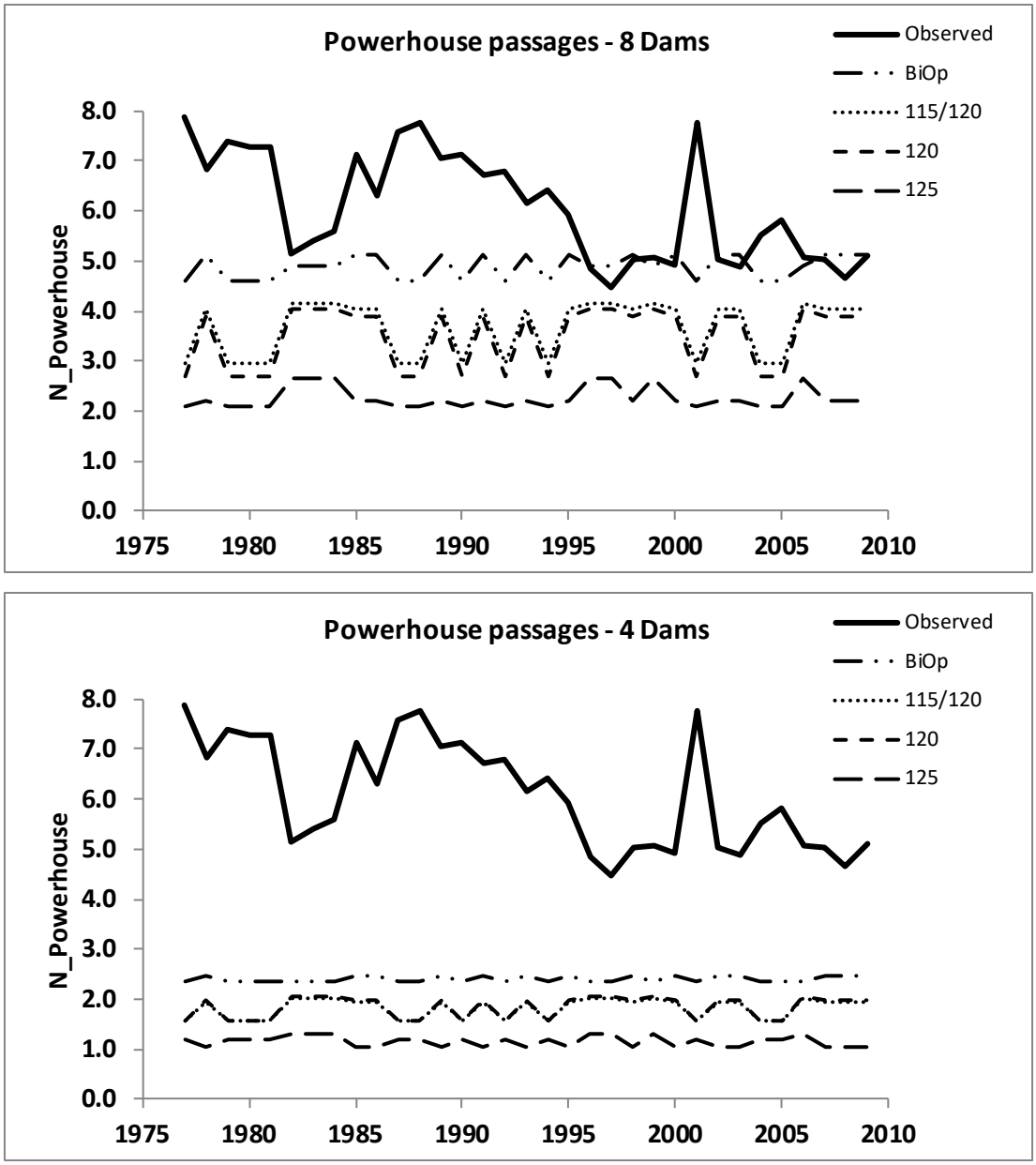


Figure 2. Estimated number of powerhouse passages for smolt migration years 1977-2009 for the alternative spill scenarios without Lower Snake River dam breach (upper panel) and with Lower Snake River dam breach (lower panel).

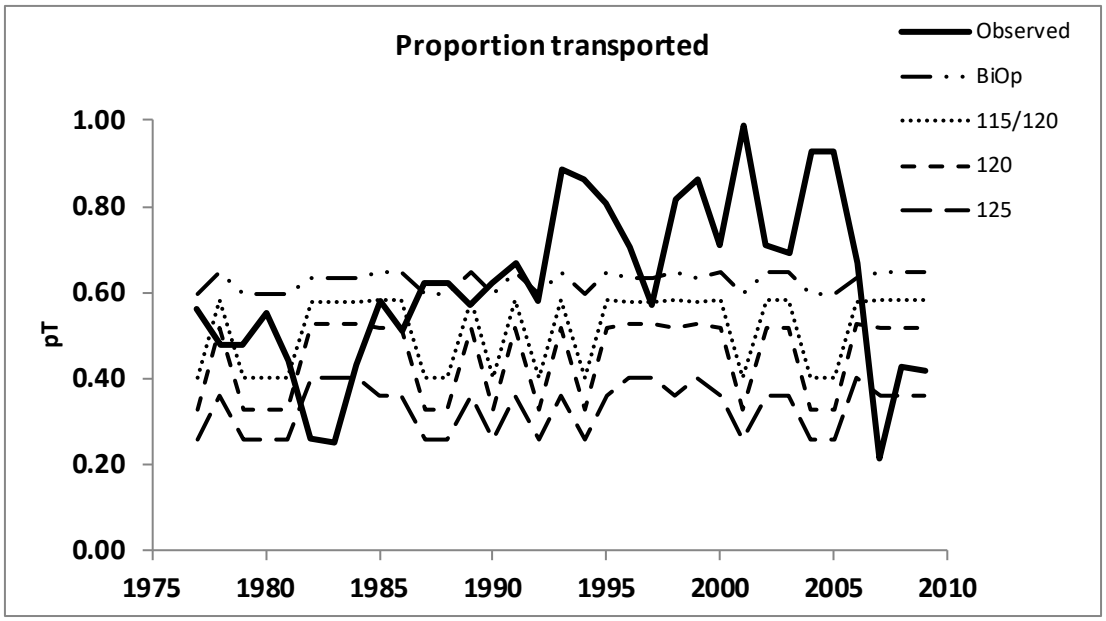


Figure 3. Estimated juvenile transport proportion (pT) for smolt migration years 1977-2009 for the alternative spill scenarios without Lower Snake Dam breach; pT would be zero with the Lower Snake River dam breach options.

Results

Chinook life-cycle survival rates, SRIs

The predicted median SRI for Snake River spring/summer Chinook during 1977-2006 smolt years (1975-2004 brood years) was -2.05 (Table 1; Figure 4), indicating that life cycle survival had declined to 13% ($e^{-2.05}$) of the historical (pre-1970 baseline) productivity. Results of the MMI prospective analysis suggest increasing spill to BiOp, 115/120, 120, and 125 gas cap levels without breaching Snake River dams would sequentially increase the median SRIs to a range of -1.92 to -1.30 for the inflow and ocean conditions experienced in 1977-2006 (Table 1; Figure 4, upper right panel). These results equate to a range of 15% to 27% of pre-1970 productivity. Breaching Lower Snake River dams for the same spill levels and environmental conditions would increase SRIs to a range of -0.60 to -0.47, or 55% to 63% of pre-1970 productivity, based on the MMI prospective model. Spill increases alone would improve median life-cycle survival rate by a factor of 1.2 over observed levels for the BiOp gas cap spill, and by 1.4, 1.6 and 2.1 for the 115/120, 120, and 125 gas cap levels, respectively, using the MMI prospective analysis (Figure 5, left panel). Spill increases combined with dam breach would increase life cycle survival by factors of 4.3, 4.4, 4.4 and 4.6, respectively using MMI (Figure 5, left panel).

Prospective model results for Chinook SRIs using the best model approach were similar to those using the MMI prospective model (Table 2; Figure 4, lower panels). Spill increases alone would

sequentially increase the median SRIs to a range of -1.94 to –1.29 for the inflow and ocean conditions experienced in 1977-2006 (Table 2; Figure 4, lower right panel); these results equate to a range of 15% to 27% of pre-1970 productivity. Breaching Lower Snake River dams for the same spill levels and environmental conditions would increase SRIs to a range of -0.60 to -0.47, or 55% to 63% of pre-1970 productivity, based on the best model approach (Table 2; Figure 4, lower left panel). Spill increases alone would improve median life-cycle survival rate by a factor of 1.2 over observed levels for the BiOp gas cap spill, and by 1.6, 1.7 and 2.2 for the 115/120, 120, and 125 gas cap levels, respectively, using the best model prospective analysis (Figure 5, right panel). Spill increases combined with dam breach would increase life cycle survival by factors of 4.6, 5.0, 5.0 and 5.4, respectively using the best model analysis (Figure 5, right panel).

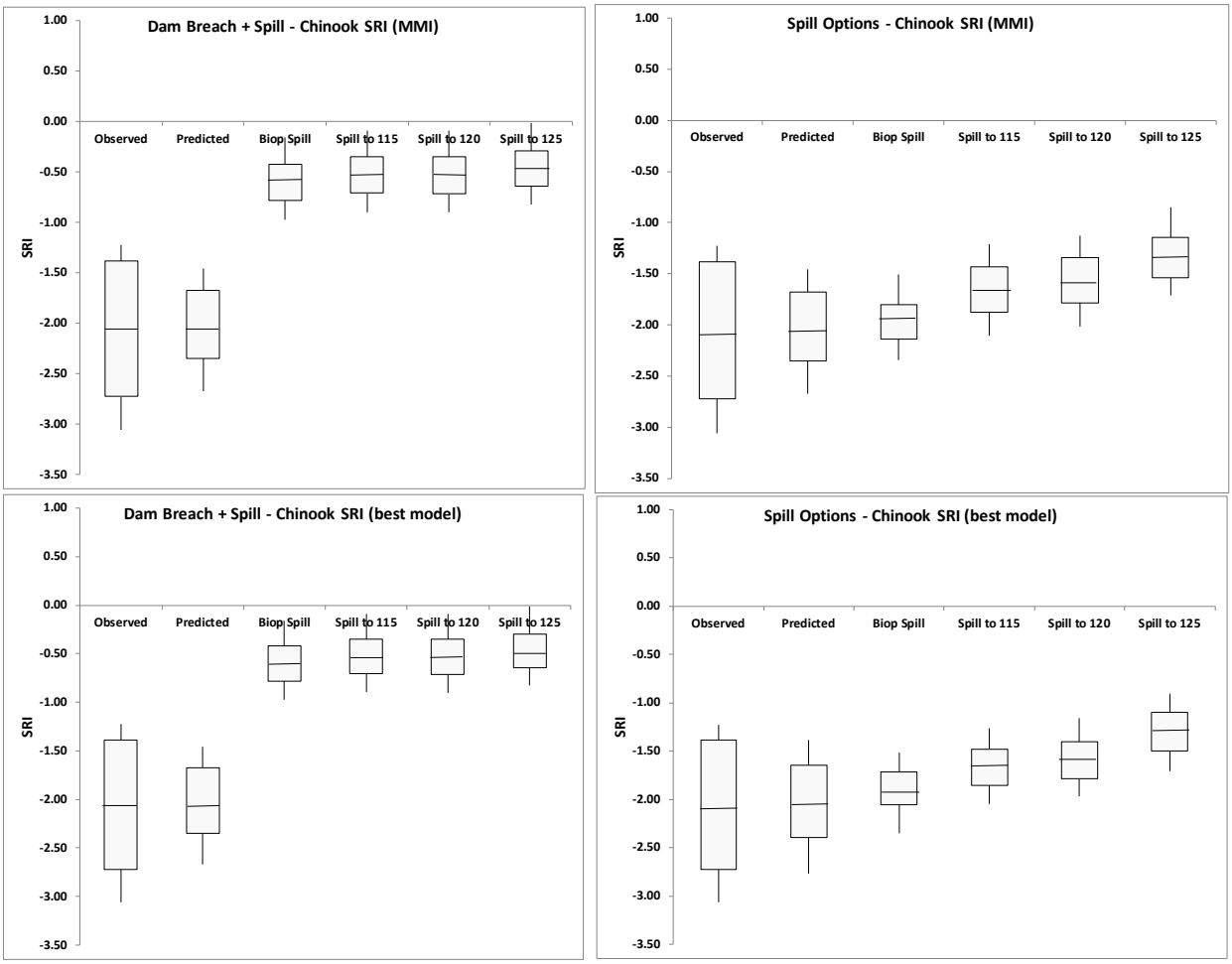


Figure 4. Historical (observed) survival rate indices (SRIs), predicted retrospective SRIs and prospective SRIs for Snake River spring/summer Chinook salmon, brood years 1975–2004. Modeled options include Lower Snake River dam breaching combined with spill management options (left column) and spill management options without breaching dams (right column). Upper row used MMI prospective analysis; lower row used best model prospective analysis. Boxes show 25th percentile, median and 75th percentile of SRIs; whiskers show 10th and 90th percentiles of SRIs.

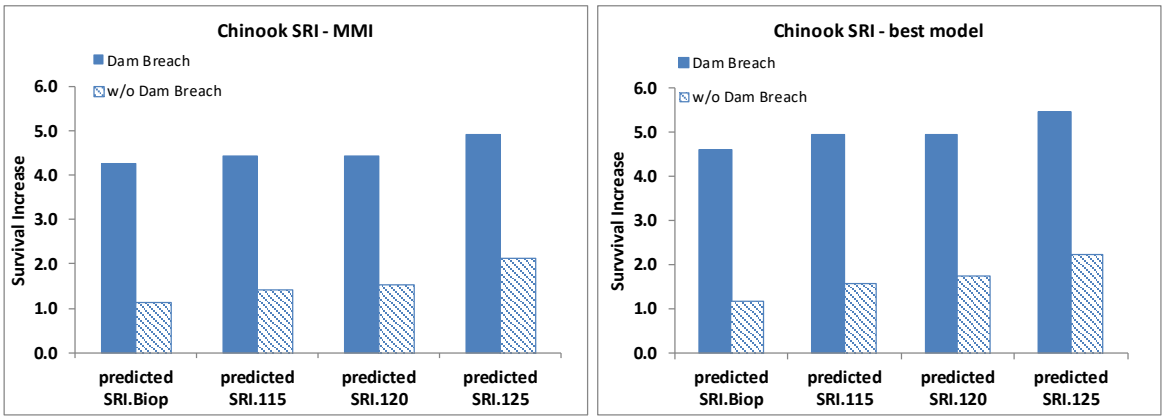


Figure 5. Predicted median change in life cycle survival of Snake River spring/summer Chinook salmon, smolt migration years 1977-2006, for MMI and best model approaches. Modeled options include Lower Snake River dam breaching combined with spill management options (solid bar) and spill management options without breaching dams (striped bar).

Table 1. Historical (observed) SRI distributions, predicted historical SRIs and prospective SRIs for Snake River spring/summer Chinook salmon using MMI model approach, smolt migration years 1977-2006. Modeled scenarios include BiOp, 115/120, 120, and 125 spill management options and Lower Snake River dam breaching with spill options.

	Observed	Predicted historical	Predicted BiOp	Predicted 115/120	Predicted 120	Predicted 125
			Spill Options			
min	-4.31	-3.24	-2.88	-2.48	-2.37	-2.22
10%ile	-3.06	-2.67	-2.35	-2.10	-2.01	-1.71
25%ile	-2.72	-2.35	-2.14	-1.88	-1.79	-1.54
median	-2.13	-2.05	-1.92	-1.69	-1.62	-1.30
75%ile	-1.38	-1.68	-1.80	-1.43	-1.34	-1.15
90%ile	-1.23	-1.46	-1.50	-1.21	-1.12	-0.85
max	-0.56	-1.02	-1.20	-1.05	-0.98	-0.67
			Spill + Dam Breach			
min	-4.31	-3.24	-1.48	-1.39	-1.39	-1.35
10%ile	-3.06	-2.67	-0.97	-0.90	-0.90	-0.82
25%ile	-2.72	-2.35	-0.78	-0.71	-0.71	-0.64
median	-2.13	-2.05	-0.60	-0.56	-0.57	-0.47
75%ile	-1.38	-1.68	-0.42	-0.35	-0.35	-0.30
90%ile	-1.23	-1.46	-0.16	-0.09	-0.09	-0.02
max	-0.56	-1.02	0.07	0.10	0.10	0.18

Table 2. Historical (observed) SRI distributions, predicted historical SRIs and prospective SRIs for Snake River spring/summer Chinook salmon using best model approach, smolt migration years 1977-2006. Modeled scenarios include BiOp, 115/120, 120, and 125 spill management options and Lower Snake River dam breaching with spill options.

	Observed	Predicted historical	Predicted BiOp	Predicted 115/120	Predicted 120	Predicted 125
			Spill Options			
min	-4.31	-3.20	-2.80	-2.49	-2.41	-2.15
10%ile	-3.06	-2.77	-2.35	-2.05	-1.97	-1.70
25%ile	-2.72	-2.39	-2.05	-1.86	-1.79	-1.50
median	-2.13	-2.10	-1.94	-1.64	-1.55	-1.29
75%ile	-1.38	-1.65	-1.71	-1.48	-1.40	-1.10
90%ile	-1.23	-1.38	-1.51	-1.26	-1.16	-0.91
max	-0.56	-1.12	-1.13	-0.97	-0.91	-0.62
			Spill + Dam Breach			
min	-4.31	-3.20	-1.42	-1.34	-1.35	-1.23
10%ile	-3.06	-2.77	-0.91	-0.83	-0.83	-0.75
25%ile	-2.72	-2.39	-0.76	-0.69	-0.69	-0.60
median	-2.13	-2.10	-0.58	-0.50	-0.50	-0.41
75%ile	-1.38	-1.65	-0.44	-0.36	-0.37	-0.27
90%ile	-1.23	-1.38	-0.21	-0.13	-0.13	-0.04
max	-0.56	-1.12	0.12	0.16	0.16	0.26

Chinook SARs

The predicted median SAR (LGR-BOA) for Snake River spring/summer Chinook during 1977-2009 smolt years was 0.90% and ranged from 0.51% to 2.22% (Table 3; Figure 6). The MMI prospective analysis results suggest increasing spill to BiOp, 115/120, 120, and 125 gas cap levels, without breaching Snake River dams, would sequentially increase the median SARs to a range of 1.10% to 1.47% for the inflow and ocean conditions experienced in 1977-2009 (Table 3; Figure 6, upper right panel). Breaching Lower Snake River dams for the same spill levels and environmental conditions would increase median SARs to a range of 1.69% to 1.96%, based on the MMI prospective model (Table 3; Figure 6, upper left panel). Spill increases alone would improve median SARs by a factor of 1.2 over observed SARs for the BiOp gas cap spill, and by 1.4, 1.4 and 1.6 for the 115/120, 120, and 125 gas cap levels, respectively, using the MMI prospective analysis (Figure 7, left panel). Spill increases combined with dam breach would increase SARs by factors of 1.9, 2.1, 2.1 and 2.2, respectively using MMI (Figure 7, left panel).

Prospective model results for Chinook SARs using the best model approach were somewhat more optimistic than were those using the MMI prospective model (Table 4; Figure 6, lower panels). Spill increases alone would sequentially increase the median SARs to a range of 1.18% to 1.96% for the inflow and ocean conditions experienced in 1977-2009 (Figure 6, lower right panel). Breaching Lower Snake River dams for the same spill levels and environmental conditions would increase median SARs to a range of 2.55% to 3.24%. Spill increases alone would improve median SARs by a factor of 1.2 over observed SARs for the BiOp gas cap spill, and by 1.5, 1.6 and 2.0 for the 115/120, 120, and 125 gas cap levels, respectively, using the best model prospective analysis (Figure 7, right panel). Spill increases combined with dam breach would increase SARs by factors of 2.7, 2.9, 2.9 and 3.4, respectively using the best model analysis (Figure 7, right panel).

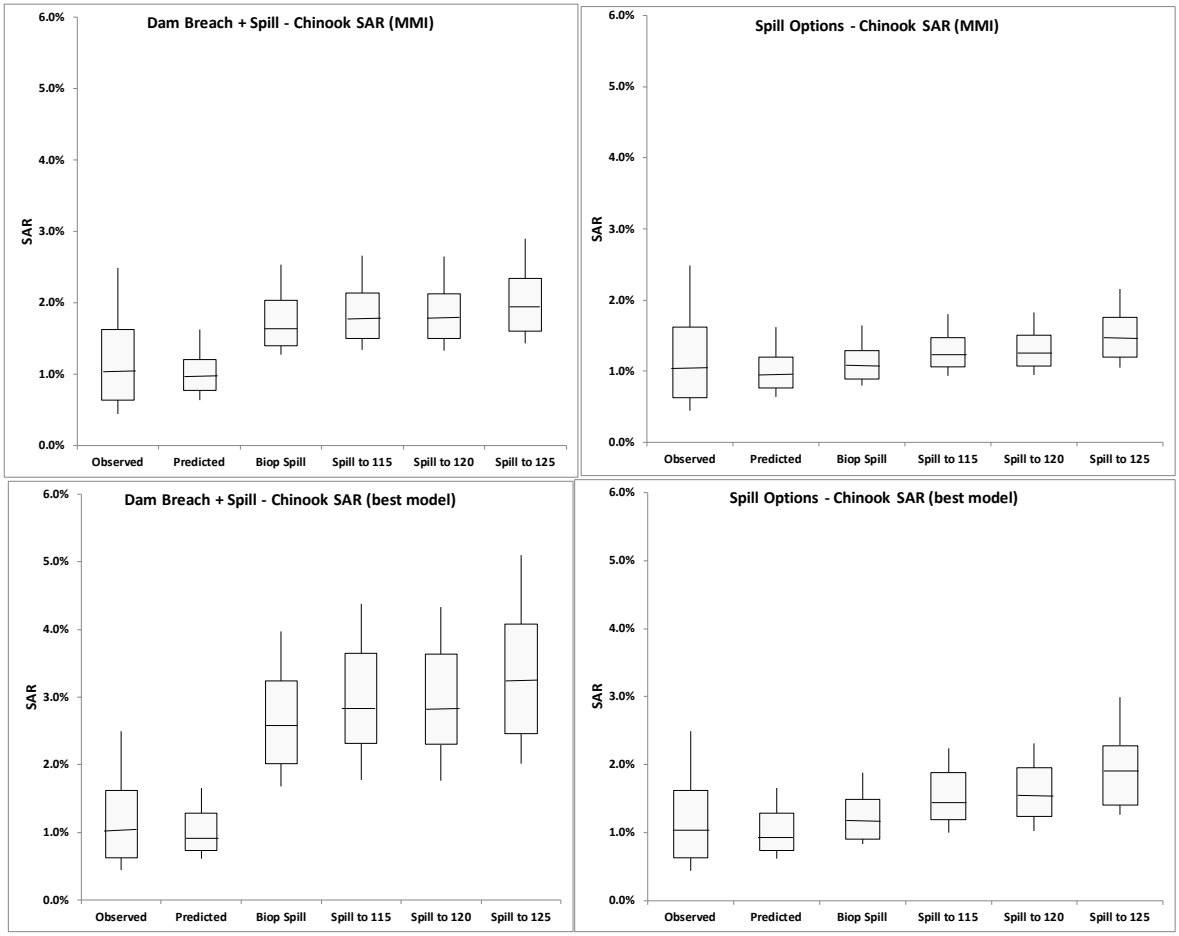


Figure 6. Historical (observed) pre-harvest SARs, predicted retrospective SARs and prospective SARs for Snake River spring/summer Chinook salmon, smolt migration years 1977–2009. Modeled options include breaching Lower Snake River dams combined with spill management options (left column) and spill management options without dam breaching (right column). Upper row used MMI prospective analysis; lower row used best model prospective analysis. Boxes show 25th percentile, median and 75th percentile SARs; whiskers show 10th and 90th percentiles of SARs.

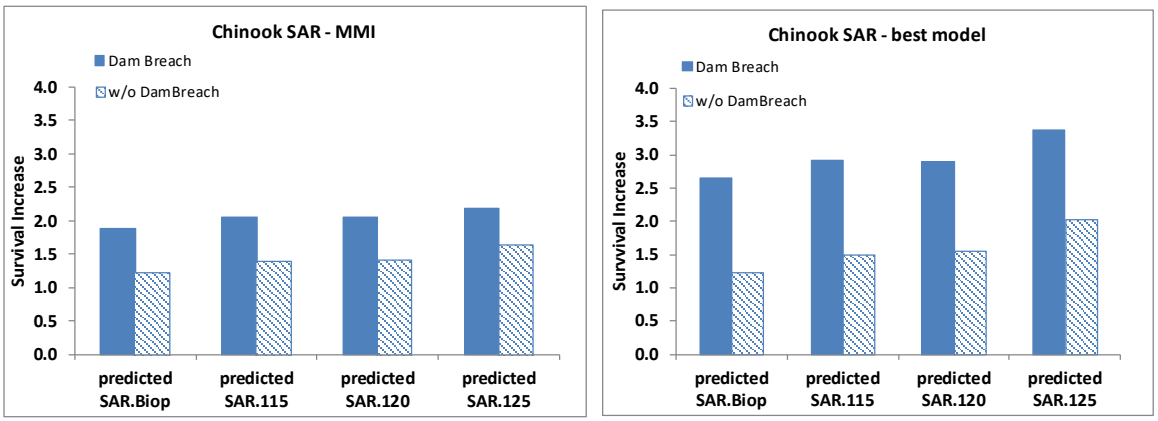


Figure 7. Predicted median change in SARs (upper dam to Columbia River mouth) for Snake River spring/summer Chinook salmon, smolt migration years 1977-2006 for MMI and best model approaches. Modeled options include Lower Snake River dam breaching combined with spill management options (solid bar) and spill management options without breaching dams (striped bar).

Table 3. Historical (observed) SAR distributions, predicted historical SARs and prospective SARs for Snake River spring/summer Chinook salmon using MMI model approach, smolt migration years 1977-2009. Modeled scenarios include BiOp, 115/120, 120, and 125 spill management options and Lower Snake River dam breaching with spill options.

Observed	Predicted historical	Predicted BiOp	Predicted 115/120	Predicted 120	Predicted 125
		Spill Options			
0.29%	0.51%	0.57%	0.65%	0.66%	0.80%
0.44%	0.63%	0.80%	0.93%	0.95%	1.06%
0.63%	0.77%	0.90%	1.06%	1.08%	1.20%
1.05%	0.90%	1.10%	1.26%	1.28%	1.47%
1.62%	1.20%	1.29%	1.48%	1.51%	1.76%
2.49%	1.62%	1.64%	1.81%	1.83%	2.16%
4.26%	2.22%	2.29%	2.49%	2.52%	2.94%
		Spill + Dam Breach			
0.29%	0.51%	0.87%	0.93%	0.93%	1.03%
0.44%	0.63%	1.27%	1.34%	1.33%	1.43%
0.63%	0.77%	1.39%	1.50%	1.50%	1.60%
1.05%	0.90%	1.69%	1.84%	1.84%	1.96%
1.62%	1.20%	2.03%	2.14%	2.13%	2.34%
2.49%	1.62%	2.53%	2.66%	2.64%	2.90%
4.26%	2.22%	3.38%	3.51%	3.50%	3.80%

Table 4. Historical (observed) SAR distributions, predicted historical SARs and prospective SARs for Snake River spring/summer Chinook salmon using best model approach, smolt migration years 1977-2009. Modeled scenarios include BiOp, 115/120, 120, and 125 spill management options and Lower Snake River dam breaching with spill options.

Observed	Predicted historical	Predicted BiOp	Predicted 115/120	Predicted 120	Predicted 125
		Spill Options			
0.29%	0.49%	0.69%	0.79%	0.80%	1.02%
0.44%	0.61%	0.83%	1.00%	1.02%	1.27%
0.63%	0.73%	0.91%	1.19%	1.24%	1.40%
1.05%	0.96%	1.18%	1.44%	1.50%	1.96%
1.62%	1.28%	1.48%	1.89%	1.95%	2.27%
2.49%	1.66%	1.89%	2.24%	2.31%	2.99%
4.26%	2.82%	2.94%	3.35%	3.42%	4.34%
		Spill + Dam Breach			
0.29%	0.49%	1.37%	1.45%	1.44%	1.64%
0.44%	0.61%	1.68%	1.78%	1.77%	2.02%
0.63%	0.73%	2.02%	2.31%	2.30%	2.46%
1.05%	0.96%	2.55%	2.80%	2.78%	3.24%
1.62%	1.28%	3.24%	3.64%	3.63%	4.09%
2.49%	1.66%	3.98%	4.38%	4.34%	5.10%
4.26%	2.82%	5.77%	6.12%	6.08%	6.93%

Steelhead SARs

The predicted median SAR (LGR-BOA) for Snake River steelhead during 1977-2009 smolt years was 3.04%, and ranged from 1.02% to 4.59% (Table 5; Figure 8). The MMI prospective analysis results suggest increasing spill to BiOp, 115/120, 120, and 125 gas cap levels, without breaching Snake River dams, would sequentially increase the median SARs to a range of 3.05% to 3.13% for the inflow and ocean conditions experienced in 1977-2009 (Table 5; Figure 8, upper right panel). Breaching Lower Snake River dams for the same spill levels and environmental conditions would increase median SARs to a range of 4.81% to 4.87%, based on the MMI prospective model (Table 5; Figure 8, upper left panel). Spill increases alone would improve median SARs by a factor of 1.002 over observed SARs for the BiOp gas cap spill, and by 1.01, 1.01 and 1.04 for the 115/120, 120, and 125 gas cap levels, respectively, using the MMI prospective analysis (Figure 9, left panel). Spill increases combined with dam breach would

increase SARs by factors of 1.58, 1.59, 1.59 and 1.60, respectively using MMI (Figure 9, left panel).

Prospective model results for steelhead SARs using the best model approach were somewhat more optimistic than were those using the MMI prospective model (Table 6; Figure 8, lower panels). Spill increases alone would sequentially increase the median SARs to a range of 3.34% to 3.97% for the inflow and ocean conditions experienced in 1977-2009 (Figure 8, lower right panel). Breaching Lower Snake River dams for the same spill levels and environmental conditions would increase median SARs to a range of 5.49% to 5.96% (Figure 8, lower left panel). Spill increases alone would improve median SARs by a factor of 1.13 over observed SARs for the BiOp gas cap spill, and by 1.21, 1.23 and 1.34 for the 115/120, 120, and 125 gas cap levels, respectively, using the best model prospective analysis (Figure 9, right panel). Spill increases combined with dam breach would increase SARs by factors of 1.86, 1.91, 1.90, and 2.01, respectively using the best model analysis (Figure 9, right panel).

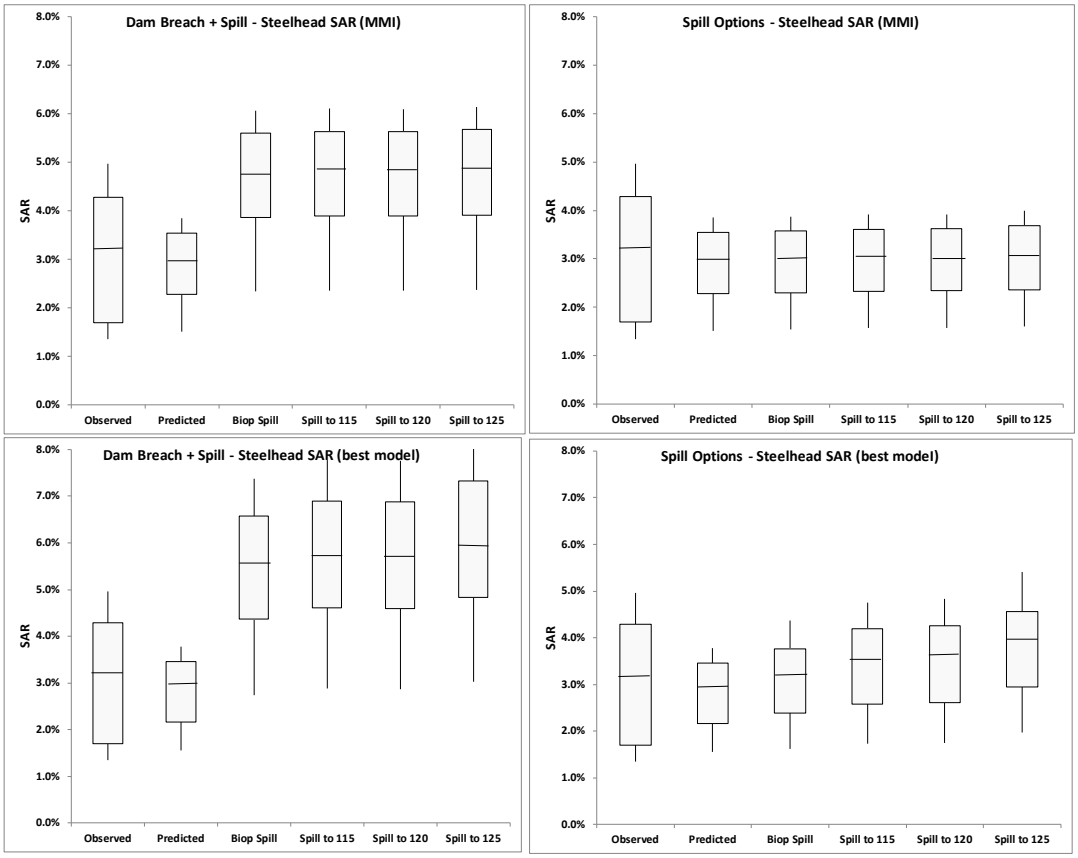


Figure 8. Historical (observed) pre-harvest SARs, predicted retrospective SARs and prospective SARs for Snake River steelhead, smolt years 1977–2009. Modeled options include Lower Snake River dam breaching combined with spill management options (left column) and spill management options without breaching dams (right column). Upper row used MMI prospective analysis; lower row used best model prospective analysis. Boxes show 25th percentile, median and 75th percentile of SARs; whiskers show 10th and 90th percentiles of SARs.

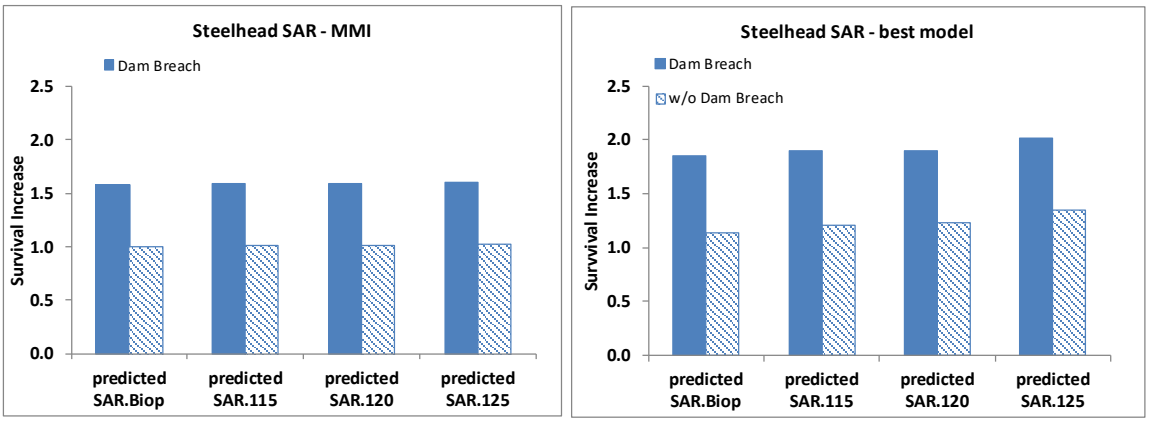


Figure 9. Predicted median change in SARs (upper dam to Columbia River mouth) for Snake River steelhead, smolt migration years 1977-2009 for MMI and best model approaches. Modeled options include Lower Snake River dam breaching combined with spill management options (solid) and spill management options without breaching dams (striped).

Table 5. Historical (observed) SAR distributions, predicted historical SARs and prospective SARs for Snake River steelhead using MMI model approach, smolt migration years 1977-2009 . Modeled scenarios include BiOp, 115/120, 120, and 125 spill management options and Lower Snake River dam breaching with spill options.

	Observed	Predicted historical	Predicted BiOp	Predicted 115/120	Predicted 120	Predicted 125
			Spill Options			
min	0.43%	1.02%	1.03%	1.05%	1.06%	1.06%
10%ile	1.35%	1.51%	1.55%	1.57%	1.58%	1.60%
25%ile	1.70%	2.28%	2.30%	2.33%	2.34%	2.37%
median	3.21%	3.04%	3.05%	3.08%	3.08%	3.13%
75%ile	4.28%	3.54%	3.57%	3.62%	3.62%	3.68%
90%ile	4.96%	3.85%	3.87%	3.91%	3.92%	3.99%
max	5.99%	4.59%	4.57%	4.63%	4.64%	4.73%
			Spill + Dam Breach			
min	0.43%	1.02%	1.81%	1.82%	1.82%	1.83%
10%ile	1.35%	1.51%	2.34%	2.36%	2.36%	2.38%
25%ile	1.70%	2.28%	3.86%	3.89%	3.89%	3.91%
median	3.21%	3.04%	4.81%	4.85%	4.85%	4.87%
75%ile	4.28%	3.54%	5.60%	5.63%	5.63%	5.67%
90%ile	4.96%	3.85%	6.06%	6.10%	6.10%	6.14%
max	5.99%	4.59%	6.99%	7.02%	7.02%	7.09%

Table 6. Historical (observed) SAR distributions, predicted historical SARs and prospective SARs for Snake River steelhead using best model approach, smolt migration years 1977-2009 . Modeled scenarios include BiOp, 115/120, 120, and 125 spill management options and Lower Snake River dam breaching with spill options.

	Observed	Predicted historical	Predicted BiOp	Predicted 115/120	Predicted 120	Predicted 125
			Spill Options			
min	0.43%	1.00%	1.07%	1.21%	1.23%	1.29%
10%ile	1.35%	1.56%	1.62%	1.73%	1.75%	1.96%
25%ile	1.70%	2.17%	2.38%	2.58%	2.61%	2.94%
median	3.21%	2.96%	3.34%	3.58%	3.64%	3.97%
75%ile	4.28%	3.45%	3.76%	4.20%	4.25%	4.56%
90%ile	4.96%	3.78%	4.37%	4.76%	4.83%	5.41%
max	5.99%	4.52%	4.65%	5.27%	5.36%	5.80%
			Spill + Dam Breach			
min	0.43%	1.00%	1.97%	2.09%	2.08%	2.14%
10%ile	1.35%	1.56%	2.74%	2.88%	2.87%	3.03%
25%ile	1.70%	2.17%	4.37%	4.60%	4.59%	4.83%
median	3.21%	2.96%	5.49%	5.64%	5.62%	5.96%
75%ile	4.28%	3.45%	6.57%	6.90%	6.88%	7.34%
90%ile	4.96%	3.78%	7.38%	7.78%	7.76%	8.13%
max	5.99%	4.52%	8.94%	9.49%	9.47%	9.75%

Discussion

The prospective analyses for the long-time series data sets based on run reconstruction showed benefits of increased spill levels to varying degrees for Snake River spring/summer Chinook and steelhead. For Chinook SRIs, increased spill to BiOp levels resulted in estimated life-cycle survival improvements of 15% to 18% over historical SRIs, depending on the prospective model used; spill to the 125 gas cap would increase life-cycle survival by 114% to 125%. Spill increases had similar effects on the Chinook SAR simulations, with BiOp spill resulting in a 23% increase in survival over historical SARs, and spill to the 125 gas cap resulting in a 64% to 104% increase in SARs, depending on the prospective model used. The modeled benefits of spill for steelhead SARs were relatively lower than for Chinook. BiOp spill simulations resulted in a 0.2% to 13% increase in steelhead SARs, and spill to the 125 gas cap resulted in a 3% to 34% increase in SARs, depending on the prospective model used.

Prospective analyses of dam breach scenarios resulted in large survival increases for Snake River spring/summer Chinook and steelhead. Snake River dam breach scenarios, combined with spill increases, resulted in predicted life-cycle survival increases in the range of 326% to 445%, depending on spill level and the prospective model used. Dam breach scenarios, combined with spill increases, resulted in predicted SAR increases of 88% to 238% for Chinook SARs and 58% to 101% for steelhead SARs, depending on spill level and the prospective model used.

This supplemental analysis for the dam breaching scenarios predicted relatively large increases in Snake River spring/summer Chinook life cycle survival and SARs. The survival increase projected for Chinook with the relatively simple statistical models in this supplemental analysis was similar to that projected using the life cycle model (LCM) from Chapter 2 of McCann et al. (2017). The LCM predicted an approximate 2-fold increase in Chinook SARs with dam breaching compared to scenarios without breach (McCann et al. 2017). If the four Lower Snake River dams were breached and the remaining four lower Columbia dams operate at BiOp spill levels, the LCM predicts a 2 to 3-fold increase in abundance above that predicted at BiOp spill in an impounded system, and up to a 4-fold increase if spill is increased to the 125% TDG limit (McCann et al. 2017). The LCM was developed for spring/summer Chinook populations in the Grande Ronde/Imnaha Major Population Group (MPG), using recruit/spawner and freshwater smolt production data sets, as well as FCRPS and environmental data. The Chinook SRIs in this supplemental analysis used the recruit/spawner response from 18 populations from four MPGs above Lower Granite Dam, including those from the Grande Ronde/Imnaha MPG (Schaller et al. 2014). Both the Grande Ronde/Imnaha and the other three MPGs include populations that could benefit from watershed habitat improvement actions and populations where habitat is not actively managed in wilderness areas.

One additional line of evidence supporting the prospective model results of large increases in survival from dam breaching options comes from SAR comparisons of populations above three (John Day River) or four (Yakima River) dams with Snake River populations above eight dams. Schaller et al. (2014) analyzed Chinook mortality patterns using methods that incorporated downriver reference populations passing fewer dams, and temporal approaches that were independent of reference populations. Their results from the alternative spatial and temporal methods consistently corroborated with spawner–recruit residuals and SAR data sets, indicating that Snake River salmon survived about one quarter as well as the reference populations. Based on this spatial and temporal corroboration, a reasonable expectation would be that life cycle survival and SARs of Snake River populations following dam breaching should be similar to those of the reference populations. Improved in-river migration conditions resulting from increased voluntary spill would additionally improve survival through the lower Columbia River downstream of the Snake River.

The model projections of expected survival improvements for Snake River spring/summer Chinook SRIs and SARs under the dam breaching scenarios appear quite realistic when compared to recent survival estimates of similar spring Chinook populations above three or four

dams. Recent SARs (based on Bonneville Dam adult returns) of John Day River and Yakima River wild spring Chinook have averaged 3.8 and 2.5 times, respectively, those of Snake River wild spring/summer Chinook (McCann et al. 2017). By comparison, the model projections for the breach scenario with BiOp spill predicted a median increase of 2.7 fold for Chinook SARs, and 4.6 fold increase in Chinook recruits/spawner.

The model projections of expected survival improvements for Snake River steelhead SARs under dam breaching scenarios also appear realistic when compared to recent survival estimates of similar steelhead populations above three or four dams. Recent SARs (based on Bonneville Dam returns) of wild steelhead from the John Day, Deschutes and Yakima rivers have averaged 2.5 times, respectively those of Snake River wild steelhead (CSS 2017). By comparison, the model projections for the breach scenario with BiOp spill predicted a median increase of 1.9 fold for steelhead SARs.

As described in CSSOC (2017), the purpose of this supplemental analysis is to examine supporting evidence for the results of the primary CSS prospective models by extending the retrospective models of Petrosky and Schaller (2010) and Schaller et al. (2014) to predict potential effects from increasing voluntary spill and/or breaching Lower Snake River dams. Multiple lines of evidence support the finding that reduced water velocity (increased WTT) and increased powerhouse passage jointly reduced survival and productivity of Snake River salmon and steelhead following construction and operation of the FCRPS (e.g., Marmorek et al. 2011). The long-time series of SRIs and SARs, evaluated here, provide empirical estimates of survival rates that span a wide range of environmental conditions and changing FCRPS configuration and management. In particular, the long-time series includes years prior to completion of the FCRPS when juveniles encountered fewer dams during their seaward migration. Models fit to shorter time series using SARs of PIT-tagged Chinook and steelhead (Haeseker et al. 2012) provide estimates within seasons, with greater precision and accuracy than the long-time series data (CSSOC 2017). The shorter time series data also provide empirical observations for the current configuration, including the installation of spillway weirs. Both long-term and short-term time series indicated that Snake River Chinook and steelhead populations have responded similarly to environmental conditions and river management. The analysis of the historical time series indicates environmental and management factors that influenced survival rates are similar to those that influenced the short-term PIT tag derived survival rates. This finding provides a weight of evidence supporting application of projection models that are based on the recent PIT-tag data.

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